THE HORIZONTALLY APPLIED TAPING SYSTEM (HATS)

THE DEVELOPMENT OF ADHESIVE TAPE FOR A TAPE-SEALED PACKAGING SYSTEM

A thesis submitted to the College of Sciences, Institute of Technology and Engineering, Massey University, Palmerston North, New Zealand, in partial fulfilment of the requirements for the degree of

Master of Technology
in
Packaging Technology

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ABSTRACT

This project details the work done to develop testing methods for adhesive tapes for a tape-seal packaging system for selection at Graphpak Services Limited in Palmerston North, New Zealand. The company developed and patented a tape-sealing system for corrugated cartons that requires the use of pressure sensitive tape. The system is used for sealing cartons for export for the meat and fisheries industry. The tape is applied horizontally around the case with a circular tape head that deforms to conform to the varying surface layers of a case with an overlapping lid, thus securing the lid to the base.

Existing packaging tapes were tested for minimum strength properties and its effectiveness for use with corrugated board. The storage conditions of export goods require a substantial time spend in cooler temperatures, thus an adhesive tape functional at a large range is favoured. The selection of The Sellotape® brand of freezer grade tape was made as an all-round performer on the experiments conducted.

To export goods representing New Zealand, the Ministry of Agriculture and Forestry logo must be visible on the carton. The tape is intended to replace the seal by incorporating the logo on the tape by the means of print. The compatibility of ink on the adhesive tape was investigated and results show that it was most feasible to print on the tape backing substrate.

To deter unscrupulous operators from reusing the carton for black market resale, the carton must be tamper evident. Tests also investigated the conditions needed for a strong adhesive bond to delaminate the corrugated fibre material upon removal of the tape. It was discovered that the treatment of hot air blown on sealed tape produced a tighter seal as well as more fibre tear.

Security features such as bar-coding is highly recommended, and when required the use of microchips implanted in the carton will allow for traceability.

The use of the brand Sellotape for the proposed tape will reduce costs as the tapes are New Zealand made.

The combination of the tape-sealed packaging system and the proposed adhesive tape is an innovative way to incorporate a method of carton closure for waste reduction and a tamper proof international export requirement all in one, a special way to represent the New Zealand export industry.

DECLARATION

I declare that this is my own, independent work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Technology at Massey University. It has not been submitted before for any degree or examination in any other University.

Vivien Wai Ying Yeung

This

First Day of June 2009

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1.0 – INTRODUCTION

1.1 GRAPHPACK SERVICES LIMITED

Graphpak Services Limited was established in 1981 in Palmerston North, New Zealand. Its core business is to service and provide engineering to the printing and packaging industry and produce unique machinery for the dairy, fibreboard packaging, print finishing and food processing industries. Own and operated by Mr John D Bradley for over 20 years, the company has undergone new structural and management change. Graphpak has since been bought by Manawatu Precision and John has formed a new company with Bob McIhatton called Lyhatton that focuses further on the development of the Horizontally Applied Taping System (HATS) project; both the tape-sealed packaging unit as well as the adhesive tape. Lyhatton has now relocated to Fielding.

Figure 1-1 Mr John Bradley, Mr Rod Collins and I pictured at Taylor Preston Meat Processing Plant in Wellington February 2002

1.1.1 THE HATS PROJECT

In 1992; John saw a need to provide a solution to replace existing polypropylene strapping in the packaging industry after recognising the reoccurring failure of holding the package together with this method. He patented a design idea of his own that would allow a horizontal taping machine to seal corrugated fibreboard that not only holds the package intact better than strapping but in addition increases the shelf life of the product. John also considered existing security requirements to which Ministry of Agriculture, MAF became interested and so too did the local produce sector.

It was clear that this innovative system had much potential which also required resources from the company that it could not provide on its own, therefore in 2001, technology in industry fellowship funding (TIF) was granted for a masterate student to take this idea to the next level, onto developing a production model. Student Rod Collins undertook this project and developed a tape head roller which makes sealing the tape horizontally possible.

1.2 TAMPER EVIDENCE

The New Zealand meat export industry has often commonly been a target to unscrupulous operators that reuse the New Zealand meat carton and Ministry of Agriculture and Forestry (MAF) seals to sell counterfeit meat products. When these products have reached their required destinations, it may be discovered that the product is counterfeit. This alone will give our products and brand to our overseas market a bad reputation.

Currently, the cardboard boxed meat products are strapped with polypropylene to secure the lid. Official Ministry of Agriculture and Forestry (MAF) seals which are adhesive labels are placed on these straps whereby the lid and base of the cardboard box meets, and usually two labels are required and used. With this type of packaging closure, it is not surprising counterfeiting is common.

Often whole shipments of meat are returned to New Zealand where a few cartons are either found to have evidence of tampering or labels have fallen off due to temperature differences and rough handling. Rough handling is common and with the use of the strapping material as handles to move the cartons and for palletisation. Seals become unstuck, the box will be reshaped due to the strapping material digging to the corners of the carton and lids are not tapered as strapping alone does not make for a uniform package. This therefore makes palletisation untidy and weak. The whole shipment may then be returned to New Zealand at our expense.

1.3 CURRENT SYSTEMS OF CARTON CLOSURE

Adhesive Taping System

- Used on regular slotted cartons (RSC).

Hot Melt Glue

- Applied to lid and side flaps of carton.

Polypropylene Strapping

- Straps are tightened and heat sealed to join.

Table 1-1 Advantages and Disadvantages of Adhesive Taping, Hot Melt Gluing and Polypropylene Strapping

FACTORS	ADHESIVE TAPING	HOT MELT GLUING	POLYPROPYLENE STRAPPING
Ease of use	✓	✓	✓
Easily removed	✓	×	✓
Environmentally friendly	✓	✓	×
Expensive	×	✓	×
Good carton structural integrity	✓	✓	×
High maintenance	×	×	✓
High Strength	×	×	✓
Manual operated	✓	✓	✓
May hinder carton loading	×		
Operational only on flat surface	×	✓	✓
Prevent ingress of foreign matter	✓	×	×
Printed message	✓	×	×
Require separation for recycling	×	✓	✓
Reshapes carton	×	×	✓
Subject to breakages/failure	✓	✓	✓
Time constraints	×	✓	×

✓ = Advantages   × = Disadvantages

1.4 PROPOSED TAPE-SEALED PACKAGING UNIT

Currently the New Zealand freezing works and Fisheries industries are looking for more effective methods of carton closure, especially for the export of goods. Their existing method is by mechanised polypropylene strapping and hot melt gluing by which causes non-recyclable waste and requires man power to operate machinery. It has also been a target to reuse and misuse of the goods overseas which spoils New Zealand's brand name. The Ministry of Agriculture and Forestry, have voiced their concern of inadequate carton seal placements which has lead to products being rejected or held pending awaiting corrective action overseas. Both parties have expressed interest for this new taping technology, a method developed by Graphpak Services Limited that seals the carton with packaging tape that can incorporate the required seals while reducing materials and waste. An endorsement from MAF can be viewed in the Appendix A.1.

This new revolutionary technology developed by Mr John D Bradley, managing director of Graphpak Services Limited has been patented and further developed by a masterate project focussing on the development of the tape-sealed packaging unit, that is the tape application equipment. The initial idea started from only a tape head roller which can be housed by a tape dispenser, figure 1-2.

Figure 1-2 Tape Head Roller (Illustration created by Mr Rod Collins)

This method of sealing boxes whereby the tape can be deformed to conform to the varying surface layers of a case with an overlapping lid. The tape is applied horizontally around the case, thus securing the lid to the base. (Figs 1-2, 1-4). Applications of this packaging system include meat, seafood and potentially other fresh or frozen produce.

Figure 1-3 Photos of a modified taping machine applying tape to a carton with lid. Modified from vertical to horizontal taping, machine supplied by The Sellotape® Company in Auckland.

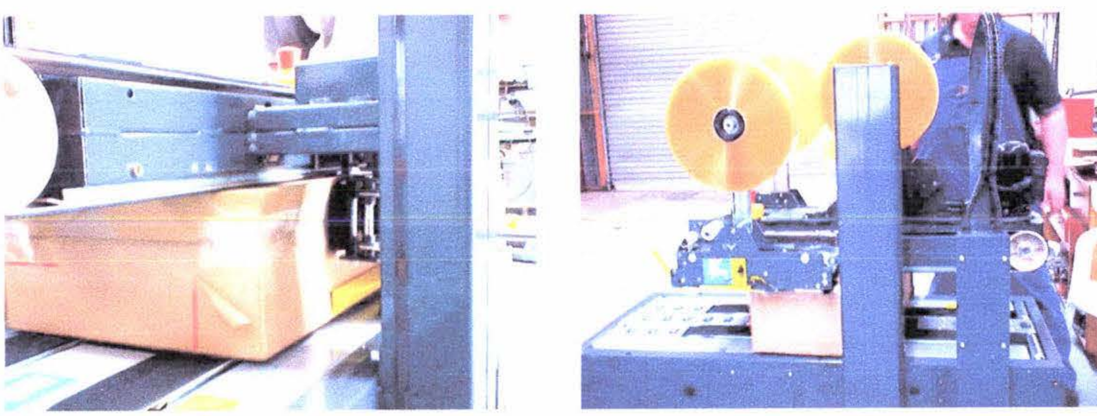
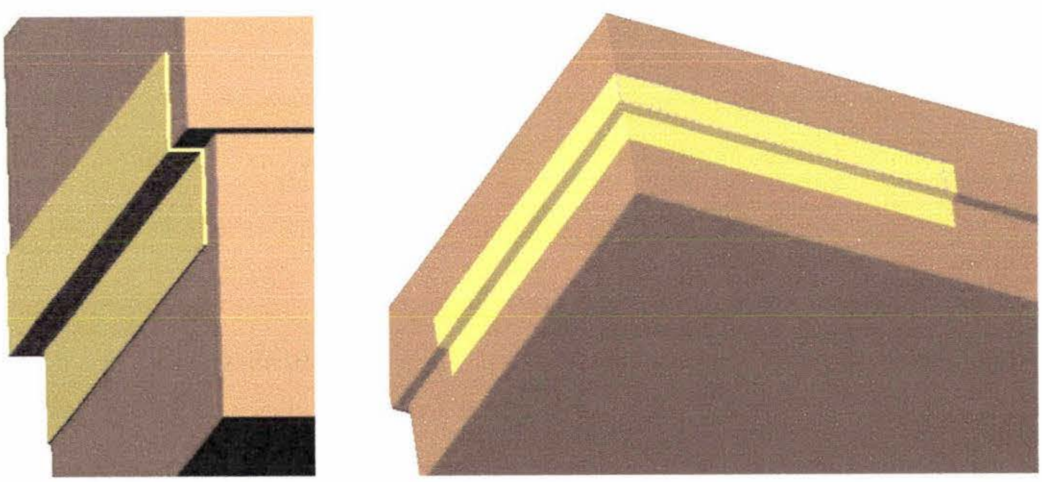


Figure 1-4 Illustrations of the results from the application of the tape-sealed unit to cartons with tape (Illustrations created by Mr Rod Collins)



The advantages of this type of closure of cartons are:

- The package is tamper evident; the carton fibre material will delaminate when the tape is removed.
- A hermetic seal is produced reducing freezer burn and eliminating the need for plastic liners for frozen products. There is no air gap in the fold of the tape to the lid.
- Structural integrity is improved allowing thinner gauge packaging materials, thus reducing packaging material.
- Better constancy of the shape of the packaging improving palletisation with less air gaps between packages, hence improving heat transfer during the freezing process.
- Corresponds to recycling requirements

The potential market and environmental factors that dominate this new method of carton closure has been explored by fellow student Rod Collins in his research of the feasibility of this project while undertaking the development in the construction of the taping system. The potential economic significance for the food packaging industry was also explored and is immense. The savings from material reduction alone will impact the large export trade that exists in New Zealand, [Charles Roderick Collins 2002, Horizontal Application of Tape System (HATS)].

This project will be successful if an adhesive sealing tape can be developed that: imparts minimum strength properties to the packed carton; is tamper evident; incorporates security features to deter fraud and allow traceability; produces an airtight seal; and allow savings in packaging materials.

This work reports on the support of the tape-sealed packaging unit and investigates potential existing packaging tapes that are likely options for use with this system. Existing freezer grade or cold temperature tapes with its vast working temperature range is favoured.

1.5 AIMS

The aims of this research are to

1. Investigate existing packaging tapes with potential for selection for use with the tape-seal packaging system.
2. Develop security measures to protect the tape and system.
3. Develop a package design for use with this tape sealing system.
4. Make recommendations for future development of the tape and system.

1.6 OBJECTIVES

1. Develop appropriate performance specifications and test methods to conduct on selected existing packaging tapes.
2. Investigate tape and adhesive substrates for suitability.
3. Explore methods of security protection of the tape and system.
4. Develop a package design to take advantage of this tape sealing system.

1.7 THESIS STRUCTURE

The literature review follows this section and provides a basic overview of relevant topics and issues that aid in attaining the project's aim. Five experimental chapters follow each including results and discussions, the topics investigated are:

1. Tape Performance Specifications and Testing.
2. Tape Material and Adhesive System.
3. Use of Ionised Air.
4. Development of Security Features.
5. Package Design.

The project then comes together again for an overall conclusion.

2.0 – LITERATURE REVIEW

2.1 ADHESIVE

An adhesive is a compound that adheres or bonds two items together.

2.1.1 HISTORY

The first adhesives were natural gum and other plant resins. In the 1700s, the first glue factory was founded in Holland, which manufactured hide glue [http://en.wikipedia.org/wiki/Adhesive]. Around 1750, the first glue or adhesive patent was issued in Britain. The glue was made from fish. Patents were then rapidly issued as development for adhesives using natural rubber, animal bones, fish, starch, milk protein or casein were discovered. Today adhesives have improved flexibility, toughness, curing rate, temperature and chemical resistance to say the least, [http://inventors.about.com/od/gstartinventions/a/glue.htm].

2.1.2 THE CLASSIFICATION OF ADHESIVES

Many types of adhesives are currently used and there is no single system of classification sufficient for all products. The adhesive industry has generally employed classification based on end-use, such as metal-to-metal adhesives, wood adhesives, general purpose adhesives, paper and packaging adhesives and so on. A limitation of this system is that a particular end-use adhesive may be useful in several other fields. Apart from end-use, adhesives may be classified according to physical form, chemical composition, method of application, various processing factors (e.g. setting action), and suitability for particular service requirements or environment, [J. Shields, 1984].

2.1.3 CATEGORIES OF ADHESIVES

Natural adhesives

Adhesives from inorganic mineral sources, or biological sources such as vegetable matter, natural resins, animal skin, and bioadhesives (natural polymer compounds).

Synthetic adhesives

Adhesives based on elastomers, thermoplastic, and thermosetting adhesives.

Drying adhesives

These adhesives are a mixture of ingredients (typically polymers) dissolved in a solvent. Examples are white glue, and rubber cements.

Contact adhesives

Contact adhesive must be applied to both surfaces and allowed some time to dry before the two surfaces are pressed together. Natural rubber and polychloroprene (Neoprene) are frequently used. Contact adhesives are used in laminates, such as bonding Formica to a wooden counter, and in footwear, for example attachment of an outsole to an upper.

Hot adhesives (thermoplastic adhesives)

Also known as "hot melt" adhesives, these adhesives are thermoplastics; they are applied hot and simply allowed to harden as they cool. A glue gun is example of a hot adhesive

Pressure Sensitive Adhesive (PSA, self adhesive, self stick adhesive)

Pressure sensitive adhesives are polymeric-based adhesives that melt at room temperature. When pressure is applied to the adhesive, they become flowable (a viscous flow) thereby covering the substrate. As the pressure is removed adhesion takes place.

It is used in pressure sensitive tapes as we commonly refer to in New Zealand cellotape, labels, note pads, automobile trim, and a wide variety of other products. It is important that surface factors such as smoothness, surface energy and removal of contaminants are favorable in order to obtain good bonding. [Donatas Satas, 1989]

PSA's are designed to form a bond at room temperature; 20 to 25°C (68 to 77°F). However, specialty adhesives are made to operate at high or low temperatures for specific application requirements. This is useful as PSAs typically reduce or loose their tack (stickiness) at cold temperatures and reduce their shear holding ability at high temperatures. It is therefore the end use that dictates the selection of the adhesive.

2.1.4 PEEL

One of the often measured characteristics of pressure sensitive adhesives is the resistance to peel that is determined by measuring the force required to peel away a strip of tape from a rigid surface. Resistance to peel is also called peel adhesion and peel force. Adhesion implies a state in which two surfaces are held together, rather than the force required to break them apart. The peel force, as measured by tests, is a function of many factors, not only of the interfacial adhesive bond.

Peel resistance data can produce more information about the adhesive character and its expected performance than other commonly used tests of pressure sensitive products: tack and resistance to creep. However, peel resistance does not necessarily relate to the adhesive performance, and it should not be assumed that the peel resistance and the strength of the adhesive bond are equal.

Peel is a special type of failure that might not be related to many other ways of failure that might take place in use.

Testing

There are several different tests to test the resistance to peel of pressure sensitive adhesive tapes. The most common is the 180 degree peel adhesion test. It is easy to carry out and yields fairly consistent results. The backing properties, however, have a larger effect on the test results than in other tests according to Donatas Satas, (1989). This will be explored as the test is carried out. The basis for most standard tests of pressure sensitive tapes is the American Society for Testing and Materials (ASTM) standards guidelines/methods. These tests have been specifically designed to internationally standardise and control testing methods to yield internationally recognised results. The Pressure Sensitive Tape Council (PSTC), a manufactures' trade association also has peel tests and these are also incorporated into the tests that are conducted.

2.1.5 MODES OF FAILURE

An adhesive failure is a failure of a bond at the interface between the adhesive and the adherend.

Cohesive failure is the failure of a bond within either the adhesive or the adherend, rather than at the interface between them. [Donatas Satas, 1989]

2.1.6 EFFECT OF ADHESIVE THICKNESS AND BACKING

According to Chan and Howard (1978), it was noted that peel adhesion increased with increasing thickness of the adhesive and so too is the increase of the backing thickness. This is because the peel force is directly proportional to the amount of the adhesive under deformation and to the energy required to deform the backing. This theory will be tested with the results of the peel adhesion tests in this project which may assist in the design on the proposed tape. A major manufacturer of pressure sensitive tapes 3M™ also believe that the strength of a tape is directly related to the backing thickness. [3M New Zealand Ltd January 2003 Version 4.0, Section 9.1].

2.1.7 PERMANENT VERSUS REMOVABLE

One of the major classifications of pressure-sensitive adhesives is permanent or removable. A basic definition of each adhesive is:

Permanent - An adhesive designed to adhere to a substrate without edge lifting which cannot be removed without damaging either the tape or the substrate.

Removable - An adhesive designed to adhere to a substrate without edge lifting which can be removed without damage to either the tape or the substrate.

Repositionable-Permanent – An adhesive designed to adhere to a substrate without edge lifting yet has an extra long tack range that allows you to lift and reposition before it cannot be removed without damaging either the tape or the substrate. [Istvan Benedek, 2001]

The definition of a permanent or removable adhesive is clear and understandable however, classifying an adhesive is not so easy. A variety of factors including the composition of the substrate, the length of time that the label is applied, and the conditions that the label is exposed to during its life, all affect the performance of the product. Also permanence or removability is a subjective evaluation that can vary from person to person.

Formulation of Permanent Adhesives

The formulation of permanent adhesives is the best developed area of pressure sensitive design and is the area where the proposed tape is based upon. This is the simplest case of formulation, where economic considerations are the determinant. Classical formulations are rubber-resin solutions. First, natural rubbers, then later natural rubber-synthetic blends were used. For permanent pressure sensitive adhesives solvent based formations and hot melt formulations are the most important products for common tapes for its suitability in characterising its properties for end use. While water based formulations are suited to labels. These processes or formulations are further explained in how pressure sensitive tape is made.

Formulation of Removable Adhesive

According to Istvan Benedek 2001, pressure sensitive adhesives can be classified as: permanent, repositionable-permanent or removable products depending on their mode of application.

For permanent and repositionable-permanent adhesives, the build up of the peel resistance with time leads to a peel resistance value, which is higher than the mechanical resistance of the substrate; where by peel resistance, is the bond strength. For the repositionable-permanent adhesive, the increase of the peel with time is slower, than for a common permanent adhesive and allows removing and readhering of the product.

For removable adhesives the initial and final peel resistance values differ only insignificantly and they are much lower than the mechanical resistance of the carrier material or of the substrate. Removability is related to debonding related which depends on the constructional characteristics of the product and on the debonding conditions. These include the nature and geometry of the product components and the build up of the pressure sensitive product. The debonding conditions describe the stress transfer to the adhesive and to the surface of the solid state laminate component during join failure. The destruction of the joint is strongly influenced by the time and temperature of the stress transfer and the deformation of the laminate. As with removable products, the destruction of the joint has to occur without the destruction of the joint components (i.e. substrate or carrier). Therefore the main deformation occurs at the interface substrate-adhesive. At the same time, the rupture energy should be transferred and absorbed in such a manner, which avoids adhesive transfer to the substrate. During debonding, extensive deformation of the specimen occurs and a considerable amount of the fracture energy is associated with the deformation.

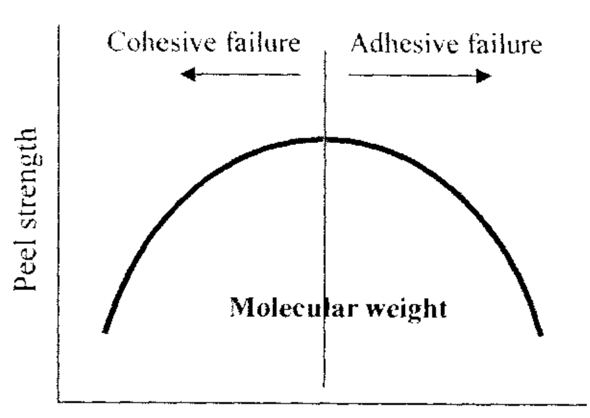
Removability also includes the nature of the bond rupture and the force level required for debonding G', which are time-temperature functions as it is dependent of polymer rheology. A simple theory of bonding and debonding can be controlled through the value of G' and through the dependence of this value on the frequency. A low G', at low frequencies, favours contact build up and controls in some measure the peel build up. The first approximation, G' holds the same small value at different frequencies (ω): $G'=f(\omega)\cong Const.$

Primarily the removability test is carried out by the rest of peel resistance but in practice is determined by the peel value, peel build up and failure nature.

Removability → Peel value
→ Peel build up
→ Failure nature

Ideally, a perfect removable product, this test would result in a low peel resistance value and no bond rupture at the adhesive/substrate interface (no adhesive residue on the substrate). As bond forming is related to the surface conditions on the adhered, removability is therefore surface and cohesion dependant

Figure 2-1 Ideal Model of the Relationship between Average Molecular Weight and Peel Strength of a PSA [Adhesives in Manufacturing Schneberger, Gerald L, 1983]



Bond rupture at the adhesive/substrate interface and at a low level of peel resistance imparts a high cohesion and controlled elastic flow of the adhesive through its viscous flow. Adhesive deformation (creep) is the tendency of any material to undergo a permanent change in dimension when subjected to mechanical stress. Under constant stress (σ_{o}), the adhesive flow i.e. deformation (ε) is a function of the time (t):

$$f(t) = \varepsilon\,(t).l/\sigma_o$$

The creep rate (v) is given the following correlation:

$$V= [\varepsilon\ f(t)/\varepsilon t]t \rightarrow 0$$

The energy dissipation (*W*), originating from the adhesive deformation as a function of creep rate:

$$W = f(E) + f\,[v(t).dt]$$

where *E* is the modulus of the elasticity of the adhesive.

Low peel resistance is achieved using harder monomers, and avoiding monomers that might impart specific adhesion to PSA. High molecular weight and high crosslink density also reduce peel strength. The molecular weight strongly influences removability. High cohesive strength and low adhesive strength are desirable for applications that require no adhesive transfer, an ideal removable adhesive.

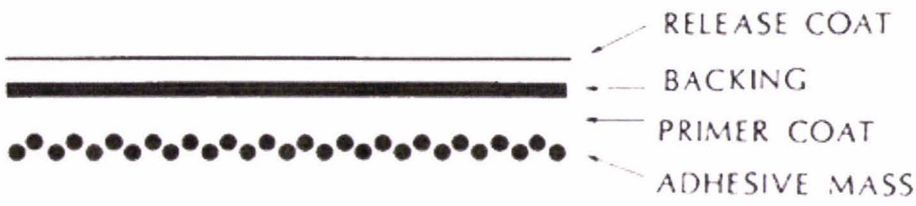
Removability of an adhesive is temperature dependent too. Removable PSAs applied at room temperature and later exposed at low temperatures may behave as permanent adhesives due to the increase of the cohesive strength.

In brief, removable adhesives are described by the value of peel resistance, by the rate of peel build up and by the character of the bond failure. For specific applications, low peel resistance and no adhesive transfers onto the substrate are sufficient. For other applications, a distinct rate of peel build up is essential as this provides time for peeling off and reapplication of the PSA.

2.2 PRESSURE SENSITIVE TAPE

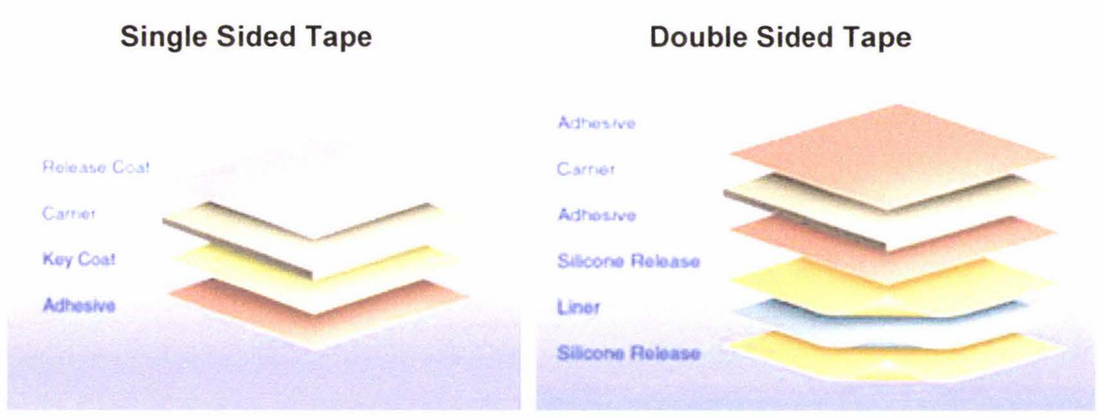
A pressure sensitive tape is classified as any adhesive tape that sticks to a variety of clean dry surfaces applied with little pressure. Permanently sticky at room temperature and does not require water, heat or solvent to activate, it is ready to use anytime [www.sellotape.com]. Typically consists of four component layers, see figure 2.2. Two of these layers are readily recognisable: the adhesive mass, which is usually composed of a synthetic or natural rubber (more recently of an acrylic polymer) and may contain a variety of softeners, antioxidants, plasticisers, and curing agents; and the backing, or carrier, which may be foil, crepe paper, fabric, cellophane, cellulose acetate, plasticised polyvinyl chloride, or any of a number of other flexible materials and may be reinforced with glass or other fibres. Less apparent but equally important are the keying coat, or primer, used between the adhesive and backing to insure good adhesion between the two (it may be based on natural or synthetic elastomers and may contain some tackifiers); and the release coat, applied to the side of the backing that is away from the adhesive mass, so the roll can be unwound without leaving any residual adhesive. Details about the nature of the adhesive mass and the backing are generally obtainable from the manufacturer, but components of the keying coat and release coat are proprietary information

Figure 2-2 Four Components of a Typical Pressure Sensitive Tape
[http://en.wikipedia.org/wiki/Pressure_sensitive_adhesive]



Pressure sensitive tape come with the adhesive coating on one side (single-sided) or both sides (double-sided) of the backing for greater flexibility in usage.

Figure 2-3 Construction of Single and Double-Sided Tape [www.sellotape.com]



2.2.1 HOW IS PRESSURE SENSITIVE TAPE MADE?

Two processes are involved in the production of pressure sensitive tape; coating and slitting. Coating is the application of the adhesive onto the backing and slitting is the cutting up of a huge 'jumbo' roll of the adhesive treated film into a variety of sizes commonly used, [www.sellotape.com].

Coating

Pressure sensitive adhesives must be made "thinner" or less viscous in order to coat the thin flexible backings as it would be extremely difficult to coat if the adhesive was "thick". There are three main ways to do this:-

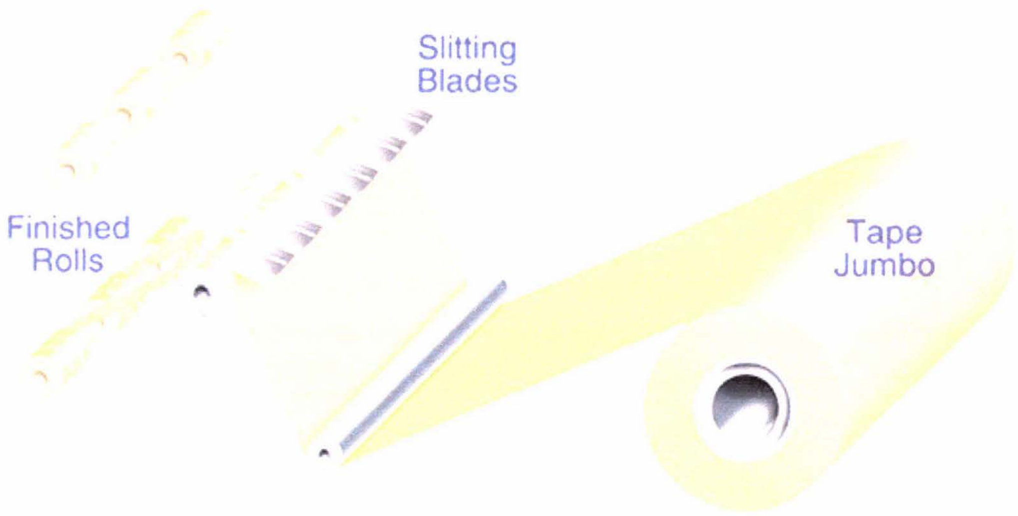
1. Solvent Coating
   The adhesive materials are dissolved into a suitable solvent. The runny solution is then coated onto the backing and the solvent is removed by evaporation through a heated oven.
2. Water-based Coating
   The adhesive materials are mixed with water and then coated onto the backing. The water is removed through a heated oven in the same way as for solvent coating.
3. Hot-melt Coating
   The adhesive materials are heated until they melt and coated as a hot liquid. The coated tape is then simply cooled to give the finished tape.

These three coating techniques are commonly used to classify pressure sensitive tape. Sellotape® in New Zealand use the solvent coating method. The techniques does not take account the type of adhesive and it is this that can have a considerable influence on the tape's performance, [Michael Graves, Sellotape® in communication 2002].

Slitting

The process has now made a 'jumbo' roll, what is call a huge roll of tape, perhaps 1.5m wide x 6000m long. It is the slitting process that turns the large jumbo into rolls useful for everyday use. The jumbo is unwound onto a machine that contains a number of razor blades. The number and distance between these blades determines the width of the tape. The backing passes over these blades cutting the tape into narrower widths and these are then wound on to cores to give the appropriate length for the finished rolls. (Figure 2.4)

Figure 2-4 Illustration of the Slitting Process [www.sellotape.com]



With many different tapes are on the market, it all depends on the definition of what constitutes a different tape and what is merely a variation of the same product. Tapes may be classified according to construction or according to use. Classification according to both criteria produces some repetition, but it also allows coverage of the various aspects of pressure sensitive tapes.

Tapes by construction	**Tapes by function**
Fabric tapes	Hospital and first aid tapes
Paper tapes	Office and graphic art tapes
Film tapes	Packaging and surface protection
Non-woven fabric tapes	Building industry products
Foil tapes	Electrical tapes
Reinforced tapes	Automotive industry products
Foam tapes	Show industry tapes
Double-face tapes	Appliance industry products
Transfer tapes	Splicing tapes
	Corrosion protective tapes
	Miscellaneous tapes and PSA

As is obvious from the construction list, the backing, rather than the adhesive, provides the main distinction among various tapes.

2.3 PACKAGING TAPES

Packaging is the largest volume application for pressure sensitive tapes. The tapes are used for closing packages, making paper boxes, protecting the labels, sealing packages against moisture, and strapping and bundling of loose parts [Donatas Satas, 1989].

Packaging uses are many and varied, and a large number of tapes are used to fill these requirements. Closing of corrugated paperboard cases is a large volume application for packaging tapes. L-shaped strips may be used to close the cases with fully overlapping flaps, heat shrinkable tapes may be used to provide a tamper-resistance seal.

Packaging tapes are used to manufacture corrugated paperboard folding cartons. They are also used to combine small packages into single units, in order to save in shipping costs. Transparent film tapes are used to protect labels. Special, easy-to-open tape closures are used for canned juices and noncarbonated drinks. The tape tab covers a hole in the can end until the customer peels it off.

2.3.1 BACKING (CARRIER) MATERIALS

Pressure sensitive adhesive tape backing can be a large variety of relatively thin flexible materials. Commonly used materials that include films (cellulose, polypropylene or PVC), fabric (cloths and polyester), paper tissues, and foam or even foil, which can be clear, coloured or printed. The choice of backing material depends on application or end use of the PSA.
The least expensive tape available usually becomes the most popular general purpose packaging tape. Currently the lightweight biaxially orientate polypropylene (BOPP) film tape has that position worldwide, although many other tapes are still used as low priced packaging tapes. Rigid vinyl film tapes in Europe, kraft paper tapes in Japan, and saturated paper tapes in the United States still enjoy a fairly wise use. BOPP tape, however, is not only replacing other pressure sensitive tapes, but also gummed paper tape. Although the latter is less expensive, BOPP tape is easier to apply and forms a bond quicker.

All 3M™ packaging tapes are made with BOPP, it is a tough resilient material that is strong lengthwise and crosswise. BOPP resists splitting between the carton flaps and breaking on the corners of the carton, [3M New Zealand Ltd January 2003 Version 4.0, Section 9.1].

2.3.2 ADHESIVES FOR PRESSURE SENSITIVE PACKAGING TAPE

Two main types of adhesives are used for pressure sensitive tapes: rubber/resin and acrylic. [Donatas Satas, 1989]

Rubber/resin adhesive is a mixture of a rubbery material and a hard resin. The rubber and the resin can come from natural or synthetic sources. Natural materials are usually extracted from trees while the synthetics come from the oil industry. The modern PSAs are a blend of an epoxy resin with natural rubber. Synthetic runner resin has a strong holding power; a thick adhesive coat gives high bond to surfaces like recycled board, polyethylene films and in cold or damp environments.

Acrylics are fully synthetic polymers, which are manufactured to give the specific adhesive properties required. The basis of pressure sensitive acrylic adhesives is acrylic esters that yield soft and tacky polymers and therefore has high initial adhesion (stickiness). Polymerisation of acrylics is relatively easy and does not require high temperature of pressure. Although more expensive this has allowed many adhesives users to polymerise acrylic adhesives for their own captive use. Acrylic adhesives are clear and do not yellow with age, however water dispersed acrylic adhesives have a significantly lower shear resistance than synthetic rubber resin, [3M New Zealand Ltd January 2003 Version 4.0, Section 9.1].

2.3.3 TACK

Pressure sensitive tack is the adhesive property related to bond formation. It has been defined as the property that enables an adhesive to form a bond with the surface of another material upon brief contact under light pressure. Understood in definition of pressure sensitive tack of commercial adhesives is the assumption that they separate from adherends cleanly, that is without leaving visible residue.

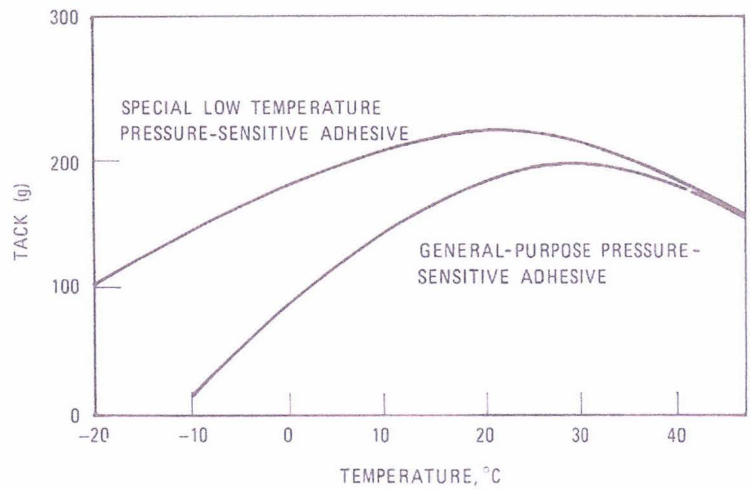
Tack has been called quick stick, initial adhesion, stickiness, quick grab to name a few and is generally considered to be a property associated by low contact pressures and short contact times. Tack is defined by the test used to measure it. The merit of a given tack test is how well it reveals the rate at which a bond forms between the adhesive and the adherend. It interprets the basic terms of the chemical and physical properties and how well it predicts an adhesive's function in proposed applications. One of the most widely used tack tests called the rolling back tack test will be preformed under the guidelines of the American Society for Testing and Materials (ASTM) standards.

2.3.4 LOW TEMPERATURE TAPES (FREEZER GRADE/COLD TEMPERATURE)

A special type of formulation is required for pressure sensitive adhesives that are used in cold environments such as for this proposed tape that is used for frozen and chilled food packaging.

Most adhesives lose their tack and adhesion properties as temperature decreases as shown on figure 2.5 which illustrate the results of probe tack measurements as a function of temperature. According to the results of Donatas Satas 1989, it is clear that if the temperature falls below 20°C, the tack decreases rather sharply, but at 0°C common adhesives are very low in aggressive tack and at -10 °C, they have no measurable tack at all.

Figure 2-5 Probe Tack as a Function of Temperature



As the need for low temperature tapes increases with industry demands, it has become an area where tape manufacturers place a great deal of technology to produce the best; that is to remain a strong and sticky tape at frozen temperatures. It is not uncommon for manufacturers to give out minimal adhesive components in order to remain competitive in the market.

2.3.5 RECYCLABILITY

PSA box sealing tape products using plastic film backing do not appreciably interfere with the corrugated recycling process and need not be removed prior to recycling.

From observations in recycling plants indicate that the adhesive stayed with the polypropylene film during the recycling and separation steps and thus would not contribute to the "stickiness" problem. This problem occurs in paper recycling operations and results from adhesive, glue and other low molecular weight resins found in miscellaneous paper scrap. Stickiness may cause unacceptable blemishes in the recycled paper product, thereby reducing visual quality. Comments from recyclers indicate that wax and hot melt glues are the major contributors to stickiness.

Tape removed in the recycling process may be safely land filled, incinerated in appropriate facilities with the heat energy reclaimed, or presumably recycled into useful products when plastic recycling processes.

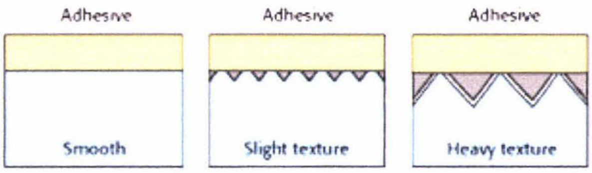
2.3.6 REQUIREMENTS FOR GOOD BOND STRENGTH

Many factors affect bond strength and can be related to both the adhesive and the substrates. The basic requirements for good bonding are as follows:

1. Good wetting on the surface of the adhered by the adhesive. For this a clean surface are essential.
2. A thin film of adhesive correctly positioned on the surfaces.
3. Increased pressure before curing (compression stage) to increase penetration of the adhesive into the porous surface and/or help air trapped at the interface to dissolve into the adhesive to attain better wetting.
4. Surface contamination such as skin oils and bodily fluids can prevent contact of the adhesive with the substrate. Surface contamination may be present if one can detect loose material on the surface of a substrate or the material feels slippery, greasy, or slimy.
5. Surface texture of a substrate can also have an impact on the PSA bond. Textured materials do not allow complete contact of the adhesive with the substrate; the less contact, the smaller the bonding area and the lower the adhesion (see Figure 2-6)

Figure 2-6 Impact of Substrates Texture on the Strength of the Adhesive Bond

[http://www.devicelink.com/mpb/archive/98/01/002c.html]



2.4 CORRUGATED FIBREBOARD

2.4.1 ORIGIN OF CORRUGATED FIBREBOARD PACKAGING

The use of corrugated paperboard apparently stemmed from clothing fashions [Fibre Box Handbook, 1994]. In 19th century England, hand-cranked corrugated roller presses were being used to press the pleats and ruffles of ruffled shirt collars and cuffs. In 1856, this press was adapted to generate corrugated paper to replace plain paper in the cylindrical liners used to keep the shape of the tall, stiff hats worn by gentlemen. The new cylinder was stronger and its flutes provided cushioning in the sweatband.

In 1871, corrugated paper was first used in the U.S. by Albert L. Jones, who patented corrugated paper to wrap bottles and glass chimneys for kerosene lamps. With the development of including a liner to prevent stretching of the flutes, over the next 20 years, machinery was progressively developed until the first "cellular board boxes" were introduced in 1894. These corrugated fibreboard boxes were much lighter and less expensive than wood boxes, and appeared suitable for the shipment of light products.

Now corrugated is not confined to the manufacture of boxes (shipping containers) [www.cccassociation.com/facts.html]. Its incredible strength, flexibility and adaptability allows it to be used to make a wide variety of commodities, from merchandising displays to corrugated pallets that can support up to several tons of product. Corrugated can even be used to make furniture!

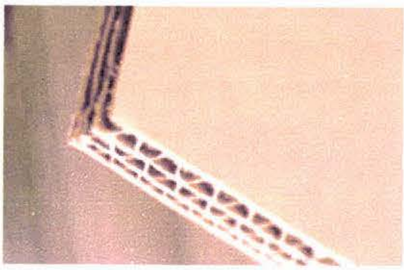
2.4.2 WHAT IS CORRUGATED FIBREBOARD [www.cccassociation.com/facts.html]

- Everybody's seen it, just think of pizza boxes, or the big boxes that hold new refrigerators and televisions. Corrugated is built like a sandwich - characteristic arches of wavy "fluting" lying between two pieces of smooth board on the outside.
- The Corrugated medium is usually made from recycled paper in New Zealand [Tom Robertson, 2004]. While the liners are virgin paper.
- Old corrugated boxes can be recycled many times to make new corrugated boxes and/or recycled paperboard.
- Corrugated allows for direct printing of high-quality, colour graphics (with non-toxic, water-based inks) to "advertise" the product or company's message.
- Corrugated is used to produce rigid shipping containers that can be cut and folded into any shape or size. "Flute" sizes and thicknesses can be customised to meet specific requirements of strength and flexibility.
- Corrugated packaging is inexpensive and always readily available. Its light weight, "knock down" ability and stackability make for inexpensive and easy-to-transport options.
- Corrugated are impact-, drop- and vibration-resistant, as well as lightweight yet durable enough to withstand the rigors of transporting products over long distances.
- Corrugated is a strong, versatile packaging material that is universally accepted for recovery and recycling, while being "environmentally friendly."
- Corrugated's unique "cushioning" and flexibility characteristics make corrugated an ideal packaging material.

2.4.3 BOX STRUCTURE

Corrugated fibreboard has two main components: the linerboard and the medium. Both are made of a special kind of heavy paper called containerboard. Linerboard is the flat facing that adheres to the medium. The medium is the wavy, fluted paper in between the liners. [cpc.corrugated.org/Basics/BasicAllAbout.aspx]

Figure 2-7 Corrugated Fibreboard [cpc.corrugated.org/Basics]

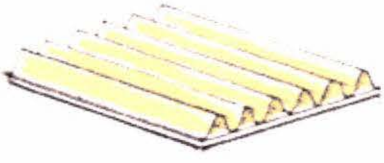


The following illustrations demonstrate four types of combined board, [cpc.corrugated.org/Basics/AboutCorrugated.aspx].

Single Faced Board:

One medium is glued to one flat sheet of linerboard; this is not used for corrugated boxes but is mainly used for pads, partitions and wrapping uneven objects.

Figure 2-8 Single Faced Fibreboard

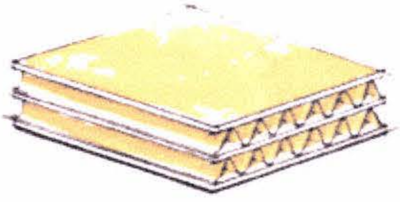


Single Wall: The medium is between two sheets of linerboard. Also known as Double Faced or Double Lined. The most common corrugated board, it has three-dimensional rigidity and is the standard board used for the manufacture of corrugated cartons and boxes.

Figure 2-9 Single Wall Corrugated

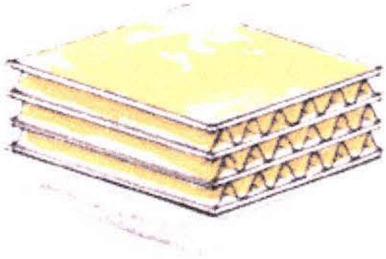
Double Wall: Three sheets of linerboard with two mediums in between, also known as Twin Cushion and provides crushing resistance, impact resistance and tensile strength flexural rigidity.

Figure 2-10 Double Wall Corrugated



Triple Wall: Four Sheets of linerboard with three mediums in between, also known as Tripe Flute, not manufactured in New Zealand

Figure 2-11 Triple Wall Corrugated



Duo Arch or Powerply board is single wall board in which two thicknesses of corrugated medium are formed and adhered together.

Figure 2-12 Duo Arch Corrugated [www.kebet.com.au/specs/materials.php]

This gives the board a very rigid quality. It may be added into twin cushion board for extra strength. Duo Arch with single or double wall is usually associated with very heavy cartons

2.4.4 FLUTES

It is known that an arch with the proper curve is the strongest way to span a given space. The inventors of corrugated fibreboard applied this same principle to paper when they put arches in the corrugated medium. These arches are known as flutes and when anchored to the linerboard with a starch-based adhesive, they resist bending and pressure from many directions. When a piece of combined board is placed on its end, the arches form rigid columns, capable of supporting a great deal of weight. When pressure of applied to the side of the board, the space in between the flutes acts as a cushion to protect the container's contents, The flutes also served as an insulator, providing some product protection from any sudden temperature changes. At the same time, the vertical linerboard provided more strength and protects the flutes from damage. [cpc.corrugated.org/Basics/BasicAllAbout.aspx]

Flutes come in several standard shapes or flute profiles (A, B, C, E, F etc...). A-flute was the first to be developed and is the largest common flute profile. B-flute was the next and is much smaller. C-flute followed and is between A and B in size. E-flute is smaller than B and F-flute is smaller yet.

In addition to these five most common profiles, new flute profiles-larger and smaller than the mentioned are being created for more specialised boards. Generally, larger flute profiles deliver greater vertical compression strength and cushioning. Smaller flute profiles provide enhanced structural and graphics capabilities for primary (retail) packaging.

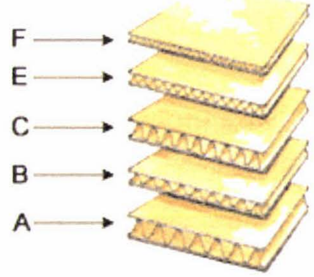
Different flute profiles can be combined in one piece of combined board, For instance, in a triple wall board; one layer of medium might be A-flute while the other two layers may be C-flute. Mixing flute profiles in this way allows designers to manipulate the compression strength, cushioning strength and total thickness of the combined board. In referring to double wall boards, it is usual to name the flute on the exterior of the container first.

Table 2-1 Corrugated Size Classification

Flute Contour	Approximate Number of Flutes/m	Flute Height/cm *(Excludes facings)*
A	100-120	0.476
B	145-165	0.238
C	120-140	0.357
E	280-310	0.119
F (micro)	420	0.075

The length of the fluting medium before corrugation to liner length can be called the theoretical take-up factor, and can be calculated by the length of the fluting medium before corrugation/ liner length ratio. On average, A flute has the higher take-up factor then C, B and E flutes.

Figure 2-13 Comparison of Flutes



2.4.5 CORRUGATED CONTAINER ATTRIBUTES

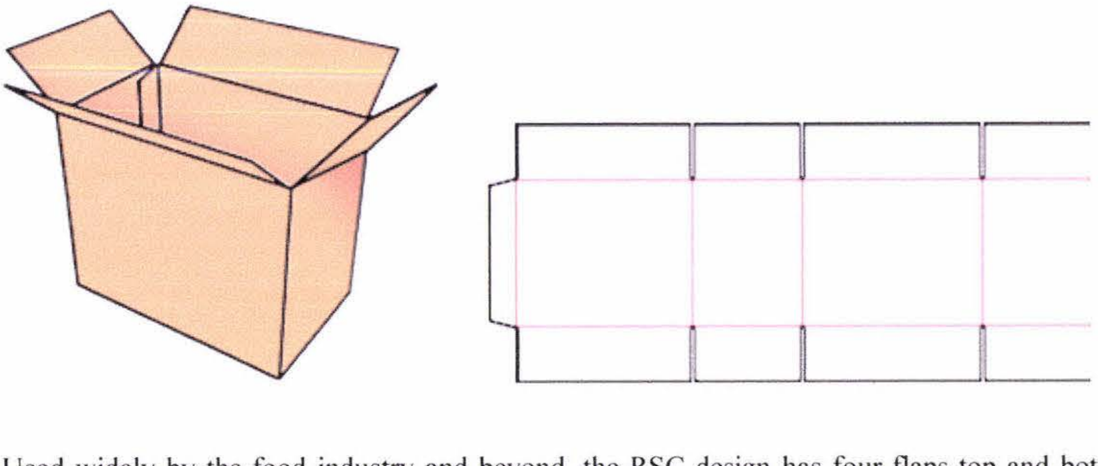
The main purpose of a corrugated box is to carry a product through the distribution cycle safely. The strength is determined by mimicking real environmental hazards by dropping to stress the fibres in the box, which when flute size is correctly chosen, the corrugated box protects its products well.

Corrugated boxes are often stacked while in storage or during transportation. A major part of the design of corrugated boxes plays down the effects of heavy stacking enabling good stackability. Various ways of determining the strength of the box where it is crush or puncture resistant connects to the strength of the box through overall containment strength determined by paper grade and flute size.

2.4.6 CONTAINER STYLES

The regular slotted container (RSC) is the most commonly assembled of the corrugated containers as it is the most economical, using board material efficiently.

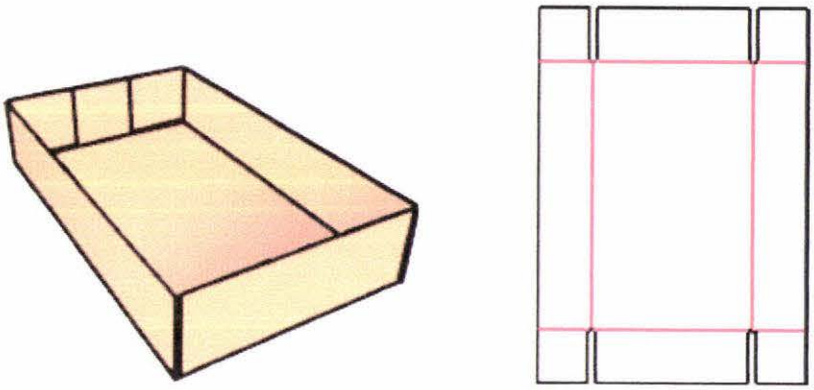
Figure 2-14 Assembled RSC with Corresponding Flat Scored and Slotted Sheet Layout



Used widely by the food industry and beyond, the RSC design has four flaps top and bottom with outer flaps meeting but inner flaps do not. The flaps that meet in the centre and can be taped, glued or stapled to close.

The half slotted container (HSC) is an RSC but with only one set of flaps plus a cover. The cover may be a telescoping half slot style or a design style tray (side slotted tray) shown below which both provide great stacking strength. HSC are generally used as a combined shipper and shelf packages.

Figure 2-15 Assembled HSC and Lid with Corresponding Flat Scored and Slotted Sheet Layout

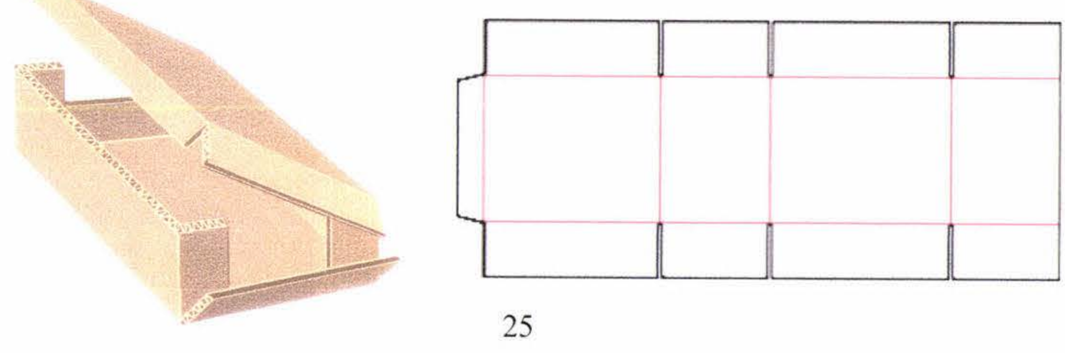


Fold and Wrap Around Blanks

A five panel folder and wraparound design container similar to below are scored sheets with tucks of specified length and are easy to store and set up by taping or with staples. The five panel folder gives extra thickness of board at the ends providing additional strength and insulation and offers extra support to prevent shipped merchandise from piercing through the ends. Suitable for shipping long items.

Figure 2-16 Assembled FPF with Corresponding Flat Scored and Slotted Sheet Layout

[Fibre Box Handbook Page 26, 1992]



2.4.7 PACKAGING FUNCTIONS

Packaging has many levels:

Primary package	The first wrap or containment of the product. It directly holds the product for sale.
Secondary package	A wrap or containment of the primary package
Distribution package or shipper	A wrap or containment whose prime purpose is to protect the product during distribution and to provide for effective handling.
Unit load	A number if distribution packages bound together and unitised into a single entity for purpose of mechanical handling, storage, and shipping.

Packages can also be defined by their intended destination:

Consumer package	A package that will ultimately reach the consumer as a unit of sale from a merchandising outlet.
Industrial package	A package for delivering goods from manufacturer to manufacturer. Industrial packaging usually, but not always, contains goods or materials for further processing.

The basic packaging functions have different degrees of importance, depending on the particular packaging level and intended destination. It is common for several packaging levels to contribute to a single function.

The resulting primary package we are designing holding the meat products are to be stacked into a unit load such as a pallet and transported to its final destination as industrial packages.

2.4.8 CORRUGATED CONTAINERS FOR FOOD PACKAGING

Advantages of using paper/paperboard in food packaging include:

- Paper or paperboard provides mechanical strength
- Paper/paperboard is biodegradable and consequently has a good environmental image
- Paper/paperboard has good printability
- Paper/paperboard is a cheap packaging material to use
- Coatings can be used to improve its "naturally" poor barrier properties, e.g. Waxes or polymeric material. PET coated paperboard is a duel-oven able material
- Suitable for use in microwave ovens

Disadvantages of using paper/paperboard in food packaging are as follows:

- Porous
- Opaque
- Poor barrier properties to oxygen, carbon dioxide and water vapour

- Does not prevent loss of flavour components or volatiles from foods
- Is not grease/fat resistant, unless previously treated
- Can not be heat sealed
- Can not be co-extruded, consequently to produce a laminate containing paper adhesive must be used
- Can be easily torn.

2.5 SUMMARY

The information highlights the vast array of packaging tapes and it is safe to say, no two tapes are alike. Manufacturers will tweak formulations to gain market share in the competitive market of adhesive tapes. However, they all strive to reach a common goal and that is to develop a tape to meet the purpose of its end use. From the history and technological advancements, we can narrow down materials and properties required to create an adhesive tape we need for a specific purpose.

The purpose of this proposed tape is to withstand the harsh cold conditions of the chiller and freezer while still able to be adhered to the substrate to seal a carton for the duration required to reach the destination intended. The required adhesive tape must be a pressure sensitive tape and the substrate is the commonly used corrugated fibreboard box. To have further explored the properties of both these items we can maximise the potential to understand what characteristics and properties we are looking for to develop this packaging tape for commercial use for the New Zealand exporting industry. We know we are now looking for:

- a pressure sensitive adhesive (PSA) tape that uses biaxially orientate polypropylene (BOPP) as the carrier/backing,
- an existing low/cold temperature tape that will not fail adhesively and cohesively in the required conditions and load,
- is a permanent pressure sensitive tape,
- PSA's that will yield high results for properties such as peel force and tack to maximise the tapes performance.

3.0 – TAPE PERFORMANCE SPECIFICATIONS AND TESTING

This chapter introduces the tape substrates chosen for investigation to tests and experiments to aid in the development of technical specifications ideal for the tape sealing system.

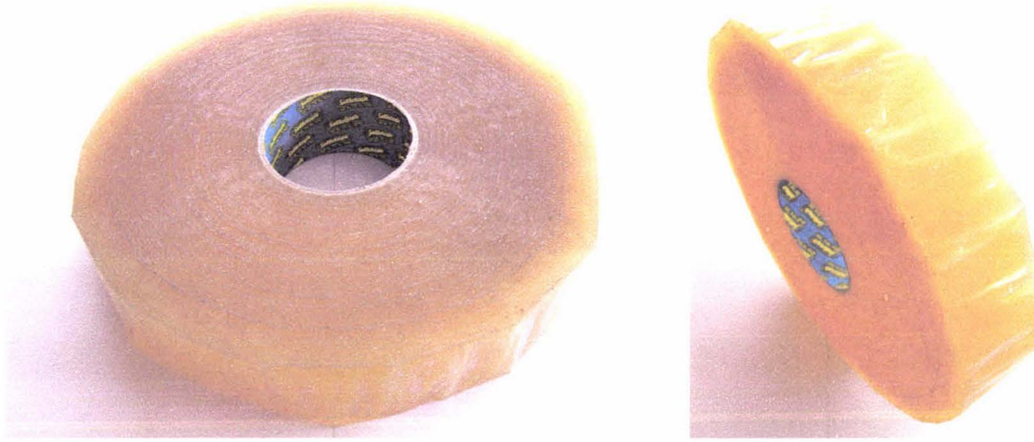
3.1. TARGET PERFORMANCE SPECIFICATIONS FOR PROPOSED TAPE

- A Pressure Sensitive Adhesive (PSA) tape
- Clear or transparent
- Have a width of < 60mm
- Be functional between –20°C to 26°C
- Impart minimum strength properties for normal use packed cartons
- Be tamper evident
- Incorporate security features to deter fraud
- Allow traceability
- Have an airtight carton seal
- Minimise costs and materials
- Use a suitable ink for labelling
- Bear the official Ministry of Agriculture and Forestry (MAF) seal
- Must be recyclable

3.2 SPECIFICATIONS OF PRESSURE SENSITIVE TAPES INVESTIGATED IN THIS PROJECT

Tape 1 Sellotape® Fresh

Figure 3-1 Photos of Sellotape® Fresh Tape



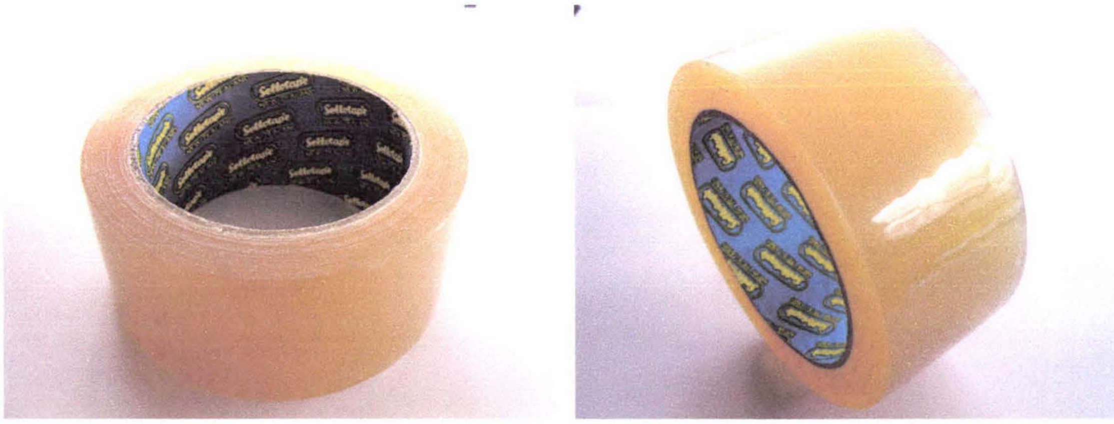
Manufacturer: Sellotape®, Made in Auckland, New Zealand

Table 3-1 Sellotape® Fresh specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Carton closure packaging tape 1545	2 weeks	30 micron biaxially oriented Polypropylene film (BOPP)	Synthetic rubber resin	Clear/tint of orange	48mm × 1000m

Tape 2 Sellotape® Freezer Grade

Figure 3-2 Photos of Sellotape® Freezer Grade Tape



Manufacturer: Sellotape®, Made in Auckland, New Zealand

Table 3-2 Sellotape® Freezer Grade specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Freezer Grade carton closure packaging tape on recycled board 1559/1588	2 weeks	30 micron biaxially oriented Polypropylene film (BOPP)	Synthetic rubber resin	Clear/tint of brown	48mm × 50m

Tape 3 Sellotape® Old Age

Figure 3-3 Photos of Sellotape® Old Age Tape

Manufacturer: Sellotape®, Made in Auckland, New Zealand

Table 3-3 Sellotape® Old Age specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Carton closure packaging tape	6 months	Biaxially oriented Polypropylene film (BOPP)	Synthetic rubber resin	Clear/tint of yellow	60mm × 50m

Tape 4 3M™ Cold Temperature

Figure 3-4 Photos of 3M™ Cold Temperature Tape

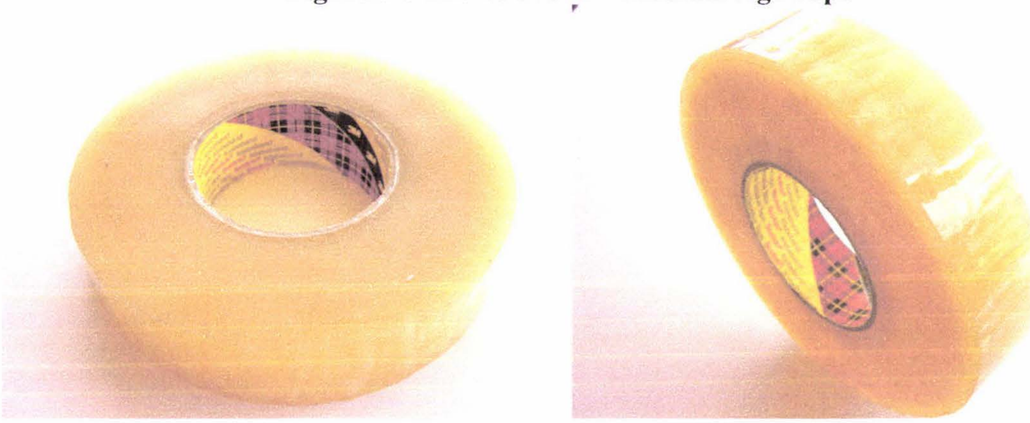
Manufacturer: 3M™ Scotch, Made in U.S.A.

Table 3-4 3M™ Cold Temperature specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Cold Temperature Carton Packaging Tape 311	3 months	28 micron biaxially orientated polypropylene (BOPP)	Water dispersed acrylic	Clear	36mm × 50m

Tape 5 3M™ Medium Age

Figure 3-5 Photos of 3M™ Medium Age Tape



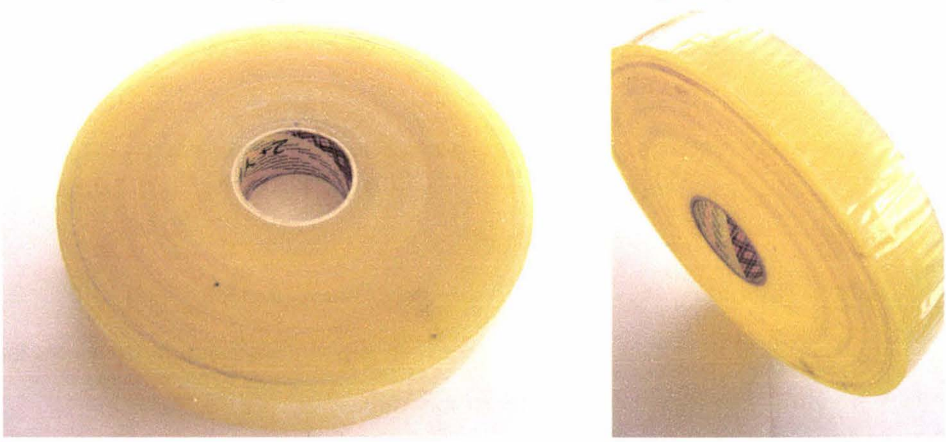
Manufacturer: 3M™ Tartan, Made in U.S.A.

Table 3-5 3M™ Medium Age specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Packaging cartons	1+ year	Biaxially orientated polypropylene (BOPP)	Synthetic rubber resin	Clear/tint of yellow	36mm × 100m

Tape 6 3M™ Old Age

Figure 3-6 Photos of 3M™ Old Age Tape



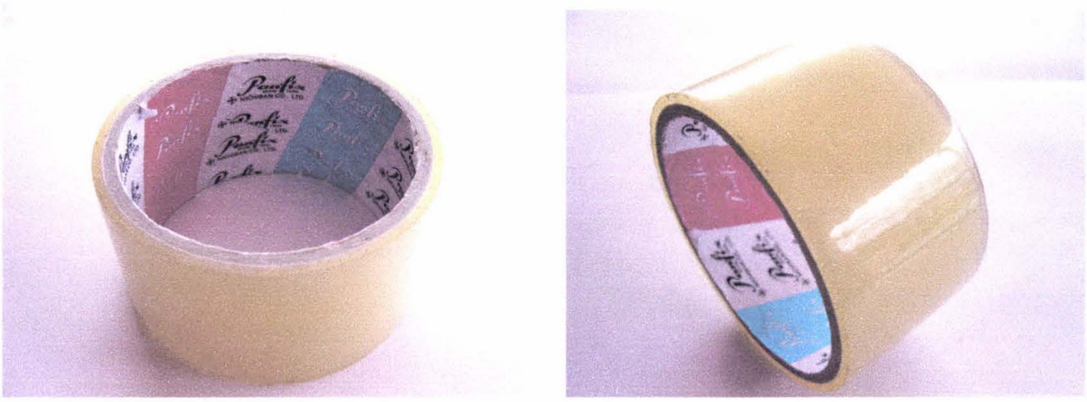
Manufacturer: 3M™ Tartan, Made in U.S.A.

Table 3-6 3M™ Old Age specifications

3Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Packaging cartons	2+ years	Biaxially orientated polypropylene (BOPP)	Synthetic rubber resin	Clear/tint of green	48mm × 1000m

Tape 7 Panfix

Figure 3-7 Photos of Panfix Tape



Manufacturer: Nichiban Co., Ltd, Made in Thailand.

Table 3-7 Panfix specifications

Tape Type	Age (received)	Backing Material	Adhesive	Colour	Size
Carton closure packaging tape on recycled board	1-2 months	30 micron biaxially orientated polypropylene (BOPP)	Natural rubber	Clear/tint of yellow	48mm × 50m

3.2.1 MANUFACTURER'S COMMENTS

Tapes that were obtained new from the manufacturer; both Sellotape® fresh and freezer grade and 3M™ cold temperature were provided with additional information to the characteristics of the tape. This information could aid in the understanding of the performance of these tapes during these experiments.

Sellotape® Fresh and Freezer Grade tapes:

- are made for use on recycled board with a tough bi-axially oriented polypropylene film as backing with an aggressive synthetic rubber adhesive,
- have high tensile strength, high impact resistance, are flexible and conform well to recycled fibre board irregular surfaces,
- have a high resistance to water, acids, alkalis and most solvents and are release coated for ease of handling,

- temperature resistant from -40°C to +70°C.

The freezer grade tape has higher adhesion strength

3M™ Cold Temperature tape:

- are made for use on recycled board of light to medium weight boxes with reliable closures.
- adheres instantly to a variety of surfaces.
- conformable backing.
- used on difficult to bond to surfaces where the load on the tape is low.
- edge tear and split resistant.
- suitable to seal in cold or damp environments (0°C to +10°C).
- performs well when subjected to below 0°C.
- suitable for cartons that are shipped in pallets.
- suitable for wax or plastic coated cartons.

3.3 INITIAL EXPERIMENT

3.3.1 FINISHED ROLL ADHESIVE COATING WEIGHT TEST

[Sellotape Quality Control Manual, 2000, Appendix B.1]

3.3.2 METHODS AND MATERIALS

1. **Definition**

1.1 The adhesive coating weight test determines the weight of adhesive and coating/backing weight and thickness of pressure sensitive tapes, an important set of measurements for comparisons, quality control and criteria acceptability.

2. **Significance**

2.1 To show the finished roll adhesive and coating weight of pressure sensitive tapes.

3. **Test Specimen**

3.1 The test specimen shall be approximately 50mm long by the nominal width of adhesive tape specimens.

3.2 The specimens for testing should be taken from the inner sample roll by discarding at least three but no more than six outer layers of tape. This applies to all sample rolls fresh or aged.

3.3 If the tape is wider than the dimensions required for this test, a specimen cutter must be used and the specimens prepared from the roll as in 3.2.

4. **Equipment**

4.1 An analytical balance to 4 decimal places, supplied by Massey University.

4.2 Adhesive tapes from 3.2 Specifications of tapes investigated.

4.3 Scissors

4.4 Paper towels

4.5 Acetone

5. **Test Method**

5.1 Cut the specimen with dimensions as in 3.1, ensuring cuts are straight, at right angles to the roll edge.

5.2 Form the strip of tape into a loop small enough to fit on the pan of the balance.

5.3 Tare the balance, then weigh the strip of tape and record its weight in grams (weight backing + adhesive).

5.4 Remove the adhesive from the loop of tape using paper towels and acetone solvent in a well ventilated area.

5.5 Dry the washed sample, particularly important for vinyl and PE tapes.

5.6 Reweigh the sample and record its weight in grams (weight backing) and thickness (average of 5 tests).

6. **Report**

6.1 Calculate the weight of adhesive (in grams) by subtracting the weight of the backing (B) from the weight of the backing + adhesive (B + A).

6.2 Calculate the area of the sample in square meters by multiplying its length in meters by its nominal width in meters.

6.3 Calculate the coating weight of the sample to the nearest 0.1 g/m^2 by dividing the weight of adhesive in grams by the area of sample in square meters.

3.3.3. RESULTS *[Appendix B.2]*

Table 3-8 Results of the Finished Roll Adhesive Coating Weight Test

Tape	Roll Width (m)	B + A Thickness (mm)	B Average Thickness (mm)	Area (m^2)	A Thickness (mm) ± 0.002
Sellotape® Fresh	0.048	0.045	0.029	0.0024	0.016
Sellotape® Freezer Grade	0.048	0.045	0.029	0.0024	0.016
Sellotape® Old Age	0.060	0.043	0.029	0.0030	0.014
3M™ Cold Temperature	0.036	0.043	0.028	0.0018	0.015
3M™ Medium Age	0.036	0.045	0.032	0.0018	0.013
3M™ Old Age	0.048	0.047	0.030	0.0024	0.017
Panfix	0.048	0.045	0.030	0.0024	0.015

Table 3-9 Recorded and calculated results of the Finished Roll Adhesive Coating Weight Test

Tape	B + A Weight (g)	B Weight (g)	A Weight (g)	Coating Weight (g/m²) ± 0.2
Sellotape® Fresh	0.116	0.065	0.051	21.3
Sellotape® Freezer Grade	0.115	0.061	0.054	22.5
Sellotape® Old Age	0.148	0.081	0.067	22.3
3M™ Cold Temperature	0.092	0.051	0.041	22.8
3M™ Medium Age	0.079	0.049	0.030	16.7
3M™ Old Age	0.121	0.067	0.054	22.5
Panfix	0.109	0.066	0.043	17.9

3.3.4 DISCUSSION

The results give a good comparison as to the measurements of its backing and adhesive components. 3M™ medium age tape has the thinnest adhesive while both Sellotape® freezer grade and 3M™ old age share the highest of the group. The range of adhesive weight differs 5.8 g/m², a substantial amount that may obstruct some tapes performance ability. These results will aid in understanding performance for the other experiments in this project as measurements of adhesive and backing make up the characteristics of tapes.

3.4 ADHESIVE EXPERIMENT

3.4.1 PEEL ADHESION TEST

A peel adhesive test can tell us whether or not the adhesive is strong enough to suit a particular requirement. In order to understand how adhesive tape behaves when adhered to a carton box over a period of time and in a particular condition, an experiment that mimics the most likely atmospheric situations of an export meat carton can tell us just that.

Two conditions can occur to a meat carton, either it is chilled or placed in a freezer after it's packed. The average length of time the meat in these cartons are packed and shipped to its destination and displayed to be sold and consumed is 6 weeks. During this time, re-palletising and shipping conditions will only vary slightly.

Tapes used: 6 types of pressure sensitive packaging tapes from three brands, Sellotape®, 3M™ and Panfix as described above.

Duration of experiment: 6 weeks

Duration of sample testing: Immediately and once weekly

Conditions: Chiller at 3°C ± 1°C and in freezer of -18°C ± 2°C [Mr Gary Radford, Massey Laboratory Technician] (situated at Massey University, Food Technology Laboratory).

Room Temperature 21°C for 2 brands of freezer grade tape

Sample size: 5

Orientation and type of corrugated panel: Vertical and Horizontal of flute size B (2.38mm thick) corrugated fibreboard

The temperature at which a sample is tested is important and may change the results, therefore it is important to test in an environment matching those conditions, however, the texture analyser can only operate at minimum 0°C. To investigate the effect on samples if taken out of their specified atmospheric conditions and tested at room temperature a thermocouple is placed between the corrugated boards and also between the tape and corrugated board from a specified atmospheric condition and timing the rate of temperature change when exposed to room temperature, 21°C. Testing can be performed if the rate of change is slow whereby testing can be finished before the change in temperature matches that of the conditions tested in. Results showed in figure 3-13.

3.4.2 METHODS AND MATERIALS

Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle

[ASTM D 3330M-96, [Metric][1] *1997 and Pressure Sensitive Council Test Methods PSTC-1, Appendix B.6,B.7]* with conditions in coordinating *[Appendix B.3, B.4, B.5]*.

1. **Definition**

1.1 Peel adhesion is a measurement of the adherence to remove a pressure sensitive tape from a standard test panel or from other surface of interest (tapes own backing).

2. **Significance**

2.1 Shows the measured peel force (relative bond strength) of pressure sensitive tape to one or more surfaces. This test is also a fair and uniform way to determine quality assurance in pressure sensitive tapes. The results can be used in combination to expected requirements for criteria acceptability.

3. **Test Specimen**

3.1 Specimen shall have the dimensions 36mm by 90mm.

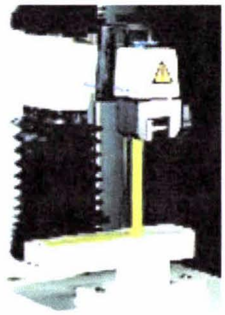
3.2 The specimens for testing should be taken from the inner sample roll by discarding at least three but no more than six outer layers of tape. This applies to all sample rolls fresh or aged.

3.3 Remove one specimen at a time from the sample roll for each test.

3.4 If the tape is wider than the dimensions required for this test, a specimen cutter must be used and the specimens prepared from the roll as in 3.2.

4. Equipment

Figure 3-8 TAXT2 Texture Analyser



4.1 Adhesion Tester (TAXT2 Texture Analyser – made in London the United Kingdom by Stable Micro Systems Limited)

4.1.1 Adhesion peel tester/peel tester

The TAXT2 Texture Analyser is designed to test in both tension and compression for cycling, flexure, constant strain and stress relaxation on such products as food, pharmaceuticals, cosmetics and adhesives.

When testing under tension the machine allows speed adjustment of extension.

For this test a uniform rate of 5m/s is required.

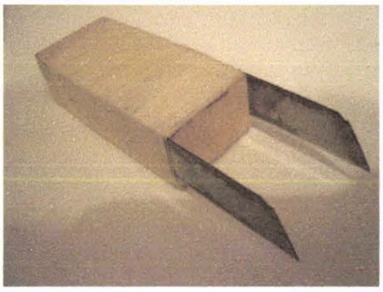
This device is fixed for sampling at the 180° position but must be made sure that the clamps fall inline to pull samples from the same plane.

The texture analyser has a real-time graphics and data acquisition software capable of capturing and displaying all peaks and transients present in the test which are simultaneously displayed while testing. Clamp faces at least wide by 36mm deep are required and shall have a light crosshatch serration.

4.2 36mm Cutter Specimen

4.2.1 The specimen cutter shall hold two single-edged razor blades in parallel planes, held together by a solid medium such as wood. A precise determined distance of 36mm apart to form a cutter to exact specimen widths. (Made by Dave Pollard from Massey University).

Figure 3-9 Photo of Specimen Cutter



4.3 Panel

4.3.1. A 36mm by 90mm corrugated panel of flute size B (2.38mm thick). Panels showing stains, discoloration, scratches or dents are not acceptable.

4.4 Roller, hand operated, rubber covered.

4.4.2 A 3M TI-1756 hand held tape dispenser roller was used. The roller, 36mm in diameter and 50mm in width, covered with rubber approximately 2mm in thickness.

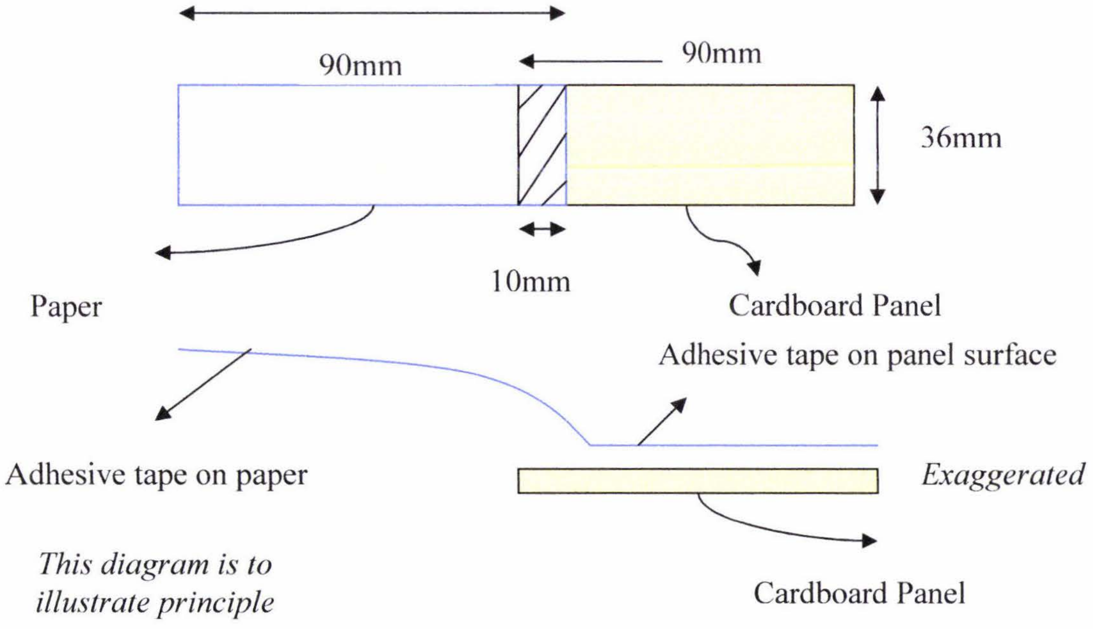
4.4.3 The roller construction should not allow the weight of the handle to increase the weight of

the roller during use. Here the application of the pressure from the roller to the specimen is purely dependent on the individual, uniform application is exercised

5. Test Method

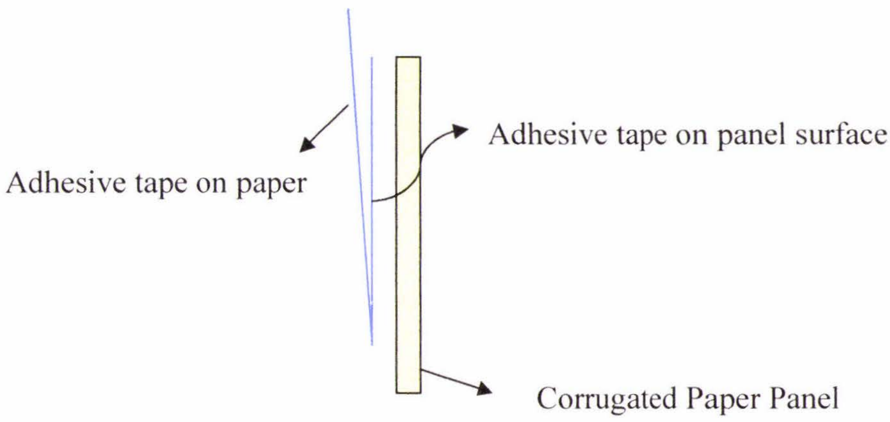
5.1 The panels of the corrugated cardboard are cut to the desired size. 10mm in from one side, a piece of cartridge paper overlaps and extends the board. A piece of tape cut to the required width is applied and rolled on using the hand roller extending to the piece of paper. See figure 3-10 below.

Figure 3-10 Cross section of specimen applied onto the panel



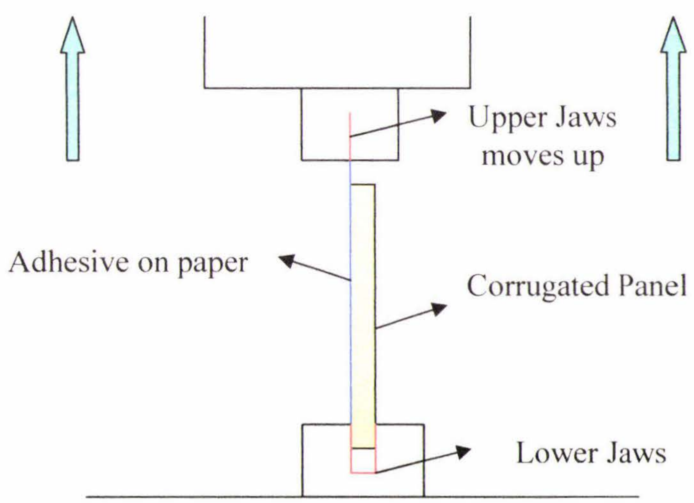
When the paper is folded up, it acts to reinforce the adhesive and must be cut at least 10mm longer than the specimen. The upper clamp can grasp the reinforced end to trigger the peeling motion. See figure 3-11 below.

Figure 3-11 Side on view



5.2 Clamp the 10mm tape free bottom end into the lower jaws of the clamps of the adhesive testing machine and the free end of the tape with paper into the upper jaws like in figure 3-12. Operate the upper jaws at 12"/min. (5m/s). After the upper jaw is started in motion, disregard the values obtained while the first inch of tape is removed mechanically. Use the average pull value obtained during peeling of the next 2" as the adhesion value.

Figure 3-12 Specimen in Adhesive Tester

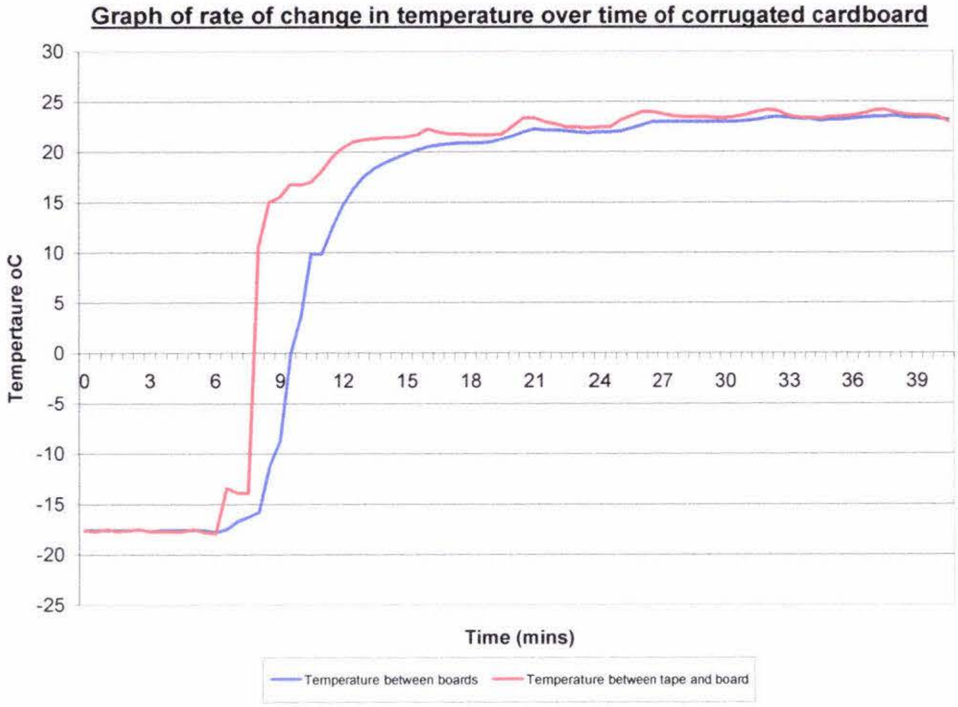


Report

6.1 Report the peel adhesion value in Newton's, N for force.

3.4.3(a). RESULTS *[Appendix B.8]*

Figure 3-13 Rate of Temperature increase of Corrugated Fibreboard from Freezer to Room Temperature



3.4.3(b). RESULTS *[Appendix B.9]*

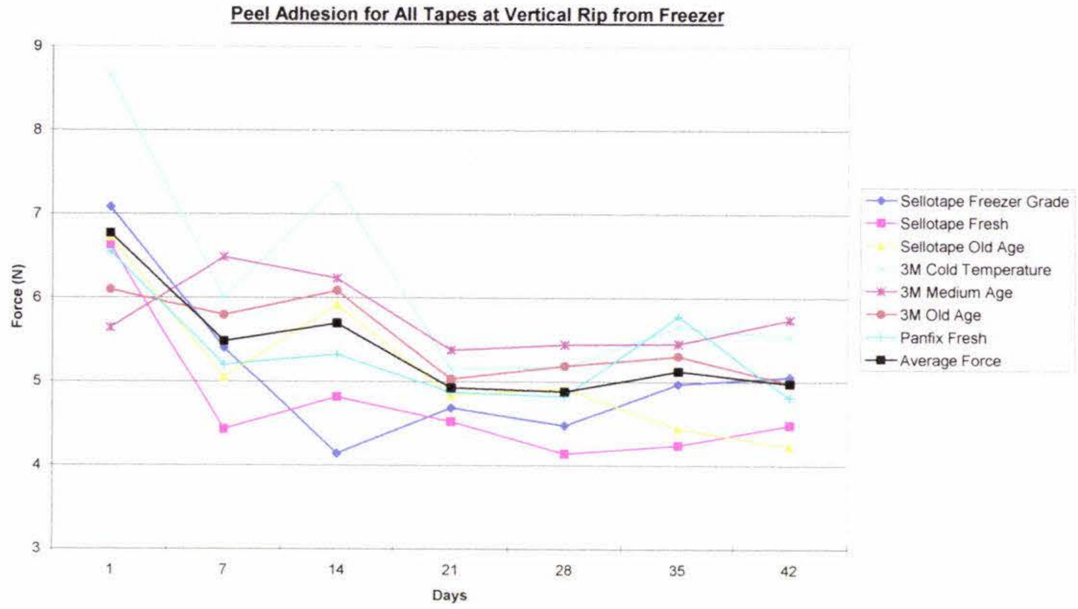
The results from the two tested conditions showed definite similarities and even more so when the tapes were compared within each test condition.

All the tapes showed a dip in force measurement after the initial test when placed in the freezer. However the majority of tapes showed an increase toward the end of the test at six weeks while moving at a random and steady measurement. As observed, the opposite of what was expected along with the results and the observation showed that a high force value doesn't necessarily mean the tape has torn more fibres, instead it took a bigger force to detach the tape from the board cleanly.

The gathered results also showed that there was a difference in which orientation of the corrugated the tape was torn from. It was clear from the entire test that the vertical orientation of the corrugated produced the lower force, therefore detaching more fibre from the board.

