International Journal For Technological Research In Engineering (IJTRE)
Volume 2, Issue 7, March-2015
ISSN: 2347-4718

Aluminium 6061 Metal Matrix Composite with Dual Reinforcement

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Abstract – **The necessity of superior feature materials for automobile and aeronautical applications lead to the manufacture of best structural composite materials. From the diverse materials, Aluminum based composites achieve enhanced results. The Aluminium 6061 (Al 6061) metal matrix composites reinforced with Multiwall Carbon Nanotube (MWCNT) and Silicon Carbide (SiC) particulates are one of new assortment of materials. Mostly the hard material is mixed with reinforcement to improve the mechanical propertie s. Those composites are very well suitable to automobile components such as engines, brake disc etc. Al 6061 metal matrix composite with MWCNT and SiC reinforcement has been fabricated by SPEX ball milling [high energy mechanical ball milling] and hot-pressing processes. It was observed that the MWCNT was better dispersed in the Al 6061 particles through SiC as mixing agent and also the high energy ball milling process leads to uniform dispersion of the high aspect ratio MWCNT and the SiC. The fabricated specimens were characterized using SEM and which validates the presence of SiC and MWCNT and its uniform dispersion. The Vicker's micro hardness of the metal matrix composite was increased considerably as compared with the hardness of Al 6061. This dually reinforced Al metal matrix composites by powder metallurgical approach could also be applied to complex matrix materials.**

Keywords: Aluminium 6061, Multiwall Carbon nanotubes (MWCNT), Silicon carbide(SiC), Metal Matrix composites (MMCs), Ball milling.

1. INTRODUCTION

Many industries are investing in the development of engineering materials with better performance because of customer demands such as high mechanical performances, lightness and better durability among other improvements [3]. Carbon nanotubes are of considerable interest for next generation industrial materials because of their unique properties, especially their hundred times greater strength and approximately five times lower density compared with conventional materials which makes them potentially useful for reinforcing composite materials [2, 7, 8, 11-13]. This unique nano-order material can not only be utilized on its own, in precision industrial fields but can also provide high performance functionality in conjunction with conventional materials. Moreover, MWCNTs are polymers of pure carbon and can be reacted and manipulated using the rich chemistry of carbon. This provides opportunity to modify the structure and to optimize the solubility and dispersion, allowing innovative applications in materials, electronics, chemical processing and energy management, to name just a few. In summary, three properties of MWCNTs are specifically interesting for the industry viz: the electrical conductivity (as conductive as copper), their mechanical strength (up to 15 to 20 times stronger than steel and 5 times lighter) and their thermal conductivity (same as that of diamond and more than five times that of copper). Carbon nanotubes have a Young's modulus of approximately 1TPa, maximum tensile strength of nearly 30GPa and the density of MWCNT is 2.6 g/cm3. A combination of these impressive properties enables a whole new variety of useful and beneficial applications. For this reason, many researchers are investigating the fabrication of CNT reinforced metal, ceramic, and polymer matrix composite materials. [4]. However, the fabrication of CNT reinforced metal matrix composites appears difficult compared to other matrix materials because of the difficulty of homogeneously dispersing the MWCNTs into the metal matrix while controlling the interfacial integrity [5]. Hybrid nanocomposites based on Al 6061 reinforced with different hybrid ratios of SiC (0.5, 1.0 and 1.5 vol. %) and B_4C (fixed 0.5 vol. %) nano particles were successfully fabricated using ultrasonic cavitations based solidification process. Silicon carbide (SiC) is a ceramic material with high strength and high hardness. However, it displays brittle behavior and has low resistance to fracture. Several methods to increase the fracture toughness of bulk SiC include modifying the SiC grain size and shape and by incorporating additional phases. Reinforcement of SiC typically is employed to increase the fracture toughness of SiC. Lu et.al [10] reported that MWCNT/SiC composites were fabricated by aqueous tape casting. The relative density of the composite was about 98% after hot-pressing at 1850°C (at 25 MPa in Ar for 30 min). The hardness of the composites decreased with the increase in MWCNTs content. The flexural strength and the fracture toughness were 742.17MPa and 4.63MPa respectively when the MWCNT content was 0.25 wt%. Further increase in MWCNT content to 0.50 wt% did not lead to the increase in mechanical properties. Most of MWCNTs were found to be located at SiC grain boundaries and pull out of the MWCNTs was observed. The fabricated cast specimens were characterized using SEM study with EDS analysis, hardness test, tension test and impact test [6]. Mica and SiC ceramic particles were incorporated into Al 356 alloy by stir-casting route. The results indicate that the better strength and hardness are achieved with Al/10SiC−3mica composites. The increase in mass fraction of mica improves the wear loss of the composites [9]. In this study, pure aluminum (Al) was reinforced with different kinds of particles aiming at tailoring the hardness response of the composite. Silicon carbide particles (SiC) were added as an active solid mixing agent for good homogeneous dispersion of CNTs in the Al powder. SiC is still widely used in the industry because of its excellent temperature tolerance, corrosion resistance, thermal shock resistance, electric conductivity and superior chemical inertness [1]. Micro scale SiC particles as well as nano scale carbon nanotubes were mixed in SPEX ball milling process with the Al powders to achieve a homogeneous dispersion. The produced blends will then be compacted together in the form of composite materials.

