Hardness and wear rate of Al LM6 hollow cylinder fabricated using horizontal centrifugal casting

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Abstract. Horizontal centrifugal casting is one of the methods to produce functionally graded materials (FGMs). The pouring temperature and rotational speed of the mold are among the main parameters affect the quality of casting. The effect of these two casting parameters on the hardness and wear properties of the Al LM6 hollow cylinder fabricated are investigated. The hardness value along the radial direction of the Al LM6 hollow cylinder fabricated is measured using Micro Hardness Vickers test. Meanwhile the wear rate of Al LM6 hollow cylinder fabricated is determined by measuring the mass loss after loaded with 5 N force and sliding distance of 75 m on silicon carbide grit paper (200 μm). The result after the testing shows that the Al LM6 hollow cylinder which is fabricated at pouring temperature 725°C and motor speed of 1500rpm produces the highest hardness sample and the cylinder fabricated at pouring temperature 690°C and motor speed of 1700rpm have the lowest wear rate value.

1. Introduction

Centrifugal casting is one of the methods in material processing where the quality of the final product are affected by the flow pattern of the molten metal [1]. This method also effective in producing a graded composite materials but there are still several process parameters that influence the characteristics of the product such as die wall temperature, pouring temperature, rotational speed of the mold, centrifugal force and many more [2]. The literature study of the fluid flow in centrifugal casting process is still inadequate. Theoretically, a true uniform cylinder should be able to produce when the mold is rotated at low speeds but practically it also depend the conditions of the molten metal where the mold need to be accelerated at a certain speed to obtain a uniform cylinder shape [3]. By using a higher speed, a uniform casting is formed due to the influence of liquid metal. To form a good casting, the molten metal must fill in the entire inner surface and then solidify. To achieve this, the melt must rotate in a high rotational speed at its low viscosity state. When the rotational speed increases, an irregular shape casting will be formed [3]. By means of the centrifugal force, the finer grain structures are produced to attain homogeneous and isotropic mechanical properties [4]. Functionally graded materials are produced through the segregation of particles due to centrifugal force during centrifugal casting process. The segregation occurs either at the outer or the inner periphery of the casting, depending on the difference in densities of the particles in the melt [5].
Important variables which affect the rate of cooling of the melt are rotational speed of the mold during solidification process. When the speed of rotation increased, the centrifugal force are increased which will produce a strong convection in the liquid pool and produce a homogenous temperature in the bulk liquid. The fluid display a different flow patterns when the speed of the motor varies [2]. A rapid solidification of the cast shows the well distribution of fine grains while slow solidification rate of the cast shows coarse grain size [6]. Solidification process in centrifugal castings is identical with other casting process where the state phenomena are changed in which governed by heat transfer. The optimal representation of solidification behavior in a horizontal centrifugal casting is to assume that crystal growth commences with the liquid metal in contact with the mold wall, and then proceeds right across the section until the last remaining liquid freezes uniformly at the inner surface [5].

Particulate reinforced aluminium alloy composites have shown a significant improvement in tribological properties, including sliding and abrasive wear resistance and seizure resistance. Thus, increased attention has been directed towards particulate metal matrix composites for tribological applications due to the advantages of MMCs such as good sliding wear resistance, high load carrying capacity and light weight. M Kok and K Ozdin [7] used three different Sic abrasive papers which are 600 grit, 360 grit and 240 grit under 2N and 5N loads to investigate the wear resistance of aluminium alloy using pin-on-disc abrasion test apparatus. The result shows that the wear volume loss of the matrix alloy and the composites almost increased linearly with increasing the sliding distance. The reinforcement of the 2024 Al matrix alloy with Al2O3 particles significantly improved the abrasion wear resistance of all composites tested against all the abrasives used, and the wear resistance of the composites was much higher than that of the unreinforced 2024 aluminium alloy. G Chirita, D Soares and F S Silva [8] investigate the advantage of mechanical properties using vertical centrifugal casting compared with traditional gravity casting. Aluminium alloy AS12UN used in the study was melted at 670ºC and it was poured inside the mold which was preheated at 130°C. The specimen was tested using Dartec tensile testing machine and the results shows that the mechanical properties shows a higher value for centrifugal casting process compared with traditional gravity casting. Besides that, the increment for centrifugal casting samples was 35% for rupture strength, 160% for rupture strain and 18% for Young’s Modulus.

