FPCM-6 (2002)
The 6th International Conference on Flow Processes in Composite Materials
Auckland, New Zealand
15 ~ 16 July 2002

THE EFFECTS OF REINFORCEMENT ASPECT RATIO ON THE MECHANICAL PROPERTIES OF AL-20VOL%AL_2O_3 METAL MATRIX COMPOSITES

X. X. Luo, K. Pickering and D. L. Zhang

Department of Materials and Process Engineering, The University of Waikato,
Private Bag 3105, Hamilton New Zealand
E-mail: xl9@waikato.ac.nz, k.pickering@waikato.ac.nz, d.zhang@waikato.ac.nz

SUMMARY: The effect of aspect ratio of ceramic reinforcement on the mechanical properties of Al-20vol%Al_2O_3 metal matrix composite materials was investigated. A powder metallurgy approach was used to manufacture the composite materials. Two forms of Al_2O_3 reinforcement were used: particulate and fibrous. Bending tests and hardness tests were carried out to examine the mechanical properties of the composite materials. It was found that the hardness achieved a peak value in particulate reinforced samples, however, the bending strength reached a maximum in fibre-reinforced samples.

KEYWORDS: Metal Matrix Composite, Powder Metallurgy, MMC, AMC, Fibre Reinforced MMC, Particulate Reinforced MMC.

INTRODUCTION

In the past ten years, materials R&D has shifted from monolithic to composite materials, adjusting to the global need for reduced weight, low cost, high quality, and high performance in structural materials.[1] Among composite materials, metal matrix composite materials are an important part of the composites family. The term metal matrix composite (MMC) encompasses a wide range of scales and microstructures. Common to them all is a continuous metallic matrix. The reinforcing constituent is normally a ceramic, although occasionally a refractory metal is preferred.[2] The idea behind MMCs is to combine the ductility and toughness of metal matrix with the rigidity and the hardness of ceramic reinforcement. Numerous processing routes have been developed, and some of them have been commercialised. However, there are several difficulties in attempting to produce quality metal matrix composites by existing processes[3]. The challenge is to find an economical and versatile way of introducing a large amount of fine ceramic dispersoids without rejection and segregation of the reinforcement and unwanted chemical reactions. In order to achieve this aim and to accelerate the further commercialisation of this class of materials, this research work utilised a new procedure to produce discontinuous fibre and particulate reinforced Al-Al_2O_3 composites with 20vol% of different forms and sizes of Al_2O_3 reinforcement. The effect of aspect ratio, size of the reinforcement, and processing parameters on the final mechanical properties of the MMCs were investigated.

MATERIALS AND EXPERIMENTAL TECHNIQUES

Figure 0 shows the procedures of sample fabrication and testing. The materials used are listed in the Table 1 below. An Al-Si-Mg alloy with a composition close to 6061 was selected to be the matrix phase. This was produced by a mechanical alloying technique. Two forms of alumina, fibrous and particulate, were used for the reinforcement. The alumina fibre had a diameter of 2 μm and was supplied by Goodfellow UK. This was cut into lengths of 0.5 and 1mm using a guillotine. Fibre of approximately 0.125 mm in length was produced by high-energy ball milling the fibres of length 5 mm in the SPEX 8000 mill for 3 minutes. For particulate reinforced composites, the matrix and Al_2O_3 powder were mixed using high energy ball mill for 2, 4 and 8 hours. Sintering and heat treatment of samples were carried out in a ceramic tube furnace with an evacuation and argon refill system. Optical microscopy and SEM were used to monitor the microstructure evolution during processing, and fracture surfaces of the samples. In the following section, each process will be described separately.