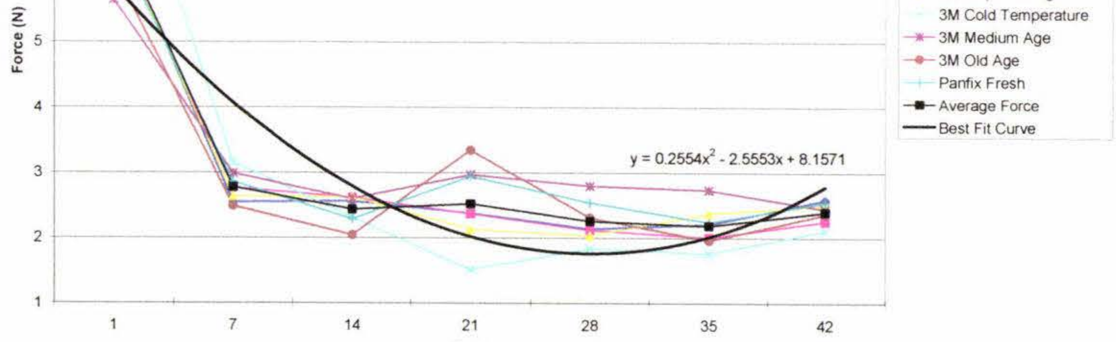
In stating that, Sellotape® Fresh Age tape performed the best followed by Sellotape® Freezer Grade as it yields an overall lowest force value throughout the six weeks of the experiment.

Figure 3-14 Force of Peel Adhesion of all tested Tapes from Freezer at Vertical Pull



The results from the chiller conditions not only showed the expected drop in measurement after the initial test, it dipped lower than those from the freezer, in fact on average of two Newton's.

Figure 3-15 Force of Peel Adhesion of all tested Tapes from Chiller at Vertical Pull



At room temperature, only the two brands of freezer grade were tested at vertical rip. Without drastic temperature changes, the results throughout the weeks were steady as expected. However, the 3M™ range actually increased in force for the first three tests until levelling for the remainder tests. From observation, the tape tore off completely clean of fibres.

3.4.4. DISCUSSION

Majority of the results graphed show a pattern of a decreasing curve with a high initial dip but an increase toward the end. The initial measurement which is at room temperature is expected to be higher than that of the rest of the experiment. The following measurements that decrease show an increase of the adhesive to adhere to the board fibres as the specimen is kept longer in the colder environments which makes for lower force on detaching.

The findings confirmed that tapes made for a certain environment do do best in that environment. In freezing conditions although the Sellotape® brand of freezer grade did not perform the best it was not far behind a fresh roll of the same brand tape, even though the results were insignificant. It is known that a fresher roll would definitely be stickier than that of an old roll with an adhesive formula not unlike one another. This could be an explanation of why the fresh roll outperformed the freezer grade that was expected to do well in freezing conditions. This also is reinforced by what we know from 2.1.6 of the literature review that the higher adhesive coating weight (see Table 3-9) yield higher peel force values.

In the chiller, the Sellotape® freezer grade followed closely but the 3M™ range performed the best throughout the experiment. Due to the nature of the formulation of the adhesive substrate of both these brands, it is clear that in chilled conditions that these tapes perform well. The results in the chiller of all the tapes yielded an overall drop to that in freezing conditions. The theory would be due to the higher temperature in the chiller over the freezer which makes the tape more manageable. As the temperature increases there's a higher chance that the fibres do adhere to the tape stronger than that of a dry and brittle condition.

From observation, it was seen that a lower force is required to pull a strip of tape from the fibreboard with detached fibres than that of tape peeled clean of fibres. This is because it is harder and requires a higher force to peel a piece of tape while trying to maintain its fibre free stickiness, usually accomplished slowly. Also, placing the tape along the same vertical plane as the corrugated flute will cause more fibre tear since the fibres are more likely to move in the same orientation of the grain of the paper.

3.5 TAPE BACKING EXPERIMENT

3.5.1 ULTIMATE TENSILE STRENGTH AND ELONGATION TEST

[ASTM D 3759M-96, [Metric][1] 1997and Pressure Sensitive Council Test Methods PSTC-31, Appendix B10,B11]

3.5.2 METHODS AND MATERIALS

Tensile Strength and Elongation of Pressure Sensitive Tapes

1. **Definition**

1.1 Tensile Strength or Ultimate Tensile Strength (UTS) – the force required, per unit width, to break the tape when tested under set conditions. It is expressed in pounds per square inch (psi) or more commonly Newton's per metre squared Nmm^{-2} (1 Nmm^{-2} = 1 MPa = 145 psi).

1.2 Elongation – the increase in length at break when the tape is tested under set conditions.

2. **Significance**

2.1 Tensile strength – The importance of breaking strength is a measurement of its consistency, quality and its ability to perform its function as well as the characterisation of its backing material.

2.2 Elongation – its importance is due to its measurement of consistency and quality, as well as an indication of its capability to mould to uneven surfaces.

3. Test Specimen

3.1 to 3.4 - see 3.1 to 3.4 of Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle.

3.5 For each specimen 4 strips of corrugated board 36mm by 10mm shall be used to reinforce the tape at the jaws so that the clamps will apply uniform pressure against the specimen.

4. Equipment

4.1 Tensile Tester (TAXT2 Texture Analyser) see 4.1.1 of Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle.

4.1.1 Test information should be displayed with real-time graphics software to plot a load-elongation curve simultaneously while testing.

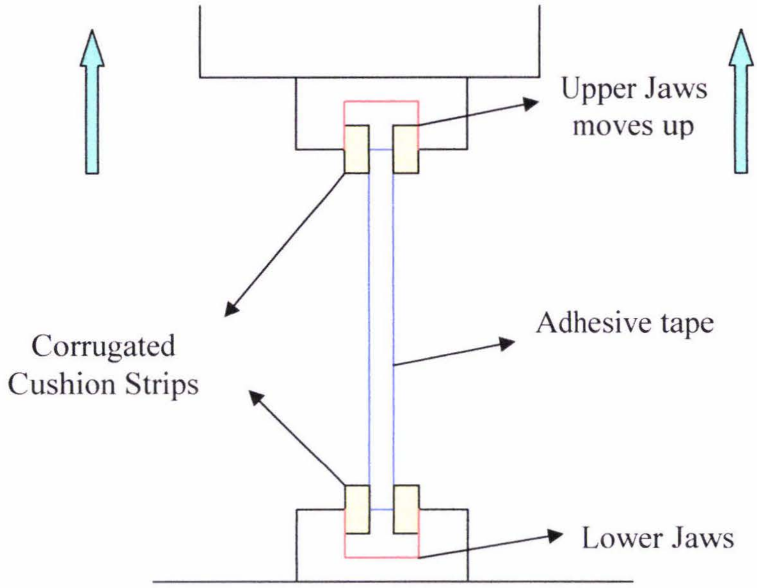
4.2 Adhesive tapes from 3.2 Specifications of tapes investigated.

4.3 36mm Specimen cutter – see 4.2 of 3.4.2 Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle

5. Test Method

5.1 Use 2 strips of precut corrugated board and sandwich between one end (one strip will adhere to the board). Place the cushion in the upper clamps but leave 1mm overlap to ensure clamps do not dig into specimen. Repeat for the bottom end of specimen with remaining 2 strips and clamp into lower jaw ensuring specimen is pulled firmly, free of wrinkles and uniform at all clamped areas. See figure 3-16 below. The test was conducted at room temperature.

Figure 3-16 Specimen in Tensile Tester



5.2 Operate the upper jaws at $5ms^{-1}$ ($12in.min^{-1}$) and ensure that the response indictor mechanism is operating to indicate both load and elongation values and graph.

5.3 When the specimen breaks, record the indicated responses of force in Newton's when the tester provides a numerical display of this information.

6. Report

6.1 Calculations

6.1.1 Ultimate Tensile Strength in Nmm^{-2}

6.1.2 Strain

6.1.3 Elongation percentage.

3.5.3. RESULTS *[Appendix B.12, B13]*

The higher the ultimate tensile strength the higher the resistance to fracture, this test produced the following results.

Table 3-10 Review of Tape Specifications

Tape	Backing Material	Adhesive Type	Backing Thickness (mm)	Adhesive Thickness (mm)
SelloFreeze	BOPP	Synthetic rubber resin	0.029	0.016
SelloFresh	BOPP	Synthetic rubber resin	0.029	0.016
SelloOld	BOPP	Synthetic rubber resin	0.029	0.014
3MColdTemp	BOPP	Water dispersed acrylic	0.028	0.015
3MMed	BOPP	Synthetic rubber resin	0.032	0.013
3MOld	BOPP	Synthetic rubber resin	0.030	0.017
PanFix	BOPP	Natural rubber	0.030	0.015

Table 3-11 Results of Ultimate Tensile Strength and Elongation Test *[Appendix B.12]*

Tape	Test Factors		
	Ultimate Tensile Strength Nmm^{-2}	**Elongation %**	**Std Dev**
SelloFreeze	118.1	120.1	5.07
SelloFresh	115.5	105.3	9.36
SelloOld	106.4	106.6	10.42
3MColdTemp	119.4	131.9	12.81
3MMed	108.7	128.3	12.76
3Mold	111.8	107.0	6.77
PanFix	107.7	124.1	9.13
Average	**112.5**	**117.6**	**9.47**

The two tapes for colder conditions performed the best for ultimate tensile strength while the other tapes followed in a random order.

The 3M™ cold temperature tape produced the highest elongation percentage even with the thinnest backing of the tapes tested followed by 3M™ medium age; where it has the thickest backing. The other tapes through these tests did not show any relationship pattern or connection and were random except for Sellotape® Old Age who performed poorly on both these tests.

3.5.4. DISCUSSION

The results did show there is no relationship with the thickness of the tape backing material and adhesive with the ultimate tensile strength or elongation. However, the performance of the 3M™ brand of cold temperature tape in both tests could be in part of the adhesive type; water dispersed acrylic; it is the only acrylic adhesive in the samples. Even under room temperature, there is great confidence in the 3M™ cold temperature tape.

3.6 CONCLUSIONS

This chapter explored the peel adhesion, tensile strength and elongation of the tape substrates, important properties in pressure sensitive tapes.

Peel adhesion is a test that measures peel force, bond strength to another surface that is important for measuring adhesive strength. To deter unauthorised reuse of the carton, fibre tear of the tape from the box is vital. To maximise fibre tear initial peel adhesion tests conducted revealed that more fibre was torn when the tape is peeled along the same vertical plane as the corrugated flute since the fibres are more likely to move in the same orientation of the grain of the paper. The observation from this test also concludes that a lower peel adhesion force is required to pull tape from the board with detached fibres than that of tape peeled clean of fibres as it requires a greater force to maintain the tapes fibre free stickiness.

This test evaluated different type of tapes in different temperature conditions. It showed that tapes perform their best at the recommended functioning temperature. The Sellotape® freezer grade tape performed well in freezing conditions while 3M™ cold temperature tape performed very well in the chiller. This proves that these cooler functioning tapes are most suitable for detaching board fibres in the desired ambience.

Tape backing material was tested with the tensile strength and elongation test, 3.5.1. The 3M™ cold temperature tape performed the best even with the thinnest backing material; therefore there was no correlation found between the thicknesses of backing material with strength and elongation.

4.0 – TAPE MATERIAL AND ADHESIVE SYSTEM

This chapter explores the tape substrates compatibility with the tape applicator unit, printing inks and the way is it applied as well as the adhesive; with more tests to provide a better understanding on tape performance to aid in the continual process of developing final tape specifications.

4.1 SELECTION AND TESTING OF TAPE AND ADHESIVE SUBSTRATE

4.1.1 TAPE APPLICATOR UNIT

The tape applicator unit designed and researched by fellow Rod Collins [Thesis "Development for a tape-sealed packaging system",2003] was design modelled on computer software. To date the machine has one prototype built by FBM in Finland. It is not vital for the tape to be tested on the machine as specifications of the tape requirements have been outlined. Dimension of the tape width is set at 70mm and is of utmost importance as this takes into account the amount of information intended to be displayed and is the ideal width that the unit can seal securely with the patented rollers.

4.1.2 PRINTING INKS

The method in deciding how to apply ink to the tape was investigated by sourcing appropriate methods available to print permanent ink onto the tape surface.

Graphpak Services Ltd. will work with Imaje Coding Technologies Ltd. in New Zealand to print the tapes. Imaje technologies produce inks with laboratories overseas.

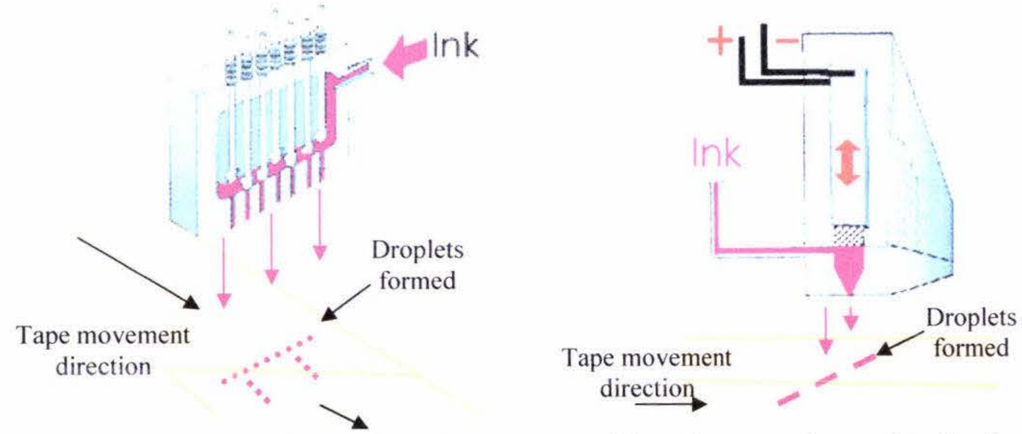
Imaje Ink Specifications [www.imaje.com]:

- A vast choice of colours
- Inks that are USDA compliant for incidental contact with foodstuffs.
- Food-grade inks with FDA and EEC compliance for direct printing on foodstuffs (e.g. sweets, cookies or eggs) or on pharmaceutical tablets and pills.
- Thermochromatic inks: the colour of the code changes when the product is sterilised.
- Opaque inks in different colours (white, yellow, blue and red) for marking on dark surfaces.
- UV cured inks that withstand solvents.

- Inks that withstand high temperatures (e.g. for marking light bulbs or industrial ceramics).
- Inks visible under UV-light to prevent counterfeiting.
- Imaje inks all comply with European CONEG standards for heavy-metal content and can therefore be recycled very easily. Imaje also supplies alcohol-based and water-based inks that are safe for the environment.

Imaje has many of the latest printing solutions and one of these products suitable to print the tape is the Imaje Large Character (ILC) ink-jet printers. The range offers two different technologies [www.imaje.com]:

Figure 4-1 Diagram of Large Character ink-jet printing methods [www.imaje.com]



Electrovalve drop-on-demand ink-jet **Piezo drop-on-demand technology**

Droplets of ink from the stationary ink-jet printer are "dropped" onto the tape as it moves along the conveyor. The electrovalve method produces images made up of dots while the Piezo method produces a continual printed image.

Table 4-1 Table of comparisons between the Electrovalve drop-in-demand and Piezo drop-on-demand technologies [www.imaje.com]

<u>**Electrovalve drop-on-demand (DOD) ink-jet**</u>	<u>**The piezo drop-on-demand technology**</u>
Solution for coding cardboard boxes and other outer packaging.	Solution for marking first quality barcodes and customising outer packaging.
No-contact marking: This no-contact technology ensures products will not be damaged during the marking operation. Whether the surface is flat or irregular, it provides high-quality marking	**No-contact marking:** Same as DOD ink-jet
Suitable for porous and non-porous materials: Make use of various ink bases (alcohol,	**Suitable for porous materials:** With their oil-based inks, Imaje ILC solutions (drop on demand piezo) perfectly

water, etc.), large-character inkjet printers offer high quality marking on a wide variety of materials (paper, laminated paper, cardboard, plastic film, etc.).	suited for porous materials (paper, cardboard). Marking in rapid bursts.
Marking in rapid bursts: Products are marked as they are conveyed under the printhead jet. Because of the high printing speeds (up to 1.5 ms^{-1}) there is no need to slow down the production line.	**Marking "on the fly":** Products are marked as they are conveyed under the printhead jet. Because of the high printing speeds (up to 3 ms^{-1}), marking will not slow down the packaging line.
Flexibility: Large-character inkjet printers are fully programmable. They can print a manufacturing date and use-by date which will change automatically every day and even have a counter that tots up in real time.	**Flexibility:** Same as DOD ink-jet
Printing of large characters and logos: This technology can print characters from 7 to 64 mm on 1 to 4 lines depending on the type of print head.	**High-resolution marking (up to 188 dpi):** The DOD piezo technology enables complete customisation of boxes including several lines of text, logos and bar codes with enlargements from 50 to 100% (EAN128, ITF14, etc.).

Both technologies are suitable for the printing of the tape and the outer carton. The use of these technologies and the areas where printing is needed will continue in Chapter 6. However, Imaje's printing technologies are suitable to print on absorbent surfaces such as cardboard and plastic film and will have a different reaction should a non-absorbent surface such as the adhesive side of the tape be printed on as this would be explored.

4.2 PRINTING INK EXPERIMENT 1

4.2.1 INK-JET PRINTING ON ADHESIVE SIDE OF TAPE TEST

Ink-jet printing on absorbent surfaces such as paper and cardboard is common and dries quickly. Printing on non-absorbent surface such as an adhesive "sticky" side of tape is uncommon as no reference could be found for film application. It is ideal to explore this as it was desired that the ink be etched onto the board surface, this can only be done when the ink is still transferable, such as being wet. This test can determine whether printing on the adhesive side of tape is suitable and how well printed material is transferred back onto paper. It would be expected that most water based inks will remain wet for approximately 10-40 seconds before solvent loss allows the ink to dry [Peter Ayson, Imaje personal communication 2002].

Double sided sticky tape with protective cover removed will be stuck onto paper and fed into the printer. An ink-jet printer will print two font sizes of written material separately onto the paper and tape. Corrugated board is then pressed onto the printed adhesive tape immediately and lifted to observe the results. The test is repeated but a wait of twenty minutes is required before corrugated is pressed and results are observed.

4.2.2 METHODS AND MATERIALS

1. **Test Specimen**

1.1 A piece of corrugated paperboard dimension 6cm squared.

2. **Equipment**

2.1 A piece of A4 sized white 80gsm premium copy paper.

2.2 A piece of dimension 4cm by 1.2cm long of Sellotape double sided sticky tape.

2.3 A computer connected to an ink-jet printer with continuous written material in two font sizes 12 and 20 both in bold of 'Times New Roman' a commonly used font style.

3. **Test Method**

3.1 On the A4 sized white paper, stick double-sided tape 1/3 of the way down and feed into ink-jet printer.

3.2 Print a page of prepared material at a time.

3.3 As soon as page has been released by the printer, immediately press the piece of corrugated board onto the ink covered adhesive tape and lift. Repeat the test but wait twenty minutes before pressing the board onto the tape.

3.4 Produce 2 specimens per font size.

4. **Report**

4.1 Report observations with two font sizes of printed material with a lift of corrugated board immediately and twenty minute delay after printing.

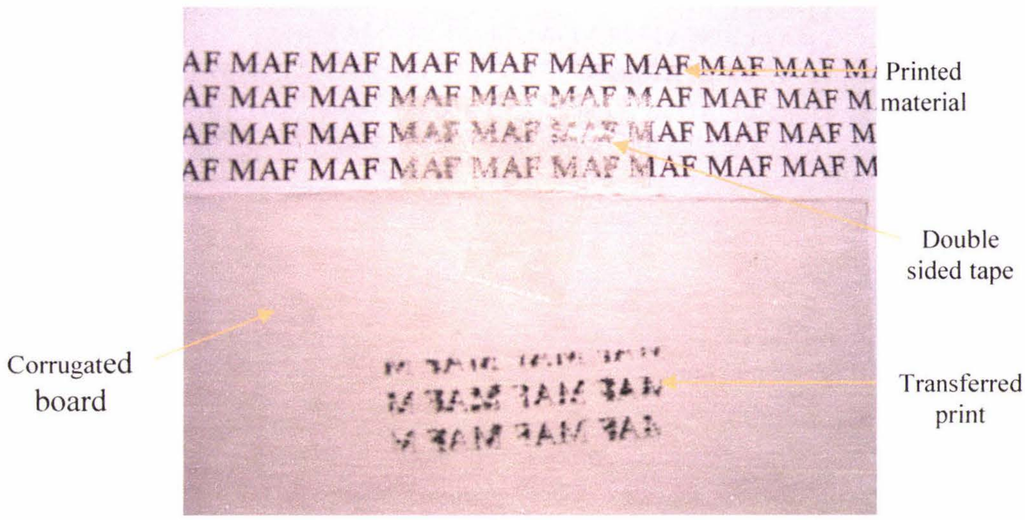
4.2.3 RESULTS

Immediate Lift

Font size 12 in Bold

Droplets of ink formed on adhesive sticky tape were transferred to the corrugated board. The words transferred could be made out as 2/3 of the ink had been transferred. Only the ink printed on the adhesive tape was transferred. (Fig 4-2)

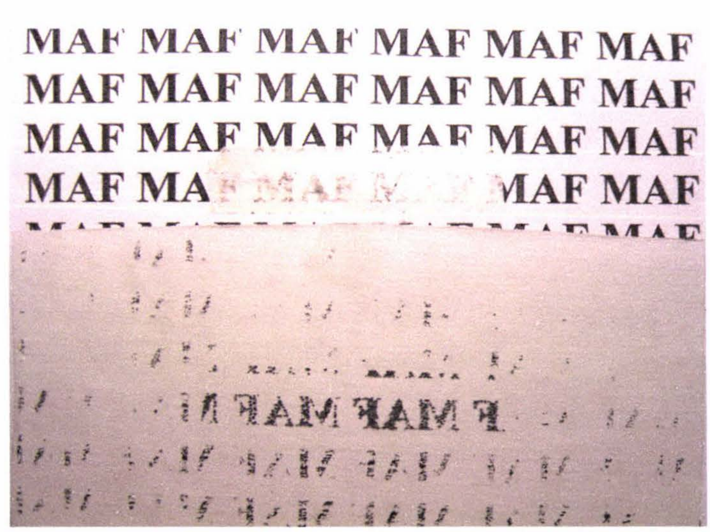
Figure 4-2 Photo of resulting immediate tape and board contact of font 12



Font size 20 in Bold

Droplets of ink formed on the tape and the ink left on the corrugated board was detailed but in dots. The pattern created was not consistent as some letters were obviously darker than others. The material printed onto the paper also transferred but was very faint. (Fig 4-3)

Figure 4-3 Photo of resulting immediate tape and board contact of font 20

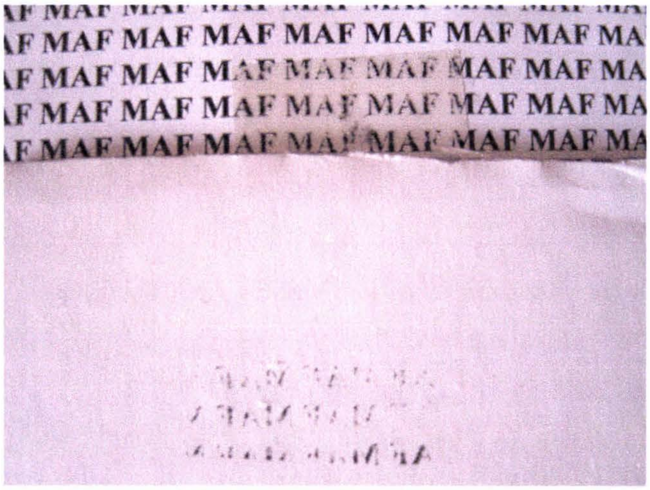


<u>20 minutes delay before corrugated board contact</u>

Font size 12 in Bold

The droplets that formed on the adhesive transferred well onto the board although somewhat smudged.

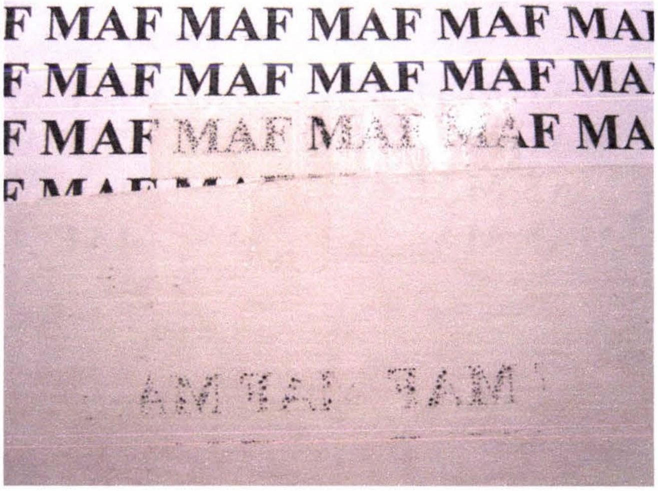
Figure 4-4 Photo of resulting delayed tape and board contact of font 12



Font size 20 in Bold

A result here were much the same as the smaller font but was slightly more readable. One letter on the adhesive tape was not transferred and still very dark on the tape.

Figure 4-5 Photo of resulting delayed tape and board contact of font 20



4.2.4 DISCUSSION

It is evident that the delay in time of transfer gave a lighter end result however still readable. What is common to all four experiments is the shape of the ink transferred; in form of small dots. This occurred as a result of the way the printer prints; in very small dots coupled with surface tension which is responsible for the shape of ink droplets by cohesive force. If this method of labelling the tape is used, a recommendation would be to increase the font size and have the tape and surface meet immediately with no time delay for maximum clarity of ink transfer.

4.3 PRINTING INK EXPERIMENT 2

4.3.1 INK STAMP WITH TAPE TEST

This experiment uses different types of ink, ink from self-ink stamps such as letter press style and pigment ink pads for rubber stamps. The result of the impact of a solid letter press style print will be explored. This test can demonstrate and continue from the last experiment to show what happens once ink has been printed onto the tape and then pressed onto a corrugated board surface and then lifted off. This then can incorporate the tape by showing what can happen when the tape is lifted and what remains if the adhesive lifts off the etching of the wet ink from the board.

Tapes will be stamped with different stamps of different ages hence affecting the quantity of ink. It is immediately peeled off to observe how much the adhesive has grabbed the board fibre and if any ink has etched into the board. Then repeat test and leave for 24 hours before peeling to also observe the resulting characteristics.

4.3.2 METHODS AND MATERIALS

1. **Test Specimen**

1.1 Two pieces of corrugated paperboard dimension 27cm by 5cm each having vertical corrugated orientation lengthways and divided into three sections

2. **Equipment**

1.1 Six pieces of Sellotape freezer grade adhesive tape as described in 3.2 Specifications of tapes investigated, to fit section dimensions.

2.2 Three different aged stamps:

1. i-Stamper i-Group, new - approximately 3 months,
2. X Stamper Shachihata from Japan, used - approximately 2 years,
3. Sanrio kids ink stamp set from Japan, old and faint, 3 years old.

Figure 4-6 Photo of stamps used in this experiment

3. **Test Method**

3.1 On each tape, stamp one of the stamps at a time in a uniform manner and immediately stick to assigned board surface and firmly press down and peel.

3.2 Repeat the test but wait 24 hours before peeling tape.

3.3 Produce 2 specimens per ink.

4. **Report**

4.1 Report observations of ink transfer and fibre tear.

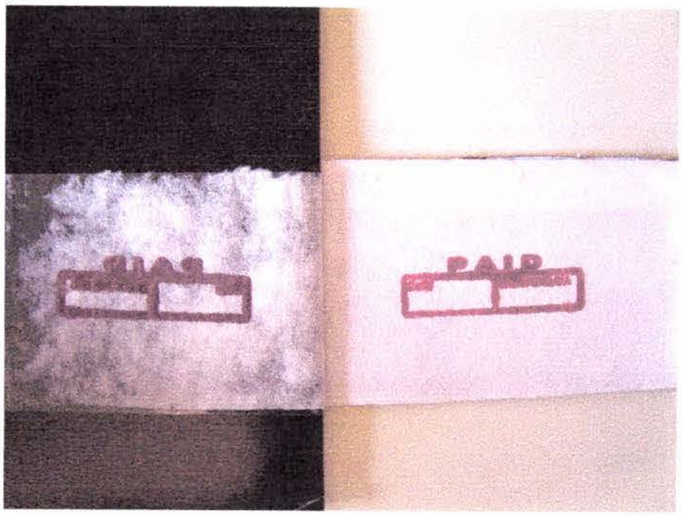
4.3.3 RESULTS

__Immediate Lift__

i-Stamper

A large amount of ink etched onto the board and it had started to saturate as it was absorbed and smudged. The pattern was still clearly visible on the board even though part of the transferred area had some fibre torn off and the ink was lighter. The peeled tape had torn off a considerable amount of fibre covering all over the tape but more toward the end in an increasing manner and the transferred image very clear.

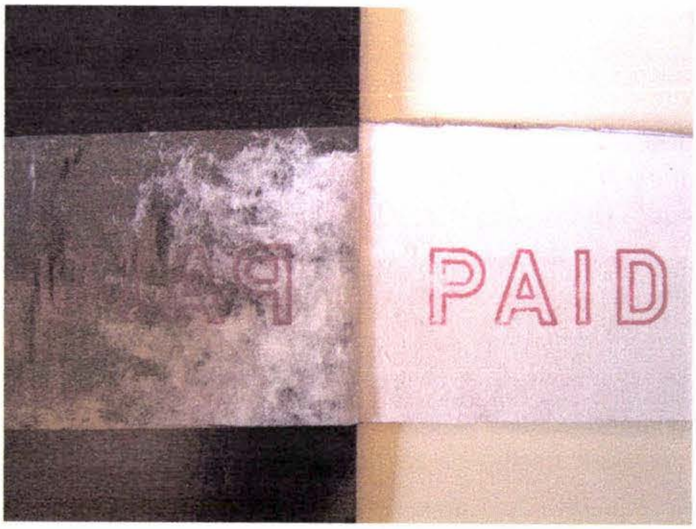
Figure 4-7 i-Stamper test specimen (right) and peeled tape substrate (left) immediate lift



X-Stamper

The ink here did etch onto the board but was clearly not absorbed as deep into the board to cause smudging. The transferred image onto the tape is clear and complete. Parts of the tape tore enough fibre to also remove the etched pattern from the board. The fibre grab was not as great as the i-Stamper specimen; it also increased toward the end of the peeling off process.

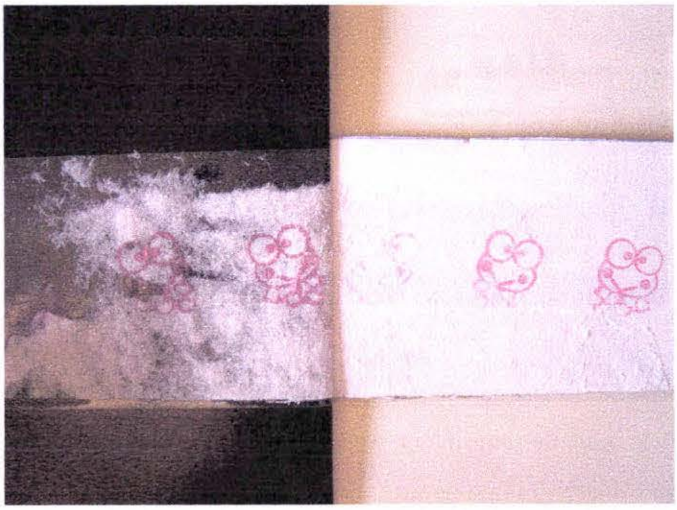
Figure 4-8 X-Stamper test specimen (right) and peeled tape substrate (left) immediate lift



Sanrio Set

The ink was faint on both tape and board, understandable as the ink was old but the pattern still clearly visible. The tape took fibres off the board by increasingly grabbing more.

Figure 4-9 Sanrio set test specimen (right) and peeled tape substrate (left) immediate lift

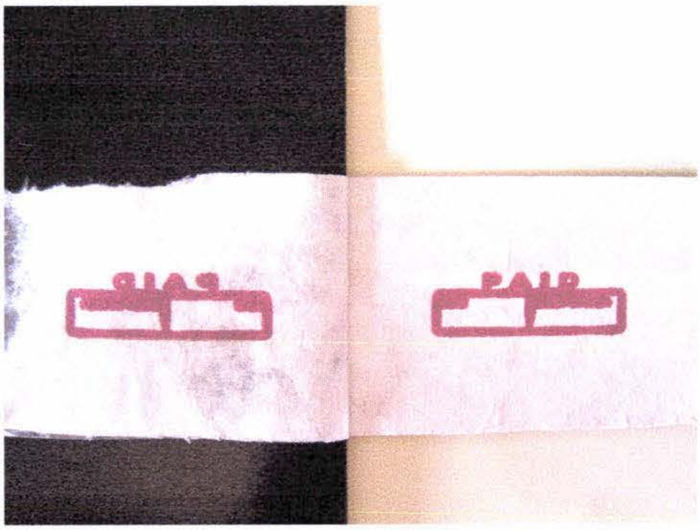


<u>**24 hours delay to peel**</u>

i-Stamper

The etched pattern created by the ink on the board was very similar to that created by the same stamp when immediately peeled. The fiber grab here is much greater without compromising the saturate etched image.

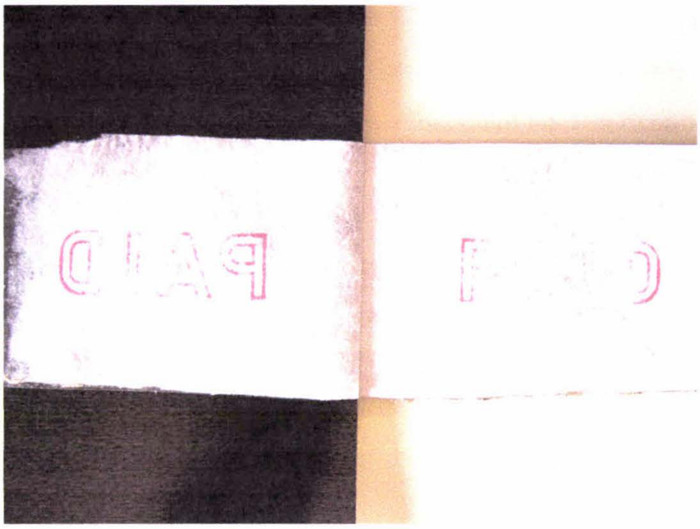
Figure 4-10 i-Stamper test specimen (right) and peeled tape substrate (left) after 24 hours



X-Stamper

The etched pattern on the board was still visible but faint. The tape took parts of the board fibres, enough to remove part of the pattern. The tape itself was soiled with fibres throughout.

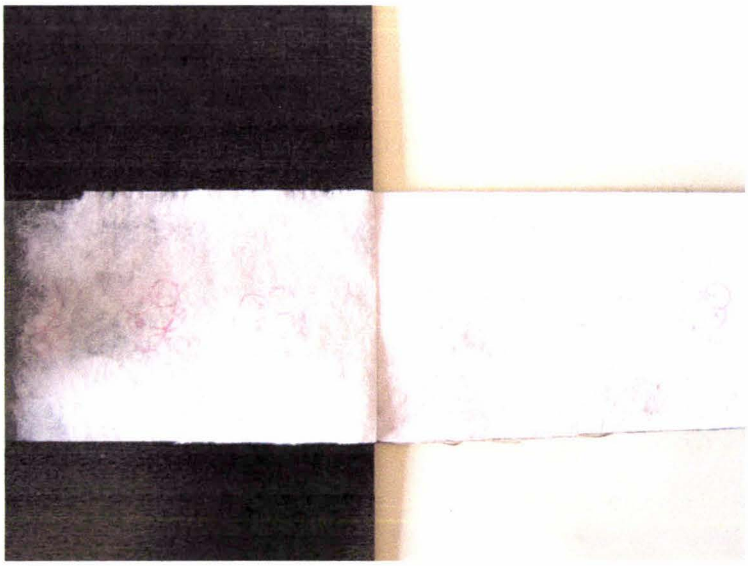
Figure 4-11 X-Stamper test specimen (right) and peeled tape substrate (left) after 24 hours



Sanrio Set

The pattern that remained on the board was very faint due to the removed layer of fibres from the board; hence the tape was heavily soiled with board fibres.

Figure 4-12 Sanrio set test specimen (right) and peeled tape substrate (left) after 24 hours



4.3.4 DISCUSSION

It can be concluded that the fresher and higher the quantity of the ink the more the ink etched into the board. When the tape was removed immediately the tape sustained a higher amount of ink than when removed a day later because the 'freshness' of the ink adhered to the adhesive on contact and due to the short contact time of the ink to the board, more ink was lifted onto the tape.

The longer the tape was in contact with the board the more fibre torn, this indicates that the adhesive has had time to cure on the board surface which has created a stronger surface bond so upon peeling, and more fibres were lifted.

There also appears to be no ink between the age of the ink and the fibre grab of the board. This is independent of one another, the fibre tear was variable for each type of ink, and only the quantity of ink is dependant on the transferred peeled substrate.

4.4 ADHESION EXPERIMENT 1

How adhesive tape works on corrugated board depends on the thickness of adhesive, as well as the quality of the backing to mould and conform to the board surface. There are varying degrees of corrugation that the tape may come into contact with. The thickness of the backing will have an impact, as will the type of backing in order to support the adhesive. The strength of the tape is directly related to the backing thickness. A thinner backing will offer more conformability, although more prone to stretch, which will encourage a tape to not fully conform, however, depending on tape type and usage this could not pose a treat. It is important that the tape is not stretched which will trigger many difficulties such as necking causing uneven stickability and uneven print if this is present. Two ways of overcoming this; one is thicker tape but less conformability, the other is to use wider tape increasing its cross sectional area. The stretch characteristics of many commercially produced adhesive tapes change little from plant to plant, country to country. [Michael Graves, Sellotape® in communication 2002].

As there are so many different grades of corrugated board [Literature review; 2.4 Corrugated Fibreboard], a need to specify and control board type is vital. Board manufactures try to lower their costs constantly and simple changes like the fibre length used in the board can have dramatic effects. Carton strength, stackability and quality of fibre tear to name a few can be compromised. [Michael Graves, Sellotape® in communication 2002].

Synthetic rubber adhesives are the most forgiving, and unfortunately the most expensive. However, for general conformability, natural rubber is better, but not so good in the under freezing conditions. [Michael Graves, Sellotape® in communication 2002]. The following tests set out to evaluate the stickiness of the tapes investigated in this project as well as the strength of them when a load is applied on it.

4.4.1 ROLLING BALL TACK TEST

[Sellotape® Quality Control Manual, 2000 and Pressure Sensitive Council Test Methods PSTC-6, Appendix 4A-4B]

Using the same previously tested adhesives tapes from Chapter 3, they are tested in an attempt to find the stickiest.

4.4.2 METHODS AND MATERIALS

1. **Definition**

1.1 The rolling ball tack test tests the adhesives capability to form a bond with the surface of another material upon short contact under practically no pressure.

2. **Significance**

2.1 The rolling ball tack test is one method of measuring the ability of an adhesive to adhere quickly to another surface.

3. **Test Specimen**

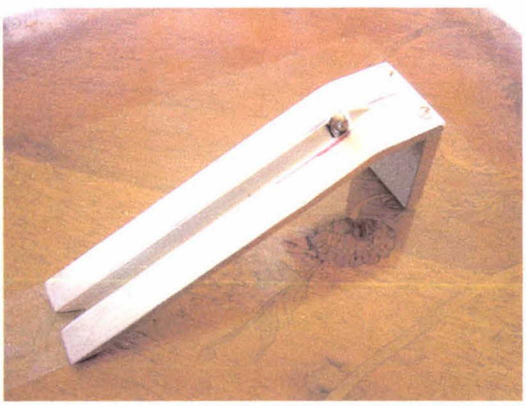
3.1 The test specimen shall be approximately 380mm long by the nominal width of adhesive tape specimens.

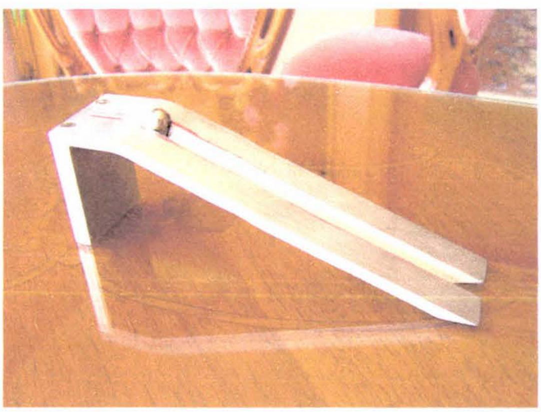
4. **Equipment**

4.1 Rolling Ball Test Metal Ramp, (made by engineer Carl from Graphpak Services Limited) to the specifications outlined from the Pressure Sensitive Council Test Methods PSTC-6 included in appendix.

4.2 A Steel Ball, 7/16" in diameter, such as a standard type ball bearing obtained from SKF Bearing Services NZ Ltd. in Palmerston North. (Ball bearings are to be stored in acetone when not in use)

Figure 4-13 Photos of Metal Test Ramp with Steel Ball Bearing





4.3 A working surface that is level, hard and smooth, such as a table top or plate glass.

4.4 Adhesive tapes from Fig 3-1 to Fig 3-7.

5. Test Method

5.1 Remove 2 to 3 layers of tape from the outside of the roll and discard.

5.2 Tape the end of the roll to the bench so that the adhesive is face up.

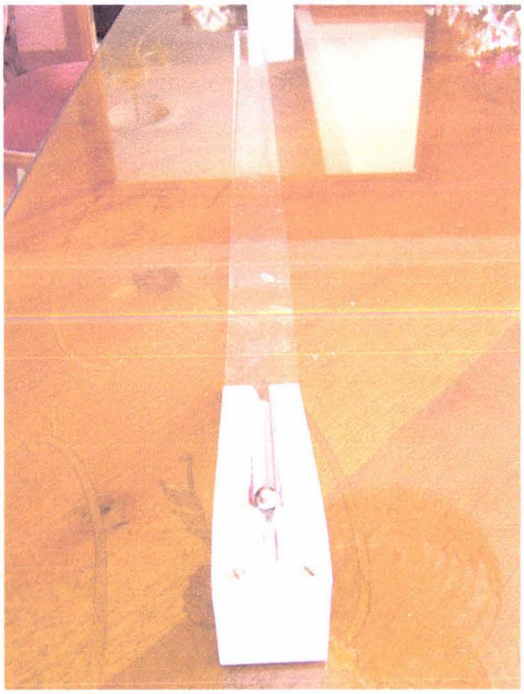
5.3 Pull tape off the roll so that there is a length of tape approximately 2 m long and face up. Cut this length from the roll and tape the free end of it to the bench using the same tape.

5.4 Prior to testing each lot of tape, thoroughly clean the raceway surface with acetone. Prior to each roll of the ball bearing, thoroughly clean the ball with the same solvent.

5.5 Remove the ball bearing from the acetone and wipe it dry.

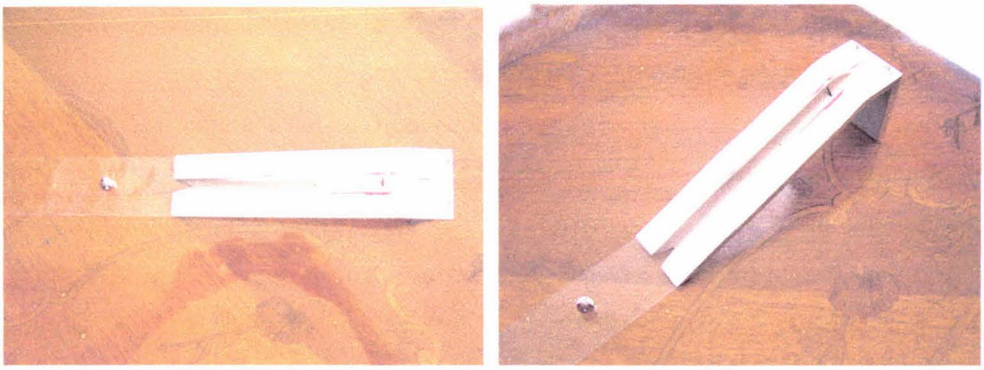
5.6 Position the ramp at one end of the strip of tape so that when the ball is released it will roll lengthwise along the strip of tape.

Figure 4-14 Photo of Test Ramp and Test Specimen Set Up



5.7 Place the ball on the upper side of the ramp and release the ball. Allow it to roll to a stop on the adhesive and record the distance it rolls in mm (the distance from the centre of the ball to the edge of the ramp).

Figure 4-15 Photos of Ball Bearing Released onto Test Specimen



5.8 Move the ramp along the tape and take a further reading, repeat until five readings have been taken.

6. Report

6.1 Report the final results as the average of the five readings to the nearest mm.

4.4.3 RESULTS *[Appendix C.3]*

Table 4-2 Results of Rolling Ball Tack Test

Tape	Distance (mm)						
	1	2	3	4	5	Average	Std Dev
Sellotape Freezer Grade	39	37	39	28	26	**34**	**5.6**
Sellotape Fresh	6	23	13	15	12	**14**	**5.0**
Sellotape Old Age	25	5	20	9	25	**17**	**6.6**
3M Cold Temp	55	45	37	25	23	**37**	**12.0**
3M Medium Age	197	100	240	220	129	**177**	**52.8**
3M Old Age	26	32	32	45	12	**29**	**10.7**
Panfix	77	26	10	22	30	**33**	**23.0**

Table 4-3 Table of Results Rearranged for Comparison

Order of Stickiest	Average (mm)	Range of rolled distance (mm)	Thickness of Tape + Adhesive (mm)	Adhesive Thickness (mm)
Sellotape Fresh	14	6 - 23	0.45	0.016
Sellotape Old Age	17	5 - 25	0.43	0.014
3M Old Age	29	12 - 45	0.47	0.017
Panfix	33	10 - 77	0.45	0.015
Sellotape Freezer Grade	34	26 - 39	0.45	0.016
3M Cold Temp	37	23 - 55	0.43	0.015
3M Medium Age	177	100 - 240	0.45	0.013

4.4.4 DISCUSSION

The stickiest tape is the brand "Sellotape" manufactured in New Zealand with the stickiest two tapes having very close results. The four following could be grouped together having similar numbers also with no statistical differences. However, the top four are packaging tapes for cartons and are suitable at room temperature. While the cooler condition tapes remained together at the bottom, it was not a surprise as they are more suitable at colder temperatures as this experiment was conducted at room temperature. The last tape is clearly different to the other two tested with the same brand. It could be that the age of the tape is in fact incorrect as tapes become sticker as they age. It is evident that tape has lost its stickiness. The thicknesses of the tapes plus the adhesives have no relationship in being the stickiest as the thicknesses are at random when placed in order. This leaves the quality and chemical nature of the adhesive more important than the amount, in order to give rise to high tack.

4.5 ADHESION EXPERIMENT 2

4.5.1 BOX TEST

[Sellotape Quality Control Manual, 2000, Appendix C.4]

The box test gives a good indication on the strength of the tape when a load is applied in a carton which mimics the environment it intends to be used.

4.5.2 METHODS AND MATERIALS

1. Definition

1.1 The box test tests the strength of tape when applied to a corrugated box with a load of 10 kg.

2. Significance

2.1 The box test attempts to measure the length of time the adhesive tape can withstand with a substantial load in a corrugated carton.

3. Test Specimen

3.1 The test specimen shall be a strip 25mm wide.

3.2 If the tape is wider than the dimensions required for this test, a specimen cutter must be used.

4. Equipment

4.1 1 regular slotted carton box (350 mm by 280mm) supplied by The Mill Liquor Save, Palmerston North. Used once for storage of goods.

4.2 Adhesive tapes from 3.2 Specifications of tapes investigated.

4.3 Razor blade

4.4 Masking tape

4.5 25mm Cutter Specimen

4.5.1. The specimen cutter shall hold two single-edged razor blades in parallel planes, held together by a solid medium such as wood. A precise determined distance of 25mm apart to form a cutter to exact specimen widths. (Made by Dave Pollard from Massey University).

4.6 2 × 5 kg sandbags

4.7 Pole and mounted wall brackets

5. Test Method

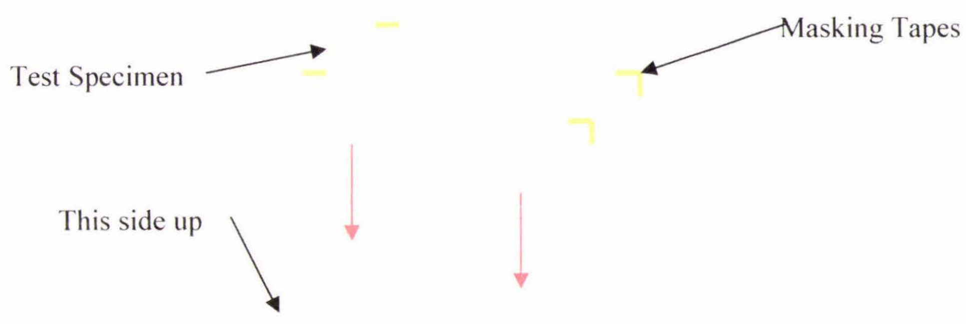
5.1 Label the box with the tape type, the date and time of test on the box.

5.2 Assemble the bottom of the box using 4 small pieces of masking tape to temporarily stabilise the joins, ensure they are at least 2cm away from the centre joins.

5.3 The tape to be tested must be 25 mm wide. If it is wider, slice a 25mm strip of tape from the wider tape.

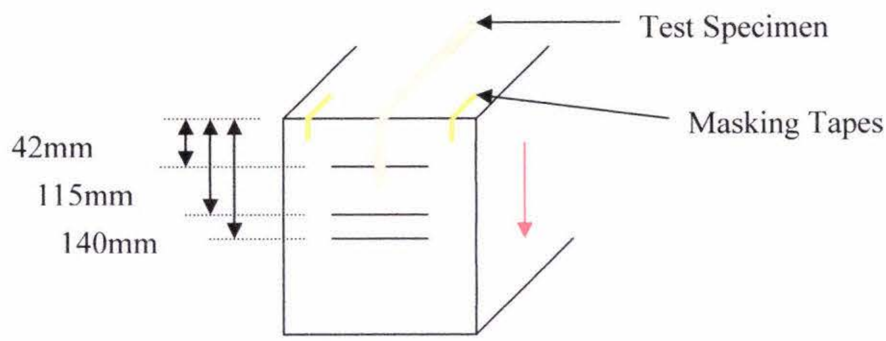
5.4 Apply the tape to the bottom end of the box and at least 5 cm up the sides. Make sure the tape has stuck to the box by rolling hand held tape dispenser across uniformly.

Figure 4-16 Test Specimen Application Illustration



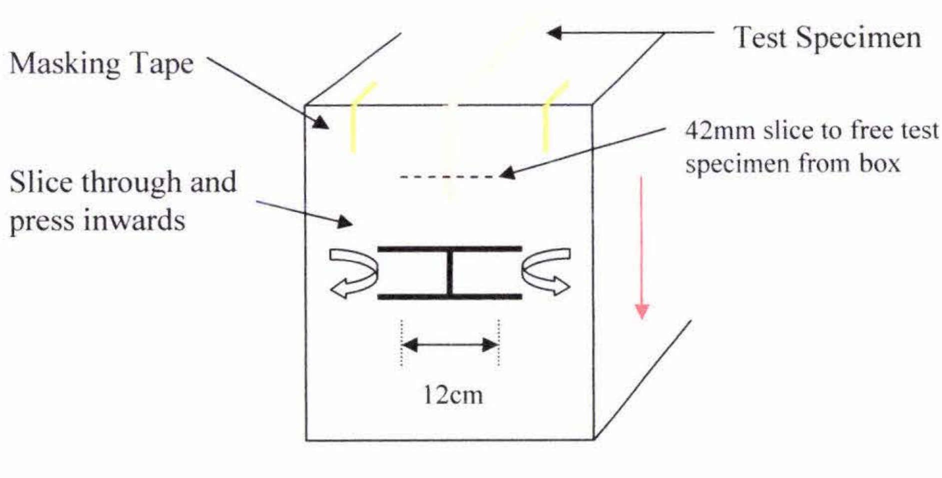
5.5 At both ends – rule a line across the side of the box at the following points, (measuring from the bottom of the box) 42 mm, 115 mm, and 140 mm as illustrated in figure 4-17.

Figure 4-17 Diagram to Interpret Instructions Above



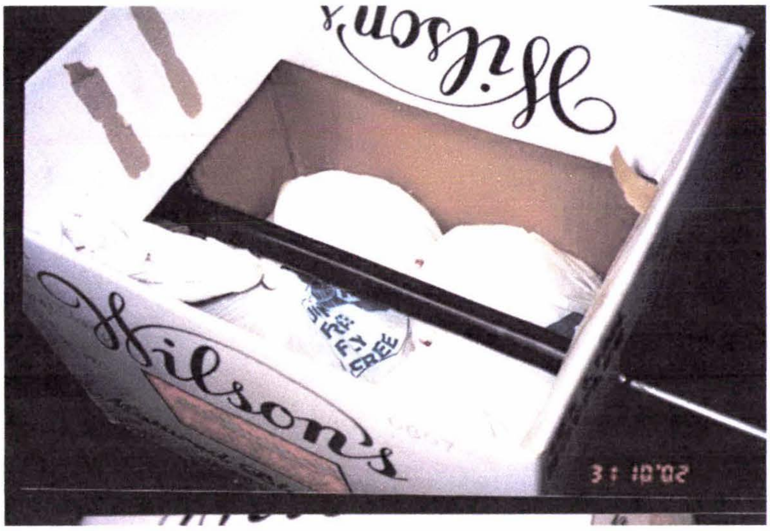
5.6 Slice gently through the tape at 42 mm. Slice right through the box at 115 mm and 140 mm, covering approximately 12 cm in the centre of the box, then slice vertically between the two. Press the cardboard inwards to make handles. Also slice through the masking tape.

Figure 4-18 Illustration of Handle Making



5.7 Place the two sandbags in the box and suspend from the pole, between the two wall brackets, as pictured below.

Figure 4-19 Picture of Box Test's finished setup, showing rod that holds the assembly of sandbags in box on bracket



5.8 Check the box daily if possible. The tape has failed the test if the sandbags fall through the bottom of the box.

5.9 Temperature and condition of the storage testing facility.

6. Report

Record the number of whole days, if less than one, record in minutes, the tape has held the sandbags in the carton. Note what part of the tape substrate failed, adhesive or backing or even the paperboard itself.

4.5.3 RESULTS

Table 4-4 Box Test Results at Ambient Temperature

Tape Type	Start Date	End Date	No. of Days
Sellotape Freezer Grade	15/7/02	21/9/02	68
Sellotape Fresh	15/7/02	15/11/02	123
Sellotape Old Age	18/11/02	12/12/02	24
3M Cold Temperature (3 tests done)	26/9/02	26/9/02	5 minutes
3M Cold Temperature	26/9/02	26/9/02	20 minutes
3M Cold Temperature	26/9/02	26/9/02	10 minutes
3M Med Age	4/10/02	2/11/02	29
3M Old Age	7/11/02	13/11/02	6
Panfix	18/11/02	8/12/02	20

Ambient temperature of the storage area was 12.2°C with relative humidity at 52.7%, tests conducted at Graphpak premises.

Failures for all the tests were from the adhesive. The failed tape substrate did not have presence of fibre grab nor any rips on the backing. The sand fell through due to low adherence to the bottom box flap, generally only one side of the flap gave out when it split open.

The same tests were conducted with 3 of the tapes and the samples were stored in a freezing environment at -18 °C ± 2°C at Massey University, the results are as follows:

Table 4-5 Box Test Results from Freezer

Tape Type	Start Date	End Date	No. of Days
Sellotape Freezer Grade	25/10/02	N/A	> 737
Sellotape Fresh	25/10/02	N/A	> 737
3M Cold Temperature	5/11/02	N/A	> 726

4.5.4 DISCUSSION

Table 4-6 Summary of results in descending order of pass days in Box Test at Ambient Temperature

Tape Type	No. of Days
Sellotape Fresh	123
Sellotape Freezer Grade	68
3M Med Age	29
Sellotape Old Age	24
Panfix	20
3M Old Age	6
3M Cold Temperature	<20 Minutes

As in 4.4.1 Rolling Ball Tack Test, Sellotape Fresh tape has proven to out perform the other tested tapes in strength with a load, and by almost twice as many days as the next strongest Sellotape freezer grade which also showed its abilities even at room temperature. Following are three packaging tapes clustered with similar results. It was a surprise as to the poor result of 3M's cold temperature tape, tested 3 times with the same outcome of less than a day, to which can be concluded is definitely not suitable at non freezing conditions. With this conclusion and completion of Chapter 5 (Use of Ionised Air 5.3); one of the resulting ideal temperatures 55°C was used to apply warm air onto the 3M cold temperature tape specimen immediately upon adhesion to the box and tested with the sandbags and observed for failure. The tape passed 19 days.

Figure 4-20 Photo of Experiment in Progress at Ambient Temperature

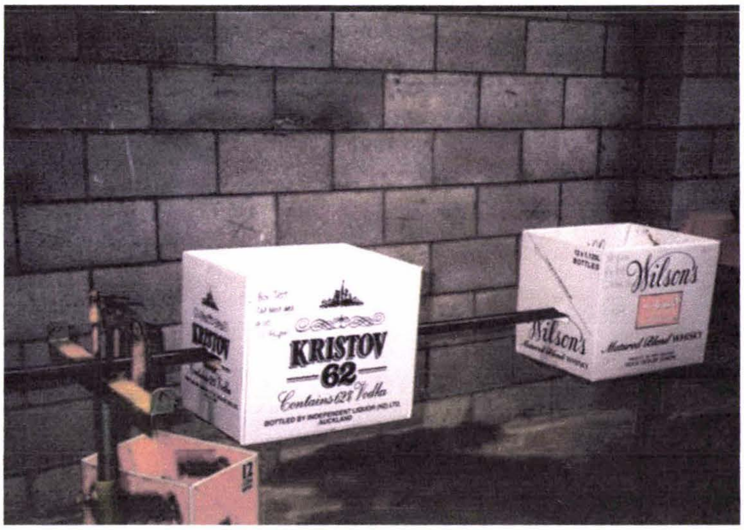
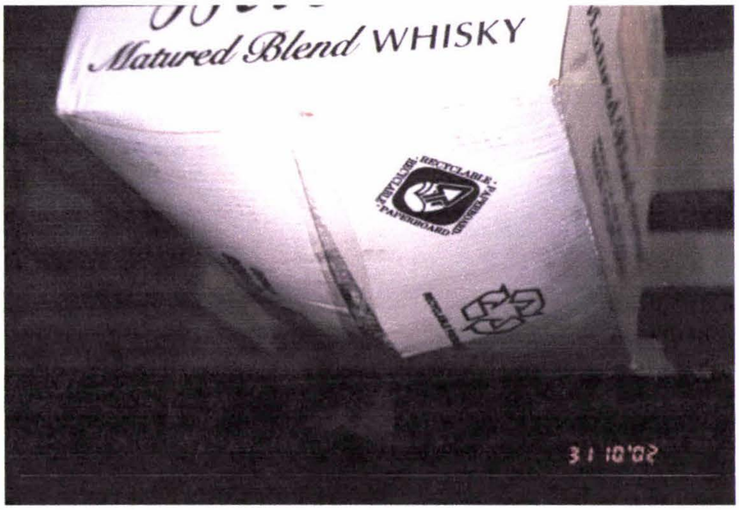


Figure 4-21 Photo of Failing Test Specimen at Ambient Temperature



The same test conducted in freezing conditions has produced no failing tapes after well over 700 days. The expected time for the tape to be used in this project aim in all temperature conditions with the intended use of containing meat is at least 6 weeks. Chilled meat can last up to 16 weeks at -1°C; hence this shows these cooler temperature tapes outperformed the required time frame. The weight of a regular carton containing meat of 20kg may exceed the 10kg tested here; however, the likelihood of the meat carton dangling in the air is small unlike this test. The intended storage of meat cartons are stacked in pallets or rested on a surface and only in the air when moved.

Figure 4-22 Photo of Experiment in Freezer

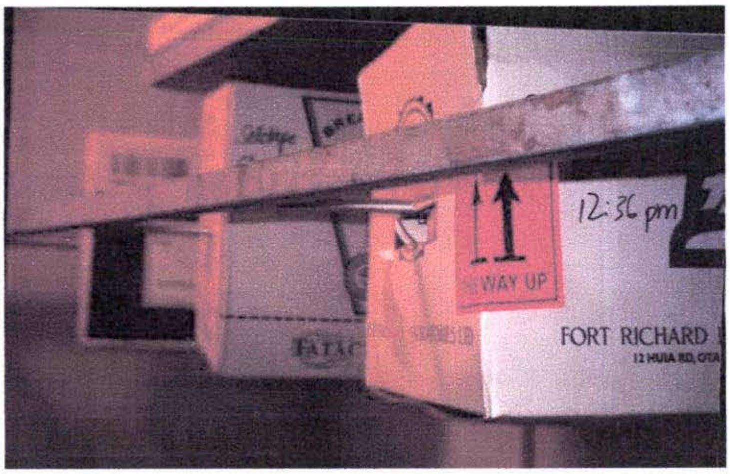
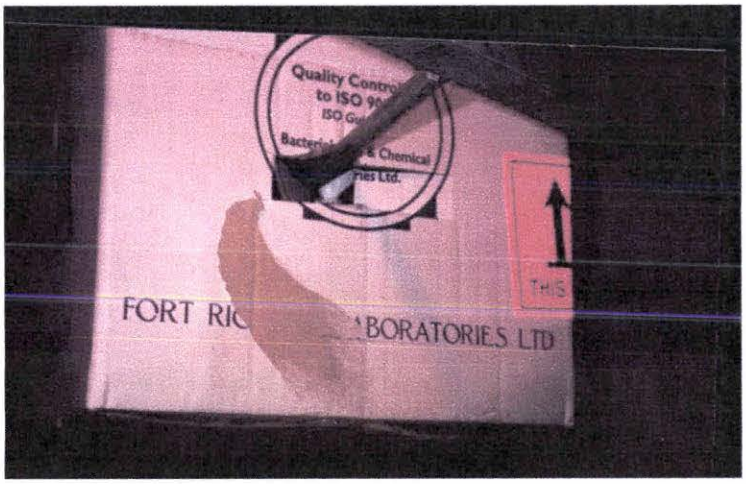


Figure 4-23 Photo of One of the Box Test in the Freezer on One Side



4.6 CONCLUSIONS

Imaje's techniques for printing ink onto the tape substrate are very compatible. Doubts voiced out by Imaje regarding printing on the adhesive surface was investigated, the experiment 4.2.1 Ink-jet printing on adhesive side of tape test conducted did conclude that surface tension created a droplet effect upon board contact which is undesirable as the image is unclear and blotchy. 4.3.1 Ink stamp with tape test, however, was more successful in ink transfer; it showed ink leached into the board from letter press style printing heads, which is one of the required specifications for this project. Although the ink was somewhat smudged, the lifted tape showed evidence of the ink as well. The amount of ink transferred depended on two factors; the quality of the ink and the time of contact of the ink to the board. The higher the quality (the amount of ink) the more the ink transferred onto the peeled tape and etched on the board. But there was no relationship between the age and quality of the ink to the amount of fibre grab. A delay to peel the tape substrate also affected the amount of fibre grab. The longer the tape was in contact with the board the more fibre was torn, this indicates that the adhesive has had time to cure on the board surface which has created a stronger surface bond. Based on these tests alone, it can be said that it would be more desirable to print on the tape backing material as to the adhesive surface due to the unclear and uneven transfer of ink. This does bring disadvantages such as the higher security need for these rolls of tape which bear the Ministry of Agriculture and Forestry (MAF) seal of approval. However, the professional look and display of important information outweighs this disadvantage which can be controlled.

The adhesive of a tape substrate is customised to the tapes end usage, and then there will be difference in characteristics of the same types of tape from different manufacturers. This is no difference with the tapes investigated in this project. Although produced by 3 different manufacturers, the results of 4.4.1 Rolling Ball Tack Test was random. It is proven in this test that the chemical nature of adhesives and not the amount are responsible for yielding high tack.

When a load is applied to test the strength of the tape substrate in use with a carton box, it was found that adhesive failure was responsible. The adhesive came away from the splitting box without any fibre grab letting the contents spill. There was no relationship with the strength of the tape to the thickness of the backing and adhesive, but the chemical nature of the adhesive as both the stickiest rolling ball tack test and load applied box test concluded Sellotape® Fresh tape as the higher performer even at a broad temperature range. Although the chemical nature of this tape is not unlike the others from the same brand investigated here, the age of this tape may have proved an important contribution that outstood the others. Sellotape® freezer grade tape also performed well at ambient and cooler conditions, this justifies the broad temperature suitability of is tape. 3M™ cold temperature tape performed the poorest by a high margin at ambient temperature.

5.0 – USE OF IONISED AIR

This chapter investigates the effectiveness of warm air onto the tape substrate to increase adhesion. Ink is added into the test so provide a better understanding of its behaviour of leaching when heat treated for tamper evidence.

5.1 IONISED AIR TO INCREASE ADHESION

Ionised air used in packaging is most beneficial in the workplace for reducing static. Besides releasing negative ions to neutralise the surface for safer handling of objects or surfaces, it also blows out warm air. It is a fact that warm/hot air is useful at reducing drying and curing time of wet matter or material required to solidify, hence it is suitable to investigate this effect of blowing warm air to the tape to reduce curing time and increase adhesion, useful when tape is quickly placed into colder environments, such as the requirement of this tape. Increasing adhesion will increase the fibre grab of the tape when peeled and it is important here because fibre torn on a carton box implies the box has been opened, hence can not be used again. This will deter unauthorised reuse of the box.

5.2 INITIAL EXPERIMENT

5.2.1 HEAT ON TAPE TEST

To test how well ionised air can cure tape onto corrugated board, a peel adhesion test will be conducted on tape that has been treated with heat. The peel adhesion test will tell us the measured force required to remove the tape from a surface, in this case corrugated fibreboard. The test procedure will be the same as 3.4.2.

An ionised system could not be obtained during testing time; hence a hot air gun Makita HG 1100, pictured below attached to a surface nozzle, was used which delivers the similar air blowing characteristics of an ionised system but without the negative charge and could be set to 2 air flow rates and different temperatures.

Figure 5-1 Makita Heat Gun 1100 with Surface Nozzle

Air flow settings of the Makita HG 1100 hot air gun

Setting 1 = 200 litres/minute

Setting 2 = 500 litres/minute

Table 5-1 Results of Temperature Test Measured with Digital Thermometer ± 5 °C

Stated Machine output temperature (°C)	Setting	Actual measured output temperature (°C)
100	1	55
100	2	70
200	1	130
200	2	136
300	1	256

Before this test can be conducted, a simple test was required to find out at what maximum temperature the tape can withstand before changing state, such as rippling and shrinking. This would not be desirable because it may change the characteristics of the tape such as backing strength. As required, when ink is applied, the image will be distorted. The measurement of actual temperature also indicates that the higher the flow rate the higher the temperature output even when set at a set temperature.

5.2.2 METHODS AND MATERIALS

5. Test Specimen

5.1 A piece of corrugated paperboard dimension of 36mm by 90mm.

6. Equipment

6.1 A hot air gun (Makita HG 1100)

6.2 A piece of Sellotape Freezer Grade tape with dimension greater than specimen.

7. Test Method

7.1 Adhere piece of tape onto corrugated specimen.

7.2 Apply heat from hot air gun at various temperatures in a slow sweeping motion approximately 5mm above specimen taking 3 seconds to complete the 90mm length of specimen board.

7.3 Wait one minute and peel back tape.

8. Report

8.1 Report observations of the condition of the tape and heat by feel of the board after treatment.

5.2.3 RESULTS

The results of this initial test are set below in Table 5-2

Table 5-2 Observations of board after treatment

Considered factors	Temperatures (°C) from hot gun				
	55	70	130	136	256
Board Heat	Warm	Warm	Hot	Hot	Very Hot
Tape Condition	No change	No change	Slight Wrinkles	Slight wrinkled and some creases	Crimples and partially melted
Peeled tape	Some fibres remained	Some fibres remained	Some fibres remained	Some fibres remained	Heavily soiled with fibres

5.2.4 DISCUSSION

A requirement of the tape on any surface is for the tape to be flat and wrinkle free. From the results from table 5-2 it is clear that the two lowest temperatures 55°C and 70°C deliver this, as well as the coolest temperatures on the board after treatment and produced some fibre tear, which is worth exploring in the peel adhesion experiment. Since the two chosen temperatures do not vary by much 130°C will also be suitable to test for any comparisons. Although the temperature of the board after treatment is hot compared to the latter which is not ideal if the corrugated box contains items susceptible to change in state if high temperatures are exposed such as meat.

5.3 ADHESION EXPERIMENT WITH HEAT TREATMENT AND INK

5.3.1 PEEL ADHESION TEST WITH HEAT TREATMENT AND INK

[ASTM D 3330M-96, [Metric][1] 1997and Pressure Sensitive Council Test Methods PSTC-1, Appendix B.6, B.7]

This peel adhesion test is the same as that of 3.4.2. Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle. To determine how adhesive tape behaves when treated with heat at various temperatures. This investigation should indicate the ideal temperature suitable for maximum fibre tear.

The experiment is put into three atmospheric environments to mimic real life situations as well as adding an additional factor of stamping ink before it is treated to allow for a re-enactment of the printed Ministry of Agricultural and Forestry (MAF) logo on the adhesive side of the tape.

The three tested temperatures are, 55°C, 70°C and 130°C with varying treatment times of 1, 2 and 3 seconds.

Tape used: Sellotape Freezer Grade

Duration of experiment: Overnight

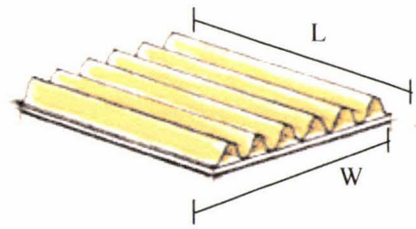
Duration of sample testing: 24 Hours after treatment

Conditions: Chiller at 3°C ± 1°C and in freezer of -18°C ± 2°C and at Room Temperature 21°C (situated at Massey University, Food Technology Laboratory)

Sample size: 3 repetitions for each temperature setting

Orientation of corrugated panel: Vertical grain at length [Figure 2-8 Single Face Board literature review]

Figure 5-2 Single Face Corrugated Fibreboard Orientation Labelled



Stamp: Letter style press stamps from i-Stamper i-Group as in experiment 4.3.1

5.3.2 METHODS AND MATERIALS

1. **Test Specimen**

1.1 See 3.4.2. - (3).

2. **Equipment**

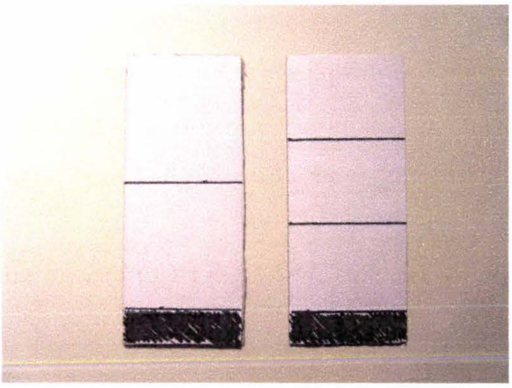
2.1 Hot air gun (Makita HG 1100)

2.2 Sellotape freezer grade pressure sensitive tape.

2.3 Pre-inked stamp

2.4 Time guides - Two pieces of corrugated cardboard with specimen dimensions with evenly ruled lines dividing board into half (2 seconds) and 1/3 (3 seconds) pictured below.

Figure 5-3 Corrugated Panel Time Guides for Peel Adhesion Heat Test



2.5 See 3.4.2. - (4).

3 **Test Method**

3.1 Use the experimental design below for reference of specimen size with their corresponding temperature and condition. Full design in Appendix D.1.

Table 5-3 Experimental Design for Peel Adhesion Test with Heat Treatment and Ink

	Factors		
Storage	**Freezer**	**Chiller**	**R.T.**
	1	0	-1
Hot Gun Temp (°C)	**55°C**	**70°C**	**130°C**
	1	0	-1
Time of Treatment (s)	1	2	3
	1	0	-1

3.1 See 3.4.2 – (5) 5.1 with addition of ink application onto the cardboard specimen (in the centre) before tape is applied and rolled.

3.2 Apply heat from hot air gun at various temperatures in a slow sweeping motion approximately 5mm above specimen using time guides for 2 and 3 seconds for even heat distribution.

3.3 After being in test conditions of 24 hours use the test procedures in 3.4.2. – (5) 5.2 to test.

4 Report

4.1 Report the peel adhesion value in Newton's, N for force, and the average and standard deviation.

4.2 Thickness of board 3 times before and after peel test in millimetres (mm) and then average. Measure at different areas of the board evenly.

4.3 Use Minitab statistical program to analyse any significance in all factors. Calculate significance at 95% and 99% for temperature, time and temperature versus time.

4.4 Analyse results by test conditions the separate by the peel adhesion force test to the amount of fibre torn.

5.3.3 RESULTS

Varying amounts of fibre tore off from the board onto the tape. From observation the ink applied under the tape was removed to many different extents. Some heavily attached to the tape leaving a faint image on the board while others were removed evenly on the top surface to some patchy areas of clear tape with partial removal of fibres at random with no particular pattern of temperature and condition.

Figure 5-4 Photo of One of the Specimens to be Tested (left) and Peeled (right), with Fibre and Ink Evident on the Tape

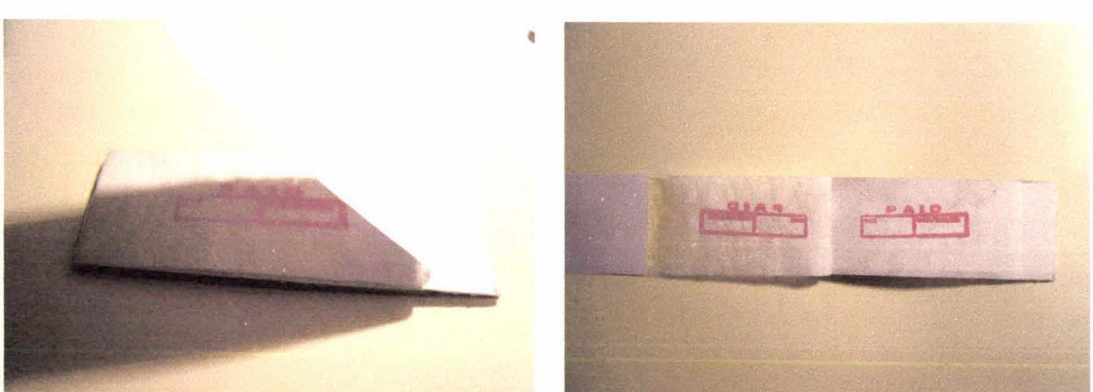


Table 5-4 Results Table of Measurements from the Freezer *[Appendix D.2]*

Temperature °C	Time (s)	Force Average (N)	Fibre Torn Average (mm)	Std Dev
55	1	4.7	0.11	0.62
55	2	4.8	0.10	0.36
55	3	5.7	0.10	1.13
70	1	5.4	0.11	0.22
70	2	4.7	0.10	0.16
70	3	4.9	0.10	0.26
130	1	4.9	0.13	0.24
130	2	5.3	0.07	0.59
130	3	5.2	0.12	0.56

Figure 5-5 Graph of Force versus Fibre Torn from Freezer *[Appendix D.3]*

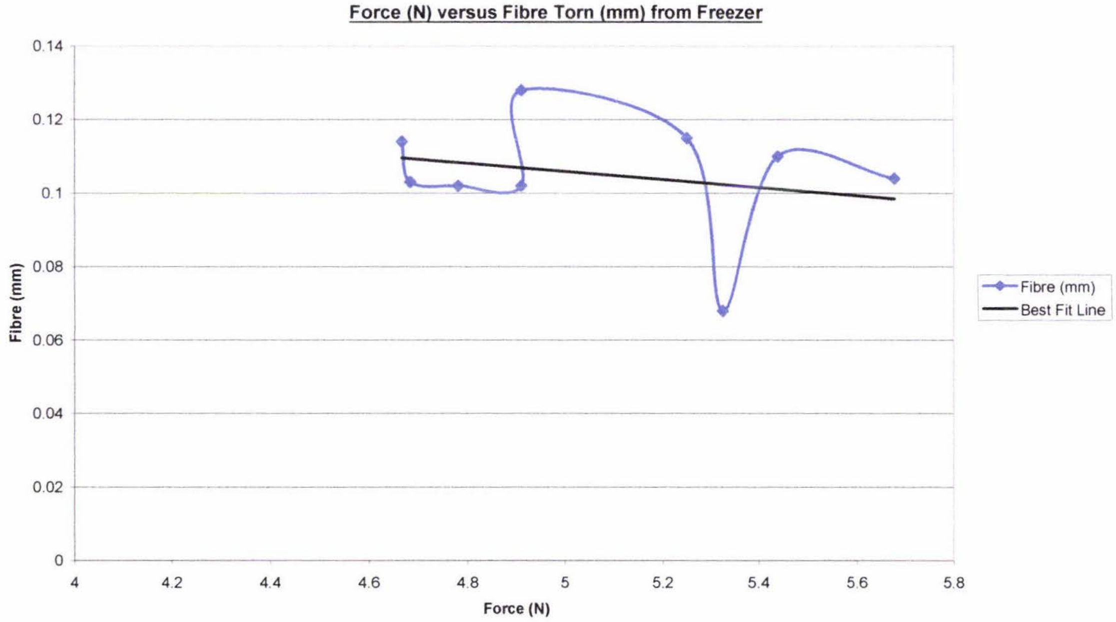


Table 5-5 Results Table of Measurements from the Chiller *[Appendix D.2]*

Temperature °C	Time (s)	Force Average (N)	Fibre Torn Average (mm)	Std Dev
55	1	3.8	0.20	0.95
55	2	4.4	0.18	0.51
55	3	4.1	0.15	0.60
70	1	3.9	0.16	0.03
70	2	4.3	0.12	0.17
70	3	4.4	0.19	1.10
130	1	4.0	0.18	0.11
130	2	3.5	0.08	0.36
130	3	2.9	0.15	0.14

Figure 5-6 Graph of Force versus Fibre Torn from Chiller *[Appendix D.3]*

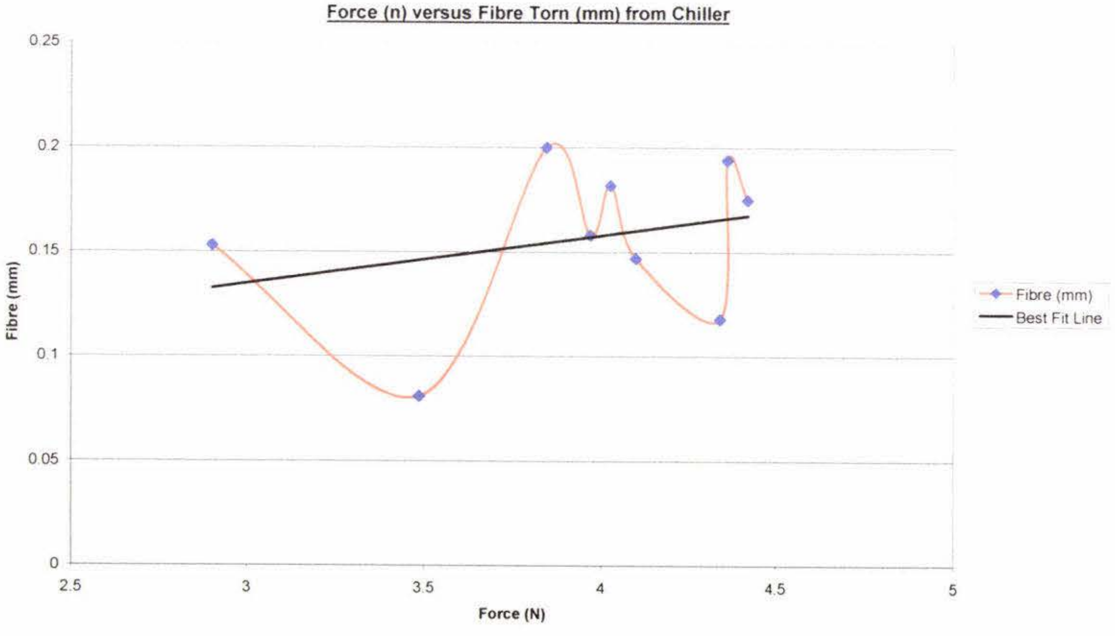
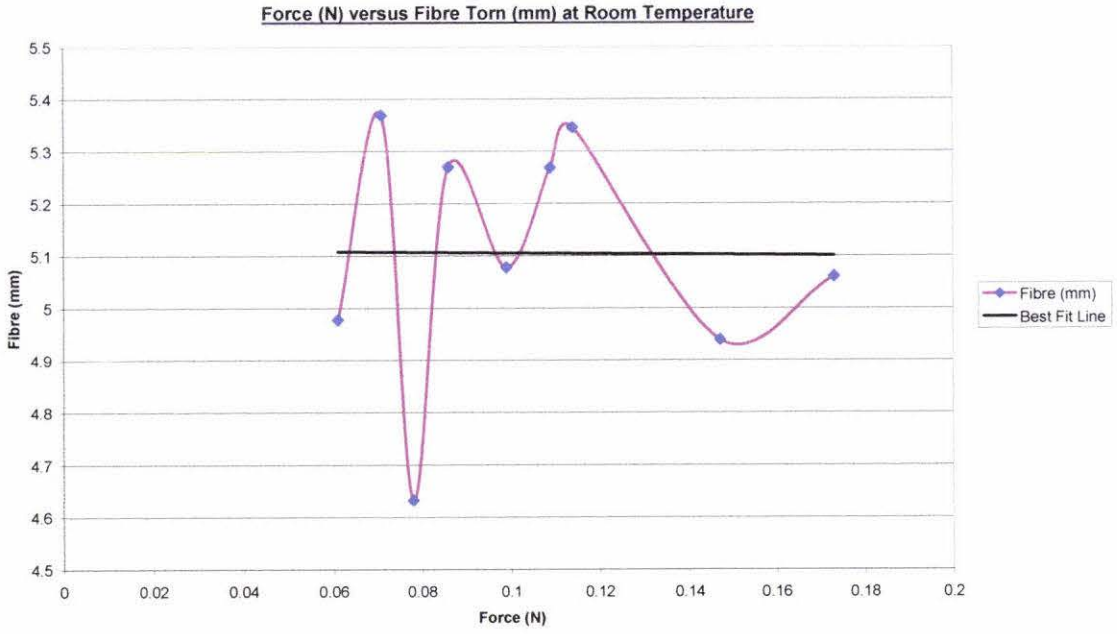


Table 5-6 Results Table of Measurements at Room Temperature *[Appendix D.2]*

Temperature °C	Time (s)	Force Average (N)	Fibre Torn Average (mm)	Std Dev
55	1	4.7	0.08	0.29
55	2	5.2	0.10	0.36
55	3	5.3	0.11	0.02
70	1	4.9	0.15	0.39
70	2	5.3	0.09	0.09
70	3	5.3	0.07	0.51
130	1	5.1	0.17	0.71
130	2	5.1	0.10	0.08
130	3	5.0	0.06	0.14

Figure 5-7 Graph of Force versus Fibre Torn at Room Temperature *[Appendix D.3]*



Calculations from Minitab *[Appendix D.4]*, showed there is a 95% significance for the peel adhesive force test for both temperature from the chiller and time at room temperature.

Of all three conditions, in the freezer the peel force was the highest at 55°C when heat treated at 3 seconds followed closely by 70°C for 1 second in the same condition.

The same was analysed for amount of fibre torn, it showed that the most ideal temperature is 55°C heat treated for 1 second from the chiller followed by 70°C for 3 seconds in the same condition; full results in Appendix D.2-D.6.

5.3.4 DISCUSSION

From the investigation in section 3.4, we know that the higher the force, the less fibre torn from corrugated board. This conclusion is reinforced here only at freezing conditions as figure 5-5 shows a decreasing best fit line when Force is graphed against fibre grab. As the force increases we should see less fibre tear as low force produces more fibres, results from the chiller and at room temperature do not support this.

The test condition for the highest value of peel force should not be the same as the condition that has the highest amount of fibre tear, and here, specimens from the freezer yield the highest peel force while the specimens in the chiller produced more fibre tear. Because the chiller is more humid than the freezer, it is not surprising that the fibres bonded to a more manageable tape temperature for maximum fibre grab.

The ideal temperatures at which results show that maximum force and fibre tear are at 55°C and 70°C, the two lower temperatures explored. It was also these temperatures that produced good measurable results and also which did not change the physical nature of the tape which is of utmost importance for its ability to conform and adhere to a surface.

These results do reinforce one conclusion from experiment 3.4.1, the specimens from the chiller show a higher fibre grab than that from the freezer since the temperature is not as low and the adhesive is more manageable than the drier and brittle condition in the freezer. However, drawing on that conclusion, the fibre grab at room temperature does not show the same reasoning as the results show the lowest amount of fibre grab. This also draws on another previous conclusion from experiment 3.4.1 that tapes suitable for operation in a specific environment do do best in that environment; in this case Sellotape freezer grade tape was used and the cooler temperature experiments worked well.

Incorporating the ink into the test, gave a better understanding of the behaviour of the ink on the specimen and how well if at all it transferred onto the tape or leave a mark on the specimen. Of all the test samples, the ink not only was evident on the peeled tape because it grabbed the top layer of fibre, in most specimens, the ink leached into the board and remained very clear and detailed. It is no doubt that the heat also contributed to the inks more prominent effect as the leaching effect was much stronger from observation than those of experiment 4.3 of the same letter press style stamp with no heat treatment.

5.4 CONCLUSIONS

The test conducted in this chapter combined the essential part of the functional requirements of the proposed tape.

From the results in 3.4, the peel adhesion force is much higher than seen here in this experiment. It confirms that heat treatment decreases the peel adhesion force. Fibre tear is also more evident from observation here as well as its uniformity but only the test from the freezer supports the previous conclusion that the lower the peel force the more the fibre grab.

The printing requirement of this proposed tape is to have printed material such as a MAF logo and other information on it. The ink applied to the underside of the tape before adhering to the board such as in experiments 4.2.1, 4.3.1 and in this chapter 5.3.1 are tests to research this with the best result being clear words or images and have an etching effect on the board.

Printing ink onto the adhesive side of the tape is rarely done and more so when printed before adhering to a surface. However, this experiment proved this technique to have advantages as well as disadvantages.

The leaching of the ink onto the board after printing and heat treating left a deep and dark image on the board, however somewhat smudgy and expanded. The heat treatment aided the ink to become more prominent on the peeled tape along with a high fibre grab. This trial has given rise to the possibility of this method being used, however, with its effective high fibre tear and leaching for tamper evidence, the unclear printed image and possible uneven tape application causing rippling and folding will be a problem for information clarity.

If a counterfeit was to reapply the peeled tape it would be difficult to return the tape to its formal unpeeled state as all the samples in this experiment showed crease marks visible at figure 5-4. When fibres are torn from a large board surface from tape, it grabs fibres in more directions than just the area of tape contact which means it's impossible to reapply the tape and fibre without soon noticing it.

Proposed Tape Specifications

- A Pressure Sensitive Adhesive (PSA) tape ✓
- Clear or transparent ✓
- Have a width of 70mm ✓
- Be functional between –20°C to 26°C ✓
- Impart minimum strength properties for normal use packed cartons ✓
- Have an airtight carton seal ✓
- Minimise costs and materials ✓
- Must be recyclable ✓

Proposed Tape Application Specifications

- Use a suitable ink for labelling ✓
- Incorporate security features to deter fraud ✓
- Be tamper evident ✓
- Bear the official Ministry of Agriculture and Forestry (MAF) seal
- Allow traceability

6.0 – DEVELOPMENT OF SECURITY FEATURES

This chapter explores and investigates features to avoid fraud and tampering of the box as well as ideas to enhance sharing of information.

Proposed Tape Security Specifications

- Use a suitable ink for labelling
- Bear the official Ministry of Agriculture and Forestry (MAF) seal
- Incorporate security features to deter fraud
- Be tamper evident
- Allow traceability

The New Zealand Meat Industry Association (Inc.) has complied a set of drawings (attached in Appendix E.1) to illustrate the placement of MAF seals under the carton sealing rules that meet both New Zealand and European Standards. With every style of box there are specific areas to adhere the seal where always at least one seal is placed over the strap.

The purpose of the proposed tape is to eliminate the use of strapping and combine the MAF seal with the new closure system; therefore we must ensure the placement of the MAF seal on the tape is evident on the box at least twice to adhere to the rules of the seals. With the different lengths of boxes this tape is used on, we must come to a distance of separation of these seals to ensure the correct coverage. Of course a continuous seal patterned along the length of tape is ideal to ensure coverage; we must take into account of costs. Upon observation of box sizes at the meat plants, a distance of 30cm between each seal is appropriate to ensure coverage of smaller boxes.

6.1 INK COMPATABILITY

The aim to finding a suitable ink and application method of the ink relates to the incorporation of security and that is to discourage reuse and misuse of the taping medium. It is proposed that the MAF seal is integrated onto the tape, printed with suitable ink or otherwise. It is preferred the carton fibre material delaminate when the tape is removed as to imply the seal has been broken, in addition to possible leaching of the ink onto the fibres to add to the difficultness of reusing the tape medium or the carton box.

