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Mechanical Properties of 7075 Aluminium Matrix Composites Reinforced By Silicon Carbide Particulates

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Abstract : *Aluminium composites reinforced by particles have received considerable attention because of their superior mechanical properties over monolithic aluminum matrix. Over the last ten years, nanocomposites with nano-sized reinforcements have become a revolutionary progress for composites because they have different strengthening mechanisms as compared to that in composites with micro-sized reinforcements. Consequently novel properties can be expected from the nanometric particulate reinforced composites. The aim of this project was to fabricate SiC (50nm)/7075 aluminium composites via a modified powder metallurgy and extrusion route. Ageing treatment was used to increase the strength of the composites and mechanical tests, including tensile test and abrasive wear test, were performed. The effects of nanometric silicon carbide particulates to the ageing behaviours and mechanical properties of the composites have been studied by optical metallography, scanning electron microscopy and transmission electron microscopy.*
Keywords : *Aluminium7075, Metallographic, Nanometric, Powder metallurgy.*

I. Introduction

Aluminium-based discontinuously reinforced metal matrix composites (MMC) have received considerable attention because of their improved strength, high modulus and increased wear resistance over conventional aluminium alloys. The size of reinforcements in commercial MMC generally ranges from a few micrometers to several hundred micrometers. Because of fabrication difficulties only recently reinforcements with nanometric size have been used. It was reported that the yield strength of pure aluminium was doubled by adding only 4vol. % Al_2O_3 particles [1], and the tensile strength and Young"s modulus of 2024 Al were increased by 35.7% and 41.3% respectively by adding only 1.0wt.% carbon nanotubes (CNTs) in the matrix [2]. However, the use of advanced composites has not been realized because of the processing difficulties and a lack of understanding of the role of nano-particulates on the resulting mechanical properties.

Previous research indicated that nano-sized alumina particles tended to reduce alloy strength by attracting certain elements. Al-SiC system was mostly studied and it is a very stable system. 7xxx aluminium alloy is the strongest heat-treatable aluminium series; hence in this study 7xxx aluminium alloy and nano-sized silicon carbide particles were used to in order to gain maximum strength. The composites were fabricated via Powder Metallurgy (P/M) method and the mechanical properties have been examined. The role of the nanometric particles on dislocation motion and ageing behaviour has been determined.

1.1 Fabrication of Aluminum Matrix Composites

A metal matrix composites (MMC) is defined as a material that consists of at least two constituent parts, the matrix being metal, the other may be a different metal or ceramics. They are bonded together along the interface in the composites.Processing of MMC can be broadly divided into two categories of fabrication technique: solid state and liquid state. The liquid state processing is generally less expensive and easier to handle, and the composites can be produced in variable shapes, using techniques already developed in the casting industry for monolithic metals. However the technical difficulties related to liquid state processing include reinforcement segregation and clustering, detrimental interfacial chemical reaction, high localized residual porosity and poor interfacial bonding which degrade the properties. Meanwhile powder metallurgy processing can avoid strong interfacial reaction and minimize the undesired reaction between the matrix and the reinforcement because generally a lower manufacturing temperature is used in powder metallurgy. The content and distribution of reinforcement, as well as the microstructure of the matrix can be controlled relatively easy. Hence the P/M products normally have superior properties over that of their cast counterparts.

1.2 Powder Metallurgy

Powder Metallurgy is the most common method for fabricating particulate metal-ceramic composites. It usually involves mixing of powders of the matrix alloy with the reinforcing particles, followed by compacting and solid state sintering.It is very important that all particles are homogeneously distributed in order to obtain a uniform microstructure. When whiskers are used as reinforcement, small particles for the matrix alloys are required for the improvement of the packing effect and to obtain a good dispersion of the fibers in the matrix [3].Although most powder consolidation and processing work is carried out below the matrix solidus temperature, sometimes it becomes necessary to maintain the consolidation temperature slightly above the solidus to minimize deformation stresses and to avoid whisker damage. In liquid-phase sintering, powder consolidation may be achieved without the use of any external pressure because a low melting phase pulls solid particles together via the force of surface tension. The higher melting temperature phase in this process should be slightly soluble in this liquid [4].

