

Computer simulation of thermoforming process and its verification using a rapid tooling mould

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Abstract. The results of computer simulation of thermoforming process made using ANSYS Polyflow software are presented in this paper. The analysis of the wall thickness distribution across an U-shaped thermoformed product manufactured using a positive mould was made. The simulation results were verified using a mould manufactured in a 3D printing process which was Fused Deposition Modelling (FDM) and a poly(ethylene terephthalate) formed sheet. It was proven that the computer simulation and a tool made with a Rapid Tooling technology can be useful for predicting the quality of a thermoformed part, particularly to find the problems with thin-walled areas.

Keywords: computer simulation, thermoforming

1 Introduction

Thermoforming technology is getting more popular recently, because of its advantages, like relatively small cost of tool, especially when compared to injection moulds. It is very common in the packaging industry, with food packaging application, because of the easy possibility to automatize the process and to reach high productivity. Another advantages is the possibility to produce large plastic parts and that's why it found its place in the automotive industry, but also the tram and train interior parts are manufactured [1,2].

Thermoplastic materials are used in this technology and one of the most important factors is the temperature of processing a plastics sheet. It should be high enough to soften the sheet and to enable its forming but also not too high because of the risk of material damage. In case of thermoforming machines it is possible to use a certain temperature distribution in order to obtain the product wall thickness as uniform as it is only possible.

A computer simulation can be made before a tool is made to predict some potential problems with the process. If the results of the simulation would indicate the problems with the tool it is necessary then to make some corrections of the tool design. The processing parameters influence on the part quality can be also predict. One of the most important parameters is the formed sheet temperature, but its distribution is also important because it impacts the wall thickness distribution of the part [3,4].

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2 Experimental

The aim of this article was to evaluate the possibility of using a Rapid Tooling mould made by Fused Deposition Modelling technology to test the correct design of a thermoformed product or to make a short run production. Moreover, the efficiency of computer simulation of product wall thickness distribution was evaluated, by comparison of the results from the thermoforming process on the machine to the result of computer simulation done using *ANSYS Polyflow* software.

2.1 Mould

The mould was designed using *Siemens NX 8.5* software. It is a positive (convex) mould with the geometrical shape corresponding to some problems occurring during this process – different radii, internal and external dimensions and a pocket - Fig. 1.

The mould was produced using Fused Deposition Modeling (FDM) 3D printing machine *golemD* from acrylonitrile-butadiene-styrene (ABS) material filament. This material was chosen because it has good temperature resistance in comparison to other polymeric materials used for 3D printing. The length and width of the mould were limited by the dimensions of the 3D printer platform.

3D printers create models layer by layer and the layers' marks can be seen on a model surface and there is a risk that they will be also visible on the product made in the thermoforming process. In the case of big models made from ABS some cracks can occur between model layers. Such gaps were eliminated from the current model by sealing the side surfaces with a polyimide tape of 0.6 mm thickness.

