Study of Mechanical Deformations on Tough Skinned Vegetables during Mechanical Peeling Process (A Review)

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***ABSTRACT*- Peeling is an essential phase of post harvesting and processing industry; however undesirable processing losses are unavoidable and always have been 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 methods are the most preferred; mechanical peeling methods do not create any harmful effects on the tissue and they keep edible portions of produce fresh. The main disadvantage of mechanical peeling is the rate of material loss and deformations. Obviously reducing material losses and increasing the quality of the process has a direct effect on the whole efficiency of food processing industry, this needs more study on technological aspects of these operations. 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 scheme 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. A computer model of mechanical peeling process will be developed in this study to stimulate the energy consumption and stress strain interactions of cutter and tissue. The available Finite Element softwares and methods will be applied to establish the model. Improving the knowledge of interactions and involves variables in food operation particularly in peeling process is the main objectives of the proposed study. Understanding of these interrelationships will help researchers and designer of food processing equipments to develop new and more efficient technologies. Presented work intends to review available literature and previous works has been done in this area of research and identify current gap in modelling and simulation of food processes.**

Keywords: Finite element model, explicit, food processing industry, material 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]. Furthermore Australian’s food processing has 20 per cent of total manufacturing industry and alternatively 18 per cent of whole employment in manufacturing sector [2]. Additionally, “ 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]. Moreover, pumpkin as a tough skinned fruits and vegetables is producing as an organic crop in Australia.

Industrial peeling process can be done applying one of the three 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. In addition, mechanical methods are environment friendly and they do not create negative effects on the environment and tissue, considering harmful effects on environment and the fruits and vegetable tissues that chemical methods cause. Besides other disadvantages that thermal peeling methods create such as cooked ring, poor appearance of tissue and charred skin remained after applying. Regarding the advantages of mechanical methods, peeling looses are the inevitable downside of these techniques. 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.

Furthermore, low flexibility is another concern in applying mechanical method of peeling for fruits and vegetable tissues [5]. 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, increasing the yield efficiency of the peeling process is highly depended on the rate of unwanted losses and deformations. Ideally a peeling process which “removes only the skin and surface defects, leaving the rest of the tissue unattached” [4] is desirable in industrial stages. Developing computer based models is one of the new methods of studying tissue damage during processing stages of fruits and vegetables. These models are time and cost efficient in comparison with experimental tests. They can be used to investigate the appropriate design parameters and optimize current mechanical methods. Moreover, developing these models will enhance the processing operations and decrease material looses and energy wastage, as well as advancing the quality and quantity of food process productions.

There are some studies have been done on mechanical properties and mathematical modelling of food processes [5, 8-17], however to date there is 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 responses of food particles under processing lines. Due to the rapid advancement of computer technologies the aim of proposed study is applying available softwares to investigate material reactions and mechanical damage of tissue during mechanical peeling process.

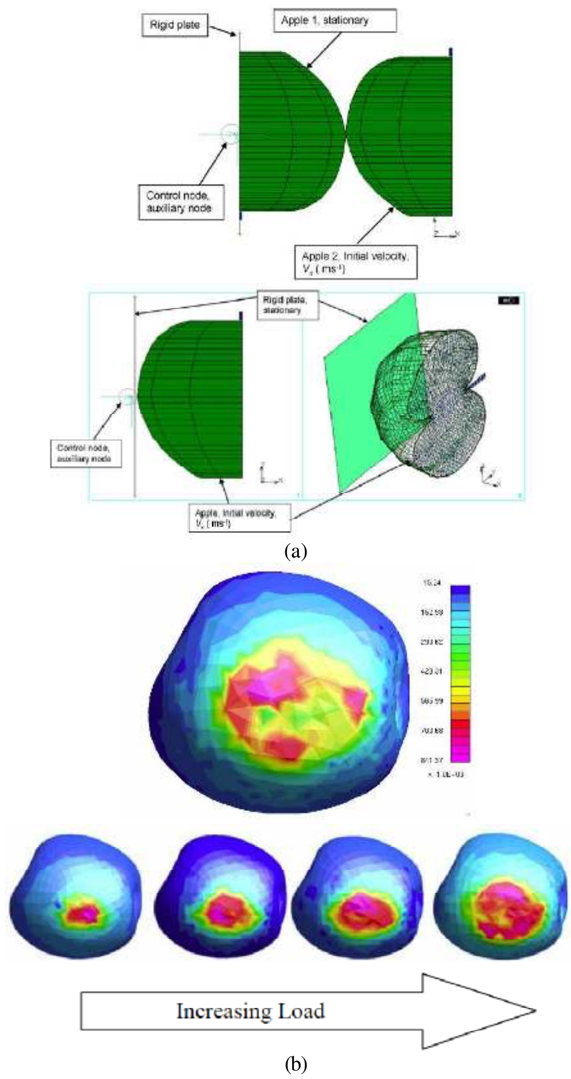
II. EXISTING KNOWLADGE AND PROBLEM

During the production of food products such as jam, marmalade, ready to cook vegetables, juice or beverages, and dried fruits removing the peel is one of the first essential operations. 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 is clear that manual peeling will not remain an economically viable processing method to provide sufficient quantity to meet the growing food demands.