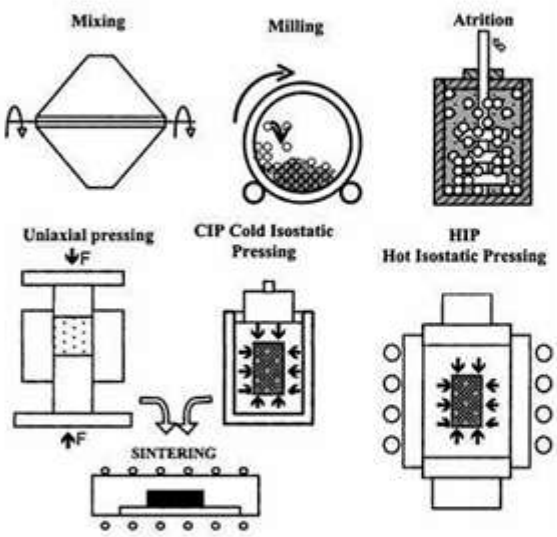

Fig.1. Conventional powder metallurgy process

II. Experimentation

1.2 Materials for preparation of composites

The starting materials used were micro-sized 7075 aluminium alloy powders (Ampal, U.S.A.) and nanometric silicon carbide powder which had average sizes of 78 µm and 50nm respectively. The chemical composition of the aluminium powder is shown in Table 2.1. Fig 2(a) is an SEM picture of as-received silicon carbide powder which shown a very large SiC with small particles on its surface and Fig 2(b) is a TEM picture of ground and ultrasonic-dispersed SiC powder. It can be seen that the SiC particulates are now less than 100nm after the ultrasonic dispersion.

Table 2.1 Chemical composition of matrix alloy (wt %)

Matrix alloy	Mg	Si	Zn	Cu	Fe	Ni	Al
7075 Al	2.23	0.06	5.71	0.98	0.10	0.01	Bal.

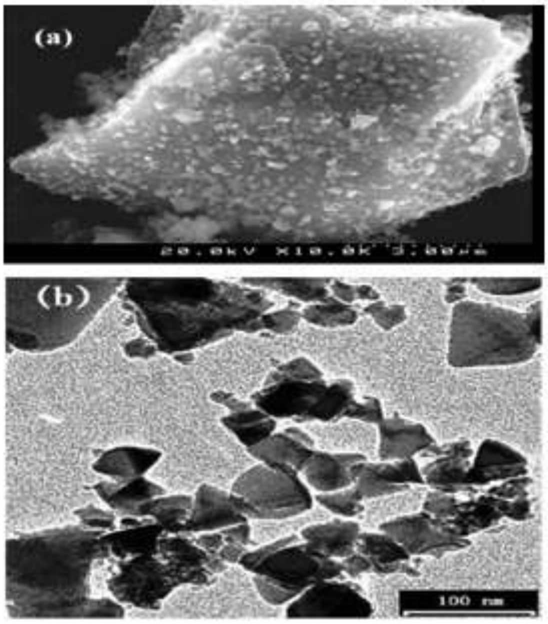

Fig.2. (a) SEM of as-received powders (b) TEM micrograph of ultrasonic-dispersed powders

1.3 Fabrication of composites by powder metallurgy process

The powder metallurgy process employed in this work includes wet mixing, cold iso-static pressing (CIP) and sintering. First the aluminum powder were mixed with different volume fractions (1 and 5 vol. %) of silicon carbide powder in pure ethanol slurry followed by ultrasonic dispersion and ball milling, then the mixture was dried at 150^{o}C and compacted by CIP. The compacted billets were sintered in nitrogen at 595^{o}C for two hours. The last step was hot-extrusion of the sintered billets with a reduction ratio of 36:1, to produce bars of 13 mm diameter. Fig. 3 is the flow chart of the composite fabrication.

