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Experimental Investigation of Process Parameters on Mechanical Properties of Aluminum Alloy Sand Cast Product

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ABSTRACT: Sand casting had become one of the most extensively used casting processes in the manufacturing environment, due its ability to produce wide variety of ferrous and non ferrous components in order to meet customers' needs and satisfaction. Globally, there is a lot of casting techniques, including sand casting. Over the 70% of castings are processed by sand casting only and the remaining are equally shared by remaining casting processes. In sand casting process pouring temperature of molten metal, permeability of sand, mould hardness plays a vital role in sand casting process to achieve the desire quality of product. Recently among other aluminium alloys available worldwide, Aluminium (6061) plays a major role in Aerospace, Automobile, Manufacturing and Marine industries. In current research work, the input process parameters considered as pouring temperature, permeability of sand, mould hardness and output responses like tensile strength, impact strength and Rockwell hardness are studied at three different levels making a combination of 27 experiments. The main objective of current study is to find out the optimal values of input variables on output responses of given process parameters in sand casting using Aluminium (6061) material. The experimental results shows that pouring temperature, permeability of sand and mould hardness play a vital role in effecting the output responses like ultimate tensile strength, impact strength and Rockwell hardness of sand casting.

Keywords: Sand casting, Aluminum (6061), Process Parameter, Mechanical Properties

1. Introduction

Casting is one of the oldest and cheapest process in any manufacturing industry among other manufacturing processes like Forging, Machining and Welding which manufactures ferrous and non ferrous materials by obtaining a metal object according to pattern prepared on solidification of the molten metal. The main purpose for every foundry company is production of high quality metal castings with minimal rejections so that they could satisfy needs and requirements of customer in the global market. According to Foundry Informatics Centre, in the World Casting Censes on December 2017, India ranks the Second Largest Casting Manufacturers in the World reported 5.4% increase in production to 11.35 million metric tons whereas China being First Largest Casting Manufacturers in the World reported a 5.4% increase since 2015 putting its total production at 47.2 million metric tons. Among most of the casting processes available worldwide, 70% of the castings are prepared only through sand casting process. Selection of Sand Casting process among the other casting processes is due to its Easy Development of Patterns, Excellent Geometrical Dimensions, Higher Rate of Production and Lesser Solidification Time.

The most common element known as aluminium exists in the form of aluminium oxide in the earth's crust.Aluminium has different physical and mechanical properties such as good electrical conductivity, brighter colour with low weight, high thermal conductivity and high corrosion

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resistance, etc. Similarly aluminium alloy casting has mechanical properties such as ultimate tensile strength, impact strength, hardness, percentage elongation, solidification time, etc.Among other Aluminium alloy materials, Aluminium Alloy 6061 has good tensile strength, Impact Strength and Rockwell Hardness. Hence it is used in many automobile and plumbing applications. The most important process parameters considered in this research are Pouring Temperature (650 ^{0}C, 700 ^{0}C and 750 ^{0}C), Permeability Number of Sand (30, 45 and 60) and Mould Hardness Number (60, 70 and 80). Permeability is the measure of ability of sand mould to emit gases from the cast part. Maximum permeability helps in removing the gases from the mould through the sand grains. All these parameters of sand casting after optimization improve quality of sand casting.

