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Material properties of Al-Si-Cu aluminium alloy produced by the rotational cast technology

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***Abstract* ---The aim of the present study is to explore microstructural and mechanical properties of cast Al-Si-Cu aluminum alloy (ADC12). To obtain excellent material properties, the cast Al alloys were produced by an originally developed mold rotational machine, namely liquid aluminum alloy is solidified during high speed rotating. The casting process was conducted under various casting conditions, in which the following factors were altered, e.g., melt temperature, metal mold temperature and different rotational speed. Microstructural characteristics were examined by direct observation using an optical microscope and a scanning electron microscope (SEM), and the secondary dendrite arm spacing of alpha-Al phase (SDAS) and the size of Si eutectic phase were identified. Mechanical properties were investigated by micro-hardness and tensile tests. Rotation speed and melt temperature were directly attributed to the SDAS, and severe shear stress arising from the rotation made fine and complicated grain structure, leading to the high mechanical properties. The extent of the shear stress was altered depending on the area of the sample due to the different shear stress. Furthermore, high melt temperature and high rotational speed decrease the size of Si eutectic phases. The high mechanical properties were detected for the cast samples produced by the casting condition as follows: melt temperature 700°C, mold temperature 400°C and rotation speed 400 rpm.**

Keywords: Al-Si-Cu alloy, rotational casting, microstructure

I. INTRODUCTION

Cast Al-Si-Cu alloy are widely used in various engineering application, especially automotive parts due to light weight, high strength and good cast ability. Because this alloy can reduce weight and energy consuming of vehicles, they have been replaced from ferrous alloys. In our society, casting processes are widely employed to consider their benefit such as the production cost, high quality and high mechanical properties. Another advantage for the cast technology is to make the sample shapes with high precision and the complicated geometry. Cast aluminum alloys commonly are produced by pressure casting processes, including squeeze casting, thixocasting, rheocasting and vacuum casting, because of low cost and high quality [1,2].

The material properties of aluminum alloys produces by various casting technology have been the studied by a number scientists. In this instance, the material properties made by six different casting processes were investigated: gravity casting, cold chamber die casting, hot chamber die casting, squeeze casting, twin rolled continuous casting and heat mold continuous casting. Despite the same aluminum alloy, their mechanical properties are different depending on casting technology due to the change of the microstructural characteristics. In this case, excellent tensile properties were obtained in the cast Al alloys with the finer grains with the smaller secondary dendrite arm spacing (SDAS) [1,3].

To make the cast aluminum alloys with more excellent mechanical properties, an attempt was made to develop a new casting system. So as to reduce the grain size, a mold rotational casting system was proposed, where liquid aluminum alloy is solidified during high speed rotating. The casting process was conducted under various casting conditions, e.g., melt temperature, metal mold temperature and different rotational speed. Thus, the aim of the present study is to investigate systematically the microstructural and mechanical properties of cast Al-Si-Cu aluminum alloy (ADC12) produced by the rotational casting machine.

II. EXPERIMENTAL PROCEDURE

2.1Material and sample preparation

In this study, commercial Al-Si-Cu alloy (ADC12) was employed, as this alloy has been employed widely in automotive industries. The chemical composition of the alloy is $Al\text{-}Si_{10.}6\text{-}Cu_{2.5}\text{-}Mg_{0.3}\text{-}Zn_{0.5}\text{-}Fe_{1.1}\text{-}Mn_{0.3}\text{-}Ni_{0.1}$(wt.%). The ADC12 ingot, cut into small pieces (20x20x10 mm^3), was melted in a crusible in furnace, and then the liquid ADC12 was pouring directly into metal mold via runner and gate of the metal mould. Fig. 1 shows our rotational casting machine. As first approach, three casting conditions were designed to understand clearly their mechanical properties. Detailed casting conditions are indicated in Table 1.

Table 1. Casting condition

Code	T. Melt (°C)	T. Mold. (°C)	Mold Rotation (rpm)
Sample I	700	400	0
Sample II	700	400	400
Sample III	900	400	400

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2.2 Mechanical testings and microstructural analysis

The mechanical properties of the cast samples were investigated experimentally, including hardness and tensile properties. The hardness was evaluated by a Vickers hardness tester, where a standard rectangular diamond indenter was used at 300 N for 15s. Tensile properties wereexaminedat room temperature using a screw driven type universal testing machine with 50 kN capacity. The test specimens were desinged on the basis of JIS Z2201-No.8. The loading speed for the tensile test was fixed at 1 mm/min up to the fracture point. The tensile strain was measured continuously using strain gauge 2 mm long.

