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A Study to Optimize the Casting Process Parameters of IS1030 Steel using Taguchi Technique

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Abstract: **Casting is an age old production technique wherein cavities are formed by a pattern into a porous and refractive material, usually sand, and then liquid metal is poured into the cavity so that it takes up the shape of the cavity, thus forming the required metal product. Green sand casting process involves many process parameters which affect the quality of the casting produced. In the present work Taguchi method is used to optimize tensile strength and hardness of green sand casting of IS1030 steel material. 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. Taguchi's L_9 orthogonal array is used for experimental design. Overall performance of the sand casting method is improved significantly by combining the experimental and analytical concepts and the most important parameter is determined on the result response. The casting samples were prepared using three different casting process parameters, Pouring temperature, Pouring time, and cooling time of the casting samples. Better parameters for highest tensile strength and hardness to the castings are predicted by Taguchi technique and then casting samples are prepared at these parameters. The experimental and analytical results proved that the Taguchi method was successful in predicting the parameters that give the highest properties. From analysis of variance (ANOVA) Pouring temperature is the mostinfluential parameter on the tensile strength and hardness results of castings.**

Index terms: Green sand casting, IS1030 steel, Taguchi Technique, Tensile strength, Hardness, NDT methods and Anova.

I.INTRODUCTION

Although there are many new advanced technologies for metal casting, green sand casting remains one of the most widely used casting processes today due to the lowcost of raw materials, a wide variety of castings with respect to size and composition, and the possibility of recycling the molding sand.

The Green sand casting process is one of the most versatile processes in manufacturing because it is used for most metals and alloys with high melting temperatures such as iron, copper, and nickel. The Green sand casting process consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking away the sand mold to remove a casting product. Green Sand casting is used to manufacture complex shapes of various sizes depending upon the customer requirements.

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

2.1 Samples preparation

TheIS1030 steel is used as a material for samples preparation Table [1] shows the chemical composition of the sample.

Table[1]chemical composition of IS1030

Element	Weight (%)
C	0.30
Mn	0.75
P	0.04
S	0.05
Fe	Reminder

An Electric furnace is used to melt the raw material, sample 1, 2 & 3 are poured at 1550^{0}C and samples 4, 5 and 6 are poured at 1650^{0}C and samples 7, 8, and 9 are poured at 1750^{0}C. A round 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 . The dimensions of the resulted castings are

200mm in length and 30mm in diameter. The pouring time and cooling time are followed as per the Table [2], the figure [1.a] shows the mould cavity before pouring, fig[1.b] shows the pouring of molten metal and figure[1.c] shows the mould after pouring and figure [1.d] shows the induction furnace.

Fig[1.a]Mould cavity before pouring

Fig[1.b]Pouring of molten metal

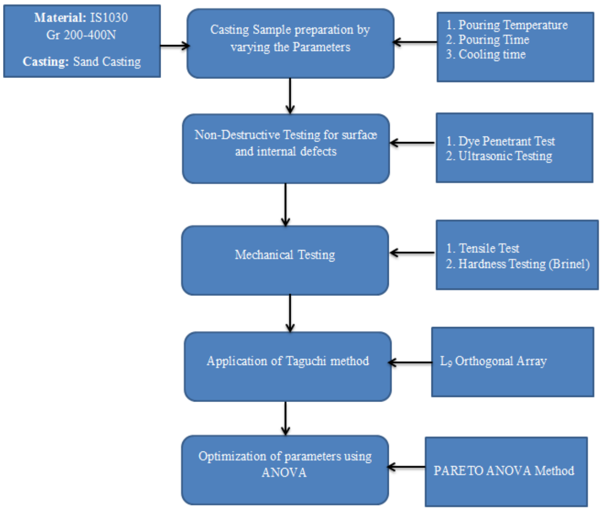
Fig[1.c] Mould after pouring

Fig[1.d] Induction Furnace

Table [2] Control factors value for Sample preparation

Sample No	Pouring temp.(^{0}C)	Pouring time (sec)	Cooling time(min)
1	1550	30	5
2	1550	40	10
3	1550	50	15
4	1650	30	10
5	1650	40	15
6	1650	50	5
7	1750	30	15
8	1750	40	5
9	1750	50	10

III. METHODOLOGY



3.1 Non Destructive Testing of samples

3.1.1 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.

