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Lateral Extrusion for Round to-Triangular Head: Experimental Studies and Three Dimensional Analyses

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Abstract

In recent years, applications of integral part instead of assembled part in different industries have been increased. In the present work, an experimental die-punch set-up for lateral extrusion is designed and the process is simulated using finite element method for estimation of load requirement and metal flow patterns. Experimental study has been carried out to find the extrusion load at different geometrical conditions taking lead as the work piece material. The predictions both in extrusion/forging load and the deformed configuration are in good agreement with the experiment qualitatively under different conditions.

Keywords: Lateral extrusion, Metal forming, Die-punch, Metal flow, Finite element method

1. Introduction

Extrusion is a common metal-forming process in which the material is extruded by forcing it to flow through a shaped opening called die. Usually, a container is required to hold the billet in position before entering the die opening. Depending on the forming direction, it is classified as forward, backward and radial or lateral extrusion (Lange, 1985). Among these processes, radial extrusion is a forming process in which the punch moves axially causing the solid cylindrical or tubular billet to flow in radial direction into the die cavity and offers a product with a central boss section having complete or segmented protrusions. The research work for lateral extrusion is not as plentiful as for forward and backward extrusion. Complex parts such as collar flanges, spur gear forms, and splines with a shaft are a few examples of the products produced by lateral extrusion.

Machine elements such as spur gears and splin**es** are mostly used to transmit heavy loads and torque by rotating at high speeds. Therefore there is an industrial demand to produce these parts with high strength and within narrow tolerances. But it is known that plastically deformed gears have a longer lifetime and higher fatigue strength when compared to machined gears made from the same material. Also forming operations offer a considerable amount of material savings when compared to machining. In order to reduce the cost of plastically formed products and become more competitive in a demanding industry, the forming must be performed to near-net or net shaped parts to reduce the subsequent operations such as machining.

Early studies on lateral extrusion were carried out by Hendry (1973) and Parsons et al. (1973) under the name of "injection upsetting". They carried out an experimental work to investigate the effects of process variables on the load requirement and relationship between the aspect ratio of deformation zone and the development of flaws. Balendra (1985, 1987, 1993), Balendra and Hijazi (1989) have studied effect of process parameters on metal flow and load requirement for complete protrusion. Lee et al. (2001) and Choi et al. (2001) studied the effect of punch diameter and the friction factor on the forming load by the FEM on the combination of lateral and forward or backward extrusion. Du Ko et al. (2001) studied the effect of die geometry parameters on material flow in this process. They showed a certain pattern in the material flow in each deformation case and studied the some die geometry parameters on the material flow by FE simulation method. Maccarini et al. (1990) correlating some relevant data obtained from the experimental with the theoretical results using FEM, the authors offer the solution to some plastic deformation processes expressing the frictional tangential stress on the upset surface as a function of the friction coefficient in order to find a solution consistent with the adherence existing between die and work piece.

In the present investigation experimental studies are carried out with a view to compare some of the experimental results with the finite element model. Experiments of lateral extrusion are performed for Triangle section using three flat dies of varying thickness. Commercially available lead is used as the working material. An extrusion test rig is designed and developed on thumb rule basis for the said purpose and all extrusions are carried out using round billets.

2. Experimental Set up

2.1 The test rig

Experiments are conducted on a 600T hydraulic press with constant ram speed of 1 mm/min. A schematic diagram of experimental setup and the die assembly has been shown in Figure 1. The apparatus mainly consists of four parts namely, the container having a cylindrical extrusion chamber of 30 mm diameter, the extruding punch of same diameter, the die holder, and the supporting block for the die holder. The diameter and height of container is taken as140mm and 120 mm respectively. The punch length is 120mm.The die assembly consists of a die holder of outer diameter 140mm, inner diameter 80mm and thickness 20mm with split dies of same inner diameter and thickness. Two flat plates of 5mm thick and profile same as that of the die are used to reduce the die thickness to subsequently 15mm and 10mm are shown in Figure 2. The die holder was made from high carbon steel round block by shaping. There is a base plate of same diameter as that of the outer diameter of the container and thickness 10mm with 4nos of bolt holes of ø12mmwhich support both extrusion chamber and die holder. Both extrusion chamber and die holder are fastened together rigidly by four hexagonal headed Allen HT bolts of ø12mm. The commercial lead billets of ø32mm were casted and machined to the required length of ø30mm. The specimens are cleaned with acetone so as to provide a similar friction condition. The inside surfaces of the extrusion chamber are flame hardened to reduce frictional wear.

