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Effect of Composition of Sand Mold on Mechanical Properties and Density of Al-Alloy Casting Using Taguchi Design Approach

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ABSTRACT
Sand casting process involves many parameters such as size of the sand grain, amount of clay, percentage of moisture, green compressive strength, permeability, number of ramming, shatter index, mold type, mold hardness, etc. to name a few. In this paper the effect of sand mold casting process parameters, especially composition of molding sand, on hardness, tensile strength and density of aluminium alloy castings are studied. While other parameters are kept constant, grain fineness number, amount of clay, amount of moisture and number of ramming are varied. Experiments are conducted based on Taguchi's L9 orthogonal array and cast specimens are tested to obtain their mechanical properties and density. The results obtained are evaluated to optimize process parameters at three different levels. . Optimum levels are found as Grain fineness number 55, two times ramming, 12 percent Clay and 13 percent Moisture. Based on optimum level of process parameters, confirmation test is conducted and results are found to be in confidence level.
Keywords - Al-alloys, Casting parameters, Mechanical properties, Mold composition, and Taguchi method.

I. INTRODUCTION

Casting is a process of obtaining metallic products by allowing molten metal to get filled and solidify in a mold. The quality of the product is determined by the quality of the mold. In this competitive environment, it is very much important to maintain the quality of products and produce them right first time and every time. If the casting process is not being managed properly, the problems may aggravate and result in defects which render the products weak and of low quality, thus making them unfit for use [1]. In spite of science getting to a new level every passing minute, there are defects, flaws or imperfections which still remain and are very difficult to eliminate from castings. Hence to overcome the problems in the casting, optimization of the process parameters should be done. Optimization is required right from the stage of selecting the sand to removal of casting from the sand mold.

Genichi Taguchi has introduced several statistical tools and concepts for quality improvement. According to him, the key element for achieving high quality and low cost product is parameter design. Through parameter design optimal levels of process parameters (or control factors) are selected such that the influence of uncontrollable (or noise) factors causes minimum variation of system performance or response. These parameters should be controlled to improve the quality of both casting process and product [2].

In this study, aluminium alloy castings of same shape and size produced by sand casting process at selected sand grain fineness number, amount of clay, amount of moisture and number of ramming. The castings produced are tested for mechanical properties and density. The aim of study is to determine the optimum levels at which these parameters produce quality castings.

II. METHODOLOGY

Objective of present study is to make out most influencing process parameters of aluminum alloy sand mold casting and to optimize them for improved mechanical properties and density to produce quality castings. Taguchi DoE methodology is applied in this study to assess the influence of process parameters on quality of castings. Selection of orthogonal array depends on number of parameters and their levels, here number of parameters is 'four' and number of levels is 'three' as given in Table 1.

Table 1: Parameters and their levels

Parameters	CODE	LEVELS		
		1	2	3
Grain Fineness No.	A	40	55	70
% of Clay	B	6	9	12
% of Moisture	C	7	10	13
No. of Ramming	D	2	3	4

Under full factorial method, number of experiments required was 3^4 = 81, using L9 (3^4) Taguchi orthogonal array (Table 2), the number of experiments are reduced to 'nine'. These nine experiments were conducted as shown in the Table 3.

Table 2: L9 Standard Orthogonal Array

Expt. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3: Experiment design table

Expt. No.	Grain Fineness No.	% of Clay	% of Moisture	No. of Ramming
	A	B	C	D
1	40	6	7	2
2	40	9	10	3
3	40	12	13	4
4	55	6	10	4
5	55	9	13	2
6	55	12	7	3
7	70	6	13	3
8	70	9	7	4
9	70	12	10	2

III. EXPERIMENTATION

3.1 Preparing Pattern

Wooden pattern of solid square section with sides of 30mm x 30mm and length of 160mm is prepared to make a sand mold to produce castings by pouring molten metal. The produced castings are used for the purpose of testing hardness, tensile strength and density.

3.2 Preparing Sand Molds

As per the experiment design table, nine dry sand molds are prepared at varying levels of grain fineness of silica sand at 40, 55 and 70, amount of clay at 6%, 9% and 12% by weight, amount of moisture at 7%, 10% and 13% by weight and number of ramming at 2, 3 and 4. All nine molds prepared are shown in the Fig. 1

Figure 1: Dry sand molds prepared for pouring

3.3 Preparing Test Castings

3.3.1 Material Composition

Material used for producing test casings is LM25 aluminium alloy. The chemical composition of the alloy is given in the Table 4.

