Behavior of Aluminum Alloy Castings under Different Pouring Temperatures and Speeds

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Abstract

The investigation studies the effect of pouring temperatures and rates on the mechanical properties of Aluminum alloy castings. The castings were produced at different pouring temperatures and speeds. The speed range is 2.0 cm/s to 16.0 cm/s, while the temperature range for the investigation is 680°C to 750°C. The specimens were subsequently tested for quality and properties such as hardness and strength. Observations and results indicated that lower pouring temperatures, nearer to the melting temperatures of the alloys produced good quality castings with the optimum values of hardness and strength as 65.5 and 112 N/mm^2 respectively. The optimum pouring speed is in the range of 2.2 cm/s to 2.8cm/s, where the hardness and strength were 65.4 and 127 N/mm^2 respectively.

Keywords

Pouring Temperature; Pouring Speed; Ultimate Tensile Strength; Rockwell Hardness; Percentage Elongation; Percentage Reduction in Area.

Introduction

To an engineer, the knowledge and understanding of casting parameters in casting different metals and alloys is as significant as the cast products. Metal casting is by definition any process of melting metal and pouring them into mould in order to produce the required shapes. Specific casting parameters such as pouring temperatures, rate of pouring, fluidity and composition of metals are of topmost importance for consideration if sound casting is to be achieved.

It has been observed [1] that melting and pouring conditions directly or indirectly affects such mechanical properties of cast materials as: hardness, percentage elongation, percentage reduction in diameter, toughness and so on. For instance an investigation on pouring rate of some ferrous metals [2] revealed that metals such as steels have very high freezing rate compared to most other alloys castings. The optimum pouring speed is also found to be a function of the casting size and shape.

The knowledge of melting temperature of metals and alloys is necessary to estimate their corresponding pouring temperature [3]. Aluminum alloy casting has melting temperature of 660°C [4] with its corresponding pouring temperature range to be between 700°C-750°C. It was also stated by Lindberg [5] that this melting temperature may be as low as 649°C.

In this paper, the efforts made in ‘sand casting’ Aluminum alloy of the same size and shape at selected pouring temperatures and rates is presented. The cast alloys were examined for mechanical properties. The aim is to determine the optimum points at which these parameters produce good quality castings. It has been stated [6] that when pouring temperature is lower than optimum, the mould cavity will not fill the gate or riser will solidify too rapidly and intercept directional solidification. On the other hand, higher pouring temperature causes shrinkage of the casting and mould warping [7]. Above all, many casting defects result because the optimum casting conditions were not used during the casting process [7].

Experimental methods

For this investigation, the casting parameters varied were the pouring temperature and the pouring rate. Specimens of sand-cast Aluminum alloy were produced with the aid of wooden pattern. The standard casting procedure, which comprises of pattern making, molding, melting, pouring and cleaning/fettling, was followed. After molding, scraps of

Aluminum alloy were melted in an oil fired crucible furnace. Charging and melting was for 1 hour. Temperature measurement was done with thermocouple, and the alloy was always heated to a temperature of 10^oC above the specified pouring temperature. This allows for temperature drops encountered during reloading and temperature loss during the time required for pouring of the castings to be compensated for. The same sizes and shapes were cast to present uniformity in measurements.

Determination of pouring speed

Pouring speed of molten metal, V may be defined as the flow of the metal per unit time. In determine the pouring speed, the parameter, V, is expressed as the distance of the ladle above the pouring basin per unit time of pouring the metal. This is expressed as:

$$V = \frac{H}{T}\left(\frac{cm}{s}\right)$$

where: V = pouring speed (cm/s); H = Height of ladle above pouring basin (cm); T = Time for pouring the molten metal (sec).

The sand mould for each specimen to be cast was placed on a mould board and the distance between the pouring basin and the ladle was measured as 80cm. The molten metal was then poured into the mould and the pouring time for each mould to be filled up was varied for eight specimens so as to obtain different pouring speeds for the castings. The pouring temperature was maintained at 700°C.

