NON-LINEAR FINITE ELEMENT ANALYSIS OF APPLE PACKAGING

Siva Rama Krishna Kankanala

May 2001

A Thesis presented in partial fulfilment of the

Requirements for the

Master of Technology

in Technology and Engineering

at

Massy University

Palmerston North

New Zealand

Indian Mythology Says "Mother, Father and the Teacher are equivalent to God"

With Respect To

My Parents Kankanala Venkat Rao & Kankanala Sambrazyam

And

My Teachers Puli Sambaiah and Dr. E. W. Smith

For their Patience and Support

ABSTRACT

The New Zealand Apple and Pears Marketing Board exports apples to over 50 countries, and is one of the New Zealand's largest export earners, netting approximately 500-600 million dollars per year. Competition on the overseas market is very high, and the importers set strict requirements on the condition of the fruit being exported. Therefore, this fruit must be in optimum condition, wherein packaging methods play a vital role to protect the fruit during handling and transit.

The packaging is very important to protect the fruit, but little research has been done on its physical and mechanical behaviour. The apple tray is the core object and an integrated part of apple packaging made out of paper pulp, called "Friday Trays", and here is studied for its mechanical and physical behaviour. The project has two phases, testing the material at different environmental conditions and stress analysis of the tray by using "Finite Element Analysis" technique. In the first phase of research, since the "Friday Trays" are handled at different temperatures and humidity levels, the paper pulp material was tested for its mechanical properties such as Stress, Strain, Young's Modulus and Creep at different moisture content levels. The physical and mechanical properties of Paper Pulp materials are affected by moisture content, which is dependent on the humidity of the surrounding environment. The function of the trays is, firstly to transport the apples from conveyor to apple boxes and remove them from the boxes and secondly to act as a cushioning between apples of different layers to prevent damage.

In the second phase of the research, the behaviour of the trays was studied in the above conditions by using finite element analysis. The technique was chosen because it can model very complex shapes. The results are displayed in graphical format and can see with maximum stresses or displacements highlighted. The Z pack 70 count trays are investigated at two different conditions of mechanical properties, at 8% moisture content and 20% moisture content. Creation of FEA models are challenging because of the complexity of the problem and vast size of the computer files. The handling situations are successfully generated and used to investigate the relative advantages of packing fully loaded trays, which are then supported at different positions. The tray performed better while being picked up by the ends of the tray and at 8% moisture content. In this situation, the deflection in trays was less when compared to the other situations and the apples less likely to fall off the tray.

It was seen that the apples themselves protected the tray from bending during handling, brought about by the apples making contact with each other. Following from this a complete shell model was generated for holding full apples that has contact between neighbouring apples. This used non-linear controls and slidelines. The results show the apples contacting and supporting each other and produce less impact in terms of load on the tray. Analysis of Friday tray is far from complete, greater computer resources will be needed, and has to be checked for the response of lower material properties. Future work should concentrate on developing a dynamic model of a full carton of apples. From the dynamic model, conclusions can be made about the behaviour of trays within the carton.

ACKNOWLEDGMENTS

I wish to express my deepest appreciation and gratitude to my supervisor Dr. E.W. Smith for his continuous guidance, encouragement, patience and spending his valuable time with me to clarify my doubts.

I would like to thank Barry Lord and Steve Kirk for their support and encouragement.

I would like to express my gratitude to my friends Hnumara Ravindra, G. Krishna Mohan, Srinath Avula and Priyanka Prakash, who have shown the meaning of friendship.

I would like to convey my sincere thanks to all those who helped me directly and indirectly in completing this project.

Finally, I would like to express my heartfelt gratitude to my parents, sister, brother-in-law, and friends for their love, affection and continual encouragement.

TABLE OF CONTENTS

TITLE	**...I**
DEDICATION	**...II**
ABSTRACT	**...III**
ACKNOWLEDGEMENTS	**...IV**
TABLE OF CONTENTS	**...V**
LIST OF FIGURES GRAPHS AND TABLES	**...IX**
CHAPTER 1: INTRODUCTION	**...1**
1.1 General Introduction	...2
1.2 Problem Description	...3
1.3 Previous Research	...4
1.4 Application of FEA to Packaging Industry	...5
1.5 Research Objectives	...6
CHAPTER 2: LITERATURE REVIEW ON APPLE PACKAGING	**...7**
2.1 Introduction	...8
2.2 Packing Methods	...8
2.2.1 Packaging of Apples	...9
2.2.2 Random Packaging	...9
2.2.3 Pattern-Packed Fruits	...9
2.2.4 Tray and Cell Packs	...10
2.2.4.1 Tray Packs	...10
2.2.4.2 Cell Packs	...12
2.3 Apple Packaging in New Zealand	...13
2.3.1 Telescopic Carton Configuration	...13
2.3.2 Z Pack Carton Configuration	...13
2.3.3 Volume Utilization	...14
2.3.4 Damage in Telescopic Cartons	...14
2.4 Performance of Moulded Trays	...15
2.4.1 Paper Pulp Properties	...16
2.4.2 Friday Trays	...17
2.4.3 Apple Trays	...17

2.4.4 Z Pack Trays ...18
2.5 Alternative Tray Designs and Materials ...18
2.5.1 Pulp Trays ...18
2.5.2 Polystyrene Trays ...18
2.5.3 High-Density PVC Trays ...19
2.5.4 Polyurethane Form Pads ...19
2.5.5 Polystyrene Form Pads ...19
2.5.6 Pressed Form ...20
2.5.7 Foam Netting ...20
2.5.8 Polybubble Sheets ...20
2.6 Testing Methods ...20
2.7 Finite Element Modelling ...21
2.8 Fruit Diameter and Tray Cup Diameter ...22
CHAPTER 3: LITERATURE REVIEW ON PHYSICAL PROPERTIES OF APPLES AND MECHANICAL PROPERTIES OF PAPER PULP ...23
3.1 Physical Properties of Apples ...24
3.1.1 Young's Modulus ...24
3.1.2 Poisson's Ratio ...26
3.1.3 Measuring Density ...26
3.2 Mechanical Properties of Paper Pulp ...28
3.2.1 Stress, Strain and Young's Modulus ...28
CHAPTER 4: EFFECT OF MOISTURE CONTENT ON MECHANICAL PROPERTIES OF PAPER PULP MATERIAL ...32
4.1 Tensile Strength Tests ...33
4.2 Sample Dimensions ...34
4.3 Enhancing Moisture Content ...37
4.3.1 Measuring Moisture Content ...37
4.3.2 Conditioning of Sample for Testing ...40
4.4 Material Properties at Various Moisture Levels ...40
4.4.1 Results and Conclusions ...42
4.5 Structure of the Paper Pulp Material at different Moisture Contents ...52
4.6 Creep Analysis ...56
4.6.1 Test Procedure ...57

4.6.2 Results and Conclusions ...59
4.7 Poisson's Ratio ...64
4.8 Density Measurements ...64
CHAPTER 5: FINITE ELEMENT ANALYSIS OF APPLE PACKING ...66
5.1 Introduction ...67
5.2 Fundamentals of "FEA" ...67
5.2.1 Stiffness Matrix for Practical Elements ...70
5.3 Package Details ...70
5.3.1 Lusas 13.1 ...71
5.3.1.1 Pre-Processing ...72
5.3.1.2 Finite Element Solver ...73
5.3.1.3 Results-Processing ...73
5.4 Application of "FEA" to Apple Trays ...74
5.5 Static Analysis ...75
5.5.1 Static Linear Analysis ...75
5.5.2 Static Non-linear Analysis ...75
5.5.2.1 Material Non-linearity ...75
5.6 Non-linear Solution in Lusas ...76
5.7 Contact Analysis ...78
5.7.1 Contact Problems in Lusas ...79
5.7.2 A 2D Example of Contact Analysis ...80
5.8 FEA Model Generation ...84
5.8.1 2D - Thin Shell Models of Apple Tray ...84
5.8.1.1 Model Generation ...84
5.8.1.2 Meshing ...86
5.8.1.3 Geometric and Material Properties ...86
5.8.1.4 Support & Loading Conditions ...87
5.8.1.5 Non-Linear Controls ...87
5.8.1.6 Analysis Technique ...87
5.8.2 Three Dimensional Tray Model ...90
5.8.2.1 Model Generation ...90
5.8.2.2 Meshing ...92
5.8.2.3 Physical Attributes ...93

5.8.2.4 Analysis of 3D Tray ...94
5.8.3 The Full Tray Model (Using Shell Elements) ...96
5.8.3.1 Model Generation ...96
5.8.3.2 Meshing ...96
5.8.3.3 Physical Attributes ...96
5.8.3.4 Analysis of Full Shell Model ...97
CHAPTER 6: RESULTS ...100
6.1 Analysis and Results of Tray Models ...101
6.1.1 Displacements at Different Moisture Contents and Lifting Methods ...101
6.1.2 Stress Results at Different Moisture Contents and Lifting Methods ...111
6.2 Three Dimensional Model ...112
6.3 The Full Shell Models – The Tray with Apples ...117
6.3.1 The Results ...117
CONCLUSIONS ...124
RECOMMENDATIONS AND FUTURE WORK ...127
REFERENCES ...128
APPENDIX 1: DESIGN SPECIFICATIONS FOR THE FRIDAY TRAY ... APPENDIX 1 - 1
APPENDIX 2: MANUFACTURE OF PULP TRAYS ...APPENDIX 2 - 1
APPENDIX 3: SLZ PACK DESIGN AND Z TRAY SPECIFICATIONS ...APPENDIX 3 - 1
APPENDIX 4: PRACTICAL RESULTS OF STRESS AND STRAIN AT DIFFERENT MOISTURE CONTENTS, APPLE DENSITY, PULP TRAY'S POISSON'S RATIO & DENSITY MEASUREMENTS ...APPENDIX 4 - 1

LIST OF FIGURES, GRAPHS AND TABLE

CHAPTER 1

Table 1.1 Percentage of Bruising on Out-turn in Europe NZAPMB ...4

CHAPTER 2

Figure 2.1 Typical Peg-Type Tray Pack Steak in a Shipping Container ...11
Figure 2.2 Spring Hammock Construction ...12

Table 2.1 Count Comparison by Pack ...13
Table 2.2 Z Pack Configuration and the Z Pack Tray Usage ...14
Table 2.3 Fruit Weight & Diameter and Tray Cup Diameter with Related to Count Size ...22

CHAPTER 3

Figure 3.1 Compression Test of an Apple Fruit between Two Plates ...25
Figure 3.2 Force/Deflection Curve for Three Point Bend Test on Apple Material ...25
Figure 3.3 Platform Scale for Measuring of Volume and Density of Irregular Shapes ...27
Figure 3.4 Straight Test Sample and Dog Bone Test Sample ...29
Figure 3.5 Stress-Strain Graph of Paper Pulp Material ...30
Figure 3.6 Three Point Bend Test on Paper Pulp Material ...31

CHAPTER 4

Figure 4.1 Selected Sample Dimensions ...36
Figure 4.2 Test Results of Samples with Different Widths ...36
Figure 4.3 Simple Arrangement to Measure the Moisture Content by Electrical Method ...38
Figure 4.4 Die and Roller to Cut the Samples ...41
Figure 4.5 An Illustration of Fibres at Dry and Wet Conditions ...53
Figure 4.6 Microscopic Structures of Paper Pulp Material with Increased Moisture Contents at 40X Magnification ...54
Figure 4.7 Microscopic Structures of Paper Pulp Material with Decreased Moisture Contents at 40X Magnification ...55
Figure 4.8 Schematic Representation of the Creep-rupture Curve ...57
Figure 4.9 A Simple Arrangement of Creep Testing ...58

Graph 4.1 Relationship between Resistance and Moisture Content of Moulded Pulp Tray Samples ...39
Graph 4.2 Relation between Stress and Strain Curves for the Samples at Room Temperature and Relative Humidity ...46
Graph 4.3 Relation between Stress and Strain Curves of 20% Moisture Content Samples ...46

Graph 4.4 Relation between Stress and Strain Curves of 40% Moisture Content Samples ...47
Graph 4.5 Relation between Stress and Strain Curves of 60% Moisture Content Samples ...47
Graph 4.6 Relation between Stress and Strain Curves of 80% Moisture Content Samples ...48
Graph 4.7 Relation between Stress and Strain Curves of 100% Moisture Content Samples ...48
Graph 4.8 Relationship between Stress and Strain Curves for No Moisture Content, 20%, 40%, 60%, 80%, and 100% Moisture ...49
Graph 4.9 Relation between Stress and Strain Curves of Samples Desiccated to 20% MC from 60% ...50
Graph 4.10 Relation between Stress and Strain Curves of Samples Desiccated to 20% MC from 80% ...50
Graph 4.11 Relation between Stress and Strain Curves of Samples Desiccated to 20% MC from 100% ...50
Graph 4.12 Relationship between Stress and Strain for 20% MC Samples Vs Samples Desiccated to 20% MC from 60%, 80% & 100% MC ...51
Graph 4.13 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 1.655 N/mm^2) and MC of 5.73 ...60
Graph 4.14 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.041 N/mm^2) and MC of 7.89 ...60
Graph 4.15 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.004 N/mm^2) and MC of 12.13...61
Graph 4.16 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 1.986 N/mm^2) and MC of 5.73 ...61
Graph 4.17 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.005 N/mm^2) and MC of 11.66...62
Graph 4.18 Creep Curve for Moulded Pulp Material at Different Moisture Content Levels ...62
Graph 4.19 Log-Log Plot of Rupture Life versus Minimum Creep Rate for Paper Pulp Material at Different Moisture Content Levels ...63

Table 4.1 Test Results of Different Samples of different Widths ...35
Table 4.2 Stress and Strain Results of Moulded Pulp Tray Samples at different Moisture Levels ...43

<u>CHAPTER 5</u>

Figure 5.1 Thin Rod Elements – Fixed at Node 1 and Free at Node 2 ...68
Figure 5.2 Thin Rod Elements – Free at Node 1 and Fixed at Node 2 ...68
Figure 5.3 Thin Rod Elements –Free at Both Nodes ...68
Figure 5.4 Light Consists of Two Thin Elements of Equal Stiffness ...69
Figure 5.5 Incremental-iterative Solution Procedure in Non-Linear Analysis ...77
Figure 5.6 Model Definition of 2D Slideline Example ...81
Figure 5.7 Meshing of 2D Slideline Example ...82
Figure 5.8 Slideline Example with Deformed Mesh Superimposed on Undeformed Mesh ...83
Figure 5.9 Plan View of Single Marked Out Cup ...84

Figure 5.10 Profile of Cup Segment ...85
Figure 5.11 Illustration of Element Bending Distorted ...86
Figure 5.12 Thin Shell Model of the Tray – Support Case A ...88
Figure 5.13 Thin Shell Model of the Tray – Support Case B ...89
Figure 5.14 Model Generation of Apple and Tray Using 3D Elements ...91
Figure 5.15 Diagram Showing Surfaces within the Apple Model ...92
Figure 5.16 Meshing of 3D Model with Tray and Apples ...95
Figure 5.17 Model Generation of Tray and Apples Using Shell Elements ...98
Figure 5.18 Model Generation of Tray and Apples Using Shell Elements and Support Conditions ...99

CHAPTER 6

Figure 6.1 Deformed Mesh of Tray Model – 8% MC and Support Case A ...103
Figure 6.2 Deformed Mesh of Tray model - 8% MC and Support Case B ...104
Figure 6.3 Deformed Mesh of Tray Model - 20% MC and Support Case A ...105
Figure 6.4 Deformed Mesh of Tray model - 20% MC and Support Case B ...106
Figure 6.5 Contours of Vertical Displacement in the Tray Model – 8%MC and Support Case A ...107
Figure 6.6 Contours of Vertical Displacements in Tray Model – 8%MC and Support Case B ...108
Figure 6.7 Contours of Vertical Displacement in the Tray Model – 20%MC and Support Case A ...109
Figure 6.8 Contours of Vertical Displacements in the Tray Model – 20%MC and Support Case B ...110
Figure 6.9 Contours of Maximum Principal Stress in the Tray Model – 8%MC and Support Case A ...113
Figure 6.10 Contours of Maximum Principal Stresses in the Tray Model – 8%MC and Support Case B ...114
Figure 6.11 Contours of Maximum Principal Stress in the Tray Model – 20%MC and Support Case A ...115
Figure 6.12 Contours of Maximum Principal Stresses in the Tray Model – 20%MC and Support Case B ...116
Figure 6.13 Deformed Mesh of Full Shell Model of the Tray with Apples – Isometric View ...119
Figure 6.14 Deformed Mesh of Full Shell Model of the Tray with Apples – Plan View ...120
Figure 6.15 Vertical Displacements of Full Shell Tray Model with Apples – Isometric View ...121
Figure 6.16 Maximum Principal Stresses Contours of Full Shell Tray Model with Apples – Isometric View ...122
Figure 6.17 Minimum Principal Stresses Contours of Full Shell Tray Model with Apples – Isometric View ...123

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The New Zealand Apple and Pears Marketing Board (NZAPMB) exports apples to over 50 countries and is one of the New Zealand's largest export earners. The majority of the exports are tray packed in 20 Kg. corrugated board cartons with a net weight of 18+/- 1 Kg. In 1996, NZAPMB packed 85% of the 18 million-carton pipfruit produced in new Z pack palletisable packaging. In comparison, only 1.5 million cartons were packed in palletisable units in 1995. The high competition in the export industry and the strict requirements of the produce being imported makes the export industry to concentrate to develop new designs in the packing industry.

Traditionally, apples come from the farmer in large bins and cleaned by water. The cleaned apples come along conveyors and correctly sized apples placed either manually or by automated machinery in the cups of the trays. The filled trays are lifted manually and placed in the cartons one on top of another. The main role of the tray is in the placement and separation of apples in 4 to 6 layers depending on the count size in standard 20kg corrugated cartons. Big size apples involve 4 or 5 layer packing and 6 layer packs are required for very small apples. The packed cartons are then transported to the cold storage and palletized for the shipment on export demand. In this scenario, the trays play a vital role in packaging system. At present, New Zealand industry manufactures about one hundred and twenty million trays per annum from recycled paper pulp.

As expressed by Ashdown (1995), the trays play three important roles in the packaging of apples, they are:

- During the packaging process the fruits are loaded onto the trays while on a conveyor, and then the trays used to transport fruit from the conveyor into the apple box. Trays are also often used to remove fruit from the box.

- The trays provide an accurate means of positioning the fruit inside the apple box in order to optimize the available space.

- The trays are stacked on top of each other within the box to provide vital cushioning between apples of different layers in order to prevent bruising during shipping.

In addition, the trays also add overall strength to the carton by absorbing the excess water from the apples.

There are variations in packing styles such as dimensioning in carton and palletisation. In the past two years NZPAMB has dramatically altered the packing designs, the on going packaging is Z pack (discussed in chapter 2) palletisation, but there is no alteration in tray designs. Approximately 60 years ago paper pulp trays were first introduced into the apple industry as a more efficient means of separating and positioning the fruit. In the mid 1930's the original patents for these trays (called 'Friday Trays', the name originated in America as Mr. Friday designed the first trays) (McLeod 1993) were taken out, though the patents have been expired for many years, are still in use.

Though the tray plays a key role in the packaging, the mechanical properties of the trays that are made out of paper pulp are not clear. Specifications for moister absorption, weight, colour, and dimensions are available but there is no consideration for strength, stiffness and energy absorption properties. The mechanical properties such as Young's Modulus, tensile strength, Poisson's ratios etc. are not clear. Such mechanical properties are used to establish the static behavior of paper pulp tray when it is loaded with full load of apples. In addition to that, the dynamic behavior of paper trays in the carton is important, to prevent the bruising and spoilage of fruits when the carton is dropped or subjected to the impact load. With the better understanding of the packing design it can be possible to make adjustments to the present system or replace with the best one available.

1.2 PROBLEM DESCRIPTION

Knowledge of the behavior of the apple tray while packing and transportation is limited and inconclusive. There are two main problems involved while packing the apples onto the trays. In traditional packing system, an apple tray was placed in the bottom of the carton, and then sized apples are placed manually in the cups of trays. When the first was filled then another tray will be placed on top of it and filled in the same way. But in automatic tray fillers, trays moves along with the conveyor belt and correct sized apples placed in them. Then the trays are lifted manually and placed in the apple cartons.

The problem experienced during this operation is that trays are bending to an extent that the trays some times tear and apples fall out and endure bruising; these trays were not designed for lifting a full load of apples. There are two methods employed in picking up the tray, either held at the sides or held at the ends. It was necessary to know which method was the most effective way to understand the dynamics of the tray behavior in the non-linear region.

The second problem was bruising of the apples in the cartons during export shipping. The percentages of bruised apples are given in Table 1.1; this is noticed by NZAPMB in their survey. The behavior of apples inside the box, in particular, the mechanisms that would cause bruising is also a major factor. Z count 70 apples (which is equivalent to 72 count apples) were chosen to analyze this problem. This is due to two main reasons, one is 70 count apples are rare and costly in the market place, and the second reason is the weight of this apples are higher then the other count apples. To gain the knowledge of static and dynamic behavior it was decided to use finite element stress analysis to create the model. By setting up the model analysis it is easy to know the apples behavior and the interaction between the apples and tray inside a carton for the given set of loading and support conditions. Once the analysis is proven realistic then the modifications in materials and shape of the tray could be changed quickly and effortlessly.

Count	% Bruising	No Fruit insp.	No Bruised	Configuration
72	1.74	518	9	2X2
80	1.66	2653	44	2X2
88	4.98	4422	220	2X2
100	1.7	5286	90	3X2
113	1.65	5285	87	3X2
125	3.46	10042	347	3X2
138	1.26	23212	293	3X2
150	1.71	20790	355	3X2
163	1.82	19838	362	3X2
175	1.44	9591	138	3X2
198	2.71	627	17	3X3

Table 1.1 Percentage Bruising on Out-turn in Europe NZAPMB (Heap, 1994).

Ashdown (1995) and Heap (1994) studied the mechanical properties of paper pulp Ashdown used FEA (Finite Element Analysis) as a tool and Heap used traditional mechanical instruments to calculate the Young's Modulus. Both researchers conducted their experiments on pulp trays in the linear region and ignoring non-linearity. Also Finite Element Models were made at two different moisture content levels as the material properties of the pulp tray changed.

Hence, it is essential to analyze the tray behavior within the non-linear region to achieve an improvement in the tray design.

1.3 Previous Research

Holt and Scoorl (1983,1984) have undertaken the majority of the published research at the University of Qeensland; much of work was done in early 1980's. Chen et al (1993, 1996) and Lu and Abbott (1996) have largely concentrated on fruit texture and vibration analysis by using Finite Element Analysis. Most of the research mainly concentrated on produce bruising and damage in packaging by using mechanical instruments on a whole carton. In the mid 1990's Heap and Ashdown focussed on the effect of apple trays on bruising, and the mechanical properties of apples and trays.

This research is an extension study of Ashdown's research and mainly focuses on the study of the behavior of apple trays within the non-linear region.

1.4 Application of FEA to Packaging Industry

Initially, FEA was used for highly complex engineering problems such as civil engineering and aeronautical problems because of its difficult analysis techniques and high capital cost. Despite extensive search through research papers, very little information has been found on the usage of FEA in the field of the packaging industry. The horticultural industry has made attempts use numerical analysis techniques in modelling the physical properties of fresh produce, but have found this extremely difficult due to the nature of the material. Fresh produce may be considered a living organism, with a complex cell structure, respiration mechanisms and intricate physical attributes. The complex shape of fruits that continuously change their physical and mechanical properties with time makes it very difficult to create an accurate model using FEA modeling packages.

For the past few years, the revolution in the computer industry has an immense impact on in mechanical engineering. For example using CAD and CAM (FEA software is one among them) packages product design and analysis of strength can be accomplished in short time periods and with great accuracy. Due to a drop in the cost of such packages FEA is being used more widely, particularly in the less sophisticated engineering areas. The absence of FEA in the field of packaging because packaging styles change very quickly, so often a package is outdated almost as soon as it goes into production. Producers therefore reluctant to spend money on analyzing a product that has a short life cycle and which effects the product cost. But packaging is an essential requirement to protect the fruit from the damage, particularly in the export business. Spending on designing good quality packages will help exporters reduce damage, giving quality produce to the customer and improving profits.

FEA was chosen for this problem because of two main reasons. Firstly, due to the complex shape of paper pulp trays other analysis techniques required large approximation. Using FEA the complex shape of the tray can modelled and the results can be reliable given proper material properties. Secondly, it provides the results at each and every point on the tray, and the results can be viewed graphically to provide an overall picture of the tray response for the given applied load. One more strength of the FEA package is once the model is formulated it is a simple exercise to modify to improve designs. Instead of spending money and time to build a prototype for physical testing, it can be easy to build different virtual models by using FEA.

1.5 Research Objectives

The research objectives for this part of the study are:

- Obtain a full set of physical properties of apples and mechanical properties of paper pulp material such as Young's modulus, Poisson's Ratio, the relation between Stress and Strain and Creep at different moisture content levels.

- Develop a working non-linear 2D finite element model of an existing tray design and analyze it under the given loading and support conditions, and at two different moisture content levels.

- To incorporate the tray model into a full 3D-model in order to gain an insight of the tray behavior under different loading conditions, and at two different moisture content levels.

- By using the data from the results of above objectives improve the tray design to strengthen to its acceptable stress levels.

By achieving these objectives, the compiled information from the practical study is then used to compare with the present packaging system and can be used for further modifications in the packaging system.

CHAPTER 2

LITERATURE REVIEW ON APPLE PACKAGING

2.1 INTRODUCTION

The market for fresh produce is large and varied. Market for fresh produce is greater then the other processed foods such as freezing, canning and drying. The basic object of packaging is to maintain the produce at the desired quality and to prevent damages. For the most part, packaging cannot delay or prevent the produce hundred percent from spoiling. Incorrect packaging accelerates spoilage. However, packaging can serve to protect against contamination, damage and excess moisture loss and packaging must be robust enough to survive transport, particular enough to facilitate easy storage and handling.

Fruits and vegetables are very high in moisture content, ranging from 75-95%. Their equilibrium humidity can be as high as 98%. Under any normal atmospheric condition they will dry rapidly. This causes wilting and shrivelling due to loss of rigidity and shrinkage of the cells (Sacharow et al, 1980). Proper packaging is able to prolong the storage life of fresh fruits and vegetables by preventing wilting. Too much moisture barrier will cause an excessively high relative humidity in the package and result in accelerated spoilage due to micro-organisms or in skin splitting on some fruits.

2.2 PACKING METHODS

The packaging of fresh produce is not new; initially, boats and horse-drawn carts transported fresh produce. Later generation boxes, barrels, baskets or sack served as a container for transporting small loads. Now a day with the available technology, packing technology has been changed to reduce spoiling, improve the quality of produce and to reduce the packaging costs. Packing styles differ from product to product, the quantity of supply and the market place.

Packing of the fruits depends on quantity of supply, either bulk supply or retail supply. In early days, shipping barrels were used, due to close packing and heavy shaking during transport the spoilage of fruit was high. Hence, suppliers have developed different packing styles to protect the fruit from bruising. For example, potatoes are supplied in corrugated boxes, apples and similar fruit are supplied in moulded trays and using foamed polystyrene trays protects easily bruised fruits.

The materials and methods used for retail packing of produce are extremely varied, however, they can be categorised as films, backings, boxes, bags, bands, closures and labels (Sacharow et al, 1980). This review is about the packing of apples in bulk supply using trays.

2.2.1 PACKAGING OF APPLES

Packing styles of apples, in particular, wholesale and bulk supply can be categorised into three main groups:

- Jumble, Random Packs
- Pattern-Packed Fruits and
- Tray and Cell Packs

2.2.2 RANDOM PACKAGING

Random packing known as "Jumble packing" is the oldest and simplest for wholesale produce packing. In this style of packing, fruits are simply poured into a shipping container at random, either manually or by a variety of filling machines. The major part of the fresh produce and vegetables are generally shipped by random packing because of the simplicity and low cost.

Filling of this type of packing is usually by weight, or less frequently, by count size with no thought of optimising the space. The major disadvantage of jumble filling is the poor packing density of the container. In addition with poor volume utilisation, fruit settling occurs from in-transit vibrations, even on short hauls (Peleg, 1985). Though this style of packing is most damage prone, yields lowest packing density, and is the least attractive looking, it is still popular in fresh produce distributing due to the low cost of packing.

2.2.3 PATTERN-PACKED FRUITS

Pattern packs known as "place packs", is used for high quality produce and is intended for distant markets. Each individual fruit is placed into its place in the pattern, either "bare" or wrapped. Most of the fruit operations are manual, although automatic wrapping machines are available in the market. The objectives of wrapping are as follows (Peleg, 1985):

- Isolation between individual fruits and between fruits and container walls, this is particularly important in wood containers with rough surface.
- The wrappers will provide cushioning effect.
- Attractive and uniform fruit appearance.
- Better control of gas exchange, mainly carbon dioxide and oxygen.
- Application of fungicide micro-atmospheres around fruits by impregnating wrappers with, for example biphenyl in citrus.

There are several benefits of wrapping to protect the fruit from damage, except cost. A new trend in pattern packing is to abandon wrapping in favour of less costly container wall liners and diphenyl-impregnated paper pads between fruit layers. For example, apples are packed bare in wire-bound wooden containers using polyethylene bags as liners and evaporation barriers, in place of individual fruit wrappers.

2.2.4 Tray and Cell Packs

Due to a large amount of mechanical injury sustained by fruit during handling and transport, were up to 30-40% (Peleg, 1985), attempts have been made to develop cushioning and isolate individual fruit to relieve the pressure and reducing impacts between the fruits. This has led to the design of internal partitions with in the packing cartons that can be classified into two main groups: Tray Packs and Cell Packs. The main function of the partitioning is to isolate the fruits, eliminate transfer of stacking loads by the fruits, and reduce the pressure on the produce. As this review is mainly concentrated with the packing of apples, and cell packs are generally not used for this purpose, this packing method can be dealt with briefly. Peleg provides a good summary of the attributes and characteristics of the cell pack.

2.2.4.1 Tray Packs

Peleg (1985) discussed tray packs and categorised them into two groups, the first is described as *Peg Type* (shown in the Figure 2.1) tray packs and the other one is *Cushioning Trays* (shown in the Figure 2.2). As explained by Peleg the description of these trays is as follows.

In peg type packaging every fruit is isolated in its own pocket formed by two consecutive trays, placed on the top of each other by means of specially constructed supporting pegs. This prevents the fruits from bearing any pressure due to stacking loads in container piles. Rather, the pressure is transmitted by the trays, as shown by the arrows in the Figure 2.1. Because of fruit size variations within counts and to prevent the fruit from bearing any part of stacking loads, headspaces between fruits and trays must be provided, as shown in the figure. Unfortunately, this headspace is also a potential source of damage due to possible bouncing of the fruits inside their cells, especially the smaller fruit size fraction. The pressure of bouncing fruits in tray packs or cell packs is easily verified by shaking the container up and down. The noise made by the bouncing fruits inside is easily distinguishable. If the transportation vibration environment contains frequencies corresponding to the natural frequency of the fruits in the trays or cells, they will be excited to bounce violently all the way. Under such circumstances, there will be some damage, no matter how soft the tray material is.

To eliminate the fruit bouncing problem is to remove the pegs from the structure of the tray and to let the container and fruits support the stacking loads, while being cushioned tightly by the trays. This type of tray known as *cushioning trays* and has a number of advantages. The cushioning-type trays keep the fruits comfortably against each other, effectively preventing any bouncing. Another advantage is better packing density, as compared with the peg type trays. Figure 2.1 shows how much container space the trays take up. Thus, the elimination of head space somewhat improves this aspect of tray packs.

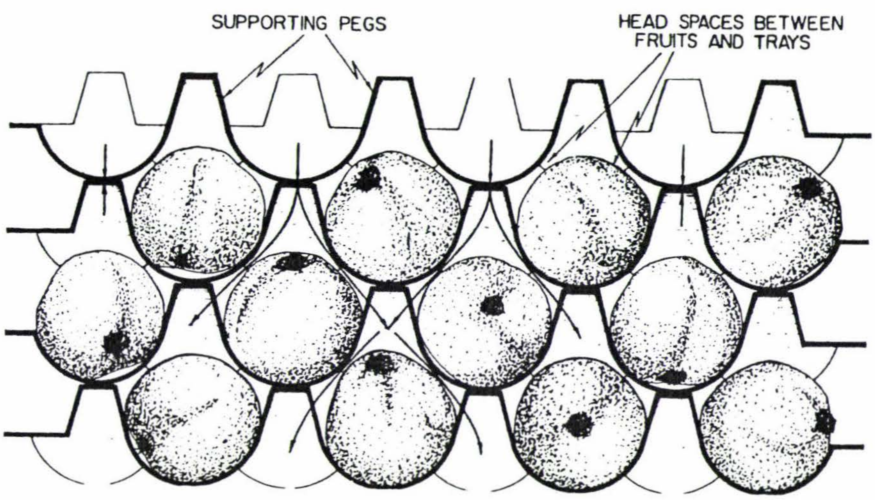


Figure 2.1 A Typical Peg-Type Tray Pack Steak in a Shipping Container (Peleg, 1985)

To alleviate the stacking load compression, however, cushion –type trays must be made to contact a maximal part of the fruit surface area. The greater the contact points supporting the fruit in the pack, the less pressure at each contact point, since the loading forces are distributed over a larger part of the fruit (Peleg, 1985). One type of construction aimed in this direction was patented by Keyes Fibre Co. and dubbed Spring Hammock (see Figure 2.2). This tray configuration is said to direct the downward pressure, due to stacking load forces, downward and away from the fruit, as shown by the broken lines. Effectively, this means more fruit content area and consequently, less pressure on the fruit.

The main packing component used by the New Zealand Apple and Pears Marketing Board is tray pack in the form of Spring Hammock cushioning tray and is called Friday tray or Z pack tray.

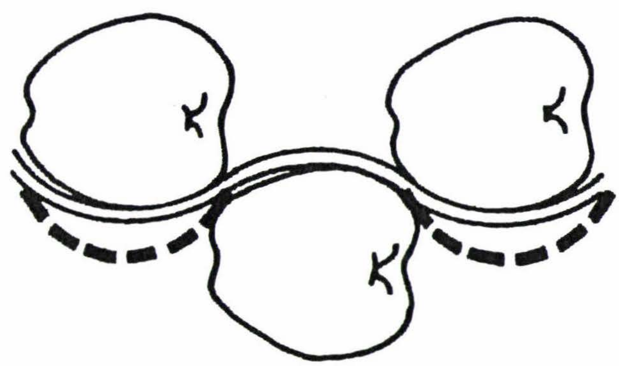


Figure 2.2 Spring Hammock construction, directs pressure downward and away from fruit, as shown by the broken arrows. (Peleg, 1985)

2.2.4.2 Cell Packs

There are three main types of cell packs: the hexagonally shaped honeycomb cell pack, the triangularly shaped honeycomb cell pack and the square-shaped cell pack. The cells of the first two types are formed from expanded paper honeycomb stock and plain paper sheets placed in between each consecutive two layers. In the square-shaped cell pack, similar plain paper sheets are used in between the layers, but the sidewalls of the cell are formed from interlocking stripe stock. All three types are usually made of heavy-duty craft paper. While the hexagonally shaped cells are most commonly used for packaging spheroid-shaped fruits, special cell configurations, e.g., triangles, may accommodate pears, avocados etc.

There is essentially no difference between peg-type (as explained in section 2.2.4.1) tray packs and cell packs, as regards their protective qualities. The honeycomb-structured cell packs are even stronger then peg-type tray packs in their ability to carry vertical stacking loads. This makes it possible to use relatively inexpensive thin wall regular slotted container (RSC) and obtain exceptionally high stacking strength, even in evaluated humidity environments. If the panels of the corrugated fibreboard container are weakened by absorbing moisture, the paper of the internal packaging, i.e., peg-type or cell pack, will not be appreciably affected and will retain most of their strength. Thus cell packs are ideal for prolonged high-rise stacking of produce in high humidity environments.

2.3 Apple Packaging in New Zealand

2.3.1 Telescopic Carton Configuration

Prior to 1995, two-piece telescopic boxes with inner and outer dimensions of L517 X W318 X H312 were used to pack the apples. These cartons were stacked onto a wooden pallet of W1626 X L1080. Apples were packed using a moulded paper pulp tray called Friday tray placed in the carton. Each count size (count size refers to the number of fruits required to makeup one carton) had its own unique arrangements to allow the correct number of fruit per carton. The count sizes are 64, 72, 80, 88, 100, 113, 125, 138,150,163,175,198 and 216 and each carton contained 18.8 Kg. of fruit.

The main types of packing involved 4 or 5 layers of fruit, whilst 6 layer packs were required for very small apples. Correct usage of apple trays was and is essential to ensure correct fruit positions in the carton, and the correct constant net weight of the fruit. The packing instructions for pack houses packing apples in the telescopic carton are given in the Table 2.1.

Standard Count	**48**	**56**	**64**	**72**	**80**	**88**	**100**
Tray Usage	A x 2 (+C)	Rev x 4(+C)	A x 2 (+C)	Rev x 4(+C)	A x 2 (+C)	Rev x 4(+C)	Rev x 5(+C)
	B x 2		B x 2		B x 2		

Standard Count	**113**	**125**	**138**	**150**	**163**	**175**	**198**
Tray Usage	A x 3 (+C)	Rev x 5(+C)	A x 3 (+C)	Rev x 5(+C)	A x 3 (+C)	Rev x 5(+C)	Rev x 6(+C)
	B x 2		B x 2		B x 2		

(+C) = An upturned tray used as a capper

Rev = Means the tray is reversible

A and B trays have different number of fruits, the A has more fruit

An extra tray used as a capper tray. It is turned over to cover encase the top layer of the fruit, the capper is a B tray or a reversible tray.

Table 2.1 Count Comparison by Pack

2.3.2 Z pack Carton Configuration

At present, as recommended by Davis, Fish and Fisher, NZAPMB is following the ISO standard packing (McLeod, 1997). Their suggestions are to use a carton with external dimensions of L500 X W330 X H278 mm (see Appendix 1 for NZAPMB specifications), which is called Z pack palletisation. This will allow for palletisation on to 1000 X 1200-

mm pallets. The commonly used counts for Z pack are 60, 70, 80, 90, 100, 110, 120, 135, 150, and 180 (called Z count), weighs 18-18.3Kg (Lenting and McLeod, 1988(a)). The weight of the fruit in the carton has to be consistent, this regardless of the number of individual fruit or size of the fruit in the carton. The Z pack configuration and the Z pack tray usage is shown in the Table 2.2.

Z count	Trays of Fruit	Fruit per Tray	Tray Usage
60	Rev x 4	15	Rev x 5
70	Ax2, Bx2	A=18, B=17	Ax2, Bx3
80	Rev x 4	20	Rev x 5
90	Ax2, Bx2	A=23, B=22	Ax2, Bx3
100	Rev x 4	25	Rev x 5
110	Ax2, Bx2	A=28, B=27	Ax2, Bx3
120	Rev x 4	30	Rev x 5
135	Rev x 5	27	Rev x 6
150	Ax3, Bx2	A=30, B=30	Ax3, Bx3
165	Rev x 5	33	Rev x 6
180	Rev x 5	36	Rev x 6

Rev = Means the tray is reversible

A and B trays have different number of fruits, the A has more fruit

An extra tray used as a capper tray. It is turned over to cover encase the top layer of the fruit, the capper is a B tray or a reversible tray.

Table 2.2 Z Pack Configuration and the Z Pack Tray Usage (McLeod, 1997)

2.3.3 Volume Utilisation

One of the major problems with the telescopic packing was the poor utilisation of space in the carton. The previous carton dimensions of 517 X 318 X 312mm, which has the volume of 0.051cubic meter contains 18.8kg of fruit compares poorly to a Z pack carton dimensions of 330 X 500 X 258mm, which has the volume of 0.042 cubic meter that contains of 18.1kg of fruit. The poor utilisation of space results in higher shipping and packing costs per one kilogram of fruit compared with the more pallet efficient Z pack. Wollim and Ledger (1985) when designing the stonefruit trays made similar observations for the Australian market.

2.3.4 Damage in Telescopic Cartons

Telescopic carton were called 'pressure packs' as the fruit was placed inside the carton in moulded pulp trays, which sat on the carton base. The cup shape in the tray covers the fruit, but in some counts the diameter of the fruit is bigger then the cup that compresses the fruit, in such case the packaging takes the load. The packaging takes the load until the pulp tray absorbs the moisture and formed around the fruit, then the carton is said to settle.

NZAPMB maintained that damage caused by the pressure in packing was considerable and the load should be removed as much as possible from the fruit. Aitken and Crosby (1982) and Barr and Cardwell (1983) conceived that pressure alone was not a major contributor to the fruit damage, but also a number of factors such as variety, apple size, carton position in transportation, fruit placement and sizing, handling conditions, pulp tray quality, carton fill, wrapping and the packing equipment. They found that 5 to 10% of the fruit was damaged prior to leaving New Zealand. This bruising appeared in the cartons independent of style, variety and count and may have originated in the pack houses when the fruit was crisp and more susceptible to damage. Aitken and Crosby (1982) reported that carton stacking strength was necessary to maintain stack stability during storage, but there was increasing evidence to suggest that dynamic effects relating to drop impact was a far more likely cause of bruising than static loading. They found that although bruising was more severe at the bottom of the stacks, the pattern of bruising in the carton indicated impact damage rather then static damage. Cartons dropped from waist height showed the bruising pattern was worst in the second to bottom layer and least in the top layer. Heap (1994) found similar bruising patterns on the cartons dropped from 600mm, but severity of the bruises varied between counts, which may have been due to the configuration of pocket placement in the trays.

2.4. PERFORMANCE OF MOULDED TRAYS

In 1996, NZAPMB packed 85% of the 18 million cartons, which contains 120 million moulded trays of pip fruit produced in new Z pack palletisable packaging. In comparison, only 1.5 million cartons were packed in palletisable units in 1995, which consumed forty five million trays.

In the past, trays were placed in the carton and then filled with apples. With the introduction of automatic tray fillers, it has been necessary to lift trays with apples on them into the carton. Hence, the tray should be capable of supporting 3.7 +/- 0.2 kg (mean) in five tray configuration and 4.6 +/- 0.25 kg (mean) in four tray configuration. In automatic filling, the trays perform three main key roles as a packaging component for apples, these are:

- With the advantage of automatic try filling machines the fruit is positioned on the tray before placing it in to the carton, where the tray should be capable of lifting the full load of apples and to withstand from tearing and bending.

- The pulp material absorbs the excess water that remains on the skin of the apple after cleaning and shorting operations. In addition to that, it absorbs the moister from the fruit to assist the try to soften and thereby providing better-fit and better protection to the fruit.

- The tray is expected to cushion the fruit and protect it from damage as it is transported from the pack house to its final destination at the marketplace.

The last explained function is the most important and the least understood despite there being several studies. Test results from different researchers are often conflicting and sometimes the performed results are unreliable or inconclusive. In terms of mechanical damage Schoorl and Williams (1972) showed that tray packed cartons with pulp trays were considerably superior to the traditional pattern packed cases with no trays, under single and multiple impacts. Holt and Schoorl (1984) showed that the pulp trays exposed for most of the energy absorption and dissipation on impact by stretching in two horizontal directions rather then compression at contact points. Their results indicated that only 15% of the kinetic energy was absorbed by the fruit, 60% was by the action of the tray stretching, and 25% was by the other actions such as carton bulging and other complex mechanisms of the tray. Because of its extensive properties most of the packaging industries uses paper pulp trays for packing of apples worldwide.

2.4.1 Paper Pulp Properties

Most of the trays used in New Zealand and internationally are made from recycled paper pulp because of its distinguished properties. The important properties of paper pulp fibre are explained as follows (http://www.online.anu.edu.au/Forestry/wood/paper/rawmat.htm).

Freeness is commonly measured in Canadian Standard Freeness (CSF), to measure the quantity of water drained from the pulp.

Fibre length, both the mean and the distribution of fibre length play a very significant role in determining the characteristics that the end product will have. Long fibres generally give strength (most closely linked with tear strength) and short fibres will give surface quality.

Fibre coarseness, this has two different measurements. One is the ratio of length to width of the fibre, the greater this ratio the more flexible the fibre is and that allows for better bonding strength. The other way is the ratio of twice the cell-wall thickness to the lumen diameter, if the ratio is high; the fibres are stiffer and less likely to collapse.

Fibre surface, a surface that is fibrillated has a very high surface area allowing for better bonding. Highly fibrillate pulp leads to a product with a high tensile strength.

Paper pulp has more freeness then any other fibres that are used to absorb moisture content from the fruits. However, paper pulp trays made out of paper pulp are widely used in packing industry because of tear strength, tensile strength and cushioning properties. The main packing component used in New Zealand Apple and Pear Marketing Board is a tray pack in the form of a spring hammock cushioning tray that is made out of paper pulp. In New Zealand three styles of pulp trays have been used in the apple industry, they are 'Friday Tray', 'Apple Tray' and 'Z Pack Tray'.

2.4.2 Friday Trays

The 'Friday Tray' is a lightweight component made out of paper pulp, which are used in corrugated apple cartons of internal measurements 500 X 300 X 277 mm (nominal), depending on count size 4 to 6 trays have been used in one carton. The name originated in America as Mr. Friday designed the first trays and can be identified by square slots at either end to facilitate lifting in and out from the carton. Trays made to original specifications are still in use all over the world, but since the original patents have been expired, there are other designs which are similar that have been produced in many countries. In New Zealand the imitated designs are called 'apple trays'. Details of the manufacturing process of these trays are given in Appendix 2.

2.4.3 Apple Trays

The 'Apple Tray', based on a Scandinavian design, has round holes at either end of the tray. It is also made out of paper pulp and to used for similar packing configurations as above. Lenting (1989a, 1989b and 1989c) undertook a series of trials to compare the performance of Apple Trays with standard Friday trays after cartons of fruits were stacked in cool-storage for a number of weeks. Bruising was assessed after the carton had been cool storage. The presence of bruising at packing was not considered, hence it was impossible to determine weather the bruising was a direct result of type of tray or not.

In the first trail, Lenting (1989a) compared the two different counts (113 and 138) of Royal gala and the fruit was cool stored for three weeks. The data was showed that Friday Trays were more prone to ripping in both count sizes compared with Apple Trays. In comparison Apple Trays showed higher bruising levels. The Apple Trays were stiffer and easier to handle resulting in less fruit damage from apples falling off the trays. In comparison, corner pockets on the Friday Trays tended to flatten out and lose rigidity. There was less rip and tears in the Apple Trays.

Lenting (1989b, 1989c) in his second and third trials found that the bruising levels were far higher and exceeded the NZAPMB standards. Lenting noticed that apples suffered more on the grader table rather then in-carton handling or from compression damage when stacked in the cool storage. From these inconclusive trails it was not possible to draw conclusions as to the performance of Friday Tray against Apple Trays.

2.4.4 Z PACK TRAYS

The geometrical construction of Z pack trays and apple trays are quite similar. Z pack trays are made to fit into 330 X 500 X 258 mm Z pack cartons with the dimensions of 476 X 322 X 100 mm (see Appendix 3 for specifications). A Z pack tray is made out of paper pulp and has also round holes at either end of the tray, and to use for similar packing configuration. NZAPM conducted the trials on the whole carton but none of the reports showed the individual experiments on Z pack trays. For compressive and impact tests, however, Z packs showed less bruising percentage then traditional packs. McLeod (1997) conducted the experiments on Z pack trays and reported that the percentage of the bruising depends upon diameter of the apple and the cup size.

2.5 ALTERNATIVE TRAY DESIGNS AND MATERIALS

A number of different materials were tested as an alternative to traditional trays to assess their effectiveness in bruising reduction and to increase the strength. Most of the trays used in New Zealand were manufactured out of recycled paper pulp. However, different types of materials are available for packing of apples such as polystyrene and compressed foam materials. These are as follows:

2.5.1 PULP TRAYS

Pulp trays, being hygroscopic, may absorb moisture from produce or surrounding atmosphere, resulting in softening and increased pliability of the trays. This, in turn, may cause the trays to better conform to the fruit shape thereby increasing contact surface area and reducing pressure. On the other hand, deformation of the cups in the bottom tray creates little flat surfaces in the bottom of the cups, effectively destroying the curved surfaces that are supposed to cushion the fruit. Since the bottom layer fruits bear the greatest compression forces, created by all the fruits above them, they must be supported by as large an area as possible. Turning part of the curved cup surface into a flat surface will cause commensurable fruit deformation since this leaves only on contact point between the fruit and the tray bottom (Peleg 1985).

2.5.2 POLYSTYRENE TRAYS

Expanded polystyrene trays are an excellent cushioning material, light in weight and attractive looking. Bottom layer cups will retain their cushioning properties and will not flatten out, even under prolonged compression (Peleg, 1985).

Trials using South African moulded polystyrene trays, NZFP (1984) reported that the form structure of moulded polystyrene trays collapsed irreversibly and split immediately under impact and compression tests. Anderson (1983) found American polystyrene trays are more promising then Friday trays under impact tests. The test results showed that polystyrene trays gave more protection against bruising in the bottom layer then Friday trays.

2.5.3 High-Density PVC Trays

High-density PVC trays are relatively thin and flexible, enabling them to conform snugly around varying fruit shapes and sizes. Their ability to bear vertical stacking loads is less then in pulp or expanded polystyrene trays. The net effect is probably a compromise between the protective properties of peg-type and cushioning –type pulp trays. Bouncing is prevented due to the snug fit of the fruits in the thin-skinned pockets, while the peg-type structure carries part of the stacking load. Because of the thin material, high-density PVC trays waste the least amount of container space. Thus, somewhat better packing densities may be expected, in comparison to pulp or expanded polystyrene trays (Peleg, 1985).

2.5.4 Polyurethane Foam Pads

Shipping trials were undertaken by Fountain (1962) using of polyurethane foam pads by placing them in between each layer of apples instead of using traditional pulp trays. The results showed comparable amount of bruising in small count apples and 150 % increment in large count apples, the severity of bruising was also more in large count apples. Crosby (1984) also conducted impact and compression tests on polyurethane foam pads, and noted that the bruise protecting characteristics of the foam sheets were not to the same standards as Friday trays.

2.5.5 Polystyrene Foam Pads

Fountain (1962) used polystyrene foam pads instead of pulp trays because of their ability to provide good cushioning. The reports shows that the polystyrene ruptured and cracked permitting direct contact between apples in adjacent layers and also bruising and severity of bruising were high. Crosby (1984) also noticed that styrene sheets were less effective then pulp trays under impact followed by compression tests; however, after being subjected to compression and then impact, styrene sheets afforded the greatest protection in terms of bruise volume.

2.5.6 PRESSED FOAM

Crosby (1984) conducted experiments on pressed foam under impact and compression tests. The report stated that foam did not perform as well as pulp trays in protecting the fruit from bruising.

2.5.7 FOAM NETTING

Crosby (1984) tested foam netting as a substitute of Friday trays. The test results under impact and compression showed foam netting was not a suitable replacement of Friday trays with ten times the bruise volume of the control fruit after impact by compression of the cartons.

2.5.8 POLYBUBBLE SHEETS

Crosby et al (1983) used polybubble sheets by placing below each tray of the apples in the carton. The data showed that there is no real advantage in using polybubble sheets in conjunction with apple trays. Using polybubble sheets instead of capper trays (inverted tray on top layer of the fruit) resulted in an increase in bruising percentage. Crosby (1984) showed that substituting polybubble sheets for pulp trays gave excess amount of bruising damage compared to Friday trays when subjected to impact test.

2.6 TESTING METHODS

Most of the researchers carried out tests on the full carton of apples and individual testing of the carton or tray itself was rare. In 1982, NZAPMB conducted the trials by anticipating static loads caused the bruise damage, so by increasing the carton strength the bruising level could be reduced. From their trails it was noticed that dynamic effects related to impacts was a more important cause of bruising then static loading. The same theory has been proved by Holt and Schoorl (1983) who stated that at high impact situations, mechanical damage was the result of energy transformation, and in the case of apple damage was directly related to the amount of energy absorbed.

Attempts have been made to increase the strength of a tray by increasing its weight. Byrom (1989) increased Friday trays weight to check whether it increases the strength of tray or not and to see the response of bruising amount. Three different tray weights were tested, with only four cartons of apples being tested for each weight, so the results were indicative rather then conclusive. Tray weights tested were standard 90 grams tray, 75 grams tray and 100grams tray. Results showed that 75 grams tray was capable of supporting a full load of apples when loaded to the carton, but the percentage of bruising is 40% more than 90 grams tray when it subjected to impact. The 100 grams tray showed very little deviation from the 90 grams tray. This indicates that increasing tray weights does not reduce the percentage of bruising; as Byrom concludes, it appears tray design will have to be modified in order to increase tray strength appreciably.

A sophisticated load generation system was constructed by DSIR a using hydraulic facility. It was capable of test on single cartons and whole pallets under a range of loading and environmental conditions (Bastin, 1991). From the test results, it was concluded that moisture content in trays was one of the most important criteria in the performance of carton and tray. Heap (1994) agrees with this hypothesis after conducting a series of drop tests on trays at different moisture conditions. Heap stated that the trays with 15% moisture content are considerably weaker then trays with 8% moisture content, the amount of splits occurring in the drier tray was greater then the moisture containing tray. Heap suggested that this might be due to the trays having greater ability to stretch at higher moisture content. Heap further states that the presence of tray splits did not seem to cause bruising in apples in close proximity to split.

Ashdown (1995) used finite element analysis as a tool to test the tray strength under static load conditions. Ashdown also conducted the experiments to find out the mechanical properties of paper pulp, and observed that the increase in moisture percentage reduces the strength. The experiments conducted by Ashdown showed that pulp material has no non-linearity, and the model prepared for finite element analysis was also liner analysis. In reality, there is a difference between the linear analysis and non-liner analysis, a 10 to15 percentage variation being expected.

2.7 Finite Element Modelling

From the literature it can be seen that trays are an integral part of the packing system and are largely responsible for protection of apples. The trays and cartons seem able to adequately protect the fruit during static compression loads but bruising is sustained during dynamic loads such as when the carton is dropped.

General agreement among the researchers is that a new tray design is required if strength is to be increased. Attempts made to increase the strength of tray by increasing the weight (in terms of thickness) have proved largely unsuccessful. Moisture content is also a very important property of trays as it helps the formation of tray tears, which are thought to be important aspect in bruise protection. Relation between the tray cup size and apple diameter is another important character in protecting the fruit from bruising. If the diameter of the cup is greater then the apple diameter then the chances of percentage bruising through vibrations are more. Before creating a finite element model, the above points about packaging have to be considered. Initially, models need to be created with the existing methods then the information above can be used to make further modifications. Two basic models will be created. One model will simulate the tray being picked up by a pack house worker while laden with apples. This model will have two separate support conditions, the tray being picked up from the ends and from the sides. The other model will attempt to simulate an entire tray of apples in three dimensional for compression tests. In both cases, models will be simulated by non-linear analysis with an extensive usage of slide-line properties. Once the existing system is successfully modelled improvements to the tray can be made. From the above practical information, a new design will have to be attempted, as efforts to strengthen the existing tray have proven unsuccessful. Results from the analysis of the existing trays should provide indications of design changes.

To define a finite element model, physical property of apples, mechanical properties and geometrical properties of apples and trays are essential. Physical properties of apples and mechanical properties of trays are discussed in the next chapter. The relations between the fruit diameter and radius of cups are discussed below.

2.7.1 Fruit Diameter and Tray Cup Diameter

McLeod (1997) conducted the experiments to establish a relation between fruit weight and diameter, and the effect of bruising related to cup size on Z pack trays. To create a finite element model the weight and diameter of the fruits and Z pack tray cup diameter are required but not the relation between them. However, the required data as given in the Table 2.3 was collected from the graphs provided by McLeod (1997). The diameter and length of fruits were measured by using calliper with the tolerance of 0.1mm and weights were recorded on electronic top pan scale with the tolerance of 0.3gms.

Apple Count	Average Fruit Weight (gms)	Tray Pocket Diameter (mm)	Range of Fruit Diameter (mm)
50	362	97.0	90-104
60	302	93.0	86-98
70	259	89.0	82-92
80	226	85.5	79-87
90	201	82.0	72-84
100	181	79.0	71-82
110	165	76.0	69-76
120	151	74.0	66-75
135	134	70.5	63-72
150	121	68.0	61-70
165	110	66.5	59-68
180	101	64.5	57-66
198	91	62.5	55-62

Table 2.3 Fruit Weight & Diameter and Tray Cup Diameter with Related to Count Size.

CHAPTER 3

LITERATURE REVIEW ON PHYSICAL PROPERTIES OF APPLES AND MECHANICAL PROPERTIES OF PAPER PULP

3.1 Physical Properties of Apples

To develop a finite element model some physical properties of the objects are required. In reality it is very difficult to measure the physical properties of biological products like fruits, animals and elements of the human anatomy. These biological products differ from mass produced products; these materials are alive and continuously undergoing change in shape, weight and representation with respect to time. The cells in the biological products will be influenced by humidity, temperature and oxygen content, which are difficult to control. In biological products the elastic properties and density will change with the age and environment. Typically researchers have found the mechanical properties when the fruit is fresh and delicious.

3.1.1 Young's Modulus

Young's modulus is a major model property for setting up an FEA analysis; there is some basic literature available on the Young's modulus of apples. Mohsenin (1970) reported the value of Young's modulus as 0.5-3.5 N/mm^2 (Golden Delicious) and Finney (1971) measured as 6.2-10 N/mm^2 (Red Delicious). Blahovec et al (1997) has given the value of E as 4.88 N/mm^2 (Golden Delicious). They measured this value until the apple reached its non-linear region; tests were performed on a Universal-testing machine FZP10/1. All the above values were calculated using compression test on whole apples. Ashdown (1995) measured the Young's modulus of Granny Smith apples as 3.95 N/mm^2. He conducted the tests using a three-point bend test on an Instron screw driven testing machine.

The shape and nature of the stress/strain curves are similar in tension and compression, however Young's modulus and Poisson's ratio give slightly different values. In homogeneous isotropic materials it is accepted that compression tests do not reliably evaluate the simple elastic properties (Ashby and Jones, 1980). In addition, compression tests will damage the flesh that will change the mechanical properties of apple. In the bend test the area of test sample remains constant and little or no damage is done to the material in the way of crushing except at the loading and support points. Whereas in compression testing the area of the test piece will change in a non-linear manner as compression proceeds. The difference between the compression tests and the bending test is shown in Figures 3.1 and 3.2, in the form of graphs. Lu and Abbott (1996), assigned the material properties of E = 4.0 N/mm^2 in his finite element modal, whereas Chen et al (1993) assumed 2.5 MPa to define material properties in his FEA model.

From the above values it was decided to take that of Ashdown, because he followed the methodology laid down by Ashy and Jones; thus a figure of 3.95 N/mm^2 for Young's modulus of apple is taken.

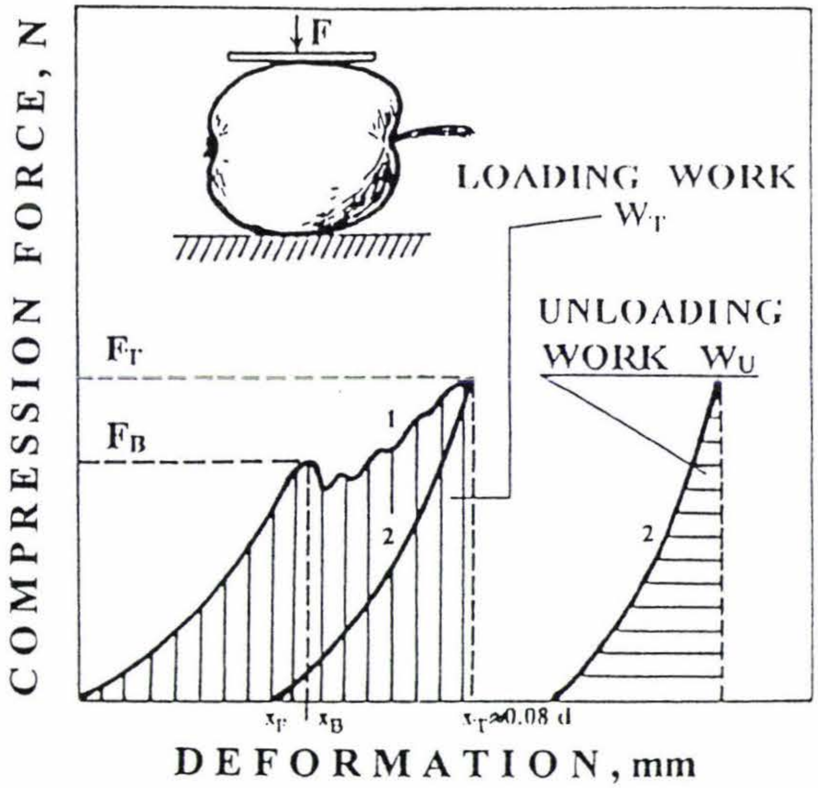


Figure 3.1 Compression Test of an Apple Fruit between Two Plates (Blahovec et al, 1997). Loading of the fruit (1) at a constant strain rate up to total compression deformation x_T, followed by unloading at the same but reversed strain (2). F_T = Total Force, F_B & X_B = The Bioyield Points, WT = Area of Total Work Loading, W_U = Unloading Work

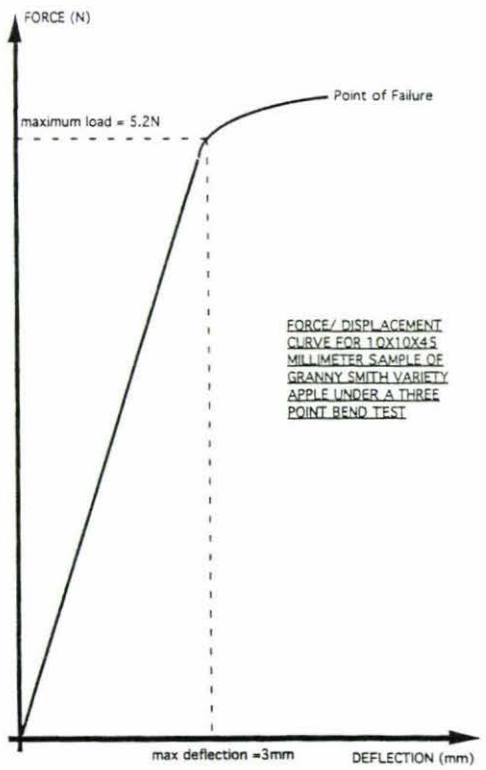


Figure 3.2 Force /Deflection Curve for Three Point Bend Test on Apple Material (Ashdown, 1995).

