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Full Length Research Paper

Tube extrusion design for some selected inner profiles

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In this study, tube extrusion process of non-circular inner sections is optimized to satisfy micro structural criteria at maximum production speed and minimum left out material in the die cavity. The die profile design is formulated as a constrained non-linear programming problem, which is solved using genetic algorithms (GA). Three extrusion processes are successfully optimized based on this approach. Computer simulations, accounting the optimized parameters are also carried out to obtain stress, strain distributions and load requirements.

Key words: Design profile, extrusion tube, dynamic material modeling, genetic algorithms, finite element.

INTRODUCTION

Extrusion of non-circular inner section tubes, due to geometrical requirements, is not uncommon in modern manufacturing. Design of the die profile and the processsing parameter are the two major issues involved in such extrusions. Die profile plays an important role on material flow, micro structural evolution, speed of production and left out material in the die. The conventional conical dies suffer from two major drawbacks. These are formation of dead metal zone if die angle is small and large size of die if die angle is small. Some of the prominent developments in this field are described below.

Samanta (1972) proposed an approach for convex shape die profile for axisymmetric extrusion and drawing using upper-bound theorem. Efficiencies of these dies exceed those of conventional conical dies. Reddy et al. (1995, 1997) reported die profile design for hot and cold extrusion using upper bound method and FEM et al. (1998) attempted shape optimal design of tube extrusion using sensitivity and rigid visco-plastic finite element approach. Kim et al. (2001) optimized die profile of axisymmetric extrusion of metal matrix composites (MMCs) using finite element method (FEM) in order to obtain uniform strain rate profile. Ponalagusamy et al. (2005) attempted to design streamlined dies using Bezier curve and upper bound theorem. Lee et al. (2000) optimized the die profile using Bezier curve to get uniform microstructure in hot extrusion. Neural networks were used in die profile design by Yan and Xia (2006) and Bhavin Mehta (1999). In recent years genetic algorithms has been successfully used in metal forming process design (Carlos et al., 2004). Poursina et al. (2006) and Carlos et al. (2005) used GAs for optimization of design parameters for forging process. Hong and Juchen (2006) applied GA in extrusion. Miha Kovacic et al. (2007) reported GA application in rolling. Tugrur et al. (2007) used genetic algorithm for determination of material parameters of Jonson Cook model. Genetic algorithms were also applied for die profile design by Wu and Hsu (2002), Chung and Hwang (1997), Narayanasamy et al. (2005). Chakraborti (2004) presented a good account of literature on GA applications in materials design and processing.

Although large amounts of literature are available on die profile design, it can be observed that they address specific aspect of manufacturing. It is very rare to find literature, which accounts for metallurgical and manufacturing aspects together. To overcome this issue, a holistic approach of die profile design using power law equation is proposed here. The important features of this are the following:

- Mathematical modeling of the die profile using power law equation.
- Selection of processing parameters using dynamic material modeling (DMM) to achieve desirable microstructure.
- Die profile design of non-circular inner section tubes to maximize the speed of production at minimum left out material in the die cavity.

The design problem is formulated as a non-linear constraint-programming problem, which is solved using GA. Three tube extrusion problems, considering different inner section geometries, are successfully designed using the proposed approach. Designed profiles and pro-

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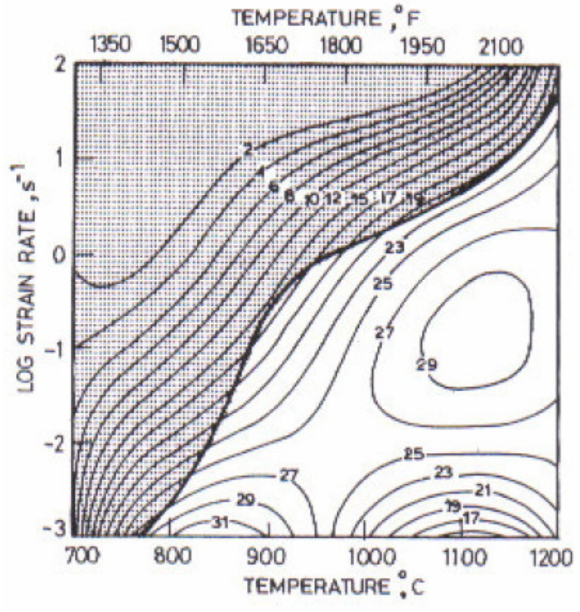

Figure 1. Processing map of 304 LN.

