FRI-1.417-1-MEMBT-05

DETERMINATION OF THICKNESS VARIATION IN ABS THERMOFORMED PRODUCTS

Assist. Prof. Olcay EKŞİ, PhD
Department of Mechanical Engineering, Engineering Faculty
Kırklareli University,
Phone: +90 288 214 05 14
E-mail: olcayeksi@klu.edu.tr

Assist. Prof. Sencer KARABEYOĞLU, PhD
Department of Mechanical Engineering, Engineering Faculty
Kırklareli University,
Phone: +90 288 214 05 14
E-mail: sencerkarabeyoglu@klu.edu.tr

Abstract: *The aim of this study is to create a prediction for thickness distribution in hemispherical, cylindrical and conical ABS thermoformed products. Initially, Acrylonytril Butadien Styrene (STYROLUTION Terluran HI-10 ABS) sheets cut and prepared in desired dimensions by machining. Then sheets with a thickness of 5 mm and a surface area of 150 x 150 mm*^{2} *were thermoformed by a lab-scale thermoforming unit. Process variations such as temperature distribution obtained by a thermal imaging cam. A digital caliper obtained thickness distribution on predetermined paths in ABS products by experimental method. Additionally Geometric Element Analysis (GEA) predicted thickness on the same predetermined paths in ABS products. Obtained and predicted thickness distributions compared to each other. As a result, GEA has produced incorrect and irrelevant thickness distributions according to experimental method at several points. GEA could predict thicknesses correctly in only some points.*

Keywords: *Thermoforming, Thickness, Geometric Element Analysis, ABS, Mould, Prediction.*

INTRODUCTION

There are many kinds of manufacturing processes for plastic products. One of the growing processes is thermoforming. Thermoforming process has grown because of developments in plastic industry. From past to present, the use of plastic materials in Europe, USA and Asia exhibited an increasing trend (Maggiani, M., 2017). In addition to this, use of plastics in manufacturing of composites made thermoforming more important than before (Effing, M., 2017).

In thermoforming, a flat plastic sheet is heated to a proper temepareture depends on the kind of plastic material. Then the sheet is clamped on to a mould and formed by positive or negative air pressure. After forming, semi-finished thermoformed product is released from the mould and trimmed if necessary. Generally thermoplastic film and sheet materials such as Polystyrene (PS), Acrylonitrile Butadiene Styrene(ABS), Polyvinylchloride(PVC) etc. are used in thermoforming. Not only thermoplastics but also biodegradable polymers and plastics can be used in thermoforming. As the interest in lightweight, biodegradable, safer and greener products increases, thermoforming will be a remarkable process for the future technologies (Nickels, L., 2017).

Most of the studies about thermoforming include variation of process parameters. Most researchers investigated the change in heating temperature, forming temperature, temperature distiribution in heated sheet, mold temperature, kind of plastic, shape of clamping ring, pressure value, duration of the pressure, even type of molds (Andena, L., Rink, M., Marano, C., Briatico-Vangosa, F., Castellani L., 2016; Radlmaier,V., Heckela, C., Winnackerb, M., Erberc, A., Koerber H., 2017; Xu, W., Wu, S., Balamurugan, GP., Thompson, M.R., Brandys, F.A., Nielsen, K.E., 2017). Beside these studies, thermoforming simulation and numerical simulation methods are the other significant topics for thermoforming (Brepols, T., Vladimirov, I.N., Reese, S., 2014). Improving new methods and materials for thermoforming is a current topic for today's engineers (Kazmi, S.M.R., Jayaraman, K., Das, R., 2016). There is a wide range of thermoforming applications. From composite material manufacturing to packaging industry, many sectors use this method (Gutierrez, M.M., Meleddu, M., Piga, A., 2017)

In this study, Acrylonytril Butadien Styrene (STYROLUTION Terluran HI-10 ABS) sheets cut and prepared in desired dimensions by machining. Then sheets with a thickness of 5 mm and a surface area of 150 x 150 mm^2 were thermoformed by a lab-scale themoforming unit. Process variations such as temperature distribution obtained by a thermal imaging cam. A digital caliper obtained thickness distribution on predetermined paths in ABS products by experimental method. Additionally Geometric Element Analysis (GEA) predicted thickness on the same predetermined paths in ABS products. Obtained and predicted thickness distributions compared to each other.

EXPOSITION

Materials and Methods

In this study, ABS sheets, which have thicknesses of 5 mm, have been used. These sheets have been extruded from STYROLUTION Terluran HI-10 ABS grades. According to technical datasheet, Terluran HI-10 is an medium flow, injection molding grade with very high resistance to impact with excellent heat distortion and suitable for injection molding and extrusion. Some properties belong to Terluran HI-10 are given in Table-1.

