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FEM modeling of micro-extrusion of square section from Al 6063 round bar using cosine die profile

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Abstract

Extrusion plays an important role in manufacture of micro-product with better mechanical property and surface integrity. Micro-products are used in different applications such as aerospace, bio-medical, nuclear, automotive and defense sector. Though a number of micro-machining methods are available for fabrication of micro products, manufacturing micro-products is very important from the enhancement of mechanical strength, surface integrity and reduction of wastage of material. Al-6063 alloy is an important material used in different application because of its specific strength and better formability. Die profile plays an important role in the process of micro-extrusion in terms of improvement of product quality. Converging non-linear die profile is very useful for gradual deformation and reduction in extrusion load. In the present investigation, FEM simulations for micro-extrusion has been carried out for extrusion of square section from Al-6063 round bar using cosine die profile. The diameter of billet is taken as 1mm. Extruded products are made using 50%, 70% and 90% reduction. Extrusion load, effective stress, effective strain and temperature have been determined.

Keywords: micro-extrusion, cosine die, square-section, round billet, Al6063

1. Introduction

Die profile plays a predominant role for extrusion of micro-product through mathematically contoured die. The shear faced die is presently used in extrusion industries only due to convenience in manufacturing. Formation of the dead metal zone, undesirable internal shear deformations, non-uniform metal flow in shear faced die requires additional power. As a result, the process efficiency and product quality deteriorates. In order to improve the quality of extruded product, the various types of curved die profiles have been investigated for extrusion of square section from square billet using upper bound method [1]. The different die profiles considered are as follows: cosine die, elliptic both concave and convex, hyperbolic both convex and concave, parabolic both concave and convex, circular both concave and convex. It was observed that extrusion pressure was minimum for cosine die profile. A mathematical contoured die profile was used for extrusion of square section from square billet based on upper bound theory [2]. Zhang et al. [3] carried out optimization of an aluminium profile extrusion process based on Taguchi's method with S/N analysis to get uniform metal flow at die exit. Die design plays a critical role in improvement of quality of extruded product. A great deal of work has been carried out in this direction by different investigators. Gordon et al.[4] proposed a die design methodology in consideration with upper bound method to provide minimum distortion. Design of die profile must satisfy the requirement of uniform and stable metal flow at its exit plane to avoid warped deformation and bending of the product. The optimization of process parameters with consideration of 32 combination of parameters for hollow and complex cross-section of AA=6063 to get a minimum velocity difference at die exit using Taguchi's method with S/N analysis [5]. Zhag et al. [6] has investigated the effect of stem speed on extrusion process to enhance the quality of the product.

In the present investigation, a cosine die profile has been designed for micro-extrusion of a square section from a round billet. The diameter of round billet is taken as 1mm. FEM modelling has been carried out using Deform software for different reduction using Al-6063 alloy as billet material. Effect of ram velocity on extrusion process has been studied. Extrusion load, effective stress, effective strain and temperature generated in the process has been studied.

2. Design of die profile

A new method of designing round to square cosine die profile has been designed (Fig.1). R is the billet radius. L is the length of die in the Z direction. √2a is the side of each square. A plane (OMNO') is passing through the die axis and makes angle ϴ to the xz plane.

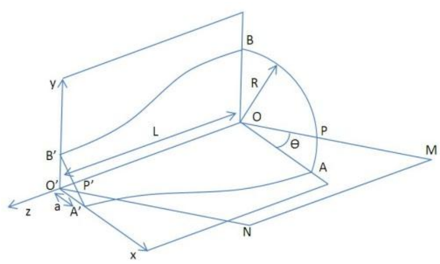

Fig. 1. One quadrant of the deformation zone with die profile

$$x = R\cos\theta,\quad y = R\sin\theta,$$

$$O'A' = O'B' \Rightarrow \angle O'A'B' = \angle O'B'A' = 45°,$$

$$\Rightarrow \angle O'P'A' = 135° - \theta$$

From the sine law,

$$\frac{O'P'}{\sin\angle O'A'P'} = \frac{O'A'}{\sin\angle O'P'A'},$$

$$\Rightarrow O'P' = O'A' \frac{\sin \angle O'A'P'}{\sin \angle O'P'A'}$$

$$x' = \frac{a \sin 45}{\sin \angle O'P'A'} \cos \theta ,$$

$$y' = \frac{a \sin 45}{\sin \angle O'P'A'} \sin \theta$$

Considering the above, from the end points (x, y) and (x_1, y_1) the co-ordinates of the die profile follows,