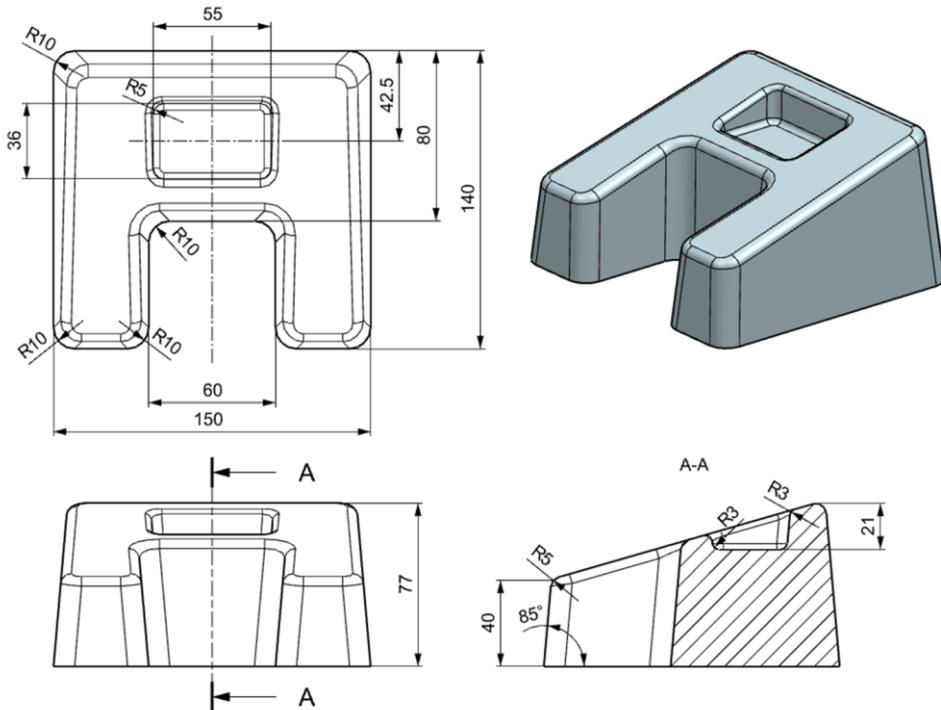


Fig. 1. The shape and main dimensions of the thermoforming mould

2.2 Thermoforming process

The test of the mould were done on the thermoforming machine *VP Minor*. The photograph of the mould placed on the machine table is shown in Fig. 2.



Fig. 2. View of the mould placed on the machine table

The processed material was PET sheet of 0.35 mm thickness, made from the recycled and origin plastic in extrusion process by *Hanex* company, Poland. The outer layers of this sheet were made from the origin material, but 70-80% of the thickness was made from the recycled material [9].

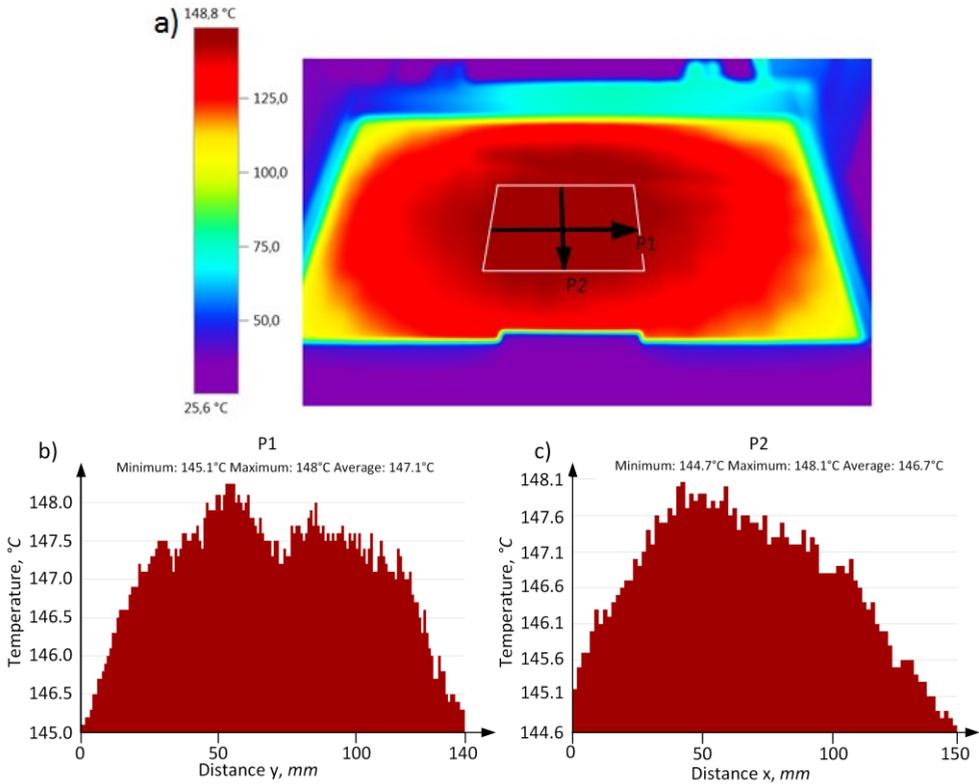


Fig. 3. PET sheet temperature distribution after 8 s of heating: a) thermovision photography of the entire sheet, b) temperature along P1 line, c) temperature along P2 line

