

**UTILIZATION OF FLY ASH WASTE AS REINFORCEMENT OF ALUMINUM MATRIX COMPOSITE PRODUCED USING POWDER METALLURGY**  
*(Pemanfaatan Limbah Abu Terbang sebagai Penguat Aluminium Metal Matrix Composite Dibuat dengan Cara Metalurgi Serbuk)*

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**Abstract**

Aluminum matrix composite (AMC) has been prepared from aluminum fine powder as a matrix and fly ash waste as reinforcement. In this research the amount of fly ash as much as 2.5, 5, 7.5 and 10 wt% was added to the aluminum fine powder. The mixture was compacted using uniaxial with a pressure of 100 MPa and it was pressureless sintered in argon atmosphere at various temperature of 500°, 525°, 550°, 575° and 600°C. Bending strength of AMC was determined using four point bending, hardness was tested using Vickers method, wear rate was tested using pin on disk method, porosity was tested using Archimedes method and the micro structure was observed using SEM. The result shows that fly ash can be used as reinforcement of AMC. The bending strength and Vickers hardness of AMC increase, wear rate and porosity of AMC decrease with increasing the fly ash content up to 7.5 wt%, while fly ash higher than 7.5 wt% causes a decrease. Porosity, bending strength, wear rate and hardness of AMC are 5.4%, 68.5 MPa, 0.0571 mg/(MPa.m) and 62.6 VHN, respectively. It shows that bending strength, hardness and wear resistance of AMC are higher than pure aluminum.

Keywords: Aluminum matrix composites; Fly ash; compaction; sintering.

**Abstrak**

*Pada penelitian ini telah dilakukan pembuatan aluminium matrix composite (AMC) dari serbuk aluminium sebagai matrik dan limbah abu terbang sebagai penguat. Sejumlah abu terbang yaitu 2,5; 5; 7,5 dan 10% berat ditambahkan pada bubuk aluminium. Campuran abu terbang dan serbuk aluminium dikompaksi secara aksial dengan tekanan 100 MPa dan dilanjutkan dengan proses sintering tanpa tekanan dengan lingkungan gas argon pada berbagai temperatur yaitu 500°, 525°, 550°, 575° dan 600°C. Pengujian kekuatan bending menggunakan metode four point bending, kekerasan menggunakan metode Vickers, laju keausan menggunakan metode pin on disk dan porositas menggunakan metode Archimedes serta struktur mikro diamati menggunakan SEM. Hasil penelitian menunjukkan bahwa kekuatan bending dan kekerasan meningkat, laju keausan dan porositas menurun seiring dengan bertambahnya abu terbang pada AMC sampai 7,5% berat, namun bila kandungan abu terbang lebih dari 7,5% berat sifat AMC menunjukkan kebalikannya. Porositas, kekuatan bending, laju keausan dan kekerasan terbaik yaitu pada AMC dengan 7,5% berat abu terbang berturut-turut sebesar 5,4%, 68,5 MPa, 0,0571 mg/(MPa.m) and 62,6 VHN. Hal ini menunjukkan bahwa kekuatan bending, kekerasan dan ketahanan aus AMC lebih baik dibanding aluminium murni.*

*Kata kunci: Aluminium matrix composite, abu terbang, kompaksi, sintering.*

## INTRODUCTION

Fly ash is produced when coal is combusted for electricity generation. It is estimated that about 2.2 million tons of fly ash is produced every year in Indonesia (Adiwardoyo, 2006). The fly ash can contaminate air and water, that make them dirty. For solving this problem, fly ash is used as engineering materials. The major contain of fly ash is silica and alumina, which can be used as a filler or reinforcement for aluminum matrix composites (AMC). Aerospace and automotive industries need materials, which have high ratio of strength and weight, high wear resistance, toughness and heat conductivity. One of the alternative material is AMC. AMC is formed by combination of two or more dissimilar materials, at least one of them is a aluminum as the matrix. Graphite, boron, alumina and silica are used as a reinforcement (Rawal, 2001).