Microstructural characteristics were examined by an optical microscope (MO), a scanning electron mirograph (SEM) and an energy dispersive X-ray specstroscopy (EDX). The secondary dendrite arm spacing of alpha-Al phase (SDAS) and the size of Si base eutectic phase measured using an image analysis.

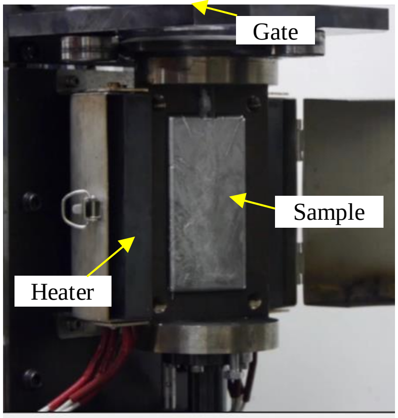

Figure 1. Photograph of rotational mold casting machine

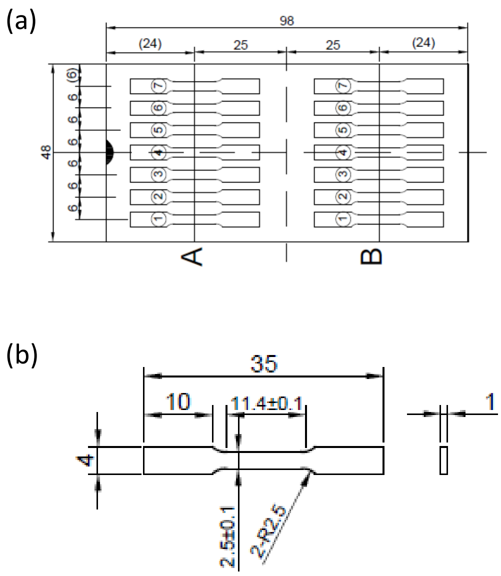

Figure 2. (a) Position of tensile specimen on sample area
(b) Dimension of tensile specimen based on JIS Z2201-No.8

III. Result and Discussion

3.1 Microstructural Characteristic

Figure 3 shows the representative cast samples produced by different casting conditions. It is clear that several flow marks are created in sample II, while smooth surface can be detected in sample I.Such cast flows could be made by the low viscosity arising from the low melt temperature. Although the flow mark is seen for sample III, that extent is lower than that for sample II. This may be affected by the high cast ability caused by the high melt temperature.

Figure 4 shows optical micrographs of the three casting alloys as shown in Table 1. Note, in this case, microstructural observation was carried out in the different areas: side-bottom region and center region. Basically, the microstructure for all samples consists of α-Al phase and Si base eutectic structure. However, the grain size and the size of Si eutectic phase are different depending on the casting condition and the observation area. From this observation, the finer microstructures are seen in the side of the cast plates compared to that for the center area, especially sample II and sample III. The reason behind this is due to rapid solidification stemmed from the rotational force. In this case, the rotational force in the sample of the side area should be higher than that for the centre area.

Figure 5a shows the secondary dendrite arm spacing (SDAS) of the three samples. SDAS for the three samples are approximately 4-7μm, which is much fine compared to that for the conventional gravity casting, e.g., SDAS=33.3 μm while that is similar level to that for die casting and squeeze casting samples, e.g., SDAS=3.7-9 μm [1].It may be considered that the rotational force directly affects the grain size. When the molten aluminium alloy was poured into the mould, nucleus growth occurs in the melt, and then that makes dendrite formation. Rotational force interfere the growth of dendrite and increase solidification rate caused smaller SDAS. That for sample III seems to be slightly coarse α-Al phase due to higher melting temperature. This induces the longer grain growth times in spite of the fact that the rotational force may interrupt the growth.