Determination of Pouring Temperatures

The pouring temperatures of the Aluminum alloy castings were measured by a thermocouple. In the pouring ladle, the tip of the instrument was allowed to make contact with the base of the molten metal contained in it. For each casting, two temperature readings were noted and recorded accordingly. The first being the temperature reading at the beginning of pouring of the molten metal into the mould and the second being the temperature reading immediately the mould is filled up. The average of these two temperatures calculated were the temperatures for the particular casting. This was done for eight castings at different temperatures. The pouring speed was maintained at 2.5cm/s.

The poured molten metal were allowed to solidify and cool, and then removed from the sand and the fettling operations were conducted on them using the normal methods.

Test of the Cast Products

Standard specimen dimensions were prepared out of the castings for the test of mechanical properties. The tests conducted are tensile and hardness tests. A tensile testing and Rockwell hardness testing machines were used for these tests.

Results and Discussions

The chemical composition of the Aluminum alloy casting is presented in Table 1.

Table1. Composition of the Aluminum Alloy Casting

Element	Composition (%)	*Standard Composition (%)
Iron	0.5	0.5
Silicon	0.4	0.3
Copper	0.1	0.1
Nickel	0.1	0.1
Magnesium	4.2	3.0 - 6.0
Manganese	0.5	0.3 - 0.7
Zinc	-	0.1
Aluminum	Balance	Balance

* - Source [9]

The composition in Table 1 can be used to compare with the properties of a typical Aluminum - Magnesium - Manganese alloy in 'as cast' condition. Kempster [9] gave their composition of such an alloy to be in the following ranges: Magnesium - (3.0 - 6.0), and Manganese - (0.3 - 0.7).

The experimental results obtained for the mechanical properties of aluminum alloy casting have been computed and plotted in graphs. A series of results were obtained for the properties at different pouring speeds, with the pouring temperature kept constant at 700^{o}C. From the tensile testing, the ultimate tensile strength, percentage elongation and reduction in area were computed. The hardness values: both across and along the axis were also determined. The variations of these properties with pouring speed are presented in figure 1 to 3

Similar properties were investigated when the pouring speed was kept constant at 2.5cm/s, while the pouring temperature was varied in the temperature range of 680.0°C and

750.0°C. The behaviours of the properties in the specified range are presented in figures 4 to 6.

Castings Properties at Different Pouring Speeds

In Fig. 1, the Rockwell hardness number determined for the casting at different pouring speeds is presented. The hardness value across axis increases initially with pouring speed from 63.0. It latter attained its maximum value of 65.4 at the speed of 2.2 cm/s. Thereafter, it falls sharply to a value of 58.0 at the rate of 3.2 cm/s. It then rose to 62.0 from where it finally falls with any increase in pouring speed. For hardness along axis, the hardness value increases initially with pouring speed from 60.0 to maximum value of 63.1 at the speed of 3.2 cm/s, until it finally fall to a value of 50.0 at the pouring speed of 16.0 cm/s.