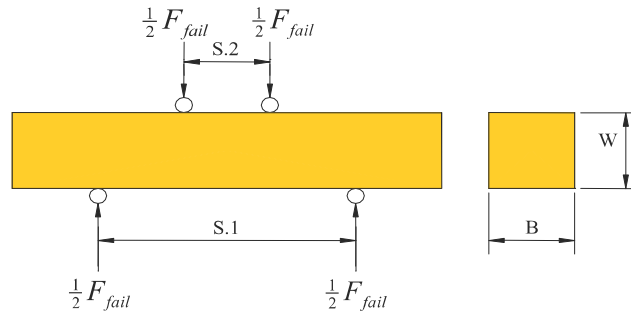
Rohatgi, et al (1997) have tested wear properties of stir-cast A356 aluminum alloy 5 vol % fly ash composite against hard SiC abrasive paper and compared to those of the A356 base alloy. The results indicate that the abrasive wear resistance of aluminum- fly ash composite is similar to that of aluminum-alumina fiber composite. It was similar with Guo and Rohatgi (1997), thy have made aluminum-fly ash particulate composite using powder metallurgy technique. Density, hardness and strength of the AMC were determined as a function of weight per cent of fly ash particles. The results showed that a slight decrease in density and strength of AMC are observed with increasing weight percent of fly ash, the hardness find to increase slightly up to 10 wt % fly ash, while fly ash higher than 10 wt% causes a decrease. Mahendra and Radhakrishna (2007) have made AMC, Al-4.5% Cu that

was used as the matrix and fly ash as the filler material. The AMC was produced using conventional foundry techniques. The results show an increase in hardness, tensile strength, compression strength, resistance to dry wear, corrosion and impact with increasing the fly ash content. The density decreases with increasing fly ash content. This present research reported the effects of sintering temperature and volume fraction of fly ash on mechanical properties of AMC/fly ash. Aluminum is classified as soft material, and its mechanical properties such as hardness, wear resistance and bending strength may be improved by addition of fly ash as reinforcement.

## EXPERIMENTAL PROCEDURE

AMC were prepared from aluminum fine powder (produced by Merck Germany) as a matrix and fly ash as reinforcement, using powder metallurgy technique. The amount of fly ash of 0, 2.5, 5, 7.5 and 10 wt%, which was taken from electric power plan Suralaya Banten, was calcinated and then added to the aluminum fine powder. Each composition was mixed using rotary mixer for 3 hr. The mixture was compacted using uniaxial compaction with a pressure of 100 MPa and it was pressureless sintered in argon atmosphere at various temperature of 500°, 525°, 550°, 575° and 600°C. Bending strength was measured using four point bending test, hardness was measured using Vickers method, wear rate was measured using pin on disk, the disk was made from cast iron and polished using 1200 abrasive papers, density was tested using Archimedes method and the micro structure was observed using SEM.

Bending test was determined using four point bending (Figure 1).



**Figure 1. Bending test ( four point bending )**

Maximum bending stress is called modulus of rupture ( $\sigma_{MOR}$ )

$$\sigma_{MOR} = \frac{My}{I} = \frac{3(S_1 - S_2)}{2.B.W^2} x F_{fail} \dots\dots\dots (1)$$

Where:

- $F_{fail}$  = maximum bending load (N)
- $M$  = moment (Nmm)
- $I$  = inertia ( $mm^4$ )
- $y$  =  $W/2$  (mm)

Hardness test was done by Vickers harness method. Vickers hardness number (VHN) is difined as load per area of penetration of identor.

$$VHN = \frac{1,854P}{L^2} \dots\dots\dots (2)$$

Where :

- VHN : Vickers hardness number ( $kg/mm^2$ )
- $P$  : load of identor (kg)
- $L$  : diagonal of penetration of identor (mm)

Density was determined by the Archimedes method, and calculated by equation 3.

$$\rho_b = \frac{Ga}{(Ga - Gw)} x \rho_w \dots\dots\dots (3)$$

Where:

- $Ga$  : weight on the air (gr)
- $Gw$  : weight in the water (gr)
- $\rho_b$  : density of bulk
- $\rho_w$  : density of water