2. Related work

This section is presenting the structured literature review of process parameters of sand casting. There is various database like Springer-link, Emerald, Elsevier, Taylor & Francis, Google Scholar etc. have been selected for downloading the research paper. N. Ducic et al. (2017) implemented Genetic algorithm to optimize the geometry of the gating system maximizing the rate of filling. The optimized ingate cross section and height are 300mm^2& 110mm increases the rate of filling raising the casting quality and less molten metal consumption. Rahaini Mohd Said et al. (2017) conducted 2^k Factorial design with 16 levels of optimised process parameters. Optimal composition of green sand consisting of 100 g silica, 21 g bentonite, 6.5 g water and 6 g coal dust, with an acceptable permeability number of 598.3 GP. Mugeri et al. (2017) proposed the technique of Magma soft simulation to minimize the defects in casting by considering filling temperature and pressure with 5 test samples of different wall thickness. They also concluded that Fillability increases as wall thickness increases due to reducing heat transfer of molten metal and mould. R. Srivathsan Iyer et al. (2017) proposed Analysis of Variance (ANOVA) on grey cast iron castings to show the effect of process parameters like Moisture Content, Clay Content, and Green strength on Surface Roughness and Brinell Hardness, The optimal parameters for the grey cast iron in its experimental work are pouring temperature 1200^{0}C, Moisture Content 5%, Green Strength 50, Clay Content 5. G. Mahesh et al. (2017) performed Design of Experiments using Taguchi Method for optimization of vent hole angle and vent hole diameter at 780 ^{0}C Pouring Temperature for Aluminium (6063) using sand casting process. Anil Rathore & Prof.F.Ujjainwala (2017) proposed L4 orthogonal array and Taguchi method for optimization of process parameters like Pouring Temperature 1390-1420 ^{0}C, Pouring Time 13 seconds for grey cast iron. Narayana Swamy.C & Natarajan.K (2016) carried out the study of various casting defects for one year from April 2014 to March 2015 in Ammarun Foundries, Coimbatore saying that the percentage of these casting defects vary from 12.87% to 15.02%. They studied casting quality depends on sand content, operating methods, molten metal consistency and environmental conditions etc. Bhushan Kamble (2016) carried a research on various casting defects and their causes. He concludes that rejection in casting just won't happen usually but due some wrong steps taken in the cycle of manufacturing a casting product which can result to about nearly 50% of rejections if not controlled. Himanshu.K & B.Ravi. (2016) showed effect of molding parameters on mechanical properties is done by Taguchi method. Optimization of mould parameters have been considered such as curing time 4h, 2.4% binder and 40 GFN gives highly dimensional quality parts. V.M.Mohammed et al.(2016)applied Taguchi's method to sand casting process with optimised parameters reduces rejections in Al-Si alloy casting also by setting the parameters like Pouring temperature 690^{0}C and Holding time 4min if are optimised

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reduces the rejections in casting. Narayanaswamy, C & Natarajan, K. (2016) carried out experiments by FMEA Techniques, ANOM and setting of process parameters is done to minimize casting defects.Optimum parameters like pouring temperature 1460^{0}C, inoculants 0.3, moisture content 3.1%, and Sand binder ratio 60:0.1 were observed. Wen-Jong Chen et.al (2016) proposed Taguchi and ANOVA the process parameters in a gating system of sand casting. The CBQPSQ algorithm reduces filling time, solidification time and oxide ratio that improves casting quality of Al A356 Alloy. Weldeanenia K. G &Abebe A. T (2016) applied the Orthogonal array, Taguchi method, ANOVA method on the process parameters of 46MnSi4 and effects were analysed using Minitab software .Also optimization of parameters such as pouring time 82 sec, pouring temperature 1672^{0}C, size of runner 62cm^2 using various methods was carried out to improve quality of casting. Datau S.G et al. (2012) varied the mould temperature and pouring temperature the mechanical properties such as impact tensile strength, hardness were studied. Also it was found that there is increase in ultimate tensile strength, elongation, hardness with the increase in the pouring and mould temperature and decrease in runner size. Pang, S., et al. (2012) carried out thermal analysis which results in increase of cooling rate decreasing solidification and Solidus temperature. Vickers hardness test enhances hardness with increasing of cooling rate. Tensile properties of UTS & TYS of GW103K alloys first increases then it decreases. AGS of α-Mg decreases from 59µm to 39µm. Cooling rate was 0.7^{0}C/s for a thickness §=30mm. Magdalen Nowak & Haribabu Nadendla. (2012) carried out Investigation through Grain refining, Thermal analysis, Micro structural analysis, and ultimate tensile Strength and Vickers hardness test. Low cooling rate (0.03-100^0/s) with novel grain refiner (Al-Ti-B) can be used to produce complicated parts with thin walls with high strength, hardness and ductility. Merlin, M., &Garagnani, G. L. (2009) concluded that Tensile Strength tests, T6-heat treatment, Taikai Analysis were performed on both full cores & empty cores.T9-heat treatment improve ductility of Al alloys and in Taikai analysis, empty cores reduces production cost, weights, time over full cores. S. Guharaja & A Noorul (2006) applied Taguchi methods at 3 levels of process parameters of range of moisture content 2.6%-3.0%, green strength 650-950 gm/cm^2, mould hardness number 70-90 and permeability number 235-275. Meneghini, A., &Tomesani, L. (2005) carried out investigation with HTC of A356 alloy was done with 2 K-type thermocouples, on 3 types of casting chills& on casting chill interface .Cu chills have greater cooling effect (4-8 kW/m^{2}K) at 375-400^{0}C, Al chills at (3-6 kw/m^{2}K) at400-420^{0}C & Grey C.I chills at(1-2 kW/m^{2}K) at 490-530^{0}C.