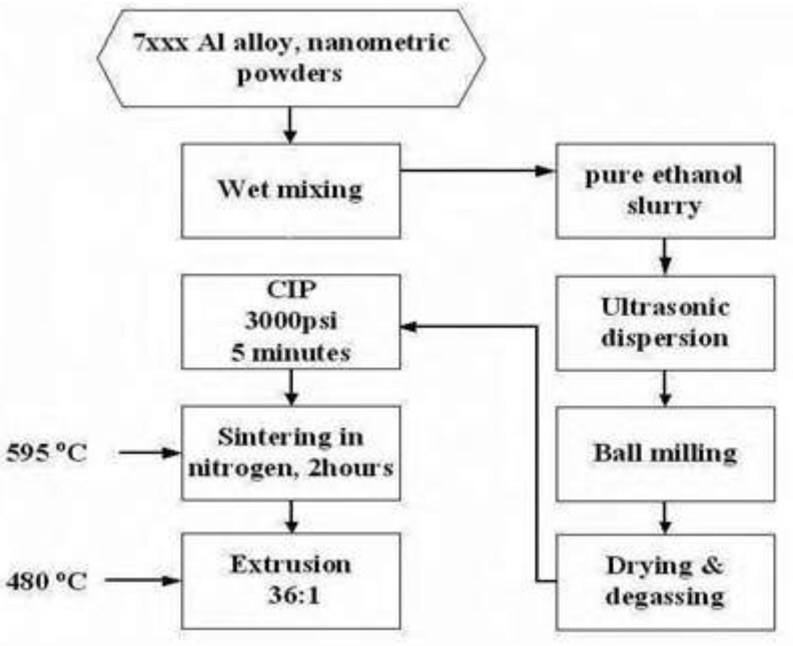

Fig.3. Powder metallurgy fabrication process for aluminium composites

1.4 Tensile test

Tensile tests were performed at room temperature on each material in peak-aging condition, using a Instron 1185 Screw testing machine at nominal applied strain rate of 1.67 x 10^{-4}/S. Laser extensometer were used for the measurement of the displacement of the samples. The dog-bone specimens were machined to have a gauge length of 30 mmand a diameter of 6mm and the surfaces of the tensile specimens were polished before tensile test. Three specimens were tested for each material.

1.5 Wear test

The abrasive wear tests, which were of the pin-on-disc type, were performed using a polishing machine [33], as shown in Fig 3. Experiments were carried out under dry condition by sliding the samples under an applied load of 10 N on a 120# abrasive paper stuck to the grinding disk which rotated at 300 rev /min. A fixed track diameter of 150mm was used and the duration time was 60 second.

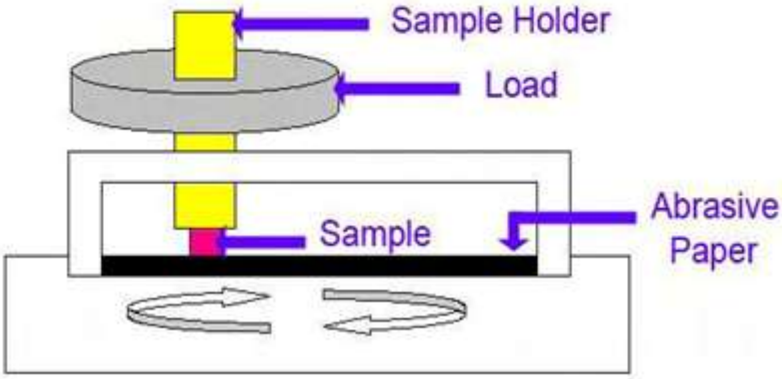

Fig.4. Schematic diagram of the pin-on-disk wear test apparatus

Each specimen was ground up to 600# abrasive paper to make the wear surface contact well with the surface of the abrasive paper. Each test was conducted on a fresh abrasive paper and three runs were conducted for each test condition. Wear losses were obtained by weighing the samples before and after wear test and the wear rate was calculated by converting the mass loss to volume loss using respective densities.

$$\text{Wear Rate } (mm^3/m) = \frac{\text{Mass Loss (g) / Density } (g/mm^3)}{\pi * \text{Wear Radius(mm)} * 10^{-3} * \text{Revolution(rev/min)} * \text{Time(min)}}$$

1.6 Hardness test

All specimens were subjected to a T6 artificial aging treatment. Firstly, 7075 aluminium alloy and the composites were solutionized at 480°C for 2 hours and water quenched. Subsequently, 7075 Al alloy and the composites were aged at 120°C for different period of time in a constant temperature oil bath.Before the hardness test, all the samples were mounted and ground successively using using a polishing machine. A LECO M-400-H1 hardness-tester was used to determine the changes in hardness during artificial ageing. A loading of 500g and a loading time of 15 seconds were used for the Vickers hardness test and 20 measurements were taken for each sample.

III. Results And Discussions

1.7 Tensile Properties

The tensile properties of the 7075 alloy and its composites .The alloy used in this project has quite similar yield strength (YS) and ultimate tensile strength (UTS) compared with data from ASM handbook [1]. It was notice that the 1vol. % SiC (50nm)/7075 aluminium composites had the greatest YS and UTS and the 5vol. % SiC (50nm)/7075 aluminium composites had the lowest strength. The ductility decreased with increase of the volume fraction of reinforcements.

