The Effect of Reinforcement Particle Size on the Microstructure and Hardness of Al/(Al_2O_3) composite Via P/M Route

Khairel Rafezi Ahmad[1], J.B. Shamsul[2], Luay Bakir Hussain[1] and Zainal Arifin Ahmad[1]

[1] School of Materials and Mineral Resources Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[2]Kolej Universiti Kejuruteraan Utara Malaysia ,
Taman JKKK,Kubang Gajah,02600 Arau, Perlis, Malaysia
(rafezi98@hotmail.com)

ABSTRACT: Particulate-reinforced metal matrix composites (MMCs) have become more attractive to researchers because of the problem of anisotropy and high cost of fibre-reinforced MMCs. Alumina particles (Al_2O_3) is the second most applied as reinforcement materials after SiC. The main reason is that Al_2O_3 is more stable and inert compared to other ceramic particles in term of interfacial reaction. This study involves the fabrication of aluminium reinforced Al_2O_3 particles composite. Compacting pressure of 250 MPa and sintered at 600°C for 5 hours. The MMC samples were prepared using 10wt% of Al_2O_3. Effect of Al_2O_3 particles sizes (3µm, 6µm, 12µm, 13µm and 25µm) on the microstructure of the composites were observed using SEM. Their hardness was measured using a Vickers microhardness tester. It is observed that the smallest reinforcement particle size (3µm) gave the highest hardness value (61.4VHN). The finer Al_2O_3 particles will provide more efficient barriers to dislocation flow in aluminium matrix. Composites reinforced with the smallest particle size has the highest number of barrier per unit area compared to composite that reinforced with larger particle size at the same weight percentage. SEM micrograph observations indicate that the smaller Al_2O_3 particle size the more homogeneously they are distributed in aluminum matrix.

KEYWORDS: aluminium metal matrix composite, alumina, ceramic reinforcement, particle reinforcement, powder metallurgy.

INTRODUCTION

There has been a wide interest in developing metal matrix composites (MMC) because of their unique mechanical properties such as light weight and high elastic modulus. Since a significant improvement in the performance of MMC has been recognized, MMC have already been used in various industries such as automotive, leisure goods, aerospace, and others [Murakami, 1991].

For a long period of time, aluminium alloys were some of the most widely used materials as the matrix in MMC compared to titanium, magnesium, superalloys and intermetallic compounds. Recent research on MMC is mainly focused in aluminium and its alloys as matrix due to the low density which is the first requirement in most composite applications. Moreover, they are cheap compared to other low density alloys such as magnesium and titanium. They also show excellent behaviour in strength, ductility, stiffness together with better wear and corrosion resistance, lower coefficient of thermal expansion and high specific heat conductivity [Murakami, 1994].

Ceramic particulate are some of the most widely use as reinforcement in the production of aluminium alloy composites. Ceramic fibers and whiskers are usually added to increase strength and stiffness while ceramic particulates are to increase wear resistant [Cylne, 2000]. SiC, TiC and Al_2O_3 are the common ceramic particles used. In term of chemical stability, Al_2O_3 is more stable and inert compared to SiC and TiC. SiC and TiC will react with Al matrix to form Al_4C_3 that are deleterious to the properties of the composites since it leads to degradation of the reinforcement and produces a brittle intermetallic compounds [Suery, (1993); Hunt, (2000)].

The powder metallurgy (P/M) route for manufacturing MMC offer some advantages compared to other technique such as casting, forming and machining. One of the main advantages of this process is the ease of mixing of the different metal powders. This leads to the possibility to create new composite materials with special physical and mechanical properties in a component which cannot be produced by melting-casting process [Yamaguchi *et al*., 1997]. Another advantage of P/M is the uniformity in the reinforcement distribution. This uniformity not only improves the structural properties but also the reproducibility level in the properties. P/M involves low manufacturing temperature that avoids strong interfacial reaction and minimizes the undesired reactions between the matrix and the reinforcement [Torralba *et al.*, 2002].

EXPERIMENTAL PROCEDURES

Powders

High purity aluminium powders (BDH 99.5%) in the form of flaky shaped powdered particles produced by BDH Laboratory Supplies, England were used. The average particle size is 25µm. Five different particles size of aluminium oxide powder used in this research *(3µm, 6 µm, 12µm, 13µm and 25µm)*. The particles size analysis was done using *Malvern MasterSizer E. version 1.2*. The Al_2O_3 are angular particles and sharp at the edges.

Each different particle size of Al_2O_3 particles were mixed with aluminium powder in a mixer. The samples are based on 10wt% of Al_2O_3 reinforcement. Al-Al_2O_3 was mixed for 8 hours to ensure the good distribution of Al_2O_3 particles in Al-matrix.

