NON-LINEAR FINITE ELEMENT ANALYSIS OF APPLE PACKAGING

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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.

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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.