Figure 1: Pictorial view of test rig

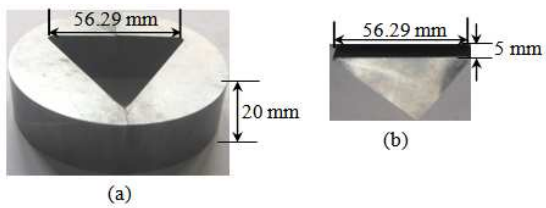

Figure 2: (a) Split triangular die and (b) Packing plate (2 nos.)

2.2 Flat dies

The flat dies used in the present series of experiments are made of two split halves for easy removal of the extruded product as shown in Figure 2(a). The orifices are so made that the respective canters of gravity lie on the billet axis. These dies are produced by wire cut EDM from 20 mm thick flat plates oil- hardened and non-shrinking EN31 hot rolled tool steel. After machining, each die set is first normalized at a temperature of 930^0C in a reducing atmosphere and then hardened by quenching in oil from the above temperature to attain a hardness, R_c, of 60-65.

3. Experimentation

Before starting the tests, the die sets, the die holder and the inside faces of the extrusion chamber are cleaned with carbon tetrachloride. The two-halves of the die set are then push-fitted into the die holder and the total assembly is secured by screwing the four bolts. The full assembly is then placed on the lower table of the universal testing machine as in the Figure 3. For carrying out an extrusion test, the sides of the lead specimen excepting the bottom face are smeared with grease and the specimen was placed inside the extrusion chamber.

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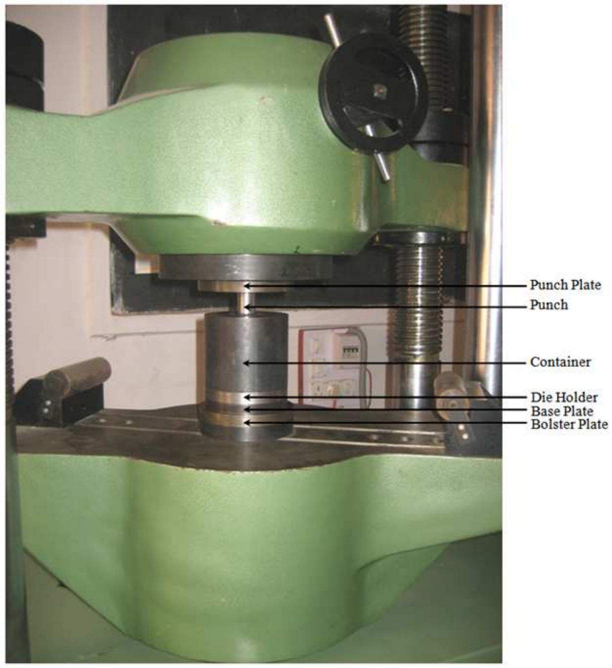

Figure 3: ***Pictorial view of experimental set up***

The punch is then inserted into its position. After centering the apparatus under the machine lower table, the machine is started and the extrusion process was continued. To avoid rate effect, the speed of the punch movement is adjusted to approximately 1 mm/min and punch load is recorded at every 1 mm of punch travel. Extrusion is continued till the specified punch movement reaches. At this point the machine is stopped and the test is terminated. The die-punch set is de-assembled to push out the product from the die holder. Experiments are conducted for three different thicknesses of triangular die cavity sections, which are 20mm, 15mm and 10mm

4. Simulation Procedure

An implicit and static finite element model "DEFORM-3D®" is adopted to analyse the plastic flow pattern of the billet within the die cavity during lateral extrusion of a Triangle section with varying thickness. The finite element code is based on the flow formulation approach using an updated Lagrange procedure. During the simulations, it is assumed that the billet is rigid plastic, and the die, the container as well as the flow guide are all rigid. The interfaces between the billet and the die, container, and the flow guide have a constant friction factor m, which is set to be 0.21 to correspond to the condition of cold forming. The four-node tetrahedron elements are used. The billet is divided into about 30,000 elements. In order to reduce the simulation time, the die cavity is filled with the billet before extrusion. The temperatures of all the objects are set as 30˚C. The isothermal condition is adopted in the finite element simulations. The iteration methods adopted for solving the nonlinear equations are the Newton–Raphson and the direct iteration methods. The direct iteration method is used to generate a good initial guess for the Newton–Raphson method, whereas the Newton–Raphson method is used for speedy final convergence. When the plastic deformation reaches the steady state, the simulation is stopped. The diameter of the billet is 30 mm. The ram speed is1 mm/min. The database of flow stress for lead billet at 30˚C in is used for the simulation.

The three dimensional FE analyses has been used to investigate the effect of some important geometrical parameters such as initial billet diameter and height, gap height as well as process condition such as friction on the process.

