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# The Influence of Mechanical Mold Vibration on Temperature Distribution and Physical Properties of Al-11.8%Si Matrix Composites

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**Abstract.** Mechanical vibration was introduced into the Aluminum alloy matrix composite during solidification process. The cooling curves of composite with mechanical vibration were measured and compared without mechanical vibration. The thermal conductivity and thermal diffusivity properties of the Al/TiC composite were investigated. The result indicated that the mechanical vibration reduces the temperature inhomogeneity of melt. The density of the composite with 10.2, 12, 15Hz and 16 Hz of mechanical vibration improved apparently compared with the composite without mechanical vibration. The thermal conductivity and thermal diffusivity properties of composites with mechanical vibration are also both improved

## Introduction

In today's competitive business world, manufacturers are aiming for reliable products with characteristics such as high-quality cast parts, defect-free output and minimal lead time, all at the lower level of investment. Metal matrix composites (MMC's) is representing new generation of engineering materials in which strong particulates is incorporated into a metal matrix to improve its properties such as thermal properties [1, 2]. These properties may be considerable significance for advanced composites in various potential applications. For example, thermal conductions play an important role in determining the resistance to thermal shock. Furthermore, combinations of high conductivity and good mechanical properties obtainable by the reinforcement of pure metals with ceramic may be more attractive than those obtainable by allowing, which often sharply reduces both thermal conductivity and thermal diffusivity [3]. During the last decade, because of their improved properties, MMC's have been extensively studied for high performance applications. Controlling the microstructure in the casting of components made by these alloys is an important challenge considered by the foundry industries [4, 5]. It includes controlling of parameters such as grain size, porosity and its distribution, morphology of metallic and non-metallic secondary phases available in microstructures, macro and micro segregations and etc. [5, 6]. Controlling and optimization of the mentioned parameters as well as considering economic parameters will lead to increase in the quality of final products [5, 6]. The main effect of vibration during solidification on the microstructural of metal and alloy is the suppression of columnar growth and formation of small equiaxed grains [7, 8].

Base on the literature, many methods have been introduced to controlling of the microstructural. Among these methods, application of energy such as vibration is an advantageous method that has been considered by investigators [5]. Chernov [5] in 1878 might be the first person who used

mechanical vibration of mold during solidification of steel and observed that final structure of primary austenite was refined.
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 [9-13].
In this research, sand casting technique combined with mechanical vibration was used in the fabrication of particulate reinforced aluminum composites an. The aim of the research is to study the influence of mechanical vibration on solidification and physical properties of particulate reinforced aluminum composites.

## 2. Material And Method

In this research, the aluminum-11.8%silicon alloy material weighing approximately 4 kgs were cut into small pieces for accommodating into the graphite crucible. It is based on British specifications that conforms to BS 1490-1988 as Aluminium-11.8% silicon alloy. It is actually a eutectic alloy having the lowest melting point that can be seen from the Aluminium-Silicon phase diagram. Aluminium-11.8% silicon alloy is corrosion resistant with average durability and strength, and possess high impact strength and ductility. The chemical composition and mechanical and thermal properties of Aluminium-11.8% silicon alloy is shown in **Table 1** and **Table 2**. The mechanical vibration of the mould was applied to the aluminum alloy matrix composite with and without vibration at a frequency 0 Hz, 10.2 Hz/120 mm, 12 Hz/0.160 mm, 15 Hz/0.207 mm and 16 Hz/0.232 mm. The titanium carbide particulate used as a second phase reinforcement in the alloy matrix was added on by different weights fraction 0.2, 0.6, 1 and 2% wt. Titanium carbide is a ceramic material normally used for aerospace applications. The molecular weight of titanium carbide is 59.89, its melting point is 3140 degree centigrade, and boiling point is 4820 degree centigrade. The density of tungsten carbide is 4.93 gm/cc and Mohs hardness at 20 degree centigrade is 3200 kg/m$^2$. The crystal structure of tungsten carbide is of cubic type. The electrical resistivity of titanium carbide ranges from 180 to 250 Micro ohm-cm. The aluminium LM6 silicon alloy ingot and Titanium Carbide in the container shown in **Fig. 1** and **Fig. 2**. The thermocouple wire was used to determine the temperature. The experimental set-up used and Flow chart of the composite fabrication process is shown in **Fig. 3** and **Fig.4 .** Thermal diffusivity of composite materials is measured using photo flash method. 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 [3, 14, 15]. The method is using a small disc-shaped specimen, the front face of which is subjected to an instantaneous, uniform energy pulse. The computer is programmed to calculate the thermal diffusivity, α, using the equation 1. A&D-GR 200 – Analytical Balance was used to conduct the density measurement. The theoretical density of each set of composites was calculated using the rule of mixtures [16]. 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 2:

