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Microstructural characterization of fly ash particulate reinforced AA6063 aluminium alloy for aerospace applications

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Abstract. Aluminium-fly ash (FA) particulate reinforced composites (AA6063-FA) have been used in automotive and aerospace industries because of their low density and good mechanical properties. Three different weight fraction of FA: 2%, 4% and 6% are added to AA6063 alloy using compocasting method. The effect of FA particulates on microstructure, density and compression strength of AA6063- FA composites are investigated. Field Emission Scanning Electron Microscope (FESEM) micrographs reveal that the FA particulates are uniformly distributed in AA6063 alloy. The results also show that density, compression strength and microstructure of the AA6063-FA composites are significantly influenced by the FA amount. The increase in the weight fraction of FA will improve the microstructure and enhance the compression strength. The density of AA6063-FA composites decreases as the incorporation of FA increases.

1. Introduction

Metal matrix composites (MMCs) are the macroscopic combination of two or more different materials (i.e. one of them is a metal and the other a non-metal) in which tailored properties are determined [1]. In recent years, MMCs have received considerable attention due to their low density and high strength and stiffness as compared to those of conventional materials [2]. The reinforcement is commonly non-metals, in the likes of conventional ceramic materials such as SiC, Al_2O_3, fly ash, etc. The composites can be used to fabricate many important components for automotive and aerospace. The design of the process is an important part of synthesis for MMCs. The processes employed usually depend on the type of reinforcement and matrix used for the composite. Stir casting is the simplest and cheapest one, but a problem associated with this process is the non-uniform distribution of the particulate due to poor wettability and also gravity regulated segregation [3]. Achieving the uniform distribution of the reinforcement within the matrix is still a challenge in the stir casting process, which directly affects the properties and quality of the produced composites. The interfacial strength between the matrix and the reinforcement plays a significant role in determining the properties of MMCs [4]. In order to achieve the desirable properties of the metal matrix composite, several factors that have to be considered that include achieving a uniform distribution of the reinforcement material in molten matrix and improving wettability or bonding between the matrix and reinforcement [5, 6]. Improvement of the wettability can be achieved by increasing surface energy, decreasing surface tension of the molten alloy and also decreasing liquid – solid interfacial energy at the interface of the reinforcement matrix [7-9].

The need for high performance and lightweight materials for a lot of applications has led to wide research efforts in the development of aluminium matrix composites. Researches on aluminium fly ash composite have shown a great promise in various applications. Fly ash is one of the materials that has low density and cheap, and it is abundantly available as a solid waste by-product during combustion of coal in thermal power plants. The chemical composition of fly ash consists of Al_2O_3, SiO_2 and Fe_2O_3 as major constituents and the oxides of Mg, K, Ca, K and Na as minor constituents [10-12]. It has been observed that there is slight decrease in density and strength of aluminium composites with increasing weight percent of fly ash while the hardness is increased slightly up to 10 wt % fly ash and decreased afterwards [13]. An increase in the volume percentages of fly ash is shown to increase the hardness, impact strength and compression strength values in aluminium – fly ash composites, but the density is decreased with content increase of fly ash [2]. Beyond 20 wt.% of fly ash, both compressive strength and hardness of the composites begin to decrease due to increase of particle clustering and decrease in solid solution strengthening [10].

AA6061-fly ash aluminium matrix composites (AMCs) have been successfully fabricated using the compocasting method [14]. It is observed there is no formation of any inter-metallic compound due to interfacial reaction. The fly ash particles are thermodynamically stable at compocasting temperature and they are dispersed homogeneously in the AMCs. The interface between the aluminium matrix and fly ash particle is clear and the bonding is proper. The incorporation of fly ash particles into semi-solid aluminium alloy improved the wettability [14]. Industrial wastes such as fly ash and granulated blast furnace (GBF) slag are utilized successfully for the production of aluminium based MMCs. Al-fly ash (ALFA) and Al-GBF slag composites have been successfully produced by stir casting method. There is a uniform distribution of reinforcement particles in the matrix phase and a good bonding between the matrix and the reinforcements is obtained. The hardness of the composites increases whereas their density decreases with the presence of reinforcement as compared to the base alloy. Higher hardness value has been reported for ALFA composite than Al-GBF slag composite, but enhanced mechanical properties are observed for both composites under compression as compared to alloy [15]. It is proven that the fly ash released the Si in the melt in reduction reactions. A sufficient quantity of Si forms an Mg_2Si phase with Mg of the melt for precipitation strengthening. Microstructural observations reveal that, after the wall of fly ash particles cracks, the molten metal will infiltrate the pores and cracks in the non-solid fly ash particles. Increasing the reaction time will reduce the porosity in the aluminium matrix composites whereas the density and hardness are increased [16]. Addition of fly ash particles enhances the hardness and tensile strength of the fabricated AMCs. The fabricated AMCs with 6wt% of fly ash reinforcement has been shown to exhibit almost 50% higher hardness and 30.4% higher tensile strength as compared to un-reinforced LM6 alloy [17].

