A Visualisation of the Results of a Thermoforming Process Simulation in the Plastics Industry

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ABSTRACT

This paper presents the SIMViewer computer program allowing users to visualise the results from the T-SIM simulation software made by Accuform in the field of plastics thermoforming. The main feature is to visualise particular thermoforming process steps of a plastic sheet in a three-dimensional space including all geometric parts of the defined model like a forming die and optional plunger. SIMViewer provides a projection of scalar quantities that characterize the thermoformed region. It is mainly focused on presenting the thickness distribution, thermoforming temperature, stress, strain and other scalars applied on the plastic sheet. This application was developed in C++ programming language, the graphical area was implemented by the OpenGL library and the user interface was created by using the MFC application framework.

Keywords
visualisation, simulation, geometry, framework, thermoforming, plastic

1. INTRODUCTION
In recent years, the industrial world has expanded into computer simulations which determine the direction of product development in terms of suitable materials usage and manufacturing technologies. Simulations are important especially today, during economic instability, when companies are forced to reduce their production costs in order to compete in the market. Here, simulations come either in the form of mathematical models based on an input set of data and characteristics and they can generate the behavior of an object in time and space, or optimize its geometric parameters for effective use. These models are currently very sophisticated based on many types of algorithms, so the simulated solutions often approach reality. This is also true for the Plastics Industry. The mathematical modeling results allow teams of skilled engineers and technologists to diagnose eventual product weak points and, for example, to optimize the consumption of material used during the product manufacturing process.

The aim was to create a 3D visualisation program that would be able to transfer data interpretation of the modeling results into a clearer graphical view. Technologists can then see the optimal plastic products wreaked by the thermoforming process. It is frequently used for the comparison and verification of final data results of different case studies.

2. THE PLASTICS PROCESSING
The plastic products manufacturing requires specific technological processes, specific machines and tools in order to achieve products like a plate, cup, toy or electrical device covering and fuel tank. It depends primarily on the complexity and shape of a final product, on used material and influences which affect the product in the real life, such as weather, chemical and physical laws. Plastics, generally called polymers, are processed by the six basic technologies like the thermoforming, blow molding or extrusion, injection, pressing and rolling.

This paper is going to focus on the thermoforming technology only by reason of its diversity in terms of applicable methods for processing of various plastic materials. The reason of preferring this technology was a presentation of the SIMViewer application developed for the visualisation of final results from a computer simulation of the thermoforming process.

2.1. The Thermoforming Technology
Thermoforming is a specific process in which a flat thermoplastic sheet is heated and deformed into the desired shape. This technology is used up for a packaging and to fabricate large items like furniture, contoured skylights and automotive parts. [1]

This processing technology consists of two main steps, heating and forming. Three basic methods are standardly used up like the vacuum, pressure and mechanical thermoforming process.

3. A COMPUTER SIMULATION OF THE THERMOFORMING PROCESS

Computer simulations have become a useful part of mathematical modeling of many natural systems, for example, in physics, chemistry, biology, and also in the process of engineering new technology, to gain insight into the operation of those specific systems. Some simulation methods have been applied in the field of thermoforming process as well.

3.1. The Finite Element Method [2]

Generally accepted method for a thermoforming simulation is Finite Element Method (FEM). The main goal of FEM in a thermoforming simulation is thickness prediction. Approximate wall thickness values for complex mold geometries are obtained by assuming that the actual shape of the mold surface is approximated by a simple geometry or series of geometries. FEM is a scheme for determining the wall thickness of well-behaved stretched membranes. The general scheme is to overlay the surface to be stressed with a grid or network (see Fig. 1).
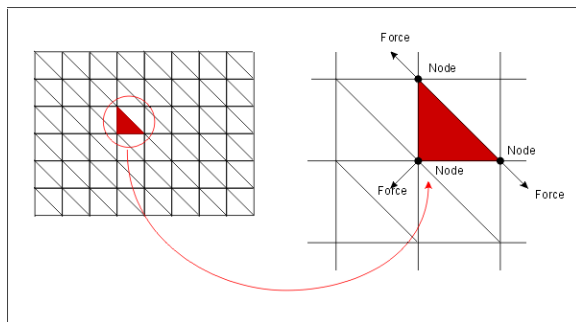

Figure 1. The FEM grid, elements and nodes

The grid pattern is usually triangular. Depending on the sophistication of the model, the elements are two-dimensional (2D) with X and Y coordinates but no thickness, or they are three-dimensional (3D), with X and Y coordinates and a finite thickness. It is thought that 3D elements are necessary when there may be heavy-gage sheet bending resistance over sharp edges or when shear is expected. For most applications, 2D or thin membrane elements are acceptable. The elements are connected via nodes. The connected elements form a discrete surface or mesh that replicates the actual continuous surface. When forces are applied to the simulated surface, the elements distort, with the extent of distortion determined by balancing the forces and moments at each intersection node. The relationship between applied force and resulting strain is called the constitutive equation of state of the material. Many thousands of such elements are usually needed to faithfully simulate structure response to applied load. Since many equations are needed for each node and

three or more nodes are on each element, thousands of equations must be solved simultaneously to affect a solution. As a result the artificial computer time step must be very small to minimize error generation during each iterative calculation.

