Study of Tissue Damage during Mechanical Peeling of Tough Skinned Vegetables

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***ABSTRACT*- Peeling is an essential phase of post harvesting and processing industry; however the undesirable losses and waste rate that occur during peeling stage are always the main concern of food processing sector. There are three methods of peeling fruits and vegetables including mechanical, chemical and thermal, depending on the class and type of fruit. By comparison, the mechanical method is the most preferred; this method keeps edible portions of produce fresh and creates less damage. Obviously reducing material losses and increasing the quality of the process has a direct effect on the whole efficiency of food processing industry which needs more study on technological aspects of this industrial segment. In order to enhance the effectiveness of food industrial practices it is essential to have a clear understanding of material properties and behaviour of tissues under industrial processes. This paper presents the outlines of research that seeks to examine tissue damage of tough skinned vegetables under mechanical peeling process by developing a novel FE model of the process using explicit dynamic finite element analysis approach. In the proposed study a nonlinear model which will be capable of simulating the peeling process specifically, will be developed. It is expected that unavailable information such as cutting force, maximum shearing force, shear strength, tensile strength and rupture stress will be quantified using the new FEA model. The outcomes will be used to optimize and improve the current mechanical peeling methods of this class of vegetables and thereby enhance the overall effectiveness of processing operations. Presented paper will focus on available literature and previous works have been done in this area of research.**

Keywords: Finite element model, explicit, food processing industry, loss

I. INTRODUCTION

The processed food and beverages industry is a largest manufacturing sector in Australia and has a notable share of economical benefit in Australia “this industry has around $79 billion and about $8billion increase from 2005 to 2006, and $19 billion in 2006-7 and around $1.5 million higher than that of 2005-6” [1]. Moreover Australian’s food processing has 20 per cent of total manufacturing industry and alternatively 18 per cent of whole employment in manufacturing sector [2]. In addition to food processing industry in Australia “ the global organic industry is fastest growing food category, with demand outstripping supply in most developed economies”, organics have been applied in 120 countries that Australia with 12.3 million hectares has the largest area and capacity to produce organic crops [2]. Among tough skinned fruits and vegetables, pumpkin is producing as an organic crop in Australia.

There are different industrial peeling methods including thermal, chemical and mechanical methods. Except some fruits such as mango, that manual peeling is common, for other kind of fruits and vegetables different types of peeling are in use, for example, mechanical peeling of tough skinned fruits, chemical peeling of citrus and thermal peeling of potato. Among different types of peeling, “mechanical methods are preferable because mechanical peeling keeps edible portions of produce fresh and damage free” [3], freshness and less damage are both ideal goals of peeling processes. Furthermore mechanical methods of peeling are environment friendly and they do not create any negative effect on the environment and tissue, compare with harmful effects on environment and the fruits and vegetable tissues that chemical methods cause. Besides cooked ring, poor appearance of tissue and charred skin remained after applying thermal peeling methods. Regarding to all advantages of mechanical peeling, peeling looses are inevitable. Material losses can be wanted or unwanted, “wanted losses are necessary to transform the raw material into the desired final product” [4] however unwanted losses decrease the productivity of peeling industry.

As it mentioned before, low flexibility is the main concern in applying mechanical method of peeling for fruits and vegetable tissues [5]. Moreover peeling losses, undesired deformation, energy consumption, material wastage, total cost of process and level of food safety and quality are the crucial concerns of food industry in Australia [6] which is one of the important industrial sectors in Australia[7].

Clearly, yield efficiency of the peeling process depends on the rate of unwanted losses and damages. An ideal peeling process is one that “removes only the skin and surface defects, leaving the rest of the tissue unattached” [4]. Computer based models are one of the innovative methods of studying tissue damage during processing stages of fruits and vegetables. Developing computer based models of mechanical peeling process will enable investigation of appropriate design parameters. As well as optimization and development of common mechanical methods which will lead to decrease in material looses and energy wastage and advance the quality and quantity of food process productions.

Although there are some studies have been done on mechanical properties of fruits and vegetables tissues and mathematical modelling of food processes [5, 8-17], to date there are no published papers on FE modelling of mechanical peeling. Regarding to low flexibility of mechanical peeling methods and the rate of loss in this operation, more studies need to be done in order to investigate material behaviours of food tissues under processing lines and optimize current common processes. Accordingly, any advancement will enhance the overall outcomes of food processing industry. Due to the rapid advancement of computer technologies the aim of proposed study is to apply available softwares to investigate material reactions and mechanical damage of tissue during mechanical peeling process. In addition to study the influence of involved variables on energy consumption and loss rate of mechanical peeling process.