Figure 6-1 Sample of MAF Seal

The investigation into the use of ink onto the tape surface was explored in chapter 4. It was not suitable as it was printing onto the adhesive surface and not transferred onto corrugated fibreboard with enough clarity to read. Another investigation showed that for more clarity, printing (self-ink stamps) onto the corrugated fibreboard surface was more effective in terms of readability but produced smudging. However, it produced a leaching effect on the board and remained after the tape was peel off.

It is clear that printing on the surface of the tape on the adhesive side is unfeasible and the formation of ink droplets is unacceptable for this high standard required for exporting and a package representing New Zealand. Although if this was a good solution the leaching effect on the corrugated would mean a mark or MAF logo in this case, would be left on the box upon peeling of the tape which will provide great evidence the box has been opened, deterring unscrupulous operators to reuse the box. The leaching effect on corrugated after fibre had been torn is an uneven and smudged one and if fresh tape was applied the condition would be notably unacceptable for reuse hence this solution is a feasible one. This means the tape used for sealing the cartons would not be as sort after by people who in the black market are wanting to seal their goods and passing them off for export as official New Zealand goods. This is a major concern as MAF seals are easy to get a hold of and many go missing even when numbered. However, the wet ink method will mean the application of the tape onto the board will have to be precise. If there are any ripples in the tape or any uneven surfaces, the image will distort and therefore ruin the information on the box.

A more feasible method would be to print on the underside of the adhesive, the backing, before the adhesive is applied. This would mean clarity of the information, which is important for export and an easier application of the tape onto the box as that will be no time constraint, the fast action of immediate contact to the box of the wet ink. The tapes would then be very sort after like the existing MAF seals; this would mean a tighter guard of these tapes will have to be enforced. Recommendations for this issue is to number tag these rolls of tapes and mark down usage on a daily basis. To only have a limited number of suppliers who can manufacture these tapes and supply directly to the processing plants whereby tapes are only assessable to a limited number of staff who log the amount used to registered suppliers.

Pre-printed design tapes are readily available and with good print quality, comvienent and do not require incorporating a printer on the taping machine.

6.2 BARCODING

The use of barcodes on products today are essential and required as part of product identification, price and traceability. Including a barcode on the corrugated box for export would be advantageous, allowing for easy product identification abroad and trackability, as well as a whole host of additional information about the product such as "from paddock to plate" idea. We could replace existing printed labels on the box with a single barcode that can tell us much more, and with the use of bar-coding machines in abundance world wide, adopting this method would mean costs can be low. The barcode must be printed on the corrugated box like many existing products today to allow for bar-coding machines to read the code and not on the tape where disadvantages of this readability issue was discussed. Printing of barcodes onto boxes in a packaging line is intricate as they are often difficult to scan.

The advantages of barcodes for meat export

Tracking
To monitor stock from production, storage, dispatch, on-route through to delivery

Stock Control
Stock is monitored; hence plant can anticipate what product is low, and how many of each product it has in stock
Storing important information: The fundamental concept of barcodes is the storage of information. Such information useful for the package in the meat exporting industry is

- Product description
- Farm identity
- Weight of product
- Date culled
- Date packaged

- Best before date
- Recommended storage temperatures
- Plant identity
- Destination

Quality Control

Barcodes can be applied to verify that the correct range of product weight is adhered to. It can also be used to monitor the production time to ensure freshness and to examine the quality of product from each origin (farm).

Print Technologies

To use this technology at the plants, the only way of incorporating personalised information is to apply bar-coding on-site with user controlled printing. This takes place at or near the point of use. The data encoded is required to be variable, hence entered by an operator through keyboard it downloaded from a host computer. There are many common barcode on-site printing technologies available but laser is the most suitable as it does not involved heat that direct thermal and thermal transfer will produce or smudge such that ink jetting will create.
Any form of heat even at small amounts will not be favoured as it will spoil the product or reduce its freshness and life expectancy. The laser delivers a high quality print that does not require set time hence it will not smudge if handled immediately. The image is formed on an electrostatically charge, photo-conductive drum using a controlled laser beam. The charged areas attract toner particles that are transferred and fused onto the substrate.

6.3ADDITONAL SECURITY OPTIONS

6.3.1 EMBOSSING

The idea of having the tape embossed with a message was investigated. Many embossed tapes were looked at and it revealed the embossing is use for more aesthetic reasons then for security. Many are coloured and of thick structure primarily used for labelling. The embossed area of tape brings the message up from the underside of the adhesive area, therefore will not leave any marks on the fibre box useful for security in this project.

6.3.2 ADHESIVE REMOVED FROM CENTRE OF TAPE

The delamination of the adhesive tape upon peeling from the fibre bought on another possible solution. Instead of printing on the tape for all to see, what type of residual would be observed if

words were written without adhesive? That is to say, words or logos were evident on the adhesive tape but etched out by the use of no adhesive.
A simple experiment was conducted using the standard 48mm tape width, by removing the adhesive from the middle of the tape at different widths with acetone. 3 widths were examined starting from 2mm, 3mm and 4mm; a typical width use for words on the size of tape used. When applied to the corrugated board and peeled (without heated air but a stand-time of 10 minutes), the fibre tear from the other parts of the tape with adhesive tore fibre from the non adhesive area. This created a non-clear visual of the adhesive free lines, hence diminishing this idea for security.

6.3.3 INCOPERATING EXISTING TAMPER EVIDENT TAPES

Tamper evidence tapes are becoming more popular as the need for them is growing. The tamper evidence tape shown in figure 6-1 is a good example of one. It is made in Germany and was brought back from supervisor Tom Robertson from a packaging trip. The tape red in colour with black writing with a message "Attention, Warning" then translated into another language beside it, peels to reveal an adhesive layer in clear colour of the same warning message in black with an addition of more warning messages in red transferred from the red colour of the above layer. The message reads "Opened, Fraud, and Void" and is also visible on the top non adhesive layer from the transferred words that are clear. This tape is a novel way of protecting sealed items, surprising the offender with this irreversible evidence of an intention to remove the tape.

This tape has great potential for use here. The tape was applied to a piece of corrugated board and removed revealing the same result. However, the adhesive layer on the board looked weak and when rubbed, it could be easily removed.

Changes required for improving the tape for this projects purpose would be the need for a stronger adhesive. However, the application of this tape to the box would mean the box would still be sealed even when the tapes top layer is removed. An offender can then cut the tape with a blade, remove its contents and reseals the tape with a clear tape fooling the receiver if without proper inspection.

Figure 6-2 Germany made Tamper Evidence Tape

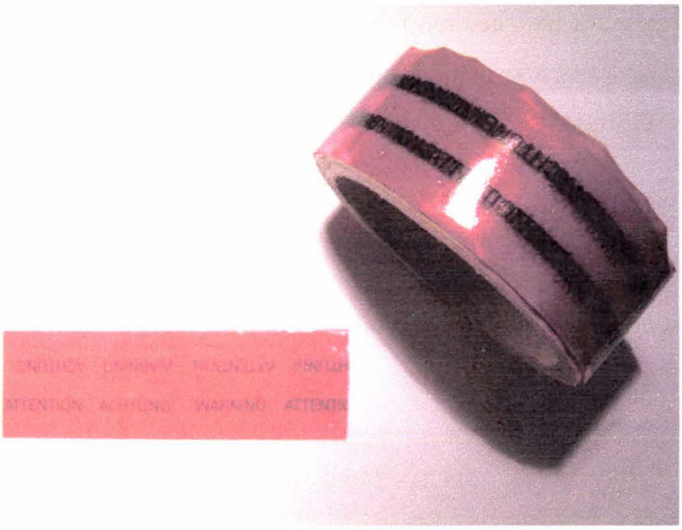
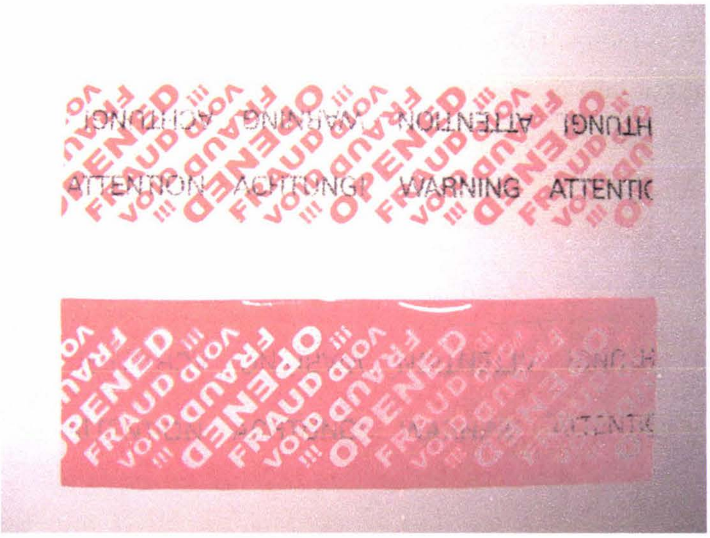


Figure 6-3 Tamper evidence tape peeled, leftover warning message (top), non adhesive top layer of tape (bottom)



6.4 CONCLUSIONS

The proposed tape not only has to impart all the qualities of the outlined specifications, it also has to be simple to use, effective and look professional as it represents MAF and New Zealand's export industry.

One of the tapes key features that are compulsory is the display and of the MAF seal. As discussed, the seals information will be printed onto the tape. As investigated, for security and clarity reasons, the seal will be printed on the underside of the tape before the adhesive is applied. This is also cost effective as many printed tapes are now being printed this way. Pre-printing will also eliminate the need on on-site printing to cut cost and to simplify the process of sealing the cartons. These tapes will need to be numbered to allow for tracking, stock and quality control, therefore safe guarded for security reasons.

Previous experiments showed the grabbing power of the adhesive even under freezing temperatures. We must rely on that and not the residual ink residue to leave a mark on the box as the tapes will be pre-printed. The fibre lift on the boxes will mean evidence that the box has been ripped open.

In co-ordination of the printed tapes will be the inclusion of the bar-coding system. The barcodes will be printed on-site straight onto the carton. Of course printing straight onto the carton will no doubt deter fraud as information that belongs with that carton stay with that carton. With information such as destination and time of arrival to that destination bar-coded onto the box, the chances of reusing the box will be reduced to nil.

To ensure this new system is put in place, the New Zealand Meat Industry, MAF and nations that receive our goods must be aware of the new rules for exporting goods from New Zealand. That is the pre-printed cold temperature tapes in combination with a barcode must be present on the carton of export goods to be deemed acceptable from New Zealand.

7.0 – PACKAGE DESIGN

This chapter combines the knowledge of existing packages and the results of conducted investigations to specifications as well as incorporating fellow masterate Rod Collins development of the taping machine to develop the most promising corrugated carton design for the use of this pressure sensitive tape.

7.1 PACKAGE INVESTIGATION

The re-design of the corrugated carton to take advantage of the tape sealed system is reasonably limited. The existing variety of board type, boxes and containers used in the meat industry for export is extensive, with each processing plant having its own range. Each style and size is utilised especially for a specific containment of cuts, suitable to hold, then chill or freeze.

The selection of meats that are placed in the chiller or freezer already have suitable corrugated boxes to maximise holding temperature such as, the boxes for freezing 20 kg of cuts. The box is a design style container with cover that uses a size B flute profile and has a double layer of corrugated at the lip of the lid for insulation.

The stacking strength of the boxes is of utmost importance as these boxes will be palletised; refer to 2.4.7 Packaging Functions). The load carrying ability of a box is related to the strength of the vertical panels in the compression. The orientation of the corrugated flutes affects the strength of the box and its ability to stay strong and not buckle. When the flute is orientated vertically in a box it is at its strongest. However, from the findings in the peel adhesion test, fibre tear is more evident when the tape is in the same orientation as the flute. The tape sealing system is designed to tape horizontally across the box, hence the re-design of the carton must incorporate this feature to maximise fibre tear consequently to tamper evidence.

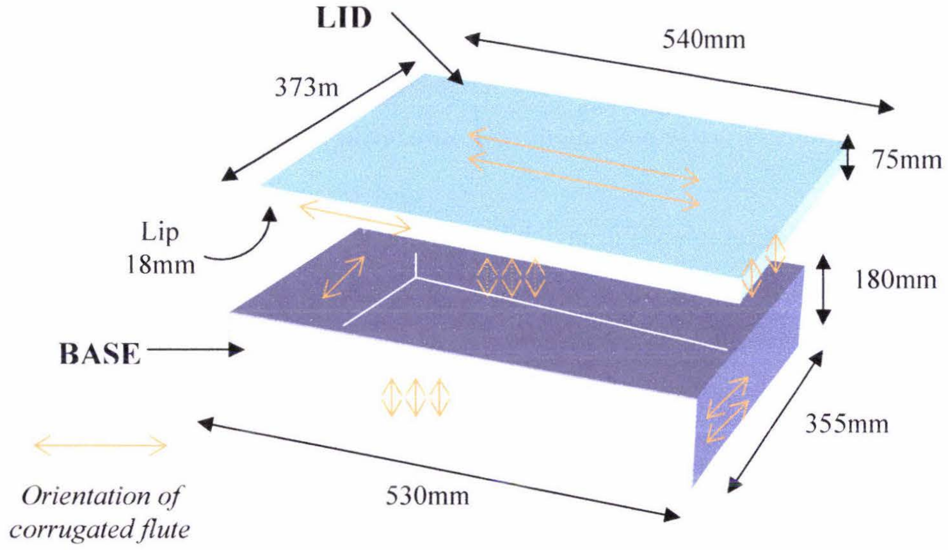
The taping system was designed with one style of box in mind, the design style container with cover, although many styles are used. The change of these box styles to one uniform one for the tape system in the meat industry seems somewhat far fetched as the use of smaller and other styles are appropriate for its products. Therefore the re-design of such a box is unnecessary; instead two existing popular styles are recommended as most suitable to the tape sealed system and maximises fibre tear from the tape.

7.2 FINAL DESIGN STYLES

DESIGN ONE – Design Style Container with Cover (DCS)

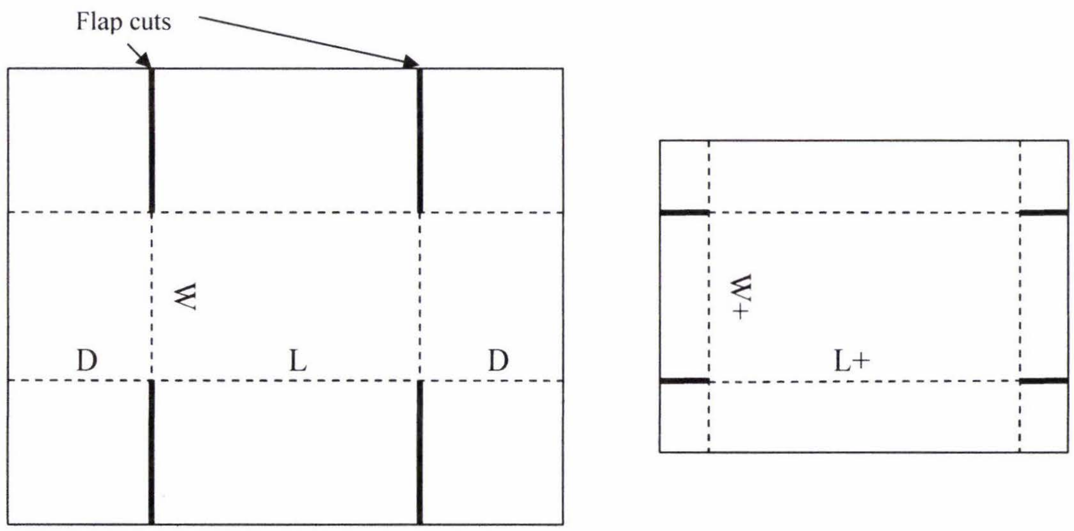
Two design style trays, one inverted and fitting over the other. The top tray is a lid with little depth and the bottom tray has considerably more depth. As the vertical orientation of the flute must exceed horizontally, the lid when covered does not aid to a high degree the stacking strength of the box, hence the two longer sides of the cover have a horizontal flute orientation for maximum fibre tear, Figure 7.1.

Figure 7-1 Design Style Container with Cover (DCS)



Flute Profile: B, Sealed with hot melt adhesive.

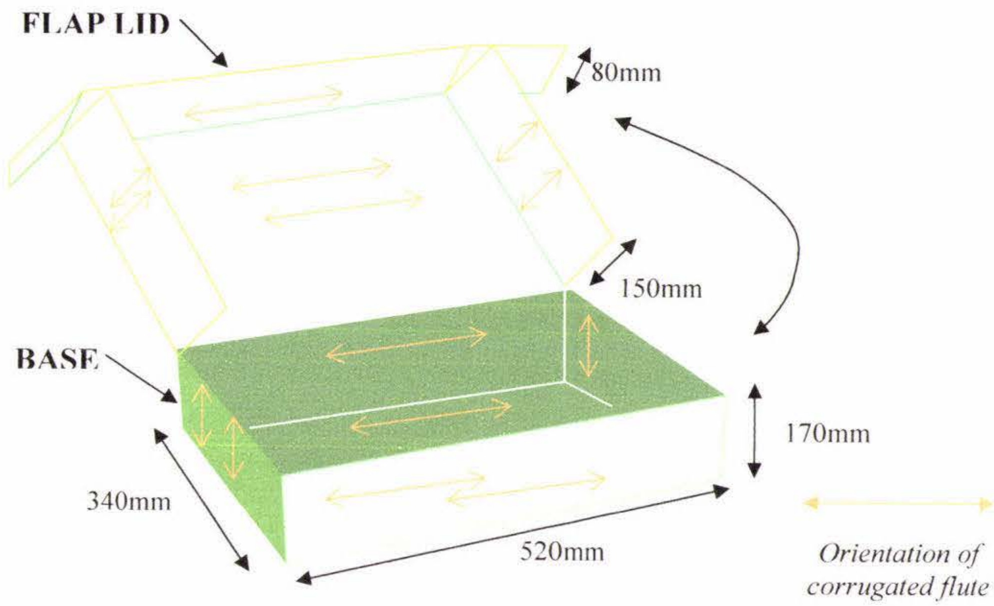
Figure 7-2 Pattern for Design Style Container with Cover



DESIGN TWO – Five Panel Folder (FPF)

A single cut and scored piece features a fifth panel used as the closing flap, completely covering a side panel. This design is not as suitable as the previous for the tape sealed system as the panels are at different lengths and only requires three sides of taping. However, this design has a horizontal flute orientation for the longer sides to allow for greater fibre tear.

Figure 7-3 Five Panel Folder (FPF)



Flute Profile: E, self locking box style.

Figure 7-4 Pattern for Five Panel Folder

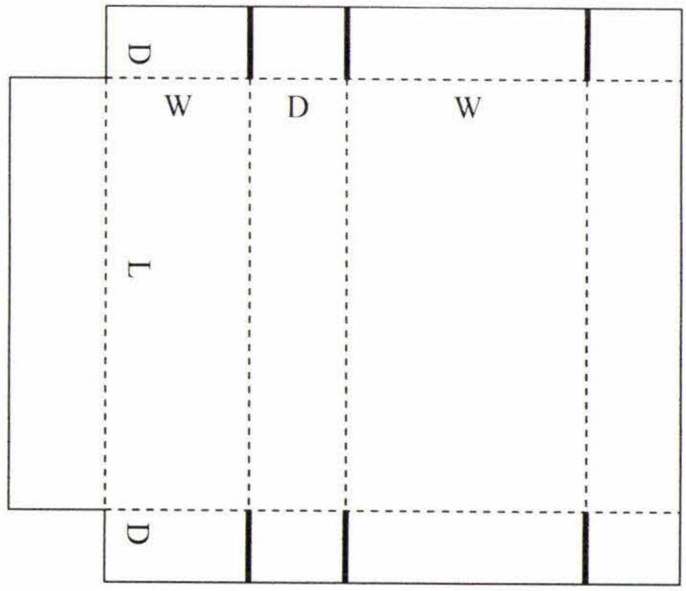


Figure 7-5 Illustration of a Five Panel Folder Unassembled

[http://www.dallascontainer.com/s_fpf.htm]

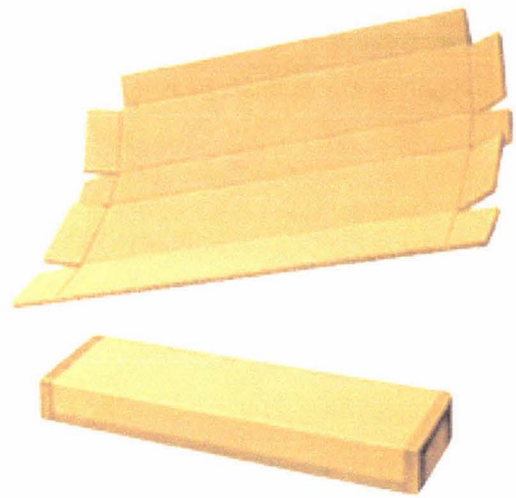
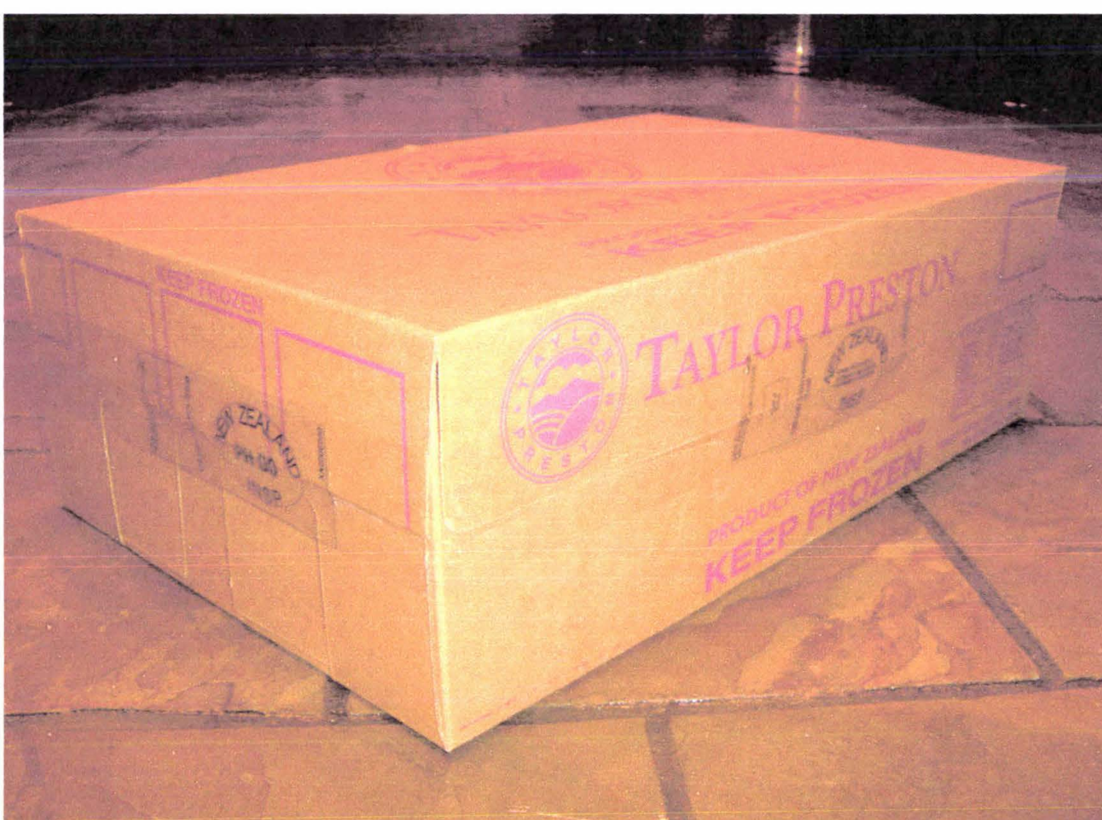
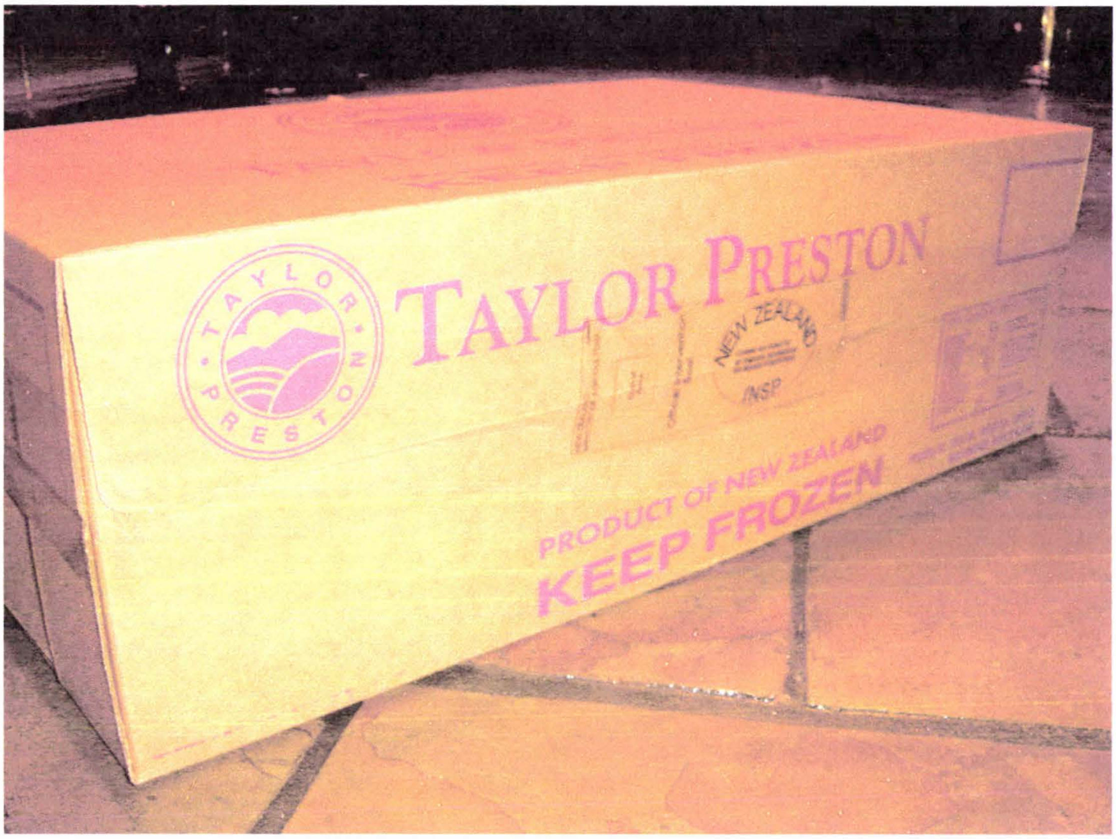


Figure 7-6 Photo of an existing five panel folder meat carton from Taylor Preston with sample MAF seals taped horizontally with PSA



The picture above shows what the final taped carton would look like bearing the official MAF seals using a five panel folder corrugated fibreboard.

Figure 7-7 Another photo of an existing five panel folder meat carton from Taylor Preston with sample MAF seals taped horizontally with PSA



7.3 MEASURING THERMAL RESISTANCE OF CORRUGATED FIBREBOARD AND WITH ADHESIVE TAPE

The heat transfer resistance of corrugated containers for the chilling and freezing foods industry is an important tool to allow for maximum efficiency when it comes to processing time, [Robertson, Tom 1998 Measuring Thermal Resistance of Corrugated Made Simple].

The following is taken out of the Packaging Technology & Engineering August 1998 Volume 7 Number 8 issue Measuring Thermal Resistance of Corrugated Made Simple article written by Tom Robertson.

7.3.1 THERMAL CONDUCTIVITY AND HEAT TRANSFER RESISTANCE EXPERIMENT *[Measuring Thermal Resistance of Corrugated Made Simple, Packaging Technology & Engineering August 1998, Volume 7 Number 8, Appendix F2 and Modelling the Heat Transfer Resistance of Corrugated Paperboard, Peer Reviewed Paper, The NZ Food Journal 29(3) by F Bilge Thompson, Tom R Robertson and Andrew C Cleland, Massey University, Appendix F2].*

Heat flux through packaging to a food product is $\boldsymbol{\varnothing / A = \lambda\, \Delta\theta/\chi = \Delta\theta / Rp}$ (Eq.1)

Where:

$\varnothing$ = dQ/dt, the rate of heat transfer (W)

A = area (m^2)

$\Delta\,\theta$ = temperature difference across the wall (K)

χ = thickness of wall (m)

λ = thermal conductivity ($Wm^{-1}K^{-1}$)

Rp = χ/λ, heat transfer resistance (m^2KW^{-1})

The net heat in a packaging system arises from two heat resistances, the surface resistance and the packaging resistance, which are treated as a single resistance and estimated from unsteady-state measurements using the method invented by Cleland and Earle, 1976. It measures time-temperature data at the surface of a semi infinite slab for short intervals after the start of cooling or heating which yields accurate results.

Equipment

Used to determine the heat resistance of the packaging was a thermostatically controlled water bath with a stainless steel tray on top giving an isothermal surface. Tylose MH-1000 with known thermal properties was used as the block.

Between 2°C and 30°C, Tylose thermal properties are: Thermal conductivity 0.496$Wm^{-1}K^{-1}$

Specific heat capacity 4,100$jkg^{-1}K^{-1}$

Density of 1,000 kgm^{-3}

7.3.2 TEST METHOD

1. The Tylose block chilled at 1°C was maintained with insulation.
2. The thermocouples were connected to the data logging system while the corrugated fibreboard sample of flute B was placed on the stainless steel plate on the water bath.
3. The Tylose block was then quickly placed on the corrugated samples with a standard weight of 10g to ensure consistent contact of the stainless steel plate and the fibreboard, Tylose and the thermocouples.
4. Temperatures were measures at the surface (θ_s) and base of the Tylose (θ_i), and the water temperature (θ_a) was measured at 20 second intervals for 10-15 minutes. Any data resulting from the thermocouples that had sunk into the Tylose were discarded.

5. The experiment was then repeated with different numbers of sample corrugated sheets, maximum three sheets were used. Then a corresponding number of layers of adhesive tape were included.

The Goodman plot system was used to analyse the data from Cleland and Earle, 1976.

Surface temperature of a semi-finite slab is accurately predicted by the following approximation:

$4/3(h/\lambda)^2 \lambda/\rho c = 1/2Y_s^2 - \frac{1}{2} + \ln Y_s$ (Eq. 2) $\qquad h = \lambda \sqrt{\frac{3}{4}\chi \rho c / \lambda}$

Slope = χ = Rise / Run

h is the effective surface heat transfer coefficient $Wm^{-2}K^{-1}$

Tylose thermo physical properties $\qquad \lambda = 0.496\ Wm^{-1}K^{-1}$
$\rho = 1000\ Kgm^{-3}$
$c = 4100\ JKg^{-1}K^{-1}$

Once h was calculated, a plot of $1/h$ will result in the heat transfer resistance $R\rho$ of a single layer of packaging. Where the thickness of the packaging was known, the thermal conductivity of the packaging material can be calculated using equation 2.

7.3.3 RESULTS *[Appendix F.1]*

1 Layer of board

$h = 12.5824803$

2 Layers of board

$h = 7.70835531$

3 Layers of board

$h = 9.359072389$

Heat Transfers Resistance $\mathbf{R\rho = 0.0136\ m^2KW^{-1}}$ for one layer of packaging

$R_{pk} = R_{liner1}$ for 220 gm^{-2} paper + R_{fl} for B flue + R_{liner2} for 220 gm^{-2} paper

$R_{pk} = 0.0042 + 0.0136 + 0.0042$
$= 0.022\ m^2KW^{-1}$ for 313, B, NK

$R_{pk} = \chi_{pk} / \lambda_{pk}$

$\lambda_{pk} = 0.00331m / 0.022\ m^2KW^{-1}$
$= \mathbf{0.150\ Wm^{-1}K^{-1}}$

1 Layer of board and 1 layer of adhesive tape

$h = 108.4566466$

2 Layers of board and 2 layers of adhesive tape

$h = 105.7188053$

3 Layers of board and 3 layers of adhesive tape

$h = 51.61885409$

Heat Transfers Resistance $\mathbf{R\rho = 0.005\ m^2KW^{-1}}$ for one layer of packaging with adhesive tape

$$R_{pk} = R_{liner1} \text{ for } 220\ gm^{-2} \text{ paper} + R_{fl} \text{ for B flue} + R_{liner2} \text{ for } 220\ gm^{-2} \text{ paper}$$

$$R_{pk} = 0.0042 + 0.005 + 0.0042$$
$$= 0.0134\ m^2KW^{-1} \text{ for 313, B, NK}$$

$$R_{pk} = \chi_{pk} / \lambda_{pk}$$

$$\lambda_{pk} = 0.00331m / 0.0134\ m^2KW^{-1}$$
$$= \mathbf{0.246\ Wm^{-1}K^{-1}}$$

7.3.4 DISCUSSION

The thermal conductivity of the corrugated fibreboard was calculated as 0.150 $Wm^{-1}K^{-1}$ compared with that of the addition of adhesive tape at 0.246 $Wm^{-1}K^{-1}$. The thermal conductivity with the addition of the adhesive tape is nearly twice that of just the corrugated indicting that the contribution of the adhesive tape enhances the heat transfer considerably. This is a great result as the adhesive tape aids in the processing time while food is being stored in the chiller and freezer.

8.0 – CONCLUSIONS

The visits to freezing works and packaging plants highlighted the need for a tape-seal packaging system that will provide a secure, tamper evident pressure sensitive tape that can package meat cartons sturdily while incorporation the Ministry of Agriculture seals as well as keeping in accordance with New Zealand and International exporting rules and regulations. The standardisation of corrugated carton boxes for this development is also required to easily manipulate the tape-sealed packaging unit developed by Masterate student Rod Collins.

The storage conditions of the products at the meat works require the tape to be at cooler temperatures more often than at room temperature. Therefore the selection of tape for the packaging system favours tapes functional at cold temperatures (-1 to 5°C) and freezing conditions (-18°C to -28°C). This project placed more emphasis on the results of conducted tests of these tapes to determine their suitability over other packaging tapes.

The adhesive these tapes contain relate to how well they work and what surfaces it prefers to adhere to. As written in the literature review, there are two types of adhesives used in today's pressure sensitive tapes. The two cold temperature tapes investigated here both have the two different types of adhesives; synthetic rubber resin and water dispersed acrylic. The 3M™ cold temperature tape has an added advantage of adhering to plastic coated cartons, a popular carton feature becoming more prominent to prevent carton wetting.

In chapter 3, investigated packaging tapes specifications were defined. When essential tape characteristic tests were carried out such as the peel adhesion test and the ultimate tensile and elongation test, the specifications aided and confused the understanding of the tapes characteristics and behaviour. The peel adhesion test showed that in freezing and chilly conditions, the freezer grade and cold temperature tapes performed the best compared to the other packaging tapes, producing the lowest forces. As discovered from observation, the lower the force required to peel the tape from the corrugated specimen, the more fibre it tore off. A performance specification sort after, of the new proposed tape for delaminating the carton fibre material. The results of that test also concluded that more fibre was torn off the corrugated specimen when the tape is peeled at the same orientation as the flute profile. For the use in this horizontal taping machine, to maximise fibre tear, the carton should be designed to have more horizontal orientated flutes without compromising carton strength. The two tapes also stood out on top of the tensile and elongation tests; although 3M™ cold temperature tape had the thinnest backing which contradicts the relationship of the thicker the backing the stronger the tape.

The suitability and manner of the use of ink and a test that defines the order of tack were determined in chapter 4. The idea of spraying ink onto the adhesive surface of the tape just immediately before adhering it to the carton is not feasible as droplets formed creating an unclear image unsuitable for the tape requirements. A reason why this is not common practice at Imaje, a printing firm Graphpak has consulted with and at Sellotape®; specialist in making a vast variety of tapes. Tack is not a strong trait for cold temperature tapes, and that carries onto the lack of ability to bottom seal a 10kg carton for the 3M™ range. However, the tape specifications for this tape did state its applications only for cartons that weigh less than 10kg.

From the investigation of the peel adhesion test, we know that the higher the force, the less fibre it tears from the corrugated board. This conclusion was reinforced when the peel adhesion test was redone with heat applied to the corrugated specimen immediately after adhesion of tape to board. Specimens from the freezer yield the highest peel force while the specimens in the chiller produced more fibre tear. Because the chiller is a more humid environment than the freezer, it is not surprising that the fibres bonded to a more manageable tape temperature for maximum fibre grab. The ideal temperatures at which results show that maximum force and fibre tear are are at 55°C and 70°C. The addition of ink in this experiment proved successful at creating a leaching effect on the board after tape was peel. The heat treatment aided the ink to become more prominent on the peeled tape along with a high fibre grab.

The experiments with the application of ink on the tape were proved more feasible to apply to the tape backing substrate before the coat of adhesive. This not only has advantages of information clarity, it will prevent smudging and distortion as well as prevent the ink rubbing off. Existing security to safe guard these tapes apply as to the current MAF seals. The use of barcode for product identification and storage of information of export products would be most advantageous. This must be printed on the box as commonly practised.

As investigated successfully, the delamination of the corrugated fibreboard from the removal of the tape provided the evidence of the carton being tampered with; this has been the primary goal in the security of the carton. With many ideas explored the most feasible is the idea of incorporating ionised air during the sealing of the tape to cure hence improves fibre grab and therefore providing certainty the unusability of the exported carton.

With the vast array of box styles and board types, each suitable to a specific containment of cuts, it would be impractical to reinvent the wheel. The most promising box design in taking advantage of the tape-seal packaging unit would be to utilise the box style the unit was intended for. That is a design style container with cover, a popular style used for exporting 20 kg of cut beef. The carton should maximise horizontal orientated flutes for greater fibre tear without compromising carton strength.

The pressure sensitive tape with most potential for selection for this tape sealing system is definitely of a cold temperature functional type. Suggestion to select the Sellotape® brand of freezer grade tape for its overall all-round performance in tests is clear. Because the tape is New Zealand made and the company is well associated with this project, time and money can be speared in the further development of this tape.

8.1 RECOMMENDATIONS

It is highly recommended that:

1. A more in-depth analysis of the properties of adhesive and backing substrate to invent or use existing materials suitable to maximise the tape-seals system.
2. Investigation into other types of printing inks such as laser is explored as a result of the preferred method of application.
3. An ionised system is used to perform the experiment in section 5, for comparison and in determining ideal temperature with actual product and final box style.
4. The technology for allowing traceability be further explored.

8.2 FURTHER WORK

The actions that need to be taken at Lyhatton are:

1. Obtaining the prototype of the tape-seal packaging unit from the makers in Finland.
2. Trial the prototype with the selected tape and final box style with product at a freezing works. Treat the trial as an actual packing process, incorporating the storage requirements and test for peel adhesion as in chapter 3.
3. Enquire about the full information required on the tape from MAF if it is to be implemented nationwide ready for export.

The expectation is that this will begin the next phase of the project of further refinement if the results produced are in favour of all the tested elements.

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GLOSSARY

Adhere – To cause two surfaces to be held together by adhesion.

Adhered – A body which is held to another body by an adhesive.

Adherend – A material surface or substrate which is attached to another substrate by an adhesive.

Adhesion – The act or state of adhering.

Adhesive – Is a compound that adheres or bonds two items together.

Adhesive Transfer – The transport of adhesive from its normal position on the tape backing to a surface to which the tape was attached, either during unwind or removal.

Backing/Carrier (substrate) – The primary component of tape upon which a relatively thin flexible material to which the adhesive is applied.

Bleeding – Penetration through the tape of a coloring material (paint, etc.) onto the surface to which the tape is applied.

Bond strength – The amount of force required to break the bond.

Bond, n – The combination of two materials with an adhesive.

Bond, v – To combine two materials with an adhesive. (See also **adhere**)

Coating Weight – The weight of a coating per unit area. In SI-units expressed as grams per square meter (g/m2).

Cohesion (Cohesive Strength, Internal Bond) – The ability of the adhesive to resist shear stress and splitting. Good cohesion is necessary for clean removal.

Conformability – Ability of a tape to make total contact with a rough or uneven surface.

Creep – The slow movement of the adhesive or backing under shear stress. Creep at room temperature is sometimes called cold flow.

Curing – Is the process during which an adhesive changed from a liquid to a soild.

Debonding – The process by which an adhesive looses its attachment to a surface.

Elastomer – An elastic, polymeric substance, such as natural or synthetic rubber.

Elongation – The measurement of a tape specimen's increase in length as a result of being stretched under constant tension, expressed as a percentage of original length.

Fatigue – A weakness resulting from stress created by repeated flexing or impact force upon the adhesive-adherend interface.

Impact – The minimum force required to cause the adhesive to fail in a single blow. May be determined in tension or shear, measures brittleness.

Peel – The stripping of a flexible member fastened with adhesive to another flexible or rigid member.

Peel Adhesion – The force per unit width required to break the bond between a pressure sensitive adhesive tape and the surface to which it has been applied when the tape is peeled back at a controlled angle at a standard rate and condition.

Pressure Sensitive Adhesive – A type of adhesive, which is permanently tacky at room temperature and when applied to a variety of surfaces, forms an immediate bond. The bond strength may be increased by pressure and/or time.

Pressure Sensitive Tape – A term used to describe a category of tape coated on one or both faces with a pressure sensitive adhesive.

Release Coating – A very thin coating applied to the impervious tape backing so as to allow the tape to be unwound at a controlled level.

Release Liner – A removable material, which protects the adhesive face or faces of the roll of tape. Most frequently found on double- sided tapes and label stocks.

Removability – Ability to remove the tape from the substrate without damaging or contaminating the substrate under specified conditions, usually after a long period of time.

Re-positionability – Ability to remove the tape from the substrate without damaging or contaminating the substrate under specified conditions, yet retaining bond strength when re-applied, usually after a short period of time.

Rheology – Is the study of the deformation and flow of matter under the influence of an applied stress.

Setting Time – Is the time elapsing between applying an adhesive to one or both surfaces, and the bringing together of those two surfaces.

Shear – Forces acting in the plane of the adhesive.

Shear Strength – The ability of the adhesive to resist force applied in the same plane as the tape.

Shelf Life – Is the period of time for which an adhesive may be stored without deteriorating to the point that performance will be unsatisfactory.

Stress – A measure of force per unit area within a body.

Stress Tension – Forces acting perpendicular to the plane of the adhesive.

Substrate – The surface to which the tape is applied.

Tack – The sticky feel of the tape. It is the initial adhesion without rub-down.

Tensile Strength – The force required to break a sample specimen of tape. This property indicates the ability of a tape to withstand stress during its application and while it is in service.

Thermoplastic – Polymers which soften when heated.

Thermosetting adhesive – An adhesive, which becomes firmer on heating and remains so on cooling. Thermosetting of adhesive improves solvent resistance and increases softening temperature.

Unwind – The force to remove or unwind the tape from a roll.

Viscosity – Is the ability of a liquid to resist flow.

Weather Resistance – The ability of the tape to resist exposure to specified conditions after application and to perform satisfactorily; these conditions are usually cold and water.

Wetting – A term used to describe the spreading of an adhesive on an adherend surface. Good wetting is a pre-requisite for good adhesion.

APPENDIX

A.1 MAF Endorsement

Ministry of Agriculture and Forestry, New Zealand
Te Manatu Ahuwhenua, Ngaherehere, Aotearoa

8 June 01

John Bradley
Managing Director
[redacted]

Dear John

Carton Taping Machine

Further to our discussion in Palmerston North on the 23rd May regarding the carton taping machine and its potential for incorporation of the MAF security mechanism.

The traditional means of officially sealing cartons (ie a seal of approx. 150mm x 50mm placed over the carton joints) is not particularly satisfactory. There are ongoing problems with application, numbers of seals used per carton depending on design, and rough handling during loading and transport. Foreign governments periodically reject product for faulty sealing, with the latest incident involving four containers of product taking place this week.

Several years ago, MAF asked the meat industry and the carton seal manufacturers to submit suggestions for a new seal of more robust design. There was none.

MAF recognises the potential of your carton tape serving a dual function as an official seal. The tape would have to display official information along its length. This information must remain legible as the tape moulds to the carton surface.

We are keen to see further work done particularly with cartons of different designs. Success in this endeavour would provide us with the first opportunity we have had in twenty years to rationalise the mechanisms and procedures for the official sealing of cartons.

Yours sincerely

P.A.R. Ward
Technical Policy Manager

MAF FOOD ASSURANCE AUTHORITY
ASB Bank House, [illegible] The Terrace, PO Box [illegible], Wellington, New Zealand
Telephone [illegible] Facsimile [illegible]

MAF Food

FINISHED ROLL ADHESIVE COATING WEIGHT METHOD

1. Remove 2 to 3 layers of tape from the outside of the roll.
2. Cut a strip of tape approximately 25 cm long from the roll. Ensure that the cuts are as straight as possible, ie. at right angles to the edges of the roll.
3. Measure the length of the strip of tape to the nearest mm. Form the strip of tape into a loop small enough to fit on the pan of the analytical balance.
4. Tare the balance, then weigh the strip of tape and record its weight in grams (weight backing + adhesive).
5. Remove the adhesive from the loop of tape using paper towels and the appropriate solvent (toluene for rubber based adhesives or acetone for acrylic adhesives)
6. Dry the washed sample, this is particularly important for vinyl and PE tapes.
7. Reweigh the sample and record its weight in grams (weight backing)
8. Calculate the weight of adhesive (in grams) by subtracting the weight of the backing from the weight of the backing + adhesive.
9. Calculate the area of the sample in square metres by multiplying its length in metres by its nominal width in metres.
10. Calculate the coating weight of the sample to the nearest 0.1 g/m^2 by dividing the weight of adhesive in grams by the area of sample in square metres.

EXAMPLE

Nominal Roll Width	36 mm	0.036 m
Length Of Sample	225 mm	0.225 m
Weight Backing + Adhesive	0.6093 g	
Weight Backing	0.4482 g	

Area	$0.036\ m \times 0.225\ m = 0.0081\ m^2$
Weight Adhesive	$0.6093\ g - 0.4482\ g = 0.1611\ g$
Coating Weight	$0.1611\ g \div 0.0081\ m^2 = 19.9\ g/m^2$

B.2 Results of Finished Roll Adhesive Coating Weight Test

Finished Roll Adhesive Coating Weight Method

Tape			*B Thickness (mm)*			*B Average (mm)*
Sello Fresh	0.029	0.029	0.030	0.030	0.029	0.029
Sello Freeze	0.029	0.030	0.030	0.029	0.029	0.029
Sello Old	0.029	0.029	0.029	0.029	0.029	0.029
3MCold	0.028	0.028	0.028	0.028	0.027	0.028
3MMed	0.031	0.031	0.032	0.032	0.032	0.032
3MOld	0.030	0.030	0.030	0.030	0.030	0.030
Panfix	0.030	0.030	0.030	0.029	0.029	0.030

	Roll Width (m)	**Length of Sample (m)**	**Weight B + A (g)**	**B + A Thickness (mm)**	**Weight B (g)**	**B Thickness (mm)**	**Area (m^2)**	**Weight Adhesive (g)**	**Coating Weight (g/m^2)**	**Adhesive Thickness (mm)**
SelloFresh	0.048	0.05	0.116	0.045	0.065	0.029	0.0024	0.051	21.3	0.016
SelloFreeze	0.048	0.05	0.115	0.045	0.061	0.029	0.0024	0.054	**22.5**	**0.016**
SelloOld	0.060	0.05	0.148	0.043	0.081	0.029	0.0030	0.067	22.3	0.014
3MCold	0.036	0.05	0.092	0.043	0.051	0.028	0.0018	0.041	22.8	0.015
3MMed	0.036	0.05	0.079	0.045	0.049	0.032	0.0018	0.030	16.7	0.013
3MOld	0.048	0.05	0.121	0.047	0.067	0.030	0.0024	0.054	22.5	**0.017**
Panfix	0.048	0.05	0.109	0.045	0.066	0.030	0.0024	0.043	17.9	0.015

Call Letters	Appendage A
Date of Issuance	6/66
Revised	11/70
Revised	8/85
Revised	8/89

Standard Conditions

1. SCOPE

 1.1 This method defines the term "standard conditions" used throughout this standard.

2. DEFINITION

 2.1 Standard conditions are a temperature of 23 ± 2°C (73.4 ± 3.6°F) and a relative humidity (RH) at that temperature of 50 ± 2%.

 2.2 Unless otherwise specified in the test method, all tests shall be conducted in the conditioned chamber or room at standard conditions.

For further information on testing conditions refer to ASTM D 685-80 Standard Method for Conditioning Paper and Paper Products for Testing and ASTM D-1000 Standard Method — Pressure Sensitive Adhesive Coated Tapes used for electrical insulation.

Call Letters	Appendage B
Date of Issuance	6/66
Revised	11/70
Revised	11/75
Revised	8/85
Revised	8/89

Test Equipment

1. **SCOPE**

1.1 This appendage describes equipment used in methods found in this standard. It includes a description of equipment used in more than one method, and a table referencing each test method and the appropriate equipment required to conduct the tests described in these methods.

2. **TEST EQUIPMENT DESCRIPTION**

2.1 This paragraph describes equipment required by more than one test method in this standard.

2.2 Adhesion testers

2.2.1 Adhesion peel tester or slip/peel tester

The testing machine will be of the constant rate of extension type composed of a device for fixing the sample in a configuration that facilitates the testing of samples in the 90° as well as the 180° position, and a clamp that falls in a position where the center of each device is in the same plane. The tester sample holders also will be oriented so that they will be parallel to the direction of stress, and so aligned so that they will hold the specimen wholly in the same plane. A stress gauge or load cell and recording device will be part of the sample-holding apparatus and will be capable of recording the force required. A means of moving the stress jaw at a uniform rate, 12"/min. for the adhesion/rolldown machine.

2.2.2 Adhesion/release tester

This equipment is the same as the above except the speed of the test can be adjusted to 12", 30", 60", 300", 600" and 1,200"/min. for the combination adhesion/release tester. The test bed stroke can be adjusted to as much as 16".

2.2.3 Tensile tester as described below in paragraph 2.3

2.3 Tensile tester

2.3.1 The testing machine shall be of the constant rate of extension type composed of two clamps whose centers shall be in the same plane, parallel with the direction of the motion of the stressing clamp, and so aligned that they will hold the specimen wholly in the same plane; an autographic device for recording the tensile load and the amount of jaw separation; and a means of moving the stressing jaw at a uniform rate, the rate to be specified in the test method.

2.3.2 The tester should have a load range such that the test mean value falls between 20% and 50% of full scale.

2.3.3 In lieu of the clamping jaws, a pair of 4" diameter cylinders shall be used when specified. These cylinders shall be constructed so that when they are attached to the tensile machine, the line of the tape during testing shall be parallel to the motion of the applied stress.

.4 Cutter, specimen.

2.4.1 The specimen cutter shall hold two single-edged razor blades in parallel planes, a precise distance apart, to form a cutter of exact specimen widths. Two cutters, 0.5 and 1" cutting width, shall be available.

2.4.2 The 0.5" cutter shall consist of a 0.5"-thick by 8" length of aluminum barstock 0.5" wide. The edges for about 5" from one end shall be rounded slightly to form a handle. The width of the bar for 3" from the opposite end shall be narrowed to exactly 0.500" minus the thickness of a single razor blade (one of two used as cutting edges). The razor blades shall be held in position using side plates. The end of the cutter shall be cut away at a 45° angle to expose the cutting edge at one end of the blades. The edges shall be separated by 0.500 ± 0.005".

2.4.3 The 1" cutter shall follow the same description as in 2.3.2, except that the barstock width shall be 1" and shall be narrowed to exactly 1.00" minus the thickness of a single razor blade.

.5 Cup, water vapor transmission rate, and water penetration rate test.

2.5.1 The test cups shall be made from materials that are nonhydroscopic. The cup shall have a zero moisture vapor transmission rate (MVTR). The cups shall be rectangular with a flat, smooth, rigid flange, and shall have the following dimensions:

Flange:Outside — 2.0 by 6.0 ± 0.02".
Inside (opening) 1.0 by 4.0 ± 0.02".

Body: Inside — 1.0 by 4.0 by 1.5 (depth) ± 0.02".

The mass shall not exceed 80% of the balance capacity used in weighing.

.6 Panel

2.6.1 A 2" by 5" by 18 gauge (no less than 0.043") panel of stainless steel 302 or 304 in accordance with ASTM Specification A 666 having a bright annealed finish.

2.6.2 Panels with other shapes and dimensions may be formed or cut from the same steel and finish when specified by an individual method. This paragraph will be cited with the necessary exceptions.

2.6.3 Panels showing stains, discoloration, or numerous scratches are not acceptable.

.7 Roller, mechanically operated, rubber covered.

2.7.1 A steel roller, 3.25" ± 0.1" in diameter and 1.75 ± 0.05" in width, covered with rubber approximately 0.25" in thickness and having a Shore scale A durometer hardness of 80 ± 5. The surface of the roller shall be a true cylinder void of any concave or convex deviations. The mass of the roller shall be 4.5 ± 0.1 lb.

2.7.1.1 A simple check to determine if the rubber surface is cylindrical is to wrap a very thin paper (onion skin) and drag it across a flat glass plate on which is placed carbon paper, face up. The carbon rubs off onto the thin paper wrapper to reveal high spots or hollows on the rubber surface.

2.7.1.2 For foil tapes only. A steel roller 5.0 ± 1" in diameter with a total weight of 10.0 ± 0.10 lb shall be used. The cylindrical surface of the roller shall be a true cylinder void of any concave or convex deviations so that the roller will apply a uniform pressure across the width of its entire surface.

2.7.2 A mechanically driven mount for the roller to move at 12 ± 0.5" per minute in one direction and return in the opposite. The mount shall hold the roller so that, during rolling, the full weight of the roller (but only the weight of the roller) shall be allowed to act on the specimen. The roller shall be free turning on its own axis. The mount shall provide a means of lifting the roller so that, at rest, the roller surface does not contact any object.

2.8 Roller, hand operated, rubber covered.

2.8.1 Roller as in 2.7.1

2.8.1.1 Roller as in 2.7.1.2

2.8.2 The roller construction shall not allow the weight of the handle to increase the weight of the roller during use.

2.9 Tear tester

2.9.1 The apparatus shall be an Elmendorf–type of tester conforming to the following:

2.9.2 A stationary clamp and a movable clamp carried on a pendulum preferably formed by a sector of a wheel or circle, free to swing on a balance or other substantially frictionless bearings;

2.9.3 A pointer and pointer stop to record the maximum arc of swing of the sector pendulum;

2.9.4 A sector release to hold the pendulum in the raised position during the mounting of the sample, and permitting it to follow through the force of gravity;

2.9.5 Pendulum carrying a circumferential graduated scale, so as to indicate the force used in tearing the specimen;

2.9.6 A knife attachment for initial slitting of the specimen.

2.9.7 With the pendulum in the raised position, the movable clamp shall lie in the same plane as the fixed clamp forming as it were an extension to the fixed clamp. This plane shall be perpendicular to the plane of oscillation of the pendulum. The gripping surface of the jaws in each clamp shall be 25 mm (0.984") by 16½ mm (0.650"). The clamps shall be separated by a distance of 2.5 mm (0.098"). The knife attachment shall slit this specimen midway between the clamps at right angles to the upper edge of the clamps. The slit shall extend from the bottom edge of the specimen to a point of 4 mm (0.157") above the top edge of the clamps leaving a distance of 43 mm (1.692") of uncut specimen perpendicular to the long dimension of the specimen. The perpendicular from the line formed by the top edge of the clamps to the axis of suspension shall be 104 mm (4.09") and shall make an angle of 27.5° with the plane of the specimen.

3. EQUIPMENT AVAILABLE FROM PSTC

3.1 The following Pressure Sensitive Tape Council (PSTC) equipment is available from Chemsultants International, 9349 Hamilton Drive, Mentor, Ohio 44061-1118. Telephone: 216/352-0218.

Adhesion peel tester
Adhesion release tester
Cutter, specimen
Cup, water vapor transmission rate and water penetration rate
Panels
Quick stick test fixture
Roller, mechanically operated
Roller, hand operated
Roller, steel (for foil tapes)
Holding power cut-off fixture
Holding power test stand — room temperature version
Holding power test stand — oven version
Unwind fixture
Variable speed unwind machine
Tack, rolling ball apparatus
Weights — TW
Weight suspension clips

Call Letters	Appendage D
Date of Issuance	6/66
Revised	11/70
Revised	8/85
Revised	8/89

Preparation for Testing

1. SCOPE

1.1 This method defines the environmental conditions required for sample roll conditioning and indicates what steps are necessary towards specimen selection.

2. SAMPLE ROLL CONDITIONING

2.1 Unless otherwise specified, the sample roll(s) shall be conditioned for at least 24 hours prior to testing in an atmosphere maintained at standard conditions (Appendage A). The sample roll shall be placed in the chamber or room in such a way that the conditioning atmosphere shall have free access to all normally exposed surfaces of the sample roll.

3. SPECIMEN SELECTION

3.1 Discard at least three but no more than six outer wraps of tape from the sample roll before taking specimens for testing. This applies to rolls in the as-received and accelerated-aged condition.

3.2 Remove one specimen per sample roll for each test to be performed unless otherwise specified. Remove it from a freely rotating roll at the rate of 20-30" per second. Where width or other factor causing a high adherence to backing makes it impossible to remove the specimen at the prescribed rate, remove it at a rate as close to 20" per second as possible. Note: Care shall be taken when unrolling glass filament or glass fabric backed tapes so as not to fracture the glass. Preventing acute angles of unwinding will assist in doing this.

3.3 When the tape is wider than the dimension specified in the method, specimens of the widest specified width are to be cut from the center of a strip removed from the roll as in 3.2.

3.3.1 A specimen cutter for use in preparing specified widths is defined in Appendage B.

Call Letters	PSTC-1
Date of Issuance	9/55
Revised	4/66
Revised	11/70
Revised	11/75
Revised	8/85
Revised	8/89

Peel Adhesion for Single Coated Pressure Sensitive Tapes at 180° Angle

1. DEFINITION

   1.1 Peel adhesion is the force required to remove a pressure sensitive tape from a test panel or its own backing.

2. SIGNIFICANCE

   2.1 In many applications the use of a pressure sensitive adhesive tape depends upon adhesion strength to give satisfactory performance. The property is also important in determining th uniformity of quality. Values obtained by the two methods are not equivalent.

3. TEST SPECIMEN

   3.1 For test specimen conditioning, selection, and test conditions, see Appendages A & D.

   3.2 The test specimen shall be no greater than 1", nor less than ½" wide and approximately 12" in length. A width tolerance of + 1/64" shall be allowed.

4. EQUIPMENT

   4.1 Adhesion tester. See Appendage B.

   4.2 Panel. See Appendage B.

   4.3 Roller, 4½ lb., mechanically operated, see Appendage B.

   4.4 Roller, 10 lb., mechanically operated, for foil tapes only. See Appendage B.

   The equipment listed above is available from Chemsultants International, telephone 216/352-0218.

5. TEST METHOD

   5.1 Before each test, clean panel per method in Appendage C.

   5.2 Adhesion to steel — Touch one end of the specimen to an end of the test panel. Hold the other end of the specimen so that it does not make contact with the panel but is positioned loosely above it. Roll the tape mechanically once in each lengthwise direction causing the roller to apply the tape to the panel. This prevents entrapment of air between the adhesive and the panel. Should this occur, discard the specimen. Where the width of the specimen i less than 1", prior to applying test specimen, apply a strip or strips of the tape to give an equivalent width of 1" for rolling purposes. Prepare each specimen individually and test immediately within one minute (longer dwell time will give different results), in accordance with paragraph 5.4. For foil tapes only, a 10 lb. roller shall be used. Pass roller over the sample 5 times in each direction.

   5.3 Adhesion to backing — Conduct the test for adhesion of a tape to its own backing as in 5.2 and 5.4 except first affix a 6" strip of the tape under test to the lengthwise surface of the cleaned panel. Do not touch the backside of this strip. Superimpose the specimen on this strip taking care to align the edges. Proceed with the steps of paragraph 5.2. For foil tapes only, a 10 lb. roller shall be used. Pass the roller over the sample 5 times in each long direction.

   5.4 Double back the free end of the tape at an angle of 180° and peel 1" of the tape from the panel at the folded end. Clamp that end of the panel, from which the tape has been removed, into the lower jaw of the adhesion testing machine and the free end of the tape into the upper jaw. Operate the lower jaw at 12"/min. After the lower jaw is started in motion, disregard the values obtained while the first inch of tape is removed mechanically. Use the average pull value obtained during peeling of the next 2" as the adhesion value.

6. **REPORT**

6.1 Report the peel adhesion value(s) in ounces per 1" width to the nearest 1 oz./in. If other than 1" widths are tested, 1" values are found as the result of dividing the observed value by the specimen width.

Another method for measuring adhesion of pressure sensitive tapes is ASTM-D 3330.

Designation: D 3330M – 96
METRIC

Standard Test Methods for Peel Adhesion of Pressure-Sensitive Tape at 180° Angle [Metric][1]

This standard is issued under the fixed designation D 3330M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the measurement of the peel adhesion of pressure-sensitive adhesive tapes.

1.1.1 Test Method A gives a measure of the adherence to a standard steel substrate or to other surface of interest for a single-coated tape (that is, adhesion to tape's own backing).

1.1.2 Test Method B gives a measure of the adherence to a standard steel substrate for double-coated tapes.

1.1.3 Test Method C gives a measure of the adherence of the release liner to the adhesive of either single-coated or double-coated tapes having a release liner.

1.2 These methods provide a means of assessing the uniformity of the adhesion of a given type of pressure-sensitive adhesive tape. The assessment may be within a roll of tape, between rolls, or between production lots.

1.3 Variations in the tape's backing and adhesive affect the response. Therefore, these methods cannot be used to pinpoint the specific cause(s) of nonuniformity.

1.4 These test methods may not be appropriate to test tapes having either relatively stiff backings, or stiff liners, or backings showing high stretch at low forces. These characteristics will result in a high variability of the test response which is not a true indication of the real nature of the adhesive bond.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—These test methods are the metric counterpart of Test Methods D 3330.

2. Referenced Documents

2.1 *ASTM Standards:*

A 666 Specification for Austenitic Stainless Steel, Sheet, Strip, Plate, and Flat Bar[2]

D 996 Terminology of Packaging and Distribution Environments[3]

D 2904 Practice for Interlaboratory Testing of a Textile Test Method that Produces Normally Distributed Data[4]

D 2906 Practice for Statements on Precision and Bias for Textiles[4]

D 3715 Practice for Quality Assurance of Pressure-Sensitive Tapes[3]

D 4332 Practice for Conditioning Containers, Packages or Packaging Components for Testing[3]

3. Terminology

3.1 *Definitions*—Terminology found in Terminology D 996 shall apply.

4. Summary of Test Methods

4.1 *Test Method A—Single-Coated Tapes*—A strip of tape is applied to a standard test panel (or other surface of interest) with controlled pressure. The tape is peeled from the panel at a specified rate, during which time the force required to effect peeling is measured.

4.2 *Test Method B—Double-Coated Tapes*—A strip of thin film is applied as a backing (substituted for the liner) and this composite is treated as a single-coated tape in accordance with Test Method A.

4.3 *Test Method C*—The tape is adhered to a rigid panel (with double-coated tape if single coated) with the liner side up. The liner is peeled from the adhesive in the same manner as in peeling a single-coated tape from a standard panel in Test Method A.

5. Significance and Use

5.1 These test methods are tools for quality assurance use. Given a specific pressure-sensitive tape and a requirement in terms of the minimum or maximum peel value expected for this tape, the data from the test can be used in conjunction with acceptance criteria.

5.2 Test Methods A or B can show the relative bond strength of a given tape to one or more surfaces (material and texture) as compared to the standard stainless steel panel. Substitution of representative samples of the materials in question for the standard steel panel would suffice to do this.

5.3 Test Methods A or B cannot be used to compare two pressure-sensitive tapes of the same type but of different manufacture for their ability to adhere to a surface. This is because the measured peel force is not normalized for a fixed area of stress. The area under stress varies with backing stiffness and adhesive rheology (firmness). Two different tapes seldom agree in these properties.

5.4 Test Method C can show the amount of pull required to remove a liner that covers the adhesive side of a tape at a specified peel rate. The pull will be different at other peel rates.

5.5 These test methods may not provide design information as there is usually no direct relationship between peel adhesion and any functional requirement.

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[1] These test methods are under the jurisdiction of ASTM Committee D-10 on Packaging and are the direct responsibility of Subcommittee D10.14 on Closure and Reinforcement.

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[2] *Annual Book of ASTM Standards*, Vols 01.03, 01.04 and 01.05.

[3] *Annual Book of ASTM Standards*, Vol 15.09.

[4] *Annual Book of ASTM Standards*, Vol 07.01.

Apparatus

6.1 *Specimen Cutter*[5]—The specimen cutter shall hold vo single-edged razor blades in parallel planes, a precise stance apart, to form a cutter of exact specimen widths. wo cutters, 12 and 24-mm cutting width, shall be available.

NOTE 2—The 12-mm cutter shall consist of a 12 mm thick by 200 m length of aluminum bar stock 12 mm wide. The edges for about 125 m from one end shall be slightly rounded to form a handle. The width the bar for 75 mm from the opposite end shall be narrowed to exactly mm minus the thickness of a single razor blade (one of two used as tting edges). The razor blades shall be held in position using side ates. The end of the cutter shall be cut away at 0.75 rad to expose the tting edge at one end of the blades. The edges shall be separated by .0 ± 0.10 mm. The 24-mm cutter shall follow the same description, cept that the barstock width shall be 24.0 mm and shall be narrowed actly 24.0 mm minus the thickness of a single razor blade.

6.2 *Dispensing System*, for solvents, such as a wash bottle.

6.3 *Panel*[5]—A 50 by 125-mm panel no less than 1.1 mm ickness of stainless steel 302 or 304 in accordance with pecification A 666 having a bright annealed finish. The rface roughness height shall be 50 ± 5 nm arithmetical verage deviation from the mean line. Panels showing stains, iscoloration, or numerous scratches are not acceptable.

6.4 *Roller*,[5] mechanically operated:

6.4.1 A steel roller 85 ± 2.5 mm in diameter and 45 ± 1.5 m in width, covered with rubber approximately 6 mm in ickness, having a Shore scale A durometer hardness of 80 5. The surface of the roller shall be a true cylinder void of ny concave or convex deviations. The mass of the roller all be 2040 ± 45 g.

6.4.2 No part of the apparatus shall increase the mass of e roller during use. The roller shall move mechanically at e rate of 5.0 ± 0.2 mm/s.

NOTE 3—A simple check to determine if the rubber surface is ylindrical is to wrap the roller in a very thin paper (onionskin) and drag across a flat glass plate on which is placed a carbon paper, face up. The rbon rubs off onto the thin paper wrapper to reveal high spots or ollows on the rubber surface.

6.5 *Adhesion Tester*—A constant-rate-of-extension (CRE) ension tester shall be used. The tester shall have two clamps ith centers in the same plane, parallel with the direction of e motion of the stressing clamp, and so aligned that they ill hold the specimen wholly in the same plane; a means of oving the stressing clamp at a uniform rate of 5.0 ± 0.2 m/s; and an autographic device for recording load. The nstrument shall be calibrated to an accuracy of 0.5 % of full cale and the scale range used for any test shall be such that he mean test level falls within 20 to 50 % of full scale.

. Reagents and Materials

7.1 *Purity of Reagents*—Reagent grade chemicals shall be sed in all tests. Unless otherwise indicated, it is intended hat all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemcal Society, where such specifications are available.[6] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Solvents*:

7.2.1 *Diacetone Alcohol*, non-residual, technical grade or better.

7.2.2 One of the following:

7.2.2.1 n-*Heptane*.

7.2.2.2 *Methyl Alcohol (95 %)*.

7.2.2.3 *Methyl Ethyl Ketone (MEK)*.

7.2.2.4 *Methyl Isobutyl Ketone (MIBK)*.

7.2.3 Where toxicity and flammability requirements are paramount, a mixture of *n*-heptane and a fluorinated hydrocarbon such as refrigerant may meet the requirements.

7.3 *Cleaning Material*, absorbent, either surgical gauze or tissue. To be suitable, materials must be lint-free during use, absorbent, contain no additives that are soluble in the solvents listed in 7.2, and be made exclusively from virgin materials.

8. Sampling

8.1 Sampling shall be in accordance with Practice D 3715.

9. Test Specimens

9.1 The specimen shall be 12 to 24 mm wide. A tolerance of ±0.5 mm shall be allowed. The length shall be approximately 300 mm.

9.2 Discard at least three but no more than six outer wraps of tape from the sample roll before taking the specimen for testing.

9.3 Remove one specimen per sample roll for each test to be performed. Remove the specimen from a freely rotating roll at the rate of 500 to 750 mm/s. Where width or other factor, causing a high adherence to backing, makes it impossible to remove the specimen at the prescribed rate, remove it at a rate as close to 500 mm/s as possible.

9.4 When the tape is wider than 24 mm, specimens of the widest specified width are to be cut from the center of a strip removed from the roll as in 9.3.

10. Conditioning

10.1 Condition the sample rolls of tape in the standard conditioning atmosphere as described in Practice D 4332 for a period of not less than 24 h. Test at these conditions.

11. Test Method A—Single-Coated Tapes

11.1 Dispense diacetone alcohol onto the panel. Scrub the panel with a clean piece of absorbent cleaning material. Dry the panel with fresh absorbent cleaning material. Dispense one of the solvents listed in 7.2.2 onto the panel wiping it to dryness with fresh absorbent cleaning material. Repeat for a total of three washes with this solvent.

NOTE 4—Discard cleaned panels showing stains, discoloration, or numerous scratches. Avoid contacting panel surface with fingers. During storage, panels should be protected by covering with protective tape.

11.2 Touch one end of the specimen to an end of the test panel. Hold the other end of the specimen so that it does not make contact with the panel but is positioned loosely above it. Roll the tape mechanically once in each lengthwise direction, causing the roller to apply the tape to the panel. This prevents entrapment of air between the adhesive and

[5] Available from Chemsultants International, 9349 Hamilton Dr., Mentor, OH 44061-1118.

[6] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemcal Soc., Washington, DC. For suggestions on the testing of reagents not listed by he American Chemical Society, see "Reagent Chemicals and Standards," by oseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."

the panel. Should this occur, discard the specimen.

NOTE 5—Where the width of the specimen is less than 24 mm, prior to applying test specimen, apply a strip of strips of the tape, to give an equivalent width of 24 mm for rolling purposes.

11.3 Individually prepare each specimen and test immediately (within 1 min).

NOTE 6—Longer dwell time will give different results. Peel adhesion increases with dwell time at different rates for various tapes. A longer dwell time may be chosen purposely.

11.4 Double back the free end of the tape at an angle of 3.14 rad and peel 25 mm of the tape from the panel at the folded end. Clamp that end of the panel into the lower jaw of the adhesion testing machine and the free end of the tape into the upper jaw. Operate the lower jaw at 5 mm/s.

11.5 After the lower jaw is in motion, disregard the values obtained while the first 25 mm of tape is mechanically peeled. Use the average pull value obtained during peeling of the next 50 mm as the adhesion value.

12. Test Method B—Double-Coated Tapes

12.1 *Face Side*—Follow the procedure of 11.1 through 11.3, then remove the liner and superimpose on the test strip a strip of 0.025 mm thick polyester film, as wide as or slightly wider than the double-coated tape. Apply this film in the manner of applying the double-coated test strip to the panel so that the roller makes the actual application of the film to the double-coated tape.

NOTE 7—The two passes of the roller used in applying polyester film may be made using a hand roller of the same size. The roller rate may be increased to 50 mm/s.

12.1.1 Continue in accordance with 11.4 and 11.5.

12.2 *Liner Side*—Adhere the face side of the specimen to a strip of 0.025-mm thick polyester film in the manner described in 11.2 so that the roller makes the actual application of the tape to the film. Trim the film to be as wide as or slightly wider than the tape. Remove the liner.

12.2.1 Continue with the procedure of 11.1 through 11.5.

13. Test Method C—Adhesion of Liner of Double-Coated and Single-Coated Tapes

13.1 *Double-Coated Tapes*—Follow 11.1. Apply 125 mm of one end of the specimen with the adhesive side (face side) down, to the panel. Make two passes with the mechanical roller, once in each direction. Separate the liner from the tape at the free end and cut away the free tape. Do not disturb the liner adhered to the tape on the panel.

13.2 *Single-Coated Tapes*—Follow 11.1. Apply a strip of double-coated tape, as wide as the specimen, the full length of the panel. Remove the liner from the double-coated tape. Superimpose 125 mm of one end of the specimen, backing side down, against the double-coated tape on the panel. Make two passes with the mechanical roller, once in each direction. Separate the liner from the tape at the free end and cut away the free tape. Do not disturb the liner adhered to the tape on the panel.

13.3 Double back the liner and proceed in accordance with 11.4 and 11.5.

14. Calculation

14.1 If observed value is not in newtons, convert to newtons. Calculate peel adhesion in newtons per 100 mm of width by dividing the pull value by the width of the tape and multiplying by 100.

15. Report

15.1 The report shall include the following:

15.1.1 Statement that this test method was used and indicating any deviations from the method as written,

15.1.2 Complete identification of each roll of tape tested, including tape, source, manufacturer's code number, and form,

15.1.3 Anomalous behavior during the test (that is, adhesive transfer or splitting),

15.1.4 Peel adhesion value in N/100 mm of width to the nearest 1 N/100 mm,

15.1.5 Which test method was used, A, B or C, and if B, whether face side or liner side, and

15.1.6 Dwell time, if greater than the standard 1 min maximum.

16. Precision and Bias

16.1 *Summary:* The difference between two single observations should not exceed 18.8 % of the average of the two observations in 95 out of 100 cases when both observations are taken by the same well-trained operator using the same piece of test equipment and specimens randomly drawn from the same sample of material. Larger differences may occur under all other circumstances. The true value of peel adhesion at 180° angle can only be defined in terms of a specific test method. Within this limitation, Test Method D 3330 has no known bias. Sections 16.2 through 16.5 explain the basis for this summary and for evaluations made under other conditions.

NOTE 8—Of the three methods in this test method only Test Method A was used in determining the precision. It is believed that the precision for Test Method B would be similar. It would probably not apply to Test Method C.

NOTE 9—The calculations for coefficient of variation and other statistics found in subsequent sections of this statement are described in Practice D 2906 and Appendix A3 of Practice D 2904.

16.2 *Interlaboratory Test Data*[7]—An interlaboratory study was made in 1980 in which randomly drawn samples of two materials were tested in each of six laboratories. Two operators in each laboratory each tested 3 specimens from each of 3 rolls of each material. The components of variance for Peel Adhesion at 180° results expressed as coefficients of variations (Note 9) and were calculated to be as follows.

	Specimens of the Same Material	Specimens of Different Material
Single-operator component	4.8 % of the average	9.7 % of the average
Within-laboratory component	2.1 % of the average	0 % of the average
Between-laboratory component	9.0 % of the average	3.7 % of the average
Replication component	4.9 % of the average	4.9 % of the average

16.3 *Critical Differences*—For the components of variance reported in 16.2, two averages of observed values should be considered significantly different at the 95 %

[7] Supporting data are available from ASTM Headquarters. Request RR: D10-1002.

probability level if the difference equals or exceeds the critical differences shown in Table 1.

NOTE 10—The tabulated values of the critical differences and confidence limits should be considered to be a general statement particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias between them, if any, must be established with each comparison being based on recent data obtained on specimens randomly drawn from one sample of the material to be evaluated.

16.4 *Confidence Limits*—For the components of variance reported in 15.2, single averages of observed values have the following 95 % confidence limits (See Note 10 and Table 2).

16.5 *Bias*—No justifiable statement can be made on the bias of Test Method D 3330 for testing peel adhesion at 180° angle since the true value cannot be established by an accepted referee method.

17. Keywords

17.1 peel adhesion at 180° angle; pressure-sensitive tape

TABLE 1 Critical Difference, Percent of Grand Average for the Conditions Noted[A,B]

Number of Observations in Each Average	Single-Operator Precision	Within-Laboratory Precision	Between-Laboratory Precision
Specimens of the Same Material:			
1	18.8	19.7	42.5
5	14.5	15.6	29.4
10	13.9	15.0	29.1
Specimens of Different Material:			
1	30.1	30.1	31.8
5	28.0	28.0	29.4
10	27.3	27.3	29.1

[A] The critical differences were calculated using $t = 1.960$ which is based on infinite degrees of freedom.

[B] To convert the values of the critical differences to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as a decimal fraction.

TABLE 2 Width of 95 % Confidence Limits, Percent of the Grand Average for the Conditions Noted[A,B]

Number of Observations in Each Average	Single-Operator Precision	Within-Laboratory Precision	Between-Laboratory Precision
Specimens of the Same Material:			
1	±13.3	±13.9	±30.0
5	±10.3	±11.0	±20.8
10	±9.8	±10.6	±20.6
Specimens of Different Material:			
1	±21.3	±21.3	±22.5
5	±19.8	±19.8	±20.8
10	±19.3	±19.3	±20.6

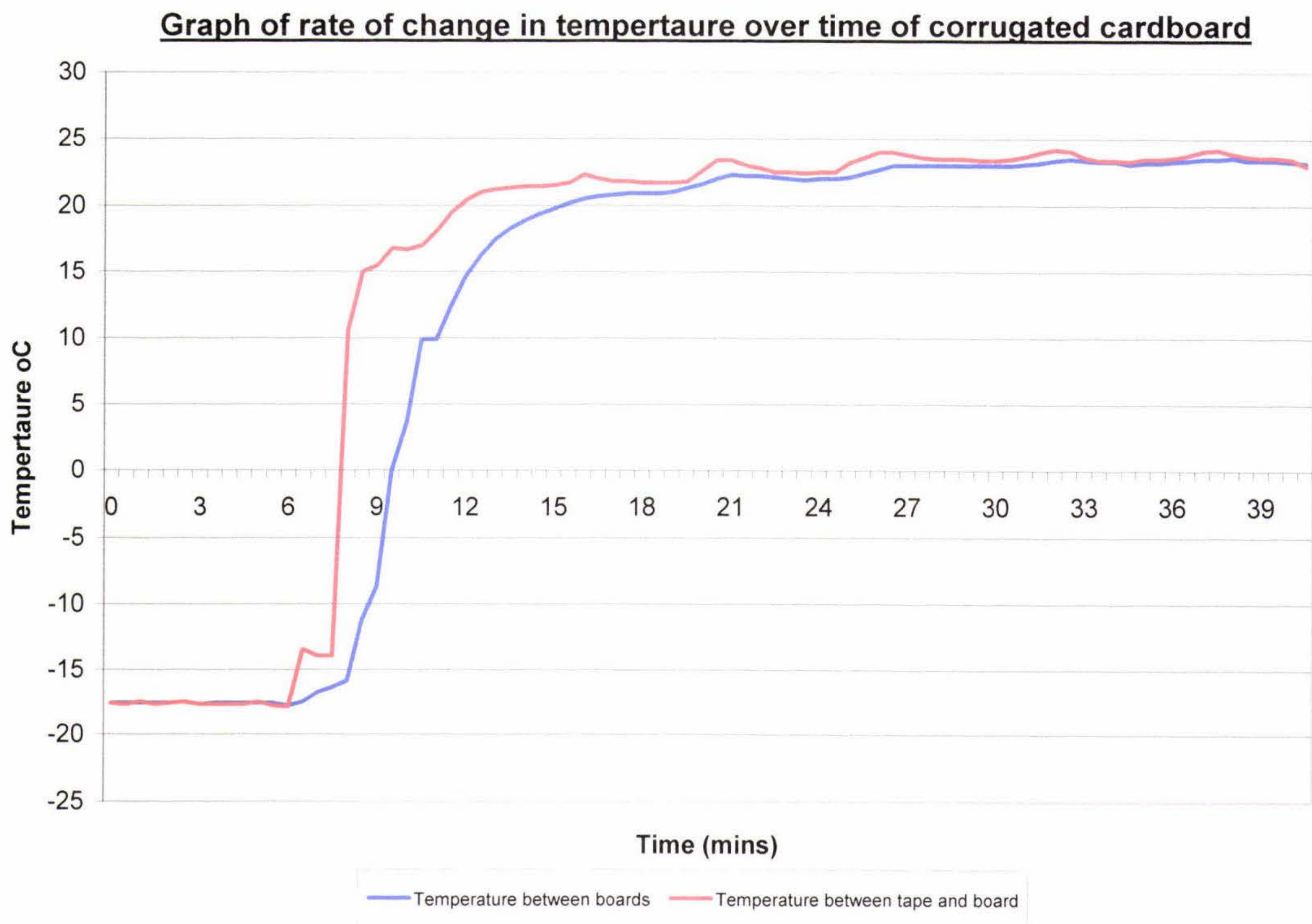
[A] The confidence limits are calculated using $t = 1.960$ which is based on infinite degrees of freedom.

[B] To convert the values of the confidence limits to units of measure, multiply the average of the specific set of data which is of interest by the confidence limits expressed as a decimal fraction.