The material was warming by the machine heaters by 8 s. The distribution of temperature after the heating stage was obtained by thermal imaging camera *TESTO 890* manufactured by *Testo* company and is presented in Fig. 3. The sheet temperature above the mould was homogenous - see P1 and P2 lines and graphs in Fig. 3b and 3c. Average value of temperature on area in the white rectangle over the mould is 146.9°C.

2.3 Computer simulation of thermoforming

The computer simulation was conducted in solver *Polyflow* which is a part of *ANSYS* software. The following geometrical models were used in the simulation: the positive thermoforming mould with the table (platform) of the thermoforming machine and poly(ethylene terephthalate) formed sheet.

The mould was symmetrical to X-axis so only its half was considered in the simulation. 2D shell geometry was applied as the representation of this mould surface (Fig. 4). The model was meshed with the options: *Face Meshing* - which allows generating a mesh composed from equal squares and *Mesh Sizing*. The size of a square of one finite element was in this case equal 9 mm, but the function *Adaptive Meshing* was also applied. The maximum number of recursive subdivisions for contact for one element was equal 3.

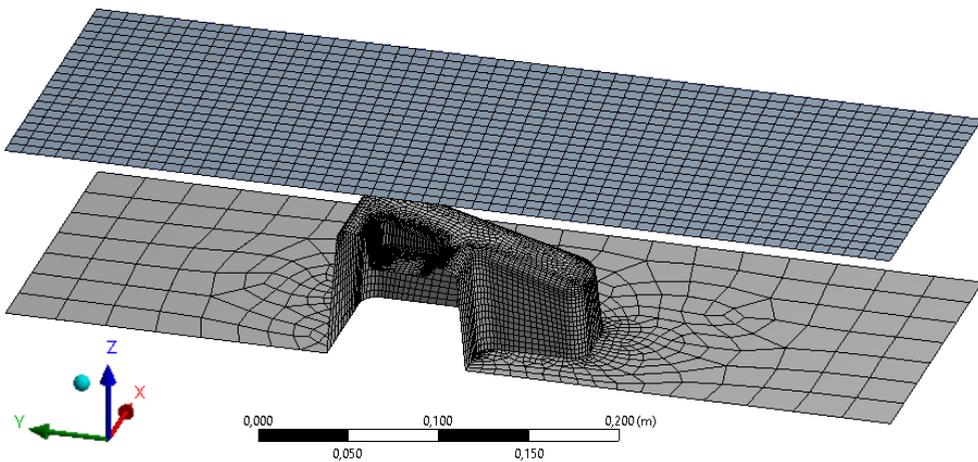


Fig. 4. Model of the plastic sheet and the mould mesh in *ANSYS Polyflow*

Thermoforming process is a time-dependent problem. The time of the total forming process considered in the simulation was equals 2 s. It included two stages:

- lifting the machine platform together with the mould, which lasts 0.5 s,
- product shaping, which starts from the time of 0.5 s and ends at 2.0 s. The value of the air underpressure was assumed to be 0.075 MPa.

The considered forming time is short therefore the changes in the temperature value were neglected.

The 0.35 mm plastic sheet is made from PET. The density of this material in the solid state is equal 1350 kg/m³. The viscosity data of PET in the liquid state can be found in the literature [10]. Based on these data the coefficients for PET in temperature 146.9°C of Carreau model (1) were calculated.

$$\eta = 67314.3 \cdot \left[1 + (0.675\dot{\gamma})^2 \right]^{-0.167} \quad (1)$$

where η - the polymer viscosity, $\dot{\gamma}$ - polymer shear rate.

