

Fuzzy Based Optimization of Aluminium Extrusion Process

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ABSTRACT: Fuzzy Logic combined with Taguchi method is used in this study to investigate optimum process parameters with maximum multiple performance characteristic index (MPCI) of direct aluminium extrusion process. Direct extrusion of Al 6063 aluminium alloy is performed according to the design of experiments (DOE). Feature angularity and weight of extrude are considered for optimization in the MPCI, whereas billet pre-heating temperature, container temperature and ram speed are considered as the process parameters. L27 full factorial design is used to obtain the values of the response parameters. Signal to noise ratio of the response parameters determined from the experimental results are considered for the multi-response analysis. Triangular membership function along with mamdani fuzzy inference system is used by using MATLAB fuzzy logic tool box to determine MPCI with lower feature angularity and lower weight of extrude.

KEYWORDS: Direct Extrusion, Design of Experiments, Fuzzy Logic.

I. INTRODUCTION

Direct extrusion is the process in which a ram compresses the metal billet loaded into the container and the metal flows into the direction of the force applied. This process is used to reduce the cross-section of the billet to the cross-section of the profile incorporated into the die. Extruded aluminium alloy cross-sections are widely used in door and window frames, cylindrical rods and wide variety of application where complex sections are involved. Lin et al. [1] applied multiple response performance index by using fuzzy logic to determine the optimum combination of process parameters which increases the material removal rate and decreases the electrode wear ratio in an electrical discharge machining process. The performance characteristic of Taguchi method contain a certain degree of uncertainty which can be overcome by multiple response parameter optimization.

Zhang et al. [2] optimized metal flow distribution throughout the cross-section of aluminium extrude and the required extrusion force using Taguchi's design of experiments and FEM simulation, along with analysis of variance to investigate the influence of process parameters on the response parameters. Artificial neural network was implemented by Lucignano et al. [3] to optimize the temperature profile at the exit of the induction heater and the exit of the die of an Al 6060 aluminium alloy, the confirmation runs had almost the same values as that of the predicted values. Multiple objective optimization was performed by Reggiani et al. [4] by developing meta-models from the numerical and experimental training designs to improve the quality of aluminium extrude as well as increase the production rate. Hsiang et al. [5] fuzzy logic with Taguchi's design of experiments to improve the quality of magnesium alloy bicycle carrier extrudes by increasing the flattening strength and lowering the load required for extrusion. Hsiang and Lin [6] also used fuzzy logic for the multi-parameter optimization of tensile strength and extrusion load of magnesium alloy sheets to increase the quality of extrude.

Reddy and Shrivani [7] worked on implementation of fuzzy logic with Taguchi method to investigate the optimum combination of process parameters for improving the surface finish and material removal rate of turning process.

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Marahleh [8] studied the effect of pre-heating on the homogenation of Al 6063 aluminium alloy and found that the unhomogenized billet possesses the same mechanical properties as that of the homogenized billet which eliminates the use of homogenized billet. Seth et al. [9] applied fuzzy logic inference rules using matlab fuzzy tool box to predict the material removal rate in flashing operation of ball bearings. Genetic algorithm was used by Jurcovic et al. [10] to optimize the die angle and friction factor to optimize the process parameters of aluminium extrusion process.

II. RELATED WORK

Direct extrusion is the simplest and most extensively utilized method of extrusion due to its low cycle time and higher production rates. The extrusion of aluminium alloys not only depends on the mechanical properties of the alloy but also number of different process parameters used during the extrusion process. Aluminium alloys are mostly extruded using the direct extrusion method to remove the oxide layer formed on the billet due to its contact with oxygen present in the air. The main focus of the forming industries is on the achievement of highest production rate with better quality of products. Therefore, along with the selection of material properties process parameter optimization is also one of the important factor. Taguchi method can only be used for single factor optimization, but most of the time multiple response optimization is required in the industries. Therefore, artificial intelligence techniques can be implemented to determine the optimum combination of process parameters for multiple factor optimization. Fuzzy logic is one of the artificial intelligence technique which deals in terms of linguistic variables to determine the fuzzy membership grade and get the optimum process parameters.

In this study multiple response characteristic index (MPCI) is used to determine the optimum combination of process parameters in extrusion of Al 6063 aluminium alloy. MPCI is determined using fuzzy inference rules in MATLAB fuzzy tool box. Analysis of variance is also used to determine the influence of process parameters on the response parameters.

