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THE INFLUENCE OF ALUMINA PARTICLE SIZE ON SINTERED DENSITY AND HARDNESS OF DISCONTINUOUS REINFORCED ALUMINUM METAL MATRIX COMPOSITE

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Abstract. This paper reports the effect of alumina (Al_2O_3) particle size on the properties of aluminum metal matrix composite (MMC), fabricated via powder metallurgy route. Mixture powders were compacted at 250 MPa and sintered at 600°C for 5 hours. The MMC samples were prepared based on 10 wt% of Al_2O_3. This paper will discuss the effect of alumina particle size on microstructure, sintered density and hardness of the composite. The densities of sintered composites were in the range of 2.78 gcm^{-3} to 2.84 gcm^{-3}. The effect of Al_2O_3 particles sizes (0.3 µm, 1.0 µm, 3.0 µm, 12.5 µm and 25.0 µm) on the microstructure of the composites were observed using Scanning Electron Microscope (SEM). The hardness value was measured using Vickers microhardness tester. It is observed that the finest reinforcement particle size (0.3 µm) gave the highest hardness value (70.1 Hv). The finer Al_2O_3 particles will provide more efficient barriers to dislocation flow in aluminum matrix. Composites reinforced with the smallest particle size have higher number of barriers per unit volume compared with composites reinforced with larger particle size at the same weight percentage.

Keywords: Metal matrix composite, aluminum matrix, alumina, particle size, powder metallurgy

Abstrak. Kertas kerja ini melaporkan kesan saiz partikel alumina (Al_2O_3) terhadap sifat-sifat komposit matriks logam aluminium (KML) difabrikasi melalui kaedah metalurgi serbuk. Serbuk campuran dipadatkan pada tekanan 250 MPa dan disinter pada suhu 600°C selama 5 jam. Sampel KML dihasilkan berdasarkan 10% berat Al_2O_3. Artikel ini akan membincangkan kesan saiz partikel alumina terhadap mikrostruktur, ketumpatan jasad sinter dan kekerasan komposit. Ketumpatan komposit yang telah disinter adalah dalam julat 2.78 gcm^{-3} hingga 2.84 gcm^{-3}. Kesan saiz partikel Al_2O_3 (0.3 µm, 1.0 µm, 3.0 µm, 12.5 µm dan 25.0 µm) ke atas mikrostruktur komposit diperhatikan menggunakan Mikroskop Imbasan Elektron. Nilai kekerasan diukur menggunakan penguji mirokekerasan Vickers. Pemerhatian menunjukkan bahawa partikel penguat halus (0.3 µm) memberikan nilai kekerasan yang tertinggi (70.1 Hv). Partikel alumina yang halus akan mewujudkan penghalang terhadap kehelan yang lebih efisien di dalam komposit aluminium. Komposit yang diperkuat dengan saiz partikel yang kecil mempunyai bilangan penghalang per unit isipadu yang tinggi berbanding dengan komposit yang diperkuat dengan partikel yang bersaiz besar pada peratus berat penguat yang sama.

Kata kunci: Komposit matriks logam, matriks aluminium, alumina, saiz partikel, metalurgi serbuk

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1.0 INTRODUCTION

Composite materials have received significant attention because of the unique properties and behaviour offered by this group of engineering materials. This is especially true in structural applications requiring high strength and light weight, as also in the field of high temperature applications. These materials have been highly successful in such areas as the aerospace industry, transportation, recreational equipment, military equipment, and various other industrial applications [1].

A composite can be defined as a material system composed of a mixture or combination of two or more micro or macroconstituents (that differ in form and chemical composition, and are essentially insoluble in each other), which possesses properties that are superior to, or important in some other manner than the properties of the individual components [2]. In other words, composite materials are the combination of two or more chemically different monolithic materials in order to produce a third material which has unique properties when compared to the monolithic material's properties [3].