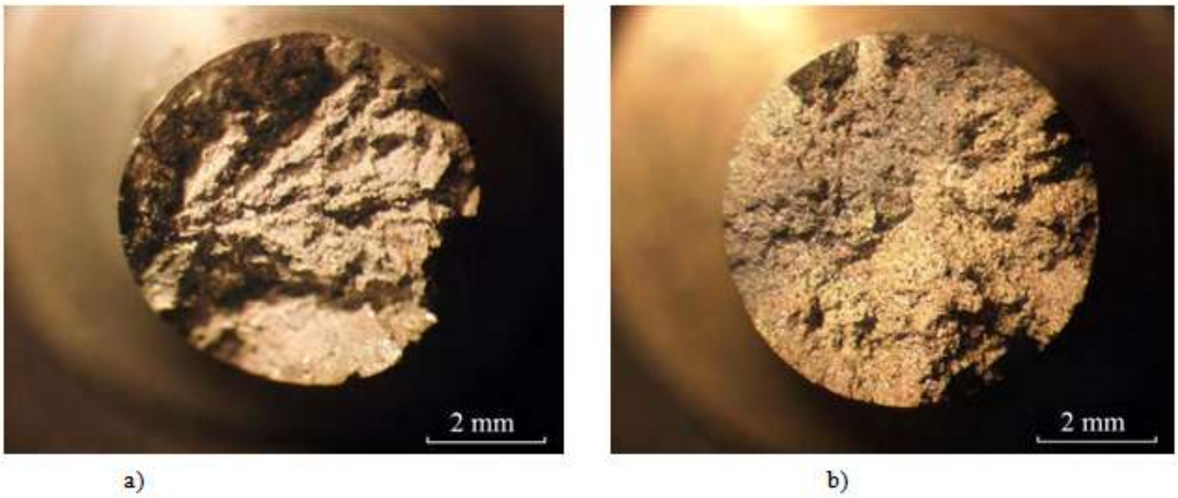

Fig.5. Fracture surface a) 1vol. % SiC(50nm)/7075 AMC   b) 5vol. % SiC(50nm)/7075 AMC

Fig 5 shows a macrostructures of cross section in transverse and longitudinal directions and it was shown that the fracture surface was getting rough with adding of nanometric reinforcements and the shear lips become much smaller for composites, while 5% composites even have no shear laps.

Table 1: Mechanical Properties of prepared composites

Composite	UTS (Mpa)	YS (Mpa)	EI (%)
7075AL	574	533	9.6
1%SIC/99%7075 AL	634	599	8.9
5%SIC/95%7075 AL	547	527	3.1

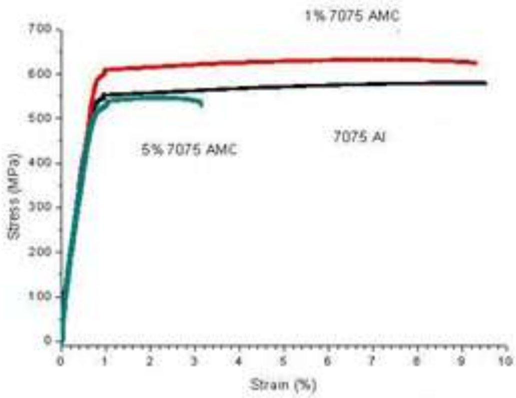

Fig.6. Stress-Strain diagram from experimental results

The fig.6 shows the stress-strain diagram for the different composites prepared with different volume fractions. From the fig. 6 it is clear that the composite material having 1% of 7075 AMC is showing good results compared to other two samples.

1.8 Abrasive Wear Properties

Peak-aged hardness and abrasive wear rates of 7075 aluminium and its composites are shown in Figs. The hardness of all materials were quite similar, while the wear rate of the composites decreased with increase of volume fraction of reinforcements and the wear rate of 1vol. % SiC(50nm)/7075 Al composites was about half of its matrix alloy.

