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THE EFFECT OF ANNEALING AND COLD FORGING ON MICROSTRUCTURE AND HARDNESS PROPERTIES OF Al-SiC COMPOSITE: A PRELIMINARY STUDY

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ABSTRACT
THE EFFECT OF ANNEALING AND COLD FORGING ON MICROSTRUCTURE AND HARDNESS PROPERTIES OF Al-SiC COMPOSITE: A PRELIMINARY STUDY. Aluminium Metal Matrix Composites (AMMCs) are among the exciting materials that have an extensive function in various applications. Reinforcement in the fabrication process of Al composites can produce superior properties such as high strength, good fracture resistance, and of course, lightweight. Therefore, many studies are interested in revealing the characteristics of Al composite materials through various methods and variations of reinforcement. This research was a preliminary study with a scope of work that includes observation on the effects of annealing and cold forging processes on microstructure morphology and hardness properties of SiC nano-ceramic reinforced of Al composites. The aluminium used in this study was a 7xxx series aluminium alloy. The fabrication process was carried out by stir-squeeze casting method. Microstructure analysis was conducted by optical microscopy and Scanning Electron Microscopy (SEM) equipped with Emission Dispersion Spectroscopy (EDS). The hardness properties of the Al-SiC composite were examined by micro Vickers hardness testing. This paper reports that annealing process influences grain refinement and hardness properties of the Al-SiC composite. The sample experiencing cold forging shows improvement in the hardness value. Increase of hardness value by forging after anneal may be promoted due to grain compression as dislocation mechanism effect. Comprehensive research is required to discover other potentials of Al-SiC composite materials.

Keywords: Al-SiC composite, annealing temperature, cold forging, hardness, microstructure.

ABSTRAK

EFEK PROSES ANIL DAN TEMPA DINGIN TERHADAP STRUKTUR MIKRO DAN SIFAT KEKERASAN KOMPOSIT Al-SiC: STUDI AWAL. Aluminium Metal Matrix Composites (AMMCs) *merupakan salah satu material menarik yang memiliki fungsi sangat luas dalam berbagai aplikasi. Dengan memanfaatkan peran penguat dalam proses fabrikasinya, komposit Al mampu menghasilkan sifat unggul seperti kekuatan yang tinggi, ketahanan patah yang baik dan tentu saja bobot yang ringan. Oleh karena itu, banyak penelitian yang tertarik untuk mengungkap karakteristik material komposit Al melalui berbagai metode dan variasi penguat. Penelitian ini merupakan studi awal dengan ruang lingkup pekerjaan antara lain mengobservasi efek dari proses anil dan tempa dingin terhadap morfologi mikrostruktur dan sifat kekerasan komposit Al berpenguat nano keramik SiC. Aluminium yang digunakan pada penelitian ini adalah paduan aluminium seri 7xxx. Proses fabrikasi komposit dilakukan menggunakan metode* stir-squeeze casting*. Analisis struktur mikro dilakukan dengan menggunakan mikroskop optik dan* Scanning Electron Microscopy (SEM) *yang dilengkapi* dengan Emission Dispersion Spectroscopy (EDS)*. Pengujian kekerasan dari sampel komposit Al-SiC dilakukan menggunakan micro vickers hardness testing. Penelitian ini melaporkan bahwa proses anil berpengaruh terhadap fenomena penghalusan butir dan nilai kekerasan pada sampel komposit Al-SiC. Sampel yang mengalami proses tempa pasca anil menunjukkan adanya perbaikan nilai kekerasan. Peningkatan nilai kekerasan bisa jadi sebagai akibat adanya pemampatan butir sebagai efek dislokasi. Perlu penelitian secara komprehensif untuk mengetahui potensi lain dari material komposit Al-SiC.*

Kata kunci*: Komposit Al-SiC, suhu anil, tempa dingin, kekerasan, struktur mikro.*

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INTRODUCTION

Composite technologies that use aluminium as the matrix are known as Aluminium Metal Matrix composites (AMMCs). AMMCs provide benefits in the form of a combination of properties between the parent (matrix) and the reinforcement. One type of aluminium alloy that is commonly used in AMMCs is the 7xxx series aluminium alloy. 7xxx series aluminium alloys have wide application such as turbine components [1], automotive [2], high-speed rail [3], aerospace [4], and even military [5] because of their superior properties, namely high strength, high fatigue resistance and lightweight. The lightweight aluminium material can reduce the carbon footprint by reducing fuel consumption in vehicles to avoid global warming. Another advantage of 7xxx series aluminium alloy is its corrosion resistance [6] and good castability [2]. Over time, the demand for materials with higher specifications has become an unavoidable issue due to technological developments. One option to achieve the requirement is by applying composite technology.