A contact between the mould and the sheet was applied when defining the boundary conditions in the simulation.

3 Results and discussion

The results of the thermoformed part wall thickness distribution obtained during the experiments and from the computer simulation were compared.

3.1 The results of thermofoming on the machine

It was found out that the optimal time of the sheet heating for the machine and mould used was 8 s. The quality of the part was very good, but drilling of 1 mm diameter venting holes was necessary inside the mould pocket - in the corners and on the edges.



Fig. 4. The exemplary product manufactured with 8 s time of heating

The formed sheet thickness was measured by the thickness measurement gauge *Olympus Magna Mike 8600*, basing on Hall-effect. A steel ball of 1/16" diameter was used. The maximum thickness value which can be measured using this ball is 2.03 mm. The measurement accuracy of this tool is in the range from ± 0.025 mm to ± 0.04 mm and depends on the measured value. The thickness was measured along four lines, marked: A, B, C and D, presented in Fig. 5.

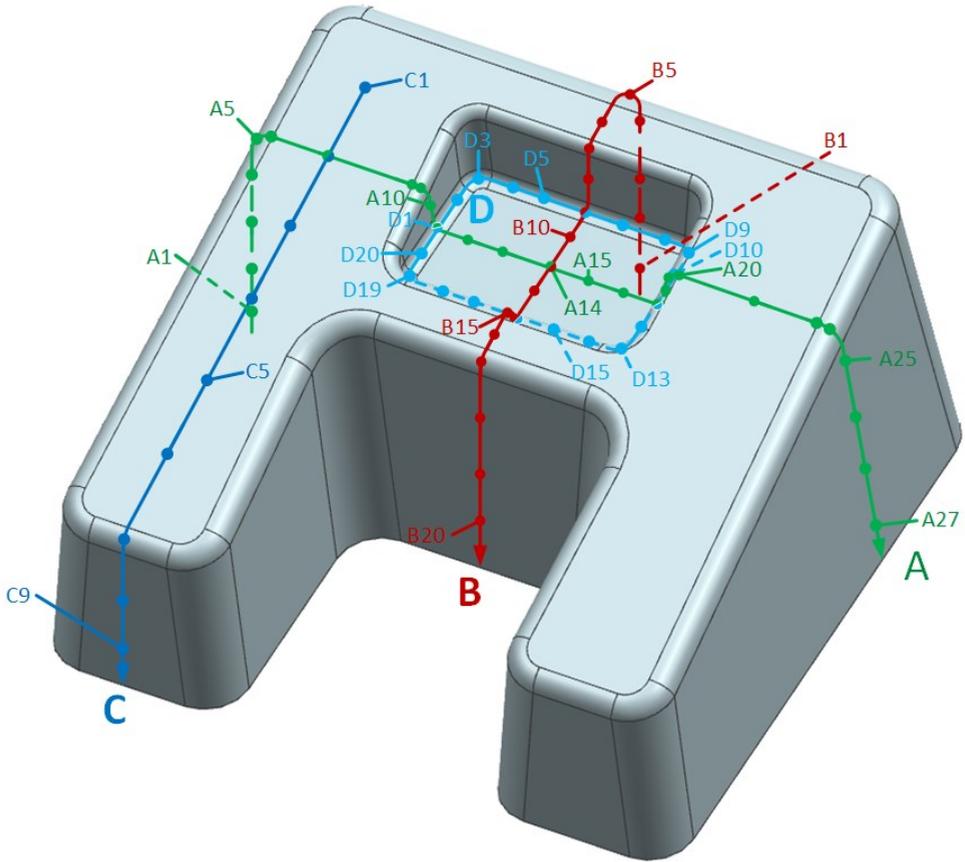


Fig. 5. The mould model with four measurement lines (A- D) and thickness measurement points marked

3.2 Computer simulation results

The result of the wall thickness distribution across the part obtained in the computer simulation is presented in Fig. 6. The distribution of thickness along A, B, C and D lines, presented in Fig. 5 was determined by the function *Probe* from menu *Tools ANSYS CFD-Post* program. The smallest thickness value can be observed in the inside corners. It is uniform on the upper surface, because the mould touched this area of the sheet as it raised just before the vacuum forming stage.