ABS sheets were cut and prepared to have dimensions of 150x150 mm by machining. Before the forming operation, operator need to put each sheet on to the mold one by one. Becaue of this, forming method is called cut-sheet thermoforming. First, operator put each sheet on to the mould. Then fix it by the clamping frame. Heaters are pulled, placed to the appropriate position and turned on.

Heating temperature for the heaters were adjusted for a quick heating operation. So temperature was chosen as 350 ^{0}C. However, it was detected that the obtained temperatures on the heated sheet changes from 120 ^{0}C to 155 ^{0}C. There are 3 heaters as radiant heating elements. Heating duration is about 4 minutes. After 4 minutes, heaters were turned off and pushed to their first position. Vacuum pump started and heated sheet deformed. After the heated sheet replicated the mold surface properly, vacuum pump stopped. During the forming, vacuum value(negative air pressure) reached the 680-690 mmHg. Formed sheet was left for 3 minutes for cooling in the mold. Clamping frame opened then formed part released from the mould. A forming cycle is thus completed.

ABS thermoplastic sheets were formed by using a lab-scale thermoforming machine in Kırklareli University, Mechanical Engineering Department. Thermoforming machine is seen in Fig. 1. This thermoforming machine is suitable for cut sheet thermoforming. That unit has a 25x25 cm^2 heating capacity and the capability of forming sheets with a thickness of 5 mm. Thermoforming machine has a vacuum pump and a compressor with a capacity of 6 bar. Air compressor is required for plug-assisted thermoforming. Three types of thermoforming molds were used in forming operations. Cylindrical, conical and hemispherical molds were employed in thermoforming machine. Cylindrical and conical molds are shown in Fig. 2.

Table 1. Some properties for Terluran HI-10

Rheological properties	**Standart**	**Value**
Melt Volume Rate 220 ^{0}C/10 kg	ISO 1133	5.5 cm^3/10 min
Mechanical properties	**Standart**	**Value**
Izod notched impact strength 23 ^{0}C	ISO 180A	36 kJ/m^2
Izod notched impact strength -30 ^{0}C	ISO 180A	14 kJ/m^2
Charpy notched impact strength 23 ^{0}C	ISO 179	35 kJ/m^2
Charpy notched impact strength -30 ^{0}C	ISO 179	13 kJ/m^2
Charpy unnotched 23 ^{0}C	ISO 179	No break
Charpy unnotched -30 ^{0}C	ISO 179	140 kJ/m^2
Tensile stress at yield 23 ^{0}C	ISO 527	38 MPa
Tensile strain at yield 23 ^{0}C	ISO 527	2.8 (%)
Tensile modulus	ISO 527	1900 MPa
Nominal strain at break 23 ^{0}C	ISO 527	9 (%)

Flexural strength	ISO 178	56 MPa
Hardness, ball indentation	ISO 2039-1	74 MPa
Thermal peoperties	**Standart**	**Value**
Vicat sortening temperature VST/B/50 (50 ^{0}C/h, 50 N)	ISO 306	90 ^{0}C
Vicat sortening temperature VST/A/50 (50 ^{0}C/h, 10 N)	ISO 306	103 ^{0}C
Coefficient of linear thermal expansion	ISO 11359	80-110 $10^{-6}/^0$C
Thermal conductivity	DIN 52612-1	0.17 W/m.K