B.8 Initial Sample Condition test Results and Graph

Date	Time	Type	Ch:1 (°C	Ch:2 (°C	Ch:3	Ch:4	Ch:5	Ch:6	Ch:7	Ch:8	Time
####	11:15:43	Interval reading	-17.6	-17.6	O/C	O/C	O/C	O/C	O/C	O/C	0
####	11:16:13	Interval reading	-17.6	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:16:43	Interval reading	-17.6	-17.5	O/C	O/C	O/C	O/C	O/C	O/C	1
####	11:17:13	Interval reading	-17.6	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:17:43	Interval reading	-17.6	-17.6	O/C	O/C	O/C	O/C	O/C	O/C	2
####	11:18:13	Interval reading	-17.5	-17.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:18:43	Interval reading	-17.7	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	3
####	11:19:13	Interval reading	-17.6	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:19:43	Interval reading	-17.6	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	4
####	11:20:13	Interval reading	-17.6	-17.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:20:43	Interval reading	-17.6	-17.5	O/C	O/C	O/C	O/C	O/C	O/C	5
####	11:21:13	Interval reading	-17.6	-17.8	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:21:43	Interval reading	-17.8	-17.9	O/C	O/C	O/C	O/C	O/C	O/C	6
####	11:22:13	Interval reading	-17.5	-13.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:22:43	Interval reading	-16.7	-13.9	O/C	O/C	O/C	O/C	O/C	O/C	7
####	11:23:13	Interval reading	-16.3	-13.9	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:23:43	Interval reading	-15.8	10.6	O/C	O/C	O/C	O/C	O/C	O/C	8
####	11:24:13	Interval reading	-11.2	15	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:24:43	Interval reading	-8.7	15.5	O/C	O/C	O/C	O/C	O/C	O/C	9
####	11:25:13	Interval reading	0	16.8	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:25:43	Interval reading	3.6	16.7	O/C	O/C	O/C	O/C	O/C	O/C	10
####	11:26:13	Interval reading	9.9	17	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:26:43	Interval reading	9.9	18.1	O/C	O/C	O/C	O/C	O/C	O/C	11
####	11:27:13	Interval reading	12.5	19.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:27:43	Interval reading	14.7	20.4	O/C	O/C	O/C	O/C	O/C	O/C	12
####	11:28:13	Interval reading	16.3	21	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:28:43	Interval reading	17.5	21.2	O/C	O/C	O/C	O/C	O/C	O/C	13
####	11:29:13	Interval reading	18.3	21.3	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:29:43	Interval reading	18.9	21.4	O/C	O/C	O/C	O/C	O/C	O/C	14
####	11:30:13	Interval reading	19.4	21.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:30:43	Interval reading	19.8	21.5	O/C	O/C	O/C	O/C	O/C	O/C	15
####	11:31:13	Interval reading	20.2	21.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:31:43	Interval reading	20.5	22.3	O/C	O/C	O/C	O/C	O/C	O/C	16
####	11:32:13	Interval reading	20.7	22	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:32:43	Interval reading	20.8	21.8	O/C	O/C	O/C	O/C	O/C	O/C	17
####	11:33:13	Interval reading	20.9	21.8	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:33:43	Interval reading	20.9	21.7	O/C	O/C	O/C	O/C	O/C	O/C	18
####	11:34:13	Interval reading	20.9	21.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:34:43	Interval reading	21	21.7	O/C	O/C	O/C	O/C	O/C	O/C	19
####	11:35:13	Interval reading	21.3	21.8	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:35:43	Interval reading	21.6	22.6	O/C	O/C	O/C	O/C	O/C	O/C	20
####	11:36:13	Interval reading	22	23.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:36:43	Interval reading	22.3	23.4	O/C	O/C	O/C	O/C	O/C	O/C	21
####	11:37:13	Interval reading	22.2	23	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:37:43	Interval reading	22.2	22.8	O/C	O/C	O/C	O/C	O/C	O/C	22
####	11:38:13	Interval reading	22.1	22.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:38:43	Interval reading	22	22.5	O/C	O/C	O/C	O/C	O/C	O/C	23
####	11:39:13	Interval reading	21.9	22.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:39:43	Interval reading	22	22.5	O/C	O/C	O/C	O/C	O/C	O/C	24
####	11:40:13	Interval reading	22	22.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:40:43	Interval reading	22.1	23.2	O/C	O/C	O/C	O/C	O/C	O/C	25
####	11:41:13	Interval reading	22.4	23.6	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:41:43	Interval reading	22.7	24	O/C	O/C	O/C	O/C	O/C	O/C	26

####	11:42:13	Interval reading	23	24	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:42:43	Interval reading	23	23.8	O/C	O/C	O/C	O/C	O/C	O/C	27
####	11:43:13	Interval reading	23	23.6	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:43:43	Interval reading	23	23.5	O/C	O/C	O/C	O/C	O/C	O/C	28
####	11:44:13	Interval reading	23	23.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:44:43	Interval reading	23	23.5	O/C	O/C	O/C	O/C	O/C	O/C	29
####	11:45:13	Interval reading	23	23.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:45:43	Interval reading	23	23.4	O/C	O/C	O/C	O/C	O/C	O/C	30
####	11:46:13	Interval reading	23	23.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:46:43	Interval reading	23.1	23.7	O/C	O/C	O/C	O/C	O/C	O/C	31
####	11:47:13	Interval reading	23.2	24	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:47:43	Interval reading	23.4	24.2	O/C	O/C	O/C	O/C	O/C	O/C	32
####	11:48:13	Interval reading	23.5	24.1	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:48:43	Interval reading	23.4	23.6	O/C	O/C	O/C	O/C	O/C	O/C	33
####	11:49:13	Interval reading	23.3	23.4	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:49:43	Interval reading	23.3	23.4	O/C	O/C	O/C	O/C	O/C	O/C	34
####	11:50:13	Interval reading	23.1	23.3	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:50:43	Interval reading	23.2	23.5	O/C	O/C	O/C	O/C	O/C	O/C	35
####	11:51:13	Interval reading	23.2	23.5	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:51:43	Interval reading	23.3	23.6	O/C	O/C	O/C	O/C	O/C	O/C	36
####	11:52:13	Interval reading	23.4	23.8	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:52:43	Interval reading	23.5	24.1	O/C	O/C	O/C	O/C	O/C	O/C	37
####	11:53:13	Interval reading	23.5	24.2	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:53:43	Interval reading	23.6	23.9	O/C	O/C	O/C	O/C	O/C	O/C	38
####	11:54:13	Interval reading	23.4	23.7	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:54:43	Interval reading	23.4	23.6	O/C	O/C	O/C	O/C	O/C	O/C	39
####	11:55:13	Interval reading	23.4	23.6	O/C	O/C	O/C	O/C	O/C	O/C	
####	11:55:43	Interval reading	23.3	23.5	O/C	O/C	O/C	O/C	O/C	O/C	40
####	11:56:13	Interval reading	23.2	23	O/C	O/C	O/C	O/C	O/C	O/C	



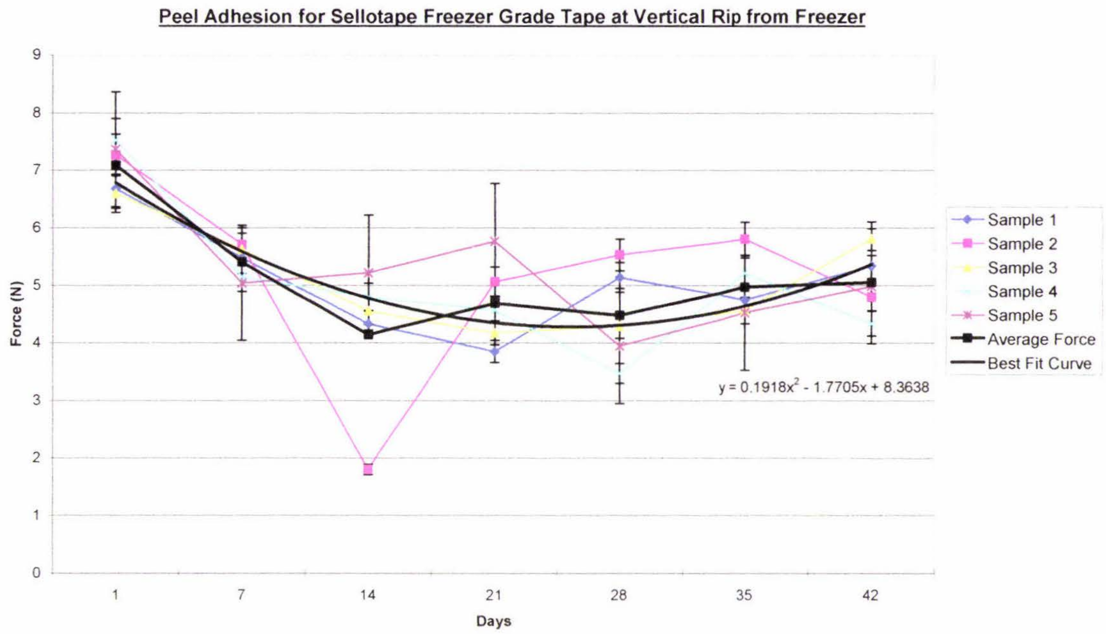
Graph of rate of change in tempertaure over time of corrugated cardboard
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
Tempertaure oC
0
3
6
9
12
15
18
21
24
27
30
33
36
39
Time (mins)
Temperature between boards
Temperature between tape and board

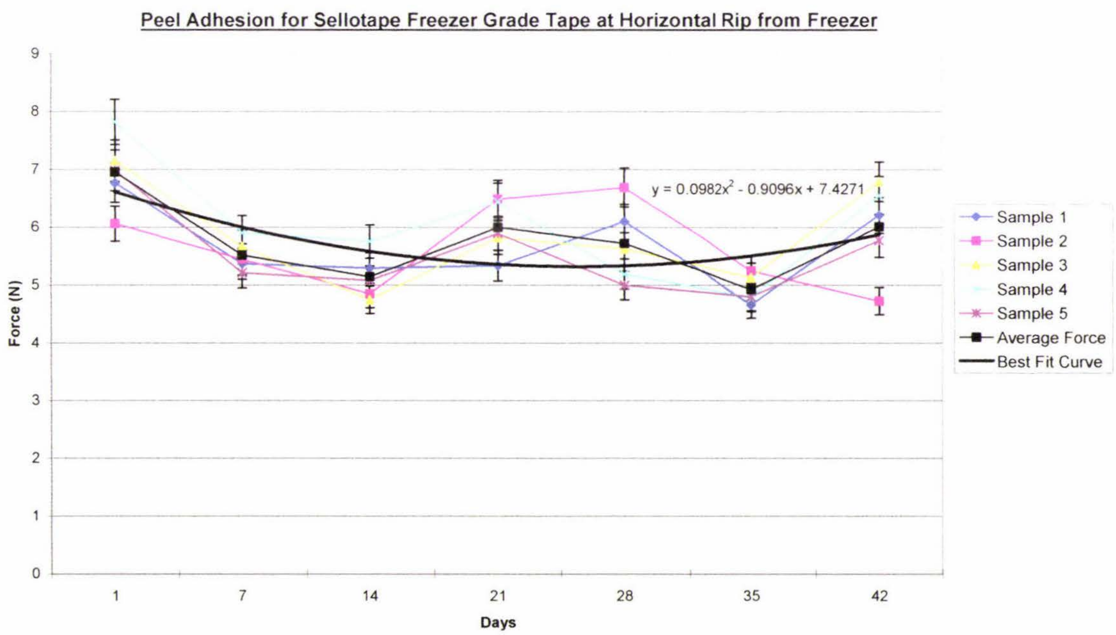
B.9 Peel Adhesion Results and Graphs – Freezer, Chiller & Room Temperature

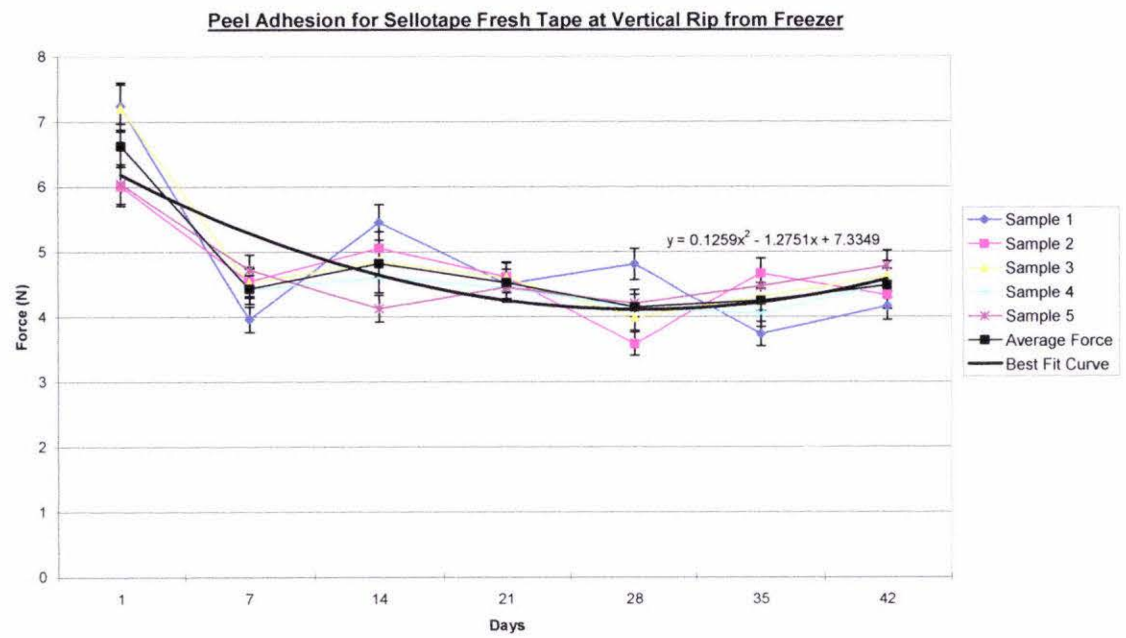
Peel Adhesion Results - FREEZER

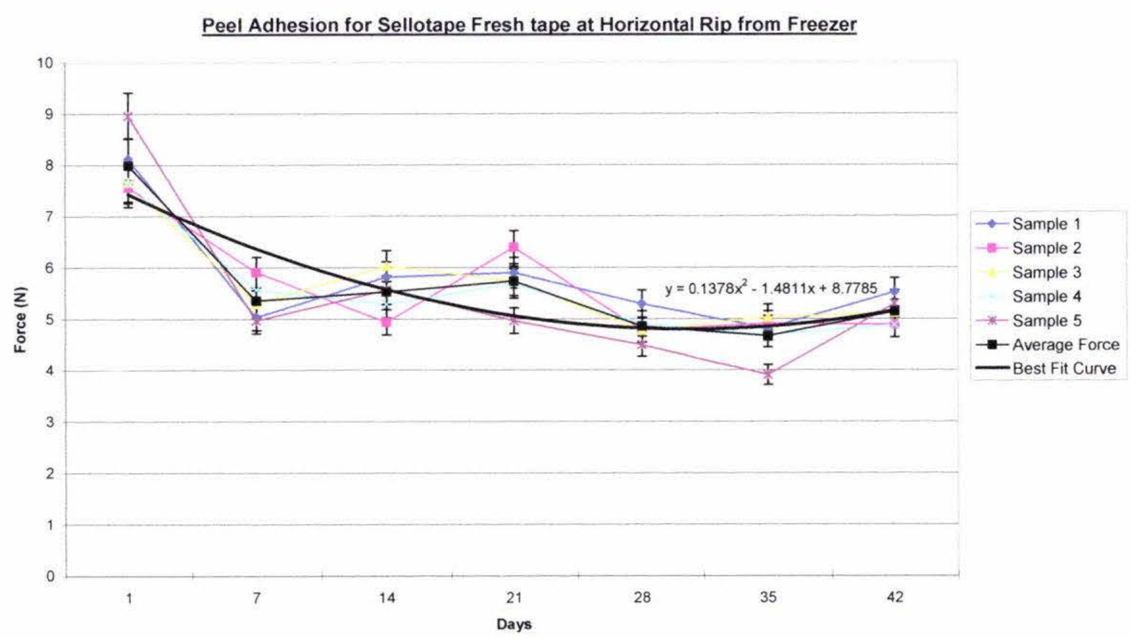
Tape Type/Days	1	7	14	21	28	35	42
SELFZ1V1	6.676	5.483	4.332	3.851	5.141	4.753	5.344
SELFZ1V2	7.265	5.713	1.799	5.068	5.532	5.808	4.804
SELFZ1V3	6.598	5.628	4.555	4.174	4.292	4.565	5.813
SELFZ1V4	7.524	5.153	4.798	4.571	3.471	5.214	4.337
SELFZ1V5	7.364	5.043	5.223	5.77	3.948	4.529	4.989
Average Force	**7.0854**	**5.404**	**4.1414**	**4.6868**	**4.4768**	**4.9738**	**5.0574**
SELFZ1H1	6.771	5.367	5.295	5.339	6.098	4.659	6.21
SELFZ1H2	6.062	5.444	4.849	6.491	6.691	5.247	4.723
SELFZ1H3	7.153	5.666	4.747	5.824	5.627	5.126	6.793
SELFZ1H4	7.823	5.905	5.754	6.445	5.192	4.783	6.554
SELFZ1H5	6.985	5.212	5.08	5.895	4.997	4.798	5.772
Average Force	**6.9588**	**5.5188**	**5.145**	**5.9988**	**5.721**	**4.9226**	**6.0104**
SELFR2V1	7.243	3.958	5.452	4.505	4.809	3.733	4.158
SELFR2V2	6.007	4.543	5.055	4.613	3.58	4.662	4.33
SELFR2V3	7.212	4.516	4.852	4.598	3.987	4.305	4.623
SELFR2V4	6.642	4.42	4.602	4.448	4.136	4.044	4.511
SELFR2V5	6.044	4.722	4.125	4.452	4.204	4.469	4.78
Average Force	**6.6296**	**4.4318**	**4.8172**	**4.5232**	**4.1432**	**4.2426**	**4.4804**
SELFR2H1	8.118	5.034	5.819	5.9	5.296	4.82	5.522
SELFR2H2	7.565	5.91	4.938	6.394	4.784	4.911	4.89
SELFR2H3	7.671	5.296	6.031	5.736	4.779	5.031	5.119
SELFR2H4	7.645	5.569	5.288	5.688	4.91	4.686	4.885
SELFR2H5	8.959	4.969	5.562	4.964	4.497	3.907	5.293
Average Force	**7.9916**	**5.3556**	**5.5276**	**5.7364**	**4.8532**	**4.671**	**5.1418**
SELOL2V1	6.337	5.104	6.024	5.058	4.756	4.401	3.855
SELOL2V2	6.562	5.42	6.369	4.669	5.097	3.891	2.493
SELOL2V3	7.514	4.845	5.721	5.126	4.824	4.239	5.337
SELOL2V4	6.521	4.337	5.669	4.476	5.012	4.91	4.257
SELOL2V5	6.71	5.547	5.83	4.853	4.919	4.769	5.217
Average Force	**6.7288**	**5.0506**	**5.9226**	**4.8364**	**4.9216**	**4.442**	**4.2318**
SELOL2H1	7.165	5.648	6.157	5.239	6.32	5.094	5.242
SELOL2H2	7.656	6.36	6.702	6.131	5.915	5.25	6.047
SELOL2H3	7.374	6.304	7.011	4.669	5.239	5.399	5.849
SELOL2H4	7.693	6.41	6.293	5.662	5	5.141	5.668
SELOL2H5	7.663	6.395	6.808	5.56	5.67	5.24	5.77
Average Force	**7.5102**	**6.2234**	**6.5942**	**5.4522**	**5.6288**	**5.2248**	**5.7152**
3MFR2V01	7.552	6.504	7.755	6.326	6.241	8.424	8.416
3MFR2V02	10.406	5.003	8.612	5.239	4.144	5.084	4.473
3MFR2V03	6.535	6.593	9.171	4.392	4.599	4.163	4.609
3MFR2V04	8.77	6.662	5.996	4.882	4.538	5.466	4.498
3MFR2V05	10.025	5.236	5.194	4.926	6.356	5.149	5.668
Average Force	**8.6576**	**5.9996**	**7.3456**	**5.153**	**5.1756**	**5.6572**	**5.5328**
3MFR2H01	10.005	6.314	9.481	4.732	6.089	4.958	7.431
3MFR2H02	9.803	10.038	11.185	3.797	4.939	5.442	4.914
3MFR2H03	9.688	4.962	6.106	4.386	5.054	4.933	6.456
3MFR2H04	10.534	6.99	6.499	4.582	4.98	4.586	6.61
3MFR2H05	9.831	8.248	9.671	4.807	5.003	5.304	6.017
Average Force	**9.9722**	**7.3104**	**8.5884**	**4.4608**	**5.213**	**5.0446**	**6.2856**

3MME2V01	5.162	6.332	5.46	5.26	4.875	5.323	5.989
3MME2V02	5.242	6.517	6.75	5.134	5.081	6.008	6.078
3MME2V03	6.163	6.798	5.7	5.777	5.463	5.863	5.527
3MME2V04	6.496	5.867	6.723	5.169	5.689	4.92	5.521
3MME2V05	5.155	6.906	6.531	5.562	6.113	5.162	5.591
Average Force	**5.6436**	**6.484**	**6.2328**	**5.3804**	**5.4442**	**5.4552**	**5.7412**
3MME2H01	7.563	6.79	7.06	6.213	7.154	7.03	6.251
3MME2H02	6.476	6.092	8.681	7.209	6.754	7.391	6.323
3MME2H03	6.669	7.373	8.178	6.386	5.941	7.352	5.88
3MME2H04	6.686	6.754	8.247	7.536	6.134	6.162	6.414
3MME2H05	7.628	7.573	7.971	6.601	6.337	6.262	6.035
Average Force	**7.0044**	**6.9164**	**8.0274**	**6.789**	**6.464**	**6.8394**	**6.1806**
3MOL2V01	6.02	5.938	4.929	5.037	3.958	5.225	4.571
3MOL2V02	5.602	6.507	6.267	4.546	5.078	5.11	5.687
3MOL2V03	6.036	5.796	5.38	4.971	4.977	5.664	4.954
3MOL2V04	6.385	5.284	5.868	5.645	5.804	5.107	4.951
3MOL2V05	6.445	5.459	7.992	4.96	6.14	5.434	4.754
Average Force	**6.0976**	**5.7968**	**6.0872**	**5.0318**	**5.1914**	**5.308**	**4.9834**
3MOL2H01	6.543	5.27	2.628	4.927	5.551	5.265	5.549
3MOL2H02	5.556	5.973	5.168	5.473	6.54	6.303	5.475
3MOL2H03	6.959	5.272	7.168	5.082	5.682	5.785	5.811
3MOL2H04	8.784	5.608	6.099	5.901	5.348	4.629	5.325
3MOL2H05	6.482	6.792	6.816	5.527	5.844	5.71	5.823
Average Force	**6.8648**	**5.783**	**5.8558**	**5.382**	**5.7932**	**5.5384**	**5.5966**
PANFX2V1	7.349	5.191	5.257	4.783	4.771	5.72	4.653
PANFX2V2	6.334	4.985	5.14	4.922	4.616	5.701	4.762
PANFX2V3	6.175	4.84	5.281	5.042	4.905	5.913	4.916
PANFX2V4	6.101	5.346	5.511	4.74	5.316	5.729	4.645
PANFX2V5	6.781	5.669	5.459	4.875	4.514	5.847	5.083
Average Force	**6.548**	**5.2062**	**5.3296**	**4.8724**	**4.8244**	**5.782**	**4.8118**
PANFX2H1	6.665	4.68	6.437	5.31	6.272	5.988	4.936
PANFX2H2	7.733	5.283	6.218	5.293	5.738	6.395	5.58
PANFX2H3	6.664	4.278	5.933	5.281	5.485	5.907	5.732
PANFX2H4	6.483	5.236	6.272	5.474	5.28	5.972	5.348
PANFX2H5	6.774	5.516	6.224	5.029	5.205	6.601	5.565
Average Force	**6.8638**	**4.9986**	**6.2168**	**5.2774**	**5.596**	**6.1726**	**5.4322**

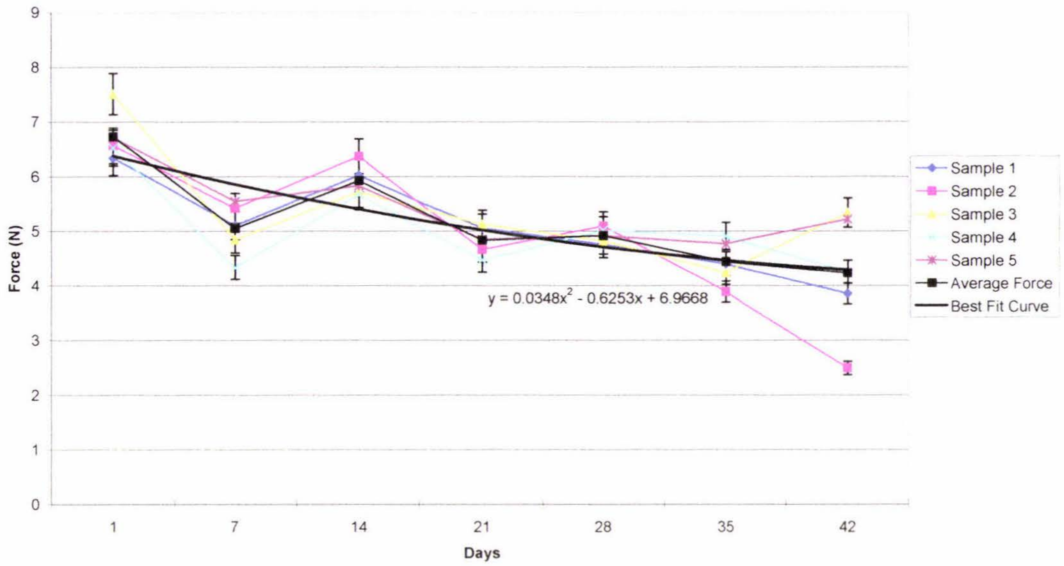

Peel Adhesion for Sellotape Freezer Grade Tape at Vertical Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.1918x2 - 1.7705x + 8.3638


Peel Adhesion for Sellotape Freezer Grade Tape at Horizontal Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.0982x2 - 0.9096x + 7.4271

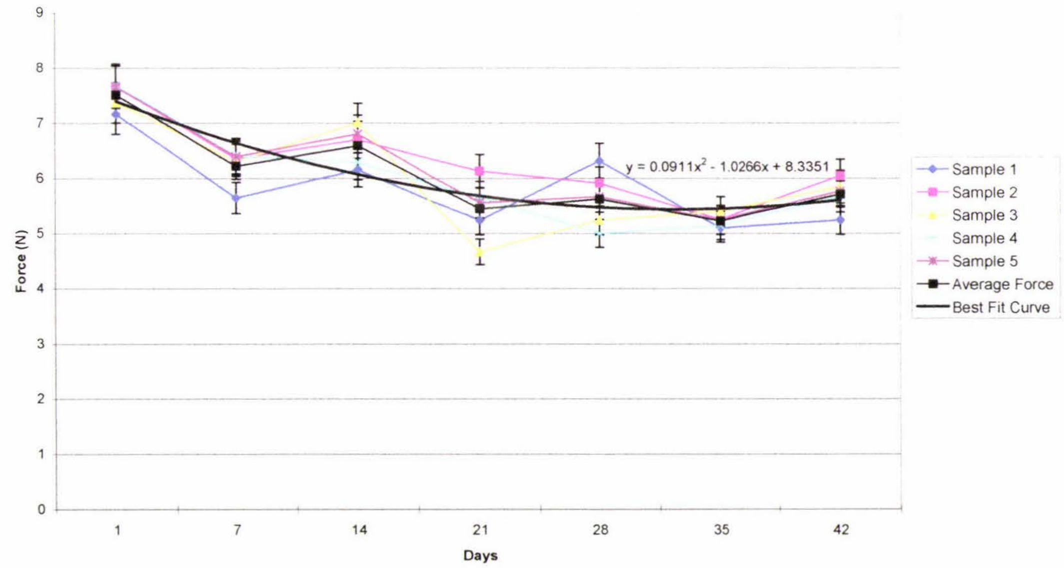

Peel Adhesion for Sellotape Fresh Tape at Vertical Rip from Freezer
Force (N)
Days
y = 0.1259x² - 1.2751x + 7.3349
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve


Peel Adhesion for Sellotape Fresh tape at Horizontal Rip from Freezer
Force (N)
Days
y = 0.1378x² - 1.4811x + 8.7785
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve

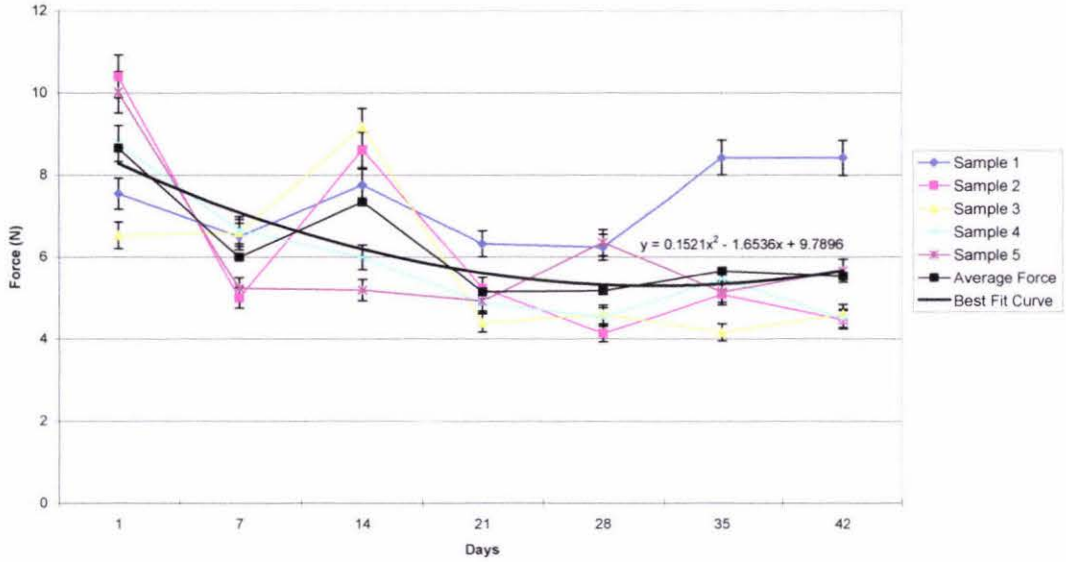
Peel Adhesion for Sellotape Old Age Tape at Vertical Rip from Freezer



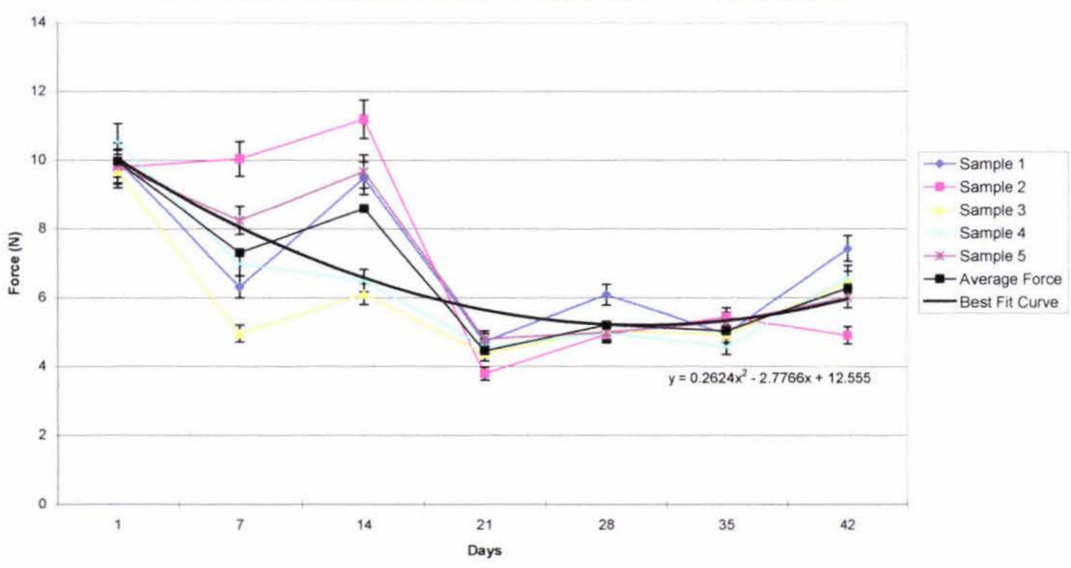
Peel Adhesion for Sellotape Old Age Tape at Horizontal Rip from Freezer



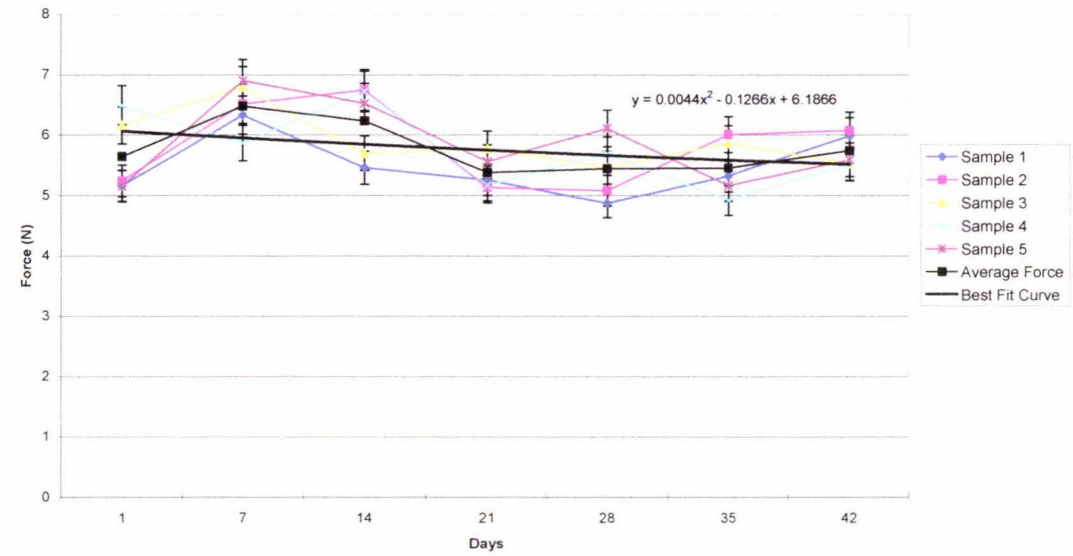
Peel Adhesion for 3M Cold Temperature Tape at Vertical Rip from Freezer



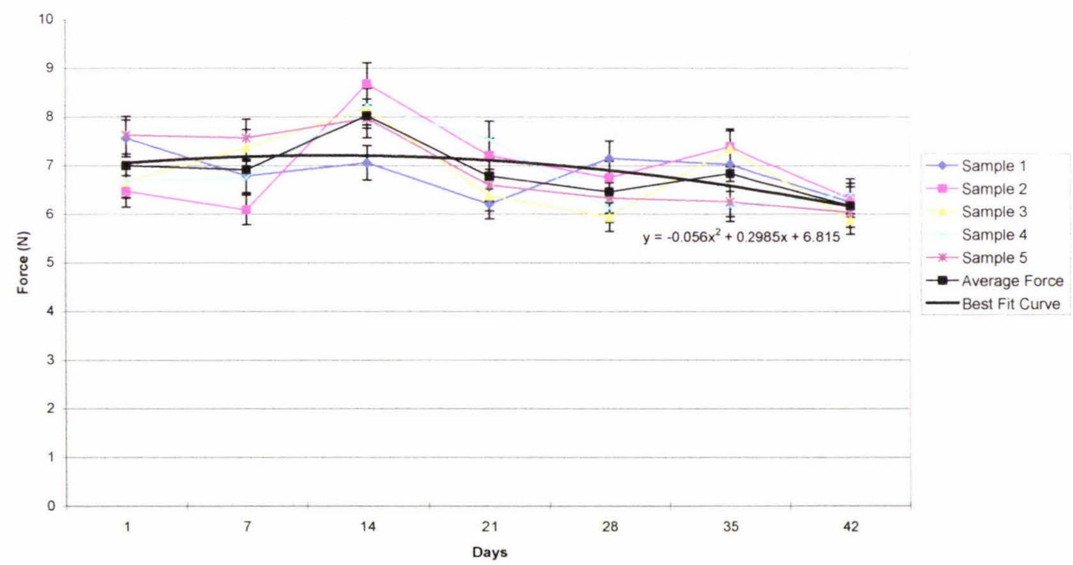
Peel Adhesion for 3M Cold Temperature Tape at Horizontal Rip from Freezer

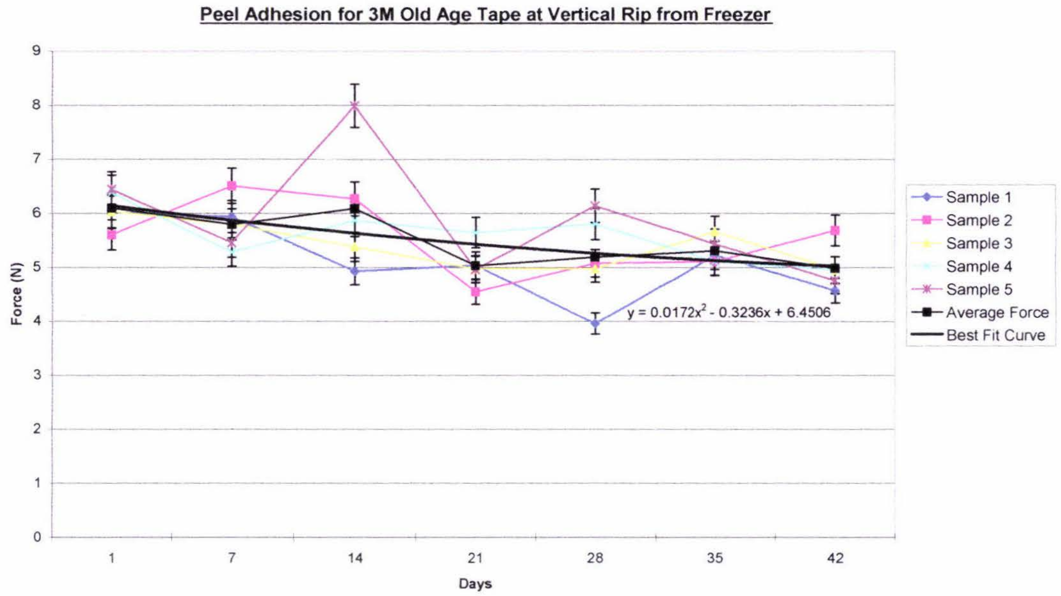


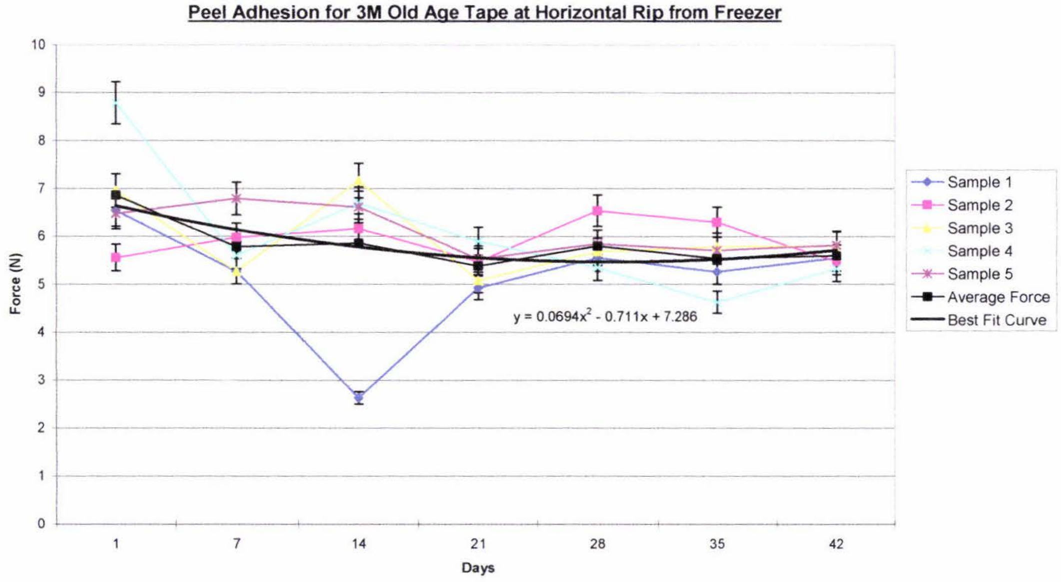
Peel Adhesion for 3M Medium Age Tape at Vertical Rip from Freezer

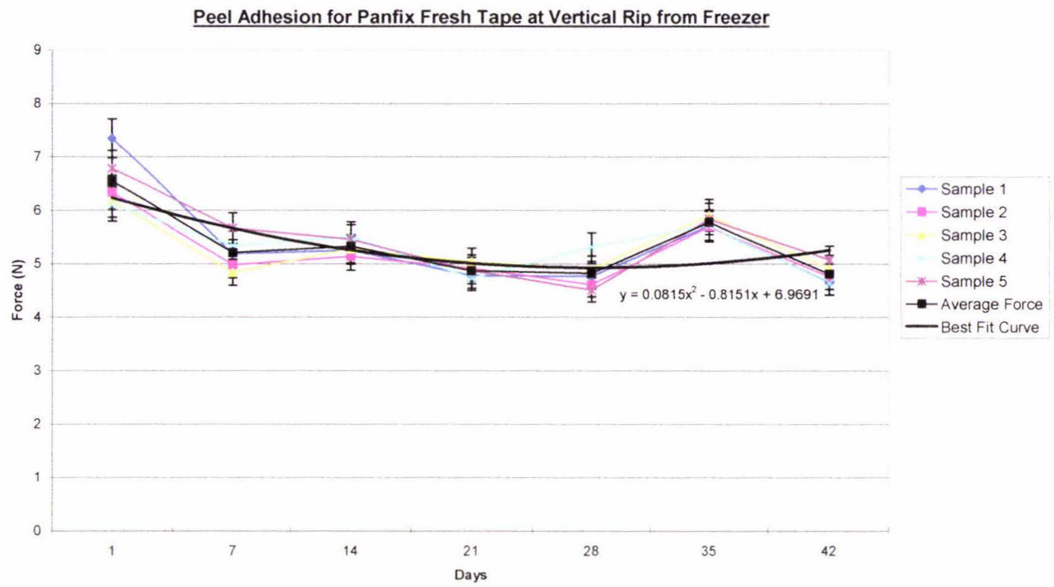


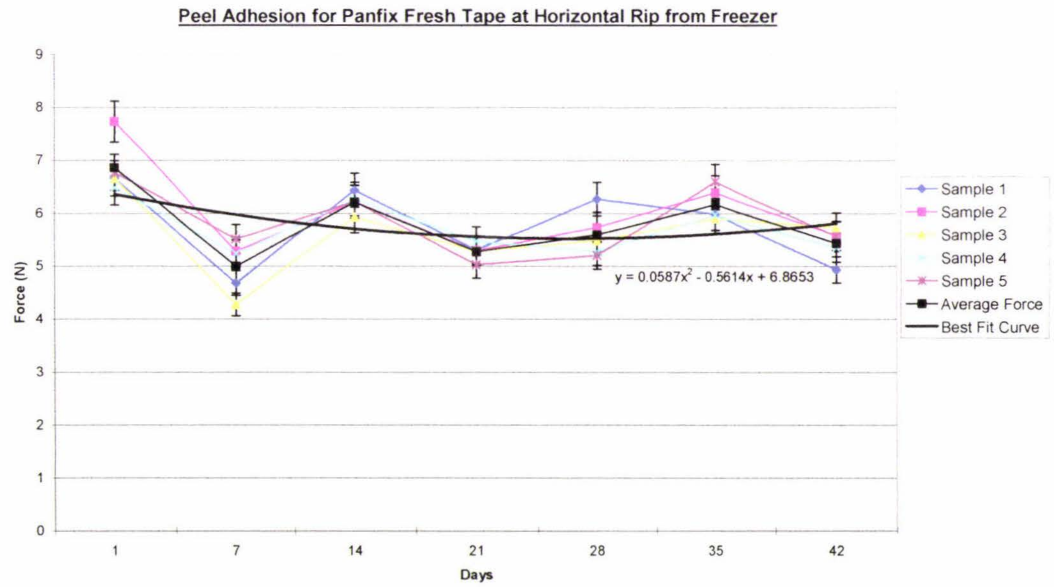
Peel Adhesion for 3M Medium Age Tape at Horizontal Rip from Freezer



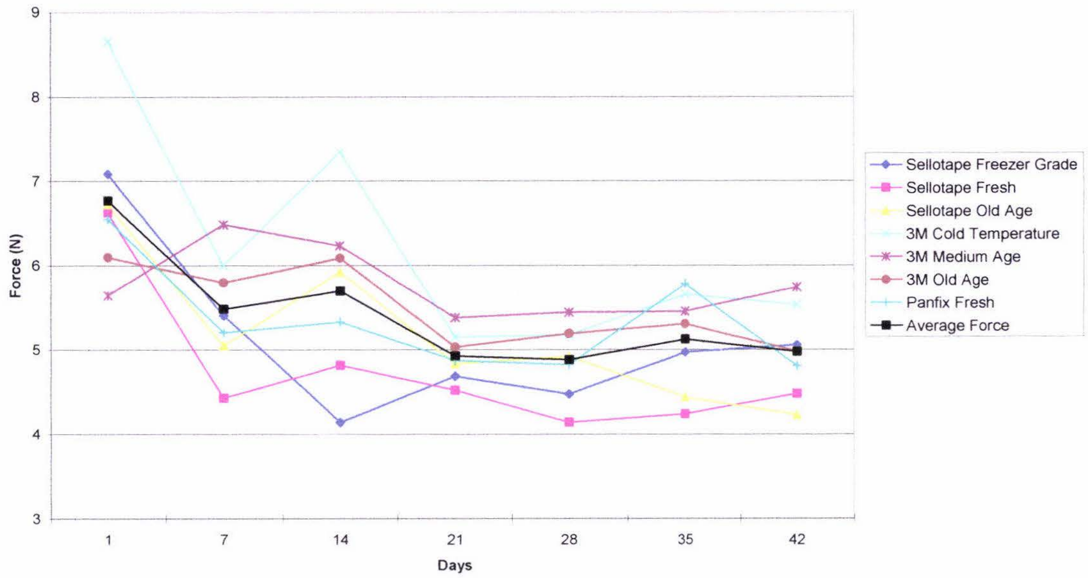

Peel Adhesion for 3M Old Age Tape at Vertical Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.0172x² - 0.3236x + 6.4506


Peel Adhesion for 3M Old Age Tape at Horizontal Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.0694x² - 0.711x + 7.286

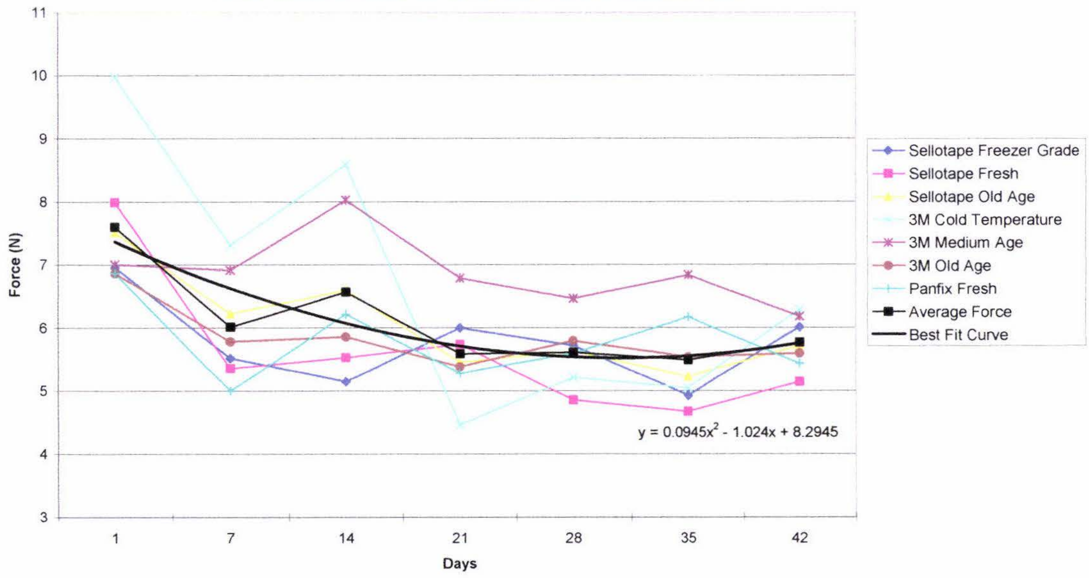

Peel Adhesion for Panfix Fresh Tape at Vertical Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.0815x² - 0.8151x + 6.9691


Peel Adhesion for Panfix Fresh Tape at Horizontal Rip from Freezer
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.0587x² - 0.5614x + 6.8653

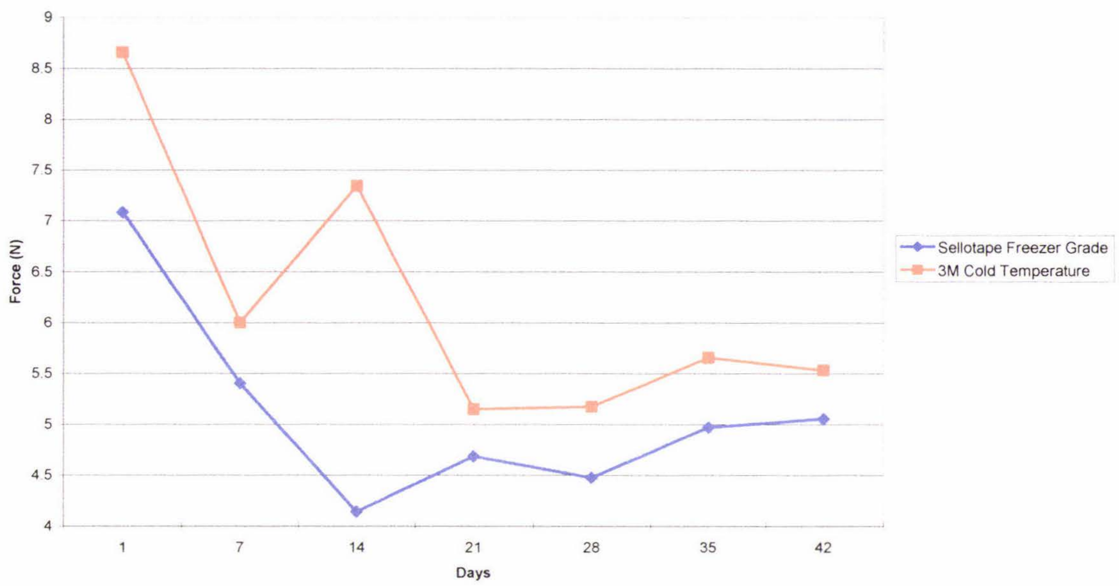
Peel Adhesion for All Tapes at Vertical Rip from Freezer



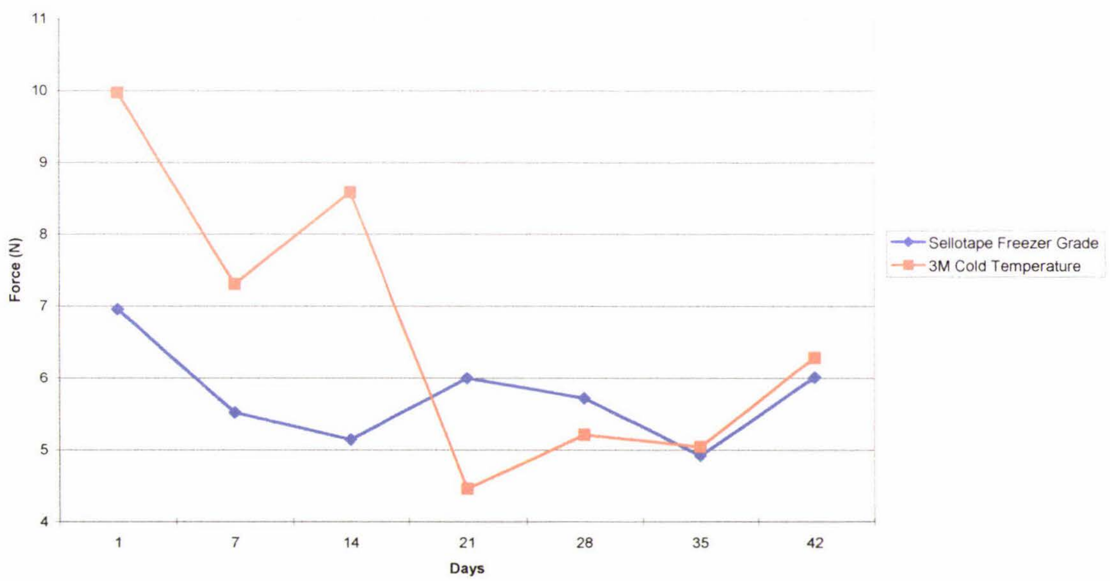
Peel Adhesion for All Tapes at Horizontal Rip from Freezer



Peel Adhesion of Freezer/Cold Temperature Tapes at Vertical Rip from Freezer



Peel Adhesion of Freezer/Cold Temperature Tapes at Horizontal Rip from Freezer

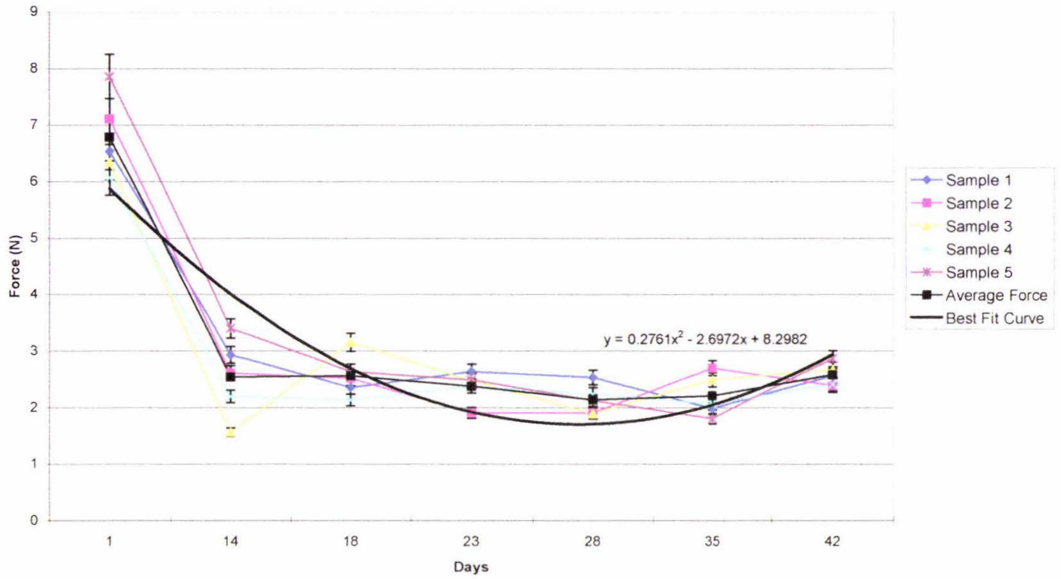


Peel Adhesion Results - CHILLER

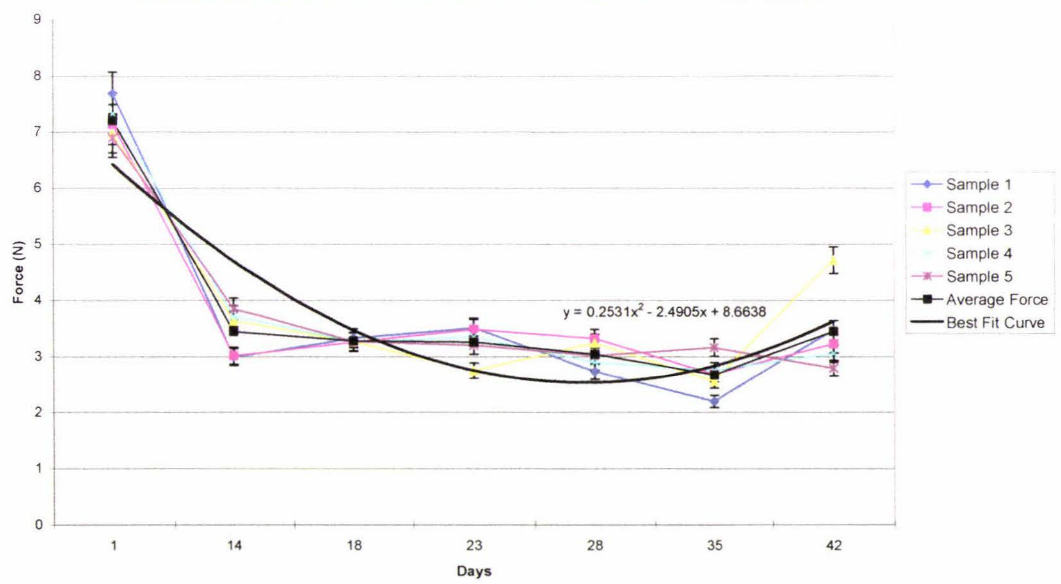
Tape Type/Days	1	14	18	23	28	35	42
CSEFZ1V1	6.534	2.935	2.358	2.641	2.536	1.989	2.565
CSEFZ1V2	7.116	2.615	2.521	1.912	1.91	2.702	2.394
CSEFZ1V3	6.342	1.569	3.157	2.482	1.897	2.495	2.672
CSEFZ1V4	6.067	2.201	2.14	2.38	2.246	2.069	2.417
CSELFZV5	7.862	3.402	2.641	2.495	2.13	1.809	2.869
Average Force	**6.7842**	**2.5444**	**2.5634**	**2.382**	**2.1438**	**2.2128**	**2.5834**
CSEFZ1H1	7.684	2.993	3.33	3.511	2.736	2.2	3.468
CSEFZ1H2	7.132	3.015	3.259	3.487	3.323	2.684	3.225
CSEFZ1H3	6.976	3.636	3.265	2.748	3.242	2.562	4.716
CSEFZ1H4	7.329	3.719	3.265	3.353	2.9	2.755	3.054
CSEFZ1H5	6.896	3.849	3.27	3.204	3.018	3.162	2.791
Average Force	**7.2034**	**3.4424**	**3.2778**	**3.2606**	**3.0438**	**2.6726**	**3.4508**
CSEFH1V1	7.243	2.409	2.244	2.785	1.892	2.078	2.6
CSEFH1V2	6.007	3.137	2.096	2.192	2.382	1.717	2.522
CSEFH1V3	7.212	3.107	3.622	2.536	2.177	1.702	2.437
CSEFH1V4	6.642	2.532	2.296	2.115	1.956	2.127	1.78
CSEFH1V5	6.044	2.645	2.826	2.228	2.212	2.419	1.937
Average Force	**6.6296**	**2.766**	**2.6168**	**2.3712**	**2.1238**	**2.0086**	**2.2552**
CSEFH1H1	8.118	2.938	3.12	2.719	2.719	2.48	3.28
CSEFH1H2	7.565	2.23	3.27	2.725	2.577	2.271	3.302
CSEFH1H3	7.671	3.046	2.99	2.873	2.885	2.308	2.546
CSEFH1H4	7.645	3.248	2.912	2.376	3.006	2.517	3.614
CSEFH1H5	8.959	3.444	2.953	2.538	2.742	2.131	3.289
Average Force	**7.9916**	**2.9812**	**3.049**	**2.6462**	**2.7858**	**2.3414**	**3.2062**
CSEOD1V1	6.337	2.013	2.494	2.455	2.139	2.433	2.43
CSEOD1V2	6.562	2.301	2.447	2.425	2.031	2.386	2.32
CSEOD1V3	7.514	2.458	2.799	2.294	2.061	2.324	2.404
CSEOD1V4	6.521	3.311	2.911	2.138	2.24	2.088	2.652
CSEOD1V5	6.71	3.083	2.488	1.358	1.724	2.654	2.665
Average Force	**6.7288**	**2.6332**	**2.6278**	**2.134**	**2.039**	**2.377**	**2.4942**
CSEOD1H1	7.165	3.343	2.97	3.062	2.622	2.599	3.72
CSEOD1H2	7.656	3.48	3.341	3.193	3.122	2.407	3.459
CSEOD1H3	7.374	3.303	3.066	2.832	2.976	2.677	3.952
CSEOD1H4	7.693	3.285	3.064	3.294	2.067	2.905	3.418
CSEOD1H5	7.663	3.33	3.225	3.316	2.773	3.254	3.129
Average Force	**7.5102**	**3.3482**	**3.1332**	**3.1394**	**2.712**	**2.7684**	**3.5356**
C3MFS1V1	7.552	2.923	2.33	1.781	1.676	1.717	1.744
C3MFS1V2	10.406	5.372	2.038	2.278	1.7	1.68	1.782
C3MFS1V3	6.535	2.904	2.288	2.237	1.937	2.142	2.438
C3MFS1V4	8.77	2.128	2.167	1.176	1.854	1.661	1.357
C3MFS1V5	10.025	2.43	2.771	0.108	2.078	1.622	3.235
Average Force	**8.6576**	**3.1514**	**2.3188**	**1.516**	**1.849**	**1.7644**	**2.1112**
C3MFS1H1	10.005	2.995	2.712	2.989	2.513	1.91	2.294
C3MFS1H2	9.803	3.059	2.518	2.554	-0.33	2.198	2.078
C3MFS1H3	9.688	3.12	2.266	2.262	3.041	1.162	1.499
C3MFS1H4	10.534	3.008	2.367	2.527	2.066	2.189	1.875
C3MFS1H5	9.831	3.088	2.449	2.499	2.146	2.164	2.345
Average Force	**9.9722**	**3.054**	**2.4624**	**2.5662**	**1.8872**	**1.9246**	**2.0182**
C3MMD1V1	5.162	2.914	2.353	2.513	2.822	2.256	2.139
C3MMD1V2	5.242	3.014	2.727	3.172	2.758	3.971	2.131
C3MMD1V3	6.163	2.884	2.708	3.2	2.803	2.267	2.684
C3MMD1V4	6.496	2.995	2.502	2.997	2.873	2.697	2.74
C3MMD1V5	5.155	3.116	2.713	2.963	2.729	2.482	2.52
Average Force	**5.6436**	**2.9846**	**2.6006**	**2.969**	**2.797**	**2.7346**	**2.4428**

C3MMD1H1	7.583	3.674	2.805	3.812	3.219	3.022	2.437
C3MMD1H2	6.476	4.465	2.993	3.756	3.696	3.125	13.19
C3MMD1H3	6.669	3.822	3.556	3.938	3.571	4.225	3.293
C3MMD1H4	6.686	8.379	3.311	3.646	3.557	2.902	3.103
C3MMD1H5	7.628	4.227	3.319	3.72	3.465	3.021	2.249
Average Force	**7.0044**	**4.9134**	**3.1968**	**3.7744**	**3.5016**	**3.259**	**4.8544**
C3MOD1V1	6.02	1.957	1.861	2.144	2.103	1.951	2.952
C3MOD1V2	5.602	2.373	2.782	6.721	2.759	1.98	2.09
C3MOD1V3	6.036	2.729	1.318	3.13	1.91	2.156	2.164
C3MOD1V4	6.385	3.109	1.77	2.415	2.138	1.727	2.457
C3MOD1V5	6.445	2.265	2.501	2.303	2.659	2.02	2.148
Average Force	**6.0976**	**2.4866**	**2.0464**	**3.3426**	**2.3138**	**1.9668**	**2.3622**
C3MOD1H1	6.543	2.358	3.342	2.957	3.267	2.758	2.803
C3MOD1H2	5.556	3.47	3.152	4.31	3.505	2.537	2.92
C3MOD1H3	6.959	3.048	2.772	3.213	3.638	2.336	2.857
C3MOD1H4	8.784	3.477	2.676	3.363	2.935	1.822	3.506
C3MOD1H5	6.482	2.468	2.798	3.143	3.19	2.691	2.832
Average Force	**6.8648**	**2.9642**	**2.948**	**3.3972**	**3.307**	**2.4288**	**2.9836**
CPAFX1V1	7.349	2.919	2.201	2.667	2.739	2.141	3.445
CPAFX1V2	6.334	2.5	2.362	2.499	2.485	2.496	2.519
CPAFX1V3	6.175	3.754	2.337	2.71	2.459	2.311	2.205
CPAFX1V4	6.101	2.335	2.259	3.428	2.64	2.043	2.075
CPAFX1V5	6.781	2.949	2.284	3.408	2.387	2.229	2.475
Average Force	**6.548**	**2.8914**	**2.2886**	**2.9424**	**2.542**	**2.244**	**2.5438**
CPAFX1H1	6.665	3.09	3.242	3.375	3.386	2.557	2.479
CPAFX1H2	7.733	3.67	3.908	3.248	3.172	2.876	3.059
CPAFX1H3	6.664	3.389	3.141	3.601	3.38	2.513	2.937
CPAFX1H4	6.483	3.211	2.929	3.482	3.623	2.952	3.103
CPAFX1H5	6.774	3.248	2.835	2.925	3.074	3.063	3.279
Average Force	**6.8638**	**3.3216**	**3.211**	**3.3262**	**3.327**	**2.7922**	**2.9714**

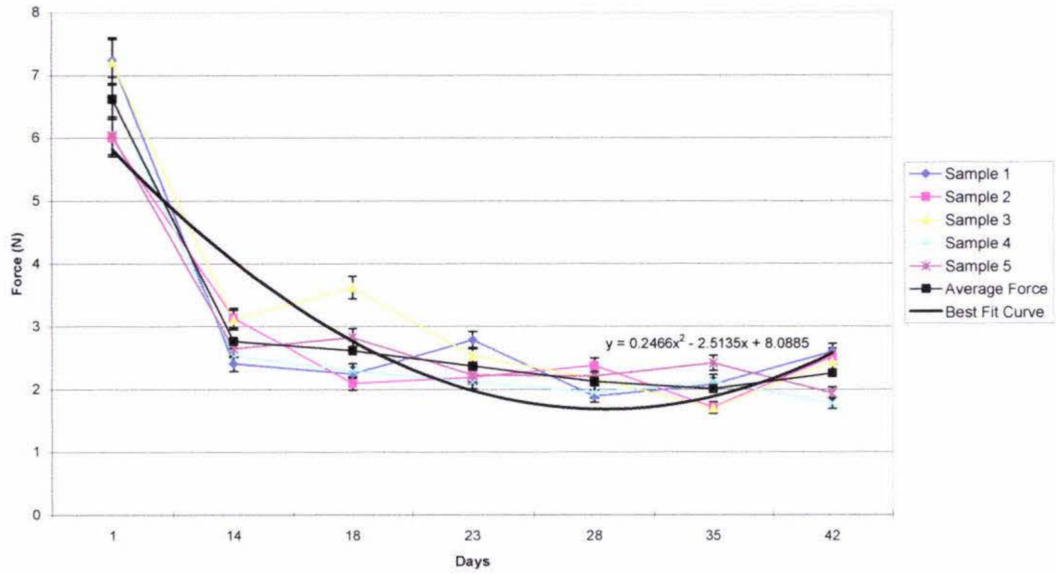
Peel Adhesion for Sellotape Freezer Grade Tape at Vertical Rip from Chiller



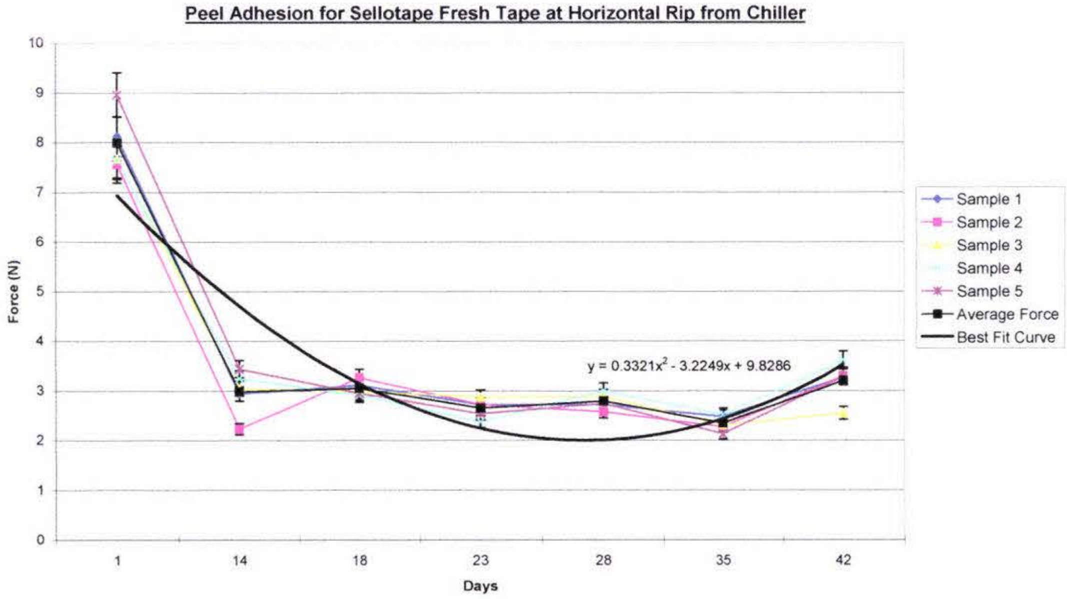
Peel Adhesion for Sellotape Freezer Grade Tape at Horizontal Rip from Chiller



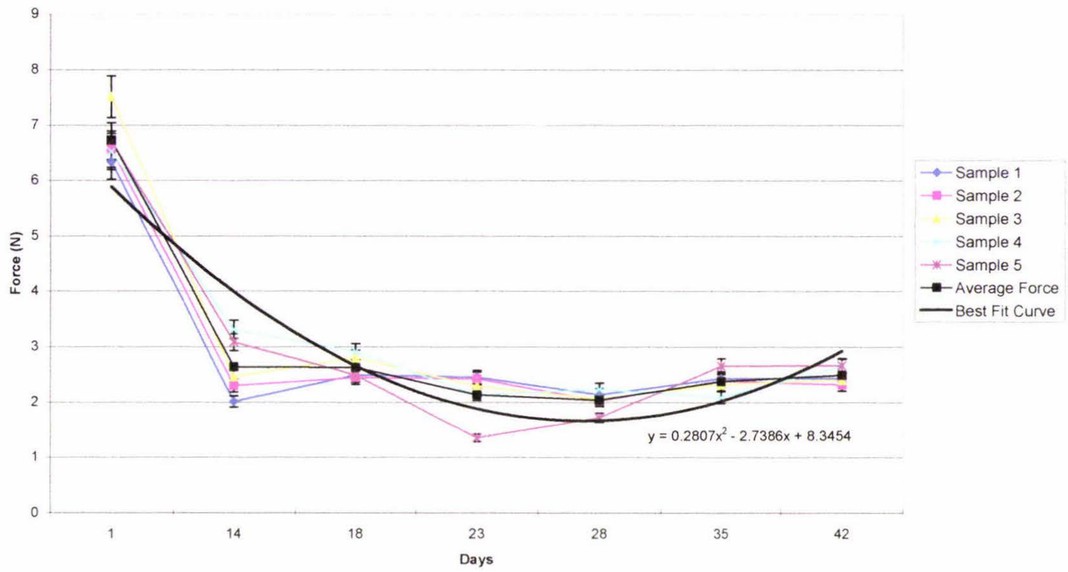
Peel Adhesion for Sellotape Fresh Tape at Vertical Rip from Chiller



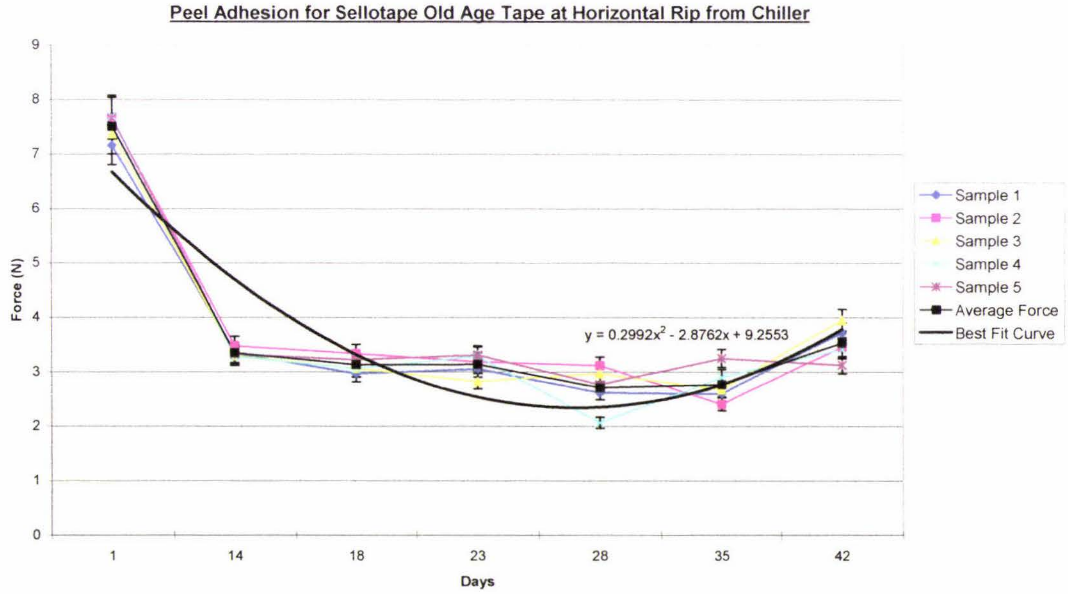
Peel Adhesion for Sellotape Fresh Tape at Horizontal Rip from Chiller

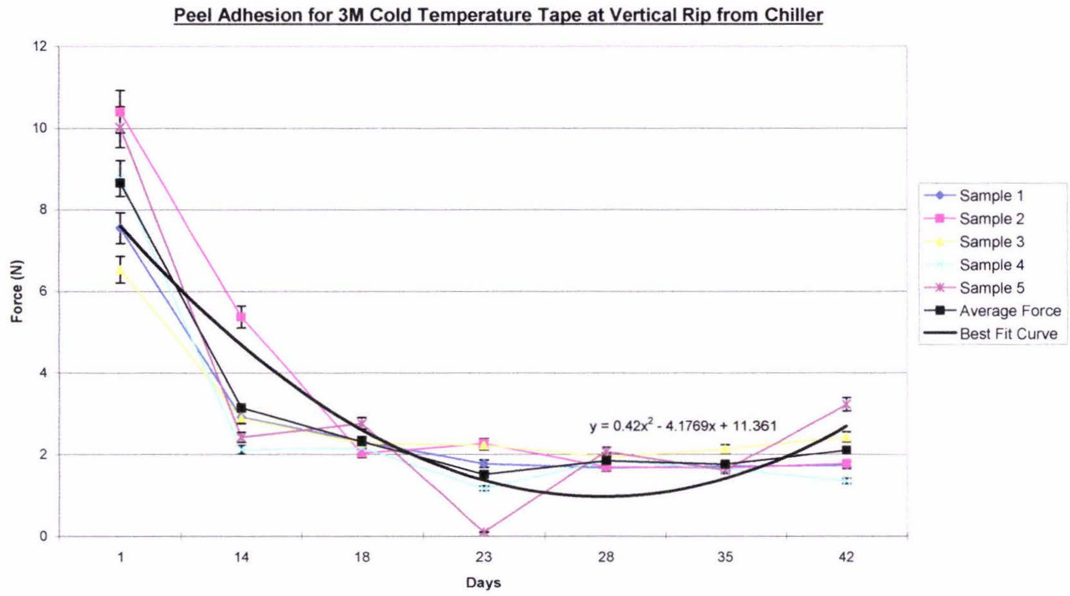


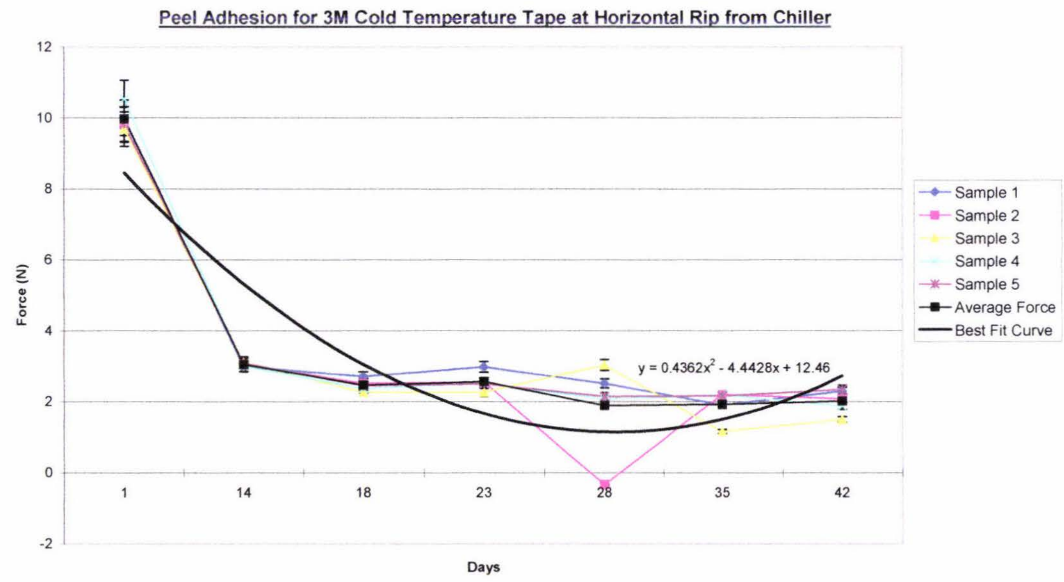
Peel Adhesion for Sellotape Old Age Tape at Vertical Rip from Chiller

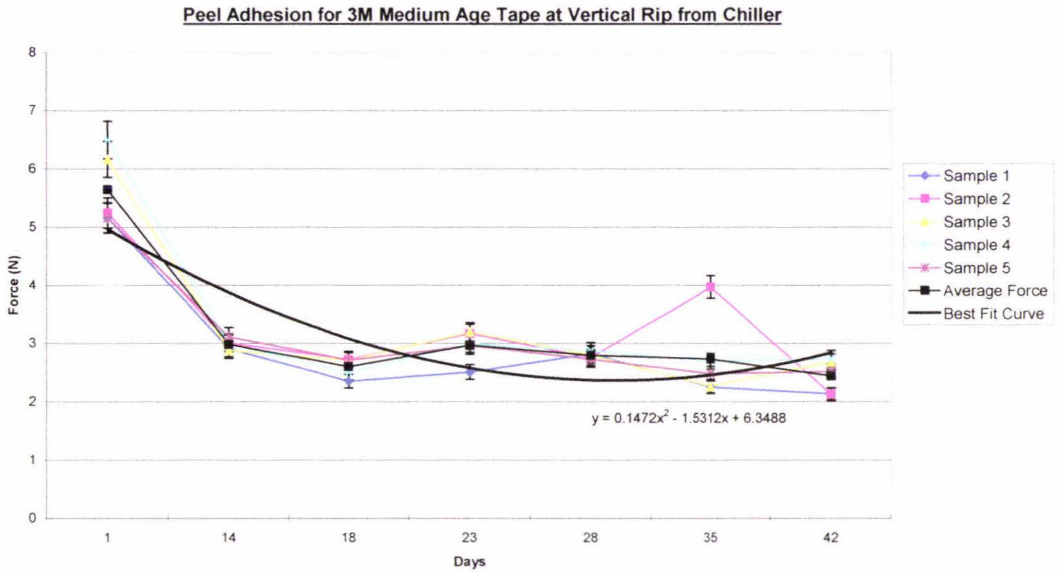


Peel Adhesion for Sellotape Old Age Tape at Horizontal Rip from Chiller

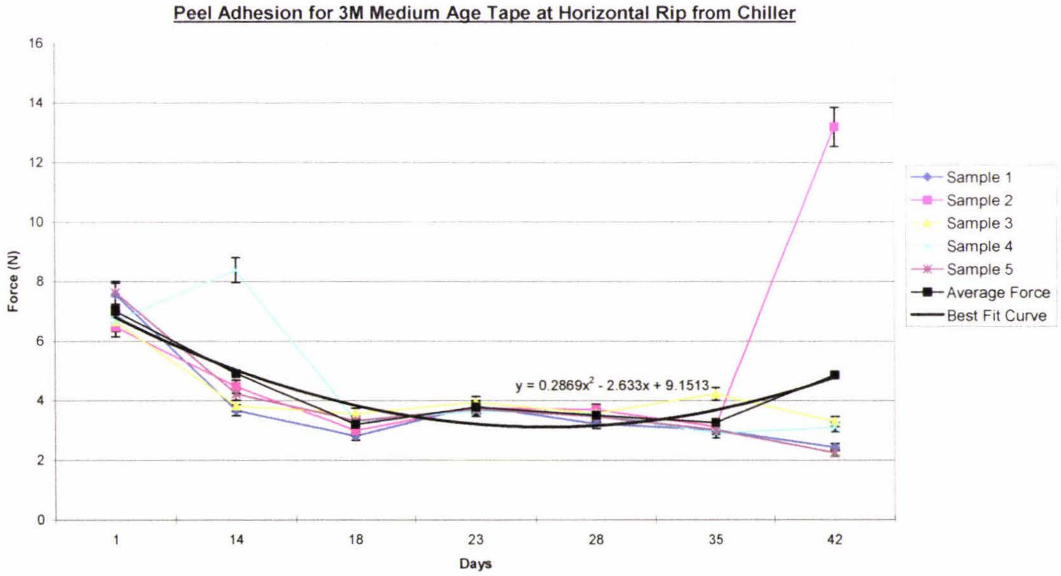



Peel Adhesion for 3M Cold Temperature Tape at Vertical Rip from Chiller
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.42x² - 4.1769x + 11.361

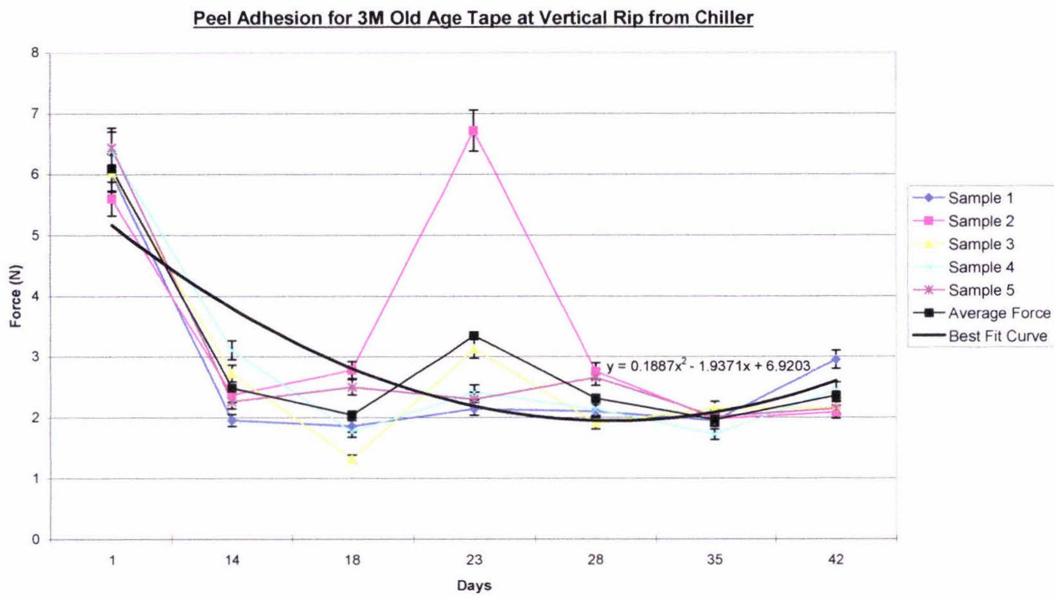

Peel Adhesion for 3M Cold Temperature Tape at Horizontal Rip from Chiller
Force (N)
Days
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.4362x² - 4.4428x + 12.46



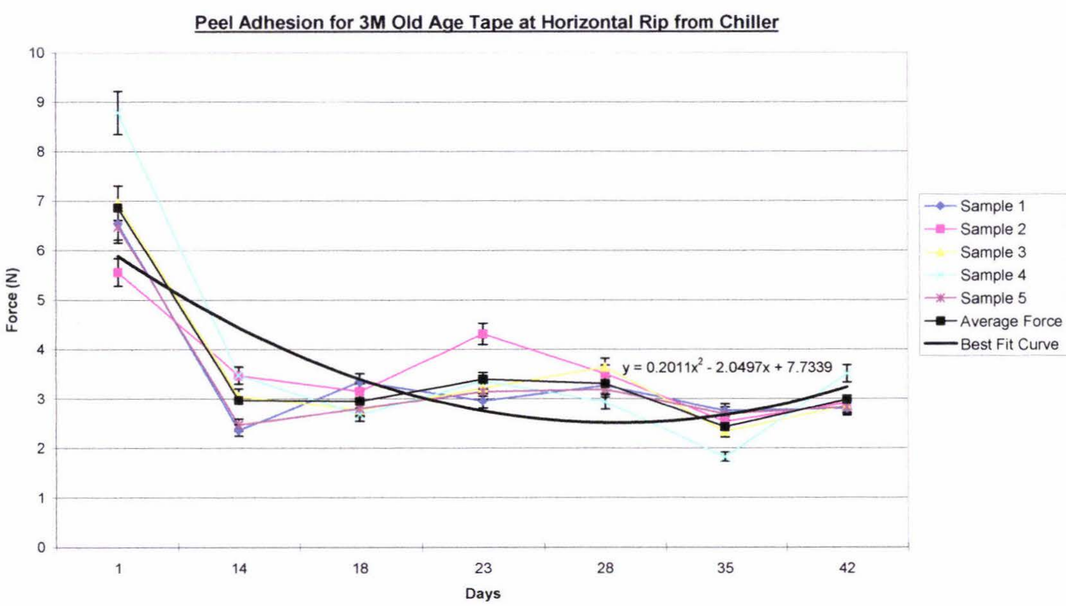
Peel Adhesion for 3M Medium Age Tape at Vertical Rip from Chiller
Force (N)
Days
1
14
18
23
28
35
42
y = 0.1472x² - 1.5312x + 6.3488
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve



Peel Adhesion for 3M Medium Age Tape at Horizontal Rip from Chiller
Force (N)
Days
1
14
18
23
28
35
42
y = 0.2869x² - 2.633x + 9.1513
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve

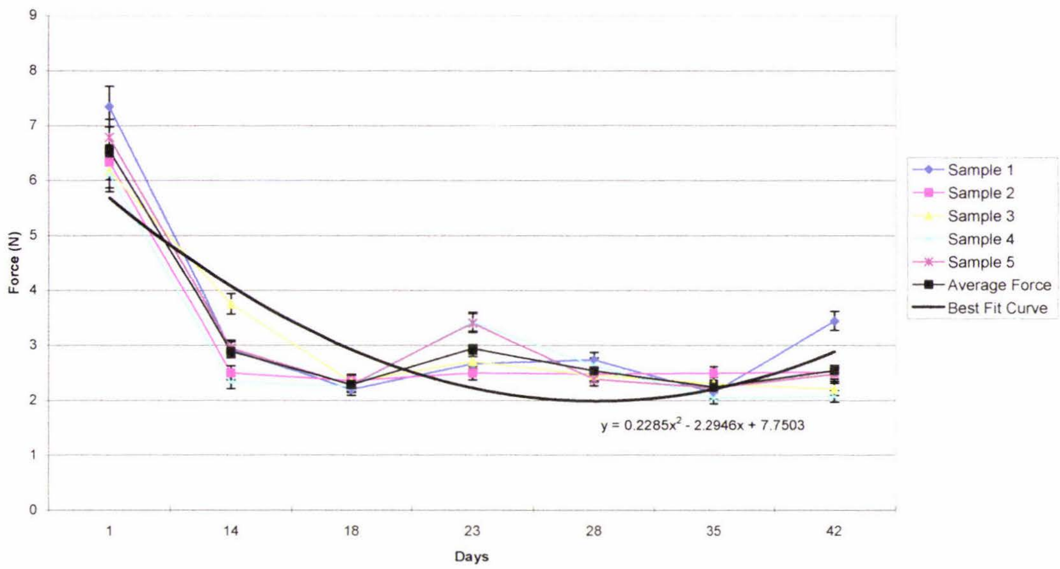


Peel Adhesion for 3M Old Age Tape at Vertical Rip from Chiller
Force (N)
Days
0
1
2
3
4
5
6
7
8
1
14
18
23
28
35
42
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.1887x² - 1.9371x + 6.9203

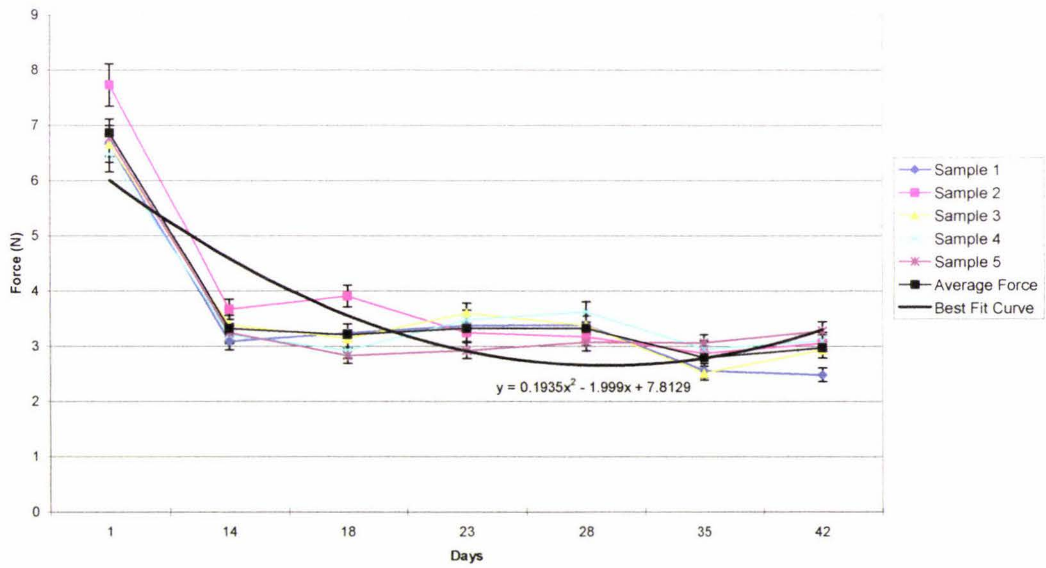


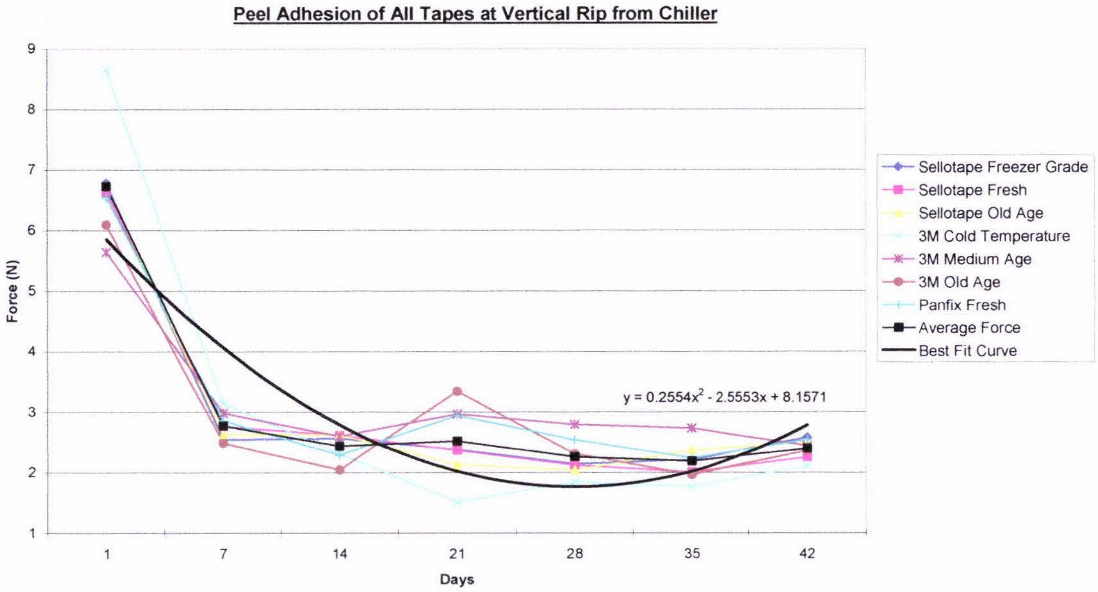
Peel Adhesion for 3M Old Age Tape at Horizontal Rip from Chiller
Force (N)
Days
0
1
2
3
4
5
6
7
8
9
10
1
14
18
23
28
35
42
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve
y = 0.2011x² - 2.0497x + 7.7339

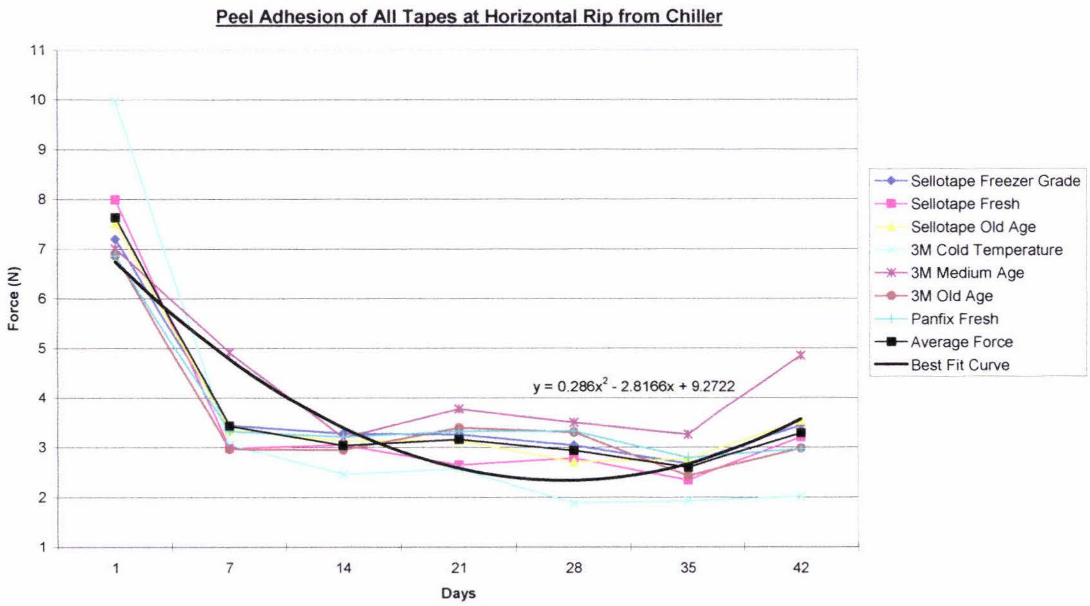
Peel Adhesion for Panfix Fresh Tape at Vertical Rip from Chiller



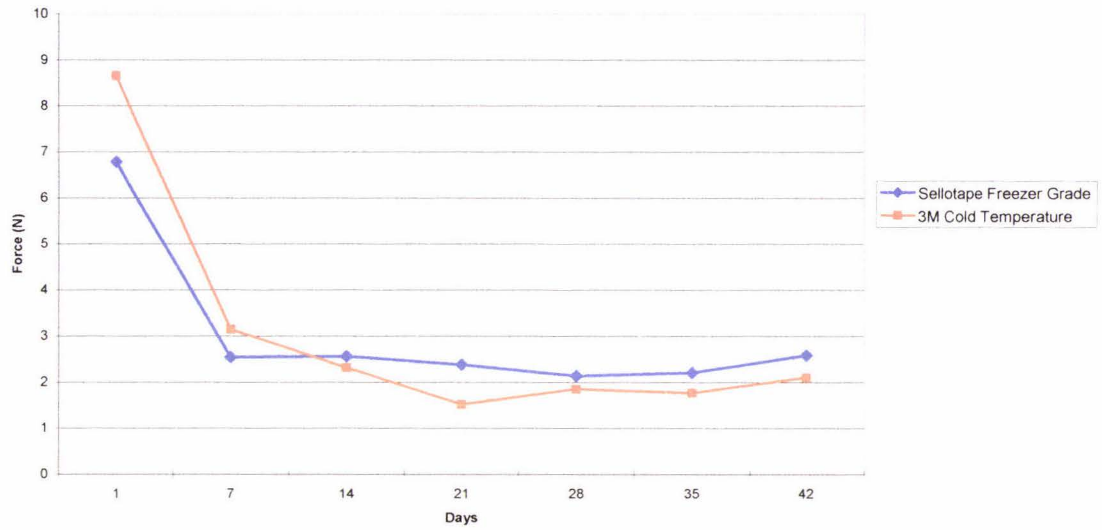
Peel Adhesion for Panfix Fresh Tape at Horizotnal Rip from Chiller



