

## PREPARATION AND CHARACTERIZATION OF STIR CAST-ALUMINUM NITRIDE REINFORCED ALUMINUM METAL MATRIX COMPOSITES

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### ABSTRACT

Preparation and characterization of aluminum metal matrix composites reinforced with aluminum nitride was carried out. A graphite crucible and a stainless steel permanent mould was used to prepare the samples. An optimum stirring speed was determined for a fixed stirring time before cast in the permanent mould. Morphology of the composite and particle distribution were investigated by optical microscopy. The reinforcing particles were clearly shown present at the edges and around grains of silicon primary, silicon needles and inter-metallic compound of  $\text{FeMg}_3\text{Si}_6\text{Al}_8$ . The result of hardness test was 44 Hv for Al-Si matrix and increased to 89 Hv for an Al-Si composite reinforced with 5% wt.% AlN powder. The higher values in hardness indicated that the AlN particles contributed to the increase of hardness of the matrix.

**Keywords:** Metal matrix composites (MMC<sub>s</sub>); Aluminium silicon alloy (Al-Si), Aluminum nitride (AlN); Stir casting

### INTRODUCTION

A good combination of high strength and ductility of the Aluminum based metal matrix composites (MMC<sub>s</sub>) have introduced the material to a wide area of possible advanced applications. Discontinuously reinforced metal matrix composites have received much attention because of their improved specific strength, good wear resistance and modified thermal properties (Rittner, 2000). There is a variety of manufacturing processes available for discontinuous metal matrix composites; stir casting is generally accepted as a particularly promising route, currently practiced commercially. In general stir casting of MMCs involves producing a melt of the selected matrix material, followed by introducing reinforcement material into the melt, obtaining a suitable dispersion through stirring. Its advantages lie in its simplicity, flexibility and applicability to large quantity production, (Hashim *et al.*, 1999). It is also attractive because, in principle this method suitable for engineering application in terms of production capacity and cost efficiency (Zhou *et al.*, 1997). Aluminum nitride (AlN) as a reinforcement material has received much interest in electronic industry

because of the need for smaller and more reliable integrated circuit. AlN suits for this application because of its properties such as high thermal conductivities, strength greater than alumina, lower thermal expansion and good electrical properties (Baik and Drew, 1996). Compared with other ceramic materials, AlN is one of the lowest densities, high specific modulus, and lowest thermal expansion. Its thermal expansion  $4.6 \times 10^{-6} \text{ m}^{\circ}\text{C}$  was close to Si offer a potential use for both monolithic and composites materials (Kuramoto and Takada, 2003).

### METHODOLOGY

Aluminum alloy was prepared with an actual chemical composition shown in Table-1 determined by Glow Discharge Profiler (Model-Horiba Jobin Yvon) was chosen as a matrix. Aluminum nitride (AlN) from Aldrich manufacturer with purity of >98% and average size of <10  $\mu\text{m}$  were uses as reinforcement material. The metal matrix composites prepared contained 2, 5 and 10 wt% of AlN. The chemical composition of the Al-Si alloy in wt% is 88% Al, 0.42%Fe, 11.1%Si, 0.02% Cu, 0.02% Zn and others element in small quantities as shown in Table 1.

The Aluminum alloy was properly cleaned with acetone in ultrasonic bath prior to melting to eliminate any impurities on it surface. It was then heated in a graphite crucible (Figure 1) under controlled argon environment. Small amount of magnesium i.e. less than 0.5% of total weight of mixture was added into the crucible which acted as wetting agent to bind molten metal and reinforcement powder. A furnace heating temperature was increased to 750°C, hold for 30 minutes until Aluminum alloy melted completely. Aluminum dross then removed from the surface of the molten metal. Small amounts particulate aluminum nitride preheated to 750° were added continuously to the molten metal through the side of vortex created by mechanical stirring by the stir impeller. The optimum stirring speed of 450 rpm was determined and selected prior to this experiment. This is to avoid excessive gas content that resulted from over agitating of melts, which led to unacceptable porosity content in the casting product (Hashim *et al.*, 2002). The impeller and stirring rod was coated with liquid alumina so as to avoid any metals contamination to the molten metal.

Table 1- Chemical composition of Al-Si matrix alloy

Element	Fe	Si	Zn	Mg	Cu	Ni	Sn	Co	Ti	Cr	Al
wt %	0.42	11.1	0.02	0.0107	0.02	0.001	0.016	0.004	0.0085	0.006	Balance

Stirring was carried out to facilitate both incorporation and uniform distribution of particulate aluminum nitride (AlN) in the molten metal. The composite melt was stirred for 5 minutes then immediately cast into a permanent mould by bottom pour technique. The solidified Al/AlN metal matrix composites (MMC), which were taken out from the mould then cut, polished with standard metallographic procedures and etched by using Keller reagent, a solution mixture of 0.5ml hydrofluoric acid, 1.5ml hydrochloric acid, 2.5ml nitric acid and balance distilled water, for microstructure analysis and hardness test. Hardness test was conducted by using digital micro-hardness tester (Model Shimadzu HMV-2000), the micro hardness of Al alloy and composites samples were determined in the as-polished condition. The micro hardness measurement were made using a pyramidal diamond having face angle 136°, 100g indenting load and dwelling time 15 second.

## RESULTS AND DISCUSSION

As-cast Al/AlN metal matrix composites containing 2-10 wt% aluminum nitride were successful produced with attribution from preheat reinforcement of the particulate powder. Pre-heating enhances wettability between molten aluminum alloy and reinforced powder by maintaining temperature of the melt, removing surface impurities and gases that associated with powder agglomeration.