Several studies have shown that AMMCs can be processed by various methods such as stir casting [7], [8], squeeze casting [9], and powder metallurgy [10]. AMMCs fabrication process has a significant influence on the physical and mechanical properties. This is related to the interaction that occurs between the metal matrix and the reinforcing element. Several studies reported that that the stir casting method in AMMCs fabrication has advantages in increasing the UTS value and yield strength [11]. In addition, the stir casting process is an accessible, inexpensive, and environmentally friendly technology [7], [8], [12]. Gangil et al. also stated that the stir process is possible to eliminate porosity and particle clustering [8]. Another method that also has benefits is squeeze casting. R. Muraliraja et al. have reported that the squeeze process reduces the potential for pitting and segregation of reinforcement [9].

Furthermore, Arunachalam et al. have been elucidated the fabricated AMMCs using the combination of the two previously mentioned processes [13]. The combination of stir and squeeze can overcome each other's weaknesses so that a quality composite product is obtained (increased strength and decreases porosity). In other research, Adithiyaa also stated that appropriate temperature and pressure settings could optimize the strength of composite products [14].

In this study, the manufacture of Al-SiC composites uses a combination of stir and squeeze casting methods. The addition of SiC as a reinforce can enhance both hardness and strength on AMMCs [7]. The effect of annealing and forging processes on microstructure and hardness properties will focus on the discussion. The data obtained can be used as a preliminary study on the SiC-reinforced Al 7075 series composite material characteristics.

METHOD

a. Fabrication Al-SiC Composite

In the present studies, the materials used were Al 7075 series fabricated with nano SiC through stir casting and squeeze casting process. The composition of Al metal is presented in Table 1. The 7075 aluminium matrix ingot is cut according to the target weight and then put into the melting furnace. The temperature then increased gradually until 850°C so that the aluminium melts evenly. At the same time, the 0.3 wt% SiC nano reinforcing particles with the size of ~50 nm produced by NILACO were exposed to UV waves, then stired vigorously, and then heated in another muffle furnace at a temperature of 900°C. The temperature was gradually increased and held for one hour.

Table 1. Chemical composition of Al 7075 (wt %).

Zn	Si	Fe	Ti	Cu	Mn	Mg	Cr	Al	Other
5.1-6.1	0.40	0.50	0.20	1.2-2.0	0.30	2.1-2.9	0.18-0.28	Bal.	0.65

Afterward, the SiC nano particulates were put into the molten metal and stirred at 500 rpm (rotations per minute) for two minutes. Subsequently, the degassing process was carried out with argon for one minute to remove hydrogen and other impurities dissolved in the composite along with slag, which was then removed and discarded. Before the molten composite is poured, the mold is preheated first to avoid thermal shock. The mold (made of stainless steel) is heated to a temperature of 300°C. Then the composite is poured into the mold and pressed with a hydraulic press with a pressure of 20 tons for two minutes. Lattermost, the metal is then allowed to stand in the mold to room temperature. Determination of material balance in the fabrication of Al-SiC composites is calculated based on the following equation [15].

$$\rho \text{ Composite} = \rho_{Al\text{-}7075}.V_{Al\text{-}7075} + \rho_{SiC}.V_{SiC} \quad (1)$$

$$\text{Mass Fraction of SiC} = (\rho_{SiC}.V_{SiC}) / (\rho_{SiC}.V_{SiC}) + (\rho_{Al\text{-}7075}.V_{Al\text{-}7075}) \quad (2)$$

In this expression, ρ and v denote the density and volume. By knowing the volume of the mold and target of SiC reinforcement, the weight of the composite and mass fraction of SiC can be determine.

b. Annealing and Forging Process

The composite sample was cut into four small pieces measuring (1.5 x 1.5 x 1.5) cm. Afterwards, samples were annealed at a temperature of 390°C and 410°C with a holding time of two minutes. Further, cold forging introduces 50 tons load for all samples, which results in a reduction of about 85% respectively. Figure 1 shows the sample before and after forging. The anneal procedure of the experiment is shown in Table 2.

Table 2. Research procedure.