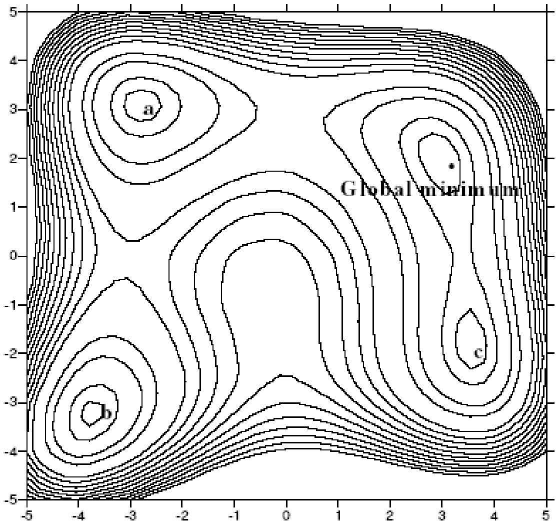

Figure 2. Local and global minima.

cess parameters are further used for computer simulations to study stress, strain distributions and load requirements.

Dynamic material modeling (DMM)

DMM is based on relationship between the deformation induced visco-plastic heat generation and the energy dissipation associated with the microstructural mechanisms occurring during deformation. DMM uses a nondimensional isoefficiency index (η) and it is given as (Prasad and Sashidhara, 1997).

$$\eta = \frac{m}{1+m} \qquad (1)$$

where m is the strain rate sensitivity of the material. The plot of iso-efficiency(η) values on the temperature-strain rate axes with the interpreted deformation mechanism mapped on to the plot constitute the 'processing map'. The regions of high efficiency regime are the desirable regions for the processing. The true stress–plastic strain values, at different strain rates, are required for computing the efficiency factor (η). The procedure of constructing the map is presented elsewhere (Prasad and Sashidhara, 1997). In Figure 1, processing map of 304 LN is shown. It can be observed that maximum iso-efficiency is about 29% and corresponding strain rate and temperature are 0.1 and 1100°C, respectively. The highest efficiency will correspond to dynamic recrystallization, which in turn will ensure good workability. DMM has been successfully used for designing of metal forming processes (Prasad, 1997; Venugopal, 2003).

Genetic algorithms

Genetic algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection (Deb, 1993). The operation of GA's begins with a population of random strings or decision variables. Thereafter, each string is evaluated to the fitness value. Three main operators viz. reproduction, crossover, and mutation are used to create a new population of points then operate the population. The population is further evaluated and tested for termination. If the termination criterion is not met, the population is iteratively operated by the above three operators and evaluated. This procedure is continued until the termination criterion is met. One cycle of these operations and the subsequent evaluation procedure is known as a generation in GA's terminology.

The basic difference of GA's with most of the traditional optimization methods are that GA uses a coding of variables instead of variables directly, a population of points instead of a single point, and stochastic operators instead of deterministic operators.

All these features make GA search robust, allowing them to be applied to a wide variety of problems. The advantage of using GA over other gradient-based methods is that the latter can be mapped on local minima whereas; GA predicts global minima, which may be hidden between several local minimas (Figure 2). In recent years GAs have been successfully applied to die design problems (Wu and Hsu, 2002; Chung and Hwang, 1997; Narayanasamy, 2005).