In this study, the effect of different casting parameter towards the hardness and wear resistance of the Al LM6 hollow cylinder fabricated is investigated. The Al LM6 is casted at three different pouring temperatures and three different speed of motor rotation. The hardness value and wear rate are measured using micro hardness Vickers test and wear test machine.

2. Methodology
Al LM6 hollow cylinders are fabricated using centrifugal casting method [9, 10, 11] with varying two casting parameters i.e. pouring temperature and motor speed. Three different pouring temperatures and motor speed set are 690, 710 and 725°C and 1300, 1500 and 1700 rpm, respectively.

The process starts by weighing small pieces of Al LM6 ingot. A total of 160 grams of ingot is required for each casting producing a hollow cylinder with volume of $5.5 \times 10^{-5}$ m$^3$ as the density of Al LM6 is 2650 kg.m$^{-3}$. Then, the ingot is melted inside a crucible using induction furnace. After melted, the molten Al LM6 is poured inside the spinning mold with the desired motor speed. The mold is keep spinning for two hours to let the molten Al LM6 solidified. The solidified Al LM6 will be removed from the mold and left for 5 hours to let it cool down. Table 1 shows the casting conditions of Al LM6 hollow cylinders fabricated.

Hardness test and wear test are carried out to characterize the hardness and wear behaviour of Al LM6 hollow cylinder fabricated. The hardness test is carried out using Micro Hardness Vickers test and prepared as per ASTM E92-82. The hardness values at five points with distance of 2 mm each along the radial direction (from inner to outer) of the hollow cylinder fabricated are measured with a test load of 100 g (980.7 mN). Figure 1 shows the cross sectional area of the hollow cylinder fabricated, prepared for Micro Hardness Test.
Table 1. Parameter of centrifugal casting of Al LM6 hollow cylinder

| Specimen | Material | Parameter | Motor Speed (rpm) | Pouring Temperature (°C) |
|----------|----------|-----------|-------------------|--------------------------|
| 1        | AL LM6   |           | 1300 (57 G)       | 690                      |
| 2        | AL LM6   |           | 1500 (75 G)       | 690                      |
| 3        | AL LM6   |           | 1700 (100 G)      | 710                      |
| 4        | AL LM6   |           | 1300 (57 G)       | 710                      |
| 5        | AL LM6   |           | 1500 (75 G)       | 710                      |
| 6        | AL LM6   |           | 1700 (100 G)      | 725                      |
| 7        | AL LM6   |           | 1300 (57 G)       | 725                      |
| 8        | AL LM6   |           | 1500 (75 G)       | 725                      |
| 9        | AL LM6   |           | 1700 (100 G)      | 725                      |

The wear test is conducted by using pin and disc method under 5N loads using an abrasive grit size of 200 μm with a sliding distance of 75 m and 50 rpm speed [12]. The specimen size of 6 mm x 6 mm x 17 mm is cut from the hollow cylinder fabricated. The mass of the samples are weighed before and after the wear test and the test are conducted three times to obtain the average value of wear rate. Figure 2 shows the position of the samples for wear test. The wear rate obtained through the calculation using the wear rate test formula which is:
where \( W \) is the wear rate in \( \text{mm}^3/\text{m} \), \( w \) is the weight loss in gram, \( \rho \) is the density of the material in gram/cc and \( S \) is the sliding distance in m.

