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Improvement in Hardness of LM-6 Aluminum Alloy Green Sand Castings by Taguchi Method

Ravneet Kumar[1*] and Chandandeep Grewal[2]

[1]*Research Scholar, University Institute of Engineering and Technology, Panjab University, Chandigarh - 160 014, India*

[2]*Department of Mechanical and Manufacturing Engineering, University of Calgary, Canada*

Email: rkkakria70@yahoo.com

***Abstract* - The green sand casting is most widely and economically used method for past years. The quality of castings and parameters control is very important. With increasing demand for high-quality castings with close tolerances, an attempt has been made in this study to get the optimal setting of the main parameters to improve the hardness of LM-6 Aluminum alloys castings in green sand casting. Five main parameters namely Bentonite clay, Grain fineness no., Moisture, Pouring temperature and Coal dust were identified. The effects of the selected process parameters on the hardness and the subsequent optimal settings of the parameters have been accomplished using Taguchi's method. L_8 (2^7) orthogonal arrays have been selected and experiments were conducted as per experimental plan given in this array. The results indicate that all the parameters except grain fineness no and coal dust are affecting both the average and variability significantly in the hardness of LM-6 Aluminum alloys castings. The confirmatory experiments have shown improvement in Rockwell hardness to be 6.9%.**

***Keywords:* Green sand Casting, LM-6 Aluminum alloy, Rockwell hardness, Taguchi L_8 (2^7) orthogonal arrays.**

I. Introduction

Casting is the oldest method used by our ancestors for shaping of metals. Casting was an art in ancient times and now it is an established science for producing automotive castings. In modern foundries, green sand moulding method is widely used for small size automotive castings. It is the least expensive method and gives optimum quality due to low cost of sand, its ingredients and its reusability for further production. Green sand moulding derives its name due to presence of moisture in it [1]. It is prepared in sand Muller machine. It is a mixture of silica sand, Bentonite clay, coal dust, wood floor, dextrin powder, fire clay and water. The sand can be reused again after casting process with addition of Bentonite clay and water according to loss of ignition (Percentage).

Quality of a casting is a measure of its dimensional accuracy, surface finish and soundness [2]. It depends upon the quality of various constituents of green sand and structural properties of green mould [1].

LM-6 aluminum alloy is basically Al-12% silicon alloy. It is supplied in cast conditions only. It possesses very good fluidity and resistance to hot tears. So, it can be easily sand, pressure and gravity die cast. It is used for very thin, pressure tight and intricate castings such as motor casings, meter casings and pump impellers. It has very high resistance to atmospheric corrosion particularly to saline water. That is why; it is mostly used for marine castings such as cylinder head and inlet and outlet manifolds and chemical and paint industry. It possesses very high ductility making it useful for bending into other shapes after casting into simple forms and used for building cladding panel.[3]

For surviving in present global scenario, it is desired to have close control of process parameters and product characteristics for consistent quality at least cost and minimum rejections.

Singh et. al. [4] have studied optimal settings of Single and double blanks of aluminium blank sand casting processes with seven control factors at three levels viz., grain size, clay content, moisture content, ramming, sprue size, riser size, and diameter to thickness (D/t) ratio of the blank. Three noise factors viz. metal flow rate, pouring temperature and humidity were identified. $L_{18}(2)^1(3)^7$ orthogonal array was used to study casting yield, surface defects, and casting density. The results have shown that single aluminium blank sand casting process is more robust than double aluminium blank sand casting process.

Syrcos [5] analyzed various significant process parameters of the die casting method of $AlSi_9Cu_{13}$ aluminum alloy to obtain optimal settings of the die casting parameters, in order to yield the optimum casting density. The process parameters considered were: piston velocity (first and second stage), metal temperature, filling time and hydraulic pressure. The effects of the selected process parameters on the casting density and the subsequent optimal settings of the parameters have been accomplished using Taguchi's method.

Guharaja *et. al.* [6] made an attempt to obtain optimal settings of the green sand casting process in order to yield the optimum quality characteristics of the spheroidal graphite (SG) cast iron rigid coupling. The effect of selected process parameters i.e. green strenght moisture content, permeabilty and mould hardness and their levels on the casting defects have been accomplished using Taguchi parameter design approach The result indiacted that the selected process parameters significantly affect the casting defects of SG cast iron rigid coupling castings.

