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A Study to Optimize the Casting Process Parameters of Al-365/LM25 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 Aluminium365/LM25 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.**

Index Term: *Aluminium365/LM25, NDT methods, casting defects, Taguchi method, Pareto Anova, Tensile strength, Hardness*.

I.INTRODUCTION

Aluminium 365/LM25 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

2.1 Samples preparation

TheAl-365/LM25 is used as a material for samples preparation LM25 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 requiredConsequently, LM25 finds application in the food, chemical, marine, electrical and many other industries and, above all, in road transport vehicles where it is used for wheels, cylinder blocks and heads, and other engine and body castings. Table [1] shows the chemical composition of the alloy.

Table [1] Chemical composition of LM25 alloy

Element	Weight (%)
Copper	0.2
Zinc	0.1
Magnesium	0.27
Lead	0.1
Silicon	7.2
Tin	0.05
Titanium	0.2
Manganese	0.3
Nickel	0.1
Iron	0.5
Aluminium	Balance

An Electric furnace is used to melt the raw material, sample 1, 2 & 3 are poured at 700^{0}C and samples 4, 5 and 6 are poured at 750^{0}C and samples 7, 8, and 9 are poured at 800^{0}C. 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 theresulted 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.

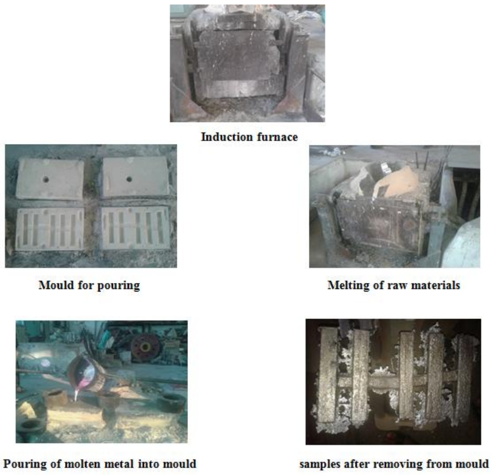
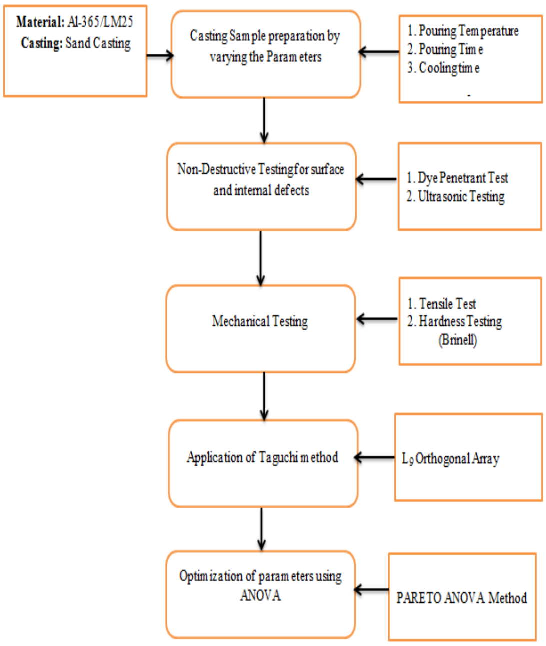


Fig [1] Experimental set up

Table [2] Control factors value for Sample preparation

Sample No	Pouring temp.(^{0}C)	Pouring time (sec)	Cooling time(min)
1	700	5	3
2	700	10	6
3	700	15	9
4	750	5	6
5	750	10	9
6	750	15	3
7	800	5	9
8	800	10	3
9	800	15	6

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. The testing procedure is shown in figure [2].

Fig [2[Steps involved in DPT

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. The figure [3] shows the UFD, TR probe and scanning of samples.

Ultrasonic flaw detector (UFD)

TR probe

Scanning of samples for defects

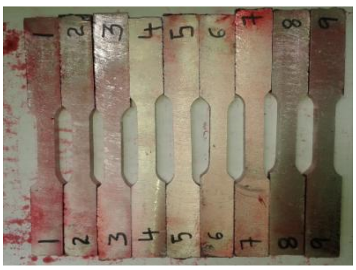
Fig[3] UFD,TR probe and scanning of samples.

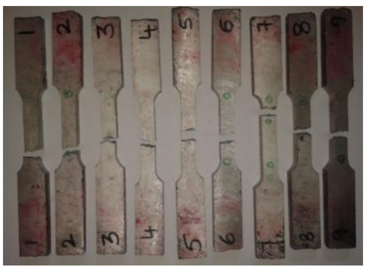
3.2 Mechanical Testing of samples

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 thickness for the holding proposes the 25 mm 12.5 mm (width and thickness) on both end is produced. The UTM is as shown in figure[4].

