A Study to Optimize the Casting Process Parameters of Al-6063 Alloy using Taguchi Technique

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Abstract— Taguchi method is a problem – solving tool which can improve the performance of the product, process design and system. This method combines the experimental and analytical concepts to determine the most influential parameter on the result response for the significant improvement in the overall performance. In this research Aluminium 6063 alloy was prepared by sand casting using three different parameters, Pouring temperature, Pouring time, and cooling time of the casting materials. Dye penetrant test and Ultrasonic test were conducted on each sample to study the surface and internal defects respectively. A tensile and hardness tests were done for the resulted castings. The primary objective is to use Taguchi method for predicting the better parameters that give the highest tensile strength and hardness to the castings, and then preparing casting sample at these parameters and comparing them with the randomly used ones. The experimental and analytical results showed that the Taguchi method was successful in predicting the parameters that give the highest properties and the pouring temperature was the most influential parameter on the tensile strength and hardness results of castings.

Key words: Aluminium6063, NDT Methods, Casting Defects, Taguchi Method, Pareto Anova, Tensile Strength, Hardness

I. Introduction

Aluminium 6063 alloy is mainly used where good mechanical properties are required in castings of a shape or dimensions requiring an alloy of excellent castability in order to achieve the desired standard of soundness. The alloy is also used where resistance to corrosion is an important consideration, particularly where high strength is also required. It has good weldability. [1]

The wide range of the application of aluminium alloys is very obvious. Their desirable characteristics of light weight, excellent resistance to corrosion in the atmosphere and water, strength and high thermal conductivity gives them an edge over other metals in the electrical, aviation, marine, aerospace, construction and automotive industries just to mention but a few. This increased usage creates the need for a deeper understanding of their mechanical behavior and the influences of processing parameters. This knowledge enables the designer to ensure that the casting will achieve the desired properties for its intended application. [6]

There is no doubt that casting as a process involves so many parameters such as melting temperature of the charge, temperature of the mould, pouring speed, pouring temperature, composition, microstructure, size of casting, runner size, composition of the alloy and solidification time just to mention but a few. Just to mention but a few have successfully carried out studies on the varying effects of casting process parameters on the mechanical properties of casted metals and their alloys. One of the recent most important optimization processes is the Taguchi method conceived and developed by Japanese scholar Engr. Dr. Genichi Taguchi in 1950. Taguchi technique is a powerful tool for the design of high quality systems. It provides a simple efficient and systematic approach to optimize design for performance, quality and cost. [1]

The methodology is valuable when design parameters are qualitative and discrete. Taguchi parameter design can optimize the performance characteristic through the setting of design parameters and reduce the sensitivity of the system performance to source of variation. [3] The Taguchi approach enables a comprehensive understanding of the individual and combined from a minimum number of simulation trials.

II. Experimental Work

A. *Samples Preparation*

An Electric furnace is used to melt the raw material, sample 1, 2 & 3 are poured at 600C and samples 4, 5 and 6 are poured at 650C and samples 7, 8, and 9 are poured at 700C. A wooden pattern is used for mould preparation and the mould is prepared from sand. The melt temperature was controlled and checked with thermocouple before pouring into a mould shown in figure (1). The dimensions of the resulted castings are (200 X 25 X 15) mm. The pouring time and cooling time are followed as per the Table [2], the figure [1] shows the experimental set up.

