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The effect of copper content on mechanical properties of Al₃Si-Al₂O₃/SiC hybrid composite

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Abstract. Ceramic particulate – reinforced aluminum composite – have been developed to improve mechanical properties of automotive component, particularly disc brake. One main factor to achieve good mechanical properties is improving the properties of aluminum matrix of composite by alloying with copper. This research studied the mechanical properties of hybrid aluminum composites with varied Cu, which reinforced with Al₂O₃/SiC particle. The aluminum matrix of Al-3Si ingot is melted inside the crucible furnace at 850 °C, stirred with 7500 rpm and then squeeze casted into preheated metal mold. The test results and metallography observations show that the highest percentage of Cu of 1.6 wt.% changed the dendritic structure to globular, also increased the mechanical properties of hybrid composite with the impact toughness of 0.240 Joule/mm² and the hardness value of 31.16 HRB.

1. Introduction

Aluminum alloy is a widely used metal in various application including household appliances, construction, automotive component, and airplanes. In the future, the utilization of aluminum is estimated to be widely open as primary material as well as supporting material, due to the abundance availability of aluminum ore. Aluminum alloy has light density, is resistant to corrosion, has good electrical conductivity, and will obtain a superior physical and mechanical characteristic if combined with other element and processed using certain method [1-3]. To improve its properties, aluminum alloy extensively are reinforced with ceramic material as Metal Matrix Composite. Metal matrix composite nowadays has been developed in various applications due to its mechanical properties such as a superior hardness and toughness. The challenge today is that not every metal matrix composite alloy has the strength to compete steel metal strength. The reinforcement particle given is in the form of ceramic material in order to gain superior mechanical characteristics such as hardness, toughness and lightweight [4,5].

A significant aspect affecting the performance of aluminum matrix composites is the type of reinforcement used and the amount of its volume fraction. Ceramic particulate of Al₂O₃ (alumina),



SiC, and Gr (graphite) are generally used as reinforcement in hybrid aluminum matrix composites [6]. Each type of reinforcement has a different role to the mechanical and tribology properties as hardness, impact toughness and wear resistance [7]. Previous research showed that an increase in SiC with a volume fraction of 10% had good mechanical properties for ballistic applications [8]. Another important factor influencing the properties is composition of the matrix composite [4,5]. Al-Si alloy is easy to process and adding Cu element will improve the aluminum structure, which previously columnar becomes globular and refine the matrix up to 69.2 % and 72.5 % [9].

Manufacturing composite is a significant factor to produce good quality product [10]. Squeeze casting is a pressurized casting process using die-punch shaped cast, where the pressure is given directly on the molten metal during solidification. By using metal cast and pressure effect, heat transfer will occur relatively fast, thus, porosity defect and shrinkage will be minimized. The squeeze process is able to increase physical and mechanical characteristic, especially on material with aluminum and magnesium alloy based. Squeeze on aluminum alloy based is able to produce casting with properties that look like it was a result of forging [12,13]. The advantage of squeeze casting is the ability to minimize void defect, porosity, and to produce a globular microstructure, whereas with such result, it will produce a superior mechanical characteristic of hardness and toughness [14]. The study focuses on developing hybrid composite ceramic particles with aluminum matrix by adding Cu alloying element to improve the mechanical properties using squeeze-casting process.

2. Experimental Methods

The process of producing hybrid composite materials of matrix of Al-3Si ingots is conducted in crucible type electrical furnace with 850°C temperature. Alloying element of Cu is added with variation of 0.84, 1.03 and 1.64 wt.%. The reinforcement particles of Al₂O₃ and SiC with total volume fraction of 15% are preheated in 1000°C temperature for one hour. The melting is conducted under 850°C temperature, and the making of aluminum matrix composite with hybrid reinforcement is conducted inside crucible furnace. The aluminum matrix melt is mixed with heated ceramic particle and stirred in 7500 rpm speed for one minute to optimize the mixing of aluminum matrix and the reinforcement, then included in degasing process using argon. The Al-3Si-Cu matrix liquids that have been stirred with alumina through stir casting process are then poured into the preheated die mold. The squeeze casting process on composite aluminum is conducted under pressure of 20 kg/cm². Pressure is applied inside die mold in a semisolid condition of composite. The previous die mold was preheated under the temperature 150°C. The composites are then characterized using spectrometry, hardness testing, impact testing, and microstructure examination.

3. Results and Discussion

Adding copper element will generate globular structure in aluminum matrix, hence improves mechanical properties. The target composition is Al-3Si with Cu variation and reinforced with 15% volume fraction of Al₂O₃ and SiC can be seen in Table 1. Chemical composition testing based on ASTM E1251 is conducted using spectrometer on hybrid composite. An increasing of Si element was due to the addition of SiC reinforcement element of 7.5%. Alloying element Si can increase hardness and cast ability.