Porosity of AMC was calculated using equation 4.

$$\Phi = \frac{(\rho_t - \rho_b)}{\rho_t} \dots\dots\dots (4)$$

Wear rate was tested using pin on disk. The disk was made from cast iron and polished using 1200 abrasive papers. Wear rate was defined as weight loss per pressure and distance of movement.

$$Wr = W.A / (Q.S) \dots\dots\dots (5)$$

Where:

- $W$  : weight loss (mg)
- $Q$  : load of pin (N)
- $A$  : area of pin ( $mm^2$ )
- $S$  : distance of movement (m)

**RESULTS AND DISCUSSION**

Results of measuring of porosity were weight on air and in the water of AMC and porosity was calculated using equation (4). The lowest porosity of AMC, which have been sintered at 575°C (Figure 2) and the fraction of fly ash was about 5% and 7.5 wt%. The porosity of AMC decreases with increasing sintering temperature up to 575°C, however if sintering temperature is higher than 575°C porosity of AMC increases. The porosity of AMC also increases with increasing fraction of fly ash up to 7.5 wt%, above 7.5 wt% fraction of fly ash the porosity of AMC increases. Low porosity of the composites for sintering temperature 500°C indicates that those specimens have

high relative density. As shown in Figure 2, it can be explained that the porosity is influenced by sintering temperature and how the fly ash particles are distributed in the matrix. When the sintering temperature is low (500°C) the porosity is high and almost every single particle is not surrounded by the matrix. This does not give good interaction or bonding between the matrix and the particle. If the sintering temperature is equal or greater than 575°C, some fly ash particles are bonded well and interaction between matrix and the particles. In this latter case, the pores are easy to occur as indicated in Figure 6a and 6b.

Figure 3 shows the bending strength of AMC as a function of sintering temperature.

The bending strength was measured using four point bending test. It can be seen in Figure 3 that the bending strength increases with increasing sintering temperature up to 575°C. Above 575°C of sintering temperature the bending strength tend to decrease. Bending strength of brittle materials is usually dominantly influenced by defects or flaws (Boresi, at al 1978). Pores in materials can be considered as flaws which give stress concentration and reduce the strength. In relation with this, it can be explained that the increase of bending strength of the composites from sintering temperature of 500°C to 575°C is due to the reducing of porosity in the materials as indicated in Figure 2.