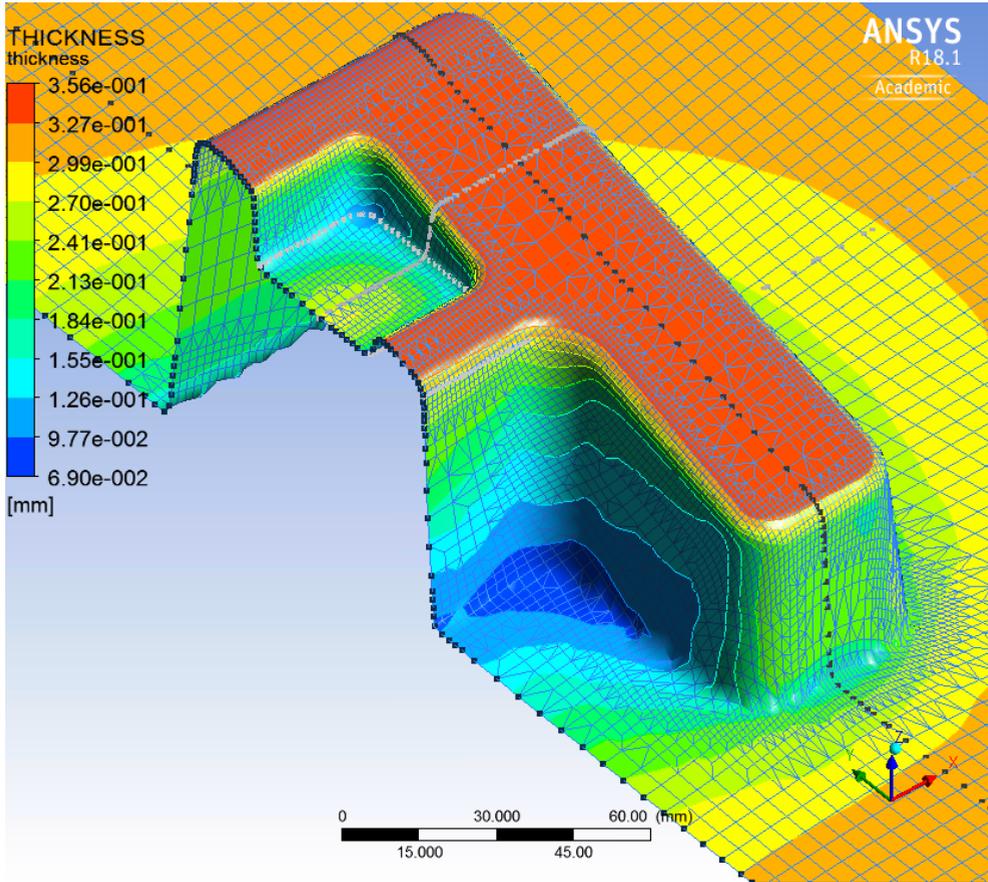
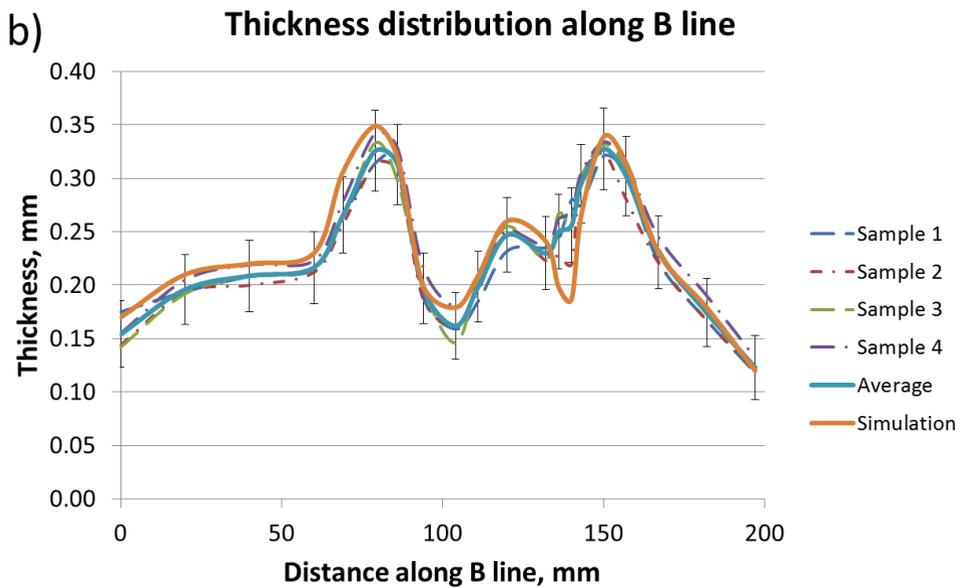