Table 1. Chemical composition of Al3Si-Cu matrix with Al₂O₃/SiC reinforcement hybrid composites

Composite	Composition (%)			
	Si	Cu	Mg	Al
Composite 1	8.59	0.84	0,0123	Bal
Composite 2	11.1	1.03	0,0125	Bal
Composite 3	10.7	1.64	0,0092	Bal

Figure 1 shows the hardness test results obtained of hybrid composites, which 1.6 wt.% Cu hybrid composite having the highest hardness of 31.16 HRB. Hybrid composite with 0.84 wt.% Cu has a hardness value of 28.42 HRB and composite with 1.03 wt.% Cu has a hardness value of 29.04 HRB that indicating the increased alloying element in the composite matrix material will improve the hardness of the hybrid composites. Figure 2 shows impact toughness of hybrid composites, which the highest average value is in 1.64 wt.% Cu hybrid composite with impact toughness value of 0.241 J/mm². It can be seen that increasing alloying Cu element will improve the impact toughness value gradually.

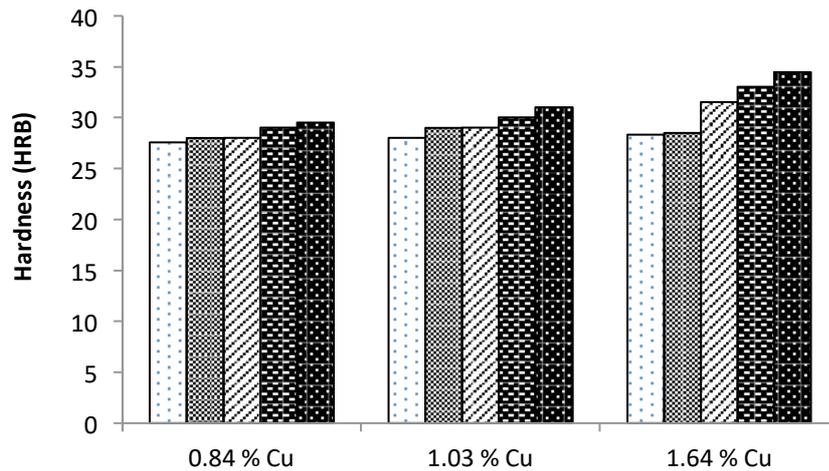


Figure 1. Hardness value of Al-3Si-Cu matrix and Alumina/SiC reinforcement hybrid composites, with Cu variation of 0.84, 1.03 and 1.64 wt.%.

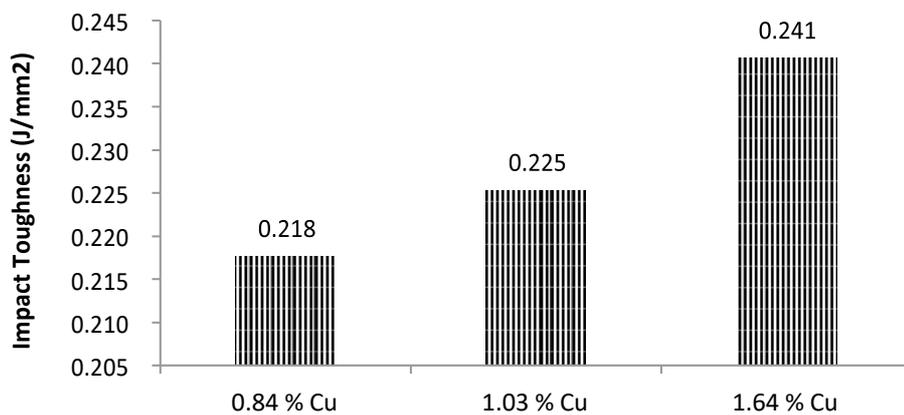


Figure 2. Impact toughness value of Al-3Si-Cu matrix and Alumina/SiC reinforcement hybrid composites, with Cu variation of 0.84, 1.03 and 1.64 wt.%.

Metallography examination was aimed to obtain an image of macro and microstructure of hybrid composite aluminum surface resulting from squeeze casting process. Metallography observations with magnification of 100 and 500 times are seen in Figure 3. The presence of agglomerated particles of ceramic particles reinforcement in one spot causing porosity at the composite of 1.6 wt.% Cu. This

condition could occur because of the process of pouring molten metal into the mold is needed to complete rapidly. Nevertheless the composite with 0.84 wt.% and 1.03 wt.% Cu have more homogenous structure, which can be comprehended from Fig. 3a and 3c. The increasing content of Cu alloyed will create the dendritic structure in matrix becomes more globular and improve the mechanical properties such as hardness, the impact toughness value of aluminum composite matrix Al-3Si-Cu.