Common commercial mechanical peelers are abrasive devices, drums, rollers, knives and milling cutters. Even though 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]. Mechanical and physical properties of fruit and vegetable tissue such as skin thickness, firmness, toughness, variety, rupture force, cutting force, maximum shearing force, shear strength, tensile strength and rupture stress, have direct effect on the effectiveness of 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 stages. However, more investigation is needed to apply and connect available properties to model actual reactions of fruits and vegetables tissues.

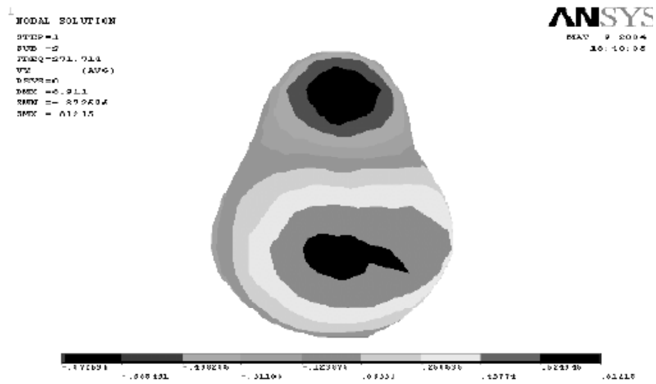
Experimental case studies on properties of food particles are the most popular methods among researchers. However case studies are costly and time demanding. Additionally they are not comprehensive enough to apply for different varieties of fruits and vegetables. Regarding the development of new methods 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].



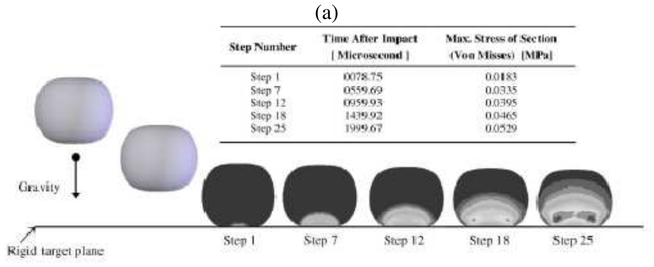
(b)
Fig.1: (a) modelling dynamic collision in apple tissue [36] (b) model of pressure and bruising on apple [37].

Computer models have become prevalent in recent years for analysing different mechanical processes such as modelling of mechanical interaction [33, 35, 38-45] and modelling vibration, pressure and bruising in different fruits [36, 37, 46, 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-(a)). 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]. Modelling pressure and bruise in apple [37] is another previous study (Fig.1-(b)) which applied linear elastic material model to develop an apple under pressure. The authors of this study also mentioned that more study need to be done using more idealistic material model for the tissue [37]. Similarly, modal analysis has been carried out for apple tissue [46], and pear tissue (Fig. 2-(a)) [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. Kebas et al. [50] also established a model of drop test on cherry tomato (Fig2-(b)). Computer models are accurate enough 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].



(a)



Step Number	Time After Impact [Microsecond]	Max. Stress of Section (Von Misses) [MPa]
Step 1	0078.75	0.0183
Step 7	0559.69	0.0335
Step 12	0959.93	0.0395
Step 18	1439.92	0.0465
Step 25	1999.67	0.0529

(b)

Fig.2: (a) Vibration analysis of pear tissue [48], (b) modelling drop test on tomato [50]

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" [51].

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 [52]. 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. The first step includes model the geometry considering boundary conditions and material models.

a) Geometry and Boundary Conditions

In order to model peeling operation of tough skinned vegetables tissue, a block of material will be modelled. One of the modelling challenges was developing a model with skin and flesh as two separate material types but with ideal contact. As in the reality, peel and flesh are tied however they behave differently. Considering these points, three models will be considered:

- A block of material as peel or flesh

Firstly, a block of material with properties of peel or flesh will give the basic details of how each material type behaves. Obviously, it is possible to change the geometry and dimensions of this block with thickness of each part.

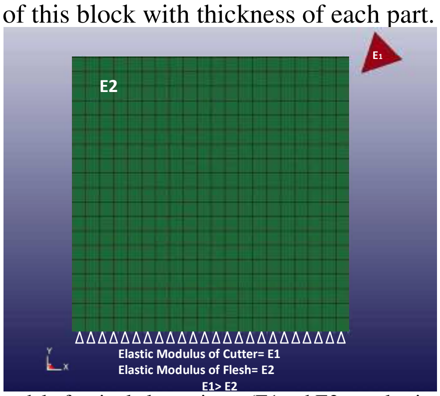


Fig.3: 2D model of a single layer tissue (E1and E2 are elastic modulus of cutter and tissue).

