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Research Article

OPTIMIZING THE GREEN SAND CASTING PROCESS PARAMETERS USING TAGUCHI BASED GREY RELATIONAL ANALYSIS

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ABSTRACT

In this present study, the influence of process parameters that affect during green sand casting process were experimentally investigated. Using Taguchi based Grey relational analysis, the optimum condition for casting process was found. Taguchi technique was coupled with grey relational analysis to obtain a grey relational grade for evaluating multiple outputs. A L27 orthogonal array was selected and designed for five parameters varied through three levels by applying Taguchi's design of experiments. The optimum level values of parameters obtained for casting process is Moisture Content of 3.2, Green Compressive Strength of 1000 g/cm^2, Permeability of 132.5, and Mould Hardness of 87.5 and Pouring Temperature of 1535°C. Percentage contribution of input parameters on output response were determined using ANOVA. The results showed that Green Compressive Strength is the prominent parameter that contributes towards output responses followed by Pouring Temperature, Mould Hardness, Permeability and Moisture Content. By adapting the derived optimum condition the quality of the green sand casting product can be improved

INTRODUCTION

Although there are many new advanced techniques for metal casting has been developed, sand casting remains one of the widely used casting processes now a days due to the low cost of raw materials, a wide variety of castings with respect to size and composition, and the possibility of recycling the molding sand (Noorul and Karuppannan 2006). The sand casting process is one of the most versatile processes in foundry industries because it is used for most metals and alloys with high melting temperatures such as iron, copper, and nickel. The sand casting process consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking away the sand mold to remove a casting product(Kumar, Satsangi, and Prajapati 2011).

Many research works were done before for determining optimal values of casting process factors to improve the quality of castings using various techniques. The optimal process factor settings are defined as the best level for each factor that optimizes the process response (Syrcos 2003). Taguchi's method is one method to determine the optimal process factor settings for the green sand casting process. The selected process factors (i.e., moisture content, green compression strength, permeability, pouring temperature and mold hardness) significantly affect the casting defects (Arunachalam 2007). Apart from Taguchi's method applied to the green sand casting process, computer based simulation technique is applied to develop a mathematical model. The researchers investigated the influence of different process factors in various molding processes (Arunachalam 2007).

And large number of experimental investigations of green sand casting process parameters relating to the casting quality have been carried out by foundry engineers over the past few decades. It has been recognized that green sand casting process parameters design plays one of the key elements in casting quality (Anastasiou n.d.). The casting process has a large number of parameters that may affect the quality, hardness and tensile strength of the castings. Some of these parameters affecting quality are controllable, while others are noise factors (Anastasiou n.d.).

The main aim of this study is to identify optimal process condition for the green sand casting process parameters to minimize the percentage of defects and to improve the tensile strength, hardness of the casting product using Taguchi based grey relational analysis.

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MATERIALS AND METHOD

Taguchi's Design of Experiments

Taguchi technique creates a standard orthogonal array to evaluate the effects of design parameters on the response value. The use of orthogonal arrays minimizes the number of total experimental runs such that the conclusions drawn from small scale experiments are valid over an entire experimental region spanned by the control factors and their settings (Mitra *et al.* 2016).

Taguchi's DoE is applied in this work for the experimental array design while considering five parameters viz., moisture content, green compressive strength, permeability, mould hardness, pouring temperature. Individual parameters are varied through three levels as given in Table 1.

Table 1 Experimental parameters with levels

Sl.No	Process Parameter	Parameter Designation	Level 1	Level 2	Level 3
1	Moisture Content (Number)	A	3.2	3.3	3.4
2	Green Compressive Strength(g/cm²)	B	950	1000	1050
3	Permeability(Number)	C	125	132.5	140
4	Mould Hardness(Number)	D	85	87.5	90
5	Pouring Temperature(°C)	E	1520	1527.5	1535

The inner L27 orthogonal array formulated for the chosen parameters using mini tap 17 and their level values are given in **Table 2.**

Performance characteristics used for analyzing the outputs in Taguchi technique comprise of three categories: Smaller-the better, Larger-the better and Nominal-the-better. The equations used to determine the S/N ratios are as follows.