Barua *et. al.* [7] shows how to obtain an optimal setting of the process parameters of the V process that may yield optimal mechanical properties to the Al-7% Si alloy castings.

Nazirudeen *et. al*.[8] used neural network model to prevent the defective castings produced, with properties such as green compression strength, green shear strength, moisture content, permeability, compactibility and mould hardness as inputs and the percentage defects produced as output. The actual outputs were found to be in good agreement with the predicted values.

In this paper, an attempt has been made to find out the optimal settings of the process parameters to get the better hardness of LM-6 aluminum alloy castings.

II. Taguchi Design

There are three approaches of Taguchi's process which are System design, Tolerance design and parameter design. Out of these three approaches, parameter design was used in LM-6 aluminum alloy casting.

It involves the following steps [9]:

1. Define the problem and determine the objective.
2. Choose relevant quality characteristics.
3. Brainstorming the potential factors.
4. Choose important factors and their range & nos. of levels
5. Determine noise factors.
6. Develop the experimental design viz. Select the orthogonal arrays, assign control factors and their interactions to column of inner array and noise factors to outer array. Describe each trail condition and decide their order and repetition.
7. Perform experimental trails and collect data.
8. Analyse the data and evaluate the optimum design.
9. Interpret the result.
10. Run the confirmatory experiment.
11. Implement the recommendations.

III. Experimental Design

The process parameters and their levels have been decided from the literature [3] for LM-6 aluminum alloy castings in synthetic sand. The range of these parameters was selected on the basis of literature review. The response parameter selected in this study is Hardness. So, an experimental layout has been set at two distinct levels for five main parameters. The parameters with their levels are given in table I.

Table I Process Parameters and Their Levels

Designation	Main parameters	Level-1	Level-2
A	Bentonite clay	4%	6%
B	Grain fineness no.	80	100
C	Moisture	3%	4%
D	Pouring temp.	710°C	730°C
E	Coal dust	1%	1.5%

There are also possibilities of two interactions between the parameters. These are:

(i) Bentonite clay and grain fineness number (A ´ B): Amount of Bentonite depends upon grain fineness number. A bigger grain requires more Bentonite clay due to larger surface area.

(ii) Bentonite clay and moisture. (A ´ C): Sand-clay onds are developed by water. So, amount of moisture depends directly on amount of Bentonite clay present in green sand mix.

A. Selection of Orthogonal Array

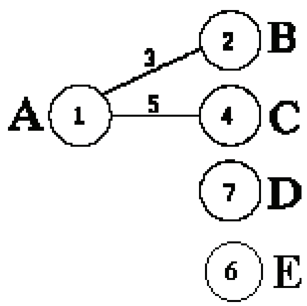


Fig 1: Linear graph of L_8 (2^7).

Orthogonal arrays are special experimental designs constructed by Taguchi that require only a small number of experimental trials to help discover main factor effects. Orthogonal arrays are fractional factorial designs and symmetrical subsets of all combinations of treatments in the corresponding full factorial designs. The Orthogonal arrays facilitate the experimental design process by assigning factors to the appropriate column.

For the selection of particular OA, the number of parameters, the number of levels and possible interactions must be taken into considerations. In order for an array to be a viable choice, the number of rows in it must at least be equal to the degree of freedom required for the case study [10]. Degree of freedom for all the above factors is $f_{total.}$ = [5×1+2×1] = 7. Taguchi's OA are selected on the basis of the condition that the total DOF of a selected OA must be greater than or equal to the total DOF required for the experiment. L_8 (2^7) O.A. has eight number of rows or 7 DOF and is therefore selected.

For this study, the utilization of an $L_8(2^7)$ array of Taguchi method has reduced the number of experimental configurations from 128 required for a full factorial study to 8 only. Figure 1 shows the linear graph of L_8 orthogonal array.

IV. Results and Analysis for Optimization of Parameters

Experiments were conducted in the foundry laboratory of one renowned engineering institute of Punjab. According to experimental layout shown in Table II, the aluminum castings were done in random order from wooden pattern with dimensions as shown in figure 2 and dictated by L_8 orthogonal array. As the layout shows, first casting was carried out by taking level 1 values of all the parameters. The casting 2 was carried out by taking the level 1 values of Bentonite and A.F.S number and level 2 values of Moisture, coal dust and temperature. Similarly other experiments were carried out.

