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Characterisation of Al-Si-TiB_2 In-situ Composite Synthesised by Stir Casting Method

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ABSTRACT

Aluminium-Silicon alloy based metal matrix composites have been recognized as an appropriate wear resistant material particularly for sliding wear applications. An attempt has been made in the present paper to highlight the performance of Al-Si-TiB_2 composites with variation in Silicon content and presence of TiB_2 synthesised by means of salt metal reaction during stir casting method. The dry sliding wear behaviour of these composites was studied using a pin-on-disc wear testing machine varying load (10, 20, 30N) with a sliding velocity of 1m.s^{-1} for a sliding distance of 1800m. The microstructures of the specimens were analyzed by Scanning Electron Microscope as well as with optical microscope and also tested for hardness using Vickers hardness tester. Wear resistance and hardness values found to increase with increased wt% of Si.

1. Introduction

Silicon can be added in adequate quantities (up to 12.6%) to cause significant decrease in the melting range without causing brittleness in hypoeutectic Al-Si alloys. Hypereutectic Al-Si alloys have won the interest of researchers for their ability to substitute cast iron parts in the transportation sectors. Hypereutectic Al–Si alloys are extensively used in aerospace industries and automotive sectors in a variety of product applications demanding high strength to weight ratio, better wear and corrosion resistance, good machinability, excellent castability and thermal expansion coefficient [1]. The properties of the hypereutectic alloys can be tailored as they significantly depend upon on the primary silicon morphology along with their size and distribution in the Al-Si alloy. Mechanical properties of the alloy can be enhanced by the concurrent refinement and modification of the primary and eutectic silicon with reinforcement of TiB_2. Reinforcing ceramic particles like TiB_2, SiC or Al_2O_3 to the aluminium based matrix phase does not increase the density noticeably but ensures considerable rise in the strength to weight ratio, modulus and wear properties [2-4].

Al-TiB_2 composites reveal useful and distinctive features with respect to its properties and synthesis route. Being a refractory compound TiB_2 exhibits exceptional characteristics such as high melting point (2790°C), high hardness (86 HRA or 960 HV) and high modulus (530 x 10^3GPa). Its high temperature strength represents itself to be a good potential reinforcing competitor in an aluminium based matrix. The dislocation density is enhanced in Al-TiB_2 composites as a result of difference in the coefficient of thermal expansion between the reinforcement and the matrix and these dislocations can also perform as sites for nucleation. In addition, the exothermic nature of reaction for producing TiB_2 in molten aluminium imparts a favourable circumstance for fabricating Al–TiB_2 composite via the in situ salt metal route. This method is also the best alternative attempt to synthesize new generation in-situ composites compared to the traditional ex-situ techniques because of excellent wettability, homogenous distribution and clean interface between the matrix and reinforcement. TiB_2 particles are responsible for grain refinement of the Al-Si alloy, pining of dislocation line, and formation of Orowan dislocation loops and also grain boundary strengthening [5-12].

In this work an effort has been made to investigate the synthesis and characterization of Al-Si hyper-eutectic alloys with 2wt. % in-situ TiB_2 through salt metal reaction with the help of stir casting method.

2. Experimental procedure

Al-xSi-2TiB_2 (x = 12.6, 15, 18 wt. %) composite samples have been synthesized by salt metal reaction and the samples were examined for their physical and mechanical properties.

2.1 Synthesis of in-situ Al- xSi-2TiB_2 composite

Commercially pure Aluminium and Al-50Si master alloy was melted in a graphite crucible in a pit type melting furnace at 800°C to prepare Al-xSi alloy. The Al-xSi-2TiB_2 composites were synthesized by exothermic salt metal reaction which consists of adding together K_2TiF_6 and KBF_4 halide salts to molten Al-Si alloy and allowed for 30 minutes of reaction time. Titanium Diboride (TiB_2) particles are formed as a result of chemical reactions of the salts in the molten base alloy. Intermittent stirring was carried out to ensure complete reaction of salts and uniform distribution of TiB_2 particles within molten Aluminium alloy. Before casting, all the lighter dross was decanted to ensure sound casting. The desired composites specimens were casted by pouring into a preheated (at 450°C) cast iron mould [9].