This work is motivated by the limited information available on AA603-FA composites. The aim of this study is to investigate the effect of fly ash addition on the microstructure, density and compression of AA6063 alloy, and to develop a benchmark of property data that can be used in future to evaluate the materials. Furthermore, it is of great importance to carry out a research based on the AA6063 alloy to improve understanding on aluminium fly ash composites.

2. Materials and Experiments

In this study, AA6063 alloy is used as the matrix alloy and fly ash as the reinforcement material to produce AA6063-FA composites. The fly ash particulates are collected from a thermal power station in Johor, Malaysia and they are sieved to 44µm to get smaller particle size. The chemical composition of AA6063 alloy and fly ash are presented in Table 1 and Table 2, respectively.

Table 1: Chemical composition of tested AA6063 in wt. %

Elements	Cu	Fe	Mg	Mn	Si	Ti	Zn	Cr	Al
wt.%	< 0.01	0.19	0.71	0.04	0.86	0.008	<0.01	<0.01	Balance

Table 2: Chemical composition of tested fly ash in wt. %

Elements	SiO_2	Al_2O_3	Fe_2O_3	TiO2	K_2O	CaO	MgO	Na_2O	CuO
wt.%	59.98	19.09	2.78	1.14	1.09	0.63	0.38	0.34	0.01

The fly ash particulates are initially preheated at temperature of 900℃ for two hours to remove the impurities and water contents, and improve the wettability of the reinforcement particles with AA6063 alloy. Weight fraction of the fly ash particulates to synthesise the composites is set between 0-6 wt.%, in steps of 2%. The AA6063 rod is cut and charged into crucible inside the induction furnace, heated to temperature of 750°C ± 50°C above the liquidus temperature of the alloy and then the temperature in the furnace is reduced to 600℃ to get semi-solid state of the alloy. At this temperature, the preheated fly ash is added to the molten AA6063 alloy and the mix is manually stirred for about 15 minutes. The composite slurry is then superheated to 750℃ and stirred using the mechanical stirrer at a speed of 300 rpm to improve the fly ash particles distribution in the molten AA6063 alloy. The slushy composites are cast into preheated steel moulds. AA6063 alloy is prepared by casting for experimentation control. The cast test samples are then heat-treated for two hours at 560°C, where they are quenched in water at room temperature and then aged for three hours at 160°C.

The specimens prepared are polished and etched as per the standard metallographic procedure. The microstructures of these etched specimens are observed using the Field Emission Scanning Electron Microscope FESEM. The etchant that is applied to reveal the microstructure in this study is 10g NaOH and 90mL HNO_3 in 190ml distilled water (caustic etch). These specimens are immersed at the room temperature. Density of the composite specimens is obtained experimentally by Archimedes principle. Archimedes' principle states that, when a body is immersed in a fluid, there is a buoyant force acting upward on the body equals to the weight of the displaced fluid. The weight of displaced fluid equals its volume when water is used (density of water = 1 g/cm^3), hence the volume of the water displaced is equal to the volume of the body immersed. The density of the samples (with dimensions of 12mm x 12mm x 100mm) is evaluated by weighing them using electronic densimeter MD-300S with resolution of 0.001g/cm^3 and 300g capacity.