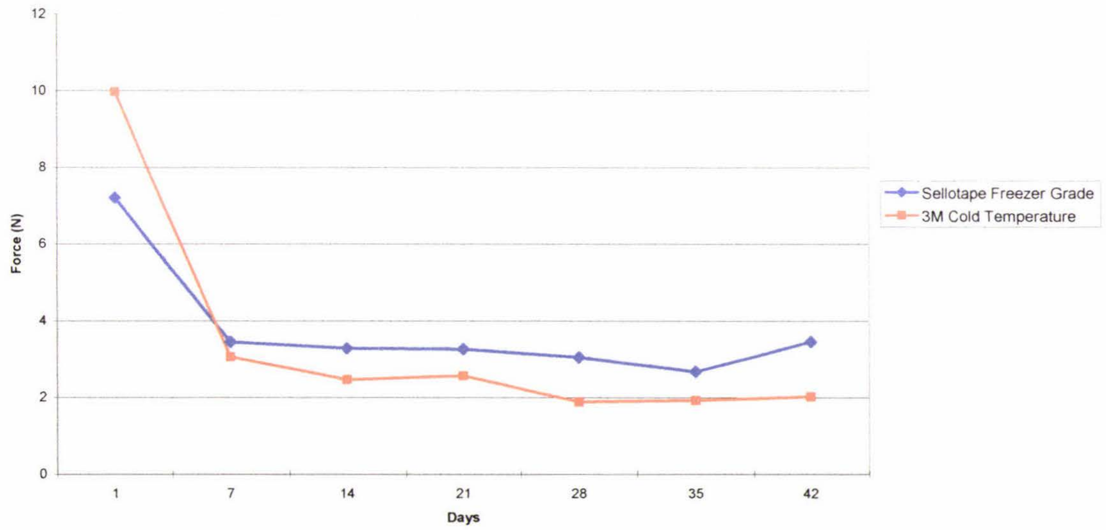

Peel Adhesion of All Tapes at Vertical Rip from Chiller
Force (N)
Days
Sellotape Freezer Grade
Sellotape Fresh
Sellotape Old Age
3M Cold Temperature
3M Medium Age
3M Old Age
Panfix Fresh
Average Force
Best Fit Curve
y = 0.2554x^2 - 2.5553x + 8.1571


Peel Adhesion of All Tapes at Horizontal Rip from Chiller
Force (N)
Days
Sellotape Freezer Grade
Sellotape Fresh
Sellotape Old Age
3M Cold Temperature
3M Medium Age
3M Old Age
Panfix Fresh
Average Force
Best Fit Curve
y = 0.286x^2 - 2.8166x + 9.2722

Peel Adhesion of Freezer/Cold Temperature Tapes at Vertical Rip from Chiller

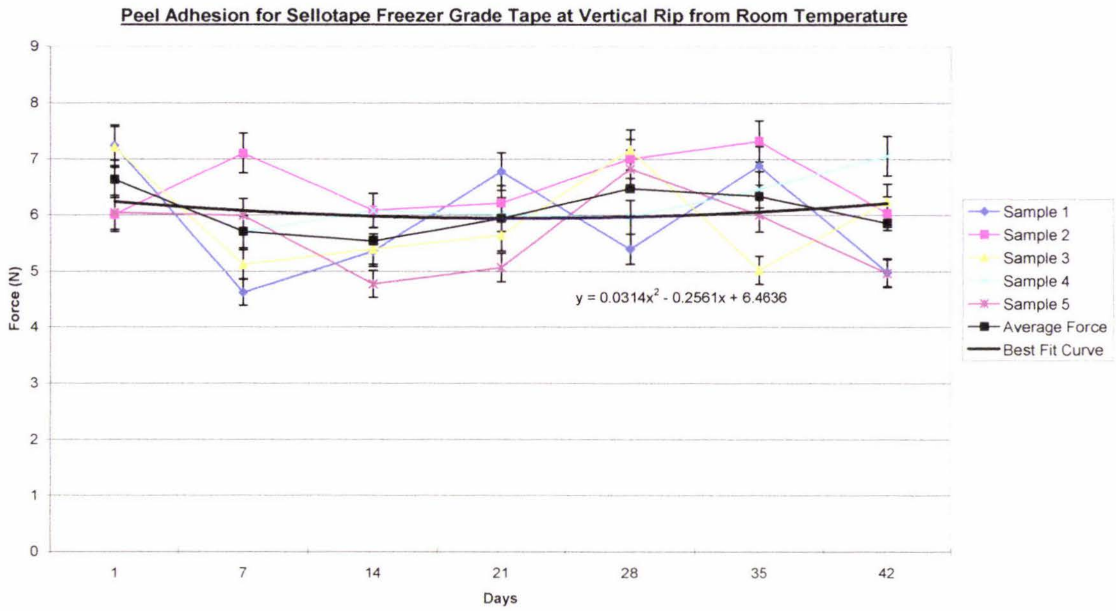


Peel Adhesion of Freezer/Cold Temperature Tapes at Horizontal Rip from Chiller

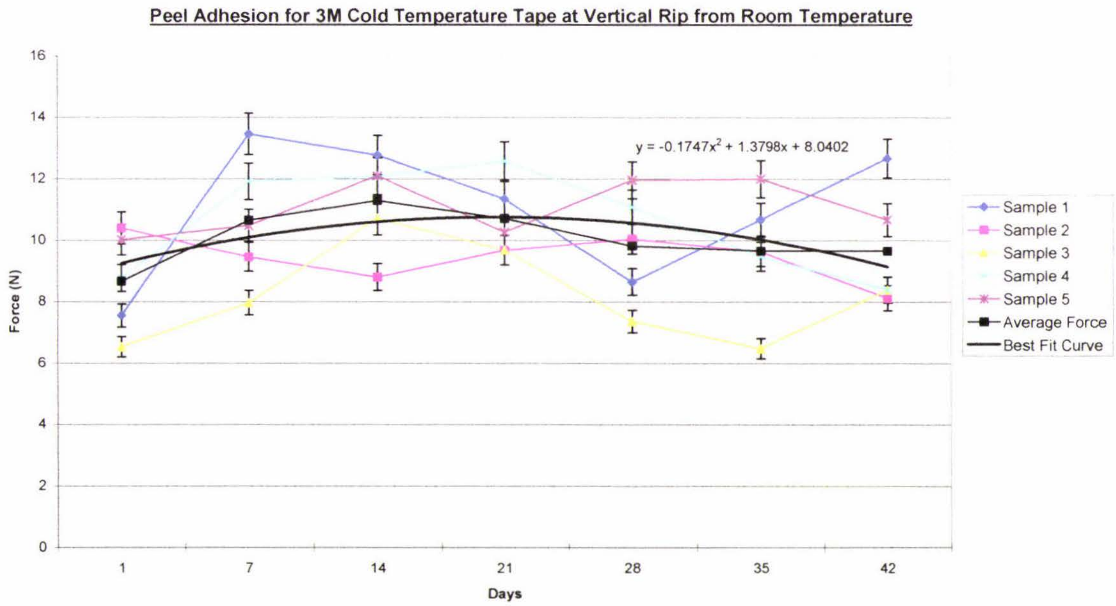


Peel Adhesion Results - Room Temperature

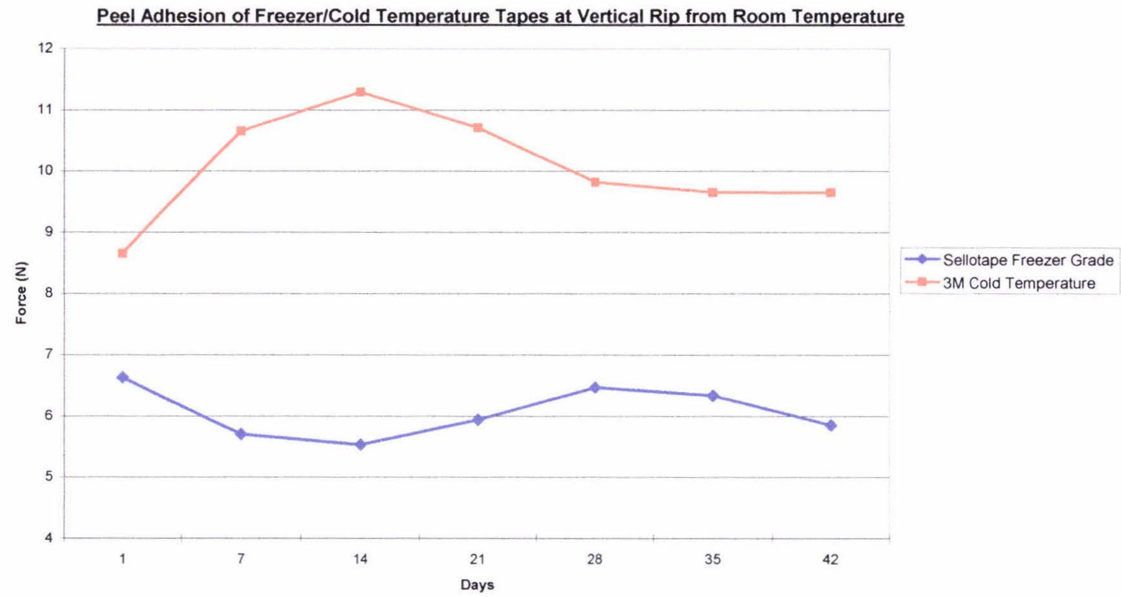
Tape Type/Days	1	7	14	21	28	35	42
SELFR2V1	7.243	4.623	5.351	6.775	5.395	6.881	4.982
SELFR2V2	6.007	7.102	6.085	6.214	7.006	7.32	6.032
SELFR2V3	7.212	5.12	5.393	5.644	7.164	5.023	6.241
SELFR2V4	6.642	5.699	6.076	6.009	5.965	6.456	7.056
SELFR2V5	6.044	5.991	4.772	5.066	6.821	6.004	4.965
Average Force	**6.6296**	**5.707**	**5.5354**	**5.9416**	**6.4702**	**6.3368**	**5.8552**
3MFR2V01	7.552	13.463	12.776	11.354	8.645	10.684	12.674
3MFR2V02	10.406	9.46	8.797	9.68	10.05	9.635	8.124
3MFR2V03	6.535	7.966	10.72	9.686	7.366	6.484	8.388
3MFR2V04	8.77	11.918	12.087	12.587	11.089	9.474	8.399
3MFR2V05	10.025	10.486	12.101	10.273	11.963	12.005	10.674
Average Force	**8.6576**	**10.6586**	**11.2962**	**10.716**	**9.8226**	**9.6564**	**9.6518**



Peel Adhesion for Sellotape Freezer Grade Tape at Vertical Rip from Room Temperature
Force (N)
Days
y = 0.0314x² - 0.2561x + 6.4636
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve



Peel Adhesion for 3M Cold Temperature Tape at Vertical Rip from Room Temperature
Force (N)
Days
y = -0.1747x² + 1.3798x + 8.0402
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Average Force
Best Fit Curve



Peel Adhesion of Freezer/Cold Temperature Tapes at Vertical Rip from Room Temperature
12
11
10
9
8
7
6
5
4
Force (N)
1
7
14
21
28
35
42
Days
Sellotape Freezer Grade
3M Cold Temperature

FREEZER

Peel Adhesion Force (N)

Vertical

Tape Type/Days	1	7	14	21	28	35	42
Sellotape Freezer Grade	7.0854	5.404	4.1414	4.6868	4.4768	4.9738	5.0571
Sellotape Fresh	6.6296	4.4318	4.8172	4.5232	4.1432	4.2426	4.4804
Sellotape Old Age	6.7288	5.0506	5.9226	4.8364	4.9216	4.442	4.2318
3M Cold Temperature	8.6576	5.9996	7.3456	5.153	5.1756	5.6572	5.5328
3M Medium Age	5.6436	6.484	6.2328	5.3804	5.4442	5.4552	5.7412
3M Old Age	6.0976	5.7968	6.0872	5.0318	5.1914	5.308	4.9834
Panfix Fresh	6.548	5.2062	5.3296	4.8724	4.8244	5.782	4.8118
Average Force	**6.770086**	**5.481857**	**5.696629**	**4.926286**	**4.882457**	**5.122971**	**4.976929**

Horizontal

Tape Type/Test	1	7	14	21	28	35	42
Sellotape Freezer Grade	6.9588	5.5188	5.145	5.9988	5.721	4.9226	6.0104
Sellotape Fresh	7.9916	5.3556	5.5276	5.7364	4.8532	4.671	5.1418
Sellotape Old Age	7.5102	6.2234	6.5942	5.4522	5.6288	5.2248	5.7152
3M Cold Temperature	9.9722	7.3104	8.5884	4.4608	5.213	5.0446	6.2856
3M Medium Age	7.0044	6.9164	8.0274	6.789	6.464	6.8394	6.1806
3M Old Age	6.8648	5.783	5.8558	5.382	5.7932	5.5384	5.5966
Panfix Fresh	6.8638	4.9986	6.2168	5.2774	5.596	6.1726	5.4322
Average Force	**7.595114**	**6.015171**	**6.565029**	**5.585229**	**5.609886**	**5.487629**	**5.766057**

CHILLER

Vertical

Tape Type/Test	1	7	14	21	28	35	42
Sellotape Freezer Grade	6.7842	2.5444	2.5634	2.382	2.1438	2.2128	2.5834
Sellotape Fresh	6.6296	2.766	2.6168	2.3712	2.1238	2.0086	2.2552
Sellotape Old Age	6.7288	2.6332	2.6278	2.134	2.039	2.377	2.4942
3M Cold Temperature	8.6576	3.1514	2.3188	1.516	1.849	1.7644	2.1112
3M Medium Age	5.6436	2.9846	2.6006	2.969	2.797	2.7346	2.4428
3M Old Age	6.0976	2.4866	2.0464	3.3426	2.3138	1.9668	2.3622
Panfix Fresh	6.548	2.8614	2.2886	2.9424	2.542	2.244	2.5438
Average Force	**6.727057**	**2.775371**	**2.437486**	**2.522457**	**2.258343**	**2.186886**	**2.398971**

Horizontal

Tape Type/Test	1	7	14	21	28	35	42
Sellotape Freezer Grade	7.2034	3.4424	3.2778	3.2606	3.0438	2.6726	3.4508
Sellotape Fresh	7.9916	2.9812	3.049	2.6462	2.7858	2.3414	3.2062
Sellotape Old Age	7.5102	3.3482	3.1332	3.1394	2.712	2.7684	3.5356
3M Cold Temperature	9.9722	3.054	2.4624	2.5662	1.8872	1.9246	2.0182
3M Medium Age	7.0044	4.9134	3.1968	3.7744	3.5016	3.259	4.8544
3M Old Age	6.8648	2.9642	2.948	3.3972	3.307	2.4288	2.9836
Panfix Fresh	6.8638	3.3216	3.211	3.3262	3.327	2.7922	2.9714
Average Force	**7.630057**	**3.432143**	**3.039743**	**3.1586**	**2.937771**	**2.598143**	**3.2886**

ROOM TEMPERTAURE

Vertical

Tape Type/Test	1	7	14	21	28	35	42
Sellotape Freezer Grade	6.6296	5.707	5.5354	5.9416	6.4702	6.3368	5.8552
3M Cold Temperature	8.6576	10.6586	11.2962	10.716	9.8226	9.6564	9.6518
Average Force	**6.156211**	**6.023869**	**7.416469**	**8.82848**	**10.11151**	**11.27671**	**12.7534**

Designation: D 3759M – 96
METRIC

Standard Test Method for Tensile Strength and Elongation of Pressure-Sensitive Tapes [Metric][1]

This standard is issued under the fixed designation D 3759M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of tensile strength (breaking strength) and stretch properties (elongation and "F" value) for pressure-sensitive tapes. It includes procedures for machine-direction and cross-direction tests and tests for tapes with low and high stretch and reinforced backings. It also includes a procedure for obtaining stretch force ("F" value) in conjunction with a determination of tensile strength. These procedures employ a constant-rate-of-extension (CRE)-type testing machine. They apply to the principle of stretching the specimen at a fixed strain rate of 25 mm per 25 mm of specimen length per minute with the exception of the procedure for reinforced tapes.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—This test method is the metric companion to Test Method D 3759 and uses specimen widths of 12 mm and 24 mm rather than ½ in. and 1 in. used in Test Method D 3759. This difference in test parameters will generally produce lower values for Test Method D 3759M.

2. Referenced Documents

2.1 *ASTM Standards:*

D 996 Terminology of Packaging and Distribution Environments[2]

D 2904 Practice for Interlaboratory Testing of a Textile Test Method that Produces Normally Distributed Data[3]

D 2906 Practice for Statements on Precision and Bias for Textiles[3]

D 3715 Practice for Quality Assurance of Pressure-Sensitive Tapes[2]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

3. Terminology

3.1 Terminology found in D 996 shall apply.

4. Significance and Use

4.1 This test method provides information that can be used in material specifications for product design and quality assurance applications. It can be used in comparing different products.

4.2 The use of this test method must be related to the purpose for which the test is performed. One purpose is for determining the relative strength of the tape in the size in which it is purchased or used. Another purpose is to identify or characterize a particular backing material.

4.2.1 When relative strength is of interest, the test should be performed on the tape as-received, that is, without cutting the material to a specimen width less than the as-received width.

4.2.1.1 Usually tapes wider than 48 mm are not tested due principally to the limitations of equipment. Tapes as narrow as approximately 3 mm can be tested.

4.2.1.2 Comparison of materials by different methods should be avoided because the test parameters of specimen dimension and crosshead velocity determine the outcome. Changes in the parameter levels will produce different results for the same material.

NOTE 2—It is usual to find the tensile strength increasing significantly with increasing crosshead velocity and therefore, strain rate.

4.2.2 When identity of material characterization is of interest, the test should be performed on a specimen cut from within the sample material boundaries using a sharp razor cutter, such as that defined in Section 5.

NOTE 3—Some of the traditional tools for specimen preparation must be avoided when the backing is comprised of thin plastic sheeting. These include chopping dies and sample cutters operating on a shearing principle. The reason for this restraint is that edges sufficiently ragged and damaged resulting from chopping or shearing cause tearing to occur before the true tensile strength level is reached. Tapes with fibrous backings may be cut to satisfactory specimens with these tools.

4.2.3 Stretch characteristics can be related to the tape's intended use or for identifying or characterizing a material.

NOTE 4—Elongation measurements become difficult to perform on stretchy materials (greater than 25 % ultimate elongation) when the ratio of specimen length to width is small (approaching 2). The results show high variability and do not allow for practical use of this information except when one wishes to demonstrate large differences between material.

5. Apparatus

5.1 *Tension Tester*—A constant-rate-of-extension (CRE) type with load cell capacity such that the maximum expected specimen strength does not exceed 90 % of its normal limit.

5.1.1 *Test Information* should be displayed in at least an alphanumeric digital display or a load-elongation curve

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[1] This test method is under the jurisdiction of ASTM Committee D-10 on Packaging and is the direct responsibility of Subcommittee D10.14 on Closure and Reinforcement of Packages.

Current edition approved March 10, 1996. Published May 1996. Originally published as D 3759M – 83. Last previous editioin D 3759M – 88 (1993)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 15.09.

[3] *Annual Book of ASTM Standards*, Vol 07.01.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

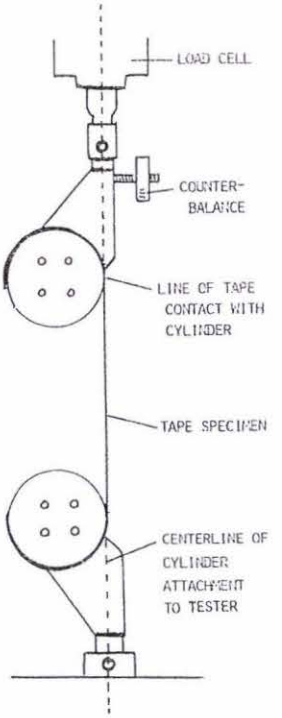

FIG. 1 Test Configuration for Reinforced Tapes

plotted by a pen or stylus responding to load and with a chart driven synchronously with the crosshead.

5.1.2 *Load-Elongation Curve*, plotted by a pen or stylus reponding to load and with a servo-chart drive or *x-y* recorder driven by an extensometer.

5.1.3 *Clamps*, preferably the pneumatic action type.

5.1.3.1 Clamp faces at least 50 mm wide by 38 mm deep. Faces shall have a light cross-hatch serration.

NOTE 5—Plastic materials are reduced in width and thickness while being stretched. This causes them to be drawn out of the clamps. Pneumatic clamps minimize this effect. It can be further reduced by the appropriate choice of surface of the clamps. The greatest improvement, both with respect to the above mentioned shrinkage problem and simple slippage, may be found from the use of urethane film which can be obtained as a pressure-sensitive tape approximately 0.5 mm thick. This material has a very high coefficient of friction, is somewhat malleable, and is easily replaced. Alternative materials are coated abrasive, rubber (neoprene or other synthetic type), or other tape.

5.1.4 *Cylinders*, in place of clamps for testing reinforced tapes. Each of two cylinders shall be approximately 100 mm in diameter by approximately 38 mm thick held in the position ordinarily occupied by the clamps so that the tape, when applied to the cylinders and extending between them, falls in the line of stress otherwise occupied by the specimens when clamps are used. See Fig. 1.

5.1.5 *Scale*, approximately 22 mm in length divided into 2-mm increments attached to each cylinder. The zero point (origin) shall be at the point of tangency of the tape with the cylinder during the test and the scale shall increase upward on the lower cylinder and downward on the upper cylinder.

NOTE 6—These scales will be used to observe and measure the tape slippage during the tension test for reinforced tapes.

TABLE 1 Tester Preparation and Specimen Dimensions

	Gage Length, mm	Cross-head Velocity, min, mm/min	Chart Velocity,[A] min, mm/min	Specimen Width,[B] mm	Length, mm
Tapes with ultimate elongation of:					
Up to 200 %:					
Machine direction	125	125	125	12–24	230
Cross direction [C,D,E]	25	25	125	12	125
200 % and up:					
Machine direction	50	50	125	12	150
Reinforced tapes	250	125	125	12–24	710

[A] The chart velocity may be set at other velocities. It should be slower than the crosshead velocity.

[B] The specimen widths shown are for tests in which the specimen is cut from within the sample dimension. See 4.2.1.1.

[C] Cross-direction (C.D.) tests are limited to sample rolls of tape at least 48 mm in width.

[D] It is unusual to test C.D. tensile strength of tapes having ultimate elongations greater than 200 %. Therefore no reference to this is made in Table 1. However C.D. tests could be under that category on the high-stretch materials.

[E] If the sample provides ample material, C.D. tests should preferably be made in the same way machine-direction (M.D.) tests are. This would occur with web material or sufficiently wide rolls.

5.2 *Cutter*,[5] holding two single-edged razor blades in parallel planes, a precise distance apart, to form a cutter of exact specimen width. Appropriate widths shall be available (refer to specimen width in Table 1) patterned after the 12-mm cutter in 5.2.1. The differences between cutters of various widths is in the final width of the bar after removing the thickness of one razor blade.

5.2.1 The cutter shall consist of a 12 mm thick by approximately 200-mm length of aluminum bar stock 125 mm from one end shall be slightly rounded to form a handle. The width of the bar, for approximately 75 mm from the opposite end, shall be narrowed to exactly 12 mm minus the thickness of a single razor blade (one of two used as cutting edges). The razor blades shall be held in position using side plates. The end of the cutter shall be cut away at a 45° angle to expose the cutting edges at one end of the blades.

6. Sampling

6.1 *Acceptance Sampling*—Sampling shall be in accordance with Practice D 3715.

6.2 *Sampling for Other Purposes*—The sampling and the number of test specimens depends on the purpose of the testing. Practice E 122 is recommended. It is common to test at least five specimens of a particular tape. Test specimens should be taken from several rolls of a tape and, whenever possible, among several production runs of a tape. Strong conclusions about a specific property of a tape cannot be based on test results of a single unit (roll) of product.

7. Test Specimens

7.1 Specimens shall have the dimensions shown in Table 1.

7.2 Unwind and discard at least three, but no more than six, outer wraps of tape from the sample roll before taking specimens for testing.

[5] Available from Chemsultants International, 9349 Hamilton Dr., Mentor, OH 44061-1118.

7.3 Test one specimen per sample roll, unless otherwise specified.

7.4 The following applies to nonreinforced tapes:

7.4.1 Specimen ends that are clamped shall be prepared by covering the adhesive with paper, some other tape, or an extension of the specimen. In the latter case the specimen must be cut at least 100 mm longer than defined in Table 1.

7.4.2 The covering shall be free of wrinkles, leaving the gage-length area uncovered and completely cover the rest of the specimen so that the clamps will apply uniform pressure against the specimen.

7.4.3 A special specimen preparation is required for cross-direction (C.D.) specimens from rolls less than 96 mm in width. Lay two rectangular sample strips on a flat surface with the adhesive side facing up. See Fig. 2. Each strip shall be as wide as the sample roll and approximately 125 mm in length. Position these strips side by side with one long edge of one strip parallel to and 25 mm separated from one long edge of the second strip.

7.4.3.1 Cut a specimen from the sample roll to have the width specified in Table 1 and length equal to the width of the roll.

7.4.3.2 Lay this specimen adhesive side up across the 25-mm separation of the strips. Position it toward one end of the sample strips so that it rests equally on both strips and at a right angle to their parallel edges.

7.4.3.3 Cut two additional strips from the sample roll having the same width as the specimen. Butt the end of one of these at one end to form a continuation of the specimen across the remainder of the sample strip. Use the second strip to butt against the other end of the specimen in like manner.

7.4.3.4 Fold each of the original sample strips over onto itself to form a three-ply tab that will be gripped by the clamps during the test.

7.4.3.5 Trim off any excess (single ply of tape) of either the sample strips or the extension strips extending beyond the two- or three-ply parts of the assembly.

NOTE 7—The extension serves to keep the clamping pressure uniform over the whole area of the specimen. This is an imperative factor to a successful test.

7.5 For reinforced tapes the specimen requires no further preparation than to have the appropriate dimensions (Table 1) and ensure that the adhesive is not contaminated so it will adhere well to the cylinders.

8. Preparation of Apparatus

8.1 Table 1 shows the tension tester settings for use with the specified test categories.

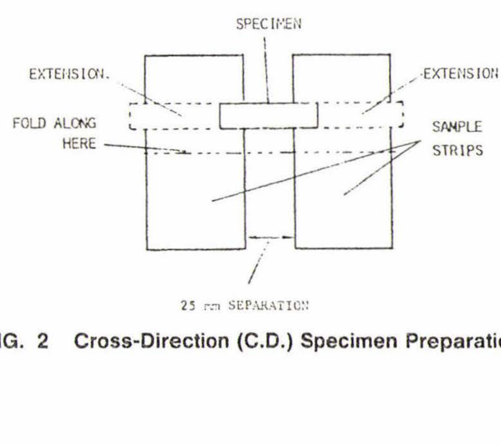

FIG. 2 Cross-Direction (C.D.) Specimen Preparation

8.2 For testing reinforced tapes, set the cylinders 150 mm apart so that at the start of a test 25 mm of tape will extend between and without contact with the cylinders.

NOTE 8—The upper cylinder should be counter-balanced in order that the line of tape contact on the cylinders intersects an imaginary line running between the points of cylinder attachment to the tester and no side forces are exerted during the test. See Fig. 1.

9. Conditioning

9.1 Condition the sample to equilibrium in an atmosphere uniformly maintained at 23 ± 2°C and 50 ± 5 % relative humidity for 24 h. Testing shall be performed at the same conditions.

10. Procedure

10.1 *Nonreinforced Tapes:*

10.1.1 Clamp the specimen in the grips of the testing machine. Take care to align the long axis of the specimen with an imaginary line running between the points of attachment of the grips and including the center of the grips. Apply no more tension to the specimen during clamping than is necessary to remove slack.

10.1.2 Start the crosshead in motion at the specified velocity (Table 1) and ensure that the mechanism that displays the response (that is charts, plotter, and digital display) is operating. Continue until the specimen ruptures.

10.1.3 Record a numerical display of the results.

10.2 *Reinforced Tapes:*

10.2.1 Adhere approximately 230 mm of the specimen on the upper cylinder beginning at the line of tape contact (see 8.2), and wrap the specimen around the top surface of the cylinder. Repeat this with the free end of the specimen on the lower cylinder, except wrap the specimen around the bottom surface of the cylinder. The applied specimen must be centered on the center line around the cylinder surface. This elimination of skewness prevents nonuniform stress loading across the width of the specimen. The specimen shall also be sufficiently taut to remove slack.

10.2.2 Mark the specimen (and cylinder if not already done), with a marking pen making a line approximately 1 mm wide at the line where the tape contacts each cylinder. These bench marks will be 25 mm apart and shall be checked to ensure this.

10.2.3 Start the crosshead in motion at the specified velocity and ensure that the response-indicator mechanism is operating to indicate both load and elongation, if the latter is required.

10.2.4 Observe the bench marks on the specimen to determine their change in position relative to the marks on the cylinders. Use the scales appended to the cylinders.

10.2.5 When the specimen breaks, record the sum of the upper and lower bench mark changes to the nearest 2 mm. This will be the correction for the elongation.

10.2.6 Also record the indicated responses for tensile strength and elongation when the tester provides a numerical display of this information.

11. Calculation

11.1 *Tensile Strength:*

11.1.1 When the recorded load-elongation curve result from the testing, calculate tensile strength as follows:

11.1.1.1 Find the farthest advance of the plotting pen or stylus from the origin in the direction representing increasing force. Record this advance as a percent of the chart scale.

11.1.1.2 Multiply the full-scale load range used during the test by the percent found in 11.1.1.1.

NOTE 9—For this calculation express the percent as a decimal fraction, that is, use 0.87 for 87 %.

11.1.1.3 Convert the value found in 11.1.1.2 to newtons per the desired basis of dimension for the final step. For N/100 mm of width, divide by the specimen width in millimetres and multiply by 100.

11.2 *Ultimate Elongation:*

11.2.1 When the recorded load-elongation curve results from the use of a synchronous chart drive, calculate elongation as follows:

11.2.1.1 Measure the distance from the start of the plot to the indicated breaking point along the motion (time) axis of the chart.

11.2.1.2 When the chart velocity equals the crosshead velocity, the distance from 11.2.1.1 divided by the gage length and multiplied by 100 equals the ultimate elongation.

11.2.1.3 When the chart and crosshead velocities are different, multiply the calculation completed in 11.2.1.2 by the ratio of the crosshead velocity to the chart velocity to obtain the correct ultimate elongation.

11.2.2 When the recorded load-elongation curve results from use of a servo-chart drive or *x-y* recorder driven by an extensometer, calculate elongation as follows:

11.2.2.1 Measure the distance from the start of the plot to the indicated breaking point. Divide this by the magnification ratio (to get the true dimension of elongation). Divide this by the gage length. Next, multiply by 100 to convert the value to percent ultimate elongation.

NOTE 10—The magnification ratio is the chart motion over the actual extensometer motion.

11.2.3 When testing reinforced tapes, the correction found in 10.2.5 shall first be subtracted from the amount of extension indicated or measured along the time axis of the recording chart and the difference divided by the original gage length. Multiply this quotient by 100 to convert it into percent ultimate elongation.

11.3 *"F" Value:*

11.3.1 When the recorded load-elongation curve results from the use of a synchronous chart drive, calculate the "F" value as follows:

11.3.1.1 Find the chart scale equivalent to the desired elongation point. (If one were determining the F-3 value, that is, the force required to stretch the specimen 3 %, one would be finding the chart scale equivalent to 3 % elongation). This equivalent is the distance measured from the start of the plot to the prescribed elongation point on the chart. To calculate the distance in terms of the chart scale, use this equation:

$$d = \frac{E \times G \times C}{100\,(H)} \tag{1}$$

where:

d = chart scale equivalent distance,
E = percent elongation where the "F" value is to be determined,
G = gage length,
C = chart velocity, and
H = crosshead velocity.

The units of these measurements shall be millimetres.

11.3.1.2 Using the calculated d, measure along the chart time axis (same as stretch, extension, or elongation axis) from the origin of the recorded plot to a point distance, d. This point shall be at zero force as was the plot origin. Draw a line from this point parallel to the force axis to intersect with the recorded plot. Measure the scale length of this line from zero force and convert this length into percent of chart scale and then into force. See 11.1.1.1, 11.1.1.2, and Note 9.

11.3.1.3 Multiply the full-scale load range used during the test by the percent found in 10.3.1.2. Express the percent as a decimal fraction. The product is the "F" value in newtons for the specimen width.

11.3.1.4 The final step is the same as 11.1.1.3, except substitute 11.3.1.3 for 11.1.1.2.

11.3.2 When the recorded load-elongation curve results from the use of a servo-chart drive or *x-y* recorder driven by an extensometer, calculate the "F" value as follows:

11.3.2.1 Find the scale equivalent to the desired elongation point using this equation:

$$d = \frac{E \times G \times M}{100} \tag{2}$$

where:

d = scale equivalent,
E = percent elongation where the "F" value is to be determined,
G = gage length, and
M = magnification ratio (see Note 10).

11.3.2.2 Using the calculated value of d from the 11.3.2.1, perform the steps in 11.3.1.2 and 11.3.1.3.

12. Report

12.1 Report the tensile strength in newtons per 100 mm of width to three significant places.

12.2 Report the ultimate elongation in percent to two significant places.

12.3 Report the "F" value in the same manner as the tensile strength (11.1).

12.4 Include the manufacturer's name and designation for the tape.

12.5 Report the following test parameters:

12.5.1 Crosshead velocity,

12.5.2 Gage length, and

12.5.3 Specimen width.

12.6 When the desired test response includes ultimate elongation, indicate whether slippage of material from within the clamps occurred and estimate the amount.

12.7 Any anomalous behavior noticed besides slippage.

TABLE 2 Components of Variation as Coefficient of Variation Percentage Point

Names of Properties	Single-Operator Component	Within-Laboratory Component	Between-Laboratory Component	Replication Component
Specimens of the Same Material:				
M.D. Tensile (nonreinforced)	4.2	2.9	12.4	5.7
C.D. Tensile (nonreinforced)	2.6	15.5	39.1	7.0
Elongation (nonreinforced)	6.6	4.4	28.3	12.6
Tensile (reinforced)	7.1	2.4	4.2	3.3
Elongation (reinforced)	3.3	4.9	27.1	8.3
Specimens of Different Material:				
M.D. Tensile (nonreinforced)	10.0	2.6	7.3	5.7
C.D. Tensile (nonreinforced)	31.8	11.4	25.1	7.0
Elongation (nonreinforced)	27.3	6.4	10.9	12.6
Tensile (reinforced)	7.5	0.0	4.2	3.3
Elongation (reinforced)	5.3	4.8	26.7	8.3

TABLE 3 Critical Differences for the Properties Noted, Percentage Points[A]

Names of Properties	Number of Observation in Each Average	Single-Operator Precision		Within-Laboratory Precision		Between-Laboratory Precision	
		Specimens		Specimens		Specimens	
		Same Material	Different Material	Same Material	Different Material	Same Material	Different Material
M.D. Tensile (nonreinforced)	1	19.5	32.1	34.8	32.9	40.3	38.6
	5	13.6	28.8	15.8	29.7	37.8	36.0
	10	12.6	28.4	15.0	29.3	37.5	35.6
C.D. Tensile (nonreinforced)	1	20.8	90.3	47.9	95.7	118.0	118.3
	5	11.3	88.6	44.3	94.1	117.0	117.0
	10	9.4	88.4	44.1	93.8	117.0	116.9
Elongation (nonreinforced)	1	39.5	83.3	41.3	85.2	88.7	90.4
	5	24.0	77.2	26.9	79.2	83.0	84.8
	10	21.3	76.4	24.5	78.4	82.3	84.1
Tensile (reinforced)	1	21.6	22.6	22.5	22.6	25.4	25.4
	5	20.0	21.1	21.0	21.1	24.1	24.1
	10	19.8	20.9	20.9	20.9	23.9	23.9
Elongation (reinforced)	1	24.7	27.2	28.1	30.4	80.7	80.1
	5	13.7	17.9	19.2	22.4	77.4	77.5
	10	11.6	16.4	17.8	21.2	77.1	77.1

[A] Critical differences were calculated using $t = 1.96$ which is based on infinite degrees of freedom.

13. Precision and Bias

13.1 *Summary*—The difference between two single observations should not exceed the following critical differences in 95 out of 100 cases when all of the observations are taken by the same well-trained operator using the same piece of test equipment and specimens randomly drawn from the same sample of material.

M.D. Tensile (nonreinforced)	19.5 % of the average
C.D. Tensile (nonreinforced)	20.8 % of the average
Elongation (nonreinforced)	39.5 % of the average
Tensile (reinforced)	21.6 % of the average
Elongation (reinforced)	24.7 % of the average

The size of the differences is likely to be affected adversely by different circumstances. The true values of M.D. tensile (nonreinforced), C.D. tensile (nonreinforced), elongation (nonreinforced), tensile (reinforced), and elongation (reinforced) can be defined only in terms of specific test methods. Within this limitation, the procedures in Test Method D 3759M for determining these properties have no known bias. Paragraphs 13.2 through 13.5 explain the basis for this summary and for evaluations made under other conditions.

13.2 *Interlaboratory Test Data*[6]—An interlaboratory study was made in 1980 in which randomly drawn samples of two materials were tested in six laboratories. Two operators in each laboratory each tested three specimens from each of three rolls of each material. The components of variance expressed as coefficient of variation were calculated to be the values listed in Table 2.

NOTE 11—The calculations for coefficient of variation and other statistics found in subsequent sections of this statement are described in Practice D 2906 and Annex A3 of Practice D 2904.

13.3 *Critical Differences*—For the components of variance listed in Table 2, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed in Table 3.

13.4 *Confidence Limits*—For the components of variance listed in Table 2, single averages of observed values have the 95 % confidence limits listed in Table 4.

NOTE 12—The tabulated values of the critical differences and confidence limits should be considered to be a general statement particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias between them, if any, must be established with each comparison being based on recent data obtained on specimens randomly drawn from one sample of the material to be evaluated.

13.5 *Bias*—No justifiable statement can be made on the bias of Test Method D 3759M for testing tensile strength and elongation since the true value cannot be established by an accepted referee method.

14. Keywords

14.1 elongation; pressure-sensitive tape; tensile strength

[6] Supporting data are available from ASTM Headquarters. Request RR: D-10-1002.

TABLE 4 Width of 95 % Confidence Limits for the Properties Noted, Percentage Points [A]

Names of Properties	Number of Observations in Each Average	Single-Operator Precision		Within-Laboratory Precision		Between-Laboratory Precision	
		Same Material	Different Material	Same Material	Different Material	Same Material	Different Material
M.D. Tensile (nonreinforced)	1	±13.8	±22.7	±24.6	±23.2	±28.5	±27.3
	5	±9.6	±20.4	±11.1	±21.0	±26.8	±25.4
	10	±8.9	±20.1	±10.6	±20.7	±26.5	±25.2
C.D. Tensile (nonreinforced)	1	±14.7	±63.9	±33.9	±67.7	±83.7	±83.7
	5	±8.0	±62.7	±31.4	±66.5	±82.7	±82.8
	10	±6.7	±62.5	±31.2	±66.4	±82.7	±82.7
Elongation (nonreinforced)	1	±27.9	±58.9	±29.2	±60.2	±62.7	±63.9
	5	±17.0	±54.6	±19.0	±56.0	±58.7	±60.0
	10	±15.1	±54.1	±17.3	±54.5	±58.2	±59.9
Tensile (reinforced)	1	±15.3	±16.0	±16.0	±16.0	±18.0	±18.0
	5	±14.2	±14.9	±14.9	±14.9	±17.0	±17.0
	10	±14.0	±14.8	±14.8	±14.8	±16.9	±16.9
Elongation (reinforced)	1	±17.5	±19.3	±19.9	±21.5	±56.7	±56.7
	5	±9.7	±12.7	±13.6	±15.9	±54.8	±54.8
	10	±8.2	±11.6	±12.6	±15.0	±54.5	±54.5

[A] Critical differences were calculated using $t = 1.96$ which is based on infinite degrees of freedom.

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Tensile Strength and Elongation of Pressure Sensitive Tapes

1. DEFINITION

1.1 Tensile strength — the force required, per unit width, to break the tape when tested under prescribed conditions.

1.2 Elongation — the increase in length at break when the tape is tested under prescribed conditions. In case of Class 1 tapes, the elongation may include creep on the jaws that is often partially compensated for by "necking" of the specimen.

2. SIGNIFICANCE

2.1 Tensile strength — Breaking strength of tape is of importance as a measurement of its uniformity, quality, and ability to withstand stress in application and service.

2.2 Elongation — Elongation of tape is important as a measurement of its uniformity and quality, as well as a rough indication of its ability to conform to contours of uneven surfaces.

Table 1

Tester Preparation and Specimen Dimensions

	Gauge length, In. (mm)	Crosshead velocity, min., In (mm)	Chart velocity[A] min, In. (mm)	Specimen width[B], In. (mm)	length In. (mm)
Tapes with ultimate elongation of:					
Up to 150%:					
Machine direction	5 (127)	5 (127)	5 (127)	½-1 (12.7-25.4)	9 (178.6)
Cross direction[C,D,E]	1 (25.4)	1 (25.4)	5 (127)	¼-½ (6.4-12.7)	5 (127)
150% and up:					
Machine direction	2 (50.8)	2 (50.8)	5 (127)	½ (12.7)	6 (152.4)
Reinforced tapes	10 (254)	5 (127)	5 (127)	½-1 (12.7-25.4)	28 (711.2)

[A]The chart velocity may be set at other velocities. It should not be slower than the crosshead velocity.
[B]The specimen widths shown are for tests in which the specimen is cut from within the sample dimensions. See 3.2.1.1.
[C]Cross-direction (CD) tests are limited to sample rolls of tape at least 2" (50.8 mm) in width.
[D]It is unusual to test CD tensile strength of tapes having ultimate elongations greater than 150%. Therefore no reference to this is made in Table 1. However, CD tests could be made under that category on the high stretch materials.
[E]If the sample provides ample material, CD tests preferably should be made in the same way machine direction (MD) tests are. This would occur with web material or sufficiently wide rolls.

3. TEST SPECIMEN

3.1 Specimens shall have the dimensions shown in Table 1.

3.2 Unwind and discard at least three, but no more than six, outer wraps of tape from the sample roll before taking specimens for testing.

3.3 Test one specimen per sample roll, unless otherwise specified.

3.4 The following applies to nonreinforced tapes:

3.4.1 Specimen ends that are clamped shall be prepared by covering the adhesive with paper, some other tape, or an extension of the specimen. In the latter case, the specimen must be cut at least 4" longer than defined in Table 1.

3.4.2 The covering shall be free of wrinkles, leaving the gauge-length area uncovered anc completely cover the rest of the specimen so that the clamps will apply uniform pressure against the specimen.

3.4.3 A special specimen preparation is required for cross direction (CD) specimens from rolls of less than 4" in width. Lay two rectangular sample strips on a flat surface wit the adhesive side facing up (see Figure 1). Each strip shall be as wide as the sample roll and approximately 5" in length. Position these strips side by side with one long edge of one strip parallel to and 1.0" separated from one long edge of the second strip.

3.4.3.1 Cut a specimen from the sample roll to have the width specified in Table and length equal to the width of the roll. When identity or material charac terization is of interest, the test should be performed on a specimen cut from within the sample material boundaries using a sharp razor cutter, such as that defined in Appendage B.

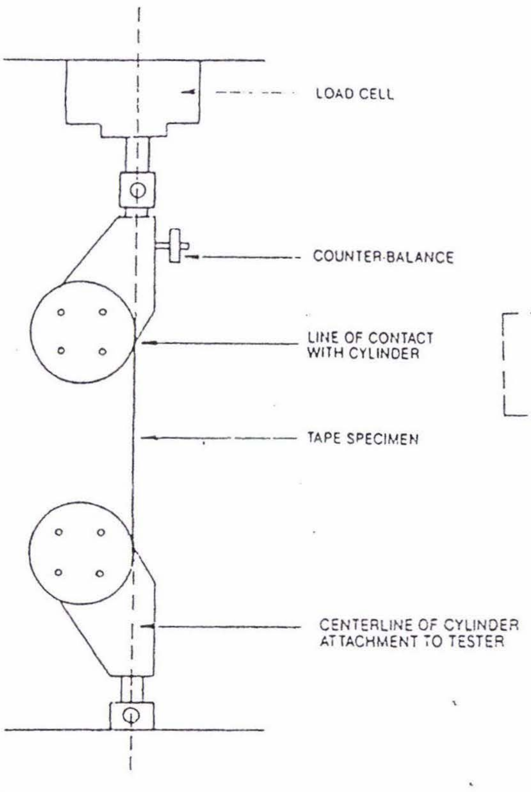


Figure 1

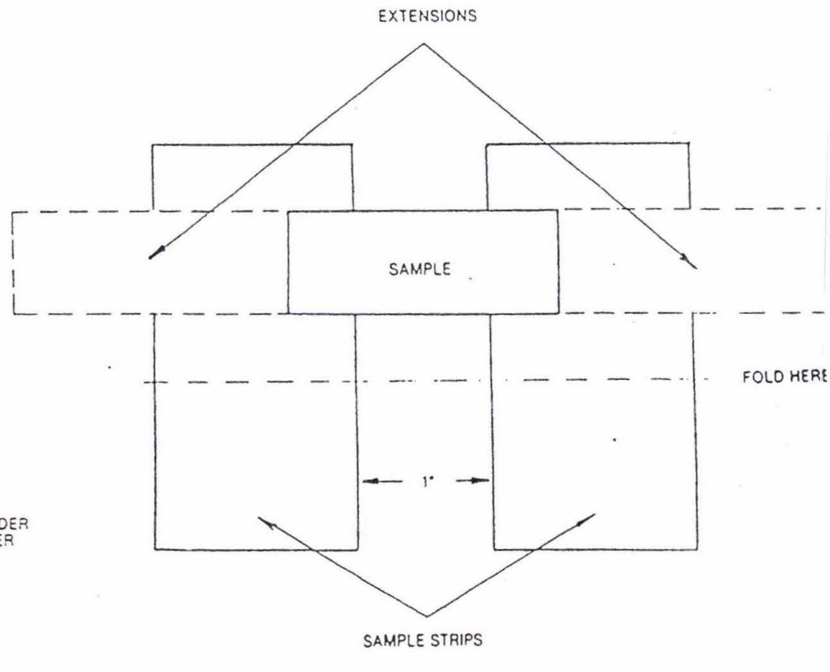


Figure 2

NOTE – Some of the traditional tools for specimen preparation, including chopping dies and sample cutters operating on a shear principle, must be avoided when the backing is composed of thin plastic sheeting. Edges sufficiently ragged and damaged resulting from chopping or shearing cause tearing to occur before the true tensile strength level is reached. Tapes with fibrous backings may be cut to satisfactory specimens with these tools.

3.4.3.2 Lay this specimen adhesive side up across the 1" separation of the strips. Position it toward one end of the sample strips so that it rests equally on both strips and at right angle to their parallel edges.

3.4.3.3 Cut two additional strips from the sample roll having the same width as the specimen. Butt the end of one of these at one end to form a continuation of the specimen across the remainder of the sample strip. Use the second strip to butt against the other end of the specimen in like manner.

3.4.3.4 Fold each of the original sample strips over onto itself to form a three-ply tab that will be gripped by the clamps during the test.

3.4.3.5 Trim off excess (single ply of tape) of either the sample strips or the extension strips extending beyond the two-ply or three-ply parts of the assembly.

NOTE – The extension serves to keep the clamping pressure uniform over the whole area of the specimen. This is an imperative factor to a successful test.

3.5 For reinforced tapes, the specimen requires no further preparation than to have the appropriate dimensions (Table 1) and ensure that the adhesive is not contaminated so it will adhere well to the cylinders.

4. EQUIPMENT

4.1 Tensile tester — A constant-rate-of-extension (CRE) type with load cell capacity such that the maximum expected specimen strength does not exceed 90% of its normal limit.

4.1.1 Test information should be displayed in at least an alphanumeric digital display or a load-elongation curve plotted by a pen or stylus responding to load and with a chart driven synchronously with the crosshead.

4.1.2 Load elongation curve, plotted by a pen or stylus responding to load and with a servo-chart drive or x-y recorder driven by an extensometer.

4.1.3 Clamps, preferably the pneumatic action type.

NOTE – Plastic materials are reduced in width and thickness while being stretched. This causes them to be drawn out of the clamps. Pneumatic clamps minimize this effect. It can be further reduced by the appropriate choice of surface of the clamps. The greatest improvement, both with respect to the above-mentioned shrinkage problem and simple slippage, can be found from the use of urethane film, that can be obtained as a pressure sensitive tape approximately 20 mils thick. This material has a very high coefficient of friction, is somewhat malleable, and is easily replaced. Alternative materials are coated abrasive, rubber (neoprene or other synthetic type), or other tape.

4.1.3.1 Clamp faces at least 2" wide by 1½" deep. Faces shall have a light cross-hatch serration.

4.1.4 Cylinders, in place of clamps for testing reinforced tapes. Each of two cylinders shall be 4" diameter by 1½" thick held in the position ordinarily occupied by the clamps so that the tape, when applied to the cylinders and extending between them, falls in the line of stress otherwise occupied by the specimens when clamps are used (see Figure 1).

4.1.5 Scale, approximately 1" in length divided into 0.1" increments attached to each cylinder. The zero point (origin) shall be at the point of tangency of the tape with the cylinder upward on the lower cylinder and downward on the upper cylinder.

NOTE – These scales will be observed and measure the tape slippage during the tension test for reinforced tapes.

4.2 Cutter — See Appendage B. The razor blades shall be spaced precisely 0.5" apart.

The equipment listed above is available from Chemsultants International, telephone 216/352-0218.

5. TEST METHOD

5.1 Table 1 shows the tension tester settings for use with the specified test categories.

5.2 For testing all reinforced tapes, set the cylinders 6" apart so that at the start of a test, 10" of tape will extend between and without contact with the cylinders.

NOTE – The upper cylinder should be counterbalanced in order that the line of tape contact on the cylinders intersects an imaginary line running between the points of cylinder attachment to the tester and no side forces are exerted during the test (see Figure 1).

5.3 Condition the sample to equilibrium in standard conditions as described in Appendage A for 24 h. Testing shall be performed at the same conditions.

5.4 Nonreinforced tapes: Clamp the specimen in the grips of the testing machine. Take care to align the long axis of the specimen with an imaginary line running between the points of attachment of the grips and including the center of the grips. Apply no more tension to the specimen during clamping than is necessary to remove slack.

NOTE – Elongation measurements become difficult to perform on stretchy materials (greater than 25% ultimate elongation) when the ratio of specimen length to width is small (approaching 2). The results show high variability and do not allow for practical use of this information except when one wishes to demonstrate large differences between materials.

5.4.1 Start the crosshead in motion at the specified velocity (Table 1) and ensure that the mechanism that displays the response (that is charts, plotter, or digital display) is operating. Continue until the specimen ruptures.

5.4.2 Record a numerical display of the results.

5.5 Reinforced tapes: Adhere approximately 9" of the specimen on the upper cylinder beginning at the line of tape contact (see 5.2), and wrap the specimen around the top surface of the cylinder. Repeat this with the free end of the specimen on the lower cylinder, except wrap the specimen around the bottom surface of the cylinder. The applied specimen must be centered on the center line around the cylinder surface. This elimination of skewness prevents nonuniform stress loading across the width of the specimen. The specimen shall also be sufficiently taut to remove slack.

5.5.1 Mark the specimen (and cylinder if not already done) with a marking pen making a line approximately 1/32" wide at the line where the tape contacts each cylinder. These bench marks will be 10" apart and shall be checked to ensure this.

5.5.2 Start the crosshead in motion at the specified velocity and ensure that the response-indicator mechanism is operating to indicate both load and elongation if the latter is required.

5.5.3 Observe the bench marks on the specimen to determine their change in position relative to the marks on the cylinders. Use the scales appended to the cylinders.

5.5.4 When the specimen breaks, record the sum of the upper and lower bench mark changes to the nearest 0.1". This will be the correction for the elongation.

5.5.5 Also record the indicated responses for tensile strength and elongation when the tester provides a numerical display of this information.

6. REPORT

6.1 Calculations:

6.1.1 Tensile strength: When the recorded load-elongation curve results from the testing, calculate tensile strength as follows:

6.1.1.1 Find the furthest advance of the plotting pen or stylus from the origin in the direction representing increasing force. Record this advance as a percentage of the chart scale.

6.1.1.2 Multiply the full-scale load range used during the test by the percentage found in 6.1.1.1.

NOTE – For this calculation, express the percentage as a decimal fraction, that is, use 0.87 for 87%.

6.1.1.3 Convert the value found in 6.1.1.2 to pounds-force per the desired basis of dimension for the final step. For lbf/in. of width, divide by the specimen width in inches.

6.1.2 Ultimate elongation: When the recorded load-elongation curve results from the use of a synchronous chart drive, calculate elongation as follows:

6.1.2.1 Measure the distance from the start of the plot to the indicated breaking point along the motion (time) axis of the chart.

6.1.2.2 When the chart velocity equals the crosshead velocity, the distance from 6.1.2.1 divided by the gauge length and multiplied by 100 equals the ultimate elongation.

6.1.2.3 When the chart and crosshead velocities are different, multiply the calculations completed in 6.1.2.2 by the ratio of the crosshead velocity to the chart velocity to obtain the correct ultimate elongation.

6.1.2.4 When the recorded load-elongation curve results from use of a servo-chart drive or x-y recorder driven by an extensometer, calculate elongation as follows:

6.1.2.4.1 Measure the distance from the start of the plot to the indicated breaking point. Divide this by the magnification ratio (to get the true dimension of elongation). Divide this by the gauge length. Next, multiply by 100 to convert the value to percent ultimate elongation.

NOTE – The magnification ratio is the chart motion over the actual extensometer motion.

6.1.2.5 When testing reinforced tapes, the correction found in 5.5.4 first shall be subtracted from the amount of extension indicated or measured along the time axis of the recording chart and the difference divided by the original gauge length. Multiply this quotient by 100 to convert it into percentage ultimate elongation.

6.1.3 "F" value: When the recorded load-elongation curve results from the use of a synchronous chart drive, calculate the "F" value as follows:

6.1.3.1 Find the chart scale equivalent to the desired elongation point. (If one were determining the F-3 value, that is, the force required to stretch the specimen 3%, one would be finding the chart scale equivalent to 3% elongation). This equivalent is the distance measured from the start of the plot to the prescribed elongation point on the chart. To calculate the distance in terms of the chart scale, use the equation:

$$d = \frac{E \times G \times C}{100(H)}$$

where:

d = chart scale equivalent distance
E = percentage elongation where the "F" value is to be determined
G = gauge length
C = chart velocity, and
H = crosshead velocity

The units of these measurements shall be inches.

6.1.3.2 Using the calculated d, measure along the chart time axis (same as stretch, extension, or elongation axis) from the origin of the recorded plot to a point distance, d. This point shall be at zero force as was the plot origin. Draw a line from this point parallel to the force axis to intersect with the recorded plot. Measure the scale length of this line from zero force and convert this length into percentage of chart scale and then into force. See 6.1.1.1 and 6.1.1.2.

6.1.3.3 Multiply the full-scale load range used during the test by the percentage found in 6.1.3.2. Express the percentage as a decimal fraction. The product is the "F" value in pounds-force for the specimen width.

6.1.3.4 The final step is the same as 6.1.1.3, except substitute 6.1.1.3 for 6.1.1.2.

6.1.3.5 When the recorded load-elongation curve results from the use of a servo-chart drive or x-y recorder driven by an extensometer, calculate the "F" value as follows:

6.1.3.5.1 Find the scale equivalent to the desired elongation point using this equation:

$$d = \frac{E \times G \times M}{100}$$

where:

d = scale equivalent
E = percent elongation where "F" value is to be determined,
G = gauge length, and
M = magnification ratio (6.1.2.4.1).

6.1.3.5.2 Using the calculated value of d from 6.1.2.5.1, perform the steps in 6.1.3.2 and 6.1.3.3.

6.2 Report

6.2.1 Report the tensile strength in pounds-force per inch of width to three significant places.

6.2.2 Report the ultimate elongation in percentage to two significant places.

6.2.3 Report the "F" value in the same manner as the tensile strength (6.2.1).

6.2.4 The following test parameters are to be reported:

6.2.4.1 crosshead velocity,

6.2.4.2 gauge length,

6.2.4.3 specimen width.

6.2.5 When the desired test response includes ultimate elongation, indicate whether slippage of material from within the clamps occurred and estimate the amount.

Another method for determining tensile and elongation of pressure sensitive tape is ASTM D 3759.

Ultimate Tensile/Strain and Enlongation of Tested Tapes

SelloFreeze W=25mm
t=0.045mm Ao=25*0.045 1.125
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	138.39	123.0133333	1.065571429	74.59	106.5571429
2	130.14	115.68	1.345857143	94.21	134.5857143
3	136.26	121.12	1.182714286	82.79	118.2714286
4	134.08	119.1822222	1.357714286	95.04	135.7714286
5	125.65	111.6888889	1.054571429	73.82	105.4571429
Mean Values	**132.90**	118.14	1.20	**84.09**	120.13
Standard Deviation		5.07			

SelloFresh W=25mm
t=0.045mm Ao=25*0.045= 1.125
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	131.6	116.9777778	1.158142857	81.07	115.8142857
2	135.91	120.8088889	1.132428571	79.27	113.2428571
3	137.59	122.3022222	1.178142857	82.47	117.8142857
4	114.04	101.3688889	0.720857143	50.46	72.08571429
5	130.59	116.08	1.076857143	75.38	107.6857143
Mean Values	**129.95**	115.51	1.05	**73.73**	105.33
Standard Deviation		9.36			

SelloOld W=25mm
t=0.043mm Ao=25*0.043= 1.075
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	104.31	97.03255814	0.865857143	60.61	86.58571429
2	124.29	115.6186047	1.251714286	87.62	125.1714286
3	126.3	117.4883721	1.323285714	92.63	132.3285714
4	105.07	97.73953488	0.914	63.98	91.4
5	112.02	104.2046512	0.975	68.25	97.5
Mean Values	**114.40**	106.42	1.07	**74.62**	106.60
Standard Deviation		10.42			

3MColdTemp W=25mm
t=0.043mm Ao=25*0.043= 1.075
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	106.23	98.81860465	0.891142857	62.38	89.11428571
2	131.47	122.2976744	1.417142857	99.2	141.7142857
3	131.51	122.3348837	1.382714286	96.79	138.2714286
4	133.33	124.027907	1.451857143	101.63	145.1857143
5	139.4	129.6744186	1.451285714	101.59	145.1285714
Mean Values	**128.39**	119.43	1.32	**92.32**	131.88
Standard Deviation		12.81			

3MMed W=25mm
t=0.045mm Ao=25*0.045= 1.125
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	108.75	96.66666667	1.066428571	74.65	106.6428571
2	107.99	95.99111111	0.994285714	69.6	99.42857143
3	129.96	115.52	1.406428571	98.45	140.6428571
4	133.74	118.88	1.474428571	103.21	147.4428571
5	130.89	116.3466667	1.475285714	103.27	147.5285714
Mean Values	**122.27**	108.68	1.28	**89.84**	128.34
Standard Deviation		12.76			

3MOld W=25mm
t=0.047mm Ao=25*0.047= 1.175
lo=70mm

Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	131.4	111.8297872	0.994285714	69.6	99.42857143
2	131.18	111.6425532	0.937428571	65.62	93.74285714
3	136.85	116.4680851	1.206428571	84.45	120.6428571
4	137.01	116.6042553	1.275	89.25	127.5
5	120.34	102.4170213	0.937428571	65.62	93.74285714
Mean Values	**131.36**	111.79	1.07	**74.91**	107.01
Standard Deviation		6.77			

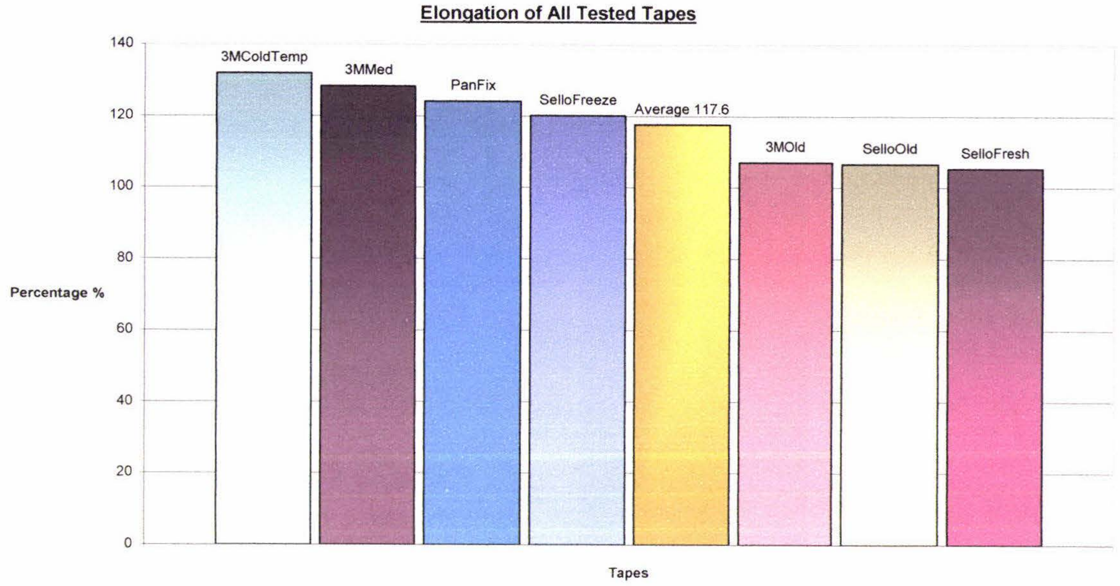
PanFix W=25mm
t=0.045mm Ao=25*0.045= 1.125
lo=70mm

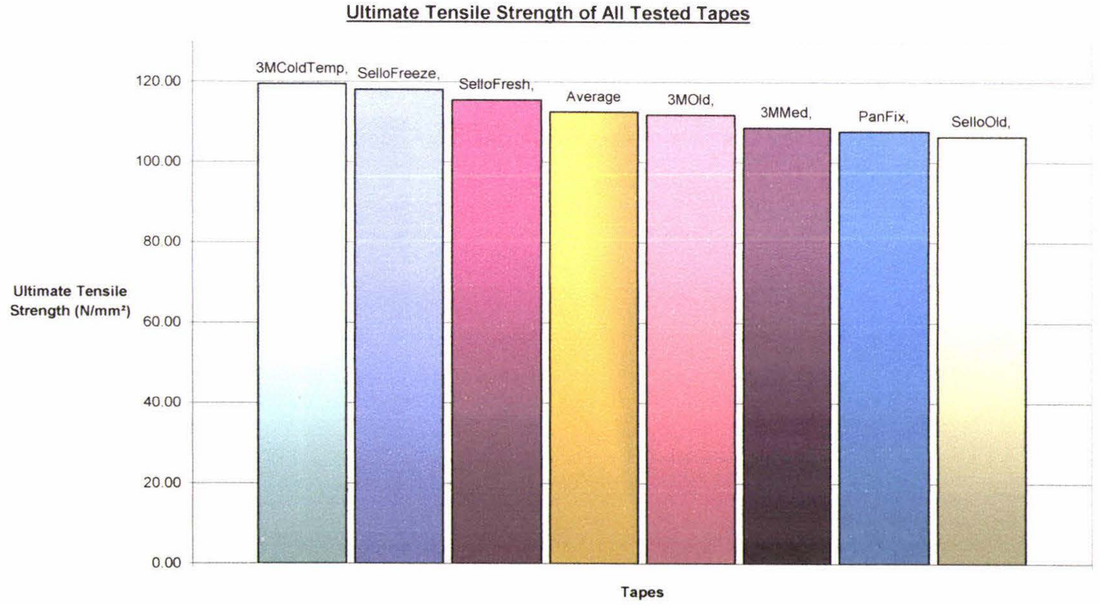
Sample No.	Force (N)	Ots (N/mm²)	En (Strain)	Extention at break (mm)	% Elongation
1	121.64	108.1244444	1.193857143	83.57	119.3857143
2	114.55	101.8222222	1.031428571	72.2	103.1428571
3	109.82	97.61777778	1.266	88.62	126.6
4	131.76	117.12	1.357285714	95.01	135.7285714
5	128.13	113.8933333	1.357428571	95.02	135.7428571
Mean Values	**121.18**	107.72	1.24	**86.88**	124.12
Standard Deviation		9.13			

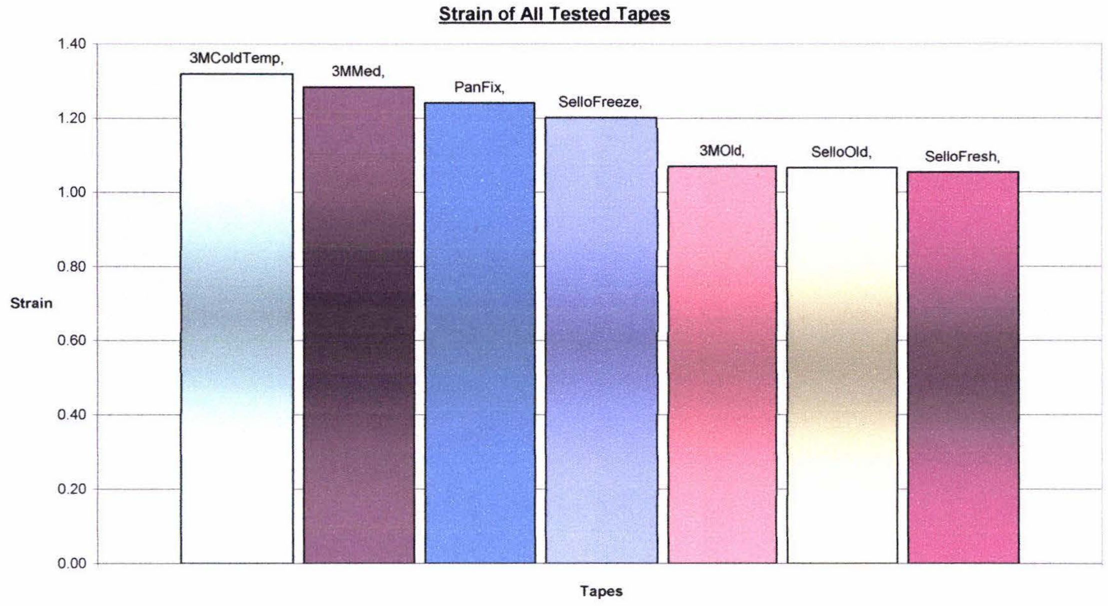
Key
W= Width
t= Thickness
lo= Length
Ao= Area

Elongation Average	117.6
UTS Average (N/mm²)	112.5

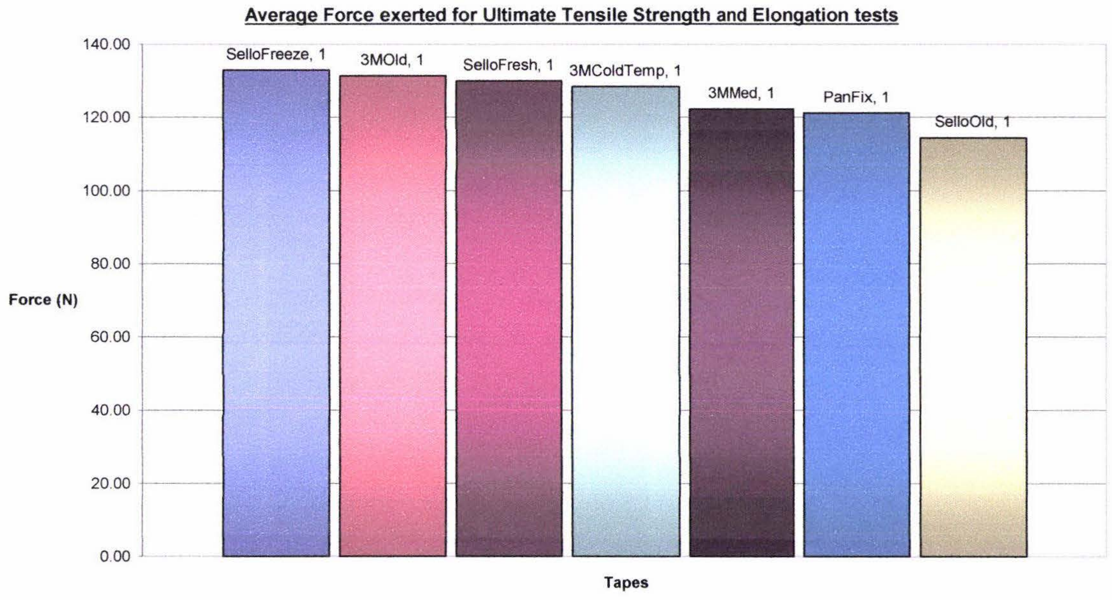
B.13


Elongation of All Tested Tapes
140
120
100
80
60
40
20
0
Percentage %
3MColdTemp
3MMed
PanFix
SelloFreeze
Average 117.6
3MOld
SelloOld
SelloFresh
Tapes


Ultimate Tensile Strength of All Tested Tapes
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Ultimate Tensile Strength (N/mm²)
3MColdTemp,
SelloFreeze,
SelloFresh,
Average
3MOld,
3MMed,
PanFix,
SelloOld,
Tapes



Strain of All Tested Tapes
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Strain
3MColdTemp,
3MMed,
PanFix,
SelloFreeze,
3MOld,
SelloOld,
SelloFresh,
Tapes



Average Force exerted for Ultimate Tensile Strength and Elongation tests
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Force (N)
SelloFreeze, 1
3MOld, 1
SelloFresh, 1
3MColdTemp, 1
3MMed, 1
PanFix, 1
SelloOld, 1
Tapes

C.1

ROLLING BALL TACK METHOD

Equipment: Metal ramp and metal balls as per PSTC method 6
(metal balls are to be stored in acetone when not in use)
Rule to measure to the nearest 1 mm

1. Remove 2 to 3 layers of tape from the outside of the roll.
2. Tape the end of the roll to the bench so that the adhesive is face up.
3. Pull tape off the roll so that there is a length of tape approximately 2m long and face up. Cut this length from the roll and tape the free end of it to the bench.
4. Remove a metal ball from the acetone and wipe it dry.
5. Position the ramp at one end of the strip of tape so that when the ball is released it will roll lengthwise along the strip of tape.
6. Release the ball, and record the distance it rolls in mm (the distance from the centre of the ball to the edge of the ramp).
7. Move the ramp along the tape and take a further reading, repeat until five readings have been obtained.
8. Report the final result as the average of the five readings to the nearest mm.

C.2

Call Letters	PSTC-6
Date of Issuance	10/64
Revised	11/70
Revised	8/85
Revised	2/89
Revised	8/89

Tack Rolling Ball

1. DEFINITION

   1.1 The rolling ball tack test is one measure of the capacity of the adhesive to form a bond with the surface of another material upon brief contact under virtually no pressure.

2. SIGNIFICANCE

   2.1 The rolling ball tack test is one method of attempting to quantify the ability of an adhesive to adhere quickly to another surface.

3. TEST SPECIMEN

   3.1 For test specimen conditioning, selection, and test conditions, see Appendages A & D.

   3.2 The test specimen shall be 2" wide by approximately 15" long.

4. EQUIPMENT

   4.1 Rolling ball test apparatus. See Appendage B. See Figure 1.

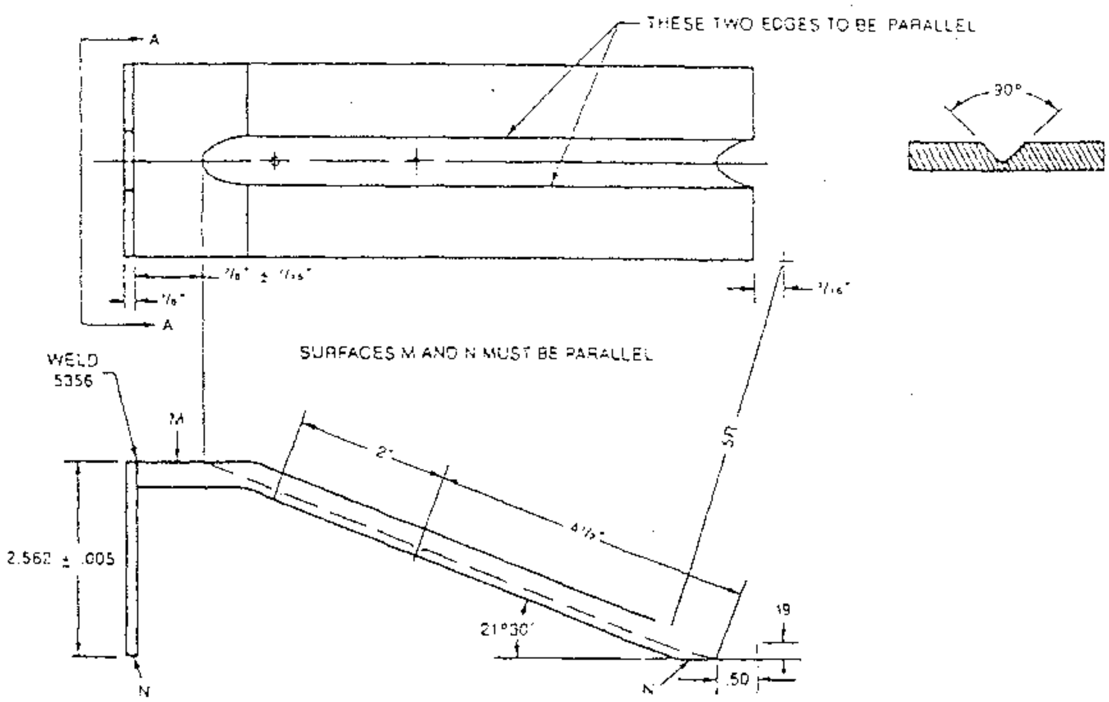


Figure 1. Incline for adhesion test.

   4.2 A steel ball, $\frac{7}{16}$" in diameter, such as a standard type ball bearing.

   4.3 A working surface that is level, hard, and smooth, such as a table top, plate glass, etc.

   The equipment listed above is available from Chemsultants International, telephone 216/352-0218.

5. **TEST METHOD**

5.1 Prior to testing each lot of tape, thoroughly clean the raceway surface with n-heptane, methyl ethyl ketone, isopropyl alcohol, or methyl alcohol. Prior to each roll of the ball, thoroughly clean the ball with the same solvent. Wipe with a lint-free, bleached, absorbent material to remove any remaining residue. After cleaning, do not touch the raceway or ball with fingers.

5.2 Arrange a specimen just removed from the roll adhesive side up in line with the raceway of the incline as shown in the illustration so that the tape specimen shall be free of any wrinkles, creases, or splices. The end of the tape opposite the incline shall be held to the table with a weight or with other tape. If sides of the tape have a tendency to lift or curl, they shall be held securely to the table with tape. Using clean, dry tongs, place the ball on the upper side of the release. Release the ball and allow it to roll to a stop on the adhesive. Measure the distance from the point where the ball initially contacts the adhesive to where the ball is in contact when it stops as shown in Figure 2.

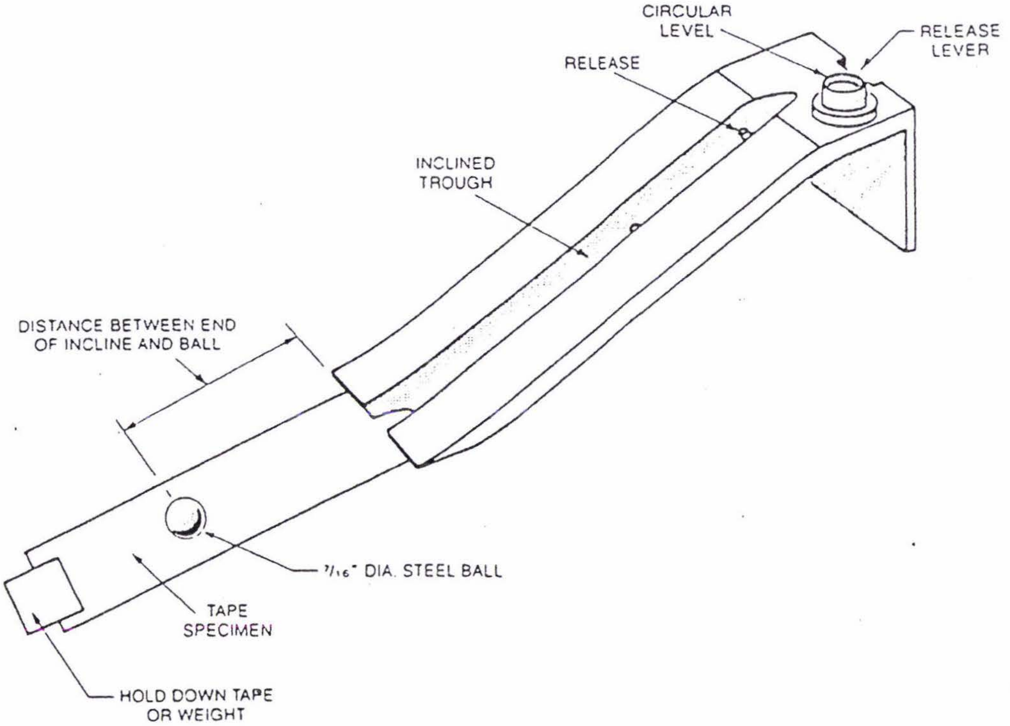


Figure 2
Adhesion test apparatus and specimen showing distance of roll that is measured.

6. **REPORT**

6.1 The average of the stopping distance measurements shall be reported in inches. Five tests shall determine the average. A fresh strip of tape shall be used to begin each test, and the ball should be cleaned after each roll in accord with the cleansing procedure outlined in Paragraph 5.1.

Another method for measuring tack rolling ball is ASTM D 3121.

TACK

BRAND	*DISTANCE (mm)*					*AVERAGE (mm)*
	1	2	3	4	5	
Sellotape Freezer Grade	39	37	39	28	26	**34**
Sellotape Cheap	6	23	13	15	12	**14**
Sellotape Old Age	25	5	20	9	25	**17**
3M Freezer Grade	55	45	37	25	23	**37**
3M Medium Age	197	100	240	220	129	**177**
3M Old Age	26	32	32	45	12	**29**
Panfix	77	26	10	22	30	**33**

ORDER OF STICKEST!

Sellotape Cheap
Sellotape Old Age
3M Old Age
Panfix
Sellotape Freezer Grade
3M Freezer Grade
3M Medium Age

C.4

BOX TEST METHOD

Equipment: 1 new CT 14 box
Razor blade
Masking Tape
25mm cutter
2 x 5 kg sandbags
Pole and mounted wall brackets

1. Label the box with the tape type and batch date (eg. 1554 6.10.00). Also note the date and time of test on the box. Start this test on a Monday, Tuesday, or Friday so it doesn't need to be read at the weekend.

2. Assemble the box using 4 small pieces of masking tape, ensuring they are at least 2 cm away from the centre join.

3. The tape to be tested must be at least 24 mm wide. If it is wider, slice a 25mm strip of tape.

4. Apply the tape to the bottom end of the box and at least 5 cm up the sides. Make sure the tape has stuck to the box.

5. At both ends:- Rule a line across the side of the box at the following points, (measuring from the bottom of the box) 42 mm, 115 mm, and 140mm.

6. Slice gently through the tape at 42 mm. Slice right through the box at 115 mm, and 140 mm, covering approximately 12 cm in the centre of the box, then slice vertically between the two. Press the cardboard inwards to make handles. Also slice through the masking tape.

7. Place the two sandbags in the box and suspend from the pole, between the two wall brackets.

8. Check the box daily if possible. The tape has failed the test if the sandbags fall through the bottom of the box before the specified number of days for that tape type, are up.

