Design and Optimization Of Extrusion Process Using FEA And Taguchi Method

[1]Thella Babu Rao, [2]A.Gopala Krishna

[1]Assistant Professor, Department of Mechanical Engineering, GITAM University, Hyderabad campus, Hyderabad, Andhra Pradesh, India – 502 329.

[2]Associate Professor, Department of Mechanical Engineering, University College of Engineering, JNTUK, Kakinada, Andhra Pradesh, India - 533 003.

Abstract

This paper addresses design and optimization of extrusion process for aluminum 6061 alloy. The extrusion temperature and load has significant on quality and cost of the extruded parts respectively. Hence, development of economical process conditions is found as vital. Forward extrusion model is developed to analyze the process responses temperature, extrusion load, extrusion ratio and blank velocity for deferent process designs. Some of the most significant design parameters ram velocity, coefficient of friction and die angle are considered. Taguchi's L_9 design is employed to simulate the experiments for each set of chosen extrusion variables via Finite Element Analysis (FEA) solver. Analysis of variance (ANOVA) is adopted to check the significance of the input variables on the output responses. Then, the optimal process parameters are determined using Taguchi's method.

***Keywords**: Extrusion, finite element analysis, temperature distribution, extrusion load, optimization, Taguchi.*

1. Introduction

In recent years, extrusion process has been applied in manufacturing of variety of the components usually long, straight, semi finished metal products in the forms of bars, tubes, strips, and solid and hollow profiles [1]. In addition, it is necessary to know the history of the process responses to control the variables of extrusion. Finite element analysis of extrusion became primal to predict the response history prior to the experimental work to in the present trend [2-4].

During extrusion friction between the die and blank has significant effect on numerous process conditions [5]. Practically, low lam speeds are advisable since heating of blank due to friction and deformation leads to rise of temperature at the end of the stroke. It results premature heating of the blank [6]. The process at low ram speeds consumes much operational time and it leads to increased cost.

The present work proposes an integrated FEA based approach to evaluate the extrusion process conditions numerically and to find the optimal process variables for the forward extrusion of Al 6061 alloy. The simulations are carried out for different ram velocities, coefficient of frictions and die angles. The simulation results of temperature, extrusion load, extrusion ratio and blank velocity are presented. Consequently optimization has been carried out for to minimize the temperature and to minimize extrusion load using Taguchi's technique.

2. Literature Survey

Al6061 is one of the most widely used aluminum alloys in the range from transportation components to machinery equipments. This is due to its excellent corrosion resistance to atmospheric conditions as well as sea water. Many authors have been performed the investigations to understanding the thermo-mechanical behavior of the aluminum blanks as well as the dies during extrusion process using numerical methods [7-9].

Zhou et al [10] studied the state of stress, strain and the temperature during extrusion with square to round dies. They concluded as the extrusion of aluminium through FEM simulation as a powerful tool to predict the thermo-mechanical changes occurring inside the billet material. Gang et al [11] investigated the influence of steps in the die flow of metal by means of 3D FEM transient state simulation. The results of this investigation revealed as the pocket step could be effectively used to balance metal flow during extrusion. Sutasn et al [12] investigated the effect of punch height on the V-bending angle. The FEM results of this investigation showing that the gap between the workpiece and the die, as well as the reversed bending zone resulted in a non-required bending angle. Luo et al [13] have successfully implemented the numerical methods to investigate the anisotropic ductile fracture of a 6260-T6 anisotropic aluminum alloy extrusion. Luis et al [14] were analyzed the temperature and the strain of aluminum alloy during equal channel angular extrusion by using FEM simulations. This analysis resulted as the increase of temperatures leads to lower stress in both the die and billet. The proposed models in this analysis allowed to accurate study of the stress inside the billet and die as a consequence of both thermal heating and plastic strain. Smith et al [15] executed the finite element investigations upon the influence of pocket die designs on metal flow in aluminium extrusion. They found as the inverse linear relationship between pocket angle and velocity. Smaller pocket angles result in large exit velocities and large pocket angles result in smaller velocity.