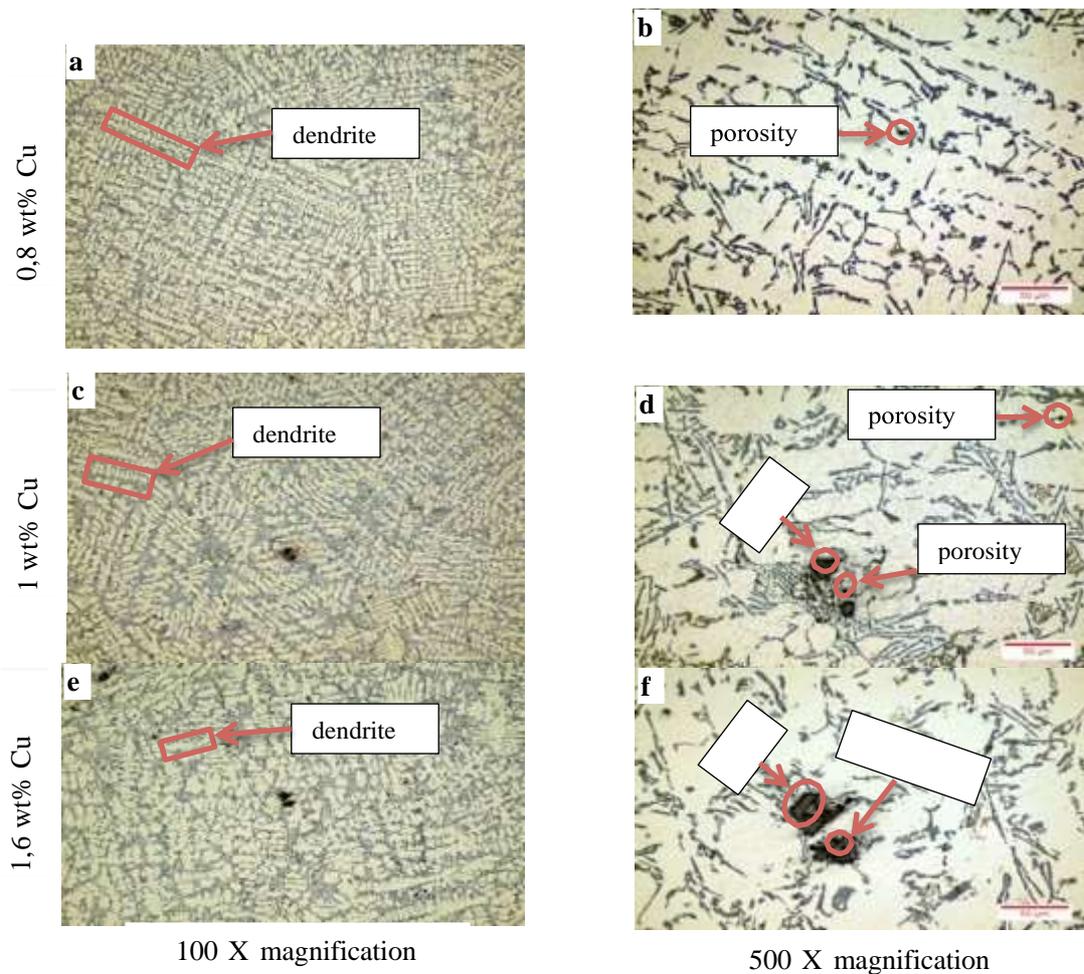


Figure 3. Microstructure of hybrid composite of Al3Si-Cu reinforced with alumina/SiC ceramic particulate

4. Conclusions

- The enhancing of Cu content of 0.84, 1.03 and 1.64 wt.% in Al-3Si-Cu matrix with alumina/SiC of 15 % volume fraction reinforcement lead to the increase of hardness value of 28.42 HRB to 29.04 HRB and 31.16 HRB.
- The highest impact toughness value of Al-3Si-Cu hybrid composite of 0.241 J/mm² was obtained by addition Cu content of 1.64 wt.%. Whereas, on the decreasing addition of Cu content reduced the impact toughness value.

- The addition of Cu alloying element in Al-3Si-Cu matrix hybrid composites is able to refine dendrite structure of matrix and produce a globular structure, therefore affecting the mechanical properties of hardness and impact toughness.

Acknowledgment

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