Fig. 1: Experimental Set Up

Sample No	Pouring Temperature(°C)	Pouring Time(sec)	Cooling Time(min)
01	600	5	3
02	600	10	6
03	600	15	9
04	650	5	3
05	650	10	6
06	650	15	9
07	700	5	3
08	700	10	6
09	700	15	9

Table 1: Experimental set up Control factors value for Sample preparation

III. METHODOLOGY

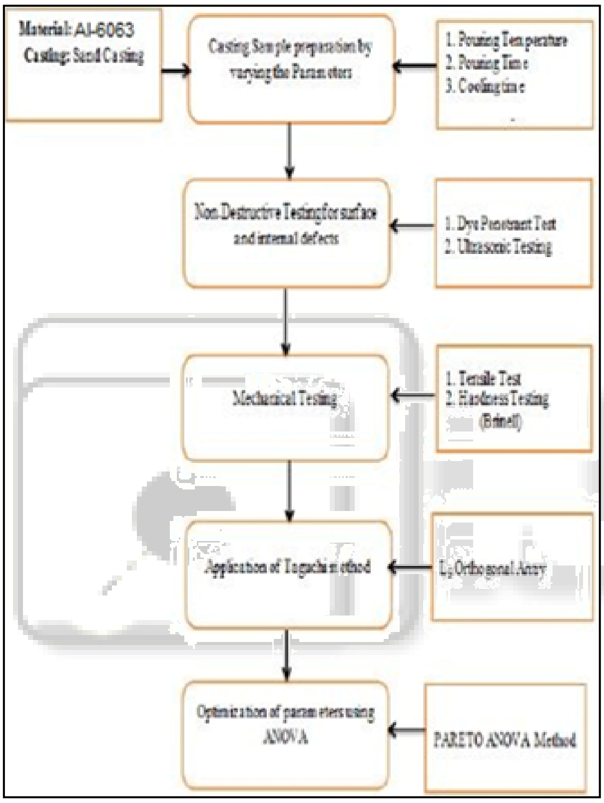


Fig. 2: Flowchart

- Non Destructive Testing of samples
- Dye Penetrant Testing (DPT)

All the nine samples are tested by dye penetrant

Testing method to detect the surface defects which are arrived during casting samples preparation. The testing procedure is shown in figure [3].

Fig. 3: Testing procedure

A. *Ultrasonic Testing (UT)*

All the nine samples are tested by ultrasonic testing to detect internal defects present in the prepared samples. An Einstein –II(R) ultrasonic flaw detector (UFD) is used to observe the echoes from the samples and Transmitter- Receiver (TR) probe is used for scanning the Samples for defects. The figure shows the UFD, TR probe and scanning of samples.

Fig. 4: UFD, TR probe and scanning of samples

B. *Mechanical Testing of samples*

1) *Tensile Testing*

The fundamental material science testing, in which a sample is subjected to uniaxial tension until failure. The properties that are directly measured via tensile test are maximum elongation, ultimate tensile test and reduction in area. The specimens were prepared as per ASTM SA370 Pat-2. The dimension of Specimen is 50 mm gauge length and 10mm thickness for the holding proposes the 25 mm 12.5mm (width and thickness) on both end is produced. The UTM is as shown in figure [5].

Fig. 5: UTM

2) Hardness Testing

Hardness test provides an accurate, rapid and economical way to determine the material deformation. The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. Hardness test has been conducted on each specimen using a load of 250 N and a steel ball indenter of diameter 5 mm as indenter. The diameter of the impression made by indenter has been measured by Brinell microscope.[7]The corresponding values of hardness (BHN) were tabulated. The figure [6] shows the Hardness Tester.

Fig. 6: Hardness Tester

C. Application of Taguchi Method

In order to observe the influencing degree of process parameters in the casting preparation, three parameters namely; (1) Pouring temperature; (2) Pouring time; and (3) Cooling time, each at three levels were considered and are listed in Table [2].Maintaining these processing parameters as constants enabled us to study the effect of Pouring temperature, Pouring time and cooling time on the resulted properties. The degrees of freedom for three parameters in each of three levels were and it is calculated as follows [1]

Degree Of Freedom (DOF) = number of levels -1

For each factor, DOF equal to:

For (A); DOF = 3 – 1 = 2

For (B); DOF = 3 – 1 = 2

For (C); DOF = 3 – 1 = 2

In this research nine experiments were conducted at different parameters, and then the specimens were machined and tested by Brinel hardness and tensile test.

