Wear Resistanceof Carbothermally Reduced of Fly Ash Reinforced Aluminum Composite

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Wear Resistance of Carbothermally Reduced of Fly Ash Reinforced Aluminum Composite

Sulardjaka, Jamasri, M.W. Wildan, Kusnanto

***Abstract*— Fly ash particles are potentially used in metal matrix composites, since they are low-cost, low-density and available in large quantities as a waste by-product in thermal power plants. The addition of fly ash into aluminum as reinforcement can potentially reduce the production cost and density of aluminum. However, mechanical properties of fly ash reinforced aluminum matrix composite (MMC ALFA) have some limitations due to the characteristic of fly ash. In this study, a carbothermal reduction process of fly ash with activated carbon powder was performed prior to produce MMC ALFA.**

The carbothermal reduction process was carried out in a furnace at 1300 °C in vacuum condition. The product was analyzed by XRD with Cu-K_α radiation. The synthesis product was subsequently used as reinforcement particle. Aluminum powder and 5, 10 and 15 % wt of carbothermally reduced powder were mixed and then uni-axially compacted at pressure of 300 MPa. Green body was sintered for 2 hours in argon atmosphere at temperature of 550 and 600 °C.

Hardness, wear resistance and density of MMC ALFA's product were tested using Brinell hardness test, ogoshi high speed universal wear testing machine and Archimedes method respectively. The results of this study shows that the reinforcement of carbothermally reduced of fly ash in general can improve the hardness and wear resistance of MMC ALFA. From XRD analysis, it shows that the synthesis process can produce SiC powder

***Index Term*— Carbothermal reduction, fly ash, MMC, wear.**

I. INTRODUCTION

FLY ash is a byproduct of the burning process at coal-fired power plant. Fly ash is obtained by electrostatic or mechanical precipitation from the flue gases of furnaces fired with pulverized coal. The current annual production of coal ash world wide is estimated around 600 millions tons, with fly ash constituting about 500 millions tons [1]. Suralaya power plant, once of the Indonesia's power plant that used coal, generated about 0.2 millions tons fly ash in 2005 [2]. The employed fly ash as a valuable resource in China is only 20 – 30 %, in Europe is about 60 % and in USA is about 30 % and the world is average only amounts of 16 %. [1,3,4]. The amount of the fly ash released by factories and thermal power plants has been increasing throughout the world, and the disposal of fly ash has become a serious environmental problem. Increasing the amount of fly ash being re-utilized will minimize disposal cost, less area is reserved for disposal and replaced some scarce or expensive natural resources. Utilization of fly ash can be in the form of an alternative to another industrial resource, process or application. Utilization of fly ash in producing novel materials, waste management and recovery of metals are the new research area that will expand the positive reuse of this abundant material, thereby helping to reduce the environmental and economical impacts of its disposal.

Fly ash particle used as filler in aluminum alloy casting reduces cost and density and increase the damping capacity [5,6]. Aluminum-fly ash composite can be prepared by powder metallurgy techniques, strength of sintered compacts decreased with increasing weight percent of fly ash, however hardness was found to increase slightly up to 10 % wt fly ash [7]. The addition of 10 and 15 % wt of fly ash decrease the tensile and impact strength of aluminum – fly ash composite [8]. Addition up to 10 wt.% as received fly ash particle (75–100 lm) after preheating in Al–12Si alloy through liquid stir casting. A linear decrease in the density and ultimate tensile strength and a linear increase in electrical resistivity of Al–12Si–fly ash composites have been observed with increasing dispersoid content [9].

The comparison of mechanical properties of some of the common aluminum matrix composites with aluminum–fly ash composites has shown that the addition of alumina and silicon carbide particles in cast and wrought aluminum alloy can enhance the tensile properties [10]. The amount of SiO_2 in fly ash is about 40 %. It is potential SiO_2 resources on carbothermal reduction process. Quartz (SiO_2) can be reacted with activated carbon powder in carbothermal reduction process to produce silicon carbide. β SiC powder had been successfully synthesized from fly ash and 8.21 μm carbon black [4]. Our previous work is also successful in synthesizing β SiC form fly ash and 32 μm activated carbon at temperature 1300 °C under vacuum atmosphere [2]. The addition of fly ash into aluminum as reinforcement can potentially reduce the production cost and density of aluminum. However, mechanical properties of fly ash reinforced aluminum matrix composite (MMC ALFA) have some limitations due to the characteristic of fly ash. Therefore, this paper proposes

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methods for enhancing coal fly ash as a reinforcement powder on aluminum metal composite. Carbothermal reduction process has been conducted on fly ash and activated carbon powder.

