OPTIMIZATION OF MOULDING COMPOSITION FOR QUALITY IMPROVEMENT OF SAND CASTING

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Article History: Received 9 August 2017; Revised 15 October 2017; Accepted 13 December 2017

ABSTRACT: Sand casting is a versatile and commonly used manufacturing process in the metal casting industry. This method can be used in almost all types of metal and the sand is recyclable. However, the defects in casting production such as blowholes, pinholes, shrinkage, and porosity cause imperfection in green sand moulding. The aim of this project is to optimise the composition of silica sand, bentonite, water, and coal dust in green sand to reduce the defects in the casting products using the 2^4-factorial experiment design method, which can produce a total of 16 runs for experiment to investigate the ratio of the four parameters. Then the experiment results of compression strength are collected and the composition effect of green sand was investigated. The results shows value of the adjusted R-square indicated that 86.92% of the total variability was explained by the model and the model predicted and actual fitted well with the experiment data. An analysis using the Design Expert software identified that bentonite and water are the main interaction effects in all of the experiments. The optimal settings for green sand composition are 95g silica sand, 24g bentonite, 8g water, and 8g coal dust. This composition has an effect of compression strength 35kN/m^2.

KEYWORDS: *Sand Casting; Optimisation; Green Sand; Green Compression Strength*

1.0 INTRODUCTION

Sand casting is a versatile and commonly used manufacturing process in the metal casting industry. The essential compositions of sand casting process are silica sand, coal powder, and clay powder (bentonite), while water plays an important role in reducing and controlling the defects in castings [1-2]. However, silica sand is not suitable to be used singly for moulding purposes because it lacks of binding properties. Therefore, silica sand must be composed of bentonite and other constituents to achieve the binding property. Bentonite acts as a binder in green sand and gives cohesiveness and strength to the sand to maintain the shape of the mould cavity after the pattern is removed. By mixing both calcium and sodium bentonites, a favourable strength of green sand throughout all phases of casting process can be achieved and the mixture is kept to be compatible with other components of green sand [3]. Coal dust is one of the composition elements in this study. Coal dust is a key component in the green sand system to improve surface finish [4].

Over the recent years, a lot of studies have been conducted to identify the optimal values of moulding process to improve the quality of sand casting using various techniques. The optimal combination of the composition of sand casting factor setting is defined as the best model for each factor that optimises the process response. Saikaew and Wiengwiset [5] applied a mixture experimental design to determine the optimal composition of moulding sand for quality improvement of iron castings. These mixtures yielded the optimal green compression strength, optimal permeability, and permeability numbers. Kumar et al. [6] applied Taguchi methods to optimise the green sand casting process parameters of a foundry such as green strength, moisture content, permeability, and mould hardness. Other methods like Response Surface Methodology (RSM) approach can be used to determine the best process factor such as clay percentage, moisture percentage and mould hardness to optimise the production of grey cast pump impellent castings [7]. The central composite design of experimental methods can be applied to determine the effect of predominance factors like bentonite, water, curing time, and sand mixture on sand mould properties [8].

From this combination, each of them plays an important role respectively to reduce and control defects in castings, where defects may occur when any one of the components is out of the optimum value. Optimal settings can be determined as the best composition of the process parameters that produce the desired response, which the good quality of castings by using Design of Experiment.

The objective of this study is to optimise the composition of the green sand parameters to improve the quality of sand casting. This paper will focus on the compression strength of sand casting mould using 2^k factorial design. Based on the experiment, all the parameters involved are considered important and there is no external factor included in these experiments. Hence, 2^k factorial design is the most appropriate method when dealing with the internal factors only.

2.0 EXPERIMENTAL

There are four parameters involved in green sand casting, which are bentonite, coal dust, silica sand, and water. All the compositions of four parameters will be mixed together as tabulated in Table 1. Each parameter consists of two levels, which are low and high levels. The notation of "+" and "−" are used to indicate the high and low levels, respectively.