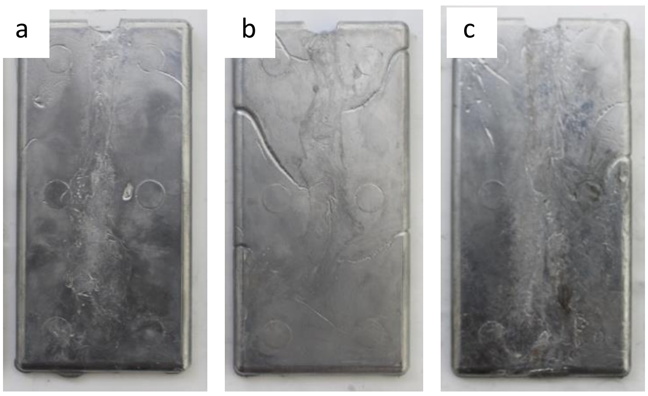

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Figure 3. Photographof cast samplesproduced by rotational mold casting at different casting conditions:(a) sample I; (b) sample II and (c) sample III.

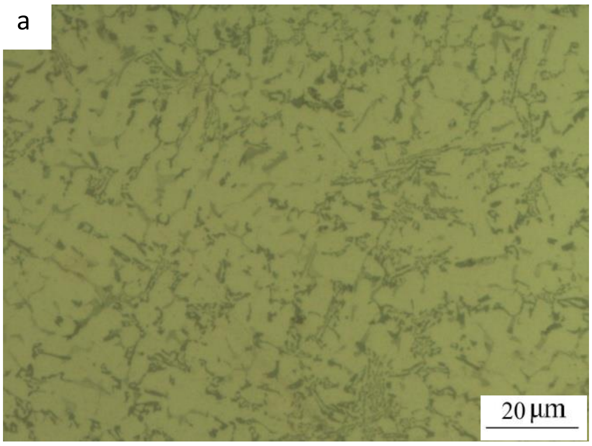
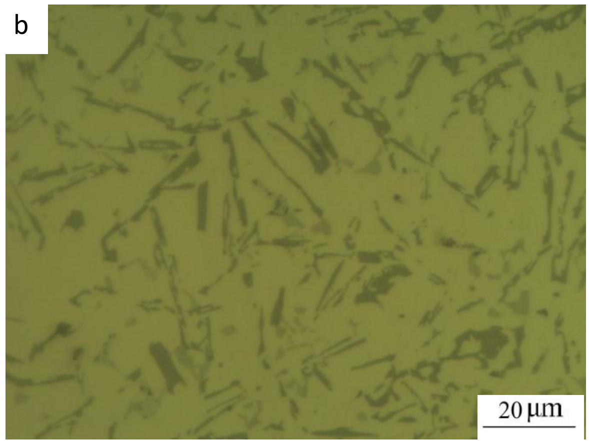
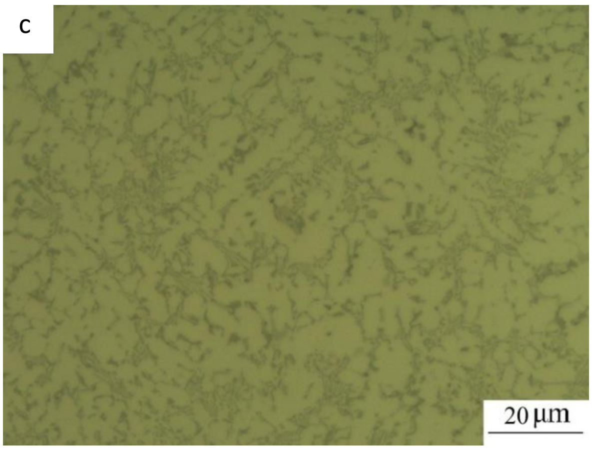
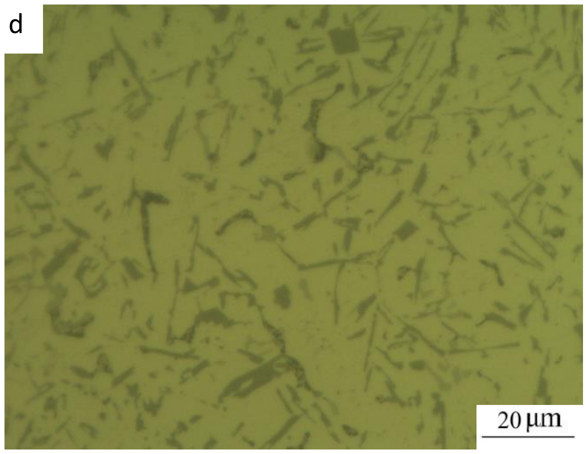
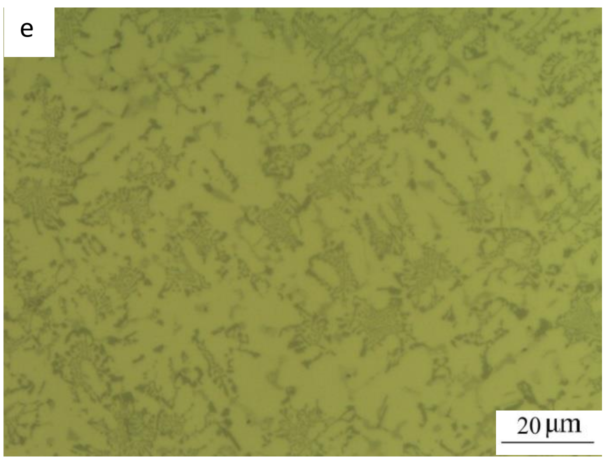
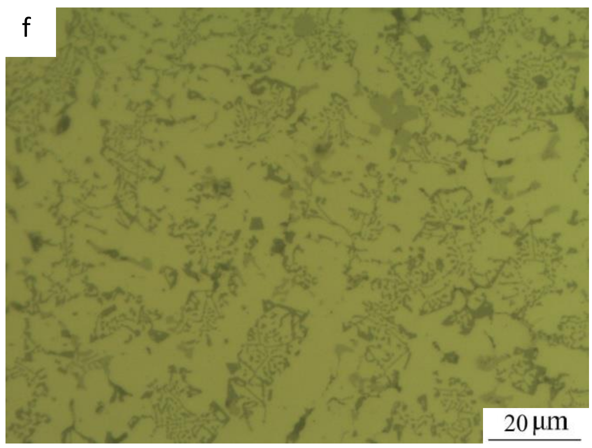
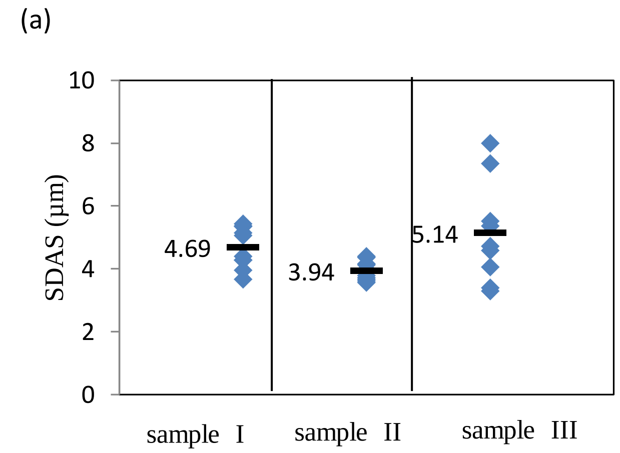
Bottom-side area	Center area
 Sample I	 Sample I
 Sample II	 Sample II
 Sample III	 Sample III