Metal matrix composites are the subject of extensive research and development activities mainly because of their interesting specific properties. Most of the work has been dealing with aluminum and other light metal matrices for applications requiring light weight in combination with high strength and stiffness. This is because conventional aluminum alloys are used in large quantities in numerous applications ranging from automotive and aircraft industry, to sports and leisure. Its excellent strength, ductility and corrosion properties of aluminum alloys are well established and they can be modified to fulfill the requirements of many different applications [4]. The aluminum matrix can be reinforced by various types of reinforcements in the form of particles, whiskers or short fibers [5].

Particulate MMCs are being used or developed for a range of industrial applications. In general, MMCs reinforced with particulates show high stiffness, low density, high hardness, adequate toughness and high wear resistant [6]. The most widely used particulate is either SiC or Al_2O_3, but others (TiB_2, B_4C, SiO_2, TiC, WC, BN, ZrO_2, W etc) have also been investigated [7]. SiC particles are the most common discontinuous reinforcements in aluminum matrix composites. This is because it is cheap and readily available. SiC can be particularly problematic due to the possibility of chemical reactions which could limit the high temperature applications and cause problems in production when incorporated into aluminum. Another widely used particulate reinforcement in aluminum matrix composites is Al_2O_3. In comparison to SiC, it is much more inert in aluminum and is also oxidation resistant. Accordingly, it is more suitable for high temperature fabrication and application. Production of particulate Al_2O_3 reinforced aluminum matrix composites is currently the most promising candidate for large scale production of relatively cheap MMCs for general applications.

Currently, there is no universally accepted model showing how different reinforcement shapes and sizes interact with various matrix to achieve optimum performance, especially for the case of toughening a hard matrix (ceramic and intermetallic toughening). The toughness of composites is controlled by complex interaction between properties of constituents and processing route [7].

2.0 MATERIALS AND METHODS

2.1 Material Selection

High purity aluminum powder (99.0%) used in this research was produced by BDH Laboratory Supplies, England, with an average particle size of 50 μm. Alumina powder used in this research is in five different sizes with particle size average of 0.3, 1.0, 3.0, 12.5, and 25.0 μm. The α-alumina powder was produced by Buehler, USA, which is normally used as polishing media. Tables 1 and 2 show chemical compositions of aluminum and alumina powders respectively. The particles size analysis was done using Malvern MasterSizer E. version 1.2 by laser diffraction method. The morphology and shape of aluminum and alumina particles are shown in Figures 1 and 2 respectively. The shape of aluminum powder is observed to be flaky (Figure 1) and alumina powder is in the form of angular shape with sharp edges (Figure 2).

Table 1 Chemical composition analysis for aluminum powder

Compound	**Al**	**Fe**
wt%	99.00	1.00

Table 2 Chemical composition analysis for alumina powder

Compound	**Al**	**Ti**	**Si**	**Fe**	**Ca**	**Zr**	**Mg**
wt%	92.00	3.30	2.40	0.63	0.42	0.40	0.33

2.2 Sample Preparation

The samples with dimension of 16 mm diameter and 5 mm thickness were prepared based on 10 wt% of Al_2O_3 reinforcement. Aluminum and alumina powders were mixed for 8 hours at 115 rpm. The powders were mixed in a cylindrical plastic jar with a few porcelain balls and 0.1 wt% stearic acid. The composite powders were compacted using Shimadzu Universal Tensile Machine. The powders were compacted at 250 ± 5 MPa. In order to avoid damage of the samples during ejection, the