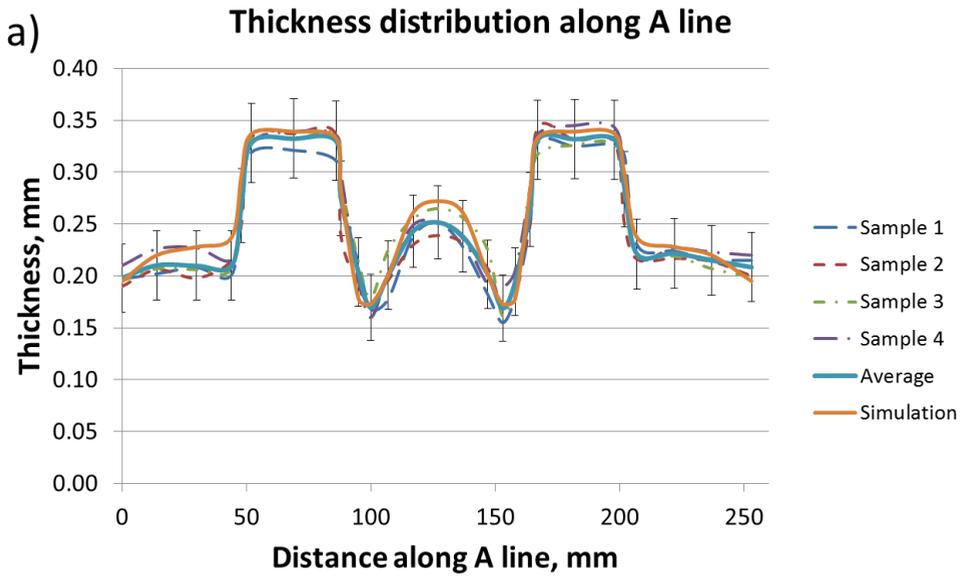