3. Taguchi's Method

Taguchi's methods are one of the widely used methods to solve the optimization problems of multiple objectives and are influenced by multiple variables. It was developed to minimize the cost and time of experimentations when the process has large number of combinations [16] by providing a systematic approach to the design of experiments. Hence, it became an extensively adopted method to solve some complex problems in manufacturing [17-21]. In this method, the performance characteristic is represented by signal-to-noise (S/N) ratio and the largest value of S/N ratio is required. These are logarithmic function of desired output and serve as objective function in the optimization process. There are three types of S/N ratio as the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio with a lower-the-better characteristic that can be expressed as [22]:

1. Lower – the – better

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

2. Higher – the - better

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (2)$$

3. Normal –the - better

$$\frac{S}{N} = -10\log\left(\frac{1}{ns}\sum_{i=1}^{n} y_i^2\right) \quad (3)$$

Where, y_i is the ith value of measured response, n is the total number of runs and s is the standard deviation.

4. Finite Element Modelling

In this investigation DEFORM-3D [23] software is used to simulate the turning process. The process parameters used for the present numerical computer simulations are given in Table 1. The initial temperatures of billet and die are set at 25°C and the billet is assumed to be as plastic in a circular shaped. The die is classified as rigid body. The model geometry of extrusion process is as shown in Fig.1. The physical properties of work material are listed Table 2. L_9 Taguchi's orthogonal array with nine experiments has been selected. The model was developed by selecting the extrusion process followed by defining the necessary process parameters. The convection heat transfer coefficient at the billet – die interface was selected as 0.1 N/sec/mm/C. Geometrically identical meshes for the thermal equations have been considered for the computation of extrusion temperature. Table 3 shows the simulation results for each set of input variables using DEFORM-3D.

Fig.2 shows the temperature distribution obtained for the first set of experimental run corresponding parameters as punch velocity 1mm/sec, coefficient of friction 0.1 µ and die angle 30o. At these levels of input parameters the predicted extrusion temperature is 86.80C. It can be observed that high temperature region is occurred at the exit of the die from the center of the blank. Fig.3 shows the effective stress distribution during extrusion. The maximum effective stress developed is 437 MPa the process variables for first FEA run. Fig. 4 shows the variation of extrusion load with respect to time for the 4th run in Table 3. The maximum extrusion load obtained in this case is 272 kN. Fig. 5 shows the velocity of blank during extrusion.

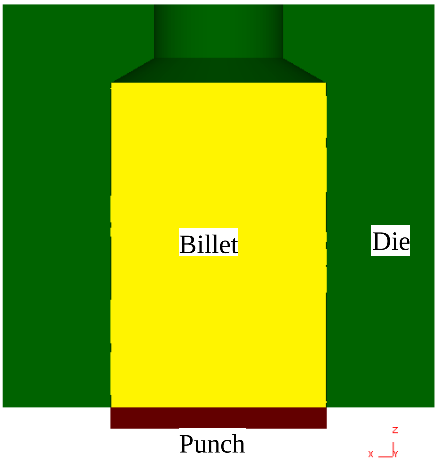

Fig. 1 FEA Modelling of Extrusion process

Table 1 Extrusion parameters and levels

Parameter	Code	Levels 1	2	3
Punch Velocity (mm)	Ev	1	1.5	2
Coefficient of friction (µ)	COF	0.1	0.15	0.2
Die Angle (deg.)	α	30	45	60