9. Take the test down after 3 days, and record the result eg. Pass 3 days, Pass 2 days, Pass 1 day, or Fail 1 day.

10. Dispose of the used box in the appropriate container in the slitting room.

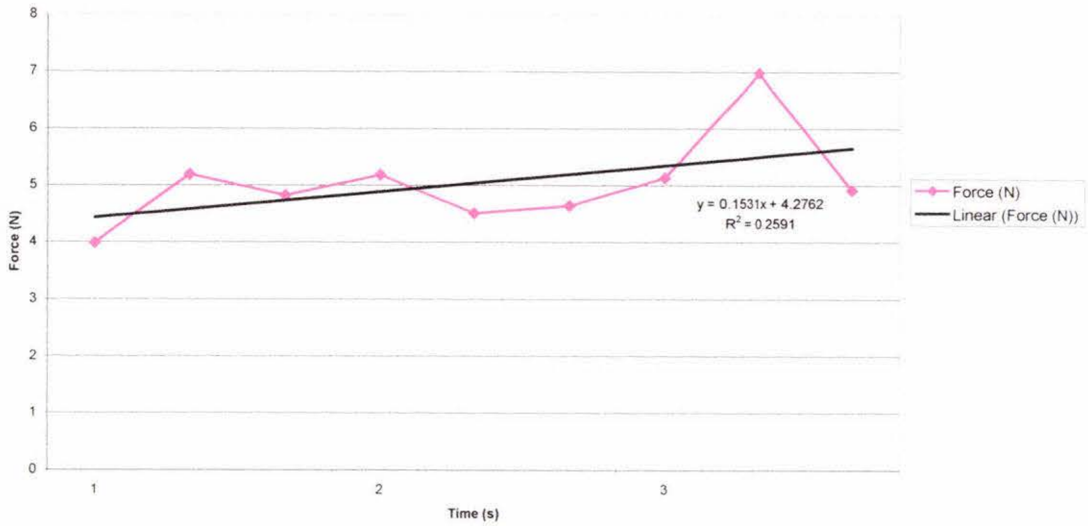
D.1

	Factors		
Storage	Freezer	Chilller	R.T.
	1	0	-1
Hot Gun Temp (oC)	55oC	70oC	130oC
	1	0	-1
Time of Treatment (s)	1	2	3
	1	0	-1
	Storage	Heat Temp	Time
	1	1	1
	0	1	1
	-1	1	1
	1	0	1
	0	0	1
	-1	0	1
	1	-1	0
	0	-1	0
	-1	-1	0
	1	1	0
	0	1	0
	-1	1	0
	1	0	-1
	0	0	-1
	-1	0	-1
	1	-1	-1
	0	-1	-1
	-1	-1	-1
	Freezer		
	1	1	1
	1	1	0
	1	1	-1
	1	0	1
	1	0	0
	1	0	-1
	1	-1	1
	1	-1	0
	1	-1	-1
	Chiller		
	0	1	1
	0	1	0
	0	1	-1
	0	0	1
	0	0	0
	0	0	-1
	0	-1	1
	0	-1	0
	0	-1	-1
	R.T.		
	-1	1	1
	-1	1	0
	-1	1	-1
	-1	0	1
	-1	0	0
	-1	0	-1
	-1	-1	1
	-1	-1	0
	-1	-1	-1

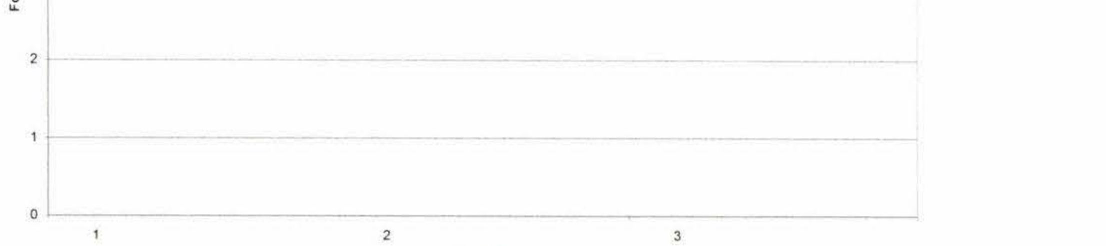
In Freezer at -18oC

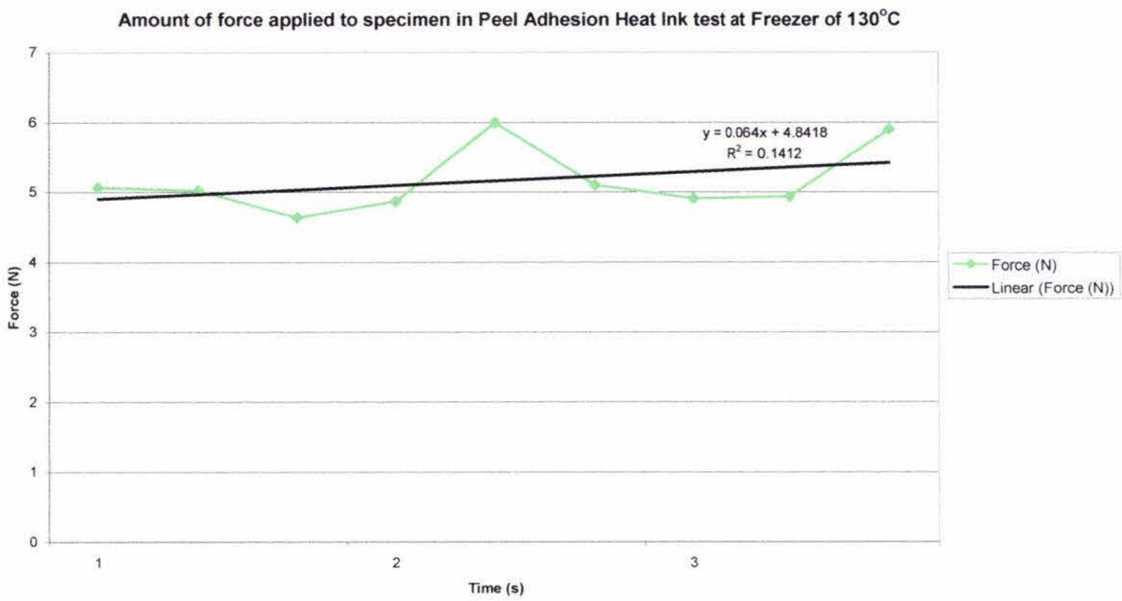
Temp (oC)	Time (s)	Number	Force (N)	Board Thickness (mm) 1	2	3	Av	Torn Board Thickness (mm) 1	2	3	Av	Amount Fibre Torn	Torn Av (mm)	Force Av (N)	Standard Deviation of Force
55	1	1	3.984	3.14	3.14	3.188	3.156	2.988	3.1	3.035	3.041	0.115	0.114	4.666	0.62
55	1	2	5.191	3.146	3.156	3.135	3.146	3.038	3.035	2.937	3.003	0.142			
55	1	3	4.824	3.107	3.472	3.0262	3.202	3.295	3.104	2.948	3.116	0.086			
55	2	1	5.186	3.135	3.191	3.144	3.157	3.174	3.195	3.085	3.151	0.005	0.102	4.781	0.36
55	2	2	4.512	3.097	3.106	3.051	3.085	2.927	2.914	3.085	2.975	0.109			
55	2	3	4.644	3.364	3.42	3.411	3.398	3.288	3.12	3.21	3.206	0.192			
55	3	1	5.137	3.205	3.34	3.062	3.202	3.293	3.203	3.028	3.175	0.028	0.104	5.678	1.13
55	3	2	6.98	3.216	3.131	3.177	3.175	3.163	3.12	3.166	3.150	0.025			
55	3	3	4.918	3.312	3.385	3.312	3.336	3.081	3.091	3.057	3.076	0.260			
70	1	1	5.515	3.275	3.283	3.092	3.217	3.075	3.051	3.102	3.076	0.141	0.110	5.438	0.22
70	1	2	5.613	3.154	3.127	3.103	3.128	3.041	2.984	3.07	3.032	0.096			
70	1	3	5.187	3.268	3.177	3.118	3.188	3.08	3.098	3.11	3.096	0.092			
70	2	1	4.723	3.237	3.238	3.251	3.242	3.126	3.188	3.114	3.143	0.099	0.103	4.683	0.16
70	2	2	4.503	3.166	3.209	3.183	3.186	3.145	3.075	3.045	3.088	0.098			
70	2	3	4.824	3.144	3.093	3.066	3.101	3.002	2.949	3.012	2.988	0.113			
70	3	1	4.811	3.175	3.229	3.099	3.168	2.997	3.022	3.032	3.017	0.151	0.102	4.911	0.26
70	3	2	4.715	3.201	3.157	3.196	3.185	3.142	3.05	3.146	3.113	0.072			
70	3	3	5.207	3.152	3.122	3.143	3.139	2.985	3.12	3.061	3.055	0.084			
130	1	1	5.068	2.955	3.113	3.146	3.071	2.958	2.933	2.898	2.930	0.142	0.128	4.912	0.24
130	1	2	5.026	3.444	3.073	3.148	3.222	3.103	3.058	3.088	3.083	0.139			
130	1	3	4.641	3.116	3.091	3.08	3.096	3.012	2.981	2.983	2.992	0.104			
130	2	1	4.871	3.281	3.232	3.022	3.178	2.966	3.056	2.974	2.999	0.180	0.068	5.324	0.59
130	2	2	5.996	3.201	3.049	3.21	3.153	3.168	3.17	3.065	3.134	0.019			
130	2	3	5.104	3.113	3.126	3.055	3.098	3.09	3.147	3.04	3.092	0.006			
130	3	1	4.914	3.185	3.126	3.119	3.143	3.069	2.972	2.999	3.013	0.130	0.115	5.250	0.56
130	3	2	4.936	3.058	3.091	3.037	3.062	2.949	3.024	2.965	2.979	0.083			
130	3	3	5.901	3.156	3.061	3.022	3.080	2.949	2.928	2.964	2.947	0.133			

Amount of force applied to specimen in Peel Adhesion Heat Ink test at Freezer of 55°C

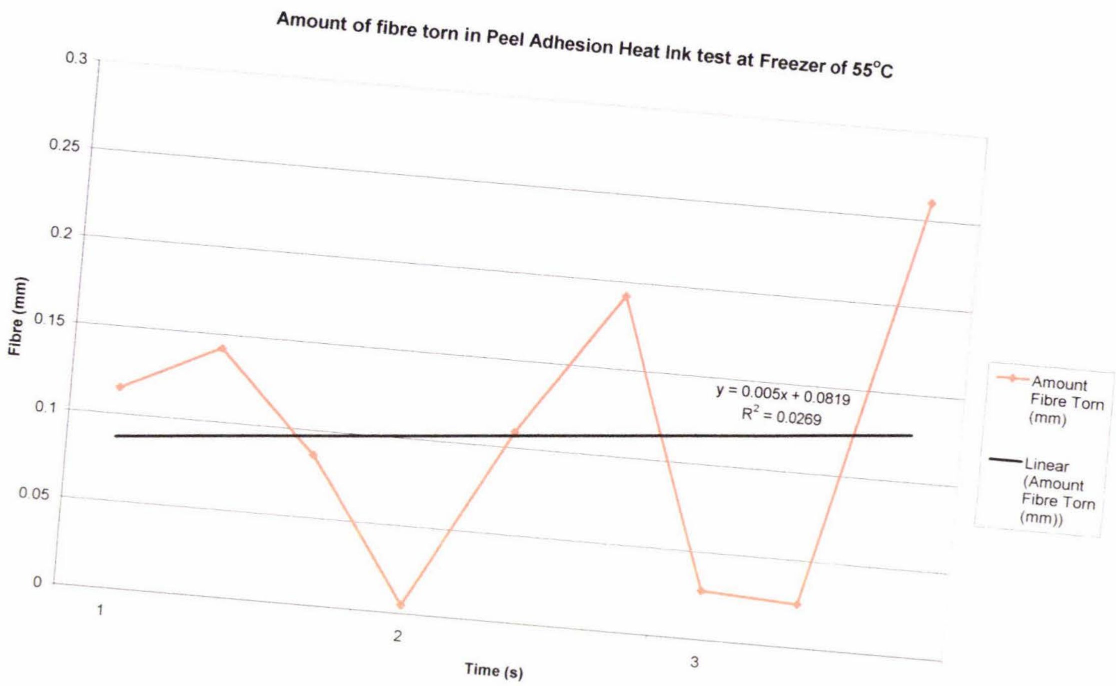


Amount of force applied to specimen in Peel Adhesion Heat Ink test at Freezer of 70°C

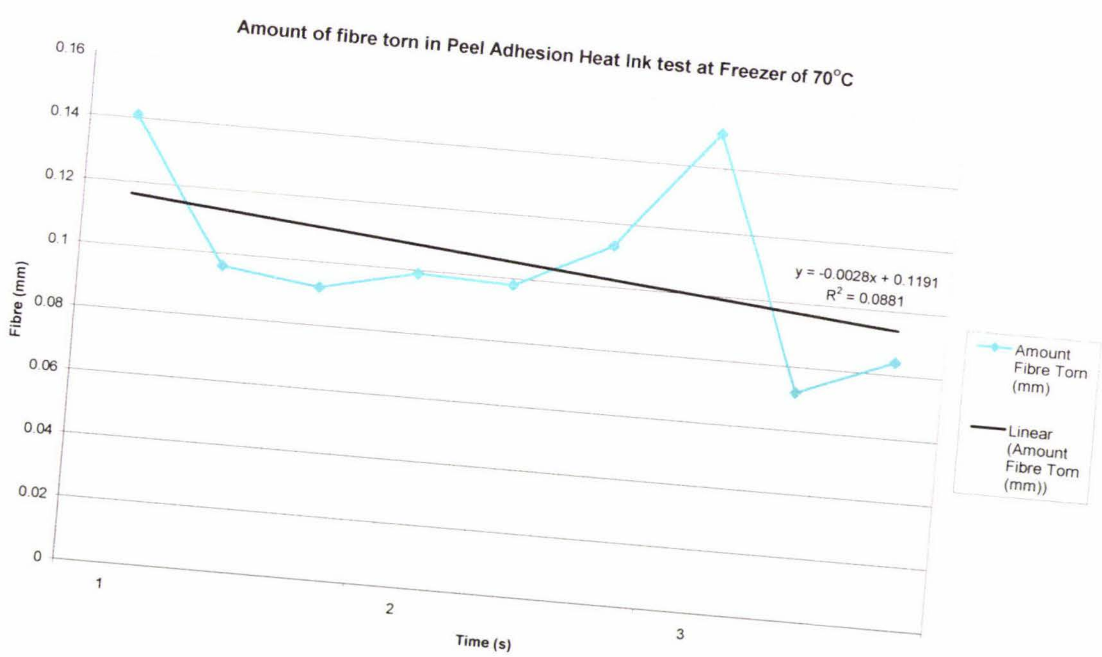




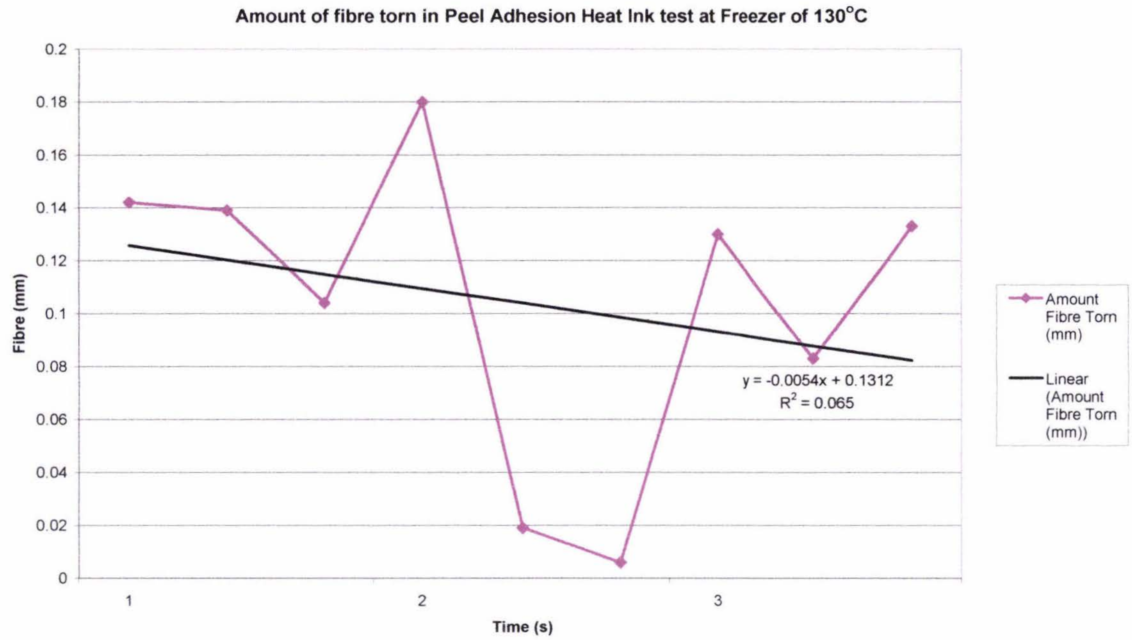
Amount of force applied to specimen in Peel Adhesion Heat Ink test at Freezer of 130°C
y = 0.064x + 4.8418
R² = 0.1412
Force (N)
Time (s)
Force (N)
Linear (Force (N))
0
1
2
3
4
5
6
7
1
2
3



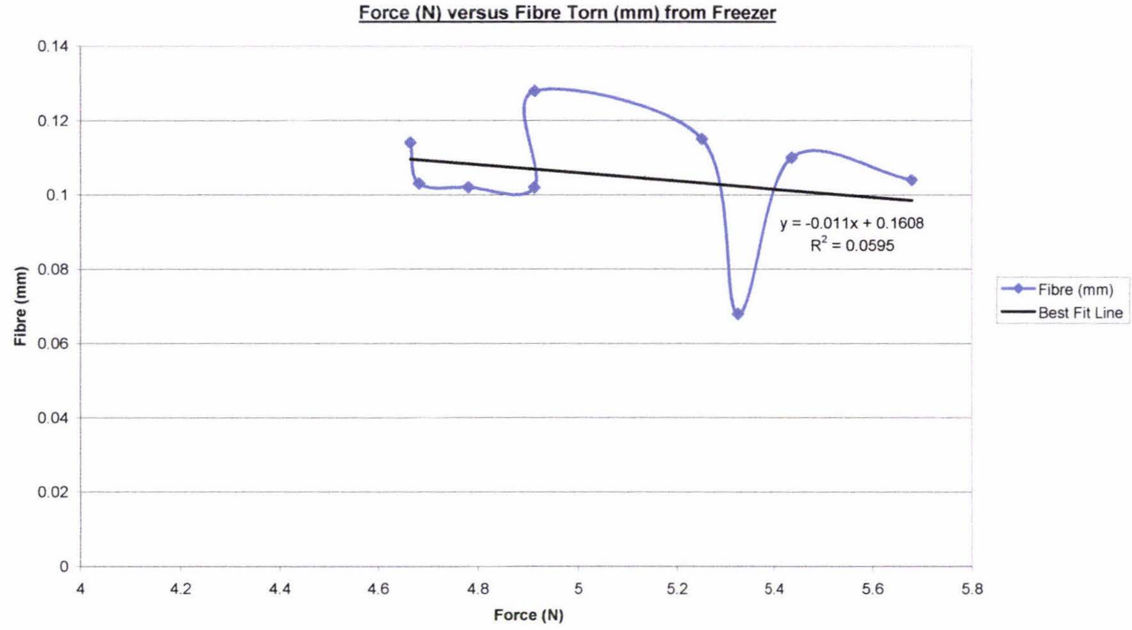
Amount of fibre torn in Peel Adhesion Heat Ink test at Freezer of 55°C
0.3
0.25
0.2
0.15
0.1
0.05
0
Fibre (mm)
1
2
3
Time (s)
y = 0.005x + 0.0819
R² = 0.0269
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))



Amount of fibre torn in Peel Adhesion Heat Ink test at Freezer of 70°C
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Fibre (mm)
1
2
3
Time (s)
y = -0.0028x + 0.1191
R² = 0.0881
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))



Amount of fibre torn in Peel Adhesion Heat Ink test at Freezer of 130°C
Fibre (mm)
Time (s)
y = -0.0054x + 0.1312
R2 = 0.065
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))

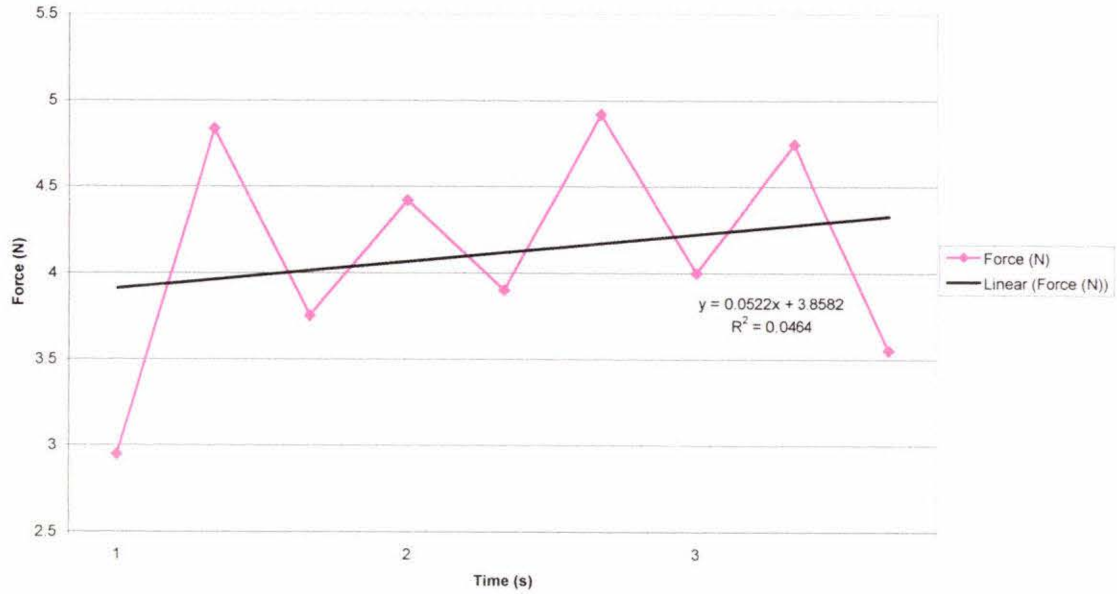


Force (N) versus Fibre Torn (mm) from Freezer
Fibre (mm)
Force (N)
y = -0.011x + 0.1608
R2 = 0.0595
Fibre (mm)
Best Fit Line

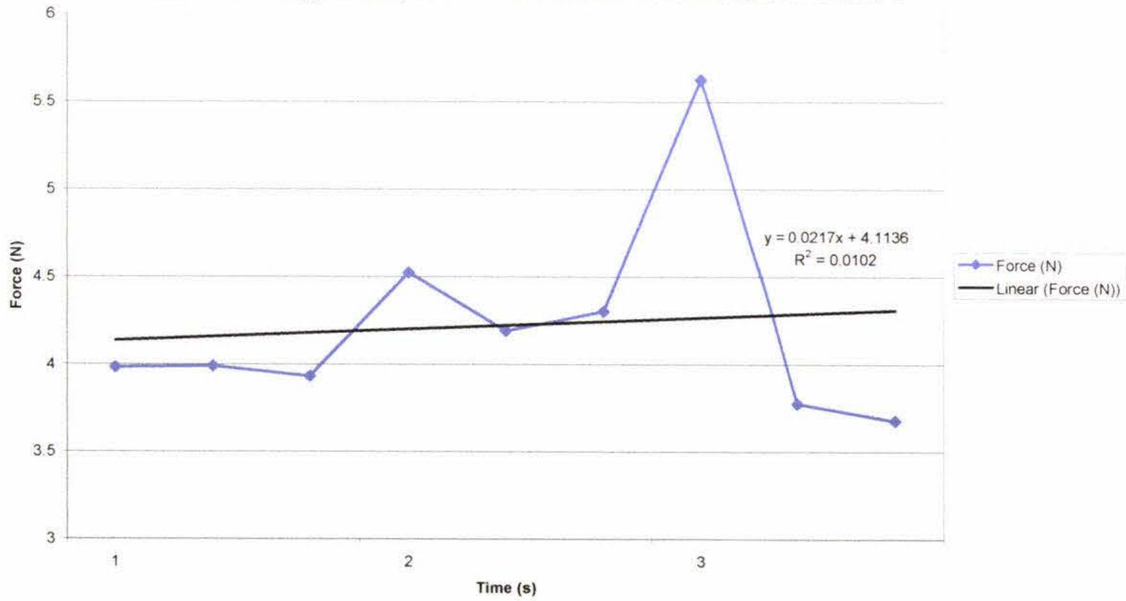
In Chiller at -3.2oC

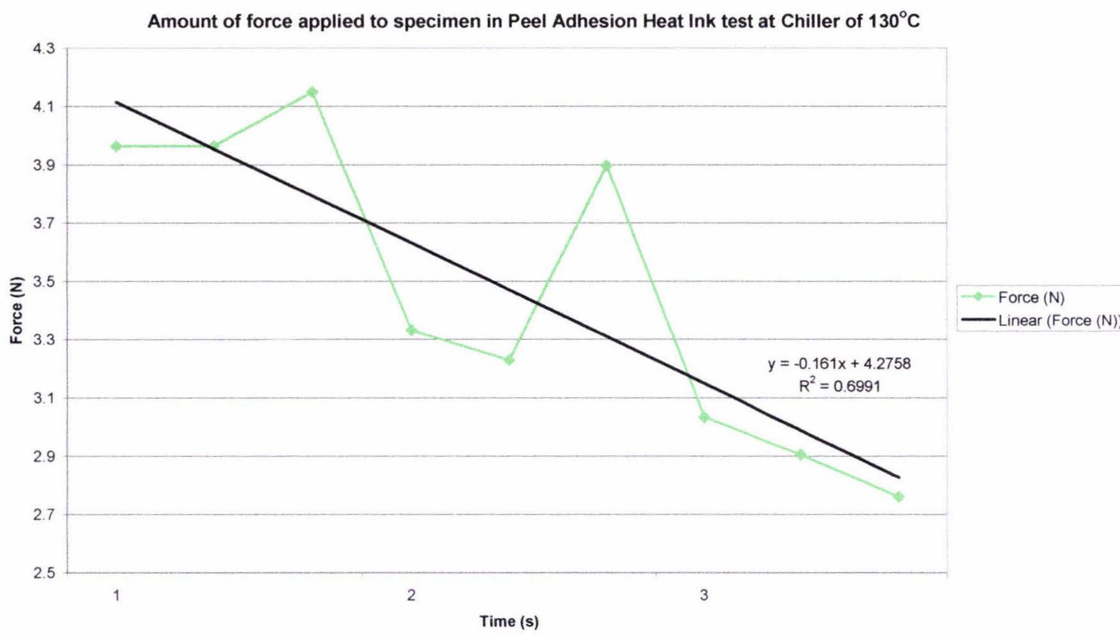
Temp (oC)	Time (s)	Number	Force (N)	Board Thickness (mm) 1	2	3	Av	Torn Board Thickness (mm) 1	2	3	Av	Amount Fibre Torn	Torn Av (mm)	Force Av (N)	Standard Deviation of Force
55	1	1	2.949	3.15	3.228	3.289	3.222	2.888	2.809	2.758	2.818	0.404	0.200	3.845	0.95
55	1	2	4.835	3.229	3.188	2.996	3.138	3.039	3.08	2.918	3.012	0.125			
55	1	3	3.752	3.095	3.113	3.148	3.119	2.983	3.122	3.038	3.048	0.071			
55	2	1	4.421	3.148	3.138	3.208	3.165	2.868	3.028	3.11	3.002	0.163	0.175	4.414	0.51
55	2	2	3.901	3.138	3.158	3.218	3.171	2.978	3.099	3.008	3.028	0.143			
55	2	3	4.92	3.159	3.239	3.248	3.215	2.954	2.966	3.069	2.996	0.219			
55	3	1	3.999	3.089	3.199	3.132	3.140	2.925	3	3.032	2.986	0.154	0.147	4.099	0.60
55	3	2	4.746	3.018	3.128	3.126	3.091	2.966	2.935	2.931	2.944	0.147			
55	3	3	3.551	3.088	3.157	3.081	3.109	2.962	2.938	3.005	2.968	0.140			
70	1	1	3.983	3.116	3.212	3.283	3.204	2.999	2.986	2.999	2.995	0.209	0.158	3.968	0.03
70	1	2	3.989	2.965	3.12	3.161	3.082	2.857	2.948	2.937	2.914	0.168			
70	1	3	3.931	3.213	3.34	3.099	3.217	3.109	3.158	3.096	3.121	0.096			
70	2	1	4.523	3.238	3.272	3.208	3.239	3.17	3.164	3.089	3.141	0.098	0.118	4.339	0.17
70	2	2	4.191	3.124	3.209	3.114	3.149	3.033	2.968	2.999	3.000	0.149			
70	2	3	4.303	2.829	3.018	3.077	2.975	2.874	2.805	2.923	2.867	0.107			
70	3	1	5.627	2.881	3.038	3.168	3.029	2.823	2.868	2.853	2.848	0.181	0.194	4.359	1.10
70	3	2	3.774	3.431	3.176	3.117	3.241	2.87	2.978	3.092	2.980	0.261			
70	3	3	3.676	3.158	3.098	3.078	3.111	2.853	3.044	3.022	2.973	0.138			
130	1	1	3.964	3.189	3.109	3.178	3.159	2.937	3.078	2.968	2.994	0.164	0.182	4.026	0.11
130	1	2	3.965	3.193	3.169	3.299	3.220	2.994	3.018	3.052	3.021	0.199			
130	1	3	4.15	3.169	3.209	3.25	3.209	3.032	3.127	2.925	3.028	0.181			
130	2	1	3.332	3.199	3.263	3.168	3.210	3.027	3.186	3.22	3.144	0.066	0.081	3.486	0.36
130	2	2	3.229	3.248	3.228	3.19	3.222	3.196	3.108	3.302	3.202	0.020			
130	2	3	3.898	3.251	3.196	3.161	3.203	3.116	3.068	2.952	3.045	0.157			
130	3	1	3.034	3.189	3.248	3.14	3.192	3.166	3.177	3.145	3.163	0.030	0.153	2.900	0.14
130	3	2	2.906	3.299	3.246	3.3	3.282	2.946	3.062	3.128	3.045	0.236			
130	3	3	2.76	3.197	3.133	3.238	3.189	2.88	3.07	3.04	2.997	0.193			

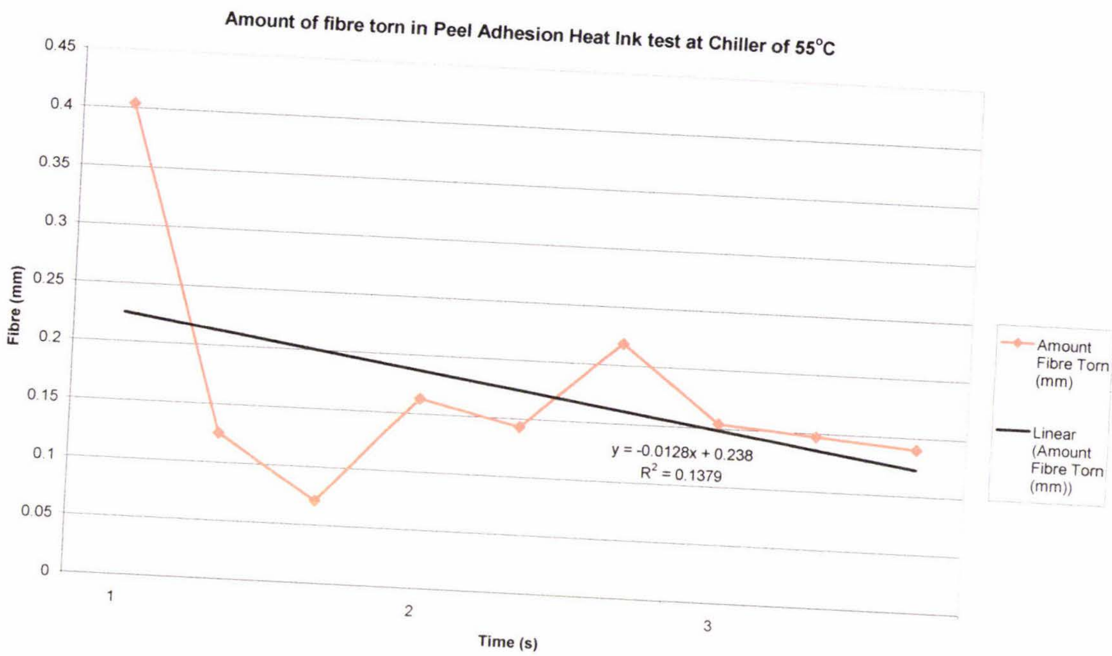
Amount of force applied to specimen in Peel Adhesion Heat Ink test at Chiller of 55°C

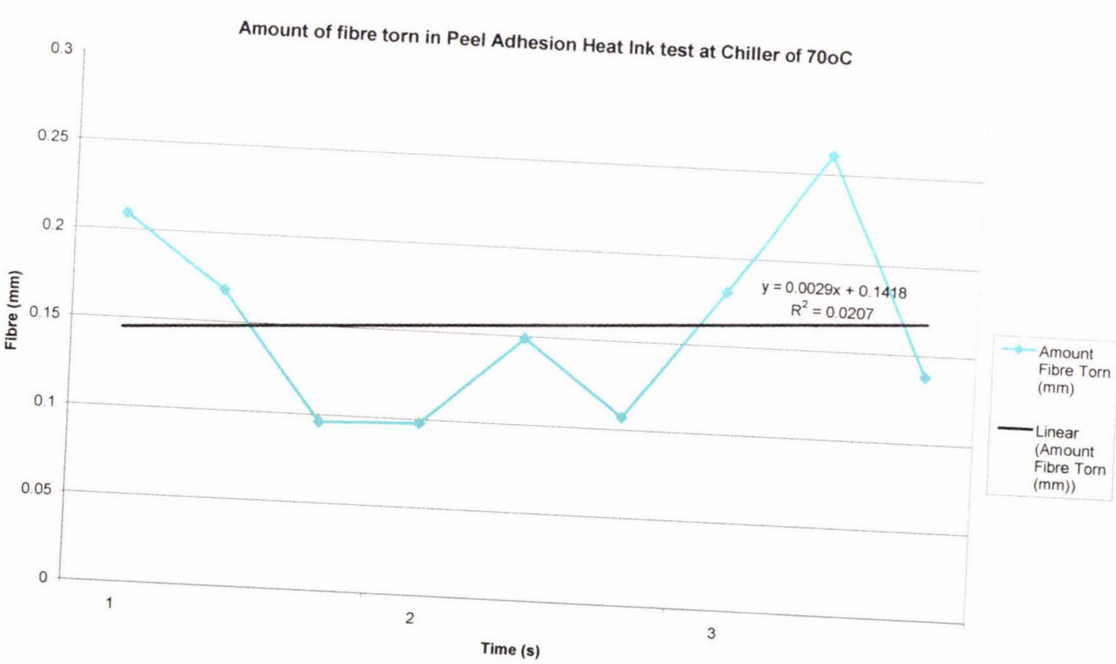


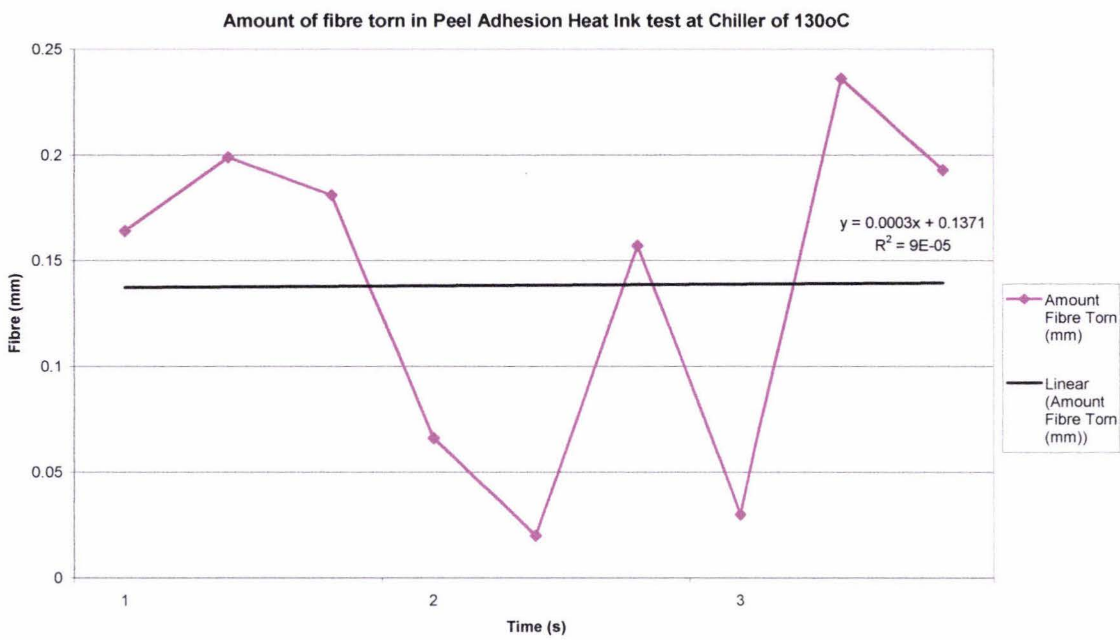
Amount of force applied to specimen in Peel Adhesion Heat Ink test at Chiller of 70°C



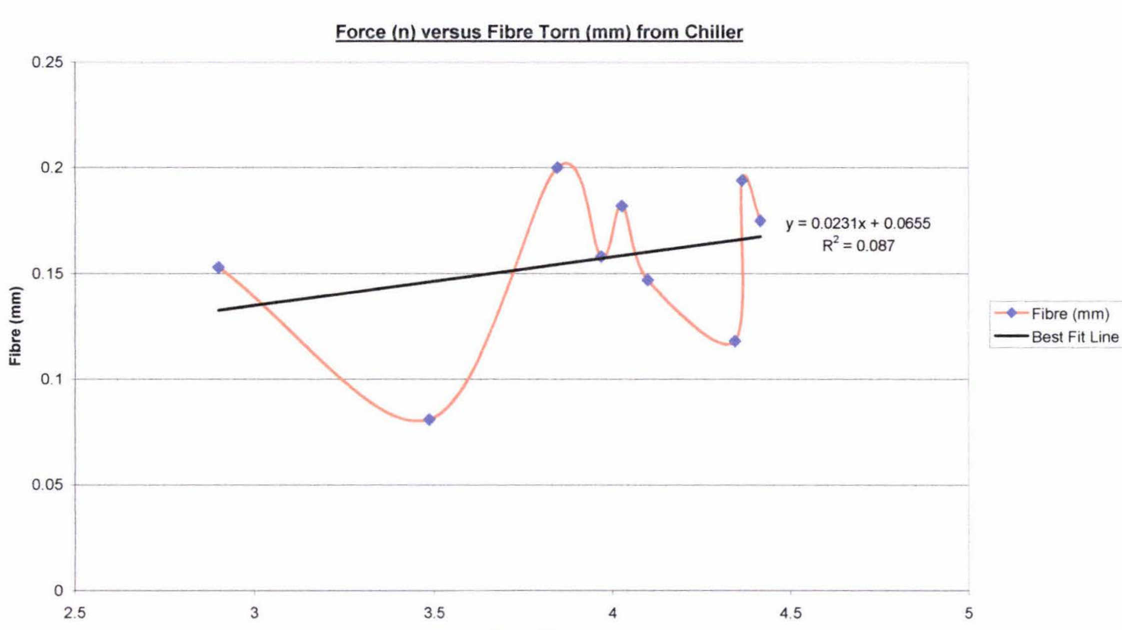

Amount of force applied to specimen in Peel Adhesion Heat Ink test at Chiller of 130°C
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
Force (N)
1
2
3
Time (s)
Force (N)
Linear (Force (N))
y = -0.161x + 4.2758
R2 = 0.6991


Amount of fibre torn in Peel Adhesion Heat Ink test at Chiller of 55°C
Fibre (mm)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Time (s)
1
2
3
y = -0.0128x + 0.238
R2 = 0.1379
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))

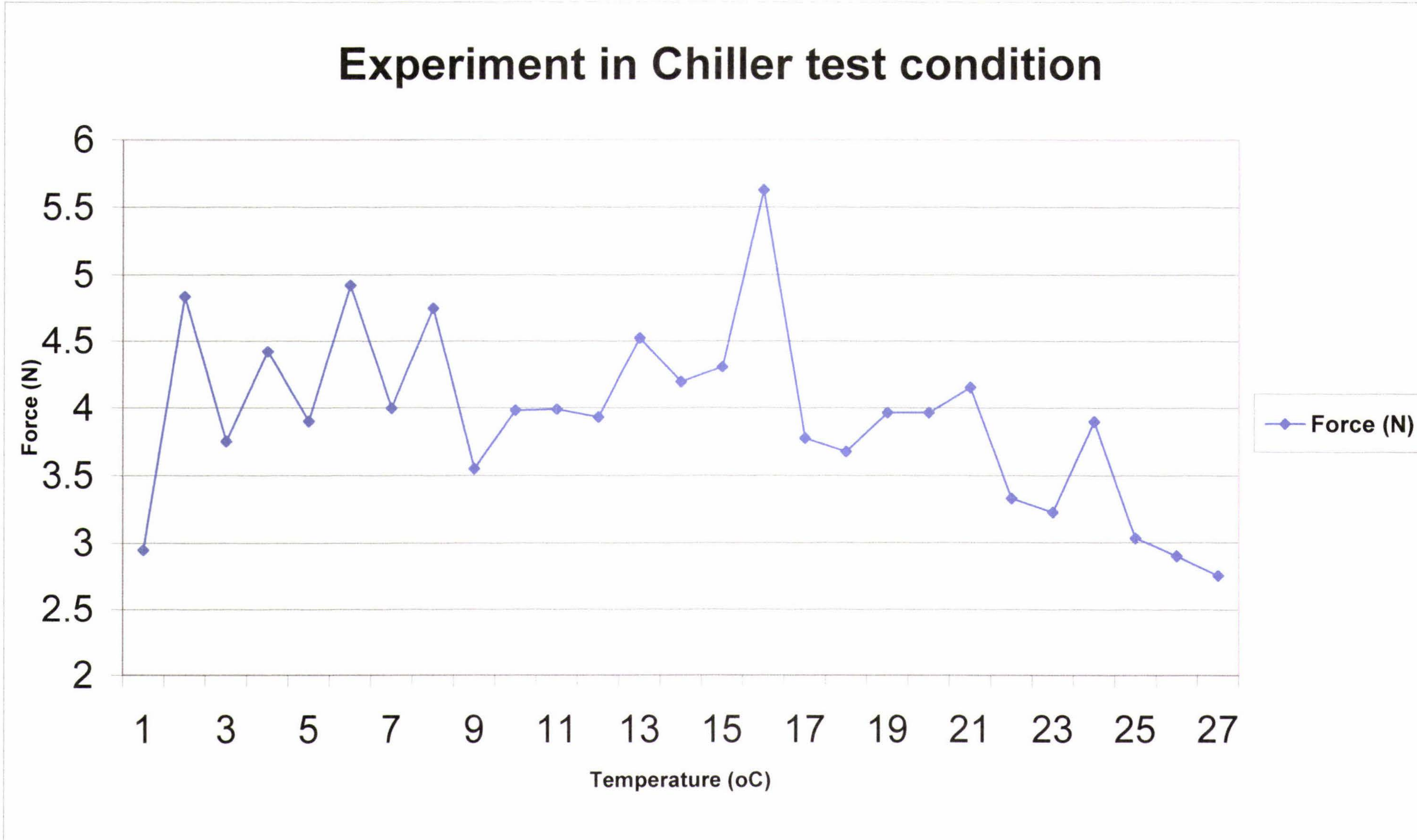

Amount of fibre torn in Peel Adhesion Heat Ink test at Chiller of 70oC
Fibre (mm)
0.3
0.25
0.2
0.15
0.1
0.05
0
Time (s)
1
2
3
y = 0.0029x + 0.1418
R2 = 0.0207
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))



Amount of fibre torn in Peel Adhesion Heat Ink test at Chiller of 130oC
Fibre (mm)
0.25
0.2
0.15
0.1
0.05
0
1
2
3
Time (s)
y = 0.0003x + 0.1371
R2 = 9E-05
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))

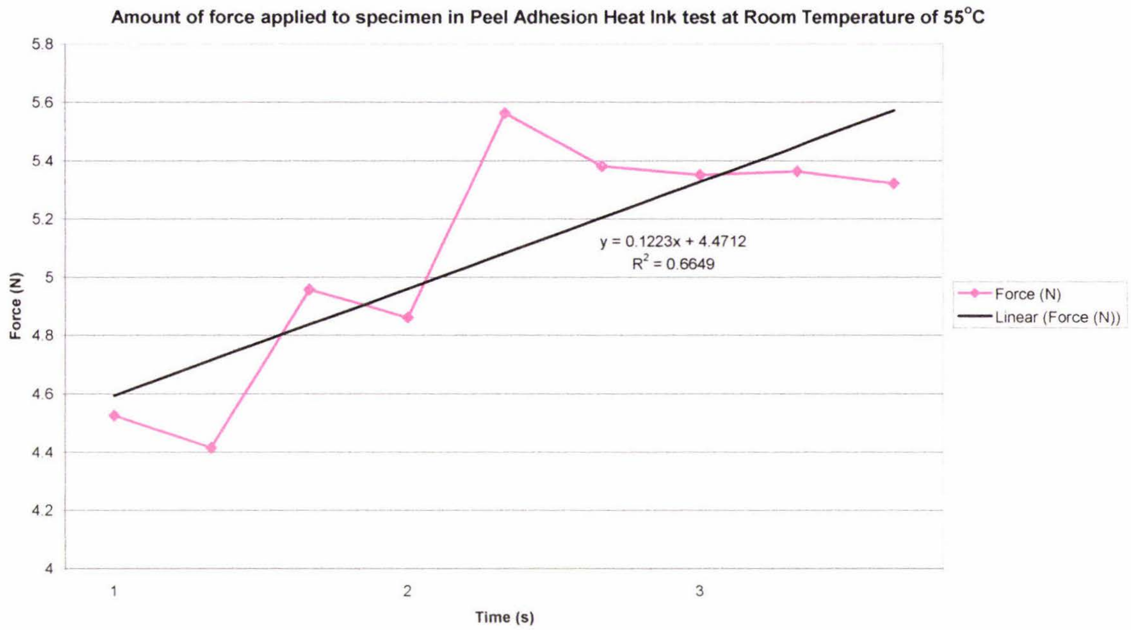


Force (n) versus Fibre Torn (mm) from Chiller
Fibre (mm)
0.25
0.2
0.15
0.1
0.05
0
2.5
3
3.5
4
4.5
5
Force (N)
y = 0.0231x + 0.0655
R2 = 0.087
Fibre (mm)
Best Fit Line

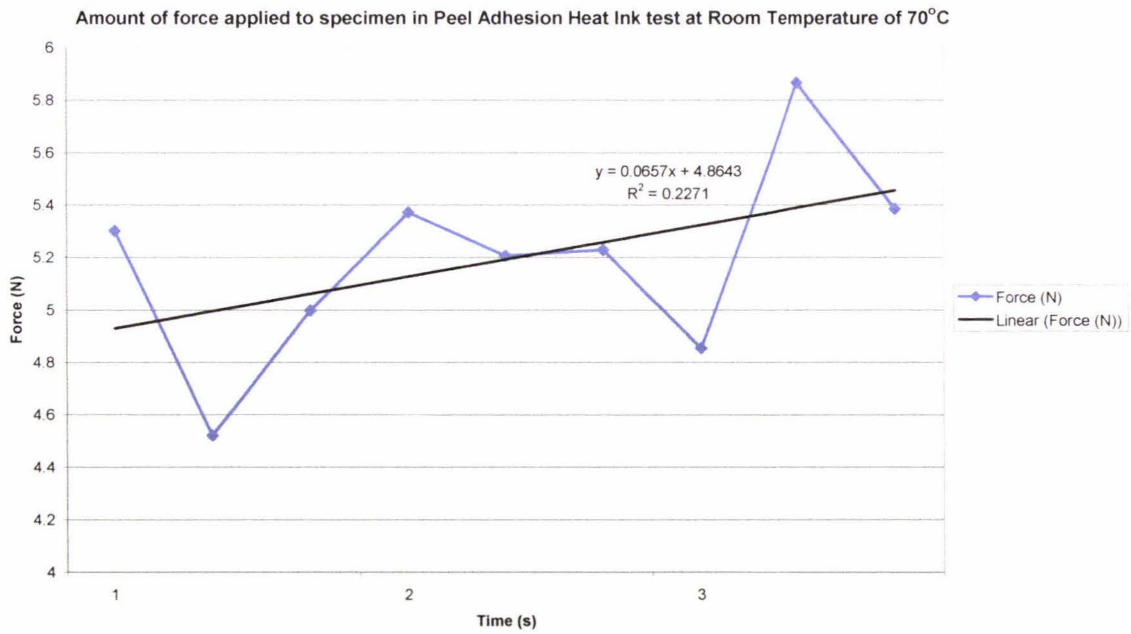

Experiment in Chiller test condition
6
5.5
5
4.5
4
3.5
3
2.5
2
Force (N)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
Temperature (oC)
Force (N)

In R.T. at 19-20oC

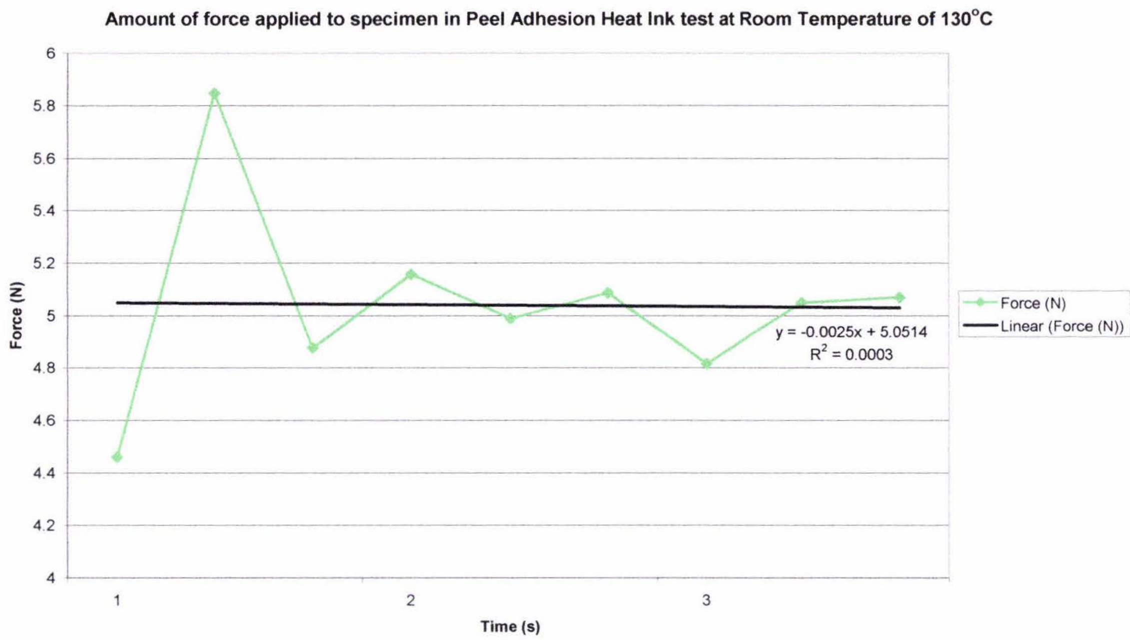
Temp (oC)	Time (s)	Number	Force (N)	Board Thickness (mm)				Torn Board Thickness (mm)				Amount	Torn	Force	Standard Deviation
				1	2	3	Av	1	2	3	Av	Fibre Torn	Av (mm)	Av (N)	for Force
55	1	1	4.526	3.149	3.137	3.138	3.141	3.171	3.085	3.051	3.102	0.039	0.078	4.633	0.29
55	1	2	4.415	3.209	3.144	3.158	3.170	2.982	3.1	3.125	3.069	0.101			
55	1	3	4.958	3.212	3.153	3.154	3.173	3.116	3.048	3.072	3.079	0.094			
55	2	1	4.862	3.059	3.097	3.174	3.110	3.002	2.994	3.015	3.004	0.106	0.109	5.269	0.36
55	2	2	5.564	3.015	3.097	3.088	3.067	3.03	3.088	2.988	3.035	0.031			
55	2	3	5.382	3.099	3.123	3.223	3.148	2.954	3.04	2.881	2.958	0.190			
55	3	1	5.352	3.11	3.173	3.173	3.152	3.063	3.067	3.058	3.063	0.089	0.114	5.346	0.02
55	3	2	5.364	3.003	3.008	3.053	3.021	2.888	2.872	2.915	2.892	0.130			
55	3	3	5.322	3.135	3.17	3.192	3.166	3.108	3.102	2.915	3.042	0.124			
70	1	1	5.302	3.115	3.128	3.174	3.139	2.899	2.896	2.993	2.929	0.210	0.147	4.940	0.39
70	1	2	4.521	3.167	3.225	3.168	3.187	3.068	2.976	3.048	3.031	0.156			
70	1	3	4.998	3.111	3.118	3.137	3.122	3.11	2.955	3.075	3.047	0.075			
70	2	1	5.372	3.14	3.228	3.16	3.176	3.012	3.1	3.033	3.048	0.128	0.086	5.270	0.09
70	2	2	5.207	3.143	3.188	3.15	3.160	3.004	3.122	3.088	3.071	0.089			
70	2	3	5.23	2.996	3.071	3.106	3.058	3.029	2.966	3.057	3.017	0.040			
70	3	1	4.854	2.976	3.058	3.106	3.047	3.023	2.986	2.941	2.983	0.063	0.071	5.369	0.51
70	3	2	5.867	3.127	3.1	3.068	3.098	2.951	3.031	2.992	2.991	0.107			
70	3	3	5.386	3.085	3.146	3.18	3.137	3.102	3.088	3.094	3.095	0.042			
130	1	1	4.46	3.314	3.216	3.125	3.218	3.021	2.976	3.045	3.014	0.204	0.173	5.061	0.71
130	1	2	5.848	3.222	3.183	3.163	3.189	3.135	3.119	3.08	3.111	0.078			
130	1	3	4.876	3.18	3.311	3.321	3.271	3.083	2.98	3.035	3.033	0.238			
130	2	1	5.157	3.08	3.131	3.126	3.112	2.972	3.04	2.899	2.970	0.142	0.096	5.078	0.08
130	2	2	4.989	3.192	3.171	3.262	3.208	3.12	3.136	3.168	3.141	0.067			
130	2	3	5.087	3.13	3.08	3.109	3.106	2.943	3.085	3.056	3.028	0.078			
130	3	1	4.816	3.159	3.099	3.106	3.121	3.07	3.054	3.061	3.062	0.060	0.061	4.978	0.14
130	3	2	5.049	3.161	3.123	3.115	3.133	3.15	3.104	3.056	3.103	0.030			
130	3	3	5.07	3.091	3.127	3.166	3.128	3.087	2.921	3.099	3.036	0.092			



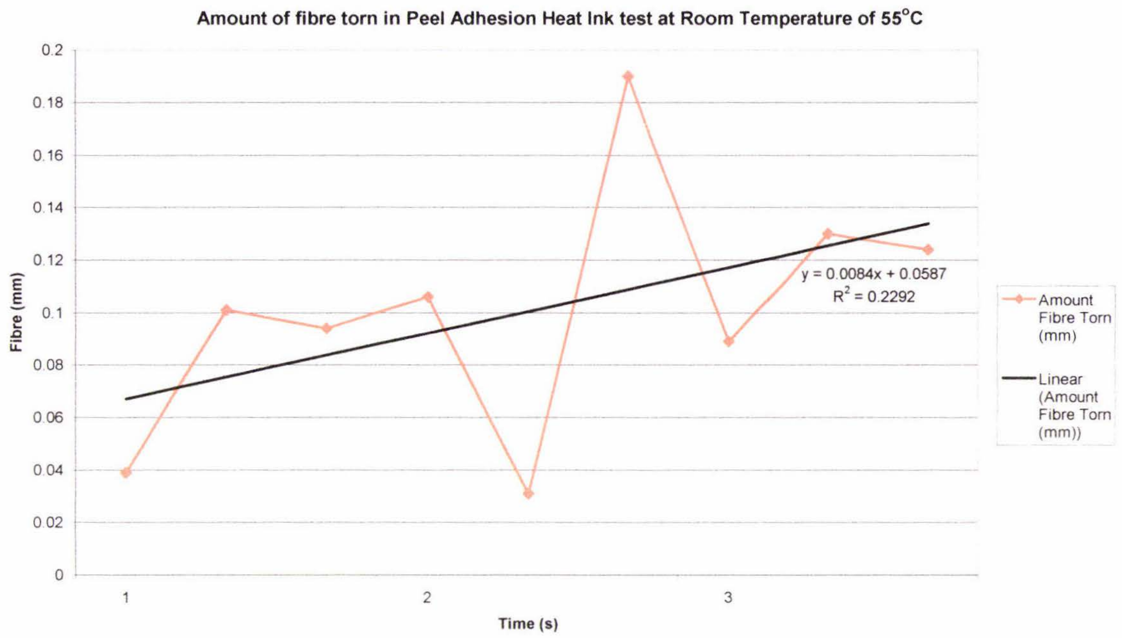
Amount of force applied to specimen in Peel Adhesion Heat Ink test at Room Temperature of 55°C
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
Force (N)
y = 0.1223x + 4.4712
R² = 0.6649
1
2
3
Time (s)
Force (N)
Linear (Force (N))

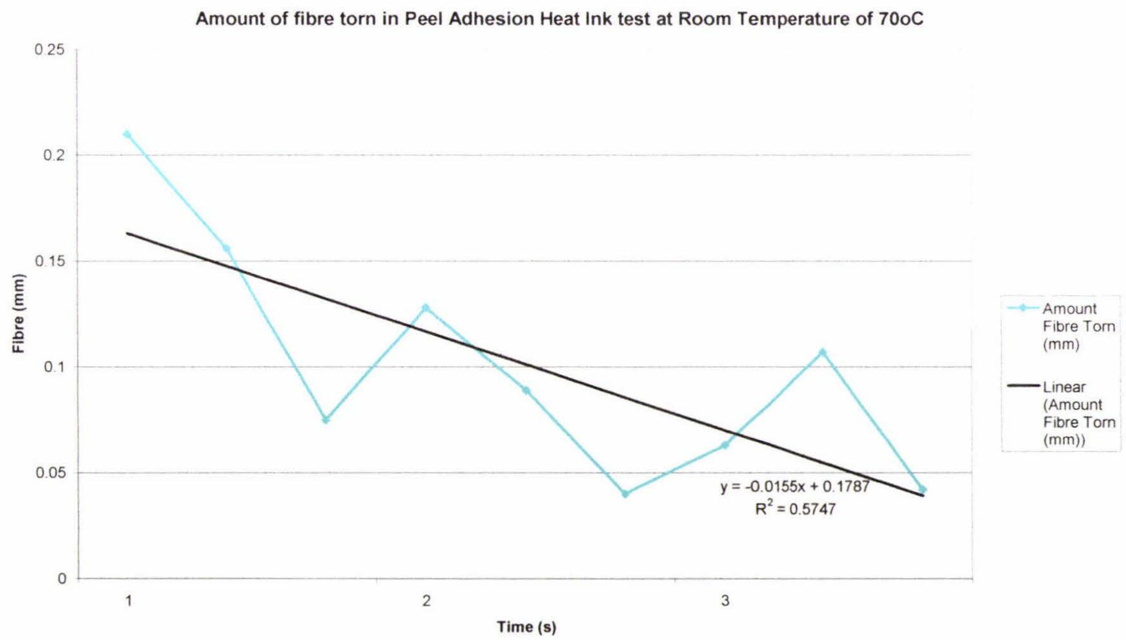


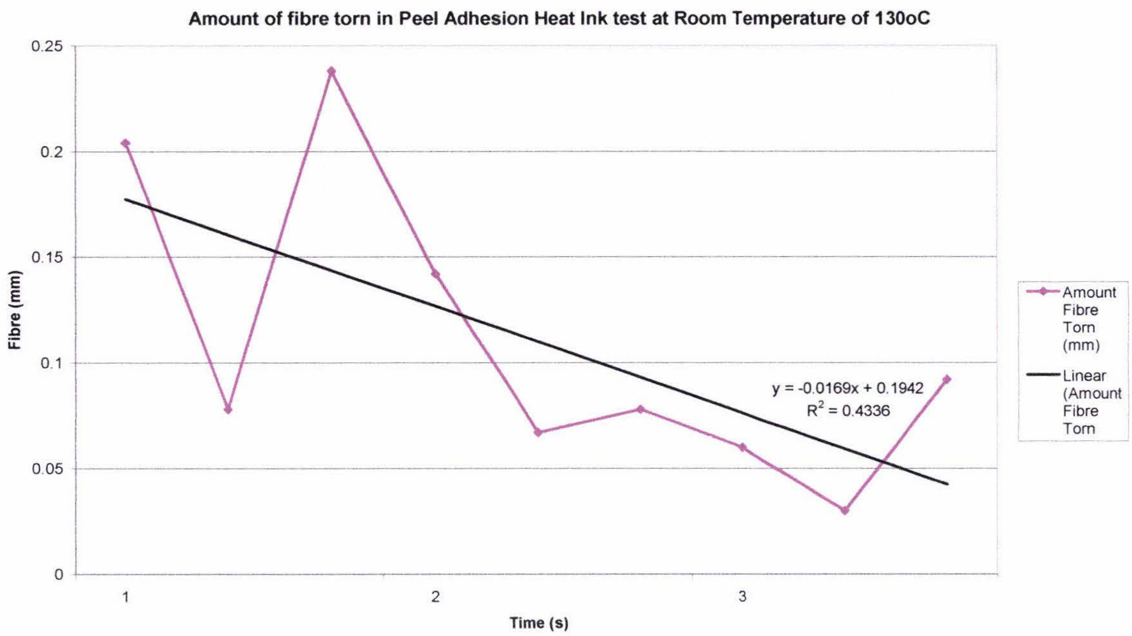
Amount of force applied to specimen in Peel Adhesion Heat Ink test at Room Temperature of 70°C
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
Force (N)
y = 0.0657x + 4.8643
R² = 0.2271
1
2
3
Time (s)
Force (N)
Linear (Force (N))

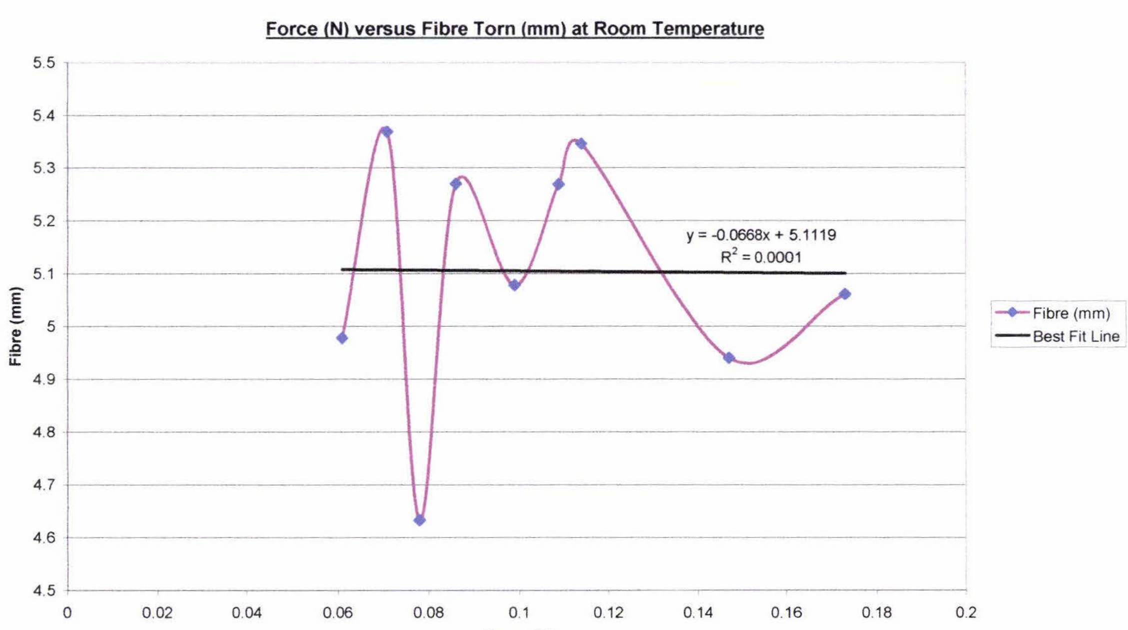


Amount of force applied to specimen in Peel Adhesion Heat Ink test at Room Temperature of 130°C
Force (N)
Time (s)
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
1
2
3
y = -0.0025x + 5.0514
R² = 0.0003
Force (N)
Linear (Force (N))


Amount of fibre torn in Peel Adhesion Heat Ink test at Room Temperature of 55°C
Fibre (mm)
Time (s)
y = 0.0084x + 0.0587
R² = 0.2292
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3


Amount of fibre torn in Peel Adhesion Heat Ink test at Room Temperature of 70oC
Fibre (mm)
Time (s)
y = -0.0155x + 0.1787
R² = 0.5747
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn (mm))
0.25
0.2
0.15
0.1
0.05
0
1
2
3


Amount of fibre torn in Peel Adhesion Heat Ink test at Room Temperature of 130oC
0.25
0.2
0.15
0.1
0.05
0
Fibre (mm)
1
2
3
Time (s)
y = -0.0169x + 0.1942
R² = 0.4336
Amount Fibre Torn (mm)
Linear (Amount Fibre Torn


Force (N) versus Fibre Torn (mm) at Room Temperature
5.5
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
Fibre (mm)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Force (N)
y = -0.0668x + 5.1119
R² = 0.0001
Fibre (mm)
Best Fit Line

D.4

Results for: Room Temperature/Peel Force

Factorial Design

General Factorial Design

```
Factors:    2      Factor Levels: 3, 3
Runs:      27      Replicates:     3
```

General Linear Model: Force versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Force, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	0.2517	0.2517	0.1258	0.37	0.698
Time	2	2.7241	2.7241	1.3621	3.97	0.037
Temperat*Time	4	2.0302	2.0302	0.5075	1.48	0.249
Error	18	6.1692	6.1692	0.3427		
Total	26	11.1752				

Unusual Observations for Force

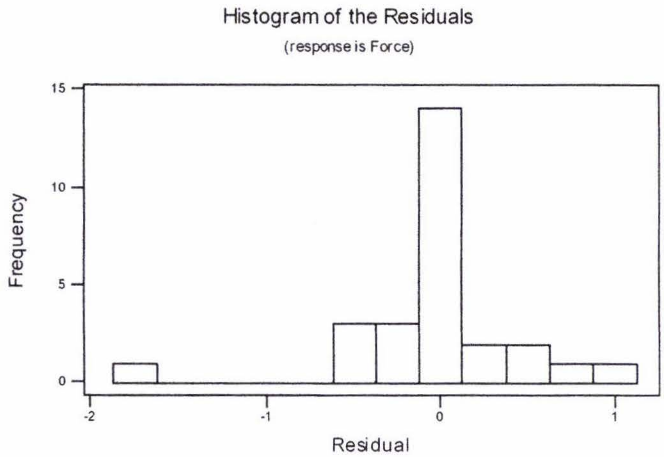
Obs	Force	Fit	SE Fit	Residual	St Resid
4	2.35200	3.94033	0.33800	-1.58833	-3.43R
22	[illegible]	[illegible]	0.33800	1.0[illegible]	2.21R

R denotes an observation with a large standardized residual.

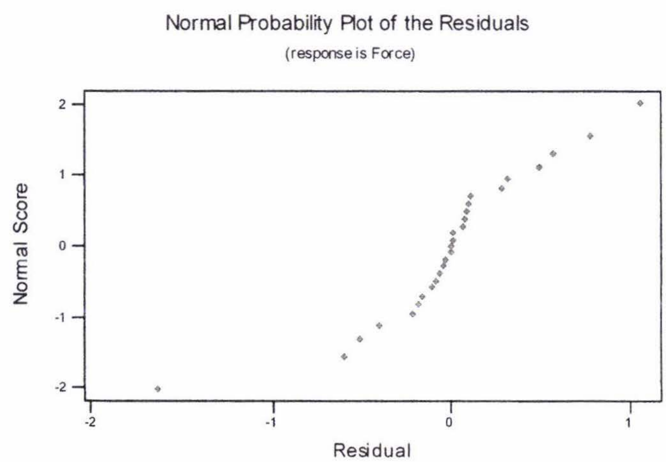
Least Squares Means for Force

Temperat		Mean	SE Mean
55		5.083	0.1951
70		4.860	0.1951
130		5.039	0.1951
Time			
1		4.545	0.1951
2		5.206	0.1951
3		5.231	0.1951
Temperat*Time			
55	1	4.633	0.3380
55	2	5.269	0.3380
55	3	5.346	0.3380
70	1	3.940	0.3380
70	2	5.270	0.3380
70	3	5.369	0.3380
130	1	5.061	0.3380
130	2	5.078	0.3380
130	3	4.978	0.3380

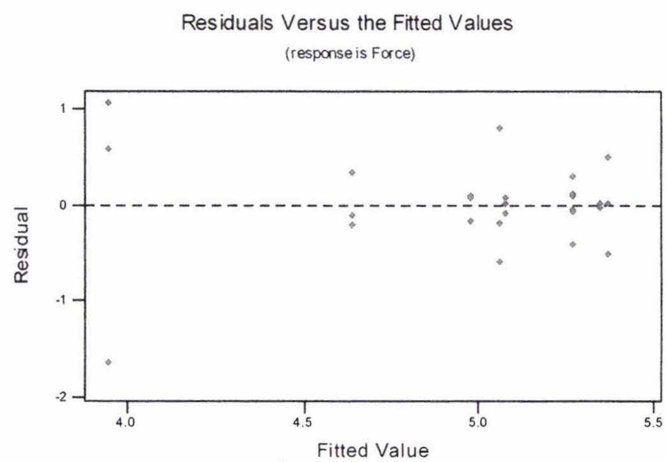
Residual Histogram for Force



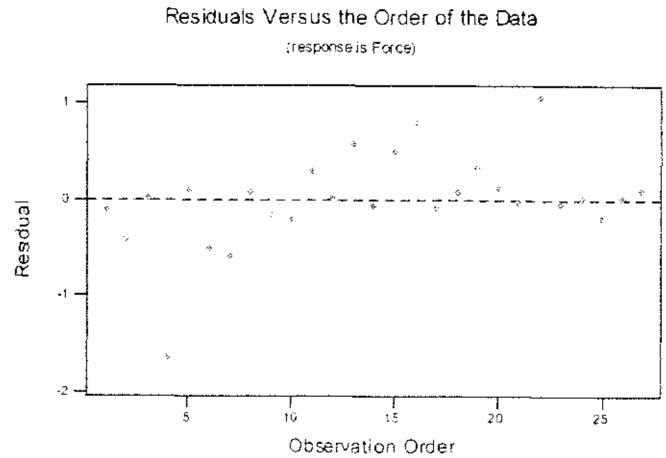
Normplot of Residuals for Force



Residuals vs Fits for Force



Residuals vs Order for Force



StdOrder	RunOrder	Blocks	Temperature	Time	Force	FITS1	RESI1	COEF1
1	1	1	55	1	4.526	4.63300	-0.10700	4.99385
2	2	1	55	2	4.862	5.26933	-0.40733	0.08893
3	3	1	55	3	5.352	5.34600	0.00600	-0.13419
4	4	1	70	1	2.302	3.94033	-1.63833	-0.44896
5	5	1	70	2	5.372	5.26967	0.10233	0.21170
6	6	1	70	3	4.854	5.36900	-0.51500	-0.00081
7	7	1	130	1	4.460	5.06133	-0.60133	-0.02515
8	8	1	130	2	5.157	5.07767	0.07933	-0.47037
9	9	1	130	3	4.816	4.97833	-0.16233	0.19830
10	10	1	55	1	4.415	4.63300	-0.21800	
11	11	1	55	2	5.564	5.26933	0.29467	
12	12	1	55	3	5.364	5.34600	0.01800	
13	13	1	70	1	4.521	3.94033	0.58067	
14	14	1	70	2	5.207	5.26967	-0.06267	
15	15	1	70	3	5.867	5.36900	0.49800	
16	16	1	130	1	5.848	5.06133	0.78667	
17	17	1	130	2	4.989	5.07767	-0.08867	
18	18	1	130	3	5.049	4.97833	0.07067	
19	19	1	55	1	4.958	4.63300	0.32500	
20	20	1	55	2	5.382	5.26933	0.11267	
21	21	1	55	3	5.322	5.34600	-0.02400	
22	22	1	70	1	4.998	3.94033	1.05767	
23	23	1	70	2	5.230	5.26967	-0.03967	
24	24	1	70	3	5.386	5.36900	0.01700	
25	25	1	130	1	4.876	5.06133	-0.18533	
26	26	1	130	2	5.087	5.07767	0.00933	
27	27	1	130	3	5.070	4.97833	0.09167	

Results for: Room Temperature/Peel Fibre

Factorial Design

General Factorial Design

Factors:	2	Factor Levels:	3, 3
Runs:	27	Replicates:	3

General Linear Model: Fibre versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Fibre, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	0.000500	0.000500	0.000250	0.09	0.915
Time	2	0.012322	0.012322	0.006161	2.19	0.141
Temperat*Time	4	0.019752	0.019752	0.004938	1.75	0.182
Error	18	0.050678	0.050678	0.002815		
Total	26	0.083252				

Unusual Observations for Fibre

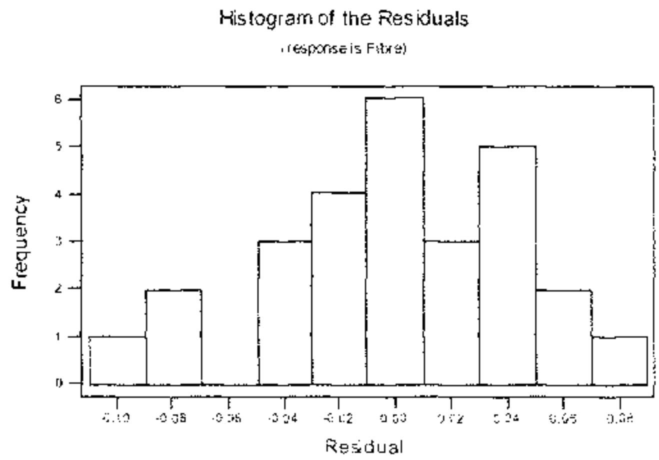
Obs	Fibre	Fit	SE Fit	Residual	St Resid
16	0.078000	0.173333	0.030635	-0.095333	-2.20R

R denotes an observation with a large standardized residual.

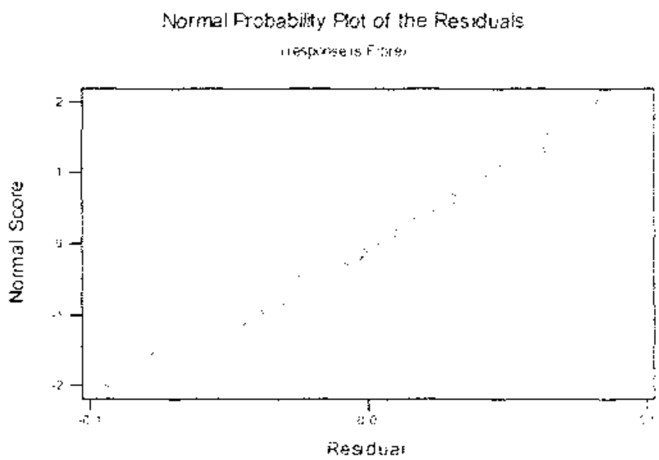
Least Squares Means for Fibre

Temperat		Mean	SE Mean
55		0.10044	0.01769
70		0.10111	0.01769
130		0.10989	0.01769
Time			
1		0.13278	0.01769
2		0.09678	0.01769
3		0.08189	0.01769
Temperat*Time			
55	1	0.07800	0.03063
55	2	0.10900	0.03063
55	3	0.11433	0.03063
70	1	0.14700	0.03063
70	2	0.08567	0.03063
70	3	0.07067	0.03063
130	1	0.17333	0.03063
130	2	0.09567	0.03063
130	3	0.06067	0.03063

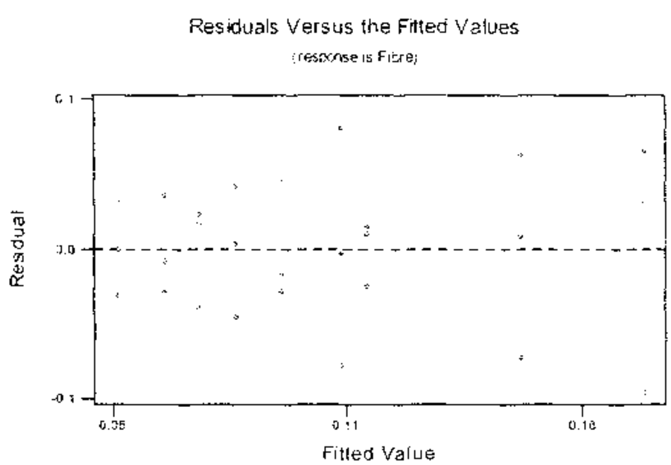
Residual Histogram for Fibre



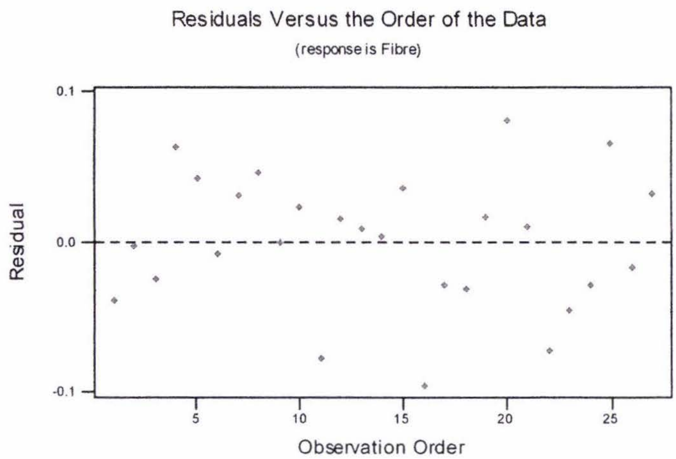
Normplot of Residuals for Fibre



Residuals vs Fits for Fibre



Residuals vs Order for Fibre



StdOrder	RunOrder	Blocks	Temperature	Time	Fibre	FITS1	RESI1	COEF1
1	1	1	55	1	0.039	0.078000	-0.0390000	0.103815
2	2	1	55	2	0.106	0.109000	-0.0030000	-0.003370
3	3	1	55	3	0.089	0.114333	-0.0253333	-0.002704
4	4	1	70	1	0.210	0.147000	0.0630000	0.028963
5	5	1	70	2	0.128	0.085667	0.0423333	-0.007037
6	6	1	70	3	0.063	0.070667	-0.0076667	-0.051407
7	7	1	130	1	0.204	0.173333	0.0306667	0.015593
8	8	1	130	2	0.142	0.095667	0.0463333	0.016926
9	9	1	130	3	0.060	0.060667	-0.0006667	-0.008407
10	10	1	55	1	0.101	0.078000	0.0230000	
11	11	1	55	2	0.031	0.109000	-0.0780000	
12	12	1	55	3	0.130	0.114333	0.0156667	
13	13	1	70	1	0.156	0.147000	0.0090000	
14	14	1	70	2	0.089	0.085667	0.0033333	
15	15	1	70	3	0.107	0.070667	0.0363333	
16	16	1	130	1	0.078	0.173333	-0.0953333	
17	17	1	130	2	0.067	0.095667	-0.0286667	
18	18	1	130	3	0.030	0.060667	-0.0306667	
19	19	1	55	1	0.094	0.078000	0.0160000	
20	20	1	55	2	0.190	0.109000	0.0810000	
21	21	1	55	3	0.124	0.114333	0.0096667	
22	22	1	70	1	0.075	0.147000	-0.0720000	
23	23	1	70	2	0.040	0.085667	-0.0456667	
24	24	1	70	3	0.042	0.070667	-0.0286667	
25	25	1	130	1	0.238	0.173333	0.0646667	
26	26	1	130	2	0.078	0.095667	-0.0176667	
27	27	1	130	3	0.092	0.060667	0.0313333	

Results for: Freezer/Peel Force

Factorial Design

General Factorial Design

Factors:	2	Factor Levels:	3, 3
Runs:	27	Replicates:	3

General Linear Model: Force (N) versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Force (N, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	0.1145	0.1145	0.0573	0.19	0.826
Time	2	0.6123	0.6123	0.3061	1.03	0.376
Temperat*Time	4	2.4205	2.4205	0.6051	2.04	0.131
Error	18	5.3271	5.3271	0.2959		
Total	26	8.4744				

Unusual Observations for Force (N

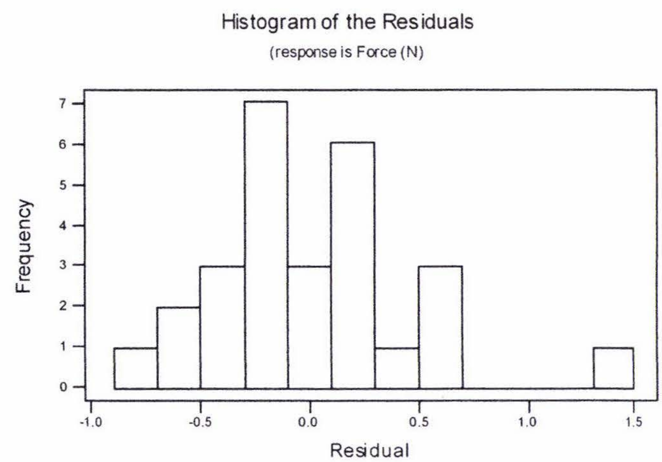
Obs	Force (N	Fit	SE Fit	Residual	St Resid
12	6.98000	5.67833	0.31409	1.30167	2.93R

R denotes an observation with a large standardized residual.

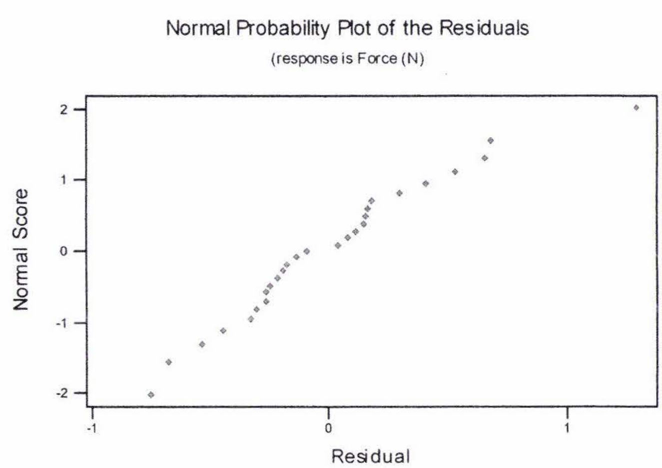
Least Squares Means for Force (N

Temperat		Mean	SE Mean
55		5.042	0.1813
70		5.011	0.1813
130		5.162	0.1813
Time			
1		5.005	0.1813
2		4.929	0.1813
3		5.280	0.1813
Temperat*Time			
55	1	4.666	0.3141
55	2	4.781	0.3141
55	3	5.678	0.3141
70	1	5.438	0.3141
70	2	4.683	0.3141
70	3	4.911	0.3141
130	1	4.912	0.3141
130	2	5.324	0.3141
130	3	5.250	0.3141

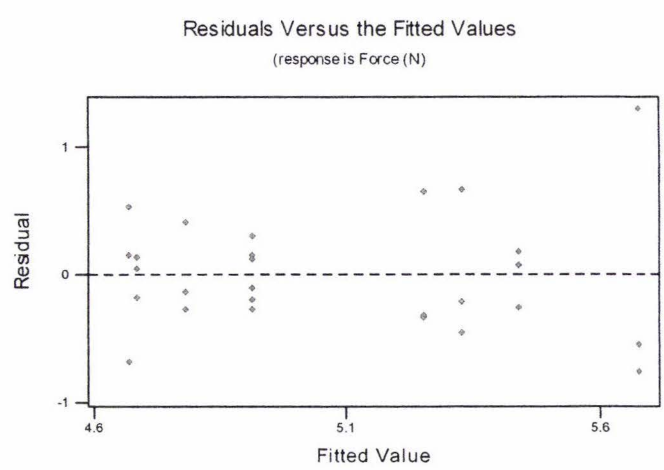
Residual Histogram for Force (N



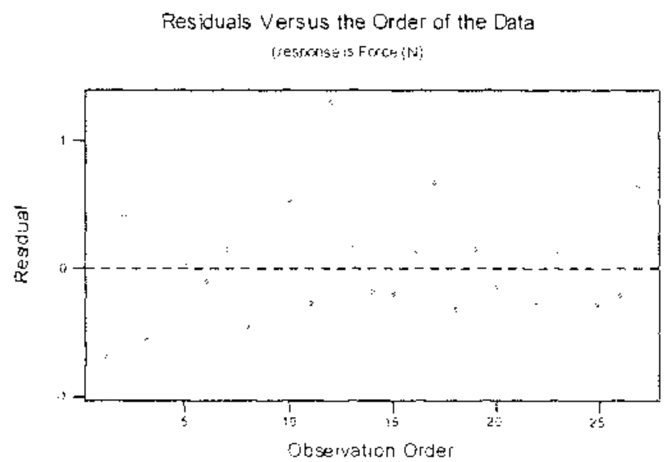
Normplot of Residuals for Force (N



Residuals vs Fits for Force (N



Residuals vs Order for Force (N



StdOrder	RunOrder	Blocks	Temperature	Time	Force (N)	FITS1	RESI1
1	1	1	55	1	3.984	4.66633	-0.68233
2	2	1	55	2	5.186	4.78067	0.40533
3	3	1	55	3	5.137	5.67833	-0.54133
4	4	1	70	1	5.515	5.43833	0.07667
5	5	1	70	2	4.723	4.68333	0.03967
6	6	1	70	3	4.811	4.91100	-0.10000
7	7	1	130	1	5.068	4.91167	0.15633
8	8	1	130	2	4.871	5.32367	-0.45267
9	9	1	130	3	4.914	5.25033	-0.33633
10	10	1	55	1	5.191	4.66633	0.52467
11	11	1	55	2	4.512	4.78067	-0.26867
12	12	1	55	3	6.980	5.67833	1.30167
13	13	1	70	1	5.613	5.43833	0.17467
14	14	1	70	2	4.503	4.68333	-0.18033
15	15	1	70	3	4.715	4.91100	-0.19600
16	16	1	130	1	5.026	4.91167	0.11433
17	17	1	130	2	5.996	5.32367	0.67233
18	18	1	130	3	4.936	5.25033	-0.31433
19	19	1	55	1	4.824	4.66633	0.15767
20	20	1	55	2	4.644	4.78067	-0.13667
21	21	1	55	3	4.918	5.67833	-0.76033
22	22	1	70	1	5.187	5.43833	-0.25133
23	23	1	70	2	4.824	4.68333	0.14067
24	24	1	70	3	5.207	4.91100	0.29600
25	25	1	130	1	4.641	4.91167	-0.27067
26	26	1	130	2	5.104	5.32367	-0.21967
27	27	1	130	3	5.901	5.25033	0.65067

Results for: Freezer/Peel Fibre

Factorial Design

General Factorial Design

```
Factors:   2     Factor Levels: 3, 3
Runs:     27     Replicates:    3
```

General Linear Model: Fibre versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Fibre, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	0.000038	0.000038	0.000019	0.00	0.996
Time	2	0.003148	0.003148	0.001574	0.35	0.712
Temperat*Time	4	0.003182	0.003182	0.000796	0.17	0.949
Error	18	0.081979	0.081979	0.004554		
Total	26	0.088348				

Unusual Observations for Fibre

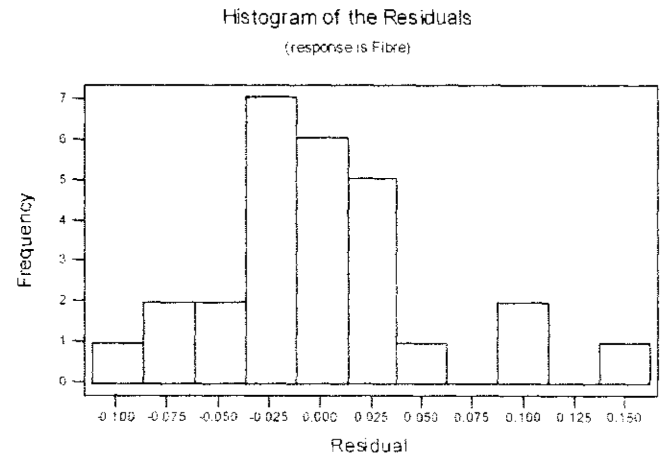
Obs	Fibre	Fit	SE Fit	Residual	St Resid
8	0.180000	0.068333	0.038963	0.111667	2.03R
21	0.260000	0.104333	0.038963	0.155667	2.83R

R denotes an observation with a large standardized residual.

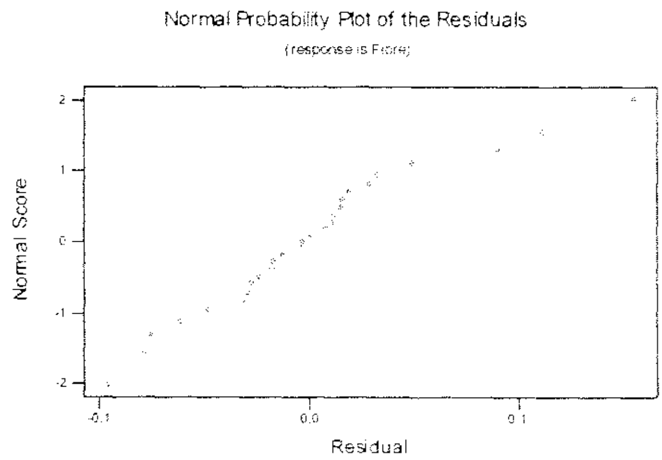
Least Squares Means for Fibre

Temperat		Mean	SE Mean
55		0.10689	0.02250
70		0.10511	0.02250
130		0.10400	0.02250
Time			
1		0.11744	0.02250
2		0.09122	0.02250
3		0.10733	0.02250
Temperat*Time			
55	1	0.11433	0.03896
55	2	0.10200	0.03896
55	3	0.10433	0.03896
70	1	0.10967	0.03896
70	2	0.10333	0.03896
70	3	0.10233	0.03896
130	1	0.12833	0.03896
130	2	0.06833	0.03896
130	3	0.11533	0.03896

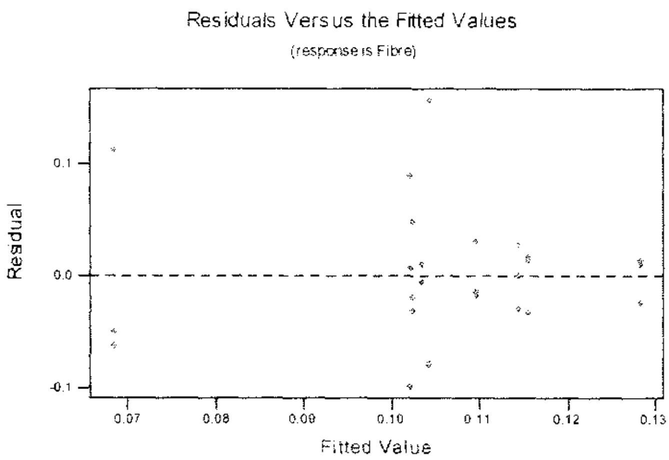
Residual Histogram for Fibre



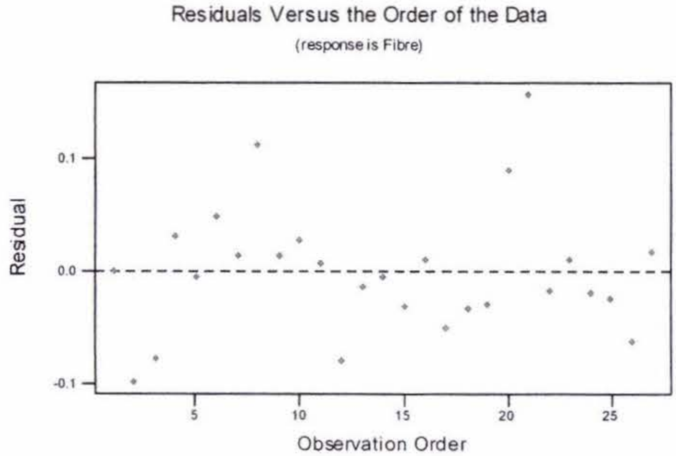
Normplot of Residuals for Fibre



Residuals vs Fits for Fibre



Residuals vs Order for Fibre



StdOrder	RunOrder	Blocks	Temperature	Time	Fibre	FITS1	RESI1	COEF1
1	1	1	55	1	0.115	0.114333	0.000667	0.105333
2	2	1	55	2	0.005	0.102000	-0.097000	0.001556
3	3	1	55	3	0.028	0.104333	-0.076333	-0.000222
4	4	1	70	1	0.141	0.109667	0.031333	0.012111
5	5	1	70	2	0.099	0.103333	-0.004333	-0.014111
6	6	1	70	3	0.151	0.102333	0.048667	-0.004667
7	7	1	130	1	0.142	0.128333	0.013667	0.009222
8	8	1	130	2	0.180	0.068333	0.111667	-0.007556
9	9	1	130	3	0.130	0.115333	0.014667	0.012333
10	10	1	55	1	0.142	0.114333	0.027667	
11	11	1	55	2	0.109	0.102000	0.007000	
12	12	1	55	3	0.025	0.104333	-0.079333	
13	13	1	70	1	0.096	0.109667	-0.013667	
14	14	1	70	2	0.098	0.103333	-0.005333	
15	15	1	70	3	0.072	0.102333	-0.030333	
16	16	1	130	1	0.139	0.128333	0.010667	
17	17	1	130	2	0.019	0.068333	-0.049333	
18	18	1	130	3	0.083	0.115333	-0.032333	
19	19	1	55	1	0.086	0.114333	-0.028333	
20	20	1	55	2	0.192	0.102000	0.090000	
21	21	1	55	3	0.260	0.104333	0.155667	
22	22	1	70	1	0.092	0.109667	-0.017667	
23	23	1	70	2	0.113	0.103333	0.009667	
24	24	1	70	3	0.084	0.102333	-0.018333	
25	25	1	130	1	0.104	0.128333	-0.024333	
26	26	1	130	2	0.006	0.068333	-0.062333	
27	27	1	130	3	0.133	0.115333	0.017667	

Results for: Chiller/Peel Force

Factorial Design

General Factorial Design

```
Factors:    2     Factor Levels: 3, 3
Runs:      27     Replicates:     3
```

General Linear Model: Force versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Force, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	2.9850	2.9850	1.4925	4.60	0.024
Time	2	0.3898	0.3898	0.1949	0.60	0.559
Temperat*Time	4	2.2927	2.2927	0.5732	1.77	0.179
Error	18	5.8354	5.8354	0.3242		
Total	26	11.5028				

Unusual Observations for Force

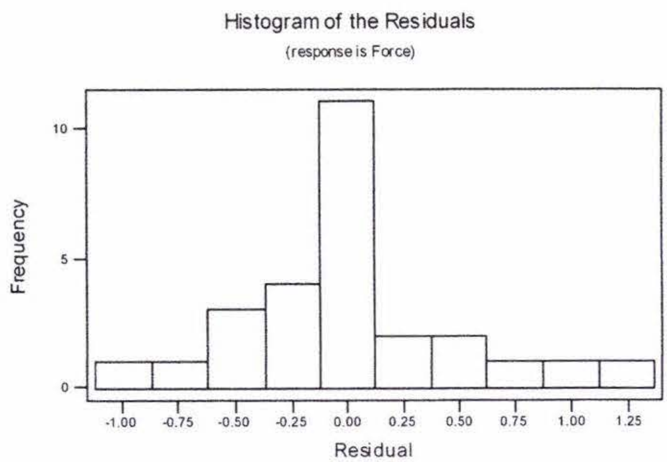
Obs	Force	Fit	SE Fit	Residual	St Resid
6	5.62700	4.35900	0.32873	1.26800	2.73R
10	4.83500	3.84533	0.32873	0.98967	2.13R

R denotes an observation with a large standardized residual.