Compression tests are carried out on the rectangular specimens of pure aluminium and Al-fly ash composites with dimensions 12mm x 12mm x 24mm and a height/width (aspect ratio) of 2 with the parallel ends. These specimens of standard dimensions are prepared using wire cutting and their edges are chamfered to minimize folding. The compressive strength is measured in accordance with standard ASTM E 9. The samples are compressed using the Instron Machine (Model 3382) at crosshead speed of 0.8mm/min. Plotting of load versus displacement is done continuously through the data acquisition system. The compression tests are carried out until 50% reduction in height. Each test is repeated three times and the average value is taken to calculate the compression strength according to Equation 1 and Equation 2, where σ_c is the compression strength in N/mm^2, F is a force in N, A is cross sectional area of the specimen in mm^2, ε is the strain of specimen, Δl is length change of the specimen and lo is the original length of specimen.

$$\sigma_c = \frac{F}{A} \quad (1)$$

$$\varepsilon = \Delta l / l_0 \quad (2)$$

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3. Results and Discussion

The particle size analysis is measured using a Malvern particle Mastersizer. The average particle size of the fly ash powder is 21.96μm and its density is found to be 2.33g/cm^3. Figure 1 depicts the FESEM micrograph that shows the shape of fly ash as a solid sphere structure. On the other hand, Figure 2 and Figure 3 are FESEM micrographs of AA6063 alloy composites reinforced with fly ash, which show a uniform distribution of FA reinforcement in the AA6063 alloy matrix. There is no evidence of crack, voids and defects in the casting. There is a very low agglomeration of fly ash in the low percentage content. Figure 3 reveals a clear interface between AA6063 alloy matrix and FA. The compocasting enhances the wettability between FA and AA6063 alloy matrix that results in a good bonding between FA and AA6063 alloy matrix. However, the problems of fly ash particles agglomeration and defects are increasing with increment of the fly ash content. The FA particulates are distributed around grain boundary as shown in Figure 2.

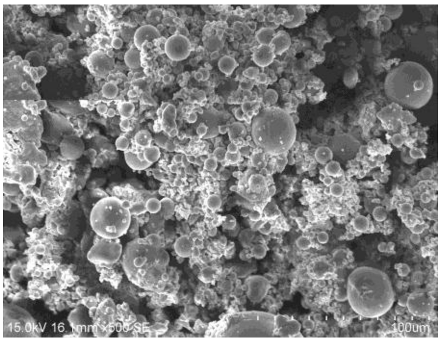
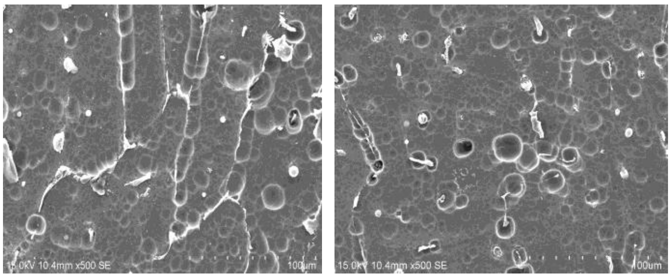


Figure 1: FESEM micrograph of FA



(a) (b)

Figure 2: Microstructure of AA6063-FA composite with different wt% fly ash (a) 4 wt. %, (b) 6 wt. %