II. EXISTING DEVELOPMENT AND ISSUES

The majority of fruits and vegetables have a peel that needs to be removed during the production of various products, such as jam, marmalade, ready to cook vegetables, juice or beverages, and dried fruits. Peeling is one of the important processing steps after harvesting. Traditional peeling methods have applied labour intensive manual peeling. Taking into account the increasing growth of processed agricultural product sector, coupled with technological developments of processing equipment, it becomes clear that manual peeling will not remain an economically viable processing method to provide sufficient quantity to meet the growing food demands.

Mechanical peeling includes different types of mechanisms that interact directly with skin and remove it. Common commercial mechanical peelers are abrasive devices, drums, rollers, knives and milling cutters. Although mechanical peelers can provide high quality fresh final products and they are environmentally friendly and nontoxic, the general downside of these methods relates to the associated material loss [18]. Skin thickness, firmness, toughness, variety, rupture force, cutting force, maximum shearing force, shear strength, tensile strength and rupture stress are some of the fruits' properties that would have direct effect on the peeling process.

There are some published studies which calculated the effective physical and mechanical properties of fruits and vegetables [13, 16, 18-32]during post harvesting processes including handling, grading, sorting, transporting, peeling and packaging. Still, there is the need of more investigation to use and connect available properties to model actual reactions of fruits and vegetables tissue which will help to diminish mechanical tissue damage and enhance total effectiveness of food industrial operations.

Most of the recent studies on different peeling methods have been applied experimental case studies, however case studies are costly and time demanding. They are not comprehensive enough to apply for all types and varieties of each fruit. Regarding the development of new methods of modelling complex processes and compared to the limitation that bound case studies which make them unable to explore the behaviour of materials owing to the complex deformation and interaction among particles and tools [33]; modelling the industrial processes provide vast opportunity of testing, evaluating and predicting complicated processes. Modelling and simulation of mechanical processes have the potential for improving "tool designs and selecting optimum conditions" of these processes [34] that can provide critically analysis and understanding of deformation that might occur during process [35].

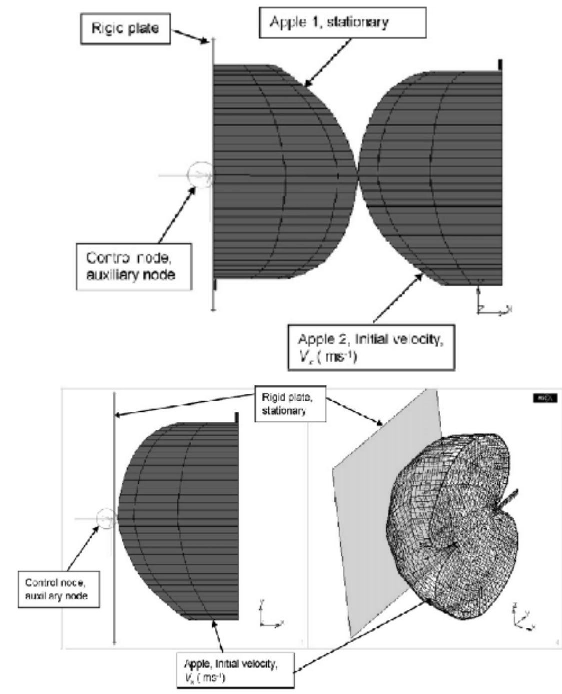

Fig.1:modelling dynamic collision in apple tissue [36]

Computer models have become prevalent in recent years for analysing different mechanical processes such as modelling of mechanical interaction [33, 35, 37-44] and modelling vibration, pressure and bruising in different fruits [36, 45-47]. These models provide "fundamental understanding of the relationships between process variables (cutting forces, tool stresses and temperatures developed) and performance measures (tool wear, tool life, and surface finish)" [34] which are crucial parameter to be studied in food processing.

For instance, in a study of dynamic collision of apple tissue it has been concluded that cortex material properties have dominant role on mechanical behaviour of the whole apple (Fig.1). In this study also it has been noted that current experimental techniques on viscoelastic behaviours of apple are not suitable for stress relaxation test as the sensitivity of them is insufficient for very short term test such as collision[36]. Similarly, modal analysis has been carried out for apple tissue [46], and pear tissue (Fig. 2) [48, 49] and the results indicated that computer based models can be replaced with Magness-Taylor method which is a destructive experimental method of firmness evaluation. Computer models are accurate and able to predict changes of involved variables in each stage of processes. Due to the capability of computational models, it is possible to study the influence of different factors without need to conduct experiments, which can reduce testing error and also the effect of tool wear [34].