3.1.2 Poisson's Ratio

Poisson's ratio is defined as the ratio of transverse strain to the corresponding longitudinal strain; it may have more then one value if the material is not isotropic (Mohsenin, 1970). It has been found that in the literature Poisson's ratio varies with the variety of the apple. Chappell and Hamann (1967, Original not seen) measured the Poisson's ratio of Red Delicious and Winesap variety apples as 0.21 and 0.29 respectively, by using the formula $\nu = at^{b}$, Where t is time and '*a*' and '*b*' are stress dependent coefficients. This time and stress dependency of Poisson's ratio revealed the non-linear viscoelastic nature of the apple flesh. Mohsenin (1970) also measured the Poisson's ratio of the McIntosh apple by using the formula $E = 3K(1-2\nu)$, where *K* is bulk modulus and *E* is elastic modulus. By applying hydrostatic pressure and considering the deformation as elastic, he found that K=3.612 N/mm^2 and E=3.198 N/mm^2, then Poisson's ratio was calculated as 0.37. Both Chappell and Hamann and Mohsenin assumed that the apple has no non-linear properties, which is not true. Chen et al (1996), while doing his experiments to measure apple impact transmission wave measurement and apple texture properties, assumed a Poisson's ratio of 0.25. Lu and Abbott (1996) modeled the apple in finite element method to measure the vibration by using the Poisson's ratio of 0.3 (data from Mohsenin). Chen et al (1993) also modelled a finite element based model to analyse the fruit firmness used Poisson's ratio of 0.3, but the source of data was not given. The Royal Gala variety of apple is defined to create the model, as explained by Mohesenin the Poisson's ratio changes with the variety, it was decided to take the value of Poisson's ratio as 0.3 which is very close to the literature values.

3.1.3 Measuring Density

It is difficult to measure the density of irregular shapes such as agricultural products. However, the density and volume of such products was resolved by measuring the displacement of water. No literature has been found for density calculations of 70 count apples, however Lu and Abbott (1996) estimated the density of apple (US size 80 and 138) as 800-kg/cubic meter and 860-kg/cubic meter (for 170 gm apple, Chen et al 1993). So it was decided to perform an experiment to measure 70-count apple density. Mohsenin (1970) explained a simple technique to obtain this value by using the "Platform Scale"; a simple platform scale is shown in Figure 3.3. The fruit is first weighed on the scale in the air then forced into water by means of a sinker rod. The second reading of the scale with the fruit submerged minus the weight of the displaced water will allow the volume to be calculated.

Volume = Weight of displaced water/ Weight density of water

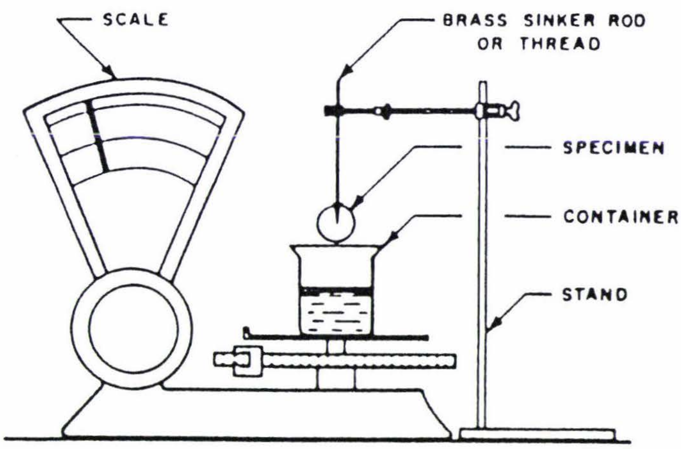


Figure 3.3 Platform Scale for Measurement of Volume and Density of Irregular Shapes (Mohsenin, 1970).

By knowing the weight and volume, the weight density of the apple is calculated by the ratio of weight to volume. A sample of twenty of 70-count apples were taken to measure the density, a table of calculations are shown in Appendix 4. The average of calculated density is 978.47kg/cubic meter.

3.2 MECHANICAL PROPERTIES OF PAPER PULP

Very little data has been found on mechanical tests for the paper pulp material. When detailing the material properties for paper pulp, most of the literature concentrated on chemical composition, burst strength and edge compression strength. The major material properties required are Young's modulus and Poisson's ratio. However, tensile tests had been conducted by assuming no non-linearity in the material, but the test procedures are not specified (Holt and Scholl, 1984). Moisture content has been found to be very important in the mechanical behavior of the trays as it contributes the formation of tray tears, which are thought to be an important aspect in preventing the apples from damage. It was found that the increase in moisture content decreases the stress and energy of failure and increases the deformation.

3.2.1 STRESS, STRAIN AND YOUNG'S MODULUS

Initially, Holt and Scholl (1984) detailed a test procedure on paper pulp material. They performed tension and compression tests by using the Instron Universal Tester and standard jaws. Heap (1994) followed the same experiments using the Instron Universal Testing machine. Holt and Scholl specified no test standards, but Heap followed the procedure as set out in test standard AS 1301.448s – 91 (Australian Standards). Both Holt and Scholl and Heap conducted the experiments when test samples were at 8% moisture content (which is as directly received from the supplier) and 14-15% moisture content (conditioned for 5 days in a cool store at 1°C). Both authors used a 'Dog Bone' shaped test sample (as shown in the Figure 3.4) for tensile strength despite the ASTM standard's requirement to use a straight sample. Heap found the failures in test sample at the grips of the test machine; specimen dimensions were as used by Holt and Schoorl. Holt and Schoorl have given the values of tensile strength as 1.39 N/mm^2 and 1.12N/mm^2 and the failure strains as 0.072 and 0.082 for 8% and 14% moisture contents respectively. Heap gives the values of stress as 4.43N/mm^2 at the deformation of 1.547mm for 8% moisture content and stress as 3.822N/mm^2 at the deformation of 2.252mm for 14% moisture content. With the above values, it was possible to calculate Young's modulus by using the formulas:

$$\text{Stress } (\sigma) = \frac{F}{A}; \qquad \text{Strain } \varepsilon = \frac{\partial_{max}}{L}; \qquad \text{Young's Modulus} = \sigma / \varepsilon$$

Where:
F = Force associated with maximum extension
L = Original Length of test piece
∂_{max} = Maximum extension of test sample
A = Cross-sectional area of test piece.

Using the stress and strain calculated from the two test results found in the literature, the values of Young's modulus were obtained:

Heap = 143.183 N/mm^2 (8% MC)
= 84.85 N/mm^2 (14% MC)

Holt and Schoorl = 19.37 N/mm^2 (8% MC)
= 15.55 N/mm^2 (15% MC)

Ashdown (1995) also performed an experiment on paper pulp material until it reached its non-linear behavior by using the Instron Screw Driven Testing Machine. He used the straight sample (as shown in the Figure 3.4) as recommended in the ASTM test standards instead of 'Dog Bone' sample, which was used by the other authors. He calculated the Young's modulus from the stress-strain graph (as shown in the Figure 3.5) using the elastic region when the test sample was conditioned to normal atmospheric conditions. Ashdown gives the Young's modulus as $221 \pm 64 N/mm^2$. He also performed experiments on samples of pulp paper that had been conditioned in a cool storage for 24 hours, which contain higher moisture. He observed that the test pieces displayed essentially linear behavior with a lower Young's modulus, giving the value of E = 150 N/mm^2.

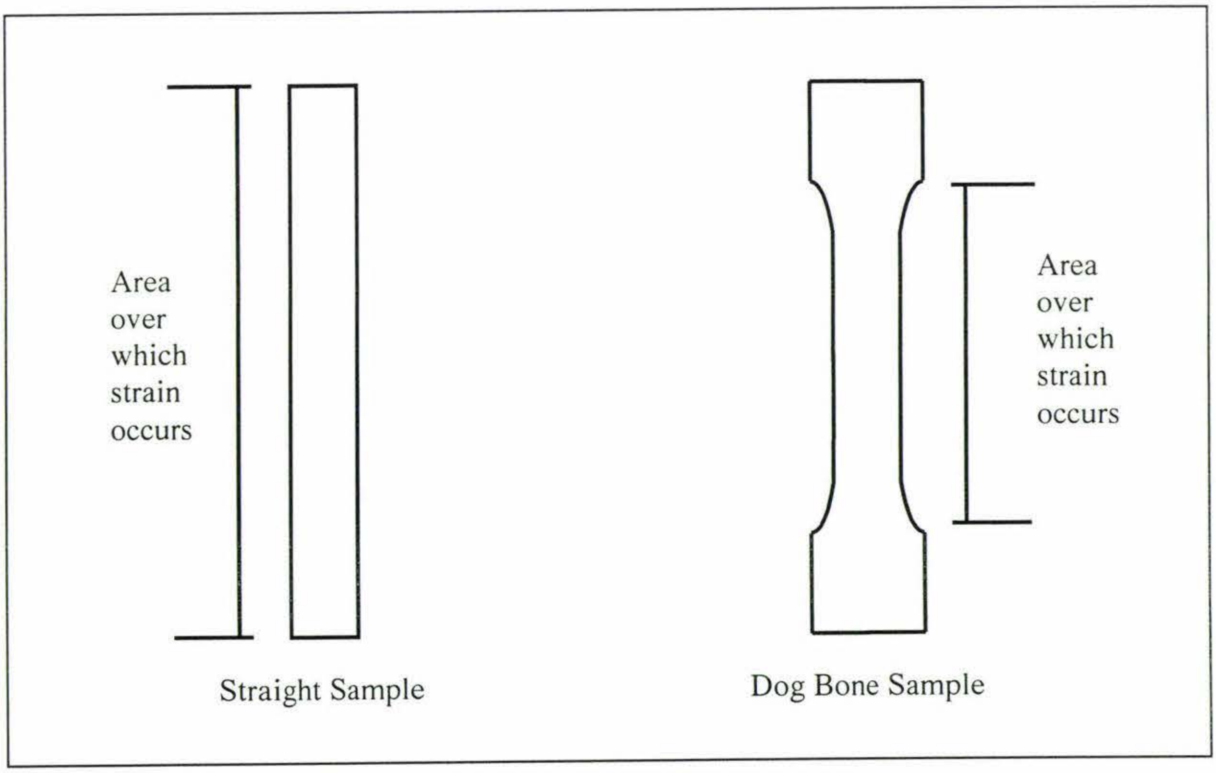


Figure 3.4 Straight Test Sample and Dog Bone Test Sample.

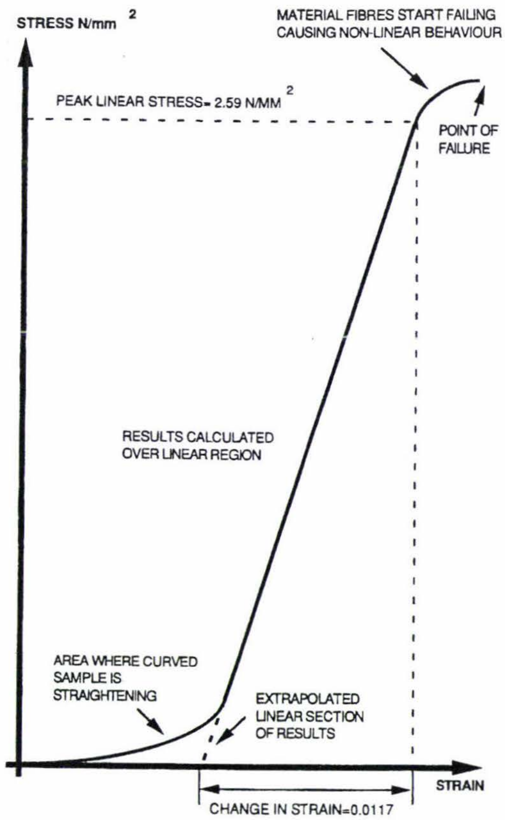


Figure 3.5 Stress-Strain Graph of Paper Pulp Material (Ashdown, 1995).

Neither Holt and Schoorl nor Heap used extensometers attached to the specimen, but simply measured movement of the test machine jaws. They assumed that all the deformation occurs uniformly along the test area, which is not true. Movement may occur due to settling in the jaws and there will be some extension to straighten the sample. Straight samples have an advantage over 'Dog Bone' samples of having a constant cross-sectional area through the entire length. All the extensions during the test, with the exception of jaw settlement can then be assumed to occur over a known cross-sectional area. This makes the results much more accurate and reliable than for the 'Dog Bone' shaped test sample.

Holt and Schoorl test pieces were cut from an actual tray and therefore curved in the contour of the tray. The values they give for extension seem to include the movement of the testing machine jaws that was required to straighten the test piece; therefore, these results are not a reliable measurement of deformation of test sample. However Ashdown measured the Young's Modulus directly from the stress-strain graph. The graph is curved at the start of the stress-strain plot, before setting into a straight line. This curve is where the test sample is to straightening out and the test machine jaws become firmly seated. Ashdown did not consider this initial curved part in measuring the Young's Modulus.

Ashdown found a big variation between his calculated values and literature values therefore he performed another experiment by using Three Point Bend Test (a three point bend test was shown in Figure 3.6). A strip of 150mm x 10mm material was simply supported at each end and loaded with a 0.1 N test weight in the middle. Theoretically, the deformation can be calculated by the formula:

$$\partial_{Max} = \frac{PL^3}{48EI}$$

Where:
∂_{Max} = Maximum Displacement
P = Applied Load
L = Length of the Test Sample
E = Young's Modulus
I = Moment of Inertia

He compared the theoretical values with practical and FEA model analysis, and he found experimental and theoretical tests give good correlation for maximum displacement. However, in a few incidents the moisture content in the tray might reach more than 18% MC, none of the authors has conducted experiments on Friday Trays beyond 18% MC and therefore it was decided to move forward to look at how the material properties will change with moisture content.

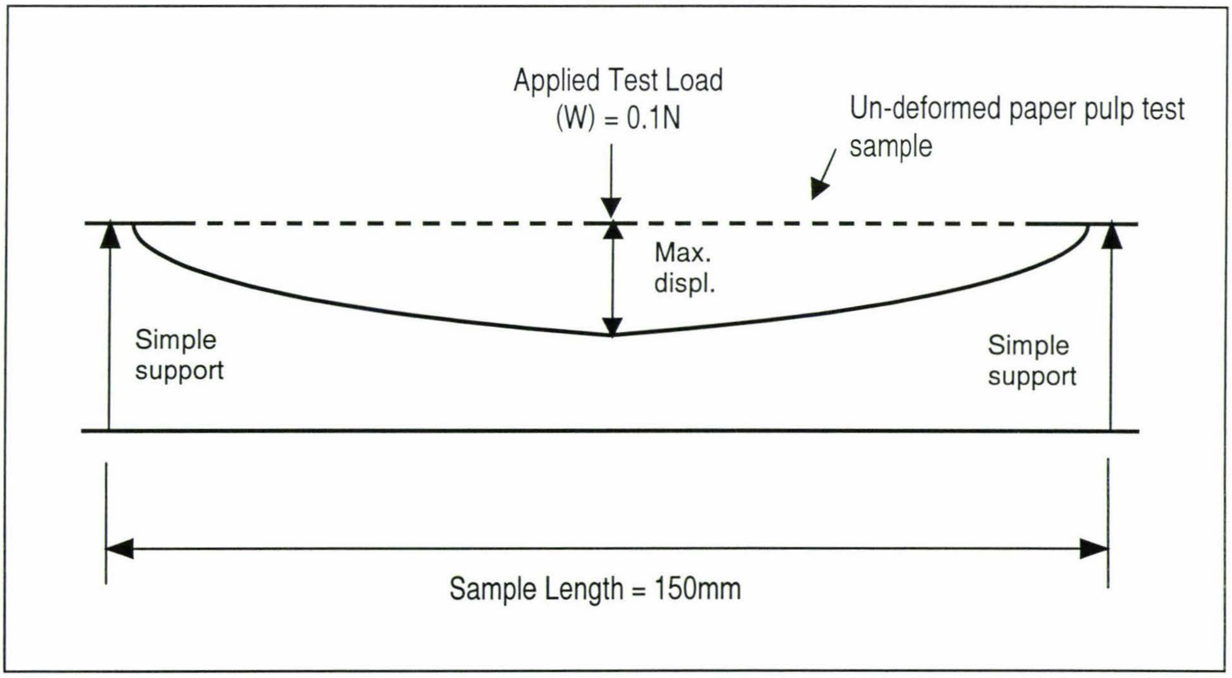


Figure 3.6 A Three Point Bend Test on Paper Pulp Material.

CHAPTER 4

EFFECT OF MOISTURE CONTENT ON MECHANICAL PROPERTIES OF PAPER PULP MATERIAL

4.1 TENSILE STRENGTH TESTS

During transit, the Friday trays are subject to complicated biaxial stresses including shear, and are handled at different temperatures and relative humidity conditions. Hygroscopic materials such as paper products, wood products, agricultural products etc will absorb moisture from the surrounding environment and tend to reach its equilibrium state (Kodandapani, 2000). The physical and mechanical properties of paper materials are affected by its moisture content, in which, it is dependent on the humidity of the surrounding environment.

The research done by Yeh et al (1991) shows that the changes in surrounding atmospheric conditions change the paper material properties and tend to exhibit non-linear mechanical behaviour. His experiments showed that increase in relative humidity from 40% to 95 % increases the percentage of moisture content in paper material from 6.63 to 23.04%, which decreases the strength (stress) from 60MPa to 30Mpa with increasing strain from 0.018 to 0.028. Heap showed that keeping the tray samples at cool storage for 24 hours will rose the moisture content from 8% to 15%, and tested for stresses and strains at only these moisture content levels. Ashdown also performed the experiments that had been conditioned for one-day in a cool storage, but the data of moisture content percentage was not given.

While reviewing the processes of apple packaging, there are three main occasions where the Friday trays can reach higher moisture levels; they are:

- When the cleaned apples placed in the cups of trays the trays will absorb water from the apples.
- When the packed cartons are placed in the cold storage for few days before going to warehouse or export.
- When the packed cartons were placed in the "Chiller" in the warehouse.

However, when testing the samples at room temperature and humidity of 21°C and 52% they exhibited 8.52% moisture content, and in the cold storage under controlled environmental conditions of 2°C and 80% RH they attained 16.72%. And also the samples where tested by placing them in a chillier at the local warehouse Pack N Save at the 1°C and 95% RH, they reached 23.76% moisture content level. It is impracticable to measure the moisture content level when the cleaned apples are placed in the cups of trays, as it is difficult to measure how much water the tray absorbs from the apples. At this stage the moisture level in tray might exceed then the previous stages. Neither Heap nor Ashdown have tested the material above 18% of moisture level. Considering these facts and lack of research in the behaviour of "Moulded Pulp Material" properties with increasing moisture content, a decision was made to investigate further. Research done by Yeh et al (1991) enthused to do further research on Apple Trays; a series of tensile strengths were therefore undertaken to assess the strength of the trays at different moisture content levels of 20, 40,60, 80 and 100%.

4.2 Sample Dimensions

Initially, all the experiments were carried out by using the Hounsfield Tensometer. As recommended by British Standards (Hounsfield Tensometer Instruction Manual) the test sample is in dog bone shape. The length of test sample is 63.5mm (testing area) and the width is 12.7mm, and the total length of sample should be 159.25mm and width of 38.1mm at the given radius of 25.4mm (L1, W1, L, W and R1 as shown in the Figure 4.1 respectively, all the dimensions were converted from inches to mm).

The Australian Standards (AS 1301.448s-91) states that rectangular samples should be used with the dimensions of 15mm wide and 250mm length that are used by Ashdown (1995). Heap (1994) found a high number of 'Jaw Breaks' where the test samples failed near to the testing machine jaws, rendering the data invalid. Therefore she followed the same dimensions, sample of 50mm length and 10mm width (testing area), which are used by Holt and Schoorl (1984). Yeh et al (1991) also used dog bone shape samples; he followed the ASTM & TAPPI testing standards. The specimens were prepared by cutting out 152.4 by 50.8mm rectangular samples, which were then cut into a dog bone shape.

When starting the initial experiments two different shapes and four types of sample dimensions were found from the literature. The was confusion as to what dimensions and shape should be used to perform the experiments. Hence, each of five sample dimensions provided by the previous researchers were prepared and tested, and most of the samples broke near to the test machine jaws. It was observed that most of the straight sample broke either at very near to the jaws or under the jaws. Samples broke at weak areas because the straight samples have varied cross-sectional area, as the samples do not have a uniform thickness. Where as in 'Dog Bone' samples, the maximum load acts on the middle section to break in the middle, as the cross-sectional area of the sample at the grippers is greater then the cross-sectional area in the middle section. Experiments showed that length of the sample did not show any influence on the splintering of samples in the middle, but the width is the major concern.

Therefore, tests using 'Dog Bone' shaped samples with a length of 100mm and different widths (test area) of 10, 15 and 20mm were carried out. All samples were firmly flattened before testing. It is very difficult to get the flat samples from Apple Trays and therefore few samples were cut from the lids of egg trays (one dozen tray boxes) and tested, assuming that both materials have similar mechanical properties as both materials were made out of paper pulp. From the results of Table 4.1 it can be observed that egg tray samples broke at high stress levels. Figure 4.2 shows different samples after testing, and it can be seen that 10 and 15mm width samples broke near to the machine jaws, 20mm sample broke in the middle and showed good correlation between the stress values. Hence, it was decided to continue the experiments with 'Dog Bone' sample with the dimensions of 100mm long and 20mm test width. The sample dimensions are shown in the Figure 4.1

S. No	Width (W)	Thickness (T)	Area (A=T*W)	Load (P)	Stress (P/A)	Observation
1-20	19.31	1.61	31.081	63.2	2.0334	Broke in the Middle
2-20	20.05	1.90	38.095	82.0	2.1525	Broke in the Middle
3-20	19.70	1.80	35.460	84.0	2.3689	Broke near to the Grips
4-20	19.38	1.59	30.806	63.0	2.0450	Broke in the Middle
5-20	19.25	1.60	30.800	62.0	2.0334	Broke in the Middle
15MM WIDTH SAMPLES						
1-15	14.53	1.52	22.086	50.5	2.2866	Broke at the Grips
2-15	15.22	1.56	23.738	62.0	2.6118	Broke near to the Grips
3-15	14.49	1.65	23.900	53.0	2.2176	Broke near to the Grips
4-15	15.12	1.83	27.585	42.0	1.5226	Broke in the Middle
5-15	14.65	1.58	23.139	53.0	2.2905	Broke near to the Grips
10MM WIDTH SAMPLES						
1-10	9.41	1.71	16.083	23.0	1.4301	Broke at the Grips
2-10	10.20	1.50	15.249	35.0	2.2952	Broke at the Grips
3-10	9.86	1.60	15.768	32.0	2.0294	Broke near to the Middle
4-10	10.10	1.86	18.786	23.0	1.2243	Broke near to the Grips
5-10	10.50	1.68	17.640	36.0	2.0408	Broke near to the Middle
EGG TRAY SAMPLES – 20MM WIDTH						
1	19.64	1.23	24.157	127.0	5.2572	Broke in the Middle
2	19.78	1.26	24.923	130.0	5.2161	Broke in the Middle
3	19.66	0.92	18.083	101.0	5.5855	Broke in the Middle
4	19.33	1.16	22.419	132.0	5.8879	Broke near to the Grips
5	20.22	0.81	16.378	76.0	4.6403	Broke near to the Grips

Table 4.1. Test Results of Different Samples of Different Widths.

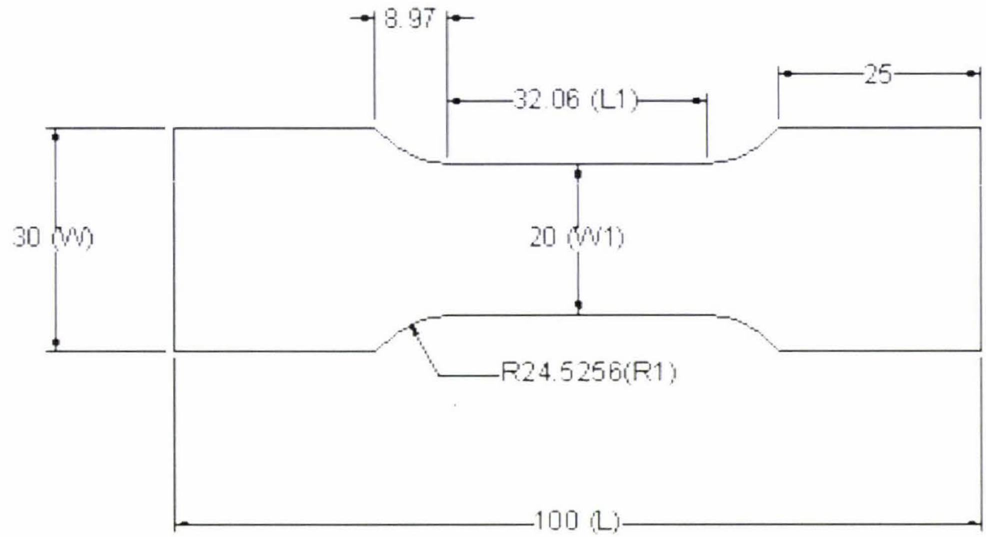


Figure 4.1. Selected Sample Dimensions (all dimensions are in mm).
(L = 159.25, W = 38.1, L1 = 63.5, W1 = 12.7, R1 = 25.4 are the dimensions of British Standards)

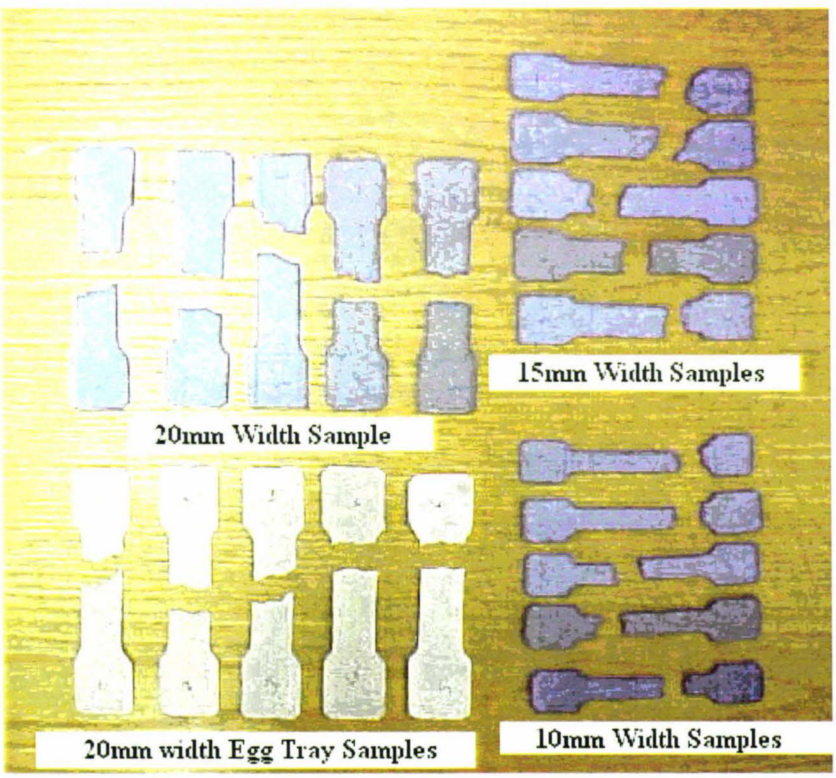


Figure 4.2. Test Results of Samples with Different Widths.

4.3 Enhancing Moisture Content

There are several ways to enhance the moisture content level in a substance; they are (Pande, 1975):

- Adsorption of gasses by charcoal.
- Conditioning the samples at low temperatures and high Relative Humidity.
- Keep the samples in steam chambers.
- Soak the samples in the water; temperature of the water affects the absorption.
- Adding chemicals such as inert acetyl (CH_3CO), Polyvinyl Alcohol and solution of salt in water etc, often these chemical adding takes place to maintain constant moisture content level.

Among all these processes, soaking the samples in water for a few minutes to accomplish desired moisture content is the easiest way and less time consuming, therefore the same technique was followed.

4.3.1 Measuring Moisture Content

Methods of moisture measurement can be broadly classified into two groups: Direct (Chemical) and Indirect (Physical) (Pande, 1975). In direct methods, moisture is removed from the material by oven drying desiccation, distillation and other physicochemical techniques, and its quantity found by weighing or observing changes in the pressure or temperature. In indirect methods, moisture is not removed from the material, but the parameters of the wet solid, which depend on the quantity of water or number of constituent hydrogen atoms present are measured. While exploring for the accurate and easy method to measure the moisture content other then Oven Drying method, it has been found that many authors have investigated that there is a relation between the moisture content of hygroscopic materials and their dc conductivity or dc resistance. Kujira and Akhari (1923, Original not seen) studied the change of resistance of paper and cloth with changing humidity conditions and found that resistance fell with increasing humidity, the logarithm of the resistance being practically a linear function of the humidity. Therefore the effect of moisture content on the electrical resistance of moulded paper pulp material has been studied. Five samples were cut from different trays and the percentage of moisture content raised to 20, 40, 60, 80 and 100 and then tested. Samples were placed on non-conductors at a distance and resistance measured with a digital voltmeter, the arrangement is shown in the Figure 4.3. The obtained results are given in Appendix 4, and a graph has been plotted between the resistance and moisture content as shown in the Graph 4.1. From the graph it can seen that the relation between resistance and moisture content are incoherent. However, the samples below 30% moisture content showed good correlation between values and are linear. According to Pande (1975), it is not reliable to measure the moisture levels above its Fibre Saturation Point (FSP approximately 30%

moisture content) by electrical method. Even below 30% moisture content samples showed big variation between the values. It is because of two reasons, thickness of the sample and sample wrenching. While measuring, if the sample moves, the relation between the resistance and moisture content of material are different. Charging currents of geometrical and internal capacitances will surpass the conductivity. The material movement can be considered as replacing the dc current by an ac current of a proper frequency. Therefore, it is not an appropriate method to measure the moisture content and resistance by using a simple Voltmeter. It is necessary to have separate calibrations made taking into account the variation of the resistance moisture characteristics due to variations in fibre, size, density and movement.

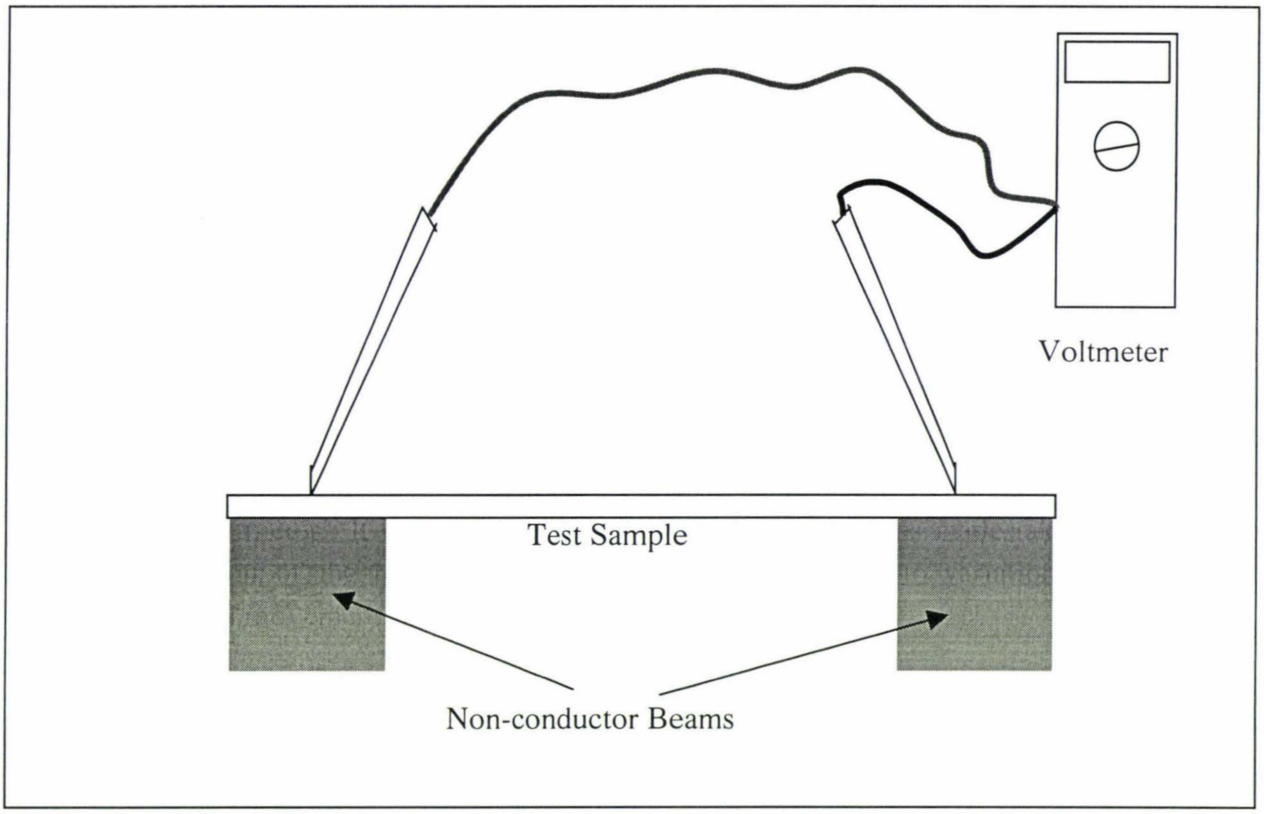
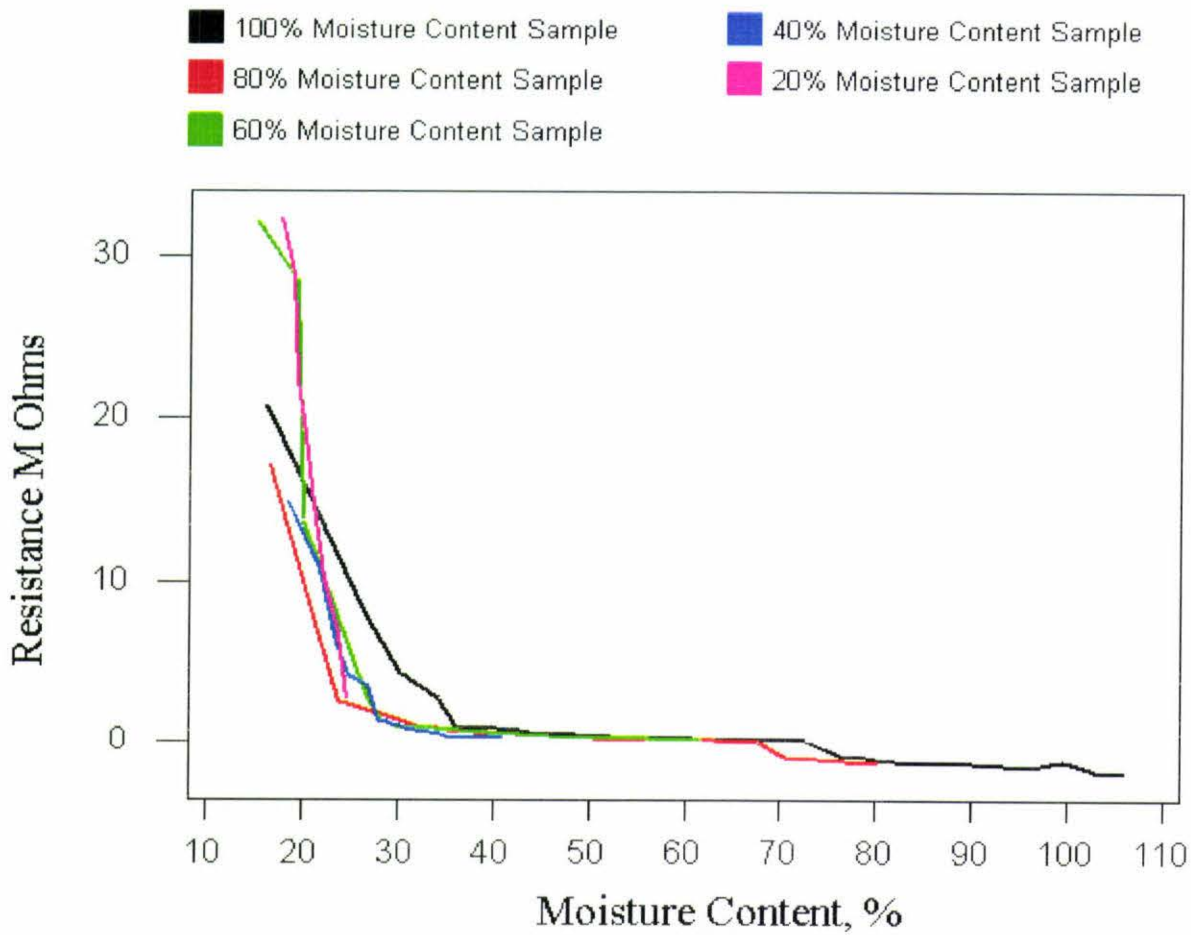


Figure 4.3 A Simple Arrangement to Measure the Moisture Content by Electrical Method.

Hence, it was decided to measure the moisture content by Oven drying. There are two procedures to measure the moisture content in the samples by oven drying method; Wet basis and Dry basis, for all scientific calculations the Dry basis method is used (Kodandapani, 2000).



Graph 4.1 Relation between Resistance and Moisture Content of Moulded Pulp Tray Samples.

$$\% \text{ Of Moisture content (Dry Basis)} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} X100$$

$$\% \text{ Of Moisture content (Wet Basis)} = \frac{\text{Wet Weight - Dry Weight}}{\text{Wet Weight}} X100$$

Moisture content of the samples was assessed by the method of Oven Drying as described in the Australian Standards AS 1301 P401s-78. The samples were weighed after drying in an oven for two hours at 105°C and cooled at room temperature and relative humidity until equilibrium moisture content was attained then re-weighed and the percentage of moisture content established by Dry Basis method.

4.3.2 Conditioning of Samples for Testing

Australian standards AS 1301.P414 86 on conditioning of paper states that prior to testing, paper samples should be conditioned for 24 hours at 20-35% Relative Humidity and a temperature not above 40°C. After conditioning as above, it was decided that in order to simulate conditions experienced within the industry and the warehouse where Friday trays are stored and used, it would be more appropriate to test trays with higher moisture content levels. Sample from 5 different trays were therefore tested direct from the supplier as per Australian Standards. The remaining samples each of five were tested at different moisture levels of 20, 40, 60, 80 and 100%.

4.4 Material Properties at Various Moisture Levels

Moulded pulp trays (as it is made of paper material) belong to the family of man-made cellular solids as they are made of interconnected networks of fibres or plates, which form the edges and faces of cells. Cellular solids have physical, mechanical, and thermal properties that are measured by the same methods as those used for fully dense solids (Gibson & Ashby, 1988). Hence, all the experiments were conducted by traditional equipment that are used to measure stress and strains in solids (metals).

Samples were taken from twelve trays at the possible sites where splitting on impact may occur, selected randomly from a bundle of different size trays. A die was made to cut the samples accurately as per the selected sample dimensions; the die is shown in Figure 4.4. Five samples were tested directly and five of each brought approximately to 20, 40, 60, 80, 100% MC. Before testing, all the samples were flattened firmly assuming that there will be no structural changes. Thickness was measured in the centre of the five regions across the sample, and the average thickness was used for stress calculation. Samples at 20, 40, 60, 80, 100% MC were selected at random from sealed plastic bags, being removed immediately prior to testing to reduce evaporation.

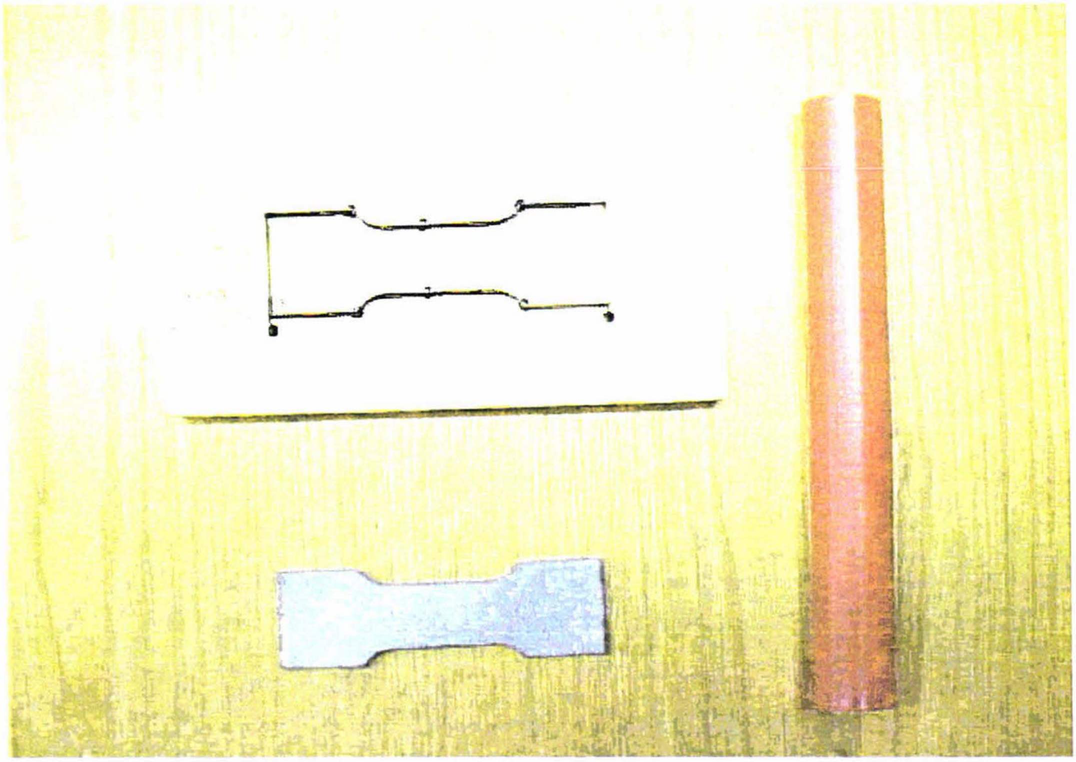


Figure 4.4 A Die and Roller to Cut the Samples.

Cell fluids contribute to the strength of open-cell foams in a completely different way. When the foam is compressed, the fluid it contains is squeezed out; when extended, fluid is drawn in. The faster the foam is deformed the more work is done; the pore fluid introduces a strongly strain-rate dependent contribution to the strength (Gibson & Ashby, 1988). Therefore a sophisticated machine Texture Analyser was selected to maintain the constant extension rate to perform the tests. The Texture Analyser is a microprocessor controlled texture analysis system, which can be interfaced to a wide range of peripherals, including PC-type computers. The main strengths of the Texture Analyser are versatility and ease of use. To obtain a great amount of analytical flexibility, the Texture Analyser was connected to an IBM PC or true equivalent running the Stable Micro Systems XT.RA Dimension software package ($TA.XT_2$ Operating Manual, 1995). The package allows the user to see a real-time graphical display of test progress and hand copy of output files. Tools are provided to make measurements such as distance, force ratio, areas, gradients and means between two points and as well as spot values. Sophisticated electronics allows the user to record Force and Distance measurements at accurate time intervals.

Samples were loaded into the jaws of a Texture Analyser testing machine set at a minimum of 47mm apart and were tested to a braking point at an extension rate of 10mm/min as recommended by the Australian Standards AS 1301.448s-91.

4.4.1 RESULTS AND CONCLUSIONS

From the results of force and distance, the raw data of stress and strain to failure are calculated by the following equations and given in the Appendix 4.

Stress = Force/Cross-Sectional Area of sample

Cross-Sectional Area = Mean Thickness X Sample Width (20mm)

Strain = Change in Length/Original Length

Results of percentage of moisture content, mean sample thickness (mm), Force (N), failure stress and strain are given in the Table 4.2. Graphs 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7 shows the obtained stress-strain curves at different moisture levels. These graphs clearly show a non-linear behaviour when the moisture content is high. Results from the tests showed that there were significant differences between the values of stress and strain at different moisture levels. Looking at the Graph 4.8 stress-strain for moisture content from zero to 100%, are observe that the samples at room temperature and RH show the highest stress levels and in 20% and 40% MC samples moisture content there is a decrease in strength with a maximum strain. It appears that the samples at biological conditions were more brittle and tend to snap rather than stretch prior to failure. Moisture in the material increases the ability to extend, but at the expense of decreased strength (Stress). With the increased moisture content, i.e. greater then 40%, the ability of the material to extend start to decrease, accompanied by a further decrease in strength. Apparently this is a change in mechanism of failure when moisture is high. Is this a breakdown in the bonds between the fibres, which would be non-recoverable? Therefore a simple experiment was set up to validate the results obtained. Each of three samples were taken up to 60, 80 and 100% MC and dried at room temperature and RH to 20% MC, and then tested. The results are given in Table 4.2 and the Graphs 4.9, 4.10 and 4.11 shows the obtained stress-strain curves of 60,80, and 100% MC samples down to 20%.

From Graph 4.12 it can be observed that samples broke at lower stress levels when compared with actual 20% MC samples. Thus samples that have been dried after being subject to high moisture (above 40%) do not fully recover their strength. Hence it can be can deduced that high moisture contents causes a permanent collapse in the fibre bonding. Hence, a decision was made to examine fibre holding together under microscope at different moisture contents. This is discussed in the next section.

Table 4.2 Stress and Strain Results of Moulded pulp tray Samples at Different Moisture Levels

* Width of the Sample = 20mm

* % of Moisture Content = (Weight After - Weight Before)*100 / Weight Before

Samples of No Moisture Content (Room Temperature and Humidity - Assuming that No Moisture content in the Sample)

Sample No.	Weight Before (m.gms)	Weight after (m.gms)	% of Moisture Content	Average Thickness (mm)	Area (mm^2)	Force in Newtons	Stress (N/mm^2)	Original Length (mm)	Change in Length (mm)	Strain
1 - 1	-	-	-	1.533	30.65	63.295	2.0651	44.15	1.788	0.0405
1 - 2	-	-	-	1.408	28.16	58.365	2.0726	65.36	2.810	0.0430
1 - 3	-	-	-	1.836	36.72	76.446	2.0819	57.90	2.430	0.0420
1 - 4	-	-	-	1.208	24.16	48.863	2.0225	46.27	1.893	0.0409
1 - 5	-	-	-	1.442	28.84	58.597	2.0318	48.47	2.000	0.0413

Samples of 20% Moisture Content

2 - 1	1343	1615	20.25	1.406	28.12	46.024	1.637	78.33	6.588	0.0841
2 - 2	923	1101	19.28	0.902	18.04	30.320	1.681	49.31	3.768	0.0764
2 - 3	1215	1465	20.58	1.318	26.36	43.121	1.636	78.93	6.108	0.0774
2 - 4	972	1167	20.06	0.948	18.96	30.870	1.628	55.79	4.170	0.0747
2 - 5	941	1138	20.94	0.906	18.12	29.364	1.621	58.43	4.390	0.0751

Samples of 40% Moisture Content

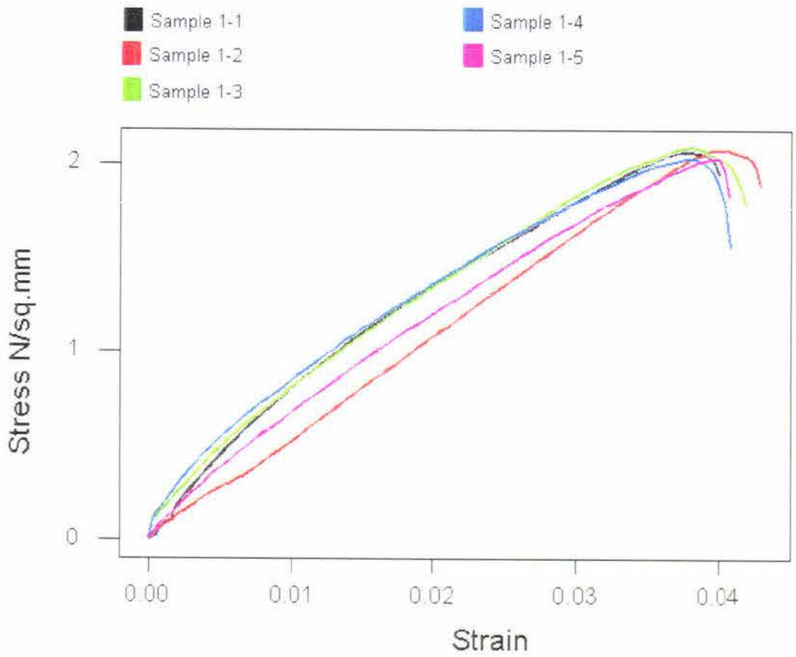
3 - 1	1280	1782	39.22	1.338	26.76	26.746	0.999	62.19	5.210	0.0838
3 - 2	987	1381	39.92	0.996	19.92	18.543	0.931	44.67	3.490	0.0781
3 - 3	975	1372	40.72	0.982	19.64	18.127	0.923	40.63	3.190	0.0785
3 - 4	1095	1525	39.27	1.140	22.8	23.071	1.012	51.63	3.790	0.0734
3 - 5	835	1179	41.20	0.850	17	5.787	0.340	58.17	1.349	0.0232

Table 4.2 Continued.

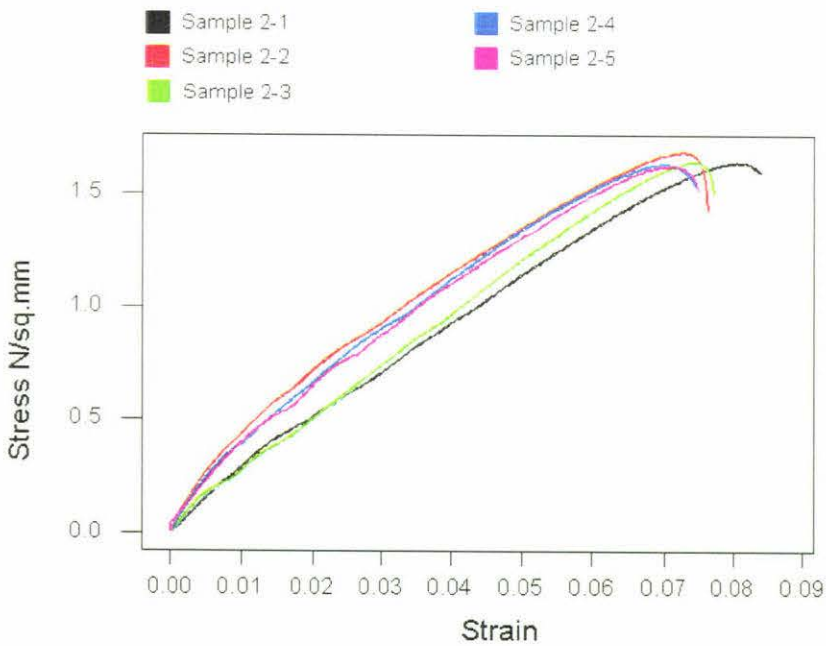
Sample No.	Weight Before (mgms)	Weight after	% of Moisture Content	Average Thickness (mm)	Area (mm^2)	Force in Newtons	Stress (N/mm^2)	Original Length (mm)	Change in Length (mm)	Strain
Samples of 60% Moisture Content										
4 - 1	1523	2453	61.06	1.602	32.04	17.699	0.552	47.39	2.693	0.0568
4 - 2	1154	1848	60.14	1.294	25.88	14.510	0.561	62.63	3.368	0.0538
4 - 3	1054	1688	60.15	1.120	22.4	12.713	0.568	44.93	2.440	0.0543
4 - 4	1571	2525	60.73	1.648	32.96	21.549	0.654	71.27	5.048	0.0708
4 - 5	991	1487	50.05	1.064	21.28	12.264	0.576	52.74	2.948	0.0559
Samples of 80% Moisture Content										
5 - 1	1317	2379	80.64	1.448	28.96	7.467	0.258	48.21	2.130	0.0442
5 - 2	1848	3341	80.79	1.944	38.88	10.62	0.273	53.35	2.388	0.0448
5 - 3	1492	2680	79.62	1.546	30.92	8.371	0.271	47.92	1.968	0.0411
5 - 4	1955	3513	79.69	2.112	42.24	11.735	0.278	60.06	2.770	0.0461
5 - 5	1643	2939	78.88	1.740	34.8	9.997	0.287	57.50	2.513	0.0437
Samples of 100% Moisture Content										
6 - 1	1237	2511	102.99	1.336	26.72	4.166	0.156	42.09	1.310	0.0311
6 - 2	1879	3748	99.47	1.776		-		57.80		
6 - 3	2034	4075	100.34	2.297	45.94	7.403	0.161	71.75	2.800	0.0390
6 - 4	1903	3811	100.26	2.045	40.9	6.654	0.163	73.50	3.260	0.0444
6 - 5	1982	4012	102.42	2.107	42.14	6.470	0.154	56.45	2.090	0.0370

Table 4.2 Continued.

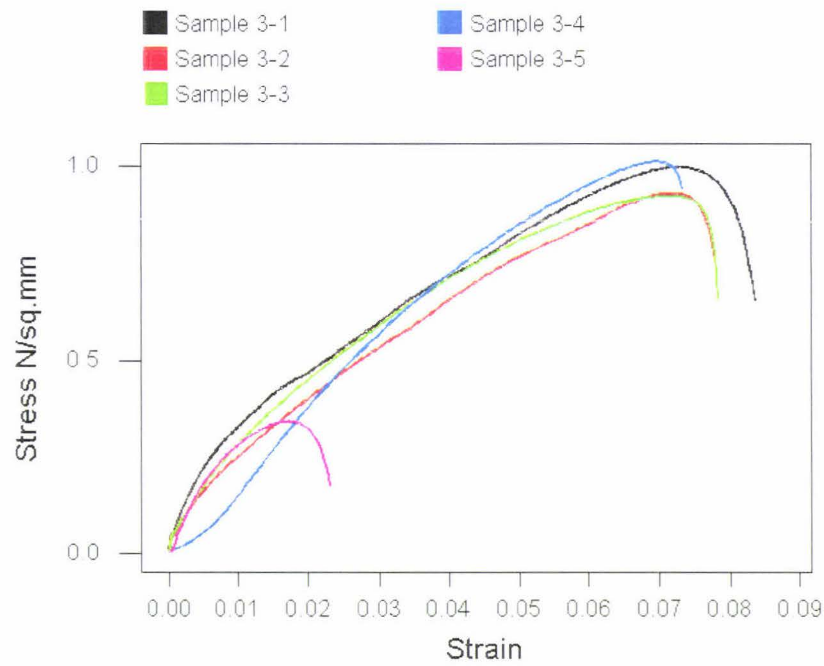
Sample No.	Weight Before (mgms)	Weight after	% of Moisture Content	Average Thickness (mm)	Area (mm^2)	Force in Newtons	Stress (N/mm^2)	Original Length (mm)	Change in Length (mm)	Strain
Samples Brought up to 60, 80 and 100% Moisture Content and then dried the samples to reach 20% Moisture content										
Samples of 60 to 20% Moisture Content										
60 - 1	1498	1798	20.03	1.598	31.96	39.882	1.248	62.39	4.760	0.0763
60 - 2	882	1087	23.24	0.890	17.8	17.005	0.955	52.63	2.693	0.0512
60 - 3	1254	1509	20.33	1.364	27.28	32.921	1.207	61.93	4.620	0.0746
Samples of 80 to 20% Moisture Content										
80 - 1	1012	1249	23.42	0.984	19.68	13.168	0.669	38.21	0.908	0.0238
80 - 2	1172	1411	20.39	1.242	24.84	21.00	0.845	71.35	2.760	0.0387
80 - 3	1352	1629	20.49	1.338	26.76	22.995	0.859	38.92	1.130	0.0290
Samples of 100 to 20% Moisture Content										
100 - 1	1197	1437	20.05	1.220	24.4	10.227	0.419	50.09	1.248	0.0249
100 - 2	1389	1678	20.81	1.422	28.44	12.910	0.454	57.21	1.490	0.0260
100 - 3	1211	1465	20.97	1.296	25.92	11.028	0.425	55.75	1.440	0.0258



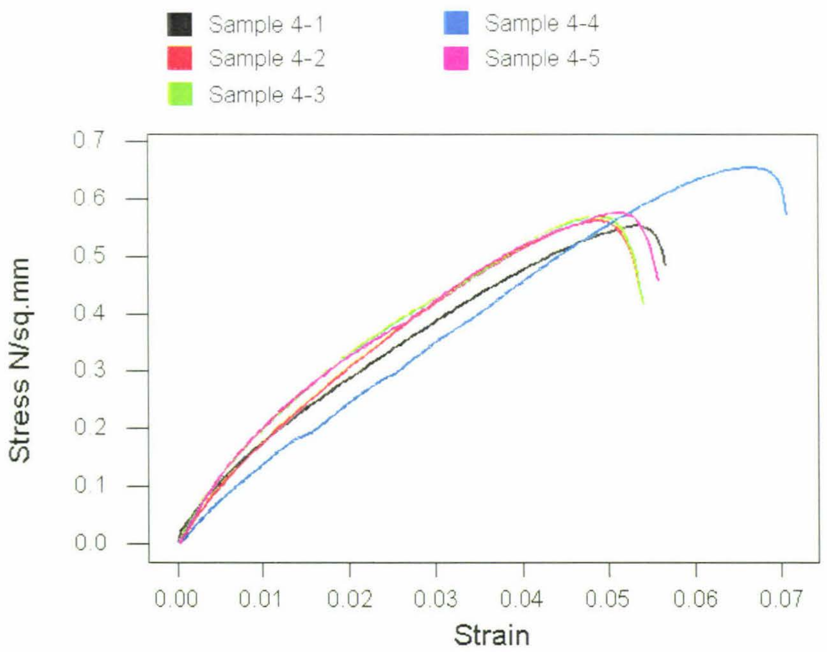
Graph 4.2 Relation between Stress and Strain Curves for the Samples at Room Temperature and Relative Humidity (No Moisture Content Samples).



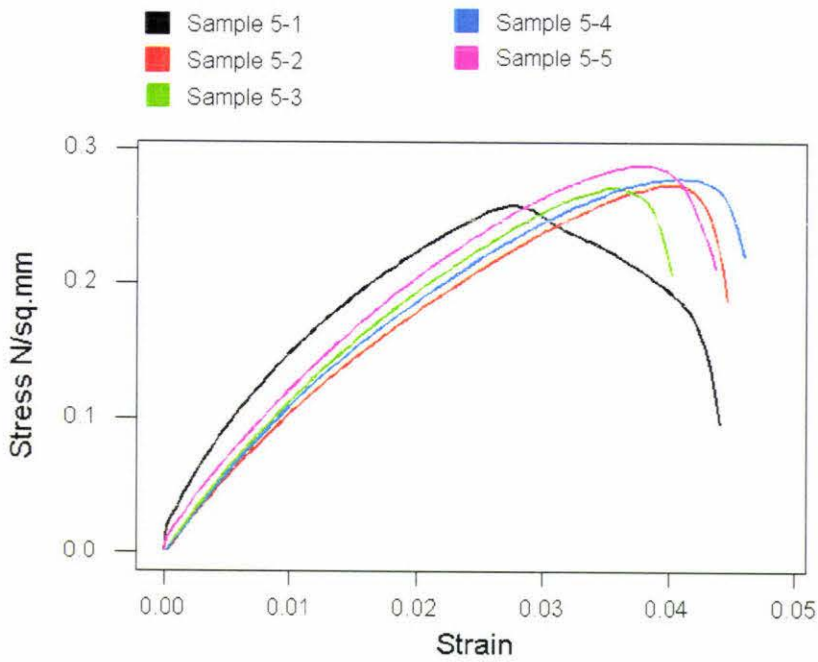
Graph 4.3 Relation between Stress and Strain Curves of 20% Moisture Content Samples.



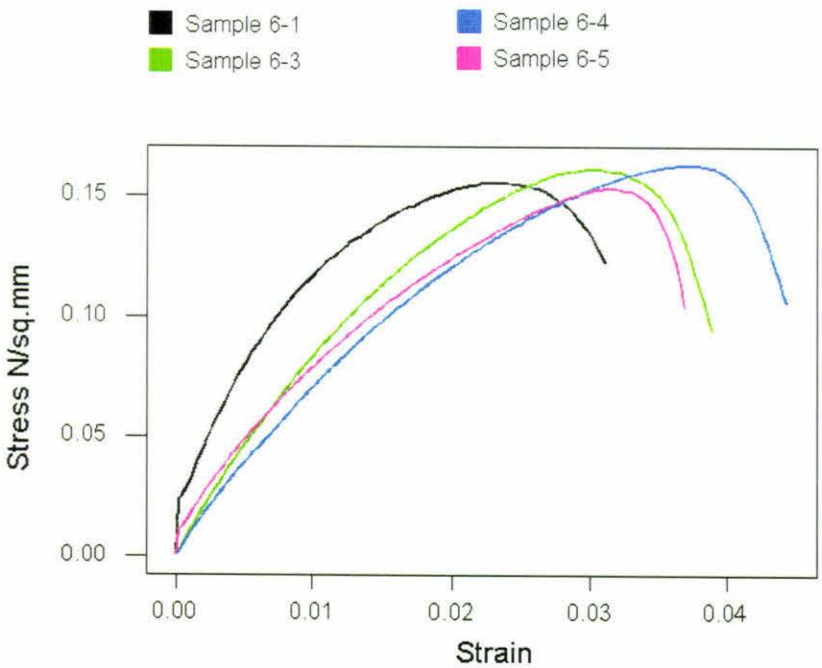
Graph 4.4 Relation between Stress and Strain Curves of 40% Moisture Content Samples.