3.2. The Process Optimization [2]

Simulation approach is increasingly being used for understanding and optimizing polymer processes. Its advantages are that the whole process can be set up on a low cost computer, and all of the variables can be changed at will to study their effects. This saves time, machinery investment, costly raw materials, and operation expenses. In addition, simulation can allow a visualisation of effect which cannot be seen or measured in the process. When investigating the thickness distribution of a plate we can only see the starting position and the end result. With simulation, the operation can be studied and understood.

The objectives for using CAE tools have changed dramatically over the years. Their preventive use in the design and development phase is now called for rather than error diagnosis on finished products. This perspective can be described as the virtual prototyping. The decision-making aid is no longer an actual product; in its place, improvements and risk calculations can be realized on virtual variants.

If one looks in detail at the design or outline of a product, one always faces an optimization task. For example, shape and material must fulfill certain criteria relating to product characteristics and manufacturability. However, also functional with economic objectives must be met in the best possible way. Quality levels usually serve here as target objectives. In most cases, they are given verbally and might, to name but a few, include the following:

- *Low distortion characteristics*

- *Minimal component weight*

- *Low production costs*

Conditions must be satisfied that not only relate to the product itself, but also to its manufacturability and the related manufacturing process.

3.3. The Optimization Techniques [2]

Various optimization techniques are used to achieve satisfactory results as follows below:

1) *Material optimization* - This promising way of optimization is development of special materials to be used in the thermoforming industry. It is becoming more evident that resins exhibiting strain hardening during elongation are more

suitable for deep draw thermoforming. These materials indicate a kind of self-healing effect beneficial for the homogeneity of deformation.

2) *Optimization of initial temperature or thickness profile* - Modification of initial temperature or thickness profile on a sheet is often used when producing large formed parts.

3) *Plug assisted forming optimization* - In plug assisted forming, using different final heights, speeds, sizes and shapes of plugs leads to many different final material thickness distributions.

4) *Material of tools* - Friction between tools and sheet plays also an important role in the process, again mainly in plug assisted forming. It is clear that when the sheet almost totally slides on the surface of a plug, the wall thickness of material at the top of the applied plug is low.

5) *Optimization of pressure/vacuum level/rate of change* - using the rate of change and level of vacuum/pressure plays also a significant role in the process. As can be expected, the higher is the speed of vacuum or pressure, the higher stresses are generated in material and it has an impact on the final thickness distribution.

6) *Optimization using sagging* - The effect of sagging can be used also to influence the final quality of a product. When a sheet sags, the thickness profile on it is quite uniform compared with the profile obtained using pre-blow.

3.4. A Math View of the Optimization [2]

Any optimization task must contain a determination of set of independent variables and usually also includes conditions characterizing allowed values of the independent variables. The conditions are called task limitations. Needed part of an optimization task is a scalar quality measure (cost function). Its values are given unambiguously by values of independent variables. Solution of an optimization task is such an allowed vector of values of independent variables, for which the cost function has an optimal value. The optimal value of the cost function is usually its minimum or maximum in an allowed range of independent variables. In the case of optimization of complicated processes such is thermoforming, the simulation of the process is quite time-consuming. As a result, it is hard to implement generally well described optimization techniques requiring many calculations of the cost function.

4. THE VISUALISATION SOFTWARE

This paper focuses on the SIMViewer visualisation software by which we are able to visualise and analyze output data results produced by the T-SIM simulation software in the field of thermoforming.

4.1. The SIMViewer application

The SIMViewer application was fully coded in C++ programming language. The specific libraries of MFC (Microsoft Foundation Classes) and OpenGL were implemented for the application framework and advanced graphic interface. [3] This application has been built, compiled and optimized for Microsoft Windows XP/Vista/7/8 - 32bit version.

The graphical user interface (GUI) of SIMViewer includes the plentiful palette of features which help users to comfortably control and edit the visualised model of plastic material product. Most of these features are accessed in the main menu. Some of them are also placed in the tool bars and have own shortcuts which simplifying the manipulation with displayed model components (see Fig. 2).
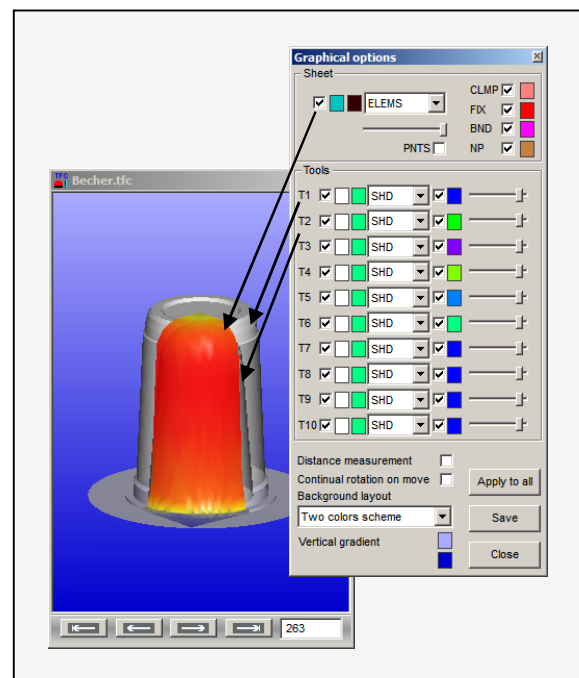