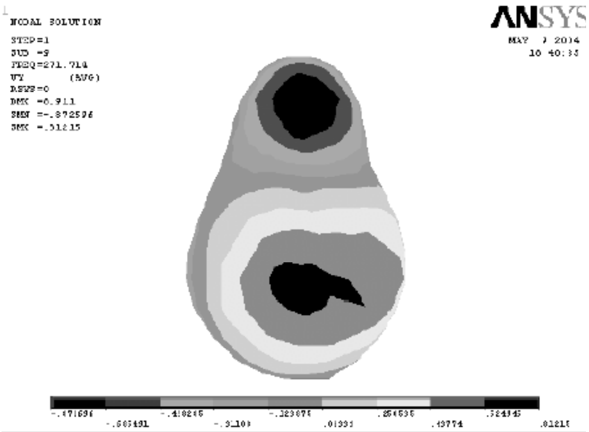

Fig.2:Vibravtion analysis of pear tissue [48]

Accordingly, technological development in food processing industry is essential for the growth of fruit and vegetable processing industry in Australia as it will provide opportunity both to raise the quality of food product and to reduce the economic factors constraining the industry such as processing costs and losses. As a result, “advances in transport, processing and packaging technologies should prove significant for the industry in general”, and any improvement in processing tools can enhance production of food processing industry which “... will continue to enhance the economic and environmental performance of these industries as well as enhancing Queensland's Smart State image” [50].

III. PROPOSED RESEARCH

Reducing flesh losses has always been one of the big challenges of peeling fruits and vegetables in large industrial scale. The aim of this research is to develop a FE explicit model of mechanical peeling process of tough skinned vegetable, pumpkin, that will help to improve and optimize current mechanical peeling technologies. Modelling will include two parts, first geometry model will be completed using MSC PATRAN which has been designed based on LS-DYNA solver. In the second part, simulation will be accomplished using LS-DYNA solver which is advanced metaphysics simulation software to model complex real world operations [51]. In order to achieve this, a simplified model will be generated. This model will be used to study the basic interaction between a single point cutting tool and a block of material with a relatively high Young’s modulus with nonlinear elasticity. In essence, this effort will be very similar to study a typical metal cutting process. This initial simplified model will help to estimate the threshold reaction forces as a function of the layer firmness. This can be serve as a basic to calculate the minimum cutting energy to initiate cutting or in this case, peeling.

Regarding the complexity of behaviours of vegetable tissue under loading, the following sub steps have been considered at the modelling stage. This stage by stage process will enable the authors to classify involved variables in the peeling operation and develop a prescribed model:

Step 1. Developing 2D model of a single layer tissue.

In the primarily level of modelling a 2D model (Fig.3) of a single tissue will be created to simulate the basic interaction between a peeler and a soft body (fruit). The first model will demonstrate a simple tissue with soft material property and with a cutter as a line in the 2D environment with higher elastic modulus than tissue.

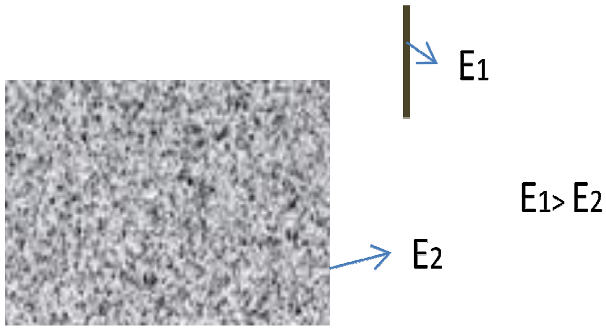

Fig.3: 2D model of a single layer tissue (E1and E2 are elastic modulus of cutter and tissue).

This model will establish the parameters required for removing a thin layer of tissue and will focus on the simulation of required force and its variation with different cutter penetration and depth. Energy consumption and surface of the tissue after removing one layer also will be part of data produced. The details of the materials are characterised as soft and stiff materials, therefore some additional simulation will be done with various types of materials such as softer and stiffer examples in each case. This stage of modelling will be essential to develop quantifiable data regarding cutting stage details such as cutting force, thickness of removed layer and penetration depth.

Step 2. Developing 2D model of a two layer tissue.

This stage will extend the single layer model to a bi-layer model (Fig.3). Fruit tissues are generally made of more than one layer depending on the kind of fruits and the thickness of peel that will be removed. Accordingly an accurate model for these kinds of tissues would be a composite tissue. In this case a 2D block with at least two layers will be created (Fig. 4) with two different material properties that will signify stiffer properties for skin and softer details for flesh. The cutter still would be a line with a higher value of elastic modulus.