Smaller the better

$S/N = -10 \log(\frac{1}{N}\sum_{I=1}^{N} Y_i^{\,2}$ (1) (Tzeng *et al.* 2008)

Lager the better

$S/N = -10\log(\frac{1}{N}\sum_{I=1}^{N}\frac{1}{Y^2_i})$ (2) (Shivapragash *et al.* 2013)

Nominal the better

$S/N = 10\log(\frac{Y}{S^2})$ (3) (Senthilkumar, Tamizharasan, and Anandakrishnan 2014)

Gray Relational Analysis

Grey relational analysis (GRA) is purely based on this theory that can be effectively applied for solution finding in complicated interrelationships between the chosen performance characteristics(Roughness *et al.* 2010). GRA is mainly applied to determine a grade that acts as an indicator for multiple performance indexes called as grey relational grade for evaluation of more than one output simultaneously and for discrete problems(Nayak, Patro, and Dewangan 2014). There are serious steps to be carried out to find optimal condition they are briefly discussed below.

The first step in Taguchi based grey relational analysis is normalization of the S/N ratio which is performed to prepare raw data for the analysis where the original sequence is transferred to a comparable sequence(Pragadish and Pradeep Kumar 2016). Normalization of the S/N ratio in the range between zero and unity is also called as the grey relational generation. Depending upon the normalization levels the condition is used are mentioned below.

Larger is better

$X_{i\chi} = \frac{Y_{i\chi} - MIN\ Y_{i\chi}}{MAX\ Y_{i\chi} - MIN\ Y_{i\chi}}$ (4) (Muthuramalingam and Mohan 2014)

$Y_{i\chi}$ for the i^{th} experimental results in the $_{\chi}$th experiment

After normalizing the original data, the next step is to calculate the grey relation coefficient(Maiyar *et al.* 2013). Grey Grey relational coefficient e is calculated to express the relationship between the ideal and actual normalize experimental results. The grey relation coefficient can be expressed as

$Z_{ij} = \frac{\min_i \min_\chi (x_i - x_{i\chi}) + \pounds\ max_i \max_\chi (x_i - x_{i\chi})}{(x_i - x_{i\chi}) + \pounds\ max_i \max_\chi (x_i - x_{i\chi})}$ (5) (Senthilkumar *et al.* 2016)

Where $x_i$is the ideal normalized results for the i^{th}performance characteristics and is the distinguishing coefficient which is defined in the range 0 1. In the present study the value of is assumed as 0.5(Suhail, Wong, and Jalil 2012).

Analysis of Variance

The analysis of variance (ANOVA) is the statistical tool most generally applied to the results of the experiment to determine the percent contribution of each factor(Khan *et al.* 2014). And main aim of the analysis of variance is to evaluate the significance of process parameters on green sand casting process and used to analyze which process parameters significantly affect the % defects, tensile strength and hardness. And it is mainly used to identify, which input process parameter is responsible for change in the process performance and by controlling this parameter the process can be improved (Pandey and Panda 2015).

RESULTS AND DISCUSSION

Once the parameters are assigned to a particular column of the L 27orthogonal array, the factors at different levels are assigned for the each trial.