$$\alpha = \frac{\left(1.37\, x\, L^2\right)}{[(3.14)^2\, x\, t_{0.5}]} \quad (1)$$

$$\rho = \frac{Wa}{(Wa - Ww)}\, x\, density\ of\ Xylene \quad (2)$$

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

**Fig. 1.** Aluminium silicon alloy ingot


**Fig. 2**. Fluka Titanium Carbide in containers

**Table 1.** Composition of Aluminium-11.8 percentage silicon alloy expressed in percentage

| Chemical composition | % |
|---|---|
| Al | 85.95 |
| Cu | 0.2 |
| Mg | 0.1 |
| Si | 11.8 |
| Fe | 0.5 |
| Mn | 0.5 |
| Ni | 0.1 |
| Zn | 0.1 |
| Lead | 0.1 |
| Tin | 0.05 |
| Titanium | 0.2 |
| Others | 0.2 |

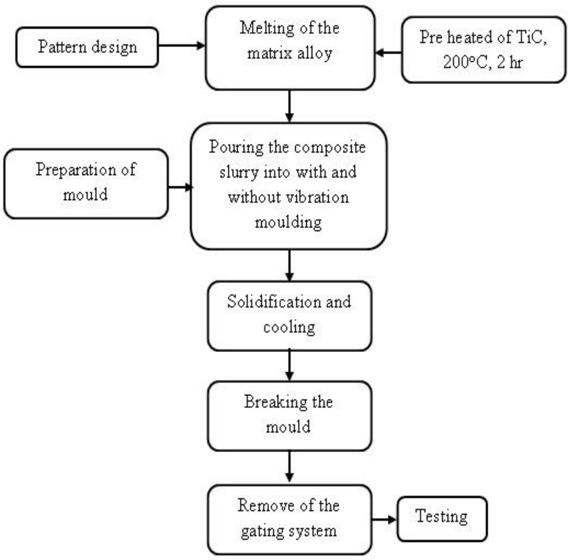



**Fig. 3.** Flow chart of the composite fabrication process

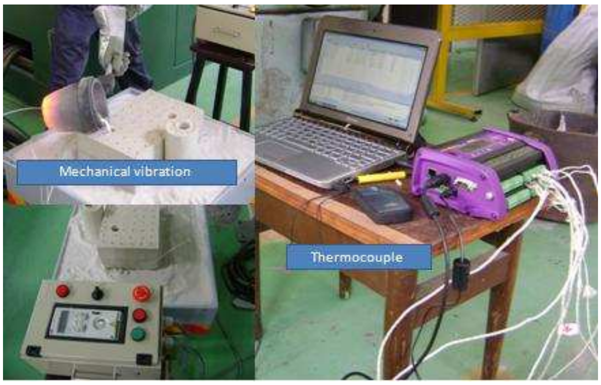



**Fig. 4** The experimental set-up of composites casting

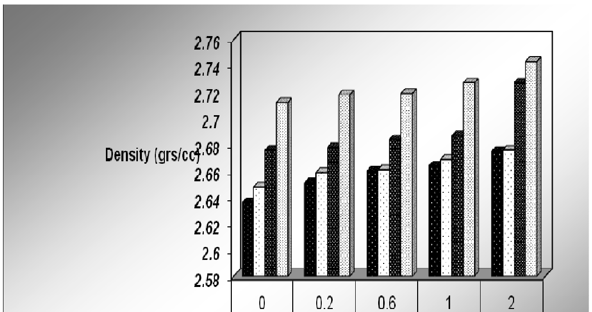
**Table 2.** Mechanical and thermal properties of Aluminium-11.8% silicon alloy