The value of Hardness was measured with the help of Rockwell Hardness tester of Fine Engineering. Instrument (Pvt.) Ltd, Miraj, Maharastra make with scale "B" It was decided to take three hardness readings at end positions and center on each step of every casting randomly at P_1, P_2, P_3 and Q_1, Q_2, Q_3 at position 1 and 2 respectively in figure 2.

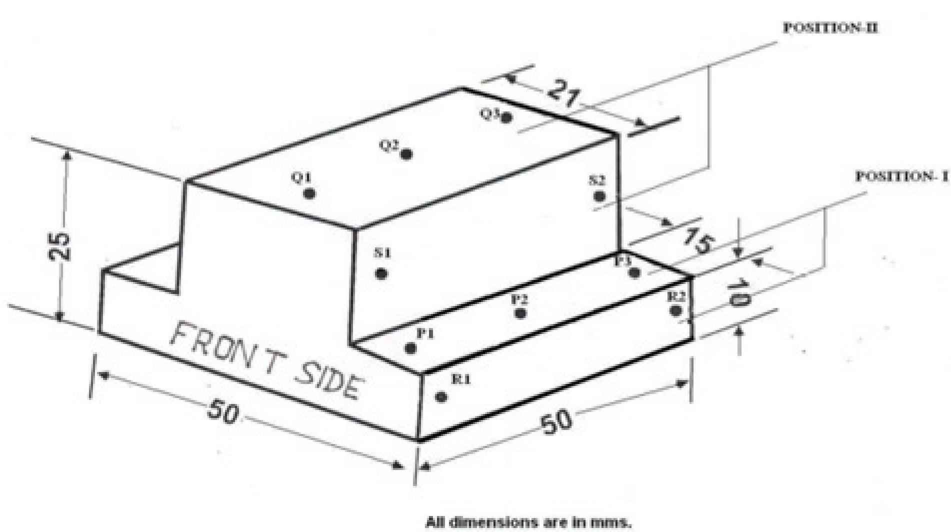


Fig 2 Dimensions of the pattern

TABLE II EXPERIMENTAL LAYOUT FOR LM-6 CASTINGS

Casting No.	Col. No.						
	1	2	3	4	5	6	7
	Parameters						
	A Bentonite. Clay (%)	**B** A.F.S. No.	**A×B**	**C** Moisture (%age)	**A×C**	**E** Coal Dust	**D** Temp. (°C)
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
# The lower and upper level of the parameters has been shown as 1 *and* 2 *respectively*.							

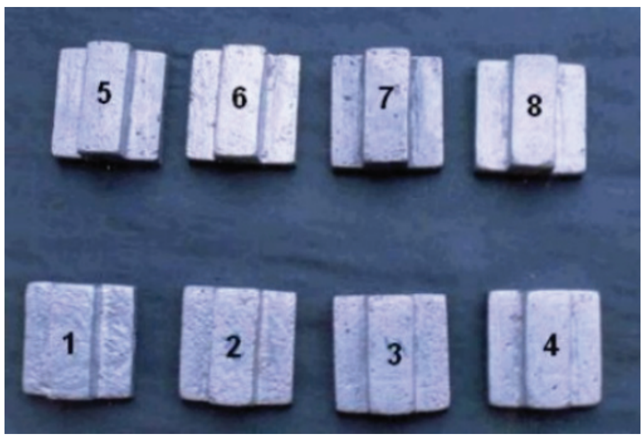


Fig 3 Photograph of Aluminum alloys sand castings

In the Taguchi method, a loss function has been defined to gauge the deviation between the experimental and desired value of a performance characteristics. The loss function is defined by the S/N ratio to determine the optimum parameters of casting process of aluminum alloy. There are three categories of the S/N ratio analysis viz. Higher the better, the nominal the better and the smaller the better. In this work, the characteristic measure was Hardness. It should be as higher as possible. In order to obtain the optimal parameters, the Higher the better type of response was considered. The S/N ratio for higher the better is given by [11].

$$SN_{HB} = -10\log\left(\frac{1}{r}\sum_{i=1}^{r} 1/Y_i^{2}\right)$$

The average value of the Hardness and those of S/N ratios for all 8 castings were calculated and are shown in table III.