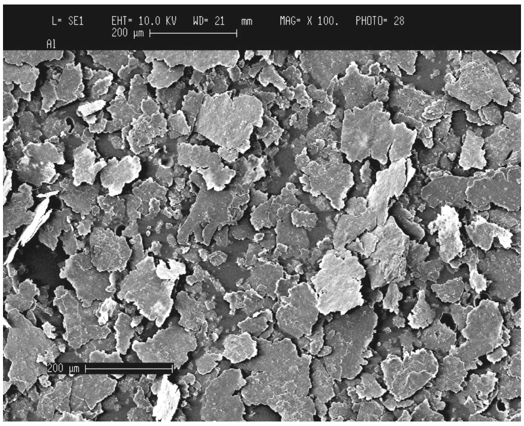


Figure 1 Morphology of aluminum powder

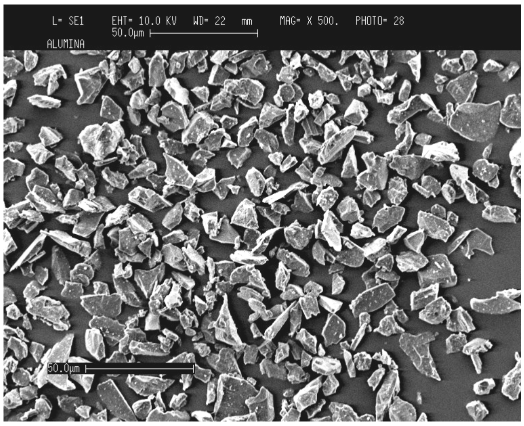


Figure 2 Morphology of alumina powder

compaction pressure was decreased to 5 MPa immediately after maximum pressure was obtained. The mould used in this study was 16 mm in diameter and 50 mm in height (Figure 3). Sintering was carried out at 600°C for 300 minutes in the CWF1100 Carbolite Furnace at normal atmosphere. Heating and cooling rate was kept constant at 50 C/min.

Samples preparation was done by grinding the surface of the composite with 400, 600, and 1200 grit SiC coated papers, respectively, and polished with 3.0, 1.0 and 0.5 µm diamond suspension. Samples were cleaned in acetone using ultrasonic. The samples were coated with thin Au-Pd layer by using sputtering coater and microstructural analysis was carried out by using Cambridge Strereoscan 200 Scanning

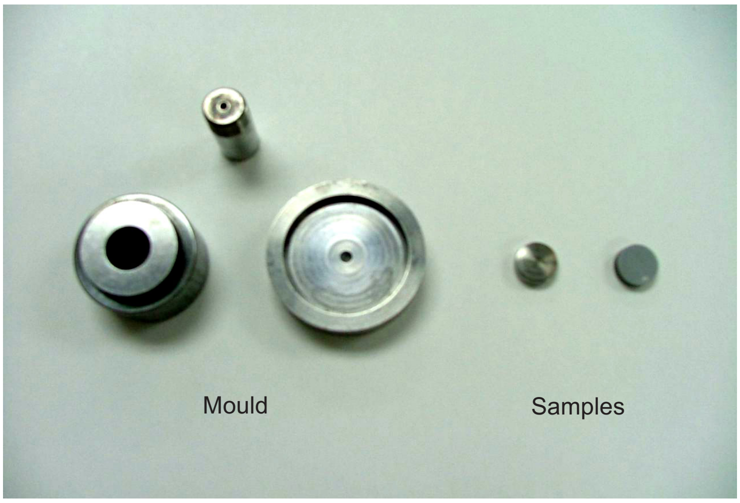


Figure 3 16 mm ∅ × 50 mm mould and samples

Electron Microscope (SEM). Sintered density was measured using gas pycnometer model AccuPyc 1330. The hardness values was determined by using a Leitz Wetzlar Vickers Microhardness Testing Machine with a load of 100 g. Five indentations were taken on the matrix for each composite and an average value was calculated. Microhardness test was carried out in this study in order to ensure that the maximum number of indentations fall on the matrix phase which represent the hardness property of the composite.