Table 1: Parameter and their levels for green sand composition

Parameter	Parameter	Parameter
Silica sand (A)	95	100
Bentonite (B)	21	24
Water (C)	6.5	8
Coal dust (D)	6	8

2^k Factorial design in Design of Experiment (DOE) will be used to find the optimising parameter combination to improve the quality of sand casting. In this experiment, 2^4 factorial designs were selected because there are four parameters involved. A factorial design is a strong candidate in evaluating the significant process parameters; hence it can be used to develop the casting process by evaluating the combined independent factors [9]. Thus, there are 16 runs all together that will be conducted in this study as tabulated in Table 2.

Table 2: Design layout and experiment results

Run	Factors				Results
	Silica sand	Bentonite	Water	Coal dust	Green Compression Strength (kN/m^2)
1	95	21	6.5	6	32
2	100	21	6.5	6	26
3	95	24	6.5	6	26
4	100	24	6.5	6	27
5	95	21	8	6	26
6	100	21	8	6	28
7	95	24	8	6	35
8	100	24	8	6	26
9	95	21	6.5	8	34
10	100	21	6.5	8	31
11	95	24	6.5	8	29
12	100	24	6.5	8	31
13	95	21	8	8	32
14	100	21	8	8	32
15	95	24	8	8	35
16	100	24	8	8	33

In this project, the weight of sand composition was predetermined to vary around 128.5g to 140g and the composition was placed in a specimen tube. The rammed sand specimens needed to achieve the height of 50mm ± 0.125mm to ensure that the specimens were broken and failure was within the strength range of the universal testing machine [9]. All 16 run sand casting mould specimens will be tested their compression strength.

Compression strength is a test to determine the cohesiveness or natural binding capacity of the sand grains under a compressive load. The test took only a few minutes. It was performed on the sand specimens by using the Universal Sand Strength Machine (USSM). The sand specimen was tested immediately once it was taken out from the sand specimen tube to prevent it from drying. A dried specimen will cause a decrease in the strength of the sample, which will lead to inaccuracy. The compressive load was applied until the specimens failed. Figure 1 shows the outline of the methodology carried out in this project.

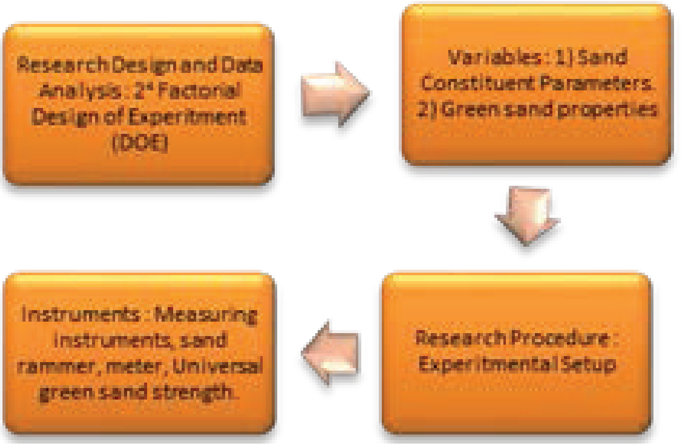

Figure 1: Block diagram of outline of the methodology

3.0 RESULTS AND DISCUSSION

3.1 Analysis of data

The results collected from the green compression strength were then analysed by using the Design Expert software. The results were summarised in the analysis of variance (ANOVA) table for further interpretation, in which a confidence level of 90% was used in all analyses of data; α=0.1.

Table 3: ANOVA for green compression strength

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob> F)	
Model	153.38	6	25.56	17.61	0.0002	significant
A-silica sand	14.06	1	14.06	9.69	0.0125	
C-water	7.56	1	7.56	5.21	0.0484	
D-coal dust	60.06	1	60.06	41.38	0.0001	
AD	5.06	1	5.06	3.49	0.0947	
BC	27.56	1	27.56	18.99	0.0018	
ABC	39.06	1	39.06	26.91	0.0006	
Residual	13.06	9	1.45			
Cor Total	166.44	15				
Std. Dev.	1.20		R-Squared		0.9215	
Mean	30.19		Adj R-Squared		0.8692	
C.V. %	3.99		Pred R-Squared		0.7520	
PRESS	41.28		Adeq Precision		12.863	