TABLE III HARDNESS & S/N RATIO

Casting No.	Average Hardness (HRB)	S/N ratio (dB)
1	88.83	38.909
2	91.17	39.136
3	68.67	36.718
4	86.33	38.870
5	77.5	37.767
6	81.83	38.135
7	92.83	39.350
8	76.33	37.614
Total	663.5	306.499

A. Analysis of Variance for Raw and S/N data

Analysis of variance (ANOVA) was performed to determine the relative significance of factors in terms of their percentage contribution to the response.

Table IV Pooled Anova of Raw Data. (Hardness)

Source	Pool	SS	f	V	F Ratio	F^*Ratio	SS*	P %
A	Y	31.69	1	31.68	1.554			
B	N	172.5	1	172.5	8.46***	7.6***	149.7	3.61
C	Y	46.02	1	46.02	2.256			
D	N	981	1	981	48.1***	43***	958.2	23.12
A×B	N	910	1	910	44.6***	40***	887.2	21.41
A×C	N	776	1	776	38.1***	34***	753.2	18.17
E	Y	22.68	1	22.68	1.112			
SS_{T1}		2940	7					
P	Y	15.19	1	15.19	0.745			
A×P	Y	42.19	1	42.19	2.068			
B×P	Y	31.69	1	31.69	1.554			
C×P	Y	54.19	1	54.19	2.657			
D×P	Y	15.19	1	15.19	0.745			
A×B×P	Y	46.02	1	46.02	2.256			
A×C×P	Y	1.021	1	1.021	0.050			
E×P	N	346.69	1	346.69	17***	15***	323.9	7.81
SS_{T2}		3492.1	15					
e_3	Y	652.66	32	20.396	-			
e_p^+		958.561	42	22.823				25.88
SS_{T3}		4144.8	47					100

*** shows 99% confidence interval.

Table V Pooled Anova of S/N Data. (Hardness)

Source	Pool	SS	f	V	F Ratio	F*Ratio	SS*	P %
A	Y	0.0735	1	0.0735	18.375			
B	Y	0.2433	1	0.2433	60.825*			
C	Y	0.1278	1	0.1278	31.950			
D	N	2.0291	1	2.0291	507***	18.09**	1.917	33.16
A×B	Y	1.5479	1	1.5479	387**	13.79**	1.436	24.84
A×C	Y	1.7550	1	1.7550	439***	15.64**	1.643	28.42
E	N	0.0040	1	0.0040	18.782			
e_p^+		0.4486	4	0.1122				13.58
Total		5.7806	7	-				100

** shows 95% confidence interval.

Table IV and Table V shows pooled ANOVA of raw and signal to noise data with percentage contribution of significant parameters. The significant parameters have be asterisk marked and made bold. Insignificant parameters have been pooled as error. The responses selected from fig 4 are also made bold.