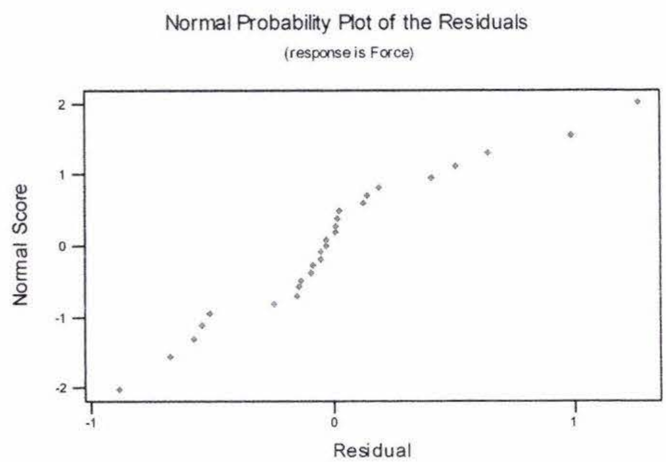
Least Squares Means for Force

Temperat		Mean	SE Mean
55		4.119	0.1898
70		4.222	0.1898
130		3.471	0.1898
Time			
1		3.946	0.1898
2		4.080	0.1898
3		3.786	0.1898
Temperat*Time			
55	1	3.845	0.3287
55	2	4.414	0.3287
55	3	4.099	0.3287
70	1	3.968	0.3287
70	2	4.339	0.3287
70	3	4.359	0.3287
130	1	4.026	0.3287
130	2	3.486	0.3287
130	3	2.900	0.3287

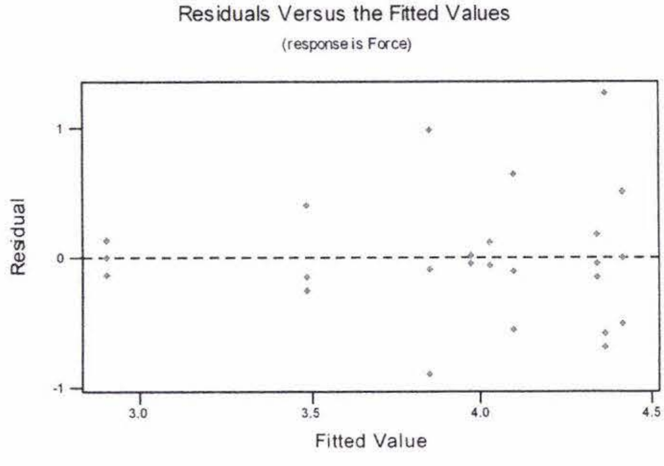
Residual Histogram for Force



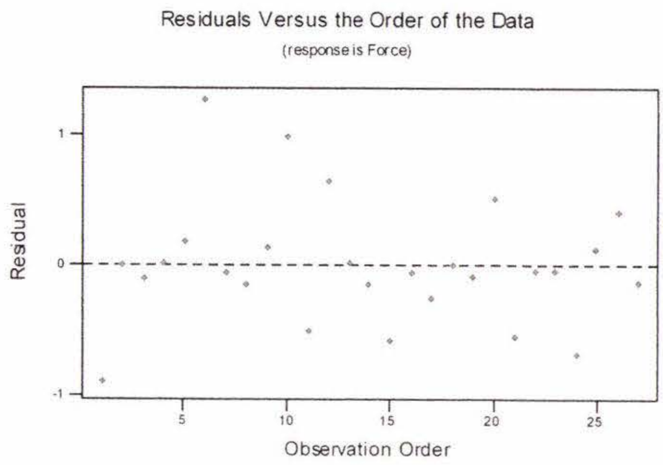
Normplot of Residuals for Force



Residuals vs Fits for Force



Residuals vs Order for Force



StdOrder	RunOrder	Blocks	Temperature	Time	Force	FITS1	RESI1	COEF1
1	1	1	55	1	2.949	3.84533	-0.89633	3.93737
2	2	1	55	2	4.421	4.41400	0.00700	0.18196
3	3	1	55	3	3.999	4.09867	-0.09967	0.28452
4	4	1	70	1	3.983	3.96767	0.01533	0.00907
5	5	1	70	2	4.523	4.33900	0.18400	0.14241
6	6	1	70	3	5.627	4.35900	1.26800	-0.28307
7	7	1	130	1	3.964	4.02633	-0.06233	0.15226
8	8	1	130	2	3.332	3.48633	-0.15433	-0.26330
9	9	1	130	3	3.034	2.90000	0.13400	-0.02530
10	10	1	55	1	4.835	3.84533	0.98967	
11	11	1	55	2	3.901	4.41400	-0.51300	
12	12	1	55	3	4.746	4.09867	0.64733	
13	13	1	70	1	3.989	3.96767	0.02133	
14	14	1	70	2	4.191	4.33900	-0.14800	
15	15	1	70	3	3.774	4.35900	-0.58500	
16	16	1	130	1	3.965	4.02633	-0.06133	
17	17	1	130	2	3.229	3.48633	-0.25733	
18	18	1	130	3	2.906	2.90000	0.00600	
19	19	1	55	1	3.752	3.84533	-0.09333	
20	20	1	55	2	4.920	4.41400	0.50600	
21	21	1	55	3	3.551	4.09867	-0.54767	
22	22	1	70	1	3.931	3.96767	-0.03667	
23	23	1	70	2	4.303	4.33900	-0.03600	
24	24	1	70	3	3.676	4.35900	-0.68300	
25	25	1	130	1	4.150	4.02633	0.12367	
26	26	1	130	2	3.898	3.48633	0.41167	
27	27	1	130	3	2.760	2.90000	-0.14000	

Results for: Chiller/Peel Fibre

Factorial Design

General Factorial Design

Factors:	2	Factor Levels:	3, 3
Runs:	27	Replicates:	3

General Linear Model: Fibre versus Temperature, Time

Factor	Type	Levels	Values
Temperat	fixed	3	55 70 130
Time	fixed	3	1 2 3

Analysis of Variance for Fibre, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperat	2	0.001758	0.001758	0.000879	0.28	0.756
Time	2	0.007129	0.007129	0.003565	1.15	0.337
Temperat*Time	4	0.026475	0.026475	0.006619	2.14	0.117
Error	18	0.055553	0.055553	0.003086		
Total	26	0.090915				

Unusual Observations for Fibre

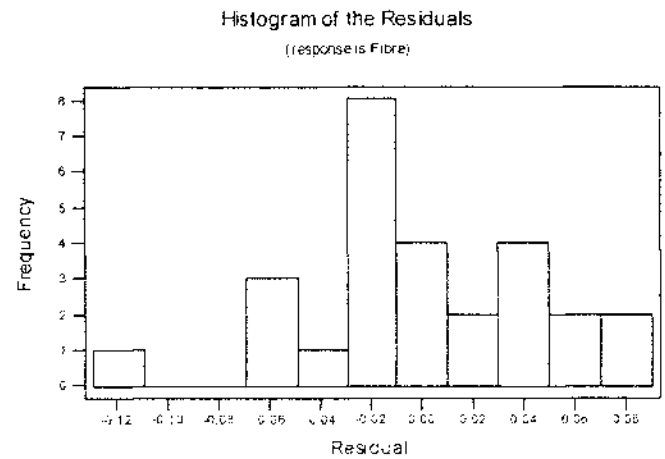
Obs	Fibre	Fit	SE Fit	Residual	St Resid
9	0.030000	0.153000	0.032074	-0.123000	-2.71R

R denotes an observation with a large standardized residual.

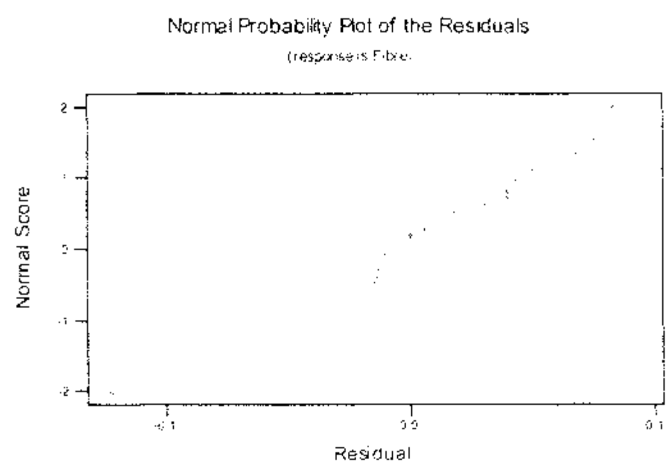
Least Squares Means for Fibre

Temperat		Mean	SE Mean
55		0.14011	0.01852
70		0.15633	0.01852
130		0.13844	0.01852
Time			
1		0.14578	0.01852
2		0.12467	0.01852
3		0.16444	0.01852
Temperat*Time			
55	1	0.09833	0.03207
55	2	0.17500	0.03207
55	3	0.14700	0.03207
70	1	0.15767	0.03207
70	2	0.11800	0.03207
70	3	0.19333	0.03207
130	1	0.18133	0.03207
130	2	0.08100	0.03207
130	3	0.15300	0.03207

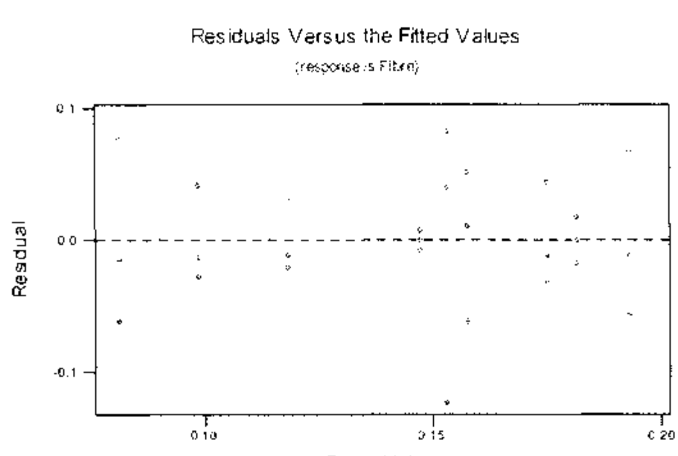
Residual Histogram for Fibre



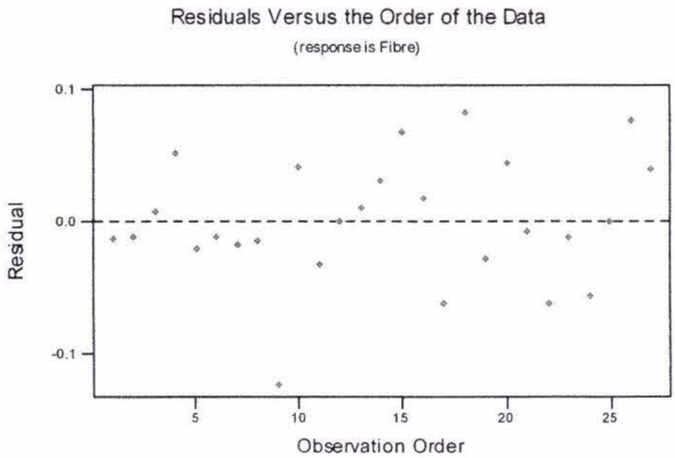
Normplot of Residuals for Fibre



Residuals vs Fits for Fibre



Residuals vs Order for Fibre

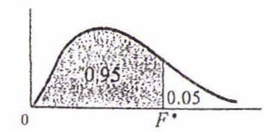


StdOrder	RunOrder	Blocks	Temperature	Time	Fibre	FITS1	RESI1	COEF1
1	1	1	55	1	0.085	0.098333	-0.013333	0.144963
2	2	1	55	2	0.163	0.175000	-0.012000	-0.004852
3	3	1	55	3	0.154	0.147000	0.007000	0.011370
4	4	1	70	1	0.209	0.157667	0.051333	0.000815
5	5	1	70	2	0.098	0.118000	-0.020000	-0.020296
6	6	1	70	3	0.181	0.193333	-0.012333	-0.042593
7	7	1	130	1	0.164	0.181333	-0.017333	0.055185
8	8	1	130	2	0.066	0.081000	-0.015000	0.000519
9	9	1	130	3	0.030	0.153000	-0.123000	-0.018037
10	10	1	55	1	0.139	0.098333	0.040667	
11	11	1	55	2	0.143	0.175000	-0.032000	
12	12	1	55	3	0.147	0.147000	-0.000000	
13	13	1	70	1	0.168	0.157667	0.010333	
14	14	1	70	2	0.149	0.118000	0.031000	
15	15	1	70	3	0.261	0.193333	0.067667	
16	16	1	130	1	0.199	0.181333	0.017667	
17	17	1	130	2	0.020	0.081000	-0.061000	
18	18	1	130	3	0.236	0.153000	0.083000	
19	19	1	55	1	0.071	0.098333	-0.027333	
20	20	1	55	2	0.219	0.175000	0.044000	
21	21	1	55	3	0.140	0.147000	-0.007000	
22	22	1	70	1	0.096	0.157667	-0.061667	
23	23	1	70	2	0.107	0.118000	-0.011000	
24	24	1	70	3	0.138	0.193333	-0.055333	
25	25	1	130	1	0.181	0.181333	-0.000333	
26	26	1	130	2	0.157	0.081000	0.076000	
27	27	1	130	3	0.193	0.153000	0.040000	

D.5

Table A-5 95th percentiles for the F distribution

The entry in column m, row n is the value F^* for which $P(0 \le F(m,n) \le F^*) = 0.95$.
m = degrees of freedom in numerator
n = degrees of freedom in denominator

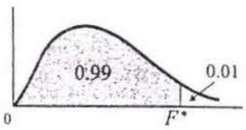


n \ m	1	2	3	4	5	6	7	8	9	10	12	15	20	24	25	30	40	60	120	∞
1	161	200	216	225	230	234	237	239	241	242	244	246	248	249	249	250	251	252	253	254
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.5	19.5
3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.63	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.52	4.50	4.46	4.43	4.40	4.37
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.83	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	5.51	3.44	3.41	3.40	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.11	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.89	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.73	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.60	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.50	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.41	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.34	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.28	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.23	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.18	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.14	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.07	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	2.02	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	2.00	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.97	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.94	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.92	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.89	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.88	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.78	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.69	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.20	1.96	1.91	1.83	1.75	1.66	1.61	1.60	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.51	1.46	1.39	1.32	1.22	1.00

Source: E. S. Pearson and H. O. Hartley, *Biometrika Tables for Statisticians*, Vol. 2 (1972), Table 5, page 178, by permission.

Table A-7 99th percentiles for the F distribution

The entry in column m, row n is the value F^* for which $P(0 \leq F(m,n) \leq F^*) = 0.99$.
m = degrees of freedom in numerator
n = degrees of freedom in denominator



n \ m	1	2	3	4	5	6	7	8	9	10	12	15	20	24	25	30	40	60	120	∞
1	4052	5000	5403	5625	5764	5859	5928	5981	6023	6056	6106	6157	6209	6235	6240	6261	6287	6313	6339	6366
2	98.5	99.0	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.5	99.5	99.5	99.5	99.5	99.5	99.5
3	34.1	30.8	29.5	28.7	28.2	27.9	27.7	27.5	27.3	27.2	27.1	26.9	26.7	26.6	26.6	26.5	26.4	26.3	26.2	26.1
4	21.2	18.0	16.7	16.0	15.5	15.2	15.0	14.8	14.7	14.5	14.4	14.2	14.0	13.9	13.9	13.8	13.7	13.7	13.6	13.5
5	16.3	13.3	12.1	11.4	11.0	10.7	10.5	10.3	10.2	10.1	9.89	9.72	9.55	9.47	9.45	9.38	9.29	9.20	9.11	9.02
6	13.7	10.9	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.30	7.23	7.14	7.06	6.97	6.88
7	12.2	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	6.06	5.99	5.91	5.82	5.74	5.65
8	11.3	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.26	5.20	5.12	5.03	4.95	4.86
9	10.6	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.71	4.65	4.57	4.48	4.40	4.31
10	10.0	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.31	4.25	4.17	4.08	4.00	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.25	4.10	4.02	4.01	3.94	3.86	3.78	3.69	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.76	3.70	3.62	3.54	3.45	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.82	3.66	3.59	3.57	3.51	3.43	3.34	3.25	3.17
14	8.86	6.51	5.56	5.04	4.70	4.46	4.28	4.14	4.03	3.94	3.80	3.66	3.51	3.43	3.41	3.35	3.27	3.18	3.09	3.00
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.28	3.21	3.13	3.05	2.96	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.41	3.26	3.18	3.16	3.10	3.02	2.93	2.84	2.75
17	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.31	3.16	3.08	3.07	3.00	2.92	2.83	2.75	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.23	3.08	3.00	2.98	2.92	2.84	2.75	2.66	2.57
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.15	3.00	2.92	2.91	2.84	2.76	2.67	2.58	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.84	2.78	2.69	2.61	2.52	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.03	2.88	2.80	2.79	2.72	2.64	2.55	2.46	2.36
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	2.98	2.83	2.75	2.73	2.67	2.58	2.50	2.40	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.93	2.78	2.70	2.69	2.62	2.54	2.45	2.35	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.64	2.58	2.49	2.40	2.31	2.21
25	7.77	5.57	4.68	4.18	3.86	3.63	3.46	3.32	3.22	3.13	2.99	2.85	2.70	2.62	2.60	2.54	2.45	2.36	2.27	2.17
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	2.96	2.82	2.66	2.58	2.57	2.50	2.42	2.33	2.23	2.13
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.93	2.78	2.63	2.55	2.54	2.47	2.38	2.29	2.20	2.10
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.90	2.75	2.60	2.52	2.51	2.44	2.35	2.26	2.17	2.06
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.87	2.73	2.57	2.49	2.48	2.41	2.33	2.23	2.14	2.03
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.45	2.39	2.30	2.21	2.11	2.01
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.52	2.37	2.29	2.27	2.20	2.11	2.02	1.92	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.10	2.03	1.94	1.84	1.73	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.93	1.86	1.76	1.66	1.53	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.78	1.70	1.59	1.47	1.32	1.00

Source: E. S. Pearson and H. O. Hartley, *Biometrika Tables for Statisticians*, Vol. 2 (1972), Table 5, page 180, by permission.

D.6 SIGNIFICANCE CALCULATIONS
Refer to *F* distribution tables for 95 and 99 percentiles

Room Temperature Force

Temperature	F= 0.37	P= 0.698
	95% F= 3.55	
	99% F= 6.01	

Therefore at 30.2%, F=0.37 **Insignificant**

Time	F= 3.97	P= 0.037
	95% F= 3.55	
	99% F= 6.01	

Therefore at 96.3%, F=3.97 **Significant**

Temperature versus Time	F= 1.48	P= 0.249
	95% F= 2.93	
	99% F= 4.58	

Therefore at 75.1%, F=1.48 **Insignificant**

Room Temperature Fibre

Temperature	F= 0.09	P= 0.915
	95% F= 3.55	
	99% F= 6.01	

Therefore at 8.5%, F=0.09 **Insignificant**

Time	F= 2.19	P= 0.141
	95% F= 3.55	
	99% F= 6.01	

Therefore at 85.6%, F=2.19 **Insignificant**

Temperature versus Time	F= 1.75	P= 0.182
	95% F= 2.93	
	99% F= 4.58	

Therefore at 81.8%, F=1.75 **Insignificant**

Chiller Force

Temperature	F= 4.60	P= 0.024
	95% F= 3.55 99% F= 6.01	

Therefore at 97.6%, F=4.60 **Significant**

Time	F= 0.60	P= 0.559
	95% F= 3.55 99% F= 6.01	

Therefore at 44.1%, F=0.60 **Insignificant**

Temperature versus Time	F= 1.77	P= 0.179
	95% F= 2.93 99% F= 4.58	

Therefore at 82.1%, F=1.77 **Insignificant**

Chiller Fibre

Temperature	F= 0.28	P= 0.756
	95% F= 3.55 99% F= 6.01	

Therefore at 24.4%, F=0.28 **Insignificant**

Time	F= 1.15	P= 0.337
	95% F= 3.55 99% F= 6.01	

Therefore at 66.3%, F=1.15 **Insignificant**

Temperature versus Time	F= 2.14	P= 0.117
	95% F= 2.93 99% F= 4.58	

Therefore at 88.3%, F=2.14 **Insignificant**

Freezer Force

Temperature	F= 0.19	P= 0.826
	95% F= 3.55 99% F= 6.01	

Therefore at 17.5%, F=0.19 **Insignificant**

Time	F= 1.03	P= 0.376
	95% F= 3.55 99% F= 6.01	

Therefore at 62.4%, F=1.03 **Insignificant**

Temperature versus Time	F= 2.04	P= 0.131
	95% F= 2.93 99% F= 4.58	

Therefore at 86.9%, F=2.04 **Insignificant**

Freezer Fibre

Temperature	F= 0.00	P= 0.996
	95% F= 3.55 99% F= 6.01	

Therefore at 0.4%, F=0.00 **Insignificant**

Time	F= 0.35	P= 0.712
	95% F= 3.55 99% F= 6.01	

Therefore at 28.8%, F=0.35 **Insignificant**

Temperature versus Time	F= 0.17	P= 0.949
	95% F= 2.93 99% F= 4.58	

Therefore at 5.1%, F=0.17 **Insignificant**

E.1

NEW ZEALAND MEAT INDUSTRY ASSOCIATION (Inc.)
Level 4, Wool House, 10 Brandon Street, PO Box 345, Wellington.
Telephone 04-473 6465, Facsimile 04-473 1731

6 June 1997

TO MATERIALS HANDLING WORKING PARTY

MISC 97/2

Carton Sealing: Standard Diagrams

As a result of the discussions late last year, a series of standard diagrams was prepared. Since then, a further set has been added.

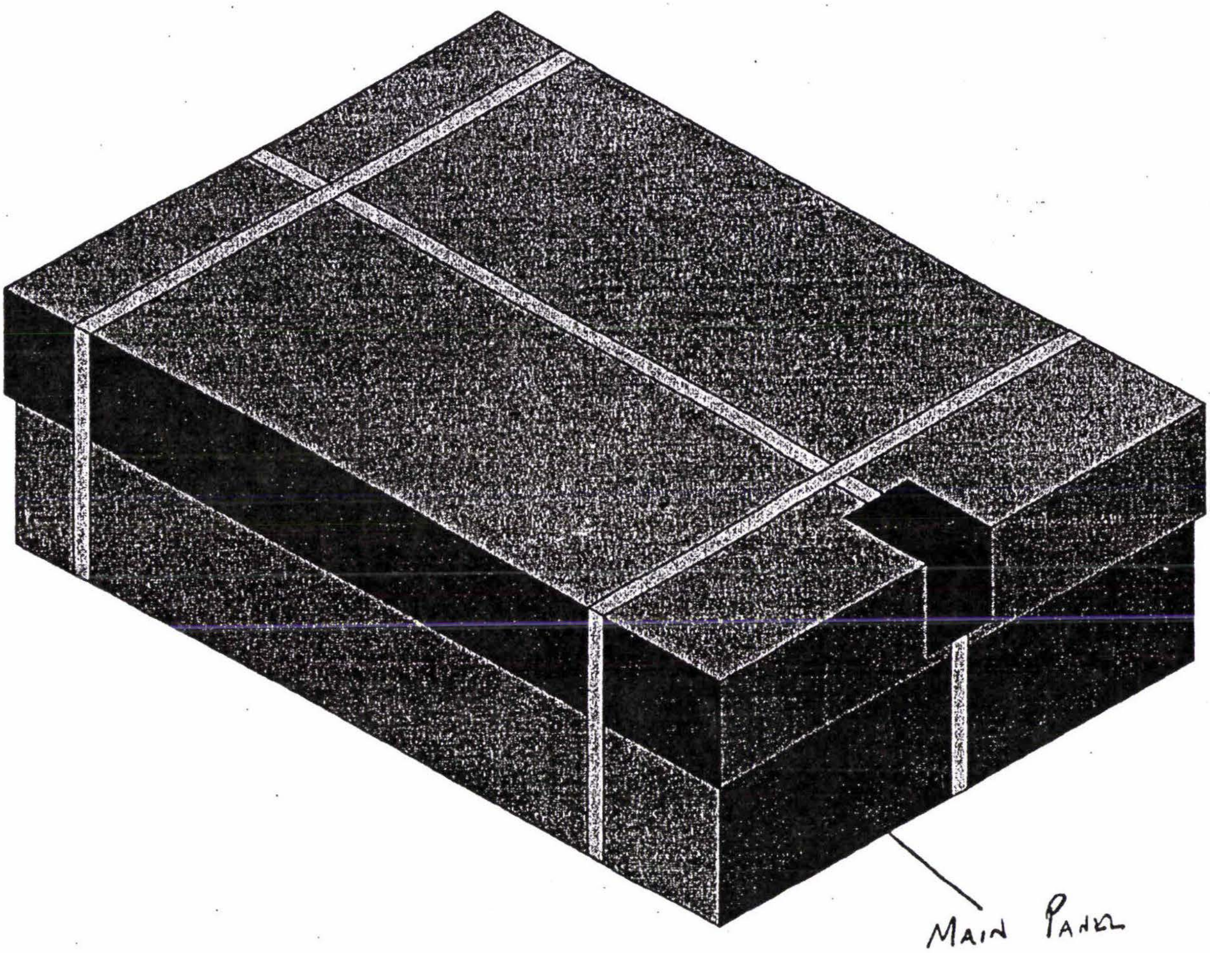
The complete set is attached.

If there is no further comment, the additional wording will be added where indicated, and arrangements made for a formal issuing of the set.

Please note that Mr P Ward has been specifically asked to review these, as well as a couple of variations provided by PPCS.

D. J. Miller
Executive Officer - Technical

NEW ZEALAND MEAT INDUSTRY ASSOCIATION (Inc.)

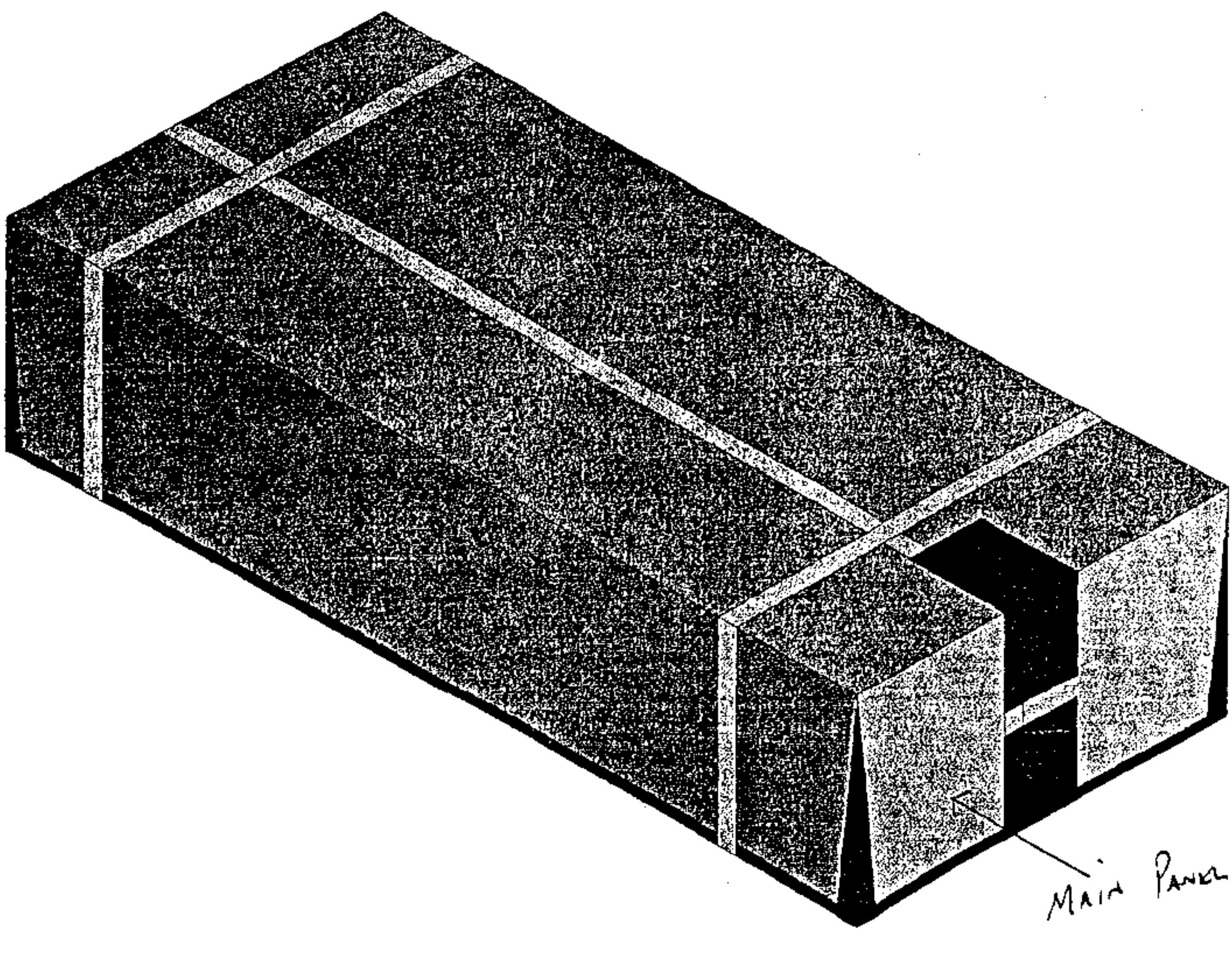


Box & Lid (Partial Depth Lid)

Seal placed over the strap and around onto the top. SEAL IS NOT REQUIRED TO BRIDGE THE BOX AND LID

This meets both New Zealand and European Standards.

NEW ZEALAND MEAT INDUSTRY ASSOCIATION (Inc.)



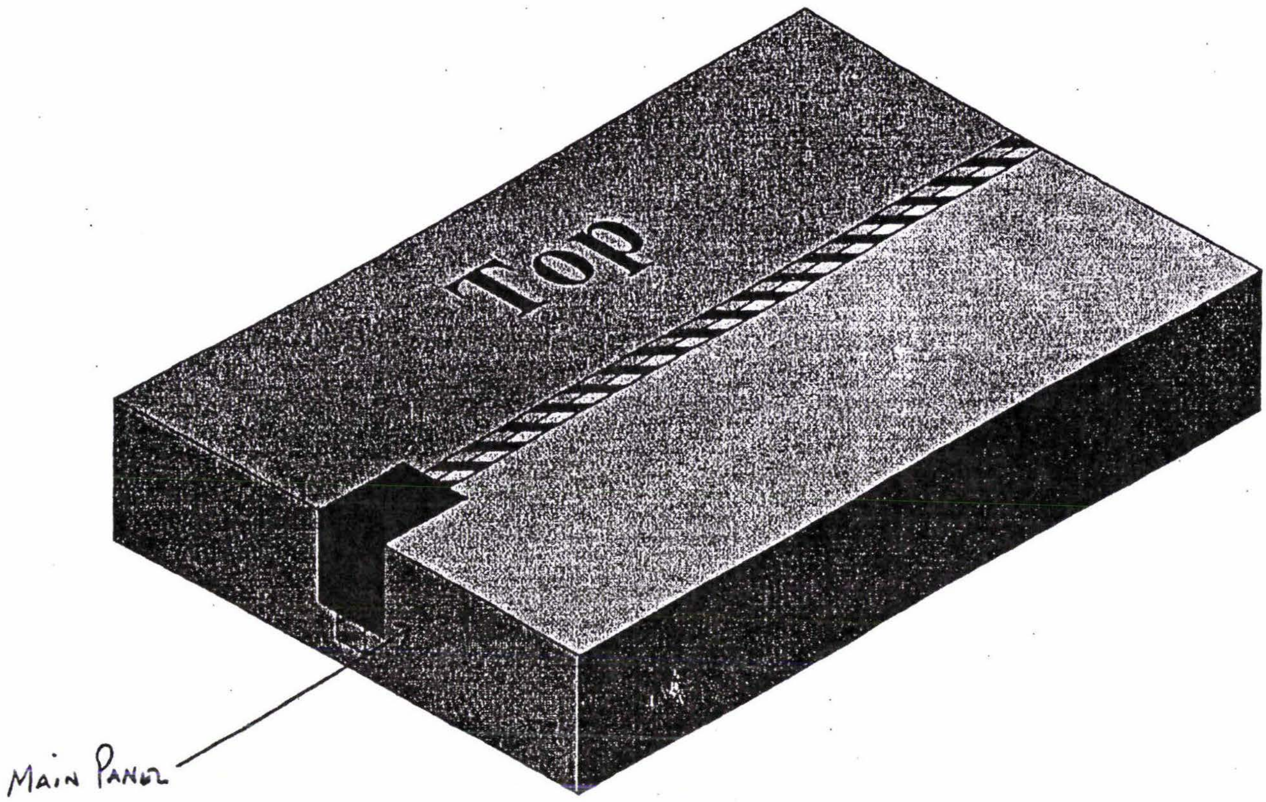
Hinged Lid (Three Flap) 1 Longitudinal Strap

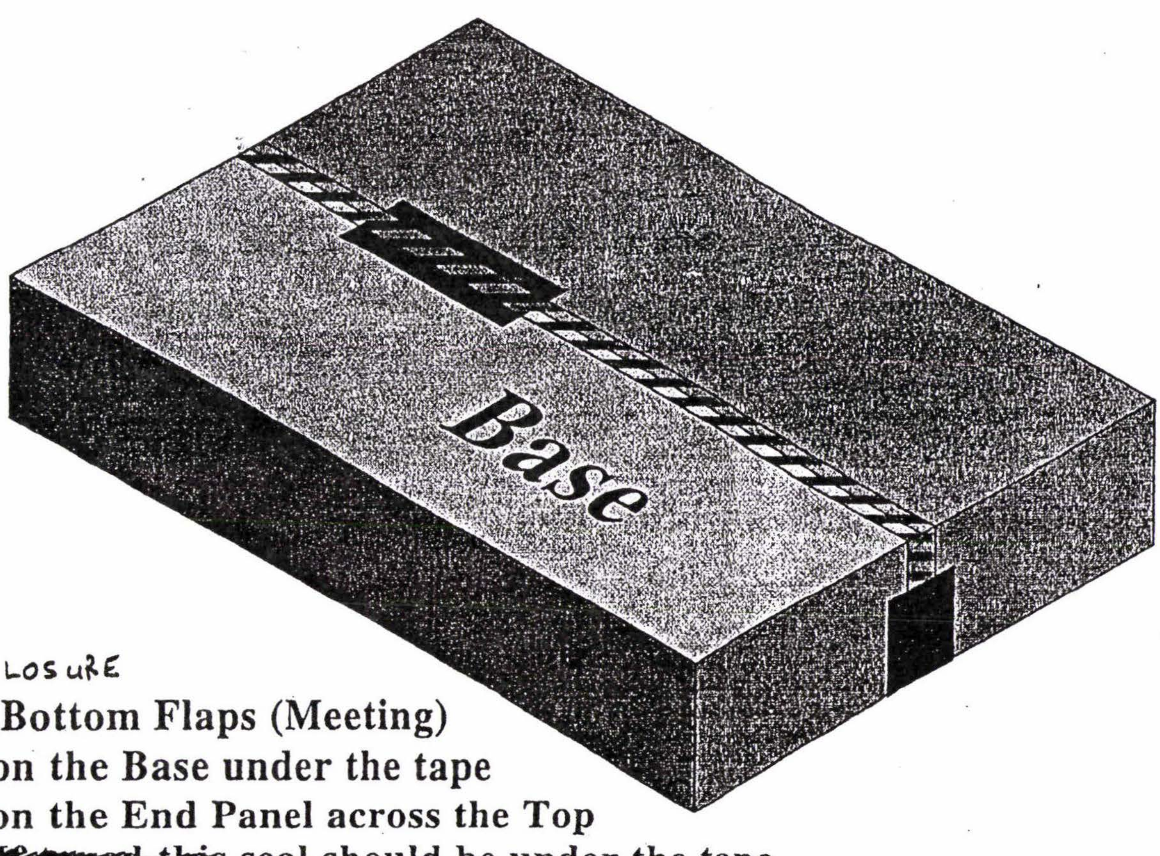
Option 1 - Seal placed over the strap at the top of the end panel following onto the top.

Option 2 - Seal placed over the strap at the bottom of the end panel following onto the base.

This meets both New Zealand and European Standards, provided the longitudinal strap is reasonably close to the front flap of the carton.

NEW ZEALAND MEAT INDUSTRY ASSOCIATION (Inc.)





TAPE CLOSURE

Top & Bottom Flaps (Meeting)

1 Seal on the Base under the tape

1 Seal on the End Panel across the Top Panel. ~~If taped this~~ seal should be under the tape.

This meets both New Zealand & European Standards.

Measuring Thermal Resistance Of Corrugated Made Simple

By Tom R. Robertson, F. Bilge Thompson and Andrew C. Cleland, Ph.D.
Massey University, New Zealand

FOCUS: The heat transfer resistance of corrugated paperboard is of vital interest to industries involved in chilling or freezing food in corrugated cases and to packaging companies supplying these industries. The method of determining the heat transfer resistance and thermal conductivity of packaging materials described is simple to operate and produces reliable results as well as time savings.

Introduction

For industries involved in the chilling and freezing of foods in corrugated containers, the heat transfer resistance of container board is critical as it substantially affects the times required for processing. For example, the chilling time for a 20 kg block of cheese can be increased by three hours by changing from solid paperboard to corrugated board. To calculate freezing and chilling times, packagers must know with sufficient accuracy the resistance of the packaging material for design and control purposes.

The existing ASTM method 177-45, *Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Heat Plate*, requires elaborate apparatus and considerable time for the temperatures to stabilize before measurements can be taken. There is an industry-wide need for an inexpensive, simple and quicker industrial method for measuring the thermal conductivity of packaging paperboards and, thus, determining the heat transfer resistance.

Thermal Conductivity and Heat Transfer Resistance

The fundamental equation for the heat flux from the ambient environment through packaging to a food product is:

$$\emptyset/A = \lambda\, \Delta\theta/x = \Delta\theta/R_p \quad (Eq.\ 1)$$

Where:
$\emptyset = dQ/dt$, the rate of heat transfer (W)
A = area (m^2)
$\Delta\theta$ = temperature difference across the wall (K)
x = thickness of wall (m)
λ = thermal conductivity ($Wm^{-1}K^{-1}$)
$R_p = x/\lambda$, heat transfer resistance (m^2KW^{-1})

In the packaging system, the net heat transfer to the product surface arises from two heat resistances in series: the surface resistance and the packaging resistance. These can be treated as a single resistance, which can be estimated from unsteady-state measurements using the method of Cleland and Earle (*1976*). This method measures time-temperature data at the surface of a semi-infinite slab (equivalent to a slab of infinite extension) for short times after the onset of cooling or heating. This method is both accurate and sensitive to changes in the surface heat transfer coefficients (*Cleland, 1990*).

Equipment

Equipment used for determining the heat resistance of the packaging was a thermostatically controlled water bath with a stainless steel tray on top giving an isothermal surface. Tylose MH-1000, a gel made from 77 percent water and 23 percent methylcellulose powder was used as the block of known thermal properties. For temperatures between 2°C and 30°C, Tylose thermal properties are: thermal conductivity 0.496 $Wm^{-1}K^{-1}$; specific heat capacity 4,100 $Jkg^{-1}K^{-1}$; and density of 1,000 kgm^{-3} (*Lovatt, 1992; Pham et al., 1994*).

Test Method

The Tylose/polystyrene block was maintained in a chiller at 1°C. The block was covered with insulation to maintain the required uniform initial temperature before it was moved to the test equipment. The thermocouples were quickly connected to the data logging system, and the paperboard sample was placed on the stainless steel plate on the water bath. The insulating cover of the Tylose block was then quickly removed, and the Tylose block was placed onto the paperboard sample. A standard weight of 10 kg was located on the Tylose block to ensure consistent contact between the stainless steel plate, paperboard sample, Tylose and the thermocouples.

Temperatures were measured at the surface (θ_s) and base of the Tylose (θ_i), and the water temperature (θ_a) was measured at 20-second intervals for 10-15 minutes. After paperboard sample removal, the positions of the thermocouples on the surface of the Tylose were checked; data from any thermocouples that had sunk into the Tylose and were thus not located on the surface were discarded. The experiment was repeated with different numbers of sheets of packaging material. For thicker corrugated (C-flute), more than three sheets slowed down the temperature change so markedly that undesirable edge heat transfer effects were potentially too high.

Analysis of the data used the Goodman plot system in the manner of Cleland and Earle (*1976*). They argued that the surface temperature would change more in response to external heat transfer resistance change than any temperature deeper into the solid body. Thus if a means of relating surface temperature vs. time profiles to overall heat transfer coefficient can be identified, the overall heat transfer coefficient can be accurately determined. The analytical solutions for a change in surface temperature with time cannot be easily manipulated to determine heat transfer coefficient by simple algebra. However, a close approximation to the analytical solution is available and is suitable. Goodman used a cubic to approximate the temperature profile vs. position relationship within the solid. He showed that the surface temperature of a semi-infinite slab is accurately predicted by the following approximation:

$$4/3(h/\lambda)^2 \lambda/pc\, t = 1/2Y_S^2 - 1/2 + \ln Y_s \quad (Eq.\ 2)$$

Where $Y_s = (\theta_s - \theta_a)/(\theta_i - \theta_a)$, the fractional unaccomplished temperature change at the surface; θ_a = ambient (water) temperature (°C); θ_i = initial temperature (°C); θ_s = surface temperature (°C); h = overall heat transfer coefficient ($Wm^{-2} K^{-1}$); λ = thermal conductivity of test material ($Wm^{-1}K^{-1}$); t = time (s); c = specific heat capacity ($Jkg^{-1}K^{-1}$); p = density of material (kgm^{-3}).

The overall heat transfer coefficient can be explicitly calculated. The complete data analysis procedure was as follows:

The temperature data collected (θ_s, θ_i, θ_a) were used to calculate Y_s. Once θ_i changed, the semi-infinite slab assumption was violated, and data at longer times were discarded.

These values were used to calculate ($1/2Y_S^2$ - $1/2$ + $\ln Y_s$) at different times, and these data were plotted. The slope of the resulting straight line segment at short times gave $4/3(h/\lambda)^2 \lambda/pc$. Using the thermal properties of the Tylose, the overall heat transfer coefficient (h) of the total heat transfer pathway from water to Tylose was calculated.

The estimated reciprocal of the overall heat transfer coefficients ($1/h$) was plotted against the number of sheets of packaging. The intercept of this plot is the same for every type of packaging material, and the slope of the plot is designated the heat transfer resistance (R_p) of a single layer of packaging.

Where the thickness of the packaging was known, the effective thermal conductivity of the packaging material was found using *Equation 2*.

Table 1

Construction of Corrugated Boards Evaluated

Liner/Medium/Liner g m^{-2}	Flute Types
220/120/220	B, C, E
120/120/120	C
160/120/160	B, E
290/120/290	B, E
290/160/220	B, C

Materials Tested and Results

Three materials with known thermal data were tested to evaluate the accuracy of the method. These were 243 µm polypropylene sheet, 500 µm PET sheet and a range of natural kraft papers of different weight per area ▶

Table 2

Experimental Thermal Conductivity Data Compared to Published Data

Material	Thermal Conductivity ($Wm^{-1}K^{-1}$) Experimental	Published
Natural kraft paper	0.079*	0.07[a]
Polypropylene (243 µm)	0.115	0.117-0.126[bcd]
PET (500 µm)	0.143	0.138-0.151[b]

* Mean value with a standard deviation of 0.006 $Wm^{-1}K^{-1}$

[a] Earle (*1983*) [b] Anon. (*1996*) [c] Milby (*1973*) [d] Hernandez (*1997*)

(grammage: 120, 160, 220, 290 gm^{-2}).

A range of corrugated paperboards were tested (Table 1).

The experimental thermal conductivitives for the three materials are compared with the published data in Table 2. The heat transfer resistance for the different corrugated paperboards tested are depicted in Table 3.

Table 3

Heat Transfer Resistance (R_p) of Corrugated Paperboard Samples

Flute	Grammage gm^{-2}	R_p $m^2K^{-1}W^{-1}$	95% Confidence Limits
E	160/120/160	0.026	0.007
	220/120/220	0.031	0.003
	220/120/220	0.032	0.005
	290/120/290	0.037	0.006
	290/120/290	0.036	0.006
B	160/120/160	0.064	0.009
	220/120/220	0.058	0.008
	220/120/220	0.058	0.005
	290/160/220	0.057	0.004
C	120/120/120	0.078	0.003
	220/120/220	0.075	0.006
	220/120/220	0.072	0.007
	290/160/220	0.077	0.006

Discussion

This method of determining the heat transfer resistance and thermal conductivity of packaging materials is simple and can produce reliable results. The simplicity and short run times (15 minutes) allow four experimental runs per hour. Sufficient data, including duplicates, can be collected within 90 minutes to determine heat transfer resistances and thermal conductivitives. The ASTM Guarded Hot Plate method usually requires several hours for the input and output temperatures to stabilize before a measurement can be taken.

Precautions needed were as follows:

a) The thermocouples on the surface of the Tylose sinking beneath the surface gave incorrect data.

b) The Tylose had to be proud of the surface of the insulation to ensure full connection between the Tylose, packaging material and the stainless steel plate.

c) The Tylose tended to dry and needed to be protected by an aluminum film and stored in a thick polyethylene bag.

d) Unreliable data were also obtained if the Tylose gel was uneven or had air voids in it.

Careful attention to these experimental conditions provided consistent heat transfer resistances and thermal conductivitives.

The method was used for 3-hour student lab sessions where sufficient data was obtained to compare two different corrugated paperboards. This experimental data was used to determine the chilling rates of 20 kg corrugated cases of cheddar cheese and provided consistent results.

Conclusion

The results (Table 3) indicate that flute size (E, B or C), not the different grammage liner paper, is a major contributor to insulation effectiveness. The thermal conductivity of the flute region has been calculated as 0.055 $Wm^{-1}K^{-1}$ compared to that of natural kraft paper of 0.079 $Wm^{-1}K^{-1}$. The flute thermal conductivity is about twice that for air, showing that the contribution of the medium paper to enhancing heat transfer is beyond that which would occur through a still air layer of the same thickness. ❑

For more information about this topic, contact the authors at +64 6 350 4941 or by e-mail at T.R.Robertson@massey.ac.nz. If this article is helpful in improving your packaging operation, **Circle 200** on Reader Service Card.

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PEER REVIEWED PAPER

Modelling the Heat Transfer Resistance of Corrugated Paperboard

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Abstract

The heat transfer resistance of corrugated paperboard is of vital interest to industries involved in chilling or freezing food in corrugated cases, and to the packaging companies supplying these industries. A method for measuring the heat transfer resistance and thermal conductivity of corrugated paperboards and their components is presented. The data obtained using this method are used to develop a model that predicts the heat transfer resistance of any corrugated paperboard of known construction. The usefulness of the overall approach in packaging selection is illustrated by means of a practical example.

Introduction

For industries involved in the chilling and freezing of foods in corrugated paperboard containers, the heat transfer resistance of the container material is important because it substantially affects the times required for processing. For example, as will be shown, the chilling time for a 20 kg block of cheese can increase by about 25% because of a change from solid paperboard to corrugated board. To calculate freezing and chilling times of packaged foods, the heat transfer resistance of the packaging material needs to be known with sufficient accuracy for design and control purposes. The existing ASTM method 177-45: Standard Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate, requires quite elaborate apparatus and considerable time for the temperatures to stabilise, usually several hours, before measurements can be taken (Milby, 1973). An inexpensive, simple and quick industrial method for measuring the thermal conductivity of packaging paperboards and thus determining the heat transfer resistance has been developed (Robertson *et al.*, 1998). In the present work, data obtained using this method are used to develop a model for predicting the thermal resistance of a wide range of corrugated paperboards to a level of accuracy satisfactory for most industrial applications.

This paper briefly discusses heat transfer resistance and the method used to measure it, and then develops the model from the data.

Thermal Conductivity and Heat Transfer Resistance

The fundamental equation for the heat flux from the ambient environment, through a packaging material constituting a container wall, to a food product is:

F.2

$$\frac{\phi}{A} = \lambda \frac{\Delta\theta}{x} = \frac{\Delta\theta}{R_{pk}} \qquad (1)$$

Where ϕ = the rate of heat transfer (W)
A = surface area (m^2)
$\Delta\theta$ = temperature difference across the container wall (K)
x = thickness of wall (m)
λ = thermal conductivity of the container wall ($Wm^{-1}K^{-1}$)
$R_{pk} = \frac{x}{\lambda}$, heat transfer resistance of the container wall (m^2KW^{-1})

Applied to a solid wall, λ is a fundamental property of the wall material. However, for a more complex structure such as corrugated paperboard this is not the case, and it is better to use the heat transfer, R_{pk}, to characterise the material.

The heat transfer resistance of a packaging material can be estimated by measuring the effective surface heat transfer coefficient of a block of known thermophysical properties whose surface is covered by the unknown packaging material (Robertson *et al.*, 1998). The method is both accurate and sensitive to changes in the surface heat transfer coefficient (Cleland 1990). This method involves analysis of measured time-temperature data for the surface of a block approximating a semi-infinite slab (a slab of infinite thickness) during short times after the onset of cooling or heating, via the layer of packaging material. By varying the number of sheets of packaging material and measuring the resulting changes in the surface heat transfer coefficient (h), the thermal resistance (R_{pk}) of a single layer of packaging material, and thus its effective thermal conductivity can be determined.

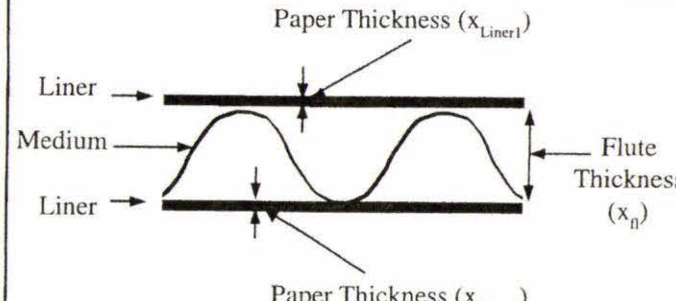
Corrugated paperboard is made up of layers of two paper liners and a medium (Fig. 1). Thus the overall resistance to heat transfer of a corrugated paperboard is the sum of a series of resistances:

$$R_{pk} = R_{Liner1} + R_{fl} + R_{Liner2} \qquad (2)$$

$$= \left(\frac{x}{\lambda}\right)_{Liner1} + R_{fl} + \left(\frac{x}{\lambda}\right)_{Liner2} \qquad (3)$$

If the individual values in eq. (3) can be determined for typical industrial corrugated paperboard components, then R_{pk} for any board can be estimated.

Figure 1: Structure of a single wallboard corrugated paperboard.



Equipment

The equipment (Fig. 2) used for determining surface heat transfer coefficients and thus the heat transfer resistance of a packaging material includes a thermostatically-controlled water bath with a stainless steel tray on top giving an isothermal surface. Tylose

MH-1000, a gel made from 77% water and 23% methylcellulose powder (Lot E1/2 20153, Hoechst A G, Frankfurt), was used as the block of known thermophysical properties. This, surrounded by polystyrene insulation on five of its six faces, approximates a semi infinite block. For temperatures between 2 °C and 30 °C, Tylose thermophysical properties are (Lovatt, 1992; Pham *et al.* 1994):

thermal conductivity 0.496 W $m^{-1}K^{-1}$;
specific heat capacity 4100 J $kg^{-1}K^{-1}$; and
density 1000 kg m^{-3}.

Test Method

The Tylose/polystyrene block was maintained in a chiller at 1 °C (θ_i). The single exposed face of the block was covered with insulation, to maintain a uniform initial temperature, before it was moved to the test equipment. The thermocouples were quickly connected to the data-logging system, the paperboard sample placed on the stainless steel plate on the water bath, and then the insulating cover of the exposed face of the Tylose block was quickly removed and the Tylose block placed on to the paperboard sample. A standard weight of 10 kg was placed on the Tylose block to ensure consistent contact between the stainless steel plate, paperboard sample, Tylose and thermocouples.

Temperatures were measured at the surface (qs), and base of the Tylose (qi), and the water temperature (qa) at 20 second intervals for 10-15 minutes. After paperboard sample removal, the positions of the thermocouples on the surface of the Tylose were checked; data from any that had sunk into the Tylose and thus were not located on the surface were discarded. The experiment was repeated with different numbers of sheets of packaging material. For thick corrugated paperboard (C flute) a maximum of three sheets was used whereas for other boards the maximum was five. These limits were chosen as those beyond which the effects of non-semi-infinite heat transfer became too significant to ignore.

Analysis of the data used the Goodman plot approach in the manner of Cleland and Earle (1976) and Goodman (1964). Robertson *et al.* (1998) provides details of the calculations and of the effectiveness of the method. The output parameter for each run was the total heat transfer resistance (the reciprocal of the overall heat transfer coefficient between the water in the waterbath and the Tylose surface). The slope of a plot of heat transfer resistance vs. number of sheets of packaging material is the heat transfer resistance of one layer of packaging material (R_{pk}).

Materials Tested

To develop a predictive model for the thermal resistance of corrugated paperboards a range of different corrugated paperboards, with different flute types, were tested (Table 1). Individual paper linerboards of different grammage (g m^{-2}) were also tested.

***Table 1:** The construction of the corrugated boards evaluated.*

Liner/Medium/Liner g m^{-2}	Flute Types
220/120/220	B, C, E
120/120/120	C
160/120/160	B, E
290/120/290	B, E
290/160/220	B, C

Results

The experimental heat transfer resistance data obtained, along with the relevant dimensions of the paper liner boards tested, are summarised in Table 2. Figure 3 is based on data similar to that shown in Table 2. The measured data for a number of corrugated paperboards are given in Table 3.

***Table 2:** Measured heat transfer resistances of common liner and medium papers used to manufacture corrugated paperboard.*

Paper Heat	Nominal Grammage (g m^{-2})	Average Thickness (mm)	Number of Samples Tested	Mean Heat Transfer Resistance R_{Liner} (m^2KW^{-1})
1	120	0.175	1	0.0022
2	160	0.236	2	0.0030
3	220	0.332	3	0.0042
6	290	0.437	2	0.0056

***Figure 2:** Schematic Diagram of the Equipment Used*

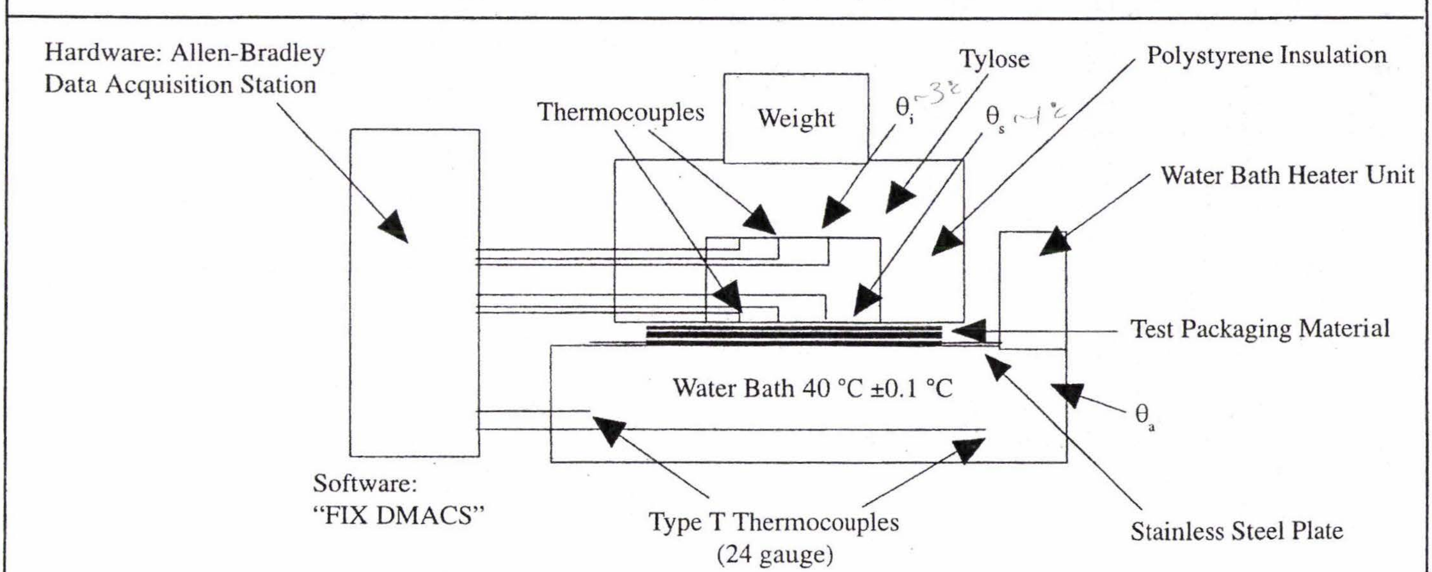
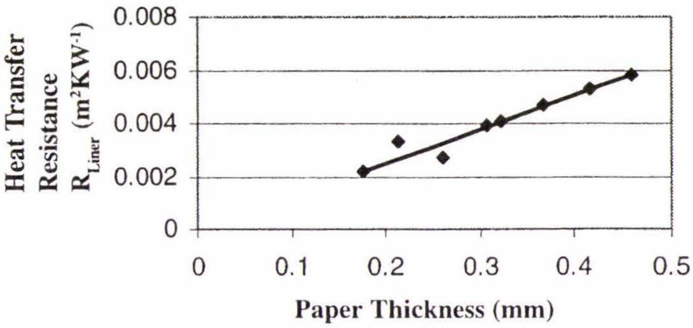


Figure 3: Heat transfer resistance of paper of different thickness.



The mean thermal conductivity of the paper linerboards calculated from the data in Table 2 was 0.079 $Wm^{-1}K^{-1}$ ±7.6% at 95% level of confidence.

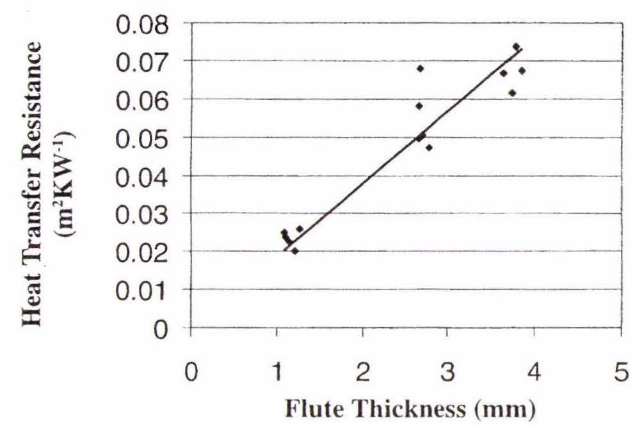
A corrugated board is constructed of layers of paper and flute (Fig. 1). The flute heat transfer resistance (R_{fl}) for each specific corrugated paperboard was calculated by rearranging Eq.3 as:

$$R_{fl} = R_{pk} - \left(\frac{x}{\lambda}\right)_{Liner1} - \left(\frac{x}{\lambda}\right)_{Liner2} \qquad (5)$$

and substituting relevant data from Tables 2 and 3.

The flute heat transfer resistance thus estimated (Table 3) was plotted vs. flute thickness to determine the relationship between these two factors (Fig. 4). As can be seen, the heat transfer resistance of the flute increases linearly with the flute thickness. The effective thermal conductivity was calculated from the slope of the line in Fig. 4 as λ_{fl} = 0.0526 $Wm^{-1}K^{-1}$ ± 10% at the 95% level of confidence, which is about twice the thermal conductivity of air, thus taking account of both the air and paper component the flute.

Figure 4: Plot of heat transfer resistance of the flute sections corrugated paperboards versus flute thickness.



Application

Generalising the results, the effective thermal conductivity for particular corrugated paperboard can be estimated by using th equation:

$$R_{pk} = R_{Liner1} + R_{fl} + R_{Liner2} \qquad (6)$$

Where R_{pk} is the effective heat transfer resistance of the corrugate paperboard packaging material.

Tables 6 and 7 give the best estimates of the various terms.

Table 3: Measured heat transfer resistances of a range of corrugated paperboards and flutes.

Types of Corrugated Paperboard		Heat Transfer Resistance R_{pk}	Thickness of Corrugated Paperboard x_{pk}	Combined Liner Thickness $x_{Liner1} + x_{Liner2}$	Flute Thickness x_{fl}*	Heat Transfer Resistance of Flute R_{fl}	Thermal Conductivity of Flute Section λ_{fl}
(Liner/medium /Liner) (gm^{-2})	Paper Grades & Flute Type	(m^2KW^{-1})	(mm)	(mm)	(mm)	(m^2KW^{-1})	($Wm^{-2}K^{-1}$)
220/120/220	313, E, NK**	0.032	1.75	0.663	1.087	0.0236	0.0461
220/120/220	313, C, NK	0.07	4.40	0.663	3.737	0.0616	0.0607
220/120/220	313, B, NK	0.058	3.31	0.663	2.647	0.0496	0.0534
220/120/220	313, E, OW1	0.031	1.80	0.663	1.137	0.0226	0.0504
220/120/220	313, C, OW1	0.075	4.31	0.663	3.647	0.0666	0.0548
220/120/220	313, B, OW1	0.059	3.35	0.663	2.687	0.0506	0.0531
120/120/120	111, C, NK	0.078	4.14	0.350	3.785	0.0736	0.0515
160/120/160	212, E, WL1	0.026	1.68	0.473	1.203	0.0200	0.0601
160/120/160	212, B, NK	0.064	3.12	0.473	2.648	0.0580	0.0457
290/120/290	616, E, NK	0.037	2.14	0.875	1.263	0.0259	0.0488
290/120/290	616, B, NK	0.079	3.54	0.875	2.66	0.0679	0.0392
290/120/290	616, E, OW1	0.036	1.95	0.875	1.075	0.0249	0.0432
290/160/220	623, C, WL1	0.077	4.63	0.769	3.856	0.0672	0.0574
290/160/220	623, B, OW1	0.057	3.55	0.769	2.781	0.0472	0.0589

* see Fig. 1 - Flute thickness xfl ** NK - natural kraft OW1 - oyster liner on one side WL1 - white liner on one side

Table 6: The heat transfer resistance of the common paper linerboards and flutes used to manufacture corrugated paperboard.

Paper Type (g m^{-2})	Average Thickness (mm)	Heat Transfer Resistance R_{Liner} (m^{2}KW^{-1})	Flute Type	Flute Thickness x_{fl} (mm)	Heat Transfer Resistance R_{fl} (m^{2}KW^{-1})
120	0.175	0.0022	E	1.153	0.023
160	0.236	0.0030	B	2.684	0.055
220	0.332	0.0042	C	3.756	0.068
290	0.437	0.0055			

For example, the thermal conductivity of a 313 C, NK corrugated paperboard would be:

$R_{pk} = R_{liner1}$ for 220 g m^{-2} paper + R_{fl} for C flute + R_{liner2} *for 200 g m^{-2} paper.*

Substituting the appropriate the heat transfer resistance data from Table 6:

$$R_{pk} = 0.0042 + 0.068 + 0.0042$$

$$= 0.0764 \text{ m}^2\text{KW}^{-1}$$

Now

$$R_{pk} = \frac{x_{pk}}{\lambda_{pk}}$$

so the effective thermal conductivity can be found:

$$\lambda_{pk} = 0.0044\text{m}/0.0764 \text{ m}^2\text{KW}^{-1}$$

$$= 0.058 \text{ Wm}^{-1}\text{K}^{-1}$$

The results will be useful for a manufacturer who wishes to make decisions on what sort of packaging would be the most suitable for any of their products, based on how much heat transfer can be tolerated. The effect of the type of the packaging on cooling rates of a packaged product can be circulated, as the following example of the cooling of a 20 kg carton of cheese in air at 0 °C flowing at 2.5 m s^{-1} shows. Comparisons are made of the rates of cooling of a 20 kg block of cheese from 36 °C to 5 °C packaged in either 626 B (290/160/290 g m^{-2}) corrugated paperboard, and the same thickness of solid paperboard. Cooling with no packaging has been calculated as a comparison. The method used to determine the centre temperature of the 20 kg block of cheese is outlined by Cleland (1990).

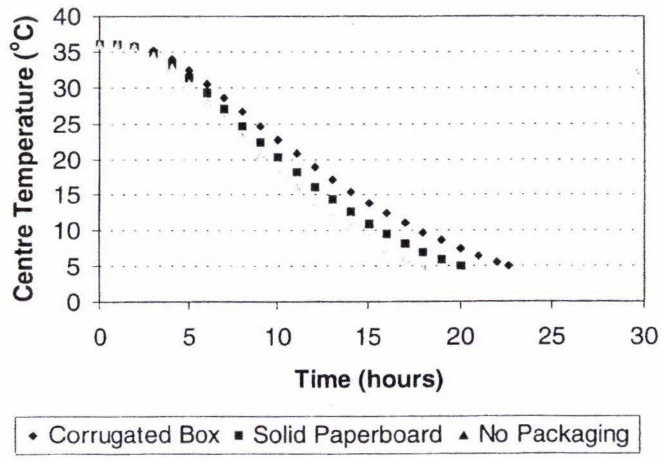
The effective surface heat transfer coefficient (h) for the packaged product is determined using the equation:

$$\frac{1}{h} = \frac{1}{h_{air}} + R_{pack} \qquad (6)$$

Where: h_{air} = 18.2 Wm^{-2}K^{-1} (set according to the air velocity)

The resulting cooling curves for the 20 kg cheese blocks are set out in Figure 5.

Figure 5: *The calculated cooling curves for a 20 kg block of cheddar cheese packaged in a 626 B corrugated box, in a solid paperboard box of similar thickness and not packaged.*



The times to reach 5 °C are 18.0 hours with no packaging, 19.8 hours with the solid paperboard, and 22.6 hours with the B flute corrugated paperboard. The slowing of the cooling rates can be quantitatively considered along with strength characteristics and costs when selecting an appropriate packaging material.

Conclusions

The additive approach to heat transfer resistance calculation, i.e. summing the heat transfer resistances of both linerboards and flutes, allows the total heat transfer resistance of any industrial corrugated paperboard to be determined to within about ± 10% at the 95% confidence level. This will facilitate improved quantitative design of both packaging and packaged food heat transfer equipment.

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F.3 Heat Transfer Results, Calculations and Graphs

Surface temperature of a semi-finite slab is accurately predicted by the following approximation:

$4/3(h/\lambda)^2 \lambda/\rho c = 1/\ 2Y_s^2 - ½ + \text{In } Y_s$ $h = \lambda \sqrt{¾\chi \rho c/ \lambda}$

Slope = χ = Rise / Run

Tylose thermo physical properties

$\lambda = 0.496\ Wm^{-1}K^{-1}$
$\rho = 1000\ Kgm^{-3}$
$c = 4100\ JKg^{-1}K^{-1}$

1 Layer of board

$$\text{Slope} = \chi = \frac{0.167441273 - 0.005510742}{1560}$$

$\chi = 0.000103802$

$h = 0.496 \sqrt{¾\ (0.000103802)\ 1000 \times 4100/0.496}$
h = 12.5824803

2 Layers of board

$$\text{Slope} = \chi = \frac{0.058805559 - 0.003485454}{1420}$$

$\chi = 0.000038958$

$h = 0.496 \sqrt{¾\ (0.000038958)\ 1000 \times 4100/0.496}$
h = 7.70835531

3 Layers of board

$$\text{Slope} = \chi = \frac{0.076400001 - 0.00288995}{1280}$$

$\chi = 0.00005743$

$h = 0.496 \sqrt{¾\ (0.00005743)\ 1000 \times 4100/0.496}$
h = 9.359072389

$$\text{Slope of } 1/h = \frac{0.106848196 - 0.079475731}{3 - 1}$$

Heat Transfers Resistance $R\rho = 0.0136\ m^2KW^{-1}$ for one layer of packaging

Using Table 3 and 6: Modelling the Heat Transfer Resistance of Corrugated Paperboard, Peer Reviewed Paper, The NZ Food Journal 29(3) by F Bilge Thompson, Tom R Robertson and Andrew C Cleland Massey University.

$R_{pk} = R_{liner1}$ for 220 gm^{-2} paper + R_{fl} for B flue + R_{liner2} for 220 gm^{-2} paper

$R_{pk} = 0.0042 + 0.0136 + 0.0042$
$= 0.022\ m^2KW^{-1}$ for 313, B, NK

$R_{pk} = \chi_{pk} / \lambda_{pk}$

$\lambda_{pk} = 0.00331m / 0.022\ m^2KW^{-1}$
$= 0.150\ Wm^{-1}K^{-1}$

1 Layer of board and 1 layer of adhesive tape

$$\text{Slope} = \chi = \frac{12.76 - 1.5}{1460}$$

$\chi = 0.007712329$

$h = 0.496 \sqrt{\tfrac{3}{4} (0.007712329)\ 1000 \times 4100/0.496}$
$h = 108.4566466$

2 Layers of board and 2 layers of adhesive tape

$$\text{Slope} = \chi = \frac{9.63 - 0.69}{1220}$$

$\chi = 0.007327869$

$h = 0.496 \sqrt{\tfrac{3}{4} (0.007327869)\ 1000 \times 4100/0.496}$
$h = 105.7188053$

3 Layers of board and 3 layers of adhesive tape

$$\text{Slope} = \chi = \frac{3.16 - 0.26}{1660}$$

$\chi = 0.001746988$

$h = 0.496 \sqrt{\tfrac{3}{4} (0.001746988)\ 1000 \times 4100/0.496}$
$h = 51.61885409$

$$\text{Slope of } 1/h = \frac{0.019372766 - 0.009220274}{3 - 1}$$

Heat Transfers Resistance $R\rho = 0.005\ m^2KW^{-1}$ for one layer of packaging with adhesive tape

$R_{pk} = R_{liner1}$ for 220 gm^{-2} paper + R_{fl} for B flue + R_{liner2} for 220 gm^{-2} paper

$R_{pk} = 0.0042 + 0.005 + 0.0042$
$= 0.0134\ m^2KW^{-1}$ for 313, B, NK

$R_{pk} = \chi_{pk} / \lambda_{pk}$

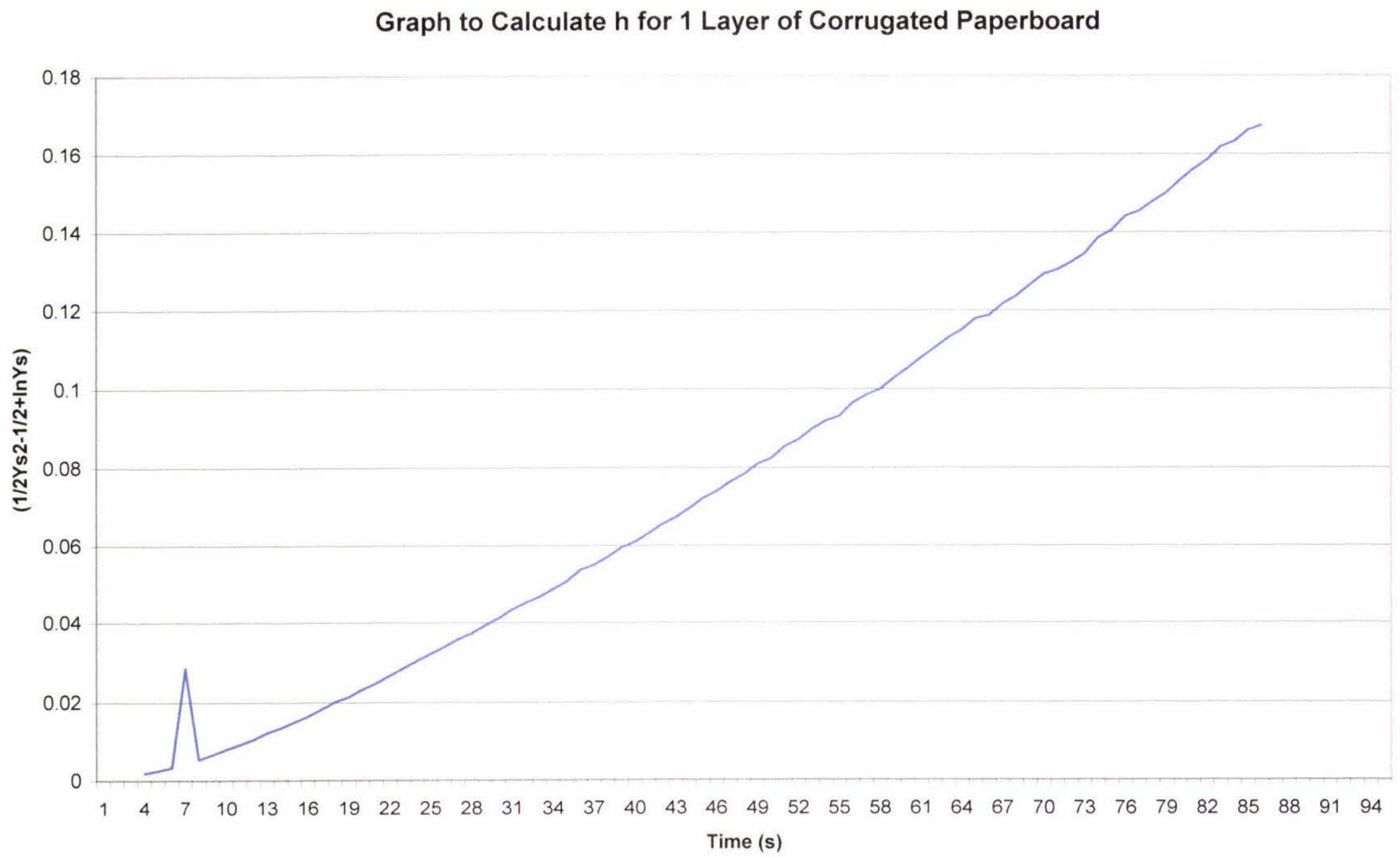
$\lambda_{pk} = 0.00331m / 0.0134\ m^2KW^{-1}$
$= 0.246\ Wm^{-1}K^{-1}$

1 Layer Corrugated Paperboard

Time	Oa	Oi		Os1	Os2	Os3	Os	Ys	1/2Ys2-1/2+lnYs
13:16:20	40.27	0.64	####	#####	#####	#####			
13:16:40	40.51	0.74	0.61	#####	#####	3.39			
13:17:00	40.63	0.84	0.76	231.9	1.45	4.1			
13:17:20	40.58	0.76	0.64	1.17	1.66	4.46	2.43	0.958061276	0.00188914
13:17:40	40.56	0.74	0.64	1.3	1.91	4.84	2.683	0.951197053	0.002589039
13:18:00	40.58	0.76	0.61	1.48	2.22	5.22	2.973	0.944416541	0.003398798
13:18:20	40.6	0.76	0.61	1.71	2.5	15.79	6.667	0.851740295	0.028742805
13:18:40	**40.34**	**0.51**	**0.41**	**1.68**	**2.52**	**5.68**	**3.293**	**0.930119675**	**0.005510742**
13:19:00	40.32	0.46	0.33	1.89	2.7	5.96	3.517	0.923314936	0.006718167
13:19:20	40.36	0.51	0.41	2.22	3.03	6.32	3.857	0.916018402	0.008165015
13:19:40	40.13	0.23	0.1	2.14	3.03	6.22	3.797	0.910609858	0.009342604
13:20:00	40.32	0.43	0.26	2.52	3.41	6.67	4.2	0.905490098	0.010542369
13:20:20	40.27	0.41	0.23	2.78	3.64	6.9	4.44	0.898896136	0.012213174
13:20:40	40.2	0.31	0.1	2.85	3.72	6.98	4.517	0.894543327	0.013395786
13:21:00	40.22	0.33	0.18	3.11	3.97	7.21	4.763	0.888861035	0.015037789
13:21:20	40.32	0.48	0.28	3.44	4.28	7.57	5.097	0.884119813	0.016495195
13:21:40	40.39	0.48	0.31	3.67	4.53	7.79	5.33	0.878476572	0.018336432
13:22:00	40.39	0.48	0.33	3.9	4.74	8	5.547	0.873047691	0.020220145
13:22:20	40.41	0.51	0.31	4.05	4.92	8.15	5.707	0.869757728	0.021416733
13:22:40	40.44	0.54	0.36	4.31	5.12	8.36	5.93	0.864912281	0.023256555
13:23:00	40.29	0.41	0.2	4.31	5.17	8.41	5.963	0.860748913	0.024912767
13:23:20	40.29	0.38	0.2	4.48	5.3	8.58	6.12	0.856176397	0.026814005
13:23:40	40.27	0.38	0.23	4.66	5.48	8.74	6.293	0.851759004	0.028734493
13:24:00	40.24	0.38	0.2	4.81	5.63	8.89	6.443	0.847884262	0.030488418
13:24:20	40.39	0.48	0.36	5.09	5.91	9.12	6.707	0.843982293	0.032321638
13:24:40	40.46	0.59	0.46	5.32	6.14	9.37	6.943	0.840648775	0.033942111
13:25:00	40.46	0.56	0.43	5.45	6.27	9.48	7.067	0.836925647	0.035812346
13:25:20	40.51	0.61	0.48	5.63	6.42	9.63	7.227	0.834168755	0.037239006
13:25:40	40.53	0.66	0.48	5.83	6.62	9.83	7.427	0.830281749	0.039312065
13:26:00	40.53	0.64	0.48	5.99	6.72	9.93	7.547	0.826857191	0.041199309
13:26:20	40.48	0.61	0.46	6.09	6.85	10.09	7.677	0.822757295	0.043535258
13:26:40	40.51	0.64	0.51	6.29	7.01	10.19	7.83	0.819663908	0.045354041
13:27:00	40.53	0.69	0.54	6.42	7.18	10.34	7.98	0.817018072	0.046948812
13:27:20	40.51	0.64	0.54	6.52	7.26	10.44	8.073	0.813560739	0.049088024
13:27:40	40.46	0.64	0.46	6.65	7.34	10.55	8.18	0.810647916	0.05093979
13:28:00	40.51	0.61	0.51	6.8	7.51	10.7	8.337	0.806349206	0.053756916
13:28:20	40.48	0.64	0.54	6.9	7.62	10.77	8.43	0.804467871	0.055022001
13:28:40	40.53	0.66	0.56	7.08	7.74	10.9	8.573	0.801521612	0.057043216
13:29:00	40.48	0.61	0.54	7.16	7.85	10.98	8.663	0.7980102	0.059516976
13:29:20	40.51	0.64	0.51	7.29	7.95	11.08	8.773	0.796003679	0.060962721
13:29:40	40.51	0.66	0.59	7.44	8.07	11.21	8.907	0.793057298	0.063128742
13:30:00	40.46	0.64	0.54	7.51	8.18	11.31	9	0.790055249	0.065389215
13:30:20	40.51	0.66	0.54	7.64	8.28	11.44	9.12	0.78770389	0.067198066
13:30:40	40.6	0.76	0.71	7.87	8.51	11.62	9.333	0.78480589	0.069474498
13:31:00	40.53	0.71	0.61	7.95	8.56	11.69	9.4	0.781767956	0.071917533
13:31:20	40.39	0.61	0.46	7.92	8.53	11.69	9.38	0.779537456	0.073748768
13:31:40	40.36	0.54	0.41	8	8.58	11.74	9.44	0.776494224	0.076299325
13:32:00	40.36	0.56	0.46	8.1	8.71	11.84	9.55	0.774120603	0.07833101
13:32:20	40.41	0.59	0.51	8.25	8.89	11.97	9.703	0.771136782	0.08093849
13:32:40	40.36	0.54	0.48	8.28	8.89	12	9.723	0.769378872	0.082502963

13:33:00	40.44	0.59	0.54	8.48	9.09	12.18	9.917	0.765955667	0.085610628	
13:33:20	40.39	0.59	0.56	8.56	9.12	12.25	9.977	0.764154104	0.087279023	
13:33:40	40.44	0.61	0.51	8.71	9.27	12.38	10.12	0.76123525	0.090031044	
13:34:00	40.58	0.79	0.74	8.97	9.53	12.61	10.37	0.759235989	0.091951408	
13:34:20	40.15	0.38	0.2	8.58	9.2	12.23	10	0.758025312	0.093128458	
13:34:40	40.15	0.31	0.26	8.69	9.27	12.3	10.09	0.75460174	0.09651547	
13:35:00	40.22	0.43	0.31	8.89	9.45	12.48	10.27	0.752617911	0.098518208	
13:35:20	40.39	0.64	0.46	9.14	9.71	12.74	10.53	0.751194969	0.099973077	
13:35:40	40.15	0.38	0.28	9.02	9.55	12.58	10.38	0.748470371	0.102802138	
13:36:00	40.15	0.38	0.28	9.12	9.65	12.66	10.48	0.746123544	0.105285175	
13:36:20	40.22	0.46	0.36	9.3	9.81	12.86	10.66	0.743544601	0.108063897	
13:36:40	40.05	0.26	0.23	9.22	9.71	12.74	10.56	0.741224763	0.110608914	
13:37:00	40.27	0.48	0.43	9.55	10.01	13.04	10.87	0.738962888	0.113132404	
13:37:20	40.27	0.54	0.43	9.68	10.14	13.12	10.98	0.737226277	0.115098419	
13:37:40	40.39	0.64	0.56	9.86	10.32	13.37	11.18	0.73475891	0.117934916	
13:38:00	40.13	0.36	0.26	9.63	10.09	13.09	10.94	0.734054145	0.118754519	
13:38:20	40.34	0.61	0.51	9.99	10.42	13.42	11.28	0.731521101	0.121735199	
13:38:40	40.22	0.48	0.43	9.96	10.34	13.35	11.22	0.72982721	0.123759195	
13:39:00	40.41	0.71	0.61	10.27	10.67	13.65	11.53	0.727455919	0.126634578	
13:39:20	40.46	0.71	0.69	10.37	10.77	13.76	11.63	0.725199161	0.129417146	
13:39:40	40.36	0.64	0.56	10.34	10.75	13.68	11.59	0.724320242	0.130513141	
13:40:00	40.29	0.56	0.46	10.34	10.72	13.65	11.57	0.722879436	0.132324841	
13:40:20	40.15	0.41	0.33	10.27	10.62	13.58	11.49	0.72118772	0.134476094	
13:40:40	40.34	0.66	0.61	10.62	11	13.93	11.85	0.717993952	0.138609157	
13:41:00	40.56	0.89	0.84	10.93	11.26	14.21	12.13	0.716578439	0.140471363	
13:41:20	40.34	0.64	0.61	10.8	11.11	14.09	12	0.713853904	0.144109009	
13:41:40	40.24	0.54	0.46	10.72	11.08	14.01	11.94	0.712930311	0.145358236	
13:42:00	40.1	0.41	0.31	10.67	11.03	13.93	11.88	0.711094314	0.147866036	
13:42:20	40.29	0.64	0.54	10.95	11.28	14.24	12.16	0.709541824	0.150012237	
13:42:40	40.08	0.41	0.36	10.85	11.13	14.09	12.02	0.707251491	0.153221863	
13:43:00	40.27	0.59	0.51	11.16	11.36	14.34	12.29	0.705225134	0.156105232	
13:43:20	40.27	0.54	0.51	11.16	11.41	14.37	12.31	0.703666415	0.158351428	
13:43:40	40.03	0.31	0.31	11.03	11.26	14.24	12.18	0.701242028	0.161894515	
13:44:00	40.2	0.51	0.48	11.28	11.49	14.44	12.4	0.700344335	0.163221853	
13:44:20	40.2	0.56	0.51	11.41	11.62	14.52	12.52	0.698368651	0.166172798	
13:44:40	**40.15**	**0.51**	**0.41**	**11.39**	**11.62**	**14.49**	**12.5**	**0.69752775**	**0.167441273**	**Highest**

t=1560 seconds



Graph to Calculate h for 1 Layer of Corrugated Paperboard
(1/2Ys2-1/2+lnYs)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94
Time (s)

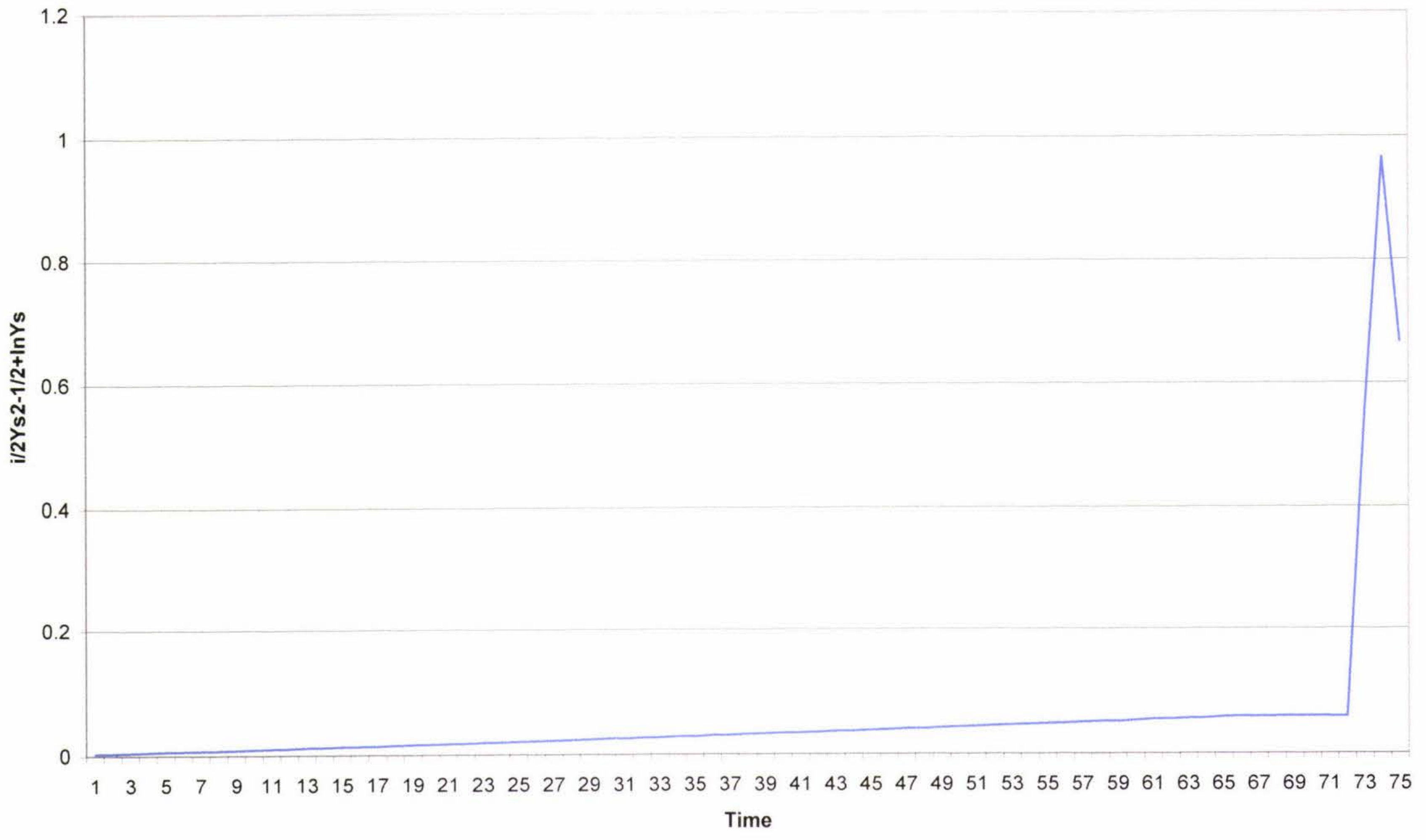
2 Layers Corrugated Paperboard

Time	Oa	Oi	Os1	Os2	Os3	Os	Ys	1/2Ys2-1/2+lnYs
13:48:00	**39.91**	**0.15**	**1.86**	**2.75**	**2.55**	**2.3867**	**0.94374581**	**0.003485454**
13:48:20	39.77	8.00E-02	1.99	2.8	2.65	2.48	0.93953137	0.004057477
13:48:40	39.93	0.23	2.27	3.13	2.96	2.7867	0.93560034	0.004634519
13:49:00	39.93	0.2	2.52	3.29	3.18	2.9967	0.92960819	0.00559685
13:49:20	39.93	0.15	2.67	3.44	3.29	3.1333	0.92500419	0.006405846
13:49:40	39.93	0.15	2.8	3.57	3.36	3.2433	0.92223898	0.006921487
13:50:00	39.96	0.18	2.93	3.72	3.46	3.37	0.91980895	0.007393372
13:50:20	39.96	0.18	3.08	3.82	3.62	3.5067	0.91637339	0.008090892
13:50:40	39.91	0.13	3.16	3.9	3.67	3.5767	0.9133568	0.008733142
13:51:00	39.81	3.00E-02	3.21	3.95	3.74	3.6333	0.90941847	0.009614325
13:51:20	39.93	0.13	3.44	4.18	3.97	3.8633	0.90619765	0.010371549
13:51:40	39.93	0.1	3.54	4.28	4.02	3.9467	0.90342288	0.011050763
13:52:00	39.55	-3.10E-01	3.31	3.97	3.8	3.6933	0.89956514	0.012037088
13:52:20	40.1	0.28	4	4.66	4.51	4.39	0.89678553	0.012778567
13:52:40	40.2	0.38	4.25	4.87	4.66	4.5933	0.89419052	0.013494471
13:53:00	39.93	0.13	4.05	4.69	4.46	4.4	0.89271357	0.013912259
13:53:20	39.86	8.00E-02	4.08	4.71	4.51	4.4333	0.89056477	0.014533619
13:53:40	39.91	8.00E-02	4.28	4.92	4.66	4.62	0.88601557	0.015902781
13:54:00	39.96	0.18	4.46	5.07	4.84	4.79	0.88411262	0.016497468
13:54:20	39.93	0.13	4.51	5.07	4.89	4.8233	0.88207705	0.017148157
13:54:40	39.86	0.00E+00	4.48	5.07	4.87	4.8067	0.87941127	0.018023326
13:55:00	40.03	0.23	4.81	5.35	5.12	5.0933	0.8778057	0.018563176
13:55:20	40.08	0.26	4.97	5.48	5.3	5.25	0.87468609	0.019639843
13:55:40	39.98	0.18	4.97	5.48	5.27	5.24	0.87286432	0.020285734
13:56:00	39.98	0.18	5.07	5.55	5.35	5.3233	0.87077052	0.021043886
13:56:20	39.93	0.13	5.15	5.6	5.37	5.3733	0.86825796	0.021976249
13:56:40	39.98	0.2	5.3	5.71	5.55	5.52	0.86626445	0.022733734
13:57:00	39.98	0.2	5.4	5.81	5.66	5.6233	0.86366683	0.023744617
13:57:20	39.98	0.15	5.45	5.86	5.68	5.6633	0.86157837	0.024577163
13:57:40	39.96	0.13	5.58	5.91	5.76	5.75	0.85890033	0.025670921
13:58:00	39.96	0.18	5.63	5.99	5.83	5.8167	0.85830401	0.025918512
13:58:20	39.98	0.18	5.76	6.09	5.91	5.92	0.85577889	0.026983422
13:58:40	39.98	0.2	5.86	6.14	5.99	5.9967	0.85428188	0.027627458
13:59:00	39.93	0.13	5.91	6.19	6.01	6.0367	0.85159129	0.028809057
13:59:20	40.03	0.2	6.09	6.32	6.16	6.1133	0.85153569	0.028833801
13:59:40	39.96	0.15	6.09	6.32	6.19	6.2	0.84802813	0.030422118
14:00:00	40.03	0.26	6.32	6.47	6.32	6.37	0.84636661	0.031193376
14:00:20	40.01	0.2	6.37	6.52	6.37	6.42	0.84375785	0.03242916
14:00:40	40.03	0.23	6.5	6.62	6.47	6.53	0.84170854	0.033421454
14:01:00	39.93	0.2	6.5	6.62	6.47	6.53	0.84067455	0.033929385
14:01:20	39.98	0.23	6.6	6.72	6.55	6.6233	0.83916143	0.034681541
14:01:40	40.03	0.26	6.72	6.8	6.65	6.7233	0.83748219	0.035528681
14:02:00	40.03	0.23	6.8	6.85	6.72	6.79	0.83517588	0.036713667
14:02:20	39.96	0.2	6.85	6.83	6.72	6.8	0.83400402	0.037325392
14:02:40	40.01	0.23	6.95	6.95	6.85	6.9167	0.83190883	0.038435443
14:03:00	39.98	0.23	7.06	7.01	6.88	6.9833	0.83010482	0.039408162
14:03:20	40.01	0.23	7.18	7.08	7.01	7.09	0.82755153	0.040812001
14:03:40	39.98	0.28	7.23	7.11	7.06	7.1333	0.82737196	0.040911941
14:04:00	40.03	0.26	7.34	7.21	7.11	7.22	0.82499371	0.042250599
14:04:20	39.93	0.2	7.36	7.21	7.13	7.2333	0.82297173	0.043410989
14:04:40	40.03	0.28	7.51	7.36	7.26	7.3767	0.82146751	0.044287656
14:05:00	40.08	0.33	7.67	7.46	7.36	7.4967	0.8197065	0.045328666
14:05:20	40.08	0.36	7.77	7.54	7.46	7.59	0.81797583	0.046367322
14:05:40	40.1	0.38	7.85	7.59	7.57	7.67	0.81646526	0.047286631