3.1.2 Ultrasonic Testing (UT)

All the nine samples are tested byultrasonic testing to detect internal defects present in theprepared 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.

3.2 Mechanical Testing of samples

3.2.1 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 diameter for the holding proposes the 25 mm diameter on both end is produced. The UTM is as shown in figure[2].

Fig[2] UTM

Samples before testing

Samples after testing

3.2.2 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 [3] shows the Hardness Tester.

Fig [3] Hardness tester

3.3 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 [3]. 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 tensile testandBrinel hardness.

Table [3]Control factors and levels

Factors	Control Factor	Level 1	Level 2	Level 3
A	Pouring temperature (^oC)	1550	1650	1750
B	Pouring time (Sec)	30	40	50
C	Cooling time (min)	5	10	15

A three level $L_9\ 3^4$ orthogonal array Shown in Table [4] 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

Table [4] L_9orthogonal array

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

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}= -10log[MSD] ……………………. (1)

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i^2}\right) \quad \text{……………………..(2)}$$

Where dB means decibel and Yi is the response value for a trial Condition repeated n times. Table [5] indicates the used parameters and the result values of tensile strength and hardness.

Table [5] Experimental Observation

Expt. No	A	B	C	Tensile strength N/mm^2	Hardness(BHN)		
					Trial 1	Trial 2	Average
1	1550	30	5	270	171	172	171.5
2	1550	40	10	289	190	189	189.5
3	1550	50	15	305	210	209	209.5
4	1650	30	10	374	205	207	206
5	1650	40	15	412	120	121	120.5
6	1650	50	5	330	156	155	155.5
7	1750	30	15	470	237	237	237
8	1750	40	5	319	219	218	218.5
9	1750	50	10	396	185	184	184.5

Expt.no: Experiment number, A: Pouring temperature (^{o}C) B: Pouring time (Sec) C: Cooling time (min)

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 L_9 3^4 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 [6].

Table [6]S/N ratio for Tensile strength and Hardness

Expt. No	A	B	C	E	S/N ratio (Tensile strength)	S/N ratio (Hardness BHN)
1	1	1	1	1	48.627	44.685
2	1	2	2	2	49.217	45.552
3	1	3	3	3	49.685	46.424
4	2	1	2	3	51.457	46.278
5	2	2	3	1	52.297	41.619
6	2	3	1	2	50.370	43.834
7	3	1	3	3	53.442	47.497
8	3	2	1	1	50.075	46.789
9	3	3	2	2	51.953	45.320

Expt.no: Experiment number, A: Pouring temperature (^{o}C), B: Pouring time (Sec), C: Cooling time (min) E: Error

Table [7] Pareto ANOVA for three level factors

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

$T=\sum A_1+\sum A_2+\sum A_3$

$S_A= (\sum A_1-\sum A_2)^2+ (\sum A_1-\sum A_3)^2+ (\sum A_2-\sum A_3)^2$

$S_B= (\sum B_1-\sum B_2)^2+ (\sum B_1-\sum B_3)^2+ (\sum B_2-\sum B_3)^2$

$S_C= (\sum C_1-\sum C_2)^2+ (\sum C_1-\sum C_3)^2+ (\sum C_2-\sum C_3)^2$

$S_E= (\sum E_1-\sum E_2)^2+ (\sum E_1-\sum E_3)^2+ (\sum E_2-\sum E_3)^2$

$S_T= S_A+ S_B+ S_C+ S_E$

IV. RESULTS AND DISCUSSIONS

5.1 Dye Penetrant Test observations

When the nine samples are tested by dye penetrant test for surface defects, sample 1 has got crack samples 2 and 3 are defect less, sample 4 has got porosity, crack and blow holes. Samples 5 and 6have got porosity, sample 7 is defectless , sample 8 has got porosity and sample 9 has got both porosity and cracks as shown in figure, .The possible causes and remedies for these defects are mentioned in Table [8].

