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# Effect of Rotating Mold Speed on Microstructure of Al LM6 Hollow Cylinder Fabricated Using Centrifugal Method

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**Abstract.** Al LM6 hollow cylinder is fabricated using horizontal centrifugal casting which produce a very fine grain on the outer surface of the structure. In this study, the effect of motor speed and pouring temperature on the microstructure of Al LM6 hollow cylinder is determined. The speed of the motor used during casting are 1300rpm, 1500rpm and 1700rpm and the pouring temperature are 690°C, 710°C and 725°C. The Al LM6 hollow cylinder is produced by pouring the molten Al LM6 into a cylindrical casting mold which is connected with a shaft and it is rotated by motor until it is solidified. Then, the cross-section is observed using OM and SEM/EDS. From the microstructure observation, the distributions of Si are more concentrated at the inner parts and the size of Si is bigger at the inner parts. The result shows that the Si particles at the inner part which is fabricated at the highest motor speed (1700rpm) have the most Si particles compared with the Si particles that are casted with other motor speeds.

## 1 Introduction

Aluminium is the most abundant metal on the earth and comprising one-twelfth of the earth crust. Aluminium has the weight of one-third of the steel weight and therefore it can be made thicker and stronger while the weight is reduced in all applications. The versatility of aluminium makes it to be used widely as it has a favourable strength property. Aluminium does not rust and it can be combined with other metal to form an aluminium alloys because there is a transparent layer of aluminium oxide present on its surface when it exposed to the atmosphere [1].

Al LM6 is an engineering material aluminium alloy that normally used in the industry such as aerospace, automotive, construction and many more because it has high endurance, high impact strength, light-weight and exhibits outstanding resistance to corrosion under both ordinary atmospheric and marine conditions. This aluminium alloys are rather difficult to machine because of the hardness is increased with the Silicon (Si) content in the alloy but the ductility is reduced. With Si content in the Al LM6, it improves its fluidity which is good to produce any product according to the desired shape. This aluminium alloy can be cast into thinner mold and more intricate parts than any of the other types of casting alloys [2].

Centrifugal castings process normally being used to produce pipes, cylinder liners, piston rings, rollers, pulleys and others. Centrifugal casting process has high reliability because it reduces the shrinkage and gas porosity in the structure [3]. One of the methods of producing functionally graded materials (FGMs) is by using centrifugal casting. The presence of FGMs in the alloy is due to the difference in density of different phases such as Al and Si particles [4]. Table 1 shows the comparison of density for Al and Si.

Table 1. Density of Al and Si [2]

| Material                     | Al   | Si   |
|------------------------------|------|------|
| Density (g/cm <sup>3</sup> ) | 2.70 | 2.34 |

Radhika and Raghu [5] investigate the microstructure at the outer of the FGM composite Al/B<sub>4</sub>C, Al/SiC, Al/Al<sub>2</sub>O<sub>3</sub> and Al/TiB<sub>2</sub> with reinforcement which are produced by using centrifugal casting. The ingot of Al-12Si-Cu alloy is cut into small pieces and then melted in the furnace in an inert gas atmosphere to reduce the defect in the cast. The reinforcement is preheated at 300°C and then added to the molten aluminium alloy. The mixing is stirred at 200rpm to produce vortex. Then, the mixing is poured into die that is preheated at 350°C of the centrifugal casting setup and it is rotated with a motor speed of 1300 rpm. The process continues until it solidified and the cast part is removed. The hollow cylinder produced has the

dimension of 150mm outer diameter and length 150mm with 18 mm of thickness. The result of microstructure study shows that the reinforcement present at the outer surface and the hardness test using Vicker's hardness test shows that the outer region have higher hardness than in the middle and inner region except for  $B_4C$  that shows variation of hardness in different region. The abrasive wear test shows that the FGM with reinforcement  $TiB_2$  have high wear resistance while FGM with reinforcement  $B_4C$  have less wear resistance. Therefore, the FGM composite have better mechanical and wear properties by using centrifugal casting.