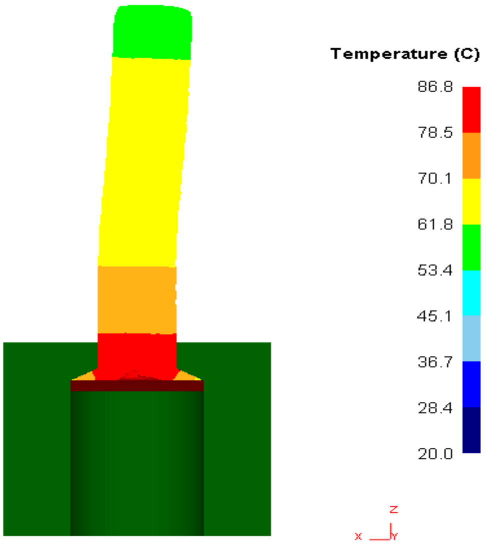

Fig.2 Temperature distribution

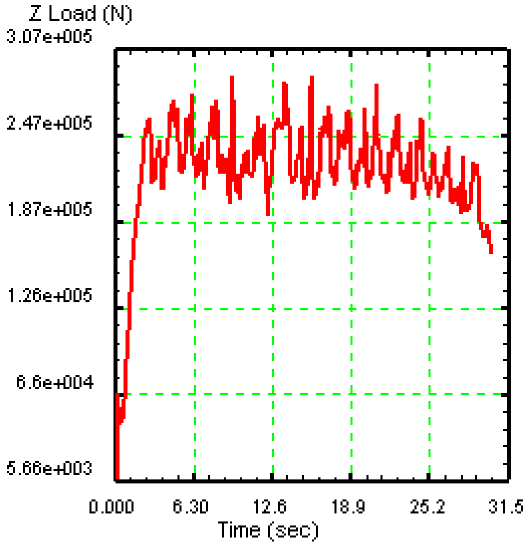

Fig.4 Load Vs Time plot

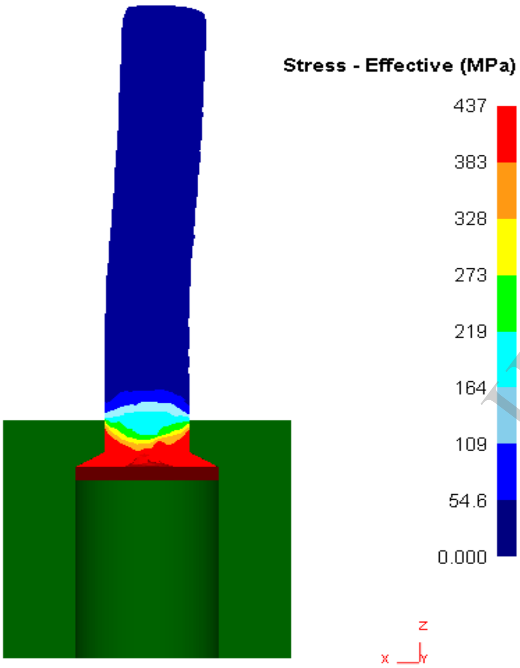

Fig.3 Distribution of Effective stress

Table 2 Physical properties of work material

Properties	
Work material	Al6061
Density (kg/m^3)	2690
Young's Modulus (N/mm^2)	69000
Poisson's ratio	0.293
Coefficient of thermal expansion (1/^{0}C)	23.6E-06
Specific heat (N/mm2/^{0}C)	2.39
Thermal conductivity (W/m/^{0}C)	180

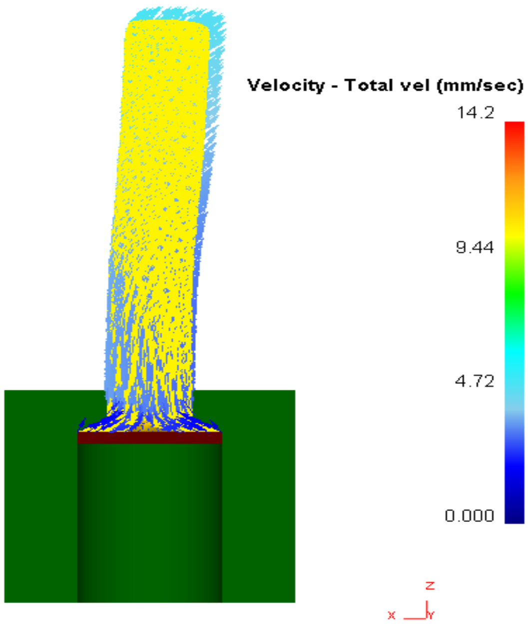

Fig.5 Velocity of the blank

5. Implementation of Taguchi

The objective of this optimization problem is to minimize the die exit temperature and extrusion load. Therefore, On the basis of maximization of S/N ratio for extrusion temperature and load, the optimal set of extrusion process parameters has been calculated using Eq. 2. The obtained values of S/N values are listed in Table 4. These optimal process parameters are depicted in Figs. 7 and 8. This figure reveals the set of optimal parameter levels. Therefore, based on the S/N the set of optimal cutting parameters for temperature is Pv = 2 mm/sec, COF = 0.15μ and die angle = 30^o and the set of optimal cutting parameters for extrusion load is Pv = 2 mm/sec, COF = 0.1μ and die angle = 60^o.