Three different material properties would be needed for this stage and as per the last stage, stiffness will be considered the main difference between layers. It is obvious that cutter should be stiffer than skin and flesh (2 layers in this model).

Thickness of layers will be more pertinent considerations so simulations will be conducted several models, emulating different thicknesses and material properties.

The relation between cutter penetration depth in tissue and required force and energy, amount of deformation are principle data types sought during this phase of simulation. Contact analysis in the area between each of the two tissue layers will be considered as a composite layer and the reactions and deformations in this zone will be analysed.

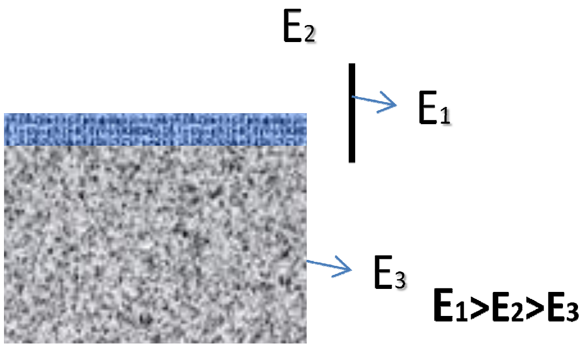

Fig.4: 2D model of a two layer tissue (E1, E2and E3 are elastic modulus of cutter, peel and flesh respectively).

Step 3. Estimation of modelling parameters and material properties using experimental results.

After completing 2D modelling, determining the real properties of fruit tissue and other significant parameters and variables will be required. The details of the structural properties of tough skinned tissue, before starting 3D modelling will require establishing proposed 3D model. As a result, some experimental case studies will be carried out to measure essential material parameters of pumpkin as a tough skin vegetable. Compression test, density measurement, Poisson ratio calculation will be parts of future empirical tests. Besides calculating material properties, developing an applicable material model for vegetable tissue will be another planned concern in this step. Then the results of case studies in combination of developed material model will be used for completing and simulating 2D model and also continuing the process modelling and create 3D model.

Step 4. Developing 3D model.

In reality 2D models cannot be extrapolated to represent ideal outputs for an industrial process, although they provide the first solid base to generate data that would be a required step for modelling process. In this phase the results generated in the simulations conducted on the 2D models will be utilised to create 3D models. 3D modelling will consists of simplified model of tissue and cutter as well as modelling of a real peeler and mechanical peeling stage.

Step 5. Validating the model.

Finally, the 3D model will be developed incorporating the results of case studies, and simulation carried out to obtain outputs of energy consumption and other involved parameters. Afterward, final 3D model will be validated using available data from previous works and publications and possible experiments. There are also some mathematical models of food processes [8, 9, 11], in addition to mathematical modelling of mechanical peeling of pumpkin [5] which will be use to validate the model as well.

IV. SUMMARY AND CONCLUSION

Many experimental studies exist on physical and mechanical properties of fruits and vegetables in post harvesting and processing operations. As well as a number of studies have been done on mechanical, thermal and chemical peeling methods of fruits and vegetable tissues. Majority of these studies applied experimental techniques to collect data and calculate material properties. Regarding the recent development of modelling and simulating methods of engineering and industrial processes in addition to growing demand for food productions, current experimental methods are not applicable and reasonable enough to study these operations. With respect to advantages of modelling methods, and attention to increasing number of studies on mechanical processes for other materials such as metals, bones and soft biomedical materials, more work need to be done in applying numerical modelling methods for studying food industrial processes.

The results of FE modelling of mechanical peeling of fruits and vegetables will enhance efficiency and quality of food industrial peeling stage and can be helpful to reduce the high rate of material loss [18]. Another significant advantage of FE models is possibility of predicting and estimating deformation and waste during and after mechanical peeling, as well as increasing and improving tool life and reducing wear tool.

The innovation of proposed research is to study and development of the first computational model to simulate tissue damage during mechanical peeling of pumpkin/ tough skinned vegetable using FEA method.

This study will generate a first dynamic explicit model of mechanical damage in mechanical peeling stage of tough skinned vegetable, pumpkin, using FE method. Consequently, numerical modelling of mechanical peeling process in the view of this study is a logical next step in food processing research's chain, which can link the available database on properties to answer questions and doubt about energy consumption and influential factors in mechanical peeling process. Accordingly, the new approach this research contributes is the provision of another toolset that can provide benefits to Australian food processing industry in terms of exports and investment.

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