Table 2 Formulated L 27 Inner Orthogonal Array And Measured Output Response

Trial No	A	B	C	D	E	% Defects	Tensile Strength	Hardness
1	3.2	950	125	85	1520	5.06	471.66	167.66
2	3.2	950	125	85	1527.5	4.86	470.66	164.33
3	3.2	950	125	85	1535	5.53	479.33	164.66
4	3.2	1000	132.5	87.5	1520	5.33	475.66	163.66
5	3.2	1000	132.5	87.5	1527.5	5.7	476.33	168.33
6	3.2	1000	132.5	87.5	1535	6.16	484.66	167
7	3.2	1050	140	90	1520	5.66	466.33	166.33
8	3.2	1050	140	90	1527.5	5.86	471.66	166.33
9	3.2	1050	140	90	1535	5.1	474.33	170.66
10	3.3	950	132.5	90	1520	5.26	469.33	168.66
11	3.3	950	132.5	90	1527.5	5.33	477.33	165.33
12	3.3	950	132.5	90	1535	5.06	481.66	167
13	3.3	1000	140	85	1520	5.53	480.33	162
14	3.3	1000	140	85	1527.5	5.8	474	163
15	3.3	1000	140	85	1535	5.5	487	165.66
16	3.3	1050	125	87.5	1520	5.53	480.33	166
17	3.3	1050	125	87.5	1527.5	5.96	479.33	163.66
18	3.3	1050	125	87.5	1535	5.3	468	166.66
19	3.4	950	140	87.5	1520	5.33	470.66	168.66
20	3.4	950	140	87.5	1527.5	6	462.33	165.33
21	3.4	950	140	87.5	1535	5.4	469	166
22	3.4	1000	125	90	1520	5.53	474.66	161
23	3.4	1000	125	90	1527.5	5.8	486.33	166.33
24	3.4	1000	125	90	1535	5.36	469.66	168
25	3.4	1050	132.5	85	1520	5.73	474.33	163.33
26	3.4	1050	132.5	85	1527.5	5.93	471	167.33
27	3.4	1050	132.5	85	1535	5.93	473	168

The casing defects that occur in each trial conditions are measured. The average of the casting defects was determined for the optimum level settings of % of defects, tensile strength and hardness as shown in table 2.

The above mentioned output response were measured for the formulated 27 trial values. For the measured values it shows that when the moisture content value was increased from 3.2 to 3.3 the % defects were increased by 0.02%, tensile strength increased by 0.62% and the corresponding hardness value decreased by 0.733% respectively. With further increase of moisture content from 3.3 to 3.4, an increase in % defects by 3.53%, decrease in tensile strength by 1.07% and increase in hardness by 0.40% were observed. When increasing the Green compressive strength value of the mold by 950 g/cm^2 to 1000 g/cm^{2}the % defects were increased by 6.02%, tensile strength increased by 1.33% and the corresponding hardness value decreased by 0.84% respectively. % of defects increased by 0.57%, decrease in tensile strength by 1.16% and 0.89% of hardness value increased by increasing Green compressive strength value from 1000 g/cm^2 to 1050 g/cm^{2}the respectively. By increasing the pouring metal temperature by 1520 °C TO 1527.5 °C the % defects were increased by 4.65%, tensile strength increased by 0.13% and the corresponding hardness value decreased by 0.17% respectively. With further increase of temperature from 1527.5°C to 1535°C, a decrease in % defects by 3.7%, increase in tensile strength by 0.41% and increase in hardness by 0.91% were observed.

Table 3 Grey Relational Coefficient and Weighted Grey Relational Grade

Trail No	Grey Relational Coefficient			GRG
	% Defects	Tensile Strength	Hardness	
1	0.3760	0.4481	0.6216	0.4819
2	0.3333	0.4323	0.4353	0.4003
3	0.5235	0.6208	0.4487	0.5310
4	0.4502	0.5245	0.4102	0.4616
5	0.6042	0.5398	0.6793	0.6078
6	1.0000	0.8436	0.5733	0.8056
7	0.5833	0.3747	0.5313	0.4964
8	0.7035	0.4482	0.5313	0.5610
9	0.3856	0.4965	1.0000	0.6274
10	0.4287	0.4129	0.7118	0.5178
11	0.4502	0.5644	0.4787	0.4978
12	0.3760	0.7021	0.5733	0.5505
13	0.5235	0.6533	0.3587	0.5118
14	0.6630	0.4900	0.3882	0.5137
15	0.5111	1.0000	0.4949	0.6687
16	0.5235	0.6533	0.5127	0.5632
17	0.7821	0.6208	0.4102	0.6044
18	0.4408	0.3951	0.5512	0.4624
19	0.4502	0.4323	0.7118	0.5315
20	0.8182	0.3333	0.4787	0.5434
21	0.4737	0.4083	0.5127	0.4649
22	0.5235	0.5031	0.3333	0.4533
23	0.6630	0.9497	0.5313	0.7147
24	0.4600	0.4176	0.6497	0.5091
25	0.6209	0.4965	0.3989	0.5054
26	0.7569	0.4376	0.5965	0.5970
27	0.7569	0.4712	0.6497	0.6259

Grey relational coefficient is calculated for individual responses after the normalizing process of data and deviation sequence. In this work, all three output responses have to be maximized and hence larger-the- better concept is used. By considering the average values of grey relational coefficient corresponding to the input parameter level value, grey relational grade is calculated as shown in Table3. For calculating the weighted grey relational grade, weightages are given to individual grey relational coefficients. Weightages are provided equally to all the output responses.