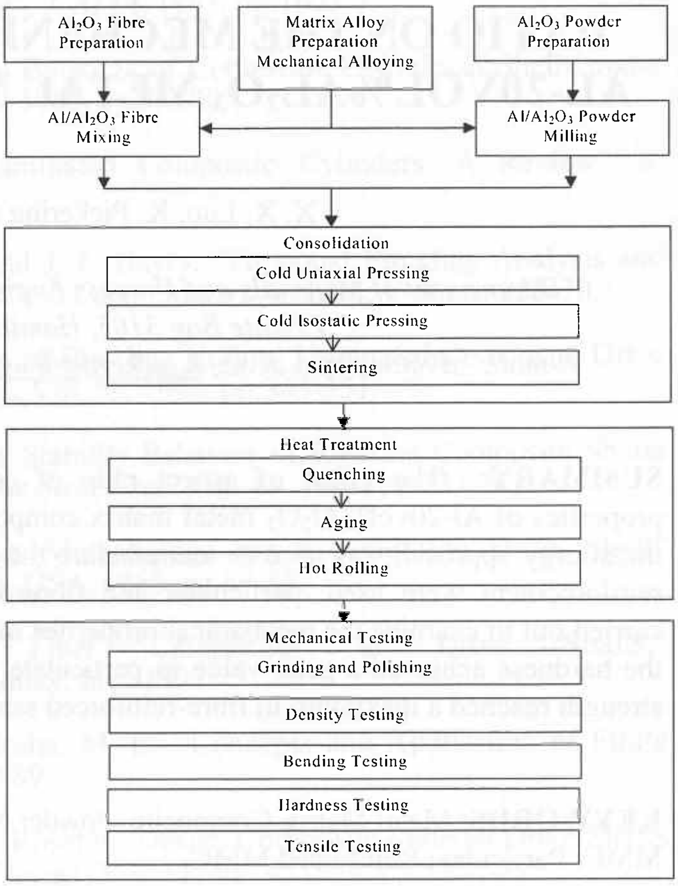


Figure 0 Schematic diagram showing the procedure of sample fabrication and testing.

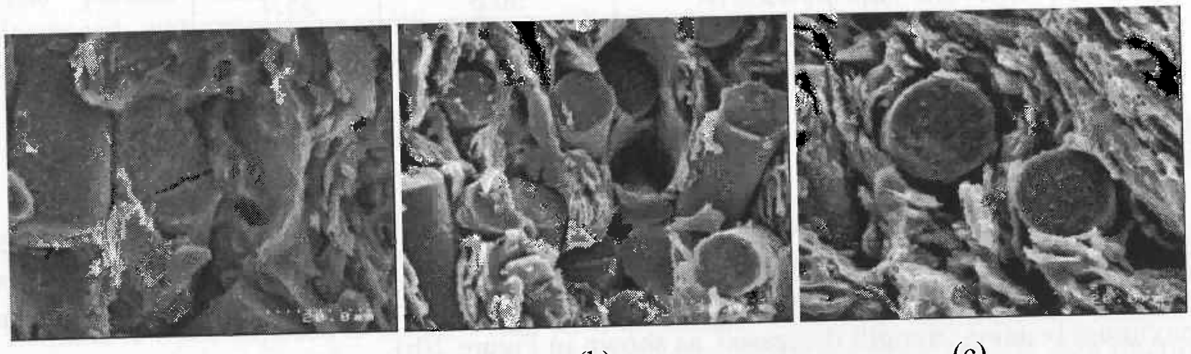
Table 1 Materials used in the experiments

Materials	Manufacturer	Purity	Particle Size
Al	Johnson Mathey CmbH	99.8%	~ 50μm
Mg	Johnson Mathey GmbH	99.9%	~ 50μm
Si	Johnson Mathey GmbH	99.5%	~ 150μm
Al_2O_3 Fibre	Goodfellow	>99 %	2 μm in Diameter
Al_2O_3 Particle	Johnson Mathey Company	99.5%	50 μm

