Parametric Optimization of Simulated Extrusion of Square to Square Section Through Linear Converging Die

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Abstract. The effect of various process parameters for determining extrusion load has been studied for square to square extrusion of Al-6061 alloy, a most used aluminium alloy series in forming industries. Parameters like operating temperature, friction condition, ram velocity, extrusion ratio and die length have been chosen as an input variable for the above study. Twenty five combinations of parameters were set for the investigation by considering aforementioned five parameters in five levels. The simulations have been carried out by Deform-3D software for predicting maximum load requirement for the complete extrusion process. Effective stress and strain distribution across the billet has been checked. Operating temperature, extrusion ratio, friction factor, ram velocity and die length have the significant effect in decreasing order on the maximum load requirement.

Keywords: Extrusion, DEFORM-3D, Aluminium alloy, Optimization

1. Introduction

Extrusion, a demanded metal forming process is versatilely admitted for production of long straight metal products having complex cross sections because of its energy saving, near net shape production with better mechanical properties along with high production rate characteristics [1]. Control over the process is influenced by number of internal variables (chemical composition of billet material, grain size, segregation, metallurgical structure and prior strain history) and number of state variables (operating temperature, friction condition, shape factor, deformation degree and rate) [2]. Effect of few state variables like extrusion ratio and ram velocity, affecting equivalent strain and dynamic recrystallization of Mg-Zn-Y alloy at the time of extrusion has been studied by Hirano et al. [3]. At the same time aforementioned parameters affect the temperature condition at various positions in the deformed zone [4]. Increase of temperature at die exit directly affects load requirement and microstructural changes.

For an efficient production process the combination of variable parameters is needed to be optimized [5]. For a good mechanical property of an extruded product, maintaining a temperature range at the time of extrusion is most vital. The range of temperatures for Al-6061 + Al2O3p alloy was found 500-560°C as an exemplary condition [6]. Operating temperature, friction factor and ram speed have the significance in decreasing order for maximum extrusion load [7].

Estimation of exact load requirement for deformation is very difficult but some analytical and numerical techniques are there for finding out the approximate load [8]. Due to the complexity of the numerical analysis, few empirical methods are staying good for the prediction of maximum load in most of the industries. Computerized simulations are now a better alternative for predicting the process outcomes than expensive empirical process. Abundant amount of work is going on for predicting various extrusion parameters like maximum load [9] , minimum surface cracks [10] etc. by FEM simulations.

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In this investigation effect of various variable process parameters on maximum extrusion load has been studied with the help of commercial simulation package DEFORM-3D. Linear converging die for square to square reduction of the well deformable material Al-6061, has been considered. The process was analysed by Taguchi optimization technique.

2. Finite Element Analysis

Finite element modeling and simulation techniques have been necessitated these days for predicting the effect of variable parameters on metal forming process before real production process to reduce the experimental trials because of its cost and time efficiency. For the simulation of metal forming process, numbers of commercial finite element codes such as Forge, Hyperextrude, LS-DYNA, SUPERFORM, DEFORM and ABACUS etc. are available. Various metal forming investigations have been carried out successfully with the application of codes in various fields [11-13]. DEFORM^{TM}-3D finite element code was used to analyse the effect of different variable parameters for extrusion of Al-6061 alloy through linear converging rigid die. The simulation process follows pre - processor, Run-engine and Post-processor sequentially for a complete analysis.

Pre-processor: A new problem can be created in this step by positioning the objects, defining mesh, defining thermal and mechanical boundary conditions. With all specific inputs the pre-processer generates a database file for simulation engine for further processing.

Run-engine: All the numerical calculations on the generated database are processed here. Depending on the number of elements and numerical method, the engine takes time to solve the problem.

Post processor: The outcome results after simulation run can be analysed in this step with a very suitable user friendly graphic interface. The step wise change of the various factors in the material model can be visualized along with the graphical presentations.