Cosine laws are as follows

$$x' = \left(R \cos \theta + \frac{a \sin 45}{\sin \angle O'P'A'} \cos \theta \right) ^{1}\!/_{2}$$

$$+ \left(R \cos \theta - \frac{a \sin 45}{\sin \angle O'P'A'} \cos \theta \right) ^{1}\!/_{2} \cos \frac{\pi z}{2}$$

$$y' = \left(R \sin \theta + \frac{a \sin 45}{\sin \angle O'P'A'} \sin \theta \right) ^{1}\!/_{2}$$

$$+ \left(R \sin \theta - \frac{a \sin 45}{\sin \angle O'P'A'} \sin \theta \right) ^{1}\!/_{2} \cos \frac{\pi z}{2}$$

3. FEM Modelling

Commercial DEFORM-3D FE code was used to analyse the influence of die profile on the process as well as to study its effects on metal flow characteristics. The software package consists of three major steps for the complete analysis of the process.
Pre-processor: A new problem can be generated in this step. The input conditions for the forming analysis can be established here. The step supports for positioning the objects, defining mesh, defining all thermal and mechanical boundary conditions. The pre-processor develops a database for further processing by the simulation engine.
Run-engine: Generated database is allowed to run in this step for solving all numerical and mathematical calculations. This step takes time to resolve the problem depending on the mesh size and iteration type selected in the pre-processor.
Post-processor: The results after simulation run can be canvassed in a very suitable user-friendly graphic interface. All the stress, strain, load, torque etc. can be plotted along with its distribution at different elements of the target body. The post-processor can also be utilized for extracting graphical and numerical result for use in other applications.
A rigid-viscoplastic material model (as elastic deformations are neglected in the bulk plastic deformation process) was considered for the investigation of hot extrusion. Load stroke plot and good pattern analysis of the billet was studied for the FE analysis to investigate the process. By considering the three-dimensional co-ordinates, the solid dies of above profiles along with billet and punch were generated by solid works software. These parts were imported to DEFORM-3D window in the form of .stl file for the data base generation. There is facility of specific mesh box for higher mesh density at the severe deformation zone.

Use the numerical system. References should be numbered sequentially throughout the text, as shown in the following examples: Hurley and Grant [1] have shown that…, in a previous paper [2] the species was identified as… All numbered references must be listed at the end of the paper in numerical order, according to the formats in the References section, for journals, books and reports respectively. Where a particular reference is cited more than once, use the same number on each occasion. Ensure that every reference is cited in the text, and that all citations are matched by references in the list. Multiple references should be indicated thus: [1,2,3].