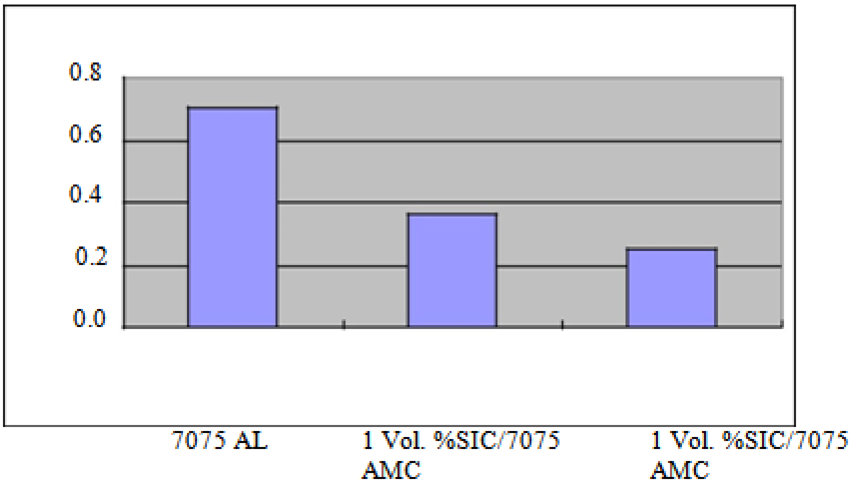

Fig.7. Abrasive wears rate of 7075 and its composites

These results indicate that hard second phase could reduce wear rate of the matrix alloy, even though their hardness was similar. However, the effect of improvements is much less notable than composites with micro-size reinforcement [66]. For composites containing the same amount of SiC particles the wear rate decreased with increasing SiC size [66, 67], but these findings were only basis on micro-size reinforcements. For nanometric reinforcements the interfacial area was much larger than that reinforced with micro-sized particulates. This increased the chance of the nanometric reinforcements to escape from the matrix, while large reinforcements could embed longer before they were broken down [68].

1.9 Hardness Properties

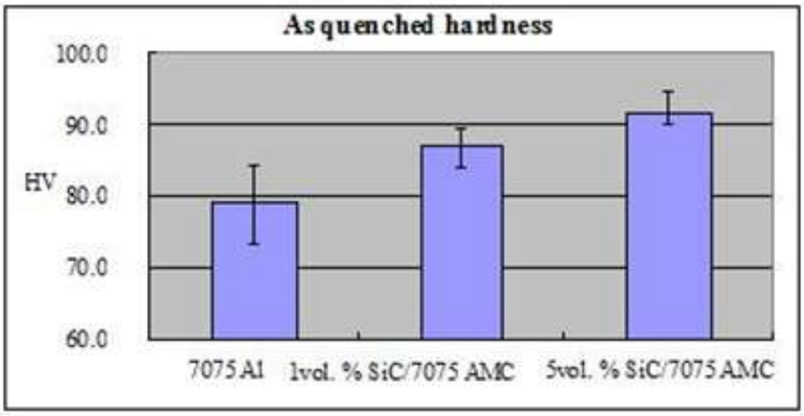

Fig.8. Hardness of 7075 aluminium and its composites

Figure 8show that hardness tended to increase with presence and increasing fraction of silicon carbide particulates, this suggested that the nanometricSiC particles can contribute to the strengthening of composites. This was less notable than the reports of other researches, which were based on nanoreinforcements including alumina particulates, silicon nitride particulates and carbon nanotubes. This could be due to the fact that the grain refinement effect is not significant for 7075 aluminium composites.

IV. Conclusions

Nanocomposites were fabricated by traditional powder metallurgy and extrusion, microstructures, ageing behavior and mechanical properties were studied in this work.

The following conclusions can be made:

- Different volume fractions of nanometric particulates could be introduced to 7075 aluminum matrix by traditional powder metallurgy technique.

- The dispersion of the nanometric particulates in aluminium matrix was not homogeneous, most reinforcements dispersed along grain boundaries and clustering were formed and aggregation tends to increase with increasing particulates content.
- Nanometric silicon carbide particulates did not change the aging kinetic and precipitates phases of 7075, but formed narrow PFZs at the interface.
- The 1% vol. SiC/7075 composites exhibited the highest YS and UTS in all materials in this work. The nanometric particulates did strengthen 7075 matix based on Orowan strengthening mechanism.
- Abrasive wear rate of SiC/7075 nanocomposites decreased with increasing reinforcements content. The improvement was not notable compared with composites reinforced by micro-sized particulates due to nanometric particulates aggregation and the large size of abrasive grit.

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