III. PROCESS PARAMETERS SELECTION AND DESIGN OF EXPERIMENTS

In this work, a direct extrusion press with the capacity of 900 MT is used. Billet with a diameter of 127 mm is used for extruding two track top profile used for sliding windows as shown in fig. 1. Thermocouples are employed at the billet pre-heating furnace and container of the extrusion press to keep in check with the constant temperature to be maintained during the extrusion process. No lubrication is used between the billet and the container lining to peel out the oxide layer formed on the periphery of the billet after pre-heating. Billet pre-heating temperature, container temperature and ram speed are the process parameters selected for the multiple optimization of feature angularity and weight of extrude. Process parameters are set at three levels each, i.e. the range varies from 480⁰C to 520⁰C for billet pre-heating temperature, 400⁰C to 425⁰C for container temperature and 4.5mm/sec to 6.0mm/sec for ram speed. Table 1 shows the process parameters with their levels used for the design of experiments. The range of process parameters is selected based on the trial experiments that were performed for the maximum range of process parameters. The response parameters selected determines the quality of extrude with reduction in the cost of material for extruding the profile.

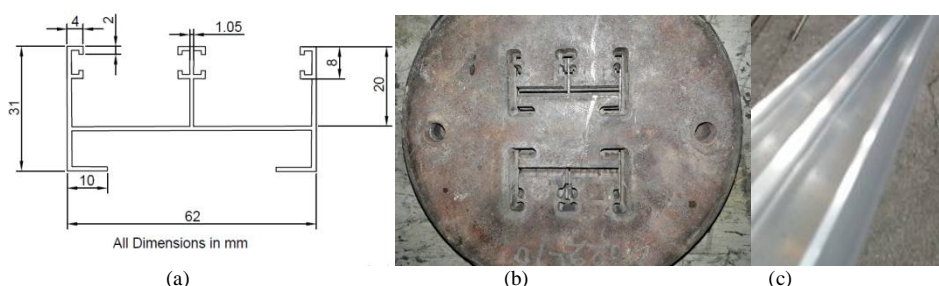


Figure 1. Two Track Top Profile (a) Schematic of Standard Profile, (b) Profile Die and (c) Extruded Profile

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Table 1 Process Parameters and their Levels

Process Parameters	Level 1	Level 2	Level 3
Billet Pre-Heating Temperature (⁰ C)	480	500	520
Container Temperature (⁰ C)	400	410	425
Ram Speed (mm/sec)	4.5	5.2	6.0

Design of experiments is the most efficient technique to determine the number of experiments and avoid the repetition of the experiments at same level, thus reducing the cost and time of experimentation. L27 full factorial design of experiments is used for the study to perform the experiments and investigate the optimal combination of process parameters. Table 2 depicts the full factorial design. The degrees of freedom for the array selected is 26 which is less than the number of experiments, which shows that the design of experiments can be considered for the study. The main objective of this study is to minimize the feature angularity and weight of extrude, which directly increases the quality of extrude. A full factorial design is selected to increase the accuracy of the results. In this study, the effect of independent response parameters is investigated rather than interactions, as interactions leads to more complexities in the investigation of results.

Table 2 Design of Experiments

Exp. No.	Billet Pre-Heating Temp. (⁰ C)	Container Temp. (⁰ C)	Ram Speed (mm/sec)
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

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IV. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, results obtained from the experiments, s-n ratio analysis and implementation of fuzzy logic to determine multiple performance characteristic index are illustrated. Experimental runs are performed randomly to reduce the effect of noise parameters. The experiments were performed using 5.3 m casted Al 6063 log which is further cut into 1.9 m billets. The die is provided with a backer and feeder, which acts as seal during the extrusion process. The ram is provided with a portable dummy block to avoid direct contact between the dummy block and the pre-heated billet to eliminate the damage of ram. The portable dummy block can be replaced after few cycles of extrusion process.

3.1 Signal-to-noise ratio

Signal-to-noise ratio as an essential tool of Taguchi method to determine the effect of process parameters relative with the noise parameters on the response parameters. Smaller the better quality characteristic is applied to determine the s-n ratio of the response parameters (feature angularity and weight of extrude). Experimental results for feature angularity and weight of extrude along with their s-n values is shown in table 3.