Jamian et al [6] has investigates the distribution of functionally graded natural fiber/epoxy (FGNF/epoxy) hollow cylinder that are fabricated using centrifugal casting method. Banana trunk is used as its natural fiber. The difference of density between natural fiber and the epoxy causes natural fiber particle to move at the outer radius of the hollow cylinder during casting. An epoxy cylinder without fiber will be used as the reference. For centrifugal casting process, three different rotating speed will be used which are 1145rpm, 1187rpm and 1240rpm. Based on the testing result, the natural fiber is graded from inner to outer surface of the FGNF/epoxy cylinders that is produced by using centrifugal casting method. The rotation of the motor and the natural fiber composition affected the graded distribution in the FGNF/epoxy cylinders. It is also found that the outer surface has a higher value of hardness, density and strength along the cylinder and reduced gradually towards the inner surface. This is because the composition of natural fiber at the outer surface is higher than at the inner surface. In conclusion, centrifugal casting method is effective in producing a better mechanical strength.

Jamian et al [7] has investigates the distribution of Si particles of Al LM6 hollow cylinder which is produced by using centrifugal casting method. In the process, the Al LM6 ingot will be melted before pouring it into the rotating mold. The speed of rotation of the mold is 1700rpm (100G) and the pouring temperatures of the Al LM6 are 690°C, 710°C and 725°C. Based on the microstructure result using OM, it shows that the Si particle content are the same at all parts in the sample. However, the particle size at the inner surface is bigger than in the middle and at the outer surface of the sample because of the difference in density between Si and Al and the expansion of Si particles during the cooling process of the sample. The size of Si particles is different for all the three samples casted with different melt temperature. It is found that the melt temperature, the density and the cooling rate affect the size and distribution of Si particles.

Based on the previous research [5-7], it shows that centrifugal casting process is the most efficient process to produce a better mechanical and wear properties. Centrifugal casting also helps in eliminate the gas porosity present during solidification process which will give the material better mechanical properties. Besides that, pouring temperature also affect the properties of the material. In this study, the distribution of Si particles inside the Al LM6 hollow cylinder fabricated using centrifugal casting is observed. The effect of mold rotating speed on the Si particles distribution is investigated.

## 2 Methodology

In this research, nine Al LM6 hollow cylinders are fabricated using centrifugal casting method. The main casting parameters considered are pouring temperature and mold rotating speed. The casting condition for the each casting is shown in Table 2. The volume of the hollow cylinder fabricated is  $5.5 \times 10^{-5} \text{ m}^3$ . The process starts by cutting the Al LM6 ingot into small pieces with the mass 160g. Then, it is put inside the crucibles and melted using induction furnace. After that, the molten Al LM6 is poured inside the rotating mold with the desired motor speed. The process is left for 2 hours to let the molten Al LM6 solidified. Next, the solidified Al LM6 is removed from the mold and left for 5 hours to let it cool down. The sample is cut to be grinded, polished and etched before observed by using OM and SEM/EDS to study its microstructure. The etching method used is wet chemical etching and the solution mixture used is NaOH 5% +  $H_2O$  95%.

**Table 2.** Parameter of centrifugal casting of Al LM6 Hollow Cylinder

| Specimen | Parameter                 |                          |
|----------|---------------------------|--------------------------|
|          | Mold Rotating Speed (rpm) | Pouring Temperature (°C) |
| 1        | 1300                      | 690                      |
| 2        | (57G)                     | 710                      |
| 3        |                           | 725                      |
| 4        |                           | 690                      |
| 5        | (75G)                     | 710                      |
| 6        |                           | 725                      |
| 7        |                           | 690                      |
| 8        | (100G)                    | 710                      |
| 9        |                           | 725                      |

### 3 Results and Discussion

Figure 1 shows the Al LM6 hollow cylinder that is fabricated using centrifugal casting method. As can be observed in Figure 1(a), there are scars on the outer surface due to the vibration of the centrifugal casting machine during solidification process. Figure 1(b), there are layers of Al present because of the high rotational speed in the mold. The inner surface of the sample is defected due to the hot tear during shrinkage process as shown in Figure 1(c).

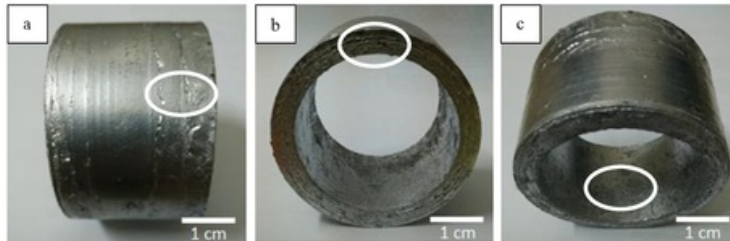


Figure 1: The physical surface from three surface views (a) outer (b) front (c) inner.