RESULTS AND DISCUSSIONS

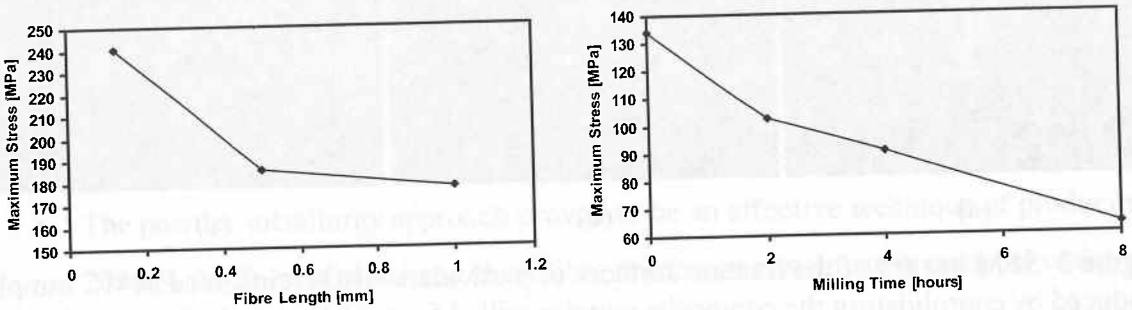
Effect of Fibre Length

Figure 1(a) shows the SEM image of the fracture surface of a 0.125 mm Al_2O_3 fibre reinforced MMC sample. The fibres were randomly orientated. Some of the fibres have been pulled out from the matrix. Some matrix material can be seen to be stuck on the Al_2O_3 fibre surface. Whereas, a large amount of the fibre was free from any matrix materials. This suggests variable bonding strength between the Al_2O_3 and matrix.. Some Al_2O_3 fibres were also broken. This is quite likely to have occurred during high energy milling. Figure 1(b) shows the SEM images of the fracture surface of a 0.5 mm Al_2O_3 fibre reinforced MMC sample. Some fibres were pulled out from the matrix and some porous areas could be observed. Figure 1(c) shows the SEM images of the fracture surface of 1 mm Al_2O_3 fibre reinforced MMC sample. The fibres were randomly orientated. Some fibres were not very well bonded to the matrix material.



(a) (b) (c)

Figure 1 SEM images of fracture surface of (a) 0.125 mm, (b) 0.5 mm and (c) 1 mm Al_2O_3 fibre reinforced AMC samples.



(a) (b)

Figure 2 (a) Maximum bending stress as a function of high energy ball fibre length, and (b) Maximum bending stress as a function of milling time.

Fibres longer than 2 mm proved impractical using a powder metallurgical approach due to the difficulty of mixing with powder. However, it was possible to mix fibres equal to and less than 1 mm long with the alloy powder by using a dry rolling method. It was observed that generally the shorter the fibres, the easier it was to mix them. With decreasing fibre length, the density and bending strength of the AMCs increased as shown in Figure 2(a). This is likely to be due to the porosity reduction observed with the reduction of fibre length. The pores are likely to be formed at bridging areas of the fibres. Therefore, the longer the fibres, the more likely that pores will form and also be deformed during isostatic pressing due to uneven mixing with alloy powder. On the other hand, fibres were broken down to segments of 10 – 20 μm during cold pressing. Therefore the initially long fibres had all been broken down to short segments and had lost some of the desired contribution to mechanical properties as long fibres. Comparing the hardness of the AMCs made from three different lengths of fibres, little difference could be found amongst them, as shown in Table 2.

Table 2 Hardness of the AMCs

Consolidation Conditions	570°Cx20h	610°Cx20h
Sample Id	Vickers Hardness	
S[P]-0	46.6	36.6
S[P]-2	136.0	52.3
S[P]-4	107.4	
S[P]-8	185.0	
S[F]-0.125	50.6	35.7
S[F]-0.5	56.2	30.7
S[F]-1.0	49.5	

Effect of Milling Time

High energy milling played two functions: one being the break-down of the Al_2O_3 particles and the other being the dispersion of the Al_2O_3 particles in the matrix. The study shows that with the increase of milling time, the density and hardness of the AMCs increased, but the maximum bending strength decreased, as shown in Figure 2(b).

