



## Fatigue Analysis of Al/Fly Ash Composite from Coal Waste using Hot Isostatic Pressing

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### ABSTRACT

Hot isostatic pressing is one of the method applied in powder technology to produce high density material. This research aims to investigate physical and mechanical properties of aluminium-fly ash composite made by hot isostatic pressing. Material uses was aluminium powder ( $\leq 53 \mu\text{m}$ ) as matrix and fly ash powder as filler ( $\leq 53 \mu\text{m}$ ). Fly ash powder was calcined at  $800^\circ\text{C}$  for 3 hours. Aluminium and fly ash composition were 95%, 100%, and 5%, 0 % weight fraction. Mixtures were stirred for 5 hours and pressed using 50 MPa and 100 MPa pressure to obtain green compacts. The green compacts were hot isostatically pressed by 120 MPa pressure at temperature variation of  $520^\circ\text{C}$ ,  $540^\circ\text{C}$ , and  $570^\circ\text{C}$  using 1 hours holding time. Fatigue analysis showed that optimum fatigue resistance was obtained at composition of aluminium 95%-5% fly ash composite made by hot isostatic pressing at  $540^\circ\text{C}$ , 120 MPa pressure, and 1 hours holding time. This composite produced minimum fatigue rate of  $0,005 \text{ mm}^3/\text{Nm}$ . The specimen experienced in situ reaction caused by aluminium oxidation during sintering process.

Keywords: *Hot isostatic pressing*, aluminium- fly ash composite, mechanical properties

### INTRODUCTION

Composite is widely developed for various purposes such as airplanes, motor vehicles, and other areas that required high strength material, but light in weight. Composite is a combination of two or more materials that unequal in shape and chemical compositions both microscopically and macroscopically

Metal composites can be fabricated by molding or powder methods. However, molding methods have drawback in producing homogeneity. Reinforced particles are tending to float or precipitate due to density differences. Meanwhile, powder methods can produce homogeneity by appropriate mixing between metals and reinforced particles. The mixtures are pressed and sintered at certain temperature to obtain homogeneity

Aluminium is a frequently used material in machines components, particularly in form of alloy. Superiority of aluminium compared to

other metals is in high corrosion resistance, electrical conductivity, heat conductivity and decorative property.

Fly ash is formed at temperature of  $920\text{--}1200^\circ\text{C}$  and collected as ash precipitator and cenosphere. Cenosphere has low density  $0.6 \text{ g.cm}^{-3}$  and can be utilized as ultra-light material composite. Meanwhile, the density of ash precipitator is  $2,0\text{--}2,5 \text{ g.cm}^{-3}$  (Bienas, et al, 2003). According to Landman (2003) and Bienas et al (2003), the main composition of fly ash is silica and alumina with magnesium oxide and calcium oxide as minority.

Metal composite using aluminium matrix as reinforced material such as SiC,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , aluminosilicates, graphite, and fly ash produce better mechanical properties (Ejiofor et al., 1997). Volume fraction affects fatigue property and material strength linearly (Kobayashi et al., 1998). This phenomena will be investigated

in the production of Al-fly ash composite using powder method.

Powder fly ash with particle size of 53-100 nm used as reinforced material as shown in Fig 2.

## METHODS

### Materials

Powder of AK12 (AlSi<sub>12</sub>CuNiMg) used as base matrix. Microstructure photograph of material can be seen in Fig. 1

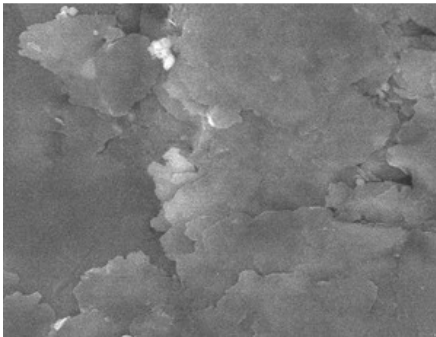


Fig.1. Aluminium powder under SEM.