4. Results and discussion

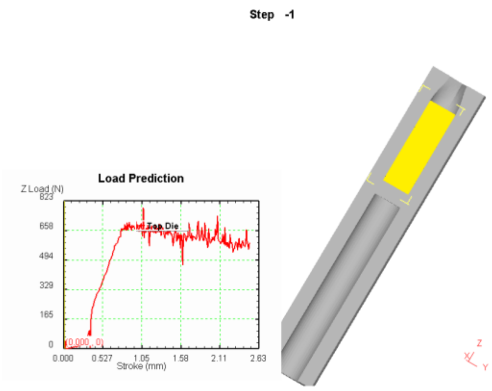

Fig. 2. 50%reduction 0_45friction

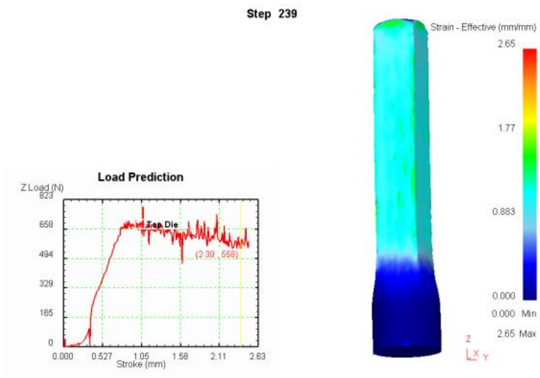

Fig. 3. 50%reduction 0_45friction

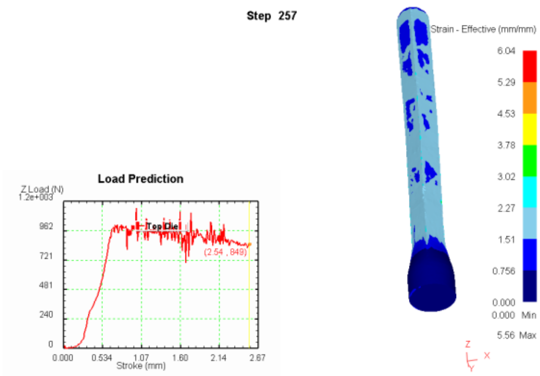

Fig. 4. 70%reduction 0_45friction

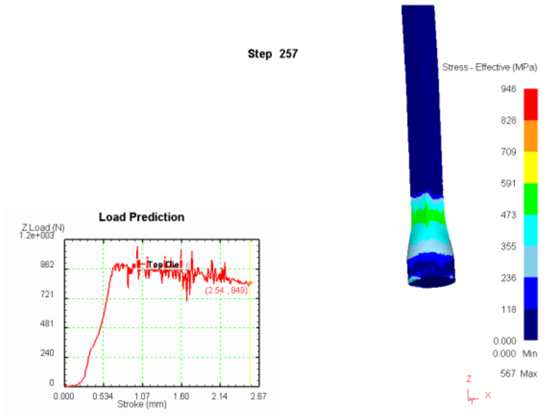

Fig. 5. 70%reduction 0_45friction

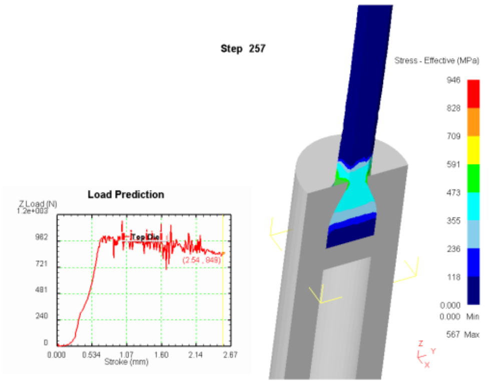

Fig. 6. 70%reduction 0_45friction

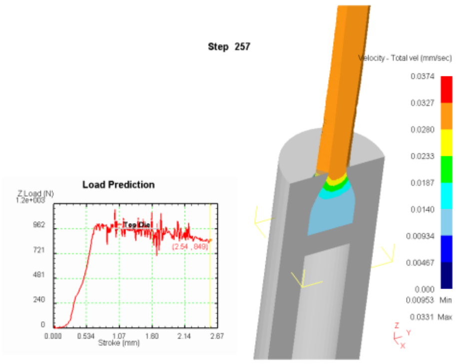

Fig. 7. 70%reduction 0_45friction

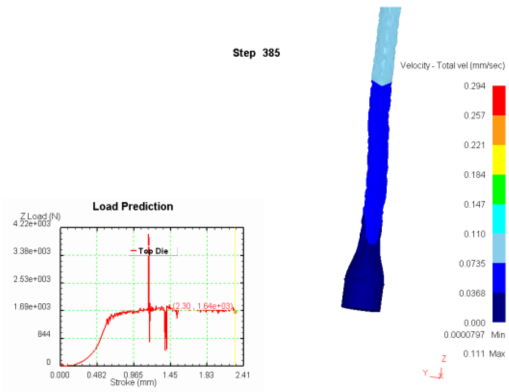

Fig. 8. 90%reduction 0_45friction

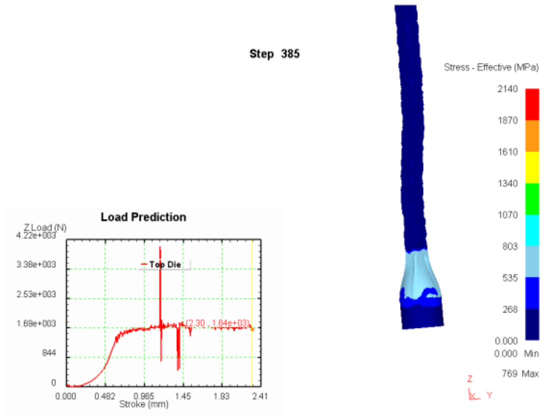

Fig. 9. 90%reduction 0_45friction

The friction factor for the present case was taken as0.45 . This was determined from ring compression test. Molykate commercial grade of lubricant was used in the ring compression test.Extrusion versus ram travel has been for different reduction(Fig.2-Fig.9). It was observed that extrusion load for micro-extrusion increased with reduction. Results are validated with experimentation for conventional extrusion. It was observed that there was good-agreement with theory and experiment. For micro-extrusion, validations with experiment is to be carried out.

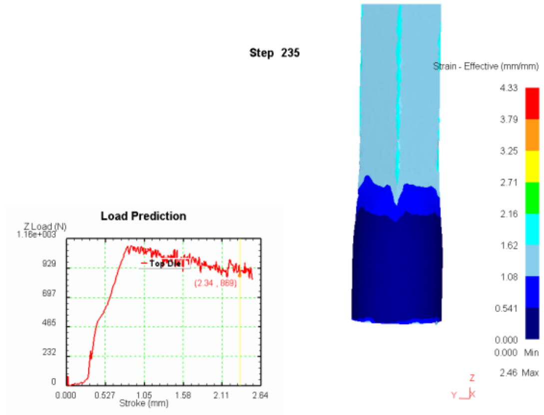

Fig. 10. 50%reduction 0_7friction