Microstructure study is carried out to observe the distribution of Si and Al inside the sample with different parameter used. The distributions are observed at the outer, middle and inner parts of the sample. Figure 2 shows the microstructure of the as-received Al LM6. The Si particles are in the needle shape with the average length of 50 $\mu$ m and distributed homogeneously. Meanwhile, Figures 3 to 11 show the microstructure of the sample fabricated under different casting condition at 1300rpm motor speed. Figures 7 to 9 shows the sample fabricated at 1500rpm motor speed and Figures 10 to 12 shows the sample fabricated at 1700rpm speed.

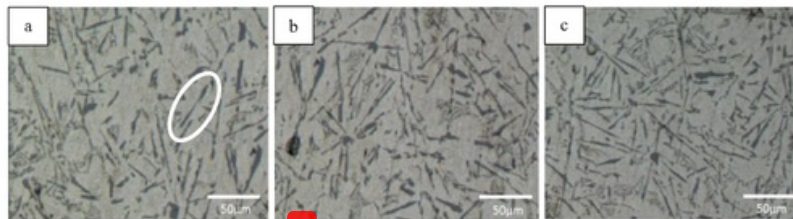


Figure 2: Microstructure of Al-LM6 before casting (a) outer, (b) middle, (c) inner

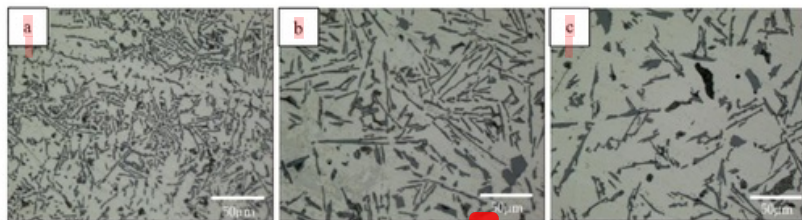


Figure 3: Microstructures of Al-LM6 cylinder with motor speed 1300rpm and melting temperature of 690 °C. (a) outer, (b) middle, (c) inner

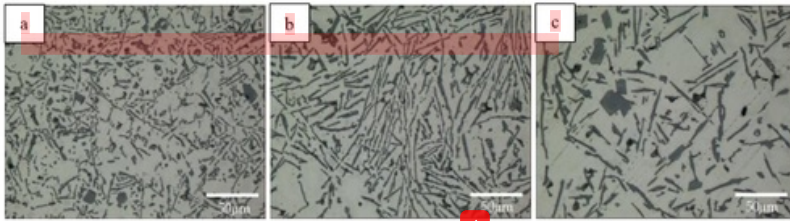


Figure 4: Microstructures of Al-LM6 cylinder with motor speed 1300rpm and melting temperature of 710 °C  
(a) outer, (b) middle, (c) inner



Figure 5: Microstructures of Al-LM6 cylinder with motor speed 1300rpm and melting temperature of 725 °C  
(a) outer, (b) middle, (c) inner

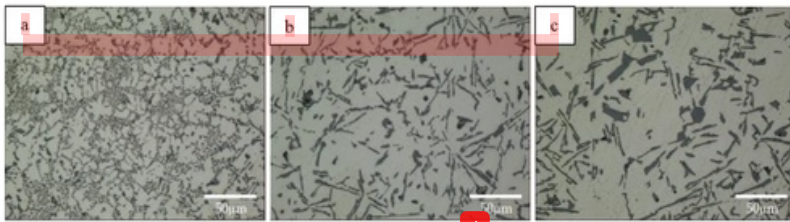


Figure 6: Microstructures of Al-LM6 cylinder with motor speed 1500rpm and melting temperature of 690 °C  
(a) outer, (b) middle, (c) inner

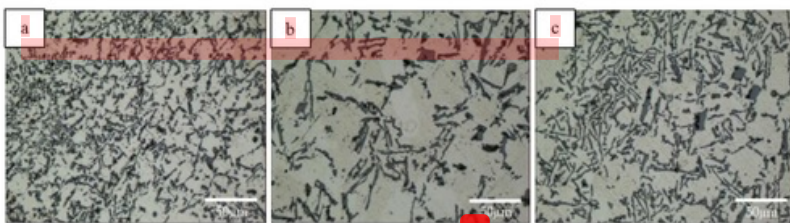


Figure 7: Microstructures of Al-LM6 cylinder with motor speed 1500rpm and melting temperature of 710 °C  
(a) outer, (b) middle, (c) inner