II. Materials and Experimental Procedure

A. Materials

Our experiment used starting materials which utilized fly ash and activated-carbon powder. The fly ash was collected from Suralaya power plant, Indonesia. Composition of the coal fly ash was analyzed by atomic absorption spectroscopy (AAS) as shown in TABLE I.

TABLE I
COMPOSITION OF SURALAYA COAL FLY ASH

Compound	Weight
SiO_2	45.51
Al_2O_3	30.35
Fe_2O_3	8.71
CaO	5.49
MgO	2.75
Na_2O	1.45
MnO	0.1
K_2O	0.64
others	until 100 %

Activated-carbon powder with particle size – 400 mesh (<32μm) was used as the carbon sources. The carbon source was made from granular activated-carbon that was ball milled and sieved with – 400 mesh sieving machine. Weight of the fly ash in starting precursor was determined based amount of SiO_2 in the fly ash. Molar ratio SiO_2 and activated-carbon powders was 1 : 4. Aluminum fine powder (99.99%) supplied by Merck was used as reinforced material.

B. Preparation of specimens and experimental methods

Carbothermal reduction was conducted in the carbolite vacuum furnace at temperature 1300 ºC, with a heating rate of 10 ºC/minute, and holding time process of 2 hours, then followed by cooling in the furnace by switching the furnace off. Schematic of carbothermal reduction process is shown in Fig. 1. For increasing SiC yield, cycling synthesis process has been developed. The cycling synthesis process is re-synthesis the product from previous synthesis process. After one cycling synthesis process, the synthesized product was added with 1 mol activated carbon powder then cruised and mixed on jar mill with steel ball for 2 hours. The objective of the cycling process is to make new surface contact between SiO_2 and C. After the synthesis process, the product was heated at temperature 850 for 4 hours in atmosphere condition to burn the excess carbon. Synthesized products were examined by X-ray powder diffraction (XRD) using Cu K_α radiation and SEM fitted with EDS. Peaks obtained from XRD test were interpreted by PANalytical software.

Aluminum fine powder (99,9 %) supplied by Merck was used in this experiment. Aluminum was mixed in turbula mill with 5, 10 and 15 % fraction weight of the carbothermal reduced product for 12 hours. Mixed powders then uni-axially compacted at pressure of 300 MPa. The green body was sintered in argon atmosphere at temperature 550 and 600 ºC. The holding time of sintering was 2 hours. Density of composites product was tested based Archimedes method. Hardness of MMC product was tested by Brinell hardness test with load 122.2 N. Wear resistance of MMC was tested by Ogoshi High Speed Universal Wear Testing Machine. Wear resistance was tested by contacted flat specimen of composites again 30 mm revolving disc (59 HR_C). Load of contact test was 12.72 Kg, abrasion speed was 0.08 m/s and abrasion distance was2.4 m. Schematic of wear resistance tested is shown on Fig.2.

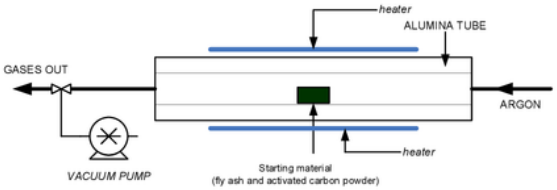

Fig. 1. Schematic process carbothermal reduction of fly ash and activated carbon powder.