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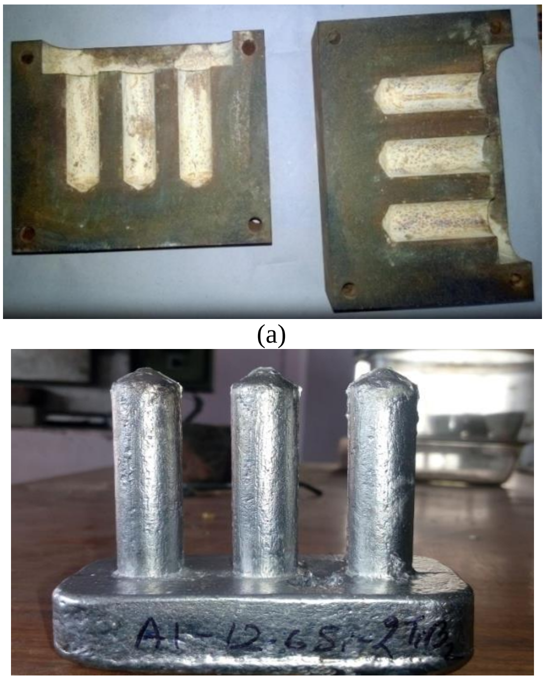
(a)

(b)

Figure 2.1. (a) Mould for casting of AMC (b) Al-12.6Si-2TiB$_2$ cast composite.

2.2 Characterization

Samples for microstructural observations were prepared following standard procedures and etched with Keller's reagent. The micrographs of the samples were examined under computerized optical microscope with varying magnifications and Scanning Electron Microscope (SEM) as well.

X-ray diffraction analysis of the prepared samples of size 10mm x 10 mm x 2mm was carried out with Cu-Kα target to recognize different phases present in the sample by matching of obtained peaks with JCPDS data files.

Hardness values of the specimens were measured in Microvicker's hardness tester using square based diamond pyramid as indenter and 1kgf applied load for 15 seconds. Care was taken to make both the horizontal faces of the test sample parallel by polishing. The Vickers Hardness values (VHN) of the samples were obtained from the measured diagonals of the indentations made at three locations of a sample. The density of the samples was measured turn by turn with the help of a density tester.

A pin on disc wear testing machine was used to investigate the dry sliding wear behaviour of the cylindrical pins of the composite sample with 10mm diameter and 30mm height. The load was varied from 10 to 30N with sliding velocity of 1 m.s^{-1} (track radius=40mm, 238 rpm) for 30 minutes at room temperature without any lubricant. The microprocessor controlled wear testing machine provides simultaneous data for height loss (in micron) coefficient of friction and frictional force. After every test, the mass loss due to wear of each specimen was determined. The role of applied load and Silicon content on wear behaviour of the prepared composites was studied.

3. Results and Discussion

3.1 Microstructure

The microstructures of Al-12.6Si-2TiB$_2$, Al-15Si-2TiB$_2$ and Al-18Si-2TiB$_2$ insitu composites are respectively shown the Figure-3.1 and 3.2. The composite with eutectic composition of the Al-Si binary alloy exhibits needle form of Silicon uniformly scattered all over the matrix but in the Al-18Si alloy primary Si particles are evident in SEM micrograph. Due to formation of TiB$_2$ particles in the composite, the space available for the growth of Si decreases, thus restrict the growth of most of the primary Silicon and also acts as nucleating sites during solidification[5-12].