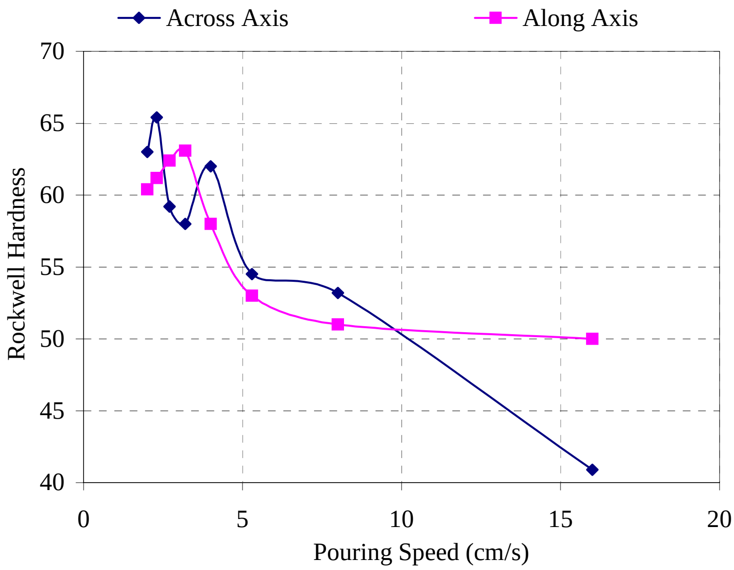

Figure 1. Variation of Hardness with Pouring Speed

In figure 2 the ultimate tensile strength decreases initially with increasing pouring speed from 123.0 N/mm^2 to 112.0 N/mm^2. It reaches a maximum value of 127.5N/mm^2 at the pouring speed of about 2.8 cm/s. Subsequent increase in pouring speed reduces the tensile strength. The lowest value of 68.5 N/mm^2 was obtained at the pouring rate of 16 cm/s.

In figure 3, the percentage elongation increase with increase in pouring speed from 1.6% to the maximum of 2.8% at 2.8cm/s. Subsequence increase in pouring speed reduces the percentage elongation. It can be observed that the lowest value obtained is 0.1% at 16.0cm/s.

The percentage reduction in diameter also follows the same trend, except that the values are lower than that percentage elongation for any given rate of pouring.

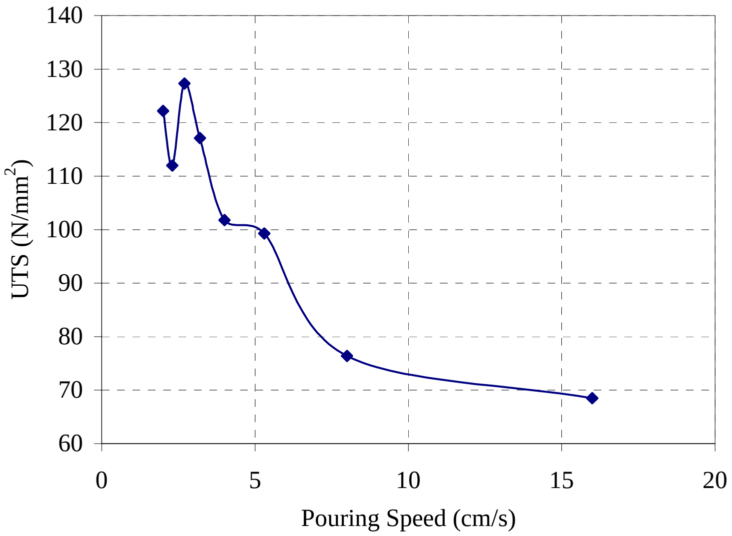

Figure 2. Variation of UTS with Pouring Speed

From these results, the maximum values obtained for the properties are consistent with the existing standards [9] when the pouring rate is in the range of 2.2 - 2.8cm/s. Thus, the hardness value of 65.4 compares well with 50.0 [10], as obtained in standards. Similarly, the maximum tensile strength and elongation are in close comparison with 140.0 N/mm^2 and 2.0 respectively as found in standards [9, 10]. Therefore, all the discussions on the variation trends would be taken to be valid.

Properties of Casting at Different Pouring Temperatures

Figure 4 shows the variation of Rockwell hardness with pouring temperature. Generally the hardness across the axis is shown to be always higher than that along axis. The hardness across the axis increases initially with pouring temperature to a maximum of 65.5 at temperature of 688°C.

The maximum hardness attained along the axis is 62.8 at the pouring temperature of 688°C. The behavior of the two hardness types follows waveforms, but generally decreases at higher pouring temperatures. For instance, at the pouring temperature of 760°C, the Rockwell hardness across the axis is 51.0, while that along the axis is 40.0.