5. Results and Discussion

5.1 Steady State Extrusion Pressure

The variation of punch load with punch travels as determined from the experiment and simulation for the triangle section dies are shown in Figures 4-6. Referring to the above diagram, it is seen that a typical diagram consists of three principal stages namely: (i) the initial compression stage in which the load gradually increases and reaches a peak value, (ii) a steady-state stage in which the load remains almost constant, and (iii) the unsteady-state stage in which there is a steep rise. The constant in load in the steady-state stage is due to the fact that actual extrusion takes place during this stage and there is an increase of load due to increase of frictional spread area. This process continues till the metal touches the outer boundary. Afterwards, in the last stage, as the metal flow is restricted and controlled, the load increases unsteadily.

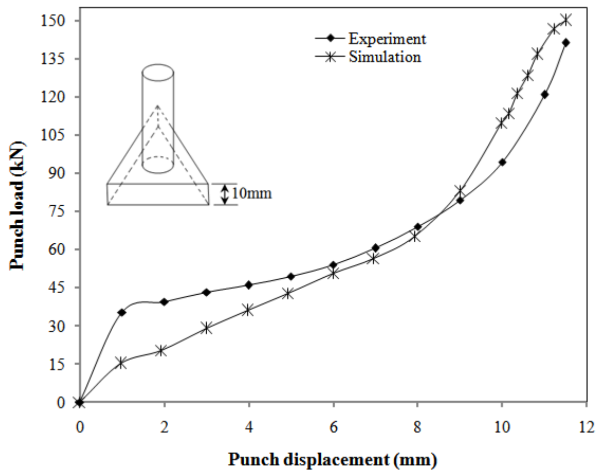

Figure 4: Variation of load with punch movement (Triangular head height=10mm)

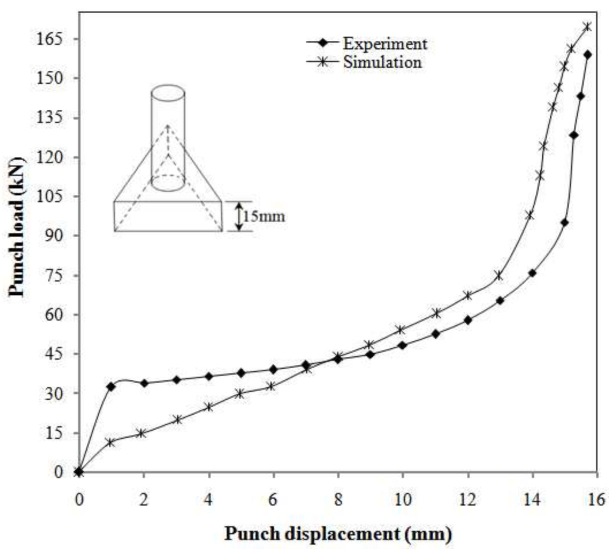

Figure 5: ***Variation of load with punch movement (Triangular head height=15mm)***

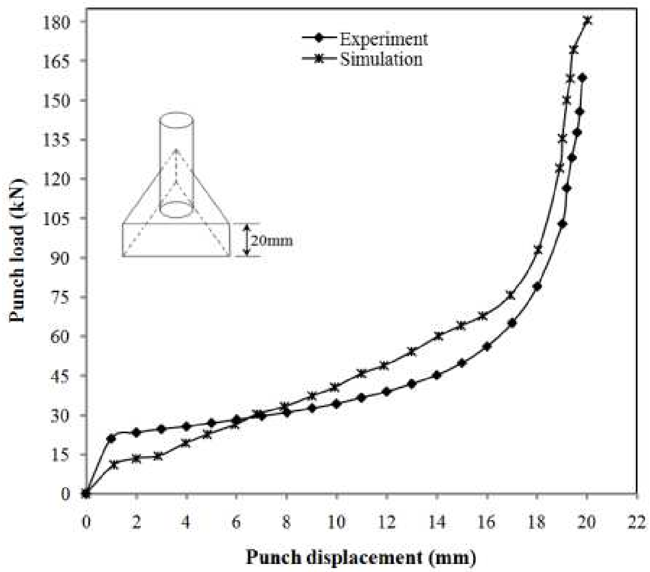

Figure 6: ***Variation of load with punch movement (Triangular head height=20mm)***

It is observed that the peak load variations between experiments and FE simulation lies within 7% and the peak load increases with increase in die thickness as shown in Table 1. In each case, it is also found that the peak load in FE simulation is more than the experimental value. It is seen that the peak loads of initial stage for experimental is more than the simulation value in each case. The experimental initial compression load increases with decreases in thickness of die head but it remains constant in case of simulation. This may be due to the redundant work carried out in the actual process. Further comparing the simulation and experiment, it is also observed that for the last stage corner filling of the die, more punch load is required as die thickness increases. It may be due to the more load requirement as the metal flow path gets elongated.