Compaction and Sintering

Al-Al_2O_3 powder mixtures were compacted using *Shimadzu Universal Tensile Machine*. The powders were compacted at 250 ± 5 MPa. In order to avoid damage to the components during ejection, the compaction pressure was decreased to 5 MPa immediately after maximum pressure was obtained. The die used in this study was 16mm in diameter. Die wall lubrication was applied by brushing a thin layer of graphite powder over the die cavity and the top punch.

Sintering was carried out at 600^0C for 300 minutes in the *CWF 1100 Carbolite Furnace* at normal atmosphere. Heating rate was kept constant at 5^0C/min.

Analysis

Microstructural analysis was carried out using *Cambridge Strereoscan 200 Scanning Electron Microscope (SEM)*. Hardness values were determined using a *Leitz Wetzlar Vickers Microhardness Testing Machine* with a load of 10 g and dwell time of 15 seconds. The Vickers microhardness value (VHN) is defined as the load divided by the pyramidal area of the indentation, in kg/mm^2.

RESULTS AND DISCUSSION

The first requirement for a composite material to show its superior performance is the homogeneous distribution of the reinforcing phases. The agglomeration of the reinforcement particles deteriorates the mechanical properties of the composite. In P/M, the matrix and reinforcement mixing process is the critical step towards a homogeneous distribution. The size and morphology of the particulates constituting the matrix and reinforcement also influence the mechanical and physical properties of the composite.

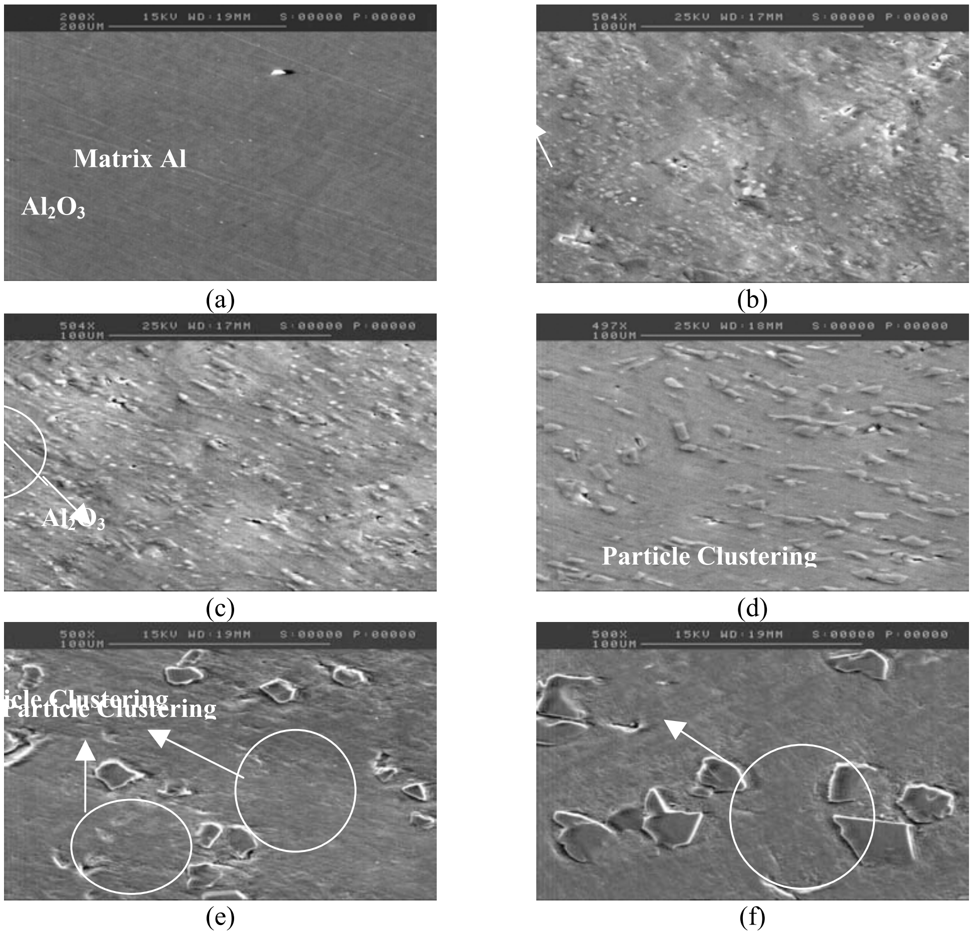

Figure 1: SEM Micrograph of aluminium metal matrix composite reinforced with various particle size of 10wt% Al_2O_3 powder (a) matrix Al with no reinforcement, (b) matrix Al reinforced with 3µm Al_2O_3 particle, (c) matrix Al reinforced with 6µm Al_2O_3 particle, (d) matrix Al reinforced with 12µm Al_2O_3 particle, (e) matrix Al reinforced with 13µm Al_2O_3 particle, and (f) matrix Al reinforced with 25µm Al_2O_3 particle.