14:06:00	40.13	0.38	7.95	7.64	7.59	7.7267	0.8151782	0.048079362	
14:06:20	40.08	0.33	7.97	7.64	7.62	7.7433	0.81350105	0.049125515	
14:06:40	40.05	0.33	8.02	7.69	7.69	7.8	0.81193353	0.050116855	
14:07:00	40.17	0.48	8.28	7.87	7.87	8.0067	0.81036365	0.051122958	
14:07:20	40.01	0.31	8.13	7.72	7.72	7.8567	0.80990764	0.05141771	
14:07:40	40.03	0.28	8.23	7.82	7.77	7.94	0.8072956	0.053127975	
14:08:00	40.01	0.31	8.36	7.9	7.87	8.0433	0.80520571	0.054523491	
14:08:20	39.98	0.31	8.36	7.9	7.9	8.0533	0.80480632	0.054792955	
14:08:40	40.05	0.33	8.48	7.95	8	8.1433	0.80328969	0.055824366	
14:09:00	40.01	0.31	8.53	7.97	8	8.1667	0.80209908	0.056643179	
14:09:20	39.96	0.23	8.58	7.97	8.02	8.19	0.79964762	0.058354573	
14:09:40	39.93	0.26	8.58	8.02	8.13	8.2433	0.79875641	0.058985316	
14:10:00	39.98	0.26	8.58	8.02	8.13	8.2433	0.79900973	0.058805559	
14:10:20	39.96	0.26	8.58	8.02	8.13	8.2433	0.79890848	0.058877363	
14:10:40	39.91	0.26	8.58	8.02	8.13	8.2433	0.7986549	0.05905745	
14:11:00	39.84	0.26	8.58	8.02	8.13	8.2433	0.7982988	0.059310966	
14:11:20	39.91	0.26	8.58	8.02	8.13	8.2433	0.7986549	0.05905745	
14:11:40	**39.98**	**0.26**	**8.58**	**8.02**	**8.13**	**8.2433**	**0.79900973**	**0.058805559**	**Highest**
14:12:00	18.05	0.26	8.58	8.02	8.13	8.2433	0.55124602	0.549854644	
14:12:20	15.49	0.26	8.58	8.02	8.13	8.2433	0.47581528	0.965753258	
14:12:40	15.54	1.66	8.58	8.02	8.13	8.2433	0.52569645	0.666224257	

t=1420 Seconds

Graph to calculate h for 2 layers of Corrugated Paperboard



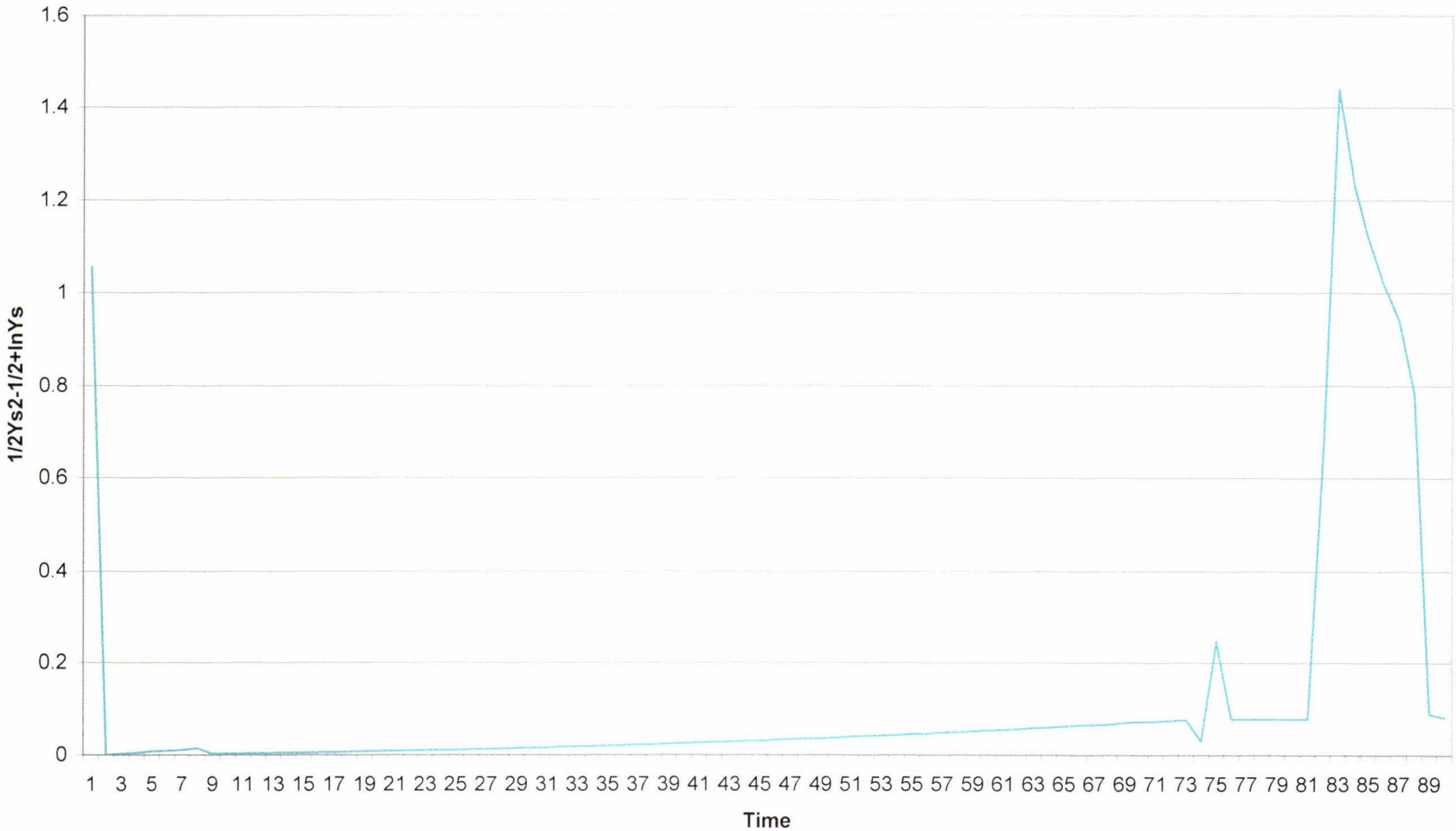
3 Layers Corruagted Paperboard

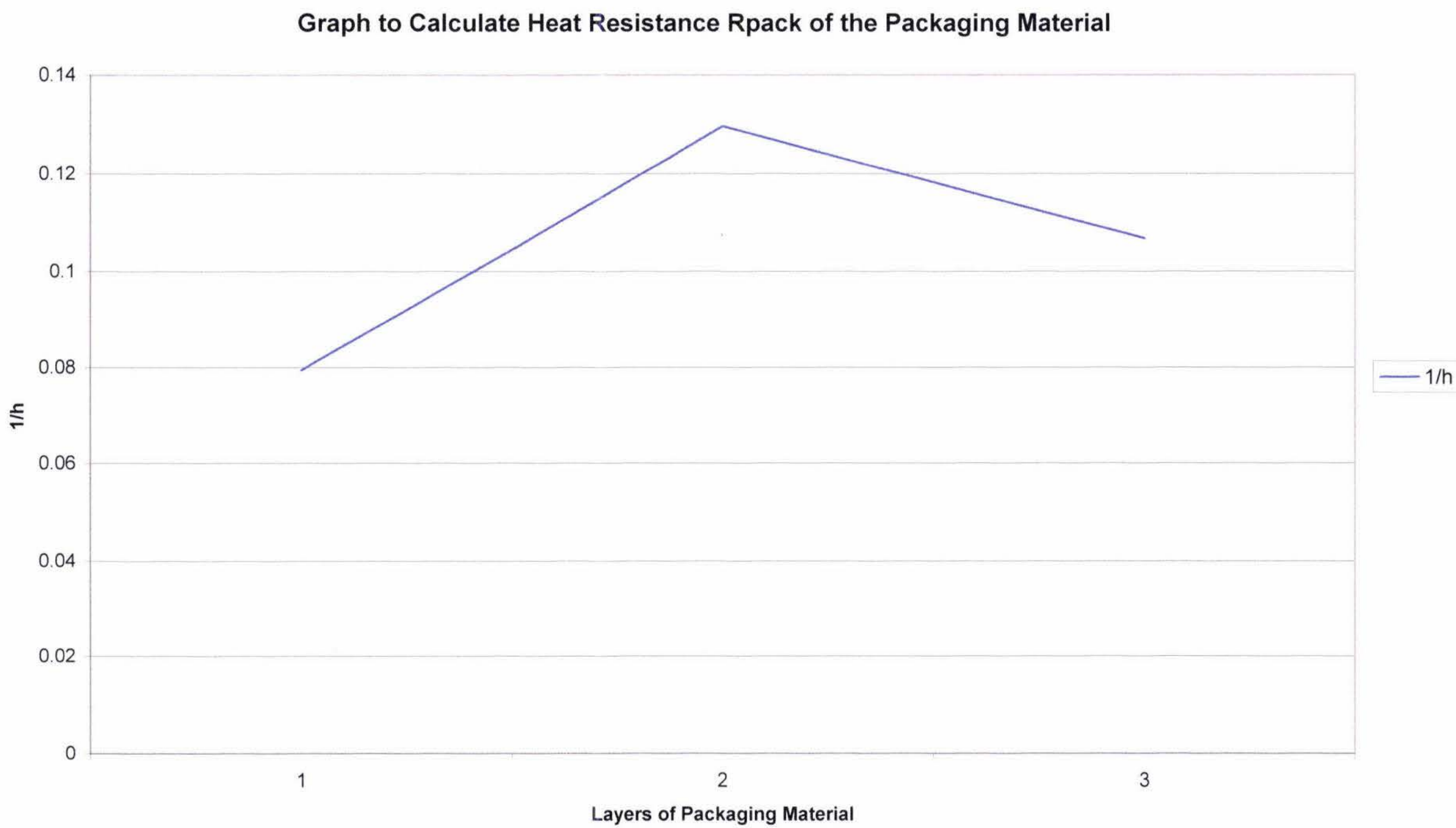
Time	Oa	Oi1	Oi2	Oi	Os		Ys
14:13:00	15.77	0.38	0.15	0.265	8.58	168.32	0.463721
14:13:20	15.87	105.23	0.13	52.68	1.1	49.76	-0.40125
14:13:40	17.04	0.71	0.18	0.445	1.3	44.19	0.948478
14:14:00	16.96	0.61	0.13	0.37	1.48	40.03	0.933092
14:14:20	16.96	0.54	0.1	0.32	1.68	37.76	0.918269
14:14:40	17.07	0.54	0.1	0.32	1.83	35.58	0.909851
14:15:00	17.55	0.82	0.41	0.615	2.24	35.96	0.904045
14:15:20	17.14	0.41	8.00E-02	2.45E-01	2.09	37.88	0.890796
14:15:40	**39.58**	**0.33**	**0.1**	**0.215**	**2.24**	**36.78**	**0.948558**
14:16:00	39.98	0.33	0.13	0.23	2.37	34.55	0.946164
14:16:20	39.96	0.26	8.00E-02	1.70E-01	2.47	33.55	0.942197
14:16:40	39.96	0.18	8.00E-02	1.30E-01	2.55	32.54	0.939242
14:17:00	39.98	0.2	0.1	0.15	2.73	32.06	0.935225
14:17:20	39.98	0.18	0.1	0.14	2.8	31.93	0.933233
14:17:40	40.03	0.26	0.18	0.22	3.03	32.01	0.929415
14:18:00	39.98	0.18	0.1	0.14	3.03	32.64	0.92746
14:18:20	40.01	0.23	0.18	0.205	3.18	32.01	0.925261
14:18:40	40.03	0.23	0.18	0.205	3.36	30.88	0.920778
14:19:00	40.08	0.28	0.18	0.23	3.49	30.93	0.918193
14:19:20	40.01	0.2	0.13	0.165	3.57	30.44	0.914544
14:19:40	39.98	0.2	0.13	0.165	3.64	30.86	0.912721
14:20:00	39.98	0.2	0.13	0.165	3.77	30.71	0.909456
14:20:20	40.01	0.23	0.13	0.18	3.92	31	0.906101
14:20:40	40.01	0.2	0.15	0.175	3.97	30.61	0.904732
14:21:00	40.03	0.26	0.18	0.22	4.1	30.73	0.902537
14:21:20	39.96	0.15	0.1	0.125	4.15	30.59	0.898958
14:21:40	39.98	0.23	0.15	0.19	4.33	30.46	0.895954
14:22:00	39.98	0.18	0.13	0.155	4.38	30.9	0.893911
14:22:20	39.96	0.18	0.1	0.14	4.51	31.25	0.890256
14:22:40	40.01	0.23	0.13	0.18	4.66	31.03	0.887522
14:23:00	39.93	0.15	0.1	0.125	4.71	31.17	0.884813
14:23:20	39.96	0.2	0.15	0.175	4.92	31.32	0.880734
14:23:40	40.03	0.23	0.18	0.205	5.04	30.81	0.878594
14:24:00	40.01	0.26	0.18	0.22	5.17	30.93	0.875597
14:24:20	39.98	0.2	0.15	0.175	5.22	31.12	0.873257
14:24:40	40.01	0.23	0.2	0.215	5.35	31.54	0.870964
14:25:00	39.96	0.18	0.15	0.165	5.4	31.71	0.868451
14:25:20	39.98	0.2	0.2	0.2	5.55	31.71	0.86551
14:25:40	39.89	0.13	0.1	0.115	5.58	32.2	0.862602
14:26:00	40.05	0.33	0.31	0.32	5.86	31.76	0.860559
14:26:20	40.05	0.26	0.26	0.26	5.96	33.53	0.856748
14:26:40	40.05	0.28	0.28	0.28	6.06	32.38	0.854664
14:27:00	40.01	0.28	0.26	0.27	6.14	32.57	0.85229
14:27:20	40.08	0.31	0.28	0.295	6.32	32.47	0.848561
14:27:40	40.03	0.31	0.28	0.295	6.37	33.21	0.847112
14:28:00	40.03	0.28	0.28	0.28	6.52	32.95	0.843019
14:28:20	40.03	0.28	0.31	0.295	6.6	33.24	0.841324
14:28:40	40.01	0.28	0.28	0.28	6.7	33.33	0.838409
14:29:00	39.96	0.26	0.23	0.245	6.72	32.54	0.836963
14:29:20	40.01	0.31	0.28	0.295	6.88	32.76	0.834194
14:29:40	40.03	0.28	0.28	0.28	7.01	33.48	0.830692
14:30:00	40.03	0.28	0.28	0.28	7.13	32.59	0.827673
14:30:20	40.03	0.28	0.31	0.295	7.21	33.38	0.825972
14:30:40	40.08	0.36	0.33	0.345	7.36	33.88	0.823455

14:31:00	40.1	0.41	0.38	0.395	7.51	33.57	0.820803	0.044678355
14:31:20	40.05	0.36	0.36	0.36	7.54	34.34	0.819098	0.045692081
14:31:40	40.08	0.36	0.36	0.36	7.69	34.77	0.815458	0.047906153
14:32:00	40.03	0.33	0.31	0.32	7.72	34.7	0.813649	0.049032653
14:32:20	40.03	0.31	0.36	0.335	7.85	33.93	0.810681	0.050918213
14:32:40	40.03	0.36	0.33	0.345	7.97	33.64	0.807862	0.05275399
14:33:00	40.03	0.33	0.36	0.345	8.07	34.17	0.805342	0.054431696
14:33:20	40.03	0.31	0.31	0.31	8.15	35.94	0.802618	0.056285089
14:33:40	39.98	0.28	0.28	0.28	8.23	36.3	0.799748	0.058283741
14:34:00	40.03	0.38	0.36	0.37	8.38	36.23	0.798033	0.059500481
14:34:20	39.98	0.33	0.31	0.32	8.46	37.11	0.794755	0.061874076
14:34:40	39.96	0.28	0.28	0.28	8.53	38.74	0.792087	0.06385363
14:35:00	39.96	0.31	0.28	0.295	8.61	38.93	0.790369	0.065150151
14:35:20	39.93	0.33	0.33	0.33	8.71	37.81	0.788384	0.066671504
14:35:40	40.01	0.33	0.33	0.33	8.89	36.2	0.784274	0.06989786
14:36:00	39.96	0.33	0.33	0.33	8.94	36.42	0.78274	0.071129185
14:36:20	40.01	0.36	0.36	0.36	9.02	36.37	0.781589	0.072063355
14:36:40	39.96	0.33	0.36	0.345	9.12	36.56	0.778493	0.074617323
14:37:00	**40.03**	**0.41**	**0.41**	**0.41**	**9.27**	**35.99**	**0.776376**	**0.076400001**
14:37:20	39.96	7.29	0.31	3.8	9.27	43.59	0.848728	0.030100956
14:37:40	26.07	0.38	0.33	0.355	9.27	43.59	0.653315	0.245756407
14:38:00	39.93	0.38	0.33	0.355	9.27	43.59	0.774732	0.077804519
14:38:20	40.03	0.38	0.33	0.355	9.27	43.59	0.775299	0.077317431
14:38:40	40.01	0.38	0.33	0.355	9.27	43.59	0.775186	0.077414481
14:39:00	39.98	0.38	0.33	0.355	9.27	43.59	0.775016	0.077560399
14:39:20	39.98	0.38	0.33	0.355	9.27	43.59	0.775016	0.077560399
14:39:40	39.93	0.38	0.33	0.355	9.27	43.59	0.774732	0.077804519
14:40:00	19.25	0.38	0.33	0.355	9.27	43.59	0.528182	0.653952778
14:40:20	15.79	0.38	0.33	0.355	9.27	43.59	0.422417	1.440365432
14:40:40	16.35	0.38	0.33	0.355	9.27	43.59	0.442638	1.236946657
14:41:00	16.76	0.38	0.33	0.355	9.27	43.59	0.456568	1.114588204
14:41:20	17.14	0.38	0.33	0.355	9.27	43.59	0.468871	1.016953496
14:41:40	17.47	0.38	0.33	0.355	9.27	43.59	0.479112	0.942370621
14:42:00	18.32	0.38	0.33	0.355	9.27	43.59	0.503757	0.784616343
14:42:20	37.83	0.38	0.33	0.355	9.27	43.59	0.762108	0.089201721
14:42:40	39.93	0.18	0.13	0.155	9.27	43.59	0.770836	0.08120472

t=1280 seconds

Graph to calculate h for 3 layers of Corrugated Paperboard





Graph to Calculate Heat Resistance Rpack of the Packaging Material
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1/h
1
2
3
Layers of Packaging Material
1/h

;
; Intellution Historical Data Report
; Generated 6/6/2002 4:00:41 PM
; Start Time: 6/6/02 13:00:00
; Duration: 00:03:00:00
; Interval: 00:00:20
; Historical Input Data path: C:\WDMACS\HTRDATA
; Retrieva (A)verage (H)igh (L)ow (R)aw
;

Date	Time	FIX:TC0	FIX:TC1.	FIX:TC2.F	FIX:TC4	FIX:TC5	FIX:TC6.F_CV (S)
6/06/2002	13:00:00	???	???	???	???	???	???
6/06/2002	13:00:20	???	???	???	???	???	???
6/06/2002	13:00:40	???	???	???	???	???	???
6/06/2002	13:01:00	???	???	???	???	???	???
6/06/2002	13:01:20	???	???	???	???	???	???
6/06/2002	13:01:40	???	???	???	???	???	???
6/06/2002	13:02:00	???	???	???	???	???	???
6/06/2002	13:02:20	???	???	???	???	???	???
6/06/2002	13:02:40	???	???	???	???	???	???
6/06/2002	13:03:00	???	???	???	???	???	???
6/06/2002	13:03:20	???	???	???	???	???	???
6/06/2002	13:03:40	???	???	???	???	???	???
6/06/2002	13:04:00	???	???	???	???	???	???
6/06/2002	13:04:20	???	???	???	???	???	???
6/06/2002	13:04:40	???	???	???	???	???	???
6/06/2002	13:05:00	???	???	???	???	???	???
6/06/2002	13:05:20	???	???	???	???	???	???
6/06/2002	13:05:40	???	???	???	???	???	???
6/06/2002	13:06:00	???	???	???	???	???	???
6/06/2002	13:06:20	???	???	???	???	???	???
6/06/2002	13:06:40	???	???	???	???	???	???
6/06/2002	13:07:00	???	???	???	???	???	???
6/06/2002	13:07:20	???	???	???	???	???	???
6/06/2002	13:07:40	???	???	???	???	???	???
6/06/2002	13:08:00	40.6	#######	-1.00E+02	#######	#######	########
6/06/2002	13:08:20	40.6	#######	-1.00E+02	#######	#######	########
6/06/2002	13:08:40	???	???	???	???	???	???
6/06/2002	13:09:00	40.72	#######	-1.00E+02	#######	#######	########
6/06/2002	13:09:20	40.7	#######	-1.00E+02	#######	#######	########
6/06/2002	13:09:40	40.63	#######	-1.00E+02	#######	#######	########
6/06/2002	13:10:00	40.7	#######	-1.00E+02	#######	#######	########
6/06/2002	13:10:20	40.63	#######	-1.00E+02	#######	#######	########
6/06/2002	13:10:40	40.58	#######	-1.00E+02	#######	#######	########
6/06/2002	13:11:00	40.63	#######	-1.00E+02	#######	#######	########
6/06/2002	13:11:20	40.6	#######	-1.00E+02	#######	#######	########
6/06/2002	13:11:40	40.56	#######	-1.00E+02	#######	#######	########
6/06/2002	13:12:00	40.46	#######	-1.00E+02	#######	#######	########
6/06/2002	13:12:20	40.51	#######	-1.00E+02	#######	#######	########
6/06/2002	13:12:40	40.48	#######	-1.00E+02	#######	#######	########
6/06/2002	13:13:00	40.44	#######	-1.00E+02	#######	#######	########
6/06/2002	13:13:20	40.46	#######	-1.00E+02	#######	#######	########
6/06/2002	13:13:40	40.41	#######	-1.00E+02	#######	#######	########
6/06/2002	13:14:00	40.41	#######	-1.00E+02	#######	#######	########
6/06/2002	13:14:20	40.46	#######	-1.00E+02	#######	#######	########
6/06/2002	13:14:40	40.46	#######	-1.00E+02	#######	#######	########
6/06/2002	13:15:00	40.41	#######	-1.00E+02	#######	#######	########

6/06/2002	13:15:20	40.56	#######	-1.00E+02	#######	#######	########
6/06/2002	13:15:40	40.39	#######	-1.00E+02	#######	#######	########
6/06/2002	13:16:00	40.39	#######	-1.00E+02	#######	#######	########
6/06/2002	13:16:20	40.27	0.64	-1.00E+02	#######	#######	########
6/06/2002	13:16:40	40.51	0.74	0.61	#######	#######	3.39
6/06/2002	13:17:00	40.63	0.84	0.76	231.91	1.45	4.1
6/06/2002	13:17:20	40.58	0.76	0.64	1.17	1.66	4.46
6/06/2002	13:17:40	40.56	0.74	0.64	1.3	1.91	4.84
6/06/2002	13:18:00	40.58	0.76	0.61	1.48	2.22	5.22
6/06/2002	13:18:20	40.6	0.76	0.61	1.71	2.5	15.79
6/06/2002	13:18:40	40.34	0.51	0.41	1.68	2.52	5.68
6/06/2002	13:19:00	40.32	0.46	0.33	1.89	2.7	5.96
6/06/2002	13:19:20	40.36	0.51	0.41	2.22	3.03	6.32
6/06/2002	13:19:40	40.13	0.23	0.1	2.14	3.03	6.22
6/06/2002	13:20:00	40.32	0.43	0.26	2.52	3.41	6.67
6/06/2002	13:20:20	40.27	0.41	0.23	2.78	3.64	6.9
6/06/2002	13:20:40	40.2	0.31	0.1	2.85	3.72	6.98
6/06/2002	13:21:00	40.22	0.33	0.18	3.11	3.97	7.21
6/06/2002	13:21:20	40.32	0.48	0.28	3.44	4.28	7.57
6/06/2002	13:21:40	40.39	0.48	0.31	3.67	4.53	7.79
6/06/2002	13:22:00	40.39	0.48	0.33	3.9	4.74	8
6/06/2002	13:22:20	40.41	0.51	0.31	4.05	4.92	8.15
6/06/2002	13:22:40	40.44	0.54	0.36	4.31	5.12	8.36
6/06/2002	13:23:00	40.29	0.41	0.2	4.31	5.17	8.41
6/06/2002	13:23:20	40.29	0.38	0.2	4.48	5.3	8.58
6/06/2002	13:23:40	40.27	0.38	0.23	4.66	5.48	8.74
6/06/2002	13:24:00	40.24	0.38	0.2	4.81	5.63	8.89
6/06/2002	13:24:20	40.39	0.48	0.36	5.09	5.91	9.12
6/06/2002	13:24:40	40.46	0.59	0.46	5.32	6.14	9.37
6/06/2002	13:25:00	40.46	0.56	0.43	5.45	6.27	9.48
6/06/2002	13:25:20	40.51	0.61	0.48	5.63	6.42	9.63
6/06/2002	13:25:40	40.53	0.66	0.48	5.83	6.62	9.83
6/06/2002	13:26:00	40.53	0.64	0.48	5.99	6.72	9.93
6/06/2002	13:26:20	40.48	0.61	0.46	6.09	6.85	10.09
6/06/2002	13:26:40	40.51	0.64	0.51	6.29	7.01	10.19
6/06/2002	13:27:00	40.53	0.69	0.54	6.42	7.18	10.34
6/06/2002	13:27:20	40.51	0.64	0.54	6.52	7.26	10.44
6/06/2002	13:27:40	40.46	0.64	0.46	6.65	7.34	10.55
6/06/2002	13:28:00	40.51	0.61	0.51	6.8	7.51	10.7
6/06/2002	13:28:20	40.48	0.64	0.54	6.9	7.62	10.77
6/06/2002	13:28:40	40.53	0.66	0.56	7.08	7.74	10.9
6/06/2002	13:29:00	40.48	0.61	0.54	7.16	7.85	10.98
6/06/2002	13:29:20	40.51	0.64	0.51	7.29	7.95	11.08
6/06/2002	13:29:40	40.51	0.66	0.59	7.44	8.07	11.21
6/06/2002	13:30:00	40.46	0.64	0.54	7.51	8.18	11.31
6/06/2002	13:30:20	40.51	0.66	0.54	7.64	8.28	11.44
6/06/2002	13:30:40	40.6	0.76	0.71	7.87	8.51	11.62
6/06/2002	13:31:00	40.53	0.71	0.61	7.95	8.56	11.69
6/06/2002	13:31:20	40.39	0.61	0.46	7.92	8.53	11.69
6/06/2002	13:31:40	40.36	0.54	0.41	8	8.58	11.74
6/06/2002	13:32:00	40.36	0.56	0.46	8.1	8.71	11.84
6/06/2002	13:32:20	40.41	0.59	0.51	8.25	8.89	11.97
6/06/2002	13:32:40	40.36	0.54	0.48	8.28	8.89	12
6/06/2002	13:33:00	40.44	0.59	0.54	8.48	9.09	12.18
6/06/2002	13:33:20	40.39	0.59	0.56	8.56	9.12	12.25
6/06/2002	13:33:40	40.44	0.61	0.51	8.71	9.27	12.38

6/06/2002	13:52:40	40.2	0.38	0.26	4.25	4.87	4.66
6/06/2002	13:53:00	39.93	0.13	-3.00E-02	4.05	4.69	4.46
6/06/2002	13:53:20	39.86	8.00E-02	-1.00E-01	4.08	4.71	4.51
6/06/2002	13:53:40	39.91	8.00E-02	-3.00E-02	4.28	4.92	4.66
6/06/2002	13:54:00	39.96	0.18	3.00E-02	4.46	5.07	4.84
6/06/2002	13:54:20	39.93	0.13	0.00E+00	4.51	5.07	4.89
6/06/2002	13:54:40	39.86	0.00E+00	-1.30E-01	4.48	5.07	4.87
6/06/2002	13:55:00	40.03	0.23	8.00E-02	4.81	5.35	5.12
6/06/2002	13:55:20	40.08	0.26	0.13	4.97	5.48	5.3
6/06/2002	13:55:40	39.98	0.18	8.00E-02	4.97	5.48	5.27
6/06/2002	13:56:00	39.98	0.18	3.00E-02	5.07	5.55	5.35
6/06/2002	13:56:20	39.93	0.13	0.00E+00	5.15	5.6	5.37
6/06/2002	13:56:40	39.98	0.2	3.00E-02	5.3	5.71	5.55
6/06/2002	13:57:00	39.98	0.2	5.00E-02	5.4	5.81	5.66
6/06/2002	13:57:20	39.98	0.15	3.00E-02	5.45	5.86	5.68
6/06/2002	13:57:40	39.96	0.13	3.00E-02	5.58	5.91	5.76
6/06/2002	13:58:00	39.96	0.18	5.00E-02	5.63	5.99	5.83
6/06/2002	13:58:20	39.98	0.18	3.00E-02	5.76	6.09	5.91
6/06/2002	13:58:40	39.98	0.2	5.00E-02	5.86	6.14	5.99
6/06/2002	13:59:00	39.93	0.13	3.00E-02	5.91	6.19	6.01
6/06/2002	13:59:20	40.03	0.2	8.00E-02	6.09	6.32	6.16
6/06/2002	13:59:40	39.96	0.15	3.00E-02	6.09	6.32	6.19
6/06/2002	14:00:00	40.03	0.26	0.13	6.32	6.47	6.32
6/06/2002	14:00:20	40.01	0.2	8.00E-02	6.37	6.52	6.37
6/06/2002	14:00:40	40.03	0.23	0.1	6.5	6.62	6.47
6/06/2002	14:01:00	39.93	0.2	3.00E-02	6.5	6.62	6.47
6/06/2002	14:01:20	39.98	0.23	3.00E-02	6.6	6.72	6.55
6/06/2002	14:01:40	40.03	0.26	8.00E-02	6.72	6.8	6.65
6/06/2002	14:02:00	40.03	0.23	0.1	6.8	6.85	6.72
6/06/2002	14:02:20	39.96	0.2	3.00E-02	6.85	6.83	6.72
6/06/2002	14:02:40	40.01	0.23	5.00E-02	6.95	6.95	6.85
6/06/2002	14:03:00	39.98	0.23	8.00E-02	7.06	7.01	6.88
6/06/2002	14:03:20	40.01	0.23	0.1	7.18	7.08	7.01
6/06/2002	14:03:40	39.98	0.28	0.1	7.23	7.11	7.06
6/06/2002	14:04:00	40.03	0.26	0.1	7.34	7.21	7.11
6/06/2002	14:04:20	39.93	0.2	5.00E-02	7.36	7.21	7.13
6/06/2002	14:04:40	40.03	0.28	0.15	7.51	7.36	7.26
6/06/2002	14:05:00	40.08	0.33	0.18	7.67	7.46	7.36
6/06/2002	14:05:20	40.08	0.36	0.26	7.77	7.54	7.46
6/06/2002	14:05:40	40.1	0.38	0.28	7.85	7.59	7.57
6/06/2002	14:06:00	40.13	0.38	0.23	7.95	7.64	7.59
6/06/2002	14:06:20	40.08	0.33	0.23	7.97	7.64	7.62
6/06/2002	14:06:40	40.05	0.33	0.18	8.02	7.69	7.69
6/06/2002	14:07:00	40.17	0.48	0.36	8.28	7.87	7.87
6/06/2002	14:07:20	40.01	0.31	0.15	8.13	7.72	7.72
6/06/2002	14:07:40	40.03	0.28	0.18	8.23	7.82	7.77
6/06/2002	14:08:00	40.01	0.31	0.18	8.36	7.9	7.87
6/06/2002	14:08:20	39.98	0.31	0.15	8.36	7.9	7.9
6/06/2002	14:08:40	40.05	0.33	0.2	8.48	7.95	8
6/06/2002	14:09:00	40.01	0.31	0.18	8.53	7.97	8
6/06/2002	14:09:20	39.96	0.23	0.13	8.58	7.97	8.02
6/06/2002	14:09:40	39.93	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:10:00	39.98	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:10:20	39.96	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:10:40	39.91	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:11:00	39.84	0.26	0.13	8.58	8.02	8.13

6/06/2002	13:34:00	40.58	0.79	0.74	8.97	9.53	12.61
6/06/2002	13:34:20	40.15	0.38	0.2	8.58	9.2	12.23
6/06/2002	13:34:40	40.15	0.31	0.26	8.69	9.27	12.3
6/06/2002	13:35:00	40.22	0.43	0.31	8.89	9.45	12.48
6/06/2002	13:35:20	40.39	0.64	0.46	9.14	9.71	12.74
6/06/2002	13:35:40	40.15	0.38	0.28	9.02	9.55	12.58
6/06/2002	13:36:00	40.15	0.38	0.28	9.12	9.65	12.66
6/06/2002	13:36:20	40.22	0.46	0.36	9.3	9.81	12.86
6/06/2002	13:36:40	40.05	0.26	0.23	9.22	9.71	12.74
6/06/2002	13:37:00	40.27	0.48	0.43	9.55	10.01	13.04
6/06/2002	13:37:20	40.27	0.54	0.43	9.68	10.14	13.12
6/06/2002	13:37:40	40.39	0.64	0.56	9.86	10.32	13.37
6/06/2002	13:38:00	40.13	0.36	0.26	9.63	10.09	13.09
6/06/2002	13:38:20	40.34	0.61	0.51	9.99	10.42	13.42
6/06/2002	13:38:40	40.22	0.48	0.43	9.96	10.34	13.35
6/06/2002	13:39:00	40.41	0.71	0.61	10.27	10.67	13.65
6/06/2002	13:39:20	40.46	0.71	0.69	10.37	10.77	13.76
6/06/2002	13:39:40	40.36	0.64	0.56	10.34	10.75	13.68
6/06/2002	13:40:00	40.29	0.56	0.46	10.34	10.72	13.65
6/06/2002	13:40:20	40.15	0.41	0.33	10.27	10.62	13.58
6/06/2002	13:40:40	40.34	0.66	0.61	10.62	11	13.93
6/06/2002	13:41:00	40.56	0.89	0.84	10.93	11.26	14.21
6/06/2002	13:41:20	40.34	0.64	0.61	10.8	11.11	14.09
6/06/2002	13:41:40	40.24	0.54	0.46	10.72	11.08	14.01
6/06/2002	13:42:00	40.1	0.41	0.31	10.67	11.03	13.93
6/06/2002	13:42:20	40.29	0.64	0.54	10.95	11.28	14.24
6/06/2002	13:42:40	40.08	0.41	0.36	10.85	11.13	14.09
6/06/2002	13:43:00	40.27	0.59	0.51	11.16	11.36	14.34
6/06/2002	13:43:20	40.27	0.54	0.51	11.16	11.41	14.37
6/06/2002	13:43:40	40.03	0.31	0.31	11.03	11.26	14.24
6/06/2002	13:44:00	40.2	0.51	0.48	11.28	11.49	14.44
6/06/2002	13:44:20	40.2	0.56	0.51	11.41	11.62	14.52
6/06/2002	13:44:40	40.15	0.51	0.41	11.39	11.62	14.49
6/06/2002	13:45:00	40.2	0.54	0.54	25.7	11.69	14.57
6/06/2002	13:45:20	40.05	7.87	0.51	25.7	11.69	14.57
6/06/2002	13:45:40	40.1	7.87	0.51	25.7	11.69	14.57
6/06/2002	13:46:00	40.17	7.87	0.51	25.7	11.69	14.57
6/06/2002	13:46:20	40.05	7.87	0.51	25.7	11.69	14.57
6/06/2002	13:46:40	40.2	7.87	0.51	25.7	11.69	14.57
6/06/2002	13:47:00	39.96	0.33	0.13	25.7	11.69	14.57
6/06/2002	13:47:20	39.93	0.36	0.13	25.7	11.69	2.37
6/06/2002	13:47:40	40.03	0.28	0.18	25.7	2.45	2.62
6/06/2002	13:48:00	39.91	0.15	0.00E+00	1.86	2.75	2.55
6/06/2002	13:48:20	39.77	8.00E-02	-8.00E-02	1.99	2.8	2.65
6/06/2002	13:48:40	39.93	0.23	5.00E-02	2.27	3.13	2.96
6/06/2002	13:49:00	39.93	0.2	8.00E-02	2.52	3.29	3.18
6/06/2002	13:49:20	39.93	0.15	3.00E-02	2.67	3.44	3.29
6/06/2002	13:49:40	39.93	0.15	3.00E-02	2.8	3.57	3.36
6/06/2002	13:50:00	39.96	0.18	0.00E+00	2.93	3.72	3.46
6/06/2002	13:50:20	39.96	0.18	0.00E+00	3.08	3.82	3.62
6/06/2002	13:50:40	39.91	0.13	-5.00E-02	3.16	3.9	3.67
6/06/2002	13:51:00	39.81	3.00E-02	-1.50E-01	3.21	3.95	3.74
6/06/2002	13:51:20	39.93	0.13	-3.00E-02	3.44	4.18	3.97
6/06/2002	13:51:40	39.93	0.1	-5.00E-02	3.54	4.28	4.02
6/06/2002	13:52:00	39.55	#######	-4.10E-01	3.31	3.97	3.8
6/06/2002	13:52:20	40.1	0.28	0.2	4	4.66	4.51

6/06/2002	14:11:20	39.91	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:11:40	39.98	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:12:00	18.05	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:12:20	15.49	0.26	0.13	8.58	8.02	8.13
6/06/2002	14:12:40	15.54	1.66	0.15	8.58	8.02	8.13
6/06/2002	14:13:00	15.77	0.38	0.15	8.58	168.32	########
6/06/2002	14:13:20	15.87	105.23	0.13	1.1	49.76	########
6/06/2002	14:13:40	17.04	0.71	0.18	1.3	44.19	########
6/06/2002	14:14:00	16.96	0.61	0.13	1.48	40.03	########
6/06/2002	14:14:20	16.96	0.54	0.1	1.68	37.76	########
6/06/2002	14:14:40	17.07	0.54	0.1	1.83	35.58	########
6/06/2002	14:15:00	17.55	0.82	0.41	2.24	35.96	########
6/06/2002	14:15:20	17.14	0.41	8.00E-02	2.09	37.88	########
6/06/2002	14:15:40	39.58	0.33	0.1	2.24	36.78	########
6/06/2002	14:16:00	39.98	0.33	0.13	2.37	34.55	########
6/06/2002	14:16:20	39.96	0.26	8.00E-02	2.47	33.55	########
6/06/2002	14:16:40	39.96	0.18	8.00E-02	2.55	32.54	########
6/06/2002	14:17:00	39.98	0.2	0.1	2.73	32.06	########
6/06/2002	14:17:20	39.98	0.18	0.1	2.8	31.93	########
6/06/2002	14:17:40	40.03	0.26	0.18	3.03	32.01	########
6/06/2002	14:18:00	39.98	0.18	0.1	3.03	32.64	########
6/06/2002	14:18:20	40.01	0.23	0.18	3.18	32.01	########
6/06/2002	14:18:40	40.03	0.23	0.18	3.36	30.88	########
6/06/2002	14:19:00	40.08	0.28	0.18	3.49	30.93	########
6/06/2002	14:19:20	40.01	0.2	0.13	3.57	30.44	########
6/06/2002	14:19:40	39.98	0.2	0.13	3.64	30.86	########
6/06/2002	14:20:00	39.98	0.2	0.13	3.77	30.71	########
6/06/2002	14:20:20	40.01	0.23	0.13	3.92	31	########
6/06/2002	14:20:40	40.01	0.2	0.15	3.97	30.61	########
6/06/2002	14:21:00	40.03	0.26	0.18	4.1	30.73	########
6/06/2002	14:21:20	39.96	0.15	0.1	4.15	30.59	########
6/06/2002	14:21:40	39.98	0.23	0.15	4.33	30.46	########
6/06/2002	14:22:00	39.98	0.18	0.13	4.38	30.9	########
6/06/2002	14:22:20	39.96	0.18	0.1	4.51	31.25	########
6/06/2002	14:22:40	40.01	0.23	0.13	4.66	31.03	########
6/06/2002	14:23:00	39.93	0.15	0.1	4.71	31.17	########
6/06/2002	14:23:20	39.96	0.2	0.15	4.92	31.32	########
6/06/2002	14:23:40	40.03	0.23	0.18	5.04	30.81	########
6/06/2002	14:24:00	40.01	0.26	0.18	5.17	30.93	########
6/06/2002	14:24:20	39.98	0.2	0.15	5.22	31.12	########
6/06/2002	14:24:40	40.01	0.23	0.2	5.35	31.54	########
6/06/2002	14:25:00	39.96	0.18	0.15	5.4	31.71	########
6/06/2002	14:25:20	39.98	0.2	0.2	5.55	31.71	########
6/06/2002	14:25:40	39.89	0.13	0.1	5.58	32.2	########
6/06/2002	14:26:00	40.05	0.33	0.31	5.86	31.76	########
6/06/2002	14:26:20	40.05	0.26	0.26	5.96	33.53	########
6/06/2002	14:26:40	40.05	0.28	0.28	6.06	32.38	########
6/06/2002	14:27:00	40.01	0.28	0.26	6.14	32.57	########
6/06/2002	14:27:20	40.08	0.31	0.28	6.32	32.47	########
6/06/2002	14:27:40	40.03	0.31	0.28	6.37	33.21	########
6/06/2002	14:28:00	40.03	0.28	0.28	6.52	32.95	########
6/06/2002	14:28:20	40.03	0.28	0.31	6.6	33.24	########
6/06/2002	14:28:40	40.01	0.28	0.28	6.7	33.33	########
6/06/2002	14:29:00	39.96	0.26	0.23	6.72	32.54	########
6/06/2002	14:29:20	40.01	0.31	0.28	6.88	32.76	########
6/06/2002	14:29:40	40.03	0.28	0.28	7.01	33.48	########

6/06/2002	14:30:00	40.03	0.28	0.28	7.13	32.59	########
6/06/2002	14:30:20	40.03	0.28	0.31	7.21	33.38	########
6/06/2002	14:30:40	40.08	0.36	0.33	7.36	33.88	########
6/06/2002	14:31:00	40.1	0.41	0.38	7.51	33.57	########
6/06/2002	14:31:20	40.05	0.36	0.36	7.54	34.34	########
6/06/2002	14:31:40	40.08	0.36	0.36	7.69	34.77	########
6/06/2002	14:32:00	40.03	0.33	0.31	7.72	34.7	########
6/06/2002	14:32:20	40.03	0.31	0.36	7.85	33.93	########
6/06/2002	14:32:40	40.03	0.36	0.33	7.97	33.64	########
6/06/2002	14:33:00	40.03	0.33	0.36	8.07	34.17	########
6/06/2002	14:33:20	40.03	0.31	0.31	8.15	35.94	########
6/06/2002	14:33:40	39.98	0.28	0.28	8.23	36.3	########
6/06/2002	14:34:00	40.03	0.38	0.36	8.38	36.23	########
6/06/2002	14:34:20	39.98	0.33	0.31	8.46	37.11	########
6/06/2002	14:34:40	39.96	0.28	0.28	8.53	38.74	########
6/06/2002	14:35:00	39.96	0.31	0.28	8.61	38.93	########
6/06/2002	14:35:20	39.93	0.33	0.33	8.71	37.81	########
6/06/2002	14:35:40	40.01	0.33	0.33	8.89	36.2	########
6/06/2002	14:36:00	39.96	0.33	0.33	8.94	36.42	########
6/06/2002	14:36:20	40.01	0.36	0.36	9.02	36.37	########
6/06/2002	14:36:40	39.96	0.33	0.36	9.12	36.56	########
6/06/2002	14:37:00	40.03	0.41	0.41	9.27	35.99	########
6/06/2002	14:37:20	39.96	7.29	0.31	9.27	43.59	########
6/06/2002	14:37:40	26.07	0.38	0.33	9.27	43.59	########
6/06/2002	14:38:00	39.93	0.38	0.33	9.27	43.59	########
6/06/2002	14:38:20	40.03	0.38	0.33	9.27	43.59	########

Corrugated Paperboard with Adhesive Tape

6/06/2002	14:38:40	40.01	0.38	0.33	9.27	43.59	########	
6/06/2002	14:39:00	39.98	0.38	0.33	9.27	43.59	########	
6/06/2002	14:39:20	39.98	0.38	0.33	9.27	43.59	########	
6/06/2002	14:39:40	39.93	0.38	0.33	9.27	43.59	########	
6/06/2002	14:40:00	19.25	0.38	0.33	9.27	43.59	########	
6/06/2002	14:40:20	15.79	0.38	0.33	9.27	43.59	########	
6/06/2002	14:40:40	16.35	0.38	0.33	9.27	43.59	########	
6/06/2002	14:41:00	16.76	0.38	0.33	9.27	43.59	########	
6/06/2002	14:41:20	17.14	0.38	0.33	9.27	43.59	########	
6/06/2002	14:41:40	17.47	0.38	0.33	9.27	43.59	########	
6/06/2002	14:42:00	18.32	0.38	0.33	9.27	43.59	########	
6/06/2002	14:42:20	37.83	0.38	0.33	9.27	43.59	########	
6/06/2002	14:42:40	39.93	0.18	0.13	9.27	43.59	########	
6/06/2002	**14:43:00**	**40.01**	**0.15**	**0.1**	**9.27**	**#######**	**1.5**	**Lowest 1**
6/06/2002	14:43:20	39.93	0.1	3.00E-02	1.3	0.33	2.04	**Layer**
6/06/2002	14:43:40	40.01	0.15	3.00E-02	1.86	0.59	2.73	
6/06/2002	14:44:00	39.96	8.00E-02	0.00E+00	2.27	0.79	3.26	
6/06/2002	14:44:20	39.96	8.00E-02	0.00E+00	2.67	1.04	3.72	
6/06/2002	14:44:40	39.96	8.00E-02	-5.00E-02	3.01	1.27	4.1	
6/06/2002	14:45:00	40.01	0.1	-3.00E-02	3.36	1.53	4.51	
6/06/2002	14:45:20	39.98	5.00E-02	-5.00E-02	3.64	1.73	4.81	
6/06/2002	14:45:40	40.01	5.00E-02	-5.00E-02	3.95	1.96	5.15	
6/06/2002	14:46:00	40.01	5.00E-02	-5.00E-02	4.23	2.19	5.48	
6/06/2002	14:46:20	40.03	8.00E-02	-8.00E-02	4.48	2.42	5.76	
6/06/2002	14:46:40	40.03	8.00E-02	-5.00E-02	4.74	2.62	6.01	
6/06/2002	14:47:00	39.93	0.00E+00	-1.00E-01	4.87	2.75	6.22	
6/06/2002	14:47:20	40.01	5.00E-02	-1.00E-01	5.15	2.98	6.5	
6/06/2002	14:47:40	40.03	3.00E-02	-8.00E-02	5.32	3.11	6.7	
6/06/2002	14:48:00	40.01	0.00E+00	-8.00E-02	5.53	3.34	6.93	

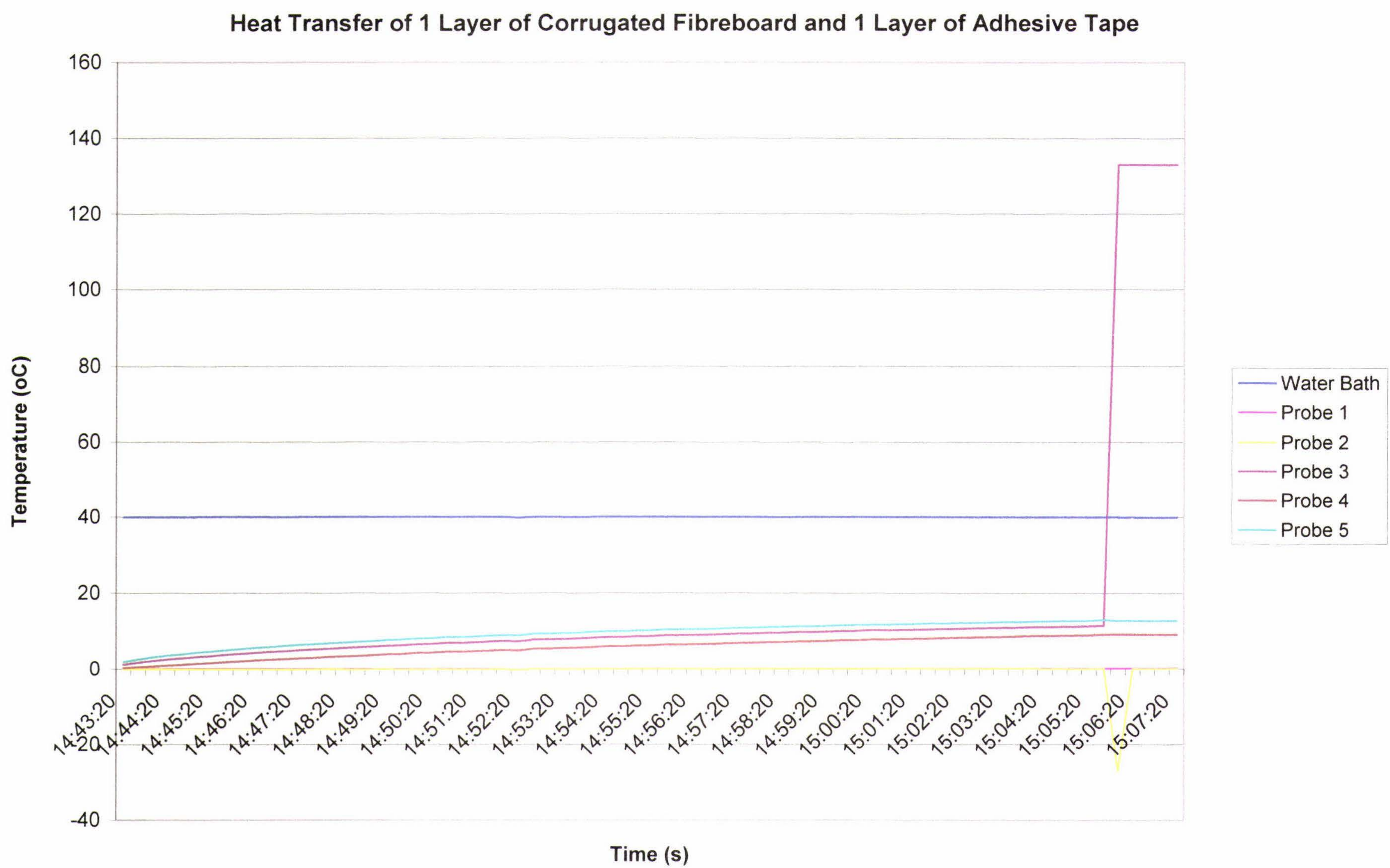
6/06/2002	15:07:00	39.96	0.13	3.00E-02	133.05	9.27	12.76	
6/06/2002	**15:07:20**	**40.03**	**0.28**	**0.13**	**133.05**	**9.27**	**12.76**	**Highest 1**
6/06/2002	15:07:40	40.03	0.18	0.00E+00	42.04	2.22	########	**Layer**
6/06/2002	15:08:00	40.01	0.15	-3.00E-02	14.88	2.32	########	
6/06/2002	15:08:20	40.03	0.15	-3.00E-02	19.06	2.45	########	
6/06/2002	15:08:40	40.03	0.18	5.00E-02	13.73	2.7	########	
6/06/2002	15:09:00	40.05	0.13	-3.00E-02	14.88	2.85	########	
6/06/2002	15:09:20	40.03	0.1	0.00E+00	15.18	3.01	########	
6/06/2002	15:09:40	40.01	0.13	0.00E+00	15.84	3.13	########	
6/06/2002	15:10:00	40.05	8.00E-02	-5.00E-02	13.27	3.24	########	
6/06/2002	15:10:20	39.98	3.00E-02	-8.00E-02	10.75	3.36	########	
6/06/2002	15:10:40	40.01	5.00E-02	-5.00E-02	10.42	3.49	########	
6/06/2002	15:11:00	40.01	5.00E-02	-5.00E-02	9.5	3.59	########	
6/06/2002	**15:11:20**	**39.98**	**0.00E+00**	**-8.00E-02**	**6.29**	**3.72**	**0.69**	**Lowest 2**
6/06/2002	15:11:40	40.05	8.00E-02	0.00E+00	4.59	3.92	2.7	**Layer**
6/06/2002	15:12:00	40.01	0.00E+00	-8.00E-02	1.58	3.97	6.04	
6/06/2002	15:12:20	40.03	3.00E-02	-5.00E-02	4.28	4.08	3.29	
6/06/2002	15:12:40	40.05	5.00E-02	0.00E+00	5.3	4.23	2.75	
6/06/2002	15:13:00	39.93	#######	-1.00E-01	3.01	4.23	5.04	
6/06/2002	15:13:20	40.01	0.00E+00	-5.00E-02	3.11	4.38	4.99	
6/06/2002	15:13:40	40.03	0.00E+00	-5.00E-02	2.01	4.51	6.6	
6/06/2002	15:14:00	40.01	#######	-3.00E-02	2.75	4.61	5.91	
6/06/2002	15:14:20	40.01	0.00E+00	-5.00E-02	4.87	4.69	3.82	
6/06/2002	15:14:40	40.03	0.00E+00	-5.00E-02	2.67	4.76	6.34	
6/06/2002	15:15:00	40.01	#######	-3.00E-02	4.18	4.84	5.17	
6/06/2002	15:15:20	40.01	3.00E-02	0.00E+00	2.62	4.94	6.67	
6/06/2002	15:15:40	40.01	0.00E+00	-3.00E-02	2.22	5.02	7.34	
6/06/2002	15:16:00	40.05	3.00E-02	3.00E-02	0.2	5.15	9.32	
6/06/2002	15:16:20	39.98	#######	-8.00E-02	#######	5.2	9.96	
6/06/2002	15:16:40	39.98	0.00E+00	-3.00E-02	#######	5.3	12.89	
6/06/2002	15:17:00	40.03	3.00E-02	-3.00E-02	#######	5.37	13.22	
6/06/2002	15:17:20	40.05	3.00E-02	0.00E+00	#######	5.45	12.58	
6/06/2002	15:17:40	40.01	3.00E-02	-3.00E-02	#######	5.53	12.86	
6/06/2002	15:18:00	40.03	3.00E-02	0.00E+00	#######	5.6	12.51	
6/06/2002	15:18:20	40.01	#######	-3.00E-02	#######	5.66	12.41	
6/06/2002	15:18:40	40.03	5.00E-02	3.00E-02	#######	5.78	12.94	
6/06/2002	15:19:00	40.01	0.00E+00	-3.00E-02	#######	5.81	11.72	
6/06/2002	15:19:20	40.03	3.00E-02	0.00E+00	#######	5.94	12.99	
6/06/2002	15:19:40	40.01	0.00E+00	0.00E+00	#######	5.96	11.28	
6/06/2002	15:20:00	40.03	3.00E-02	0.00E+00	#######	6.04	12.81	
6/06/2002	15:20:20	40.08	8.00E-02	5.00E-02	0.13	6.19	11.59	
6/06/2002	15:20:40	40.01	0.00E+00	0.00E+00	#######	6.19	14.6	
6/06/2002	15:21:00	40.01	3.00E-02	3.00E-02	#######	6.24	12.1	
6/06/2002	15:21:20	40.03	0.00E+00	0.00E+00	#######	6.32	13.45	
6/06/2002	15:21:40	40.03	5.00E-02	3.00E-02	#######	6.42	12.66	
6/06/2002	15:22:00	40.03	8.00E-02	5.00E-02	#######	6.5	12.35	
6/06/2002	15:22:20	39.98	0.00E+00	0.00E+00	#######	6.47	12.99	
6/06/2002	15:22:40	40.08	8.00E-02	5.00E-02	#######	6.62	13.12	
6/06/2002	15:23:00	40.03	5.00E-02	5.00E-02	#######	6.67	12.58	
6/06/2002	15:23:20	40.01	0.00E+00	0.00E+00	0.71	6.7	11.92	
6/06/2002	15:23:40	40.08	8.00E-02	8.00E-02	0.69	6.78	12.2	
6/06/2002	15:24:00	40.03	5.00E-02	8.00E-02	0.94	6.85	11.84	
6/06/2002	15:24:20	39.98	3.00E-02	5.00E-02	1.76	6.88	11.23	
6/06/2002	15:24:40	40.01	8.00E-02	8.00E-02	4.84	6.95	8.33	
6/06/2002	15:25:00	40.01	5.00E-02	8.00E-02	3.26	7.06	10.06	
6/06/2002	15:25:20	40.01	3.00E-02	3.00E-02	5.35	7.11	8.13	

6/06/2002	14:48:20	40.01	0.00E+00	-8.00E-02	5.73	3.49	7.13
6/06/2002	14:48:40	39.98	#######	-1.00E-01	5.91	3.64	7.31
6/06/2002	14:49:00	39.98	0.00E+00	-8.00E-02	6.09	3.82	7.49
6/06/2002	14:49:20	40.08	5.00E-02	-3.00E-02	6.34	4.05	7.77
6/06/2002	14:49:40	40.01	3.00E-02	-1.30E-01	6.44	4.15	7.87
6/06/2002	14:50:00	40.03	5.00E-02	-1.00E-01	6.67	4.38	8.1
6/06/2002	14:50:20	39.98	#######	-8.00E-02	6.8	4.46	8.23
6/06/2002	14:50:40	40.08	0.1	-3.00E-02	7.03	4.71	8.46
6/06/2002	14:51:00	40.01	#######	-1.30E-01	7.06	4.76	8.51
6/06/2002	14:51:20	39.98	#######	-1.30E-01	7.18	4.87	8.61
6/06/2002	14:51:40	39.98	3.00E-02	-8.00E-02	7.36	5.02	8.84
6/06/2002	14:52:00	40.05	8.00E-02	-3.00E-02	7.57	5.2	9.02
6/06/2002	14:52:20	39.81	#######	-2.80E-01	7.44	5.09	8.92
6/06/2002	14:52:40	40.08	5.00E-02	3.00E-02	7.87	5.5	9.32
6/06/2002	14:53:00	40.01	3.00E-02	-8.00E-02	7.92	5.55	9.37
6/06/2002	14:53:20	40.03	5.00E-02	-5.00E-02	8.05	5.71	9.53
6/06/2002	14:53:40	39.96	0.00E+00	-8.00E-02	8.13	5.76	9.58
6/06/2002	14:54:00	40.03	5.00E-02	0.00E+00	8.33	5.94	9.78
6/06/2002	14:54:20	40.03	8.00E-02	0.00E+00	8.46	6.09	9.93
6/06/2002	14:54:40	39.98	0.00E+00	-5.00E-02	8.48	6.14	9.96
6/06/2002	14:55:00	40.03	5.00E-02	-3.00E-02	8.66	6.29	10.14
6/06/2002	14:55:20	39.98	5.00E-02	-3.00E-02	8.76	6.37	10.21
6/06/2002	14:55:40	40.05	8.00E-02	0.00E+00	8.94	6.57	10.37
6/06/2002	14:56:00	40.01	3.00E-02	-3.00E-02	8.99	6.6	10.44
6/06/2002	14:56:20	39.98	5.00E-02	-3.00E-02	9.09	6.72	10.52
6/06/2002	14:56:40	39.98	3.00E-02	-5.00E-02	9.14	6.8	10.62
6/06/2002	14:57:00	40.01	5.00E-02	0.00E+00	9.3	6.93	10.75
6/06/2002	14:57:20	40.01	5.00E-02	0.00E+00	9.4	7.03	10.83
6/06/2002	14:57:40	40.01	5.00E-02	3.00E-02	9.48	7.13	10.95
6/06/2002	14:58:00	39.98	5.00E-02	-3.00E-02	9.58	7.26	11.06
6/06/2002	14:58:20	39.96	3.00E-02	0.00E+00	9.68	7.31	11.11
6/06/2002	14:58:40	40.03	8.00E-02	5.00E-02	9.81	7.46	11.28
6/06/2002	14:59:00	39.98	8.00E-02	0.00E+00	9.83	7.51	11.28
6/06/2002	14:59:20	39.98	3.00E-02	-3.00E-02	9.93	7.59	11.39
6/06/2002	14:59:40	40.01	0.13	5.00E-02	10.06	7.74	11.51
6/06/2002	15:00:00	40.01	5.00E-02	3.00E-02	10.14	7.79	11.62
6/06/2002	15:00:20	40.03	0.13	8.00E-02	10.32	7.95	11.72
6/06/2002	15:00:40	39.98	8.00E-02	5.00E-02	10.34	7.97	11.72
6/06/2002	15:01:00	40.01	8.00E-02	5.00E-02	10.42	8.1	11.87
6/06/2002	15:01:20	40.03	8.00E-02	8.00E-02	10.49	8.18	11.92
6/06/2002	15:01:40	40.01	8.00E-02	8.00E-02	10.55	8.25	12.02
6/06/2002	15:02:00	40.03	8.00E-02	3.00E-02	10.67	8.36	12.07
6/06/2002	15:02:20	40.05	0.13	8.00E-02	10.75	8.46	12.2
6/06/2002	15:02:40	40.03	0.13	5.00E-02	10.83	8.53	12.25
6/06/2002	15:03:00	40.03	0.13	8.00E-02	10.9	8.64	12.33
6/06/2002	15:03:20	40.01	0.15	0.1	10.98	8.69	12.46
6/06/2002	15:03:40	40.03	8.00E-02	5.00E-02	11.06	8.79	12.46
6/06/2002	15:04:00	40.08	0.2	0.18	11.21	8.97	12.58
6/06/2002	15:04:20	39.98	0.15	0.00E+00	11.21	8.94	12.63
6/06/2002	15:04:40	39.98	0.13	0.1	11.28	9.04	12.69
6/06/2002	15:05:00	39.98	0.1	3.00E-02	11.34	9.09	12.74
6/06/2002	15:05:20	40.01	0.13	8.00E-02	11.44	9.17	12.86
6/06/2002	15:05:40	40.01	0.2	0.1	11.59	9.32	13.04
6/06/2002	15:06:00	39.98	0.13	-2.71E+01	133.05	9.27	12.76
6/06/2002	15:06:20	39.93	0.13	3.00E-02	133.05	9.27	12.76
6/06/2002	15:06:40	39.98	0.13	3.00E-02	133.05	9.27	12.76

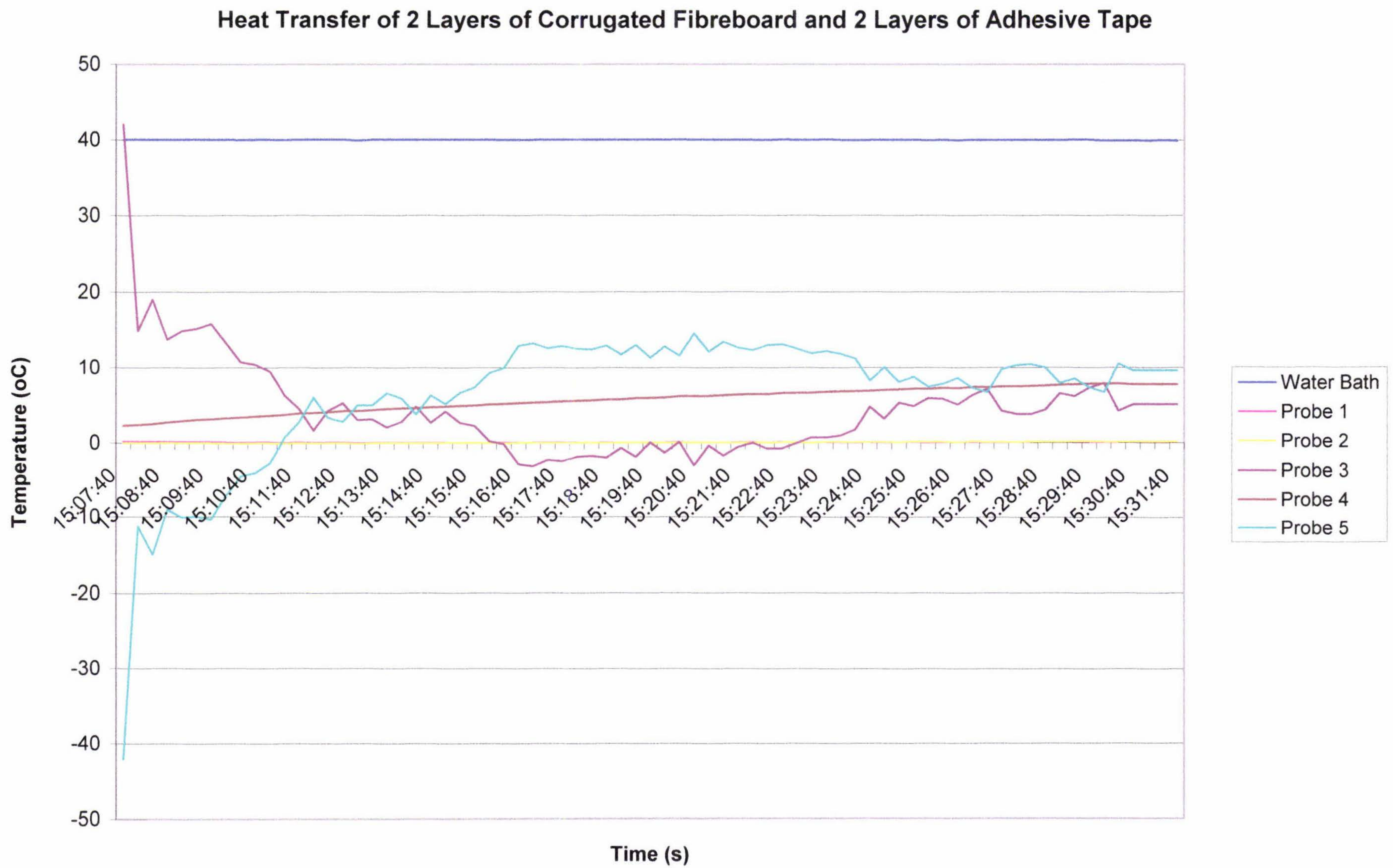
6/06/2002	15:25:40	40.05	0.13	0.15	4.89	7.23	8.84	
6/06/2002	15:26:00	39.98	5.00E-02	0.1	5.96	7.23	7.51	
6/06/2002	15:26:20	40.05	8.00E-02	0.13	5.88	7.34	7.9	
6/06/2002	15:26:40	39.96	3.00E-02	3.00E-02	5.12	7.29	8.66	
6/06/2002	15:27:00	40.05	0.13	0.18	6.37	7.46	7.36	
6/06/2002	15:27:20	40.01	5.00E-02	8.00E-02	7.23	7.46	6.75	
6/06/2002	15:27:40	40.03	8.00E-02	0.13	4.31	7.54	9.81	
6/06/2002	15:28:00	40.01	5.00E-02	5.00E-02	3.87	7.54	10.34	
6/06/2002	15:28:20	40.03	0.1	0.15	3.85	7.62	10.47	
6/06/2002	15:28:40	40.03	0.1	0.13	4.43	7.69	10.01	
6/06/2002	15:29:00	40.03	0.1	0.13	6.62	7.79	8.02	
6/06/2002	15:29:20	40.08	0.13	0.18	6.22	7.85	8.61	
6/06/2002	15:29:40	40.05	0.1	0.18	7.39	7.9	7.41	
6/06/2002	15:30:00	39.96	8.00E-02	0.15	8	7.9	6.8	
6/06/2002	15:30:20	39.96	0.1	0.1	4.31	7.97	10.55	
6/06/2002	15:30:40	39.98	0.13	0.15	5.15	7.85	9.63	
6/06/2002	15:31:00	39.93	0.13	0.15	5.15	7.85	9.63	
6/06/2002	15:31:20	40.03	0.13	0.15	5.15	7.85	9.63	
6/06/2002	**15:31:40**	**39.96**	**0.13**	**0.15**	**5.15**	**7.85**	**9.63**	**Highest 2**
6/06/2002	**15:32:00**	**39.96**	**37.49**	**51.26**	**5.15**	**7.85**	**0.26**	**Lowest 3**
6/06/2002	15:32:20	39.91	198.44	14.98	5.15	0.28	0.28	**Layers**
6/06/2002	15:32:40	39.96	198.44	4.94	0.38	0.38	0.36	
6/06/2002	15:33:00	39.91	198.44	1.53	0.33	0.36	0.36	
6/06/2002	15:33:20	39.98	198.44	0.92	0.38	0.41	0.46	
6/06/2002	15:33:40	39.93	198.44	0.71	0.38	0.41	0.46	
6/06/2002	15:34:00	39.96	198.44	0.61	0.41	0.48	0.51	
6/06/2002	15:34:20	39.89	198.44	0.41	0.36	0.41	0.48	
6/06/2002	15:34:40	39.91	198.44	0.41	0.38	0.51	0.54	
6/06/2002	15:35:00	39.96	198.44	0.38	0.43	0.56	0.59	
6/06/2002	15:35:20	39.93	198.44	0.33	0.46	0.59	0.61	
6/06/2002	15:35:40	39.96	198.44	0.36	0.51	0.64	0.64	
6/06/2002	15:36:00	39.96	198.44	0.28	0.54	0.69	0.66	
6/06/2002	15:36:20	39.96	198.44	0.31	0.59	0.76	0.76	
6/06/2002	15:36:40	39.93	198.44	0.23	0.56	0.71	0.71	
6/06/2002	15:37:00	39.96	198.44	0.2	0.64	0.79	0.76	
6/06/2002	15:37:20	39.96	198.44	0.2	0.66	0.84	0.79	
6/06/2002	15:37:40	39.96	198.44	0.18	0.69	0.89	0.82	
6/06/2002	15:38:00	40.01	198.44	0.2	0.71	0.92	0.92	
6/06/2002	15:38:20	39.98	198.44	0.15	0.71	0.94	0.87	
6/06/2002	15:38:40	39.98	198.44	0.18	0.79	1.02	0.94	
6/06/2002	15:39:00	39.93	198.44	0.13	0.74	0.99	0.92	
6/06/2002	15:39:20	39.93	198.44	0.1	0.82	1.04	0.94	
6/06/2002	15:39:40	40.01	198.44	0.18	0.92	1.15	1.07	
6/06/2002	15:40:00	39.93	198.44	0.1	0.89	1.12	1.04	
6/06/2002	15:40:20	39.93	198.44	8.00E-02	0.87	1.15	1.07	
6/06/2002	15:40:40	39.98	198.44	0.13	0.99	1.25	1.12	
6/06/2002	15:41:00	39.96	198.44	0.15	1.02	1.25	1.17	
6/06/2002	15:41:20	39.96	198.44	0.13	1.02	1.27	1.2	
6/06/2002	15:41:40	40.03	198.44	0.2	1.12	1.4	1.32	
6/06/2002	15:42:00	39.91	198.44	5.00E-02	1.07	1.32	1.22	
6/06/2002	15:42:20	39.93	198.44	0.13	1.12	1.4	1.3	
6/06/2002	15:42:40	39.98	198.44	0.15	1.17	1.48	1.38	
6/06/2002	15:43:00	39.93	198.44	0.1	1.17	1.45	1.38	
6/06/2002	15:43:20	39.96	198.44	0.1	1.25	1.53	1.43	
6/06/2002	15:43:40	39.96	198.44	0.15	1.27	1.58	1.45	
6/06/2002	15:44:00	39.91	198.44	5.00E-02	1.27	1.55	1.45	

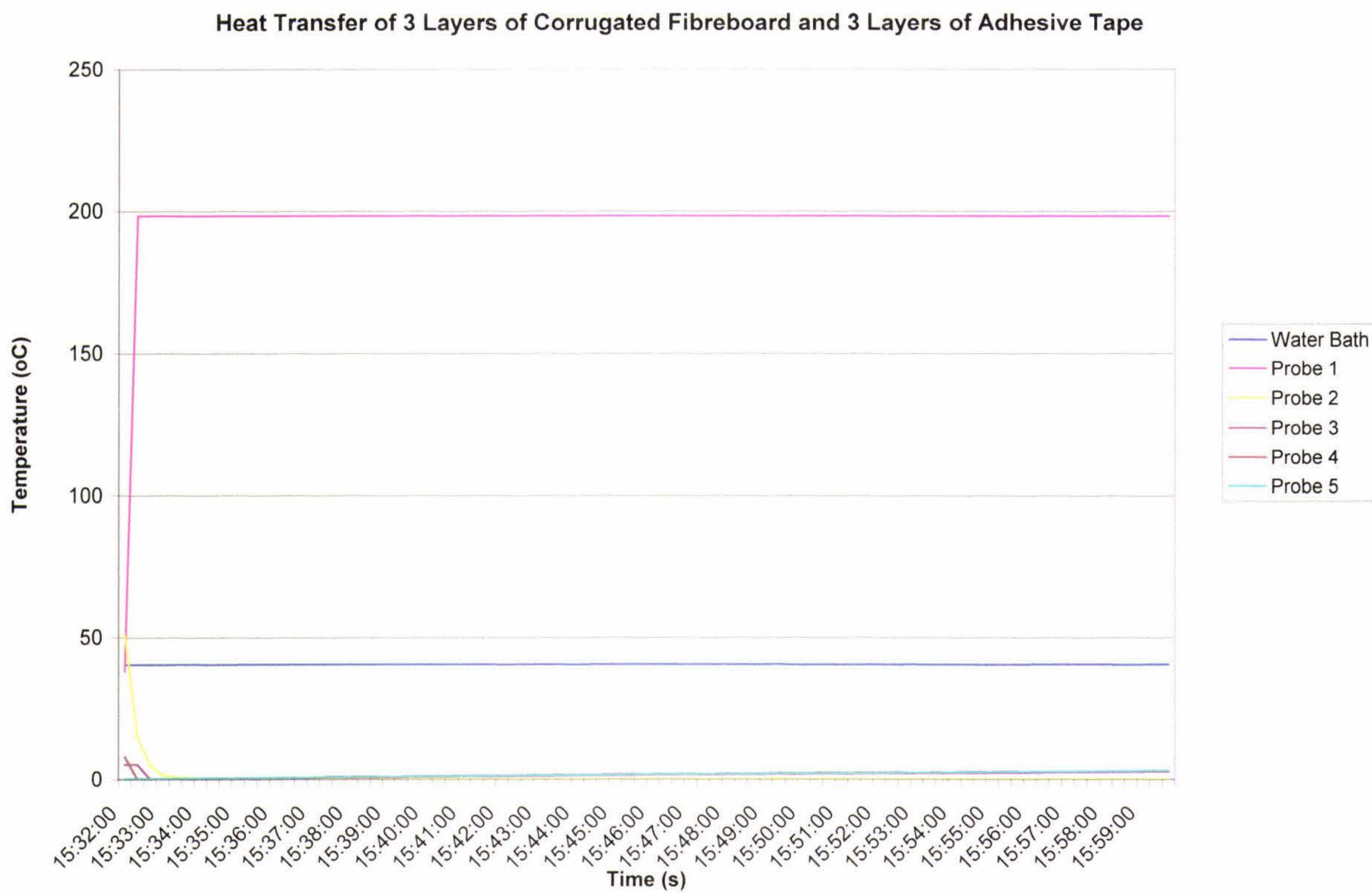
6/06/2002	15:44:20	39.93	198.44	8.00E-02	1.32	1.61	1.5	
6/06/2002	15:44:40	39.96	198.44	5.00E-02	1.35	1.66	1.5	
6/06/2002	15:45:00	39.93	198.44	8.00E-02	1.43	1.71	1.61	
6/06/2002	15:45:20	39.93	198.44	8.00E-02	1.43	1.73	1.61	
6/06/2002	15:45:40	39.93	198.44	8.00E-02	1.53	1.76	1.71	
6/06/2002	15:46:00	40.01	198.44	0.13	1.58	1.86	1.76	
6/06/2002	15:46:20	39.93	198.44	8.00E-02	1.53	1.86	1.76	
6/06/2002	15:46:40	39.96	198.44	8.00E-02	1.63	1.91	1.81	
6/06/2002	15:47:00	39.98	198.44	0.1	1.68	1.96	1.83	
6/06/2002	15:47:20	39.96	198.44	0.13	1.66	1.96	1.89	
6/06/2002	15:47:40	39.93	198.44	8.00E-02	1.68	1.99	1.89	
6/06/2002	15:48:00	39.98	198.44	0.1	1.73	2.04	1.94	
6/06/2002	15:48:20	39.93	198.44	0.1	1.73	2.01	1.94	
6/06/2002	15:48:40	39.93	198.44	8.00E-02	1.76	2.04	1.96	
6/06/2002	15:49:00	39.93	198.44	8.00E-02	1.81	2.09	1.99	
6/06/2002	15:49:20	40.13	198.44	0.31	2.01	2.32	2.27	
6/06/2002	15:49:40	39.91	198.44	5.00E-02	1.83	2.14	2.06	
6/06/2002	15:50:00	39.86	198.44	8.00E-02	1.89	2.17	2.06	
6/06/2002	15:50:20	39.96	198.44	0.13	1.96	2.27	2.17	
6/06/2002	15:50:40	39.91	198.44	0.1	1.96	2.27	2.11	
6/06/2002	15:51:00	39.89	198.44	8.00E-02	1.94	2.24	2.17	
6/06/2002	15:51:20	39.91	198.44	0.1	2.04	2.34	2.22	
6/06/2002	15:51:40	39.96	198.44	0.15	2.06	2.39	2.29	
6/06/2002	15:52:00	39.93	198.44	8.00E-02	2.06	2.37	2.29	
6/06/2002	15:52:20	39.91	198.44	8.00E-02	2.11	2.42	2.29	
6/06/2002	15:52:40	39.96	198.44	0.13	2.11	2.47	2.42	
6/06/2002	15:53:00	39.96	198.44	0.13	2.14	2.47	2.42	
6/06/2002	15:53:20	39.91	198.44	0.13	2.17	2.5	2.45	
6/06/2002	15:53:40	39.91	198.44	0.15	2.22	2.55	2.5	
6/06/2002	15:54:00	39.91	198.44	0.15	2.24	2.6	2.57	
6/06/2002	15:54:20	39.96	198.44	0.18	2.29	2.62	2.57	
6/06/2002	15:54:40	39.91	198.44	8.00E-02	2.22	2.6	2.57	
6/06/2002	15:55:00	39.96	198.44	0.18	2.34	2.7	2.7	
6/06/2002	15:55:20	39.91	198.44	0.1	2.29	2.67	2.62	
6/06/2002	15:55:40	39.91	198.44	0.13	2.29	2.67	2.67	
6/06/2002	15:56:00	39.96	198.44	0.15	2.39	2.75	2.75	
6/06/2002	15:56:20	39.93	198.44	0.15	2.42	2.78	2.8	
6/06/2002	15:56:40	39.96	198.44	0.15	2.5	2.83	2.83	
6/06/2002	15:57:00	39.93	198.44	0.15	2.5	2.88	2.85	
6/06/2002	15:57:20	39.93	198.44	0.18	2.52	2.9	2.9	
6/06/2002	15:57:40	39.96	198.44	0.18	2.57	2.93	2.96	
6/06/2002	15:58:00	40.01	198.44	0.2	2.62	2.98	3.03	
6/06/2002	15:58:20	39.91	198.44	0.15	2.6	2.98	3.01	
6/06/2002	15:58:40	39.91	198.44	0.15	2.6	2.96	3.01	
6/06/2002	15:59:00	39.96	198.44	0.2	2.73	3.06	3.11	
6/06/2002	15:59:20	39.93	198.44	0.2	2.73	3.08	3.13	
6/06/2002	**15:59:40**	**39.93**	**198.44**	**0.18**	**2.73**	**3.13**	**3.16**	**Highest 3 Layers**

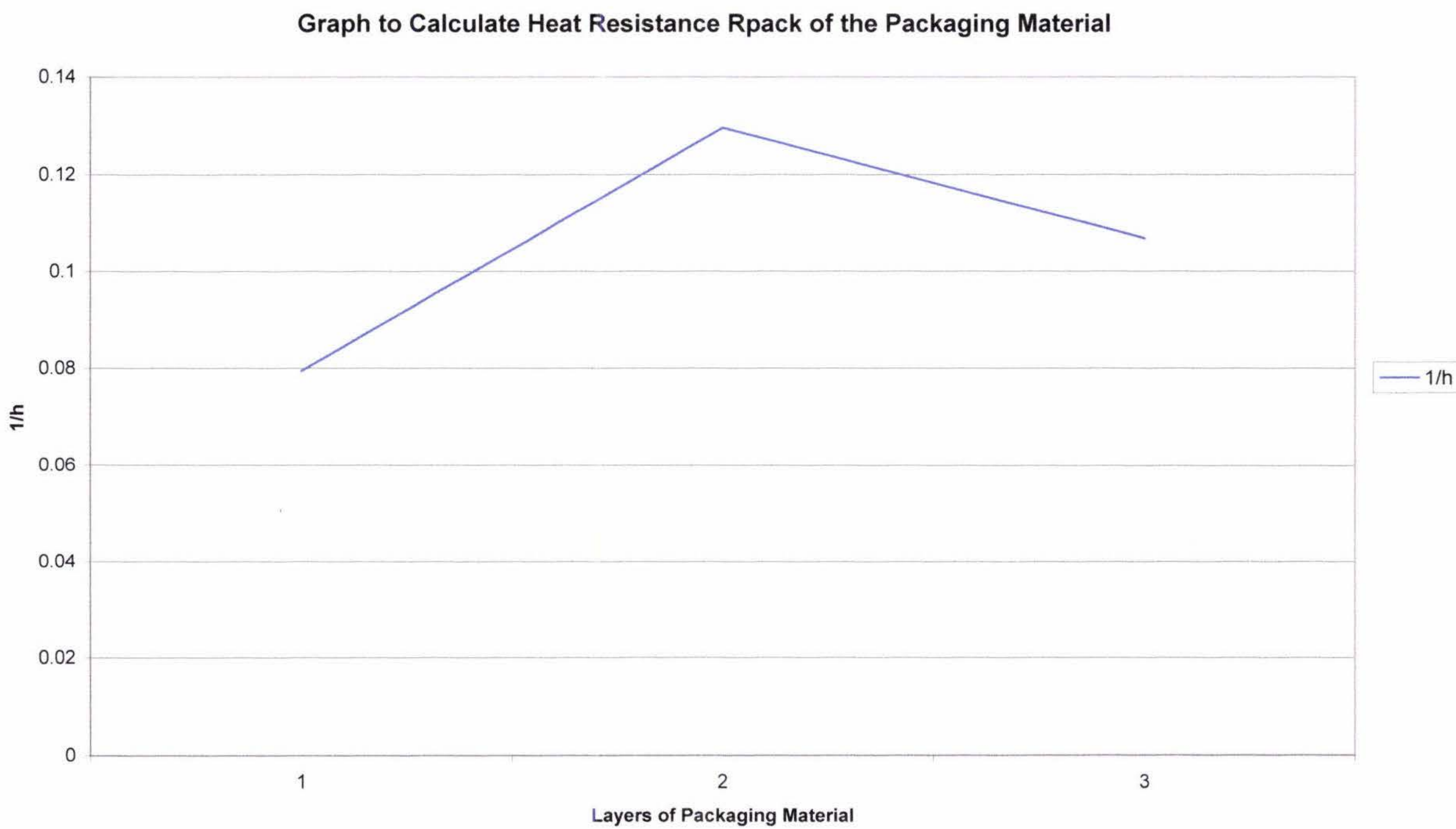
t=1460 seconds for 1 Layer
t=1220 seconds for 2 Layers
t=1660 seconds for 3 layers



Heat Transfer of 1 Layer of Corrugated Fibreboard and 1 Layer of Adhesive Tape
Temperature (oC)
160
140
120
100
80
60
40
20
0
-20
-40
14:43:20
14:44:20
14:45:20
14:46:20
14:47:20
14:48:20
14:49:20
14:50:20
14:51:20
14:52:20
14:53:20
14:54:20
14:55:20
14:56:20
14:57:20
14:58:20
14:59:20
15:00:20
15:01:20
15:02:20
15:03:20
15:04:20
15:05:20
15:06:20
15:07:20
Time (s)
Water Bath
Probe 1
Probe 2
Probe 3
Probe 4
Probe 5


Heat Transfer of 2 Layers of Corrugated Fibreboard and 2 Layers of Adhesive Tape
Temperature (oC)
50
40
30
20
10
0
-10
-20
-30
-40
-50
15:07:40
15:08:40
15:09:40
15:10:40
15:11:40
15:12:40
15:13:40
15:14:40
15:15:40
15:16:40
15:17:40
15:18:40
15:19:40
15:20:40
15:21:40
15:22:40
15:23:40
15:24:40
15:25:40
15:26:40
15:27:40
15:28:40
15:29:40
15:30:40
15:31:40
Time (s)
Water Bath
Probe 1
Probe 2
Probe 3
Probe 4
Probe 5


Heat Transfer of 3 Layers of Corrugated Fibreboard and 3 Layers of Adhesive Tape
Temperature (oC)
250
200
150
100
50
0
Time (s)
15:32:00
15:33:00
15:34:00
15:35:00
15:36:00
15:37:00
15:38:00
15:39:00
15:40:00
15:41:00
15:42:00
15:43:00
15:44:00
15:45:00
15:46:00
15:47:00
15:48:00
15:49:00
15:50:00
15:51:00
15:52:00
15:53:00
15:54:00
15:55:00
15:56:00
15:57:00
15:58:00
15:59:00
Water Bath
Probe 1
Probe 2
Probe 3
Probe 4
Probe 5


Graph to Calculate Heat Resistance Rpack of the Packaging Material
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1/h
1
2
3
Layers of Packaging Material
1/h