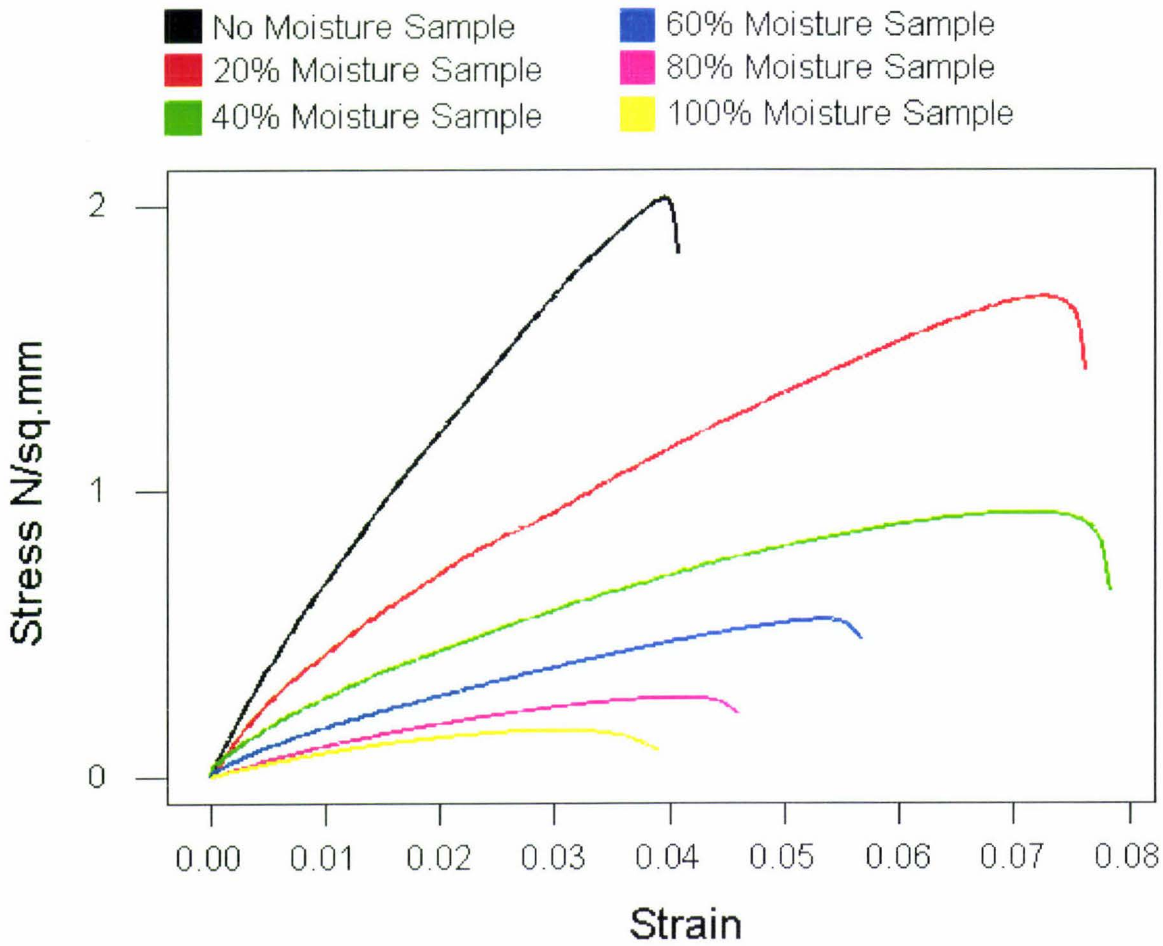
Graph 4.5 Relation between Stress and Strain Curves of 60% Moisture Content Samples.



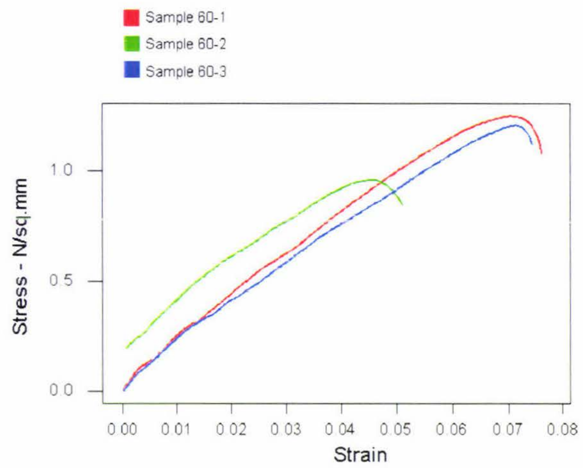
Graph 4.6 Relation between Stress and Strain Curves of 80% Moisture Content Samples.



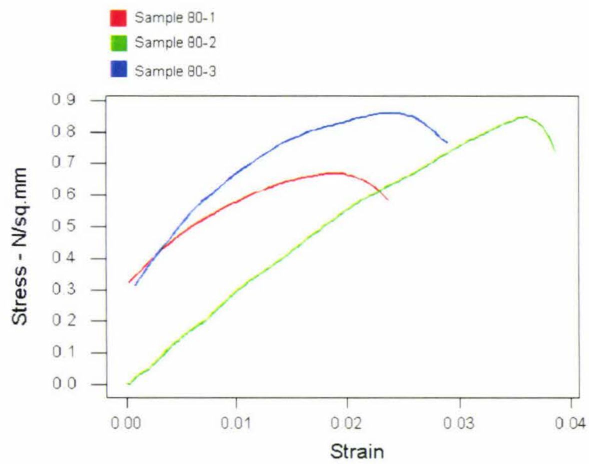
Graph 4.7 Relation between Stress and Strain Curves of 100% Moisture Content Samples.



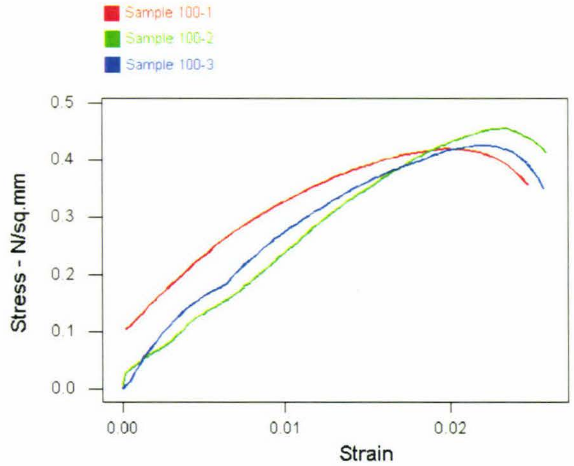
Graph 4.8 Relationship between Stress and Strain for No Moisture Content, 20%, 40%, 60%, 80% and 100% Moisture.



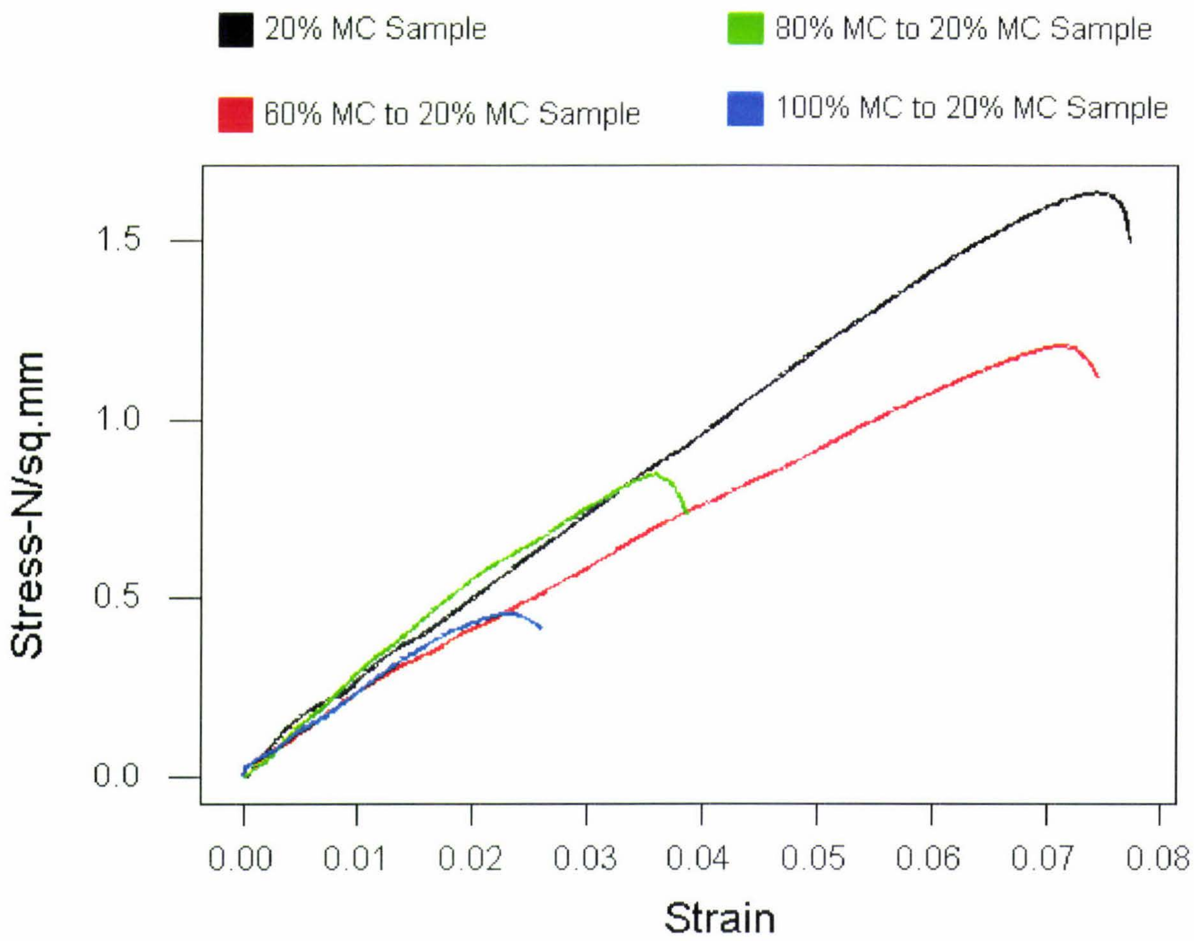
Graph 4.9 Relation between Stress and Strain Curve of Samples Desiccated to 20% MC from 60% MC.



Graph 4.10 Relation between Stress and Strain Curve of Samples Desiccated to 20% MC from 80% MC.



Graph 4.11 Relation between Stress and Strain Curve of Samples Desiccated to 20% MC from 100% MC.



Graph 4.12 Relationship between Stress and Strain for 20% MC Sample Vs Samples Desiccated to 20% MC from 60, 80 & 100 % MC.

From the Graphs 4.4, 4.6, 4.7, 4.9, and 4.10, it can be observed that some of the samples failed at lower than stress levels. This trend follows the literature as the moulded tray cells are elongated or aligned in particular directions, and this gives them properties that depend on the direction in which they are measured (Gibson & Ashby, 1988).

From the results the strain is high compared with the literature values. Literature shows that total strain is the combination of creep strain and elastic strain (Ashby and Jones, 1980). Therefore a decision was made to perform creep tests on the moulded pulp tray material to find out the creep strain with respect to time.

4.5. Structure of the Paper Pulp Material at different Moisture Contents

The properties of the material are dependent on the material's structure. In man-made composite materials the orientation of the fibres plays a major role in the strength of the product. The strength of the cellular materials depend on not only on the orientation but also on factors such as (Jacobs and Kilduff, 1985)

- The length-diameter ratio of the fibres.
- The degree of bonding between the fibres and the resin matrix, which cannot be easily quantified.
- The orientation of fibres in a particular composite, which may depart from the ideal.

Fibre orientation may be unidirectional, bi-directional, multidirectional and random. Using Confocal Laser Scanning Microscope examined the structure of the paper pulp material at different moisture contents; it was observed that the arrangements of fibres are random oriented (it can be seen in Figure 4.6a). Confocal Laser Scanning Microscopy is a relatively new light microscopical imaging technique that has found wide applications in the biological sciences (www.mih.unibas.ch/booklet/booklet96/chapter1/chapter1.html).

In the initial stage, a few samples were tested under the microscope to make sure that all the samples demonstrating same kind of structure. The samples were tested in two different ways:

- Increasing the moisture content of the samples and then sectioning before checking under microscope.
- A few samples were sectioned and then their moisture content raised and finally checked under microscope.

In both conditions, the structure showed little significant change. Therefore, one sample was taken to increase the moisture content from 0 to 30, 60 and 100% and then examined under microscope. The same sample was used to decrease the moisture content from 100 to 60, 30 and 0%, and the structure inspected. The figures 4.6a to 4.6d shows the structure of paper pulp mater at increased moisture content. And the Figures 4.7a to 4.7c shows the structure at decreased moisture content.

With a careful assessment of these structures it can be observed that the matrix expansion might not be affected but the paper pulp fibres are affected by the immersion of water. The fibres are enlarged with increased moisture content and this acts as a mechanical plasticiser thereby causing a loss in strength. The fibres are an oval shape (see Figure 4.6a) when there is no moisture content in the material so that the surface area of bonding between neighbouring fibres is more. At the increased moisture content the fibres become circular, in this situation the surface area of the bonding between the fibres is decreased causing a loss in strength (as illustrated in the Figure 4.5). The moisture in the fibres also causes a decrease in elongation.

From the Figures 4.7a to 4.7c it can be noticed that the structures from 100% MC to 30% did not return to the original form. Though the structure is back to 0% moisture content, the fibres still remain hollow and circular and the material cannot recover to its original state.

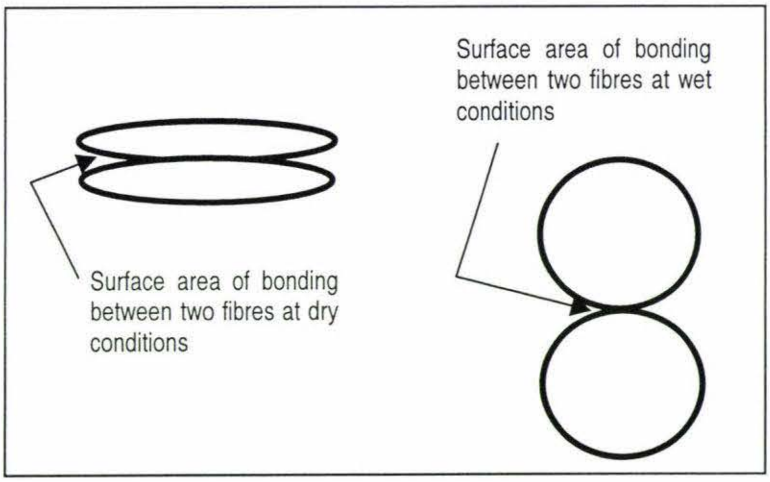
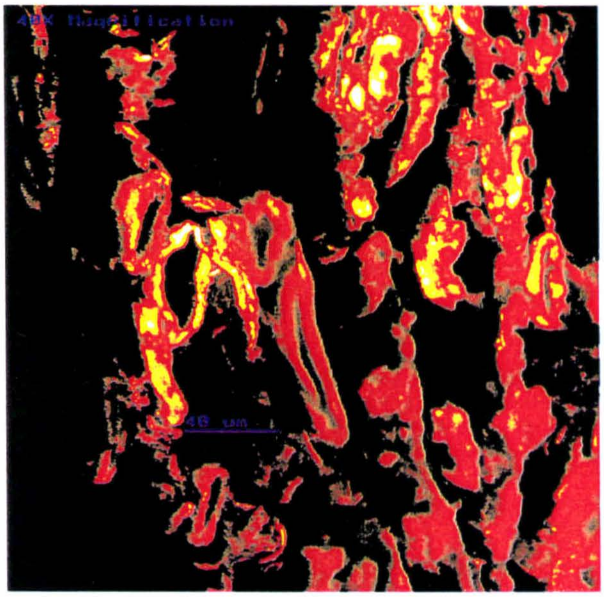
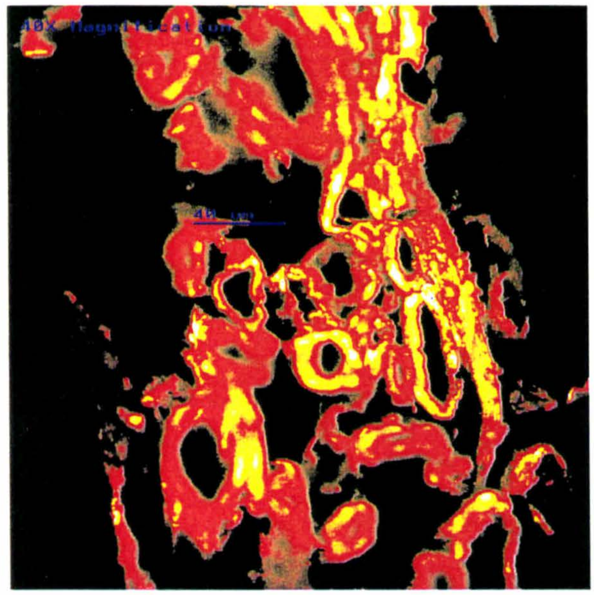


Figure 4.5 An Illustration of Fibres at Dry and Wet Conditions



(a) No Moisture Content

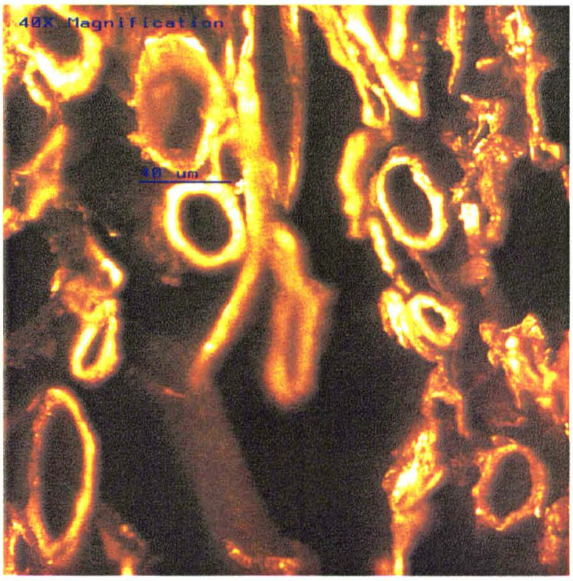


(b) 30% Moisture Content

(c) 60% Moisture Content

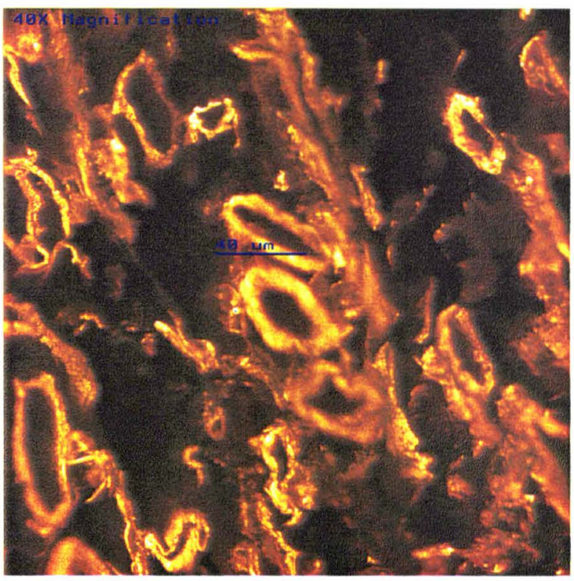
(d) 100% Moisture Content

Figure 4.6 Microscopic Structures of Paper Pulp Material with Increased Moisture Contents at 40X Magnification.



(a) Back to 60% MC

(b) Back to 30% MC



(c) Back to 0% MC

Figure 4.7 Microscopic Structures of Paper Pulp Material with Decreased Moisture Contents at 40X Magnification.

4.6 Creep Analysis

A specimen undergoing continuous deformation under a constant load or stress is said to creep (Garofalo, 1965). Creep is slow, continuous deformation with time: the strain depends not only on stress but also temperature and time (Ashby and Jones, 1980).

$$\varepsilon = f(\sigma, t, T) \text{ Creeping Solid.}$$

This is in contrast to the room-temperature behaviour of most metals, in which the strain is, for the practical purposes, independent of time:

$$\varepsilon = f(\sigma) \text{ Elastic/Plastic solid.}$$

In common the creep refers to strain that is time dependent and may include elastic, viscous and plastic deformations. An understanding of creep and creep-rupture involves an examination of elastic deformations, viscous deformations, a number of modes of plastic deformations at the microscopic and sub microscopic levels and other properties such as self-diffusion. Garofalo (1965) categorised creep into three stages, "Primary Creep", "Secondary (or Steady State) Creep" and "Tertiary Creep". As explained by Garofalo the description of creep is as follows.

Creep of metals and non-metals can be demonstrated directly by a creep curve, which represents graphically the function between creep strain and time. An idealized creep curve is shown schematically in Figure 4.8.

The strain ε_0 is obtained immediately upon loading and exhibits characteristics of plastic deformation that includes elastic deformation. Between ε_0 and ε_1 the creep rate decreases continually; this period of the creep is called "Primary Creep". Between ε_1 and ε_2 the creep rate remains nearly constant, indicting a nearly steady-state condition. This portion of the creep history is called "Secondary (or Steady State) Creep". The secondary creep rate, ε_s, is given by

$$\varepsilon_s = \frac{\varepsilon_2 - \varepsilon_1}{t_2 - t_1}$$

Beyond ε_2 the creep rate increases continually until rupture occurs at the strain ε_r and rupture time t_r. The period of increasing rate is called "Tertiary Creep".

There are two ways to measure the creep, either by constant load method or constant stress method. Creep strongly depends upon stress and therefore the basic creep studies should be made under a constant stress. However, for experimental convenience creep data on engineering materials are often obtained under a constant tensile load.

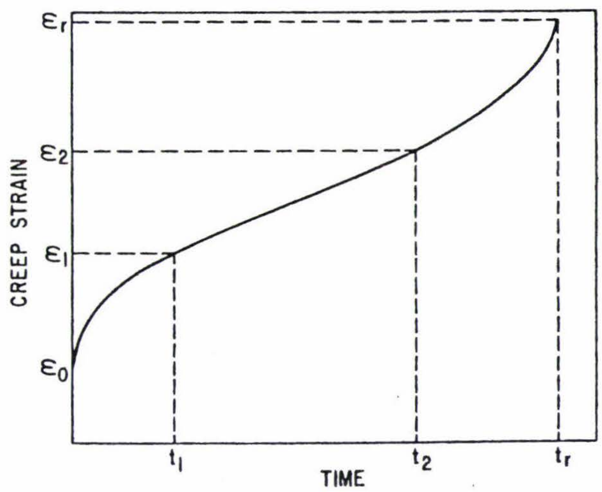


Figure 4.8 Schematic Representation of the Creep-rupture Curve (Garofalo, 1965).

4.6.1 TEST PROCEDURE

An experiment was designed and conducted to evaluate the creep strain over time. The experimental set-up is as shown in the Figure 4.9. The test sample was placed in between clamps at minimum distance of 60 mm apart. A dial gauge indicator with an accuracy of 0.01mm was positioned on top of the weights to measure the strain. No testing procedures were followed because creep-testing procedures for paperboard do not appear to be covered by ASTM or similar standards. Nevertheless, distinctive care was taken to prevent shear stresses and strains; all the clamps, tensile load and sample were aligned in vertical line. In addition the whole equipment was protected from vibrations and moments to measure accurate values.

Creep tests, are by their nature time consuming; hence, only five samples were tested. Tests were conducted at different temperatures and RH to achieve different moisture content levels.

The first sample was tested at room temperature 25°C and 40% RH with a MC of 5.73; the sample took approximately two days to break with an initial stress of 1.65 N/mm^2 at the given load of 58.5N. Initially, it was thought that samples would perform differently in creep compared with single crystals and the polycrystals of metals and alloys. But the creep curves of the samples were seen to behave just the same as metals.

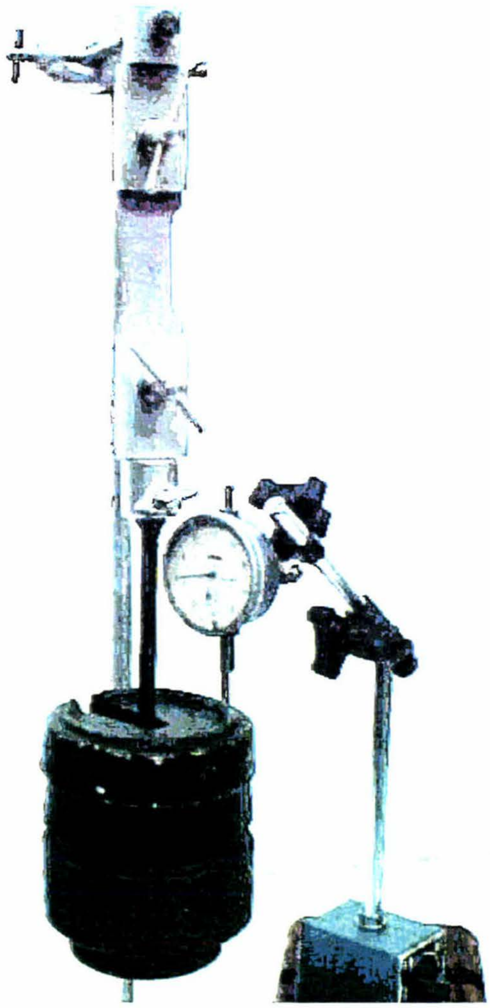


Figure 4.9 A Simple Arrangement of Creep Testing.

Hence a decision was made to increase the initial stress level to test the other samples. Two samples were tested at the controlled temperature of 21±1°C and RH of 50±2, with the initial stress of 2±0.05 N/mm^2 given by the load of 54.5N. Another two samples were kept in cool storage at 15°C and 65% RH and tested in the cool storage itself as the samples attained approximately 12% of MC. These samples were also tested at the load of 54.5N and the given initial stress of 2±0.005 N/mm^2.

4.6.2 Results and Conclusions

Results of displacements with respect to time, and the calculated creep strains are given in Appendix 4. From the Graphs 4.13, 4.14, 4.15, 4.16 and 4.17 it can be observed that at the lower initial stress and lower moisture content levels, it took more time to break the sample. The creep tests, as with the tensile tests showed more elongation to failure with increased moisture content. And also from the given graphs it can be observed that the percentage of moisture in the samples increases the Primary Creep and Tertiary Creep with a decrease in Secondary (or Steady State) Creep. It was not possible to measure the strain above 12% MC, as it was found very difficult to maintain the temperature and RH.

The research done by Monkman and Grant (1956) shows that it is possible to estimate the rupture life once the minimum creep rate has been determined for a particular creep-rupture test. Practically, creep tests in metals are usually designed to be long-term tests for as long as ten or twenty years or more at high temperatures. Therefore, there is a considerable interest in estimating long-term lives from tests of relatively limited duration. In metallic alloys the creep rate increases with respect to temperature but in hygroscopic materials the increased moisture content increases creep rate, at the given constant load. However, in long-time tests, once a minimum creep rate has been determined, the rupture life may be estimated from the empirical relationship given in the equation below.

$$\log T_r + m \log(\text{mcr}) = c \qquad \text{...Equation 3.1}$$

Where

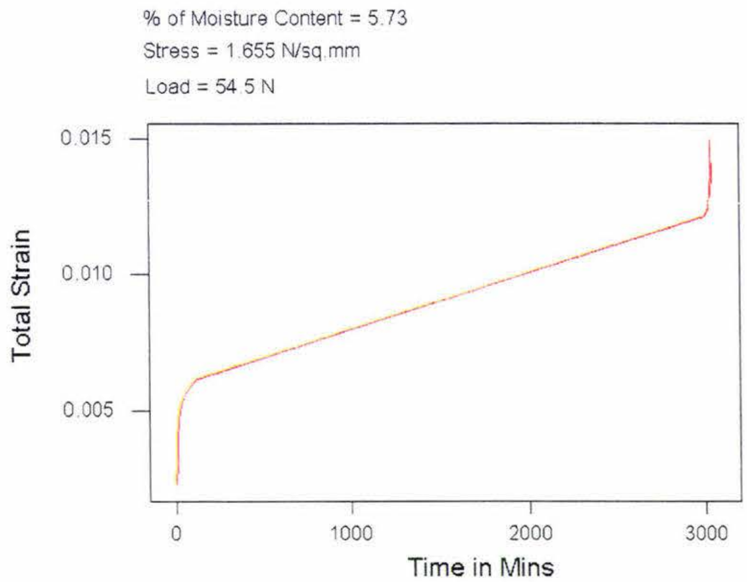
T_r = the rupture life

mcr = the minimum creep rate

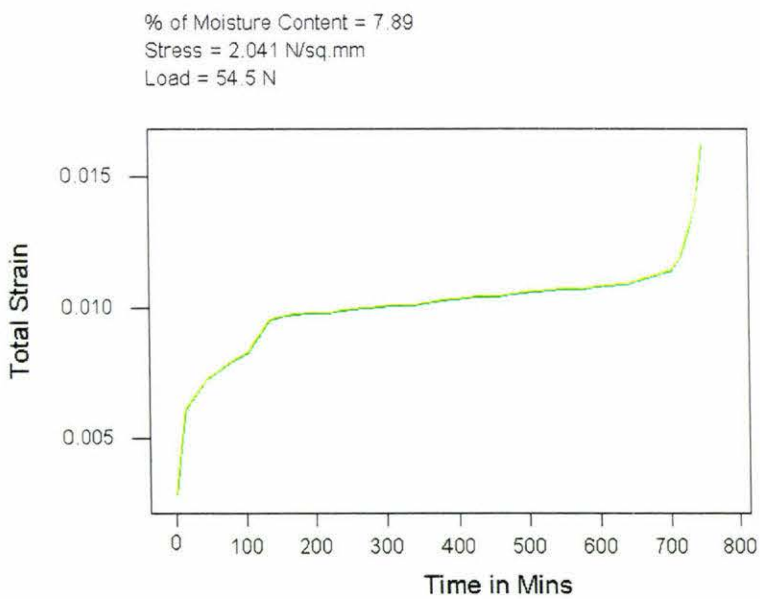
m and c = constants

Within experimental error, this equation is independent of testing temperature, stress and chemical variation for a particular material system at elevated temperatures. The minimum creep rate – rupture life relationship can be used with caution in estimating long-time creep-rupture data from short-term data and in serving as a check on the reliability of individual creep-rupture data.

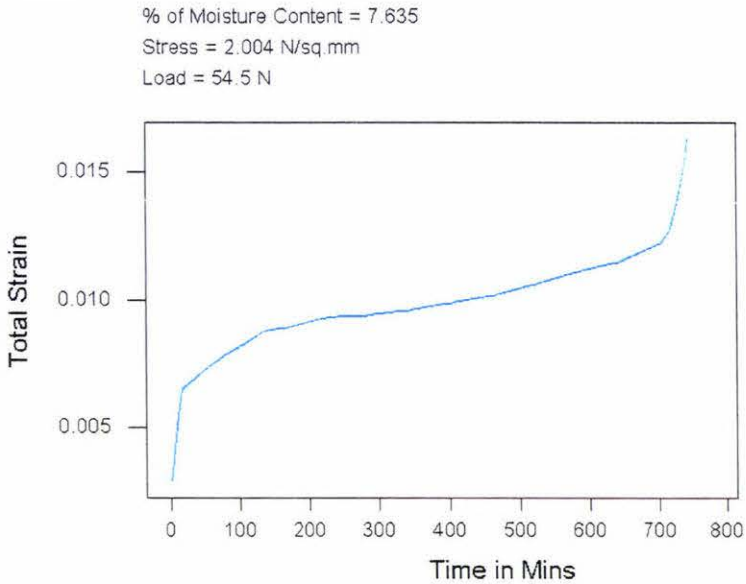
It was found that it is very difficult to have the samples of the same thickness therefore the tests were carried out at different starting stress levels. For this reason, samples were broke at different strain rates; nonetheless, there is good liaison between the acquired total elongations. The samples 2 and 5 have approximately the same range of initial stress at the given constant loading conditions thus these two samples were selected to solve the constants '*m*' and '*c*'. Once the constant were solved it is very easy to acquire the rupture life with the given minimum creep rate.



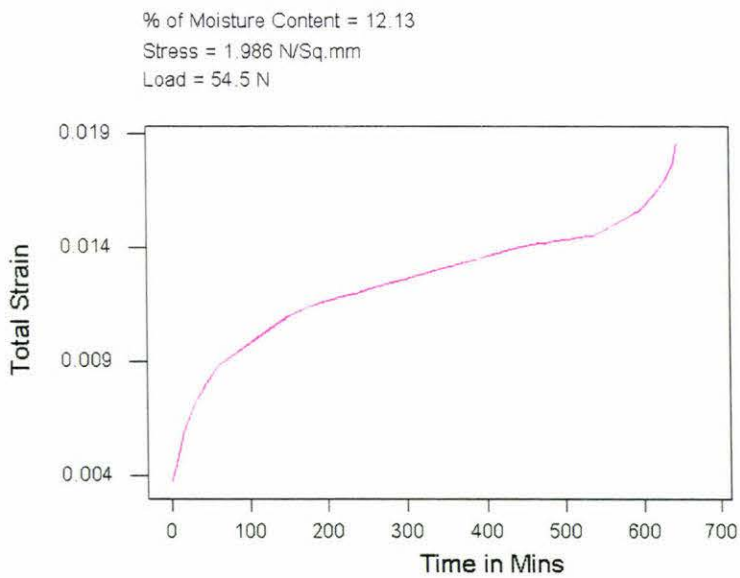
Graph 4.13 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 1.655 N/mm^2) and MC of 5.73.



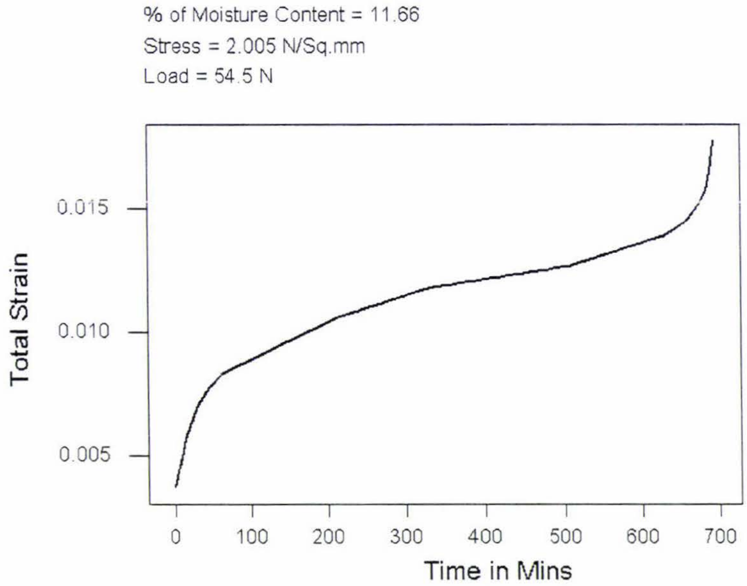
Graph 4.14 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.041 N/mm^2) and MC of 7.89.



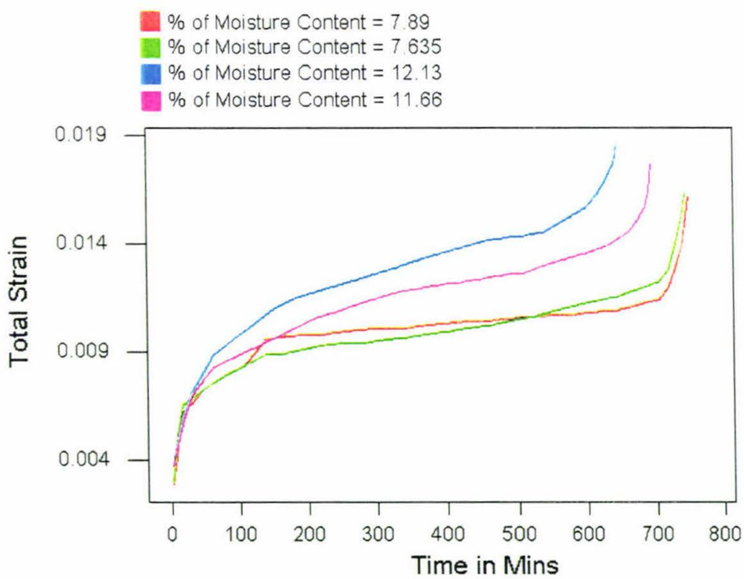
Graph 4.15 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.004 N/mm^2) and MC of 7.635.



Graph 4.16 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 1.986 N/mm^2) and MC of 12.13.



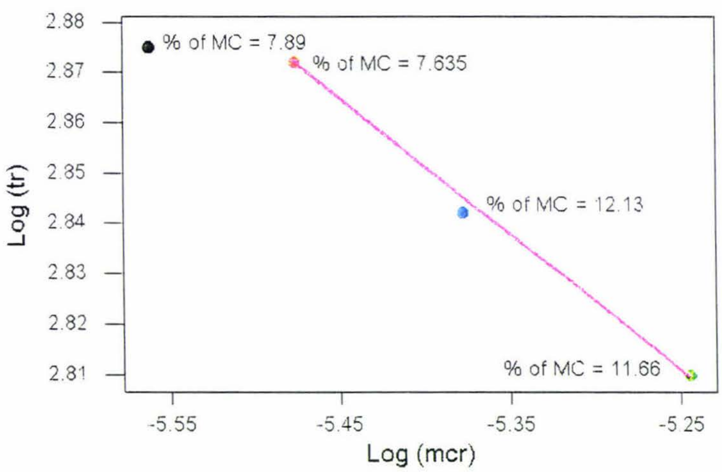
Graph 4.17 Creep Curve for Moulded Pulp Material at Constant Tensile Load of 54.5 N (Stress = 2.005 N/mm^2) and MC of 11.66.



Graph 4.18 Creep Curves for Moulded Pulp Material at Different Moisture Content Levels.

From the Graphs 4.14 and 4.17 the calculated minimum creep rate (mcr) is $3.34X10^{-6}$ and $4.2X10^{-6}$ at the given rupture life (T_r) of 745 and 695 minutes respectively. By substituting these values in Equation 3.1, the obtained values for 'm' and 'c' are –0.31 and 1.1763 correspondingly.

From the Graph 4.19 it can be observed that the creep rate changes with respect to the initial stress. By running a number of complete creep rupture tests, the empirical relationship can be established at different moisture conditions, permitting an estimate of the rupture life for a selected or desired minimum creep rate and vice versa.



Graph 4.19 Log-Log Plot of Rupture Life versus Minimum Creep Rate for Paper Pulp Material at Different Moisture Content Levels.

From the Table 4.2 the average stress of the samples is 2.055N/mm^2 at room temperature (20°C) and RH (50), from the Graphs 4.12 and 4.13 the total strain at the same conditions is 0.0162±0.001. From these values the calculated Young's Modulus is **140±15 N/mm^2**. From the Table 4.2 the average stress at 20% MC is 1.6406N/mm^2. A few test were conducted to find out the minimum creep rate and calculate the rupture life and then calculate the total strain, the calculated total strain at 20% MC is 0.0224. From the given stress and strain values the calculated Young's Modulus is **73.25 N/mm^2**. These determined values are then used in the finite element modelling of apple trays.

4.7 Poisson's Ratio

No values of Poisson's ratio are found in the literature. Initially, it was decided to take the Poisson's Ratio as 0.1 to run the basic model. The 2D non-linear model was completed successfully, hence, it was decided to conduct an experiment by using a "Hounsfield Tensometer" and "Laserscan Micrometer" used to measure displacements, which can measure the dimensions accurately up to eight decimal points.

All the samples were cut form the edges of the Friday tray where a large reliable flat sample can be obtained. Initially, while doing the experiments, failures were found in the test samples at the jaws of the test machine. The failures are due to the heavy weight of the machine jaws. In addition, these jaws are producing bending movement in the test sample. Thus, it was decided to tie the jaws parallel to the test sample to prevent the bending movement. The Laserscan was placed in the middle and perpendicular to the test sample anticipating that the major displacements in the transverse direction will occur in the centre of the test piece. The displacements in the longitudinal direction are measured directly from the Hounsfield test machine. The graph scale was set to 1:4 for plots of force versus displacements in the longitudinal axis. The displacements in transverse and longitudinal direction are recorded; thus, the strain and Poisson's ratio can be calculated by using the formulas:

$$\text{Strain } (\varepsilon) = \frac{\text{Displacement}}{\text{Original length or width}}$$

$$\text{Poisson's Ratio } (\nu) = \frac{\text{Strain in Transverse Direction}}{\text{Strain in Longitudinal direction}}$$

The calculated values were shown in Appendix 4, the Poisson's ratio is calculated only for five samples, all samples given proximal values. The average of calculated Poisson's ratio is 0.084

4.8 Density Measurements

Ashdown (1995) measured the density of the paper pulp and explained the assumptions and measuring procedure, but the data was not given. Due to the unavailability of data it was decided to perform density measurements. Thirty samples were collected from the different positions on the tray, 2/3 of the samples were gathered form the area between cups. This was done for two reasons. Firstly, this was the area where trays are known to split during handling (Holt and Schoorl, 1984). Secondly, this was the only area large enough to cut a reliable sample. The most important physical property of the tray was thickness, therefore, 1/3 of the samples were collected from different areas of the tray. All the collected samples were in rectangular shape; special care was taken to cut the samples with a sharp knife. The weight of the samples was measured by using a sensitive scale, and the length, width, and thickness were measured by using a Digital Micrometer. The volume of the test samples was calculated, and knowing the weight it was then possible to determine the ratio of weight to volume. The average of calculated density is 272.80-kg/cubic meter; a table of calculations is shown in Appendix 4.

CHAPTER 5

FINITE ELEMENT ANALYSIS OF APPLE PACKING

5.1 INTRODUCTION

Finite element analysis is a mathematical technique for obtaining solution for various kinds of problems where the domain of solution consists of a set of discrete elements. Each element has a series of equations, which can be solved using linear algebra. In problems, where discrete elements do not exist, we artificially create a set of discrete elements, a process which introduces a certain degree of approximation into the problem. Finally, the behaviour of the system is characterised by combining the behaviours of these simple elements. To this end, in many cases, we have to create a simplified model of the behaviour of this small element as well.

Finite element analysis has found many applications in diverse fields such as thermal engineering, fluid/hydraulics engineering, electromagnetic, stress & strain analysis and vibration analysis. In most cases, the finite element technique yields an approximate solution to the problem, the degree of approximation being dependent on the simplifying assumptions made during the analysis and it is used only in cases where an exact solution is not available. Therefore, we need to be careful in applying this method to a problem. It would be dangerous to apply this technique blindly without knowing the limitations of the method and, thus, it remains an analysis tool of the skilled engineer who is equipped with "engineering insight" and "engineering judgment".

In order to analyse a complex object accurately, a large number of elements are often required. This means that the matrix of equations that must be generated and solved is huge (many thousands of equations per matrix). In the past, it has never been economical to do this manually due to the complexity, the time required and possible unreliability. However, with the development of computers to model creation, solving and viewing the results to analyse the problem with in the short time period, FEA packages are becoming popular and economical methods of analysis.

5.2 FUNDAMENTALS OF "FEA"

The majority of finite element analysis methods are based on using stiffness values to establish the displacements at the nodes of the loaded mesh and thereby to determine the stress in each element (Reddy, 1993). The stiffness of elastic material may be given as:

$$F = K X$$

Where

K = Stiffness; F = Applied Force, X= Displacement

While the displacement varies with the applied force, the stiffness remains constant for a particular component. As like other authors, the authors explained the formulations of stiffness matrix as follows:

Consider a single element consisting of a thin, light, elastic rod of stiffness value 'K'.

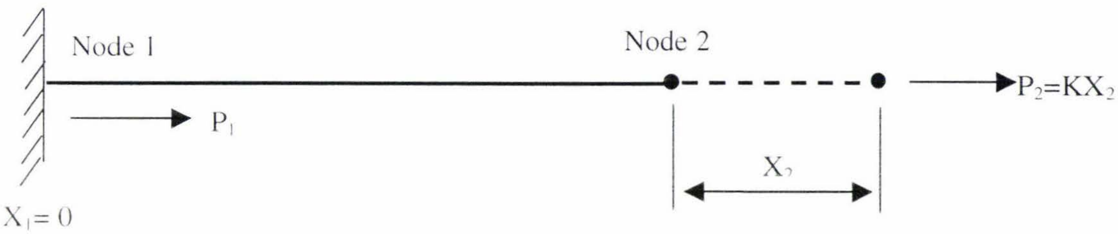


Figure 5.1 Thin Rod Elements – Fixed at Node 1 and Free at Node 2 (Case 1)

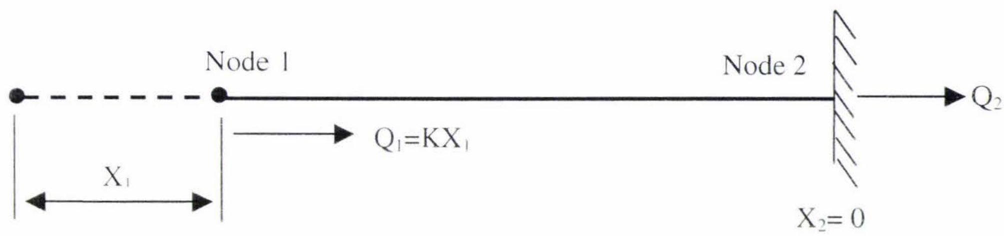


Figure 5.2 Thin Rod Elements – Free at Node 1 and Fixed at Node 2 (Case 2)

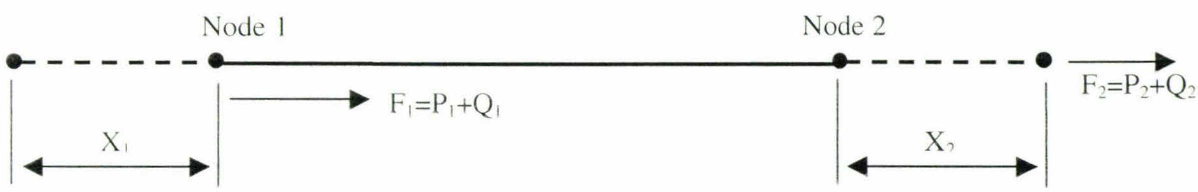


Figure 5.3 Thin Rod Elements – Free at Both Nodes (Case 3)

In Figure 5.1, assume that node 1 is fixed and the node 2 is free to move through displacement 'X_2' under of the force P_2.

Now $P_2 = KX_2$ for equilibrium $P_1 + P_2 = 0$; i.e. $P_1 = -P_2$

In Figure 5.2, assume that node 2 is fixed and that node1 is free to move through displacement 'X_1' under the action of force Q_1.

Now $Q_1 = KX_1$ and for equilibrium $Q_1+Q_2 = 0$; i.e. $Q_2 = -Q_1$

In Figure 5.3, assume that nodes 1 and 2 are both free to move. This effectively combines case A and case B with resultant forces F1 and F2 at node 1 and node 2 respectively.

Combining cases A and case B at node 1:

$F_1 = P_1 + Q_1 = -P_2 + Q_1 = -KX_2 + KX_1$
$F_2 = P_2 + Q_2 = P_2 - Q_1 = KX_2 - KX_1$

Thus in summary:

$F_1 = KX_1 - KX_2$
$F_2 = -KX_1 + KX_2$

This may also be expressed in the matrix form as follows:

$$\begin{pmatrix} F_1 \\ F_2 \end{pmatrix} = \begin{pmatrix} K & -K \\ -K & K \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \end{pmatrix}$$

Nodal Forces | Stiffness Matrix | Nodal Displaceme

The stiffness matrix may be considered as the main building block of all stress work finite element mesh calculations. Now, consider a mesh, whose elements are: two thin light rods of equal stiffness 'K', connected in series, and subjected to a force at each of the three nodes as shown in the Figure 5.4.

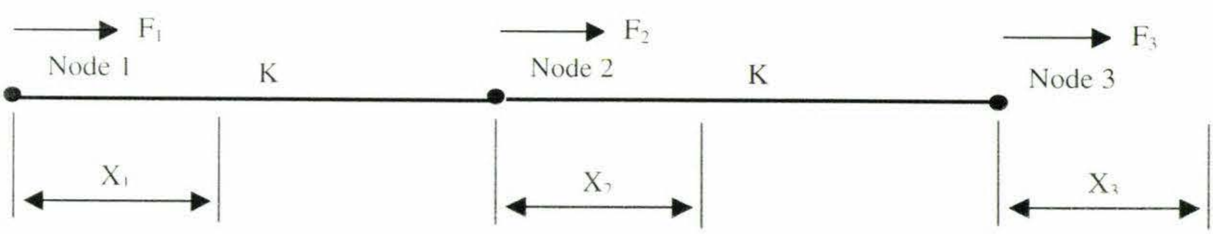


Figure 5.4 Light Consists of Two Thin Elements of Equal Stiffness.

Using the same argument as those in the case of the single element, the following matrix equation may be obtained.

$$\begin{pmatrix} F1 \\ F2 \\ F3 \end{pmatrix} = \begin{pmatrix} K & -K & 0 \\ -K & 2K & -K \\ 0 & -K & K \end{pmatrix} \begin{pmatrix} X1 \\ X2 \\ X3 \end{pmatrix}$$

Nodal Forces   Stiffness Matrix   Nodal Displacement

Thus in the same way, for any object whose geometry is known can be made up of a number of smaller elements. A shape such as circles or curves can be approximated by a finite number of straight lines; the more lines used to approximate a shape, the more accurate the model would be expected to become. Once the element equations are defined then they can be assembled together in matrix form to give the global equation. This equation is of the same form as the element equation but represents the entire body, instead of just one element. Boundary conditions, or constraints can then applied. These are restrictions the body will experience and have a critical effect on the results. These set of simultaneous equations are then solved using Gaussian or interactive methods. This will provide the primary quantity that is the unknown of the original equations. The primary quantity can now be used to calculate the secondary quantities: i.e. if the primary quantity is displacement then stresses, strains and moments can be calculated as secondary quantities by making use of the relationships.

5.2.1 Stiffness Matrix for Practical Elements

Engineering components are rarely made from simple elements such as thin rods. For areas and volumes, the relationship between force and displacement is considerably affected by the stiffness value (Chandrupatla and Belegundu, 1991). Therefore, the stiffness matrix must be derived form a complex algebraic procedure involving a number of constituent matrixes each of which are of highly advanced form. The general expression for the stiffness matrix is given as:

Stiffness matrix = $V(B)^t(D)(B)$

(B) = Is a matrix describing the element geometry

(D) = Is a matrix-relating stress & strain, which includes Young's Modulus and Poisson's ratio values.

$(B)^t$ = Is the tranpose Matrix of (B)

(V) = Is the volume of the element

5.3 Package Details

Most of the FEA packages have three essential processes involved in solving a problem, they are: Pre-Processing, Processing (Solution), and Post-Processing.

Prior to the analysis of a structure by the application of the finite element method a decision has to be made on how the structure should be partitioned into a finite number of elements and which type of elements is to be used. Since the finite element method leads to a stiffness matrix equation for solving for displacements at the partitioning nodes, the nodes should be sequentially numbered. In order to examine the partitioning pattern to decide whether it is adequate or should be modified, a plot or display of the partitioning with labelling of the nodes and element is necessary. Programs, prepared for implementing such a need are known as "Pre-Processing".

After solving the stiffness matrix equation of a structure to obtain the nodal displacements, the deformed shape of the structure can be plotted or displayed. Also the strains and subsequently the stresses can be computed throughout the structure by utilizing the nodal displacements along with the stiffness matrices of all the constituent elements. In most of the cases, stress and strain distributions need to be plotted or displayed for study. Programs prepared for producing these needs are known as "Post-Processor".

5.3.1 Lusas 13.1

Lusas is an associative feature-based modeller. The model geometry is entered in terms of features that are sub-divided (discretised) into finite elements in order to perform the analysis. Increasing the discretisation of the features will usually result in an increase in accuracy of the solution, but with a corresponding increase in solution time and disk space required. Lusas is one among the finite element packages, which is capable of solving a wide range of engineering problems such as:

- Linear and Non-Linear Static Analysis
- Linear and Non-Linear Dynamic Analysis
- Creep Analysis
- Natural Frequency Analysis
- Buckling Analysis
- Spectral and Harmonic Response Analysis
- Fourier Analysis
- Transient Fluid Analysis
- Coupled Thermo-Mechanical Analysis

A complete finite element analysis in Lusas involves three stages.

- Pre-Processing
- Finite Element Solver
- Results-Processing

The Lusas finite element system consists of two parts to perform a full analysis:

- LUSAS modeller is a fully interactive pre- and post-processing graphical user interface.
- LUSAS solver performs the finite element analysis.

5.3.1.1 Pre-Processing

Pre-Processing involves creating a geometric representation of the structure, then assigning properties, then outputting the information as a formatted data file (.dat) suitable for processing by Lusas.

Creating a Model

A model is a graphical representation consisting of Geometry (Points, Lines, Combined Lines, Surfaces, and Volumes) and Attributes (Materials, Loading, Supports, Mesh, etc.). Each part of the model is created in two steps:

- Define the Feature or Attribute.
- Assign the Attribute or Attributes

Features can be defined by entering coordinates, selecting points on the screen or by using utilities such as transformations. An attribute is first defined by creating an attribute dataset. The dataset is then assigned to chosen features. For example, assign a point load (Attribute) to a point (Feature) representing the corner of a platform. The key success of any finite element analysis is the mesh used to model the problem. If the mesh is inappropriate the results of the analysis are unlikely to be correct. There are basically four techniques that are in common use in any finite element pre-processors. They are, mapping methods, cell decomposition, surface or volume triangulation and synthesis methods (Yeo et al 1993). The user should be very careful while defining the mesh, where the solution depends upon the shape of the element. One of the most important rules while creating the mesh is that the inclined angle at the corner nodes of a quadrilateral element must be less then 180° which means that we cannot have a concave quadrilateral for an element shape. In general, the inclined angle between any two adjacent sides of a triangle or quadrilateral must not be close to 180° or 0°. A safe range for the included angle is in between15° and 165° and the best angle is 90°. Another feature of the element shape has to do with the "aspect ratio" of the element (defined as an average width divided by an average length). An element with very small or very large aspect ratio leads to an ill conditioned stiffness matrix, which leads to an inaccurate solution. A good element must have an aspect ratio around one. This implies that a square shape and equilateral triangle shapes are the best shapes for meshing. This heuristic rule is quite important and should not be neglected while discretsaising the domain into finite elements. Automatic mesh generation is also used by some of the finite element packages where the size of problems that routinely solved. Finally, to complete the model it may be necessary to define additional utilities called control datasets such as non-linear increments, slide lines, etc. These are used to control the progress of advanced analysis.

5.3.1.2 Finite Element Solver

Once the model has been created, a solution command is performed to begin the solution stage. LUSAS creates a data file from the model, solves the stiffness matrix, and then produces a results file (.mys). While processing the model, LUSAS writes a file that contains every step of the analysis procedure, called an output file (.out). If at any stage the process encounters an error in the data file that prevents it from continuing the analysis, it will terminate the run. The output file can be viewed to find out at what stage the problem occurred and what can be done to fix it. The results file will contain some or all of the following data.

- Stresses
- Strains
- Displacements
- Velocities
- Accelerations
- Residuals
- Reactions
- Yield Flags
- Potentials
- Fluxes
- Gradients
- Named Variables
- Combination Datasets
- Envelope Definitions
- Fatigue Datasets
- Strain Energy

5.3.1.3 Results-Processing

Results processing involves using a selection of tools for viewing and analysing the results file produced by the Solver. Many different ways of viewing results are supported:

- Contour plots (averaged / smoothed)
- Contour plots (un-averaged / un-smoothed)
- Un-deformed / Deformed Mesh Plots
- Wood-Armer Reinforcement Calculations
- Animated display of models / Load increments
- Section Line / Slice Plots
- Yield Flag Plots
- Graph Plotting
- Vector Plots

If desired, print files can be made of the graphical displays presented on the screen. To do this, a picture file is created containing all the graphics required in the printout. A program called EXPOSE then processes the picture file; then it will convert the picture file into a print format suitable for the requested printer.

5.4 Application of "FEA" to Apple Trays

Finite element analysis can be applied to many engineering areas where the problem involves physical forces, electrical domain, heat transformation, magnetic fields etc. Finite element analysis has been renowned as one of the most expensive analysis technique as the model set-up was done manually in the olden days. This has kept finite element analysis technique to very narrow engineering sectors such as aeronautical engineering, large civil constructions, dams and bridges, nuclear power plants etc., for which the capital cost is very high. In recent days, due mainly in the development of computing technology, it has become very easy to simulate the model on smaller computers such as personal computers (desk tops). This has led the engineers to use FEA more widely, particularly in less sophisticated engineering areas where previously such analysis would not have been cost effective. Another cause for increasing in usage of FEA is that customers are moving towards quality and reliable products that is forcing manufacturers to re-evaluate the design technique to ensure that the best designs are used to give the best product.

Packing is often viewed by the manufactures as an additional expense that increases the product cost. Packing styles and various designs are used to attract the customers to increase sales and at the same time to protect the product, but in bulk packing for export the packing will not seen by the customer and therefore the packing cannot be used as a marketing tool to increase sales. However, it is being realized that packing can mean the difference between a quality product reaching the customer or a damaged product that the customer does not want. This is particularly true with agricultural produce and food products as these products are delicate and can be spoil very easily. Packaging is often overlooked, as the capital cost is usually very low when considered on an individual basis. If considered in the light that each item of packaging could mean the difference between a sold item and a returned item, then it becomes obvious that the value of the packaging is equal to the value of the product it is transporting. Also, each individual packaging unit may only cost a few cents, however if a large number is produced then the overall expense can be very large indeed and warrant close attention at the design stage. These facts are particularly applicable to the apple industry, where a single apple or tray of apples are worth very little on their own, but if considered in view if millions of apples exported each year, and the million of trays produced then the capital cost becomes very large. The cost of a poor quality product reaching the customer can mean not only the expense of a shipment, but also the possible loss of market, which could be disastrous.

Hence, spending a few dollars, the packaging designs that are responsible to perform the required task can be altered or modified easily. It is very difficult to analyse the strength of apple trays with the traditional strength analysis as it takes more time and so many assumptions. The finite element analysis technique is capable of correctly designing some of the complex shapes and materials used in packaging, and the mistakes and assumptions can be altered effortlessly. Thus the usage of FEA to analyse the apple trays is very attractive. FEA is becoming a common design tool even in packaging and associated handling systems because of the decreasing cost of FEA packages and the increasing accuracy and efficiency of computerized packages available in the market.

5.5 STATIC ANALYSIS

Static analysis is the most common analysis carried out by the engineers, and assumes that the loads are applied instantaneously; hence any transition effects are ignored. Lusas supports various solver types, if no solver selection is made then the frontal solver will be used and if no optimiser is specified then the Sloan optimiser is used by default (Lusas user manual, 1999). Frontal (Direct) Technique is a direct solution technique based on Gaussian elimination method. Stiffness and load arrays are read into memory during solution and assembled into the structure stiffness and load matrix. Frontal solution must be used for non-linear analyses.

5.5.1 STATIC LINEAR ANALYSIS

For linear static analysis it is assumed that the loaded body instantaneously develops a state of internal stress so as to equilibrate the total applied loads. In linear analysis, it assumes that the overall structural response is linear, and implies linearity of both the geometric and material response, i.e., the deformations are directly proportional to the applied load and if graphed would result in a straight line. A classic example of this situation is an elastic material (e.g. glass), the resulting deformations are said to be linear as they are directly proportional to the applied load.

5.5.2 STATIC NON-LINEAR ANALYSIS

In a non-linear static analysis, joint elements and 'slide-lines' may be used to model contact or frictional behaviour between any two bodies. Three types of non-linear analysis may be modelled using Lusas; Geometric non-linearity, Boundary non-linearity and Material non-linearity. Geometric non-linearity arises from significant changes in the structural geometry during loading. Common examples of geometric non-linearity are plate structures, which develop membrane behaviour, or the geometric bifurcation of truss or shell structures (Lusas user manual, 1999). In non-linear boundary condition analysis, deformation dependent boundary condition models account for the modifications to the external restraints resulting from lift-off, or smooth or frictional contact during the process within an analysis.

5.5.2.1 MATERIAL NON-LINEARITY

Materially non-linear effects arise from a non-linear constructive model (that is, progressively disproportionate stresses and strains). The non-linear deformation of materials is accompanied by accumulation of internal defects (micro-cracks, microspores) (Dyskin et al 1993). Common examples of non-linear material behaviour are the plastic yielding of metals, the ductile fracture of granular composites such as concrete, or time dependent behaviour such as creep. Lusas incorporates a variety of non-linear constructive models, covering the behaviour of the more common engineering materials. Also a facility exists to define any particular non-linear constitutive material property, as long as the nature of the stress-strain curve is known. The solution technique for non-linear material analysis differs in different packages. The displacement finite element method is one of the well-known methods to analyse the behaviour of non-linear materials, the total load is broken up into a number of increments and each of these is applied in sequence. The size of these increments, which is not necessarily uniform, has a major influence on the accuracy of the solution that is obtained. This method treats the load deflection equations as a large system of ordinary differential equations that are integrated adaptively. The system of equations to be solved can be expressed in rate form as $\dot{u} = K^{-1}\dot{f}$ where $\dot{u}$ is a vector of un-known displacement rates, K is the tangent stiffness matrix (which may depend on the current stress level and a set of hardening parameters), $\dot{f}$ is a vector of applied force rates, and the superior dot denotes a derivative with respect to time (Sloan et al 1993). The technique of solving the governing equations of material non-linear analysis can be broadly classified as being either iterative or incremental. Newnton-Rafson, modified Newton-Raphson, initial stress and initial strain methods are all iterative techniques. The most common incremental integration scheme is the first order Euler method. Higher order Runge-Kutta schemes, in particular second order midpoint schemes, have also been used in incremental solution techniques (Sloan et al 1993).

5.6 NON-LINEAR SOLUTION PROCEDURE IN LUSAS

For non-linear analysis, since it is no longer possible to directly obtain a stress distribution, which equilibrates a given set of external loads, a solution procedure is usually adopted in which the total load is applied in a number of increments. Within each increment a linear prediction of the non-linear response is made, and subsequent iterative corrections are performed in order to restore equilibrium by the elimination of residual or 'out balance' forces. The iterative corrections are referred to some of the convergence criteria which indicates to what extent an equilibrate state has been achieved. This method of solution technique is referred as incremental-iterative or predictor-corrector method, the graphical representation of this method is shown in Figure 5.5 (Lusas user manual, 1999).

