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FABRICATION OF HIGH STRENGTH AL-BASE ALLOY COMPOSITES REINFORCED WITH SIC NANOPARTICLES COATED WITH Al AND Cu

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Abstract

Composites find an important place as new advanced materials in last decades; those especially produced with nanoparticles reinforcements, attracts researchers and a number of researches were executed on this topic. In this study, Al-base 2024 alloy composites reinforced with SiC nanoparticles were fabricated and the effects of two different coating materials were investigated. Coatings were pure Al and Cu powder with constant grain particle size. The results show that the Al coating has impacts on grain size and the interface layer between reinforcement and matrix. The mechanism of formation of interface layer between SiC nanoparticles and the Al-base 2024 matrix with reinforced with Cu coated SiC particles is quite different.
Keywords: Stir casting, Aluminum Nanocomposite, SiC, Coating.

Introduction

Extensive researches have been recently focused on Al and Mg based metal matrix composites (MMC) and their production methods, and, in particular, their exclusive microstructural and mechanical properties. Between all classes of MMCs, Al and Mg based nanocomposites have attracted the focus of researches because of their significant specific strength and stiffness, ductility, wear resistance, better thermal and mechanical fatigue and creep resistance as compared with common Al and Mg based composites[1-4].

Application of stir casting method for the fabrication of metal matrix composites can lead to production complex-shaped components. In order to achieve a good distribution of reinforcement particles in a cast metal matrix composite [2], stirring action must be efficient enough to disperse the particles in a homogenous way. In this method, the matrix material is melted under an inert gas atmosphere, then nanoparticles,

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which have already been coated, are added to the melt and the stirring stage will start [1-2].

Stir casting is the most cost-effective method among the existing processes owing to its easier control, cheaper equipment and shorter period of processing. Also, using master powder instead of pure powder as reinforcement will help to overcome the difficulties which may originate from raw feeding of reinforcements. In order to improve the wettability of particles, coatings were applied to nanoparticles due to the fact that particles have a large surface to volume ratio which easily leads to agglomeration and clustering [1-8].

Although the potential use of this modified stir casting method has been well established for Al and Mg base nanocomposite, there is not sufficient study on Al base nanocomposites with reinforcement of nano-sized SiC particles, especially Al 2024 alloy as the matrix [4-15].

In this study, the effects of coating on particles were investigated, while the main parameters of stirring such as stirring speed and temperature were considered as crucial parameters for producing the composite. Solidification process of the samples was the main goal of this study; therefore, mechanical properties of cast nanocomposite have not been examined. The present study aims at fabrication of Al 2024/SiC nanocomposite with Al and Cu pure coating using stir casting method, and the effects of coating on microstructure.

Materials and Methods

The starting material used in this study is a commercial Al alloy designated as 2024. The composition of this alloy is given in Table .1.

Two different master powders were produced by mechanical milling of pure Al (type A) and pure Cu (type B) powders with a mean size of 60µm, and each containing 1wt.% SiC nano-powder (50 nm) as a reinforcement. Mechanical milling was performed for 1 h at the rotational speed of 900 RPM with steel balls with 10 mm diameter.

Melting and subsequent casting were performed with no preheat treatment to avoid surface oxidation. Each charge consisted of 450 g commercial Al-2024 alloy in which 18 g of master powders were added. These master powders were separately added to the melt, and in two separate molds for each composite. The temperature of the melt was 750ºC and afthe stirring process began at 512 RPM for 6 minutes. In the next step, melt was poured to a cylindrical steel mold. It should be noted that each casting process was held under inert atmosphere.

Schematic diagram of the device used for stir casting process in shown in Fig. 1.

All samples were cut, grinded and then polished with 0.3µm sized Al_2O_3 powder. Samples were etched by HF solution (1wt %) to identify grain features. To have a better insight of microstructure, scanning electron microscopy (SEM, VEGA TESCAN) has been used.

Table 1. Chemical composition of the commercial 2024 alloy.

Elements	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
wt%	Bal.	0.50	0.50	4.9	0.9	1.8	0.10	0.25	0.15

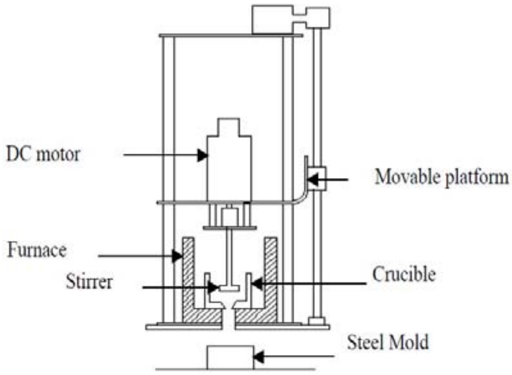

Fig. 1 Schematic drawing of the utilized rheocaster device.

