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PARAMETRIC OPTIMIZATION OF THE SAND CASTING PROCESS BY TAGUCHI AND ANOVA METHOD: A CASE STUDY

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Abstract

In this study, the effect of sand casting process parameters such as pouring temperature, permeability, sand particle size, mould hardness and moisture on the Axel End Cover (AEC), a product of "Nandratan Foundry & Engineering Works", was investigated to reduce casting defects. The experimental study was conducted on the AEC as per the L_{27} orthogonal array of the Taguchi method to determine optimal casting parameters. We performed the Analysis of Variance (ANOVA) to determine the significant effect of the response and the percentage contribution of individual parameters over the response. A confirmation test was carried out to validate the test results. The results revealed that an average (3-months) 4.31 % reduction in the rejection of the AEC with suggested optimum process parameters.

Keywords: Sand casting, Taguchi method, ANOVA.

1. INTRODUCTION

The "Nandratan Foundry & Engineering Works Pvt. Ltd." is a leading organization situated at Sarigam, Valsad. The organization manufactured an Axle End Cover, rear cover etc., through the sand casting process for the Indian railway. Sand casting processes are an important casting process, and the chances of getting the defects are also higher. In the decades of 90' [6,9] provides the information and quality control for casting process about the "DOE" in the foundry, especially off-line. The various process design methods used for experiments and analysis such as "DOE techniques such as Taguchi approach, response surface methodology (RSM), integrated approach of Taguchi and RSM, FEA (Finite Element Analysis), casting simulation techniques such as Auto CASTX, Artificial Neural Network (ANN) etc. [6,9]."

As per the literature review of last decade, various parameters are used to optimize sand casting for various reasons. Based on that, the researcher highlighted some of the research papers in Table 1 regarding materials, parameters, and impact. Table 1 indicated that the researchers [2,11,12,15] used aluminum alloys to test the effect on hardness or tensile strength by using different parameters and ranges. Sunil [15] reviewed various research papers on the sand casting process for the quality improvement in foundry and the optimization of casting process, Yazad [5] reviewed the researcher's papers from the year 1994 to 2014 and shortened the importance of process parameters and optimization. The Shraban [3] and Priyank [16] investigated the sand casting process through the Taguchi [13] and ANN using MATLAB software. They proposed the ANN model for the optimization of sand casting processes. Manojkumar [1] has done parametric optimization of the Furan No-Bake casting process through Grey Relational Analysis in "Krislur Castomech Pvt. Ltd., Bhavnagar," and he found that sand inclusion is the major defect in the industry. Based on the literature, a novel combination of controlled parameters for the case study is selected.

Table 1. Literature review

Author	Material	Parameters										Impact/ Conclusion
		Moisture contents	Clay contents	Grain fitness number	Green compression strength	Mould hardness	Mould temperature	Mould pressure	permeability	Pouring temperature	Pouring time	
[10]	Grey Cast Iron	✓	✓	✓								Increased tensile strength.
[4]	Ductile Iron				✓	✓			✓			Reduce rejection.
[14, 15]	Aluminum alloy						✓			✓		Impcat on hardness and energy.
[8]	Cast Iron alloy		✓		✓					✓		Reduce defects.
[17]	Aluminum	✓			✓	✓			✓			Reduce rejection.
[11]	Aluminum alloy	✓	✓		✓							Increased tensile strength.
[12]	LM25 alloy									✓	✓	Reduce defects.
[7]	Spheroidal graphite	✓		✓	✓	✓						Reduce defects.
[21]	Cast Iron+	✓			✓	✓			✓			Enhanced the quality & productivity.
[19]	Cast Iron				✓			✓	✓	✓		Reduce defects.
[22]	46 $MnSi_4$ alloy steel									✓	✓	Pouring temp. is the major factors which influenced the quality of product.
[18]	Grey Cast Iron									✓	✓	Reduce cold shut defects.
[2]	Aluminum alloy	✓	✓	✓								Predict the hardness value of the developed model.

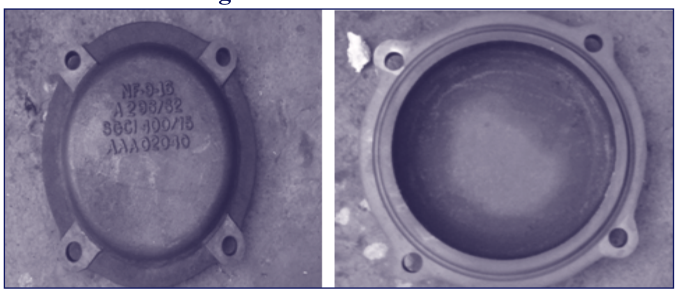
2. EXPERIMENTAL WORK

2.1 Product Material and basic details

Due to the requirement of the Indian railway, the material was fixed for AEC. In this study, the material used as per the drawing provided by the Indian railway. The details of the product given below:

Product name: Axel End Cover
Material: Aluminium alloy (LM-6)
Process: The sand casting process
Weight of casting: 4 Kgs.

