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Manufacturing of TiC Particulate Reinforced Al–11.8%Si Matrix Composites by Mechanical Vibration Mould

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This research paper discusses on the manufacturing and mechanical testing of titanium carbide particulate reinforced aluminium-11.8% silicon alloy composite castings. Composite castings in the form of a slab containing 0.2, 0.6, 1, and 2% weight fraction of titanium carbide particulate equally reinforced in the LM6 alloy are made by vibration moulding sand casting process with the frequencies of 10.2 Hz, 12 Hz and 15 Hz. The results showed that the impact and hardness of the composites increased with an increase in the frequency of vibration and increasing titanium carbide particulate reinforcement in the LM6 alloy matrix composites.

Keywords: Manufacturing, Titanium Carbide Particulate, Composite Castings, Vibration Mould.

1. INTRODUCTION

The technology and evolution of metal matrix composite systems has been developed over the past 20 years with primary support from and emphasis on aerospace, airframe requirements, automotive and electronic applications. Among the many reasons for the recent resurgence of interest in metal matrix composites are the mechanical properties, physical properties and other engineering properties of these composites.[1–3] The overall advantages of aluminium matrix composites compared to unreinforced conventional materials are as follows:[4,5] greater strength, reduced density (weight), improved stiffness, improved high temperature properties, improved damping capabilities, improve abrasion and wear resistance, enhanced and tailored electrical performance, control of mass (especially in reciprocating applications), thermal/head management and controlled thermal expansion coefficient.

On using the mechanical, ultrasonic, and electromagnetic vibrations during solidification may have the advantage of promoting grain refinement of the composite, by reducing the shrinkage porosities, with an increased density.[6] The ultrasonic vibration has proven to be a potentially new method of improving the quality of cast light metals. The introduction of high intensity ultrasonic vibration into the melt may control the columnar dendrite structure, reduce the size of equiaxed grains, and under some conditions, produce globular non-dendrite grains.[7] Chernov first studied the application of vibration during the solidification in 1868.[8] The application of the mechanical, sonic, and ultrasonic vibrations has a number of notable effects such as grain refinement, increased density, reduced shrinkage, and on the shape, size, and distribution of the second phase.[9,10] Vertical vibration is the most commonly used vibration mode, because it strongly influences on the growing grains.[11] Increase in the volume fraction of particulate, increases the strength of the composites as the volume fraction of the reinforcement particles increases, and more loads are transferred to the reinforcement particles.[12] These results in the higher elastic modulus, macroscopic yield strength and tensile strength coupled with lower ductility.[13] Moreover, an increase in the volume fraction of reinforcement particles increases the "apparent work hardening" in the material.[14–16] In the present study, the objective of this work is to study the effect of mechanical mould vibrations on the impact and the hardness of the Titanium Carbide particulate reinforced aluminium-silicon alloy matrix composite.

2. MATERIALS AND METHODS

2.1. Material Selection

The material used in this research work was aluminium-11.8% silicon alloy. This matrix was chosen because of excellent

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Table I. Chemical composition of LM6.

Element	Al	Cu	Fe	Mg	Mn	Ni	Pb	Si	Sn	Ti	Zn
wt %	85.95	0.1	0.6	0.1	0.5	0.1	0.1	11.8	0.05	0.2	0.1

combination of strength and damage tolerance at elevated temperatures. The chemical composition of the matrix is given in Table I. The reinforcement was Titanium carbide particles of size 44 microns were used as the dispersoid, respectively. Casting method and mechanical vibration moulding was used for processing of the composite.

2.2. Fabrication of Composites

In this investigation, large ingots of aluminium-11.8%silicon alloy material weighing approximately 4 kgs were cut into small pieces for accommodating into the graphite crucible. The mechanical vibration of the mould was applied to the aluminium alloy matrix composite with and without vibration at a frequency 0 Hz, 10.2 Hz, 12 Hz and 15 Hz. 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.

In this research work, the particulate were preheated to 200 °C in a heat treatment muffle furnace for 2 hours and was then 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 vibration mould, which was attached on the system that provides the mechanical vibration with 0 Hz, 10.2 Hz, 12 Hz and 15 Hz (Fig. 1(a)) and without vibration or normal position (Fig. 1(b)). Then, the casting was ejected from the mould after solidification and gating system was removed to get the specimens. In the final stage, the specimen was prepared to the accurate dimensions according to the standard.