3.0 RESULTS AND DISCUSSION

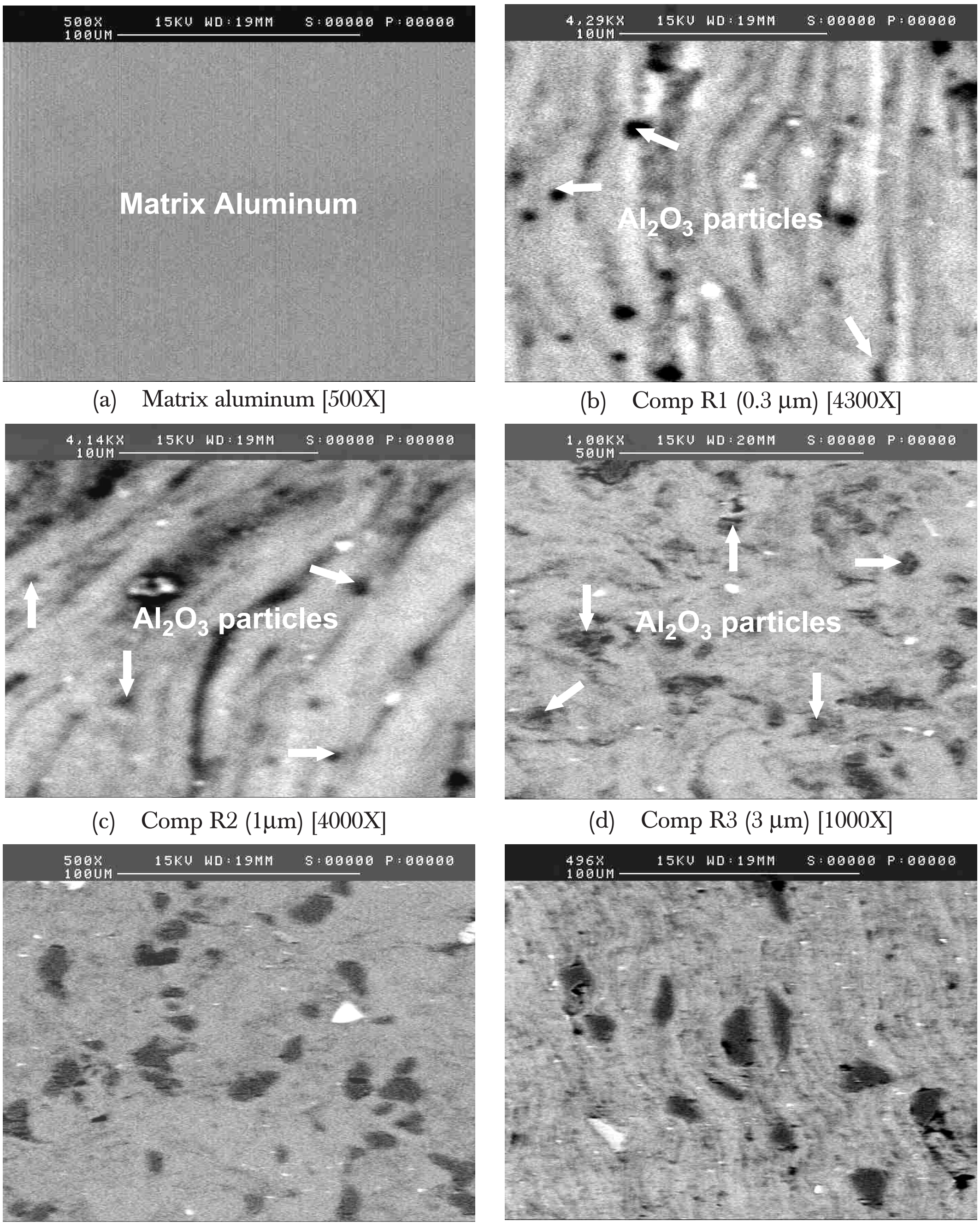
3.1 Microstructure

Figure 4 shows the SEM micrograph of aluminum metal matrix composite reinforced with 10 wt% alumina particle synthesized via powder metallurgy route. Figure 4(a) shows the SEM micrograph of pure aluminum matrix and Figures 4(b) to 4(f) show the micrographs of composites reinforced with 10 wt% Al_2O_3 with various particle sizes namely, 0.3, 1.0, 3.0, 12.5 and 25.0 μm respectively. The microstructure of the composites was observed using a backscattered mode. The distribution of 0.3 and 1.0 μm alumina particles were difficult to observe in the matrix region due to its very small size. However, the reinforcement particle of the composites with 3.0, 12.5 and 25.0 μm Al_2O_3 particles, can be seen clearly embedded in aluminum matrix region. Aluminum matrix appeared to be grey and the alumina particles were black (Figure 4). The microstructure and texture of metal matrix composite are determined by the manner in which it is processed. Homogeneous distribution of the reinforcement in the matrix is essential to form a composite with uniform mechanical properties.