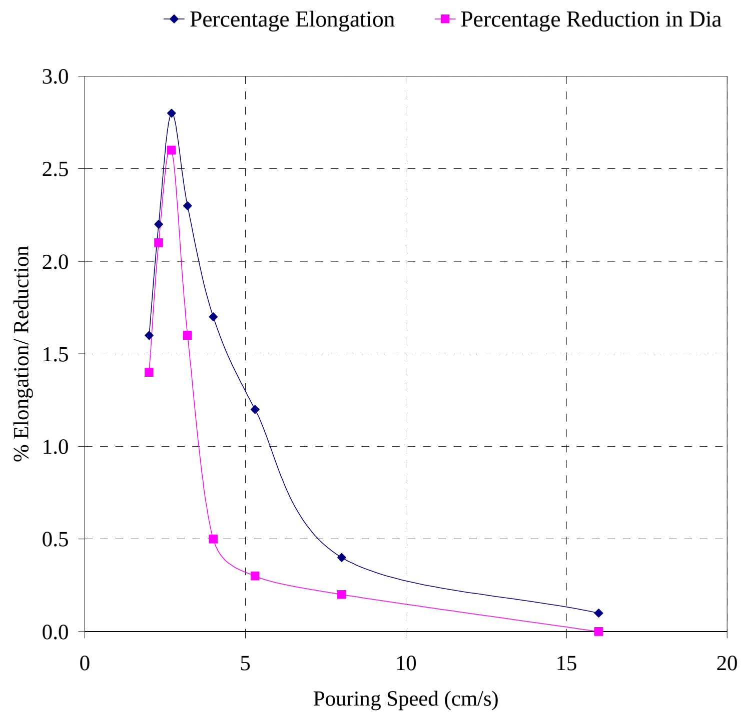

Figure 3. Effect of Pouring Speed on Deformation of Aluminum Alloy Casting

It has been observed [5] that pinholes in aluminum castings are caused by the absorbed hydrogen. This can be minimised by pouring the alloy at temperatures just necessary for casting. Therefore, once this optimum pouring temperature is identified, it should be properly applied.

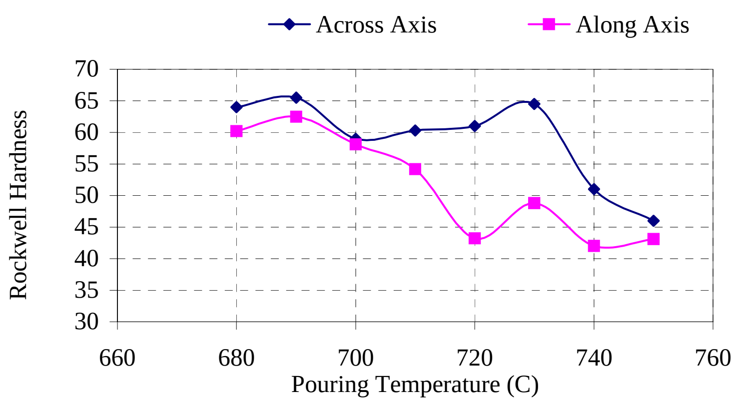

Figure 4. Variation of Hardness with Pouring Temperature

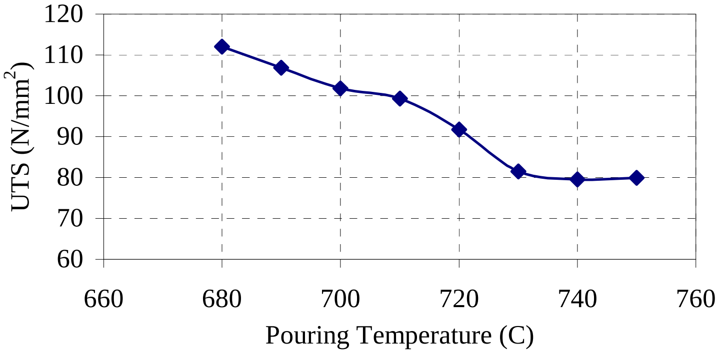

Figure 5. Variation of UTS with Temperature

The ultimate tensile strength decreases with increasing pouring temperature (fig 5). The minimum value attained is 79.5N/mm^2 at the pouring temperature of 740°C.

In Figure 6, the percentage elongation is seen to increase with pouring temperature from 2.8% to a maximum value of 3.1%.

