Functionally Graded Dual-Nanoparticulate-Reinforced Aluminum Matrix Composite Materials

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Abstract. Functionally graded carbon nanotubes (CNT) and nano Silicon carbide (nSiC) reinforced aluminum (Al) matrix composite materials were fully densified by a simple ball milling and hot-pressing processes. The nSiC was used as a physical mixing agent to increase dispersity of the CNT in the Al particles. It was observed that the CNT was better dispersed in the Al particles with a nSiC mixing agent compared to without it used. SEM micrograph showed that the interface of the each layers had very tightly adhesion without any serious pores and micro-cracks. This functionally graded dual-nanoparticulate-reinforced Al matrix composite by powder metallurgical approach could also be applied to comples matrix materials.

Keywords; Carbon nanotubes (CNT), Nano silicon carbide (nSiC), Metal matrix composites (MMCs), Ball milling, Hot-pressing

1. Introduction

Functionally graded materials (FGMs) are compositionally gradient materials which were first proposed in Japan in 1984 [1]. “They have been suggested as a way of fabricating bulk materials with tailored properties because they can achieve the controlled distribution of the desired characteristics within the same bulk material. This FGM can be applied for engineering parts instead of coated materials. However, careful selection of the component materials, particularly the reinforcement, is required to reliably achieve a high performance from the FGM.” To evaluate the potential of aluminum light weight composite materials with tailored functionally graded mechanical performances is produced.”[1]. “Carbon nanotubes (CNT) are attractive next generation materials due to their unique properties, which lead to high mechanical, electrical, and thermal performance [2-4]. 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. For this reason, many researchers are investigating the fabrication of CNT reinforced metal, ceramic, and polymer matrix composite materials.”[5]. However, “The fabrication of CNT-reinforced metal matrix composites appears difficult compared to other matrix materials because of the difficulty of homogeneously dispersing the CNTs into the metal matrix while controlling the interfacial integrity" [6]. It is very important that the achievement of a sufficiently good dispersion, which is a prerequisite to obtaining any benefit from the unique.

In this study, aluminum alloy (Al) will be reinforced with different kinds of particles aiming at tailoring the hardness response of the composite. "Silicon carbide nanoparticles (nSiC) 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"[6]. Microscale and nanoscale SiC particles as well as carbon nanotubes will be mixed in a high energy mill process with the Al powders to achieve a homogeneous dispersion. The produced blends will then be compacted together in form of multilayer composite materials.

2. Experimental procedure

Multiwalled CNTs (Baytubes C150P, Bayer material science, purity 99.5%, diameter: 20 nm, length: 30 μm) and gas-atomized Al5Mg powder (ECKA Granules, purity 99.5%, mean particle size: 63 μm) were used as the starting materials. The nSiC particles were produced in an inductively coupled plasma (ICP) reactor (the process is described in detail elsewhere [7]), producing an average particle size between 20 and 30 nm. The Al powder and the nanoparticulate materials (5 and 10vol% CNT and/or 1 and 10vol% nSiC) were mixed in a planetary ball mill (Retsch GmbH, PM400) for 20 h under argon atmosphere at 360 rpm, using Ø10 mm balls, a 10:1 ball to powder weight ratio, and 20 wt.% of heptane as a process control agent (PCA). The Al-nSiC-CNT composite powders were assembled in a layered structure inside a 55x55x5 mm die, with compositions ranging from Al5Mg to 1vol%nSiC-5vol%CNT, 10vol%nSiC-10vol%CNT, and 10vol%nSiC, respectively followed by hot-pressing (Walter+bai ag Testing machines, 400kN) consolidating at 500 ^{o}C for 10 sec under an uniaxial pressure of 570 MPa. The density of the FGMs were measured according to the Archimedes principle and the micro Vickers hardness (Paar MTH4 microhardness-tester) of the ball milled powders and gradient layers were measured using the loads 0.02 kgf and 20 kgf for at least five measurements per sample. The interlayer microstructure of FGM was observed using optical microscopy (Zeiss Axioplan light microscope), high resolution cold field emission scanning electron microscopy (SEM) (Hitachi, HRCFE-SEM S-4800).

3. Results and Discussion

A cross-section of the plate confirms the high density of the composite, some pores are present in the layer with the highest nSiC and CNT content. Furthermore, the cross-section shows a good cohesion between the layers without cracks either in the layers or at the interfaces (Fig. 1).

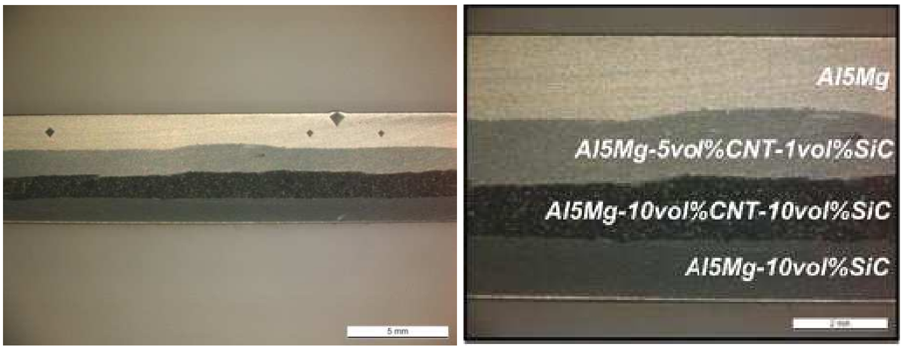

Fig. 1. Cross section of the multilayer plate showing the different layers and their interfaces.