TEST SAMPLE SL NO	RECORDED INDICATIONS	COMMENTS /REMARKS
Sample 1		Crack
Sample 2		Defectless
Sample 3		Defectless

TEST SAMPLE SL NO	RECORDED INDICATIONS	COMMENTS /REMARKS
Sample 4		Porosity ,cracks and blow holes
Sample 5		Porosity
Sample 6		Porosity

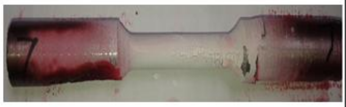
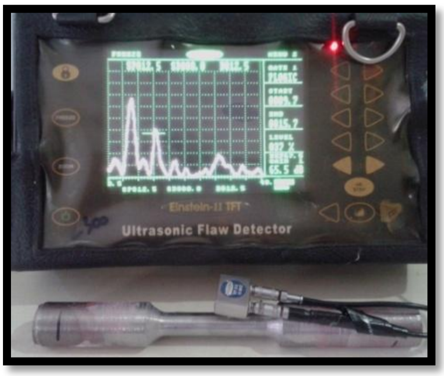
TEST SAMPLE SL NO	RECORDED INDICATIONS	COMMENTS /REMARKS
Sample 7		Defectless
Sample 8		Porosity
Sample 9		Porosity and blow hole

Table [8] Possible causes and remedies for casting defects

Defect	Possible causes	Remedies
Porosity	➢ Metal pouring temperature too low ➢ Pouring too slowly	➢ Increase metal pouring temperature ➢ Pour metal as rapidly as possible without interruption.
Crack	➢ Excessive temperature while pouring	➢ Sufficient cooling of the casting in the mold.
Blow holes	➢ Inadequate core venting ➢ Excessive release of gas from core	➢ provide venting channels ➢ Reduce amounts of gas

