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Impact of pouring temperature on the mechanical properties of Al5.9Cu1.9Mg alloy

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ABSTRACT

Purpose: This experiment aims to determine the influence of pouring temperature on the hardness, impact energy, tensile strength, and changes in the microstructure of the Al-5.9Cu-1.9Mg alloy.

Design/methodology/approach: A total of three samples of aluminium alloy were heated to 688, 738, and 788°C, and poured into permanent moulds in form of plates at a constant temperature of 220°C. The cast products are machined according to testing standards for hardness, impact tests, and tensile strength.

Findings: The results showed that the metal hardness and impact energy increased to 103 BHN and 7.48 J at 788°C, respectively, while the tensile strength rises as the temperatures decreases. Furthermore, the changes in the microstructure were affected, which indicated that all the properties of the aluminium alloy were influenced by the variations in temperature.

Research limitations/implications: During the metal casting process, only three different pouring temperatures affected the properties of the metal alloy, therefore, there is a need for more variations.

Practical implications: The proposed pouring temperature parameter is an important condition for industrial foundry applications to obtain the right product for use in a machining element.

Originality/value: This research shows the influence of the difference in pouring temperatures on the properties of metal alloys due to casting, where they will be adapted for a particular use.

Keywords: Mechanical properties, Al-Cu-Mg alloy, Casting metal, Pouring temperature

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PROPERTIES

1. Introduction

Aluminium alloys of various series have been extensively applied to aircraft, automotive, and military parts. Moreover, several methods are used to improve the properties of metal alloys such as controlling the casting process parameters and molten treatment during solidification. Previous research also showed that some product conditions can reduce the properties of metal alloys such as defects in cast products, which include hot tearing [1]. Metal casting processes including high-pressure die and centrifugal are some of the methods commonly used to reduce defects [2]. In previous decades, the effect of pouring temperature on the mechanical properties of materials during casting was reported. These include Mg-10Gd-3Y-0.4Zr alloy, which was investigated by a sand casting process at 680, 720, 750, and 780°C. The results show that higher temperature can increase the yield stress, Ultimate Tensile Strength (UTS), and solute concentration [3].

The effect of pouring temperature and the cooling rate has also been evaluated on Al-Si-Cu aluminium alloy. It was discovered that at 750°C, the best combination of ductility and alloy strength was obtained, which affected the characteristics of the microstructure and the mechanical properties of the Al-Si-Cu. The difference in the temperature during metal casting has also been observed in changes in the distance of the dendritic arms. The results showed that the variations influenced the nucleation of the molten, where higher temperature increased microhardness and UTS [4].

The influence of temperature and melt treatment on the microstructure of the Al-Si alloy was investigated by the lost foam casting process at 700, 720, 740, 760, and 780°C. The morphology of the microstructure of the alloy was significantly affected and a finer grain size structure was discovered at lower temperatures [5]. Furthermore, its influence on the evolution of microstructure and mechanical properties has also been determined in alloy AA-6063 using a variation of temperatures, such as 700, 720, 740, 760, and 780°C. The results show that UTS increases as the temperature rises, while the elongation and hardness are also affected [6].

The solidification process was also affected leading to the evolution of microstructure, variation in material density, and hardness of Al-Si alloys (hyper-eutectic). Meanwhile, the two parameters observed include the pouring temperature (663-121.5, 380-116.5, 711-122.5, 723-126.5, 738-130.5, 755-125, 775-124) and the mould temperature (810-128°C) respectively, where higher values cause an increase in hardness and density. Based on observation of the microstructure, the primary silicon was not properly distributed at low temperatures [7]. Previous research also stated that process parameters have a significant influence on the castability of aluminium alloys [8]. The changes in the microstructure can be achieved through two techniques, namely chemical and physical. An investigation of aluminium alloys' solidification and microstructure was carried out using the variations of 620, 625, 630, and 635°C [9]. The temperatures 973, 1,003, 1,033, and 1,063 K were also discovered to cause hot tears [10], which affected the cooling rate and the mechanical properties of the alloy [11-15].