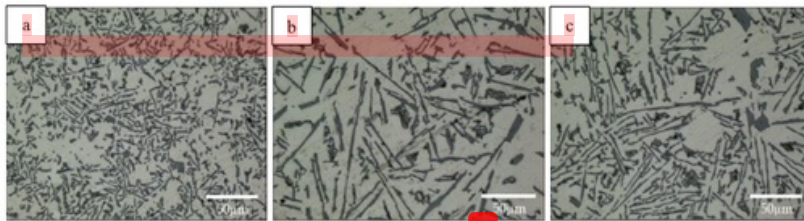


Figure 8: Microstructures of Al-LM6 cylinder with motor speed 1500rpm and melting temperature of 725 °C. (a) outer, (b) middle, (c) inner



Figure 9: Microstructures of Al-LM6 cylinder with motor speed 1700rpm and melting temperature of 690 °C. (a) outer, (b) middle, (c) inner

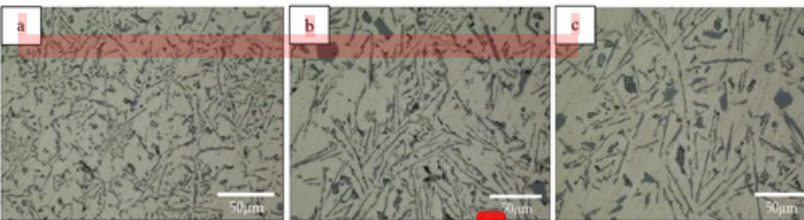


Figure 10: Microstructures of Al-LM6 cylinder with motor speed 1700rpm and melting temperature of 710 °C. (a) outer, (b) middle, (c) inner

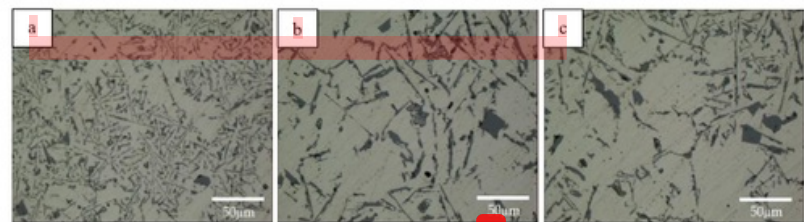


Figure 11: Microstructures of Al-LM6 cylinder with motor speed 1700rpm and melting temperature of 725 °C. (a) outer, (b) middle, (c) inner

It can be seen in the Figures 3 to 11 that the Si particles are more concentrated at the inner surface while the Al particles are more concentrated on the outer surface. This is because Si has lower density compared to Al which makes the Si to move

inward. Besides that, the size of Si in the inner are bigger than the outer surface due to the difference in cooling rate where the cooling rate at the inner surface is much slower than the outer which gives it more time to combine and form a larger size of Si. The Si particles are free to move and distributed unevenly at the sample due to its properties of high viscosity and melting temperature [8]. Moreover, the porosity present at the inner surface is because the gas bubbles are trapped during casting process because it has low density [9]. Comparing the distribution of Si particles at the inner surface for the sample fabricated at 1300 rpm (Figure 3(a)), 1500 rpm (Figure 6(a)) and 1700 rpm (Figure 9(a)) with 690°C pouring temperature, clearly observed that the concentration of Si particles increase as the mold rotating speed increase.

The percentage of Si accumulation can be determined by using Energy Dispersive Spectroscopy (EDS). Figures 12 – 14 shows the image taken from EDS for sample 8 and Table 3 shows the weight and atomic percentage for both Al and Si content in the sample. EDS is used to analyse the composition of Si and Al in the sample. From the EDS result, the weight percentage of Si is the highest at the inner part which is 20.47% and it decreases at the middle which is 16.56%. At the outer parts, the weight percentage of Si is the lowest which is 16.51%. The atomic percentage for Si in the inner part is 19.83%, at the middle part is 16.01% and at the outer part is 15.96%. Based on the microstructure observation, the size of Si is bigger at the inner part than the size of Si at the outer part. Therefore, the data shows that the Si particles are more concentrated at the inner part of the sample. Other elements are also presented during the EDS analysis however the value are less than 1% which is too small compared with the Si and Al content [10].