Figure 4. Optical micrograps of casting samples under variational condition a,b) Sample I c,d) Sample II e,f) Sample III



between SDAS and hardness value of three sample. Decreasing SDAS will increase the hardness value. It is accordance with the Hall–Petch relationship, the smaller grain size will increase

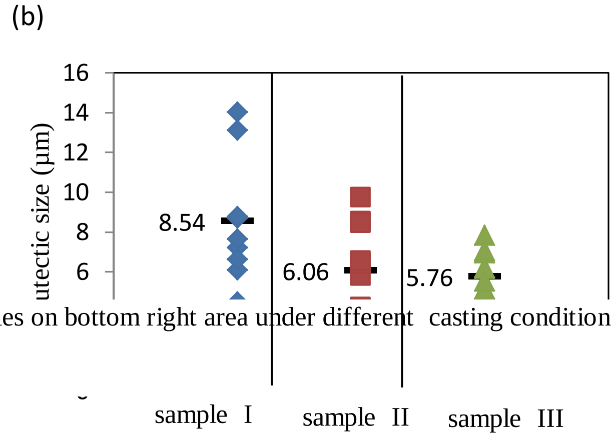


Figure 5 (a) Secondary arm spacing; (b) Si Eutectic Size for samples on bottom right area under different casting condition