Fig(4) 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 [5] shows the Hardness Tester.

Fig [5] 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 Brinel hardness and tensile test.

Table [3]Control factors and levels

Factors	Control Factor	Level 1	Level 2	Level 3
A	Pouring temperature (^oC)	700	750	800
B	Pouring time (Sec)	5	10	15
C	Cooling time (min)	3	6	9

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)

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

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 1,2,3,6 and 9have indicated porosity as shown in figure, sample 8 has indicated porosity and cracks as shown in figure and sample4,5, and 7 are defectless 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 4		Defectless
Sample 5		Defectless
Sample 6		Porosity

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

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

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.

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].

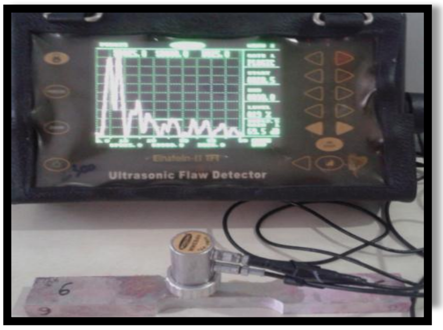
Sample 1 Defective

Sample 2 Defective

Sample 3 Defectless

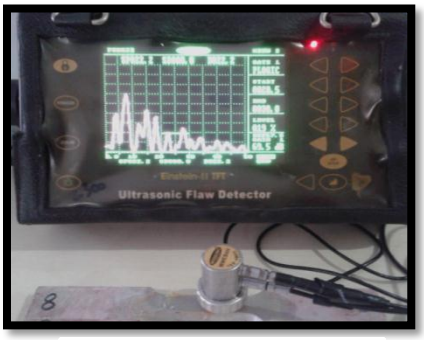
Sample 4 Defectless

Sample 5 Defectless

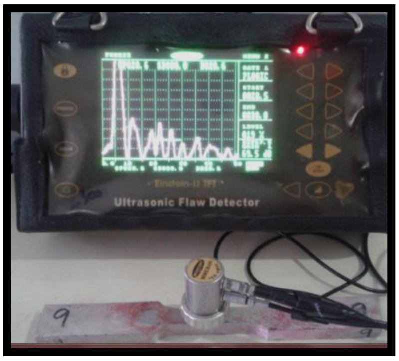


Sample 6 Defective

Sample 7 Defectless



Sample 8 Defective



Sample 9 Defective

Table [9]UT Observations

Sample No	UT Observations
1	At a depth of 12.6 mm a sharp echo is observed it is a defect
2	After first backwall echo At a depth of 18 mm a sharp echo is observed it is a defect
3	At a depth of 25.6 mm a sharp echo is observed it is a defect
4	Only four back wall echoes are observed at 10,20,30 & at 40mm so no defect is present
5	Only four back wall echoes are observed at 10,20,30 & at 40mm so no defect is present
6	At a depth of 12.8 mm,25mm 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 in between first and second back wall echoes that is in between 10-20mm these all related to defects
9	More echoes are observed in after first and second back wall echoes these all related to 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

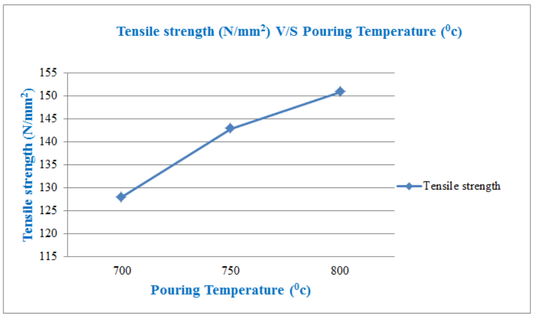
Factors	A	B	C	E	Total
Sum at factor level	126.41	128.46	128.04	128.35	386.35
	129.26	128.90	128.84	128.64	
	130.68	128.99	129.42	129.34	
Sum of squares of difference	28.372	0.483	3.082	1.539	33.476
Degree of freedom	2	2	2	2	8
Contribution ratio	84.75	1.45	9.20	4.60	100
Optimum level	(1)	(3)	(2)		
	A_3	B_3	C_3		
Optimum values	800^0C	15sec	9min		