In Lusas, the incremental-iterative solution is based on Newton-Raphson procedure. For the Newton-Raphson solution procedures it is assumed that a displacement solution may be found for a given load increment and that, within each load increment, the load level remain constant. This method is used where the function f (x) and its derivative f' (x) are continuous and is mostly used for its speed and simplicity (Kreyszig, 1988). The details of the solution procedure are controlled using the Non-linear Control properties assigned to the load case.

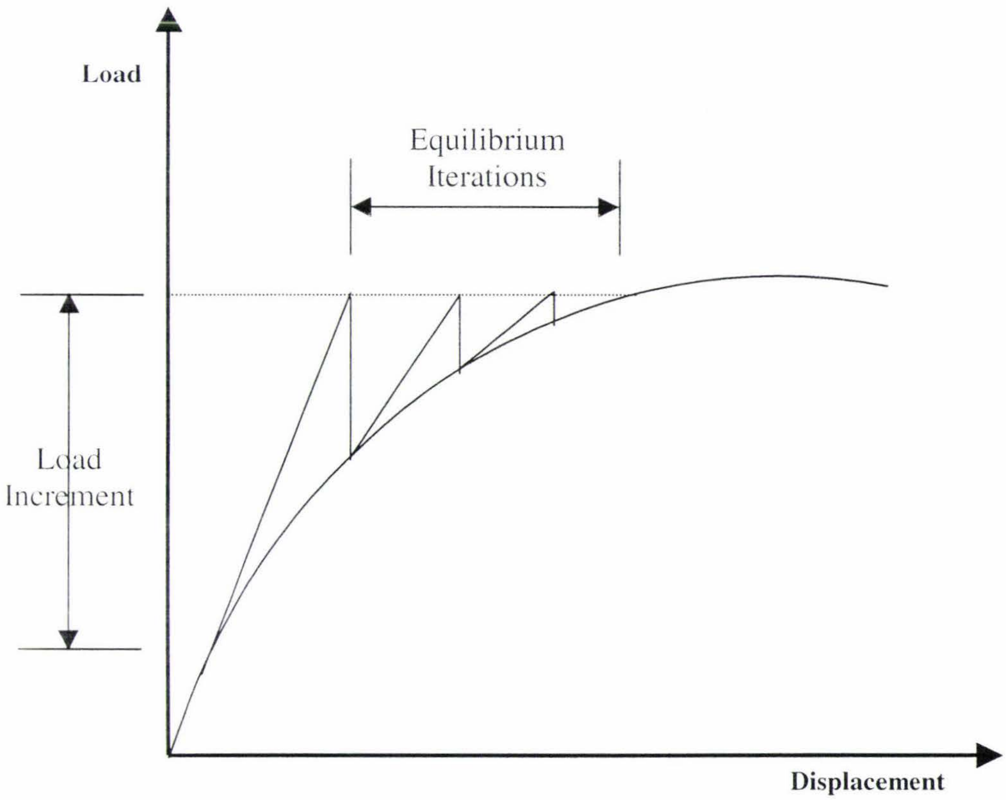


Figure 5.5 Incremental-iterative Solution Procedure in Non-Linear Analysis.

While defining the non-linear model within Lusas, the specification of Non-linear Control section is required. This section consists of three areas:

- Incremental Control: Incremental control determines the starting load, what load is applied at each increment, and what total load that is to be.

- Constant Control: The constants section specifies the number of iterations required per increment, and conversance criteria that dictates when equilibrium has been achieved to within satisfactory accuracy for that increment.

- Output: the output section controls the files that are generated and the frequency they are updated.

During the Lusas analysis, the first load increment is applied to the model and the resultant deformations calculated. When the deformations are calculated to within the required accuracy, the next load increment is applied and the process repeated until the required load level has been applied to the model. During the analysis, Lusas creates a series of separate models, with the results from each model being the starting point for the next. The load increments must be small compared to the total load; otherwise the incremental search technique proves inaccurate. Hence, the non-linear analysis will take longer time as each iteration within every increment is considered as an individual linear analysis.

5.7 Contact Analysis

Contact problem can also occur with non-linear surfaces. Contact between objects (two or more) is more complex and difficult to solve then non-contact problems. Solutions to these problems require an algorithm from finite deformation contact problems. In engineering, attempts to adopt finite element methods for contact problems have been made since the introduction of finite element method, and many papers have appeared providing different approaches for both small and finite deformation contact problems. The key aspect of an algorithm for; contact problem is deciding how to implement the contact constraints assuming that the possible contact condition is already known. Different methods have been used for this purpose. Some of the methods such as the Lagrange multiplier and the unit load method require additional equations to deal with the contact constraints. One of the classical methods for calculating contact problems often adopts Hertz's theory. The theory assumed simplified conditions. It is suitable for simple geometric shape. Where large contact areas are involved, these methods may not be efficient, and with the advancement of numerical calculations, the numerical method of contact problem has been widely used and fine results have been obtained (Yongping and Zohongkai, 1993). The penalty method is also used for many large contact problems. Gen et al, 1993 developed a finite element algorithm for finite deformation contact problems, which can be easily incorporated into standard non-linear finite element programs. In the present approach, the transformation matrix method is used to implement contact constraints. The unique feature of this approach is that the number of equilibrium equations with contact constraints decreases as the number of contact nodes increases.

In general, the finite element methods of contact problems can be classified into three categories according to the finite element formulation (Yongping and Zohongkai, 1993).

General Finite Element Method: This method needs to build the whole stiffness matrix of contact objects. While calculating, the whole stiffness matrix would be changed and assembled repeatedly according to different contact states. So the amount of calculations will be increased greatly.

Mixtured Finite Element Method: This method is that the flexibility matrix that is only relating to nodes of contact region will replace the whole stiffness matrix. The solution for whole objects is condensed into a solution procedure about contact surfaces.

Mathematical Programming Method: In this method the contact problem could be changed into a special mathematical programming problem.

5.7.1 Contact Problems in Lusas

In Lusas, Slidelines are one of the attributes that are used to model contact and impact problems, or to tie dissimilar mesh together. They can be alternative to joint elements or constraint equations, and have advantages when there is no exact prior knowledge of the contact process. Their applications range from projectile impact, vehicle crash worthiness, the containment of failed components such as turbine blades, to interference fits, rock joints and bolt/plate connections. Due to the fact that slidelines are constantly changing the load and support conditions of the model as more and more nodes contact, the slideline facility is inherently non-linear, except for tied slidelines used in an implicit dynamic or static analysis where the solution may be linear (Lusas user manual, 1999).

The functioning of Slidelines is defined by two surfaces that contact each other. One surface is selected as Master surface and the other as Slave surface. In two-dimensional problems, lines have to select instead of surfaces and the line with greatest mesh density is usually defined as the Slave line. For three-dimensional models, the defining of slideline properties to master and slave surfaces is immaterial. As the two surfaces move towards the contact conditions, the nodes on the slave surface perform a search over a specified area. When a node from the opposing surface moves within that search area, it is attached to the element face on the slave surface and is said to have connected. Mesh discretisation in the region of slideline contact must be fairly fine and the loading increments must be very small. If too coarse a mesh or too large load application is used, the surfaces may penetrate each other undetected, as the moment resulting from the load will carry the surfaces right through the slave surface search area in one step. This means slideline analysis tend to take large amount of time relative to the size of the model as a lot of load increments are necessary in the non-linear analysis. Lusas offers five different types of slidelines:

- Null Slidelines: Used to perform a straightforward linear analysis ignoring the slide definition.

- No Friction: Used for contact analyses but ignores the friction between the two surfaces.

- Friction: Used for contact or intermittent contact or impact.

- Tied: Used to tie together two dissimilar meshes.

- Sliding: Used for problems where surfaces are kept in contact, allowing sliding without friction.

An example of two-dimensional slideline problem is discussed below.

5.7.2 A 2-D Example of Contact Analysis

The problem that was studied was a two-dimensional half circle, moving down and contacting with another half circle. The geometry of the model is shown in the Figure 5.6. The model was proposed to be a two dimensional approximation to an apple coming into contact with the tray and then deforming the tray. Once the two-dimensional situation works satisfactory then it was anticipated that three-dimensional model would then created. The elements used are plane stress quadrilateral and triangle shape as illustrated in Figure 5.7. The slideline was a general slideline with friction, and can be seen in Figure 5.6 representing red arrows. Loading was divided into three concentrated loads and applied on top of the body in the downward direction at three different places as shown in the Figure 5.6. Support conditions are displayed by the green arrows. As suggested by the FEA (Lusas) Ltd. the apple was joined by a two dimensional joint element as shown in the Figure 5.7 by the two Z's which mark its ends. The joint was set at a 2-translation/membrane stiffness of 1/100 in X and Y directions, this stiffness will not affect the results of the model. These joint elements joined the bodies effectively but left them free to act separately. A non-linear & transient data set were defined and assigned to the load case. This model used thirty load increments with a starting load factor of 1 and 4 iterations per increment with a maximum number of iterations of 12. This analysis was for two-dimensional model, although simple in concept, it proved difficult to run to get a complete satisfactory solution. Figure 5.8 shows the final result of deformed mesh and un-deformed mesh together.

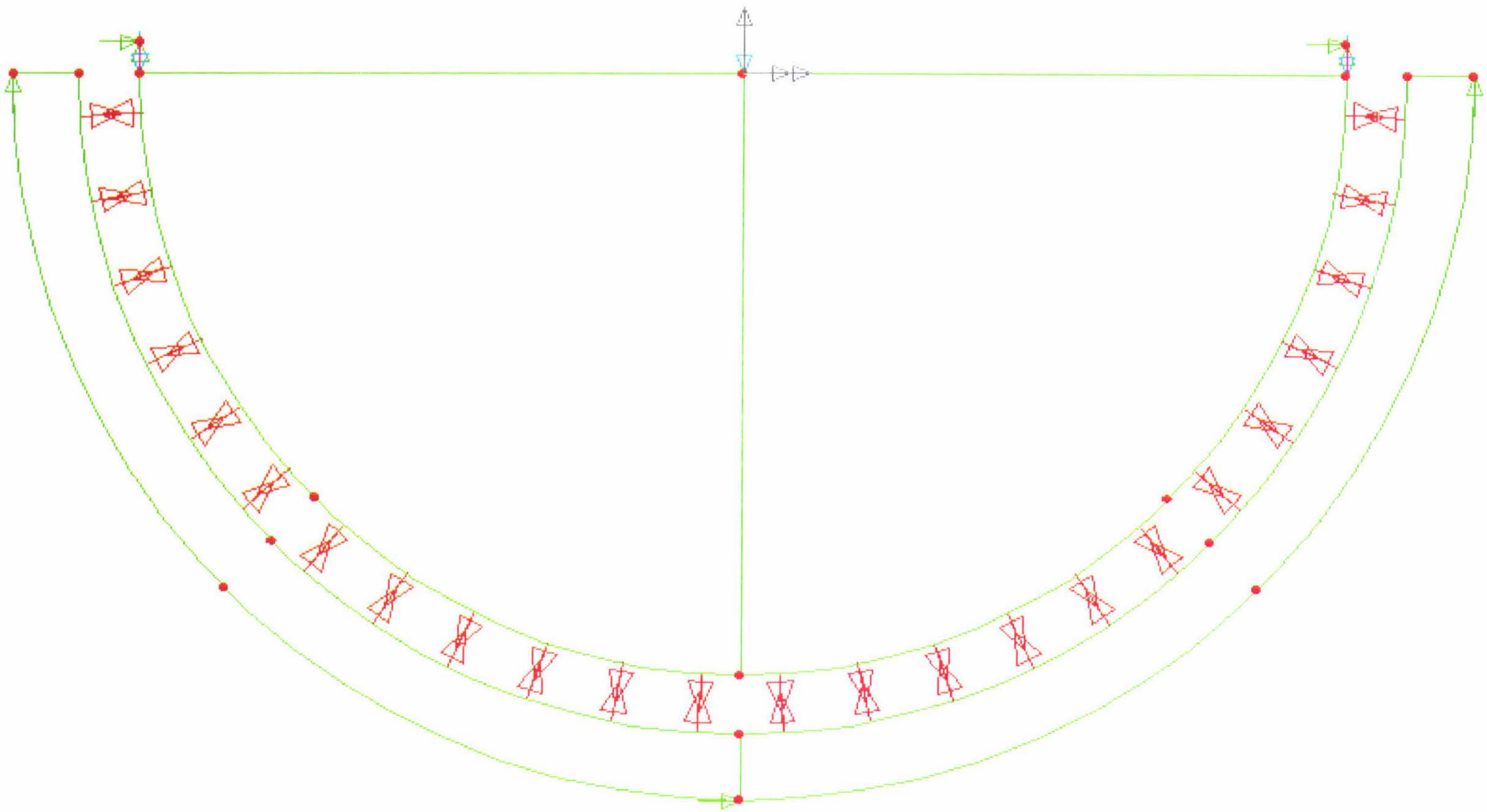


Figure 5.6 Model Definition of 2D Slideline Example

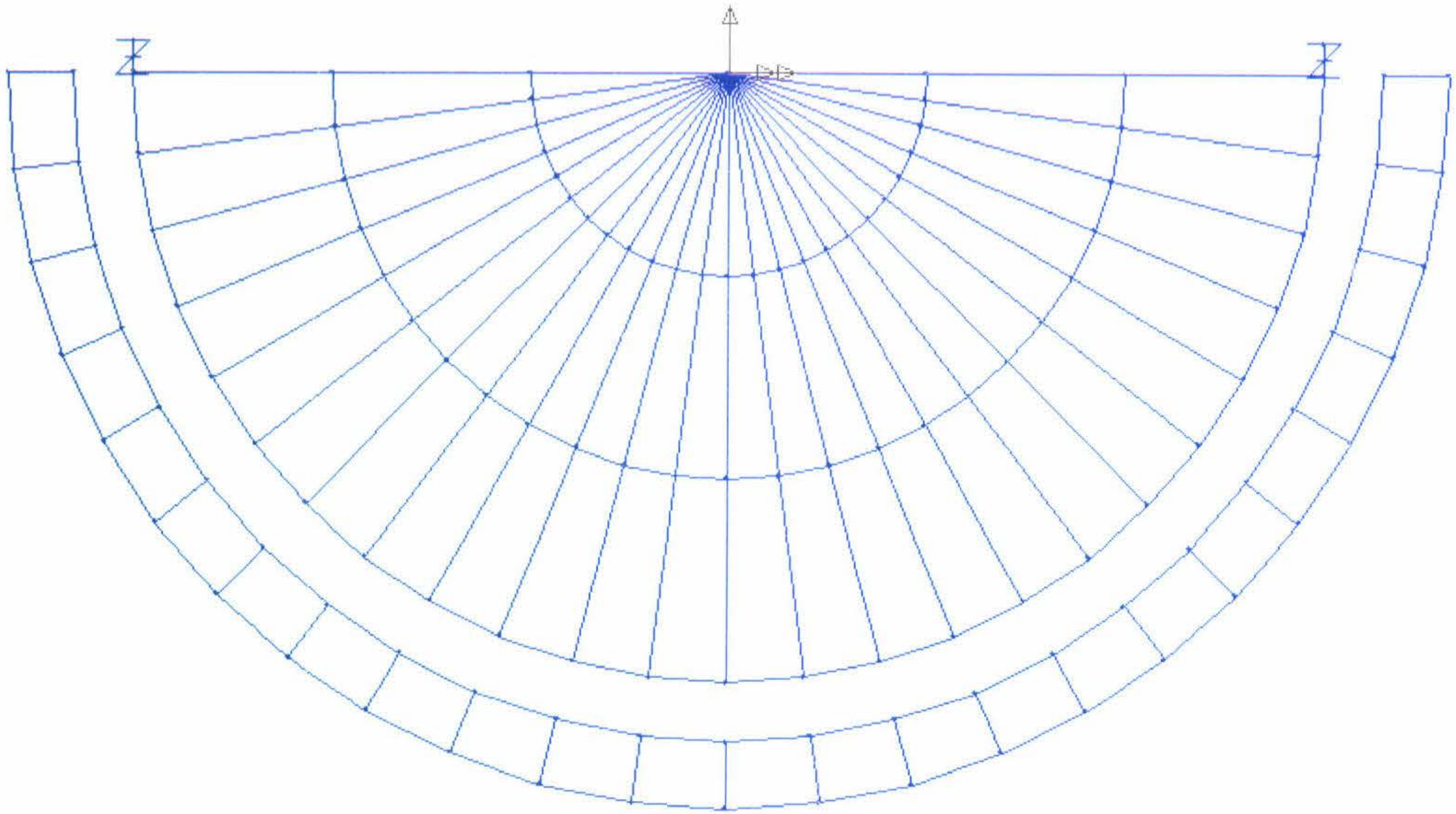


Figure 5.7 Meshing of 2D Slideline Example

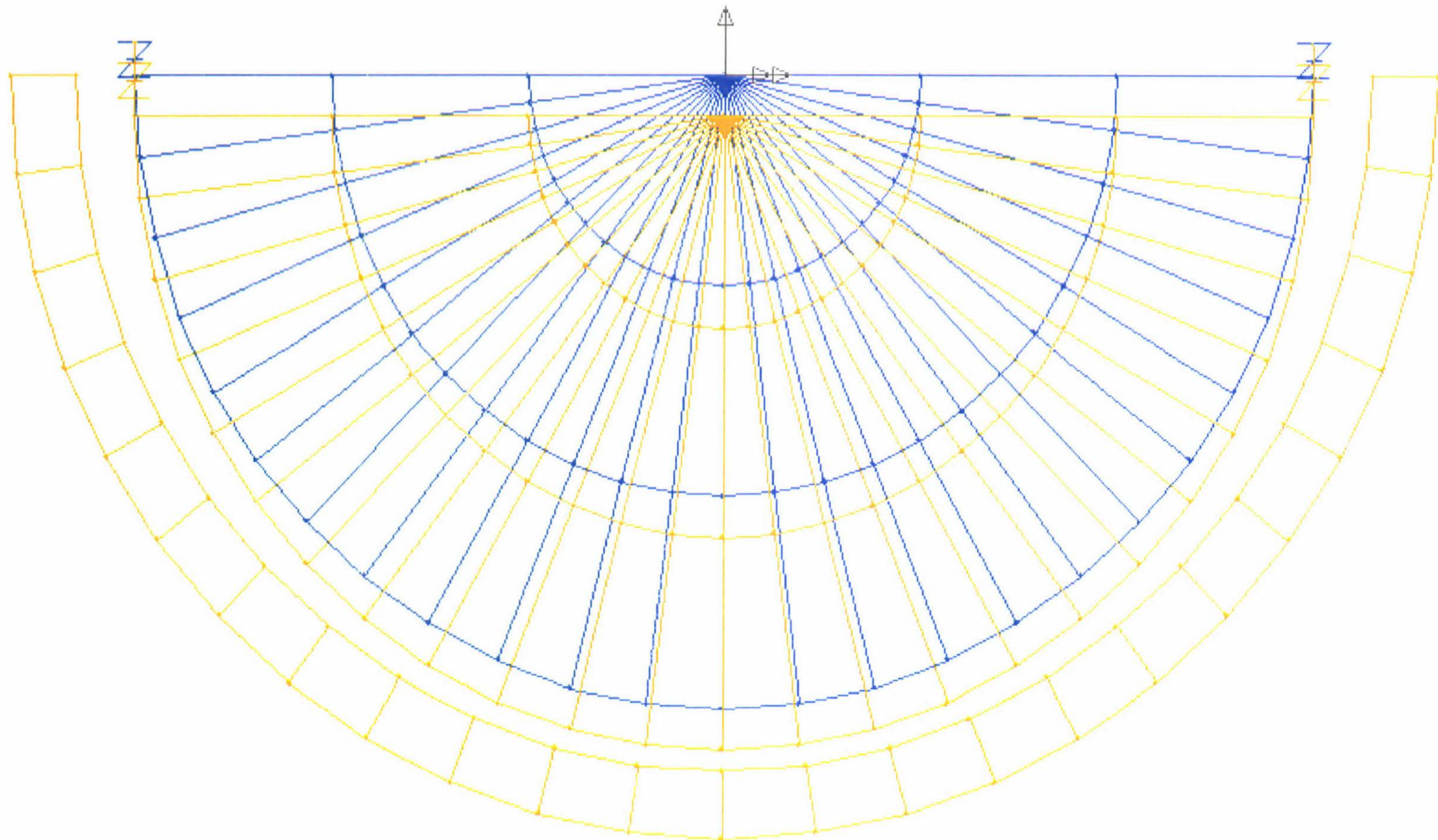


Figure 5.8 2D Slideline Example with Deformed Mesh (Orange) Superimposed on Undeformed Mesh (Blue)

5.8 FEA Model Generation

The following part will deal with the creation of Finite Element Analysis Models that were created in the course of research. The models were analysed at two different moisture content levels as the material properties changes with the given environmental conditions, by creating the models at different % of MC. Comparison in tray performance was made.

5.8.1 2D - Thin Shell Models of Apple Tray

The first model is an approximation of the original tray. The model was defined by using two dimensional shell elements, so the thickness of the model is a geometrical function. Loading was also simplified, instead of generating the apple; the weight of the apple was taken and applied as simple point loads in the middle of the tray cups. Certainly, these simplifications are not the accurate simulation of the real conditions of the model but it was anticipated that the model would be a starting point that will provide some useful information about the behaviour of the trays under different lifting conditions.

5.8.1.1 Model Generation

Initially, to create the model it was necessary to obtain a set of co-ordinates that would precisely describe the curvature of the cup of the apple tray. Attempts were made to obtain the drawings from the manufactures but it was unsuccessful as the moulds were made many years ago and drawings no longer existed. Due to the lack of availability of measuring equipment and imprecision of available measuring devises it was decided to measure the cup dimensions physically. A single cup was cut from the tray and then measured and marked out as shown in the Figure 5.9

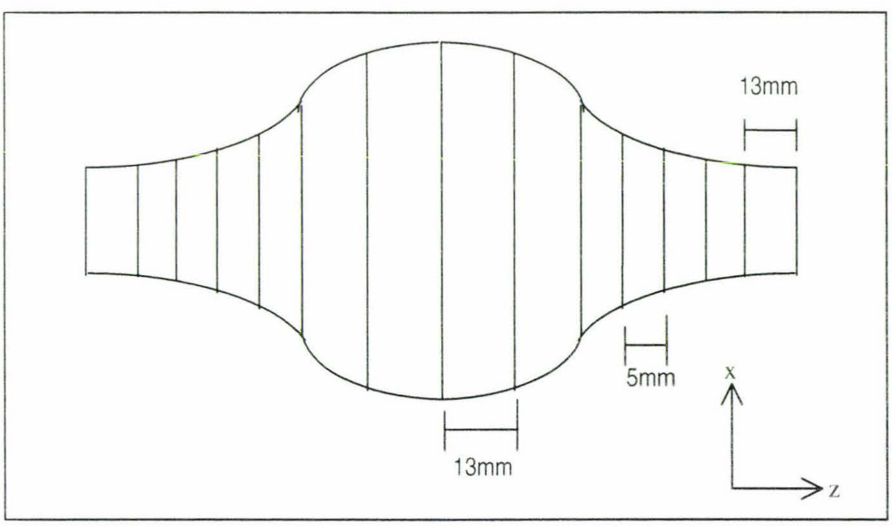


Figure 5.9 Plan View of a Single Marked Out Cup

These dimensions were used to define the z co-ordinates in model. Using a sharp stiletto the cup was cut in the middle along the longitudinal axis to measure the depth of the cup, as illustrated in the Figure 5.10. The profile of the strip was traced on the paper, using the reference line set normally at y=0, x and y co-ordinates were obtained by measuring the distance from the reference line to the traced profile. This was done for all the cut profiles, providing a set of x, y and z co-ordinates that accurately approximated that curving counters of the cup. The cups are symmetrical about the axis therefore it is necessary to obtain the co-ordinates for a quarter of the cup.

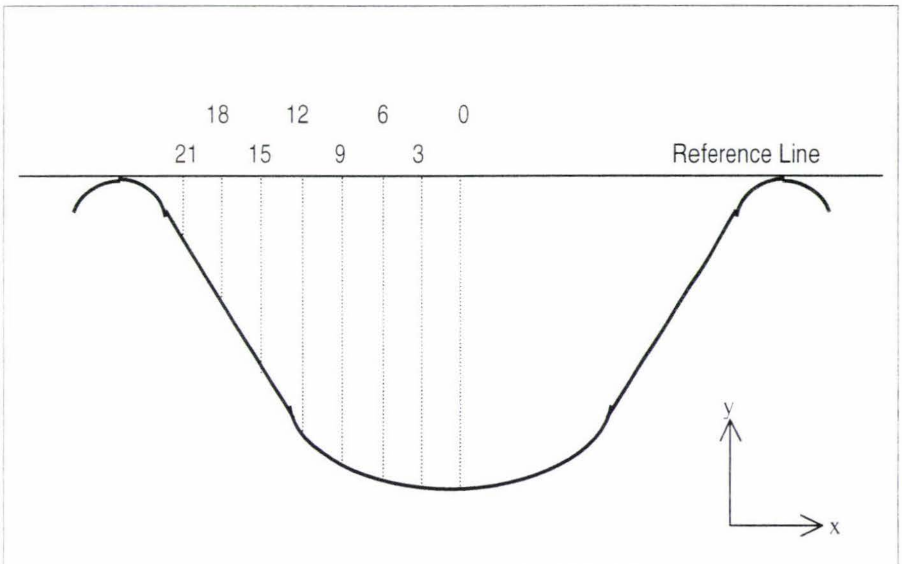


Figure 5.10 Profile of Cup Segment.

The points were entered into Lusas modeller and used to define a set of surfaces. Once a quarter of a cup was defined correctly it was a simple matter to copy the surfaces to create the full cup, then copy that cup several times to complete the internal section of the tray. The edge is a flat section that extends down each side of the tray; to draw the edges of tray was more difficult. Initially, cup surfaces are extended to define the flat edges, but analysis by the Lusas processor was not possible. The reason for this was due to excessive double curvature of the surface; as they bend up from the bottom of the cup, then bend back for the flat edges. This causes the surfaces to form an S shape. When a mesh is fitted to this shape, unless a large number of elements are used, the elements buckle and bend when they are forced to conform to curves. If the element bends beyond a certain limit, then the mid side node are said to be insufficiently central, causing the processor to abort the analysis with the error message that an illegal Jacobian determinant has occurred at the offending element. This situation is illustrated in Figure 5.11.

This problem occurred in all surfaces that had been modified to include the edge of the tray. To counteract this, the edge was defined as series of separate surfaces that were joined to the main body of the tray. The ends of the trays were cut, marked out, and measured in much the same way as the original cup had been.

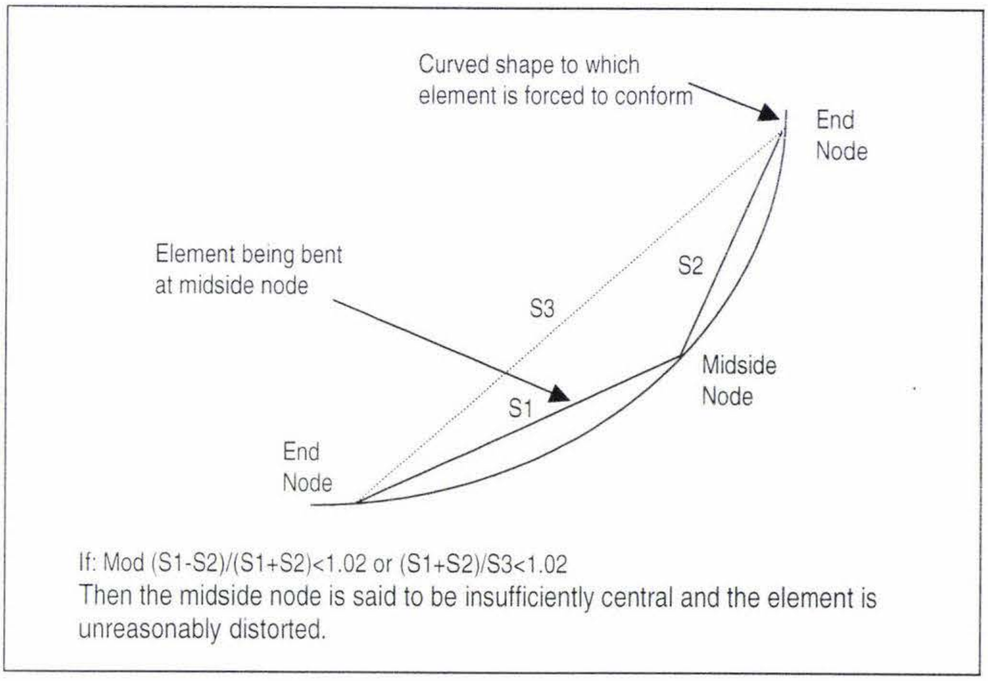


Figure 5.11 Illustration of Element Bending Distorted.

5.8.1.2 Meshing

Two dimensional thin shell elements were considered as an extension to the plate bending elements. They have additional nodes to describe a thin walled 3D curved profile. 3D bending stress analysis is available via rotational degrees of freedom (DOF) along three axes at each node. A choice of quadrilateral or triangular elements are available, and at the end of the tray it is not possible to define the quadrilateral elements and therefore the total model was defined by triangular elements. Each cup surface was defined by twelve triangular elements whereas six elements were used for the surfaces of the edges. This was the smallest number of elements that could be used. If the curvature of the cup were defined by fewer elements, then the mid-side node problem discussed in the previous section would occur.

5.8.1.3 Geometric and Material Properties

The average thickness of the tray is approximately 1.5mm, and was defined as a geometric function and assigned to all surfaces.

The models were analysed at two different moisture content levels as the material properties change with the given environmental conditions. The models were created at two different Moisture contents, one at room temperature & humidity that has 8% MC and 20% moisture content. For first model the material properties of Young's Modulus 140±15 N/mm^2, and for the second model the Young's Modulus of 73.25 N/mm^2 and Poison's ratio of 0.8 were assigned to the model.

5.8.1.4 Support & Loading Conditions

A simple support data set was set in the y direction as the model was defined in x-y-z co-ordinate system to prevent vertical displacement. Assigning of supports in the vertical direction allows the tray to lift at the sides and it is free to move inwards when bending takes place. The defined supports were placed in the middle of the tray edges (in the direction of length) to simulate it being lifted at the ends by a pair of hands, and in another situation, to simulate being held at the sides (in the direction of width). Both these support conditions are applied to the completed model shown in the Figures 5.12 and 5.13.

Loading was defined as a simple concentrated load and assigned exactly to the points that are in the middle of each cup. The load is equal to the average weight of the apples, which gives a force of 1.71N.

5.8.1.5 Non-Linear Controls

Loading was applied by a non-linear data set, which applies the load in very small steps and then greater loads could gradually be applied. These models used forty load increments, some with up to six iterations per increment.

5.8.1.6 Analysis Technique

The Lusas processor uses a method of solving equilibrium equations that is called the *Frontal Technique*. During the solution the element stiffness and load matrices are read into the computer memory and assembled into the structure stiffness and load matrix. Any equations that are complete are immediately eliminated so the size of the structure stiffness matrix and thus the memory requirements, are minimised. The frontwidth is the number of equations in the structure stiffness matrix at any time. By default, equations are processed in the order the elements are defined, which often leads to a very inefficient solution process. Lusas therefore offers a facility where the solution order may be optimised by using a *frontwidth optimiser*. This facility solves the element equations in such an order as to keep the structure stiffness matrix as small as possible. Two types of optimisers are available: the Standard Lusas optimiser, and the Akhras-Datt optimiser. The standard optimiser was used for this model.

Figure 5.12 Thin Shell Model of the Tray – Support Case A

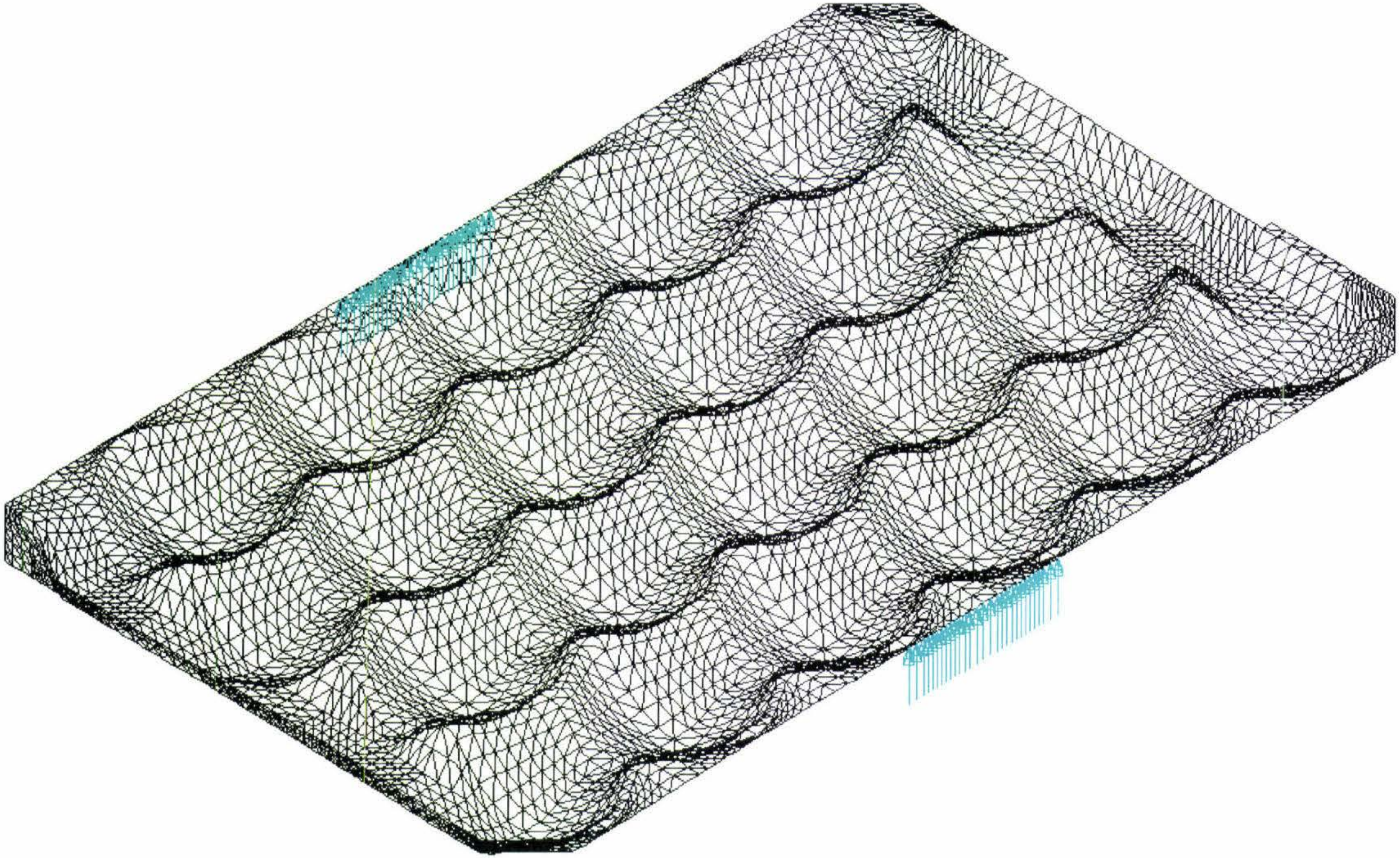


Figure 5.13 Thin Shell Model of the Tray – Support Case B

5.8.2 Three Dimensional Tray Model

When examining the apple trays under handling conditions, it was noticed that when the trays were picked up and then bent due to the weight of apples, the apples themselves touched and forming a bridge across the tray and prevented further bending. Hence, in the handling situation the apples are the major component to provide more strength to the tray. Therefore the previous models are not accurate due to the absence of the apples within the models. Hence, it was decided to define the models, which incorporates the apples within the tray.

5.8.2.1 Model Generation

The first consideration while generating the model was to control the model size to be as minimal as possible. The tray with apples is symmetrical about the longitudinal axis, so it is possible to crate a half of the model, with the missing half being compensated by the use of the correct constraints. Half of the tray was extracted from the 2-dimensional model and transformed into volumes with a thickness of 1.5mm. It is impossible to mix two-dimensional elements with three-dimensional element within the analysis, and because the apples that were to be introduced to the model are the volumes, therefore the tray was transformed into volumes.

In order to obtain the co-ordinates of the apple, a random selection of Red Delicious apples were measured for length and width, the average of these measurements were calculated. These apples were then sliced length wise through the core and the profile of the cut surface traced on a paper. Using this technique the co-ordinates of the apple surface were measured, these co-ordinates were entered into Lusas modeller and fitted with a spline. The position of this line was then adjusted until it was close to the inside of the curve defining the cup centre profile, in a similar manner as an apple would be when placed in a cup. The spline was then rotated about the central axis in order to obtain the outer shape of the apple; this shape could then be filled in to create a solid. Initially, it was thought to make hallow section of the apple in order to save the number of elements used. Figure 5.14 is an example of earlier attempts at apple definition, and also we can see how the tray is now defined as having thickness. This idea was discarded because it was realised that it would be very difficult to model the loading accurately. Point loads would be ineffective, as it was not known where to place them in order to accurately simulate the apple weight. It was necessary therefore to create a solid apple, using very few elements. The first step in saving elements was to model only half the apple. It was thought that the top half of the apple did not perform any essential function other than adding weight and therefore was it only adding unnecessary elements to the model. The original spline of the apple profile was then broken up into a series of lines, each of which was joined to a corresponding line which lay on the apple's longitudinal axis (as shown in the Figure 5.15) to form the surfaces.

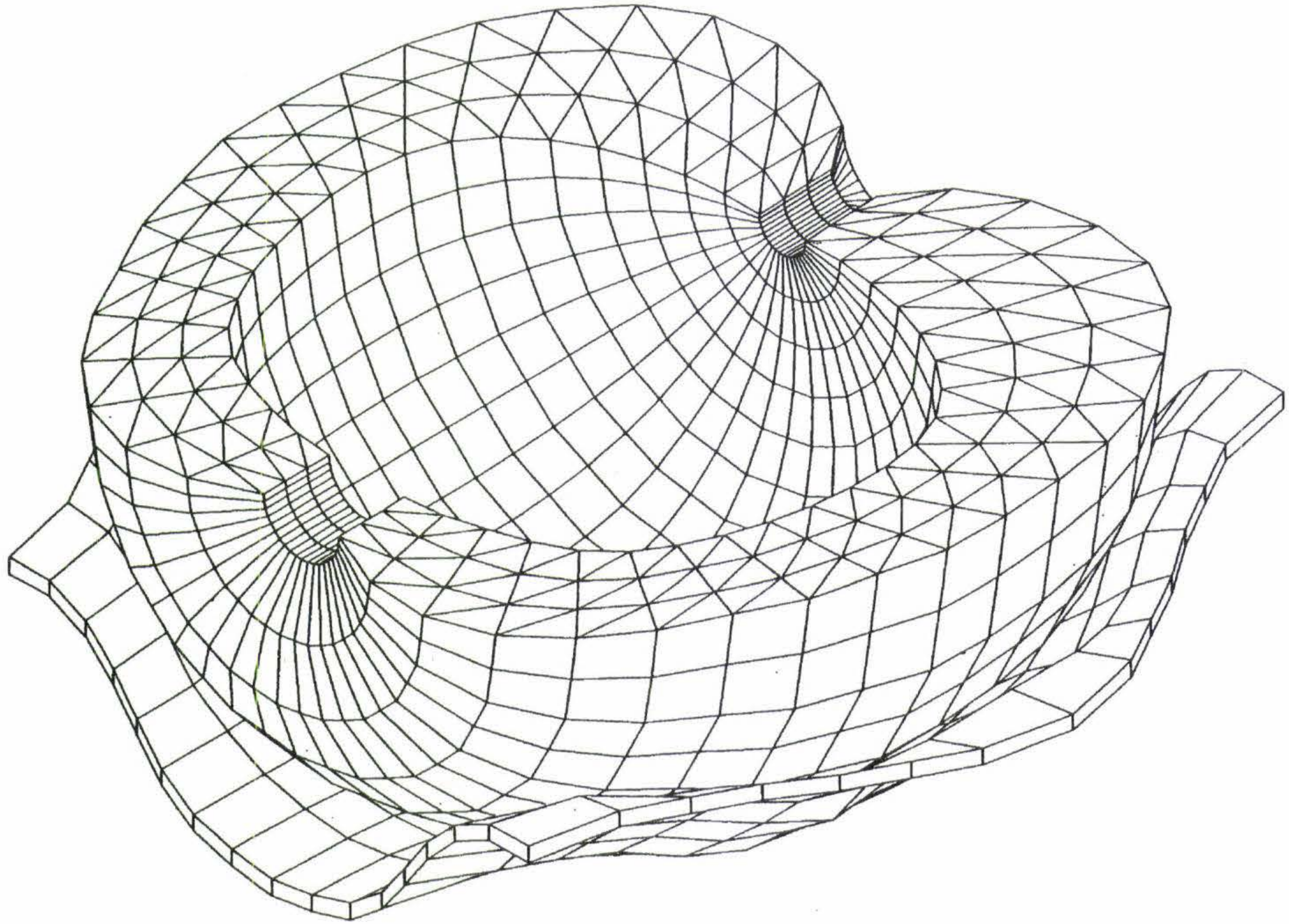


Figure 5.14 Model Generation of Apple and Tray Using 3D Elements

These surfaces could then be rotated seventy degrees in each direction to form volumes. These surfaces could then be rotated another twenty degrees in each direction to form another set of volumes which finished off the half apple. The reason for rotating the surfaces only seventy degrees instead of a full ninety degrees was because it had the effect of creating a series of volumes that could be classified into two groups; those close to the tray and those at the top of half apple.

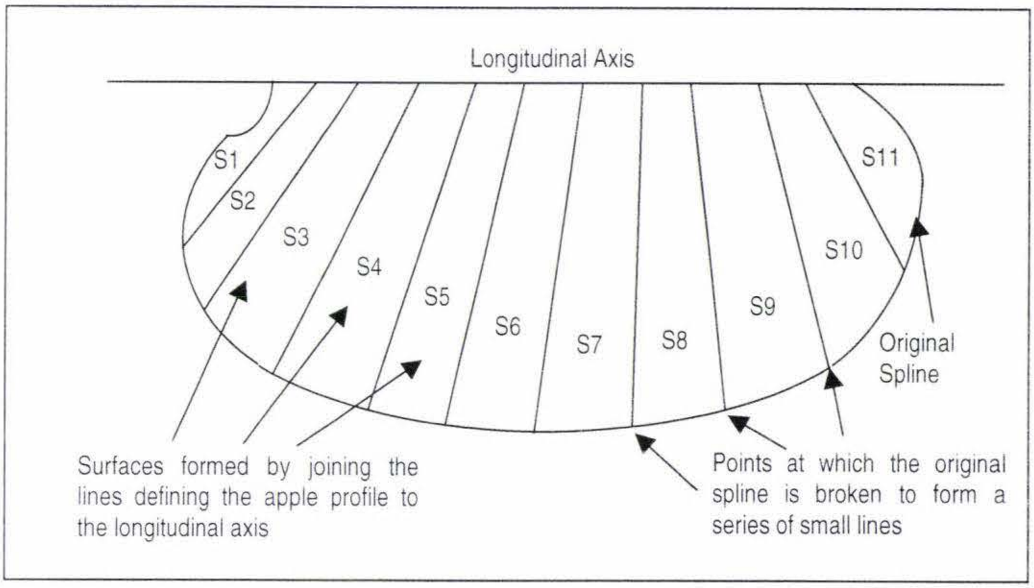


Figure 5.15 Diagram Showing Surfaces within the Apple Model.

When it came time to apply mesh to the volumes, it would be desirable to have a fairly high density close to the tray, but further away a loose mesh would be enough. By braking up the volumes it was possible to have a control over the mesh. The apple was further broken up into inner and outer section. These sections consisted of the main body of the apple surrounded by a thick skin. Doing this gave further control over the mesh discretisation.

5.8.2.2 MESHING

Several types of element were available for volume meshes, including tetrahedral, pentahedral and hexagonal elements. Hexagonal elements with 8, 16 or 20 nodes are available. The choice of the modified hexagonal element using eight nodes was made, as this element was better suited to slideline problems and was most efficient in its use of nodes. The entire tray was meshed with these elements, the main body of the tray being fitted with nine elements per surface, while the edging was only fitted with one.

The inside section of the apple was meshed using tetrahedral elements. These were used because the element has a square base that tapers up to a single line at the top of the element. This meant that all the elements filling the internal section of the apple could meet at a common line in the centre of the apple, while the elements themselves were fanned out forming a semi-circle. The outside section was meshed using eight node hexagonal elements. Though these two types of elements are different, the two elements were compatible because they had the same amount of nodes on the common joining element face. The entire mesh structure is shown in Figure 5.16.

5.8.2.3 Physical Attributes

Geometrical properties need not to be assigned to the model, as the whole model was created in volumes, which have all geometric properties inherently defined.

The apple material properties used were those explained in section 3.1, with the exception of the density of the apple. The density of the apple was doubled as only half apples were being used in the model; doubling the density effectively makes the half apples weigh the same as whole apple. The tray material properties were defined as those measured and detailed in section 4.6.2

Half of the model was defined, as it is symmetrical about the axis with symmetrical loading, supports have to be defined to compensate the remaining half the model. Care was taken to assign the supports because in FEA analysis supports can drastically affect the results. Vertical restraints were assigned to the sides of the tray, near the cut, to simulate the tray being picked up at the sides. Along the cut face of both apples and tray, moment in z-axis (down the length of the tray) and rotation about the x-axis (across the width of the tray) were restrained. Moment in the y direction (vertically), rotation about the z-axis and y-axis, and the moment in the x-direction were all left free in order to let the tray bend as the real tray would.

The slideline properties were also incorporated into the model between the apples and tray. Once the small loads were applied by the non-linear control load dataset, the apples contact the tray first, then the more load applied the apples' surface would touch the tray as the apples settled into the cup.

Loading was defined by a constant body force (CBS) load, which requires a density to generate a load and was defined as a material property of the apple. CBS assigns a weight to an object in a specified gravitational field. It was important to use this loading technique as apples tend to be weighted off centre, which is difficult to model other than by the CBF method. Loading was applied by a non-linear data set, which applies the load in very small steps and then greater loads could gradually be applied. These models used forty load increments, some with up to six iterations per increment as in the previous analysis.

5.8.2.4 Analysis of 3D Tray

The Akhras-Dhatt frontal optimiser was used for this analysis, as the standard optimiser was incompatible with this model. If a model has unconnected elements (i.e. between the apple and tray) then the standard frontal optimiser will not operate effectively. The analysis was aborted due to the lack of Lusas memory; it was also tried with reduced elements but there was no response. Due to this, no results were obtained from the 3D tray model.

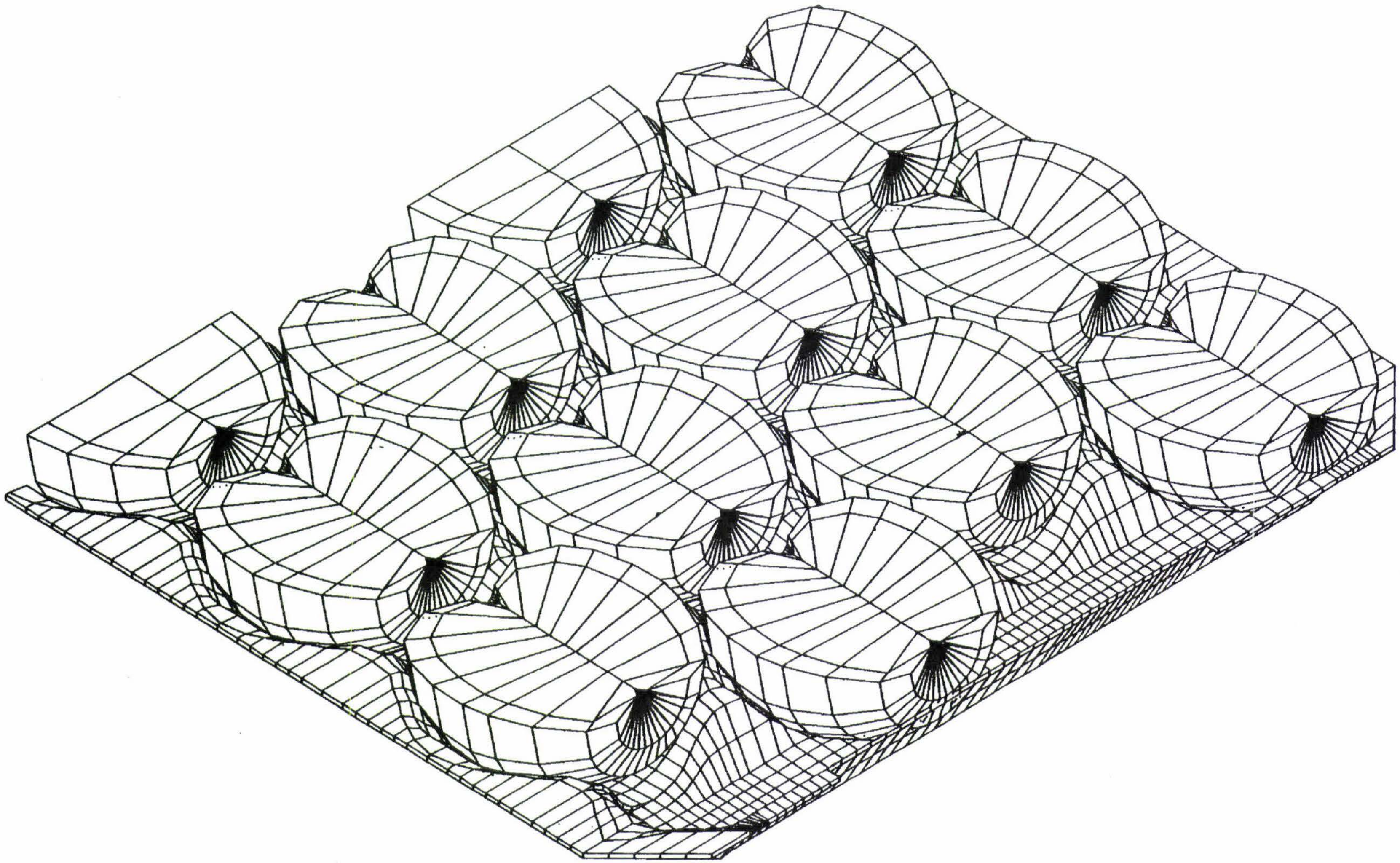


Figure 5.16 Meshing of 3D Model with Tray and Apples.

5.8.3 The Full Tray Model (Using Shell Elements)

After the uncompleted analysis of the 3D tray the model was re-evaluated. The apples are the main function as they contact each other to protect the tray from further bending. Thus it was decided to focus more on the apple definition rather then the application of the load. The focus therefore shifted from the mass of the apple to the shape of the apple. Hence, it was decided to remodel the 3D tray using hollow apples and two-dimensional elements. This would result in a huge reduction in the model size.

5.8.3.1 Model Generation

A half tray was extracted from the shell model, and this model was retained as a two-dimensional model. For the apples, the apple profile was extracted from the 3D model and broken up into a series of lines. The length of these lines exactly matched the width of the surfaces defining the cup in the tray. The profile was then rotated 360° in a series of 90° steps. This created a set of surfaces that defined the entire shape of an apple in two dimensions. These surfaces were then copied and placed in each of the cups in such a way that each of the surfaces defining the apple lined up to a surface on the cup in which it sat.

5.8.3.2 Meshing

For the full shell model, thick quadrilateral elements were used to define the tray and apple meshing. These had to be used as they were the only shell elements compatible with slidelines. In addition, two-dimensional joint elements were assigned to the lines connecting the apples to the tray and also the lines between the apples. Slidelines had been shown to work better when the two surfaces contacting each other were connected in some way, which was why the joint elements were placed between the apples. The stiffness of the joint element was set at about 1/1000 of the stiffness of the tray for the joints connecting the apples. This low stiffness is to ensure the joints do not affect the results in any way.

Figures 5.17 and 5.18 shows two views of the full shell model. The support conditions are illustrated in Figure 5.18.

5.8.3.3 Physical Attributes

The thickness of 1.5mm was defined and assigned as a geometric function to all surfaces of the tray, while a 5mm thickness was assigned to the apple skin.

The model was analysed at two different moisture contents of 8% MC and 20% MC. For the first model the material properties of Young's Modulus 140±15 N/mm^2, and for the second model the Young's Modulus of 73.25 N/mm^2 and Poison's ratio of 0.084 were assigned to the model. The Young's Modulus for the apples was increased. This was done because the apple was now being modelled by only a thick skin, which would have very little strength if assigned the correct material properties for apple. By increasing the stiffness of apple to approximately $100GN/m^2$, it was ensured that the apples would not deform excessively. As the tray is the subject of the analysis and the apples are only required to provide support, results would not be affected by the increased stiffness.

Loading was assigned as a point load in the centre of each cup. The load was 2.06N except on the cups that had been halved by the axis of symmetry. These cups were loaded with 1.03N as only half the cup was being used in the model and therefore only half the load should be used. Loading was applied by a non-linear data set, which applies the load in very small steps and then greater loads could gradually be applied. These models also used forty load increments, some with up to six iterations per increment.

Support conditions were defined exactly the same as for the 3D tray model.

Slide lines were assigned between adjacent apples on the two surfaces closest to each other and between the apples and the edge of the tray. This meant some apples had four sets of slidelines in common with neighbouring apples.

5.8.3.4 Analysis of Full Shell Model

There was a huge reduction in the model size from 3D tray model to 2D shell model. This is about as small as the model could be, though it is possible the model may have been slightly smaller if quadrilateral element had been used. The standard optimiser was used for this model. Using a *frontal optimiser* eventually solved this problem.

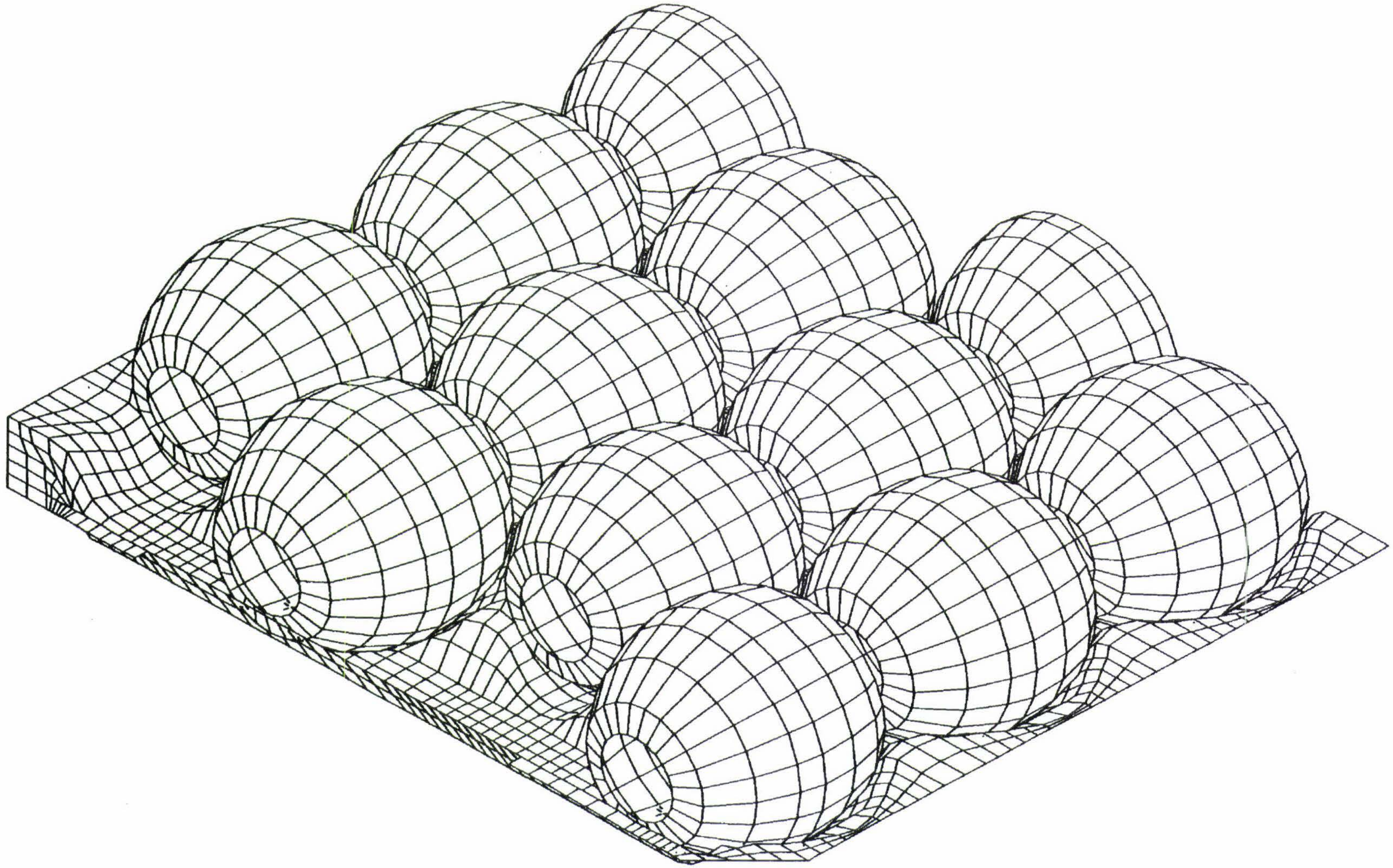


Figure 5.17 Model Generation of Tray and Apples Using Shell Elements.

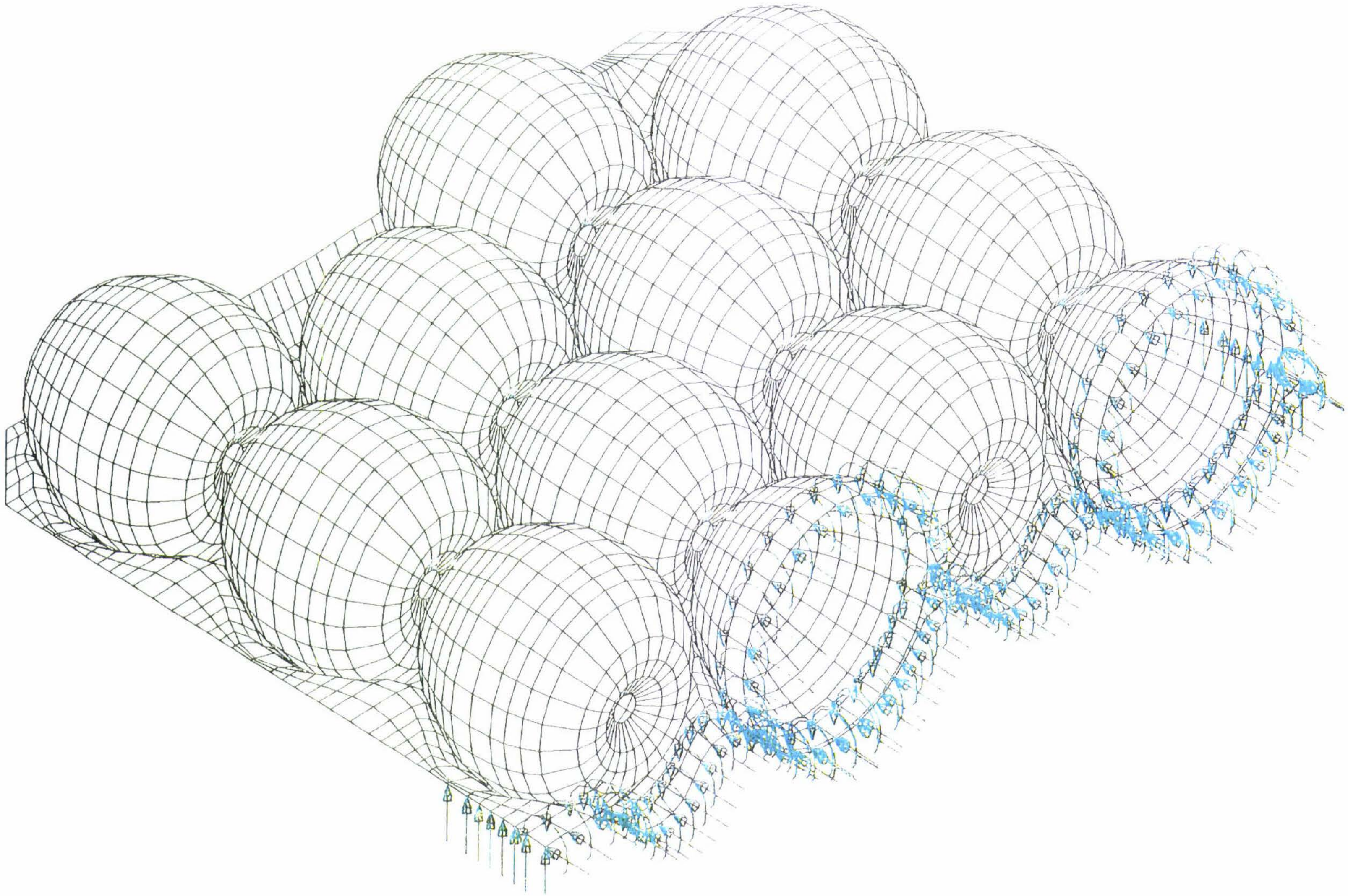


Figure 5.18 Model Generation of Apples and Tray Using Shell Elements and Support Conditions.

CHAPTER 6
RESULTS AND DISCUSSION

6.1 Analysis and Results of Tray Models

The results obtained from the analysis of the tray models at different moisture contents and at two different lifting methods will be discussed and compared together. Three different types of output were obtained for each of the trays:

- A deformed structure of the tray
- A graphical format of displacements in the vertical direction
- A graphical format of maximum principal stresses

These are not only the results that could be produced by the package, however for this type of problem they are the most useful and relevant. The deformed mesh diagrams are useful to demonstrate the mechanism of how the structure deforms during the loading conditions. The maximum displacement coloured contour plots provide the numerical results and visually demonstrates the regions on the tray where maximum displacements occur. The maximum principal stress contour plots are the most useful results, these results shows the peak stress areas on the tray and allow evaluation of where the tray would fail.