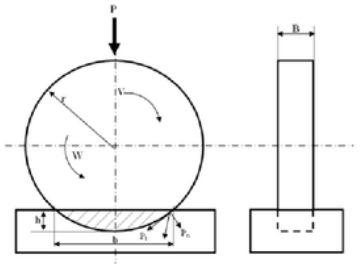

Fig. 2. Schematic of wear resistance test

III. Results and Discusion

According to ASTM standard fly ash collected from Suralaya power plant is classified as type C. Fig.3. shows the XRD pattern of carbothermally product of fly ash at temperature reaction 1300 ºC for 1, 2 and 3 times cycling synthesis. By carbothermally reduced, some of SiO_2 in fly ash reacts with carbon to form SiC. There are possibility two mechanisms that produce β SiC. First, β SiC is produced through diffusion process mechanism that follows reaction of : $SiO_2(s1)+3C(s)\rightarrow SiC(s)+2CO(g)$ and second, β SiC is resulted through reaction of $Fe(Si^m,C^n)\leftrightarrow SiC+Fe(Si^{m1},C^{n1})$ that involves catalyst of Fe_2O_3. It shows that carbothermally reduced of fly ash contains : 53.5 % SiC; 7.1 % Fe_3Si; 21.4 % albite and 17.8 % SiO_2 (quartz). Morphology of carbothermally reduced of fly ash and activated carbon powder is shown in Fig.4. It shows

that carbothermally reduced of fly ash and activated carbon powder results SiC powder and SiC whiskers.

Density of composites decreases by increasing sintering temperature and % wt of reinforcement powder as shows in Fig. 5. The measured density of MMCs is lower than obtained from the calculation. Fig. 6 shows that porosity of MMCs increases with increasing sintering temperature and % wt reinforcement.

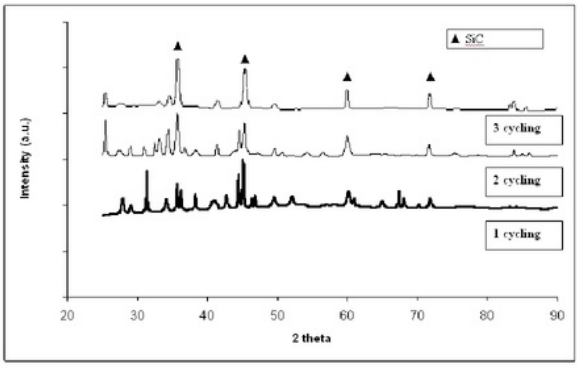

Fig. 3. XRD pattern of carbothermal reduction of fly ash and activated carbon powder on temperature 1300 °C for 2 hours with 1,2 and 3 cycling synthesis process.

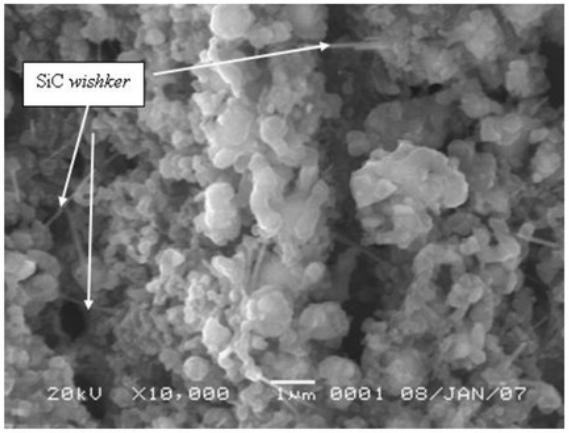

Fig. 4. Morphology of carbothermally reduced of fly ash and activated carbon powder.

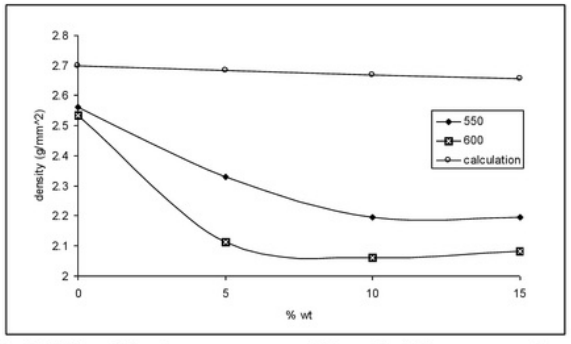

Fig. 5. Effect of sintering temperature and % wt of reinforcement powder on density of composites.