2.3. Mechanical Testing of Samples

The impact test was conducted in accordance with ASTM E 23–05 standards at room temperature using izod impact tester and the A&D-GR 200 – Analytical Balance for density, respectively.

2.4. Hardness Measurement

The hardness testing was done on a Rockwell Hardness Tester. The hardness of composites was tested by using MITUTOYO

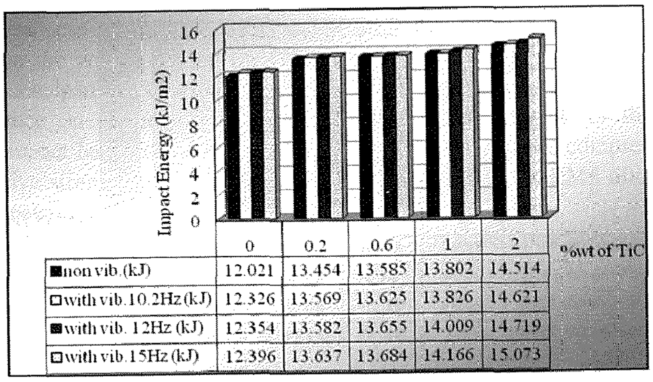


Fig. 2. The summary of impact energy.

ATK-600 MODEL hardness testing machine. For each sample, ten hardness readings were taken randomly from surface of the samples. Hardness values of different types of the processed composites are determined for different weight fraction % of titanium carbide particulate containing aluminium-11,8% silicon alloy and graphs are plotted between the hardness value and the corresponding type of particulate addition on weight fraction basis.

2.5. Metallography

Metallography is the study of internal physical structure in metals and alloys. The surface of metallographic samples of the composites is prepared in accordance with standard procedures used for metallographic analysis. This involved coarse polishing of the samples using 300, 600 and 1000-grit silicon carbide impregnated emery paper followed by fine polishing using 0.05 μm colloidal silica as the lubricant. The as-cast composite samples were etched with Keller's reagent containing 95% distilled water, 1.5 ml hydrochloric acid, 1,5% hydrofluoric acid and 2,5% nitric acid. It is used to reveal the phases present in the composites.

3. RESULTS AND DISCUSSION

Results and data are obtained from the tested samples taken from the titanium carbide reinforced LM6 alloy slab composite castings made in sand molds. The values are reported for the mechanical properties, hardness and microstructures features of titanium carbide particulate distribution for each weight fraction percentage addition to the LM6 alloy matrix and different

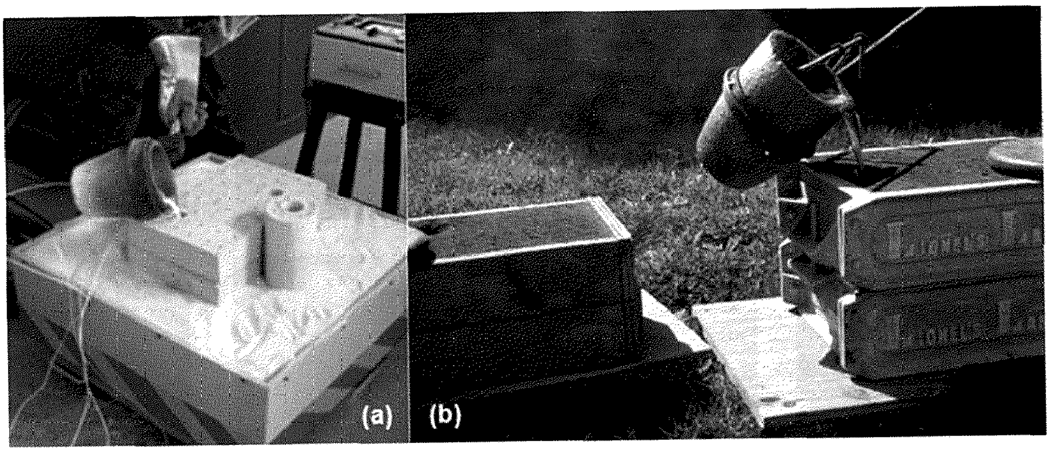
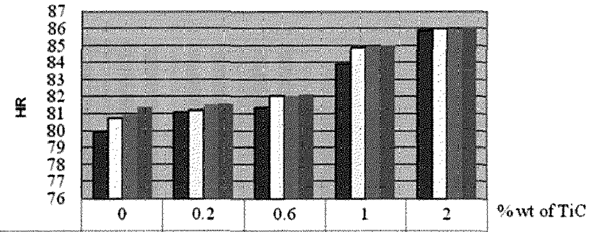


Fig. 1. (a) With vibration mould, (b) Normal Position.