Table (11) Pareto ANOVA for Hardness

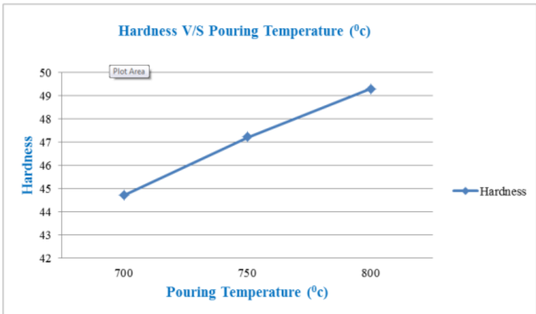
Factors	A	B	C	E	Total
Sum at factor level	98.535	98.837	100.611	99.083	299.617
	100.134	100.647	99.353	97.738	
	100.948	100.133	99.653	102.796	
Sum of squares of difference	9.042	5.220	2.590	41.179	58.031
Degree of freedom	2	2	2	2	8
Contributio n ratio	15.59	8.99	4.46	70.96	100
Optimum level	(1)	(2)	(3)		
	A_3	B_2	C_1		
Optimum values	800^0C	10Sec	3min		

5.4 Effect of Pouring Temperature on Tensile Strength and Hardness

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

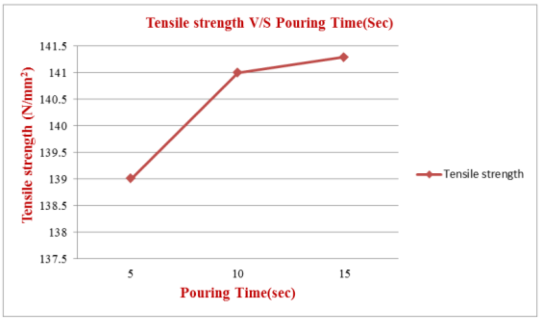


Graph:2 Main effect plot for pouring temperature on Hardness

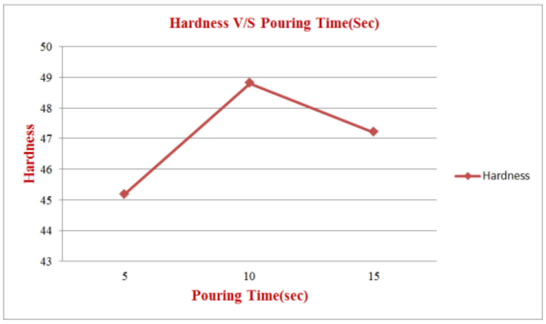


5.5 Effect of Pouring Time on Tensile Strength and Hardness

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

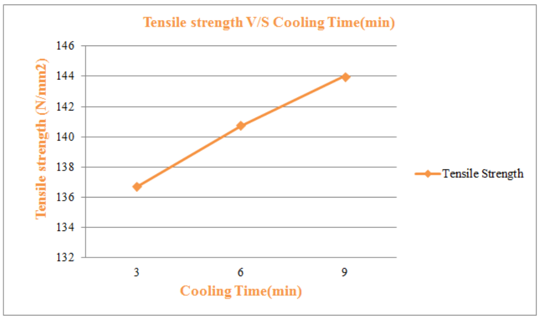


Graph:4 Main effect plot for pouring time on Hardness

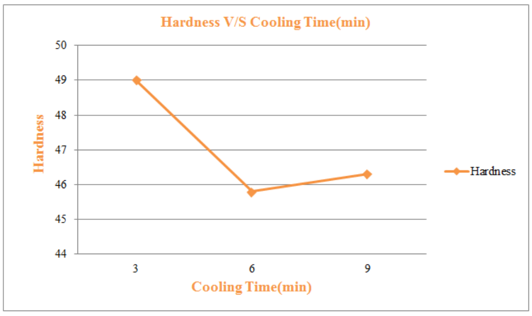


5.6 Effect of Cooling Time on Tensile Strength and Hardness

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 800^{0}C Pouring temperature). The highest summation for factor (B) is at the third level (i.e. B_3, which is 15 seconds pouring time) and the highest summation for factor (C) is at the third level (i.e. C_3, which is 9 minutes cooling time). These predicted parameters are not used in the casting sample preparation which indicated in table [2].

We conducted an experiment at the predicted parameters (A=800^{0}C, B=15 Sec and C=9 min), and tested the resulted sample by Tensile test. The resulted tensile strength was 170.64N/mm^2 which is greater than the tensile strength values in table [5] .These results have proved the success of Taguchi method in the prediction of the optimum parameters for higher tensile strength.

In table [11] it can be seen that the highest summation is at A3 (800^{0}C Pouring temperature), B2 (10 seconds Pouring time), and C1 (3 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.

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 Aluminium 365/LM25 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 365/LM25 are 800^0C pouring temperature, 10 seconds Pouring time And 9 minutes cooling time for tensile strength and 800^0C 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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