ANOVA for the response compression strength quadratic model is tabulated in Table 3. It was noted that all the parameters involved were less than 0.1 in p-value, meaning that all parameters were statistically significant at 90% confidence level, where the p-value of regression model was considered. However, if the p-values were less than 0.1, they indicated that the model terms were not significant. Hence, it can be understood that most of the parameters contributed in controlling the defects of casting. The value of the adjusted R-square indicated that 86.92% of the total variability was explained by the model. Hence, the second order polynomial model equation can be used to find an approximation for the functional relationship between the composition parameters and

Compression Strength =

$$30.19 - 0.94A + 0.69C + 1.94D + 0.6AD + 1.31BC + 1.56ABC. \quad (1)$$

The normal probability of residuals and the residuals versus predicted plots were the methods to validate the model. These methods were used to predict and verify the response using the optimum values of the composition parameters involved in the experiment. Figure 2 shows that the point almost fell in a straight line, meaning that the errors were normally distributed. As shown in Figure 3, there was no obvious pattern and it can be considered that the structure affecting variance was stable.

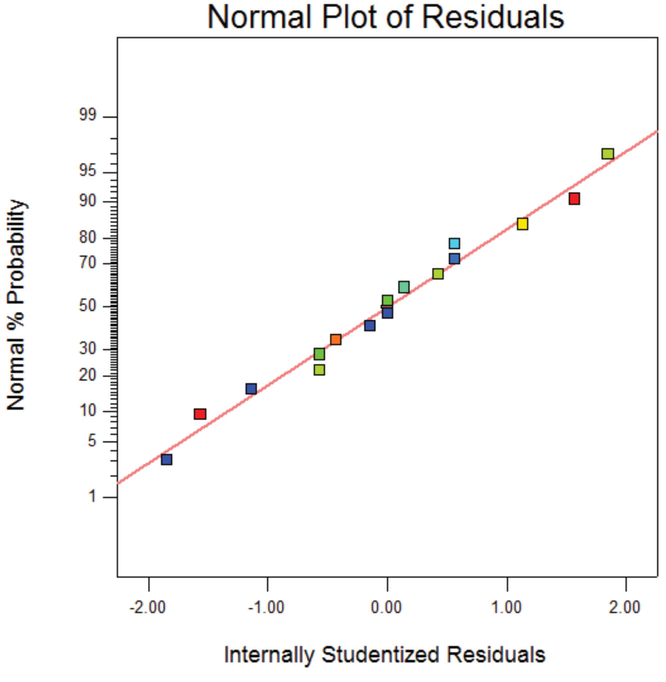

Figure 2: Normal of residuals plot

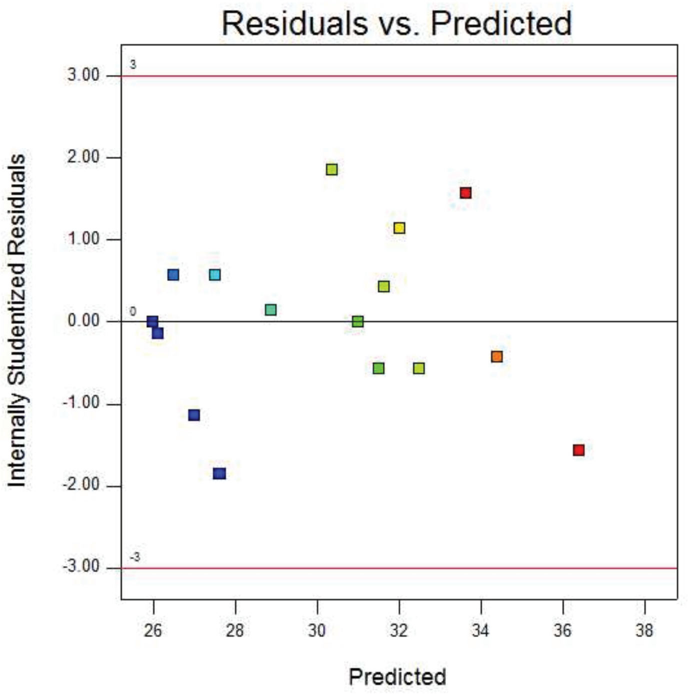

Figure 3: Residuals versus predicted plot

The coal dust acts as the key factor to affect the green compression strength of green sand. However, to improve the moisture absorption of the strength of coal dust, it was found to exhibit a better compaction with higher green compressive strength [11]. The coal dust causes an increase in total fines and moisture system of the sands. Finer sand grain presents a better compaction of the sand system and hence, creates higher compression strength. As well as the moisture system of the sands, the higher the moisture content in the sand, the stronger the sand holds