Results and Discussion

Generally, pure Al and pure Cu served as coatings on SiC nano-particles in master powders. In this way coatings enable better distribution of SiC nano-paticles into the Al matrix due to a better wettability and decreased interfacial tension between the matrix and the reinforcement.

Fig. 2 shows the SEM microstructure of Al-2024 alloy with added Al and Cu master powders. The average size of grain in these samples for type A is about 50 µm and for type B is about 100 µm.

Addition of master powder to the melt leads the melt to behave as a viscous solution. Stirring temperature, in this study, was selected at 750ºC for several reasons. In one hand for homogenous distribution of nano SiC reinforcement, shear stress and also stirring has to provide turbulence current in melt. In this situation, the behavior of the slurry is similar to mixing of two different fluids with different viscosities and different fluid behaviors. Interfacial tensions do not happen in the melt due to the similarity in composition of master powder and matrix compositions.

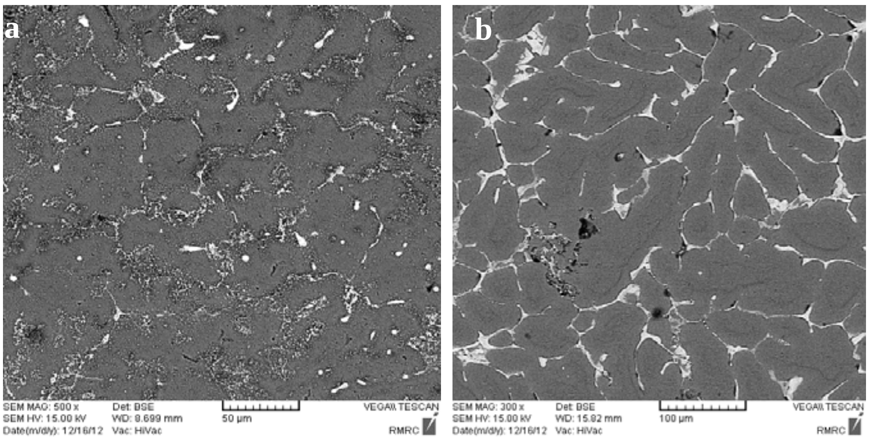

Fig. 2. Microstructure of stir cast nanocomposites: a) Type A with grain size of 50 µm b) type B with grain size of 100 µm

When facing with mixing of two liquids which have no tendency of miscibility, many affecting parameters such as rheological properties of the master drops and the liquid matrix can play important roles in the stir casting process. The extent of turbulency and the way fluid behave while mixing, i.e. Newtonian or non- Newtonian can be taken into an account as significant agents. When a turbulent flow pattern takes place in slurry with small ratio of second phase droplet, a more efficient and effective mixing occurs. This is because of the better distribution of second phase throughout slurry. The flow type in slurry in a mechanically stirred vessel was determined by Reynolds' Number which is calculated by:

$$Re = \rho D^{2} N / \eta \quad (1)$$

Where ρ is density, D is impeller diameter, N is impeller speed and η is dynamic viscosity if mixture. In this case ρ and D are constant and the viscosity depends on N and η parameters. In addition, slurry's viscosity is a function of melt and master drops temperature [2].

Moreover, it is also known that viscosity experiences a drop by increasing the temperature. Hence, in a constant stirring speed, the flow type changes to turbulent, by increasing the stirring temperature. So the augmentation in stirring speed will help the homogenous distribution of SiC nanoparticles [1-4].

Fig.3 (a and b) shows that the nano SiC particles are dispersed homogeneously in the matrix of composite Type A. Interestingly, nanoparticles are not agglomerated which was the result of coating on SiC particles. In fact, good castability of reinforcement depends on optimum casting temperature and sufficient wettability due to the lower melting point of Al-coating on SiC nanoparticles causing a non-agglomerated distribution of these particles in the composite matrix.

As a comparison, the microstructure of nanocomposite type B is shown in Fig.3(c and d). The nanoparticles are highly agglomerated due to higher melting temperature of copper coating master powder which resulted in increasing the viscosity of slurry.

Preheating process was not applied on master powders (either type A and B) because this process may cause oxidation of powders and the oxide layer may reduce the wettability of powder in melt during the stirring.