Sample Code	Anneal Temp. (°C)	Forging Load (tons)	Holding time (minute)
As-cast	-	-	-
Sample 1	390	50	2
Sample 2	410	50	2

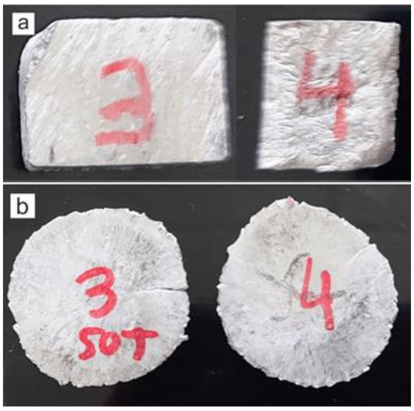

Figure 1. The sample of Al-Si composite. (a) Before forging; (b) After forging.

The hardness test will be conducted as evidence in conjunction with the influence of annealing temperature on the plasticity of composite Al. Afterward, optical microscopy and scanning electron microscopy observations will be presented to get information about the microstructure behavior of the composite Al.

RESULTS AND DISCUSSIONS

a. Hardness Testing

The anneal process subjected to the Al-SiC composite sample affects the hardness properties. Al-SiC composite hardness value can be seen in Figure 2. It is shown that the decrease in hardness in the annealed sample compared to the as-cast sample reached ~16 %. Meanwhile, samples at an annealing temperature of 390°C and 410°C was slightly similar. Lin Hua et al. reported that the annealing process on Al-SiC composites exhibit an increase in tensile elongation and a decrease in yield strength [16]. Lin also explained that the fracture characteristics of the Al-SiC composite samples after the anneal process were mostly ductile fracture morphology consist of dimple and tearing ridges [16]. Hence, tensile testing should be performed in this study to identify the correlation between the reduction in hardness values between as-cast and post annealed forged samples.

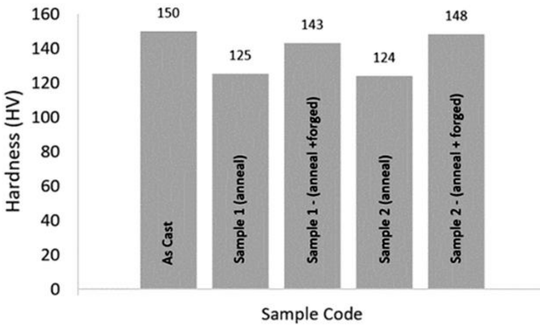

Figure 2. Hardness value of composite Al-SiC.

On the other hand, hardness improvement on the Al-SiC composite sample occurs due to the forging process is applied. Figure 2 exhibits an improvement hardness value (3.3% increase) in the post forging between samples 1 and 2. The grain refinement mechanism may ensue during the forging process. This phenomenon will be discussed further by observing the microstructure data.

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b. Microstructure Observation

The metallography examination gives an information about the morphology of dendrite and grains on the samples. Fig.3 depicts the optical observation of as-cast Al-SiC composite.

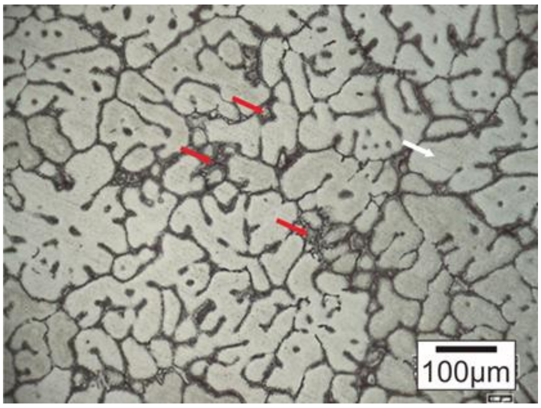

Figure 3. Optical microstructure of as received Al-SiC composite.

The red arrows indicate the presence of SiC reinforce, which has homogenous distribution on the Al matrix (white arrows). SiC reinforcement appears at the grain boundaries of the Al matrix. However, there is no dendritic observed on the microstructure.

In general, the reinforcement mechanism of SiC ceramics in the Al matrix involves the dissolution-precipitation process. These happen in the temperature range of 657 - 827°C. Furthermore, the reaction between SiC and Al matrix introduces new compounds (Al_4C_3) that will enhance the mechanical properties of the composite material itself.

Afterwards, the appearance of the grains undergoing size reduction post forging is depicting in Figure 4. Sample 2 (Fig.4d) shows a denser forging imprint distance than sample 1 (Fig.4b). This condition shows fairness if the hardness value of sample 2 is higher than sample 1. The load imposed on the sample during the forging process causes plastic deformation. This plastic deformation is the forerunner to the movement of dislocations in the Al-SiC composite sample. These are related to the contribution of increasing the hardness to the sample post forging treatment.

