Behaviour of Aluminium Alloy Casting with the variation of Pouring Temperature and Permeability of Sand

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Abstract: The effect of pouring temperature and permeability of sand on the mechanical and metallurgical properties of aluminium alloy part produced through sand casting was investigated. Al-4%Si alloy was used as a molten metal and silica sand was used for preparing the mould. The pouring temperature ranges of 700 ^{0}C, 800 ^{0}C and 900 ^{0}C and permeability range of moulding sand 30 and 60 Darcy was considered. The mechanical properties of aluminium alloy casting studied were hardness and impact strength. The result showed that the selected parameters significantly influence the mechanical and metallurgical properties of aluminium alloy casting. As the pouring temperature increased, fine grain structure of casting formed and hardness was increased but impact strength decreased. If the permeability of moulding sand was kept high, the hardness was high and impact strength was low and also fine grain structures of cast were formed.

Keyword: Aluminium Alloy, Hardness, Impact Strength, Microstructure, Pouring Temperature, Permeability of sand, Sand Casting.

1 Introduction

The sand casting is an oldest process of manufacturing of any desired product. For an engineer, the knowledge and understanding of different casting parameters in casting metals and alloys is as significant as the cast products. Sand casting is defined as pouring the molten metal in the desired shape of cavity followed by solidification process and finally a cast is obtained of required dimensions [1]. Specific casting parameters such as pouring temperatures, rate of pouring, fluidity, composition of metal and permeability of sand are of the top most importance for consideration if sound casting is to be achieved [2]. In recent years, aluminium alloy become one of the most important engineering material in views of machinability, formability, weldablity and castablity. Aluminium alloy is classified into wrought alloys or cast alloy. One of the cast alloys is aluminium silicon alloy which show excellent castability and good pressure tightness. It has good flow characteristics and a typically ultimate tensile strength of 140-270 MPa [3]. The difference in the structure of the casting occurs due to the non-uniform cooling of the molten metal in the mould. This difference results in low mechanical properties, if not controlled will affect the performance of the casting while in use [4]. It is established that to ensure uniform cooling of the molten metal in the mould, the law of uniform flow must be maintained. The task of ensuring that a uniform microstructure is formed in a casting depends on the ability to maintain a law of uniform flow during the feeding of the mould. In casting, especially sand casting, it is difficult to maintain this law because of the difficulty of controlling its process parameters. Therefore, it is difficult to produce a casting with uniform microstructure. The non uniform formation of microstructure in castings can result to poor mechanical properties and this has been one of the main problems with which physical metallurgy is concerned [5]. Solidification time is one of the very important parameters used for assessing the properties of the material. Aluminum casting alloys with silicon as the major alloying elements are the most important commercial casting alloys because of their superior casting characteristics. The influence of different casting method on solidification time and mechanical properties of Al-Si alloys against both the molding conditions and silicon content showed that different cooling rates and solidification times can produce substantial variation in the resulting structure and properties [6]. The study of modeling by using the Network Analysis Software and experimental investigation of solidification process in sand casting 2-ingate mould and 3-ingate mould of sand results that the experimental temperature curves are generally higher than modeling for mould. This is because trapped air and porosity of the sand mould. Since the sand mould has a lot of air gaps, the temperature should be higher than expected in the simulation [7]. The different casting parameters such as modification, superheat temperature, mould hardness and mould design can change the microstructure and residual stresses of castings. The microstructure of Al-Si cast alloys

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is influenced by the morphology of silicon particles (shape, size and distribution), aluminum grain size and dendrite parameters. Dimensional changes resulting from casting caused by residual stresses can particularly affect the quality of near net shape castings [8]. The micro structural changes associated with these parameters can be study by optical microscopy, scanning electron microscopy and image analysis. The residual stresses decreases with lowered superheat, temperature and mould hardness and the residual stress increases both with adding a eutectic modifier and with change of casting design [9]. There is also influence of mould preheating, gating design and wall thickness on the microstructure and tensile properties of cast specimens. Casting and mould preheating temperatures have minor influence on mechanical properties. However, gating design (bottom filling, top filling) also affect the microstructure and tensile properties of cast specimens which leads to casting defects that seriously impaired the mechanical properties. Generally, tensile properties increased with a decrease of section thickness due to a reduction of dendrite arms spacing and grain size [10]. Most important is the effect of runner size, mould temperature and pouring temperature on the mechanical properties in the sand casting product. These effects can be decreased by tapering the size runner towards the mould cavity and preparing the mould by preheating with the temperature range of 25- 230 ^{0}C while having the pouring temperature within the range of 700 - 850 ^{0}C [11].