Factors	Control Factor	Level 1	Level 2	Level 3
A	Pouring Temperature (°C)	600	650	700
B	Pouring Time (sec)	5	10	15
C	Cooling Time(min)	3	6	9

Table 2: Control Factor

A three level L9 34 orthogonal array Shown in Table [3] with nine experimental runs was selected. The total degree of freedom is calculated from the following

Total DOF = no. of experiments – 1

The total DOF for the experiment is = 9 – 1 = 8

Experiment No	A	B	C
01	1	1	1
02	1	2	2
03	1	3	3
04	2	1	2
05	2	2	3
06	2	3	1
07	3	1	3
08	3	2	1
09	3	3	2

Table 3: Experiment

Taguchi method stresses the importance of studying the response variation using the signal – to – noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The tensile strength and hardness were considered the quality characteristic with the concept of "the larger the better". The S/N ratio used for this type response is given by

$$S/N_{LTB} = -10\log[MSD] \quad (1)$$

Where dB means decibel and Yi is the response value for a trial Condition repeated n times.

Table [4] indicates the used parameters and the result values of tensile strength and hardness (2)

Expt. No	A	B	C	Tensile Strength N/mm^2	Hardness
01	600	5	3	78.7	48
02	600	10	6	107.6	52
03	600	15	9	85.1	52
04	650	5	6	70.2	47
05	650	10	9	94.9	57
06	650	15	3	79.7	48
07	700	5	9	69.7	32
08	700	10	3	59.1	28
09	700	15	6	35.3	36

Table 4: Experimental observation

The casting samples preparation parameters, namely pouring temperature (A), pouring time (B), and cooling time (C) were assigned to the 1st, 2nd and 3rd column of L9 34 array, respectively. The 4th column was assigned as error (E), and was considered randomly. The

S/N ratios were computed for tensile strength and hardness in each of the nine trial conditions and their values are given in Table.

Expt. No	A	B	C	E	S/N ratio (Tensile Strength)	S/N ratio (Hardness BHN)
1	1	1	1	1	37.9196	33.624
2	1	2	2	2	40.633	34.32
3	1	3	3	3	38.6985	34.32
4	2	1	2	3	36.926	33.44
5	2	2	3	1	39.545	35.1175
6	2	3	1	2	38.029	33.624
7	3	1	3	3	36.846	30.1029
8	3	2	1	1	35.4317	28.943
9	3	3	2	2	30.955	31.126

Table 5: S/N ratio for Tensile strength and hardness

Factors	A	B	C	E	Total
Sum at factor level	$\sum A_1$	$\sum B_1$	$\sum C_1$	$\sum E_1$	T
	$\sum A_2$	$\sum B_2$	$\sum C_2$	$\sum E_2$	
	$\sum A_3$	$\sum B_3$	$\sum C_3$	$\sum E_3$	
Sum of squares of difference	S_A	S_B	S_C	S_E	S_T
Degree of freedom	2	2	2	2	8
Contribution ratio (X 100)	$\frac{S_A}{S_T}$	$\frac{S_B}{S_T}$	$\frac{S_C}{S_T}$	$\frac{S_E}{S_T}$	100

Table 6: Pareto ANOVA for three level factors

T=∑A1+∑A2+∑A3
SA= (∑A1-∑A2)2+ (∑A1-∑A3)2+ (∑A2-∑A3)2
SB= (∑B1-∑B2)2+ (∑B1-∑B3)2+ (∑B2-∑B3)2
SC= (∑C1-∑C2)2+ (∑C1-∑C3)2+ (∑C2-∑C3)2
SE= (∑E1-∑E2)2+ (∑E1-∑E3)2+ (∑E2-∑E3)2
ST= SA+ SB+ SC+ SE