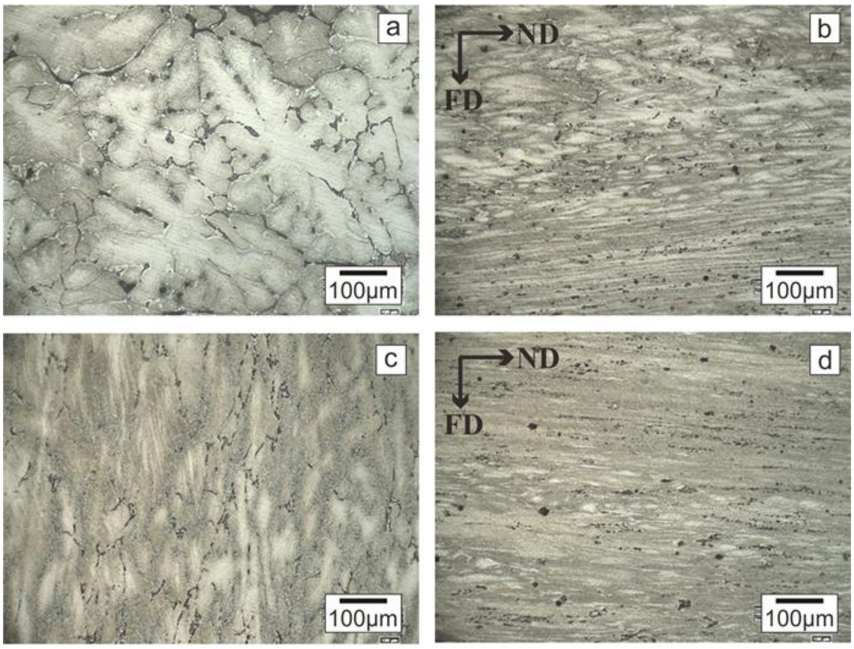

Figure 4. Comparison of Al-SiC microstructure pre and post forging. (a) Sample 1; (b) Sample 1-Forged; (c) Sample 2; (d) Sample 2-Forged. (ND for Normal Direction; FD for Forging Direction).

Chak reported that the deformation process applied to the Al-SiC composite sample would have advantage such as reducing voids and smoothing grains contributing to the hardness improvement [17]. Regarding the decrease in the hardness value between the as-cast sample and the forging post-annealed sample, further analysis is required, such as tensile testing to evaluate whether the drop in hardness occurs owing to compensation for tensile strength.

Further confirmation for the presence of SiC reinforcement in the Al matrix was carried out using Scanning Electron Microscopy (SEM) equipped with Energy Dispersive Spectroscopy (EDS). The EDS spectrum shown in Fig. 5 indicate the existence of a SiC reinforcement.

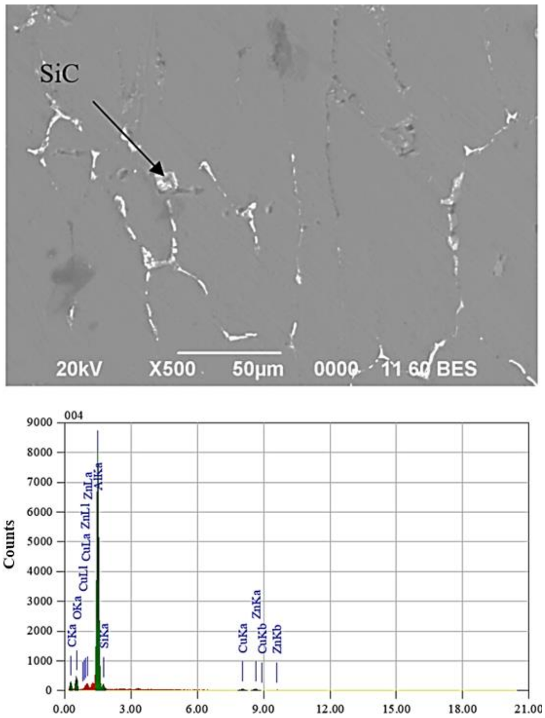

Figure 5. SEM and EDS observation of Sample with annealing temperature 410 °C.

CONCLUSION

Aluminium Metal Matrix Composite with nano SiC-reinforced was successfully fabricated through the stir-squeeze casting process. The results of the analysis show the effects due to the annealing and forging process. The combination methods (annealing and forging) affect decreasing the hardness compared to as-cast samples. Furthermore, an increase in the hardness value occurred in post-forged samples 1 and 2 due to the grain refinement effect. The decrease in hardness values between as-cast and annealing samples requires further investigation, one of them is through tensile testing to determine their relationship.

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CONTRIBUTORSHIP STATEMENT

Main contributors in this manuscript are Bintang Adjiantoro and Muhammad Yunan Hasbi.

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