Meanwhile, the mechanical properties of AlSi12 alloys modified with Sr or Al-Sr were improved by a rapid cooling process [16]. The evaluation of changes in the shape and morphology of the primary crystals were analysed using precipitation hardening treatment and the solidification rate of the AlMg10 alloy. The highest mechanical properties are obtained in the cast products produced by the sand casting method and pressing in the liquid state. The mechanical properties of AlMg10 alloy can also be significantly improved by heat treatment conditions [17]. Research has also been carried out on the evaluation of morphology and grain size in the aluminium sand casting process with the addition of nickel (Ni) (1, 2, 3 wt.%). The results showed that the morphology of the granular form after the addition of Ni was 1-2 % (weight percent), while that of the elongated shape was discovered in 3 wt. % Nickel [18]. The shot peening process can also be used to enhance the mechanical properties of metal alloys. Its duration and distance have been investigated to increase hardness and corrosion resistance [19]. Therefore, this research aims to determine the effect of three variations of pouring temperatures, such as 688, 738, and 788ºC, on Al5.9Cu1.9Mg alloy on hardness, impact energy, tensile strength, and percentage elongation.

2. Materials and methods

The cylindrical rods of commercial aluminium alloy AA-2024 of 1,500 mm length and 50.8 mm in diameter were cut into small pieces to fit into crucibles for re-melting. The chemical composition of the aluminium alloys after re-melting is shown in Table 1. It was analysed using spectroscopy's metal standard (Spectrolab Jr CCD Spark Analyser).

The alloy AA-2024 was re-melted in an electric resistance furnace, cut into small pieces, cleaned of slag impurities, and continued with manual stirring. Subsequently, it was moulded in a steel mould with square dimensions (Fig. 1). The melting temperature of the 2024 alloy is approximately 638°C, therefore in this experiment, three variations of pouring temperatures including 688, 738, and 788°C were used. The steel mould was preheated and the temperature was kept constant at 220°C (+ 3°C).

Table 1.
The chemical compositions (wt.%)

Elements	Wt.%
Si	0.160
Fe	0.253
Cu	5.931
Mn	0.733
Mg	1.936
Cr	0.012
Ni	0.012
Zn	0.184
Ti	0.014
Al	Bal.

The aluminium alloy product obtained is rectangular (Fig. 1b), it was machined to the correct dimensions for impact and tensile testing, according to ASTM standards. The cast products are made into impact test samples through a machining process that follows the ASTM 23 standard (Fig. 2a). Furthermore, the sample was given an impact load using the Charpy method with a 1 kg until the sample fractured (room temperature). The tensile test samples were produced by machining process based on the ASTM E8-09 standard as shown in Figure 2b. Subsequently, a load of 2,000 kg was applied at room temperature and recorded through the Universal Servo-hydraulic testing machine.

