The analysis of composite properties reinforced with particles from palm oil industry waste produced by casting methods

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Abstract. Palm oil processing industries are very attractive because they offer plenty products with high economic value. The CPO factory processes not only produces crude palm oil but also generates fly ash (FA) particles waste in its final process. The purpose of this investigation to analyze and increase the benefits of particles as reinforcement materials for fabricating aluminum matrix composites (AMC’s) by different casting route. Stirring, centrifugal and squeeze casting method was conducted in this study. Further, the chemical composition of FA particles, densities and mechanical properties have been analyzed. The characteristics of composite material were investigated using an Optical microscope, scanning electron microscope (SEM), hardness (Brinell), impact strength (Charpy). The pin on disc method was used to measure the wear rate. The results show that SiO₂, Fe₂O₃, and Al₂O₃ are the main compounds of fly ash particles. These particles enhanced the hardness and reduce wear resistance of aluminum matrix composites. The squeeze method gives better results than stir and centrifugal casting.

Keywords: composite; fly ash particles; casting

1. Introduction
The palm oil processing yield shell products are used as energy sources to generate electrical. The results of a combustion process in the chamber not only create the electricity energy but also fly ash particles waste from palm oil. The main composition particles consist of SiO₂ reach 55.20% [1] and the additional oxide compound. The elements have an attractive characteristic with high melting point temperatures such as oxide materials. Fly ash from different source has been applied as reinforcement particles of composite material [2],[3],[4],[5]. The strength of composites influenced by particles shape, type, such SiC [6] and a number of FA elements [5]. The addition of fly ash improves the hardness, otherwise decrease the density of composites [7],[8] and reduce wear rate [9]. The process production technique composite reinforced by fly ash very diverse such as common stir casting [10],[11] squeeze casting [2]. From previous research known that fly ash used as reinforcement material of composites have been successful. Fly ash particles from palm oil processing are a potential candidate for the composites material cause it primary compositions are is different compared with fly ash from coal. The purpose of this research to investigate fly ash characteristics and fabrication of composites reinforced with fly ash from palm oil by several casting technique.

2. Methods

2.1. Preparation of fly ash particles
Particles fly ash are used in this research taken from palm oil industry located in North Sumatera. The grinding process was conducted to achieve small size about 0.074μm and more homogenous particles. This element heated at 800°C to eliminate the moisture and an element that can still burn. The gravimetry and spectrometry methods were conducted to analyze the composition of fly ash particles. the group compound of fly ash particles was investigated by FTIR (Fourier Transform Infra Red) method. The characteristic of density reinforcement material was examined by briquettes method with 85, 90, 95, 100 and 105 pressure ratio.

2.2. Composite production process by casting route
Aluminum matrix composites (AMC’s) production reinforced by fly ash particles use stir casting, centrifugal and squeeze casting technique was conducted. 2.5wt.% fly ash elements added to aluminum matrix when the semi-solid phase followed by stirring slowly for 5 minutes. The Magnesium element about 5wt.% added to the composite melt to increase of wettability. Further, pouring temperature at 760°C. Centrifugal casting has been done with 360 rpm of speed and molding temperature at 450°C. Additionally, squeeze casting with 4 MPa pressure and mold temperature at 300°C was conducted.

2.3. Aluminum matrix composites (AMC’s) product testing
Composite products have been tested to know the characteristics of the composite material. The examination consists of an optical microscope (OM), scanning electron microscope (SEM) to see the microstructure composite, Brinell hardness test using 500 kg of load. The impact test by Charpy method and pin on disc test to investigate the wear resistance with varying in sliding speed 0.3534, 0.4712, 0.589, 0.7068 and 0.8246 m/s. the wear test for composites that manufactured by squeeze casting technique with 2.5wt.% fly ash compared with raw material (A356).

3. Result And Discussion

3.1. The result of composition test
The testing of particles was conducted to knows the main elements of fly ash from palm oil. The result as shown in Table 1 below.

| compound | wt.% | methods   |
|----------|------|-----------|
| SiO₂     | 36.73| Gravimetry|
| Al₂O₃    | 6.83 | Spectrometry|
| Fe₂O₃    | 0.69 | AAS       |
| CaO      | 0.53 | AAS       |
| MgO      | 3.11 | AAS       |
| K₂O      | 6.54 | AAS       |
| SO₃      | 0.92 | Gravimetry|
| Others   | balance | -         |

The main composition of particles are oxide compounds such SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, K₂O and SO₃, the oxide formation in the particles due to this product is the residual of shell combustion in the boiler combustion chamber, in this process the oxygen element tends to interact with the elements contained in the fuel. Silicon dioxide (SiO₂) is the highest about 36.73%, This is appropriate with previous research silicon dioxide, ferric oxide and aluminum oxide are the main contents of fly ash [1]. This oxide compound between aluminum matrix will act as reinforcement material in the composite materials. The addition of oxide particles improve the hardness and wear resistance of composite materials.
3.2. **FTIR test result**
The group compound of fly ash particles has been analyzed by FTIR method. The result (figure 1) shows the material consist type of compound such as alkane at a frequency of 3001.24 (1/cm) with strong absorption, alkane compound with high intensity at the frequency of 2877.79 (1/cm). The frequency area 802.39 (1/cm) is an aromatics ring with low absorption.