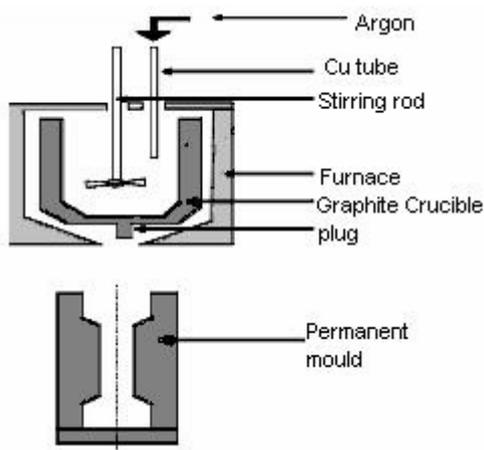


Figure 1 Schematic diagram experimental stir cast set-up

A vortex created by mechanical force of stirring process continuously dispersed AlN particulates in Al-Si melt. Aluminum nitride powders analyzed by scanning electron microscope (Model-LEO 1450VP) was shown in Figure 2(a) with average size of less than 10 microns. Generally, microstructure of master

alloy Al-Si in Figure. 2(b) consists of mainly  $\alpha$ -Al, and primary silicon surrounded uniformly by sharp edges silicon needles. Moldolfo (1979) said an addition of silicon content of less than 12wt% and 0.4wt% Mg of less than Fe weight percent in the Al-Si alloy will lead to the formation of an inter-metallic compound,  $FeMg_3Si_6Al_8$  which commonly known as Chinese script .

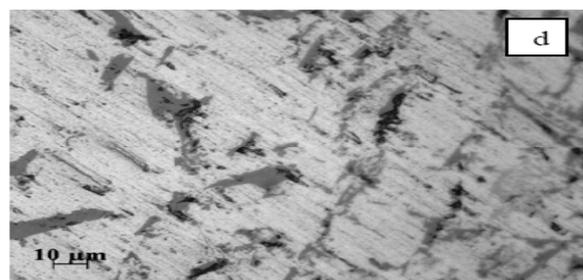
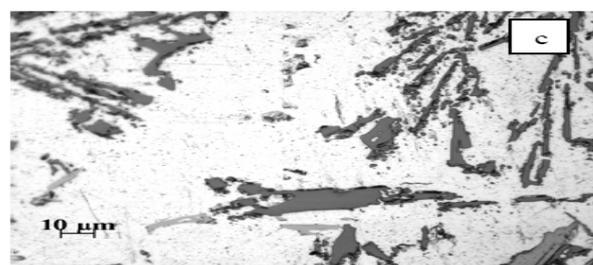
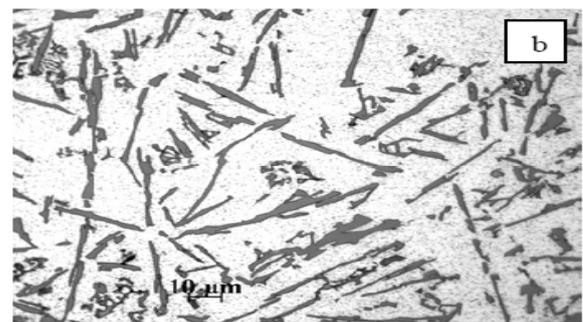
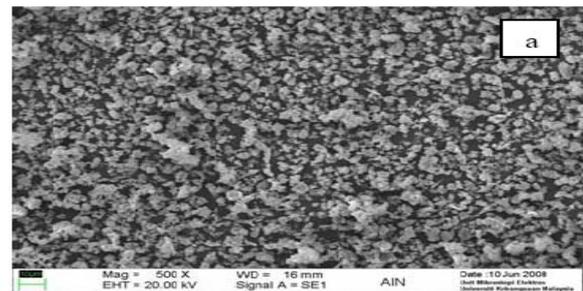


Figure 2: (a) SEM micrograph of AlN powder, (b) Microstructure Al-Si alloy, (c) Al/ 5wt%AlN<sub>p</sub> and (d)Al/10wt%AlN<sub>p</sub>

The microstructure of as-cast aluminum composites reinforced with aluminum nitride is shown in Figure 2(c & d) with AlN particulates entrapped at the edges of silicon randomly. The presence of reinforced particles in the composite refined the primary silicon crystals while its morphology is relatively unaffected.]. The growth of  $\alpha$ -Al appears to push aluminum nitride particles to the surface of Si grains (Figure 2(c & d).

The hardness values of Al-S master alloy, Al/AlN composites are shown in Table 2. A significant increase in hardness of the alloy matrix can be seen with addition of AlN reinforced powder. A hardness reading showed a higher value of hardness indicating that the existence particulates in the matrix has improved the overall hardness of the composites. This is true due to aluminum is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites. The presence of stiffer and harder AlN reinforcement leads to the increase in constraint to plastic deformation of the matrix during the hardness test (Charles and Arunachalam, 2003). Thus increase of hardness of composites could be attributed to the relatively high hardness of AlN itself.

Table 2: Hardness values of Al matrix and Al/AlN composites with 2-10% wt AlN at room temperature

Material	Hardness Value (HV)
Pure Al alloy	44 ± 7
Al-2% AlN	59 ± 3
Al-5% AlN	67 ± 5
Al-10% AlN	94 ± 5

## CONCLUSIONS

A stir casting process which was set at 750°C was successfully utilized for casting Al-Si matrix composites reinforced with AlN particles. The distribution of aluminium nitride particles surrounding Si phase has improved the hardness of the composites. Lack of porosity exhibited in the microstructure of Al-Si matrix composite indicates there is a rather good particulate-matrix interface bonding.

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