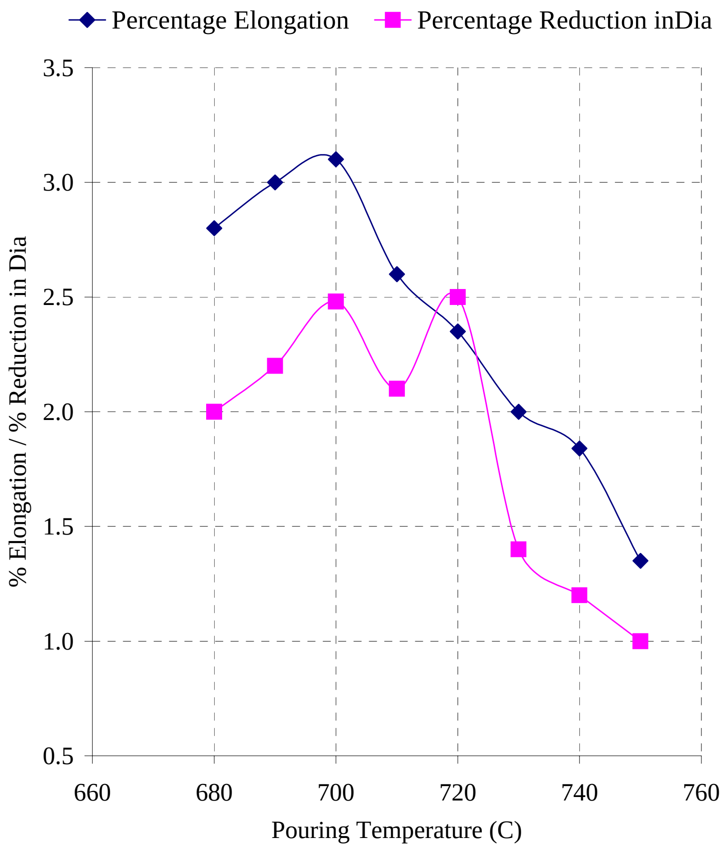

Figure 6. Effect of Pouring Temperature on Deformation

Further increases in pouring temperature reduce the percentage elongation. On the other hand, the percentage reduction in diameter increases initially with pouring temperature from 2.0% to 2.5% at the temperature of 700°C. It then decreases to 2.2% after which it increases to a maximum value of 2.5%. Thereafter it falls sharply to 1.0%. Since these properties compared favorably well with the castings of similar alloy compositions, the products can be used in areas such as food and chemical industries as well as marine and architectural works.

Quality Assessment of the Castings

For aluminum alloys, the optimum pouring temperature range is 700°C to 750°C. At temperatures higher than this range, the casting results in large crystals, low strength and gases are entrapped in the castings, leading to defects known as blowholes.

Result of Visual Inspection of the Castings

From castings, the best surface finish was obtained at the pouring temperature range of 680°C - 700°C. At higher temperatures, castings with sticky sand and very rough surfaces were obtained.

Pouring speed also affects the quality of castings. The speed range of 2.0cm/s -2.7cm/s gave the best surface finish. The degree of surface finish deteriorated as the speed increases.

Internal Defects

The castings produced at pouring temperatures less than 730°C were free from internal defect. This implied that the temperature were sufficient. Also castings at different pouring speeds on machining showed variation in internal defects with cast specimens. The castings produced at higher speeds {8.0cm/s to16.0cm/s} were found to have either inclusions or dross and gas holes. These defects may be as a result of turbulence flow condition of the molten metal as it is poured through the gating system into the mould.

Conclusions

From both the quality and mechanical property assessments, it was found that for Aluminum alloys the optimum pouring temperature range is between 700^{o}C and 750^{o}C. This is the region where good quality casts are produced with good mechanical properties.

The pouring speed range, which gave the best surface finish, is between 2.0cm/s and 2.8cm/s. Optimum values of hardness, tensile strength and deformations were obtained at this temperature range.

Further studies on the metallurgical investigations on the castings produced at varied ranges of these parameters {temperature & speed} are currently in progress. This is to check the grain sizes, non- metallic inclusions and submicroscopic pinholes.

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