3. **Materials and Methodology**

3.1 Material used

Aluminium alloy 6061 is a flexible heat-handling extruded silicone and magnesium-containing alloy. It has excellent welding characteristics, relatively high strength, better workability and higher resistance to corrosion. Aluminium 6061 has its application in construction of aircraft structures such as wings and fuselages of Homebuilt Aircrafts, Yacht construction, Manufacturing of automotive parts like master cylinder and chassis of Audi A8, SCUBA (Self Contained Underwater Breathing Apparatus) Tanks, Manufacturing of Bicycle Frames, Packaging of foods and Beverages and Helicopter Rotor Components.

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Table 3.1: Composition of material

Element	Si	Mg	Fe	Cu	Mn	Cr	Zn	Ti	Other	Al
Amount (wt. %)	0.4-0.8	0.8-1.2	Max 0.7	0.15-0.40	Max 0.15	0.04-0.35	Max 0.25	Max 0.15	Max 0.05	95.85-98.56

3.2 Experimental Methodology

The current research work carried out by experimentation work of sand casting parameters for better results. Sand casting process is used for experimental work. The experimental works are having the combination of pouring temperature, permeability of sand and mould hardness. The range of input variable of sand casting process with proper combination at pouring temperature of 650, 700 and 750 ^{0}C are shown in figure 3.1, 3.2 and 3.3 respectively.

3.3 Sand Casting Process Parameters:

In sand casting process, there are many parameters but the most significant parameters considered in current study are Pouring Temperature (^{0}C), Permeability (Number) and Mould Hardness (Number). The range of Pouring Temperature was selected as (650-750^{0}C), Permeability Number as (30-60) and Mould Hardness Number as (60-80) as shown in table 3.2.

Table 3.2: Process Parameters with their ranges and values at three levels

SN.	**Input Parameters**	**Levels**		
		Level 1	Level 2	Level 3
1.	Pouring Temperature(^{0}C)	650	700	750
2.	Permeability (Darcy)	30	45	60
3.	Mould Hardness (Number)	60	70	80

3.5 Preparation of a Cast

The preparation the 27 sand moulds have been done varying Pouring temperatures 650 ^{0}C, 700 ^{0}C and 750 ^{0}C, Permeability of sand 30 Darcy,45 Darcy and 60 Darcy and Mould Hardness Number 60,70 and 80 second step is to pour the molten metal in the cavity of mould. The aluminium material is heated in diesel crucible furnace and temperature is measured using K-type Thermocouple. First of all, take the pouring temperature of 650^{0}C and pour it in the mould which having high permeability of sand and Mould Hardness Number 80. The pouring of molten metal in high permeability sand mould is shown in figure 3.1. Then take the second sand mould which having medium permeability of silica sand and pour the molten material with same pouring temperature of 650^{0}C through runner in the mould. Finally, take the third sand mould which is having low permeability of silica sand and pour the molten material with same pouring

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temperature of 650 ^{0}C and mould hardness number 60 The procedure is same for different specimens casted at 700^{0}C and 750^{0}C

Figure 3.11: Molten material pouring (temperature 650^{0}C)

3.6 Tensile Testing

A casting specimen is found from the above sand casting process and now it is required to make a specimen for the tensile testing for the universal testing machine. The piece is machined to the required specification as shown in Figure 3.17. The equipment used for the tensile test is universal testing machine, model SSRT 31342. The capacity of machine is 100 KN and it is hydraulically operated. Totally about twenty seven tensile tests have been performed in which first nine tests are performed at pouring temperature 650^{0}C varying permeability of sand as 30, 45 and 60 Darcy and mould hardness number 60, 70 and 80. Another nine tensile tests at 700^{0}C with varying permeability of sand 30, and mould hardness number and similarly the last nine tensile tests have been performed at 750^{0}C.

