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Mechanical Properties of Aluminum Matrix Composite Reinforced by Carbothermally Reduced of Fly Ash

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Abstract. The addition of fly ash into aluminum as reinforcement can potentially reduce the production cost and density of aluminum. However, mechanical properties of aluminum matrix composite reinforced by fly ash (MMC ALFA) have some limitations due to the characteristic of fly ash. In this study, a carbothermal reduction process of fly ash and activated carbon powder with particle size < 32 μm was performed prior to produce MMC ALFA.
The process was carried out in a furnace at 1300 ^{o}C in vacuum condition under argon flow. Synthesis product was analyzed by XRD with Cu-K_{α} radiation. From XRD analysis, it shows that the synthesis process can produce SiC powder. The synthesis product was subsequently used as reinforcement particle. Aluminum powder was mixed with 5, 10 and 15 % of the synthesized powder, and then uni-axially compacted at pressure of 300 MPa. The compacted product was sintered for 2 hours in argon atmosphere at temperature variation of 550 and 600 ^{o}C. Flexural strength, hardness and density of MMC ALFA's product were respectively evaluated using a four point bending test method based on ASTM C1161 standard, Brinell hardness scale and Archimedes method. The result of this study shows that the increase of weight of reinforcement can significantly increase the hardness and flexural strength of MMCs. The highest hardness and flexural strength of the MMC product are 300 kg/mm^2 and 107.5 MPa, respectively.

Keywords: carbothermal reduction, fly ash, MMC, mechanical properties

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

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about 30 % and the world average only amounts of 16 %. [1,3,4]. A substantial amount of fly ash is still disposed of in landfill. Disposal of fly ash will soon be too costly.

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. For instance, fly ash particle used as filler in aluminum alloy casting reduces cost and density, and increase the damping capacity [5,6]. The presence of fly ash in pure Al matrix decreases its coefficient thermal expansion [7].

Aluminum-fly ash composite can be prepared by powder metallurgy techniques such as done by Rothagi et. al [8]. In this research, strength of sintered compacts decreased with increasing weight percent of fly ash, however hardness was found to be increased slightly up to 10 % wt of fly ash. The addition of 10 and 15 % wt of fly ash decreases the tensile and impact strength of aluminum – fly ash composite [9]. Furthermore, the addition of fly ash into aluminum as reinforcement can potentially reduce the production cost and density of aluminum. However, mechanical properties of aluminum matrix composite reinforced by fly ash (MMC ALFA) have some limitations due to the characteristic of fly ash. In this study, a carbothermal reduction process of calcinated fly ash and activated carbon powder with particle size < 32 μm has been performed prior to produce MMC ALFA.

MATERIALS AND METHODS

This experiment utilized fly ash and activated-carbon powder as starting materials. 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 1. Calcination process of fly ash was done in the carbolite vacuum furnace at temperature of 850^{o}C for 4 hours in atmosphere condition. Activated-carbon powder with particle size of 400 mesh (<32μm) was used as carbon sources. The carbon sources were made from granular activated-carbon that was ball milled and sieved with a 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 made 1 : 4. The fly ash and activated carbon powder were mixed using a magnetic stirrer for 6 hours in ethanol solution. Carbothermal reduction process was subsequently conducted in the carbolite vacuum furnace under argon flow. Temperature of the process was maintained at 1300 ^{o}C for 2 hours and then cooled naturally. Schematic of carbothermal reduction process is shown in FIGURE 1. After the carbothermal reduction process, the product was heated at 850 ^{o}C for 4 hours in atmosphere condition in order to burn the excess carbon. Carbothermal reduction product was then examined by X-ray powder diffraction (XRD) using Cu K_{α} radiation and SEM fitted with EDAX.