Figure 1 shows the SEM micrograph of aluminium metal matrix composite reinforced with 10wt% alumina particle synthesized via P/M route. Figure 1(a) shown the SEM micrograph of pure aluminium and Figure 1(b) to 1(f) shown the micrograph of composites that reinforced with 10%wt Al_2O_3 with various particle sizes i.e. 3µm, 6µm, 12µm, 13µm and 25µm, respectively. It is observed that the Al_2O_3 particulates with small particle size, 3µm and 6µm homogeneously distributed around the aluminium matrix region. No large agglomerations of Al_2O_3 particulates and porosity were noticed. But composites with larger

Al_2O_3 particulates (12μm, 13μm and 25μm), reinforcement particles tend to cluster in the matrix region.

This is because the fine particles are easier to incorporate into metal powder during mixing and tend to give a homogenous reinforcement distribution. Larger particles are more susceptible to gravity settling and can result in clustering and agglomeration of reinforcement in matrix region. Particle clustering occurs because of a high surface area of particle and the action of the Van der Waals attraction force of large particle. Morphology of reinforcement and matrix particle also influence the homogeneity of particle distribution. The flowability of angular shaped Al_2O_3 particles in the flaky shaped Al particles decrease during mixing, with the flowability inversely proportional to the particle size.

Particle clustering does not have an influence on the bulk properties of composite, such as Young's modulus, but does affect those properties that are susceptible to microstructural inhomogeneity, such as hardness, strength and ductility.

Figure 2 shows the hardness values of Al-10wt%Al_2O_3 composites reinforced with various particle size of Al_2O_3. The size of Al_2O_3 particle was found to have considerable role in determining the hardness of composites. The smaller the particle size, the higher hardness values as shown in Figure 2. Composites reinforced with 3μm Al_2O_3 have the highest hardness values at 61.4VHN. Meanwhile composites that reinforced with 25μm Al_2O_3 have the lowest hardness values at 45.7VHN.

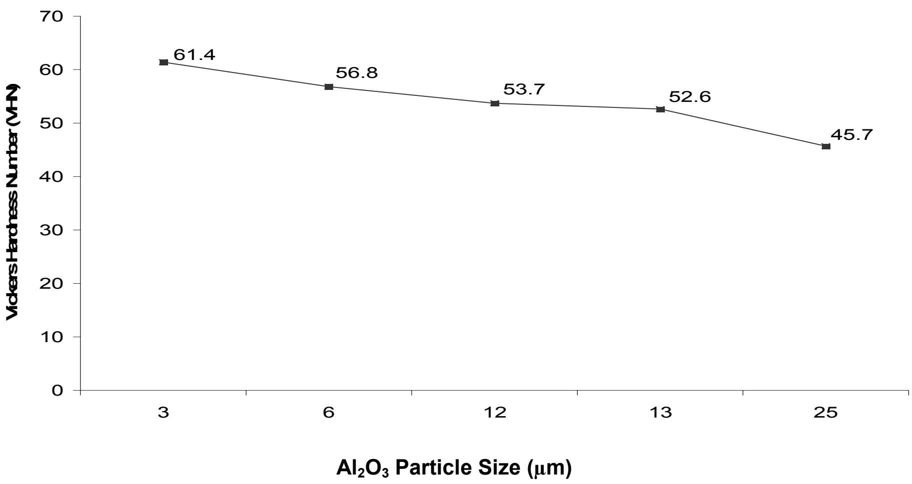

Figure 2: Hardness values of Al-10wt%Al_2O_3 composite reinforced with various particle size reinforcement.

Small reinforcement particles permit larger contact area with aluminium particles. On the other hand, the larger sizes of the reinforcement particles prohibit the contact and prevent the diffusion process from progressing. Al_2O_3 particles act as barriers to dislocation flow in aluminium matrix. Composite reinforced with smaller Al_2O_3 particles has the highest number of barriers per unit area compared to composites reinforced with larger particles at the same weight percentage [Khairel *et al.*, 2003].

CONCLUSIONS

The production of Al_2O_3 particle reinforced aluminium matrix composites in the form of near net shape component can be achieved through the conventional P/M route i.e. cold uniaxial pressing and sintering processing technology. Large particle tend to form clusters in the matrix region. Small particle reinforcement (Al_2O_3) gave higher hardness values compared to larger particles.

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