Formulation of the design problem

Let D_b and D_e be the outer diameters of billet and transition zone of the die. Extrusion die profile can be modeled

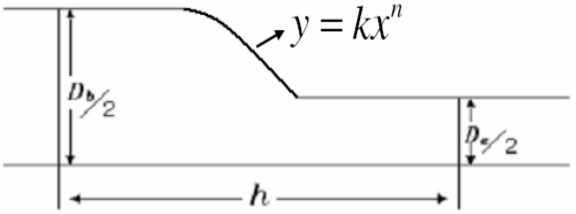

Figure 3. Die profile.

Table 1. GA parameters.

S.No	GA parameter	Value
1.	Population	30
2.	Generations	100
3.	Reproduction type	2 points crossover
4.	Selection type	Sigma scaling
5.	Mutation probability	0.005
6.	Reproduction probability	0.85
7.	Selection probability	0.85

by power law equation (Figure 3):

$$y = \frac{(D_b - D_e)}{2}\left(\frac{x}{h}\right)^n \tag{2}$$

Where, n is the power exponent. Material volume required to fill the die cavity is:

$$V = \pi h\left\{\frac{D_b^{\ 2}}{4} - \left(\frac{D_b}{2} - \frac{n(D_b - D_e)}{2(2n+1)}\right)\frac{(D_b - D_e)}{(n+1)}\right\} - A_{\sec}h \tag{3}$$

Where A_{sec} is the area of different section geometries.

(a). Triangular section: $A_{\sec} = \frac{\sqrt{3}}{4}l^2$

(b). Square section: $A_{\sec} = l^2$

(c). Hexagonal section: $A_{\sec} = \frac{3\sqrt{3}}{2}l^2$

Where l is the length of one side of the section. If v is the ram velocity, time to fill this volume will be:

$$T = \frac{4V}{(\pi D_b^{\ 2} - A_{\sec})v} \tag{4}$$

Now strain rate can be calculated by:

$$\dot{\varepsilon} = \frac{\ln R}{T} \tag{5}$$

Where R is the extrusion ratio given by:

$$R = \frac{\pi D_b^{\ 2} - 4A_{\sec}}{\pi D_e^{\ 2} - 4A_{\sec}} \tag{6}$$

Selection of strain rate and temperature can be carried out via the processing map to satisfy metallurgical aspects. Using thus selected process parameters, ratio of velocity to cavity volume can be maximized to result in faster production at minimum wastage of material. The whole design can be put into following optimization problem:

Max v/V ....(7)

Subject to $\dot{\varepsilon}(v,h,n) = c$

$$v_{\min} \le v \le v_{\max}$$
$$h_{\min} \le h \le h_{\max}$$
$$n_{\min} \le n \le n_{\max}$$
$$v,h,n \ge 0$$

Here, v ,V and c are ram velocity, volume of the die cavity and strain rate obtained from the processing map. Min and max are the limits of different parameters. GA parameters adopted in solving this optimization problem are given in Table 1.

RESULTS AND DISCUSSION

Outer billet and tube diameters are considered as 50 and 24 mm. The limits on nis 0 to 5, on v is 0.1 to 5 mm/s and on h is 0 to 20 mm. The billet material is 304 LN steel. Rate power law, given below, carries out the material modeling:

$$\sigma = K\dot{\varepsilon}^n \tag{8}$$

Where K and n are the strength and strain rate hardening exponents. The coefficients K and n for the favorable processing parameters are 141.3 and 0.17, respectively. Yield strength is accounted as 141.3 MPa. Processing strain rate ‘c’ for 304 LN, as obtained from the processing map, is 0.1. The optimized profiles and parameters are further used for computer simulation using MSC-Superforge software (Ref.27). Three types of non-circular sec-tion geometries viz. triangular, square and hexagon as shown in Figure 4 (a,b,c), are studied