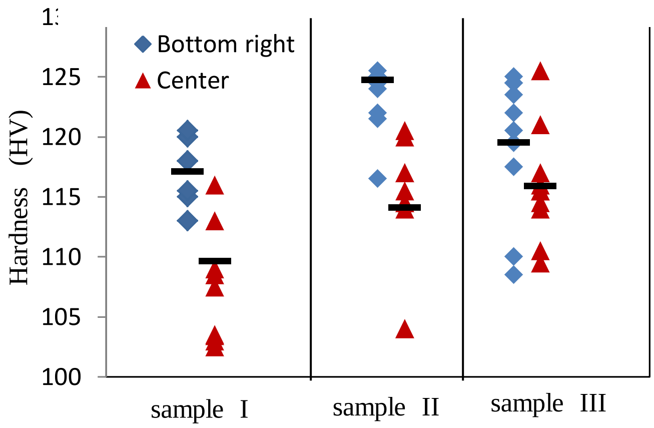


Figure 6. Hardness value of casting samples with different casting condition

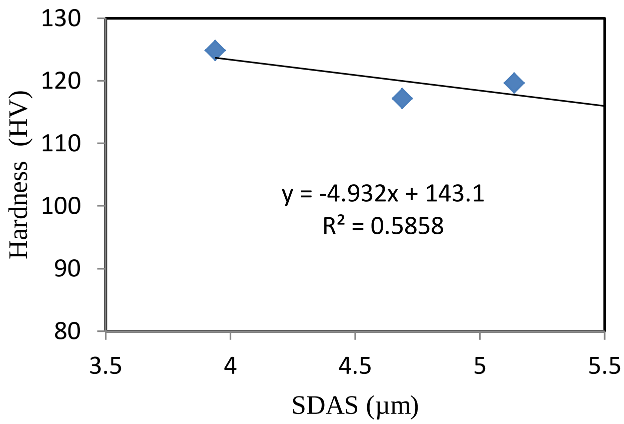


Figure 7. Correlation between hardness value and SDAS

Figure 5b displays the size of Si eutectic phases for the three samples in the side-bottom area. For sample I, there is apparently bigger size of eutectic Si phase, which might be attributed to the non-rotation condition. Sample II has smaller size than sample I. It is indicated that rotational force not only affects SDAS but also decrease the size of Si eutectic. Sample III has the finer grain size and tiny spheroid particle of Si eutectic phase. It is caused by the higher melt temperature and the high rotational speed. Spheroidal particle of Si eutectic commonly was found after heat treatment process. It can be improved to make high ductile material [4,5].

3.2 Vickers hardness

Figure 6 Displays the hardness value in center and side bottom right area of sample under different casting condition. Over all, hardness values in the bottom-right side area are higher than the center area due to the small grain size. The higher hardness value achieves at sample II (124Hv), because of the tiny grain size. However, sample III has higher hardness value than sample I despite sample 1 has smaller SDAS, but sample III has fine spheroid particle of Si eutectic that improve the mechanical properties. Figure7 shows the correlation

obstacle of dislocation movement that increase the mechanical properties. Figure 7 Shows the correlation between SDAS and hardness value of three sample. Decreasing SDAS will increase the hardness value. It is accordance with Hall–Petch relationship, the smaller grain size will increase obstacle of dislocation movement that increase the mechanical properties.

3.3 Tensile Properties

Figure 8(a) shows representative stress-strain curves for bottom area and upper are for each sample. In bottom area, it is clear that side are has a good mechanical properties compare with the center area of sample III has good tensile properties than sample II, this is different trend with hardness data in Fig.5(a) This is due to smaller size of Si eutectic on sample III increase the ductility of aluminium alloy. In the upper area, also indicate weak properties at center compare with side area.

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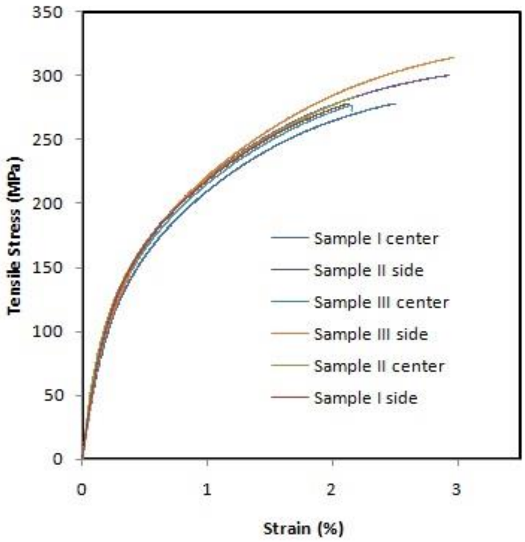
The weak properties at upper area are due to porosity and flow casting.