Table 4 Response table of grey relational grade

Process Parameter	Level 1	Level 2	Level 3	Rank
Moisture Content	0.5526	0.5434	0.5495	5
Green Compressive Strength	0.5021	0.5829	0.5603	1
Permeability	0.5245	0.5744	0.5465	3
Mould Hardness	0.5373	0.5605	0.5475	4
Pouring Temperature	0.5026	0.56	0.5828	2

The optimum condition of input parameters chosen were determined by considering the average values of weighted grey relational grade, that corresponds to the level values of individual parameters as shown in Table 4. Observations made from response table reveals that the most critical parameter is Green Compressive Strength of the mold, which has a higher deviation of average grey relational grade. From response table, optimum conditions are moisture content of3.2, Green Compressive Strength of 1000 g/cm^2, Permeability of 132.5, Mould Hardness of 87.5 and pouring temperature of 1535 ° C represented as A1B2C2D2E3. Main effects plot is drawn for the weighted grey relational grade from the response table, as shown in Figure 1.

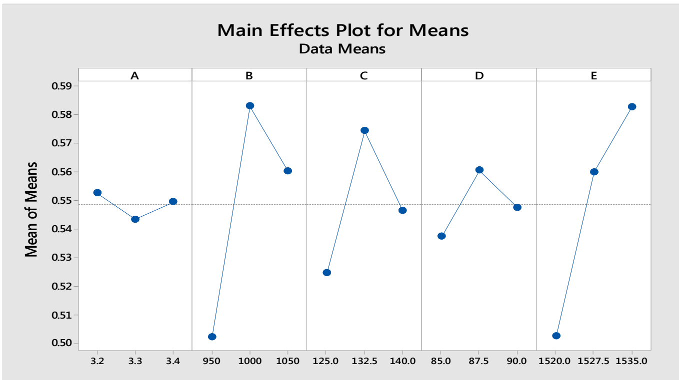

Figure 1 Main effects plot for grey relational grade

ANOVA is performed to find the most influential parameter that contributes towards the outputs and how the variation in inputs affects the outputs. Table 5 shows that the green compressive strength is the most influential factor due to its higher percentage contribution (15.65%) among the process parameters, which is followed by pouring temperature 15.39 %, permeability by 5.63% and mould hardness by 1.21%.

Table 5 Analysis of variance for grey relational grade

Source	DF	Adj SS	Adj MS	F-value	P-value	% contribution
A	2	0.0004	0.0002	0.03	0.975	0.19802
B	2	0.0313	0.01565	2.02	0.165	15.6504
C	2	0.01126	0.00563	0.73	0.498	5.63218
D	2	0.00244	0.00122	0.16	0.856	1.21865
E	2	0.0308	0.0154	1.99	0.169	15.3993
Error	16	0.12379	0.00774			
Total	26	0.19998				

CONCLUSION

This study proposes an approach integrating the Taguchi method and GRA to identify optimal combination of process parameters required to meet multiple quality objectives in Green sand casting process. The silent features of this present study are lesser experiments with less process time and less amount of time utilization by Taguchi based multi-response optimization. By applying Taguchi-GRA technique, the optimized condition obtained for casting process is Moisture Content of 3.2, Green Compressive Strength of 1000g/cm^2, Permeability of 132.5, and Mould Hardness of 87.5 and Pouring Temperature of 1535°C. ANOVA result shows that Green Compressive Strength is the most significant and influencing input parameter contributing towards the grey relational grade by 15.65%, then followed by Pouring Temperature, Mould Hardness, Permeability and Moisture Content. The study discloses that, the quality of the casting product can be improved in better way by optimizing its process parameters.

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