Figure 1. Axel End Cover



2.2 Problem identification

The organization has faced AEC's rejection in the sand casting process (approx. 5.39 percentage) every month. To increase the quality as well as productivity of the AEC, we did the brainstorming process with the manager and COE of the organization and based on the literature survey; we decided to work on the process parameters of the sand casting process. After a detailed analysis of existing data of three months, it has been found that there are mainly three defects that occurs in the manufacturing of the AEC, which are blow holes (around 43 percentage), shrinkage (around 17 percentage), inclusion (around 17 percentage) and others. After an effective discussion and analysis, we decided to do the parametric optimization and find the optimum value of the process for further experiment and analysis.

2.3 Taguchi experiments design and analysis

2.3.1 Selection of process parameters and levels

Based on the literature and the organization's opinions, we have taken five process parameters such as pouring temperature, permeability, sand particle size, mould hardness and moisture in this experiments. The range of the parameters have been taken from the organization, and three levels are selected to design orthogonal array (L27) by Taguchi method with the help of MINITAB software.

Table 2. Selection of process parameters and levels

Parameter	Range	Level A	Level B	Level C
Pouring temperature (°C)	1300-1350	1300	1320	1350
Permeability	170-200	170	185	200
Sand particle size (Afs)	60-65	60	62	64
Mould hardness (Nu)	85-95	85	90	95
Moisture	4-6	4	5	6

2.3.2 Design of orthogonal arrays

We designed an orthogonal array (L27) by Taguchi method for 5-factors and 3-levels with the help of MINITAB software mentioned in Table 3.

2.3.3 Analysis of experimental results

We have taken the casting density as the response factor because the higher the density, lower the internal defects. The density of casting (see the results in Table 3) by using the following equation:

$\rho_c = (W_1 / (W_1 - W_2)) * \rho_w$

Where, ρ_c= Density of casting (gm/cm^3);

W_1= Weight of casting in thAir (grams);
W_2= Weight of casting in water (grams);
ρ_w= Density of water, 1 (gm/cm^3)

A precision balancing machine measures the weight of the casting in air and water. The S/N ratio for each level of process parameter has been computed (see Table 3) by using a quality characteristics larger-the-better because if the casting density is higher than the internal defects of the casting are lower.

$S/N = -10 * \log(\Sigma(1/Y^2)/n)$; larger is better

Where, Y= Measured value of quality characteristics;
n= Repetition of experiments

The results obtained by the calculation for all the trials are given in Table 3.

Table 3. SNR of trial experiments

Trial No.	A	B	C	D	E	W_1	W_2	Density of casting	SNR	MEAN
	Pouring temp. (°C)	Permeability	Sand Particle Size (Afs)	Mould hardness (Nu)	% Moisture					
1	1300	170	60	85	4	4000.22	3950.8	80.94	38.16362	80.94334
2	1300	170	60	85	5	4000.28	3950.6	80.52	38.11818	80.52093
3	1300	170	60	85	6	4000.33	3949.98	79.45	38.00193	79.45045
4	1300	185	62	90	4	4000.18	3955.08	88.70	38.95806	88.69579
5	1300	185	62	90	5	4000.19	3953.22	85.16	38.6052	85.16479

6	1300	185	62	90	6	4000.22	3954.68	87.84	38.87382	87.8397
7	1300	200	64	95	4	4000.24	3953.66	85.88	38.67773	85.87892
8	1300	200	64	95	5	4000.31	3953.98	86.34	38.72463	86.34384
9	1300	200	64	95	6	4000.33	3955.09	88.42	38.93146	88.42462
10	1320	170	62	95	4	4000.12	3960.03	99.78	39.98074	99.7785
11	1320	170	62	95	5	4000.16	3960.34	100.46	40.03952	100.4561
12	1320	170	62	95	6	4000.21	3960.52	100.79	40.06803	100.7863
13	1320	185	64	85	4	4000.26	3962.12	104.88	40.41415	104.8836
14	1320	185	64	85	5	4000.28	3962.48	105.83	40.49197	105.8275
15	1320	185	64	85	6	4000.32	3962.54	105.88	40.49666	105.8846
16	1320	200	60	90	4	4000.31	3952.65	83.93	38.47879	83.93433
17	1320	200	60	90	5	4000.35	3952.78	84.09	38.4953	84.09397
18	1320	200	60	90	6	4000.36	3952.85	84.20	38.50628	84.20038
19	1350	170	64	90	4	4000.36	3958.25	95.00	39.55428	94.99786
20	1350	170	64	90	5	4000.36	3958.51	95.59	39.60807	95.58805
21	1350	170	64	90	6	4000.37	3958.54	95.63	39.61225	95.63399
22	1350	185	60	95	4	4000.22	3950.92	81.14	38.18474	81.14037
23	1350	185	60	95	5	4000.25	3950.96	81.16	38.18657	81.15744
24	1350	185	60	95	6	4000.28	3950.99	81.16	38.18663	81.15804
25	1350	200	62	85	4	4000.22	3952.34	83.55	38.43859	83.54678
26	1350	200	62	85	5	4000.25	3952.39	83.58	38.44229	83.58232
27	1350	200	62	85	6	4000.28	3952.42	83.58	38.44235	83.58295