- Two separate layers with tied contact

In reality, fruits and vegetables have more than one layer consisting of at least two layers: skin and flesh.

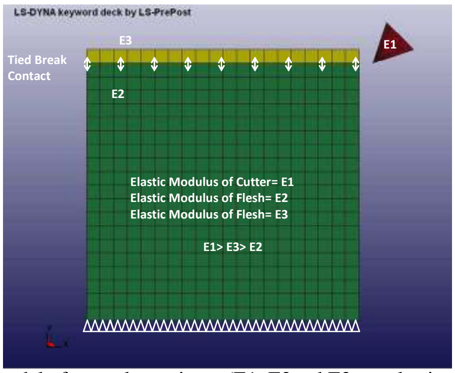


Fig.4: 2D model of a two layer tissue (E1, E2and E3 are elastic modulus of cutter, flesh and peel respectively) and a tied break contact between flesh and peel.

As a result in the second stage of modelling a block with two layers will model. The main concern in this step is developing two types of material models for these layers. In addition to material model, type of contact between the layers is important. In this case a tied break contact will be added to the model to attach peel and flesh.

- A partitioned block with two material properties

Available FE softwares give the option of modelling flesh and skin as one block with different material types. In this regard, a block will be modelled and portioned to two layers. The advantage of this method is the flesh and skin will be a part of same body, similar to the real fruit or vegetable tissue. However it will be possible to apply different mesh size and material types for each of them. The other useful benefit is, there will not be any need to apply contact type which will help to establish a more real model.

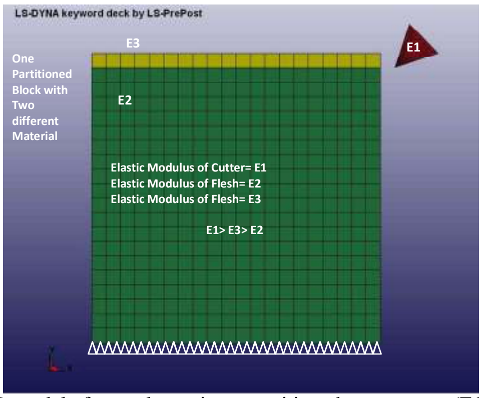


Fig.4: 2D model of a one layer tissue partitioned to two parts (E1, E2and E3 are elastic modulus of cutter, flesh and peel respectively).

For all the models cutter material will be a stain steel, with a rigid body. Cutter also will move toward the tissue with different velocities. The body will be fixed with fixed support on the bottom end. An automatic single surface contact also will be applied to establish an ideal contact between cutter and tissue. Additionally, the tissue will be the slave and cutter will be the master in this contact.

b) Modelling Material Properties

Regarding the complexity of behaviours of vegetable tissue under loading, developing an appropriate material model for tissue will have a significant effect on the results. It is also important to mention that there are a few studies which worked on the modelling of nonlinear-plastic material type of fruit and vegetables tissue. The proposed study will apply empirical tests to calculate material properties. Compression and indentation test will be performed on skin, tissue and unpeeled samples of pumpkin. Additionally the results of available studies on pumpkin tissue will be use to develop the model [53, 54].

After developing 2D model and establishing material model for peel and flesh, the results of stress strain and energy consumption will be compare with available literature. Furthermore, results of energy requirements will be evaluate using available mathematical models of food processes [5, 8, 9], in addition possible experimental test will be considered to validate the model.

IV. SUMMARY AND CONCLUSION

There are number of experimental studies on physical and mechanical properties of fruits and vegetables. As well as a number of previous studies with focus on mechanical, thermal and chemical peeling methods of fruits and vegetable tissues. 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 time and cost demanding and not 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.

Understanding of interaction between cutter and tissue and the effects of involved variables are major objectives of FE modelling of mechanical peeling of fruits and vegetables. This will provide details of tissue behaviours in order to enhance the efficiency and quality of food industrial peeling stage which will lead researchers and designers to reduce the high rate of material loss [18]. Predicting and estimating deformation and waste during mechanical peeling is another considerable advantage of FE model as well as improving tool life and reducing wear tool.

The innovation of proposed research is to study and development of a computer model of mechanical peeling process of pumpkin/ tough skinned vegetable to simulate tissue damage using FEA method.

In addition to a dynamic explicit model of mechanical damage in mechanical peeling stage of tough skinned vegetable, pumpkin, an appropriate material model for peel and flesh will be develop. Consequently, in the view of this study, applying available FE models and softwares 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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