Table 3 Experimental Results and S-N values of Response Variables

Exp. No.	Feature Angularity (degree)	S/N Ratio (Feature Angularity)	Weight of Extrude (Kg)	S/N Ratio (Weight of Extrude)
1	5.85	-15.3431	1.367	-2.71537
2	3.38	-12.361	1.364	-2.68354
3	4.17	-9.91089	1.359	-2.63237
4	5.35	-16.6884	1.363	-2.67078
5	6.83	-15.0102	1.36	-2.63879
6	6.33	-11.1981	1.381	-2.61953
7	5.25	-17.1828	1.372	-2.66439
8	5.83	-15.4317	1.385	-2.68354
9	4.15	-12.7298	1.362	-2.62596
10	6.95	-14.4032	1.371	-2.74708
11	4.83	-10.5783	1.388	-2.69629
12	3.35	-3.69383	1.356	-2.658
13	5.63	-15.8057	1.355	-2.71537
14	3.57	-14.5671	1.368	-2.68992
15	3.63	-10.5009	1.352	-2.64519
16	7.23	-16.8397	1.359	-2.74075
17	8.75	-14.5833	1.393	-2.72172
18	6.33	-12.4027	1.392	-2.66439
19	6.92	-16.0281	1.387	-2.87278
20	4.33	-13.6789	1.353	-2.84779
21	6.95	-11.0534	1.371	-2.72172
22	4.65	-16.8021	1.385	-2.84153
23	7.23	-15.3134	1.359	-2.829
24	6.17	-11.664	1.367	-2.68354
25	3.13	-18.8402	1.354	-2.8603
26	3.83	-13.3491	1.362	-2.829
27	1.53	-16.0281	1.358	-2.80387

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3.2 Fuzzy Logic

Fuzzy logic deals in terms of linguistic values rather than crisp values. Fuzzy logic consists of four parts, i.e. fuzzifier, fuzzy inference system (FIS) with a rule base and defuzzifier. Fuzzifier converts the crisp value into fuzzy values which are analysed by fuzzy inference system and further the results from FIS are converted into crisp values by using defuzzifier. Fuzzy inference system consists of input parameters and output parameters in terms of membership functions. The inference rules are used to perform the analysis of the fuzzy input values.

In this study, s-n ratio values of the response variables are used to create fuzzy input values membership functions as low medium and high, whereas MPCII is defined by five membership functions as very low (VL), low (L), medium (M), high (H) and very high (VH). Triangular membership function is used for defining input and output variables. Mamadani inference system is used to determine the MPCII and centre of gravity method is used to convert fuzzy values in crisp values. A set of nine fuzzy rules are derived by considering the larger s-n ratio values. Mamdani fuzzy inference system consists of if-then rules with inputs x_1 and y_1 and output as z_1 . The general format of rules is

If x_1 is A_1 and y_1 is B_1 then z_1 is C_1 else

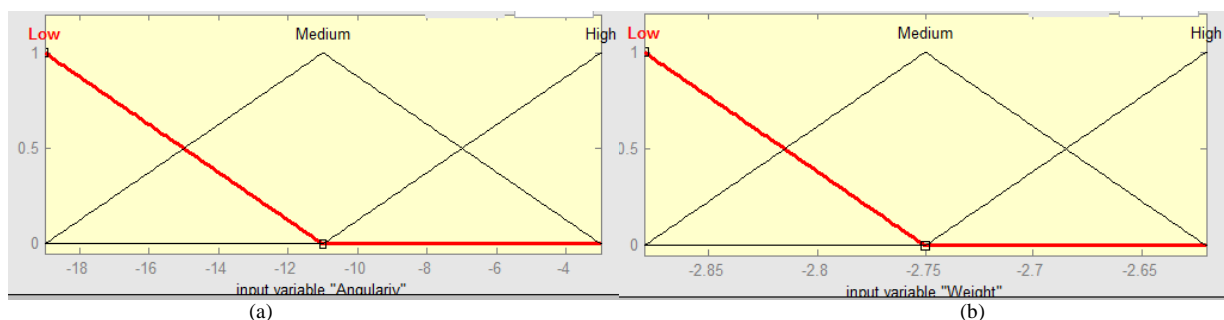
If x_2 is A_2 and y_2 is B_2 then z_2 is C_2 else

Where A and B are the membership functions of the two input variables and C is the membership function of the output variable. The fuzzy inference rules constructed for this study are depicted in the fig. 2.