2 Experimental Works

Preparation of the Mould

At first, moulding sand was prepared according to low and high permeability. The permeability is the amount of air can trapped through the sand and it depends upon the size of sand grains. If the size of grains of moulding sand are coarse resulting permeability is high. Otherwise low permeability of moulding sand will be there. Then the moulding sand was added to the pattern and rammed, properly. After ramming the mould box containing the pattern was turned upside down and the parting sand was applied. The cope was placed on the drag. The position of the gate and the circular wooden riser were located in the mould box. When properly rammed, the cope and the pattern were removed. By repeating this process, the total six moulds were prepared by using three low permeability sand and others three using high permeability sand.

Casting of Specimens

To study the effect of the pouring temperature and permeability of moulding sand, a total 6 specimens were produced as follows:

First the molten metal was poured at temperature of 700 ^{0}C in two moulds which having low and high permeability of moulding sand respectively. Again repeated this process at the pouring temperatures of 800 ^{0}C and 900 ^{0}C.

Specimen for Impact Test

The specimens for impact test were machined to specifications using a shaper machine as shown in Fig. 1. The impact testing machine has the capacity of 150 joule. The pendulum was raised to the maximum height and the test piece was placed horizontally at the specimen holder. The pointer's reading was noted. The pendulum was released which strikes the specimen at the notch. The pointer's reading was noted again. The difference between the readings is the energy that was used to fail the specimen. This process was repeated for other specimens. The specimens after impact testing with different pouring temperature are shown in Fig. 2.

The impact strength of the specimen was determined as follows= energy expended/ cross sectional area of the specimen.

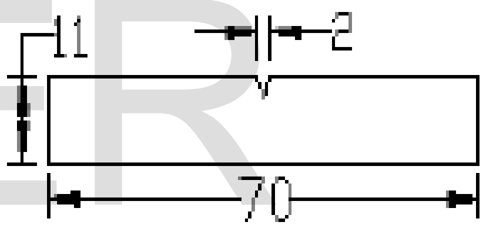

Fig. 1. Specimen for Impact test

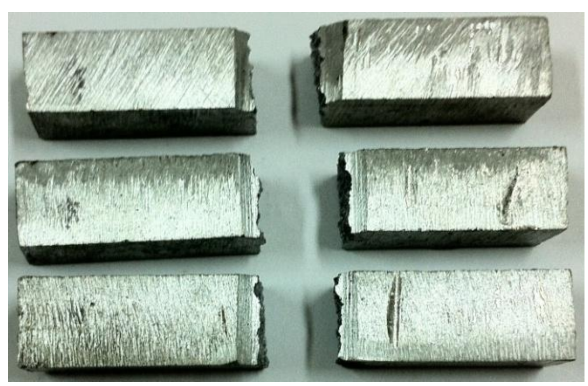

Fig. 2. Specimens after Impact test

Specimen for Hardness Test

The specimen which was used for hardness testing having the dimensions as shown in Fig. 3. By using this specimen; the value of hardness was recorded at three different locations on the same sample. The Rockwell tester was used for testing the hardness of the specimen. 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 Rockwell test the depth of the indenter penetration into the specimen surface is measured. The indenter may be either a hardened steel ball with diameter 1/16”, 1/8”.

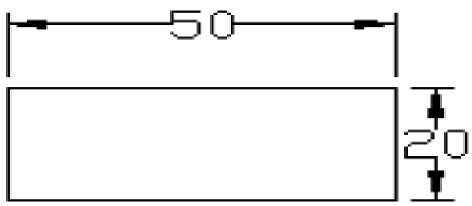

Fig. 3. Specimen for Hardness test

Specimen for metallurgical testing

The microstructure testing is done by using metallographic testing machine in the metallurgy lab. Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 10x magnification. The microstructure of a material (which can be broadly classified into metallic, polymeric, ceramic and composite) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance, and so on, which in turn govern the application of these materials in industrial practice. The specimen which was used for metallurgical testing is shown as Fig. 4.