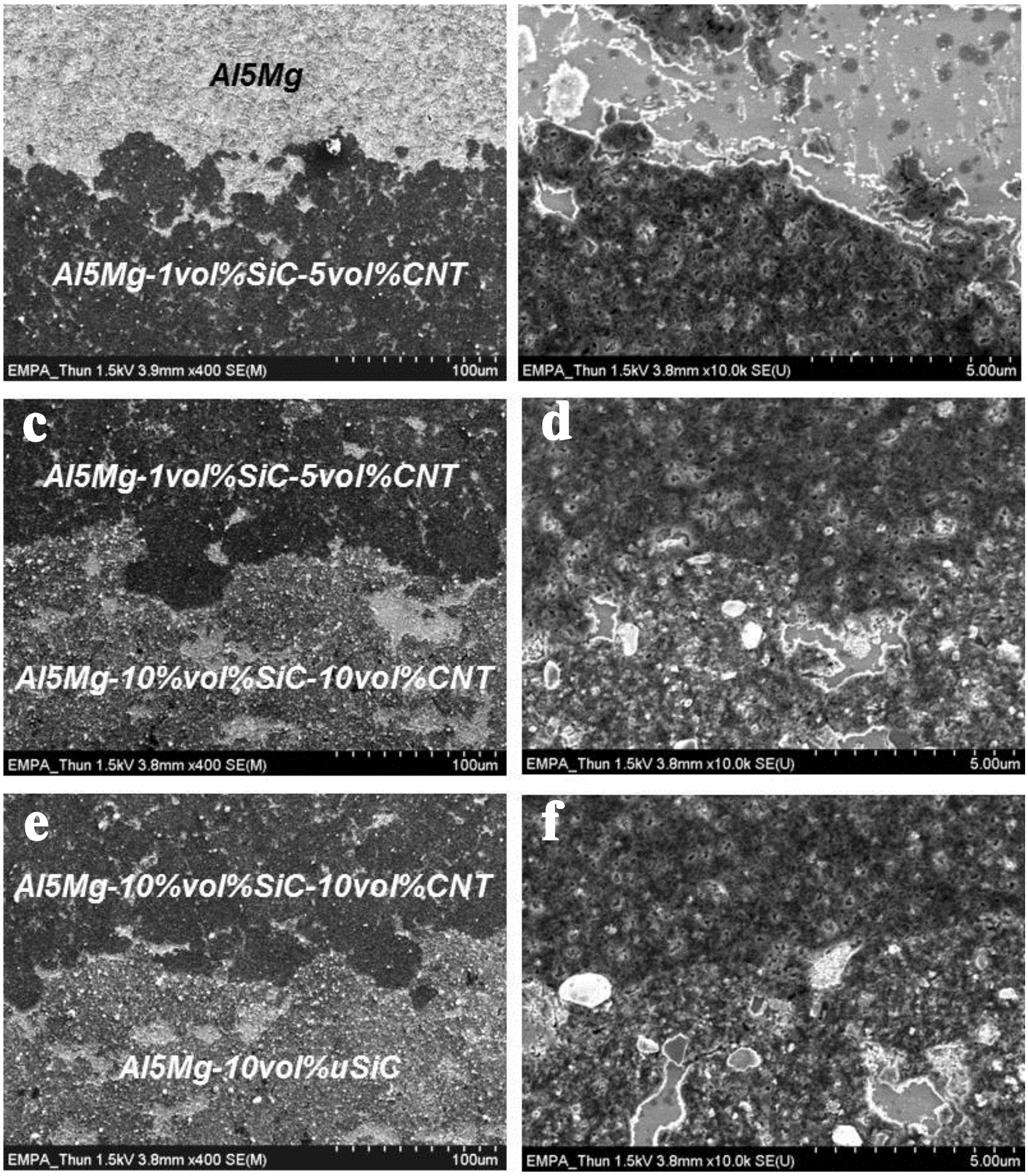

Fig. 2. SEM micrographs of the interfaces between the layers in the composite plate.

Some hardness prints are visible in the different layers in Fig. 1(a). Indeed, hardness measurements were performed in each layer. The results are shown in the table 1 below. Fig. 2 shows SEM micrographs of the interfaces between the functionally graded layers in the composite plate. The interface between Al5Mg and Al5Mg-1vol%nSiC-5vol%CNT(Fig.2a and b), Al5Mg-1vol%nSiC-5vol%CNT and Al5Mg-10vol%nSiC-10vol%CNT (Fig.2c and d), and Al5Mg-10vol%nSiC-10vol%CNT and Al5Mg-10vol%μ-SiC (Fig.2e and f). The multi composition layers were well bonded regardless of the amount of nanoparticles ratio.

Table 1. Hardness measurement of the layers in the final composite material

Samples	HV_{20}	±	$HV_{0.3}$	±
Al5Mg + 10 vol.% μ-SiC (F1200)	121	10	123	3
Al5Mg + 10 vol.% nSiC + 10 vol.% CNT	281	20	269	4
Al5Mg + 1 vol.% nSiC + 5 vol.% CNT	291	10	308	1
Al5Mg	58	1	64	0

4. Conclusions

High energy milling is a possible route to effectively disperse nanoparticulate materials into a metal matrix using a solid mixing. Thus the hardness of an Al5Mg alloy could be increased by a factor of 5-6. Hot pressing of powder blends allows the fabrication of multilayer composite materials. However due to high dilatation stresses during cooling, delamination occurred in the hardest layer. This had then to be “diluted” with pure alloy. One potential improvement of the concept would be to increase the thickness of each layer. This concept if validated is not only interesting for light weight bulletproof vests but can be extended to other metal matrices and to other armor applications like for instance combat aircrafts, tank and battle ship etc.

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