6. ANOVA

Analysis of variance is employed for the obtained FEA results. Tables 5 and 6 represent the ANOVA of extrusion temperature and load respectively. From Table 5, it can be found those extrusion velocity and die angle are significant for extrusion temperature. From Table 6, the extrusion velocity is significant for affecting load.

Table 3 Simulation results of Extrusion

Sl. No	Pv (mm/s)	COF (μ)	α (deg.)	T (^{0}c)	P (kN)
	X1	X2	X3	Y1	Y2
1.	1	0.1	30	86.8	124
2.	1	0.15	45	80.9	229
3.	1	0.2	60	70.4	309
4.	1.5	0.1	45	105	272
5.	1.5	0.15	60	88.1	347
6.	1.5	0.2	30	114	312
7.	2	0.1	60	106	393
8.	2	0.15	30	134	368
9.	2	0.2	45	130	382

Table 4 S/N ratio for responses

Exp.No.	η(Y1)	η (Y2)
1.	38.77039	41.86843
2.	38.15897	47.19671
3.	36.95145	49.79917
4.	40.42379	48.69138
5.	38.89952	50.80659
6.	41.13810	49.88309
7.	40.50612	51.88785
8.	42.54210	51.31696
9.	42.27887	51.64127

Table 5 ANOVA analysis for Temperature

Source	DF	Seq SS	Ad jSS	Adj MS	F	P
X1	2	2.9E3	2.9E3	1.4E3	240.6	0.004
X2	2	48.06	48.06	24.03	3.99	0.201
X3	2	882.36	882.36	441.18	73.19	0.013
Error	2	12.06	12.06	6.03		
Total	8	3844.15				

Table 6 ANOVA analysis for Extrusion load

Source	DF	Seq SS	Adj SS	Adj MS	F	P
X1	2	38.7E3	38.7E3	19.3E3	21.79	0.044
X2	2	8144.7	8144.7	4072.3	4.58	0.179
X3	2	10.4E3	10.4E3	5212.3	5.86	0.146
Error	2	1778	1778	889		
Total	8	59088				

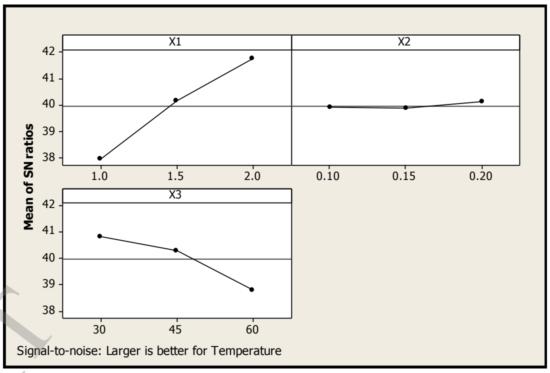

Fig.6 S/N ratios plot for Temperature

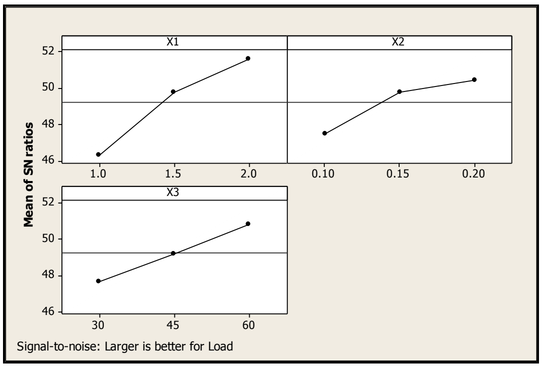

Fig.7 S/N ratios plot for Extrusion load

7. Conclusions

The finite element analysis of temperature and extrusion load during the extrusion of aluminum 6061 alloy is carried out in the present work. The optimal set of extrusion variables for the chosen responses was obtained. The experimental runs were conducted based on the Taguch's L_9 design matrix. ANOVA is employed to identify the significance of variables on the responses. Also, the percentage of contributions of each variable on each response was represented graphically. The set of optimal process variables was obtained with the help of Taguchi optimization method on the basis of maximum S/N ratio. These optimal process variables help to extrude the chosen aluminum alloy with minimum Die exit temperature and using minimum extrusion load. Hence, the quality of the extruded product improved with minimum energy.

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