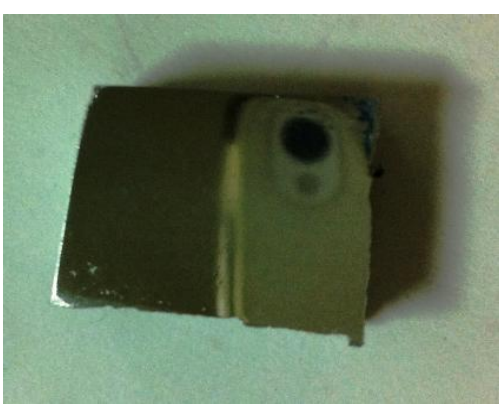

Fig. 4. Specimen for metallurgical test as crystal clear shown the mirror image of camera

3 Results and Discussions

The chemical composition of the aluminum alloy is presented in Table 1. The results of the pouring temperature and permeability of moulding sand on mechanical properties of aluminum alloy parts are shown in Table 2.

From Table 2, it was observed that an increase in pouring temperature resulted to decrease in the impact strength. However, for the same increase in the pouring temperature, the hardness increased. When pouring temperature increased, the rate of cooling was also increased and with the increase of cooling rate, fine grain structure of casting were used to formed. The fine grain structures always have high hardness. But the impact strength is inversely proportional to hardness, so with increasing of hardness, the impact strength was decreased.

Table 1: The chemical composition of the aluminum alloy

Element	Al	Si	Fe
Concentration (wt%)	93.9	4.0	1.5

Table 2: The mechanical properties at different pouring temperature and permeability of sand

Pouring Temperature (^0C)	Permeability of moulding sand (Darcy)	Rockwell Hardness (HRB)	Impact strength N/mm^2X10^{-2}
700	30	34.2	6
	60	38.0	4
800	30	45.0	5
	60	48.7	3.6
900	30	48.0	3.2
	60	65.0	2.4

From Fig. 5(a), it is shown that when the permeability of sand was low, the hardness was increased very rapidly from 700 ^0C to 800 ^0C but increasing slowly from 800 ^0C to 900 ^0C because at high temperature the crystal of molten metal start to burn and gases escaped out which are trapped in the cast product. But from Fig. 5 (b), the hardness is increase by more rates at pouring temperature from 800 ^0C to 900 ^0C than 700 ^0C due to fast cooling rate at high permeability of sand.

From Fig. 6, 7 and 8, the variation of Mechanical Properties at different permeabilities of sand with respect to the pouring temperature of 700 ^{0}C, 800 ^{0}C and 900 ^{0}C of molten metal are shown respectively.

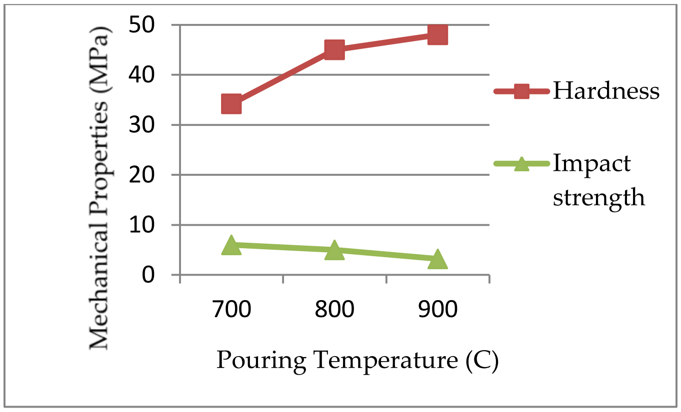

Fig 5(a): Effect of pouring temperature on mechanical properties at low permeability of moulding sand