The addition of master powders provokes under-cooling of the melt to about 600ºC, inducing highly increased nucleation in the melt. Stirring can reduce the ultimate effects of nucleation. During this time span, some dendrites under effect of stirring experience deformations and become spherical as can be seen in Fig. 2. In addition, this high nucleation rate makes grains finer and equiaxed [2].

Upon further stirring, melt surrounds coated nanoparticles and in next step, coating dissolves in the slurry. This phenomenon has positive effects on fabrication of nanocomposite (type A): firstly, it allows particles to move freely in the melt and secondary, it improves the coherency and bonding between matrix and reinforcements by producing Al-rich zones around particles.

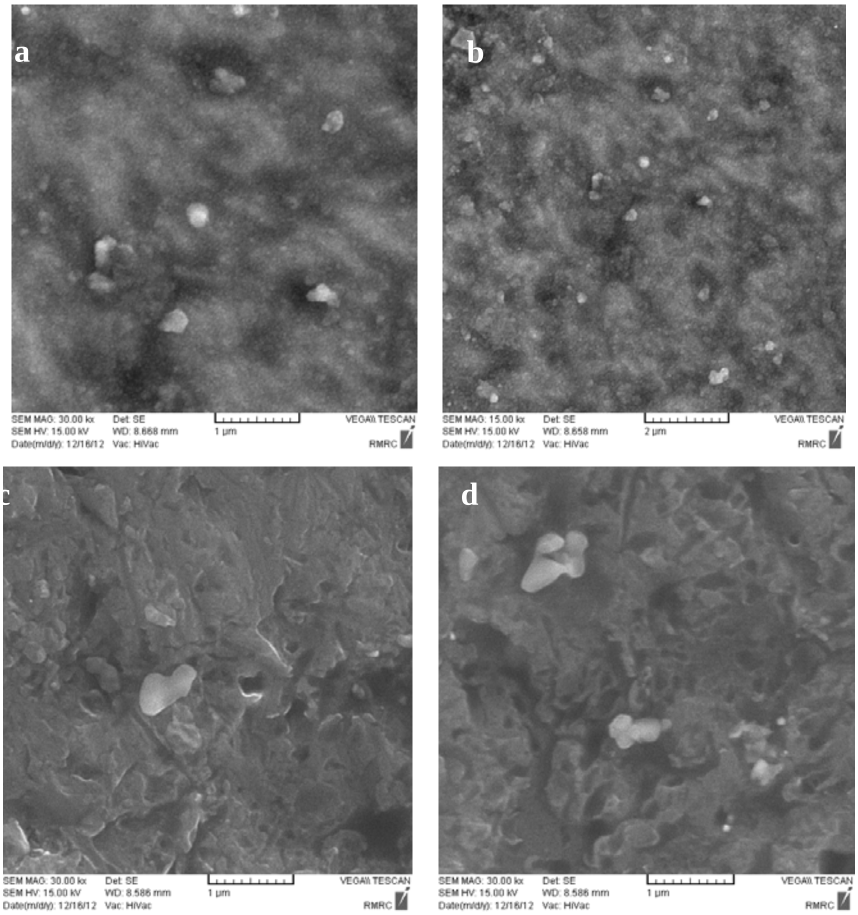

Fig. 3. Distribution of nanoparticles in bulk of samples. a and b: Type A, c and d: Type B

It seems that another mechanism controls the distribution of Cu coated nanoparticles (type B). In this master powder, when the matrix (Al-2024) surrounds particle, it cannot fuse the Cu layer around particles, so only diffusion bonds are produced in interface between the molten matrix and particles. The Cu-rich alloy which is produced in the interface has higher melting point than that containing Al (type A), hence, it takes more stirring time to create strong bonds between the particle and the matrix. Also, Cu-rich alloys can cause agglomeration and porosities due to their low speed of movement in the matrix during the stirring process.

Conclusion

The feasibility of distribution of SiC nanoparticles in Al-2024 matrix alloy with two different coatings was studied. Optimum conditions of stir casting and casting temperature were considered regarding to past studies. Micrographs showed that Al coated particles due to their lower melting point which causes higher wettability and have better dispersion in the matrix and also this dispersion induces particles to act as grain refiner of the melt. Hence, grains become finer. In addition**,** high nucleation rate in melt which is result of great temperature difference between master powder and melt lead results in spherical and rosette-shaped grains**,** so this phenomena can reduce the viscosity of melt during casting process.

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