	0	0.2	0.6	1	2
Non Vib.	79.91	81.06	81.32	83.9	85.88
With vib.10.2Hz	80.72	81.2	82.04	84.86	85.96
With vib. 12Hz	80.94	81.55	82.06	84.96	85.97
With vib. 15Hz	81.4	81.58	82.14	85.01	86.08

Fig. 3. The summary of hardness.

of vibration frequency are explained. In this section, the above-mentioned composites are analyzed and the results are presented in the corresponding graphs shown below in Figures 2 to 4.

3.1. Impact Test

The impact properties of particulate reinforced aluminum alloy matrix composite with and without vibration composite are shown below in Figure 2.

The mechanical properties of the composite with vibration are always better than that of correspondent without vibration. As shown in the figure, the impact energy value increases with increase in percent weight fraction of titanium carbide and with using vibration during solidification. 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.[6,8,17] These improved features lead to improve mechanical properties and lower susceptibility to cracking. Literature review on the effects of vibration on casting and reported an improvement of mechanical properties by as much as 40%.[12] It can be concluded that these effects play an important role on the improvement of impact energy.

3.2. Hardness Measurement

The data on the hardness of combined particulate reinforced composites made in sand mold was analyzed. It is found that the hardness value increased gradually with the increased addition percentage by weight with and without vibration and it is shown in Figure 3. The maximum hardness value based Rockwell superficial 15 N-S scale is 85.88 for 2% without vibration and 86.08 with vibration.

Based on Figure 3, the variation in the hardness value of the composites corresponding to the variation in the weight fraction of the titanium carbide particulate can be known. Moreover, the hardness values of the processed composites increases with the increasing in addition of titanium carbide particulate by weight fraction % are shown in Figure 3. Regarding the hardness results, hardness is much higher for the vibrated 15 Hz. It is clearly shows a tendency of increasing properties from 0.2, 0.6, 1 and 2% wt of TiC in all the composite process. This implies that the hardness improves as the weight fraction of precipitates, very hard TiC particles in particular, increases. Therefore, the TiC with 2% weight and 15 Hz of vibration has the best hardness because