Triangular section

The side of equilateral triangle is 15.59 mm. In this way, extrusion ratio comes out to be 5.35. Optimized n, v and h are 3.97, 1 mm/s and 19.95 mm, respectively. The CAD model of the extrusion processing is shown in Figure 5. The plastic strain contour is shown in Figure 6. It can be observed that maximum strain evolved is above 1.5

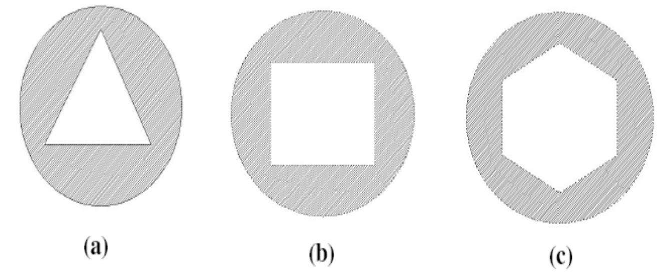

Figure 4. Section geometries-(a). triangular (b). square (c). hexagonal.

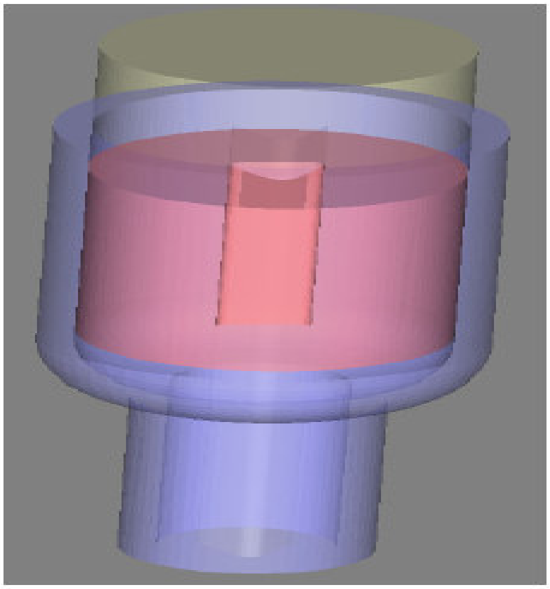

Figure 5. CAD model: triangular rod.

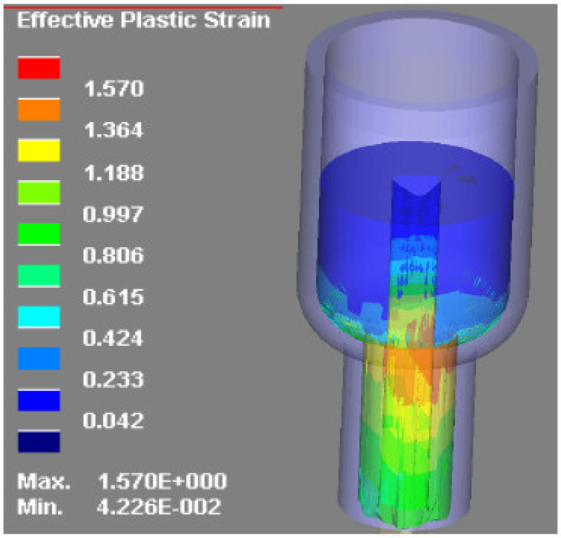

Figure 6. Effective plastic strain contour.

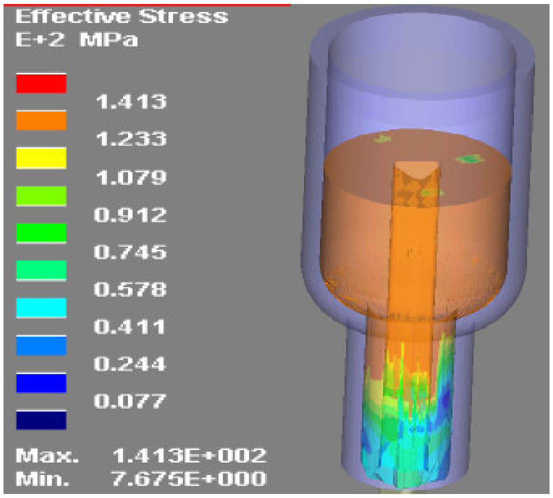

Figure 7. Effective stress contour.

which is quite high. Effective stress contour is shown in Figure 7. It can be visualized that most of the billet material has yielded during extrusion. Load stroke curve is shown in Figure 8. The maximum load requirement for the extrusion is 2.61 MN.