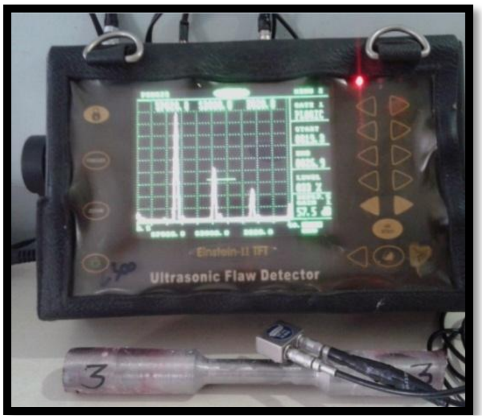
5.2 Ultrasonic Test observation

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

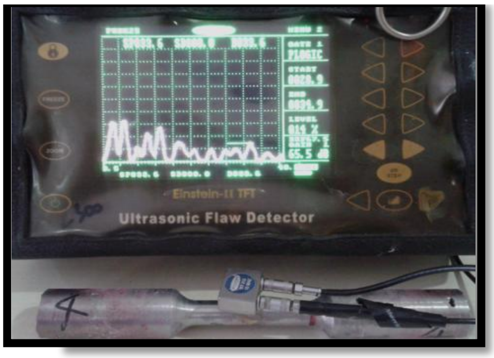


Sample 1 Defective

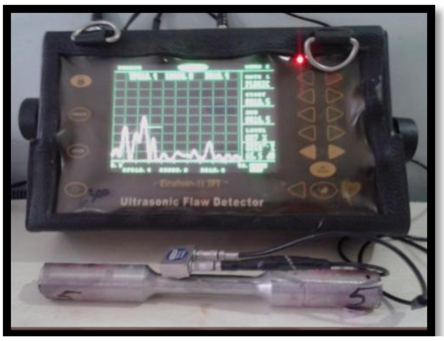
Sample 2 Defectless



Sample 3 Defectless



Sample 4 Defectless

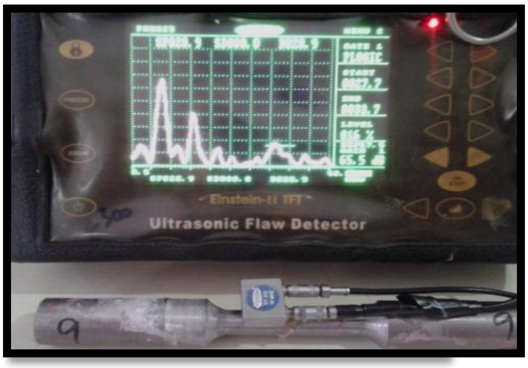


Sample 5 Defective

Sample 6 Defective

Sample 7 Defectless

Sample 8 Defective



Sample 9 Defective

Table [9]UT Observations

Sample No	UT Observations
1	At a depth of 12.5mm a sharp echo is observed it is a defect
2	Only four back wall echoes are observed at 10,20,30 & at 40mm so no defect is present
3	Only four back wall echoes are observed at 10,20,30 & at 40mm so no defect is present
4	At a depth of 33.6 mm a sharp echo is observed it is a defect
5	At a depth of 10.4mm and 30.4mm echoes are observed after the back wall echoes and these are the defects
6	At a depth of 13.8 mm and 31.2mm echoes are observed after the back wall echoes and these are the defects
7	Only four back wall echoes are observed at 10,20,30 & at 40mm so no defect is present
8	More echoes are observed at 12.9 mm these all related to defects
9	At a depth of 15.5mm and 28.9mm echoes are observed and they related defects

5.3 Pareto ANOVA observations

Computation scheme of Pareto ANOVA (ANalysis Of VAriance) for three level factors is shown in table [7]. 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 [10] and [11] respectively.

Table [10] Pareto ANOVA for Tensile strength

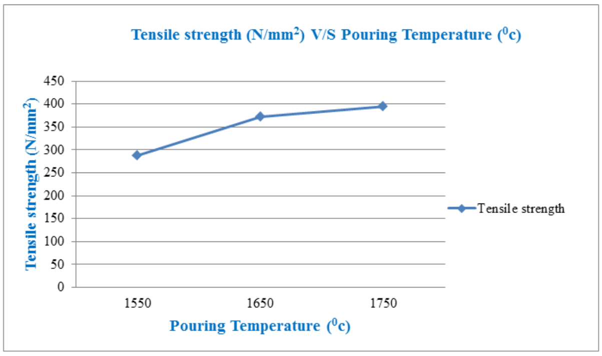
Factors	A	B	C	E	Total
Sum at factor level	147.529	153.526	149.072	150.997	457.123
	154.124	151.589	152.627	151.540	
	155.470	152.008	155.424	154.584	
Sum of squares of difference	108.365	6.232	60.809	22.410	197.816
Degree of freedom	2	2	2	2	8
Contribution ratio	54.78	3.15	30.74	11.33	
Optimum level	(1)	(3)	(2)		
	A_3	B_1	C_3		
Optimum values	1750^0C	30Sec	15min		

Table [11] Pareto ANOVA for Hardness

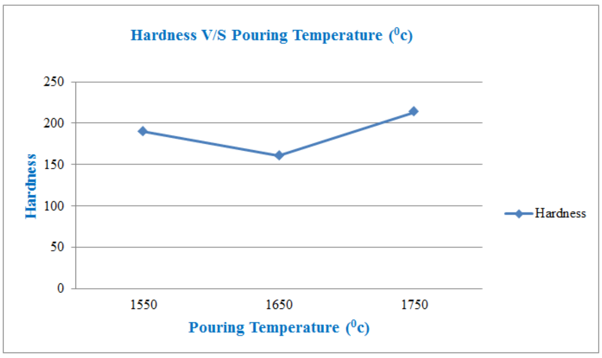
Factors	A	B	C	E	Total
Sum at factor level	136.886	139.026	135.308	134.642	410.338
	133.280	135.509	137.150	134.706	
	140.172	135.803	137.880	140.990	
Sum of squares of difference	71.251	22.844	10.541	79.790	184.426
Degree of freedom	2	2	2	2	8
Contribution ratio	38.63	12.39	5.72	43.26	100
Optimum level	(1)	(2)	(3)		
	A_3	B_1	C_3		
Optimum values	1750^0C	30Sec	15min		