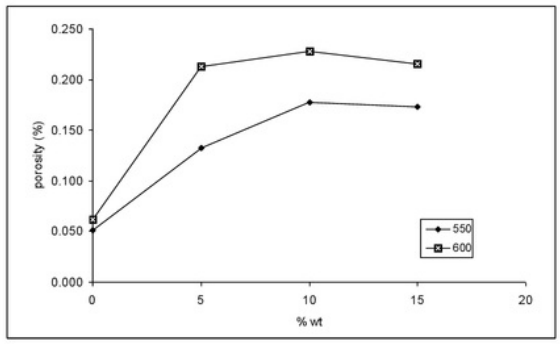

Fig. 6. Effect of sintering temperature and % wt of reinforcement powder on porosity of composites.

At both sintering temperature, i.e. 550 and 600 °C, hardness of composite increases with increasing % wt of reinforcement powder. The effect of sintering temperature and % wt on hardness of composite is shown in Fig.7. At sintering temperature 550 °C for 2 hours, hardness of composite with 5 % wt, 10 % wt and 15 % wt are 98 BHN, 124 BHN and 146 BHN respectively. At sintering temperature 600 °C for 2 hours 93 BHN, 118 BHN and 125 BHN respectively. Sintering at temperature 550 °C for 2 hours gives higher hardness than sintering at temperature 600 °C for 2 hours. From Fig. 5, it is shown that porosity at sintering temperature 600 °C is higher than porosity at sintering temperature sintering 550 °C. Highest hardness of composites is 146 BHN at sintering temperature 550 °C for 2 hours with 15 % wt reinforcement powder.

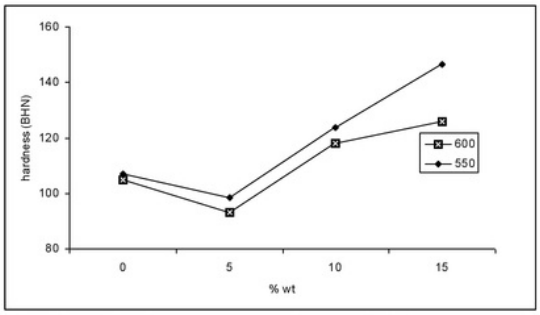

Fig. 7. Effect of sintering temperature and % wt of reinforcement powder on hardness of composites.

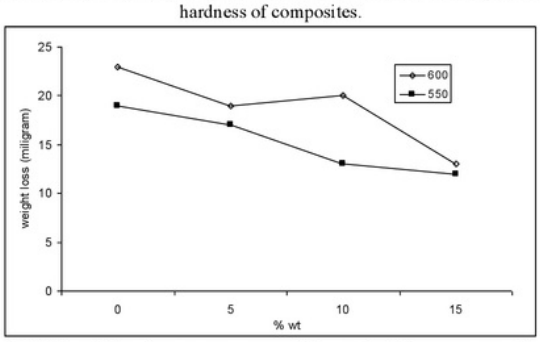

Fig. 8. Effect of sintering temperature and % wt of reinforcement powder on weight loss of composites.

Fig. 8. shows effect of sintering temperature and 5 wt of reinforcement powder on wear resistance of composite products. Weight loss of composite products decrease with increasing % wt of reinforcement powder. Wear resistance of composites sintered at temperature 550 ºC for 2 hours is higher than wear resistance of composites sintered at temperature 600 ºC for 2 hours. Sintering at temperature 550 ºC give better mechanical properties than sintering at temperature 600 ºC for 2 hours.

IV. Conclusion

1. The densification of aluminum matrix composite reinforced with carbothermally reduced of fly ash decrease with increasing sintering temperature and weight percent of reinforcement powder.
2. Carbothermally reduced of fly ash produces SiC phase that enhance reinforcement of fly ash on aluminum matrix with increases hardness and wear resistance of MMC product.
3. Sintering at temperature 550 ºC for 2 hours give higher hardness than sintering at temperature 600 ºC for 2 hours.
4. Composite sintered at temperature 550 ºC for 2 hours has better hardness and wear resistance than sintered at 600 ºC for 2 hours.

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