2. EXPERIMENTAL PROCEDURE

MWCNTs (Redex Technologies, purity 97%, diameter: OD -20 nm, ID-5nm, length: 50 µm) and Al6061 powder (purity 99%, mean particle size 200µm) and SiC (300µm) were used as the starting materials. The properties of MWCNT and the compositions of Al6061 are shown in table 1 and 2 respectively.

Table1. Properties of MWCNT

Aspect Ratio	~1000
Specific Surface Area	SSA 350 m^2/g
Purity – wt%	>97%
Average Outer Diameter	20 nm
Average Inner Diameter	5nm
Number of walls	5-15
Length	50 Micrometer

Table2. Properties of Aluminium

Elements	Si	Mn	Cr	Mg	Sn	Fe	Ti	Cu
% Composition	0.477	0.048	0.191	0.864	0.063	0.436	0.008	0.307

The Al6061 powder and the reinforcing materials (1, 3 and 6 volume percentage MWCNT and SiC) were mixed in a SPEX ball milling machine for two hours under argon atmosphere at 360 rpm, using Ø10 mm balls, a 10:1 ball to powder weight ratio, and 2 weight percentage of strearic acid as a process control agent (PCA). At the end of the process, the tight bowl containing the powder blend was transferred to a glove-box with a controlled inert atmosphere. After passivation in the glove-box, the powder was introduced into a high temperature steel mold of 50mm diameter and 10mm thickness with compositions ranging from Al6061 to 1 vol % MWCNT and SiC, 3 vol % MWCNT and SiC, and 6 vol % MWCNT and SiC respectively. The mold was then heated under air at 85% melting temperature of the matrix material for 1.5 hours and transferred rapidly (less than 5 seconds) to the hydraulic press. A pressure of 320MPa was then applied for 4 seconds to get the resulting samples with a 50 mm diameter and a thickness of 10 mm. The Vicker’s micro hardness of the ball milled and hot pressed composites were measured with the loads 0.02kgf and three measurements per sample. The microstructure of MMCs was observed using high resolution Scanning Electron microscopy (Zeiss).

3. RESULTS AND DISCUSSION

The figure 1 and figure 2 shows the TEM and the SEM micrograph of as received MWCNT. The raw MWCNT has an extremely curved and twisted morphology with a high aspect ratio of 1000. The Al6061 and SiC particles have an irregular, roughly spherical shape. The SEM of ball milled Al6061 and the agglomeration of it is shown in figure3. In figure 4 the SEM of 1volume % MWCNTand SiC with Al6061 is shown with a bunch of MWCNT's in the middle and is mixed with Al6061 by means of SiC.