6.1.1 Displacements at Different Moisture Contents and Lifting Methods

Figures 6.1 to 6.4 shows the deformed meshes of the tray model at two different moisture contents and at both support conditions modelled. These support conditions were simulating the trays being held by a pack house worker at the ends and the tray being held at the sides. For identification, the support case simulating the tray being held at the ends will be referred as "Support Case A" and the supports at the sides shall be referred as "Support Case B".

Figures 6.5 to 6.8 shows the coloured contour plots of the tray model at two different moisture contents and at support cases, where the coloured contours are representing the results for vertical displacements. As the model units were defined in Newtons and millimetres, the diagrams display the quantitative results in millimetres and the negative sign indicates that the displacement occurred in the downward direction.

The tray models at 8%MC displays a distinct difference between the displacements experienced at both support cases. Support case A shows a maximum displacement of 62.3mm where as support case B has more then twice as much movement with 126.2mm of displacement, indicating that the tray is considerably stiffer when the tray is picked up by the ends. The tray model at 8%MC (at support case A) certainly performed better then the similar support case at 20%MC, which deflected by 84.8mm. The deformed mesh plots clearly highlights this difference between the results at both moisture contents. For support case B, the tray did not perform well at either moisture content.

The tray models show that the displacements for both handling situations are basically centralized on the tray. For support case A the maximum displacement is slightly off to one side, reflecting the lack of symmetry down the length of the tray. This indicates that the tray would tip over due to eccentric loading if the tray was on a pivot. In the case of a reasonable board support such as a worker's hand there is a little danger of this as the eccentricity is small. At worst the worker may feel the tray is slightly heavier on one side. More importantly, the maximum displacement being centralized means that if the displacements were large enough to cause an apple to role from its cup, it would tend to role into the centre of the tray. The apples already occupying the cups in the tray centre would prevent this movement thus makes the tray stable. The tray model, with the tray being held at the ends i.e. the support case A, is obviously the best method as it makes full use of the trays inherent stiffness characteristics. Though the displacements at 20%MC are higher then the 8%MC, the strain values of the material at 20%MC are higher then 8%MC that would prevent splits in the tray, in order to decide this it is necessary to examine the stress results. The support case A is therefore better for tray models at both moisture contents.

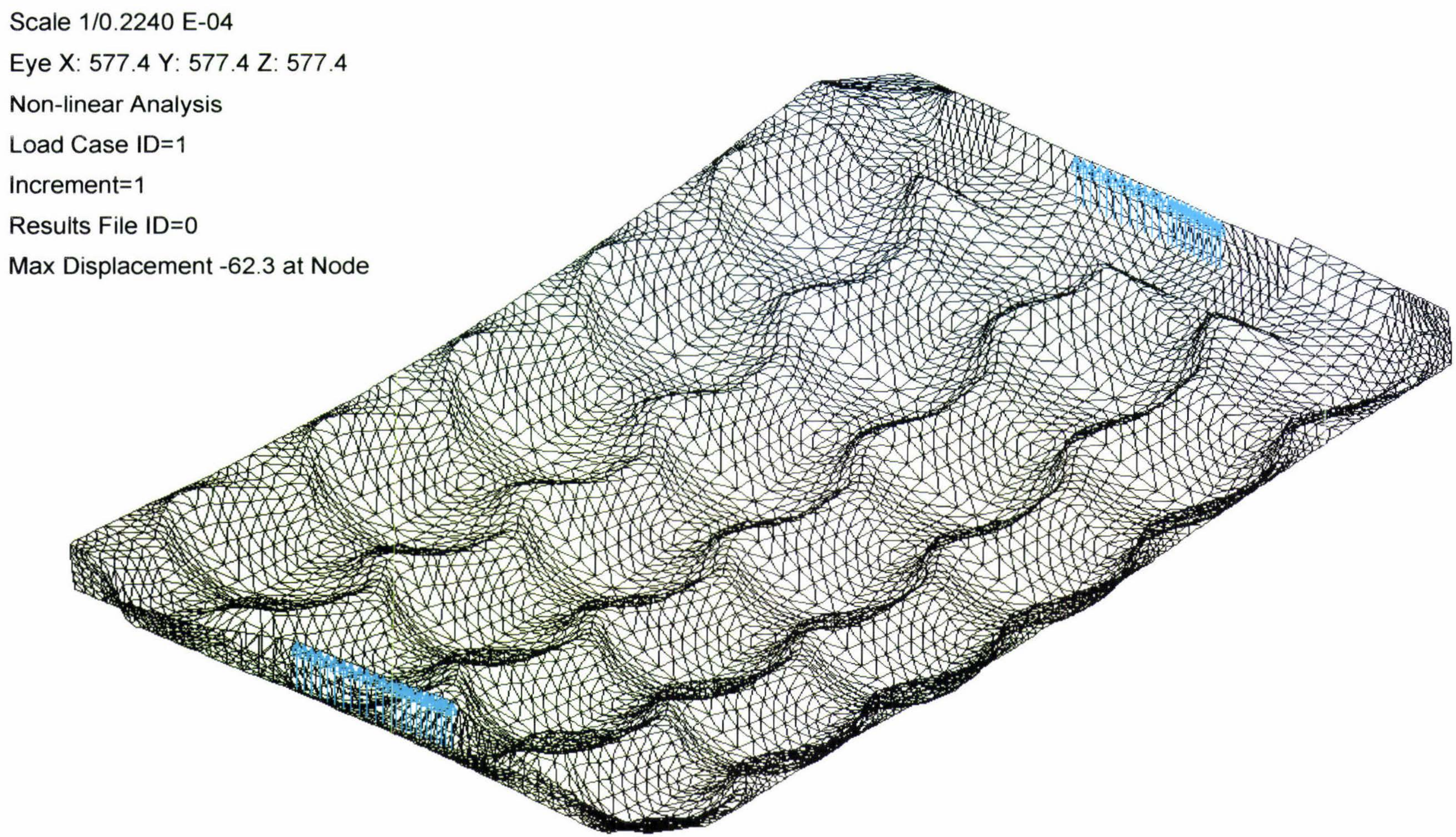


Figure 6.1 Deformed Mesh of Tray Model – 8% MC and Support Case A.

Figure 6.2 Deformed Mesh of Tray model - 8% MC and Support Case B.

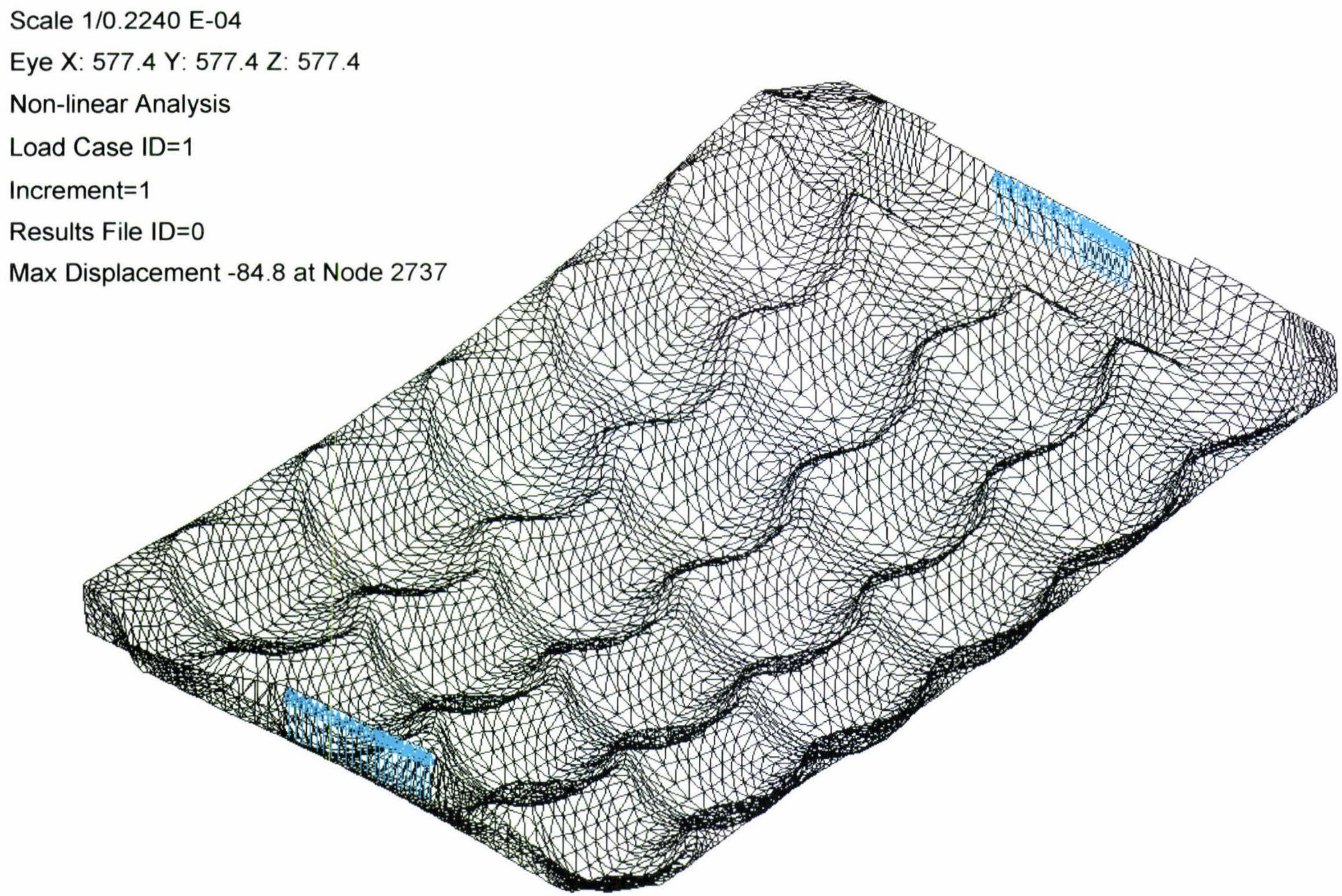


Figure 6.3 Deformed Mesh of Tray Model - 20% MC and Support Case A.

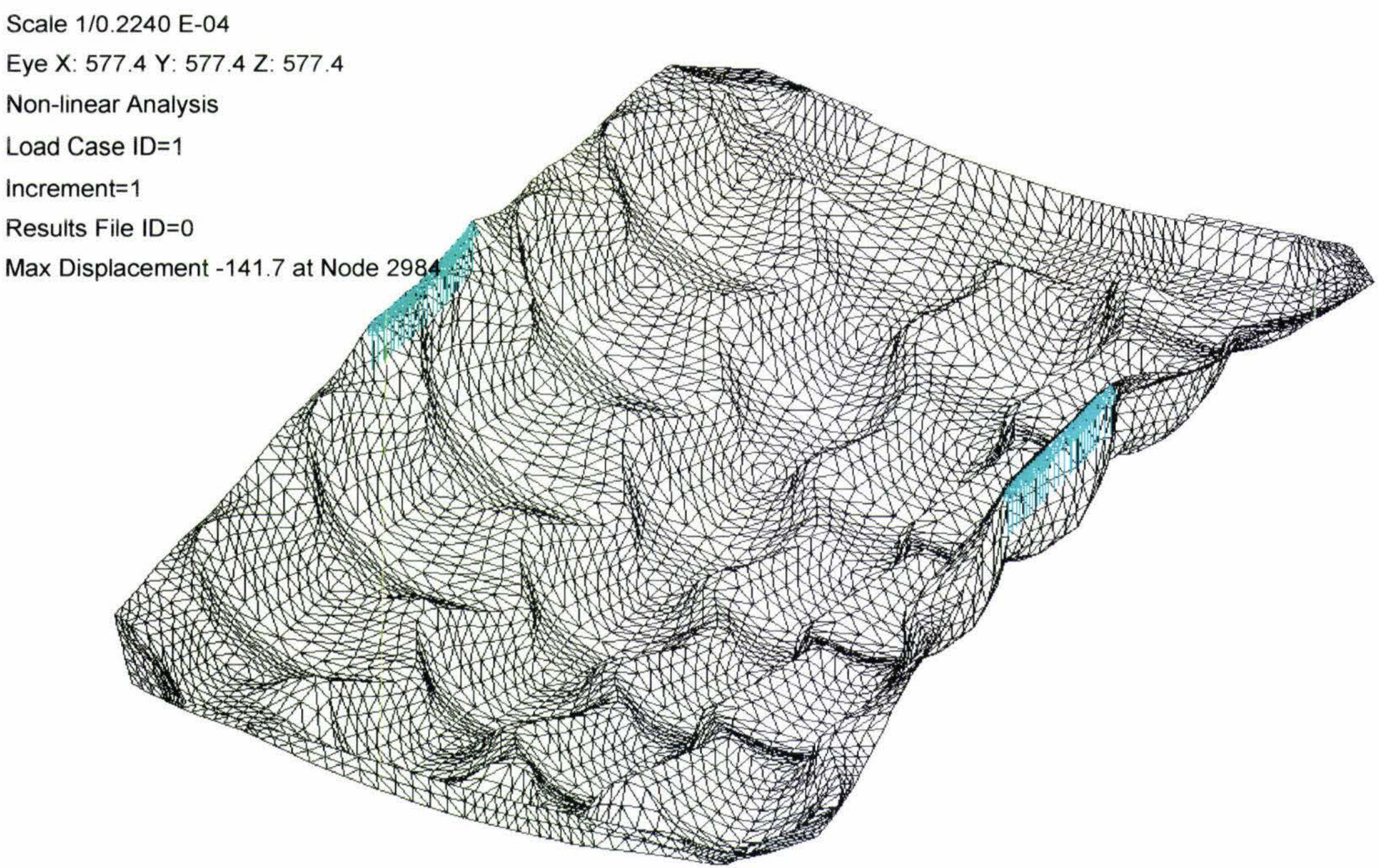


Figure 6.4 Deformed Mesh of Tray model - 20% MC and Support Case B.

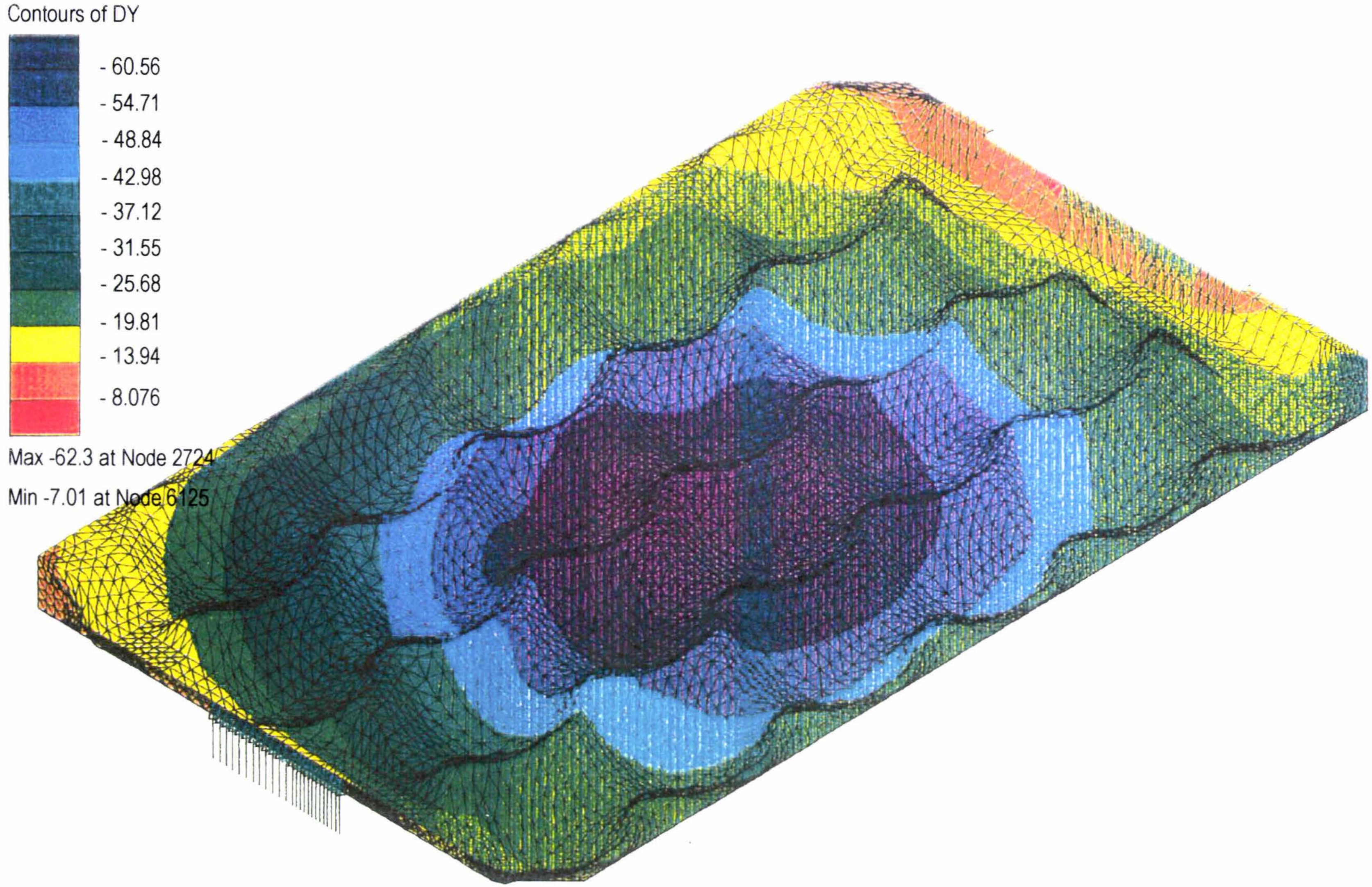


Figure 6.5 Contours of Vertical Displacement in the Tray Model – 8%MC and Support Case A.

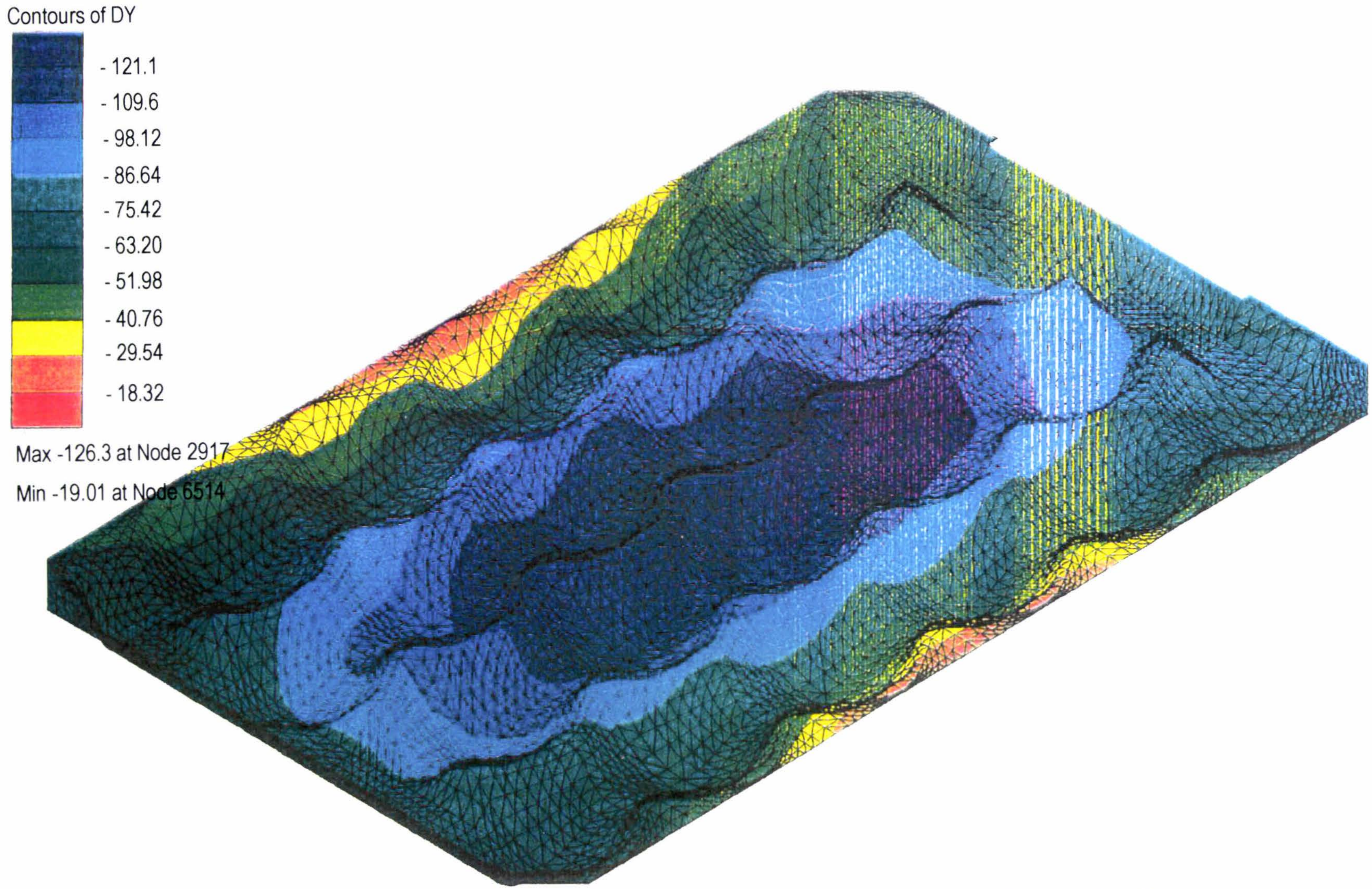


Figure 6.6 Contours of Vertical Displacements in Tray Model – 8%MC and Support Case B.

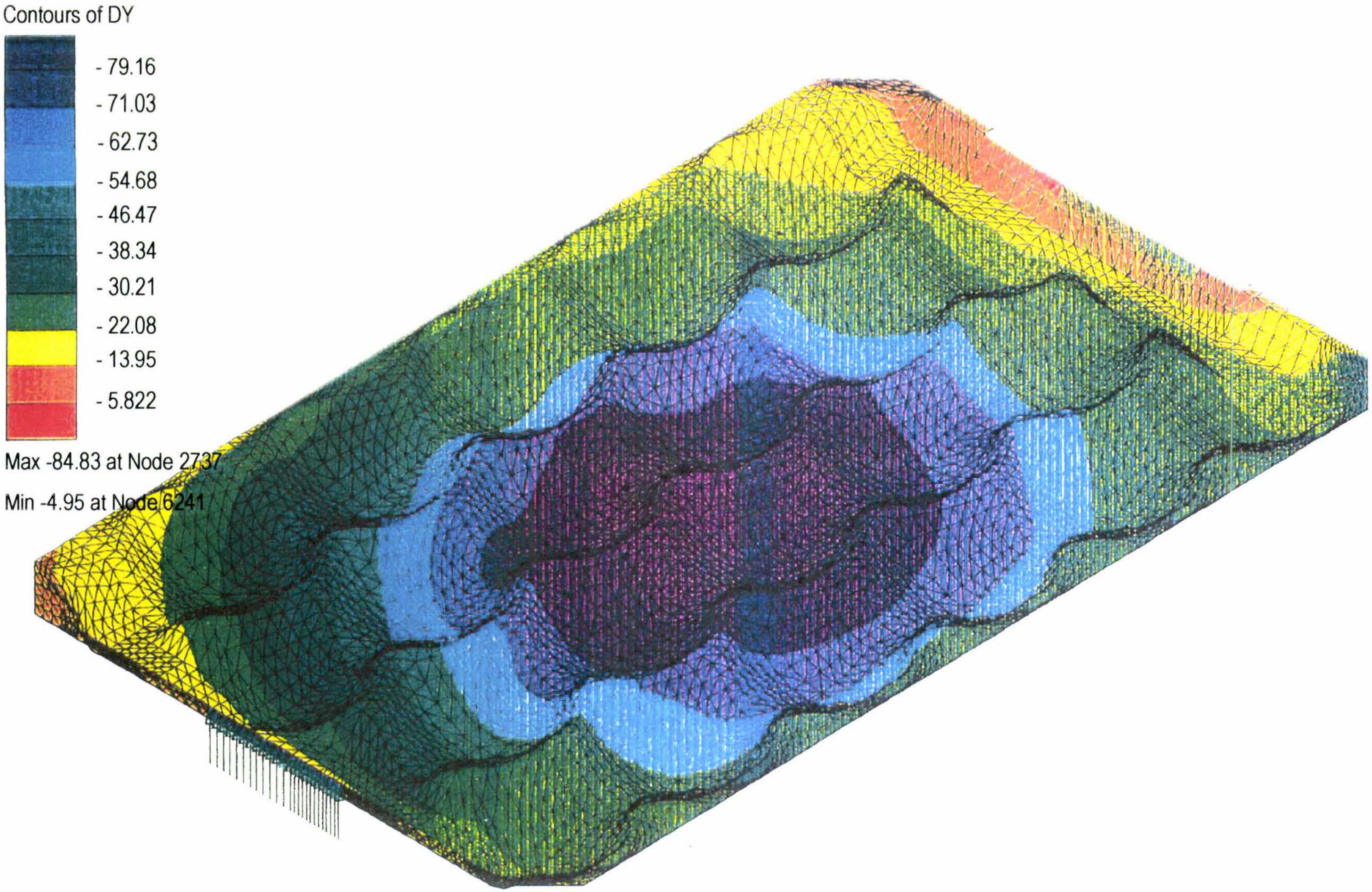


Figure 6.7 Contours of Vertical Displacement in the Tray Model – 20%MC and Support Case A.

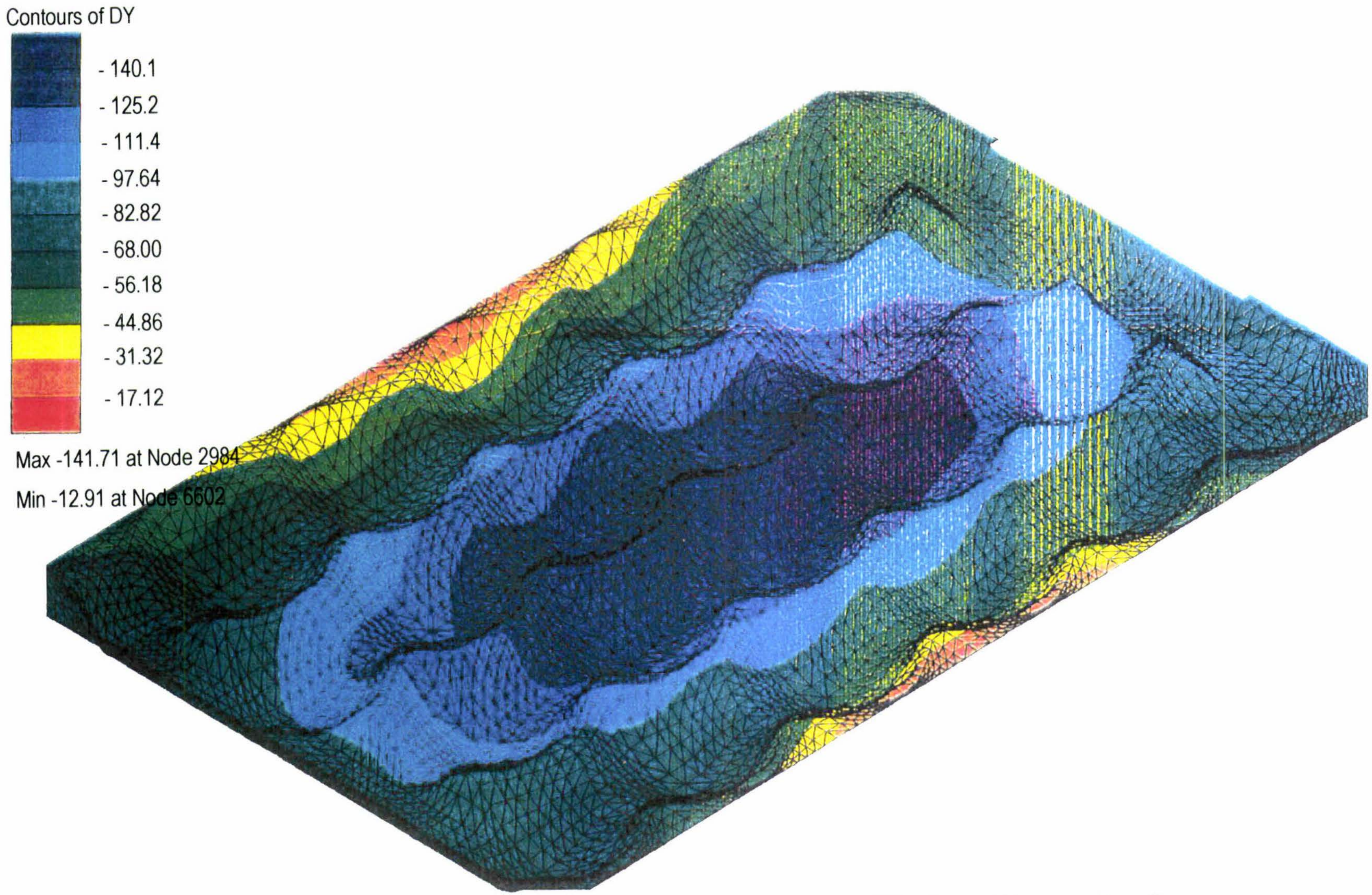


Figure 6.8 Contours of Vertical Displacements in Tray Model – 20%MC and Support Case B.

6.1.2 STRESS RESULTS AT DIFFERENT MOISTURE CONTENTS AND LIFTING METHODS

Figures 6.9 to 6.12 display the colour contours of maximum principal stresses for the tray models. Maximum tensile stress is displayed by red contours and all the values are given in N/mm^2.

In support case A, the maximum stress occurs slightly off centre on the very ends of the trays. High stress regions are also present on the areas between the cups in the centre of tray where the maximum displacements occurs. For support case B the maximum stress again appears where the supports were placed, with one side of the tray displaying slightly higher stress then the other due to the eccentric load. Other then these and few other localized stress concentrations, the majority of stress contours in both A and B support cases are zero.

The contour values of maximum stress for each handling case are quit different. Support case A at 8%MC shows a peak of 6.514 N/mm^2 while support case B shows a maximum tensile stress of 9.615 N/mm^2. Support case A at 20%MC shows a maximum tensile stress of 9.517 N/mm^2 compared with support case B of 15.816 N/mm^2. The higher stresses in the support case B are a direct result of the position of the supports. With the support in the middle of the longest side, the bending moment on the tray is created by a lever arm of 250mm with the evenly distributed weight of half the apples in the tray supplying the load. If the support is in the middle of the end of the tray, the lever arm is only 152mm with the same apple weight as support case B i.e. half the apples in the tray, distributed evenly along it. These dimensions come from the tray model which is 500mm x 303mm. With the same load evenly distributed over a longer cantilever mechanism, the support case B experiences a higher bending moment then support case A.

The support case A handling situation now seems to have greater structural integrity as well as providing a much more stable situation for the apples. It is generally superior to support case B as a method of handling.

The material test data is produced in Table 4.2, for which the ultimate tensile strength of the tray material at 8%MC and at 20%MC was found to be 2.05 N/mm^2 and 1.65 N/mm^2 respectively. The results gained form the LUSAS analysis were obviously at odds with these results from the practical work; the stresses are high enough to tear the tray material. The material does not tear under normal conditions and the practical work shows that the tray does tear at 20%MC. It was known the models were working properly and that all the variables entered were accurate. The only approximation used was replacing the apples with point loads. This was the area that was investigated.

From the practical experiments it was discovered that the apples themselves provide a crucial support for the tray, without which the tray is inadequate to deal with the load.

When the tray sags under the weight of the apples, the curvature of the sag brings the apples closer together until they finally touch. At this stage the friction co-efficient between the apples is sufficient that they form an arched bridge across the tray, and prevent further deformation in the tray. This happens in both handling situations, it is more pronounced in support case A. From the results it can be concluded that the support case A at 0%MC is the ideal handling condition.

6.2 Three Dimensional Model

A 3D tray model with apples was created (explained in section 5.8.2) as it was realized from the shell models that the apples played a vital role in the strength of the tray during handling. However, as explained in section 5.8.2 the 3D model was too large and the memory of the package is not sufficient to solve therefore no results are obtained from the analysis, though some of the useful observations can be noticed.

The 3D model was the most accurate model created as it fully defined all the physical properties of the apples and the tray. The friction between the tray and the apples was also defined by using slideline properties. Half of the 3D model was generated, as the tray model was symmetrical about the centre axis in order to reduce the model size. No assumptions were used that could have reduced the size of the model. This leads to conclude that to create a full apple carton, which complicated shapes of apples and the tray and the attributes such as the interaction between the apples and the tray, would be a difficult task. By introducing some assumptions the model size can be decreased but this then questions the validity of the results obtained.

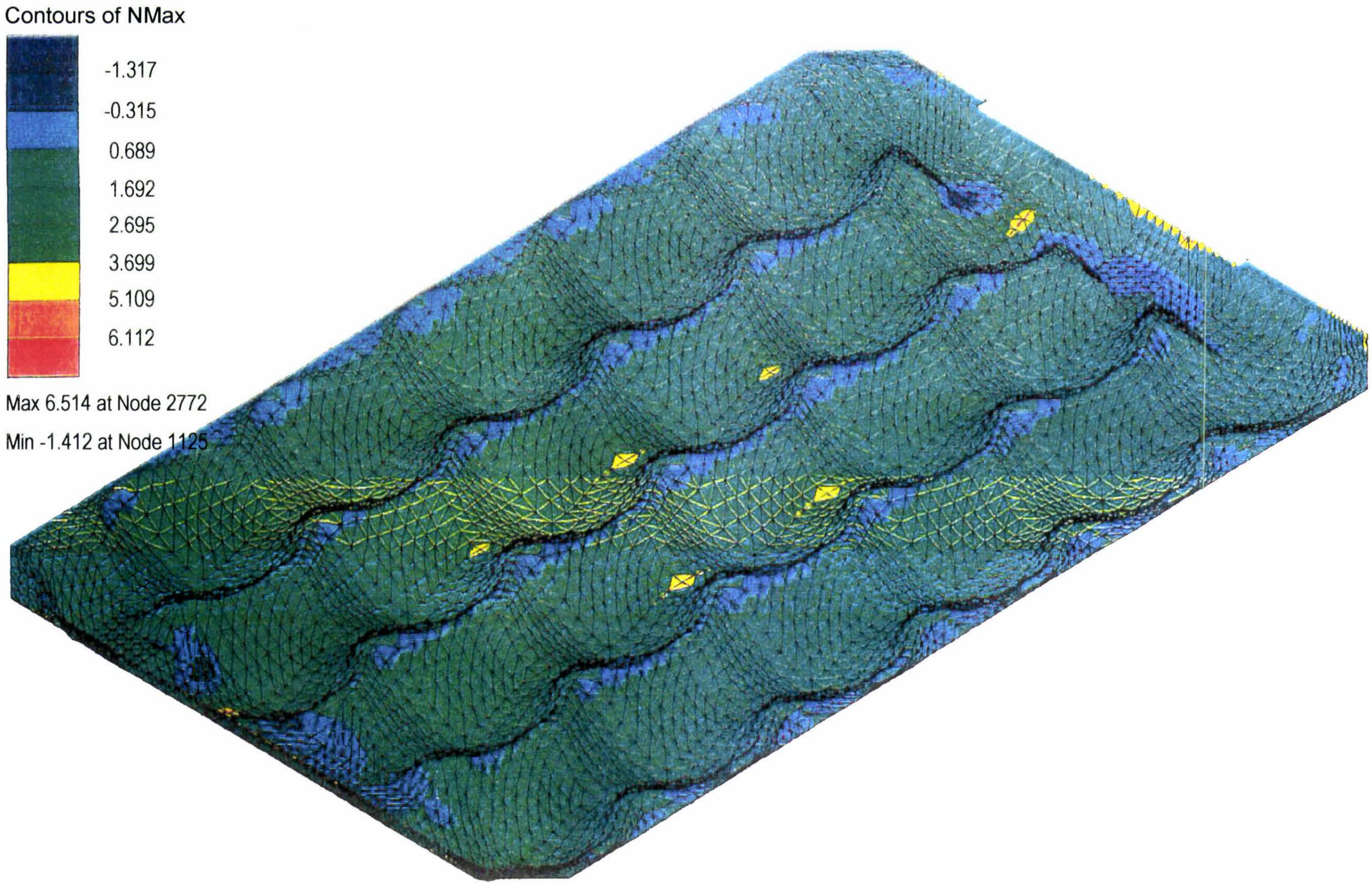


Figure 6.9 Contours of Maximum Principal Stress in the Tray Model – 8%MC and Support Case A.

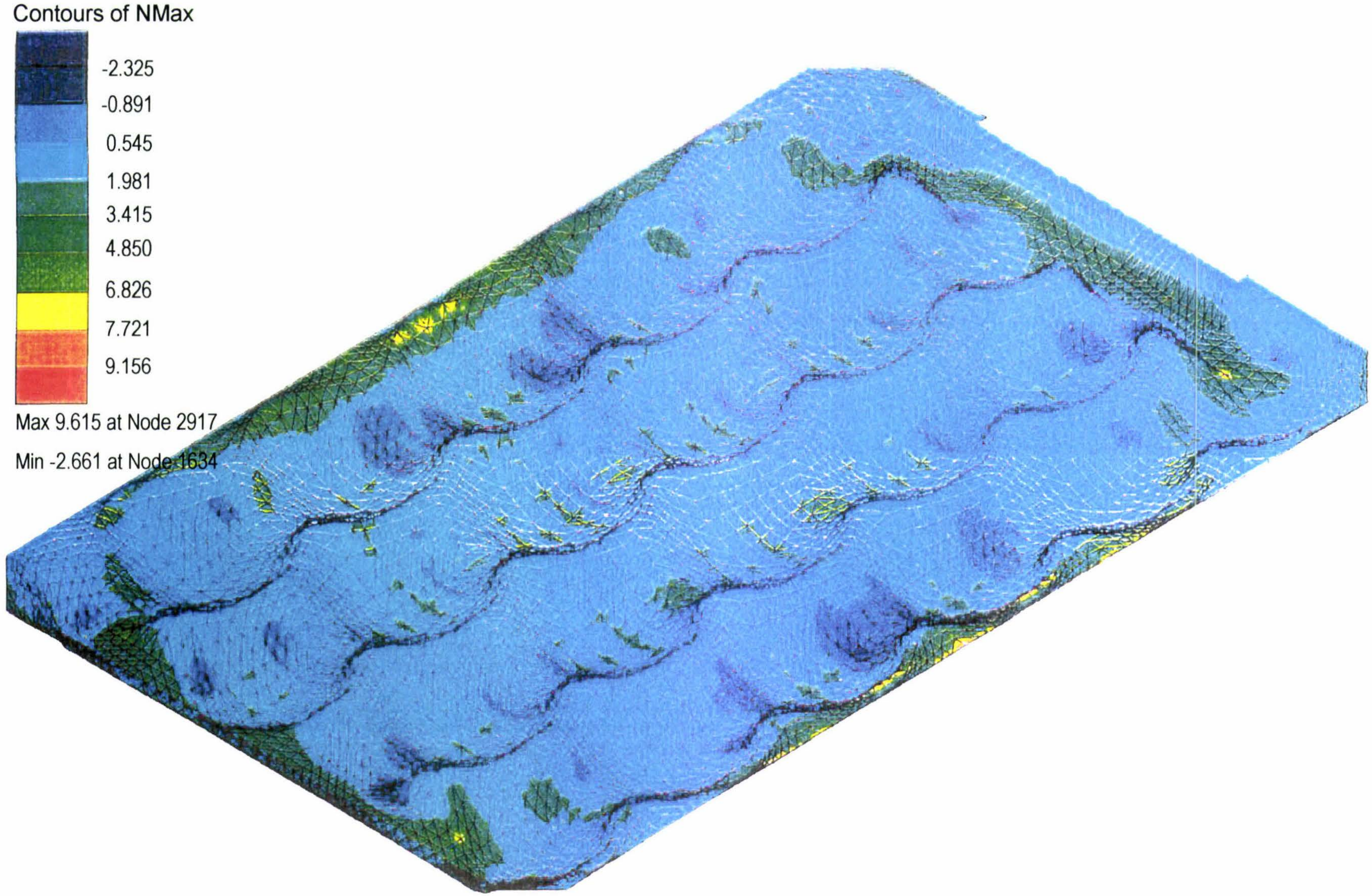


Figure 6.10 Contours of Maximum Principal Stresses in the Tray Model – 8%MC and Support Case B.

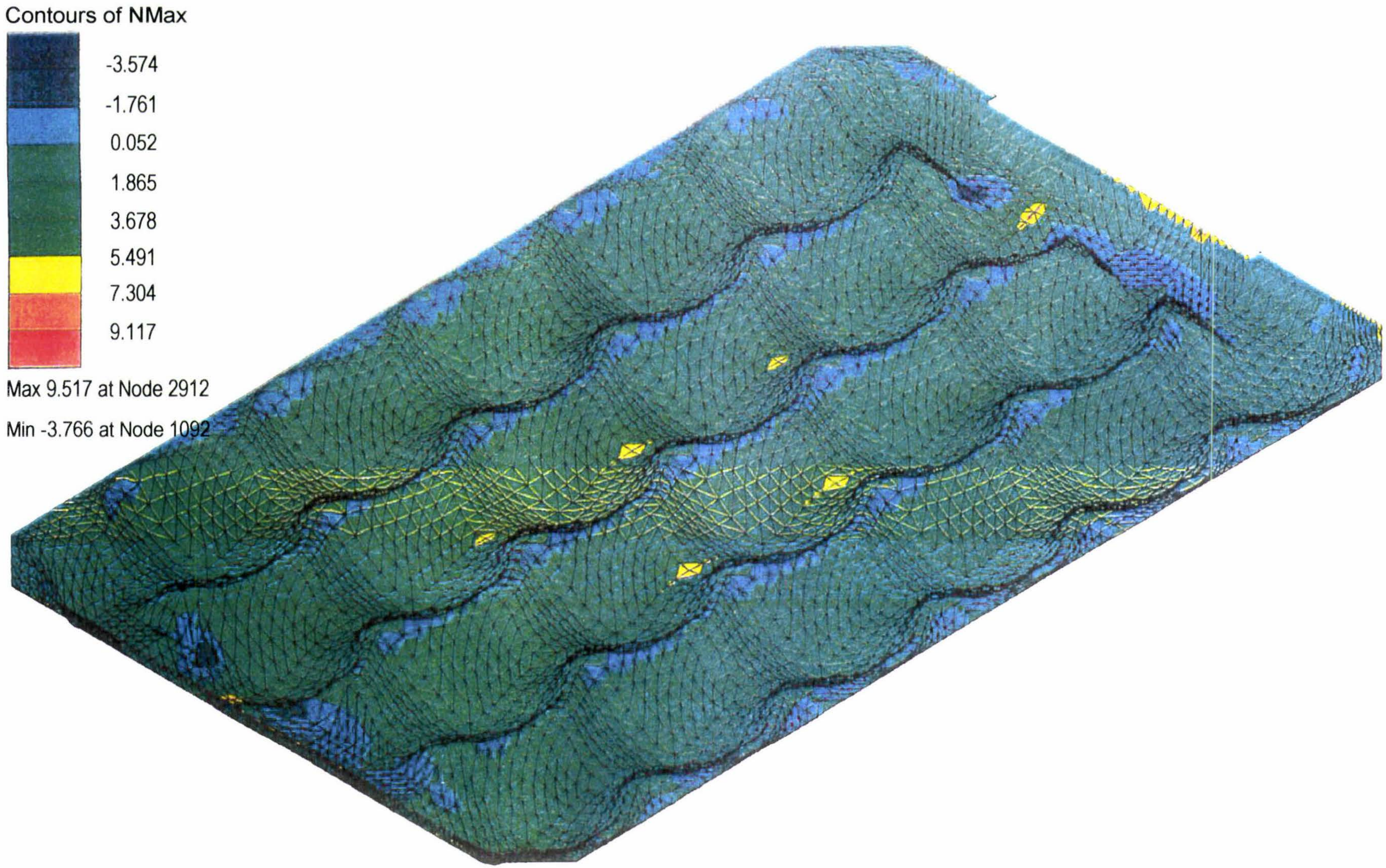


Figure 6.11 Contours of Maximum Principal Stress in the Tray Model – 20%MC and Support Case A.

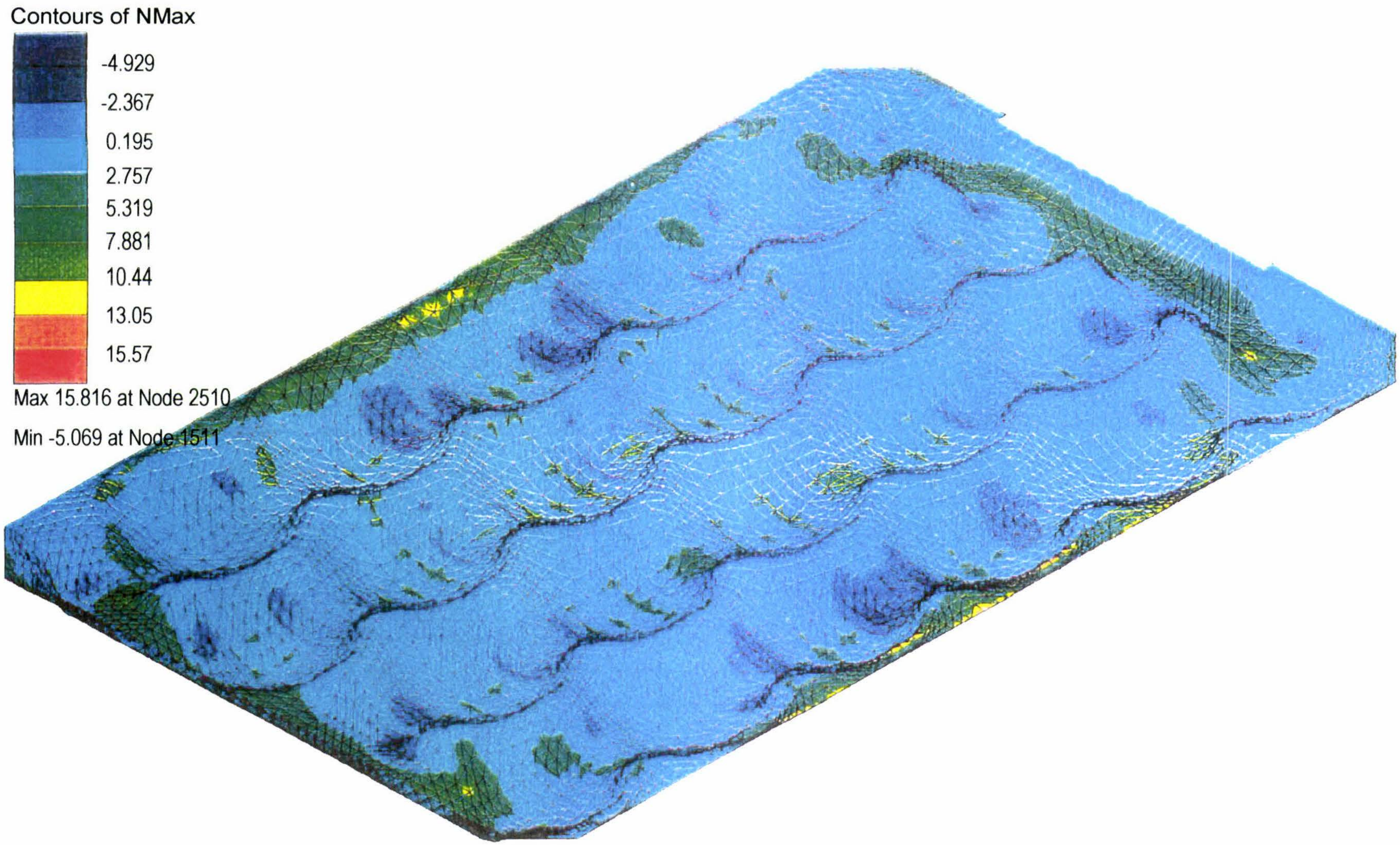


Figure 6.12 Contours of Maximum Principal Stresses in the Tray Model – 20%MC and Support Case B.

6.3 The Full Shell Models – The Tray with Apples

With the results from the tray models, combined with the information gathered from the 3D model, it was realized that the most important function the apples performed in a tray handling model was not the precise application of load but rather the support of the tray, thereby preventing deflection. This lead to the formation of the full shell models that incorporates the apples within the trays. This model used two dimensional shell elements in an attempt to reduce the model size.

A few assumptions were made with the model:

- The model was created from two-dimensional elements, which meant the third dimension has to be entered as a function. This was a suitable approach for the tray as it exhibits a uniform thickness throughout.

- The apples were modelled as thin skin spherical solids; the Young's Modulus of the material was increased to ensure that the apple skins were stiff enough to hold their shape. This was a valid approach as, in the handling situation, only the trays stress behaviour is of interest and the apples transmitting load through their shape.

- The load was applied as a point load in the centre of each cup as this was a simpler method then assigning a gravitational load to the apples. Assigning this type of load would have been nearly impossible on the apple skin models. This should not affect the model through as the apples are not needed for their loading, only their supporting role.

All these assumptions have the net affect of creating a model that does not perfectly reflect the real life case. The affect on the results would be very small, as the changes to the model have been carefully made in areas that do not affect the results. The assumptions also have the advantage that they allow the model to be created small enough to be successfully processed.

6.3.1 The Results

Figures 6.13 and 6.14 show two views of the deformed mesh generated by the LUSAS analysis. Several points can be made from these diagrams. Firstly, it can be seen that the analysis was successful. The tray has deformed in such a way as anticipated and the apples themselves have connected without any interpenetration. There are some aspects of the diagrams that are not clear however. It is not known why the deformation is so great, nor why some of the apples have actually swelled in size. Despite careful checking of the model, no answer could be found to these problems.

Figure 6.15 shows the contours of the vertical displacements. Comparing these results for those obtained for the tray model (Support Case B) there are some surprising results. Despite the fact that the trays themselves are exactly the same and the only difference is the apples attached to the tray model. The results of maximum displacements obtained from the full shell model (191.95 mm) are greater then the tray model (126.2mm); which was expected to be less. The full shell model contours show the maximum displacement occurring at the end of the tray, where as in the previous models it was indicated that the maximum displacements would occur in the middle of the tray.

Figure 6.16 and 6.17 show the maximum and minimum principal stresses. Both these contour results clearly show peak stress regions where the apples would contact each other, thereby indicating that the slidelines placed in these areas have worked successfully and the apples are supporting the load. However, the reason for the magnitude of stresses is not clear. The maximum principal stresses ranging from $2012 N/mm^2$ in tension to $400 N/mm^2$ in compression. Double-checking of all the input criteria for the model revealed that they were all correct and had been entered with the appropriate units. The only explanation for the variance is that the slidelines and/or the joint elements that were introduced to the model with the apples have affected the model to produce such excessive results. The stress results do not correlate with the displacement data for the model. The difference between the two models indicates an error in the analysis or in the model definition.

A tray packed with complete apples and the incorporation of the slideline function has been successfully analysed. Further work on this model can concentrate on the fine-tuning of the slidelines now that their basic operation is understood and more realistic results generated.

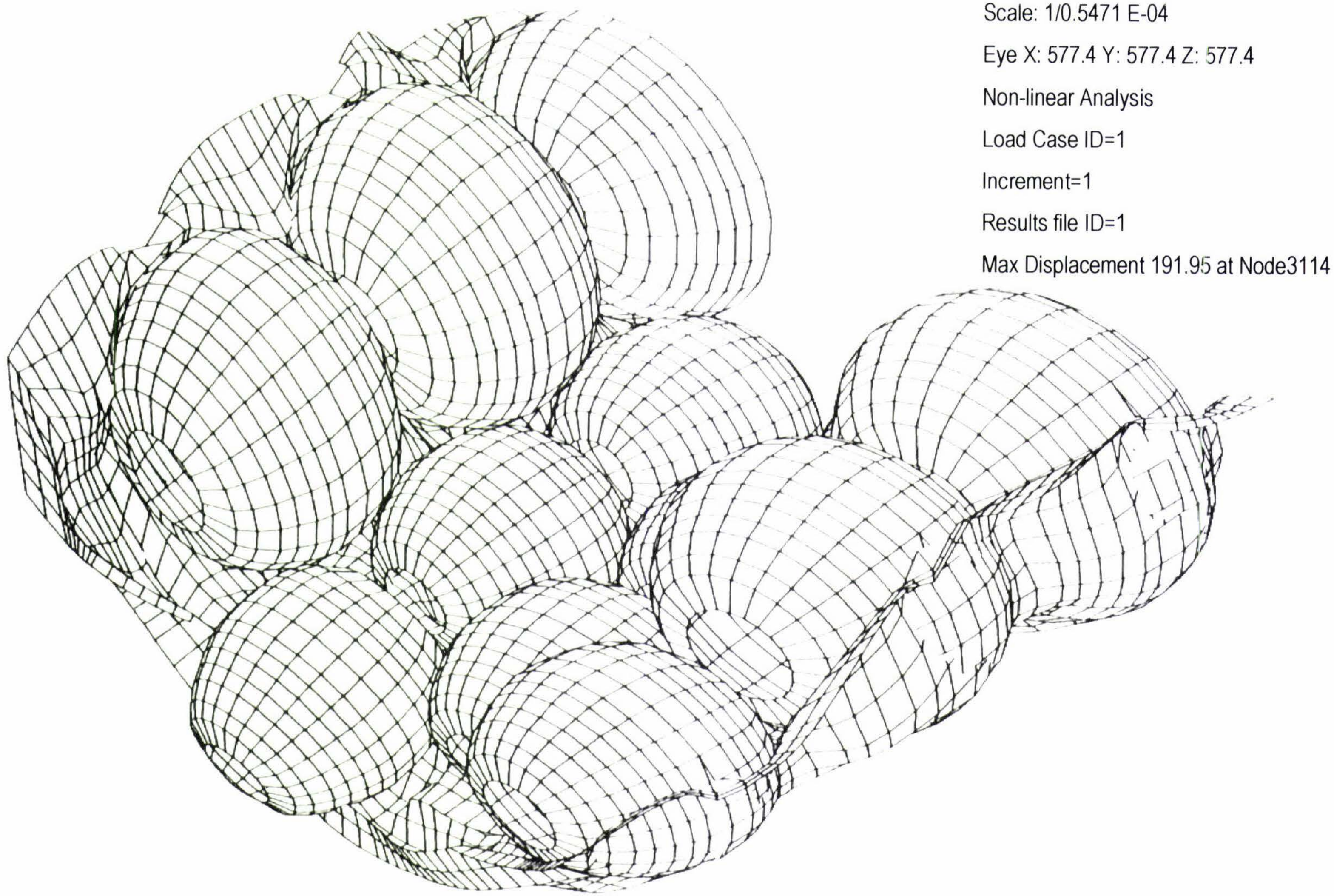


Figure 6.13 Deformed Mesh of Full Shell Model of the Tray with Apples – Isometric View.

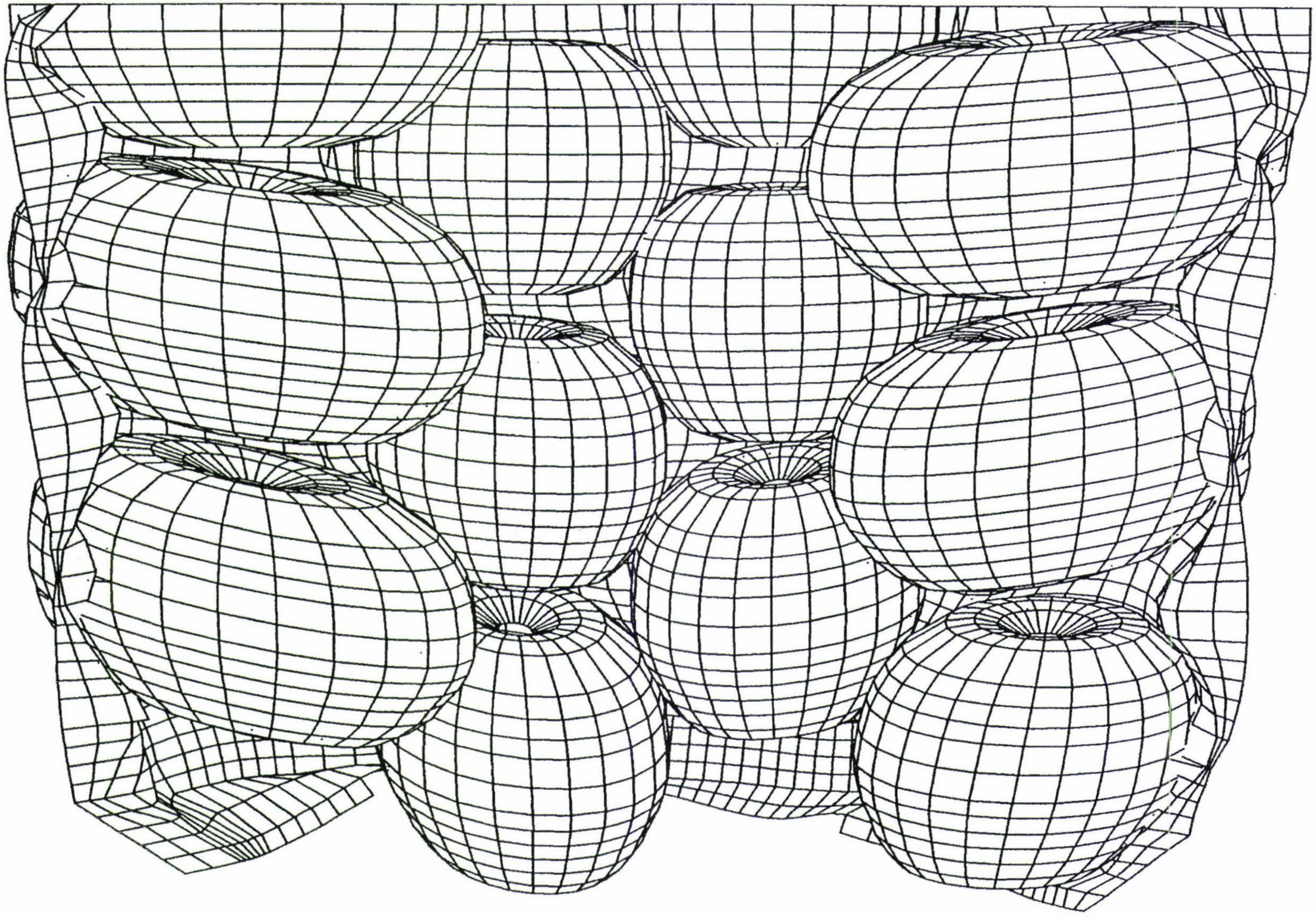


Figure 6.14 Deformed Mesh of Full Shell Model of the Tray with Apples – Plan View.

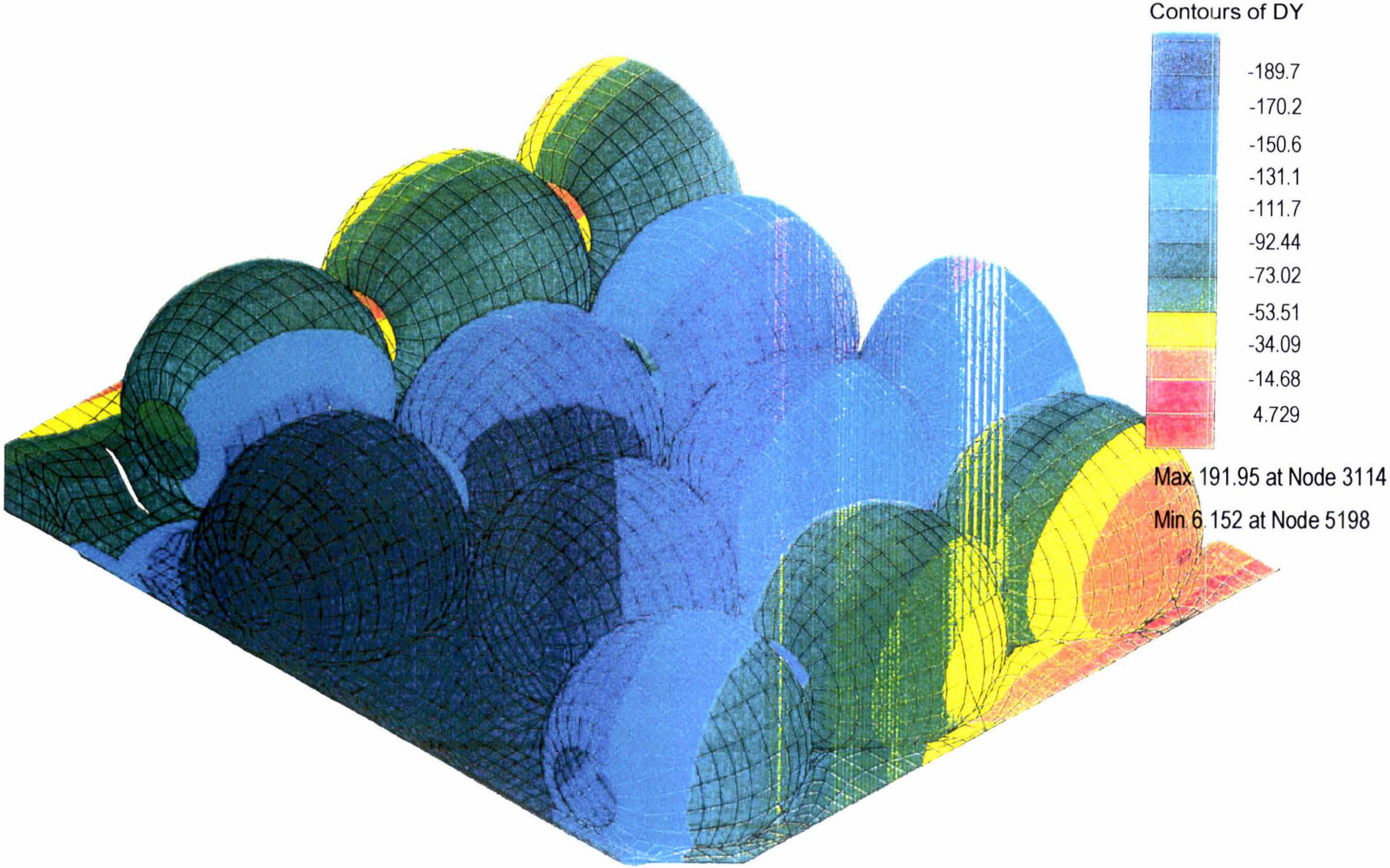


Figure 6.15 Vertical Displacements of Full Shell Tray Model with Apples – Isometric View.