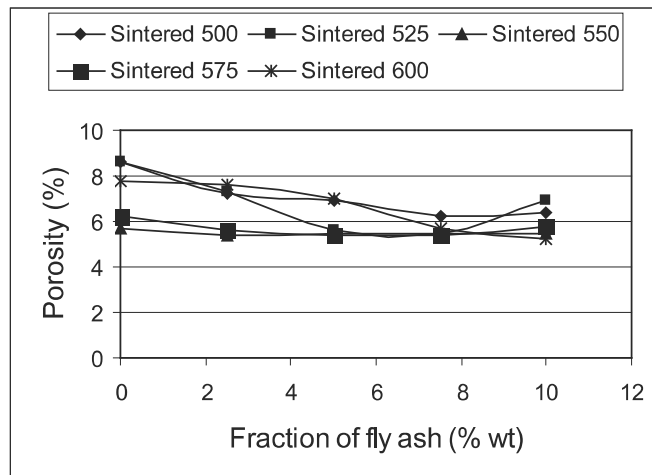


Figure 2. Porosity versus fraction of fly ash of AMC

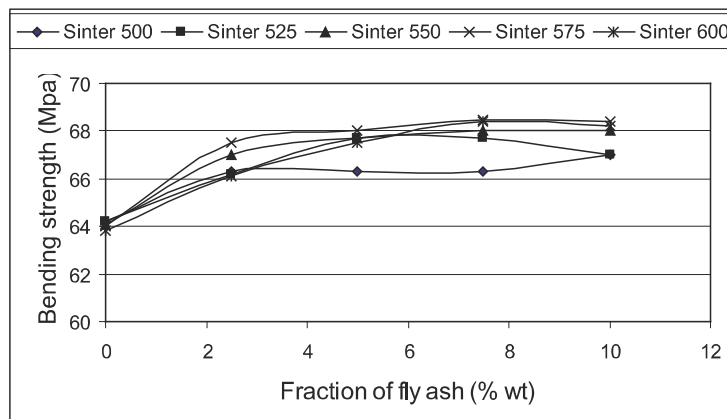
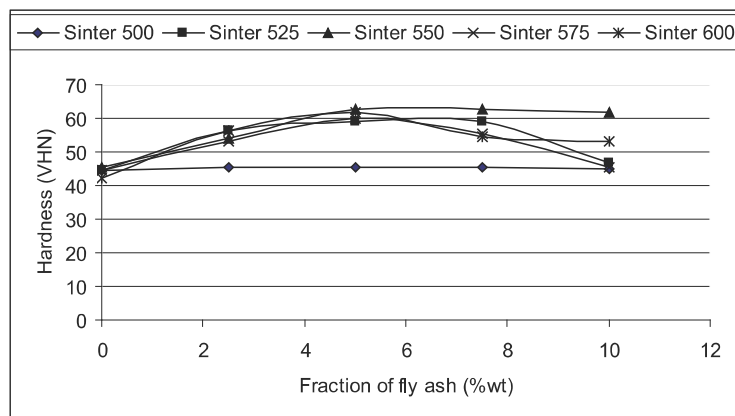


Figure 3. Bending strength versus fraction of fly ash of AMC

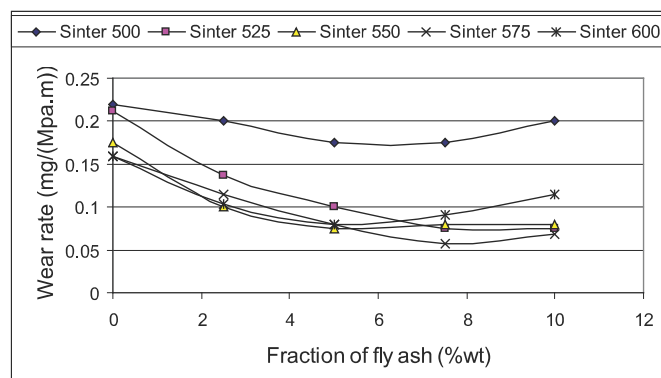
Results of measuring Vickers hardness test was maximum load and diagonal of penetration of indentor so Vickers hardness number could be calculated using equation (2), it is shown in Figure 4. It is similar with bending test that Vickers hardness number of AMC increases with increasing the fly ash up to 5 wt%. and the maximum Vickers hardness number is 62.6 on the AMC with 5% and 7.5 wt% fly ash and sintering temperature at 550°C. In general, this increase of Vickers hardness of the composites is due to fly ash (which consists of most metal oxide) that has higher Vickers hardness compared to that of aluminum.

Results of measuring of wear test was maximum load, pin diameter of specimen and number of rotation of disk, and wear rate could be calculated using equation (5), the

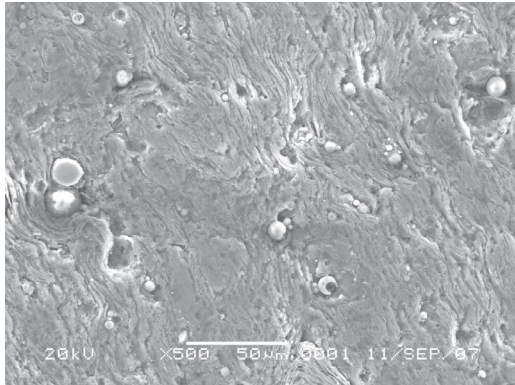
results of calculation are shown in Figure 5. Wear rate of AMC increases with increasing the fly ash up to 7.5 wt%. and then constant with increasing the fly ash until 10 wt%. Minimum wear rate is 0.04 mg/MPa.m on the AMC with 5 until 10 wt% fly ash and sintering temperature at 575°C. In general, this decrease of wear rate of the composites is due to fly ash (which consists of most metal oxide) has higher wear resistance compared to that of aluminum. However, the wear rate should be also influenced by strength of the bonding between fly ash particles and the matrix. In particular, the composite sintered at 500°C has high wear rate, this is due to at that temperature, sintering of the composite has not been occurred properly, so the particles are easy to pull out during wear test.