A square billet, punch and dies of varying dimensions have been designed with solid works software and imported to DEFORM interface as .stl file. Al-6061 billet of dimension (40×40×100) mm^3 was divided into 130000 numbers of tetrahedral mesh elements. The billet was allowed only to flow through the linear converging die for different reductions with different die length. The properties of work material selected from the software database are given in Table 1. In the present investigation, the die, billet and container were modeled as rigid bodies, whereas the billet was modeled as rigid-plastic object.

Table 1. Properties of Al-6061

Material	Young's Modulus (MPa)	Poison's ratio	Thermal expansion (1/°C)	Thermal Conductivity (W/m/°C)	Heat capacity (N/mm^2/°C)	Emissivity
Al-6061	68947.6	0.30	22×10^{-6}	180.181	2.43369	0.7

The flow stress adopted for simulation is effective strain, effective strain-rate and temperature dependent:

$$\bar{\sigma} = \bar{\sigma}(\bar{\varepsilon}, \dot{\bar{\varepsilon}}.T) \qquad (3)$$

Von-Mises yield criterion model is used for finding effective stress of the isotropic billet metal i.e.

$$\bar{\sigma} = 1/(\sqrt{2})\ \sqrt{\{((\sigma1-\sigma2)\ \hat{}2+(\sigma2-\sigma3)\hat{}2+(\sigma3-\sigma1)\hat{}2\ \}} \qquad (4)$$

where σ1, σ2 and σ3 are the principal stresses. Interface friction model is considered as shear type (constant friction) and the friction factor m (o ≤ m ≤1) is expressed as

$$\tau = m(\bar{\sigma})/(\sqrt{3}) \quad [11] \tag{5}$$

Where τ is frictional shear stress, $\bar{\sigma}$ is the effective flow stress of the deforming material. The process parameters and friction factors considered for the simulation are listed in Table 2. The value of friction condition for the die - billet interface and the other interface is assumed as a variable parameter.

3. Taguchi optimization technique

Five variable parameters have been considered for optimizing the process. Those are operating temperature (T), extrusion ratio (R), ram velocity (V), die length (L) and friction factor (m). The values of the factors have been considered in five levels and an orthogonal array of 25 combinations of parameters was set for the simulation process.

Table 2. Parameters considered for the simulation

Parameters	Values
Billet length (mm)	100
Billet cross section area (mm^2)	40*40
Operating temperature (T) (°C)	250, 300, 350, 400, 450
Extrusion ratio (R)	2, 5, 10, 15, 20
Ram velocity (V) (mm/sec)	0.1, 1, 2, 3, 4
Die length (L) (mm)	15, 20, 25, 30, 35
Friction factor at die-billet interface (m)	0.3, 0.4, 0.5, 0.6, 0.7

4. Results and Discussion

Figure 1 shows post processor result analysis with a load-stroke plot for run-3 (R=2, L=25mm, m=0.5, V=2 mm/sec, T=350°C) combinationl set. The figure also shows the effective stress distribution of the work material. Figure 2 shows (a) the effective strain and (b) velocity distribution of the billet material across the die profile. The value of the effective stress as well as the couresponding strain at the die exit is maximum. The value is gradually increasing from inlet to die exit. From the velocity profile it is clear that there is no dead metal zone, so there is no extra energy consumption to overcome redundant work which only minimizing the maximum load requirement.

