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COLD BACKWARD EXTRUSION OF POLYMERS

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ABSTRACT

Polymers are conventionally processed by heating of starting material above the softening point, after which liquefied material is formed by means of different dies and techniques (mold injection, thermoforming, extrusion etc). In addition, it is possible to shape polymeric materials in solid-phase without any heating (cold forming process). Compared with conventional procedure, cold forming of polymers offers several advantages, especially in terms of process time and energy saving. However, cold forming of polymers is still in its early stages of research and commercial development. Present study is an attempt to change the state in this field.

This paper gives the results of numerical and experimental investigation of cold backward can extrusion process of polyethylene (PE) and polyamide (PA) billets. Finite element method (FEM) and Simufact.Forming 10.0 software were employed for the process simulation. FEM predicted results agree well with that from the experiment.

Key words: Polymer solid-phase forming, backward extrusion, FEM, Simufact.Forming

1. INTRODUCTION

Polymeric components are conventionally manufactured by heating to melt plastic material before being shaped into their final forms. But this way of processing polymers is not always optimal and exhibits some demerits mainly related to high energy consumption, low production rates affected by the long cooling time, poor mechanical properties of plastic parts, high cost of mold making etc. Limitations of molding processes arise also from the difficulty in producing thick parts and the difficulty in processing high density materials [1]

Having above mentioned in mind, in early seventies of last century development of procedures different from the classical molding process were initiated. [1,2]. Basically these are metal forming processes, in which final product is formed by processing cold or solid-phase polymer billet. In case of cold forming there is no heating of material and tooling, as the solid-forming is performed with the material that is heated below melting point and formed while in a heated solid state. In literature these terms are sometimes used interchangeably [1]. Forming operations for processing polymers can be divided into three main groups: forging, sheet forming and drawing operations.

Compared with molding processes, polymer cold and solid-phase forming has several advantages. Particularly, cold forming is able to reduce cycle time and production cost, process difficult-to-mold materials, produce part without flash, trim or weld lines, and enhance mechanical properties through self-reinforcement [1,3]. With other side, the cost of preparing billets and excessive elastic recovery of deformed part are the main disadvantages of these procedures.

Wide range of polymeric materials can be processed by metal forming processes. Generally, employed materials must possess sufficient ductility and strength in order to avoid local necking or cracking when exposed to tensile stresses [1]. In addition, to minimize spring-back effects and ensure dimensional stability of final part the recovery or “memory” features of materials must be as low as possible. [3]. Polycarbonates, polypropylene, celluloses, ABS, rubber modified polymers etc., as well some glass reinforced materials can be easily formed, while brittle materials such are polystyrenes and acrylics can not [1,4]. It is possible to form even soft rubbery polymers such as polyethylene, but forming process is followed with excessive springback of workpiece. Thus, long forming cycles have to be applied. For the fast pre-selection and rating of polymers data obtained by simple uniaxial tension and compression tests could be practiced.

In contrary to cold forming of metal materials, cold forming of polymers is still in its early stages of research and development. This can be partially attributed to the lack of fundamental understanding of the process (primarily related to the behavior of material during forming), recovery phenomena, and lack of a modeling and simulation capability. In the Laboratory for metal forming, rapid prototyping and virtual manufacturing Faculty of technical sciences Novi Sad, possibilities of applying the conventional cold metal forming methods and standard forming tools in processing of thermoplastic materials have been investigated for few years. In the present study, some results of experimental and Finite Element Method (FEM) investigation of backward can extrusion of cylindrical specimens made from commercial high density polyethylene (HDPE) and polyamide (PA) are given. All necessary material data and process parameters essential for process modeling and simulations were determined according to the methodology used in metal forming.

2. EXPERIMENT

Experimental investigations were comprised several segments. In the first step, for selected thermoplastics data about yield strength and friction coefficient which are necessary for numerical calculation were determined. Afterwards a process of cold upsetting backward can extrusion is accomplished. All experiments were performed on 6.3 MN, Sack and Kiesselbach hydraulic press.

2.1. Flow curve

Yield stress and flow curves for both materials were determined by applying Rastegaev test (Fig.1) [5]. Specimens after Rastegaev test are shown in Fig.2. In this procedure shallow cavities on forehead’s surfaces of specimen are filled with lubricant (stearin here) with goal to eliminate friction and avoid bulging process by splitting up contact surfaces between dies and specimen. It assures unaxial stress state in specimen thus effective stress can be directly calculated by dividing actual forming load and cross section of specimen. After statistical processing of experimental data the next analytical expressions for flow curves in Ludwig’s form are obtained [6]:

- for PA $K = 20 + 56.42 \cdot \varphi^{0.77}$
- for HDPE $K = 10 + 27.2 \cdot \varphi^{0.467}$

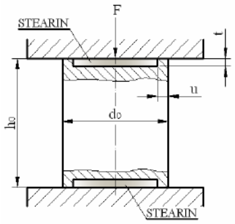

Figure 1. Scheme of upsetting according Rastegaev method

Figure 2. Specimens made from PA (left) and HDPE (left) after Rastegaev test

2.2. Friction coefficient

Method of free upsetting of ring specimen was used for calculation of Amonton’s coefficient of friction (μ). As it known, the way of the inner diameter behavior during ring upsetting depends on friction [7]. Increase of inner ring diameter indicates the lower friction and vice-versa. This had been used as a base for the design of so cold etalon-diagram in which the change of the inner diameter deformation ε_D with respect to deformation of ring height ε_H is given. By incremental way the ε_D - ε_H curves for PA and HDPE were calculated and incorporated into standard etalon diagram. Comparing the results with standard curves, the following values of the coefficient of friction when mineral oil is used as lubricant are estimated: μ=0.03 for PA and μ=0.05 for HDPE [6], respectively (Fig. 5). In case of upsetting of PA ring specimens without lubrication friction coefficient was μ=0.06.