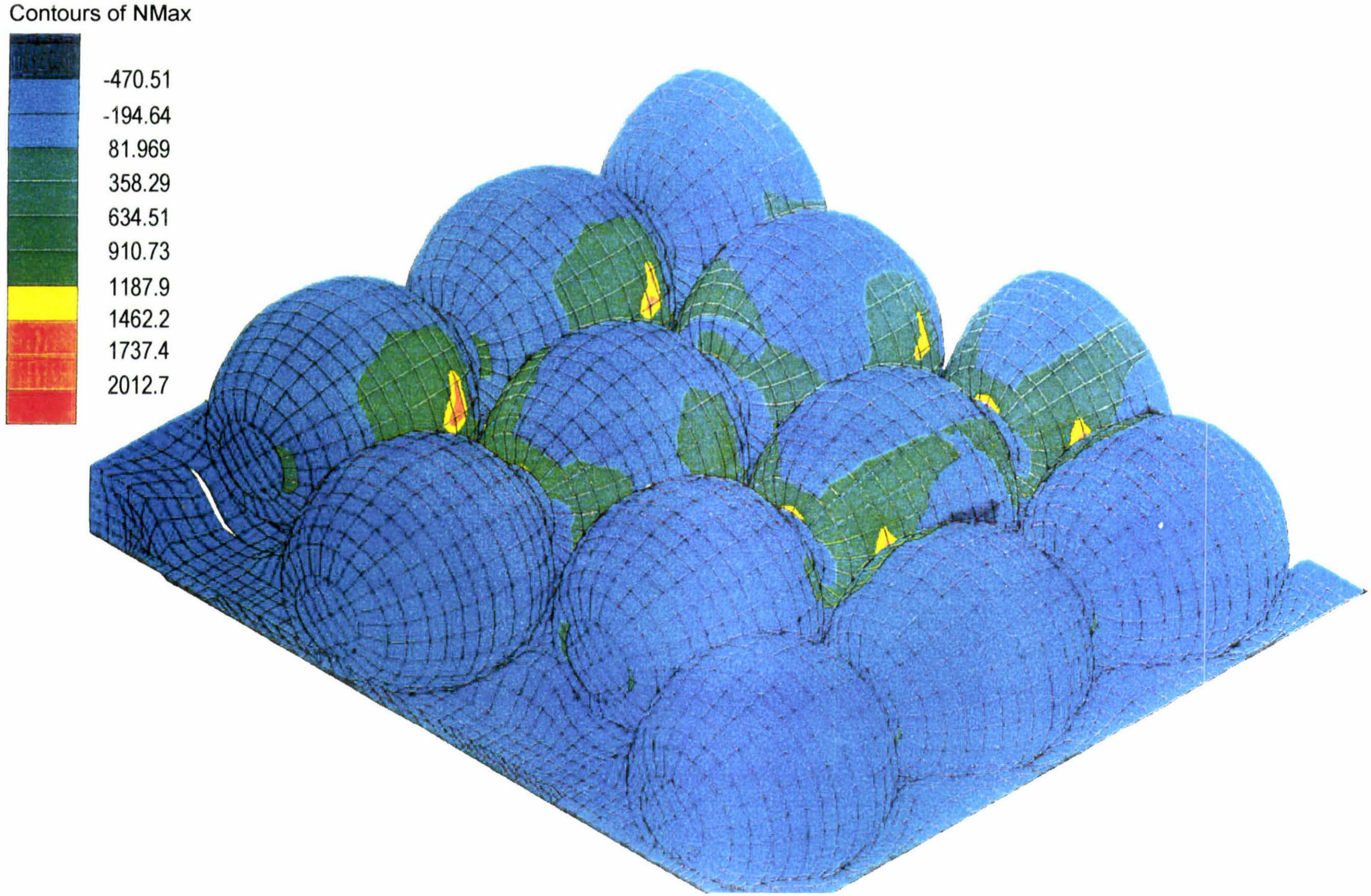


Figure 6.16 Maximum Principal Stresses Contours of Full Shell Tray Model with Apples – Isometric View.

Figure 6.17 Minimum Principal Stresses Contours of Full Shell Tray Model with Apples – Isometric View.

CONCLUSIONS

The first objective of the research was to find out the material properties of the Friday trays, which are made out of paper pulp. At the initial stages, work was mainly focused on measuring the relationship between stress and strain at different moisture content as the Friday trays are used at different environmental conditions. To develop a finite element model it was necessary to have the material properties such as Young's Modulus, Poisson's ratio and density of the material. In later research, it was of interest to find out other relationships such as resistance versus moisture content and creep tests. In addition, concern arose in selecting dimensions of the test sample. Test samples of different dimensions and shapes provided by the previous researchers were tested to establish the best dimensions, all the samples broke near to the grippers, however further tests were conducted to obtain the best sample shape and dimensions. In addition, the relationship between the moisture content and the electrical resistance are inconclusive, as it was not reliable to measure the moisture levels of the paper pulp material above its fibre moisture saturation point.

It was a difficult task to find the relation between stress and strain exactly at 20, 40, 60, 80 and 100% moisture contents, as the %MC mainly depends on surrounding temperature and humidity. Therefore it was found that small variations occurred in values of stress and strain. It was a difficult task to measure the extension in the jaws, and the force acting mainly near the jaws that gives the higher strain values, i.e. the measured extension is the combination of the extension of the jaws and the original extension of the sample. Realising that the total strain is the union of creep strain and elastic strain, creep tests were conducted to obtain the accurate values of strain.

It appears that the samples in the natural day condition were more brittle and tended to snap rather than stretch extensively before failure. Moisture in the material increases the ability to extend, but at the expense of decreased strength (UTS). But with the increased moisture content, i.e. greater then 40%, the ability of the material to extend started to decrease, accompanied by a further decrease in strength. Apparently this is a change in mechanism of failure when moisture is high. Is this a breakdown between fibres which would be non-recoverable? Samples were brought up to 60, 80 and 100% MC and dried at room temperature and RH to 20% MC, and then tested. It was observed that samples broke at lower stress levels when compared with actual 20% MC samples. Thus, samples that have been dried after being subject to high moisture (above 40%) do not recover their ability to extend or their strength. From the microscopic structures, observations made that the expansion of the matrix is not affected but the paper pulp fibres are affected by the immersion of water. The fibres are enlarged with increased moisture content and this acts as a mechanical plasticiser thereby causing a loss in strength. The fibres are an oval shape when there is no moisture content in the material so that the surface area of bonding between neighbouring fibres is more. At the increased moisture content the fibres become circular, in this situation, the surface area of the bonding between the fibres is decreased causing a loss in strength. The moisture in the fibres also causes a decrease in elongation. Hence, it can be assumed that high moisture contents cause a permanent collapse in fibre bonding.

Creep tests were also performed to find out time dependent strain, but tests above 12%MC were no possible because of lack of temperature and humidity controlled rooms. However, once the minimum creep rate (T_r) is established the rupture life (*mcr*) will be estimated by the equation $\log T_r + m\log(mcr) = c$, as the constants m and c are established by running only a few complete creep rupture tests.

The second objective of the research was to create the finite element models of the Friday trays. From these models more complex models could be generated and analysed for any modifications. To simplify the model and due to symmetry half of the tray with apples was generated and the remaining half was replaced with suitable boundary conditions. However, stress and strain distribution was unknown across the tray and no boundary conditions were known for the individual cups, as the cup of the tray was the repetition of the model. Therefore, in the end a whole tray had to be analysed, as the boundary conditions for a whole tray only were known.

The size of the models is one of the biggest problems encountered in the research. The solution process takes enormous time to solve the problem, and if any problem occurs the processor terminates the solution processes, the problem is then fixed and has to start from the beginning. Therefore, only after careful study of the FEA system were the models able to be fine-tuned. The 3D models proved too large to analyse. The incorporation of slidelines and non-linear controls in 2D models provided an important insight into the interaction between the apples and tray. This information could then lead to the development of a larger three-dimensional model of a full apple carton. The shell models also used slidelines and non-linear controls. However, the results obtained are not realistic, but the models show the slidelines are working perfectly to define the interaction in between apples and the apples and tray.

The original tray models that were created, at two different handling situations and at two different material properties, has provided very good numerical results. From these results the following observations about the handling of the tray can be made.

One of the most important observations in the tray during handling was that the apples themselves form a structural support to protect the tray from bending. As the tray deformation increases, the apples move closer to each other and gradually come into contact and start to support each other, without this support the trays would have failed at low stress levels. This feature proved extremely difficult to incorporate into a model. The existing tray models did allow some conclusions to be established. The stress and deformation results for the tray shell models clearly highlighted the optimum handling method at two different moisture contents. At 8% moisture conditions, the shell models displayed considerably less displacements and lower stress values when supported at the ends compared with supports at the sides. When supported at the ends, the displacements were centralised on the tray so any apple would move towards the centre of the tray, in this situation the apples are very stable in the tray. At the 20% moisture content situation, the models displayed more displacements and more stress in both lifting situations. However, at the 20% moisture content condition, the material shows higher strain values when compared with 8% moisture content, and the structural support of the apples to the tray protected the tray from damage.

From the thin shell models, it could be concluded that the geometry of the tray is the major concern to prevent bending during handling and not the material properties of the tray. An increase in the weight of the tray might be ineffectual; there will be a significant change in bending resistance by changing the geometry of the tray. The most effective modification from this point of view is to increase the depth of the cup thus increases the relative height of the ridges in the tray, which accordingly increases the second moment area.

The creation of FEA models of a tray was successful; the handling function of the Friday tray was able to be successfully analysed using a non-liner analysis. Further work should now look at the models of full cartons; this would allow a comparison of the performance of the trays at different stacking stages while in the box. In this situation, the slidelines should be used not only in between the tray and apples but also between the neighbouring apples. Further work is recommended. This should concentrate on the non-linear analysis of a 3D model and the dynamic analysis a full carton loaded with apples when the carton is dropped during handling.

RECOMMENDATIONS & FUTURE WORK

The research should be continued in two areas, to find out a full set of mechanical properties of the paper pulp material and the creation of FEA models.

Measuring the mechanical properties in both longitudinal and vertical directions at variable environments gives information for design improvements, which could prevent the excess use of material and energy. To do the further experiments a controlled environmental chamber is needed and an apparatus that measures the deformation of the sample in both transverse and longitudinal directions. Then it is possible to measure the effect of moisture content on direction, initial elastic moduli, Poisson's ratio, initial shear modulus, and the non-linear shapes of longitudinal direction and transverse direction uniaxial stress-strain curves. The data then will be used to define a Finite Element Analysis model to perform a non-liner material analysis.

Any research that is done on this area will require large memory of the package. When the 3D model was analysed error messages show that the package needs more memory then at the present. To attempt a complete analysis of a fully loaded carton with apples will be an exciting project. This will have to be modelled as a material non-linear analysis with the extensive use of slidelines between neighbouring apples and the tray.

When the complete carton is fully modelled and working correctly, the next stage is a dynamic analysis looking at when a carton is dropped during handling. It was well known that tray tearing and apple bruising are a result of dynamic load being placed on the carton, as opposed to a static compressive force such as when the apples are stacked. This would then allow the researcher to accurately compare the behaviour of several different types of trays under realistic simulations.

At this stage only the existing trays have been investigated. If the accurate models of the trays are working accurately, the problem areas can be easily identified. By eliminating these problems attempts could be made to change the tray design, which is one of the objectives. Finite element models would then be produced of the new designs so that testing could proceed without the expense of having to manufacture a prototype.

Though these models may be time consuming and expensive initially, once the models are created it is an easy matter to modify the model for any further designs. Compared with the cost of thousands of physical drop tests which use new fruit each time and take months to perform, as well as having to be re-performed for each new packaging modification or fruit variety, the initial cost of developing a finite element model would not appear so high.

REFERENCES

Aitken, B. J. and Crosby, A.C., 1982, "*Export Apple Packaging Trail 1982*", Report to New Zealand Apple and Pears Marketing Board.

Anderson, B., 1983, "*Carton Drop Trail*", New Zealand Apple and Pears Marketing Board, Hastings.

Ashby, M. F., and Jones, D.R.H., 1980, "*Engineering Materials: An Introduction to their Properties and Applications*", Pergamon Press, Oxford.

Ashdown, K. G., 1995, "*Finite Element Analysis of Apple Packaging*", A Thesis Presented for Master of Technology, Massey University, Palmerston North, New Zealand.

Australian Standard, "*Tensile Strength of Paper and Paperboard*", AS 1301.448s-91.

Australian Standard, "*Conditioning of Paper for testing*", Appita P414-86.

Barr, R. J. and Cardwell, R. D., 1983, "*Export Apple Packaging Trail 1983*", Report to New Zealand Apple and Pears Marketing Board.

Bastin, G. T., 1991, "*Laboratory Trailing of Horticultural Packaging*", DSIR, New Zealand.

Blahovec, J., Patocka, K., and Bares, J., 1997, "*Low-Level Bruising of Stored Apples Due to Quasi-Static Loading up to Contact Compression Strain*", Journal of Texture Studies, Vol.28, Pg. 87-99.

Byrom, G., 1989, "*Summary Report Weight Trails Count 80 Friday Trays*", Fibre Products Limited, Auckland, New Zealand.

Chandrupatla, T. R. and Belegundu, A. D., 1991, "*An Introduction to Finite Elements in Engineering*", Prentice Hall of India (PVT) Limited, New Delhi.

Chen, H., & De Baerdemaeker, J., 1993, "*Finite Element Based Modal Analysis of Fruit Firmness*", American Society of Agricultural Engineers, Vol.36, Pg. 1827-1833.

Chen, H., Duprat, F., Grotte, M., Loonis, D. and Pietri., E., 1996, "*Relationship of Impact Transmission Wave to Apple Texture During Ripening*", Journal of Texture Studies, Vol.27, Pg. 123-141.

Crosby, A., 1984, "*Packaging Vs Apple Bruising Trail-1984*", New Zealand Apple and Pears Marketing Board, Hastings.

Crosby, A., Barr, R.J. and Cardwell, R.D., 1983, "*Export Apple Packaging Trail*", New Zealand Apple and Pears Marketing Board, Hastings.

Dyskin, A. V. and Freij-Ayoub, R., 1993, "*Computer Experiment on Defect Accumulation for a Linear Arrangement of 2-D Defects*", Computational Mechanics, Valliappan, Pulmano & Tin-Loi (eds) ISBN9054103337, pg.663-668

Finney, E. E., Jr, 1971, "*Dynamic Elastic Properties and Sensory Quality of Apple Fruit*", Journal of Texturel Studies, 2: pg. 62-74.

Fountain, J. B., 1962, "*Evaluation of Shipping Trays and Pads for Pears and Apples*", United States Department of Agricultural Marketing Research, Report no.530.

Gan, L., Ly, N. G. and Steven, G. P., 1993, "*A Finite Element Algorithm for Finite Deformation Contact Problems*", Computational Mechanics, Valliappan, Pulmano & Tin-Loi(eds) ISBN9054103337, pg.77-82.

Garofalo, F., 1965, " *Fundamentals of Creep and Creep-Rupture in Metals*", The MacMillan Company, New York.

Gibson, J. L. and Ashby, M. F., 1988, "*Cellular Solids – Structure & Properties*", Pergamon Press Australia Pty Ltd., Australia.

Heap, R. A., 1994, "*Performance of Recycled Paper Pulp Trays in Relation to Impact Damage in Apple Cartons*", A Thesis Presented for Master of Horticultural Science, Massey University, Palmerston North, New Zealand.

Holt, J. E., and Schoorl, D., 1983, "*Mechanical Damage in Agricultural Products*", A Basis for Management of Agricultural systems, 11, pg. 143-157.

Holt, J. E., and Schoorl, D., 1984, "*Package Protection and Energy Dissipation in Apple Packs*", Scientia Hortic, 24: 165-176.

Jacobs, J. A. and Kilduff, T. F., 1985, "*Engineering Materials Technology* ", Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Kodandapani, C., 2000, Personal Communication, Department of Agricultural Engineering, Coyambatoor Institute of Technology, India.

Kreyszig, K., 1988, *Advanced Engineering Mathematics*, McGraw Hill, New York.

Lenting, G., 1989a, "*Trail Report Coolstorage Trail of Printpac UEB Moulded Pulp Apple Trays*", Printpac UEB Ltd., Auckland.

Lenting, G., 1989b, "*Trail Report Coolstorage Trail of Printpac UEB Moulded Pulp Apple Trays with Granny Smith Apples*", Printpac UEB Ltd., Auckland.

Lenting, G., 1989c, "*Trail Report Coolstorage Trail of Printpac UEB Moulded Pulp Apple Trays with Sturmer Apples*", Printpac UEB Ltd., Auckland.

Lenting, G. and McLeod, S. P. 1988(a), "*Investigation of Apple Packs and Palletising Systems*", Pallet Pack Trail 1988, Report to NZAPMB.

"*Lusas Modeller User Manual*", 1999, Version 13, FEA Ltd., Surrey, United Kingdom.

Lu, R., and Abbott, J. A., 1996, "*Finite Element Analysis of Modes of Vibration in Apples*", Journal of Texture Studies, Vol.27, Pg. 265-286.

McLeod, S., 1993, "*Lab Report*", Packing Division, New Zealand Apple and Pears Marketing Board, Hastings.

McLeod, S. P., 1997, "*Palletisation of New Zealand Pipfruit*", Thesis of Post-Graduate Diploma in Agricultural Engineering, Massey University, New Zealand.

Mohsenin, N. N., 1970, "*Physical Properties of Plant and Animal Materials*", Vol.1, Gordon and Breach Publications, New York.

Monkman, F. C. and Grant, N. J., 1956, "*An Empirical Relationship Between Rupture Life and Minimum Creep Rate in Creep-Rupture Tests*", American Socity for testing Materials, Proceedings, Vol: 56.

NZFP, 1984, "*A Summary of the Important Aspects of an Investigation into the Reduction of Apple Bruising*", New Zealand Forest Products.

Pande. A, 1975, Vol.1, Vol.2, Vol.3, " *Handbook of Moisture determination and Control*", Marcel Dekker Inc, New York.

Peleg, K., 1985, "*Produce Handling, Packaging and Distribution*", The AVI Publishing Co Inc, Westport, Connecticut, USA.

Pulp and Paper in Australia, 1998, "*Pulp Properties*", http://www.online.anu.edu.au/Forestry/wood/paper/rawmat.htm.

Reddy, J. N., 1993, "*An Introduction to Finite Element Method*", 2nd Edition, McGraw-Hill International Edition.

Sacharow, S., and Griffin, R. C. Jr., 1980, "*Principles of Food Packaging*", The AVI Publishing Company Inc, Westport, Connecticut, USA.

Schoorl, D. and Williams, 1972, "*Prediction of Drop Testing Performance of Apple Packs*", Queensland Journal of. Agriculture and Animal Science, Vol.29: 187-197.

Sloan, S. W. and Aboo, A. J., 1993, *Automatic Load Path Control in Non-linear Finite Element Analysis*, Computational Mechanics, Valliappan, Pulmano & Tin-Loi (eds) ISBN9054103337, pg.1295-1300

"TA.XT$_2$ Operating Manual", (Version 5-16, 31 Oct. 1995), ISS2

Wollin, A. S. and Ledger, S. N., 1985, "*Computer Optimised Stonefruit Tray Pack*", Appita Vol.38, No.1, pp. 44-48.

www.mih.unibas.ch/booklet/booklet96/chapter1/chapter1.html

Yeo, M. F., Mumford, B. and Zwar, M., 1993, "*A Simple Interactive or Automatic Mesh Generation Scheme"*, Computational Mechanics, Valliappan, Pulmano & Tin-Loi(eds) ISBN9054103337, pg.1345-1350

Yeh, K. C., Considine, J. M. and Suhling, J. C., 1991, "*The Influence of Moisture Content on the Non-Linear Constructive Behavior of Cellulosic Materials*", International Paper Physics Conference, pg. 695-711.

Yongping, H. and Zohongkai, E., 1993, "*Elastic Contact Finite Element Analysis of Spiral Bevel Gear Meshing"*, Computational Mechanics, Valliappan, Pulmano & Tin-Loi(eds) ISBN9054103337, pg.107-111.

Appendix 1

Design Specifications for the Friday Tray

SPECIFICATION - FIBRE TRAYS

1.0 PURPOSE

The purpose of this procedure is to define the way Fibre Trays made for NZAPMB shall be produced.

2.0 POLICY

It shall be the policy of NZAPMB that all Fibre Trays produced for them shall meet this specification.

3.0 RESPONSIBILITY

It shall be the responsibility of the Fibre Tray manufacturers to ensure that trays produced for NZAPMB meet this specification.

4.0 SPECIFICATION

4.1 Weight:
80 ± 5g oven dry (Averaged over four trays). Test method based on AS1301.401s-78.

4.2 Dimensions:

Fibre Products	500 x 300mm
PRINTPAC-UEB	500 x 304mm

4.3 Moisture Content:
Aim 10%, Max 13% when packed (Averaged over four trays).
Test Method based on AS1301.401s-78.

4.4 Ventilation Spaces/Hand Holds:
Hand holds shall be provided at the ends of each tray.

4.5 Colour:
To be confirmed.

4.6 Tray Finish:
Top Side - Area in contact with the fruit shall be smooth and free from all lumps and foreign matter which will damage the fruit.

SPECIFICATION - FIBRE TRAYS

Underside - To be confirmed.

4.7 Foreign Matter:
Foreign matter shall not be permitted in areas which will cause damage to the fruit. No more than 20 flecks/tray shall be permited. These must be clearly discernableon the upper surface of the tray, held at arms length. The flecks must be at least 2mm long.

4.8 Edges:
Excessive flash which prevents the tray fitting into the case neatly shall not be permitted. Trays with folded or rolled edges must not be in bundles.

4.9 Identification:
Each tray shall be clearly identified with the count number.

4.10 Tears:
No tears or holes off machine shall be permitted.

4.11 Packaging:
Each bundle shall be strapped and contain 125 trays. Each bundle shall have its own count label and a manufacturing date. All palletised trays shall be shrowded.

4.12 Palletising:
Each pallet shall contain 63 bundles, 9 bundles per layer, 7 bundles high. The pallet shall be covered using a protective shroud to stabilise the pallet load and to give protection for 1 years outside storage. The pallet is to be sufficiently stabilised to allow movement of the unwrapped pallet. The count size label with manufacturing date is to be weather proof and clearly visible from the outside of the pallet shroud. Pallet size is 1500 x 1080mm.

4.13 Hygiene:
To be confirmed.

4.14 Chemical Additives:
All chemical additives used in the manufacture of moulded pulp trays must comply with the following or their equivalent:

FDA Regulation 176:170 - Components of paper and paperboard in contact with aqueous and fatty foods.

SPECIFICATION - FIBRE TRAYS

FDA Regulation 176:180 - Components of paper and paperboard in contact with dry food.

The USFDA has not granted specific approval for any dyestuff used in paper colouration. The usage of the dyestuff used at present is based on a history of safe use which is recognised by the FDA and demonstrable non-migration as determined by appropriate testing.

Appendix 2
MANUFACTURE OF PULP TRAYS

The NZAPMB draws trays from three plants in New Zealand, the majority of the trays being produced by Printpac UEB Moulded Fibre in their Auckland and Nelson plants. There is some variation in the design of the dies used at each plant, but they all adhere to the same manufacturing specifications provided by the board regarding weight, dimensions and other factors. It can be noticed that within these specifications, there are no criteria pertaining to the strength of the tray.

Raw Materials: The Friday trays are being made wholly from recycled paper. Printpac UEB have a contract with a waste paper collection company (Paper Chase) and take all the paper from road side recycling programmes in Auckland and Christchurch. The bulk of their supply is newspaper. Chequer Moulded Pulp have a contract with Telecom and use recycled telephone books in combination with Kraft paper. The type of paper used ultimately affects the final product strength and characteristics. Glossy paper, carton manufacturer waste, and paper with a high wet strength if used in large quantities will lead to an inferior product. Kraft paper has relatively long fibers, which is believed to increase the cushioning properties of the trays.

Manufacturing Process: The recycled paper is then processed in batches of about twenty kilograms and is broken down into fibre. The fibre is then transferred to a shredding process or through a rotating drum operating in similar manner to a concrete mixer, rotating approximately 15 rpm and mixing the paper with hot water as it is pulped. The paper, once reduced to 4% pulp, is fed through a magnetic cleaning system that removes any metallic objects such as staples, and passed into a centrifuge to remove any other solid matter such as sand and stones. A vibration screen completes the cleaning process by removing larger pieces of pulp, which are then recycled through a mincer to improve their consistency. Various chemicals are added depending on the nature of the pulp mix and may include kymenes and rosins to give wet strength to the pulp during manufacturing, dyes and dye fixatives, defoamers, acid to raise the pH, alum to bond the chemicals, and the wax for water repulsion in the final product.

Dies to make the trays rotate through a vat of pulp. The dies consist of a brass former covered in one or two layers of fine mesh. The brass former has holes in it through which a suction of 0.8 bar pressure is used to stick pulp onto the die. Placement of these holes dictates the thickness of the pulp in specific regions of the tray. As the loaded die moves out of the vat, warm water is sprayed onto the back of it to force fine particles into the tray, to remove any feathering round the edges and also to give a smoother surface finish. By reversing the suction, the tray is blown off the die onto another rotating roller which drops it onto a conveyor and into the drying oven. The ovens are gas fired and run at 200°C taking approximately four minutes for the tray to dry.

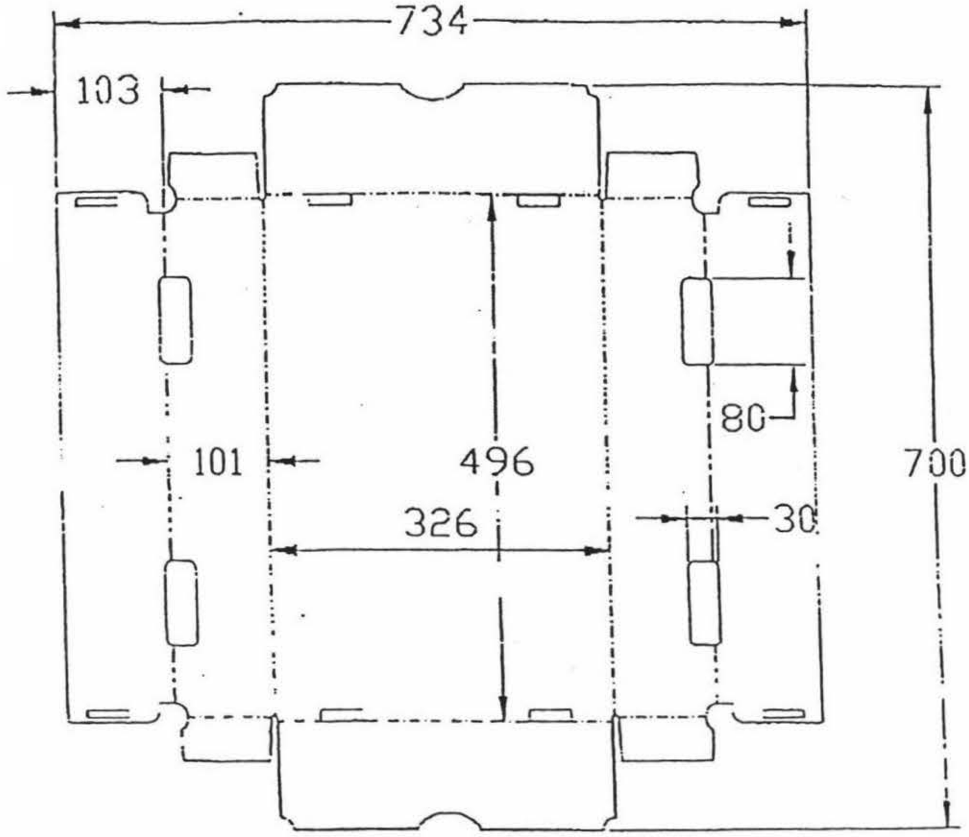
Quality control procedures operate to ensure that the trays are produced to the correct weight. Because of the drying time, it takes approximately five minutes of a production run to check any changes made. Necessary changes are generally made on a trail and error basis. If the trays are too heavy, either the speed of the rotating dies is increased or water added to the pulp mix. Conversely, if the trays are too light the speed is adjusted so that the dies spent longer in the pulp vat. Tests are also conducted on water resistance and colour to ensure that specifications are met.

Appendix 3

SLZ Pack Design and Z tray Specifications

SLZ PACK DESIGN

Title PLB Single Layer Z Tray (SL-Z) - 100mm



All dimensions are in mm. Case viewed from the inside.

Title PLB Single Layer Z Tray (SL-Z) - 100mm

Stock Item Code:	072 Enza PLB Single Layer Z Tray - 100mm 151 Select PLB Single Layer Z Tray - 100mm
Pack Style:	PLB machine erected tray
Grade And Flute:	3113C Body, 3113C End Pieces.
Print Colours:	Refer to the individual SIC specifications for colours and print layout.
Board Treatment:	Water Resistant Starch
Manufacturer Joint:	N/A
Internal Dimensions:	476 x 322 x 100mm (nominal)
Tare Weight:	

Appendix 4

RELATION BETWEEN RESISTANCE, TIME AND MOISTURE CONTENT
RELATION BETWEEN STRESS AND STRAIN AT DIFFERENT %MC
CREEP TESTS ON PAPER PULP MATERIAL
APPLE DENSITY MEASUREMENTS
PULP TRAY POISSON'S RATIO CALCULATIONS
PAPER PULP MATERIAL DENSITY MEASUREMENTS

Relation between Resistance, Time and Moisture Content

Sample1:
Room Temperature and Humidity : 23.8/42.1
Sample weight before: 1.5992grms

Time after in Min	Weight in Grams	Moisture contant in the sample	Resistance in MOhms
0	1.9975	24.91	2.672
1	1.9894	24.40	4.540
2	1.9807	23.86	6.721
3	1.9706	23.22	8.223
4	1.9587	22.48	10.121
5	1.9495	21.90	12.050
6	1.9395	21.28	14.650
7	1.9247	20.35	18.920
8	1.9140	19.68	22.340
9	1.9057	19.17	28.870
10	1.8854	17.90	32.430

Sample 2:
Room Temperature and Humidity : 22.9/41.7
Sample weight before: 1.6774grms

Time after in Min	Weight in Grams	Moisture content in the sample	Resistance in MOhms
0	2.3693	41.25	0.226
2	2.3505	40.13	0.253
4	2.3296	38.88	0.276
6	2.3070	37.53	0.298
8	2.2814	36.01	0.313
10	2.2675	35.18	0.447
12	2.2389	33.47	0.676
14	2.2141	32.00	0.804
16	2.1954	30.88	0.947
18	2.1727	29.53	1.167
20	2.1495	28.14	1.372
22	2.1286	26.90	3.560
24	2.0982	25.09	4.100
26	2.0742	23.66	6.170
28	2.0450	21.91	10.742
30	1.9892	18.59	14.983

Sample :3
Room Temperature and Humidity : 21.3/56.8
Sample weight before: 1.6286grms

Time after in Min	Weight in Grams	Moisture content in the sample	Resistance in MOhms
0	2.6351	61.80	0.103
3	2.6093	60.22	0.117
6	2.5851	58.73	0.134
9	2.5658	57.55	0.188
12	2.5440	56.21	0.231
15	2.5212	54.81	0.215
18	2.4985	53.41	0.242
21	2.4718	51.77	0.273
24	2.4490	50.37	0.262
27	2.4211	48.66	0.287
30	2.3981	47.25	0.311
33	2.3760	45.89	0.368
36	2.3542	44.55	0.433
39	2.3252	42.77	0.503
42	2.2969	41.04	0.578
45	2.2737	39.61	0.667
48	2.2481	38.04	0.708
51	2.2242	36.57	0.721
54	2.2072	35.53	0.787
57	2.1809	33.91	0.842
60	2.1540	32.26	0.898
63	2.1325	30.94	0.935
66	2.1162	29.94	0.978
69	2.0945	28.61	1.362
72	2.0683	27.00	2.672
91	1.9575	20.20	13.725
96	1.9459	19.48	28.554
99	1.8759	15.18	32.312

Sample :4
Room Temperature and Humidity : 20.9/52.3
Sample weight before: 1.6216grms

Time after in Min	Weight in Grams	Moisture content in the sample	Resistance in MOhms
0	2.9235	80.28	-1.326
5	2.8668	76.79	-1.232
10	2.8227	74.07	-1.112
15	2.7659	70.57	-0.996
20	2.7203	67.75	0.025
25	2.6446	63.09	0.119
30	2.5651	58.18	0.141
35	2.5141	54.80	0.204
40	2.4490	50.59	0.271
45	2.3774	45.98	0.395
50	2.3191	42.40	0.537
55	2.2478	38.02	0.612
60	2.2032	35.28	0.819
65	2.1521	32.14	1.063
70	2.0196	24.01	2.549
75	1.9824	21.72	6.816
80	1.9011	16.73	17.117

Sample :5
Room Temperature and Humidity : 20.9/52.3
Sample weight before: 1.6397grms

Time after in Min	Weight in Grams	Moisture content in the sample	Resistance in MOhms
0	3.3805	106.17	-1.912
5	3.3268	102.89	-1.862
10	3.2741	99.68	-1.174
15	3.2256	96.72	-1.597
20	3.1722	93.46	-1.443
25	3.1186	90.19	-1.376
30	3.0740	87.47	-1.271
35	3.0014	83.05	-1.347
40	2.9535	80.12	-1.081
45	2.8912	76.32	-0.876
50	2.8334	72.80	0.103
55	2.7645	68.60	0.119
60	2.6906	64.09	0.192
65	2.6391	60.95	0.256
70	2.5647	56.41	0.305
75	2.5012	52.54	0.387
80	2.4379	48.68	0.489
85	2.3621	44.06	0.687
90	2.3025	40.42	0.894
95	2.2329	36.18	1.074
100	2.2032	34.37	2.745
105	2.1401	30.52	4.216
110	2.0794	26.82	7.917
115	1.9895	21.33	14.665
120	1.9073	16.32	20.741

Samples of no Moisture Content - At Room Temperature and Humidity

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Count	1
Trigger Type	Auto
Trigger Force	0.10N

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 30.65 sq.mm		C/S Area = 28.16 sq.mm		C/S Area = 36.72 sq.mm		C/S Area = 24.16 sq.mm		C/S Area = 28.84 sq.mm	
Original Length = 44.15mm		Original Length = 67.36mm		Original Length = 57.9mm		Original Length = 46.27mm		Original Length = 48.47mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.02976	0.00063	0.03132	0.00015	0.08668	0.00017	0.11130	0.00028	0.03592	0.00041
0.08982	0.00109	0.03800	0.00046	0.11590	0.00052	0.15037	0.00071	0.07497	0.00080
0.09465	0.00154	0.05309	0.00076	0.14480	0.00086	0.19752	0.00115	0.10853	0.00124
0.18209	0.00197	0.06950	0.00107	0.17426	0.00121	0.24350	0.00158	0.13669	0.00165
0.22506	0.00245	0.08569	0.00138	0.20327	0.00155	0.28601	0.00201	0.16650	0.00206
0.26705	0.00290	0.10344	0.00168	0.23219	0.00190	0.32765	0.00244	0.20319	0.00248
0.30692	0.00335	0.12191	0.00199	0.26021	0.00225	0.36784	0.00287	0.23603	0.00289
0.34760	0.00381	0.13967	0.00229	0.28657	0.00259	0.40592	0.00331	0.26356	0.00330
0.38692	0.00426	0.15494	0.00260	0.31419	0.00294	0.44226	0.00374	0.28831	0.00371
0.42568	0.00471	0.17031	0.00291	0.34483	0.00328	0.47558	0.00417	0.32015	0.00413
0.46349	0.00516	0.18722	0.00321	0.37595	0.00363	0.51031	0.00460	0.35184	0.00454
0.50046	0.00562	0.20366	0.00352	0.40569	0.00397	0.54292	0.00504	0.37583	0.00495
0.53608	0.00607	0.21911	0.00382	0.43461	0.00432	0.57235	0.00547	0.39955	0.00536
0.57038	0.00652	0.23413	0.00413	0.46288	0.00466	0.60240	0.00590	0.42840	0.00578
0.60473	0.00698	0.24751	0.00444	0.49031	0.00501	0.63195	0.00633	0.45801	0.00619
0.63788	0.00743	0.26122	0.00474	0.51634	0.00535	0.66126	0.00676	0.48204	0.00660
0.67041	0.00788	0.27362	0.00505	0.54126	0.00570	0.68630	0.00720	0.50517	0.00701
0.70183	0.00834	0.28622	0.00535	0.56607	0.00604	0.71275	0.00763	0.53273	0.00743
0.73246	0.00879	0.30021	0.00566	0.58954	0.00639	0.73887	0.00806	0.56082	0.00784
0.76307	0.00924	0.31264	0.00597	0.61174	0.00674	0.76540	0.00849	0.58492	0.00825
0.79272	0.00969	0.32546	0.00627	0.63374	0.00708	0.78982	0.00893	0.60607	0.00867
0.82072	0.01015	0.33736	0.00658	0.65605	0.00743	0.81523	0.00936	0.62958	0.00908
0.84874	0.01060	0.34908	0.00688	0.67783	0.00777	0.84089	0.00979	0.65531	0.00949
0.87618	0.01105	0.36484	0.00719	0.69935	0.00812	0.86602	0.01022	0.67708	0.00990
0.90271	0.01151	0.38303	0.00750	0.72209	0.00846	0.88953	0.01065	0.69809	0.01032
0.92894	0.01196	0.40185	0.00780	0.74412	0.00881	0.91316	0.01109	0.72115	0.01073
0.95566	0.01241	0.42099	0.00811	0.76503	0.00915	0.93796	0.01152	0.74431	0.01114
0.98284	0.01287	0.43942	0.00841	0.78440	0.00950	0.96196	0.01195	0.76571	0.01155
1.00832	0.01332	0.45707	0.00872	0.80477	0.00984	0.98485	0.01238	0.78658	0.01195
1.03315	0.01377	0.47383	0.00903	0.82552	0.01019	1.00749	0.01282	0.80853	0.01238
1.05752	0.01420	0.49055	0.00933	0.84551	0.01054	1.03133	0.01325	0.83228	0.01279
1.08274	0.01468	0.50735	0.00964	0.86438	0.01088	1.05526	0.01368	0.85482	0.01320
1.10737	0.01513	0.52372	0.00994	0.88412	0.01123	1.07678	0.01411	0.87850	0.01362
1.13171	0.01558	0.53967	0.01025	0.90340	0.01157	1.09801	0.01455	0.90132	0.01403
1.15527	0.01604	0.55671	0.01056	0.92181	0.01192	1.12136	0.01498	0.92393	0.01444
1.17935	0.01649	0.57585	0.01086	0.93935	0.01226	1.14325	0.01541	0.94487	0.01485
1.20248	0.01694	0.59293	0.01117	0.95771	0.01261	1.16432	0.01584	0.96585	0.01527
1.22538	0.01740	0.60930	0.01147	0.97756	0.01295	1.18469	0.01625	0.98804	0.01568
1.24711	0.01785	0.62539	0.01178	0.99521	0.01330	1.20650	0.01671	1.00964	0.01609
1.27028	0.01830	0.64361	0.01209	1.01334	0.01364	1.22724	0.01714	1.03017	0.01651
1.29334	0.01875	0.66044	0.01239	1.03184	0.01399	1.24789	0.01757	1.05274	0.01692
1.31524	0.01921	0.67667	0.01270	1.05128	0.01434	1.26751	0.01800	1.07497	0.01733
1.33622	0.01966	0.69375	0.01300	1.06974	0.01468	1.28870	0.01844	1.09469	0.01774
1.35765	0.02011	0.71143	0.01331	1.08840	0.01503	1.30981	0.01887	1.11380	0.01816
1.37856	0.02057	0.72898	0.01362	1.10703	0.01537	1.33042	0.01930	1.13336	0.01857
1.39814	0.02102	0.74656	0.01392	1.12565	0.01572	1.35066	0.01973	1.15354	0.01898
1.41693	0.02147	0.76406	0.01423	1.14322	0.01606	1.37111	0.02016	1.17288	0.01939
1.43690	0.02193	0.78086	0.01453	1.16168	0.01641	1.39176	0.02060	1.19168	0.01981
1.45811	0.02238	0.79744	0.01484	1.18004	0.01675	1.41238	0.02103	1.21217	0.02022
1.47794	0.02283	0.81381	0.01515	1.19818	0.01710	1.43183	0.02146	1.23464	0.02063
1.49821	0.02328	0.83068	0.01545	1.21623	0.01744	1.45091	0.02189	1.25447	0.02104
1.51817	0.02374	0.84879	0.01576	1.23355	0.01779	1.47053	0.02233	1.27327	0.02146
1.53850	0.02419	0.86484	0.01606	1.25000	0.01813	1.49185	0.02276	1.29313	0.02187
1.55794	0.02464	0.88068	0.01637	1.26762	0.01848	1.51147	0.02319	1.31342	0.02228
1.57680	0.02510	0.89656	0.01668	1.28361	0.01883	1.53092	0.02362	1.33353	0.02269
1.59635	0.02555	0.91325	0.01698	1.30076	0.01917	1.55137	0.02405	1.35409	0.02311
1.61726	0.02600	0.93040	0.01729	1.31721	0.01952	1.57107	0.02449	1.37614	0.02352
1.63811	0.02646	0.94798	0.01759	1.33429	0.01986	1.58932	0.02492	1.39736	0.02393
1.65847	0.02691	0.96545	0.01790	1.35144	0.02021	1.60753	0.02535	1.41671	0.02434
1.67896	0.02736	0.98263	0.01821	1.36939	0.02055	1.62483	0.02578	1.43648	0.02476
1.70111	0.02781	1.00011	0.01851	1.38619	0.02090	1.64305	0.02622	1.45704	0.02517
1.72137	0.02827	1.01694	0.01882	1.40240	0.02124	1.66064	0.02665	1.47784	0.02558
1.74075	0.02872	1.03299	0.01912	1.41800	0.02159	1.67686	0.02708	1.49854	0.02600
1.76020	0.02917	1.05057	0.01943	1.43410	0.02193	1.69450	0.02751	1.51883	0.02641
1.78173	0.02963	1.06740	0.01974	1.45098	0.02228	1.71320	0.02794	1.53828	0.02682
1.80160	0.03008	1.08303	0.02004	1.46781	0.02263	1.73059	0.02838	1.56078	0.02723
1.82127	0.03053	1.09897	0.02035	1.48625	0.02297	1.74685	0.02881	1.57975	0.02765
1.84046	0.03099	1.11570	0.02065	1.50332	0.02332	1.76320	0.02924	1.59792	0.02806
1.86065	0.03144	1.13182	0.02096	1.52029	0.02366	1.78158	0.02967	1.61637	0.02847
1.88111	0.03189	1.14876	0.02127	1.53679	0.02401	1.79901	0.03011	1.63596	0.02888
1.89984	0.03234	1.16502	0.02157	1.55392	0.02435	1.81511	0.03054	1.65489	0.02930
1.91847	0.03280	1.18175	0.02188	1.57113	0.02470	1.83195	0.03097	1.67368	0.02971
1.93674	0.03325	1.19929	0.02218	1.58777	0.02504	1.84996	0.03140	1.69116	0.03012
1.95608	0.03370	1.21694	0.02249	1.60458	0.02539	1.86552	0.03183	1.70936	0.03053
1.97419	0.03416	1.23356	0.02280	1.62356	0.02573	1.88084	0.03227	1.72857	0.03095
1.99057	0.03461	1.25004	0.02310	1.64093	0.02608	1.89586	0.03270	1.74820	0.03136

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 30.65 sq.mm		C/S Area = 28.16 sq.mm		C/S Area = 36.72 sq.mm		C/S Area = 24.16 sq.mm		C/S Area = 28.84 sq.mm	
Original Length = 44.15mm		Original Length = 67.36mm		Original Length = 57.9mm		Original Length = 46.27mm		Original Length = 48.47mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
2.00662	0.03506	1.26634	0.02341	1.65752	0.02642	1.91171	0.03313	1.76637	0.03177
2.02388	0.03552	1.28448	0.02371	1.67255	0.02677	1.92724	0.03356	1.78363	0.03218
2.03830	0.03597	1.30128	0.02402	1.68916	0.02712	1.94276	0.03400	1.80007	0.03260
2.05021	0.03642	1.31616	0.02433	1.70613	0.02746	1.95604	0.03443	1.81546	0.03301
2.05954	0.03687	1.33182	0.02463	1.72307	0.02781	1.97016	0.03486	1.83103	0.03342
2.06470	0.03733	1.35018	0.02494	1.73900	0.02815	1.98328	0.03529	1.84501	0.03384
2.06512	0.03778	1.36857	0.02524	1.75773	0.02850	1.99251	0.03573	1.86082	0.03425
2.06183	0.03823	1.38374	0.02555	1.77397	0.02884	2.00199	0.03616	1.87684	0.03466
2.05772	0.03869	1.39915	0.02586	1.78938	0.02919	2.01134	0.03659	1.89251	0.03507
2.04617	0.03914	1.41470	0.02616	1.80479	0.02953	2.01805	0.03702	1.90680	0.03549
2.01853	0.03959	1.43100	0.02647	1.82021	0.02988	2.02202	0.03745	1.92240	0.03590
1.94542	0.04005	1.44780	0.02677	1.83633	0.03022	2.02248	0.03789	1.93797	0.03631
End of Results		1.46396	0.02708	1.85202	0.03057	2.02094	0.03832	1.95239	0.03672
		1.48171	0.02739	1.86735	0.03092	2.01192	0.03875	1.96581	0.03714
		1.49893	0.02769	1.88301	0.03126	1.98874	0.03918	1.97979	0.03755
		1.51555	0.02800	1.89853	0.03161	1.95149	0.03962	1.99442	0.03796
		1.53242	0.02830	1.91217	0.03195	1.88613	0.04005	2.00725	0.03837
		1.55099	0.02861	1.92519	0.03230	1.77570	0.04048	2.01838	0.03879
		1.56804	0.02892	1.93848	0.03264	1.55430	0.04091	2.02725	0.03920
		1.58441	0.02922	1.95142	0.03299	End of Results		2.03180	0.03961
		1.60007	0.02953	1.96422	0.03333			2.02479	0.04002
		1.61705	0.02983	1.97623	0.03368			1.97500	0.04044
		1.63391	0.03014	1.98663	0.03402			1.82628	0.04085
		1.65078	0.03045	1.99662	0.03437			End of Results	
		1.66726	0.03075	2.00705	0.03472				
		1.68480	0.03106	2.01762	0.03506				
		1.70256	0.03136	2.02688	0.03541				
		1.71964	0.03167	2.03720	0.03575				
		1.73558	0.03198	2.04755	0.03610				
		1.75170	0.03228	2.05784	0.03644				
		1.76737	0.03259	2.06702	0.03679				
		1.78278	0.03289	2.07451	0.03713				
		1.79759	0.03320	2.07933	0.03748				
		1.81396	0.03351	2.08186	0.03782				
		1.82919	0.03381	2.08091	0.03817				
		1.84492	0.03412	2.07587	0.03851				
		1.86044	0.03442	2.06797	0.03886				
		1.87575	0.03473	2.05596	0.03921				
		1.89197	0.03504	2.04330	0.03955				
		1.90806	0.03534	2.03001	0.03990				
		1.92173	0.03565	2.02037	0.04024				
		1.93626	0.03595	2.00738	0.04059				
		1.95032	0.03626	1.98263	0.04093				
		1.96420	0.03657	1.93597	0.04128				
		1.97713	0.03687	1.87274	0.04162				
		1.98977	0.03718	1.78205	0.04197				
		2.00320	0.03748	End of Results					
		2.01655	0.03779						
		2.02770	0.03810						
		2.03732	0.03840						
		2.04741	0.03871						
		2.05735	0.03901						
		2.06605	0.03932						
		2.06996	0.03963						
		2.07262	0.03993						
		2.07259	0.04024						
		2.07060	0.04054						
		2.06637	0.04085						
		2.05927	0.04116						
		2.05249	0.04146						
		2.04812	0.04177						
		2.03928	0.04207						
		2.01942	0.04238						
		1.97638	0.04269						
		1.88210	0.04299						

Relation Between Stress and Strain - 20% Moisture Content

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Count	1
Trigger Type	Auto
Trigger Force	0.10N

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 28.12 sq.mm		C/S Area = 18.04 sq.mm		C/S Area = 26.36 sq.mm		C/S Area = 18.96 sq.mm		C/S Area = 18.12sq.mm	
Original Length = 78.33mm		Original Length = 49.31mm		Original Length = 78.93mm		Original Length = 55.79mm		Original Length = 58.43mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00010	0.00000	0.00016	0.00000	0.00010	0.00000	0.00014	0.00000	0.00000
0.00569	0.00036	0.02677	0.00057	0.00425	0.00035	0.02178	0.00050	0.04288	0.00017
0.01220	0.00061	0.05222	0.00095	0.01415	0.00061	0.04272	0.00084	0.05121	0.00051
0.01927	0.00087	0.07661	0.00138	0.02523	0.00086	0.06234	0.00122	0.06496	0.00086
0.02717	0.00111	0.10227	0.00178	0.03672	0.00110	0.08207	0.00158	0.08019	0.00120
0.03485	0.00138	0.12550	0.00219	0.04825	0.00137	0.09921	0.00194	0.09305	0.00154
0.04303	0.00163	0.14678	0.00260	0.05869	0.00162	0.11624	0.00229	0.10618	0.00188
0.05156	0.00189	0.16768	0.00300	0.06866	0.00188	0.13360	0.00265	0.11683	0.00222
0.05999	0.00214	0.18753	0.00341	0.07781	0.00213	0.15137	0.00301	0.12759	0.00257
0.06839	0.00240	0.20704	0.00381	0.08775	0.00238	0.16709	0.00337	0.14023	0.00291
0.07681	0.00266	0.22461	0.00422	0.09628	0.00264	0.18312	0.00373	0.15447	0.00325
0.08506	0.00291	0.24285	0.00462	0.10505	0.00289	0.19953	0.00409	0.16722	0.00359
0.09328	0.00317	0.26037	0.00503	0.11392	0.00314	0.21577	0.00445	0.18135	0.00394
0.10153	0.00342	0.27688	0.00544	0.12299	0.00340	0.23059	0.00480	0.19443	0.00428
0.10939	0.00368	0.29241	0.00584	0.13107	0.00365	0.24415	0.00516	0.20795	0.00462
0.11746	0.00393	0.30748	0.00625	0.13949	0.00390	0.25733	0.00552	0.22014	0.00496
0.12592	0.00419	0.32256	0.00665	0.14700	0.00416	0.27094	0.00588	0.23300	0.00531
0.13318	0.00444	0.33686	0.00706	0.15455	0.00441	0.28391	0.00624	0.24641	0.00565
0.14129	0.00470	0.35006	0.00746	0.16127	0.00466	0.29652	0.00660	0.25911	0.00599
0.14929	0.00495	0.36369	0.00787	0.16703	0.00492	0.30891	0.00695	0.27169	0.00633
0.15704	0.00521	0.37694	0.00827	0.17261	0.00517	0.32110	0.00731	0.28411	0.00667
0.16437	0.00546	0.38936	0.00868	0.17811	0.00542	0.33201	0.00767	0.29586	0.00702
0.17233	0.00572	0.40183	0.00909	0.18338	0.00568	0.34204	0.00803	0.30778	0.00736
0.18016	0.00597	0.41341	0.00949	0.18904	0.00593	0.35079	0.00839	0.31915	0.00770
0.18791	0.00623	0.42705	0.00990	0.19355	0.00618	0.35986	0.00875	0.33057	0.00804
0.19484	0.00649	0.44041	0.01030	0.19848	0.00644	0.36809	0.00911	0.34288	0.00839
0.20220	0.00674	0.45288	0.01071	0.20269	0.00669	0.37611	0.00946	0.35381	0.00873
0.20903	0.00700	0.46591	0.01111	0.20611	0.00694	0.38407	0.00982	0.36485	0.00907
0.21497	0.00725	0.47894	0.01152	0.21017	0.00720	0.39277	0.01018	0.37660	0.00941
0.22084	0.00751	0.49252	0.01190	0.21377	0.00745	0.40269	0.01052	0.38813	0.00976
0.22728	0.00776	0.50471	0.01233	0.21692	0.00770	0.41155	0.01090	0.39834	0.01010
0.23279	0.00800	0.51663	0.01274	0.21988	0.00794	0.42173	0.01126	0.40828	0.01044
0.23876	0.00827	0.52949	0.01314	0.22352	0.00821	0.43381	0.01161	0.41760	0.01078
0.24470	0.00853	0.54218	0.01355	0.22849	0.00846	0.44515	0.01197	0.42831	0.01112
0.25167	0.00878	0.55322	0.01395	0.23448	0.00872	0.45643	0.01233	0.43764	0.01147
0.26024	0.00904	0.56358	0.01436	0.23964	0.00897	0.46688	0.01269	0.44708	0.01181
0.26796	0.00929	0.57539	0.01476	0.24507	0.00922	0.47727	0.01305	0.45651	0.01215
0.27582	0.00955	0.58525	0.01517	0.25193	0.00948	0.48819	0.01341	0.46600	0.01249
0.28382	0.00980	0.59645	0.01557	0.26051	0.00973	0.49800	0.01377	0.47467	0.01284
0.29097	0.01006	0.60576	0.01598	0.26893	0.00998	0.50675	0.01412	0.48328	0.01318
0.29861	0.01032	0.61630	0.01639	0.27644	0.01024	0.51767	0.01448	0.49018	0.01352
0.30548	0.01057	0.62639	0.01679	0.28327	0.01049	0.52885	0.01484	0.49680	0.01386
0.31287	0.01083	0.63714	0.01720	0.29131	0.01074	0.53855	0.01520	0.50408	0.01421
0.32070	0.01108	0.64828	0.01760	0.29871	0.01100	0.54747	0.01556	0.51153	0.01455
0.32820	0.01134	0.65959	0.01801	0.30535	0.01125	0.55754	0.01592	0.51595	0.01489
0.33521	0.01159	0.67101	0.01841	0.31161	0.01150	0.56888	0.01628	0.52152	0.01523
0.34257	0.01185	0.68315	0.01882	0.31832	0.01176	0.57885	0.01663	0.52765	0.01557
0.34975	0.01210	0.69374	0.01923	0.32542	0.01201	0.58776	0.01699	0.53366	0.01592
0.35690	0.01236	0.70421	0.01963	0.33175	0.01226	0.59715	0.01735	0.53996	0.01626
0.36334	0.01261	0.71491	0.02004	0.33759	0.01252	0.60686	0.01771	0.54702	0.01660
0.36999	0.01287	0.72522	0.02044	0.34389	0.01277	0.61561	0.01807	0.55497	0.01694
0.37685	0.01312	0.73492	0.02085	0.34958	0.01302	0.62310	0.01843	0.56120	0.01729
0.38321	0.01338	0.74523	0.02125	0.35455	0.01328	0.63233	0.01878	0.57014	0.01763
0.38898	0.01363	0.75538	0.02166	0.35876	0.01353	0.64109	0.01914	0.58129	0.01797
0.39506	0.01389	0.76591	0.02206	0.36358	0.01378	0.65042	0.01950	0.59338	0.01831
0.40075	0.01415	0.77522	0.02247	0.36787	0.01404	0.65870	0.01986	0.60375	0.01865
0.40622	0.01440	0.78415	0.02288	0.37174	0.01429	0.66741	0.02022	0.61462	0.01900
0.41127	0.01466	0.79385	0.02328	0.37564	0.01454	0.67695	0.02058	0.62533	0.01934
0.41533	0.01491	0.80299	0.02369	0.37986	0.01480	0.68645	0.02094	0.63659	0.01968
0.42013	0.01517	0.81236	0.02409	0.38354	0.01505	0.69626	0.02129	0.64735	0.02002
0.42472	0.01542	0.82001	0.02450	0.38862	0.01530	0.70564	0.02165	0.65740	0.02037
0.43055	0.01568	0.82855	0.02490	0.39446	0.01556	0.71577	0.02201	0.66711	0.02071
0.43606	0.01593	0.83681	0.02531	0.39989	0.01581	0.72590	0.02237	0.67677	0.02105
0.44129	0.01619	0.84484	0.02571	0.40622	0.01606	0.73470	0.02273	0.68664	0.02139
0.44666	0.01644	0.85089	0.02612	0.41210	0.01632	0.74362	0.02309	0.69581	0.02174
0.45149	0.01670	0.85793	0.02653	0.41753	0.01657	0.75290	0.02345	0.70386	0.02208
0.45629	0.01695	0.86652	0.02693	0.42291	0.01683	0.76255	0.02380	0.71275	0.02242
0.46081	0.01721	0.87273	0.02734	0.42898	0.01708	0.77205	0.02416	0.72219	0.02276
0.46568	0.01746	0.87932	0.02774	0.43448	0.01733	0.78059	0.02452	0.72942	0.02310
0.46977	0.01772	0.88703	0.02815	0.43919	0.01759	0.78956	0.02488	0.73698	0.02345
0.47383	0.01798	0.89468	0.02855	0.44439	0.01784	0.79826	0.02524	0.74476	0.02379
0.47678	0.01823	0.90360	0.02896	0.45080	0.01809	0.80765	0.02560	0.75155	0.02413
0.48009	0.01849	0.91114	0.02937	0.45778	0.01835	0.81524	0.02599	0.75773	0.02447
0.48346	0.01874	0.91940	0.02977	0.46502	0.01860	0.82289	0.02635	0.76286	0.02482
0.48688	0.01900	0.92871	0.03018	0.47113	0.01885	0.83070	0.02671	0.76816	0.02516
0.49125	0.01925	0.93836	0.03058	0.47758	0.01911	0.84024	0.02707	0.77274	0.02550