3.2 Sintered Density

The sintered density of the composites containing 10 wt% Al_2O_3 of different particle size is shown in the Figure 5. The results obtained revealed that the density of sintered composites show a slight decrease with the increase of particle size. The densities of the composites were in the range of 2.78 to 2.84 gcm^{-3} and density of pure aluminum was 2.69 g cm^{-3}. The sintered density of the composites was lower than theoretical density. Based on the results obtained, it can be concluded that the effect of reinforcement particle size on sintered density of the composite is not significant.

Sintered density is known to depend on the volume of the voids between composite particles and the efficiency of the diffusion process. The volume of voids is affected by the relative particle size and volume fraction of Al_2O_3. The coarser reinforcement particles, the bigger the voids and this result in lower density. The efficiency of the diffusion process is dependent on the degree of contact of the composite constituents. The heat during sintering makes the atoms liable for diffusion at the interface. The



(a) Matrix aluminum [500X]

(b) Comp R1 (0.3 μm) [4300X]

(c) Comp R2 (1μm) [4000X]

(d) Comp R3 (3 μm) [1000X]

(e) Comp R4 (12.5 μm) [500X]

(f) Comp R5 (25 μm) [500X]

Figure 4 SEM micrograph of aluminum matrix composite reinforced with different Al_2O_3 particles size at 10 wt%: (a) Matrix aluminum, (b) Aluminum composite reinforced with 0.3 μm Al_2O_3 [Comp R1], (c) Aluminum composite reinforced with 1.0 μm Al_2O_3 [Comp R2], (d) Aluminum composite reinforced with 3.0 μm Al_2O_3 [Comp R3], (e) Aluminum composite reinforced with 12.5 μm [Comp R4]. (f) Aluminum composite reinforced with 25.0 μm [Comp R5]