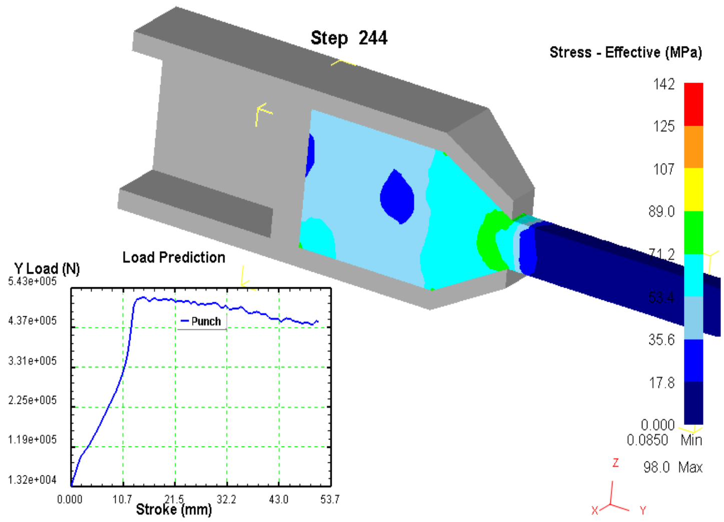
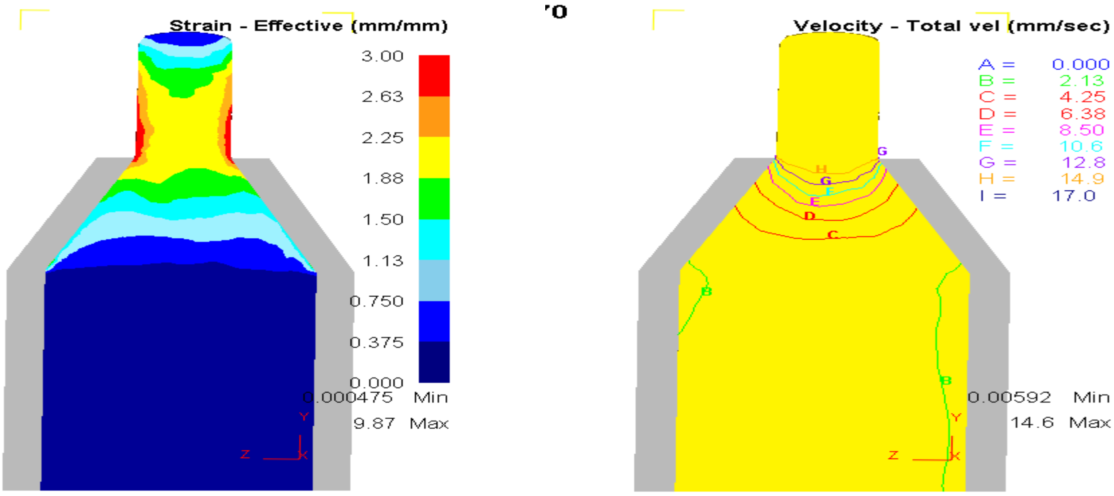


Figure 1. Prediction of Load-stroke plot and Effective stress distribution from the post-processor analysis



(a) (b)

Figure 2. (a) Effective strain distribution and (b) velocity profile distribution across thedie profile

The load versus stroke curves have been determined for twenty five sets of simulations. Maximum extrusion load for each run in L_{25} orthogonal array is mentioned in Table 3.

Table 3. Set of 25 combinations of parameters along with output

Run	Extrusion Ratio	Die Length (mm)	Friction Factor (m)	Ram Velocity (mm/sec)	Operaing Temperature (°C)	Manimum Extrusion Load (N)
1	2	15	0.3	0.1	250	589000
2	2	20	0.4	1	300	555000
3	2	25	0.5	2	350	517000
4	2	30	0.6	3	400	401000
5	2	35	0.7	4	450	402000
6	5	15	0.4	2	400	427000
7	5	20	0.5	3	450	404000
8	5	25	0.6	4	250	1030000
9	5	30	0.7	0.1	300	906000
10	5	35	0.3	1	350	546000
11	10	15	0.5	4	300	873000
12	10	20	0.6	0.1	350	740000
13	10	25	0.7	1	400	639000
14	10	30	0.3	2	450	410000
15	10	35	0.4	3	250	1030000
16	15	15	0.6	1	450	512000
17	15	20	0.7	2	250	1340000
18	15	25	0.3	3	300	836000
19	15	30	0.4	4	350	702000
20	15	35	0.5	0.1	400	569000
21	20	15	0.7	3	350	867000
22	20	20	0.3	4	400	557000

23	20	25	0.4	0.1	450	400000
24	20	30	0.5	1	250	1280000
25	20	35	0.6	2	300	1150000

The value of loss function used for measuring performance characteristics which deviates form required one, recommended by Taguchi is further converted into a signal-to-noise (S/N) ratio. As it is a minimization problem, the performance category for smaller the better is chosen.