Fig. 1. The thermoforming machine in Laboratory

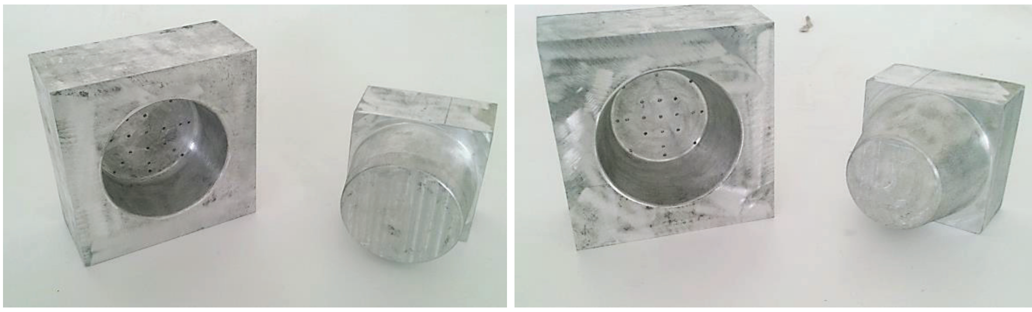

Fig. 2. Cylindrical and conical thermoforming molds

Geometric Element Analysis(GEA) is a numerical prediction method that is used in thickness distribution in thermoforming. This method can only be used for simple thermoforming molds. In addition to this, it is known that GEA does not reveal very accurate results. Since the molds used in this study have had simple geometries, GEA was used for prediction of thickness distribution in three different thermoformed products. Three sheets were formed for each thermoforming mold. Thickness distribution was calculated and measured for each of the three thermoformed products by GEA and a Mitutoyo digital caliper (Resolution: 0.01 mm). Average thickness distribution was considered in calculated and measured thicknesses for each type of thermoformed product (Cylindrical, conical and hemispherical). Dimensions of conical and hemispherical thermoforming products are shown in Fig. 3. and Fig. 4. respectively. Thermoformed products were divided into two pieces by machining. Then wall thickness measurements were performed on these half samples. In spherical product, thickness was measured and predicted on 25 points from the center of the base to the outer edge of the product. The comparative thickness distribution was determined for the cylindrical product by following the same method. Because of its shape and dimensions, thickness distribution calculated and measured for 28 points in conical product. Measured and calculated thickness distributions compared to each other with graphical method.

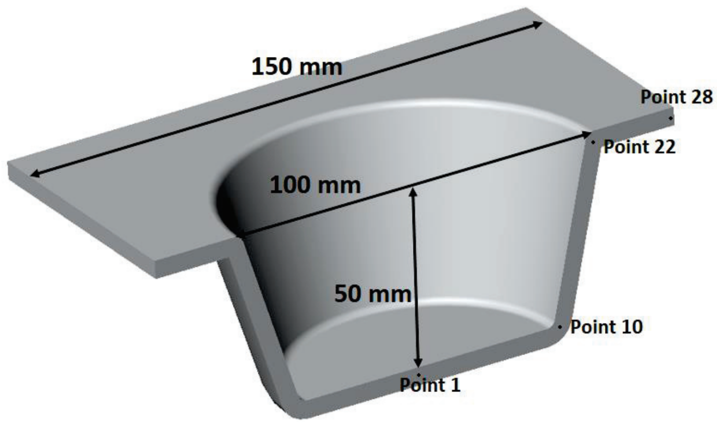

Fig. 3. Dimesions of conical semi-product and locations where thickness was measured, from 1 to 28 respectively.

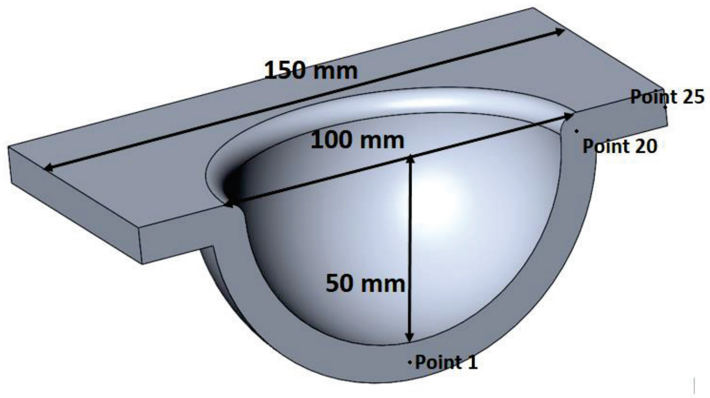

Fig. 4. Dimesions of spherical semi-product and locations where thickness was measured, from 1 to 25 respectively.

Results and Discussion

Comparative thickness distributions for each of the thermoformed products are given in Fig. 5, 6 and 7.

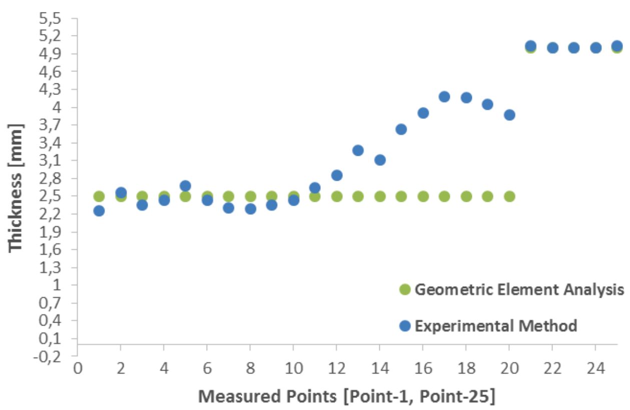

Fig. 5. Comparative thickness distribution for spherical product.

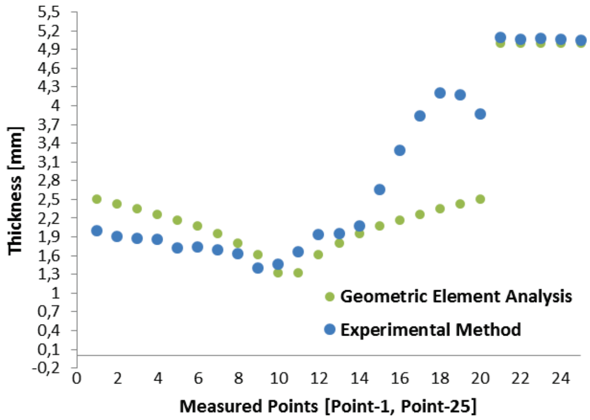

Fig. 6. Comparative thickness distribution for cylindrical product.