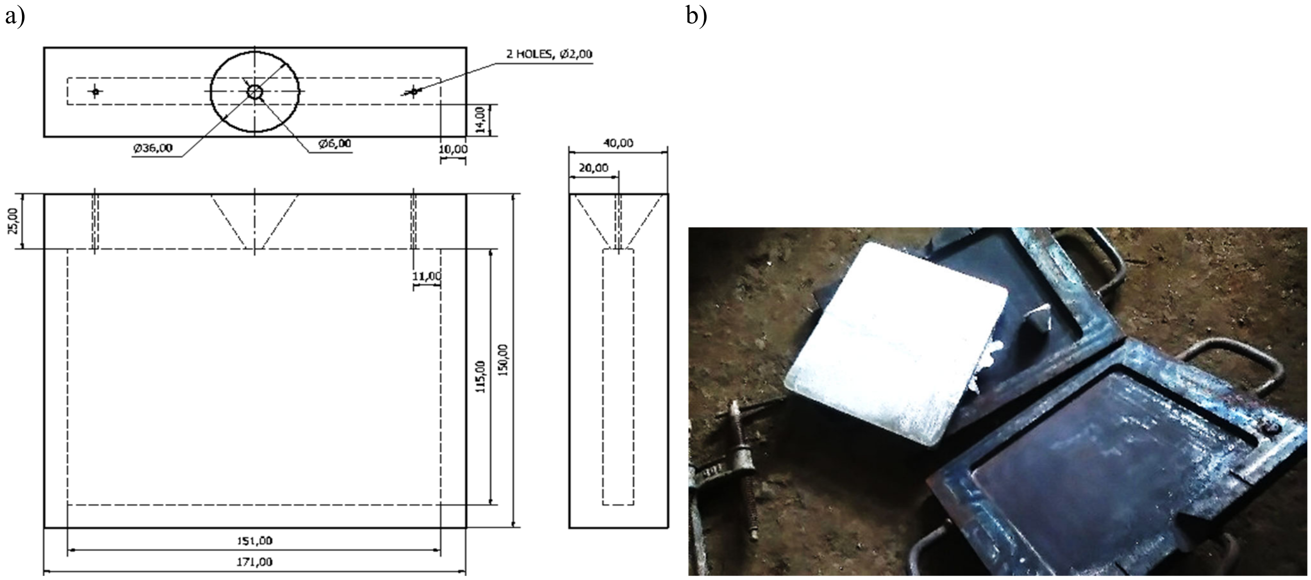

Fig. 1. a) Dimensional details of steel moulds and b) cast products

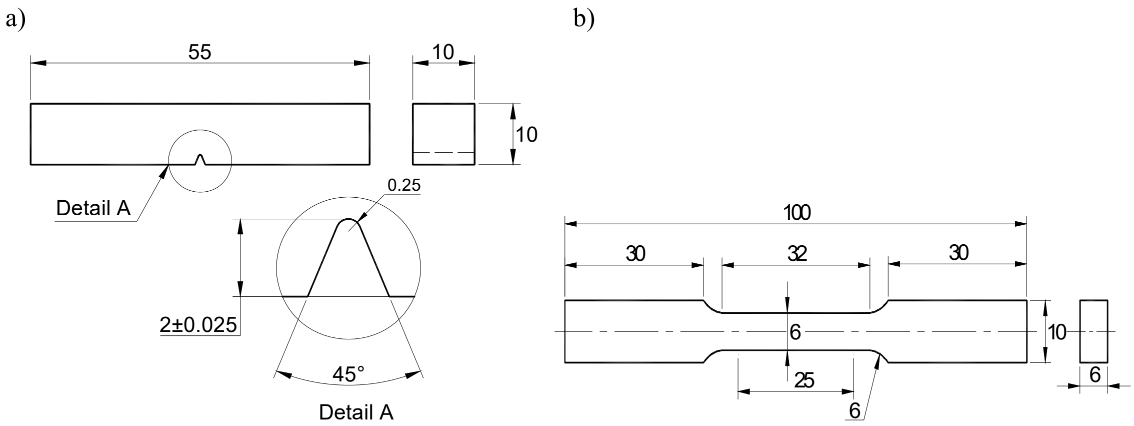

Fig. 2. a) Schematic of the impact test sample and b) the tensile test sample

Metal hardness was measured using the Frank-PTI gmbh Brinell hardness test and its index was determined with a spherical indent of 2.5 mm diameter and a load of 613 N (ASTM E 10). The hardness value is calculated using Equation (1).

$$BHN = \frac{P}{\left[\left(\frac{\pi D}{2}\right)\left[D-(D^2-d^2)^{\frac{1}{2}}\right]\right]} \qquad (1)$$

where P is the load in kg, D is the diameter of the ball in mm, and d is the indentation diameter in mm.

The microscopy of the cast alloy was observed through an optical microscope. Samples for microstructure observation were prepared based on the standard metallographic procedures such as grinding, polishing, and etching using Keller's reagent.

3. Results and discussions

Figure 3a shows the hardness values of the alloys with different pouring temperatures. Based on the calculation from the diagonal indentation, the highest hardness is 103.67 BHN at 788°C, while the lowest is 95.67 BHN at 688°C. From previous research, the effect of temperatures 710, 760, and 810°C on the hardness properties was investigated on alloys of Al1.3Zn1.19Si, Al1.66Si1.35Zn, and Al2.81Zn2.6Si. The maximum hardness obtained was 62.83 BHN at a pouring temperature of 810°C [20]. Kumar, et al. also reported that the hardness value of the Al-6Cu alloy was 152 BHN [21]. Furthermore, Adeleke, et al. obtained 42.4 BHN for the non-treated Al-1.56Cu-8.33Zn and 49.2 BHN for the precipitation hardened alloy [22]. The hardness of Al-3.25Cu-6.16Zn without heat treatment was 53.40 BHN and 64.6 BHN for alloys subjected to precipitation hardening, while Al-Zn was 38.43 BHN [23]. However, this comparative study did not treat the molten metal during casting. Meanwhile, this study evaluates the variation of pouring temperature on the hardness of aluminium alloys.