Fig. 6. Thermoformed product wall thickness distribution (with A-D lines marked)

The results of the real thermoformed product thickness (four samples of good quality were considered) are presented in Fig. 7 and compared with the case from the computer simulation. There is a good accordance between the simulation results and the real case. The thickness values from simulation are usually bigger than the real values in the higher areas of the product (further from the machine table surface) while they are smaller than the real values in the bottom areas of the product. This means that in the simulation the behaviour of the polymeric sheet is slightly different, depending on the degree of stretching.



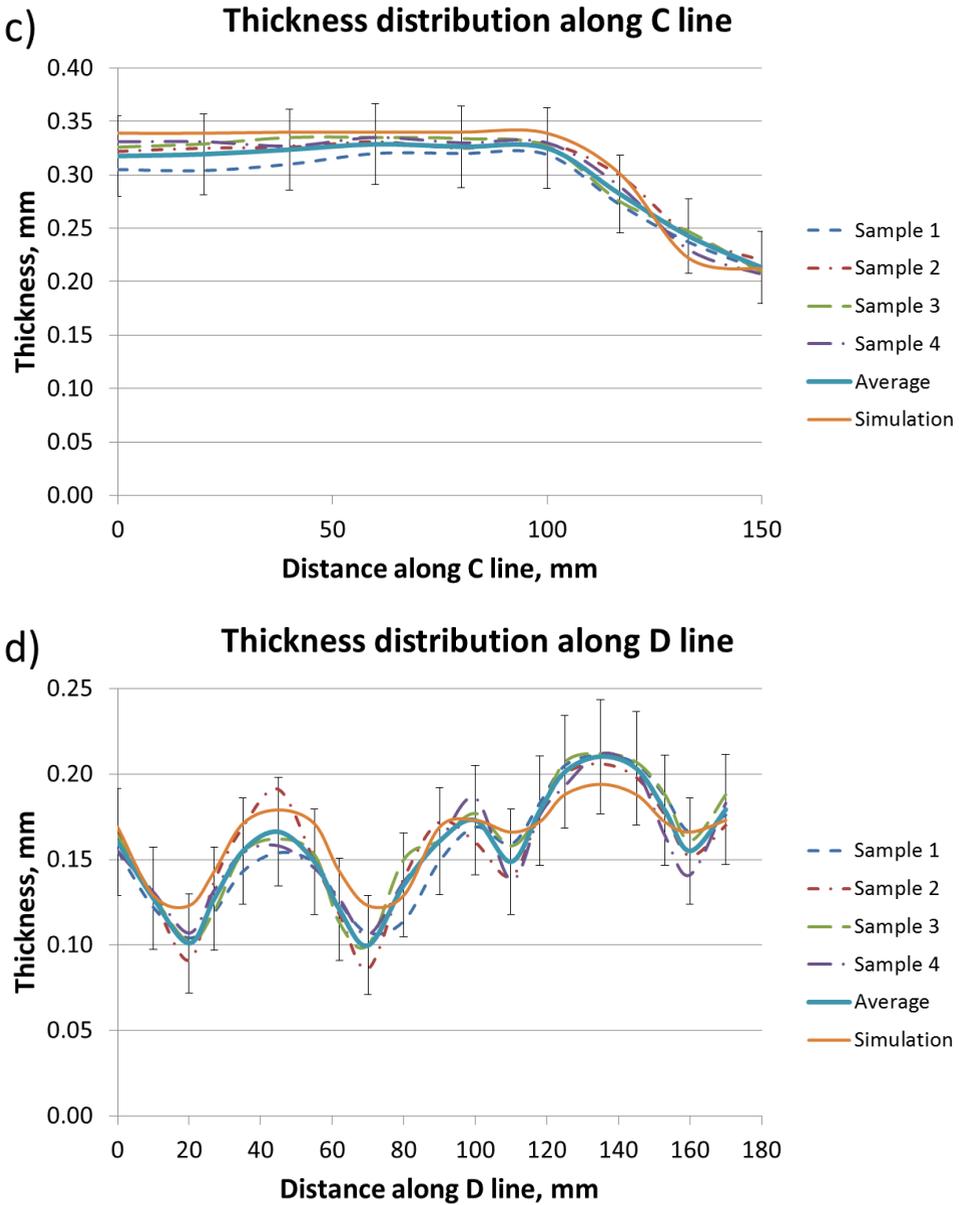


Fig. 7. Plots of wall thickness along: A-D lines

Conclusion

Computer simulation can be a useful tool to predict the quality of thermoformed parts. It was found out that the deviation of the wall thickness between the simulation and the experiment is not more than 23.4 %. Average value of this deviation is 2,5 %. The approach of using simulation in the first step of the design process can give some benefits since it can help to avoid excessively thinned areas of the product by redesigning the mould before its manufacturing.

It is possible to use Rapid Tooling moulds made by FDM technology in short run production or in trials of a newly designed tool. As it was proved on the case analysed in this paper, this kind of mould can work well and thermoformed product of a good quality can be obtained while the time of mould making is usually short.

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