3. Result and Discussion

Figures 3 to 5 shows the hardness values along the radial direction of the hollow cylinder fabricated. From the figures, it found that there are significant different in term of hardness value along the radial direction due to the different of Si content and size. As shown in our previous work [9, 10] the size of Si is the biggest at the inner part and causes the bonding of Al and Si particles becomes low. At a normalized radial distance between 2 to 6, it shows that all of the samples have a decreasing in hardness. This is because the cooling rate during solidification process is non-uniform inside the mold which might affect the distribution of Si particles at the middle part of the sample. Besides that, the inner surface of the samples is low due to the presence of gas porosity. This gas bubbles are thrown at the inner surface because it has low density and by the means of centrifugal force during casting process [10].

Averaging the five hardness value of each specimen shown that Sample 6 which is fabricated with 1500rpm motor speed and 725°C pouring temperature gives the highest value of hardness with the average value of 63.3 Hv while sample 2 that is fabricated with 1300 rpm motor speed and 710°C gives the lowest value with the average value of 55.6 Hv. This is due to the effect of viscosity and cooling rate of the molten metal during solidification process. Viscosity of the material is important parameter in order to move the molten along the mold.

![Figure 3. The hardness value along radial direction (motor speed of 1300 rpm).](image1)

![Figure 4. The hardness value along radial direction (motor speed of 1500 rpm).](image2)
Bonollo et al [12] states that a low melting temperature with a high viscosity causing the particles to move freely which will gives a better result. However, a suitable pouring temperature and a suitable speed must be obtained in order for the particles of Al and Si to distribute uniformly. A uniform distribution of Al and Si will gives a better hardness result.

Figure 6 below shows the wear rate for all of the hollow cylinders fabricated. From the figure, the wear rate for samples that is fabricated at 710°C increases as the speed of motor rotation increases. For the samples that are fabricated at 690°C, it shows that the wear rate is highest when it is fabricated at 1500rpm but for samples that are fabricated at 725°C the wear rate is lowest when it is fabricated at 1500 rpm. From the figure, it shows that sample 8 has the highest wear rate which is 2.803x10^{-4} mm^3/m while sample 7 that is fabricated with 690°C pouring temperature with 1700rpm motor speed has the lowest wear rate which is 1.605x10^{-4} mm^3/m. Lowest wear rate indicates that the sample has high resistance towards wear while highest wear rate indicates that the sample has low resistance towards wear.
At optimum speed, the formation of fine grains leads to better mechanical properties and hence improved wear resistance [3]. In Figure 6, it shows that sample 7 have the lowest wear rate hence the pouring temperature of 690°C with motor speed of 1700 rpm is at its optimum parameter. The next lowest wear rate is sample 1 with wear rate of 1.645x10^{-4} mm^{-3}/m and pouring temperature of 690°C with motor speed of 1300 rpm followed by sample 6 with wear rate of 1.872x10^{-4} mm^{-3}/m and pouring temperature of 690°C with motor speed of 1500 rpm.

The abrasive wear of a material mainly depends on its material characteristics, test parameters, and also environmental conditions. The material characteristics include properties of matrix material and reinforcement phase, hardness and fracture toughness. The major test parameters include applied load, sliding speed, time duration, sliding distance and wear track diameter. The grit size of abrasive particle and orientation of individual grit particles represent the nature of counter surface. It was noted that grit size of abrasive and hardness of material will have a direct influence on nature of wear mechanism and wear rate [13].

4. Conclusion

In conclusion, it can be conclude that this study have achieve its objectives to study the effect of pouring temperature and speed of motor rotation to produce an Al LM6 hollow cylinder by using horizontal centrifugal casting method.

Pouring temperature and the speed of motor rotation during casting are the important parameter to produce the best specimen. From the mechanical testing of hardness, sample 6 gives the best result due to the influence of viscosity and cooling rate which gives the parameter of pouring temperature 725°C and motor speed of 1500rpm produces the highest hardness sample and sample that is fabricated at pouring temperature 690°C with 1700motor speed gives the lowest result in hardness. The result from wear test shows that sample 7 gives the lowest value of wear rate and sample 5 gives the highest value of wear rate because the different pouring temperature and different motor speed influence the nature of wear mechanism and wear rate.

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