Square section

The side of square is 12.73 mm. Extrusion ratio is 6.20. Optimized n, v and h are 3.44, 0.99 mm/s and 18.68 mm, respectively. The CAD model of the extrusion processing is shown in Figure 9. The plastic strain contour is shown in Figure 10. It can be observed that maximum strain evolved is above 1.9, which is quite high. Effective stress contour is shown in Figure 11. It can be observed that most of the billet has yielded during the extrusion. Load stroke curve is shown in Figure 12. The maximum load requirement for the extrusion is 2.32 MN.

Hexagonal section

The side of the hexagon is 9 mm. In this way, extrusion ratio comes out to be 7.24. Optimized n, v and h are 3.11, 0.84 mm/s and 19.93 mm, respectively. The CAD model of the extrusion processing is shown in Figure 13. The plastic strain contour is shown in Figure 14. Here also, maximum strain is above 1.5, which is quite high. Effective stress contour is shown in Figure 15. It can be observed that most of the billet is yielded during extrusion. Load stroke curve is shown in Figure 16. The maximum load requirement for the extrusion is 3.59 MN, which is the maximum among the three sections considered.

Conclusions

In this study, a new approach for tube extrusion process

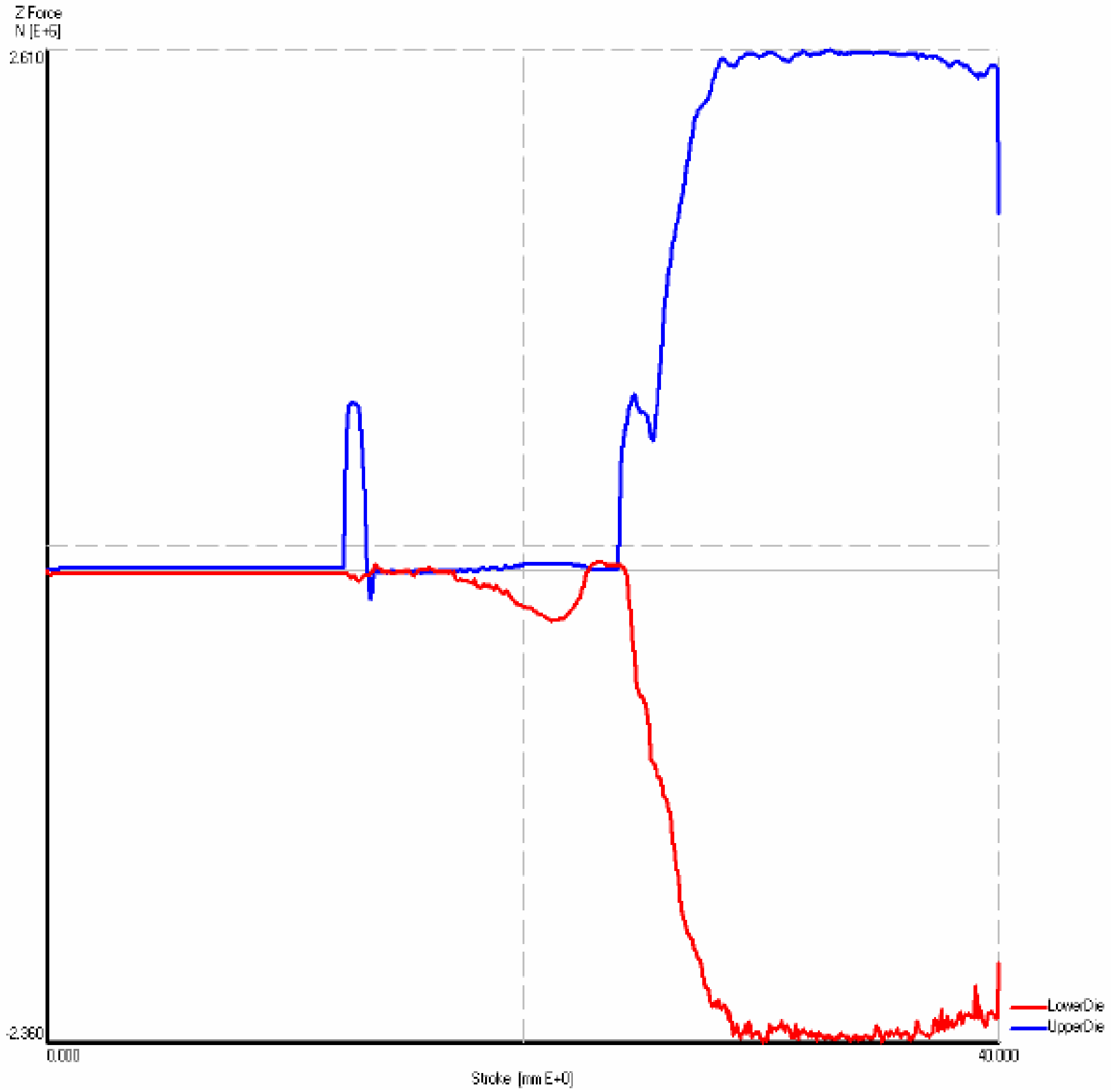

Figure 8. Load stroke plot.

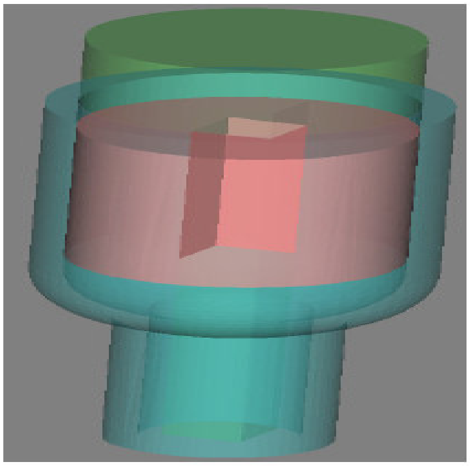

Figure 9. CAD model: square rod

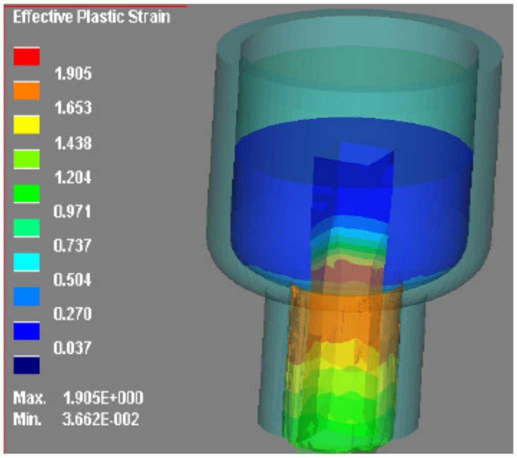

Figure 10. Effective plastic strain contour.

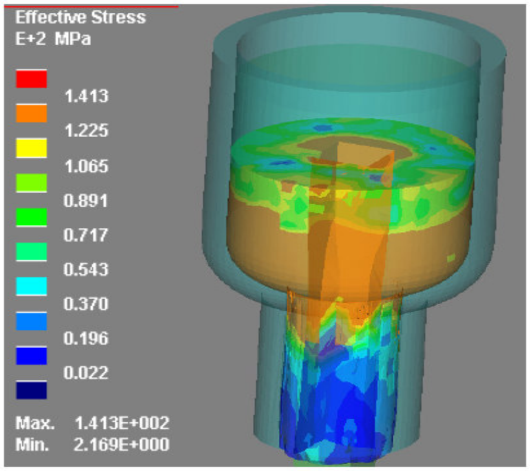

Figure 11. Effective stress contour.