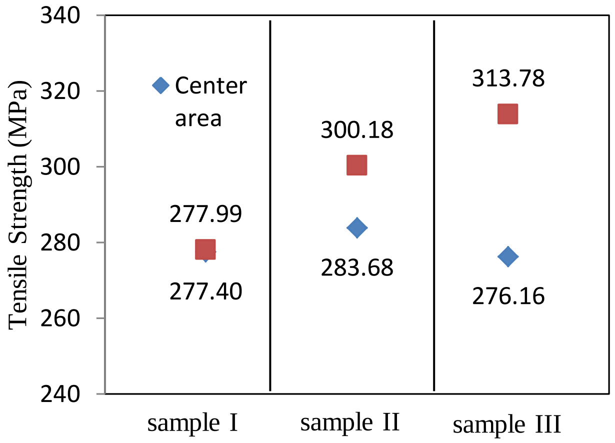
Figure 8b shows the tensile strength of each sample with different position. The higher tensile strength of 338 MPa is obtained for sample III. It is higher than the conventional cold chamber die casting sample ,e.g.,(250 MPa) and hot chamber die casting sample (320 MPa) and squeeze casting (270 MPa)[1]. Sample III also has the higher elongation fracture at 3.17 % than sample I and II due to spheroid particle of Si eutectic.

Bottom area

a) Stress-strain curve



b) Tensile strength



c. Elongation

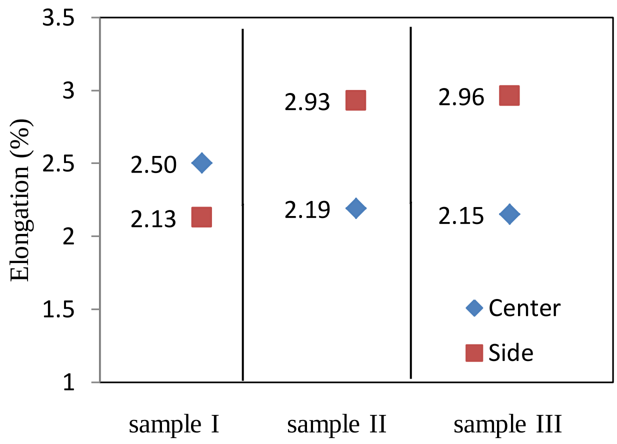
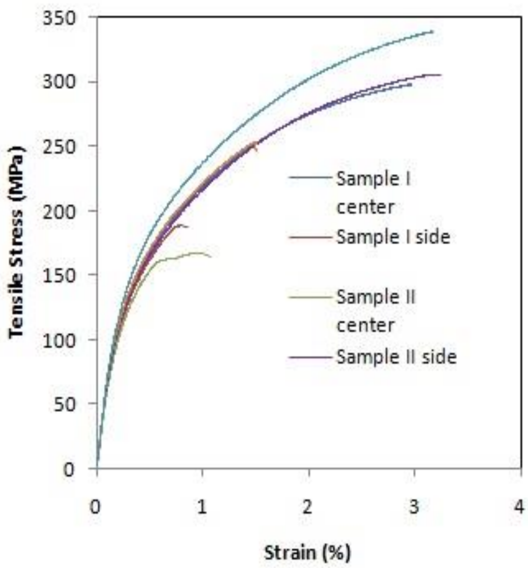
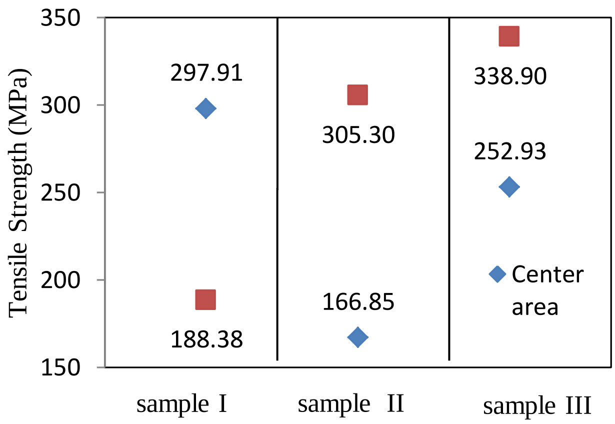
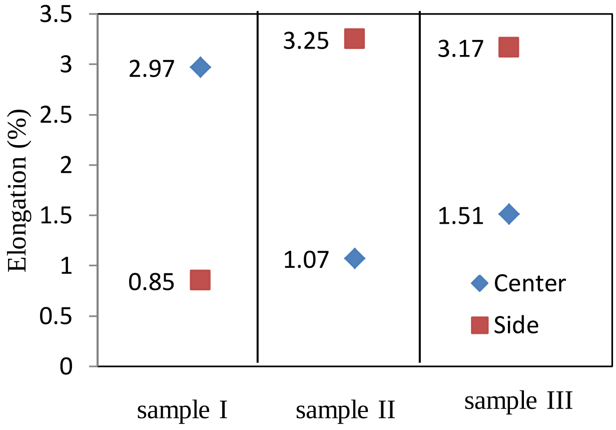