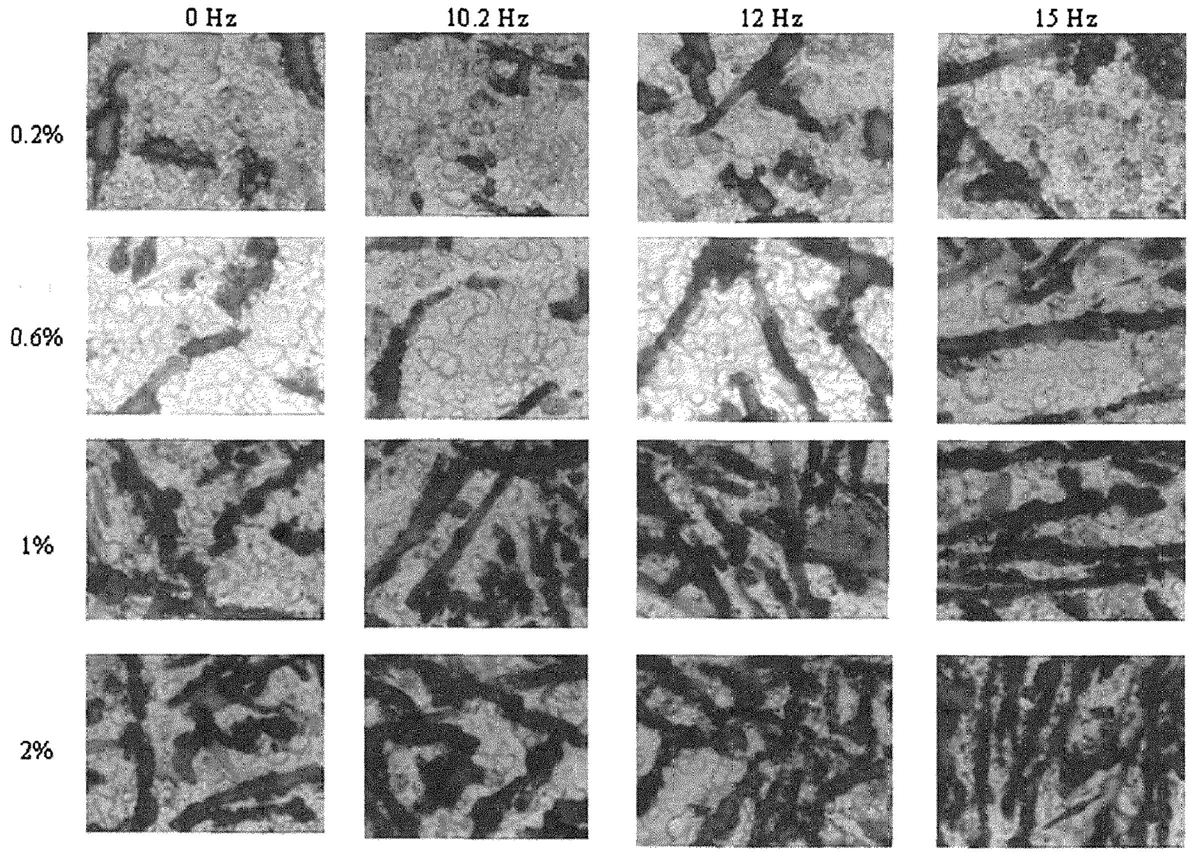


Fig. 4. Microstructure of TiC composite with 100× magnification.

of the abundant precipitates and the high hardness of the matrix and uniformly of the particulate in composites.

3.3. Metallography

The samples are viewed at different magnifications and photomicrographs are captured to predict the confirmation of the presence of the particulates in the alloy matrix. Then, it is further studied to identify the particulate distribution. From the in-depth research on this, it is confirmed the presence and distribution of embedded particulates in the matrix is uniform. The alloy matrix grains are finer and the bonding between particulate surface and the matrix material is satisfactory. It is found that, the morphological distribution of combined particulate for every weight fraction percentage addition increases. In this section, a number of captured photomicrographs are shown below in Figure 4 for better understanding.

Reference to the to the above micrographs, one can see clearly that the composite by using a mold vibration better and more evenly distributed TiC particles in the composite compared with without of vibration. This is because the vibration can flatten the whole TiC composite. In the composite with vibration 10.2 Hz, TiC very little and being unequally compared to 12 Hz, 15 Hz as well as more equitable than the 12 Hz. All of this microstructure is taken with 100X magnification. Even though there is no agglomeration and segregation of the TiC particles, it can be seen that reaction products of various morphology and size are observed in the Al matrix, as well as in the vicinity of the TiC particles according to the fabrication conditions ((b) through (e)). As the fabrication vibration increases from 10.2 Hz to 15 Hz, both the size and the amount of the reaction products increase. In addition, reaction products increased with increasing particulate and frequency of vibration (Fig. 4).

4. CONCLUSION

The optimum process was found in this study for production of TiC reinforced aluminium alloy matrix composite by casting technique using mechanical vibration during solidification. Impact energy and hardness of MMC were investigated. The following conditions have been drawn:

(1) The impact energy and hardness values increased gradually as the TiC content in the composite increased from 0.2%, 0.6, 1% and to 2% by percentage weight fraction and vibration. The hardness of the processed composite had a strong dependence on the weight fraction addition of the second phase reinforcement particulate on the alloy matrix. Its vibration has an influence on impact and hardness properties. The reason for this impact behavior is due to the dominating nature of the compressive strength of the TiC particulate reinforced in the LM6 alloy matrix.

(2) During the fabrication of composites, reaction products with various morphologies and sizes were formed in the Al matrix as well as in the vicinity of the TiC particles by the interfacial reaction between the Al alloy and the TiC particles.

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