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 28.12 sq.mm		C/S Area = 18.04 sq.mm		C/S Area = 26.36 sq.mm		C/S Area = 18.96 sq.mm		C/S Area = 18.12sq.mm	
Original Length = 78.33mm		Original Length = 49.31mm		Original Length = 78.93mm		Original Length = 55.79mm		Original Length = 58.43mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.49705	0.01951	0.94789	0.03099	0.48392	0.01936	0.84731	0.02742	0.77815	0.02584
0.50423	0.01976	0.95737	0.03139	0.48991	0.01961	0.85438	0.02778	0.78140	0.02619
0.51063	0.02002	0.96807	0.03180	0.49484	0.01987	0.86218	0.02814	0.78720	0.02653
0.51707	0.02027	0.97788	0.03220	0.50061	0.02012	0.86925	0.02850	0.79321	0.02687
0.52315	0.02053	0.98653	0.03261	0.50634	0.02037	0.87648	0.02886	0.80149	0.02721
0.52909	0.02078	0.99573	0.03302	0.51127	0.02063	0.88286	0.02922	0.81049	0.02755
0.53453	0.02104	1.00510	0.03342	0.51730	0.02088	0.89172	0.02958	0.81882	0.02790
0.53862	0.02129	1.01513	0.03383	0.52367	0.02113	0.89847	0.02993	0.82759	0.02824
0.54285	0.02155	1.02406	0.03423	0.53050	0.02139	0.90496	0.03029	0.83808	0.02858
0.54687	0.02181	1.03193	0.03464	0.53722	0.02164	0.91134	0.03065	0.84735	0.02892
0.55025	0.02206	1.04124	0.03504	0.54291	0.02189	0.91804	0.03101	0.85541	0.02927
0.55317	0.02232	1.05089	0.03545	0.54928	0.02215	0.92495	0.03137	0.86269	0.02961
0.55633	0.02257	1.05865	0.03585	0.55561	0.02240	0.93112	0.03173	0.87114	0.02995
0.56095	0.02283	1.06674	0.03626	0.56184	0.02265	0.93792	0.03208	0.87864	0.03029
0.56668	0.02308	1.07522	0.03667	0.56787	0.02291	0.94467	0.03244	0.88466	0.03063
0.57258	0.02334	1.08426	0.03707	0.57405	0.02316	0.95132	0.03280	0.89095	0.03098
0.57877	0.02359	1.09324	0.03748	0.58061	0.02341	0.95759	0.03316	0.89851	0.03132
0.58499	0.02385	1.10067	0.03788	0.58695	0.02367	0.96445	0.03352	0.90602	0.03166
0.59147	0.02410	1.10870	0.03829	0.59310	0.02392	0.97157	0.03388	0.91325	0.03200
0.59772	0.02436	1.11829	0.03869	0.59860	0.02417	0.97975	0.03424	0.92086	0.03235
0.60277	0.02461	1.12738	0.03910	0.60520	0.02443	0.98877	0.03459	0.93002	0.03269
0.60832	0.02487	1.13553	0.03951	0.61184	0.02468	0.99726	0.03495	0.93841	0.03303
0.61380	0.02512	1.14357	0.03991	0.61798	0.02493	1.00654	0.03531	0.94619	0.03337
0.61888	0.02538	1.15233	0.04032	0.62382	0.02519	1.01582	0.03567	0.95508	0.03372
0.62326	0.02564	1.16225	0.04072	0.62986	0.02544	1.02363	0.03603	0.96507	0.03406
0.62713	0.02589	1.17034	0.04113	0.63562	0.02569	1.03207	0.03639	0.97357	0.03440
0.63083	0.02615	1.17700	0.04153	0.64116	0.02595	1.04051	0.03674	0.98190	0.03474
0.63425	0.02640	1.18498	0.04194	0.64651	0.02620	1.05000	0.03710	0.99045	0.03508
0.63773	0.02666	1.19451	0.04234	0.65156	0.02645	1.05918	0.03746	1.00011	0.03543
0.64157	0.02691	1.20249	0.04275	0.65728	0.02671	1.06751	0.03782	1.00855	0.03577
0.64559	0.02717	1.21042	0.04316	0.66294	0.02696	1.07500	0.03818	1.01634	0.03611
0.65039	0.02742	1.21763	0.04356	0.66787	0.02721	1.08418	0.03854	1.02401	0.03645
0.65551	0.02768	1.22627	0.04397	0.67295	0.02747	1.09309	0.03890	1.03273	0.03680
0.66142	0.02793	1.23359	0.04437	0.67853	0.02772	1.10121	0.03925	1.04078	0.03714
0.66714	0.02819	1.24080	0.04478	0.68456	0.02797	1.10939	0.03961	1.04790	0.03748
0.67262	0.02844	1.24878	0.04518	0.69067	0.02823	1.11746	0.03997	1.05519	0.03782
0.67742	0.02870	1.25743	0.04559	0.69662	0.02848	1.12579	0.04033	1.06380	0.03817
0.68225	0.02895	1.26524	0.04599	0.70311	0.02873	1.13412	0.04069	1.07086	0.03851
0.68851	0.02921	1.27195	0.04640	0.70983	0.02899	1.14130	0.04105	1.07787	0.03885
0.69371	0.02947	1.27999	0.04681	0.71635	0.02924	1.14905	0.04141	1.08405	0.03919
0.69922	0.02972	1.28952	0.04721	0.72200	0.02949	1.15812	0.04176	1.09045	0.03953
0.70423	0.02998	1.29701	0.04762	0.72830	0.02975	1.16619	0.04212	1.09829	0.03988
0.71038	0.03023	1.30460	0.04802	0.73464	0.03000	1.17310	0.04248	1.10453	0.04022
0.71636	0.03049	1.31292	0.04843	0.74108	0.03025	1.18117	0.04284	1.11038	0.04056
0.72262	0.03074	1.32079	0.04883	0.74697	0.03051	1.18998	0.04320	1.11755	0.04090
0.72824	0.03100	1.32905	0.04924	0.75334	0.03076	1.19821	0.04356	1.12478	0.04125
0.73432	0.03125	1.33625	0.04965	0.75956	0.03101	1.20517	0.04391	1.13206	0.04159
0.74043	0.03151	1.34412	0.05005	0.76567	0.03127	1.21292	0.04427	1.13946	0.04193
0.74676	0.03176	1.35327	0.05046	0.77155	0.03152	1.22131	0.04463	1.14619	0.04227
0.75263	0.03202	1.36092	0.05086	0.77754	0.03177	1.22896	0.04499	1.15370	0.04262
0.75907	0.03227	1.36807	0.05127	0.78350	0.03203	1.23597	0.04535	1.16087	0.04296
0.76497	0.03253	1.37544	0.05167	0.78980	0.03228	1.24346	0.04571	1.16777	0.04330
0.77077	0.03278	1.38348	0.05208	0.79575	0.03254	1.25253	0.04607	1.17445	0.04364
0.77685	0.03304	1.39108	0.05248	0.80273	0.03279	1.26044	0.04642	1.18339	0.04398
0.78314	0.03330	1.39823	0.05289	0.80884	0.03304	1.26825	0.04678	1.19073	0.04433
0.78915	0.03355	1.40582	0.05330	0.81506	0.03330	1.27500	0.04714	1.19691	0.04467
0.79488	0.03381	1.41391	0.05370	0.82049	0.03355	1.28333	0.04750	1.20486	0.04501
0.80068	0.03406	1.42195	0.05411	0.82644	0.03380	1.29135	0.04786	1.21214	0.04535
0.80672	0.03432	1.42905	0.05451	0.83346	0.03406	1.29873	0.04822	1.21915	0.04570
0.81284	0.03457	1.43620	0.05492	0.83896	0.03431	1.30512	0.04858	1.22655	0.04604
0.81810	0.03483	1.44335	0.05532	0.84454	0.03456	1.31234	0.04893	1.23300	0.04638
0.82351	0.03508	1.45078	0.05573	0.85008	0.03482	1.31999	0.04929	1.24045	0.04672
0.82841	0.03534	1.45831	0.05613	0.85618	0.03507	1.32695	0.04965	1.24730	0.04706
0.83378	0.03559	1.46524	0.05654	0.86108	0.03532	1.33370	0.05001	1.25353	0.04741
0.83937	0.03585	1.47195	0.05695	0.86548	0.03558	1.34140	0.05037	1.26038	0.04775
0.84410	0.03610	1.47960	0.05735	0.87026	0.03583	1.34826	0.05073	1.26534	0.04809
0.84876	0.03636	1.48697	0.05776	0.87591	0.03608	1.35585	0.05108	1.27274	0.04843
0.85462	0.03661	1.49324	0.05816	0.88115	0.03634	1.36224	0.05144	1.27903	0.04878
0.85946	0.03687	1.50011	0.05857	0.88600	0.03659	1.36851	0.05180	1.28538	0.04912
0.86369	0.03712	1.50754	0.05897	0.89067	0.03684	1.37605	0.05216	1.29123	0.04946
0.86785	0.03738	1.51402	0.05938	0.89628	0.03710	1.38344	0.05252	1.29757	0.04980
0.87351	0.03764	1.52134	0.05979	0.90137	0.03735	1.38987	0.05288	1.30552	0.05015
0.87891	0.03789	1.52766	0.06019	0.90603	0.03760	1.39583	0.05324	1.31137	0.05049
0.88389	0.03815	1.53520	0.06060	0.91024	0.03786	1.40280	0.05359	1.31556	0.05083
0.88894	0.03840	1.54185	0.06100	0.91533	0.03811	1.40881	0.05395	1.32163	0.05117
0.89477	0.03866	1.54739	0.06141	0.92086	0.03836	1.41493	0.05431	1.32820	0.05151
0.90046	0.03891	1.55382	0.06181	0.92599	0.03862	1.42152	0.05467	1.33438	0.05186
0.90615	0.03917	1.56064	0.06222	0.93164	0.03887	1.42806	0.05503	1.34045	0.05220
0.91127	0.03942	1.56752	0.06262	0.93794	0.03912	1.43470	0.05539	1.34779	0.05254
0.91746	0.03968	1.57367	0.06303	0.94435	0.03938	1.44140	0.05574	1.35480	0.05288
0.92319	0.03993	1.57955	0.06344	0.95042	0.03963	1.44699	0.05610	1.36220	0.05323
0.92838	0.04019	1.58692	0.06384	0.95630	0.03988	1.45311	0.05646	1.36882	0.05357
0.93329	0.04044	1.59257	0.06425	0.96263	0.04014	1.45923	0.05682	1.37610	0.05391
0.93958	0.04070	1.59839	0.06465	0.96939	0.04039	1.46519	0.05718	1.38317	0.05425
0.94424	0.04095	1.60322	0.06506	0.97568	0.04064	1.47141	0.05754	1.38979	0.05460
0.94929	0.04121	1.61131	0.06546	0.98213	0.04090	1.47727	0.05790	1.39564	0.05494
0.95388	0.04147	1.61685	0.06587	0.98820	0.04115	1.48386	0.05825	1.40298	0.05528
0.95861	0.04172	1.62267	0.06627	0.99564	0.04140	1.49024	0.05861	1.40971	0.05562

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 28.12 sq.mm		C/S Area = 18.04 sq.mm		C/S Area = 26.36 sq.mm		C/S Area = 18.96 sq.mm		C/S Area = 18.12sq.mm	
Original Length = 78.33mm		Original Length = 49.31mm		Original Length = 78.93mm		Original Length = 55.79mm		Original Length = 58.43mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.96415	0.04198	1.62744	0.06668	1.00159	0.04166	1.49573	0.05897	1.41617	0.05596
0.96863	0.04223	1.63320	0.06709	1.00778	0.04191	1.50174	0.05933	1.42246	0.05631
0.97315	0.04249	1.63891	0.06749	1.01347	0.04216	1.50828	0.05969	1.42930	0.05665
0.97813	0.04274	1.64368	0.06790	1.01976	0.04242	1.51398	0.06005	1.43758	0.05699
0.98329	0.04300	1.64911	0.06830	1.02675	0.04267	1.51967	0.06041	1.44249	0.05733
0.98873	0.04325	1.65222	0.06871	1.03232	0.04292	1.52479	0.06076	1.44840	0.05768
0.99349	0.04351	1.65748	0.06911	1.03759	0.04318	1.53059	0.06112	1.45469	0.05802
0.99844	0.04376	1.66203	0.06952	1.04359	0.04343	1.53681	0.06148	1.46109	0.05836
1.00423	0.04402	1.66508	0.06992	1.05027	0.04368	1.54172	0.06184	1.46760	0.05870
1.00935	0.04427	1.66774	0.07033	1.05671	0.04394	1.54689	0.06220	1.47357	0.05905
1.01486	0.04453	1.67145	0.07074	1.06187	0.04419	1.55216	0.06256	1.48052	0.05939
1.02041	0.04478	1.67522	0.07114	1.06798	0.04444	1.55865	0.06291	1.48543	0.05973
1.02674	0.04504	1.67711	0.07155	1.07451	0.04470	1.56303	0.06327	1.49145	0.06007
1.03286	0.04530	1.67888	0.07195	1.08020	0.04495	1.56714	0.06363	1.49724	0.06041
1.03894	0.04555	1.68032	0.07236	1.08612	0.04520	1.57226	0.06399	1.50259	0.06076
1.04470	0.04581	1.68071	0.07276	1.09177	0.04546	1.57790	0.06435	1.50861	0.06110
1.05004	0.04606	1.67988	0.07317	1.09784	0.04571	1.58223	0.06471	1.51451	0.06144
1.05615	0.04632	1.67849	0.07358	1.10470	0.04596	1.58592	0.06507	1.52058	0.06178
1.06159	0.04657	1.67611	0.07398	1.11074	0.04622	1.59177	0.06542	1.52550	0.06213
1.06757	0.04683	1.66984	0.07439	1.11681	0.04647	1.59636	0.06578	1.53201	0.06247
1.07294	0.04708	1.65854	0.07479	1.12272	0.04672	1.60042	0.06614	1.53731	0.06281
1.07962	0.04734	1.63902	0.07520	1.12906	0.04698	1.60369	0.06650	1.54183	0.06315
1.08546	0.04759	1.60998	0.07560	1.13479	0.04723	1.60749	0.06686	1.54658	0.06349
1.09118	0.04785	1.55344	0.07601	1.14014	0.04749	1.61055	0.06722	1.55193	0.06384
1.09673	0.04810	1.42201	0.07641	1.14727	0.04774	1.61361	0.06757	1.55756	0.06418
1.10235	0.04836	End of Results		1.15307	0.04799	1.61672	0.06793	1.56336	0.06452
1.10782	0.04861			1.15880	0.04825	1.62147	0.06829	1.56744	0.06486
1.11309	0.04887			1.16453	0.04850	1.62389	0.06865	1.57191	0.06521
1.11853	0.04913			1.17045	0.04875	1.62500	0.06901	1.57655	0.06555
1.12504	0.04938			1.17697	0.04901	1.62558	0.06937	1.58074	0.06589
1.13069	0.04964			1.18240	0.04926	1.62690	0.06973	1.58444	0.06623
1.13563	0.04989			1.18706	0.04951	1.62816	0.07008	1.58797	0.06658
1.14008	0.05015			1.19374	0.04977	1.62748	0.07044	1.59426	0.06692
1.14563	0.05040			1.19985	0.05002	1.62584	0.07080	1.59812	0.06726
1.15117	0.05066			1.20740	0.05027	1.62389	0.07116	1.60121	0.06760
1.15608	0.05091			1.21222	0.05053	1.62168	0.07152	1.60320	0.06794
1.16078	0.05117			1.21737	0.05078	1.61867	0.07188	1.60640	0.06829
1.16636	0.05142			1.22261	0.05103	1.61234	0.07224	1.60922	0.06863
1.17201	0.05168			1.22800	0.05129	1.60517	0.07259	1.61153	0.06897
1.17777	0.05193			1.23304	0.05154	1.59641	0.07295	1.61330	0.06931
1.18183	0.05219			1.23919	0.05179	1.58803	0.07331	1.61545	0.06966
1.18730	0.05244			1.24495	0.05205	1.57690	0.07367	1.61656	0.07000
1.19264	0.05270			1.25000	0.05230	1.56461	0.07403	1.61821	0.07034
1.19765	0.05296			1.25470	0.05255	1.54684	0.07439	1.61849	0.07068
1.20263	0.05321			1.26020	0.05281	1.52547	0.07474	1.62053	0.07103
1.20765	0.05347			1.26567	0.05306	End of Results		1.61987	0.07137
1.21319	0.05372			1.27113	0.05331			1.61943	0.07171
1.21792	0.05398			1.27640	0.05357			1.61661	0.07205
1.22265	0.05423			1.28137	0.05382			1.61451	0.07239
1.22792	0.05449			1.28687	0.05407			1.61170	0.07274
1.23350	0.05474			1.29287	0.05433			1.60795	0.07308
1.23855	0.05500			1.29829	0.05458			1.60044	0.07342
1.24356	0.05525			1.30322	0.05483			1.59310	0.07376
1.24833	0.05551			1.30835	0.05509			1.58135	0.07411
1.25381	0.05576			1.31404	0.05534			1.56540	0.07445
1.25964	0.05602			1.32030	0.05559			1.54354	0.07479
1.26494	0.05627			1.32485	0.05585			1.51275	0.07513
1.26952	0.05653			1.33005	0.05610			End of Results	
1.27464	0.05679			1.33570	0.05635				
1.28058	0.05704			1.34158	0.05661				
1.28578	0.05730			1.34693	0.05686				
1.29036	0.05755			1.35273	0.05711				
1.29516	0.05781			1.35827	0.05737				
1.30089	0.05806			1.36377	0.05762				
1.30633	0.05832			1.36939	0.05787				
1.31102	0.05857			1.37432	0.05813				
1.31604	0.05883			1.38020	0.05838				
1.32127	0.05908			1.38555	0.05863				
1.32720	0.05934			1.39048	0.05889				
1.33193	0.05959			1.39628	0.05914				
1.33698	0.05985			1.40186	0.05939				
1.34257	0.06010			1.40747	0.05965				
1.34794	0.06036			1.41252	0.05990				
1.35263	0.06062			1.41741	0.06015				
1.35743	0.06087			1.42170	0.06041				
1.36291	0.06113			1.42785	0.06066				
1.36803	0.06138			1.43327	0.06091				
1.37269	0.06164			1.43691	0.06117				
1.37738	0.06189			1.44230	0.06142				
1.38268	0.06215			1.44807	0.06167				
1.38759	0.06240			1.45322	0.06193				
1.39278	0.06266			1.45785	0.06218				
1.39730	0.06291			1.46320	0.06244				
1.40260	0.06317			1.46810	0.06269				
1.40761	0.06342			1.47356	0.06294				
1.41227	0.06368			1.47822	0.06320				
1.41686	0.06393			1.48365	0.06345				
1.42148	0.06419			1.48873	0.06370				

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 28.12 sq.mm		C/S Area = 18.04 sq.mm		C/S Area = 26.36 sq.mm		C/S Area = 18.96 sq.mm		C/S Area = 18.12sq.mm	
Original Length = 78.33mm		Original Length = 49.31mm		Original Length = 78.93mm		Original Length = 55.79mm		Original Length = 58.43mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
1.42688	0.06445			1.49302	0.06396				
1.43144	0.06470			1.49772	0.06421				
1.43599	0.06496			1.50243	0.06446				
1.44093	0.06521			1.50736	0.06472				
1.44637	0.06547			1.51165	0.06497				
1.45107	0.06572			1.51529	0.06522				
1.45512	0.06598			1.52075	0.06548				
1.45928	0.06623			1.52553	0.06573				
1.46369	0.06649			1.52914	0.06598				
1.46849	0.06674			1.53361	0.06624				
1.47283	0.06700			1.53759	0.06649				
1.47681	0.06725			1.54211	0.06674				
1.48154	0.06751			1.54712	0.06700				
1.48638	0.06776			1.55186	0.06725				
1.49107	0.06802			1.55596	0.06750				
1.49435	0.06828			1.56058	0.06776				
1.49872	0.06853			1.56449	0.06801				
1.50359	0.06879			1.56844	0.06826				
1.50818	0.06904			1.57185	0.06852				
1.51216	0.06930			1.57648	0.06877				
1.51600	0.06955			1.58039	0.06902				
1.52027	0.06981			1.58475	0.06928				
1.52475	0.07006			1.58778	0.06953				
1.52845	0.07032			1.59139	0.06978				
1.53215	0.07057			1.59514	0.07004				
1.53595	0.07083			1.59894	0.07029				
1.54036	0.07108			1.60228	0.07054				
1.54435	0.07134			1.60493	0.07080				
1.54808	0.07159			1.60865	0.07105				
1.55185	0.07185			1.61191	0.07130				
1.55473	0.07211			1.61449	0.07156				
1.55807	0.07236			1.61707	0.07181				
1.56195	0.07262			1.62022	0.07206				
1.56572	0.07287			1.62291	0.07232				
1.56931	0.07313			1.62439	0.07257				
1.57237	0.07338			1.62671	0.07282				
1.57518	0.07364			1.62921	0.07308				
1.57913	0.07389			1.63153	0.07333				
1.58247	0.07415			1.63304	0.07358				
1.58553	0.07440			1.63380	0.07384				
1.58837	0.07466			1.63456	0.07409				
1.59189	0.07491			1.63581	0.07434				
1.59502	0.07517			1.63585	0.07460				
1.59847	0.07542			1.63437	0.07485				
1.60057	0.07568			1.63304	0.07510				
1.60363	0.07594			1.63179	0.07536				
1.60722	0.07619			1.62910	0.07561				
1.60982	0.07645			1.62458	0.07586				
1.61195	0.07670			1.61791	0.07612				
1.61444	0.07696			1.61077	0.07637				
1.61718	0.07721			1.59731	0.07662				
1.61949	0.07747			1.57621	0.07688				
1.62077	0.07772			1.54230	0.07713				
1.62344	0.07798			1.49200	0.07739				
1.62592	0.07823			End of Results					
1.62752	0.07849								
1.62913	0.07874								
1.63080	0.07900								
1.63247	0.07925								
1.63378	0.07951								
1.63453	0.07977								
1.63538	0.08002								
1.63677	0.08028								
1.63738	0.08053								
1.63748	0.08079								
1.63691	0.08104								
1.63645	0.08130								
1.63670	0.08155								
1.63574	0.08181								
1.63435	0.08206								
1.63204	0.08232								
1.62952	0.08257								
1.62600	0.08283								
1.62112	0.08308								
1.61636	0.08334								
1.61049	0.08360								
1.60373	0.08385								
1.59449	0.08411								

Relation between Stress and Strain - 40% Moisture Contant

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Count	1
Trigger Type	Auto
Trigger Force	0.10N
Break Detect	Off

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Ares = 26.76 sq.mm		C/S Ares = 19.92 sq.mm		C/S Ares = 19.64 sq.mm		C/S Ares = 22.8 sq.mm		C/S Ares = 17 sq.mm	
Original Length = 62.19mm		Original Length = 44.67mm		Original Length = 40.63mm		Original Length = 51.63mm		Original Length = 58.17mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00014
0.04421	0.00016	0.03815	0.00022	0.04445	0.00025	0.00658	0.00019	0.01359	0.00048
0.05673	0.00048	0.04965	0.00067	0.05570	0.00074	0.00846	0.00058	0.02853	0.00083
0.07096	0.00080	0.06210	0.00112	0.06945	0.00123	0.01123	0.00097	0.04547	0.00117
0.08483	0.00113	0.07565	0.00157	0.08462	0.00172	0.01518	0.00136	0.06053	0.00150
0.09903	0.00145	0.08931	0.00201	0.09969	0.00222	0.01754	0.00174	0.07524	0.00186
0.11214	0.00177	0.10191	0.00246	0.11354	0.00271	0.02110	0.00213	0.08935	0.00220
0.12541	0.00209	0.11275	0.00291	0.12714	0.00320	0.02434	0.00252	0.10253	0.00254
0.13767	0.00241	0.12425	0.00336	0.14058	0.00369	0.02864	0.00291	0.11665	0.00289
0.14985	0.00273	0.13494	0.00381	0.15305	0.00418	0.03250	0.00329	0.12812	0.00323
0.16188	0.00306	0.14518	0.00425	0.16548	0.00468	0.03728	0.00368	0.13900	0.00358
0.17283	0.00338	0.15437	0.00470	0.17795	0.00517	0.04180	0.00407	0.15006	0.00392
0.18259	0.00370	0.16295	0.00515	0.18946	0.00566	0.04623	0.00445	0.16035	0.00426
0.19286	0.00402	0.17254	0.00560	0.20097	0.00615	0.05162	0.00484	0.17041	0.00461
0.20295	0.00434	0.18163	0.00604	0.21141	0.00665	0.05675	0.00523	0.17929	0.00495
0.21233	0.00466	0.19011	0.00649	0.22200	0.00714	0.06232	0.00562	0.18841	0.00529
0.22100	0.00498	0.19754	0.00694	0.23284	0.00763	0.06868	0.00600	0.19729	0.00564
0.22993	0.00531	0.20638	0.00739	0.24308	0.00812	0.07465	0.00639	0.20512	0.00598
0.23890	0.00563	0.21300	0.00784	0.25255	0.00861	0.08171	0.00678	0.21229	0.00633
0.24690	0.00595	0.22078	0.00828	0.26247	0.00911	0.08860	0.00717	0.21935	0.00667
0.25392	0.00627	0.22851	0.00873	0.27225	0.00960	0.09570	0.00755	0.22718	0.00701
0.26091	0.00659	0.23504	0.00918	0.28203	0.01009	0.10329	0.00794	0.23365	0.00736
0.26876	0.00691	0.24207	0.00963	0.29053	0.01058	0.11110	0.00833	0.24059	0.00770
0.27608	0.00724	0.24975	0.01007	0.29929	0.01108	0.11886	0.00872	0.24712	0.00805
0.28225	0.00756	0.25617	0.01052	0.30937	0.01157	0.12789	0.00910	0.25400	0.00839
0.28808	0.00788	0.26350	0.01097	0.31792	0.01206	0.13658	0.00949	0.25947	0.00873
0.29473	0.00820	0.27073	0.01142	0.32699	0.01255	0.14535	0.00988	0.26518	0.00908
0.30060	0.00852	0.27781	0.01186	0.33513	0.01304	0.15386	0.01027	0.27065	0.00942
0.30665	0.00884	0.28429	0.01231	0.34430	0.01354	0.16325	0.01065	0.27565	0.00976
0.31226	0.00917	0.29207	0.01276	0.35305	0.01403	0.17224	0.01104	0.28100	0.01011
0.31816	0.00949	0.29915	0.01321	0.36161	0.01452	0.18167	0.01143	0.28576	0.01045
0.32369	0.00981	0.30628	0.01366	0.36879	0.01501	0.19070	0.01181	0.28988	0.01078
0.32919	0.01013	0.31255	0.01410	0.37719	0.01551	0.20035	0.01220	0.29453	0.01114
0.33423	0.01045	0.31973	0.01455	0.38518	0.01600	0.20969	0.01259	0.29953	0.01148
0.33935	0.01077	0.32641	0.01500	0.39308	0.01649	0.21860	0.01298	0.30306	0.01183
0.34454	0.01110	0.33238	0.01545	0.40051	0.01698	0.22785	0.01336	0.30741	0.01217
0.35026	0.01142	0.33886	0.01589	0.40840	0.01747	0.23724	0.01375	0.31041	0.01252
0.35568	0.01174	0.34538	0.01634	0.41645	0.01797	0.24588	0.01414	0.31512	0.01286
0.36102	0.01206	0.35326	0.01679	0.42490	0.01846	0.25504	0.01453	0.31812	0.01320
0.36693	0.01238	0.35914	0.01724	0.43208	0.01895	0.26408	0.01491	0.32147	0.01355
0.37287	0.01270	0.36611	0.01769	0.43880	0.01944	0.27368	0.01530	0.32382	0.01389
0.37848	0.01302	0.37385	0.01813	0.44684	0.01994	0.28268	0.01569	0.32759	0.01423
0.38389	0.01335	0.37997	0.01858	0.45428	0.02043	0.29171	0.01608	0.33000	0.01458
0.39002	0.01367	0.38630	0.01903	0.46085	0.02092	0.30061	0.01646	0.33188	0.01492
0.39552	0.01399	0.39287	0.01948	0.46843	0.02141	0.30930	0.01685	0.33400	0.01527
0.40060	0.01431	0.39829	0.01992	0.47556	0.02190	0.31781	0.01724	0.33565	0.01561
0.40546	0.01463	0.40537	0.02037	0.48320	0.02240	0.32610	0.01763	0.33688	0.01595
0.41061	0.01495	0.41200	0.02082	0.48941	0.02289	0.33487	0.01801	0.33765	0.01630
0.41551	0.01528	0.41782	0.02127	0.49664	0.02338	0.34355	0.01840	0.33853	0.01664
0.42007	0.01560	0.42430	0.02171	0.50351	0.02387	0.35237	0.01879	0.33935	0.01698
0.42429	0.01592	0.43097	0.02216	0.51130	0.02437	0.36031	0.01917	0.34041	0.01733
0.42889	0.01624	0.43690	0.02261	0.51762	0.02486	0.36833	0.01956	0.33929	0.01767
0.43262	0.01656	0.44227	0.02306	0.52347	0.02535	0.37732	0.01995	0.33829	0.01802
0.43700	0.01688	0.44880	0.02351	0.53040	0.02584	0.38557	0.02034	0.33712	0.01836
0.44051	0.01721	0.45457	0.02395	0.53798	0.02634	0.39404	0.02072	0.33565	0.01870
0.44395	0.01753	0.46034	0.02440	0.54465	0.02683	0.40127	0.02111	0.33294	0.01905
0.44720	0.01785	0.46596	0.02485	0.55061	0.02732	0.40939	0.02150	0.32912	0.01939
0.45071	0.01817	0.47239	0.02530	0.55799	0.02781	0.41772	0.02189	0.32512	0.01974
0.45333	0.01849	0.47801	0.02574	0.56451	0.02830	0.42531	0.02227	0.31982	0.02008
0.45639	0.01881	0.48404	0.02619	0.57159	0.02880	0.43298	0.02266	0.31371	0.02042
0.45882	0.01913	0.49036	0.02664	0.57755	0.02929	0.44114	0.02305	0.30488	0.02077
0.46196	0.01946	0.49583	0.02709	0.58442	0.02978	0.44860	0.02344	0.29541	0.02111
0.46454	0.01978	0.50181	0.02754	0.59196	0.03027	0.45518	0.02382	0.28247	0.02145
0.46861	0.02010	0.50833	0.02798	0.59776	0.03077	0.46307	0.02421	0.26747	0.02180
0.47343	0.02042	0.51376	0.02843	0.60372	0.03126	0.47096	0.02460	0.24906	0.02214
0.47780	0.02074	0.51933	0.02888	0.61013	0.03175	0.47846	0.02499	0.22647	0.02249
0.48180	0.02106	0.52445	0.02933	0.61660	0.03224	0.48583	0.02537	0.20112	0.02283
0.48591	0.02139	0.52932	0.02977	0.62286	0.03273	0.49355	0.02576	0.17118	0.02317
0.49043	0.02171	0.53494	0.03022	0.62882	0.03323	0.50009	0.02615	End of Results	
0.49462	0.02203	0.53991	0.03067	0.63508	0.03372	0.50715	0.02653		
0.49828	0.02235	0.54493	0.03112	0.64114	0.03421	0.51386	0.02692		
0.50220	0.02267	0.55030	0.03156	0.64710	0.03470	0.52132	0.02731		
0.50605	0.02299	0.55587	0.03201	0.65285	0.03520	0.52768	0.02770		
0.50972	0.02332	0.56024	0.03246	0.65886	0.03569	0.53461	0.02808		
0.51383	0.02364	0.56451	0.03291	0.66492	0.03618	0.54193	0.02847		

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Ares = 26.76 sq.mm		C/S Ares = 19.92 sq.mm		C/S Ares = 19.64 sq.mm		C/S Ares = 22.8 sq.mm		C/S Ares = 17 sq.mm	
Original Length = 62.19mm		Original Length = 44.67mm		Original Length = 40.63mm		Original Length = 51.63mm		Original Length = 58.17mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.51857	0.02396	0.56958	0.03336	0.67077	0.03667	0.54904	0.02886		
0.52339	0.02428	0.57415	0.03380	0.67637	0.03716	0.55496	0.02925		
0.52814	0.02460	0.57846	0.03425	0.68208	0.03766	0.56136	0.02963		
0.53236	0.02492	0.58358	0.03470	0.68798	0.03815	0.56768	0.03002		
0.53688	0.02525	0.59011	0.03515	0.69399	0.03864	0.57487	0.03041		
0.54111	0.02557	0.59629	0.03559	0.69964	0.03913	0.58110	0.03080		
0.54567	0.02589	0.60206	0.03604	0.70458	0.03963	0.58781	0.03118		
0.54974	0.02621	0.60748	0.03649	0.70988	0.04012	0.59425	0.03157		
0.55321	0.02653	0.61401	0.03694	0.71527	0.04061	0.60044	0.03196		
0.55777	0.02685	0.62008	0.03739	0.72037	0.04110	0.60675	0.03235		
0.56211	0.02717	0.62610	0.03783	0.72561	0.04159	0.61294	0.03273		
0.56641	0.02750	0.63178	0.03828	0.73070	0.04209	0.61917	0.03312		
0.57037	0.02782	0.63760	0.03873	0.73666	0.04258	0.62482	0.03351		
0.57485	0.02814	0.64408	0.03918	0.74190	0.04307	0.63092	0.03390		
0.57848	0.02846	0.64970	0.03962	0.74633	0.04356	0.63715	0.03428		
0.58266	0.02878	0.65532	0.04007	0.75153	0.04406	0.64263	0.03467		
0.58681	0.02910	0.66175	0.04052	0.75698	0.04455	0.64917	0.03506		
0.59088	0.02943	0.66707	0.04097	0.76166	0.04504	0.65487	0.03544		
0.59548	0.02975	0.67244	0.04141	0.76604	0.04553	0.66066	0.03583		
0.60056	0.03007	0.67796	0.04186	0.77067	0.04603	0.66675	0.03622		
0.60463	0.03039	0.68298	0.04231	0.77561	0.04652	0.67263	0.03661		
0.60863	0.03071	0.68876	0.04276	0.78075	0.04701	0.67798	0.03699		
0.61293	0.03103	0.69428	0.04321	0.78488	0.04750	0.68342	0.03738		
0.61734	0.03136	0.69990	0.04365	0.78875	0.04799	0.68917	0.03777		
0.62126	0.03168	0.70472	0.04410	0.79364	0.04849	0.69531	0.03816		
0.62571	0.03200	0.71109	0.04455	0.79776	0.04898	0.70123	0.03854		
0.62997	0.03232	0.71616	0.04500	0.80295	0.04947	0.70649	0.03893		
0.63423	0.03264	0.72068	0.04544	0.80698	0.04996	0.71237	0.03932		
0.63868	0.03296	0.72560	0.04589	0.81120	0.05046	0.71776	0.03971		
0.64234	0.03329	0.73052	0.04634	0.81527	0.05095	0.72289	0.04009		
0.64682	0.03361	0.73509	0.04679	0.81970	0.05144	0.72851	0.04048		
0.65138	0.03393	0.73966	0.04724	0.82281	0.05193	0.73399	0.04087		
0.65531	0.03425	0.74347	0.04768	0.82648	0.05242	0.73943	0.04126		
0.65871	0.03457	0.74854	0.04813	0.83040	0.05292	0.74500	0.04164		
0.66278	0.03489	0.75306	0.04858	0.83549	0.05341	0.75013	0.04203		
0.66644	0.03521	0.75633	0.04903	0.83890	0.05390	0.75461	0.04242		
0.67044	0.03554	0.76059	0.04947	0.84236	0.05439	0.76018	0.04280		
0.67444	0.03586	0.76571	0.04992	0.84633	0.05489	0.76627	0.04319		
0.67896	0.03618	0.76943	0.05037	0.85010	0.05538	0.77110	0.04358		
0.68229	0.03650	0.77329	0.05082	0.85382	0.05587	0.77579	0.04397		
0.68539	0.03682	0.77651	0.05126	0.85672	0.05636	0.78053	0.04435		
0.68845	0.03714	0.78042	0.05171	0.86095	0.05685	0.78592	0.04474		
0.69133	0.03747	0.78479	0.05216	0.86456	0.05735	0.79162	0.04513		
0.69492	0.03779	0.78850	0.05261	0.86726	0.05784	0.79544	0.04552		
0.69851	0.03811	0.79217	0.05306	0.87077	0.05833	0.80053	0.04590		
0.70194	0.03843	0.79629	0.05350	0.87398	0.05882	0.80601	0.04629		
0.70516	0.03875	0.80010	0.05395	0.87724	0.05932	0.81075	0.04668		
0.70927	0.03907	0.80351	0.05440	0.88070	0.05981	0.81487	0.04707		
0.71233	0.03940	0.80683	0.05485	0.88294	0.06030	0.81947	0.04745		
0.71499	0.03972	0.80964	0.05529	0.88615	0.06079	0.82434	0.04784		
0.71775	0.04004	0.81421	0.05574	0.88956	0.06128	0.82952	0.04823		
0.72089	0.04036	0.81717	0.05619	0.89226	0.06178	0.83386	0.04862		
0.72328	0.04068	0.82144	0.05664	0.89394	0.06227	0.83803	0.04900		
0.72623	0.04100	0.82470	0.05709	0.89715	0.06276	0.84351	0.04939		
0.72956	0.04132	0.82856	0.05753	0.90071	0.06325	0.84781	0.04978		
0.73255	0.04165	0.83268	0.05798	0.90285	0.06375	0.85145	0.05016		
0.73539	0.04197	0.83650	0.05843	0.90438	0.06424	0.85592	0.05055		
0.73748	0.04229	0.84001	0.05888	0.90652	0.06473	0.86066	0.05094		
0.73984	0.04261	0.84362	0.05932	0.90840	0.06522	0.86548	0.05133		
0.74331	0.04293	0.84774	0.05977	0.91044	0.06571	0.86987	0.05171		
0.74664	0.04325	0.85281	0.06022	0.91171	0.06621	0.87377	0.05210		
0.75019	0.04358	0.85643	0.06067	0.91309	0.06670	0.87829	0.05249		
0.75265	0.04390	0.86114	0.06111	0.91548	0.06719	0.88232	0.05288		
0.75635	0.04422	0.86586	0.06156	0.91701	0.06768	0.88623	0.05326		
0.76039	0.04454	0.87113	0.06201	0.91736	0.06818	0.89044	0.05365		
0.76413	0.04486	0.87515	0.06246	0.91792	0.06867	0.89544	0.05404		
0.76805	0.04518	0.87972	0.06291	0.91945	0.06916	0.89961	0.05443		
0.77265	0.04551	0.88384	0.06335	0.92123	0.06965	0.90281	0.05481		
0.77653	0.04583	0.88730	0.06380	0.92138	0.07015	0.90697	0.05520		
0.78053	0.04615	0.89132	0.06425	0.92189	0.07064	0.91145	0.05559		
0.78427	0.04647	0.89458	0.06470	0.92281	0.07113	0.91548	0.05598		
0.78819	0.04679	0.89864	0.06514	0.92296	0.07162	0.91917	0.05636		
0.79200	0.04711	0.90256	0.06559	0.92256	0.07211	0.92289	0.05675		
0.79570	0.04744	0.90562	0.06604	0.92123	0.07261	0.92684	0.05714		
0.80019	0.04776	0.90863	0.06649	0.92108	0.07310	0.93044	0.05752		
0.80385	0.04808	0.91140	0.06694	0.92042	0.07359	0.93474	0.05791		
0.80788	0.04840	0.91476	0.06738	0.91838	0.07408	0.93776	0.05830		
0.81170	0.04872	0.91697	0.06783	0.91589	0.07458	0.94136	0.05869		
0.81562	0.04904	0.91938	0.06828	0.91283	0.07507	0.94548	0.05907		
0.81898	0.04936	0.92209	0.06873	0.90677	0.07556	0.94816	0.05946		
0.82231	0.04969	0.92410	0.06917	0.89908	0.07605	0.95175	0.05985		
0.82541	0.05001	0.92636	0.06962	0.88641	0.07654	0.95579	0.06024		
0.82933	0.05033	0.92771	0.07007	0.86777	0.07704	0.95921	0.06062		
0.83262	0.05065	0.92932	0.07052	0.83574	0.07753	0.96224	0.06101		
0.83625	0.05097	0.93012	0.07096	0.77581	0.07802	0.96535	0.06140		
0.83980	0.05129	0.93153	0.07141	0.65290	0.07851	0.96864	0.06179		
0.84342	0.05162	0.93062	0.07186	End of Results		0.97140	0.06217		
0.84705	0.05194	0.93072	0.07231			0.97500	0.06256		

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Ares = 26.76 sq.mm		C/S Ares = 19.92 sq.mm		C/S Ares = 19.64 sq.mm		C/S Ares = 22.8 sq.mm		C/S Ares = 17 sq.mm	
Original Length = 62.19mm		Original Length = 44.67mm		Original Length = 40.63mm		Original Length = 51.63mm		Original Length = 58.17mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.84993	0.05226	0.93087	0.07276			0.97763	0.06295		
0.85370	0.05258	0.92982	0.07320			0.98075	0.06334		
0.85725	0.05290	0.92791	0.07365			0.98443	0.06372		
0.86039	0.05322	0.92480	0.07410			0.98759	0.06411		
0.86319	0.05355	0.92134	0.07455			0.98974	0.06450		
0.86663	0.05387	0.91566	0.07499			0.99149	0.06488		
0.86984	0.05419	0.90843	0.07544			0.99373	0.06527		
0.87328	0.05451	0.89744	0.07589			0.99640	0.06566		
0.87612	0.05483	0.88298	0.07634			0.99925	0.06605		
0.87990	0.05515	0.86350	0.07679			1.00101	0.06643		
0.88303	0.05548	0.83604	0.07723			1.00285	0.06682		
0.88647	0.05580	0.79980	0.07775			1.00504	0.06721		
0.88920	0.05612	0.75306	0.07820			1.00737	0.06760		
0.89241	0.05644	End of Results				1.00877	0.06798		
0.89567	0.05676					1.00969	0.06837		
0.89865	0.05708					1.01009	0.06876		
0.90138	0.05740					1.01154	0.06915		
0.90471	0.05773					1.01167	0.06953		
0.90785	0.05805					1.01189	0.06992		
0.91114	0.05837					1.01167	0.07031		
0.91375	0.05869					1.01061	0.07070		
0.91633	0.05901					1.00917	0.07108		
0.91981	0.05933					1.00566	0.07147		
0.92298	0.05966					1.00228	0.07186		
0.92552	0.05998					0.99583	0.07224		
0.92758	0.06030					0.98579	0.07263		
0.93150	0.06062					0.96974	0.07302		
0.93386	0.06094					0.94145	0.07341		
0.93617	0.06126					End of Results			
0.93901	0.06159								
0.94174	0.06191								
0.94451	0.06223								
0.94709	0.06255								
0.94951	0.06287								
0.95247	0.06319								
0.95549	0.06352								
0.95759	0.06384								
0.95927	0.06416								
0.96158	0.06448								
0.96469	0.06480								
0.96697	0.06512								
0.96887	0.06544								
0.97108	0.06577								
0.97336	0.06609								
0.97560	0.06641								
0.97724	0.06673								
0.97862	0.06705								
0.98072	0.06737								
0.98270	0.06770								
0.98378	0.06802								
0.98554	0.06834								
0.98830	0.06866								
0.98976	0.06898								
0.99036	0.06930								
0.99167	0.06963								
0.99297	0.06995								
0.99432	0.07027								
0.99552	0.07059								
0.99596	0.07091								
0.99847	0.07123								
0.99873	0.07155								
0.99865	0.07188								
0.99880	0.07220								
0.99922	0.07252								
0.99940	0.07284								
0.99948	0.07316								
0.99892	0.07348								
0.99884	0.07381								
0.99798	0.07413								
0.99686	0.07445								
0.99477	0.07477								
0.99339	0.07509								
0.99215	0.07541								
0.99096	0.07574								
0.98860	0.07606								
0.98688	0.07638								
0.98490	0.07670								
0.98169	0.07702								
0.97694	0.07734								
0.97231	0.07767								
0.96764	0.07799								
0.96297	0.07831								
0.95605	0.07863								
0.94851	0.07895								
0.94167	0.07927								
0.93315	0.07959								
0.92309	0.07992								
0.91244	0.08024								

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Ares = 26.76 sq.mm		C/S Ares = 19.92 sq.mm		C/S Ares = 19.64 sq.mm		C/S Ares = 22.8 sq.mm		C/S Ares = 17 sq.mm	
Original Length = 62.19mm		Original Length = 44.67mm		Original Length = 40.63mm		Original Length = 51.63mm		Original Length = 58.17mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.90108	0.08056								
0.88789	0.08088								
0.87182	0.08120								
0.85250	0.08152								
0.83105	0.08185								
0.80643	0.08217								
0.77993	0.08249								
0.75187	0.08281								
0.72235	0.08313								
0.69006	0.08345								
0.65138	0.08378								

Relation between Stress and Strain - 60% Moisture Content Samples

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Count	1
Trigger Type	Auto
Trigger Force	0.10N

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 32.04 sq.mm		C/S Area = 25.88 sq.mm		C/S Area = 22.4 sq.mm		C/S Area = 32.96 sq.mm		C/S Area = 21.28 sq.mm	
Original Length = 47.39mm		Original Length = 62.63mm		Original Length = 44.93mm		Original Length = 71.27mm		Original Length = 52.74mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00000	0.00000	0.00013	0.00000	0.00000	0.00000	0.00011	0.00000	0.00015
0.02194	0.00027	0.00502	0.00045	0.01121	0.00045	0.00258	0.00039	0.00808	0.00053
0.02906	0.00070	0.01144	0.00077	0.02219	0.00089	0.00683	0.00067	0.01790	0.00091
0.03767	0.00112	0.01944	0.00109	0.03402	0.00134	0.01144	0.00095	0.02857	0.00129
0.04600	0.00154	0.02620	0.00139	0.04487	0.00178	0.01581	0.00122	0.03853	0.00165
0.05371	0.00196	0.03342	0.00172	0.05558	0.00223	0.02075	0.00152	0.04850	0.00205
0.06136	0.00238	0.04077	0.00204	0.06585	0.00267	0.02558	0.00180	0.05808	0.00243
0.06948	0.00281	0.04753	0.00236	0.07580	0.00312	0.03019	0.00208	0.06706	0.00281
0.07684	0.00323	0.05421	0.00268	0.08549	0.00356	0.03495	0.00236	0.07594	0.00319
0.08408	0.00365	0.06047	0.00300	0.09446	0.00401	0.03917	0.00264	0.08402	0.00356
0.09126	0.00407	0.06631	0.00332	0.10335	0.00445	0.04360	0.00292	0.09234	0.00394
0.09797	0.00449	0.07241	0.00364	0.11196	0.00490	0.04794	0.00320	0.10023	0.00432
0.10478	0.00492	0.07794	0.00396	0.12022	0.00534	0.05243	0.00348	0.10851	0.00470
0.11114	0.00534	0.08393	0.00428	0.12853	0.00579	0.05640	0.00376	0.11584	0.00508
0.11792	0.00576	0.08945	0.00460	0.13580	0.00623	0.06065	0.00404	0.12326	0.00546
0.12397	0.00618	0.09482	0.00492	0.14402	0.00668	0.06396	0.00432	0.13008	0.00584
0.13034	0.00660	0.10066	0.00524	0.15165	0.00712	0.06799	0.00460	0.13755	0.00622
0.13624	0.00703	0.10564	0.00556	0.15821	0.00757	0.07178	0.00488	0.14394	0.00660
0.14157	0.00745	0.11070	0.00588	0.16504	0.00801	0.07591	0.00516	0.15052	0.00698
0.14757	0.00787	0.11669	0.00620	0.17210	0.00846	0.07964	0.00544	0.15733	0.00736
0.15331	0.00829	0.12179	0.00651	0.17929	0.00890	0.08325	0.00572	0.16358	0.00774
0.15893	0.00871	0.12655	0.00683	0.18674	0.00935	0.08668	0.00601	0.17021	0.00812
0.16458	0.00914	0.13107	0.00715	0.19330	0.00979	0.09041	0.00629	0.17594	0.00849
0.16976	0.00956	0.13590	0.00747	0.19982	0.01024	0.09430	0.00657	0.18191	0.00887
0.17497	0.00998	0.14069	0.00779	0.20647	0.01068	0.09782	0.00685	0.18792	0.00925
0.18031	0.01040	0.14548	0.00811	0.21295	0.01113	0.10103	0.00713	0.19384	0.00963
0.18533	0.01083	0.14996	0.00843	0.21893	0.01157	0.10461	0.00741	0.19967	0.01001
0.19042	0.01125	0.15475	0.00875	0.22549	0.01202	0.10780	0.00769	0.20503	0.01039
0.19529	0.01167	0.15970	0.00907	0.23205	0.01246	0.11141	0.00797	0.21053	0.01077
0.20050	0.01209	0.16426	0.00939	0.23763	0.01291	0.11481	0.00825	0.21612	0.01115
0.20524	0.01251	0.16886	0.00971	0.24420	0.01335	0.11802	0.00853	0.22152	0.01153
0.20974	0.01294	0.17349	0.01001	0.24960	0.01380	0.12151	0.00880	0.22697	0.01189
0.21486	0.01336	0.17813	0.01035	0.25580	0.01424	0.12512	0.00909	0.23200	0.01229
0.21985	0.01378	0.18257	0.01067	0.26147	0.01469	0.12822	0.00937	0.23773	0.01267
0.22469	0.01420	0.18690	0.01099	0.26737	0.01513	0.13177	0.00965	0.24272	0.01305
0.22971	0.01462	0.19115	0.01130	0.27299	0.01558	0.13550	0.00993	0.24770	0.01342
0.23430	0.01505	0.19664	0.01162	0.27915	0.01602	0.13893	0.01021	0.25291	0.01380
0.23929	0.01547	0.20089	0.01194	0.28513	0.01647	0.14272	0.01050	0.25742	0.01418
0.24376	0.01587	0.20495	0.01226	0.29022	0.01692	0.14587	0.01078	0.26320	0.01456
0.24844	0.01631	0.20885	0.01258	0.29585	0.01736	0.14973	0.01106	0.26720	0.01494
0.25272	0.01673	0.21356	0.01290	0.30196	0.01781	0.15285	0.01134	0.27204	0.01532
0.25715	0.01716	0.21766	0.01322	0.30696	0.01825	0.15646	0.01162	0.27688	0.01570
0.26174	0.01758	0.22183	0.01354	0.31214	0.01870	0.15980	0.01190	0.28163	0.01608
0.26645	0.01800	0.22624	0.01386	0.31777	0.01914	0.16320	0.01218	0.28609	0.01646
0.27129	0.01842	0.23026	0.01418	0.32241	0.01959	0.16629	0.01246	0.28976	0.01684
0.27581	0.01884	0.23470	0.01450	0.32808	0.02003	0.16966	0.01274	0.29389	0.01722
0.27999	0.01927	0.23895	0.01482	0.33241	0.02048	0.17269	0.01302	0.29906	0.01760
0.28377	0.01969	0.24324	0.01514	0.33813	0.02092	0.17552	0.01330	0.30352	0.01797
0.28842	0.02011	0.24834	0.01546	0.34241	0.02137	0.17822	0.01358	0.30728	0.01835
0.29288	0.02053	0.25170	0.01578	0.34804	0.02181	0.18067	0.01386	0.31208	0.01873
0.29722	0.02095	0.25599	0.01609	0.35290	0.02226	0.18249	0.01414	0.31626	0.01911
0.30109	0.02138	0.25997	0.01641	0.35679	0.02270	0.18413	0.01442	0.31960	0.01949
0.30568	0.02180	0.26379	0.01673	0.36125	0.02315	0.18620	0.01470	0.32331	0.01987
0.31071	0.02222	0.26843	0.01705	0.36603	0.02359	0.18844	0.01499	0.32796	0.02025
0.31498	0.02264	0.27249	0.01737	0.37054	0.02404	0.19017	0.01527	0.33177	0.02063
0.31919	0.02306	0.27604	0.01769	0.37433	0.02448	0.19132	0.01555	0.33496	0.02101
0.32275	0.02349	0.28068	0.01801	0.37862	0.02493	0.19442	0.01583	0.33867	0.02139
0.32737	0.02391	0.28489	0.01833	0.38335	0.02537	0.19763	0.01611	0.34309	0.02177
0.33193	0.02433	0.28872	0.01865	0.38741	0.02582	0.20079	0.01639	0.34680	0.02215
0.33583	0.02475	0.29258	0.01897	0.39143	0.02626	0.20413	0.01667	0.35038	0.02253
0.33973	0.02517	0.29648	0.01929	0.39522	0.02671	0.20755	0.01695	0.35348	0.02290
0.34398	0.02560	0.30031	0.01961	0.39946	0.02715	0.21053	0.01723	0.35700	0.02328
0.34788	0.02602	0.30429	0.01993	0.40379	0.02760	0.21402	0.01751	0.36029	0.02366
0.35209	0.02644	0.30827	0.02025	0.40759	0.02804	0.21751	0.01779	0.36391	0.02404
0.35599	0.02686	0.31182	0.02057	0.41116	0.02849	0.22093	0.01807	0.36607	0.02442
0.36061	0.02728	0.31561	0.02088	0.41513	0.02893	0.22433	0.01835	0.37096	0.02480
0.36461	0.02771	0.31982	0.02120	0.41897	0.02938	0.22819	0.01863	0.37364	0.02518
0.36860	0.02813	0.32342	0.02152	0.42254	0.02982	0.23116	0.01891	0.37679	0.02556
0.37260	0.02855	0.32724	0.02184	0.42576	0.03027	0.23444	0.01919	0.37942	0.02594
0.37662	0.02897	0.33149	0.02216	0.42964	0.03071	0.23799	0.01948	0.38224	0.02632
0.38093	0.02939	0.33501	0.02248	0.43393	0.03116	0.24150	0.01976	0.38581	0.02670
0.38489	0.02982	0.33918	0.02280	0.43790	0.03160	0.24472	0.02004	0.39013	0.02708
0.38904	0.03024	0.34250	0.02312	0.44134	0.03205	0.24791	0.02032	0.39417	0.02746
0.39304	0.03066	0.34648	0.02344	0.44589	0.03249	0.25179	0.02060	0.39784	0.02783
0.39728	0.03108	0.34981	0.02376	0.44982	0.03294	0.25446	0.02088	0.40263	0.02821
0.40115	0.03150	0.35375	0.02408	0.45371	0.03339	0.25798	0.02116	0.40658	0.02859

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 32.04 sq.mm		C/S Area = 25.88 sq.mm		C/S Area = 22.4 sq.mm		C/S Area = 32.96 sq.mm		C/S Area = 21.28 sq.mm	
Original Length = 47.39mm		Original Length = 62.63mm		Original Length = 44.93mm		Original Length = 71.27mm		Original Length = 52.74mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.40465	0.03193	0.35696	0.02440	0.45790	0.03383	0.26126	0.02144	0.41034	0.02897
0.40846	0.03235	0.36047	0.02472	0.46246	0.03428	0.26417	0.02172	0.41447	0.02935
0.41295	0.03277	0.36387	0.02504	0.46683	0.03472	0.26717	0.02200	0.41894	0.02973
0.41673	0.03319	0.36816	0.02536	0.47147	0.03517	0.27021	0.02228	0.42274	0.03011
0.42038	0.03361	0.37141	0.02567	0.47496	0.03561	0.27279	0.02256	0.42655	0.03049
0.42450	0.03404	0.37481	0.02599	0.47902	0.03606	0.27573	0.02284	0.43087	0.03087
0.42890	0.03446	0.37859	0.02631	0.48348	0.03650	0.27837	0.02312	0.43553	0.03125
0.43240	0.03488	0.38211	0.02663	0.48795	0.03695	0.28092	0.02340	0.43947	0.03163
0.43614	0.03530	0.38570	0.02695	0.49192	0.03739	0.28340	0.02368	0.44314	0.03201
0.43989	0.03572	0.38903	0.02727	0.49580	0.03784	0.28592	0.02397	0.44713	0.03239
0.44295	0.03615	0.39289	0.02759	0.50009	0.03828	0.28829	0.02425	0.45160	0.03276
0.44663	0.03657	0.39594	0.02791	0.50473	0.03873	0.29017	0.02453	0.45526	0.03314
0.45006	0.03699	0.39954	0.02823	0.50813	0.03917	0.29187	0.02481	0.45865	0.03352
0.45387	0.03741	0.40305	0.02855	0.51183	0.03962	0.29427	0.02509	0.46245	0.03390
0.45755	0.03783	0.40630	0.02887	0.51625	0.04006	0.29636	0.02537	0.46706	0.03428
0.46092	0.03826	0.40912	0.02919	0.51969	0.04051	0.29879	0.02565	0.47035	0.03466
0.46423	0.03868	0.41252	0.02951	0.52299	0.04095	0.30240	0.02593	0.47425	0.03504
0.46738	0.03910	0.41615	0.02983	0.52665	0.04140	0.30579	0.02621	0.47782	0.03542
0.47054	0.03952	0.42013	0.03015	0.53063	0.04184	0.30953	0.02649	0.48111	0.03580
0.47456	0.03995	0.42276	0.03046	0.53406	0.04229	0.31308	0.02677	0.48449	0.03618
0.47787	0.04037	0.42608	0.03078	0.53728	0.04273	0.31638	0.02705	0.48825	0.03656
0.48093	0.04079	0.42937	0.03110	0.54085	0.04318	0.31936	0.02733	0.49121	0.03694
0.48421	0.04121	0.43253	0.03142	0.54393	0.04362	0.32279	0.02761	0.49380	0.03732
0.48730	0.04163	0.43582	0.03174	0.54719	0.04407	0.32597	0.02789	0.49727	0.03769
0.49051	0.04206	0.43864	0.03206	0.54996	0.04451	0.32916	0.02817	0.50103	0.03807
0.49360	0.04248	0.44216	0.03238	0.55210	0.04496	0.33262	0.02846	0.50352	0.03845
0.49685	0.04290	0.44494	0.03270	0.55491	0.04540	0.33589	0.02874	0.50648	0.03883
0.50009	0.04332	0.44838	0.03302	0.55817	0.04585	0.33877	0.02902	0.50949	0.03921
0.50334	0.04374	0.45097	0.03334	0.56058	0.04629	0.34217	0.02930	0.51316	0.03959
0.50627	0.04417	0.45394	0.03366	0.56112	0.04674	0.34533	0.02958	0.51565	0.03997
0.50871	0.04459	0.45761	0.03398	0.56344	0.04718	0.34876	0.02986	0.51828	0.04035
0.51220	0.04501	0.46105	0.03430	0.56478	0.04763	0.35143	0.03014	0.52068	0.04073
0.51498	0.04543	0.46383	0.03462	0.56625	0.04807	0.35446	0.03042	0.52368	0.04111
0.51742	0.04585	0.46689	0.03494	0.56665	0.04852	0.35674	0.03070	0.52594	0.04149
0.51998	0.04628	0.46994	0.03525	0.56679	0.04897	0.35959	0.03098	0.52867	0.04187
0.52291	0.04670	0.47268	0.03557	0.56754	0.04941	0.36238	0.03126	0.53153	0.04224
0.52581	0.04712	0.47635	0.03589	0.56652	0.04986	0.36490	0.03154	0.53445	0.04262
0.52809	0.04754	0.47894	0.03621	0.56460	0.05030	0.36793	0.03182	0.53665	0.04300
0.53059	0.04796	0.48188	0.03653	0.56129	0.05075	0.37063	0.03210	0.53872	0.04338
0.53308	0.04839	0.48509	0.03685	0.55634	0.05119	0.37324	0.03238	0.54117	0.04376
0.53558	0.04881	0.48771	0.03717	0.55009	0.05164	0.37588	0.03266	0.54408	0.04414
0.53752	0.04923	0.49038	0.03749	0.53938	0.05208	0.37828	0.03295	0.54572	0.04452
0.53964	0.04965	0.49339	0.03781	0.52406	0.05253	0.38113	0.03323	0.54704	0.04490
0.54189	0.05007	0.49606	0.03813	0.50518	0.05297	0.38425	0.03351	0.54873	0.04528
0.54382	0.05050	0.49880	0.03845	0.48049	0.05342	0.38686	0.03379	0.55127	0.04566
0.54582	0.05092	0.50151	0.03877	0.44862	0.05386	0.38926	0.03407	0.55273	0.04604
0.54757	0.05134	0.50402	0.03909	0.41366	0.05431	0.39266	0.03435	0.55442	0.04642
0.54919	0.05176	0.50672	0.03941	End of Results		0.39515	0.03463	0.55625	0.04680
0.55053	0.05218	0.50985	0.03973			0.39818	0.03491	0.55883	0.04717
0.55144	0.05261	0.51233	0.04004			0.40112	0.03519	0.56048	0.04755
0.55222	0.05303	0.51491	0.04036			0.40379	0.03547	0.56325	0.04793
0.55240	0.05345	0.51712	0.04068			0.40737	0.03575	0.56518	0.04831
0.55212	0.05387	0.51974	0.04100			0.41029	0.03603	0.56776	0.04869
0.55128	0.05429	0.52233	0.04132			0.41350	0.03631	0.56988	0.04907
0.54888	0.05472	0.52430	0.04164			0.41663	0.03659	0.57133	0.04945
0.54410	0.05514	0.52693	0.04196			0.41993	0.03687	0.57209	0.04983
0.53755	0.05556	0.52952	0.04228			0.42336	0.03715	0.57397	0.05021
0.52625	0.05598	0.53184	0.04260			0.42658	0.03744	0.57528	0.05059
0.50858	0.05640	0.53373	0.04292			0.42894	0.03772	0.57603	0.05097
0.48159	0.05683	0.53613	0.04324			0.43249	0.03800	0.57627	0.05135
End of Results		0.53829	0.04356			0.43532	0.03828	0.57632	0.05173
		0.54022	0.04388			0.43835	0.03856	0.57528	0.05210
		0.54219	0.04420			0.44141	0.03884	0.57298	0.05248
		0.54405	0.04452			0.44445	0.03912	0.57054	0.05286
		0.54598	0.04483			0.44772	0.03940	0.56635	0.05324
		0.54768	0.04515			0.45046	0.03968	0.55968	0.05362
		0.54919	0.04547			0.45319	0.03996	0.54986	0.05400
		0.55073	0.04579			0.45598	0.04024	0.53877	0.05438
		0.55270	0.04611			0.45916	0.04052	0.52580	0.05476
		0.55425	0.04643			0.46217	0.04080	0.50996	0.05514
		0.55529	0.04675			0.46508	0.04108	0.48727	0.05552
		0.55618	0.04707			0.46763	0.04136	0.45653	0.05590
		0.55777	0.04739			0.47093	0.04164	End of Results	
		0.55850	0.04771			0.47385	0.04193		
		0.55920	0.04803			0.47691	0.04221		
		0.56020	0.04835			0.47943	0.04249		
		0.56086	0.04867			0.48246	0.04277		
		0.56028	0.04899			0.48516	0.04305		
		0.56066	0.04931			0.48796	0.04333		
		0.55958	0.04962			0.49135	0.04361		
		0.55873	0.04994			0.49414	0.04389		
		0.55715	0.05026			0.49736	0.04417		
		0.55471	0.05058			0.50021	0.04445		
		0.55189	0.05090			0.50313	0.04473		
		0.54880	0.05122			0.50555	0.04501		
		0.54339	0.05154			0.50868	0.04529		
		0.53686	0.05186			0.51107	0.04557		
		0.52805	0.05218			0.51405	0.04585		

Continued...