The results of the Charpy impact test, namely the impact energy required to fracture the cast aluminium alloy sample due to different pouring temperatures are shown in Figure 3b. The maximum impact energy measured was 7.48 J at 788°C, while the minimum was 7.19 J at 688°C. According to Kumar, et al., the impact energy of Charpy Al-6Cu is 8 J [21]. Adeleke et al. obtained 6.12 J for the non-heat treated Al-1.56Cu-8.33Zn and 6.392 J for the precipitation hardened alloy [22]. Furthermore, the impact energy of the untreated Al-3.25Cu-6.16Zn was 5.984 J and 6.256 J for the depositionally hardened alloy, while the Al-Zn alloy was 7 J [23]. Some of these studies differ from the current research reported in this paper. This experiment treats molten metal during casting, which evaluates the variation of pouring temperature on the response of the impact energy of the aluminium alloy. The variations in pouring temperatures have a significant effect on the Brinell hardness. The results showed that the hardness increases with higher temperatures. However, the impact energy decreased due to the re-melting of alloy 2024 and porosity as shown in its microstructure.

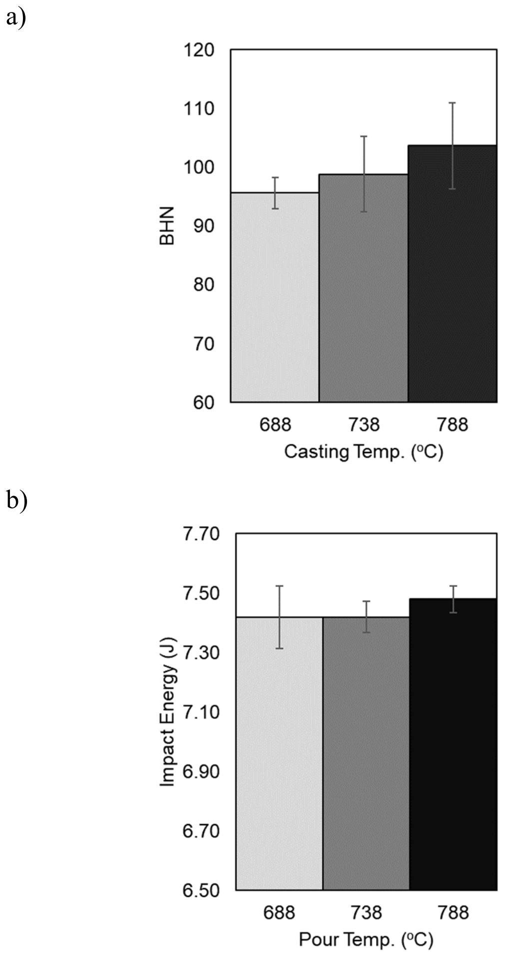

Fig. 3. a) Brinell hardness and b) impact energy

Figure 4 shows the stress vs. strain profile of Al5.9Cu1.9Mg alloy with different pouring temperatures. The stress-strain profile that cast-sample products with pouring temperatures at 788°C show higher strain, followed by cast-sample products at 738 and 688oC, respectively. The mean UTS values of the alloys were also investigated as indicated in Figure 5. The tensile strength curves of the

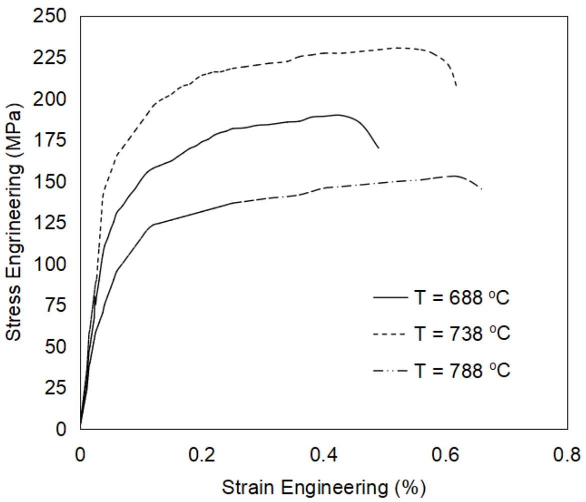

Fig. 4. Relationship between stress and strain of Al-5.9Cu-1.9Mg alloy for different pouring temperatures