Metal matrix composite was prepared by powder metallurgy technique. Commercially pure (99,9 %) aluminum fine powder supplied by Merc was used in this experiment. The aluminum fine powder was mixed in jar mill with 5, 10 and 15 % weight of the carbhotermal reduction product, and then uni-axially compacted at pressure of 300 MPa. The green body was sintered in argon atmosphere at temperature variation of 550 and 600 ^{o}C. The holding time of sintering process was kept for 2 hours. Mechanical properties of MMC product were evaluated by means of flexural test and hardness measurement. Flexural test was conducted by four point flexural method based on ASTM C1161 standard, hardness test was done by Brinell hardness scale and density was measured according to the Archimedes method.

TABLE 1. Composition of calcinating fly ash collected from Suralaya power plant, Indonesia

No.	Component	% wt
1.	SiO_2	45.52
2.	Al_2O_3	30.3
3.	Fe_2O_3	8.72
4.	CaO	5.5
5.	MgO	2.75
6.	Others	7.21

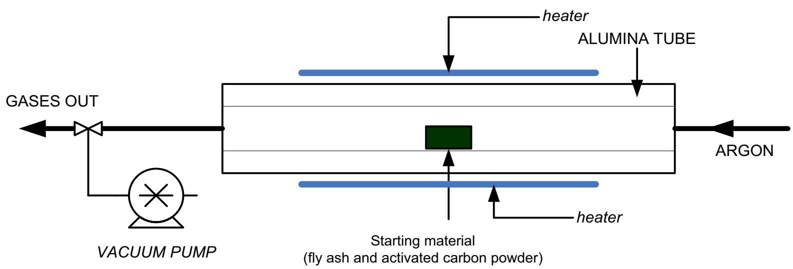


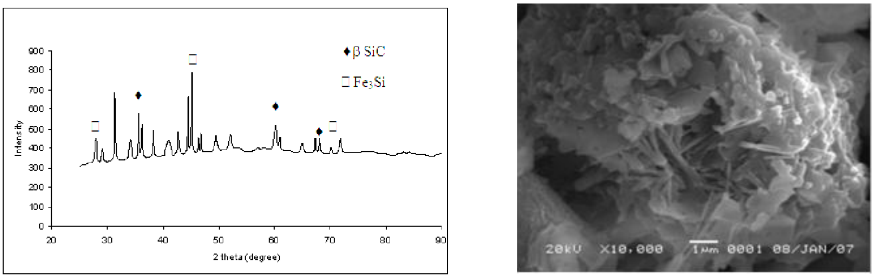
FIGURE 1. Schematic of carbothermal reduction process

RESULTS AND DISCUSION

Phases and morphology of carbothermally reduction product are shown in FIGURE 2(a) and 2(b) respectively. It shows that there are peaks at $2\theta = 35.6\,^{o}$, 41.3 ^{o}, 60.1 ^{o} and 72.1^{o} which are caused by β SiC phase. From XRD analysis can be concluded that carbothermal reduction process produces β SiC an d Fe_3Si as major phases [2]. Percent relatives of phases from carbothermal reduction process are shown in FIGURE 3. It is shown that composition of carbothermally reduced of fly ash is 53.5 % SiC; 7.1 % Fe_3Si; 21.4 % albite and 17.8 % SiO_2 (quartz).

The effect of sintering temperature and % wt reinforcement on density of aluminum matrix composite reinforced by carbothermally reduced of fly ash is shown in FIGURE 4(a). Density of composites is decreased by increasing sintering temperature and % wt of reinforcement powder. The measured density of MMCs is lower than obtained from the calculation. Porosity of MMCs increases with increasing sintering temperature and % wt reinforcement as shown in FIGURE 4(b).

FIGURE 5 shows the effect of sintering temperature and % wt reinforcement on hardness of composite. Both at sintering temperature of 550 and 600 ^{o}C, hardness of composite is increased with the increase of temperature, and the highest hardness is 300 kg/mm^2 which is achieved at 15 % wt of reinforcement powder and sintering temperature 550 ^{O}C.



