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Die Profile Design for Tube Extrusion and its Experimental Verification

In this study, experimental verification of a proposed extrusion die profile design approach, which aims to satisfy microstructural criteria at maximum production speed and minimum left out material in the die cavity, is presented. The design problem is formulated as a nonlinear programming problem, which is solved using genetic algorithm (GA). Selection of the processing parameters is carried out using dynamic material modeling (DMM). Microstructural study reveals considerable grain refinement in the extruded tube.
***Keywords:** dynamic recrystallization, die profile, microstructure, processing parameters, extrusion, genetic algorithms*

Introduction

Extrusion die profile plays an important role on material flow, microstructural 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 large, and large size of die if die angle is small. Some of the prominent researches in the area of die profile design are as below: Samanta (1972) proposed an approach for convex shape die profile for axisymmetric extrusion and drawing using upper-bound theorem. Efficiencies of these dies exceeded those of conventional conical dies. Venkata Reddy, Dixit and Lal (1995, 1997) reported die profile design for hot and cold extrusion using upper bound technique and Finite Element Method (FEM). Joun and Hwang (1998) attempted die shape optimal design for extrusion of different shapes like polygons and T-cross sections using sensitivity and rigid visco-plastic finite element approach. Kim et al. (2001) optimized die profile of axisymmetric extrusion of Metal Matrix Composites using coupled FEM in order to obtain uniform strain rate distribution in the deforming region. Ponalagusamy et al. (2005) designed streamlined dies using Bezier curve and polynomial equations. Bazier curve dies were found to take lower extrusion pressure. Lee et al. (2000) optimized the die profile using Bezier curve to get uniform microstructure in hot extrusion. The optimized die was also validated experimentally. Bhavin Mehta et al. (1999) employed neural network for die profile design using design of experiments results and found it to be efficient in terms of computational time and accuracy. In recent years, GA has been successfully used in metal forming process design. Carlos C. Antonio et al. (2004, 2005) proposed evolutionary GA to calculate optimal shape geometry and optimized several forging processes. Poursina et al. (2006) used FEM and GA to design optimal preform dies for multi stage hot forging. Yan and Xia (2006) proposed an approach for the optimal design of technological variables in the profile extrusion process by integrating F.E.M., neural network and GA, which was also verified by experiments. Miha Kovacic et al. (2007) successfully used Genetic Programming to predict bending capability of rolled Titanzinc metal sheet. For this data were generated by experiments considering various material and process parameters. Tugrul Ozal et al. (2007) used GA for identification of constitutive parameters of Johnson-Cook (JC) model, which was claimed to be better than classical data fitting solutions. Wu and Hsu (2002), and Chung and Hwang (1997) applied GA along with FEM for die profile design for extrusion that would satisfy minimum force and strain criteria. Narayanasamy et al. (2005) used GA to optimize the die cone angle and friction factor that could be used for any objective function. Chakraborti (2004) presented a good account of literature on GA applications in materials design and processing. Pathak et al. (2009) accounted metallurgical and manufacturing aspects together.

The present study is related to experimental verification of the approach proposed by the authors (Pathak et al. 2009). A tube extrusion die profile for aluminum is successfully designed using this approach. Thus, designed profile is used for fabrication of die upon which extrusion experiment is conducted and microstructure study is carried out. It is observed that the proposed approach of die profile design is quite effective in terms of surface finish and grain refinement.

Nomenclature

R_b = *diameters of billet, mm*
R_e = *diameter of extruded tube, mm*
m = *strain rate sensitivity*
n = *power law exponent*
c = *optimum strain rate*
$\dot{\varepsilon}$ = *strain rate*
v = *ram velocity*
V = *material volume in cavity*
H = *length of transition zone*
x,y = *die profile parameters*
η = *iso-efficiency index*

Dynamic Material Modeling (DMM)

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

$$\eta = \frac{m}{1+m} \tag{1}$$

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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 constitutes the 'processing map'. The regions of high efficiency regime are the desirable regions for the processing, because it will lead to dynamic recrystallization (DRX). DRX refers to the occurrence of simultaneous recrystallization during deformation by nucleation and growth process. The DRX characteristics are decided by the rate of nucleation versus rate of growth under given imposed conditions of temperature and strain rate. DRX is a beneficial process in hot deformation since it not only gives stable flow and good workability to the material by simultaneously softening it, but also reconstitutes the microstructure. DRX is a chosen domain for optimizing hot workability and controlling the microstructure and is a safe domain for bulk material working. For more details on DRX and procedure of constructing the processing map, Prasad and Sashidhara (1997) may be referred. In Fig. 1, processing map for 99.9% Al is shown. It can be observed that maximum efficiency is 55% corresponding to 550 °C and 0.001 strain rate. 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 and Sasidhara, 1997; Srinivasan, 2002; Venugopal 2003).