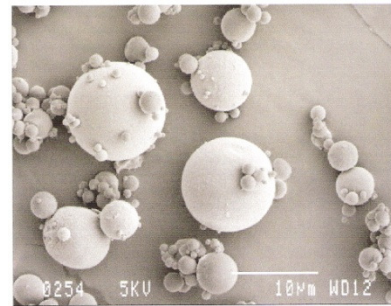


Fig. 2. Fly ash particles under SEM

### Composite Production

Composite production using hot isostatic pressing method was conducted according to the following steps (Fig 3).

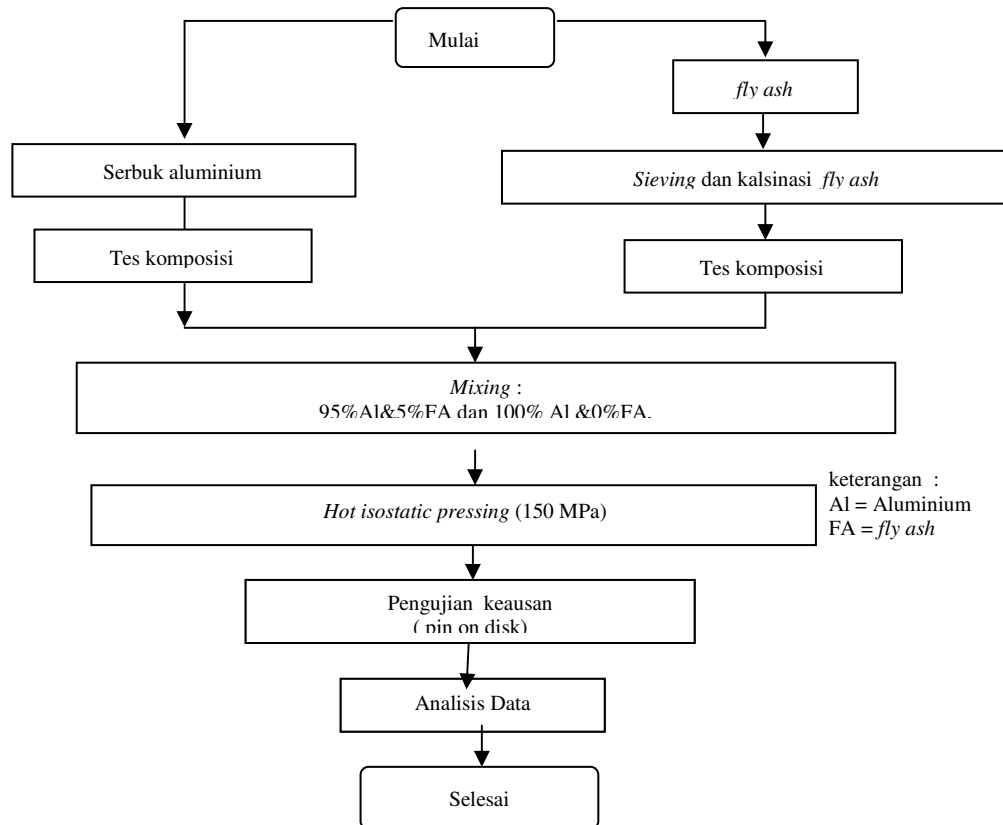


Fig 3. Composite fabrication steps

## RESULTS AND DISCUSSIONS

Fatigue analysis was conducted using pin on abrasive disc method on cylindrical specimen that previously sanded according to ASTM standard (ASTM G 99-95a, 2003). Relative fatigue was calculated based on loss of specimen weight (pin) by abrasion using 1,4  $\mu\text{m}$  surface roughness disc rotated at 80 rpm and 1.7 kg load. Rate of fatigue was measured by abrasion volume per load and abrasion distance.