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
C/S Area = 32.04 sq.mm		C/S Area = 25.88 sq.mm		C/S Area = 22.4 sq.mm		C/S Area = 32.96 sq.mm		C/S Area = 21.28 sq.mm	
Original Length = 47.39mm		Original Length = 62.63mm		Original Length = 44.93mm		Original Length = 71.27mm		Original Length = 52.74mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
		0.51828	0.05250			0.51684	0.04613		
		0.50638	0.05282			0.51963	0.04642		
		0.49150	0.05314			0.52233	0.04670		
		0.47156	0.05346			0.52473	0.04698		
		0.44610	0.05378			0.52737	0.04726		
		End of Results				0.53022	0.04754		
						0.53286	0.04782		
						0.53525	0.04810		
						0.53789	0.04838		
						0.54090	0.04866		
						0.54366	0.04894		
						0.54606	0.04922		
						0.54857	0.04950		
						0.55124	0.04978		
						0.55370	0.05006		
						0.55601	0.05034		
						0.55843	0.05062		
						0.56195	0.05091		
						0.56365	0.05119		
						0.56641	0.05147		
						0.56829	0.05175		
						0.57100	0.05203		
						0.57351	0.05231		
						0.57546	0.05259		
						0.57764	0.05287		
						0.58037	0.05315		
						0.58265	0.05343		
						0.58516	0.05371		
						0.58683	0.05399		
						0.58923	0.05427		
						0.59129	0.05455		
						0.59342	0.05483		
						0.59572	0.05511		
						0.59782	0.05539		
						0.60024	0.05568		
						0.60261	0.05596		
						0.60440	0.05624		
						0.60631	0.05652		
						0.60874	0.05680		
						0.61080	0.05708		
						0.61296	0.05736		
						0.61444	0.05764		
						0.61663	0.05792		
						0.61854	0.05820		
						0.62069	0.05848		
						0.62254	0.05876		
						0.62427	0.05904		
						0.62633	0.05932		
						0.62758	0.05960		
						0.62943	0.05988		
						0.63119	0.06017		
						0.63292	0.06045		
						0.63434	0.06073		
						0.63577	0.06101		
						0.63762	0.06129		
						0.63883	0.06157		
						0.63996	0.06185		
						0.64132	0.06213		
						0.64266	0.06241		
						0.64433	0.06269		
						0.64539	0.06297		
						0.64618	0.06325		
						0.64815	0.06353		
						0.64857	0.06381		
						0.64970	0.06409		
						0.65006	0.06437		
						0.65073	0.06466		
						0.65146	0.06494		
						0.65225	0.06522		
						0.65255	0.06550		
						0.65249	0.06578		
						0.65379	0.06606		
						0.65373	0.06634		
						0.65352	0.06662		
						0.65361	0.06690		
						0.65337	0.06718		
						0.65291	0.06746		
						0.65221	0.06774		
						0.65121	0.06802		
						0.65076	0.06830		
						0.64915	0.06858		
						0.64654	0.06886		
						0.64296	0.06915		
						0.63911	0.06943		
						0.63431	0.06971		
						0.62655	0.06999		
						0.61502	0.07027		
						0.59821	0.07055		
						0.57060	0.07083		

Relation between Stress and Strain - 80% Moisture Content

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Count	1
Trigger Type	Auto
Trigger Force	0.10N

Sample 1		Sample 2		Sample 3		Sample4		Sample5	
C/S Area = 28.96 sq.mm		C/S Area = 38.88 sq.mm		C/S Area = 30.92 sq.mm		C/S Area = 42.24 sq.mm		C/S Area = 34.8 sq.mm	
Original Length = 48.21mm		Original Length = 53.35mm		Original Length = 47.92mm		Original Length = 60.06mm		Original Length = 57.50mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00000	0.00000	0.00015	0.00000	0.00017	0.00000	0.00013	0.00000	0.00000
0.02065	0.00021	0.00494	0.00052	0.00611	0.00058	0.00391	0.00047	0.01089	0.00017
0.02745	0.00062	0.00908	0.00090	0.01158	0.00098	0.00836	0.00080	0.01503	0.00052
0.03436	0.00104	0.01417	0.00127	0.01734	0.00142	0.01210	0.00113	0.01983	0.00087
0.04195	0.00145	0.01880	0.00163	0.02335	0.00184	0.01629	0.00145	0.02466	0.00122
0.04879	0.00187	0.02338	0.00202	0.02875	0.00225	0.02034	0.00180	0.02902	0.00157
0.05559	0.00228	0.02788	0.00240	0.03389	0.00267	0.02467	0.00213	0.03368	0.00191
0.06184	0.00270	0.03212	0.00277	0.03926	0.00309	0.02898	0.00246	0.03859	0.00226
0.06868	0.00311	0.03660	0.00315	0.04470	0.00351	0.03277	0.00280	0.04305	0.00261
0.07507	0.00353	0.04066	0.00352	0.04955	0.00392	0.03686	0.00313	0.04736	0.00296
0.08046	0.00394	0.04465	0.00390	0.05411	0.00434	0.04117	0.00346	0.05164	0.00330
0.08598	0.00436	0.04846	0.00427	0.05896	0.00476	0.04517	0.00380	0.05572	0.00365
0.09178	0.00477	0.05255	0.00465	0.06394	0.00518	0.04889	0.00413	0.05948	0.00400
0.09706	0.00519	0.05651	0.00502	0.06860	0.00559	0.05284	0.00446	0.06345	0.00435
0.10183	0.00560	0.06044	0.00540	0.07245	0.00601	0.05637	0.00480	0.06750	0.00470
0.10708	0.00602	0.06407	0.00577	0.07730	0.00643	0.06042	0.00513	0.07144	0.00504
0.11181	0.00643	0.06790	0.00615	0.08166	0.00684	0.06409	0.00546	0.07534	0.00539
0.11675	0.00685	0.07153	0.00652	0.08583	0.00726	0.06750	0.00579	0.07874	0.00574
0.12096	0.00726	0.07526	0.00690	0.08991	0.00768	0.07102	0.00613	0.08250	0.00609
0.12535	0.00767	0.07860	0.00727	0.09395	0.00810	0.07472	0.00646	0.08652	0.00643
0.12987	0.00809	0.08169	0.00765	0.09822	0.00851	0.07813	0.00679	0.09020	0.00678
0.13412	0.00850	0.08529	0.00802	0.10226	0.00893	0.08139	0.00713	0.09376	0.00713
0.13867	0.00892	0.08884	0.00840	0.10582	0.00935	0.08473	0.00746	0.09707	0.00748
0.14199	0.00933	0.09223	0.00877	0.10990	0.00977	0.08795	0.00779	0.10023	0.00783
0.14648	0.00975	0.09540	0.00915	0.11387	0.01018	0.09112	0.00813	0.10411	0.00817
0.14972	0.01016	0.09918	0.00952	0.11763	0.01060	0.09453	0.00846	0.10753	0.00852
0.15345	0.01058	0.10237	0.00990	0.12109	0.01102	0.09721	0.00879	0.11095	0.00887
0.15746	0.01099	0.10558	0.01027	0.12497	0.01144	0.10062	0.00912	0.11376	0.00922
0.16112	0.01141	0.10849	0.01065	0.12904	0.01185	0.10372	0.00946	0.11721	0.00957
0.16461	0.01182	0.11178	0.01102	0.13260	0.01225	0.10670	0.00979	0.12069	0.00991
0.16834	0.01224	0.11499	0.01140	0.13616	0.01269	0.10973	0.01012	0.12374	0.01026
0.17131	0.01265	0.11795	0.01175	0.13952	0.01311	0.11276	0.01044	0.12684	0.01061
0.17483	0.01307	0.12088	0.01215	0.14301	0.01352	0.11567	0.01079	0.13034	0.01096
0.17787	0.01348	0.12433	0.01252	0.14651	0.01394	0.11861	0.01112	0.13336	0.01130
0.18135	0.01390	0.12719	0.01290	0.14971	0.01436	0.12128	0.01146	0.13629	0.01165
0.18439	0.01431	0.12976	0.01327	0.15278	0.01477	0.12398	0.01179	0.13934	0.01200
0.18785	0.01473	0.13266	0.01365	0.15686	0.01519	0.12706	0.01212	0.14267	0.01235
0.19075	0.01514	0.13578	0.01402	0.16045	0.01561	0.12981	0.01245	0.14563	0.01270
0.19410	0.01556	0.13861	0.01440	0.16345	0.01603	0.13248	0.01279	0.14876	0.01304
0.19686	0.01597	0.14133	0.01477	0.16649	0.01644	0.13501	0.01312	0.15172	0.01339
0.19990	0.01639	0.14403	0.01515	0.16963	0.01686	0.13767	0.01345	0.15497	0.01374
0.20283	0.01680	0.14673	0.01552	0.17283	0.01728	0.14020	0.01379	0.15790	0.01409
0.20559	0.01722	0.14954	0.01590	0.17616	0.01770	0.14321	0.01412	0.16057	0.01443
0.20860	0.01763	0.15216	0.01627	0.17911	0.01811	0.14588	0.01445	0.16319	0.01478
0.21102	0.01805	0.15460	0.01664	0.18250	0.01853	0.14839	0.01479	0.16609	0.01513
0.21357	0.01846	0.15741	0.01702	0.18503	0.01895	0.15097	0.01512	0.16917	0.01548
0.21682	0.01888	0.16019	0.01739	0.18862	0.01937	0.15348	0.01545	0.17181	0.01583
0.21944	0.01929	0.16301	0.01777	0.19140	0.01978	0.15594	0.01578	0.17428	0.01617
0.22175	0.01971	0.16548	0.01814	0.19437	0.02020	0.15840	0.01612	0.17753	0.01652
0.22438	0.02012	0.16821	0.01852	0.19748	0.02062	0.16091	0.01645	0.18020	0.01687
0.22704	0.02054	0.17068	0.01889	0.20029	0.02104	0.16349	0.01678	0.18310	0.01722
0.22980	0.02095	0.17328	0.01927	0.20301	0.02145	0.16570	0.01712	0.18580	0.01757
0.23184	0.02136	0.17580	0.01964	0.20537	0.02187	0.16839	0.01745	0.18862	0.01791
0.23419	0.02178	0.17863	0.02002	0.20834	0.02229	0.17053	0.01778	0.19164	0.01826
0.23688	0.02219	0.18112	0.02039	0.21148	0.02270	0.17306	0.01812	0.19394	0.01861
0.23892	0.02261	0.18364	0.02077	0.21400	0.02312	0.17562	0.01845	0.19626	0.01896
0.24095	0.02302	0.18593	0.02114	0.21672	0.02354	0.17775	0.01878	0.19922	0.01936
0.24316	0.02344	0.18807	0.02152	0.21944	0.02396	0.17997	0.01911	0.20161	0.01970
0.24530	0.02385	0.19087	0.02189	0.22183	0.02437	0.18205	0.01945	0.20437	0.02005
0.24727	0.02427	0.19339	0.02227	0.22422	0.02479	0.18449	0.01981	0.20670	0.02040
0.24872	0.02468	0.19552	0.02264	0.22639	0.02521	0.18686	0.02015	0.20925	0.02075
0.25110	0.02510	0.19805	0.02302	0.22911	0.02563	0.18906	0.02048	0.21164	0.02110
0.25356	0.02551	0.20031	0.02339	0.23166	0.02604	0.19134	0.02081	0.21437	0.02144
0.25473	0.02593	0.20270	0.02377	0.23418	0.02646	0.19354	0.02115	0.21635	0.02179
0.25566	0.02634	0.20494	0.02414	0.23645	0.02688	0.19581	0.02148	0.21897	0.02214
0.25670	0.02676	0.20707	0.02452	0.23887	0.02730	0.19804	0.02181	0.22109	0.02249
0.25756	0.02717	0.20939	0.02489	0.24098	0.02771	0.19991	0.02214	0.22359	0.02283
0.25784	0.02759	0.21173	0.02527	0.24331	0.02813	0.20223	0.02248	0.22555	0.02318
0.25767	0.02800	0.21366	0.02564	0.24557	0.02855	0.20436	0.02281	0.22799	0.02353
0.25698	0.02842	0.21572	0.02602	0.24787	0.02896	0.20663	0.02314	0.23037	0.02388
0.25615	0.02883	0.21806	0.02639	0.25023	0.02938	0.20864	0.02348	0.23259	0.02423
0.25456	0.02925	0.22022	0.02677	0.25188	0.02980	0.21080	0.02381	0.23448	0.02457
0.25176	0.02966	0.22245	0.02714	0.25382	0.03022	0.21283	0.02414	0.23629	0.02492
0.24924	0.03008	0.22443	0.02752	0.25563	0.03063	0.21489	0.02448	0.23868	0.02527
0.24706	0.03049	0.22629	0.02789	0.25754	0.03105	0.21697	0.02481	0.24101	0.02562
0.24451	0.03091	0.22827	0.02827	0.25970	0.03147	0.21887	0.02514	0.24310	0.02597

Continued...

Sample 1		Sample 2		Sample 3		Sample4		Sample5	
C/S Area = 28.96 sq.mm		C/S Area = 38.88 sq.mm		C/S Area = 30.92 sq.mm		C/S Area = 42.24 sq.mm		C/S Area = 34.8 sq.mm	
Original Length = 48.21mm		Original Length = 53.35mm		Original Length = 47.92mm		Original Length = 60.06mm		Original Length = 57.50mm	
Stress1	Strain1	Stress2	Strain2	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.24258	0.03132	0.23050	0.02864	0.26155	0.03189	0.22086	0.02547	0.24494	0.02631
0.23981	0.03174	0.23256	0.02902	0.26290	0.03230	0.22285	0.02581	0.24684	0.02666
0.23809	0.03215	0.23457	0.02939	0.26442	0.03272	0.22474	0.02614	0.24894	0.02701
0.23643	0.03257	0.23657	0.02977	0.26565	0.03314	0.22656	0.02647	0.25078	0.02736
0.23470	0.03298	0.23891	0.03014	0.26672	0.03356	0.22834	0.02681	0.25261	0.02770
0.23270	0.03340	0.24056	0.03052	0.26792	0.03397	0.23045	0.02714	0.25425	0.02805
0.23135	0.03381	0.24223	0.03089	0.26889	0.03439	0.23205	0.02747	0.25632	0.02840
0.22977	0.03423	0.24408	0.03127	0.27041	0.03481	0.23383	0.02781	0.25776	0.02875
0.22797	0.03464	0.24594	0.03164	0.27057	0.03523	0.23556	0.02814	0.25971	0.02910
0.22569	0.03505	0.24771	0.03201	0.27063	0.03564	0.23724	0.02847	0.26124	0.02944
0.22317	0.03547	0.24913	0.03239	0.27073	0.03606	0.23946	0.02880	0.26299	0.02979
0.22110	0.03588	0.25095	0.03276	0.26999	0.03648	0.24067	0.02914	0.26466	0.03014
0.21854	0.03630	0.25244	0.03314	0.26886	0.03689	0.24254	0.02947	0.26647	0.03049
0.21606	0.03671	0.25409	0.03351	0.26682	0.03731	0.24411	0.02980	0.26807	0.03083
0.21354	0.03713	0.25545	0.03389	0.26481	0.03773	0.24600	0.03014	0.26968	0.03118
0.21177	0.03754	0.25743	0.03426	0.26145	0.03815	0.24754	0.03047	0.27069	0.03153
0.20925	0.03796	0.25890	0.03464	0.25650	0.03856	0.24877	0.03080	0.27230	0.03188
0.20618	0.03837	0.26070	0.03501	0.24971	0.03898	0.25033	0.03114	0.27333	0.03223
0.20352	0.03879	0.26193	0.03539	0.23942	0.03940	0.25180	0.03147	0.27526	0.03257
0.20086	0.03920	0.26340	0.03576	0.22513	0.03982	0.25341	0.03180	0.27632	0.03292
0.19820	0.03962	0.26499	0.03614	0.20530	0.04023	0.25488	0.03213	0.27761	0.03327
0.19499	0.04003	0.26613	0.03651	End of Results		0.25672	0.03247	0.27888	0.03362
0.19161	0.04045	0.26708	0.03689			0.25798	0.03280	0.28014	0.03397
0.18823	0.04086	0.26803	0.03726			0.25904	0.03313	0.28129	0.03431
0.18432	0.04128	0.26896	0.03764			0.26030	0.03347	0.28227	0.03466
0.17980	0.04169	0.27001	0.03801			0.26188	0.03380	0.28302	0.03501
0.17358	0.04211	0.27058	0.03839			0.26338	0.03413	0.28411	0.03536
0.16540	0.04252	0.27137	0.03876			0.26439	0.03447	0.28511	0.03570
0.15401	0.04294	0.27251	0.03914			0.26553	0.03480	0.28572	0.03605
0.13874	0.04335	0.27307	0.03951			0.26700	0.03513	0.28615	0.03640
0.11968	0.04377	0.27287	0.03989			0.26813	0.03546	0.28698	0.03675
0.09506	0.04418	0.27299	0.04026			0.26913	0.03580	0.28727	0.03710
End of Results		0.27287	0.04064			0.27003	0.03613	0.28710	0.03744
		0.27271	0.04101			0.27124	0.03646	0.28727	0.03779
		0.27158	0.04139			0.27214	0.03680	0.28744	0.03814
		0.26965	0.04176			0.27296	0.03713	0.28759	0.03849
		0.26741	0.04214			0.27334	0.03746	0.28707	0.03883
		0.26394	0.04251			0.27427	0.03780	0.28615	0.03918
		0.25877	0.04289			0.27479	0.03813	0.28471	0.03953
		0.25116	0.04326			0.27536	0.03846	0.28388	0.03988
		0.24069	0.04364			0.27571	0.03879	0.28158	0.04023
		0.22659	0.04401			0.27623	0.03913	0.27917	0.04057
		0.20903	0.04439			0.27689	0.03946	0.27555	0.04092
		0.18645	0.04476			0.27718	0.03979	0.27109	0.04127
		End of Results				0.27739	0.04013	0.26537	0.04162
						0.27760	0.04046	0.25911	0.04197
						0.27782	0.04079	0.25152	0.04231
						0.27775	0.04113	0.24359	0.04266
						0.27739	0.04146	0.23402	0.04301
						0.27723	0.04179	0.22388	0.04336
						0.27711	0.04212	0.21152	0.04370
						0.27647	0.04246	End of Results	
						0.27538	0.04279		
						0.27427	0.04312		
						0.27294	0.04346		
						0.27114	0.04379		
						0.26851	0.04412		
						0.26480	0.04446		
						0.25978	0.04479		
						0.25284	0.04512		
						0.24368	0.04545		
						0.23232	0.04579		
						0.21986	0.04612		

Relation between Stress and Strain - 100% Moisture content

Mode	Measure Force in Tension
Option	Repeat Until Count
Pre-Speed	2.0mm/s
Test Speed	0.5mm/s
Post-Speed	10.0mm/s
Distance	10.0mm
Trigger Type	Auto
Trigger Force	0.10N

Sample 1		Sample 3		Sample4		Sample 5	
C/S Area = 26.72 sq.mm		C/S Area = 45.94 sq.mm		C/S Area = 40.9 sq.mm		C/S Area = 42.14 sq.mm	
Original Length = 42.09mm		Original Length = 71.75mm		Original Length = 73.50mm		Original Length = 56.45mm	
Stress1	Strain1	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.02347	0.00024	0.00246	0.00028	0.00196	0.00027	0.01070	0.00018
0.02743	0.00071	0.00538	0.00056	0.00445	0.00054	0.01241	0.00053
0.03361	0.00119	0.00808	0.00084	0.00692	0.00082	0.01569	0.00089
0.04053	0.00166	0.01117	0.00111	0.00936	0.00109	0.01891	0.00124
0.04678	0.00214	0.01369	0.00139	0.01183	0.00136	0.02181	0.00159
0.05337	0.00261	0.01661	0.00167	0.01399	0.00163	0.02513	0.00195
0.05917	0.00309	0.01926	0.00195	0.01623	0.00190	0.02824	0.00230
0.06441	0.00356	0.02209	0.00223	0.01848	0.00218	0.03142	0.00266
0.06976	0.00404	0.02499	0.00251	0.02064	0.00245	0.03405	0.00301
0.07519	0.00451	0.02717	0.00279	0.02267	0.00272	0.03673	0.00337
0.07994	0.00499	0.02943	0.00307	0.02482	0.00299	0.03951	0.00372
0.08454	0.00546	0.03261	0.00334	0.02685	0.00327	0.04229	0.00407
0.08851	0.00594	0.03452	0.00362	0.02895	0.00354	0.04445	0.00443
0.09255	0.00641	0.03714	0.00390	0.03064	0.00381	0.04718	0.00478
0.09644	0.00689	0.03933	0.00418	0.03279	0.00408	0.04967	0.00514
0.10007	0.00737	0.04186	0.00446	0.03467	0.00435	0.05206	0.00549
0.10337	0.00784	0.04417	0.00474	0.03665	0.00463	0.05418	0.00585
0.10674	0.00832	0.04645	0.00502	0.03822	0.00490	0.05641	0.00620
0.10992	0.00879	0.04876	0.00530	0.04020	0.00517	0.05876	0.00655
0.11272	0.00927	0.05098	0.00557	0.04213	0.00544	0.06106	0.00691
0.11497	0.00974	0.05305	0.00585	0.04372	0.00571	0.06293	0.00726
0.11800	0.01022	0.05512	0.00613	0.04518	0.00599	0.06545	0.00762
0.12070	0.01069	0.05734	0.00641	0.04692	0.00626	0.06766	0.00797
0.12362	0.01117	0.05962	0.00669	0.04858	0.00653	0.06953	0.00833
0.12496	0.01164	0.06173	0.00697	0.05039	0.00680	0.07155	0.00868
0.12758	0.01212	0.06365	0.00725	0.05176	0.00707	0.07326	0.00903
0.13016	0.01259	0.06569	0.00753	0.05342	0.00735	0.07546	0.00939
0.13200	0.01307	0.06798	0.00780	0.05535	0.00762	0.07748	0.00974
0.13350	0.01354	0.06979	0.00808	0.05689	0.00789	0.07905	0.01010
0.13518	0.01402	0.07183	0.00836	0.05866	0.00816	0.08106	0.01045
0.13761	0.01449	0.07403	0.00864	0.06061	0.00844	0.08296	0.01081
0.13941	0.01497	0.07564	0.00892	0.06244	0.00871	0.08486	0.01116
0.14079	0.01544	0.07780	0.00920	0.06411	0.00898	0.08654	0.01151
0.14270	0.01592	0.07973	0.00948	0.06560	0.00925	0.08832	0.01187
0.14416	0.01639	0.08152	0.00976	0.06741	0.00952	0.09010	0.01222
0.14562	0.01687	0.08309	0.01003	0.06910	0.00980	0.09200	0.01258
0.14644	0.01734	0.08513	0.01031	0.07081	0.01007	0.09357	0.01293
0.14779	0.01782	0.08698	0.01059	0.07225	0.01034	0.09509	0.01329
0.14903	0.01829	0.08859	0.01087	0.07369	0.01061	0.09699	0.01364
0.15037	0.01877	0.09031	0.01115	0.07548	0.01088	0.09877	0.01399
0.15097	0.01924	0.09197	0.01143	0.07689	0.01116	0.10045	0.01435
0.15232	0.01972	0.09375	0.01171	0.07846	0.01143	0.10197	0.01470
0.15322	0.02019	0.09528	0.01199	0.07978	0.01170	0.10368	0.01506
0.15382	0.02067	0.09717	0.01226	0.08149	0.01197	0.10543	0.01541
0.15434	0.02115	0.09898	0.01254	0.08259	0.01224	0.10669	0.01577
0.15438	0.02162	0.10037	0.01282	0.08406	0.01252	0.10802	0.01612
0.15539	0.02210	0.10194	0.01310	0.08584	0.01279	0.10978	0.01647
0.15558	0.02257	0.10348	0.01338	0.08729	0.01306	0.11146	0.01683
0.15535	0.02305	0.10531	0.01366	0.08880	0.01333	0.11296	0.01718
0.15543	0.02352	0.10681	0.01394	0.09024	0.01361	0.11443	0.01754
0.15591	0.02400	0.10838	0.01422	0.09174	0.01388	0.11573	0.01789
0.15524	0.02447	0.10977	0.01449	0.09301	0.01415	0.11747	0.01825
0.15494	0.02495	0.11141	0.01477	0.09440	0.01442	0.11872	0.01860
0.15430	0.02542	0.11276	0.01505	0.09589	0.01469	0.12010	0.01895
0.15356	0.02590	0.11450	0.01533	0.09714	0.01497	0.12117	0.01931
0.15311	0.02637	0.11563	0.01561	0.09846	0.01524	0.12257	0.01966
0.15213	0.02685	0.11722	0.01589	0.09985	0.01551	0.12418	0.02002
0.15034	0.02732	0.11855	0.01617	0.10137	0.01578	0.12546	0.02037
0.14832	0.02780	0.12013	0.01645	0.10271	0.01605	0.12672	0.02073
0.14656	0.02827	0.12140	0.01672	0.10374	0.01633	0.12812	0.02108
0.14420	0.02875	0.12303	0.01700	0.10479	0.01660	0.12940	0.02143
0.14072	0.02922	0.12429	0.01728	0.10621	0.01687	0.13030	0.02179
0.13716	0.02970	0.12558	0.01756	0.10775	0.01714	0.13168	0.02214
0.13353	0.03017	0.12680	0.01784	0.10897	0.01741	0.13282	0.02250
0.12837	0.03065	0.12795	0.01812	0.11022	0.01769	0.13379	0.02285
0.12234	0.03112	0.12917	0.01840	0.11161	0.01796	0.13543	0.02321
End of Results		0.13034	0.01868	0.11269	0.01823	0.13636	0.02356
		0.13178	0.01895	0.11386	0.01850	0.13747	0.02391
		0.13285	0.01923	0.11513	0.01878	0.13859	0.02427
		0.13404	0.01951	0.11638	0.01905	0.13949	0.02462
		0.13531	0.01979	0.11741	0.01932	0.14063	0.02498
		0.13640	0.02007	0.11851	0.01959	0.14165	0.02533
		0.13737	0.02035	0.11980	0.01986	0.14279	0.02569
		0.13866	0.02063	0.12093	0.02014	0.14381	0.02604
		0.13977	0.02091	0.12188	0.02041	0.14454	0.02640
		0.14077	0.02118	0.12303	0.02068	0.14547	0.02675

Continued...

Sample 1		Sample 3		Sample4		Sample 5	
C/S Area = 26.72 sq.mm		C/S Area = 45.94 sq.mm		C/S Area = 40.9 sq.mm		C/S Area = 42.14 sq.mm	
Original Length = 42.09mm		Original Length = 71.75mm		Original Length = 73.50mm		Original Length = 56.45mm	
Stress1	Strain1	Stress3	Strain3	Stress4	Strain4	Stress5	Strain5
		0.14168	0.02146	0.12435	0.02095	0.14627	0.02710
		0.14264	0.02174	0.12538	0.02122	0.14713	0.02746
		0.14384	0.02202	0.12645	0.02150	0.14808	0.02781
		0.14486	0.02230	0.12741	0.02177	0.14903	0.02817
		0.14567	0.02258	0.12834	0.02204	0.14957	0.02852
		0.14665	0.02286	0.12949	0.02231	0.15047	0.02888
		0.14756	0.02314	0.13056	0.02259	0.15095	0.02923
		0.14850	0.02341	0.13137	0.02286	0.15123	0.02958
		0.14917	0.02369	0.13252	0.02313	0.15185	0.02994
		0.15000	0.02397	0.13347	0.02340	0.15249	0.03029
		0.15098	0.02425	0.13445	0.02367	0.15280	0.03065
		0.15187	0.02453	0.13526	0.02395	0.15304	0.03100
		0.15242	0.02481	0.13619	0.02422	0.15354	0.03136
		0.15309	0.02509	0.13733	0.02449	0.15320	0.03171
		0.15403	0.02537	0.13797	0.02476	0.15316	0.03206
		0.15461	0.02564	0.13866	0.02503	0.15285	0.03242
		0.15529	0.02592	0.14000	0.02531	0.15233	0.03277
		0.15586	0.02620	0.14073	0.02558	0.15187	0.03313
		0.15660	0.02648	0.14171	0.02585	0.15102	0.03348
		0.15716	0.02676	0.14225	0.02612	0.14962	0.03384
		0.15790	0.02704	0.14318	0.02639	0.14808	0.03419
		0.15795	0.02732	0.14384	0.02667	0.14563	0.03454
		0.15901	0.02760	0.14491	0.02694	0.14283	0.03490
		0.15932	0.02787	0.14545	0.02721	0.13906	0.03525
		0.15962	0.02815	0.14606	0.02748	0.13474	0.03561
		0.15969	0.02843	0.14699	0.02776	0.12907	0.03596
		0.15999	0.02871	0.14802	0.02803	0.12190	0.03632
		0.16032	0.02899	0.14890	0.02830	0.11336	0.03667
		0.16062	0.02927	0.14932	0.02857	0.10316	0.03702
		0.16080	0.02955	0.14990	0.02884	End of Results	
		0.16114	0.02983	0.15051	0.02912		
		0.16082	0.03010	0.15130	0.02939		
		0.16091	0.03038	0.15188	0.02966		
		0.16071	0.03066	0.15267	0.02993		
		0.16064	0.03094	0.15335	0.03020		
		0.16043	0.03122	0.15411	0.03048		
		0.16003	0.03150	0.15455	0.03075		
		0.15977	0.03178	0.15504	0.03102		
		0.15962	0.03206	0.15575	0.03129		
		0.15951	0.03233	0.15621	0.03156		
		0.15901	0.03261	0.15685	0.03184		
		0.15823	0.03289	0.15733	0.03211		
		0.15760	0.03317	0.15773	0.03238		
		0.15694	0.03345	0.15844	0.03265		
		0.15592	0.03373	0.15885	0.03293		
		0.15496	0.03401	0.15932	0.03320		
		0.15381	0.03429	0.15963	0.03347		
		0.15274	0.03456	0.16005	0.03374		
		0.15131	0.03484	0.16054	0.03401		
		0.14989	0.03512	0.16076	0.03429		
		0.14743	0.03540	0.16112	0.03456		
		0.14549	0.03568	0.16161	0.03483		
		0.14303	0.03596	0.16171	0.03510		
		0.14027	0.03624	0.16205	0.03537		
		0.13696	0.03652	0.16235	0.03565		
		0.13328	0.03679	0.16235	0.03592		
		0.12926	0.03707	0.16269	0.03619		
		0.12451	0.03735	0.16262	0.03646		
		0.11966	0.03763	0.16257	0.03673		
		0.11452	0.03791	0.16308	0.03701		
		0.10916	0.03819	0.16296	0.03728		
		0.10374	0.03847	0.16264	0.03755		
		0.09861	0.03875	0.16269	0.03782		
		0.09330	0.03902	0.16247	0.03810		
		End of Results		0.16232	0.03837		
				0.16183	0.03864		
				0.16134	0.03891		
				0.16125	0.03918		
				0.16027	0.03946		
				0.15961	0.03973		
				0.15873	0.04000		
				0.15763	0.04027		
				0.15648	0.04054		
				0.15469	0.04082		
				0.15313	0.04109		
				0.15088	0.04136		
				0.14834	0.04163		
				0.14570	0.04190		
				0.14208	0.04218		
				0.13839	0.04245		
				0.13430	0.04272		
				0.12993	0.04299		
				0.12504	0.04327		
				0.12002	0.04354		
				0.11545	0.04381		
				0.11032	0.04408		
				0.10526	0.04435		

Stress and Strain Relation - Brought up to 60, 80 and 100% MC and dried to 20% Moisture Content

Sample 60-1	Area = 31.96 sq.mm	Sample 80-1	Area = 19.68 sq.mm	Sample 100-1	Area = 24.4 sq.mm
	Original Length = 62.39mm		Original Length = 38.21mm		Original Length = 50.09mm
Sample 60-2	Area = 17.8 sq.mm	Sample 80-2	Area = 24.84 sq.mm	Sample 100-2	Area = 28.44 sq.mm
	Original Length = 52.63mm		Original Length = 71.35mm		Original Length = 57.21mm
Sample 60-3	Area = 27.28 sq.mm	Sample 80-3	Area = 26.76 sq.mm	Sample 100-3	Area = 25.92 sq.mm
	Original Length = 61.93mm		Original Length = 38.92mm		Original Length = 55.75mm

60% to 20% Samples						80% to 20% Samples						100% to 20% Samples					
Stress 1-1	Strain 1-1	Stress 1-2	Strain 1-2	Stress 1-3	Strain 1-3	Stress 2-1	Strain 2-1	Stress 2-2	Strain 2-2	Stress 2-3	Strain 2-3	Stress 3-1	Strain 3-1	Stress 3-2	Strain 3-2	Stress 3-3	Strain 3-3
0.000	0.0000	0.190	0.0006	0.000	0.0000	0.321	0.0002	0.000	0.0000	0.314	0.0008	0.103	0.0002	0.000	0.0000	0.000	0.0000
0.010	0.0003	0.201	0.0010	0.004	0.0003	0.336	0.0007	0.003	0.0003	0.338	0.0013	0.113	0.0006	0.027	0.0002	0.012	0.0004
0.021	0.0006	0.211	0.0013	0.014	0.0006	0.356	0.0013	0.012	0.0006	0.363	0.0018	0.124	0.0010	0.035	0.0005	0.028	0.0007
0.031	0.0010	0.220	0.0017	0.025	0.0010	0.376	0.0018	0.020	0.0008	0.387	0.0023	0.135	0.0014	0.043	0.0009	0.043	0.0011
0.042	0.0013	0.228	0.0021	0.035	0.0013	0.394	0.0023	0.028	0.0011	0.412	0.0028	0.146	0.0017	0.050	0.0012	0.058	0.0014
0.053	0.0016	0.235	0.0025	0.045	0.0016	0.410	0.0028	0.035	0.0014	0.435	0.0033	0.158	0.0022	0.056	0.0016	0.072	0.0018
0.064	0.0019	0.240	0.0029	0.056	0.0019	0.428	0.0033	0.040	0.0017	0.458	0.0039	0.169	0.0026	0.063	0.0019	0.085	0.0022
0.075	0.0022	0.244	0.0032	0.065	0.0023	0.444	0.0039	0.046	0.0020	0.481	0.0044	0.180	0.0030	0.069	0.0023	0.097	0.0025
0.085	0.0026	0.252	0.0036	0.073	0.0026	0.458	0.0044	0.054	0.0022	0.502	0.0049	0.191	0.0034	0.074	0.0026	0.110	0.0029
0.094	0.0029	0.262	0.0040	0.081	0.0029	0.471	0.0049	0.063	0.0025	0.522	0.0054	0.201	0.0038	0.082	0.0030	0.120	0.0032
0.103	0.0032	0.272	0.0044	0.087	0.0032	0.485	0.0054	0.074	0.0028	0.543	0.0059	0.212	0.0042	0.092	0.0033	0.131	0.0036
0.110	0.0035	0.283	0.0048	0.094	0.0036	0.497	0.0060	0.084	0.0031	0.561	0.0064	0.222	0.0046	0.101	0.0037	0.139	0.0039
0.116	0.0038	0.293	0.0051	0.100	0.0039	0.509	0.0065	0.094	0.0034	0.578	0.0069	0.231	0.0050	0.111	0.0040	0.147	0.0043
0.121	0.0042	0.304	0.0055	0.106	0.0042	0.520	0.0070	0.104	0.0036	0.595	0.0075	0.240	0.0054	0.120	0.0044	0.155	0.0047
0.126	0.0045	0.314	0.0059	0.113	0.0045	0.532	0.0075	0.113	0.0039	0.610	0.0080	0.249	0.0057	0.127	0.0047	0.162	0.0050
0.131	0.0048	0.324	0.0063	0.120	0.0048	0.542	0.0081	0.123	0.0042	0.625	0.0085	0.258	0.0061	0.132	0.0051	0.168	0.0054
0.136	0.0051	0.334	0.0067	0.126	0.0052	0.553	0.0086	0.132	0.0045	0.640	0.0090	0.266	0.0065	0.139	0.0054	0.173	0.0057
0.140	0.0054	0.344	0.0070	0.133	0.0055	0.563	0.0091	0.139	0.0048	0.654	0.0095	0.274	0.0069	0.144	0.0058	0.178	0.0061
0.145	0.0058	0.352	0.0074	0.141	0.0058	0.573	0.0096	0.146	0.0050	0.668	0.0100	0.281	0.0073	0.150	0.0061	0.186	0.0065
0.150	0.0061	0.360	0.0078	0.149	0.0061	0.580	0.0102	0.154	0.0053	0.680	0.0105	0.289	0.0077	0.156	0.0065	0.197	0.0068
0.156	0.0064	0.369	0.0082	0.157	0.0065	0.588	0.0107	0.161	0.0056	0.693	0.0110	0.296	0.0081	0.162	0.0068	0.207	0.0072
0.164	0.0067	0.378	0.0086	0.164	0.0068	0.597	0.0112	0.169	0.0059	0.706	0.0116	0.302	0.0085	0.169	0.0072	0.217	0.0075
0.173	0.0071	0.387	0.0089	0.172	0.0071	0.606	0.0117	0.176	0.0062	0.719	0.0121	0.309	0.0089	0.178	0.0075	0.226	0.0079
0.182	0.0074	0.395	0.0093	0.180	0.0074	0.612	0.0122	0.182	0.0064	0.730	0.0126	0.316	0.0093	0.186	0.0079	0.235	0.0083
0.191	0.0077	0.404	0.0097	0.188	0.0078	0.620	0.0128	0.188	0.0067	0.741	0.0131	0.323	0.0097	0.194	0.0082	0.244	0.0086
0.199	0.0080	0.413	0.0101	0.195	0.0081	0.626	0.0133	0.195	0.0070	0.752	0.0136	0.328	0.0101	0.203	0.0086	0.253	0.0090
0.207	0.0083	0.422	0.0105	0.202	0.0084	0.633	0.0138	0.203	0.0073	0.763	0.0141	0.334	0.0105	0.211	0.0089	0.261	0.0093
0.216	0.0087	0.431	0.0108	0.209	0.0087	0.639	0.0143	0.213	0.0076	0.772	0.0146	0.340	0.0109	0.220	0.0093	0.268	0.0097
0.225	0.0090	0.440	0.0112	0.216	0.0090	0.644	0.0149	0.223	0.0078	0.781	0.0152	0.346	0.0113	0.229	0.0096	0.275	0.0100
0.233	0.0093	0.449	0.0116	0.222	0.0094	0.649	0.0154	0.232	0.0081	0.788	0.0157	0.351	0.0117	0.237	0.0100	0.283	0.0104
0.240	0.0096	0.458	0.0120	0.230	0.0097	0.654	0.0159	0.242	0.0084	0.795	0.0162	0.357	0.0121	0.245	0.0103	0.289	0.0108
0.249	0.0099	0.465	0.0124	0.238	0.0100	0.657	0.0164	0.251	0.0087	0.801	0.0167	0.362	0.0125	0.254	0.0107	0.296	0.0111
0.256	0.0103	0.474	0.0127	0.245	0.0103	0.661	0.0170	0.260	0.0090	0.807	0.0172	0.367	0.0129	0.262	0.0110	0.302	0.0115
0.263	0.0106	0.483	0.0132	0.251	0.0107	0.664	0.0175	0.268	0.0093	0.812	0.0177	0.372	0.0133	0.271	0.0114	0.309	0.0118
0.270	0.0109	0.491	0.0135	0.258	0.0110	0.667	0.0180	0.277	0.0095	0.819	0.0182	0.376	0.0137	0.280	0.0117	0.315	0.0122
0.275	0.0112	0.499	0.0139	0.265	0.0113	0.669	0.0185	0.286	0.0098	0.822	0.0188	0.381	0.0141	0.288	0.0121	0.322	0.0126
0.281	0.0115	0.506	0.0143	0.271	0.0116	0.668	0.0191	0.295	0.0101	0.827	0.0193	0.385	0.0145	0.296	0.0124	0.328	0.0129
0.287	0.0119	0.514	0.0147	0.277	0.0119	0.669	0.0196	0.302	0.0104	0.831	0.0198	0.389	0.0149	0.304	0.0128	0.334	0.0133
0.291	0.0122	0.521	0.0151	0.282	0.0123	0.665	0.0201	0.311	0.0107	0.837	0.0203	0.392	0.0153	0.311	0.0131	0.340	0.0136
0.295	0.0125	0.529	0.0154	0.288	0.0126	0.660	0.0206	0.318	0.0109	0.842	0.0208	0.396	0.0157	0.319	0.0135	0.346	0.0140
0.299	0.0128	0.537	0.0158	0.294	0.0129	0.653	0.0211	0.326	0.0112	0.846	0.0213	0.400	0.0161	0.326	0.0138	0.351	0.0143
0.303	0.0131	0.545	0.0162	0.299	0.0132	0.644	0.0217	0.333	0.0115	0.851	0.0218	0.403	0.0165	0.332	0.0142	0.356	0.0147
0.306	0.0135	0.552	0.0166	0.303	0.0136	0.634	0.0222	0.340	0.0118	0.855	0.0224	0.406	0.0169	0.339	0.0145	0.362	0.0151
0.309	0.0138	0.559	0.0170	0.309	0.0139	0.621	0.0227	0.347	0.0121	0.858	0.0229	0.409	0.0173	0.346	0.0149	0.367	0.0154
0.314	0.0141	0.566	0.0173	0.314	0.0142	0.605	0.0232	0.353	0.0123	0.858	0.0234	0.411	0.0177	0.352	0.0152	0.371	0.0158
0.320	0.0144	0.573	0.0177	0.318	0.0145	0.584	0.0238	0.359	0.0126	0.859	0.0239	0.413	0.0181	0.359	0.0156	0.376	0.0161
0.328	0.0147	0.581	0.0181	0.323	0.0149	End of Results		0.365	0.0129	0.859	0.0244	0.415	0.0185	0.365	0.0159	0.381	0.0165
0.335	0.0151	0.587	0.0185	0.328	0.0152			0.373	0.0132	0.858	0.0249	0.416	0.0189	0.372	0.0163	0.385	0.0169
0.343	0.0154	0.593	0.0189	0.334	0.0155			0.380	0.0135	0.854	0.0254	0.418	0.0193	0.379	0.0166	0.389	0.0172
0.351	0.0157	0.599	0.0192	0.337	0.0158			0.387	0.0137	0.849	0.0260	0.419	0.0197	0.385	0.0170	0.392	0.0176
0.358	0.0160	0.606	0.0196	0.341	0.0161			0.394	0.0140	0.838	0.0265	0.419	0.0201	0.391	0.0173	0.395	0.0179
0.365	0.0163	0.611	0.0200	0.345	0.0165			0.401	0.0143	0.826	0.0270	0.418	0.0205	0.397	0.0177	0.398	0.0183
0.372	0.0167	0.616	0.0204	0.351	0.0168			0.409	0.0146	0.811	0.0275	0.418	0.0209	0.403	0.0180	0.403	0.0187
0.379	0.0170	0.621	0.0208	0.357	0.0171			0.417	0.0149	0.796	0.0280	0.416	0.0213	0.408	0.0184	0.407	0.0190
0.385	0.0173	0.627	0.0211	0.365	0.0174			0.424	0.0151	0.779	0.0285	0.415	0.0217	0.413	0.0187	0.411	0.0194
0.390	0.0176	0.631	0.0215	0.372	0.0178			0.431	0.0154	0.765	0.0290	0.411	0.0221	0.418	0.0191	0.415	0.0197
0.397	0.0180	0.638	0.0219	0.379	0.0181			0.440	0.0157	End of Results		0.407	0.0225	0.423	0.0194	0.418	0.0201
0.403	0.0183	0.645	0.0223	0.384	0.0184			0.448	0.0160			0.403	0.0229	0.427	0.0198	0.420	0.0204
0.410	0.0186	0.651	0.0227	0.390	0.0187			0.455	0.0163			0.396	0.0233	0.431	0.0201	0.422	0.0208
0.416	0.0189	0.658	0.0230	0.397	0.0191			0.463	0.0165			0.389	0.0237	0.435	0.0205	0.424	0.0212
0.422	0.0192	0.664	0.0234	0.402	0.0194			0.471	0.0168			0.379	0.0241	0.439	0.0208	0.425	0.0215
0.429	0.0196	0.670	0.0238	0.407	0.0197			0.478	0.0171			0.369	0.0245	0.442	0.0212	0.425	0.0219
0.436	0.0199	0.676	0.0242	0.411	0.0200			0.485	0.0174			0.357	0.0249	0.445	0.0215	0.425	0.0222
0.443	0.0202	0.682	0.0246	0.415	0.0203			0.492	0.0177			End of Results		0.448	0.0218	0.425	0.0226
0.451	0.0205	0.688	0.0249	0.420	0.0207			0.500	0.0179					0.451	0.0222	0.423	0.0230
0.458	0.0208	0.694	0.0253	0.424	0.0210			0.507	0.0182					0.452	0.0225	0.420	0.0233
0.465	0.0212	0.702	0.0257	0.429	0.0213			0.514	0.0185					0.453	0.0229	0.416	0.0237
0.472	0.0215	0.708	0.0261	0.435	0.0216			0.520	0.0188					0.454	0.0232	0.412	0.0240
0.478	0.0218	0.715	0.0265	0.442	0.0220			0.527	0.0191					0.454	0.0236	0.404	0.0244
0.485	0.0221	0.722	0.0268	0.448	0.0223			0.535	0.0193					0.451	0.0239	0.395	0.0248
0.492	0.0224	0.729	0.0272	0.454	0.0226			0.542	0.0196					0.448	0.0243	0.383	0.0251
0.499	0.0228	0.735	0.0276	0.459	0.0229			0.549	0.0199					0.443	0.0246	0.368	0.0255
0.505	0.0231	0.741	0.0280	0.464	0.0233			0.556	0.0202					0.437	0.0250	0.349	0.0258
0.512	0.0234	0.747	0.0284	0.470	0.0236			0.563	0.0205					0.431	0.0253	End of Results	
0.518	0.0237	0.752	0.0287	0.475	0.0239			0.569	0.0207					0.422	0.0257		
0.525	0.0240	0.758	0.0291	0.480	0.0242			0.575	0.0210					0.412	0.0260		
0.531	0.0244	0.763	0.0295	0.485	0.0245			0.581	0.0213					End of Results			
0.538	0.0247	0.768	0.0299	0.490	0.0249			0.587	0.0216								
0.543	0.0250	0.772	0.0303	0.495	0.0252			0.593	0.0219								
0.549	0.0253	0.777	0.0306	0.500	0.0255			0.598	0.0221								

Continued...

60% to 20% Samples						80% to 20% Samples						100% to 20% Samples					
Stress 1-1	Strain 1-1	Stress 1-2	Strain 1-2	Stress 1-3	Strain 1-3	Stress 2-1	Strain 2-1	Stress 2-2	Strain 2-2	Stress 2-3	Strain 2-3	Stress 3-1	Strain 3-1	Stress 3-2	Strain 3-2	Stress 3-3	Strain 3-3
0.554	0.0256	0.782	0.0310	0.506	0.0258			0.602	0.0224								
0.559	0.0260	0.787	0.0314	0.513	0.0262			0.608	0.0227								
0.564	0.0263	0.793	0.0318	0.520	0.0265			0.614	0.0230								
0.569	0.0266	0.801	0.0322	0.526	0.0268			0.618	0.0233								
0.573	0.0269	0.808	0.0325	0.532	0.0271			0.623	0.0235								
0.578	0.0272	0.815	0.0329	0.538	0.0275			0.628	0.0238								
0.582	0.0276	0.821	0.0333	0.544	0.0278			0.633	0.0241								
0.587	0.0279	0.828	0.0337	0.549	0.0281			0.638	0.0244								
0.593	0.0282	0.834	0.0341	0.555	0.0284			0.642	0.0247								
0.598	0.0285	0.840	0.0344	0.560	0.0287			0.648	0.0249								
0.604	0.0289	0.847	0.0348	0.566	0.0291			0.654	0.0252								
0.610	0.0292	0.853	0.0352	0.572	0.0294			0.659	0.0255								
0.615	0.0295	0.859	0.0356	0.578	0.0297			0.663	0.0258								
0.619	0.0298	0.865	0.0360	0.584	0.0300			0.668	0.0261								
0.625	0.0301	0.870	0.0363	0.591	0.0304			0.674	0.0263								
0.630	0.0305	0.876	0.0367	0.596	0.0307			0.680	0.0266								
0.635	0.0308	0.881	0.0371	0.602	0.0310			0.685	0.0269								
0.639	0.0311	0.888	0.0375	0.609	0.0313			0.693	0.0272								
0.645	0.0314	0.893	0.0379	0.614	0.0316			0.700	0.0275								
0.651	0.0317	0.897	0.0382	0.621	0.0320			0.705	0.0278								
0.657	0.0321	0.902	0.0386	0.627	0.0323			0.711	0.0280								
0.663	0.0324	0.908	0.0390	0.633	0.0326			0.717	0.0283								
0.670	0.0327	0.912	0.0394	0.639	0.0329			0.724	0.0286								
0.677	0.0330	0.917	0.0398	0.645	0.0333			0.729	0.0289								
0.684	0.0333	0.922	0.0401	0.651	0.0336			0.735	0.0292								
0.690	0.0337	0.926	0.0405	0.657	0.0339			0.741	0.0294								
0.698	0.0340	0.930	0.0409	0.663	0.0342			0.747	0.0297								
0.704	0.0343	0.934	0.0413	0.670	0.0346			0.753	0.0300								
0.710	0.0346	0.938	0.0417	0.675	0.0349			0.757	0.0303								
0.716	0.0349	0.941	0.0420	0.681	0.0352			0.763	0.0306								
0.723	0.0353	0.945	0.0424	0.687	0.0355			0.768	0.0308								
0.729	0.0356	0.947	0.0428	0.693	0.0358			0.773	0.0311								
0.736	0.0359	0.949	0.0432	0.699	0.0362			0.778	0.0314								
0.742	0.0362	0.950	0.0436	0.704	0.0365			0.784	0.0317								
0.749	0.0365	0.953	0.0439	0.710	0.0368			0.790	0.0320								
0.757	0.0369	0.954	0.0443	0.715	0.0371			0.794	0.0322								
0.762	0.0372	0.956	0.0447	0.720	0.0375			0.799	0.0325								
0.768	0.0375	0.957	0.0451	0.726	0.0378			0.804	0.0328								
0.775	0.0378	0.958	0.0455	0.732	0.0381			0.809	0.0331								
0.781	0.0381	0.958	0.0458	0.737	0.0384			0.814	0.0334								
0.787	0.0385	0.957	0.0462	0.742	0.0388			0.818	0.0336								
0.793	0.0388	0.955	0.0466	0.746	0.0391			0.823	0.0339								
0.799	0.0391	0.953	0.0470	0.751	0.0394			0.827	0.0342								
0.805	0.0394	0.949	0.0474	0.755	0.0397			0.832	0.0345								
0.811	0.0397	0.944	0.0477	0.759	0.0400			0.835	0.0348								
0.817	0.0401	0.939	0.0481	0.763	0.0404			0.838	0.0350								
0.822	0.0404	0.932	0.0485	0.768	0.0407			0.842	0.0353								
0.828	0.0407	0.924	0.0489	0.772	0.0410			0.844	0.0356								
0.834	0.0410	0.913	0.0493	0.777	0.0413			0.845	0.0359								
0.840	0.0414	0.902	0.0496	0.781	0.0417			0.845	0.0362								
0.845	0.0417	0.891	0.0500	0.787	0.0420			0.842	0.0364								
0.851	0.0420	0.876	0.0504	0.792	0.0423			0.837	0.0367								
0.857	0.0423	0.859	0.0508	0.798	0.0426			0.832	0.0370								
0.863	0.0426	0.843	0.0512	0.803	0.0430			0.823	0.0373								
0.869	0.0430	End of Results		0.809	0.0433			0.813	0.0376								
0.874	0.0433			0.814	0.0436			0.800	0.0378								
0.881	0.0436			0.819	0.0439			0.784	0.0381								
0.887	0.0439			0.824	0.0442			0.763	0.0384								
0.892	0.0442			0.829	0.0446			0.734	0.0387								
0.898	0.0446			0.834	0.0449			End of Results									
0.903	0.0449			0.838	0.0452												
0.910	0.0452			0.842	0.0455												
0.915	0.0455			0.847	0.0459												
0.920	0.0458			0.852	0.0462												
0.927	0.0462			0.856	0.0465												
0.933	0.0465			0.860	0.0468												
0.938	0.0468			0.864	0.0472												
0.944	0.0471			0.870	0.0475												
0.950	0.0474			0.875	0.0478												
0.956	0.0478			0.880	0.0481												
0.962	0.0481			0.886	0.0484												
0.967	0.0484			0.892	0.0488												
0.973	0.0487			0.897	0.0491												
0.978	0.0490			0.903	0.0494												
0.984	0.0494			0.908	0.0497												
0.989	0.0497			0.915	0.0501												
0.994	0.0500			0.920	0.0504												
1.000	0.0503			0.926	0.0507												
1.005	0.0506			0.931	0.0510												
1.009	0.0510			0.937	0.0513												
1.015	0.0513			0.943	0.0517												
1.021	0.0516			0.948	0.0520												
1.026	0.0519			0.953	0.0523												
1.031	0.0523			0.961	0.0526												
1.037	0.0526			0.966	0.0530												
1.042	0.0529			0.972	0.0533												
1.048	0.0532			0.977	0.0536												
1.053	0.0535			0.982	0.0539												
1.058	0.0539			0.987	0.0543												

Continued...

60% to 20% Samples						80% to 20% Samples						100% to 20% Samples					
Stress 1-1	Strain 1-1	Stress 1-2	Strain 1-2	Stress 1-3	Strain 1-3	Stress 2-1	Strain 2-1	Stress 2-2	Strain 2-2	Stress 2-3	Strain 2-3	Stress 3-1	Strain 3-1	Stress 3-2	Strain 3-2	Stress 3-3	Strain 3-3
1.064	0.0542			0.992	0.0546												
1.069	0.0545			0.997	0.0549												
1.074	0.0548			1.002	0.0552												
1.079	0.0551			1.008	0.0555												
1.085	0.0555			1.013	0.0559												
1.089	0.0558			1.017	0.0562												
1.093	0.0561			1.022	0.0565												
1.098	0.0564			1.028	0.0568												
1.103	0.0567			1.033	0.0572												
1.108	0.0571			1.038	0.0575												
1.113	0.0574			1.043	0.0578												
1.117	0.0577			1.049	0.0581												
1.123	0.0580			1.054	0.0585												
1.128	0.0583			1.058	0.0588												
1.132	0.0587			1.063	0.0591												
1.136	0.0590			1.068	0.0594												
1.141	0.0593			1.073	0.0597												
1.146	0.0596			1.078	0.0601												
1.151	0.0599			1.082	0.0604												
1.155	0.0603			1.088	0.0607												
1.159	0.0606			1.093	0.0610												
1.164	0.0609			1.098	0.0614												
1.168	0.0612			1.102	0.0617												
1.172	0.0615			1.107	0.0620												
1.176	0.0619			1.112	0.0623												
1.181	0.0622			1.117	0.0627												
1.185	0.0625			1.122	0.0630												
1.189	0.0628			1.126	0.0633												
1.192	0.0632			1.131	0.0636												
1.196	0.0635			1.135	0.0639												
1.200	0.0638			1.139	0.0643												
1.204	0.0641			1.142	0.0646												
1.207	0.0644			1.147	0.0649												
1.210	0.0648			1.151	0.0652												
1.214	0.0651			1.155	0.0656												
1.217	0.0654			1.158	0.0659												
1.219	0.0657			1.163	0.0662												
1.222	0.0660			1.167	0.0665												
1.225	0.0664			1.170	0.0668												
1.227	0.0667			1.173	0.0672												
1.229	0.0670			1.178	0.0675												
1.232	0.0673			1.181	0.0678												
1.234	0.0676			1.184	0.0681												
1.236	0.0680			1.187	0.0685												
1.238	0.0683			1.190	0.0688												
1.241	0.0686			1.194	0.0691												
1.242	0.0689			1.196	0.0694												
1.244	0.0692			1.199	0.0698												
1.245	0.0696			1.201	0.0701												
1.246	0.0699			1.203	0.0704												
1.248	0.0702			1.205	0.0707												
1.248	0.0705			1.206	0.0710												
1.248	0.0708			1.207	0.0714												
1.247	0.0712			1.207	0.0717												
1.246	0.0715			1.206	0.0720												
1.245	0.0718			1.204	0.0723												
1.243	0.0721			1.199	0.0727												
1.241	0.0724			1.192	0.0730												
1.240	0.0728			1.184	0.0733												
1.237	0.0731			1.174	0.0736												
1.232	0.0734			1.161	0.0740												
1.226	0.0737			1.144	0.0743												
1.219	0.0741			1.119	0.0746												
1.210	0.0744			End of Results													
1.200	0.0747																
1.186	0.0750																
1.170	0.0753																
1.148	0.0757																
1.118	0.0760																
1.076	0.0763																

Creep Tests on Paper Pulp Material

Sample 1

Thickness = 1.647mm Original Length = 66.87mm
Area = 32.93 sq.mm Temp = 25.3 C
Load = 54.5 N RH = 41.2
Stress = 1.655 N/sq.mm % of Moisture Content = 5.73

Time	Displacement X 0.01	Strain
0	15	0.00224
5	21	0.00314
10	26	0.00389
15	31	0.00464
30	35	0.00523
60	38	0.00568
120	41	0.00613
1560	61	0.00912
3000	81	0.01211
3030	83	0.01241
3045	86	0.01286
3050	89	0.01331
3040	93	0.01391
3045	100	0.01495

Sample 2:

Thickness = 1.335mm Original Length = 64.23mm
Area = 26.7 sq.mm Temp = 21.5 C
Load = 54.5 N RH = 57.27
Stress = 2.041 N/sq.mm % of Moisture Content = 7.89

Time	Displacement X 0.01	Strain
0	18	0.0028
5	24	0.0037
10	32	0.0050
15	39	0.0061
45	46	0.0072
75	50	0.0078
105	53	0.0083
135	61	0.0095
165	62	0.0097
225	63	0.0098
285	64	0.0100
345	65	0.0101
405	66	0.0103
465	67	0.0104
525	68	0.0106
585	69	0.0107
645	70	0.0109
705	73	0.0114
720	77	0.0120
730	83	0.0129
740	89	0.0139
745	96	0.0149
750	104	0.0162

Sample 3:

Thickness = 1.36mm Original Length = 61.5mm
Area = 27.2 sq.mm Temp = 21.1 C
Load = 54.5 N RH = 55.81
Stress = 2.004 N/sq.mm % of Moisture Content = 7.635

Time	Displacement X 0.01	Strain
0	18	0.0029
5	26	0.0042
10	34	0.0055
15	40	0.0065
45	44	0.0072
75	48	0.0078
105	51	0.0083
135	54	0.0088
165	55	0.0089
225	57	0.0093
285	58	0.0094
345	59	0.0096
405	61	0.0099
465	63	0.0102
525	65	0.0106
585	68	0.0111
645	71	0.0115
705	75	0.0122
720	79	0.0128
730	86	0.0140
740	94	0.0153
745	100	0.0163

Sample 4

Thickness = 1.372mm Original Length = 68.21mm
Area = 27.44 sq.mm Temp = 15 C
Load = 54.5 N RH = 65
Stress = 1.986 N/sq.mm % of Moisture Content = 12.13

Time	Displacement X 0.01	Strain
0	25	0.003665152
5	30	0.004398182
10	35	0.005131212
15	40	0.005864243
30	49	0.007183697
45	55	0.008063334
60	60	0.008796364
90	65	0.009529395
120	70	0.010262425
150	75	0.010995455
180	78	0.011435273
210	80	0.011728486
240	82	0.012021698
270	84	0.01231491
300	86	0.012608122
330	88	0.012901334
360	90	0.013194546
390	92	0.013487758
420	94	0.013780971
450	96	0.014074183
480	97	0.014220789
510	98	0.014367395
540	99	0.014514001
570	103	0.015100425
600	107	0.015686849
615	111	0.016273274
630	116	0.017006304
640	121	0.017739334
645	127	0.018618971

Sample 5

Thickness =	1.359mm	Original Length = 65.52mm	
Area =	27.18 sq.mm	Temp =	15 C
Load =	54.5 N	RH =	65
Stress =	2.005 N/sq.mm	% of Moisture Content = 11.66	

Time	Displacement X 0.01	Strain
0	24	0.003663004
5	28.5	0.004349817
10	32	0.004884005
15	37	0.005647131
30	46	0.007020757
45	50.5	0.00770757
60	54	0.008241758
90	57	0.008699634
120	60	0.009157509
150	63	0.009615385
180	66	0.01007326
210	69	0.010531136
240	71	0.010836386
270	73	0.011141636
300	75	0.011446886
330	77	0.011752137
360	78	0.011904762
390	79	0.012057387
420	80	0.012210012
450	81	0.012362637
480	82	0.012515263
510	83	0.012667888
540	85	0.012973138
570	87	0.013278388
600	89	0.013583639
630	91	0.013888889
660	95	0.014499389
675	99	0.01510989
685	103	0.015720391
690	108	0.016483516
695	116	0.017704518

Calculation of Density of Apple:

S.No.	Mass (Kg)	Volume (liters)	Volume (m^3)	Density (Kg/m^3)
1	0.259	0.260	0.000260	994.35
2	0.313	0.320	0.000320	977.59
3	0.288	0.295	0.000295	974.58
4	0.237	0.239	0.000239	991.63
5	0.245	0.261	0.000261	938.70
6	0.305	0.310	0.000310	983.87
7	0.310	0.320	0.000320	968.75
8	0.275	0.281	0.000281	978.65
9	0.261	0.265	0.000265	984.91
10	0.277	0.281	0.000281	985.77
11	0.254	0.262	0.000262	969.47
12	0.300	0.311	0.000311	964.63
13	0.258	0.268	0.000268	962.69
14	0.298	0.304	0.000304	980.26
15	0.265	0.270	0.000270	981.48
16	0.269	0.272	0.000272	988.97
17	0.312	0.321	0.000321	971.96
18	0.267	0.269	0.000269	992.57
19	0.253	0.257	0.000257	984.44
20	0.295	0.297	0.000297	993.27

Average: 978.43 Kg/m^3

Poisson's Ratio of Paper Pulp

Test Sample Dimensions	Displacement in Transverse Direction (mm)	Displacement in Longitudinal Direction (mm)	Strain (Transverse Direction) (A)	Strain (Longitudinal Direction) (B)	Poisson's Ratio (A/B)
65 * 11.57	0.018	1.25	0.001555748	0.019230769	0.08089888
63 * 11.141	0.014	0.875	0.00125662	0.013888889	0.09047662
59 * 12.815	0.017	0.9375	0.00132657	0.015889831	0.0834855
60 * 10.57	0.015	1	0.001419111	0.016666667	0.08514664
63 * 12.56	0.012	0.75	0.000955414	0.011904762	0.08025478

Average: 0.084

Calculation of Density of Paper Pulp:

S.No.	Mass (gm)	Thickness (mm)	Width (mm)	Length (mm)	Volume (m^3)	Density (gm/mm^3)
1	0.455	1.74	32.20	28.15	0.0015771	288.50
2	0.110	1.65	17.83	14.31	0.0004214	261.06
3	0.073	1.70	13.11	11.99	0.0002674	271.13
4	0.242	2.20	28.04	14.78	0.0009108	265.71
5	0.130	2.02	16.14	15.72	0.0005125	253.67
6	0.089	1.70	15.46	11.86	0.0003120	285.26
7	0.090	1.70	16.48	11.73	0.0003292	273.39
8	0.142	1.73	20.09	15.19	0.0005271	269.40
9	0.120	1.70	18.20	13.39	0.0004146	289.45
10	0.090	1.80	16.38	11.26	0.0003328	270.41
11	0.585	2.12	35.70	29.23	0.0022122	264.44
12	0.412	1.75	31.11	26.65	0.0014509	283.96
13	0.095	1.89	15.69	12.16	0.0003606	263.45
14	0.122	1.91	14.8	16.33	0.0004616	264.29
15	0.082	1.32	12.92	18.21	0.0003107	263.94
16	0.088	1.72	12.59	15.66	0.0003391	259.50
17	0.441	1.73	30.20	31.15	0.0016248	271.41
18	0.190	1.63	25.40	17.95	0.0007412	256.35
19	0.093	1.45	9.55	24.69	0.0003414	271.55
20	0.275	2.08	22.96	21.13	0.0010107	272.10
21	0.122	2.01	15.13	14.45	0.0004387	278.12
22	0.335	2.29	23.08	24.56	0.0012957	258.55
23	0.088	1.68	15.98	11.10	0.0002973	294.33
24	0.133	1.40	19.08	19.48	0.0005192	256.18
25	0.116	1.50	18.25	15.98	0.0004369	265.48
26	0.089	1.80	15.27	11.24	0.0003094	287.64
27	0.385	2.00	27.70	24.23	0.0013423	286.81
28	0.377	1.756	29.11	25.65	0.0013112	287.53
29	0.085	1.92	15.9	9.89	0.0003019	281.53
30	0.134	1.71	14.8	18.33	0.0004639	288.86

Average: 272.80 Kg/m^3