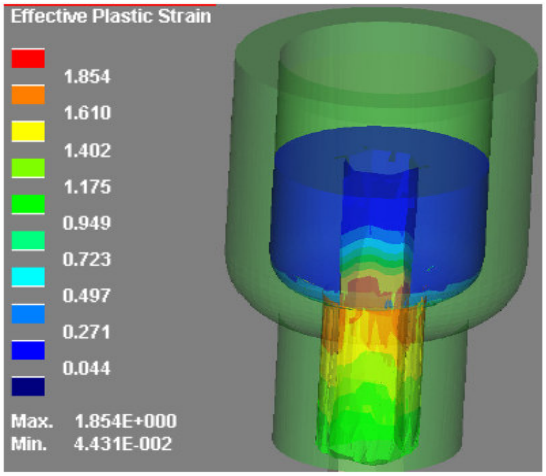

Figure 14. Effective plastic strain contour.

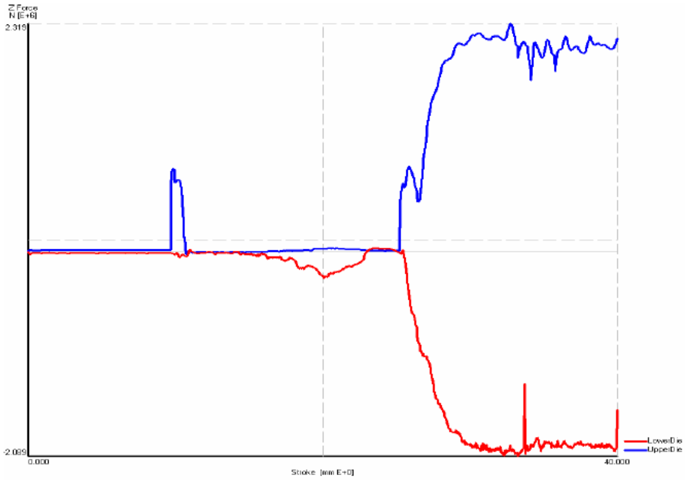

Figure 12. Load stroke plot.

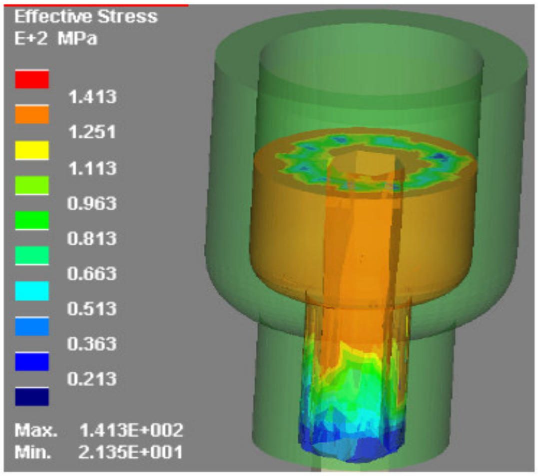

Figure 15. Effective stress contour.

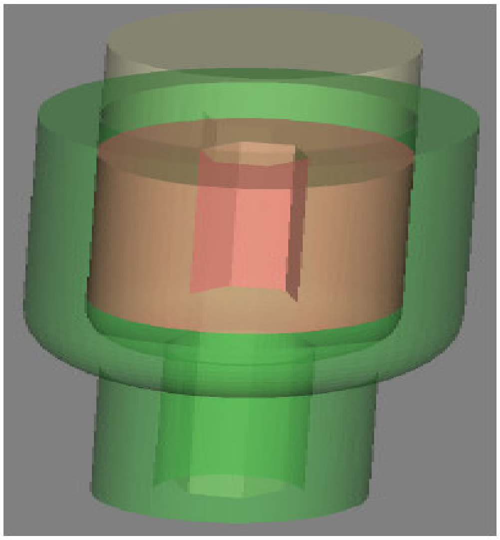

Figure 13. CAD model: hexagonal rod.

