IMPROVING QUALITY OF SAND CASTING USING TAGUCHI METHOD AND ANN ANALYSIS

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Abstract

The Taguchi method is a powerful problem solving technique for improving process performance, yield and productivity. Green sand casting process involves many process parameters which affect the quality of the castings produced. An analysis of significant process parameters of green sand casting process is made in this paper. The parameters considered are Green strength, moisture content, permeability and mould hardness. Using Taguchi analysis the effect of various process parameters at different levels on casting quality is analyzed and optimal settings of the various parameters have been accomplished. The outcome of this paper is the optimized process parameters of the green sand casting process which leads to improved process performance, reduced process variability and thus minimum casting defects. Also a neural network model is developed to map the complex non-linear relationship between process conditions and quality characteristic, namely casting defects.

Keywords: Green sand casting, Casting defects ,Taguchi method ,Statistical process control. Artificial neural network

I. INTRODUCTION

A. Taguchi Method

The quality engineering method that Taguchi proposed is commonly known as Taguchi method. This is form of DOE with special application principles. The work of practioner is made simple by providing a clear understanding of the variation nature and economic consequences of quality engineering in the world of manufacturing. The philosophy of Taguchi is broadly applicable and has three stages in process development [1].

1. System Design

2. Parameter Design

3. Tolerance Design.

Taguchi recommends that statistical experimental design methods can be employed to assist in quality improvements particularly during parameter and tolerance design. DOE and Taguchi methods have wide applications in analyzing manufacturing and production processes. Green sand casting is one of the most widely used processes to produce parts that cannot be produced by other manufacturing processes. The parameters/ variables that affect the process are many and these directly affect the quality of the finished casting [2,3].

This paper summarizes the following:

I. Improving quality of green sand castings through process control, keeping the effects of uncontrolled parameters at a minimum level

ii. Analyze and select the most significant parameters that affect quality characteristics.

iii. Select an appropriate OA (orthogonal array) and suitable levels of parameters. Collect the related experimental data.

iv. Analyze the data using DOE software and generate ANOVA table, interaction graphs and response graphs.

v. Decide on the optimal settings for the control parameters

vi. Validate the optimum setting levels in reducing the level of the Quality Characteristic (casting defects)

B. Artificial Neural Network

ANN s are widely accepted as a technology offering an alternative way to simulate complex and ill-defined problems. They have been used in diverse applications in control, robotics, pattern recognition, forecasting, power systems, manufacturing, optimization, signal processing, etc., and they are particularly useful in system modeling. A neural network is a computational structure, consisting of a number of highly interconnected processing units called neurons. The neurons sum weighted inputs and then applies a linear or non-linear function to the resulting sum to determine the output and the neurons are arranged in layers and are combined through excessive connectivity [4].

C. Process Parameters of Green sand casting

The following process parameters are identified as significant and their levels are listed in table 1: (Based on the industry practice for Ferrous green sand casting)

Table 1. Factors and Levels

Process parameter/Factor	Designation	High level	Low level
Moisture content (%)	A	4.0	2.0
Green strength(g/cm²)	B	1200	700
Mould hardness	C	100	60

The permeability is another factor which contributes for casting defects in greens and casting. However as reveled by the earlier studies [5], this factor doesnot affect the process significantly and so not considered in this study.

II. EXPERIMENTAL PLANNING

A. Taguchi

The first step in Taguchi method is to select an appropriate OA (orthogonal array). The choice of a suitable OA design is critical for the success of the experimental design and this depends on the total degrees of freedom required to study the main and interaction effects, resource availability and time constraints[6]. Amongst the standard OAs, L_4, L_8, L_{16} L_{16}, L_{32} etc., L_8 was found most appropriate to study 3 factors at two levels as this OA covers both main effects of factors, two factors interaction and three factors interaction as well.The OA selected, process parameters and interactions assigned are given in table2.

Table 2. L_8 ARRAY

Exp./trial No..	A	B	AXB	C	AXC	BXC	AxBXC
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

B. ANN

The neuron number of the input layer of ANN is determined by the number of variables selected, and the neuron number of the output layer is determined by the number of the objective indexes. In this paper, a three-layer ANN model with one hidden layer was used, where the neuron number of the hidden layer was determined by trials. The transfer function between the input layer and the hidden layer is 'Tansig', while the transfer function between the hidden layer and the output layer is 'Purelin'.

III. TAGUCHI OPTIMISATION

A. Experimental procedure

The experiments are conducted against the trial conditions tabulated in table 2, with three replicates. The defects resulting from molding process only are identified, and the percentage defects (as a ratio to total number of defects)was calculated and recorded in table 3.The quality characteristic is Casting defects and so "Lower is better" analysis is performed. In addition, to produce statistically more reproducible conditions for multiple run experiments S/N ratio analysis was preferred over standard analysis using average values.