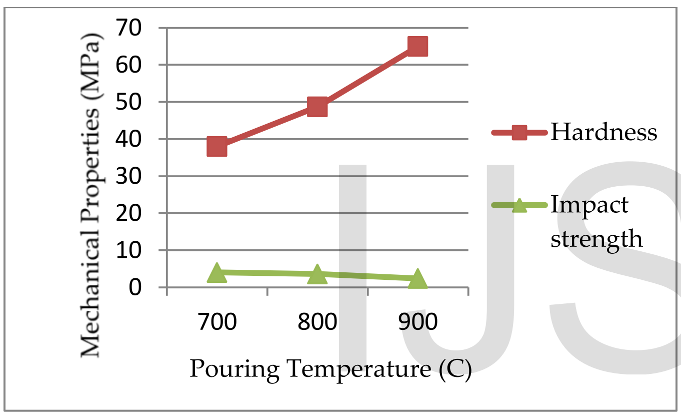

Fig 5(b): Effect of pouring temperature on mechanical properties at high permeability of moulding sand

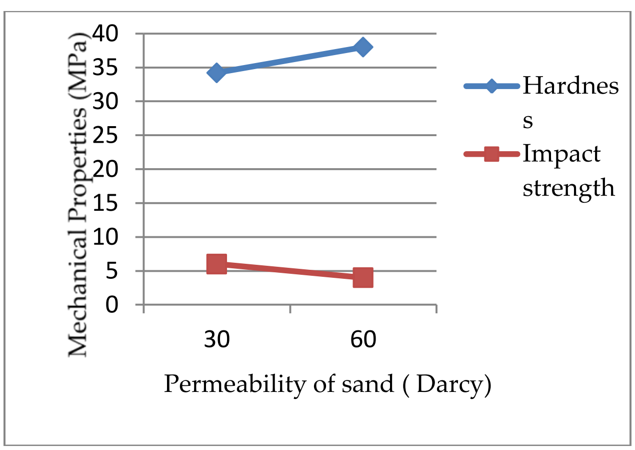

Fig 6: Effect of permeability of sand on mechanical properties at pouring temperature of 700 ^{0}C

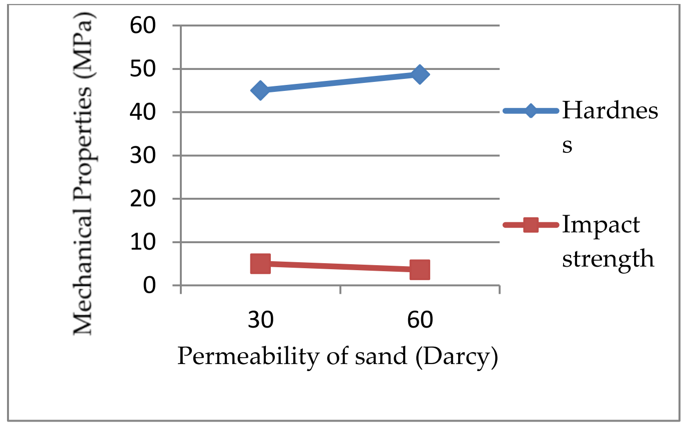

Fig 7: Effect of permeability of sand on mechanical properties at pouring temperature of 800 ^{0}C

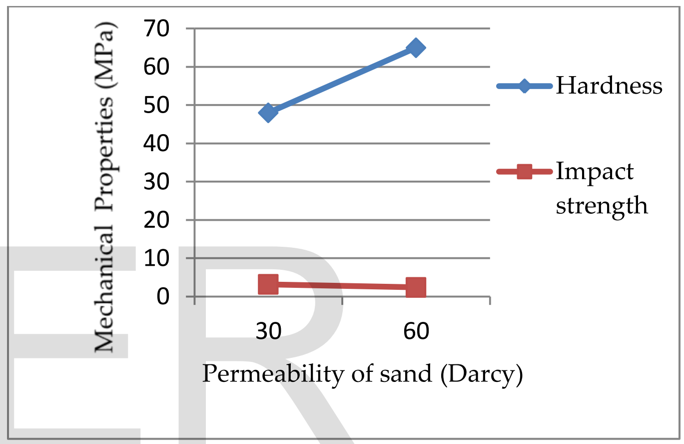

Fig 8: Effect of permeability of sand on mechanical properties at pouring temperature of 900 ^{0}C

For any material, the mechanical properties mainly depend upon the micro structure of the material. In the micro photo the number of grains is calculated by using one standard formula given below in equation 1:-

$N= 2^{n-1}$ --------- (1)

Here N = number of grains per square inch.

n = ASTM grain number

Here one square inch from the photo micrograph taken at the magnification of 15. At a magnification of 10, one square inch region from the 15 magnification image would appear as 0.64 inch^2. This ASTM number will be different for each micro structure phase. If the magnification power of micro scope is decrease then the grain per square inch is increase.