IV. Results and Discussions

A. *Dye Penetrant Test Observations*

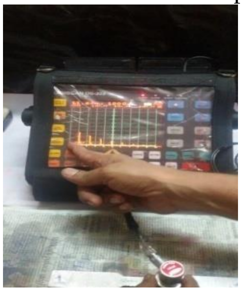
When the nine samples are tested by dye penetrant test for surface defects, sample 1,4,6,8 and 9 have indicated porosity as shown in figure, sample 7 has indicated blow hole and cracks as shown in figure and sample2, 3 and 5 are defectless as shown in figure. The possible causes and remedies for these defects are mentioned in Table

Test Sample Sl. No	Recorded Indications	Comments
01		Cluster Porosity
02		Defectless
03		Defectless
04		Porosity
05		Defectless
06		Cluster Porosity
07		Blow Hole
08		Porosity & Cracks
09		Porosity

Table 7: Sample

B. *Ultrasonic Test Observation*

When the samples are scanned ultrasonic flaw detector and TR probe sample 2,3,5 are found with backwall echoes and samples 1,4,6,7,8,9 were found with indication of presence of internal defects in the samples along with the


Sample 1 Defective


Sample 2 Defective


Sample 3 Defectless


Sample 4 Defective


Sample 5 Defectless


Sample 6 Defective


Sample 7 Defective


Sample 8 Defective

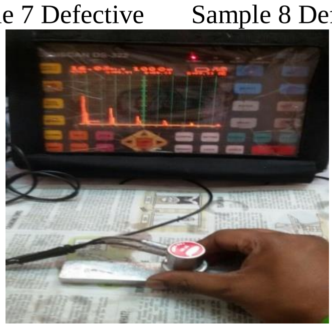

Sample 9 Defective

Fig. 7: Samples

Pareto ANOVA observations Computation scheme of Pareto ANOVA (Analysis Of Variance) for three level factors is shown in table. In order to study the contribution ratio of the process parameters, Pareto ANOVA was performed for tensile strength and hardness. The details are given in tables and respectively.

Factors	A	B	C	E	Total
Sum at factor level	117.25	111.69	111.69	111.69	334.983
	114.5	115.61	111.51	111.056	
	103.23	107.68	111.058	111.056	
Sum of squares of difference	331.068	94.30	34.79	0.805	460.9
Degree of freedom	2	2	2	2	08
Contribution ratio	71.82	20.5	7.54	0.1746	100
Optimum level	1	2	2		
	A 1	B 2	C 3		
Optimum values	600°C	10sec	6min		

Table 7: Pareto Anova for Tensile Strength

Factors	A	B	C	E	Total
Sum at factor level	102.264	111.69	115.69	111.69	294.599
	102.1814	115.60	111.508	111.0562	
	90.1719	107.682	111.0562	111.0562	
Sum of squares of difference	290.22	87.26	34.797	0.8034	413.080
Degree of freedom	2	2	2	2	08
Contribution ratio	70.257	21.12	8.42	0.1949	100
Optimum level	1	2	1		
	A 1	B 2	C 3		
Optimum values	600°C	10sec	3min		

Table 9: Pareto Anova for Hardness

V. Conclusion

In this work Taguchi's off – line quality control method was applied to determine the optimal process parameters which maximize the mechanical properties of Aluminium 6063alloy prepared by Sand casting. For this purpose, concepts like orthogonal array, S/N ratio and ANOVA were employed. After determining the optimum process parameters, one confirmation experiment was conducted.

From results the following conclusions were drawn.

- The optimum level of process parameters to obtain good mechanical properties for the sand casting of Aluminium 6063 are 600C pouring temperature, 10 seconds Pouring time And 9 minutes cooling time for tensile strength and 600C pouring temperature, 10 second pouring time and 3 minutes cooling time for hardness.
- From the pareto analysis it was evident that the Pouring temperature is a major contributing factor for improving tensile strength and hardness.
- Taguchi method has proved its success in predicting the optimum parameters to reach the best properties.
- From observation it is conclude that the porosity will occur because of steep temperature gradient due to low and high pouring temperature and cracks are formed due to high pouring temperature.

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