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The Influence of Mechanical Vibration Moulding Process on Thermal Conductivity and Diffusivity of Al-TiC Particulate Reinforced Composites

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Abstract. Titanium carbide particulate reinforced composites were fabricated by vibrational moulding sand casting technique. Titanium carbide particulate added as a reinforcement phase in the LM6 alloy matrix and the percentage of addition varied from 0.2, 0.6, 1 and 2% on weight fraction basis. The thermal conductivity and diffusivity of TiC composites were determined. Increasing frequency of vibration and TiC content helps to improve density, thermal conductivity, thermal diffusivity and purification of the grain boundaries. The dispersed particles increased the thermal conductivity and diffusivity according to an effective media theory.

Introduction

Aluminium is the most commonly used matrix for metal matrix composites (MMCs). The aluminium alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high vibration damping capacity [1] The resulting materials are strong and light weight, elastic modulus, strength, structural rigidity, dimensional stability, control of physical properties such as density, and have excellent high temperature properties, good corrosion resistance, good thermal shock, electrical, and wear characteristics [2-4]. Their ease of forming makes them useful for wide spread applications. Some of the properties are high longitudinal and transverse strengths at normal and elevated temperatures, near-zero coefficients of thermal expansion, good electrical and thermal conductivities, and excellent antifriction, anti abrasion, damping, mechanical performance and machinability properties [5, 6]. However, a review of the literature reveals that the application of mechanical, sonic and ultrasonic vibration has a number of notable effects such as grain refinement, increased density, degassing, shrinkage, and the shape, size and distribution of the second phase. Vibration energy has been used in many processes within the metallurgical and engineering fields [7]. According to the review by [8], the application of vibration during solidification was first studied in 1800s. In this research work, MMC consisting of aluminum reinforced Titanium Carbide (TiC) particles were produced by sand casting without and with using mechanical vibration mould during solidification process. The thermal conductivity of aluminum reinforced Titanium Carbide particles is discussed as influenced of vibration mould.

Experimental

Fabrication of composites. The mechanical vibration of the mould was applied to the aluminium alloy matrix composite at a frequency 10.2 Hz and 0.120mm amplitude. The experimental set-up used is shown in Figure 1. The material, which is used in this research work, is aluminium-

11.8%silicon alloy. The titanium carbide particulate is used as a second phase reinforcement in the alloy matrix added on it by different weights fraction such as 0.2, 0.6, 1 and 2%. The size of the Titanium carbide particulate is 325 mesh and the average particle size is equal to 44 microns (µm). In this research work, liquid stirring vortex metallurgical technique is employed for mixing the liquid LM6 alloy with the selected, combined and preheated particulates in a crucible. The particulates are preheated to 200 degree centigrade in a heat treatment muffle furnace for 2 hours and it is transferred immediately in the crucible containing liquid LM6 alloy for mixing by an impeller blade of the vortex stirring machine. Next, the composite liquid material was poured into the mould, which was attached on the system that provides the mechanical vibration with 10.2 Hz and 0.120mm amplitude (Figure 1c). Then, the casting is ejected from the mould after it solidified and gating system will cut off to get the specimens. In the final stage, the specimens will be prepared with accurate dimensions according to the standards.

a. LM6 ingots b. Casting process c. Pouring Process

Figure 1. Processing of the composite specimen

Thermal diffusivity measurement. Thermal diffusivity of composite materials is measured using photo flash method. The laser flash method illustrated in Figure 2 is one of the most popular. The photoflash detection system consists of a light source, sample holder, thermocouple, low noise pre amplifier, oscilloscope, photodiode and a personal computer. The temperature rise at the back surface of the sample is detected by the thermocouple. The detected signal is amplified by a low-noise preamplifier and the processed by a digital oscilloscope [9, 10].

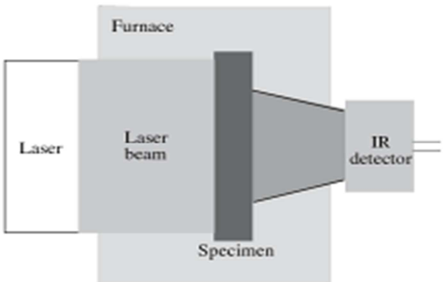


Figure 2. Schematic sketch of the laser flash method used for measuring thermal conductivity

The voltage supplied to the camera flash is always maintained below 6 Volt before switching on the main power supply. The sample is machined as a flat surface to obtain better quality result and it is attached directly to the thermocouple. The camera flash is located at 2 cm in front of the sample holder. It is checked that the set-up has already tested the standard material such as aluminium before starting any experiment. Measurement is carried out at every 10 minutes to allow the sample to thermally equilibrate at room temperature. Analyze the data before running the next measurement.