design of non circular inner sections using dynamic material modeling (DMM) and genetic algorithms is proposed. The objective is to satisfy micro structural criteria at maximum production speed and minimum left out material in the die cavity. Three extrusion processes are successfully optimized based on this approach. Computer simulations, considering optimized parameters, are also carried out to obtain stress and strain distributions and load requirements. It can be observed that the proposed approach provides a holistic solution for extrusion process design of non-circular inner section tubes.

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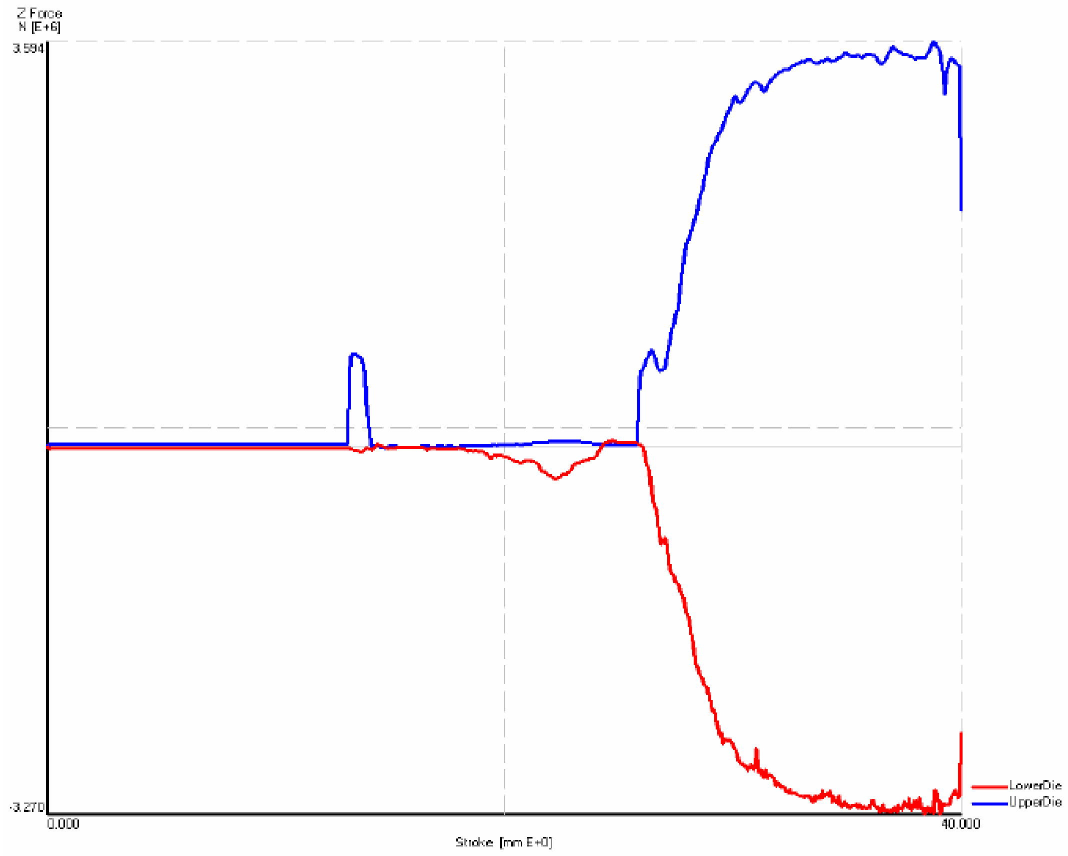

Figure 16. Load stroke plot.

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