In this study, the value of ASTM number n is calculated at the magnification of 15 for different pouring temperature of 700 ^{0}C, 800 ^{0}C and 900 ^{0}C by using equation 1, the value of

ASTM number n is calculated and these values are shown in Table 3, 4 & 5 for pouring temperature of 700 ^{0}C, 800 ^{0}C and 900 ^{0}C respectively.

Table 3: The value of ASTM number (n) at different permeability of sand with pouring temperature of 700 ^{0}C

Permeability of sand (Darcy)	Grain per square inch (N)	ASTM number (n)
30	8	4.8
60	10	5.0

Table 4: The value of ASTM number (n) at different permeability of sand with pouring temperature of 800 ^{0}C

Permeability of sand (Darcy)	Grain per square inch (N)	ASTM number (n)
30	11	5.13
60	12	5.32

Table 5: The value of ASTM number (n) at different permeability of sand with pouring temperature of 900 ^{0}C

Permeability of sand (Darcy)	Grain per square inch (N)	ASTM number (n)
30	13	5.43
60	15	5.65

From the Fig. 9(a) & 9(b), the microstructure of the aluminium alloy cast with the low and High permeability of sand at pouring temperature of 700 ^{0}C are shown. In this microstructure, the white patches are α aluminium and dark patches are eutectic α+Si. The numbers of grain per square inches are calculated by considering the area of 1 inch^2 in the micrograph by the main scale.

Consider one square inch from the photo micrograph taken at a magnification of 15. At the magnification of 10, one square inch region from the 15 magnification image would appear as

$$1 \text{ inch}^2 (10/15)^2 = 0.66 \text{ inch}^2$$

$$N = 10/0.66 = 15.15 \text{ grain/inch}^2$$

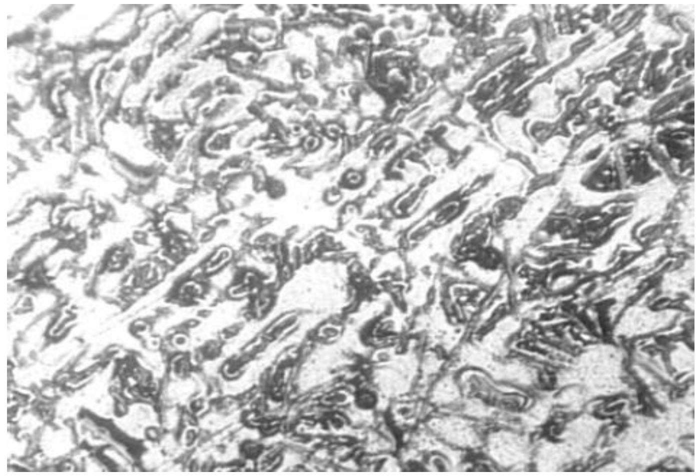

Fig. 9(a). Micrograph of Aluminum alloy sand cast at pouring temperature of 700 ^{0}C with low permeability of sand (x15)

Fig. 9(b). Micrograph of Aluminum alloy sand cast at pouring temperature of 700 ^{0}C with high permeability of sand (x15)