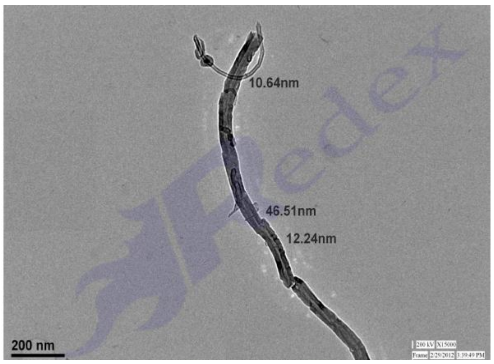

Figure 1: TEM image of MWCNT

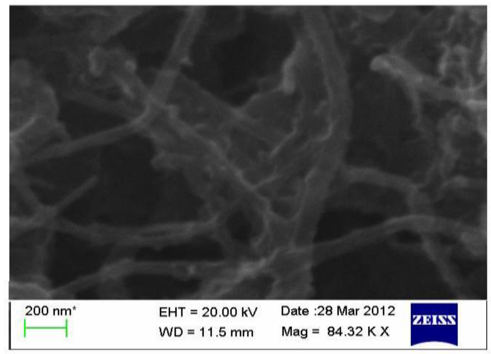

Figure 2: SEM image of MWCNT

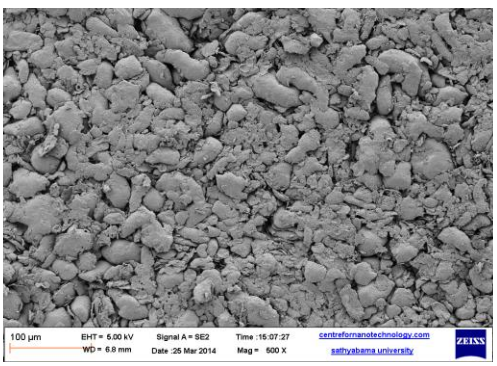

Figure 3: Ball milled Al6061

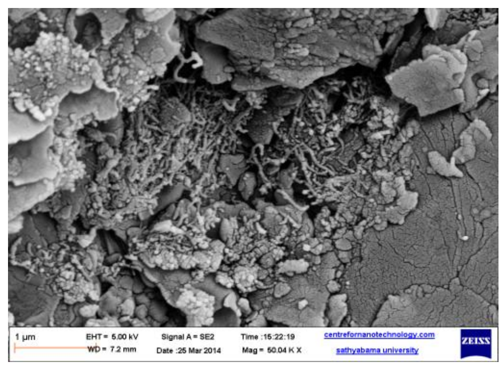

Figure 4: Al6061 +1vol % MWCNT- 1vol%SiC

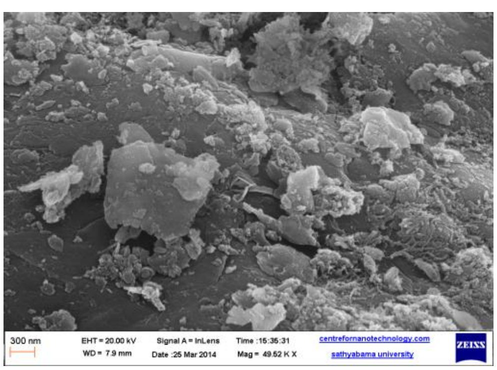

Figure 5: Al6061 + 3vol % MWCNT- 3vol%SiC

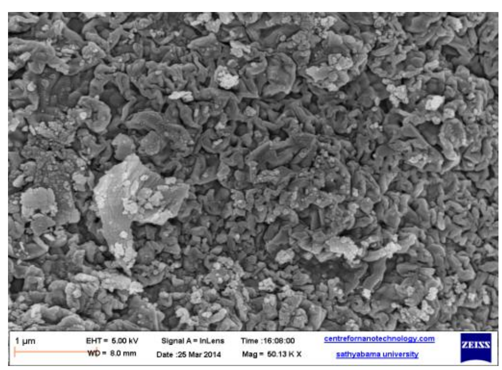

Figure 6:Al6061 + 6vol % MWCNT- 6vol%SiC

Figure 5 shows SEM image of Al6061 with 3vol % MWCNT and SiC which also clearly interprets the dispersion of MWCNT with Al6061 by SiC and figure 6 displays the SEM image of 6 vol % MWCNT and SiC with Al6061as small curved agglomerates of the composite. It indicates the uniform distribution of nanoparticle (MWCNT) in the aluminum matrix. The mean Al6061 particle size decreased after ball milling process, although some larger particles are still observed. According to high magnification observations these larger particles are agglomerates made of fine particles[7]. Several MWCMT's are still observed in the composite powders by SEM as shown in figure 3 to figure 6. The Multi wall carbon nanotubes appear either as short fibers, curved tubes or dots when the tubes are embedded in the ductile aluminium matrix. It is however noteworthy that the CNT's were cut during the ball milling process as its initial length is more than a few tens of micrometers. The different crystalline phases present in the 6vol % MWCNT and SiC composite powder in addition to Al6061 matrix material. The ball milled and hot pressed pellets of the composites were subjected to Vicker's micro hardness test to compare the hardness of Al6061 as sample1 with the composite as sample2. The load of 0.2kgf is applied over a dwell period of fifteen seconds. Three different indentations are made at different sites on each of the sample and the average is taken as a final result and are shown in figure 7a and 7b and it can be interpreted that the Vickers hardness value(HV) of the composite(21.1HV) is considerably increased as compared with the pure Al6061 (15.97 HV).

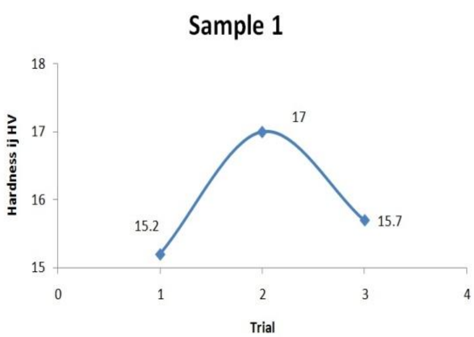

Figure 7a. Vicker's hardness of Al6061

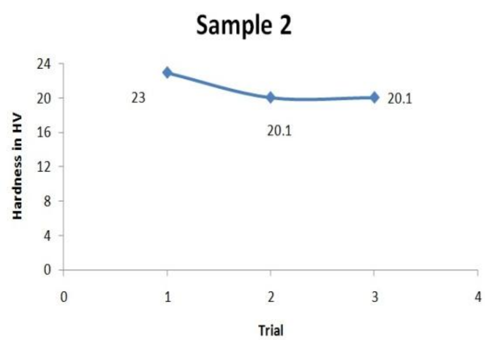

Fig. 7b HV of composite (1vol % MWCNT- 1vol%SiC)

4. CONCLUSIONS

High energy ball milling and hot pressing is a promising route to fabricate MWCNT and SiC reinforced Al6061 metal matrix composite materials. The addition of SiC particles allowed a better dispersion of the MWCNT's into the Al6061 matrix, as established by the micro and nano structural analysis. Also the micro hardness values of the composites are increased than that of the Al6061 matrix material. The dual reinforcement dispersal method may be applied to the systems other than the aluminium matrix composites, thus offering a new potential for nano-structured composite materials. This work is a preliminary study; detailed study is required to evaluate the contribution of SiC and MWCNT particles on the mechanical properties of the hybrid composites.

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