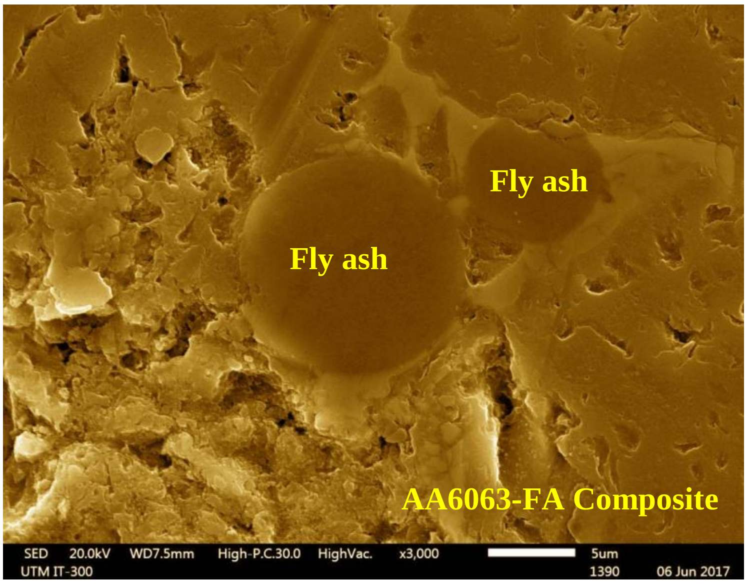


Figure 3: FESEM micrograph for a good interfacial bonding microstructure

The bulk density and apparent porosity measurements of the cast AA6063-FA composite samples with different weight percentage of fly ash are determined by Archimedes' method with water as the immersion medium. The variation of the density of composites with different fly ash content samples is shown in Figure 4. It is observed that the bulk density values decrease with increasing reinforced fly ash particles. Since the density of fly ash (2.33g/cm^3) is less than that of AA6063 alloy (2.6871g/cm3), the overall density of the AA6063-FA composites is reduced by increasing amount of porosity in the casting conditions. AA6063-FA composites containing 0 wt. %, 2 wt. %, 4 wt. % and 6 wt. % of FA particulates exhibit densities 2.6871g/cm^3, 2.6588 g/cm^3, 2.6468 g/cm^3 and 2.6396 g/cm^3, respectively.

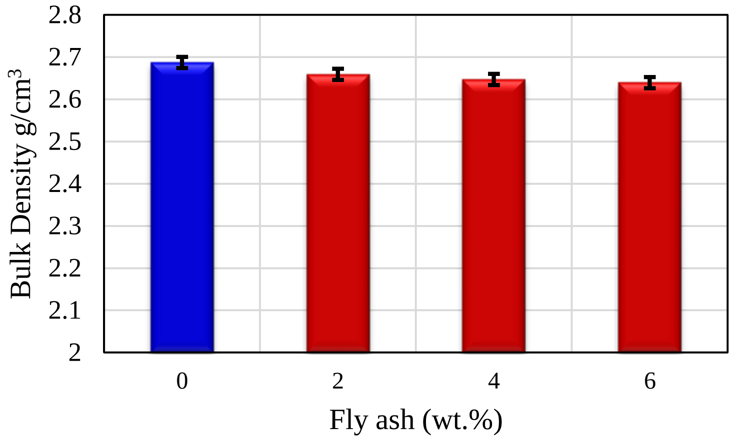


Figure 4: Density variations for different percentage compositions of AA6063–FA composites

Figure 5 reveals the typical stress strain diagrams for AA6063 matrix and AA6063–FA composites under compression test. The average ultimate compression strength (UCS) of AA6063–FA composites with various wt. % of FA is presented in Figure 6. It can be observed that the compressive strength is significantly increased with an increase in the weight percentage of fly ash particles. The maximum ultimate compression strength is found at 6 wt. % with 510MPa, which the improvement percentage is 100.1%. This is due to the hardening of the base alloy by fly ash particles [2, 18]. As the deformation increases, the hardness is also increasing. For the pure AA6063-fly ash composites, the rate of increase is greater for higher deformation with larger fly ash content. This might be due to the existence of the strain hardening effects from matrix alloy and mixture rule of composites strengthening [19].

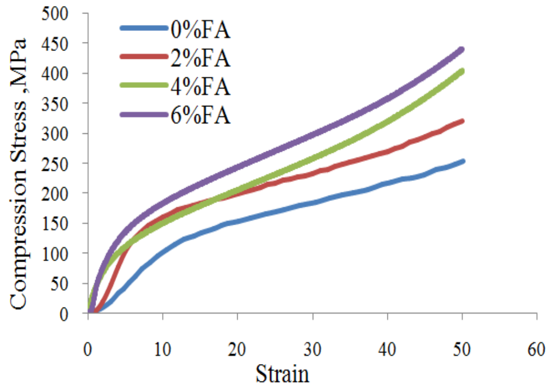


Figure 5: Stress vs. strain in compression for AA6063 alloy and AA6063–FA composites