Photoflash detection system is not an expensive method and the standard thermal diffusivity value for aluminium is equal to 0.83 cm^2/sec for thickness greater than 0.366 cm [11]. In the photo flash system, the excitation source consists of a high intensity camera flash. This method is well suitable for aluminium, aluminium alloys and aluminium-silicon particulate metal matrix composites [12]. The thermal diffusivity values can be obtained for different thicknesses of the test samples. The thermal diffusivity, α determines the speed of propagation of heat waves by conduction during changes of temperature with time. It can be related to α, the thermal conductivity through the following equation [13, 14].

$$K = \alpha.\rho.\mathrm{Cp} \quad \ldots\ldots \quad (1)$$

Where density ρ and specific head Cp.

The photo flash technique is originally described by Parker and it is one of the most common ways to measure the thermal diffusivity of the solid samples. The computer is programmed to calculate the thermal diffusivity, α, using the equation:

$$\alpha = \frac{\left(1.37\, x\, L^2\right)}{[(3.14)^2\, x\, t_{0.5}]} \quad \ldots\ldots \quad (2)$$

Where L = thickness in mm and $t_{0.5}$ = half rise time in seconds.

Density measurement. A&D-GR 200 – Analytical Balance was used to conduct the density measurement (Figure 3). The theoretical density of each set of composites was calculated using the rule of mixtures [15]. Each pellet was weighed in air (Wa), then suspended in Xylene and weighed again (W). The density of the pellet was calculated according to the formula:

$$\rho = \frac{Wa}{(Wa - Ww)}\, x\, density\, of\ Xylene \quad \ldots\ldots \quad (3)$$

Result and Discussion

The values of density in composites increase with increasing weight fraction of the particles and with using vibration mould during solidification, because density of particles is higher than the Aluminium -11.8% Si Alloy (the density of LM6 is 2.65grs/c^3 and of TiC is 4.93grs/c^3) and hence the increase in wt.% of TiC will increase the density of the composite based on the role of mixtures [16, 17]. Mechanical vibration makes solidification microstructure of aluminium matrix composite fine and homogeneous and decrease the amount of defect such as shrinkage cavity and inclusions. The effect of vibration to help in the promotion of nucleation and thus reducing as-cat grain size, reducing hydrogen, reducing shrinkage porosities due to improved metal feeding, and producing a more homogenous composites structure [18-20].