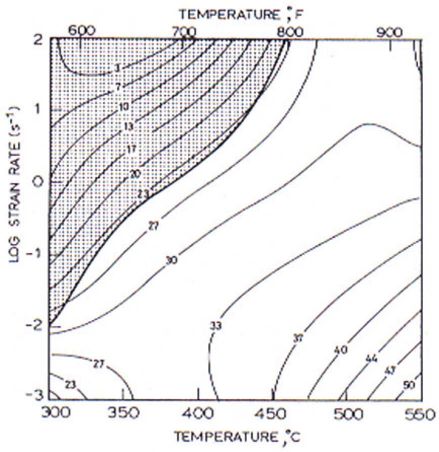

Figure1. Processing map of Al 99.9%.

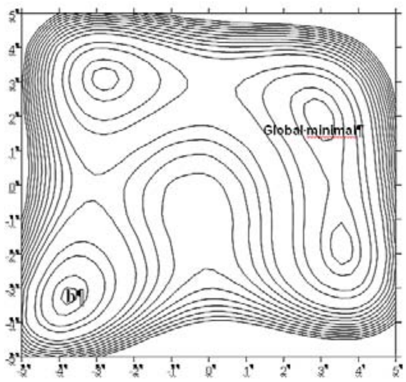

Figure 2. Local and global minima.

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. 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 differences between GA and 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 minima (Fig. 2). In recent years, GAs have been successfully applied to die design problems (Wu and Hsu, 2002; Chung and Hwang, 1997; Narayanasamy, 2005).

Die Profile Design Methodology

In Fig. 3, a schematic of tube extrusion die is shown. Die profile is modeled by power law equation given below.

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

where R_b and R_e are the diameters of billet and extruded tube respectively and h is the length of the transition zone of the die and n is the power exponent. If V is the material volume in the die cavity and v is the ram velocity, then die profile design can be formulated into the following optimization problem:

$$\text{Max} \quad v/V \tag{3}$$

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

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

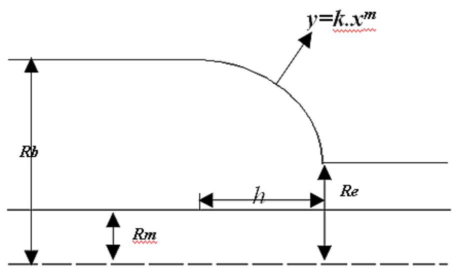

Figure 3. Die profile.

Selection of strain rate 'c' can be carried out via the processing map to meet out 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. 'Min' and 'max' are the limits of different parameters. The detailed formulation of the design problem can be referred from Pathak et al. (2009). GA parameters adopted to solve this optimization problem are given in Table 1.

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

Experimental Verification

Die profile for aluminum tube extrusion is designed using proposed approach (Pathak et al., 2009). Diameters of billet, extruded tube and mandrel are 50, 24 and 17.2 mm respectively. In this way extrusion ratio comes out to be 7.87. Rod of commercial aluminum has been used as billet for extrusion experiment. The chemical analysis of the billet material was conducted and the elements present in it are given in Table 2. It can be observed that the material is almost Al 99.9 %. Processing map of 99.9% Al is shown in Figure 1. The maximum iso-efficiency is about 50% and corresponding strain rate and temperature are 0.001 and 550 °C respectively. Using these parameters the optimization of the above mentioned objective function is carried out using GA. The minimum and maximum limits on velocity (v), transition length (h) and power exponent (n) are 0.01 & 1 mm/s, 20 & 25 mm and 1 & 5 respectively. The optimized ram velocity, length of the transition zone and power exponent came out to be 0.088 mm/s, 20 mm and 4.64 respectively. Putting these values of R_b, R_e and n in the power law equation takes to the following form:

$$y = (25-12)\left(\frac{x}{20}\right)^{4,64}$$

$$y = 13\left(\frac{x}{20}\right)^{4.64} \qquad (4)$$

Table 2. Chemical analysis of the material.

S.No	Element	%age
1.	Fe	0.08
2.	Mn	0.04
3.	Si	0.08
4.	Al	99.80

Using this equation, an extrusion die was fabricated. The schematic sketch of the extrusion die, and fabricated die and mandrel are shown in Fig. 4 and Fig. 5 respectively.

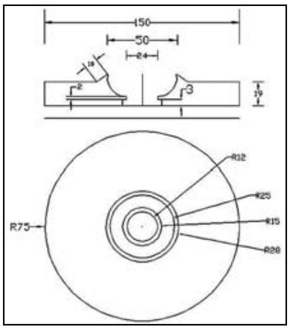

Figure 4. Die drawing.