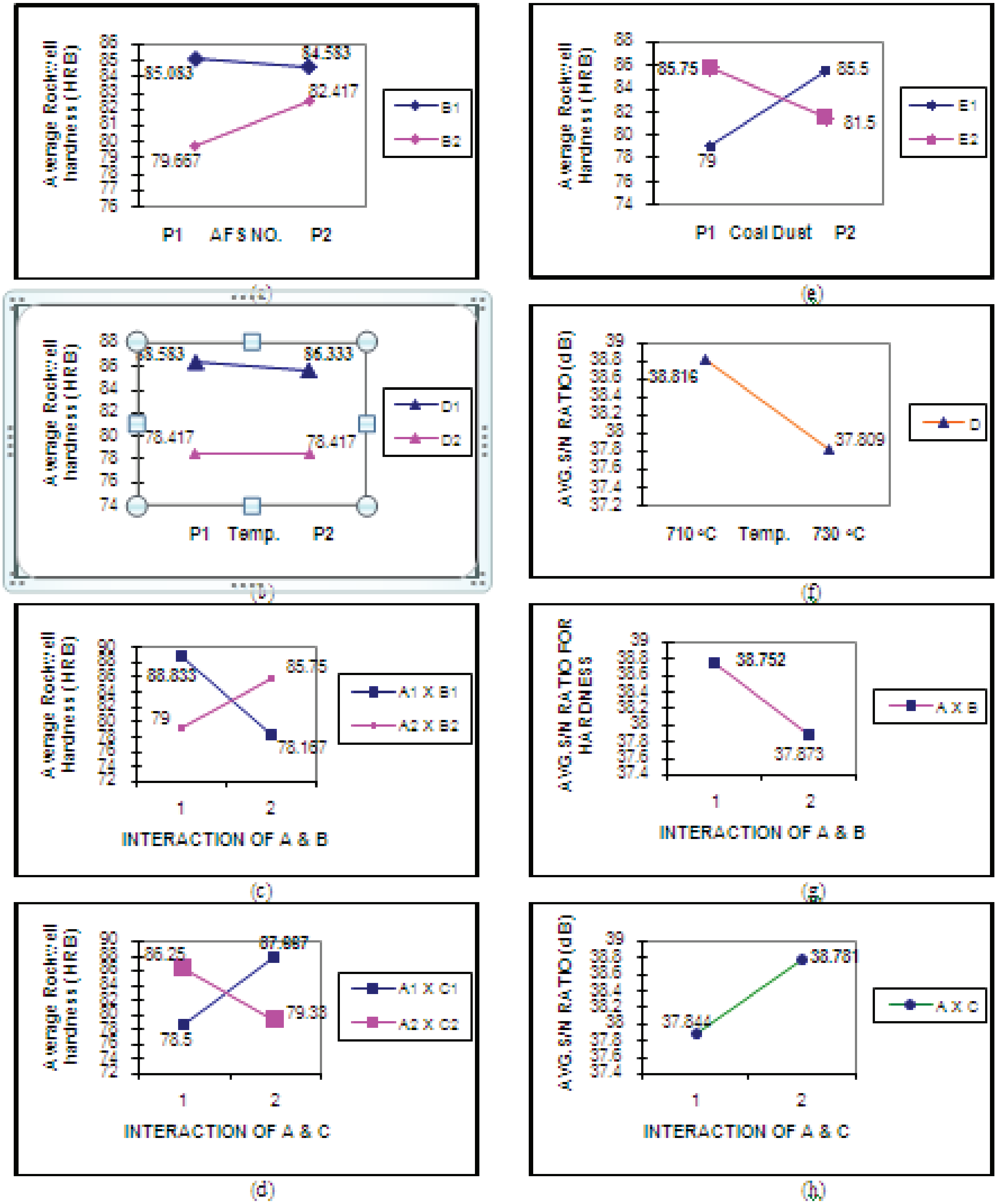
The factors of LM-6 aluminum alloy sand castings experiment for Hardness can be classified as:

Factors	Level affecting average	Level affecting variability
A	1	1
B	1	-
C	2	2
D	1	1
E	2	-

It is found that the optimal parameter combination of Green sand casting process for best Hardness corresponded to a Bentonite clay addition to 4%, Grain Fineness number of 80, a moisture level of 4%, Pouring Temperature of 710°C and Coal dust addition of 1.5%. Therefore, $A_1B_1C_2D_1E_2$. commended for achieving best Hardness for LM-6 aluminum alloys castings in Green sand.

The Lower temperature is found to affect the Hardness of aluminum casting the most at both positions of castings. This may be due to better diffusion of silicon to form Fine eutectic structure.

Lower percentage of Bentonite clay combined with higher percentage of water resulted in better clay bonding



(a),(b),(c),(d)& (e) shows effects of B,D,A´B,A´C& E on process average and (f), (g) & (h) effects of D, A´B & A´C on S/N data.

Fig. 4 Response plots for Rockwell hardness of significant parameters only to give better Hardness. Lower percentage of Bentonite clay combined with Lower Grain fineness number resulted in optimum clay coating on sand grains give better Hardness.

Both the interactions were found to affect both the average and variability of the Casting Hardness. The effect of these interactions are unknown to metallurgist can be investigated further to know the effect of mould characteristics on solidification phenomenon.

Higher percentage of Coal dust was found to produce best hardness at position 1 on castings. The Lower Grain fineness number individually was found to affect the Casting Hardness the least of all parameters. Both these parameters were found to affect only the average of the Casting Hardness.