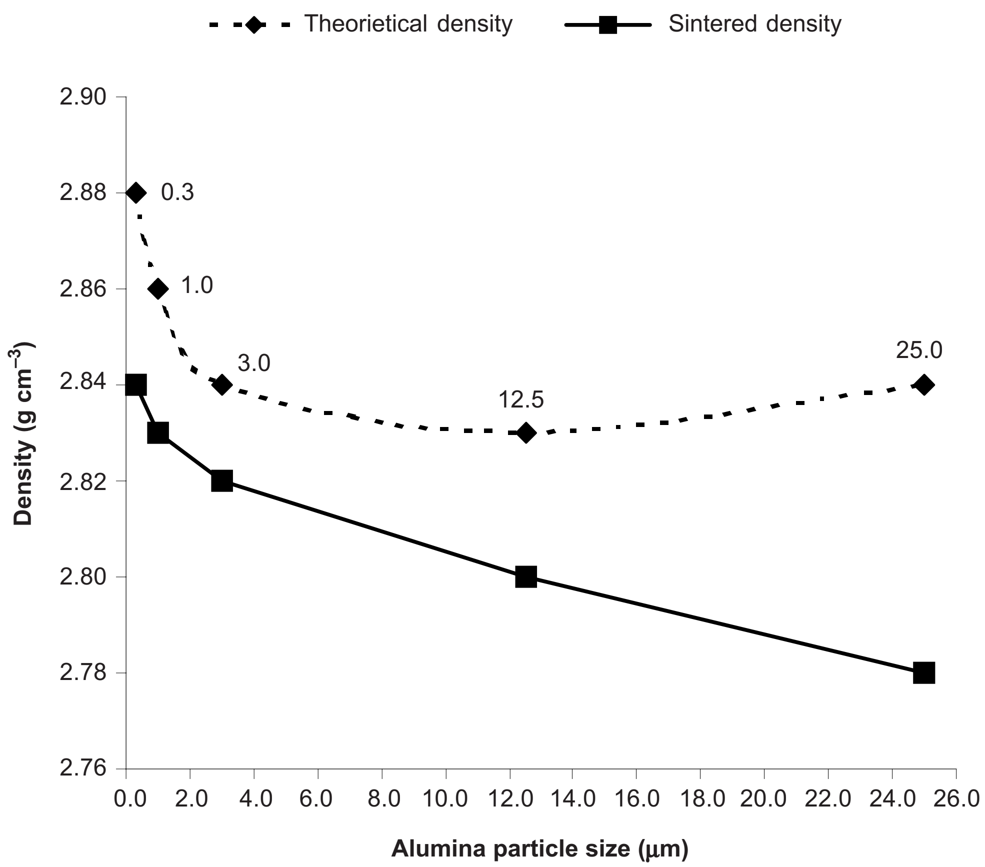


Figure 5 Theoretical and sintered density of synthesized composites with 10 wt% Al_2O_3

existence of Al_2O_3 particles affects the degree of intimacy contact between aluminum particles [8].

3.3 Hardness

The size of Al_2O_3 particles was found to have influence in determining the hardness of the composites. The smaller the reinforcement particle size, the higher the hardness would be. This result is shown in Figure 6. Composites reinforced with 0.3 µm Al_2O_3 have the highest hardness values of 70.1 Hv. Meanwhile, composites which were reinforced with 25.0 µm Al_2O_3 have the lowest hardness values of 45.7 Hv. Hardness values of pure aluminum matrix was 38.0 Hv. Small reinforcement particles permit larger contact area with aluminum particles. On the other hand, large reinforcement particles have small area of contact and prevent the diffusion process from progressing. Al_2O_3 particles act as barriers to dislocation flow in aluminum matrix. Composites reinforced with smallest Al_2O_3 particles have higher number of

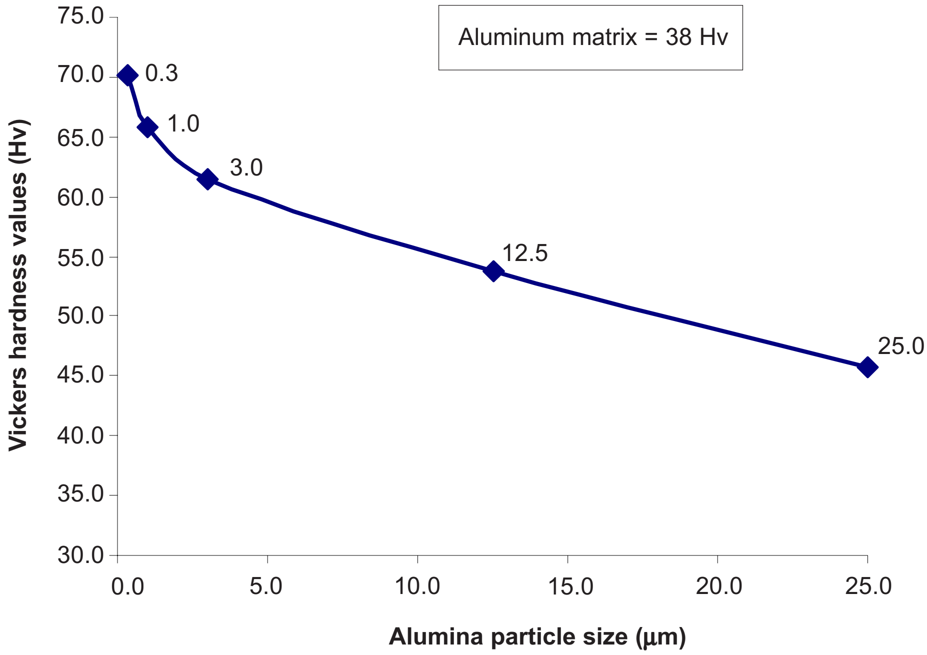


Figure 6 Hardness values of aluminum composite reinforced with 10 wt% for various alumina particle size

barrier per unit area compared to composites reinforced with larger particle at the same weight percentage [8, 9].

4.0 CONCLUSION

The influence of the reinforcement particles size on sintered density was small. Larger particle (25 µm) reinforcement gave lower sintered density compared to other particle size reinforcement at the same weight percentage. Composites reinforced with smaller reinforcement particle (3.0 µm) gave a higher hardness values.

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