Table 4: Chemical composition of LM25 Al-alloy

Elements	% Composition	Elements	% Composition
Al	92.1	Zn	0.05
Si	6.29	Ti	0.03
Fe	0.70	Pb	0.02
Mg	0.34	Cr	0.01
Mn	0.33	Ni	0.01
Cu	0.05		

3.3.2 Melting of metal

The furnace used for melting of aluminum alloy is lift out crucible type coke fired pit furnace as shown in the Fig. 2.

Figure 2: Coke fired pit furnace

3.3.3 Degassing process

Degassing is done to flush out the gases absorbed in the molten metal during melting. Hydrogen gas absorption in molten metal is shown in equation 1. The liberated hydrogen gas occupies interstitial spaces of metal which may lead to formation of porosity if not removed.

$$2Al + 3H_2O \rightarrow Al_2O_3 + 6H \uparrow \quad \text{-------- (i)}$$

Tablets of hexachloroethane (C_2Cl_6) are added to molten aluminium for degassing purpose. Chemical reaction that liberates stable chlorine gas is shown in the equation 2, which flushes hydrogen gas by creating partial pressure in molten aluminium[3].

$$C_2Cl_6 \rightarrow 2C + 3Cl_2 \uparrow \quad \text{-------- (ii)}$$

3.3.4 Fluxing process

For the protection of molten metal from getting oxidized, coveral-36 powder is used as flux which is spread on the top of the molten charge as shown in Fig. 3.

Figure 3: Adding flux to molten metal

3.3.5 Temperature Measurement

Digital temperature indicators connected to k-type thermocouples are used for measuring temperature of molten metal for pouring the casings.

3.3.6 Pouring of molds

All nine molds prepared are poured (as shown in Fig. 4) to produce test casting (as shown in Fig. 5). Fettling process is done to take out castings after solidification and cooling of molds.

Figure 4: Molds after pouring

Figure 5: Test castings after fettling

Finally machining is done on CNC machine to prepare eighteen standard test specimens (as shown in Fig. 6) as per ASTM A370 standards for testing tensile strength.

Figure 6: Tensile test specimens

Universal tensile strength testing machine (UTE-40) is used for measurement of tensile strength; Hardness is measured using Dynamic hardness tester (DHT-6); and measurement of density is done by using Archimedes Principle.

IV. RESULTS AND DISCUSSION

As two test samples are prepared for each experiment, average value of two test samples are taken and the results obtained are listed *against each experiment* as shown in *Table 5.*

Table 5: Experimental Results

Expt. No.	Response		
	Hardness (BHN)	Tensile Strength (MPa)	Density (g/cm^3)
1	41	104	2.527
2	41	107	2.556
3	51	126	2.676
4	40	103	2.513
5	46	119	2.641
6	44	118	2.628
7	42	111	2.583
8	42	109	2.571
9	42	115	2.601
Total	391	1012	23.296
Mean	43.44	112.4	2.59

4.1 Calculating S/N ratios

For analysis of results obtained from experiments, the S/N ratios were calculated [4]. As hardness, tensile strength and density were selected as a quality characteristics, for all the three responses ‘larger the better’ S/N ratio is considered.

For larger the better S/N ratio is

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

4.1.1. S/N ratio for Hardness

S/N ratio for experiment 1 for Hardness is

$$S/N_1 = -10\log_{10}\left(\frac{1}{1}\left(\frac{1}{41^2}\right)\right)$$

= 32.25

Similarly, S/N ratio values for all the nine experiments for hardness, tensile strength and density are calculated and tabled as shown in the *Table 6.*

Table 6: S/N – Ratios for responses

Expt. No.	S/N Ratios		
	Hardness	Tensile strength	Density
1	32.25	40.38	8.052
2	32.25	40.57	8.151
3	34.15	41.98	8.549
4	32.04	40.24	8.003
5	33.25	41.52	8.435
6	32.86	41.41	8.392
7	32.46	40.91	8.242
8	32.46	40.74	8.202
9	32.86	41.19	8.302

The average S/N values are calculated for each factor and each level.

$S/N_{A,1}$ = Average S/N ratio for factor A at level 1

$S/N_{A,1}$ = (32.25+32.25+34.15)/3 = 32.88

Similarly the average S/N values are calculated for each factor and level for hardness, tensile strength and density and tabulated as shown in the Tables 7, 8 and 9 respectively.