B. Estimation of Optimum Hardness

The averages of the level of factor B, D, E, AB and AC are:

$$\overline{B_1} = 84.83 \quad \overline{D_1} = 87.46 \quad \overline{A_1 B_1} = 87.29$$
$$\overline{A_1 C_1} = 78.92 \quad \overline{E_1} = 82.25 \quad \overline{T} = 82.94$$

$$\overline{B_2} = 81.04 \quad \overline{D_2} = 78.42 \quad \overline{A_2 B_2} = 78.58$$
$$\overline{A_2 C_2} = 86.96 \quad \overline{E_2} = 83.63$$

So, optimum levels are:

$$\overline{B_1} = 84.83 \quad \overline{D_1} = 87.46 \quad \overline{A_2 C_2} = 86.96$$
$$\overline{E_2} = 83.63$$

The estimated average results, when the control factors are at their better level is:

$$\mu_{B1,\,D1,\,E2\;\&\;A2\times C2} = \overline{B_1} + \overline{D_1} + \overline{A_2 \times C_2} + \overline{E_2} - 3\,\overline{T} \quad \ldots\ldots (1)$$
$$= 84.83 + 87.46 + 86.96 + 83.63 - 3(82.94)$$
$$= 94.06 \text{ HRB}$$

The 99% confidence interval (C.I.) for the population and the confirmation experiments of 2 parts is calculated as:

(a) For population:

$$CI_{pop} = \pm \sqrt{\frac{F_{\alpha(fi\ \&\ fe)} \times V_e}{n_{eff}}} \quad \ldots. (2)$$

(b) For confirmation experiment:

$$CI_{CE} = \pm \sqrt{F_{\alpha(fi\ \&\ fe)} \times V_e \times \frac{1}{n_{eff}} + \frac{1}{r}} \quad \ldots. (3)$$

Where,

$$n_{eff.} = \frac{\text{Total number of observations}}{1 + (\text{Total degree of freedom associated with items used in estimating } \mu)}$$

By substituting the following: $F_{0.99\ (1\&\ 42)} = 7.28$; $V_e = 22.823$; $n_{eff.} = 48/5$; $r = 12$, C.I. is calculated to be ± 5.582 HRB. Therefore the 99% confidence interval should be given by

$$88.478 < \mu_{CE} < 99.642 \text{ HRB} \quad \ldots. (4)$$

C. *Confirmation Experiments*

As part of the confirmation tests, two samples have been cast at the optimum condition with Rockwell hardness at position 1 &2 are 84, 91, 89; 94, 87, 90; 93, 93, 90; 88, 84 and 81 HRB respectively. The samples were evaluated following the same criteria used for the original experiments. The average of the sample has been found to be 88.667 HRB, which is within the confidence interval given in equation 4. The expected improvement in Rockwell hardness has been found to be 6.9%.

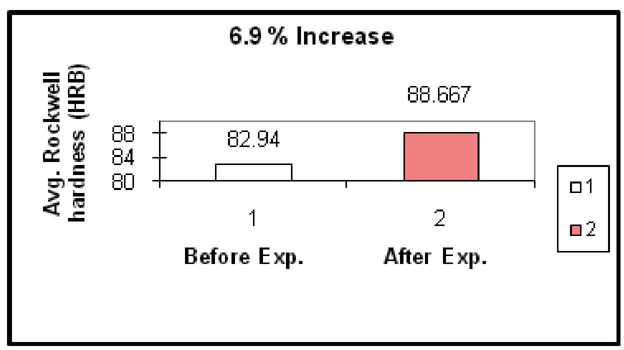


Fig. 5 Expected improvement after validation

V. CONCLUSION

The study investigated the optimisation of Sand Casting process factors and levels using Taguchi Method for Hardness of LM-6 aluminum alloys castings in green sand by hand molding. The results are summarized as follows:

The optimal parameter combination of Green sand casting process for best Hardness corresponded to a Bentonite clay addition to 4%, Grain fineness number of AFS 80, a moisture level of 4%, Pouring Temperature of

1. 710 ^{O}C and Coal dust addition of 1.5%. Therefore, $A_1B_1C_2D_1E_2$ is recommended for achieving best hardness for LM-6 aluminum alloys castings in Green sand.
2. The predicted optimal range for the confirmation experiment of two experiment is given by $88.478 < \mu_{CE} < 99.642$ HRB.
3. The Pouring Temperature was contributing the most (33.16%) of variability of process followed by interaction of Bentonite clays and moisture (28.42%) and Bentonite clay and Grain Fineness number (24.84%) respectively.
4. The confirmation experiment was conducted to validate the experimental work done. It showed expected improvement of 6.9% in average Hardness of the castings.
5. Grain fineness number and coal dust were found to affect the process average only.
6. Pouring Temperature, interactions of Bentonite clay and grain fineness number and Bentonite clay and moisture were found to affect both average and variability of the process.

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