2.3. Backward extrusion

Backward can extrusion of thermoplastic specimens was performed with tooling (punch and die) whose geometry is designed for specimens made from steel. In figure 3 dimensions of specimens before and after shaping are given. Fine turning were applied for preparing billets (6 of each material) in order to attain high surface quality. Figure 4 shows the form of specimen made from PA after process of backward can extrusion.

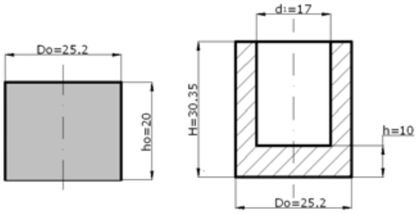

Figure 3. Dimensions of billet and final part

Figure 4. Specimens of PA after backward can extrusion

3. FEM SIMULATION

2D axisymetric FEM analysis of investigated backward can extrusion was performed by using commercial software package Simufact.Forming 10.0. In process simulation model of elastic-plastic material for workpiece was chosen, as punch and die are considered as rigid bodies. The Young's modulus, Poisson's ratio and density of investigated thermoplastics are E=3000MPa, ν=0.34, ρ=1130kg/m^3 in case of PA and E=810Mpa, ν=0.34, ρ=980kg/m^3 for HDPE, respectively [8]. Amonton's friction model is applied in FEM analysis with previously determined friction coefficients. The specimens were meshed with quad's elements which are generated upon the size criteria. In simulation remeshing of starting elements had to be applied for highly deformed zones of workpieces. Remeshing procedure was performed on every 5 increments in order to minimize the effect of tool penetration through elements due to the large workpiece deformations.

4. ANALYSIS OF RESULTS AND CONLUDING REMARKS

Load – stroke diagrams obtained by experiment and FEM simulation for both materials are depicted in Fig.5 and Fig.6. It can be seen from diagrams that FEM predicted forming loads are similar in the form and show the same trend as experimentally recorded curves. However, there are certain degrees of discrepancy in absolute values. In the case PA specimen (Fig.5), experimental load is greater by about 20-40% of the value obtained by simulation. For the specimen made from HDPE the relationship is opposite- FEM gives higher values for about 20%. These discrepancies can be partly explained by improper description of the mechanical and physical properties of used materials which are essential for accurate numerical analysis [11].

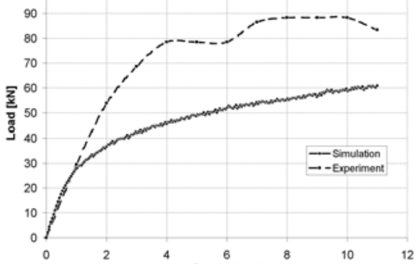

Figure 5. Load–stroke diagram for PA specimen

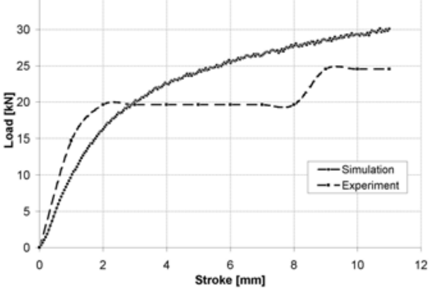

Figure 6. Load–stroke diagram for HDPE specimen

Distribution of effective stress and effective strain for both materials are simultaneously displayed in Fig.7 and Fig.8. As it can be seen, stress-strain distribution over workpiece is very heterogeneous. In the process of backward extrusion maximum values of effective strain appears on the inner surface with the pick at the zone around the wall-bottom edge. On the top of workpiece there is zone which is not almost included in deformation process-so called dead zone. It is noticeable that at the points with similar values of effective strains differences between corresponding effective stresses are almost 3 times in favor of PA specimen.

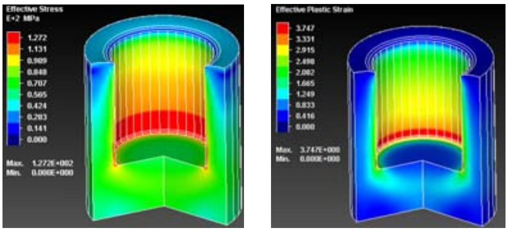

Figure 7. Effective stress (left) and strain (right) – PA specimen

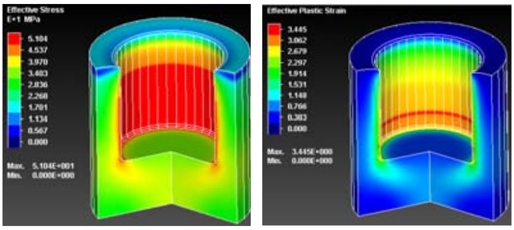

Figure 8. Effective stress (left) and strain (right) – HDPE specimen

As for the accuracy of the specimens after forming, parts made from PA showed better dimension stability and less shape variation from desired geometry in comparison to those from HDPE. This is a direct consequence of large springback which occurs in case of HDPE specimens. Problem with accuracy of HDPE specimens comes also from very low strength of this thermoplastic so even small contact pressure can generate local errors in part form. Also, significant differences in the quality of part surfaces can be noticed. Better quality is obtained in case of PA specimens.

5. ACKNOWLEDGEMENT

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