(a) **(b)**

FIGURE 2. (a). XRD pattern of carbothermally reduced of fly ash
(b). Morphology of carbothermally reduced product

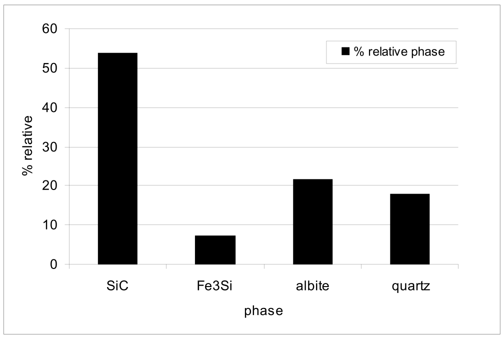
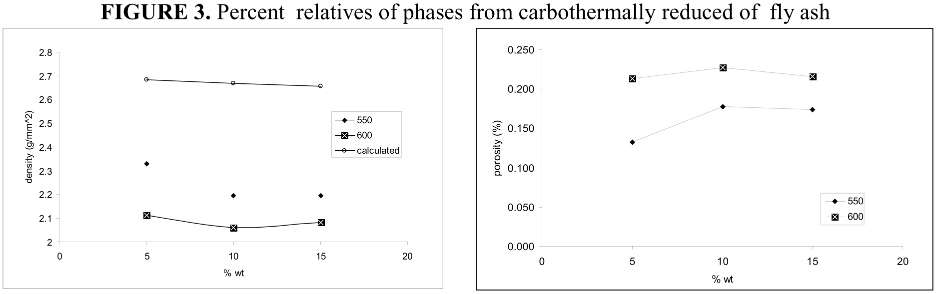


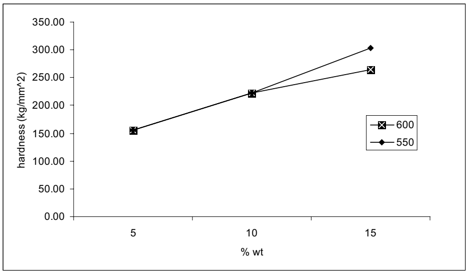
FIGURE 3. Percent relatives of phases from carbothermally reduced of fly ash



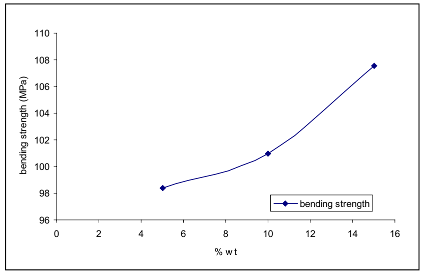
(a) **(b)**

FIGURE 4. (a). Effect of sintering temperature and % wt on density of MMC
(b). Porosity of MMC product

Flexural strength of MMC reinforced by carbothermally reduced of fly ash sintered at temperature 550 ^{o}C for 2 hours is shown in FIGURE 5(b). It can be seen that the flexural strength of MMC increases with the increase of weight percent of reinforcement powder, in which the flexural strength of Al + 5 % wt, Al + 10% wt and Al + 15% wt are 98 MPa; 100 MPa and 107 MPa, respectively. Study performed by Guo et.al [8] and Gikuno [9] shows that the addition of fly ash in aluminum up to 10 % causes the decrease of tensile strength and hardness of composite. However, in this experiment, increasing of weight percent of reinforcement powder up to 15 % can significantly increase the hardness and flexural strength of MMCs product which is caused by the presence of SiC as the product of carbothermal reduction process.



(a)



(b)

FIGURE 5. (a). Effect of sintering temperature and % wt of reinforcement on hardness of MMC ALFA

(b). Effect of % weight of reinforcement on flexural strength of MMC ALFA at sintering temperature of 550 ^{o}C for 2 hours

CONCLUSION

1. Carbothermally reduced of fly ash can produce SiC phase that enhances reinforcement of fly ash on aluminum matrix with increasing flexural strength and hardness of MMC product.
2. The increase of fly ash powder reinforcement up to 15% wt will significantly increase the hardness and flexural strength of MMC ALFA.
3. The density of MMC reinforced by carbothermally reduced of fly ash product will slightly decrease as the sintering temperature and weight percent of reinforcement is increased.

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