![Figure 1. FTIR test result of fly ash particles from palm oil](image)

3.3. **Density of fly ash particles**
The density of fly ash particles was examined by briquettes technique, the results as shown in figure 2 below.

![Figure 2. Effect of pressure ratio on density of fly ash particles](image)

Figure 2 shows the increase with increasing the pressure ratio, the maximum density of particles obtained 0.978 gr/cm$^3$ at 105 pressure ratio. This value lower than the density of aluminum matrix.
about 2.78 gr/cm$^3$. The density of reinforcement material and matrix are very different, this causes both of them are difficult to coalesce homogeneously by conventional casting technique. Otherwise, the advantage fly ash particles as reinforcement material are reducing the density of the composite material. The density composite is the important factor in design technique of material to reduce energy consumption.

3.4. Microstructure test results

The microstructures examine was conducted to knows the distribution of fly ash particles between aluminum matrix. Optical microscope results as shown in figure 3 below.

![Microstructure of composite material](image)

**Figure 3.** microstructure of composite material with 2.5wt.% fly ash (a) raw material, (b) stir cast, (c) squeeze cast and (d) centrifugal cast method

Figure 3a shows the microstructures of an aluminum cast, this microstructure consists of $\alpha$-aluminum with bright color (A) and silicon particle (B) gray color between aluminum matrix. Silicone elements play an important role to improve yield strength, microhardness and reduce of ductility [12]. The addition fly ash particles by using stir casting technique (figure 3b) exhibit successful inserted fly ash particles into the aluminum matrix. The particles tend to form the cluster between $\alpha$-Al matrix, and solid solution phase difficult to formed with aluminum due the different of characteristics. Microstructures produced by squeeze (figure 3c) and centrifugal casting (3d) route have successfully inserted fly ash particles (C) into solution with the dark color. The squeeze casting technique obtained smaller $\alpha$-aluminum grain size, in this procedure more rapid core forming process occurs due to the pressure on mold promote heat transfer quickly. The pressure applied to this process alter the size of the silicon structure [4], reduce the number of porosity [13]. Scanning electron microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDS) were conducted to know the microstructures and composition of the composite material. The test result is shown in figure 4, the dark point (A) shows
the main component consists of aluminum, silicon, and oxygen. Al element acts as composite matrix with the main alloy element is silicone, the presence of Si element tends to improve the hardness composite. Chinese script (B) structure Formed on this alloy and the bright color (C) is α-Aluminum.

Figure 4. SEM and EDS test result of MMC reinforced by 2.5wt% fly ash

3.5. Hardness test result

The hardness test was obtained by Brinell method on raw material A356 alloy and aluminum matrix composites (AMC’s) reinforced by 2.5wt% fly ash. The result as shown in figure 5 below

Figure 5. The hardness of MMC’s reinforced by fly ash with different route

The addition of 2.5wt% particles on composite production has been successful to increase the hardness by various casting route. The increase of fly ash composition has been successful improve the hardness of composite [14]. Silica compound contained in the fly ash (FA) acts an important role to enhance the hardness of material [15]. The highest hardness about 76.85 BHN obtained by using squeeze method with 4 MPa pressure. This method increases the hardness up to 32% than raw material (A356) due to oxide particles dispersed between Al, these element acts as a barrier to dislocation movement.
3.6. Impact test result

The impact test was conducted by the Charpy method to know the effect of casting procedure on strength of composites material with load suddenly at room temperature. The results as shown in figure 6 below.

![Impact test bar chart](image)

**Figure 6.** Impact strength for various casting technique with 2.5wt% fly ash and raw material

The addition of particles tends to reduce impact strength of the composite material for all casting procedure. It means, the toughness of materials decreased. This corresponds to diminish in composite toughness with enhanced in reinforcing particles [16]. The highest toughness obtained on A356 material produced by casting with value about 25.57 joules. Additionally, aluminum matrix composite has the lowest strength about 21.13 joule by squeeze casting technique. The phenomenon of decreasing impact strength in this case due to the addition of particles wouldn't be formed solid solution state with α-Al and the porosity in others side were formed. Furthermore, this phenomenon affects the strength of materials such as metal matrix composite (AMC) material [17].

3.7. Wear test result

Wear resistance of composite materials obtained by pin on disc test method in dry sliding condition for various sliding speed.

![Wear test graph](image)

**Figure 7.** Effect of sliding speed on wear rate of composite and raw material
The wear test result as shown in figure 7 above shows the increase sliding speed tends to increase wear rate both of raw and composite material. This phenomenon correlated with wear resistance [18]. The increase sliding speed generates the temperature and enhance ductility [19] between pin and surface material. The increase temperatures promote wear more easily formed. From the figure 7 obtained that composite material reinforced with fly ash from palm oil has lower wear rate than the raw material in various sliding speed.