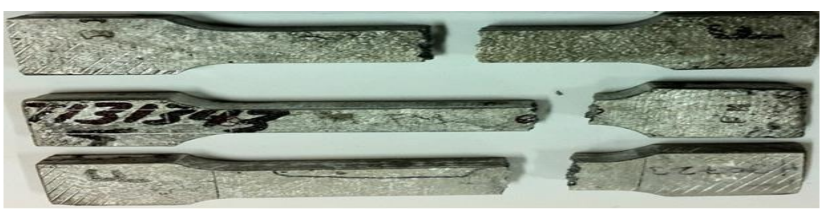

Figure 3.17: Specimens for Tensile Testing

3.7 Impact Testing

The casting specimen had been used for making the impact testing sample. The three samples from each combination of pouring temperature and permeability of sand is prepared for impact testing. The equipment used for this test is the impact testing machine, WOLPERT, model SM 201011. The capacity of machine is 150 Joule. The pendulum is raised to the maximum height and the test specimen is placed in horizontal direction at the specimen holder. The notch side is placed in the opposite direction of pendulum strikes. Then set the pointer at zero reading in the given scale. The pendulum is released and strikes the specimen at the notch. The pointer reading is noted. The difference between initial reading and final reading is the amount of energy that is used for failure of the specimen. The specimen for impact test is machined to specification using a milling machine shown in Fig 3.32. Totally about 27 impact tests have been performed in which first nine tests are performed at pouring temperature 650^{0}C varying Permeability of sand as 30, 45 and 60 Darcy and mould hardness number 60, 70 and 80. Another nine tests at 700^{0}C

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with varying permeability of sand and mould hardness number and similarly the last nine tensile tests have been performed similarly at 750^0C.

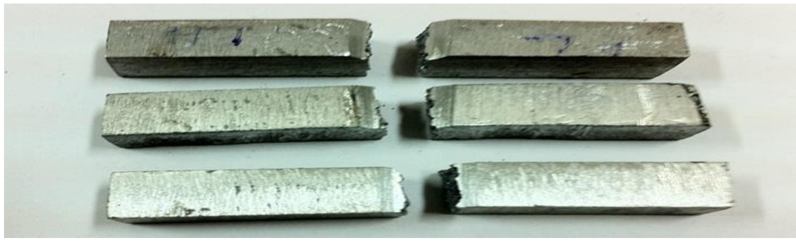

Figure 3.32: Specimens for Impact Testing

3.8 Hardness Testing

Hardness is the measurement of resistance of a metal to plastic deformation.

Rockwell hardness test: The Hardness Tester Rockwell tests penetration resistance. The Rockwell tester tests the thickness and the hardness is shown on a cell connected to the press, instead of measuring the print diameter. In the outside circle, the dial numbers are black and the inside numbers are red. Difference between penetration depth and low loads is the basis for Rockwell hardness numbers.

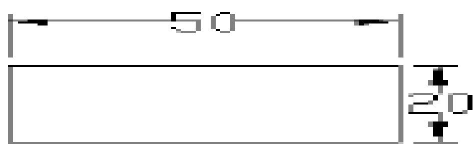

Figure 3.39: Specimen for Hardness

The specimen which is used for hardness testing having same dimension as shown above is at three value of hardness is recorded. It is carried out in 7.5 seconds and the reading was taken for every specimen at different point on the specimen. The hardness is determined by the depth of indent produced by a steel ball. The correct indenter and a selected pre-load stop of 100 kg at 10 kg is 5 mm. The test specimen is placed on the table. A hand wheel is used manually to raise the spindle toward the interior until the small needle has made this full turn which signal the application of the pre-load to the exact zero setting on the scale ring of the dial gauge. In the same way as the tests performed for tensile and impact strength similarly about twenty seven hardness tests have been performed varying pouring temperatures, permeability of sand and mould hardness number as shown in table 4.1

4. Result and Discussion

4.1 Testing Result of Sand Cast Product

The values of mechanical properties as tensile strength, impact strength and impact strength have been estimated by various testing methods and the results are shown in table 4.1.