Figure 2. The Graphical options dialog box used for controlling of an active child window.

The SIMViewer application also defines input data files which are mostly in the binary form. The main data file has the TFC extension as a post-processing profile that defines all involved files to the project. This file has a text form and includes a specification of source sheet (BCS), tools (TOL), process behavior (PCT), project file (TFF) and other related files describing input parameters needed for the solver of

simulator. The next important files are defined with the numbered extensions 000 - 999 and they contain data in a binary format for all simulation steps.

The SIMViewer application allows taking advantage of advanced graphical and analyzing features to get required details of the simulation case study. For example, there are some disposable features intended for handling of the model on a scene, selectable cutting of the geometry parts, projecting of the sheet and each tool as a solid view, wireframe or combined both views. Furthermore, the application is able to provide a numeral and graphical analysis of wall thickness distribution, thermoforming temperature, stress, strain and other scalars in the place of defined cutting curve (see Fig. 3) that lies on the sheet in any selected step of the simulation process.

There are many other features in this application like an optional setting of the visibility, transparency, scalar scale ranges, background colors and color of each geometrical part on the screen. A user is also able to get details about particular nodes, elements or to obtain an overview about the currently displayed simulation step and project specification. This paper includes two video sequences to present particular simulation steps that unambiguously prove a gradual decrease of wall thickness in certain zones.
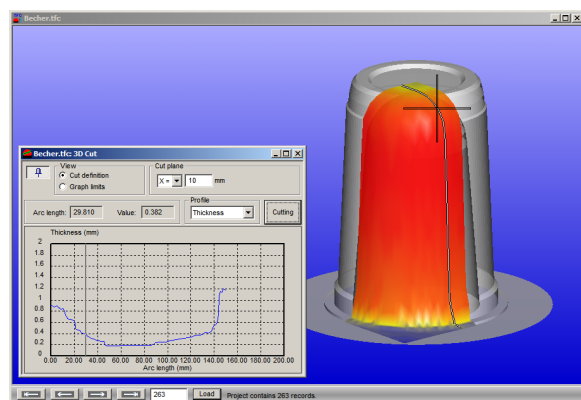

Figure 3. The analysis of deformed sheet by the cutting curve tool with the graphic chart.

5. SOFTWARE DEPLOYMENT

The SIMViewer application has been developed and deployed for interested students or customers who dispose of final data results produced by the T-SIM simulation software intended for thermoforming. The T-SIM simulator is fully commercial software with paid and registered license. If any user does not have this complex software installed on a computer by reason of that paid license, then he can simply use up this visualisation application. It is alternative software that is free of charge for anyone.

6. CONCLUSION

This contribution deals with the visualisation related to the thermoforming process simulation of plastic materials. The SIMViewer application was designed and built for the graduation theses at our faculty realized last year. This application processes specific data records incoming from the T-SIM simulation software developed by Accuform.

Technologists and people involved in the field of thermoforming work, they obtained an advanced visualisation application that is able to provide them various features for displaying, manipulating or editing and analyzing file data results from the solved project. The visualised data records represent an actual wall thickness distribution, thermoforming temperature, stress, strain and other scalars.

We have the next vision for an improvement of the application in the near future. It especially concerns on loading and displaying of 20 forming optional tools newly on the scene instead of 10 existing tools which represent an older data format. There also could be created a bounding box. This box should include the dynamic ruler in each axial direction to facilitate the exact measurement of sheet deforming through simulation steps (see Fig. 4).
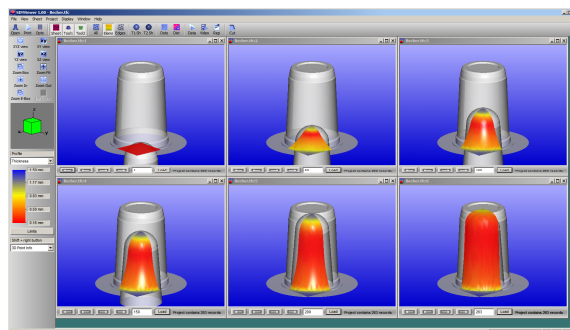

Figure 4. The thermoforming steps indicating their wall thickness distribution.

7. ACKNOWLEDGEMENTS

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