1. If (Angulariy is Low) and (Weight is Low) then (MPCI is VL) (1)
2. If (Angulariy is Low) and (Weight is Medium) then (MPCI is L) (1)
3. If (Angulariy is Low) and (Weight is High) then (MPCI is M) (1)
4. If (Angulariy is Medium) and (Weight is Low) then (MPCI is L) (1)
5. If (Angulariy is Medium) and (Weight is Medium) then (MPCI is M) (1)
6. If (Angulariy is Medium) and (Weight is High) then (MPCI is H) (1)
7. If (Angulariy is High) and (Weight is Low) then (MPCI is M) (1)
8. If (Angulariy is High) and (Weight is Medium) then (MPCI is H) (1)
9. If (Angulariy is High) and (Weight is High) then (MPCI is VH) (1)

Figure 2 Fuzzy Inference Rules

Fuzzy input and output variables with membership function are shown in fig. 3. The input variables are represented with three triangular membership functions each whereas output membership function is represented with five triangular membership functions. The MPCII values for optimization can be determined by using this membership functions.



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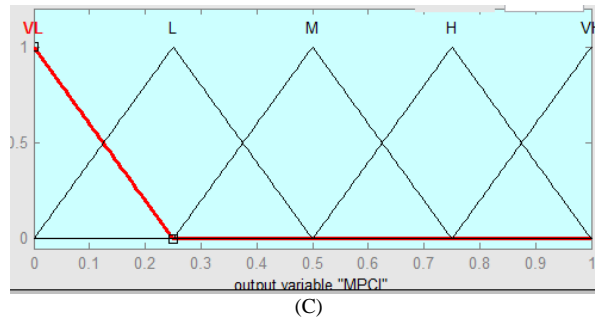


Figure 3 Membership Functions (a) Feature Angularity, (b) Weight of Extrude, (c) Multiple Performance Index (MPCI)

Fig. 4 shows the rule base that is used for the determining the value of MPCI. The required input values are entered into in the rule base and the output values are depicted by the MPCI. Thus, the required out values of MPCI are obtained from the fuzzy inference system which can be used to optimize the aluminium extrusion process.

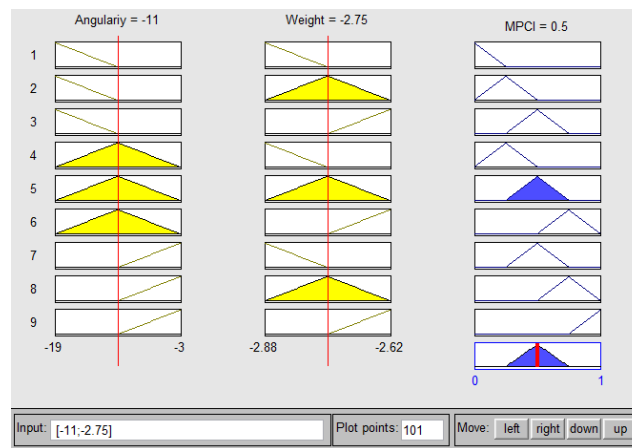


Figure 4 Rule base to investigate MPCI

The MPCI is determined according to the input values from the results obtained from the experimental results. The value of MPCI for each input values is given by the fuzzy rule base. Fuzzy rule base to investigate MPCI is also shown in fig. 4. The MPCI determined from fuzzy inference system are shown in table 4.

Exp. No.	MPCI
1	0.45
2	0.624
3	0.721
4	0.481
5	0.575
6	0.741
7	0.476
8	0.493
9	0.665

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10	0.399
11	0.608
12	0.773
13	0.441
14	0.502
15	0.692
16	0.357
17	0.454
18	0.593
19	0.225
20	0.309
21	0.562
22	0.291
23	0.326
24	0.597
25	0.159
26	0.341
27	0.328

The mean value for each level is shown in table 5. From the mean values of MPCII for each process parameters, the maximum value MPCII for billet pre-heating temperature is obtained at 480°C, whereas MPCII for container temperature and ram speed is obtained at 400°C and 6.0 mm/sec respectively.

Table 5 Mean Values of MPCII

Process Parameters	MPCII		
	Level 1	Level 2	Level 3
Billet Pre-Heating Temperature (°C)	0.581	0.535	0.348
Container Temperature (°C)	0.519	0.516	0.429
Ram Speed (mm/sec)	0.364	0.470	0.63

V. CONCLUSIONS

The use of fuzzy logic for determining the optimum combination of process parameters to enhance the multiple performance index of direct aluminium extrusion process is presented in this paper. The quality characteristics such as feature angularity and weight of extrude is optimized simultaneously by using a fuzzy inference system.

1. The optimum combination of process parameters obtained are 480°C for billet pre-heating temperature, 400°C for container temperature and 6.0 mm/sec for ram speed.
2. The ram speed has the maximum influence on the multiple response parameters as observed from the MPCII values obtained from the fuzzy inference system.
3. The container temperature has the list influence as observed from the MPCII values obtained from the fuzzy inference system.

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