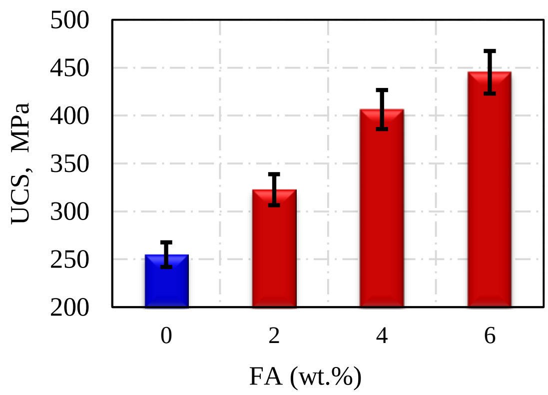


Figure 6: Effect of weight percentage of fly ash on ultimate tensile strength

4. Conclusion

The effects of weight fraction of FA on AA6063 aluminium alloy with regards to the properties of the AA6063-FA composites are investigated. Fabrication of the AA6063-FA particulate composites have been successfully done by compocasting technique and a good wettability is obtained. Based on the FESEM micrographs, the FA particulates are homogenously dispersed in the AA6063 matrix alloy. In addition, density of the AA6063-FA composites specimen decreases with an increase in FA particulate weight fraction. The increase in the weight fraction of FA particulates also results in an increase in the strength compression of the AA6063- FA composites, where the fabricated composite with 6 wt. % of

FA reinforced exhibits almost 100.1% higher compression strength as compared to the un-reinforced AA6063 aluminium alloy. Moreover, preheating the reinforcement particles and using compocasting technique without agents' addition are the engineering methods used to increase the wettability in this work. It is possible to study the improvement of the AA6063-FA composites' properties and increase the fly ash content by adding wettability agent, fluxes addition and coating the reinforcement particles. Effect of different heat treatment temperatures on the mechanical and physical properties of AA6063-fly ash can also be investigated in future.

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References
[1] Prasad D S, Shoba C and Ramanaiah N 2014 *Journal of Materials Research and Technology* **3** 79-85
[2] Mahendra K. and Radhakrishna K 2007 *Materials Science-Poland* **25** 57-68
[3] Sarkar S, Sen S, Mishra S C, Kudelwar M K and Mohan S 2010 *Journal of Reinforced Plastics and Composites* **29** 144-8
[4] Akbari M K, Baharvandi H and Mirzaee O 2013 *Composites Part B: Engineering* **52** 262-8
[5] Hashim J, Looney L and Hashmi M 1999 *Journal of Materials Processing Technology* **92** 1-7
[6] Tjong S C and Ma Z 2000 *Materials Science and Engineering: R: Reports* **29** 49-113
[7] Singh V K, Chauhan S, Gope P C and Chaudhary A K 2015 *High Temperature Materials and Processes* **34** 163-70
[8] Laha T, Kuchibhatla S, Seal S, Li W and Agarwal A 2007 *Acta Materialia* **55** 1059-66
[9] Razzaq A M, Majid D L, Ishak M R and Uday M B 2017 *IOP Conference Series: Materials Science and Engineering* **203** 012002
[10] Shanmughasundaram P, Subramanian R and Prabhu G 2011 *European Journal of Scientific Research* **63** 204-18
[11] Tang Z, Chen X, Liu D, Zhuang Y, Ye M, Sheng H and Xu S 2016 *Journal of Environmental Sciences* **48** 169-78
[12] Barroso J, Ballester J, Ferrer L M and Jimenez S 2006 *Fuel Processing Technology* **87** 737-52
[13] Guo R, Rohatgi P and Nath D 1997 *Journal of Materials Science* **32** 3971-4
[14] Selvam J D R, Smart D R and Dinaharan I 2013 *Materials & Design* **49** 28-34
[15] Murthy I N, Babu N A and Rao J B 2014 *Journal of Minerals and Materials Characterization and Engineering* **2014**
[16] Fan L-J and Juang S H 2016 *Materials & Design* **89** 941-9
[17] Efzan M E, Syazwani N S and Abdullah M M A B 2016 *IOP Conference Series: Materials Science and Engineering* **133** 012046
[18] Anilkumar H, Hebbar H and Ravishankar K 2011 *International Journal of Mechanical and Materials Engineering* **6** 41-5
[19] Rao J B, Rao D V and Bhargava N 2010 *International Journal of Engineering, Science and Technology* **2** 50-9