Figure 2. Main effect plot for SNR

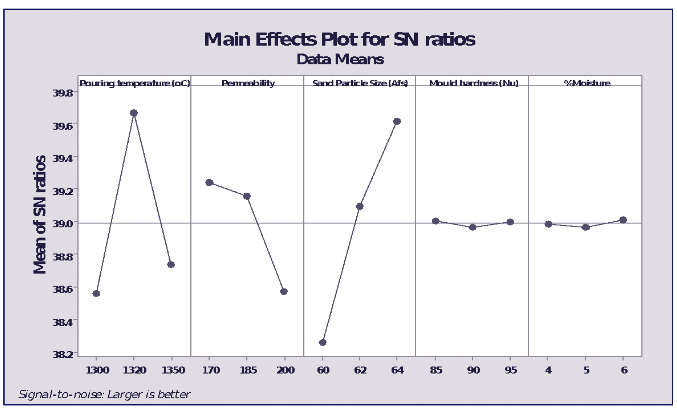


Table 4. Response Table for Signal to Noise Ratios

LEVEL	A	B	C	D	E
1	38.56	39.24	38.26	39	38.98
2	39.66	39.16	39.09	38.97	38.97
3	38.74	38.57	39.61	39	39.01
Delta	1.1	0.67	1.35	0.04	0.05
Rank	2	3	1	5	4

2.3.4 Optimum value for each factor

In this study, the researcher considered that it is better to have higher the S/N ratio to reduce the defects. The optimum value for each factor for the manufacturing of AEC by the casting is found.

Table 5. Optimum value for each factor

FACTOR	SNR	LEVEL	OPTIMUM VALUE
Pouring temp.	39.7	B	1320
Permeability	39.24	A	170
Sand Particle Size	39.6	C	64
Mould hardness	39.02	A	85
% Moisture	39.02	C	6

2.4 ANOVA analysis

We further performed Analysis of Variance (ANOVA) to find the F-Value and P-Value to know the significant effect of each factor and to find the percentage contribution of each factor from the fined factors. We considered 95% as a confidence level considering alpha as 0.05. The values obtained after the analysis is, as mentioned below in the Table 6 for F-values, p values and the percentage contribution of each defined factor.

Table 6. Results of ANOVA

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
A	2	727.99	363.997	484.51	0.000	37.65277
B	2	281.22	140.611	187.17	0.000	14.54513
C	2	907.44	453.719	603.94	0.000	46.93421
D	2	3.69	1.843	2.45	0.118	0.190853
E	2	1.07	0.537	0.71	0.504	0.055342
Error	16	12.02	0.751			
Total	26	1933.43				

3. RESULTS AND DISCUSSION

The results of the parametric optimization by Taguchi are mentioned in Figure 2. The response Table 4 indicated the SNR, which shows that the process parameters' rank starts from sand particle size, pouring temperature, permeability, moisture and mould hardness respectively. ANOVA results (Table 6) show that sand particle size contributes most by 46.93%, and this is followed by pouring temperature 37.65%, permeability 14.54%, mould hardness 0.19% and moisture 0.55%. This proves that sand particle size and pouring temperature and permeability are the most significant parameters towards that sand casting defects. The other two parameters are the low effects less than one percentage towards the sand casting defects. By considering the optimum value of the process parameters (Table 5), we worked with the optimum parameters for the next three months. We found that the rejection of the AEC reduced from 5.39 to 1.08 percentage per month (approx. 35/650 rejection). It means that 4.31 percentage improved the rejection ratio due to casting defects by using optimized process parameters values.

4. CONCLUSION

This study finds the optimum process parameters for sand casting of aluminum alloys through the Taguchi and ANOVA methods. We also see the contribution of the parameters most by sand particle size 46.93%, and this followed by pouring temperature 37.65%, permeability 14.54%, mould hardness 0.19% and moisture 0.55%. These will help increase the quality of the products and decrease the rejection of the product. The results reveal that for the 'AEC', sand casting of aluminum alloys materials is the best combination of the process parameters in terms of casting defects: pouring temperature 1320^{o} C, permeability 170, sand particle size 64 (Afs), mould hardness 85 (Nu) and moisture 6. This study concludes that the key factors are helping casting industries to improve the quality of the product and academicians or researchers to get the new directions for the research work.

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