For minimization case: smaller –is-the better: S/Ns = -10 log $(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2})$ (6)

Where n is the number of observations and y is observed result.

For all the results SN ratio has been calculated and main effect plot for load required for extrusion by linear converging die profile is shown in Figure 3. The optimum combinations for minimum load is the highest level of SN ratio i.e 'T'=450℃, 'R'=2, 'V'=0.1mm/sec, 'L'=15 mm and 'm'=0.1.

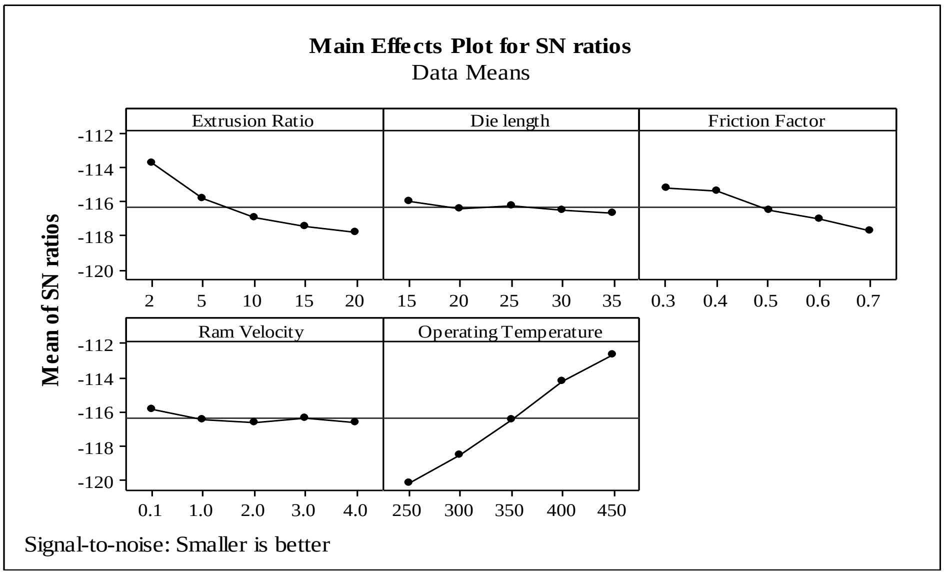


Figure 3. Main effects plot for maximum load in extrusion

The significant effects of individual parameters on the process was studied. It was observed that operating temperature; extrusion ratio, friction factor, die length and ram velocity have the effect on extrusion load in decreasing order.

4.1 Confirmatory test

By considering the optimal setting of parameters simulation has been carried out for checking the maximum extrusion load. The maximum extrusion load was found as 228000N. Also by changing only extrusion ratio and keeping other parameters same in the optimal combination the simulations have been conducted to confirm the process. For extrusion ratios R=5, 10, 15, and 20 with all other optimum combinations the extrusion load requirement was 299000, 352000, 380000, 401000N respectively. The result given by the confirmatory test is quite satisfactory. It was found a great amount of energy saving with considering the optimum parameter setting.

5. Conclusion

Modeling and simulation of extrusion of Al-6061alloy has been carried out successfully by considering a wide range of variable operating parameters. An optimum combination of parameters set successfully for the extrusion of square section from square billet in concern to minimize the maximum extrusion load. Operating temperature, extrusion ratio and friction factor have the maximum significance in decreasing order, whereas ram velocity and die length have minimum effect, but not negligible for load requirement. At high operating temperature condition, effect of friction and strain rate is more pronounced.

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