4. Conclusion

The metal matrix composite products by various casting route were conducted. From the data of this research, it can be concluded in some points

- The main composition of fly ash particles contains SiO$_2$, Fe$_2$O$_3$, Al$_2$O$_3$, and alkane as the main group compound.
- The density of materials increases when the pressure ratio increase.
- The addition of fly ash particles have been effectively dispersed into aluminum matrix.
- The production of aluminum matrix composites (AMC’s) by casting route has been successful to increase the hardness of the material. The highest hardness obtained by squeeze cast method. This technique also reduces wear rate material compared with raw material.
- The impact strength of AMC’s slight to decrease in various casting method compared with the A356 cast material.

5. References

[1] Abdullah K and Hussin M 2010 Fire Resistance Properties of Palm Oil Fuel Ash Cement Based Aerated Concrete Concrete Research vol.1 (3) pp 107-114
[2] Bienias J, Walczak M, Surowska B and Sobczak J 2003 microstructure and corrosion behaviour of aluminum fly ash composites Journal of Optoelectronics and Advanced Materials Vol. 5 No. 2 pp 493 - 502
[3] Lokesh G N, Ramachandra M and Mahendra K V 2014 Evaluation of Al-4.5%Cu alloy reinforced fly ash and SiC by stir and squeeze casting with rolled composites International Journal on Mechanical Engineering and Robotics (IJMER) vol.2 pp 6-11
[4] Prasad K N P and Ramachandra M 2013 Effect of Squeeze pressure on the hardness and wear resistance of Aluminium flyash composite manufactured by stir-squeeze casting International Journal of Engineering Inventions vol 3 pp 01-08
[5] Suragimath P K and Purohit G K 2013 A Study on mechanical properties of aluminium alloy (LM6) reinforced with SiC and fly Ash IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) vol.8 pp 13-18
[6] Meena K L, Manna A, Banwait S S and Jaswanti 2013 An analysis of mechanical properties of the developed Al/SiC-MMC’s American journal of mechanical engineering Vol. 1 pp14-19
[7] Lokesh G N, Ramachandra M, Mahendra K V and Sreenith T 2013 Effect of Hardness, Tensile and Wear Behavior of Al-4.5wt%Cu Alloy/Flyash/SiC Metal Matrix Composites International Journal of Modern Engineering Research (IJMER) vol.3 pp 381-385
[8] Mahendra K V and Radhakrishna K 2007 Fabrication of Al–4.5% Cu alloy with fly ash metal matrix composites and its characterization Materials Science-Poland Vol. 25 pp 57-68
[9] Suresh N, Venkateswaran S and Seetharamu S 2010 Influence of cenospheres of fly ash on the mechanical properties and wear of permanent moulded eutectic Al–Si alloys Materials Science-Poland, Vol. 28 pp 55-65
[10] Hashim J 2001 The production of cast metal matrix composite by a modified stir casting method jurnal Teknologi 35(A) pp 9-20
[11] Singla D and Mediratta S R 2013 Evaluation of mechanical properties of al 7075-fly ash composite material International Journal of Innovative Research in Science, Engineering and Technology Vol. 2 pp 951-959
[12] Gupta M and Ling S 1999 Microstructure and mechanical properties of hypo/hyper-eutectic Al–Si alloys synthesized using a near-net shape forming technique *Journal of Alloys and Compounds* Vol. 287 pp 284-294

[13] Prasad K N P and Ramachandra M 2013 Evaluation of factors affecting sliding wear behaviour of Al-fly ash metal matrix composites by using design of experiments *International Journal of Modern Engineering Research (IJMER)* Vol.3 pp 2591-2599

[14] Kesavulu A, AnandRaju F and Deva Kumar, M L S 2014 Properties of aluminium fly ash metal matrix composite *International Journal of Innovative Research in Science,Engineering and Technology* Vol.3 pp 17160-17164

[15] Subarmono, Jamasri, Wildan M W and Kusnanto 2008 Pemanfaatan limbah abu terbang sebagai penguat aluminium matrix composite *Jurnal Teknik Mesin* Vol. 10 pp 109–114

[16] Alaneme K K and Bodunrin M O 2013 Mechanical behaviour of alumina reinforced aa 6063 metal matrix composites developed by two Step – stir casting process *Acta Technica Corviniensis Vol.3* pp 105-110

[17] Aqida S N, Ghazali M I and Hashim J 2004 Effects of porosity on mechanical properties of metal matrix composite: an overview *Jurnal Teknologi Vol.40(A)* pp 17–32

[18] Kandeva M, Vassileva L, Rangelov R and Simeonova S 2011 Wear-resistance of aluminum matrix microcomposite materials *Tribology in industry, Vol. 33* pp 57-62

[19] Kumar V, Dev Gupta R and Batra N K 2014 Comparison of Mechanical Properties and effect of sliding velocity on wear properties of Al 6061, Mg 4%, Fly ash and Al 6061, Mg 4%, Graphite 4%, Fly ash Hybrid Metal matrix composite *Procedia Materials Science Vol.6* pp 1365 – 1375