5.4 Effect of Pouring Temperature on Tensile Strength and Hardness

Graph: 1 Main effect plot for pouring temperature on Tensile strength

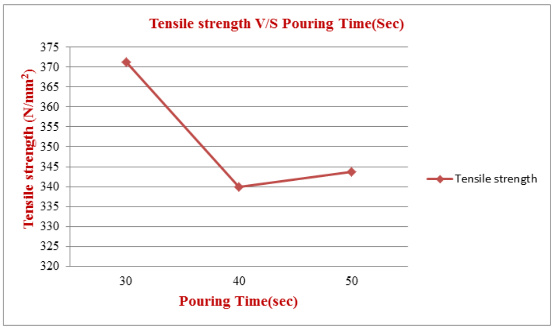


Graph:2 Main effect plot for pouring temperature on Hardness

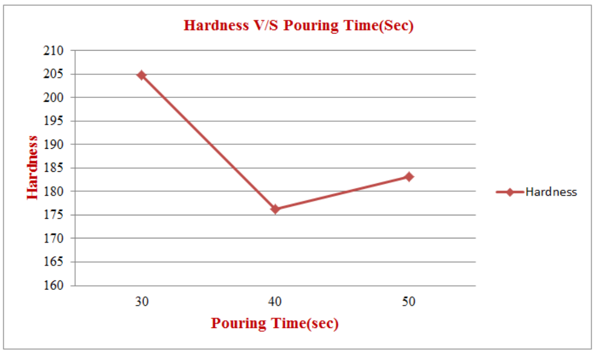


5.5 Effect of Pouring Time on Tensile Strength and Hardness

Graph: 3 Main effect plot for pouring time on Tensile strength

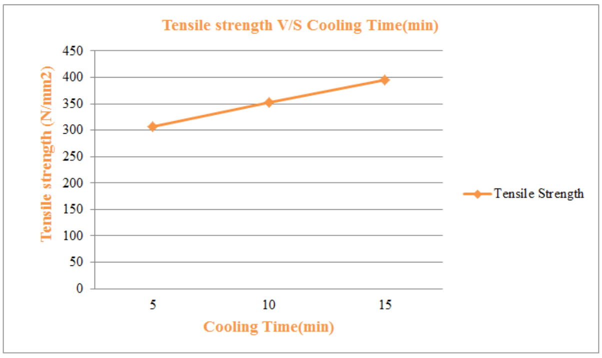


Graph:4 Main effect plot for pouring time on Hardness

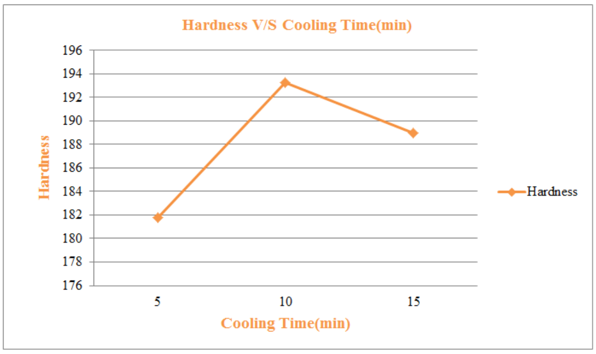


5.6 Effect of Cooling Time on Tensile Strength and Hardness

Graph: 5 Main effect plot for cooling time on Tensile strength



Graph: 6 Main effect plot for cooling time on Hardness



5.7 Discussion

From table [10], it can be seen that the third level of factor (A) give the highest summation (i.e. A_3, which is 1750^0C Pouring temperature). The highest summation for factor (B) is at the first level (i.e. B_1, which is 30 seconds pouring time) and the highest summation for factor (C) is at the third level (i.e. $C_{3,}$ which is 15 minutes cooling time). These predicted parameters are used in the casting sample preparation which indicated in table [2].

In table [11] it can be seen that the highest summation is at A_3 (1750^0C Pouring temperature), B_1(30 seconds Pouring time), and C_3 (15 minutes Cooling time). The predicted parameter for giving the highest hardness by Taguchi method is already used in our experiments as shown in Table [2] and it gives the highest hardness. This also proves the success of Taguchi method.

In both tables [10] and [11], it was found that the Pouring temperature contributes a larger impact on Tensile strength and Hardness of the casting samples when compared to cooling time and pouring time.

These results have proved the success of Taguchi method in the prediction of the optimum parameters for higher tensile strength.

VI.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 IS1030 steel 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 IS1030 steel are 1750^0C pouring temperature, 30 seconds Pouring time And 15minutes cooling time for tensile strength and 1750^0C pouring temperature, 30 second pouring time and 15 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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