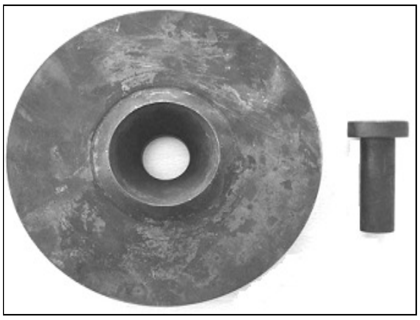

Figure 5. Die and mandrel.

The extrusion experiment was performed at AMPRI Bhopal. A hydraulic press of 400 Tonne (Fig. 6) was used for this purpose. The billet of 50 mm length was precisely cut using a power hacksaw. A through hole of 17.25 mm diameter is drilled in the billet to accommodate the mandrel. The extrusion die was fitted on the extrusion press with the help of the die holders.

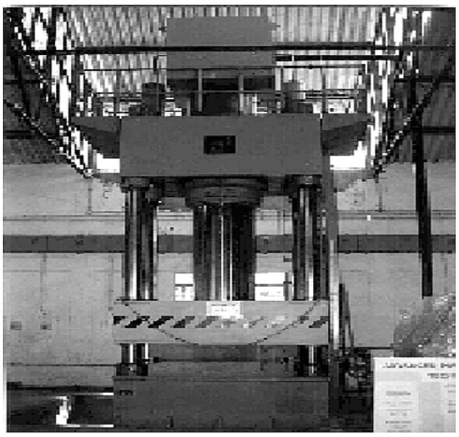

Figure 6. 400 Tonne hydraulic press.

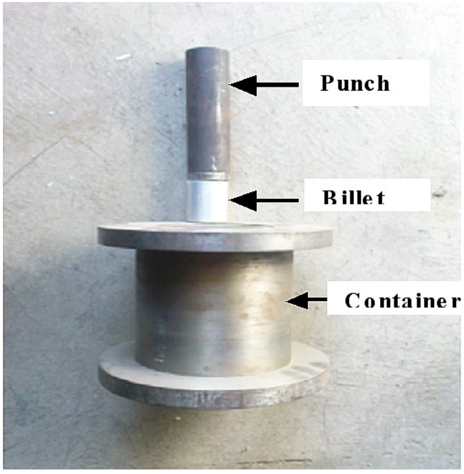

Figure 7. Billet, punch and container.

The billet, punch and container are shown in Fig. 7. The billet was heated in an electric furnace at 550 °C. The preheating of the extrusion die was carried out at 300 °C and arrangement for this is shown in Fig. 8. The ram velocity was kept as 0.088 mm/sec. The extruded tube is shown in Fig. 9. Good surface finish is apparent from the figure. The microstructures of the billet and extruded tube, taken at 100X zoom along the longitudinal direction, are shown in Fig. 10 and Fig. 11, respectively. It can be observed that considerable grain refinement, with respect to billet material, has taken place.

Figure 8. Heating arrangement.

Figure 9. Extruded tube.

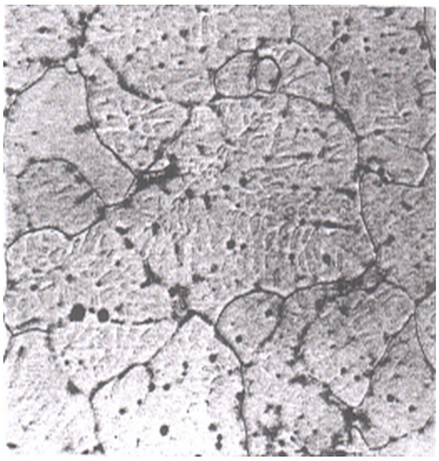

Figure 10. Microstructure of billet material.

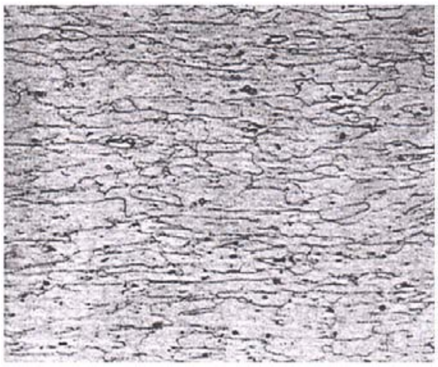

Figure 11. Refined microstructure of the extruded rod.

Conclusions

This study is related to experimental validation of extrusion die profile, which is optimized to produce tube of desirable microstructure at maximum production speed and minimum left out material in the die. The die profile design is formulated as a constrained non-linear programming problem, which is solved using GA. Extrusion die profile for aluminum tube is successfully designed based on this approach. Microstructural study reveals considerable grain refinement in the extruded tube. It can be observed that study proposed provides a holistic approach for design of the extrusion die profile.