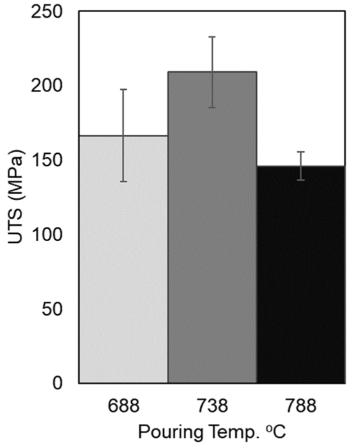

Fig. 5. UTS for Al-5.9Cu-1.9Mg alloy

re-rolled alloys printed with three different temperatures showed that the tensile strength of the alloys can also be affected. Based on the results, the maximum tensile strength was 209.14 MPa at 738°C, while the minimum was 146.05 MPa at 788°C. The highest percentage of elongation measured on the cast sample was 5.06 at 688°C, while the smallest was 1.08 at 788°C. This shows that the tensile strength initially increases and subsequently decreases with higher pouring temperatures. Similar research was also carried out on Al-Cu-Mg alloys, where the pouring temperature was discovered to affect the tensile strength of the cast alloy [24].

Micro-structural visualizations shown in Figure 6 were obtained from cast samples of alloys with the three pouring temperatures. Copper particulates were uniformly distributed in the Al-5.9Cu-1.9Mg matrix. All micro-structures showed coarse grains of solid aluminium in a solution with copper inter-metallic particles in the grain boundaries (dark colour). The microstructure with three different pouring temperatures from the casting samples shows alpha-Al phases (light colour) and theta-$AlCu_2$ phases (blackish grey). These can influence the hardness, impact energy, and tensile fracture behaviour of the alloy.

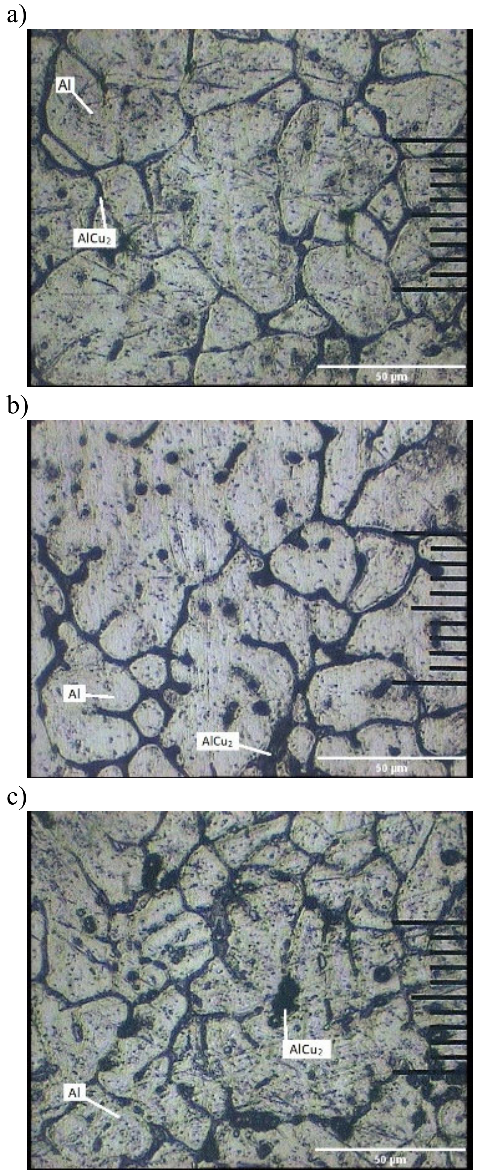

Fig. 6. Microstructure of Al5.9Cu1.9Mg alloy with various melt-pouring temperature: a) 688°C, b) 738°C, and c) 788°C

4. Conclusions

This research was carried out to determine the effect of pouring temperature on the hardness, impact, and tensile strength of Al5.9Cu1.9Mg alloy. The cast samples were produced using three variations of temperature, namely 688, 738, and 788°C during the moulding process. Based on the results, the hardness value of the cast product increases with higher temperature, where a maximum of 103.67 BHN was obtained at 788°C. The variation of pouring temperature does not have a significant effect on the impact of energy, which was 7.48 J at 788°C, while the minimum value was 7.42 J at 688 and 738°C, respectively. The tensile strength initially rises and subsequently decreases with increasing pouring temperature. The results of the observation of the microstructure show that the grains are generally coarse and dendritic in shape due to the difference in the temperature of the Al-Cu-Mg alloy. This showed that these variations can cause changes in the microstructure, thereby affecting the physical properties of the material such as hardness, impact energy, and tensile strength.

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