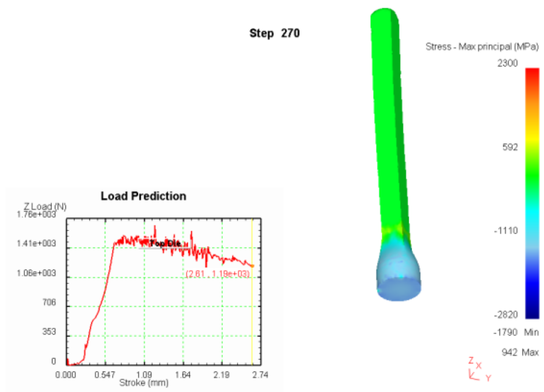

Fig. 11. 70%reduction 0_7friction

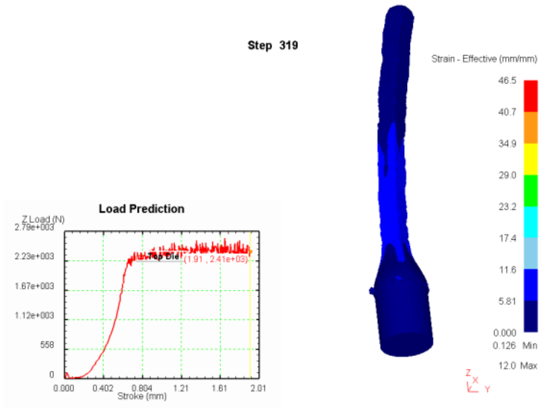

Fig. 12. 90%reduction 0_7friction

Extusion load versus ram travel was given in Fig.10 to Fig.12 for friction factor m=0.7. This will be valid when other lubricant having high frictional resistance is used. Extusion load increases with increase in ram velocity.

5. Conclusions

1. A die profile has been designed for micro extrusion considering 1mmbillet diameter with different percentage of reductions 50%, 70% and 90% respectively.
2. Extrusion load increases with increase in frictional resistance at the die-billet interface and reductions. Present FEM simulations are suitable for Al6063.
3. Effective stress, extrusion load, effective strain, temperature have been determined to know more details about mode of deformation of micro-extrusion.
4. Modellings have been carried out for friction factor 0.75 which will be valid for other lubricant.
5. Experimental verification for micro-extrusion is to be carried out, though validation for conventional extrusion. It was observed that the least extrusion load with gradual deformation was obtained in case of the cosine die profile.

References

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