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Table 4.1: Results of all Process Parameters

Pouring Temperature	Permeability	Mould Hardness	Tensile Strength	Impact Strength	Rockwell Hardness
650	30	60	64.867	6.0	34.2
		70	62.955	7.0	33.0
		80	61.238	7.9	32.1
	45	60	66.860	5.0	37.0
		70	64.138	6.4	36.1
		80	62.834	7.1	34.8
	60	60	68.868	4.0	38.0
		70	66.765	5.0	37.8
		80	65.533	5.9	35.9
700	30	60	90.353	5.0	45.0
		70	88.636	6.5	43.9
		80	87.130	7.1	42.1
	45	60	94.033	4.1	46.0
		70	92.910	5.4	44.2
		80	90.450	6.2	42.9
	60	60	97.714	3.6	48.7
		70	95.310	4.7	46.8
		80	94.225	5.6	45.6
750	30	60	101.226	3.2	48.0
		70	100.510	4.3	49.7
		80	98.675	5.0	47.4
	45	60	103.003	2.6	56.7
		70	100.975	3.4	54.6
		80	99.732	4.6	53.1
	60	60	105.00	2.4	65.0
		70	103.510	3.1	61.1
		80	102.410	4.1	58.7

4.2 Tensile strength of specimen at pouring temperature of 750 ^{0}C

From the experimentation work, it has been observed that if the permeability of silica sand for sand mould is increased; the tensile strength of cast is increased. It is because the rate of cooling in coarse grain will be high due to more heat transfer rate by air cooling in between the space of grains available. So tensile strength is high at high permeability of sand (60).The value of tensile strength at different permeability of sand is shown in table 4.4

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Table 4.4: Tensile strength with different permeability of sand at pouring temperature 750 ^{0}C

Permeability of sand	Tensile strength (MPa)
30	101.226
45	103.003
60	105.000

Mould Hardness	Tensile strength (MPa)		
	30	45	60
60	101.226	103.003	105.00
70	100.510	100.975	103.510
80	98.675	99.732	102.410

From the graph of figure 4.43, it is observed that if the permeability of silica sand is increased; the tensile strength is increased.