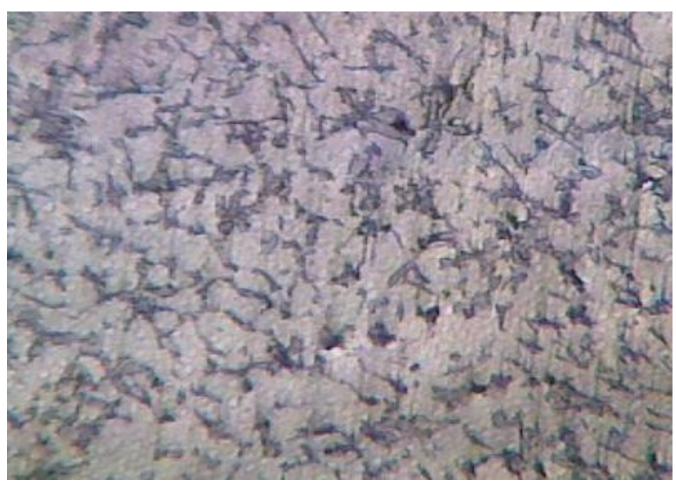

Fig. 10(a). Micrograph of Aluminum alloy sand cast at pouring temperature of 800 ^{0}C with low permeability of sand (x15)

Fig. 10(b). Micrograph of Aluminum alloy sand cast at pouring temperature of 800 ^{0}C with high permeability of sand (x15)

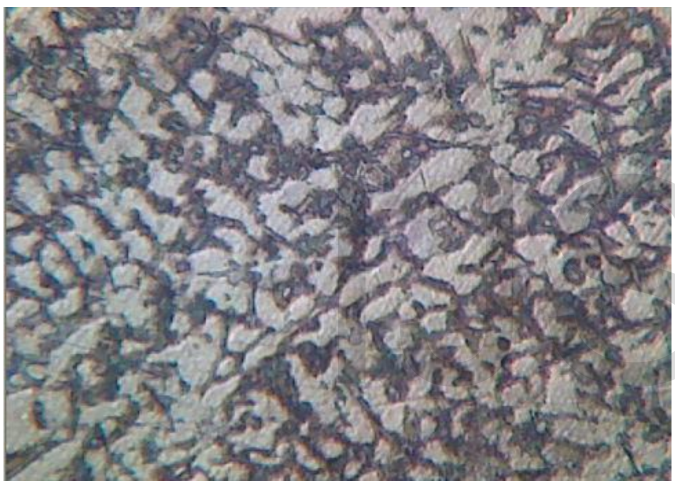

Fig. 11(a). Micrograph of Aluminum alloy sand cast at pouring temperature of 900 ^{0}C with low permeability of sand (x15)

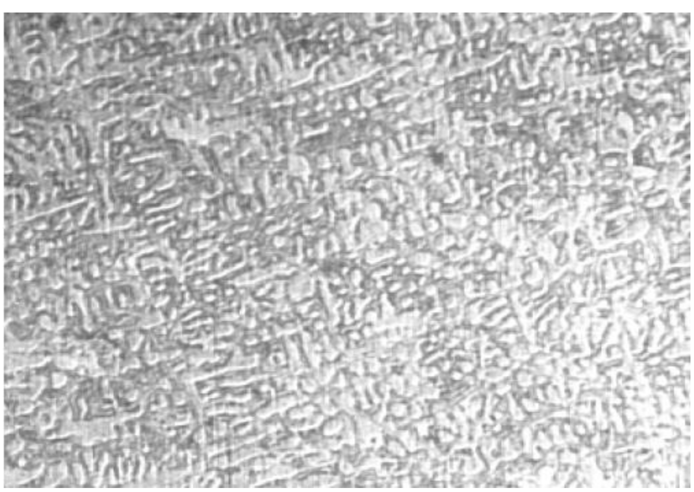

Fig. 11(b). Micrograph of Aluminum alloy sand cast at pouring temperature of 900 ^{0}C with high permeability of sand (x15)

4 Conclusions

1. It is discovered that the pouring temperatures and the permeability of moulding sand significantly affect the mechanical properties of sand casted aluminum alloy. With the increasing the pouring temperature and permeability of sand, the hardness was increased due to increasing the cooling rate of molten metal resulting in formation of fine grain structure of aluminium alloy cast. But impact strength was decreased due to fine grain formation which absorbed less energy.

2. When the pouring temperature increased, the ASTM number is increased, so the fine grain of aluminium alloy cast was formed.

3. When the permeability of sand increased, the ASTM number of microstructure was increased. So the fine grain was formed.

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