Table 3. Experimental trial results and S/N ratios (Trial no. and % defects)

Trial no	%Defects Replicate 1	%Defects Replicate 2	%Defects Replicate 3	S/N ratio
Trial no 1	4.66	6.87	6.12	-15.497
2	3.89	3.54	4.78	-12.263
3	7.37	7.23	8.69	-17.873
4	7.11	6.78	6.67	-16.722
5	3.87	4.89	5.76	-13.807
6	3.23	4.78	4.67	-12.642
7	6.89	6.56	5.78	-16.162
8	3.61	4.64	4.28	-12.369

Average: Trials: 5.512 ,   Std. Deviation: 1.847 ,   Average S/N : 14.454

B. Analysis of results

Standard software packages are used to analyze and interpret results. Average effects of factors and interactions are tabulated in Figure 1.

Column # / Factors	Level 1	Level 2	L2 - L1
1 Moisture content	-15.579	-13.762	1.817
2 Green compression	-13.552	-15.789	-2.238
3 INTER COLS 1 x 2	-14.09	-15.25	-1.161
4 Mold hardness	-15.824	-13.516	2.307
5 INTER COLS 1 x 4	-14.603	-14.738	-.135
6 INTER COLS 1 x 7	-14.617	-14.724	-.107
7 INTER COLS 1 x 6	-15.255	-14.086	1.169

Fig. 1. Average effects of factors and interactions (S/N Ratio)

The plots for main effects and interactions are shown in Figure 2. Figure 3 shows the interaction severity graph.
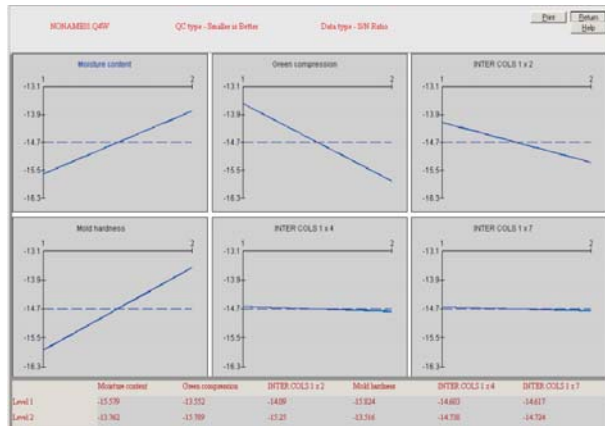
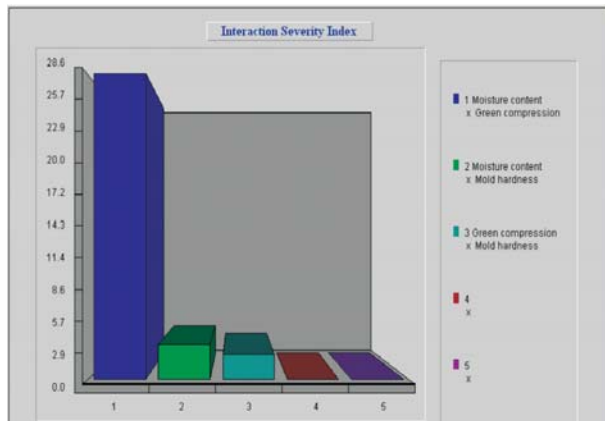

Fig. 2. Multiple graphs of main effects.

Fig. 3. Interaction severity graph.

The ANOVA table after pooling until the DOF of the error term is approximately half the total DOF of the experiment is shown in Figure 4 along with PIE chart in Figure 5.

Fig. 4. ANOVA table (S/N Ratio)
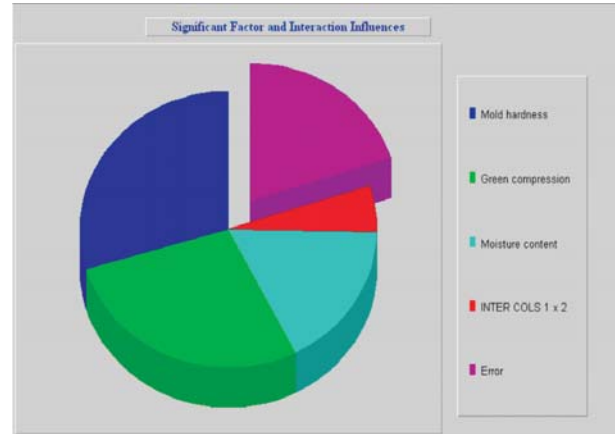
Fig. 5. ANOVA table's PIE chart

The optimal conditions and performance factors were shown in Figure 6. The optimal conditions of the control factors are as under:

Moisture content: 2.0%, Green strength: 1200g/cm^2, Mould hardness : 60 The variation reduction plot is shown in Figure 7.