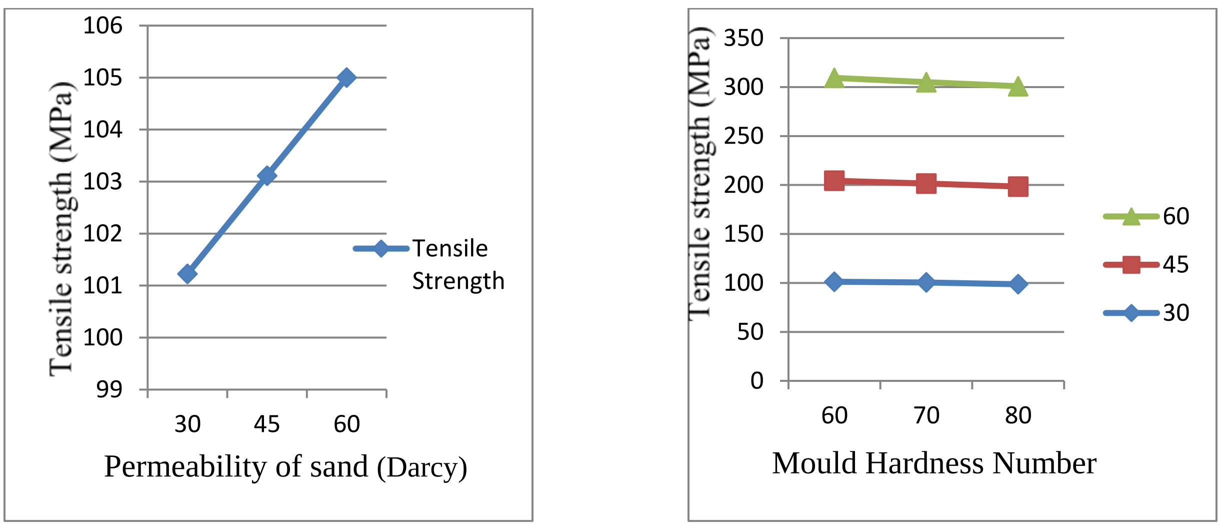

Figure 4.43: Effect of Permeability of sand and Mould Hardness Number on Tensile strength at Pouring Temperature of 750 ^{0}C

4.3 Impact strength of specimen at pouring temperature of 750 ^{0}C

The experimentation work is shown that if the permeability of mould sand is increased then impact strength is decreased. It is because at high permeability of mould sand there fine grain of cast is formed due to rapid cooling of molten metal. So they can store less energy that resist to failure. In the table 4.8, it is shown that when the permeability of sand is increased from 30 to 60, the impact strength decreased from 5.0 joule/mm^2 to 3.6 joule/mm^2.

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Table 4.8: Impact strength with different Permeability of sand at pouring temperature 750 ^{0}C

Permeability of Sand (Darcy)	Impact strength	Mould Hardness	Impact Strength (Joule/mm^2)		
	Mean		30	45	60
30	3.2	60	3.2	2.6	2.4
45	2.6	70	4.3	3.4	3.1
60	2.4	80	5.0	4.6	4.1

The graph shows that if permeability of mould sand is increased then impact strength is decreased as shown in figure 4.47

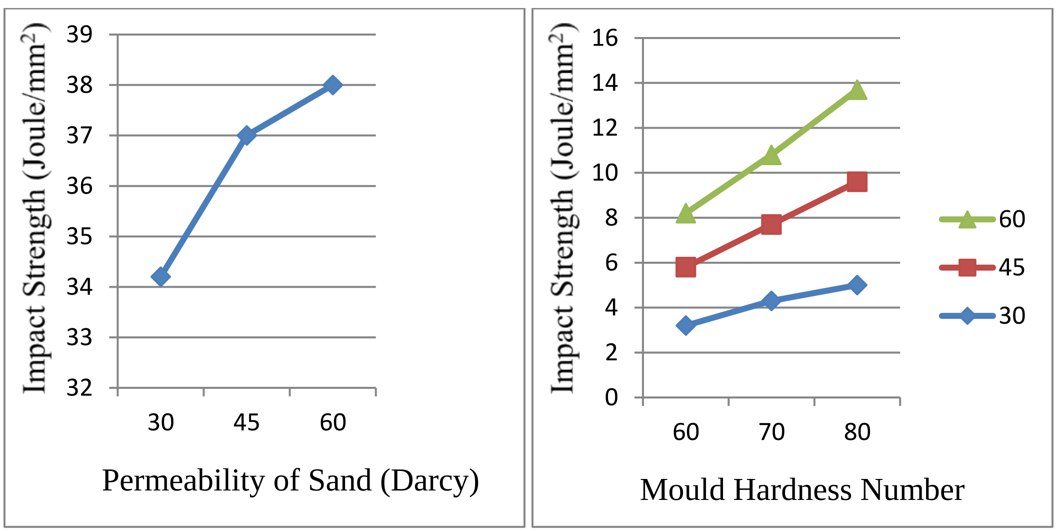

Figure 4.47: Effect of permeability of sand and mould hardness on impact strength at pouring temperature of 750 ^{0}C

4.4 Hardness of specimen at pouring temperature of 750 ^{0}C

Here it is observed that if the permeability of mould sand is increased then the macro hardness (Rockwell hardness) is increased because the cooling rate is increased with increase the grain size of mould sand. And if cooling rate is fast then fine grain is formed and so Rockwell hardness is increased with increasing the permeability of sand. This is shown in table 4.12

Table 4.12: Hardness with different permeability of sand at pouring temperature 750^{0}C

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Permeability of sand (Darcy)	Rockwell Hardness
	Mean
30	48.0
45	56.7
60	65.0

Mould Hardness	Rockwell Hardness (HRB)		
	30	45	60
60	48.0	56.7	65.0
70	49.7	54.6	61.1
80	47.4	53.1	58.7

In the figure 4.51, the graph is showing that if permeability of sand is increased with pouring temperature of 750 ^{0}C, then the value of hardness is increased.