Table 1: Comparison of peak loads between experiment and simulation at different die thickness

Sl. No.	Die thickness (mm)	Expt. Peak load (kN)	Simulation peak load (kN)	% variation in peak load
1	10	141.25	149.8913	6.1
2	15	158.78	169.602	6.8
3	20	170.02	180.5959	6.2

5.1 Steady State Extrusion Pressure

As an illustration, Figure 7 shows the photograph of the flow pattern for a lateral extrusion of triangle section at different punch movement for both in FEM analysis and experimental investigation. The gridlines distortion indicates that the process utilizes the maximum amount of redundant work to create the extruded product. It is also clarified that the corner filling takes place first at the bottom of the die during the steady state and then the flow proceeds towards the top corners of the die. Progressive change in shape of extruded product at different punch movement for both simulation and experimental are shown in Figure 8.

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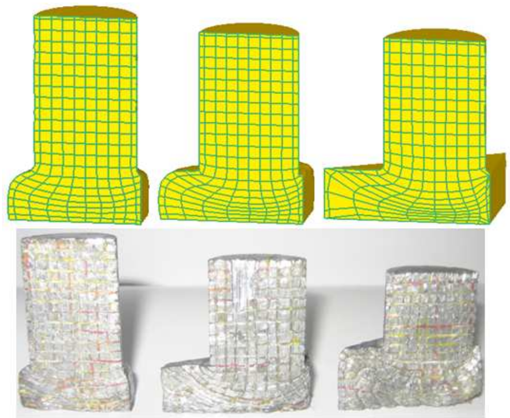


Figure 7: ***Comparison of flow pattern between simulation and experiment***

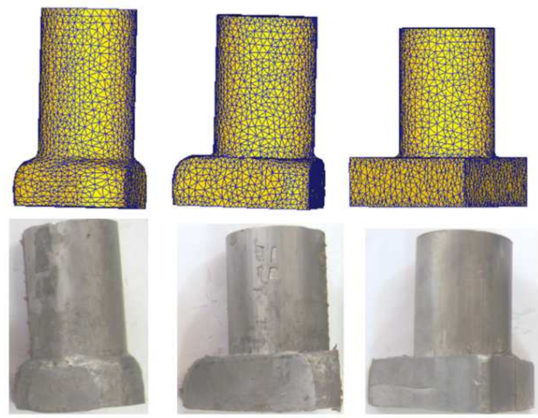
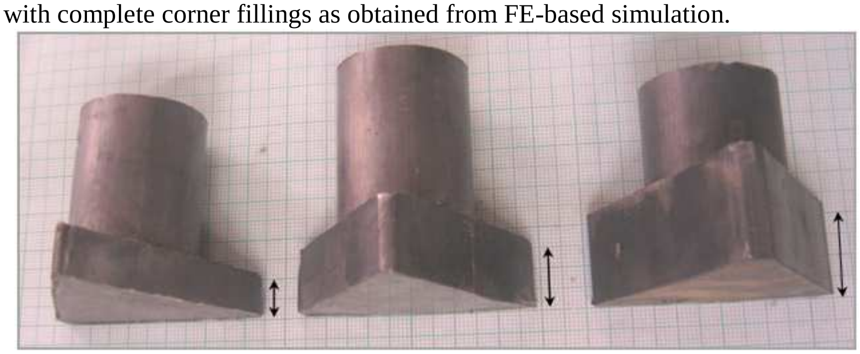


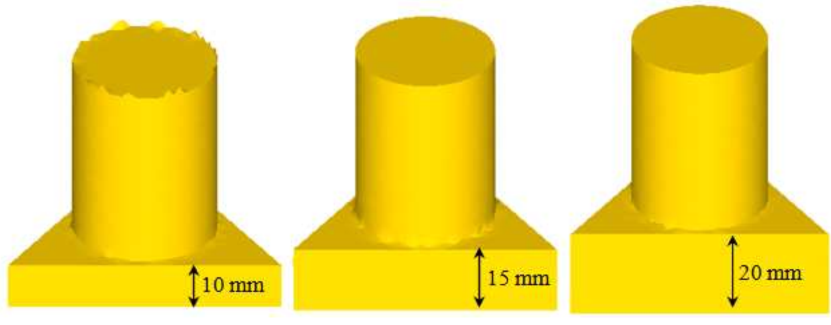
Figure 8: ***Progressive change in shape of extruded product both for simulation and experiment***

5.2 Extruded products

The photographs of the extruded triangle sections are shown in Figure 9. It is observed that the extruded products are fairly straight with complete corner fillings as obtained from FE-based simulation.



(a)



(b)

Figure 9: ***Extruded product; (a) obtained experimentally and (b) obtained FE-based simulation***

6. Conclusions

The FE results are compared with experimental data in terms of forming load and material flow in different regions. The comparison between the simulation and the experimental results show good agreement. The simulation and experimental results show the effectiveness of above mentioned parameters on the forming load and material flow.

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A Brief Author Biography

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