Table 7: S/N Ratio response table for hardness

LEVEL	A	B	C	D
1	32.88	32.25	32.52	32.78
2	32.71	32.65	32.38	32.52
3	32.59	33.29	33.28	32.88
Max-Min	0.29	1.04	0.90	0.36
Rank	4	1	2	3
Optimum level	A_1	B_3	C_3	D_3

Table 8: S/N Ratio response for tensile strength

LEVEL	A	B	C	D
1	40.97	40.51	40.99	41.03
2	41.05	40.94	40.64	40.96
3	40.94	41.52	41.47	40.98
Max-Min	0.11	1.01	0.83	0.07
Rank	3	1	2	4
Optimum level	A_2	B_3	C_3	D_1

Table 9: S/N Ratio response table for density

LEVEL	A	B	C	D
1	8.250	8.099	8.215	8.263
2	8.276	8.262	8.152	8.261
3	8.248	8.414	8.408	8.251
Max-Min	0.028	0.315	0.283	0.012
Rank	3	1	2	4
Optimum level	A_2	B_3	C_3	D_1

4.2 Response Curves

From the S/N ratio response tables, the response curves drawn are as follows.

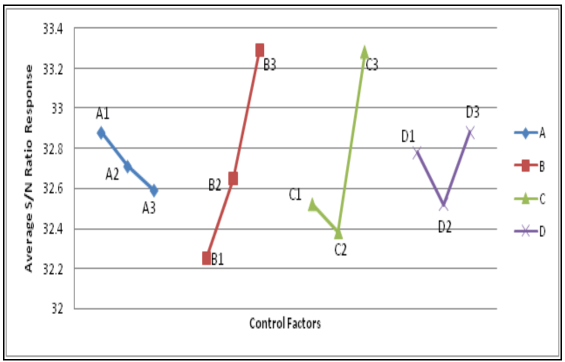

Figure 7: Response curve for hardness

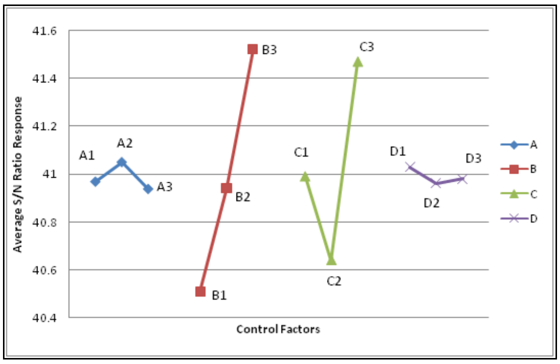

Figure 8: Response curve for tensile strength

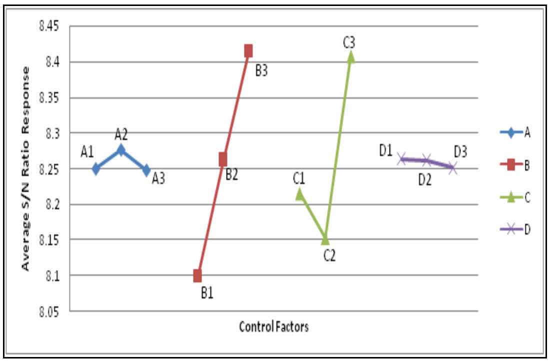

Figure 9: Response curve for density

Where,
A – grain fineness number, B – amount of clay, C – amount of moisture, and D - number of rammings.

From the S/N Ratio response curves, the optimum level for process parameters are grain fineness number – 55, amount of clay – 12%, amount of moisture – 13%, and Number of rammings – 2.

4.3 Confirmation Test:

Confirmation test is conducted based on optimum level of process parameters, the results obtained from confirmation test are hardness - 53 BHN, tensile strength - 130 MPa, and density - 2.69g/cm^3. These values are found to be with in the confidence level.

Hence hardness, tensile strength and density of aluminum alloy castings produced by sand casting process is increased from 41 BHN, 104 MPa and 2.52 g/cm^3 to 53 BHN, 130 MPa and 2.69g/cm^3 respectively.

V. CONCLUSIONS

The experiments conducted have shown that the process parameters selected have significant influence on mechanical properties and density of sand casting. The optimum levels for process parameters are grain fineness number – 55, amount of clay – 12%, amount of moisture – 13%, and Number of rammings – 2. Amount of clay and amount of moisture are the significant control factors among the selected factors. The confirmation test results obtained for hardness, tensile strength and density are 53 BHN, 130 MPa, and 2.69 g/cm^3 respectively. These results are found to be in confidence level.

Casting defects occur because optimum conditions were not met during casting process. By this study it is concluded that the data obtained can be applied to set the parameters at optimum level to improve mechanical properties (hardness, tensile strength) and enhance density so as to minimize defects and improve quality of aluminium alloy sand castings.

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