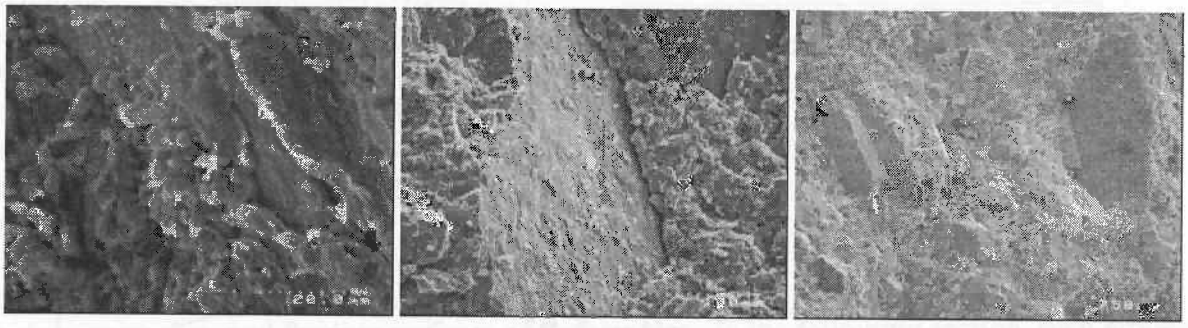

(a) (b) (c)

Figure 3 SEM images of the fracture surfaces of particulate Al_2O_3 reinforced MMC sample produced by consolidating the composite powder milled for (a) 0 hours, (b) 2 hours and (c) 8 hours.

Figure 3(a) shows the SEM images of the fracture surface of a particulate Al_2O_3 reinforced MMC samples produced by consolidating alloy matrix and Al_2O_3 powder. It shows the fracture area of the matrix alloy and Al_2O_3 particle clusters. Due to the fact that the Al_2O_3 particles form clusters which are brittle areas, no load could be shared and transformed by these areas. Hence, the bending strength decreases compared to that of the matrix alone. For the 2 and 4 hours milled composite powder, it shows that some large areas were segregated and some Al_2O_3 particles were separated from the matrix during the fracture processing, as shown in Figure 3(b). Figure 3(c) shows the SEM images of the fracture surface of Al_2O_3 particulate reinforced MMC samples produced by consolidating the composite powder milled for 8 hours. Some large delaminated areas could be observed. Some pores can be observed under higher magnification.

The increase of density with milling time would appear to be due to the reduction of porosity accompanied by the reduction of powder particle size. The AMC samples made from compacting the powder mixture of Al-Mg-Si alloy/Al_2O_3 particles, as shown in Figure 4, contained large Al_2O_3 clusters and pores. Whereas, the AMCs produced by compacting the high energy ball milled composite powders had no Al_2O_3 clusters, much smaller Al_2O_3 particles and less porosity. The particle size and the homogeneity increased with increasing milling time. The porosity decreased accordingly. As a result, the density and the hardness increased.

Figure 4 SEM back scattered image of the cross section of AMC sample made by consolidating the powder mixture of Al alloy powder and Al_2O_3 powder.

In order to find reasons for the decrease in bending strength, the process used for preparation was reviewed. It was observed that the composite powder produced after high energy ball milling was fine and very reactive when exposed to the atmosphere. The powder had to be stabilized with a slow oxidation process. This process took longer for the powder produced after longer milling, especially for the powder produced after 8 hours of milling, where it was flammable when exposed to the air. After slow oxidation, the outside surface of the composite powder was covered with a layer of aluminium oxide. With the finer particle size obtained from a longer time milling, the fraction of aluminium oxide became significant. This made the sintering very difficult and the composite powder particles tended to stay separated. As a result, the bending strength decreased with milling time. In order to take advantage of high energy milling for processing of MMCs using a powder metallurgy approach, an inert atmosphere for handling the powder would appear to be critical.

CONCLUSIONS

- The powder metallurgy approach proved to be an effective technique of producing Al-20wt.% Al_2O_3 particulate and short fibre reinforced metal matrix composite materials.
- Milling is an effective mixing technique for blending short fibres with alloy matrix powders, but not for fibres longer than 2 mm.
- Increasing high energy milling time is favourable for the increase of composite density, bending strength and hardness.
- Increasing reinforcement fibre length using this method tends to decrease the composite density and bending strength due to increased porosity.

REFERENCES

1. J. U. Ejiofor and R. G. Reddy, *JOM*, November 1997, pp.31.

2. T. W. Clyne and P. J. Withers: Introduction of Metal Matrix Composite Materials, 1992, Cambridge.

3. V. M. Kevorkijan and B. Sustarsic, “A New Production Technology for Discontinuously Reinforced Al-SiC Composites”, *Key Engineering Materials*, Vols. 127-131, 1997, pp.471.