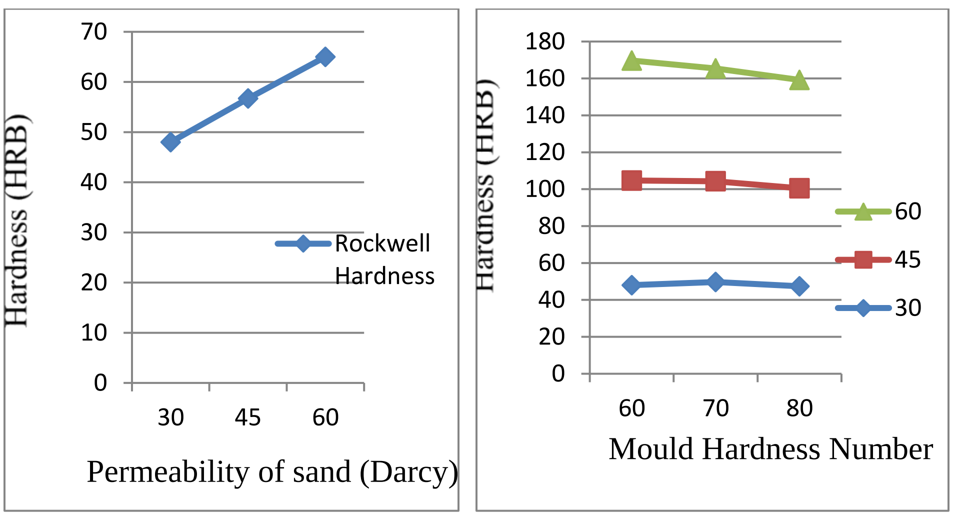

Figure 4.51: Effect of Permeability of sand on Hardness at pouring temperature of 750 ^{0}C

5. Conclusion and Future Scope

This experimental investigation is used to predict ultimate tensile strength, impact strength and Rockwell hardness of Aluminum (6061)by sand casting process using Experimental Method. The ultimate tensile strength is measured using Universal testing machine and Impact strength is measured using impact testing machine, Hardness using Rockwell hardness testing machine. Casting of Aluminum (6061) material is presented with enhanced mechanical properties and process parameters such as pouring temperature, permeability of sand and mold hardness effect the output response like tensile strength, impact strength and hardness.

- It is discovered that the pouring temperature and permeability of mould sand significantly affect the mechanical and metallurgical properties of sand cast aluminum alloy. The tensile strength and hardness increased with increased the pouring temperature of molten metal due to increasing the cooling rate of molten metal.

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- It is investigated that if permeability of mould silica sand is increasing, the tensile strength and hardness is increasing because the fine grains of cast formed with high permeability of mould sand.
- The impact strength of aluminum sand cast is decreased with increased the pouring temperature of molten metal and the permeability of mould sand because the energy storage capacity of fine grains are less.
- As the pouring temperature is increased from 650^0C to 750^0C and the permeability of mould sand is increasing from 30 to 60, a fine grain structure of aluminum sand cast is formed. Because the ASTM grain number are increased with increasing the pouring temperature and permeability of sand.
- For this alloy, the pouring temperature to achieved improved mechanical properties ranges from 700 ^{0}C to 750 ^{0}C. Also for good mechanical properties, the permeability of sand should be at least 50.

These results are helpful for small scale and large scale foundry industries for increasing the production rate and enhancing mechanical properties of the material. Based upon this experimental investigation the tensile strength, impact strength and hardness are superior at ‘larger is better’ condition. This study is precious for researchers, manufacturers compared to previous industrial process and gives the enhanced knowledge of Aluminum (6061) in sand casting process.The future scope on this study is to check the mechanical and metallurgical testing by changing the composition of molten metal for sand casting.

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