Multi-Response Optimization of Compression Moulding Parameters for SS316L using Taguchi Method with Grey Relational Analysis

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ABSTRACT – In this paper, optimization of compression moulding parameters such as mould temperature, weight of material, and preheat time on the multi-response mechanical properties of stainless steel 316L using Taguchi method was studied. However, Taguchi method is only applicable to optimize a single response instead of multiple response. Therefore, the optimization of multi-response was simplified with a technique called grey relational analysis (GRA). From the ANOVA result, it is found that the weight of material with 49.97% is the highest percentage contribution parameter for GRG followed by preheat time and mould temperature with 44.24% and 5.8% respectively.

1. INTRODUCTION

Nelabhotla et al. [1] stated that Taguchi method design is used to optimize a single response at a time and it is not suitable to optimize multiple response simultaneously. Optimization of complicated multiple performance characteristics can be simplified with a technique called as GRA. Despite the fact that the Taguchi technique reduces the number of experimental runs, it may provide different set of optimal parameters for each response. As a result, some researchers used a multi-response optimization technique called the Taguchi approach with GRA [2] [3]. Hence, in this study grey relational analysis (GRA) method is used to optimize multi response by optimizing the compression moulding parameters such as mould temperature, weight of material and preheat time on mechanical properties such as ultimate tensile strength (UTS), Young's modulus (YM), percentage of elongation (%EL) and yield strength (YS) of SS316L.

2. METHODOLOGY

Table 1 shows the experimental matrix that consists of total 4 runs by using Taguchi method. Further, Table 2 shows the experimental result of all responses.

In order to perform tensile testing, the sample was cut into a dumbbell-shaped according to ASTM E8M using wire-cut EDM machine Mitsubishi RA90. Tensile testing was performed using Universal Testing Machine 50kN INSTRON at a crosshead speed of 1 mm/min. Mechanical properties were determined from three replicates for each sample and the specimen with gauge length of 25 mm.

Table 1 Experimental matrix

Run	Process Parameters		
	Mould Temperature	**Weight of Material**	**Preheat Time**
1	230	110	3
2	230	134	7
3	290	110	7
4	290	134	3

Table 2 Experimental result

Run	Responses			
	UTS (MPa)	**YM (GPa)**	**%EL (%)**	**YS (MPa)**
1	95.19	39.30	1.08	75.52
2	157.34	44.97	2.36	98.71
3	120.05	43.91	1.88	81.62
4	120.30	44.36	1.74	84.67

3. RESULTS AND DISCUSSION

3.1 Optimization using Grey relational analysis (GRA)

The first step in the grey relational analysis is grey relational generation, in which data is first normalised in the 0–1 range. This step is called as normalization of the responses. The data to be used in grey analysis must be preprocessed into quantitative indices for normalizing raw data for another analysis. In this study, the expected data sequence is in the form "the-higher-the-better" for all responses and normalized using Equation (1). The normalized values of all responses are tabulated in the Table 3.

$$x_i^*(k) = \frac{x_i^0(k) - min\, x_i^0(k)}{max\, x_i^0(k) - min\, x_i^0(k)} \quad (1)$$

Where x^0_i (k) is the original sequence, $x^*_i(k)$ the sequence after the data preprocessing, max $x^0i(k)$ the largest value of $x^0_i(k)$ and min $x^0_i(k)$ imply the smallest value of $x^0_i(k)$.

Table 3 GRA normalized sequence after data processing

Run	Normalized data			
	UTS (Mpa)	YM (GPa)	%EL (%)	YS (MPa)
1	0	0	0	0
2	1	1	1	1
3	0.4	0.8131	0.6250	0.2630
4	0.4040	0.8924	0.5156	0.3946

Next, grey relational coefficient (GRC) were calculated from the normalized numerical data to express the relationship between the normalized experimental results and the actual experiment as shown in Table 4. GRC can be calculated using Equation (2).

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (2)$$

Where, Δ_{min} is zero, Δ_{max} is one; ζ is distinguishing coefficient is 0.5 and Δ_{oi} (k) is the deviation sequence of the experiment trial.

Table 4 Grey relational coefficient (GRC)

Run	Grey Relational Coefficient				Total GRC
	UTS (Mpa)	YM (GPa)	%EL (%)	YS (MPa)	
1	0.333	0.333	0.333	0.333	1.333
2	1	1	1	1	4
3	0.455	0.728	0.571	0.404	2.158
4	0.456	0.823	0.508	0.452	2.239

The overall evaluation of multi-performance characteristics is always based on grey relational grade or GRG (γ_i). It is an average sum of the GRC. GRG is calculated using the following Equation (3).

$$\gamma_i(k) = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (3)$$

After the GRC calculation, normally the average of the GRC is taken as the GRG. the complete estimation of the multiple response is based on the GRG. The higher the value of GRG represents that the corresponding process parameters combination is closer to the optimal condition as shown in Table 5.

Table 5 Grey relational grade (GRG)

Run	1	2	3	4
GRG	0.3333	1	0.5395	0.5598
Rank	4	1	3	2

From the graph shown in Figure 1, the optimum parametric combinations for GRG are at mould temperature 230°C, weight of material 134g, and preheat time 7min.

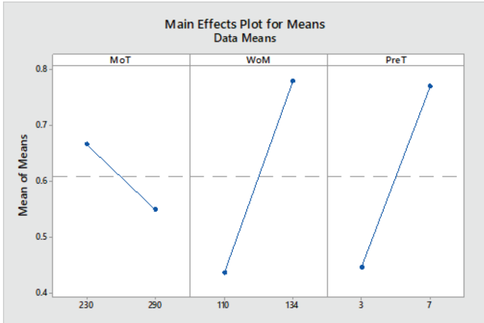

Figure 1 Main effects plot of GRG

3.2 *Analysis of Variance (ANOVA) of GRG*

From the ANOVA result as shown in Table 6, the mould temperature shows less significant to the GRG where the weight of material and preheat time are more significant to GRG.

Table 6 The analysis of variance (ANOVA) for GRG

Parameters	DOF	Sum of Squares	% of Contribution
Mould Temperature	2	0.01369	5.8%
Weight of Material	2	0.1180	49.97%
Preheat Time	2	0.1045	44.24%
Error	0		
Total	6	0.23614	100

4. CONCLUSIONS

The multi-response optimization of ultimate tensile strength (UTS), Young's modulus, percentage of elongation and yield strength are investigated by implementing GRA technique. One set of optimum parameters setting for the multi-response is successfully obtained where mould temperature is 230°C, weight of material is 134g, and preheat time is 7min. In addition, ANOVA result shows that mould temperature has the lowest significant effect on GRG compared to weight of material and preheat time.

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