| **Physical properties** | **Values** |
|---|---|
| Density (gm/cc) | 2.66 |
| **Mechanical properties** | **Values** |
| Tensile strength, Ultimate (MPa) | 290 |
| Tensile strength, Yield (MPa) | 131 |
| %Elongation break (%) | 3.5 |
| Poisson's ratio | 0.33 |
| Fatigue strength (MPa) | 130 |
| Machinability | 30 |

| | |
|---|---|
| Shear strength (MPa) | 170 |
| Hardness ( BHN) | 50 |
| Modulus of elasticity, E ($N/mm^2$) | 71000 |
| **Thermal properties** | **Values** |
| CTE, linear $20^oC$ (µm/m-$^oC$) | 20.4 |
| CTE, linear $250^oC$ (µm/m-$^oC$) | 22.4 |
| Heat capacity (J/g- $^oC$) | 0.963 |
| Heat of fusion (J/g) | 389 |
| Thermal conductivity (W/m-K) | 155 |
| Melting point ($^oC$) | 574 |
| Solidus, ($^oC$) | 574 |
| Liquidus ($^oC$) | 582 |

**3. Result And Discussion**

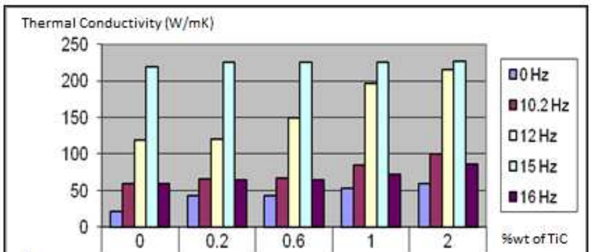
**Fig. 5** offer the comparison of the mechanical vibration effect and weight fraction of the particles effect on the density. It is easy to draw a conclusion that, by mechanical vibration during solidification, the size of shrinkage cavity and inclusion are reduced and the amount of defects is also decreased. The densities of the samples are measured using A&D-GR 200 – Analytical Balance. It can be found that the density is higher in the sample with mechanical vibration mould than in without vibration mould. It is obvious that the amount of defect such as shrinkage cavity and inclusion is decreased and the compactness is enhanced due to applied mechanical vibration during the solidification process. The values of density in composites also increase with increasing weight fraction of the particles, 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




| | 0 | 0.2 | 0.6 | 1 | 2 |
|---|---|---|---|---|---|
| Non vibratin (grs/cc) | 2.636 | 2.651 | 2.66 | 2.664 | 2.675 |
| With vibratin 10.2Hz (grs/cc) | 2.648 | 2.659 | 2.661 | 2.669 | 2.676 |
| With vibration 12Hz (grs/cc) | 2.676 | 2.678 | 2.684 | 2.687 | 2.727 |
| With vibration 15Hz (grs/cc) | 2.712 | 2.718 | 2.719 | 2.727 | 2.743 |

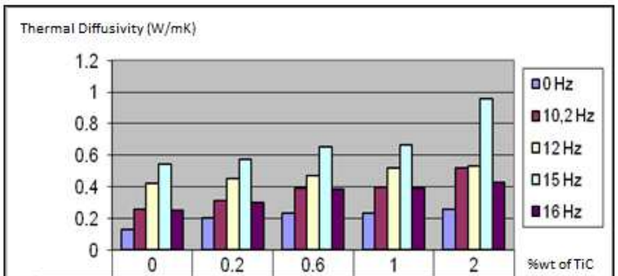
**Fig. 5** Average of density energy vs wt.% of TiC

The vibration parameters used in this research was 0 Hz, 10.2 Hz/120 mm, 12 Hz/0.160 mm, 15 Hz/0.207 mm and 16 Hz/0.232 mm, approximately. **Fig. 6** and **Fig. 7** clearly show that the maximum thermal conductivity and diffusivity of all the samples that were solidified under vibration has increased when compared to the samples solidified without vibration. The thermal conductivity and diffusivity of the Al-TiC particulate composites increases as the frequency increases and it begins to decrease at 16 Hz. 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. The increase of thermal conductivity has highest effect on the refinement on microstructure [13, 17].