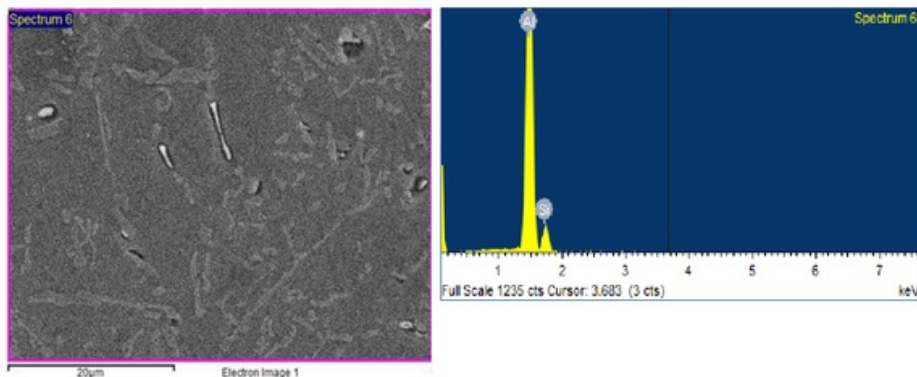


Figure 12: EDS of outer part of sample 8

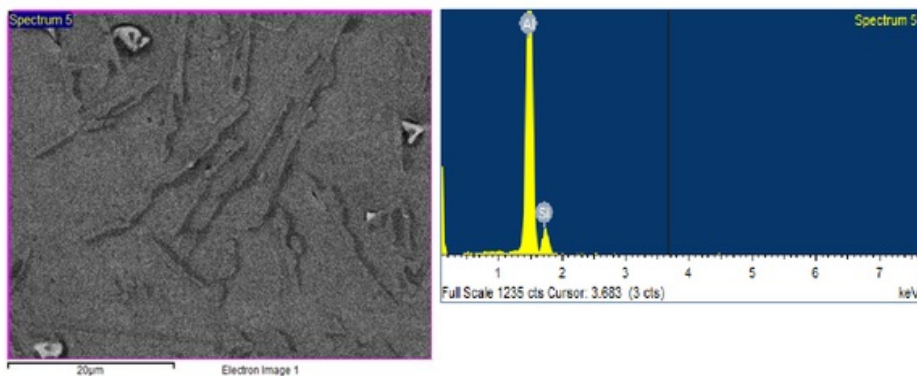


Figure 13: EDS of middle part of sample 8

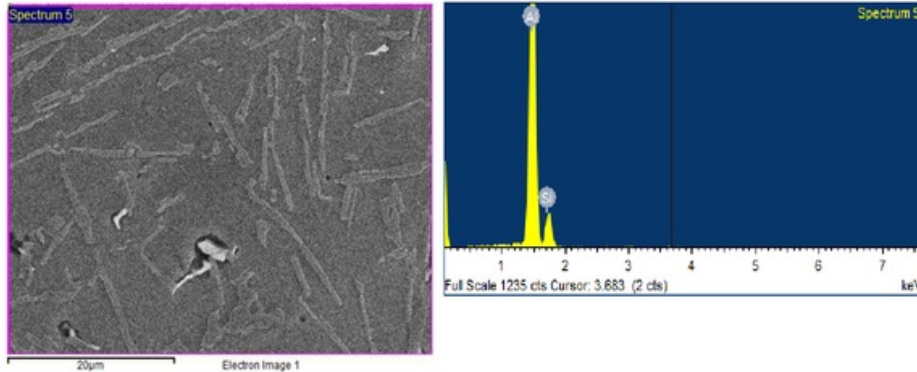


Figure 14: EDS of inner part of sample 8

**Table 3.** Weight and atomic percentage value for sample 8 at three different parts.

| Part   | Element | Weight % | Atomic % |
|--------|---------|----------|----------|
| Outer  | Al K    | 83.49    | 84.04    |
|        | Si K    | 16.51    | 15.96    |
|        | Totals  | 100.00   | 100.00   |
| Middle | Al K    | 83.44    | 83.99    |
|        | Si K    | 16.56    | 16.01    |
|        | Totals  | 100.00   | 100.00   |
| Inner  | Al K    | 79.53    | 80.17    |
|        | Si K    | 20.47    | 19.83    |
|        | Totals  | 100.00   | 100.00   |

## Conclusion

In conclusion, this study <sup>4</sup> 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.

From the microstructure study, it shows that the Si particles are distributed at the whole part of the sample and the Si particles are more concentrated at the inner part of the sample while Al are more concentrated at the outer part of the sample. This is because Al has higher density compared to Si which makes the Al to move outward. Besides that, the particles of Si at the inner part are bigger than the outer part for all of the samples because of the difference in cooling rate in which the inner part will have a slow cooling rate that gives the Si more time to combine to form a larger particles.

## 13 Acknowledgement

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Comment [S1]: A Part added

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