References

Bhavin, V. Mehta, Hamza Ghulman, Rick Gerth, 1999, "Extrusion die design: a new methodology for experimental design as a precursor to neural networks", *JOM*, Vol. 51, No. 9.

Carlos António C., Catarina Castro F., Luísa Sousa C., 2004, "Optimization of metal forming processes", *Computers & Structures*, Vol. 82, No. 17-19, pp. 1425-1433.

Carlos António C., Catarina Castro F., Luísa Sousa C., 2005, "Eliminating forging defects using genetic algorithms", *Material and Manufacturing Processes*, Vol. 20, No. 3, pp. 509-522.

Chakraborti N., 2004, "Genetic algorithms is material design and processing", *International Material Reviews*, Vol. 49, No. 3-4, pp. 246-260.

Chung, J.S. and Hwang, S.M., 1997, "Application of genetic algorithm to the optimal design of the die shape in extrusion", *Journal of Material Processing and Technology*, Vol. 72, pp. 69-77.

Deb Kalyanmoy, 1993, "Optimization for Engineering Design Algorithms and Examples", Prentice Hall of India Private Limited, New Delhi.

Hong Yan, Juchen Xia, 2006, "An approach to the optimal design of technological parameters in the profile extrusion process", *Science and Technology of Advanced Materials*, Vol. 7, No. 127-131.

Joun, M.S. and Hwang, S.M., 1998, "Die shape optimal design in three-dimensional shape metal extrusion by the finite element method", *International Journal for numerical methods in engineering*, Vol. 41, pp. 311-335.

Kim, N.H., Kang, C.G., Kim, B.M., 2001, "Die design optimization for axisymmetric hot extrusion of metal matrix composites", *International Journal of Mechanical Sciences*, Vol. 43, pp. 1507-1520.

Lee, S.K., Ko, D.C., Kim, B.M, 2000, "Optimal die profile design for uniform microstructure in hot extruded product", *International Journal of Machine Tools & Manufacture,* Vol. 40, pp. 1457-1478.

Miha Kovacic, Peter Uratnik, Miran Brezocnik, Radomir Turk, 2007, "Prediction of the bending capability of rolled metal sheet by genetic programming", *Material and Manufacturing Processes*, Vol. 22, No. 5, pp. 634-640.

Narayanasamy, R., Venkatesan, R. and Ponalagusamy, R., 2005, "Extrusion die profile and extrusion pressure optimization using genetic algorithm", *Journal of the Institution of Engineers, Singapore*, Vol. 45, No. 3.

Pathak, K. K., Lomash, S., Jha, A.K., Ramakrishnan, N., 2009, "Process and die profile design for tube extrusion of γ iron", *Structural and Multidisciplinary Optimization*, Vol.40, No.1, pp.491-496.

Ponalagusamy, R., Narayanasamy, R., Srinivasan, P., 2005, "Design and development of streamlined extrusion dies a Bezier curve approach", *Journal of Materials Processing Technology,* Vol. 161, pp. 375-380.

Poursina, M., Parvizian, J. and Antonio, C.A.C., 2006, "Optimum pre-form dies in two-stage forging", *Journal of Materials Processing Technology,* Vol. 174, No. 1-3, pp. 325-333.

Prasad, Y.V.R.K., Sasidhara, S., 1997, "Hot Working Guide: A Compendium of Processing Maps", ASM International Park, OH.

Samanta, S.K., 1972, "A new die profile with high process efficiency", *Flow Turbulence and Combustion*, Vol. 25, No. 1.

Srinivasan, N., Ramakrishnan, N., Venugopal Rao, A. and Swamy, N., 2002, "CAE for forging of titanium alloy aero-engine disc and integration with CAD–CAM for fabrication of the dies", *Journal of Materials Processing Technology,* Vol. 124, No. 3.

Tugrul Ozel, Yigit Karpat, 2007, "Identification of constitutive material model parameter for high strain rate metal cutting condition using evolutionary computational algorithms", *Material and Manufacturing Processes*, Vol. 22, No. 5, pp. 659-667.

Venkata Reddy, N., Dixit, P.M. and Lal, G.K., 1995, "Die design for axisymmetric extrusion", *Journal of Materials Processing Technology,* Vol. 55, pp. 331-339.

Venkata Reddy N., Dixit P. M. and Lal G. K., 1997, Die design for axisymmetric hot extrusion, *Int. J. Math. Tools Manufac,* Vol. 37, No.11, pp. 1635-1650.

Venugopal, S., Sivaparsad, P.V., 2003, "A journey with Prasad's processing maps", *J. Mat. Engg. Perfor,* Vol. 12, No. 6.

Wu, C.Y. and Hsu, Y.C., 2002, "Optimal shape design of an extrusion die using polynomial networks and genetic algorithms", *Int. J. Advanced Manufacturing Technology*, Vol. 19, pp. 79-87.