| | 0 | 0.2 | 0.6 | 1 | 2 |
|---|---|---|---|---|---|
| 0 Hz | 21.035 | 42.561 | 43.096 | 52.9543 | 58.96 |
| 10.2 Hz | 59.041 | 65.686 | 66.088 | 84.683 | 99.831 |
| 12 Hz | 118.298 | 119.933 | 149.584 | 196.341 | 215.826 |
| 15 Hz | 219.231 | 224.852 | 225.347 | 225.687 | 226.874 |
| 16 Hz | 58.452 | 64.563 | 64.578 | 72.369 | 85.354 |

**Fig. 6** Thermal Conductivity (W/mK) vs %wt of TiC particulate composites




| | 0 | 0.2 | 0.6 | 1 | 2 |
|---|---|---|---|---|---|
| 0 Hz | 0.1317 | 0.2032 | 0.2306 | 0.2327 | 0.2598 |
| 10,2 Hz | 0.259 | 0.3102 | 0.3931 | 0.3984 | 0.5203 |
| 12 Hz | 0.4223 | 0.4514 | 0.4721 | 0.5203 | 0.5311 |
| 15 Hz | 0.5427 | 0.5728 | 0.6513 | 0.6628 | 0.9575 |
| 16 Hz | 0.2481 | 0.3002 | 0.3834 | 0.3915 | 0.4293 |

**Fig. 7** Thermal Diffusivity (W/mK) vs %wt of TiC particulate composites

From **Fig. 8** it can be seen that the cooling rates are different for four different frequencies. The thermocouple readings have been used to find the temperature profile as a function of time corresponding to the liquidus front passing by each thermocouple. All the thermocouple readings have shown a decrease in temperature as a result of applying vibration. The temperature profile of the composite using mechanical vibration rapid solidification compared the temperature profile of the composite without vibration. This faster cooling results in finer microstructure, homogenous and improvement of mechanical and physical properties of Al-TiC particulate composites. The temperature longitudinal gradient inside the casting is also more uniform under the influence of vibration [4]. In casting processes, as the temperature of the liquid is lowered, solidification starts by heterogeneous nucleation at the mold wall through the so-called "big bang" theory [13]. This mechanism also operates during vibration producing grain refinement [7]. The total solidification time of the Al-TiC composite was reduced by vibration. Kocatepe [7] also found that the total solidification time of LM6 alloy was reduced by low frequency vibration.

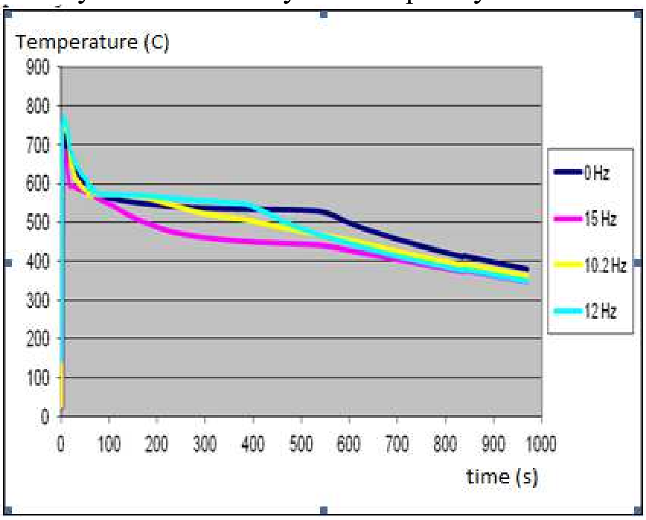



**Fig. 8** Cooling curve with different frequency

**4. Conclusion**

Thermal conductivity and thermal diffusivity 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, but the thermal properties of the composite decrease at 16 Hz of vibration. At the 15 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.

The temperature profile of the composite using mechanical vibration rapid solidification compared the temperature profile of the composite without vibration. The forced convention caused by mechanical vibration changes the head transferring and mass transferring. The rapid head transferring and mass transferring makes an environment with realative uniformity of temperature and composition of Al-TiC composite in the sand mold.

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