Figure 8. Tensile properties in bottom area and upper area of sa
(b) Tensile strength; (c) Elongation fracture

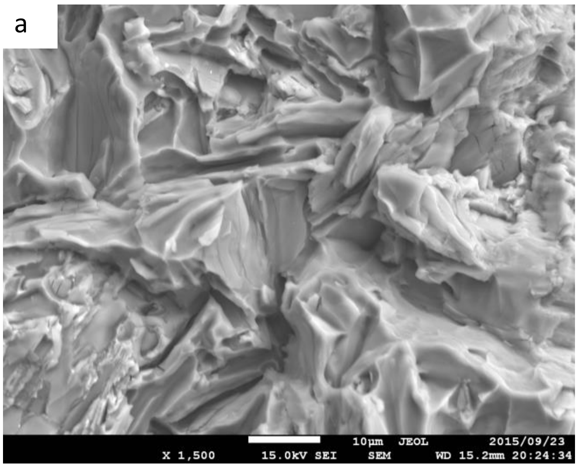
Upper area







2. Higher hardness obtain at sampel II is 124 Hv. However, the higher tensile strength and higher ductility obtain at sample III. This is due to the higher melt tempertuire, which makes the fine spheriod Si eutectic. This could lead to increment of the ductility .



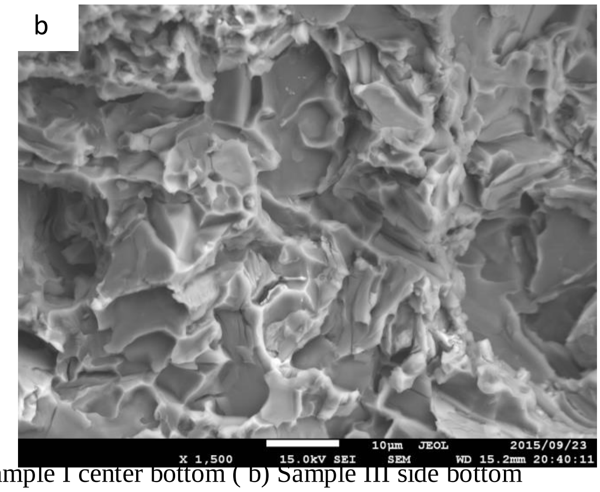


Figure 9. Fracture surface after tensile test: (a) sample I center bottom (b) Sample III side bottom

3. 4. Fractografy

Fig. 9 displays SEM images showing the fracture surfaces after tensile test for sample I on the center-bottom region and for sample III on the side bottom area. It is clear that different fracture modes are clarified.Fracture surface of sample I shows cleavage like fracture which makes generally brittle fracture mode, and the sample III diplays some dimple formation, resulting in high ductility of material.

Conclusions

The mechanical properties of cast Al-Si-Cu alloys made by the rotational mold casting technology has been studied, and the obtained results can be summerized as follows.

1. Rotational mold increase the mechanical properties of alloys due to rotational force affect solidification process obtain fine microstructures and fine spheriodical Si eutectic. Rotational force at side area is higher than center area affect the difference microstructure and mechanical properties betwen center area and side area.

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