The expected value of QC is found to be 3.1434 at low level and 3.936 at high level.

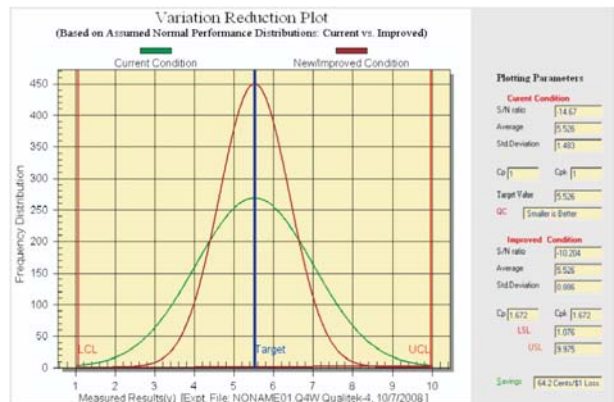Fig. 6. Optimal conditions and performance factors (S/N Ratio)
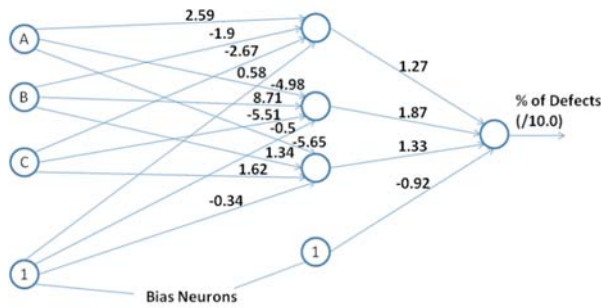

Fig. 7. Variation reduction plot

Fig. 8. ANN model for sand casting defects

IV. ANN ANALYSIS

The complex relationships between casting quality and process parameters could not be expressed by any analytic model. Traditional modeling methods are mostly relied on assumptions for model simplifications, and thus may lead to inaccurate results. On the other hand, the characteristic of the ANN technique make it suitable for modeling the quality prediction of cast parts, and therefore is utilized.

A. Model Development:

There is a complex relationship between the percentage of casting defects and the corresponding process parameters viz. moisture content, green strength, and mould hardness. In order to capture this relationship, it was decided (and experimentally verified) to build an artificial neural network with one hidden layer. Two bias neurons were also required to successfully predict the percentage of casting defects within a low margin of error. One bias neuron was added to the input layer, while the other bias neuron was added to the hidden layer.

In addition to the bias neurons, the model also has three additional hidden neurons that receive all the input values. The outputs from the neural network are scaled down by a factor of 10 just to normalize the results. The ANN model was prototyped using the open source Fast Artificial Neural Networks (FANN) library.

B. Model Analysis:

The predictions from our ANN model are shown in Figure 9. As seen in the figure, the targeted outputs are in close conformity with the predicted values. The general trend with varying process parameters is successfully predicted by our ANN model.
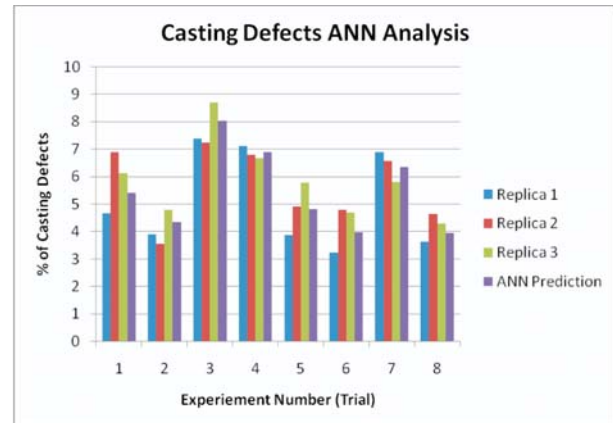

Fig. 9. ANN analysis

V. CONCLUSION

The following are the conclusions

I) All The control factors and interaction between compression strength and moisture content have significant effect on the QC, percentage defects, as evidenced by the percentage contribution and interaction graphs.

ii) The optimum levels of control factors are found as under:

Moisture content   : 2.0 %

Green strength   : 1200 g/cm^2

Mould hardness   : 60

iii) The predicted range of optimum defect level is between 3.134 and 3.936, reflecting higher yield level using this optimization.

iv) The optimum level of control factors as above are the levels at which the effect of noise factors on the response parameters is less.

v) The ANN technique has been shown as an effective method to model the complex relationship between the control factors and the quality index, casting defects. This model can predict the possible defects at various levels of factors reliably, which the Taguchi method cannot.

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