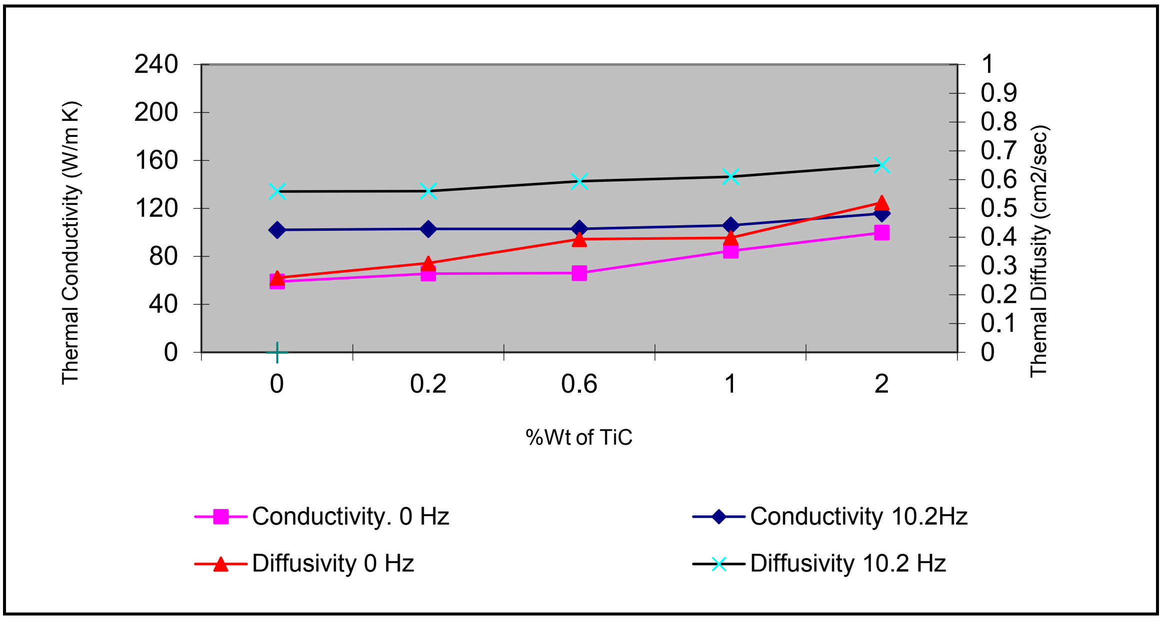
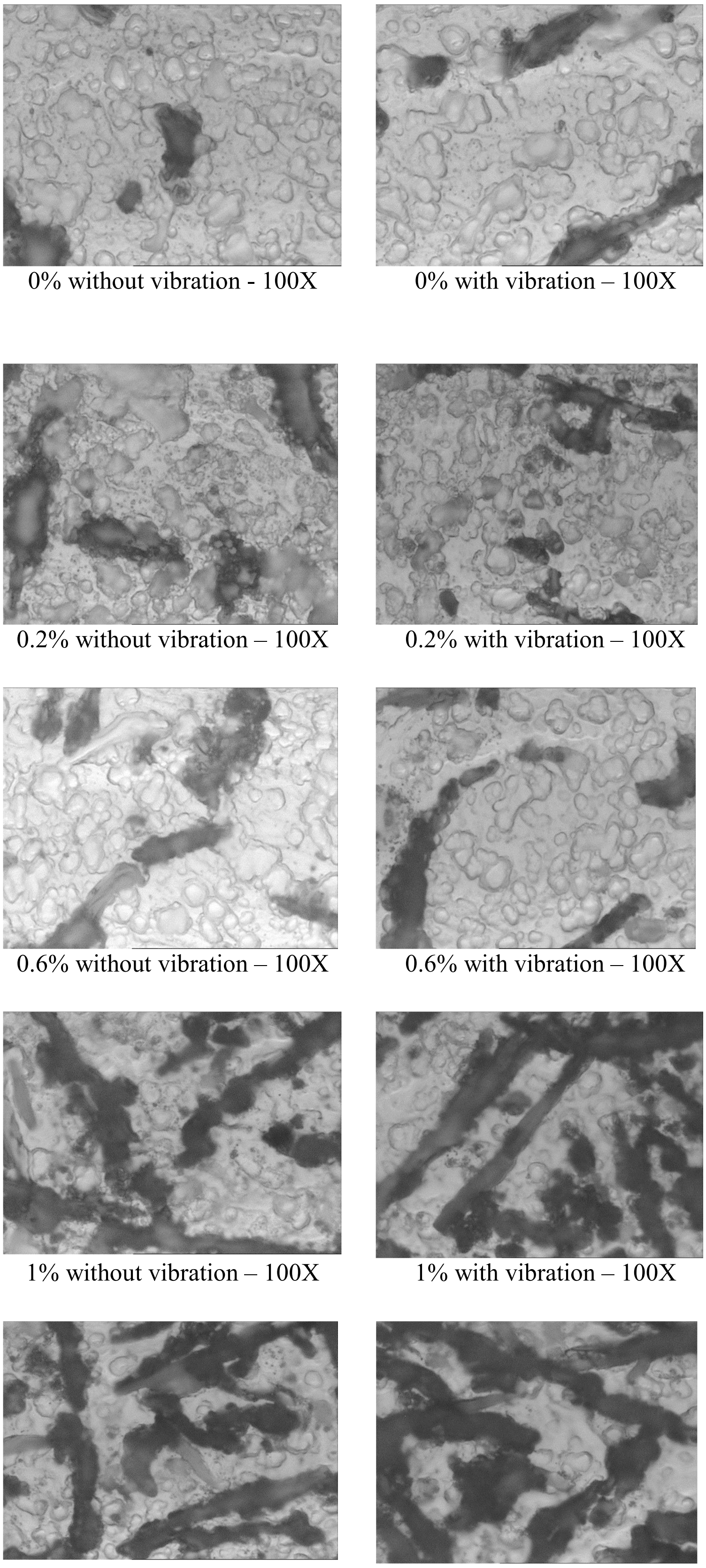


Figure 3. Thermal Diffusivity and Conductivity of Al-TiC particulate composites

Figure 3 shows the influence of mechanical vibration and various percentage of TiC on thermal conductivity of Al-TiC particulate composites. As expected, the thermal conductivity for Al-TiC composite increase with increasing percentage of TiC. The thermal conductivity of TiC is much larger than that Al, so the addition of TiC to Al matrix will result in an increased in thermal conductivity of the composite. The thermal conductivity of aluminum-matrix composites also depends on the particulate and its weight fraction, the alloy matrix heat treatment condition, and the filler matrix interface. From the microstructure study, it can be seen that the particle distribution and aluminium contact is improved by increasing content of TiC and frequency of vibration. Mechanical vibration can enhance the compatibility between the matrix and the particles thus enhance the dispersion of the particles, improved wet out between the matrix and particles which in turn improve the thermal conductivity ability of the Al-TiC particulate composites. Comparison between morphology of with and without vibration and various percentage of TiC particulate is shown in Figure 4.



0% without vibration - 100X
0% with vibration – 100X
0.2% without vibration – 100X
0.2% with vibration – 100X
0.6% without vibration – 100X
0.6% with vibration – 100X
1% without vibration – 100X
1% with vibration – 100X
2% without vibration – 100X
2% with vibration – 100X

Figure 4. Microstructure of Al-TiC particulate composite without and with vibration (10.2 Hz)

Summary

Density and Thermal conductivity of Al-TiC particulate composites increased with increasing particles and applied vibration during solidification. Appropriately used, applied vibrations during solidification create significant improvements in the properties of Al-TiC composite. 10.2 Hz of vibration is able to produce good dispersion of particles in matrix, increase density, thermal conductivity, while maintaining mechanical properties. This research proved that there is possible to increase thermal conductivity of metal matrix composite even at low vibration and particle concentrations.

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