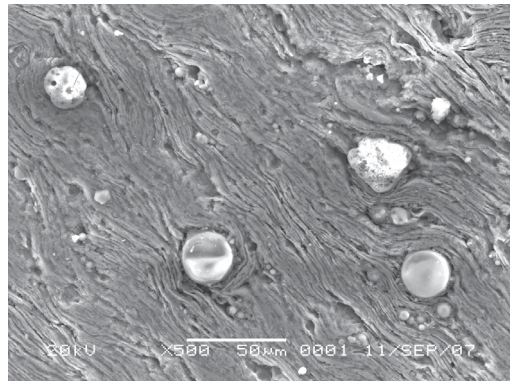
**Figure 4. Hardness versus fraction fly ash of AMC**



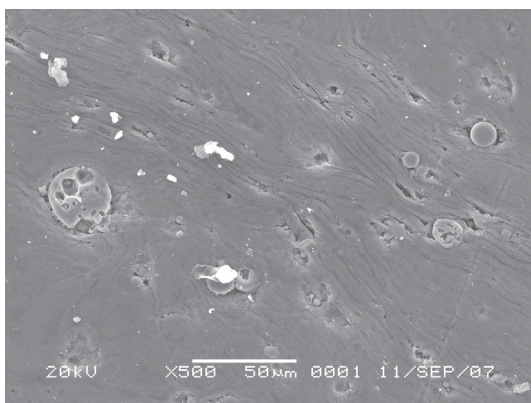
**Figure 5. Wear rate versus fraction of fly ash of AMC**



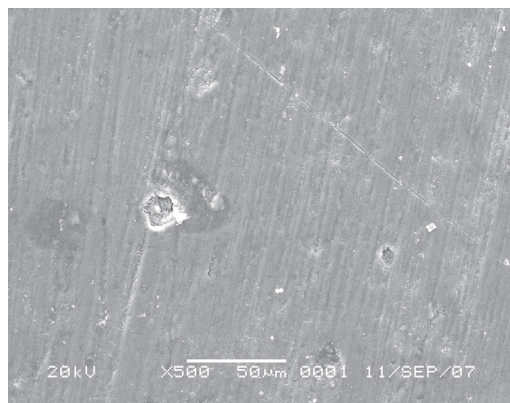
(a)



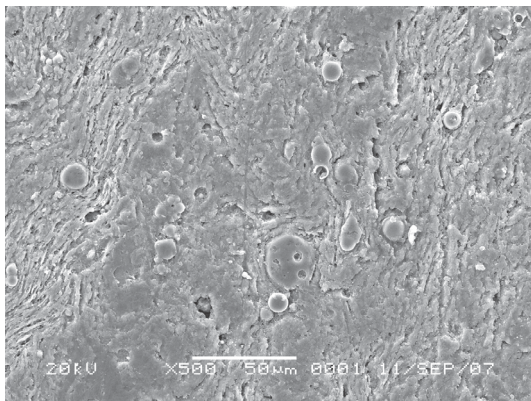
(b)



(c)



(d)



(e)

**Figure 6. Micro structure of AMC 7.5 wt% of fly ash and sintering temperature (a) 500°C, (b) 525 °C, (c) 500 °C, (d) 575 °C and (e) 600 °C**

### CONCLUSION

Fly ash can be used as reinforcement of AMC, as it can increase bending strength and hardness of AMC, also decrease porosity and wear rate of AMC. Bending strength, hardness, porosity and wear rate of 7.5 wt% fly ash of AMC are 68.5 MPa, 62.6 VHN, 5.4 % and 0,0571 mg/MPa.m, respectively. It showed that bending strength, hardness and wear resistance of AMC are higher than pure aluminum.

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