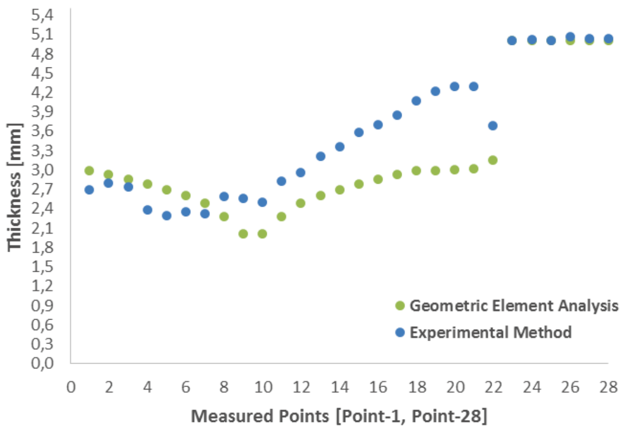

Fig. 7. Comparative thickness distribution for conical product.

Based on the results obtained from Fig. 5., 6. and 7., GEA method is insufficient especially in the thickness distribution in the spherical product. As seen in Fig. 5., difference between the GEA and the experimental method arises especially in the determination of the thickness of the side walls(From point 10 to 20). GEA calculates the thickness as a same value of 2.5 mm along the sidewall. However, the thickness actually varies from point 10 to 20. In addition to this it is seen that the thickness does not show a significant change from point 20 to 25. The same trend can be seen in points between 20 and 25 in cylindrical product(Fig. 6.), and points between 22 nd 28 in conical product(Fig. 7.). In Fig. 6. (From point 10 to 20) thickness values predicted with GEA are quite different from the values obtained with the experimental method. Points between 10 and 20 are located on the sidewall of the cylindrical product(Fig. 6.). In Fig. 7. it can be seen that there are large differences in the obtained and predicted thickness values belong to points between 10 and 22(sidewall of the conical product).

CONCLUSION

Geomteric Element Analysis generates thickness distribution results based only on mold geometry without using material parameters. This makes GEA ineffective compared to other methods. A simulation software that uses material parameters for prediction, can be used instead of GEA method. As a result, GEA gives a preliminary explanation of how the thickness change, instead of precisely estimating the thickness distribution.

ACKNOWLEDGEMENTS

This paper has results of a Scientific Research Project entitled “DETERMINATION OF THERMOFORMING PROCESS PARAMETERS OF THERMOPLASTIC SHEETS USED IN PACKAGING SECTOR” and supported by Kırklareli University. Authors would like to give their special thanks to Kırklareli University and Kıklareli University Scientific Projects Coordination Unit.

REFERENCES

Andena, L., Rink, M., Marano, C., Briatico-Vangosa, F., Castellani L. (2016). Effect of processing on the environmental stress cracking resistance of high-impact polystyrene. Polymer Testing, 54, 40-47.

Brepols, T., Vladimirov, I.N., Reese, S. (2014). Numerical comparison of isotropic hypo- and hyperelastic-based plasticity models with application to industrial forming processes. International Journal of Plasticity. 63, 18–48.

Effing, M. (2017). Expert insights in Europe’s booming composites market. Reinforced Plastics, Article in Press, https://doi.org/10.1016/j.repl.2017.06.086, 1-5.

Gutierrez, M.M., Meleddu, M., Piga, A. (2017). Food losses, shelf life extension and environmental impact of a packaged cheesecake: A life cycle assessment. Food Research International, 91, 124–132.

Kazmi, S.M.R., Jayaraman, K., Das, R. (2016). Single-step manufacturing of curved polypropylene composites usinga unique sheet consolidation method. Journal of Materials Processing Technology, 237, 96–112.

Maggiani, M. (2017). Italian plastics, rubber processing machinery, and molds industry Reinforced Plastics, 61(3), 157-159.

Nickels, N. (2017). Car with a biodegradable core. Reinforced Plastics, Article in Press, https://doi.org/10.1016/j.repl.2017.07.073, 1-3.

Radlmaier, V., Heckela, C., Winnackerb, M., Erberc, A., Koerber H. (2017). Effects of thermal cycling on polyamides during processing. Thermochimica Acta, 648, 44–51.

Xu, W., Wu, S., Balamurugan, G.P., Thompson, M.R., Brandys, F.A., Nielsen, K.E. (2017). Evaluating shape memory behavior of polymer under deep-drawing conditions. Polymer Testing, 62, 295-301.