together. Therefore, there is no denying that the coal dust as inherent moisture plays an important role in the compression strength of green sand [10]. As shown in Figure 4, the interaction factor affects bentonite and water. The bentonite effect is small when water is at the high level and a larger effect when the water is at a low level. The best result was obtained at the high level of water and bentonite. The interaction between bentonite and water demonstrates their role in holding the sand grain and hence increases the adhesive system in the green sand as well as the compression strength.

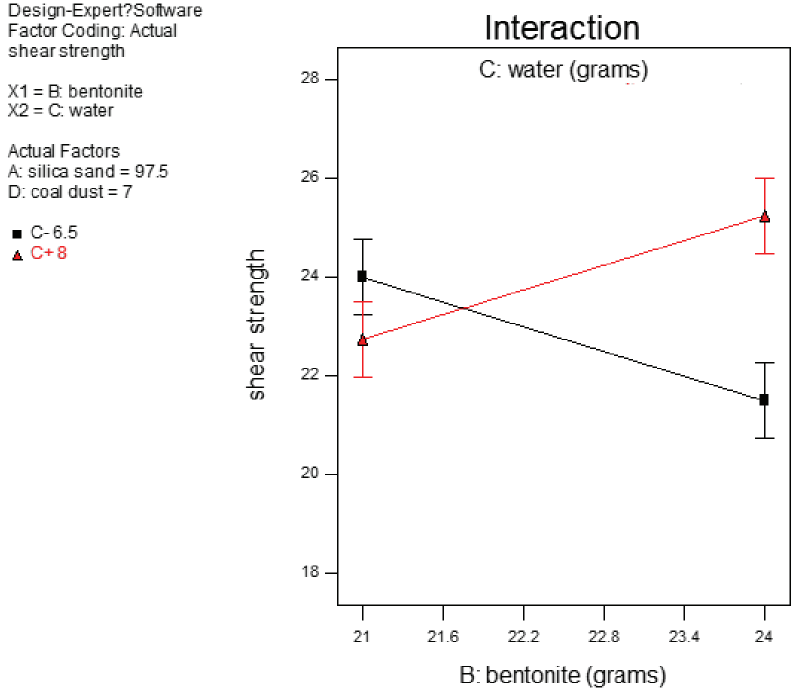

Figure 4: Interaction factor effect plot

4.0 CONCLUSION

Generally, the analyses evaluated the main factors affecting the compression and shear strength tests of the experiment in order to identify the optimal setting parameters for all factors.

The following conclusions were drawn based on the green sand characteristic study, which was compression strength:

i. ANOVA analysis identified that green compression and shear strengths were both affected by coal dust and two interactions between bentonite and water.

ii. The optimum conditions were obtained from the numerical optimisation of the Design Expert software. The suggested optimal settings are as follows:
   - Silica sand: 95g (low level)
   - Bentonite: 24g (high level)
   - Water: 8g (high level)
   - Coal dust: 8g (high level)

In conclusion, the objective of the study was achieved. The compression strength was maintained at a range of 30-100 kN/m2. The optimum parameter for every factor was obtained through the study. By using the optimal setting parameter, it is believed that the green sand composition can produce a sound casting.

ACKNOWLEDGMENTS

The author would like to acknowledge the financial support from Universiti Teknikal Malaysia Melaka under the grant number PJP/2015/FTK(18C)/S01436 and also express gratitude and appreciation to the group members who supported from the beginning until the completion of this paper.

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