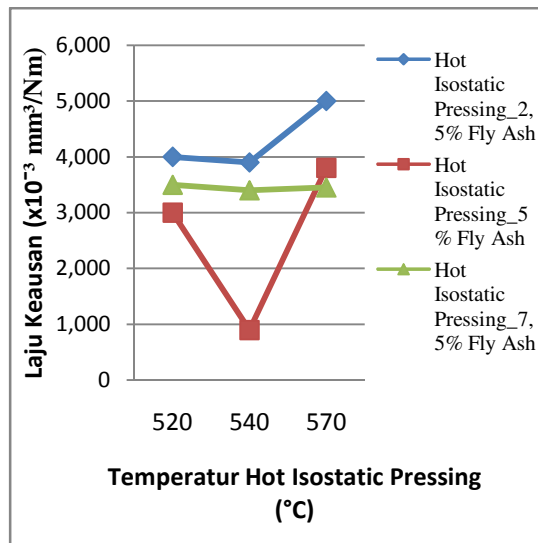


Fig 4. Effect of sintering temperature on fatigue rate

Result of fatigue analysis is shown in fig 4. The lowest rate was obtained at 540 °C that produced fatigue rate  $0,016 \pm 0,0057 \text{ mm}^3/\text{Nm}$  indicating the high resistance of material. On other hand, the highest rate was produced at 520 °C with fatigue rate of  $0,034 \pm 0,0007 \text{ mm}^3/\text{Nm}$  in accordance with the results of hardness test and density measurement. Both material density and hardness are the lowest.

Fly ash addition at percentage of 5% was reduced fatigue rate to  $0,016 \pm 0,0057 \text{ mm}^3/\text{Nm}$  compared to fatigue rate at 100% aluminium, i.e.  $0,188 \pm 0,016 \text{ mm}^3/\text{Nm}$ . This result indicates an increase in fatigue resistance due to fly ash addition in accordance with Miyajima (2003). Smaller fly ash particles with hard and round shape can fill the aluminium matrix well. Higher density will produce higher fatigue resistance, therefore will decrease fatigue rate.

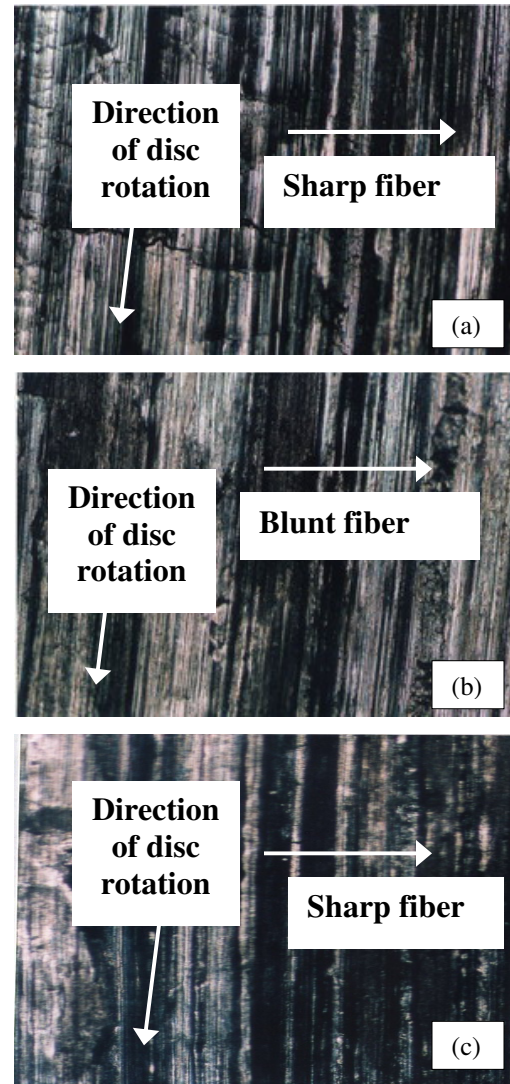


Fig 5. Surfaces of composites consist of aluminium/5% fly ash at sintering temperatures (a). 520°C, (b) 540°C dan (c) 570°C.

Observation of material surfaces in Fig 5. shown the formation of blunt fibers on highly fatigue material (5a) compared to sharp fibers of low fatigue material (5c).

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