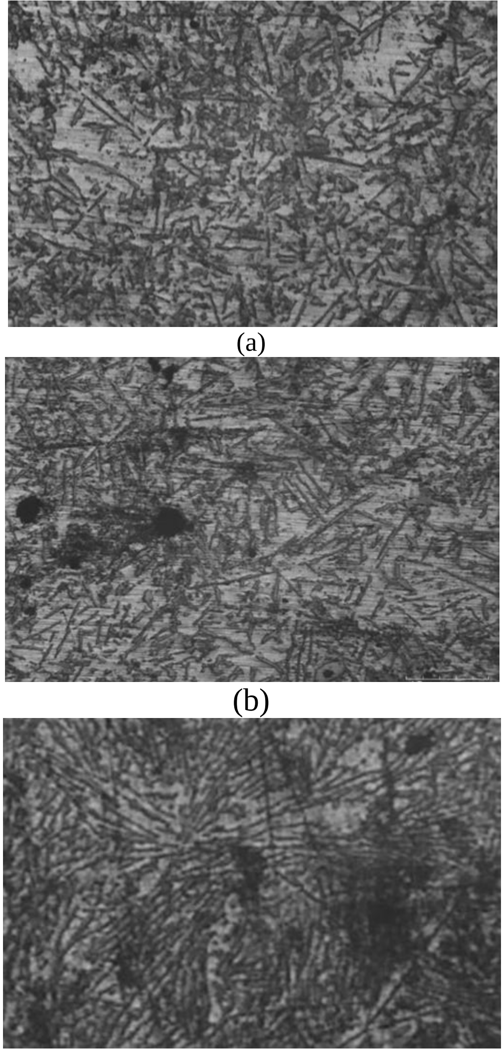
(a)

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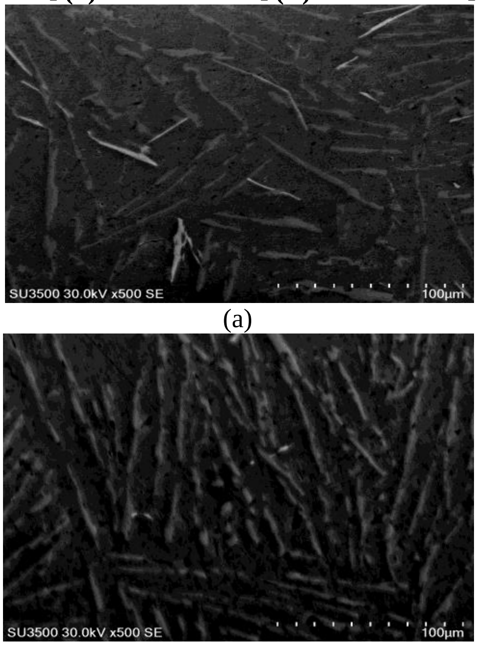
Figure 3.1. Optical micrograph at (100X) of (a) Al-12.6Si-2TiB$_2$ (b) Al-15Si- 2TiB$_2$ (c) Al-18Si-2TiB$_2$.



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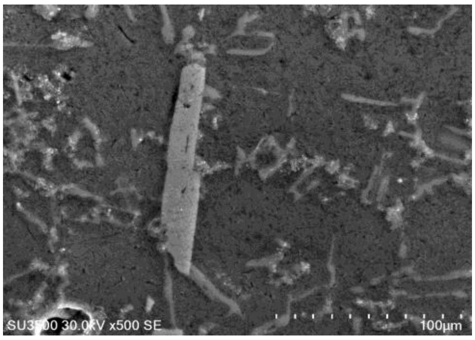

(c)

Figure 3.2. SEM micrograph at (500X) of (a) Al-12.6Si-2TiB$_2$ (b) Al-15Si-2TiB$_2$(c) Al-18Si 2TiB$_2$.

3.2 XRD Analysis of in-situ Composite

The largest peaks in the obtained XRD results describe the presence of Aluminium. Minor peaks signify the existence of Silicon and TiB$_2$ particles. It is also noticed that the intensity of the peaks of Silicon increases with its increase in the weight percentage in the base alloy. Very small peaks of TiB$_2$ in the XRD pattern corroborate the occurrence of TiB$_2$ in the selected alloy matrix.

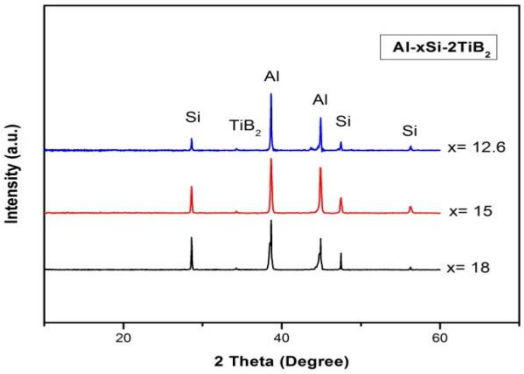

Figure 3.3. XRD analysis of in-situ composites.

3.3 Hardness and Density

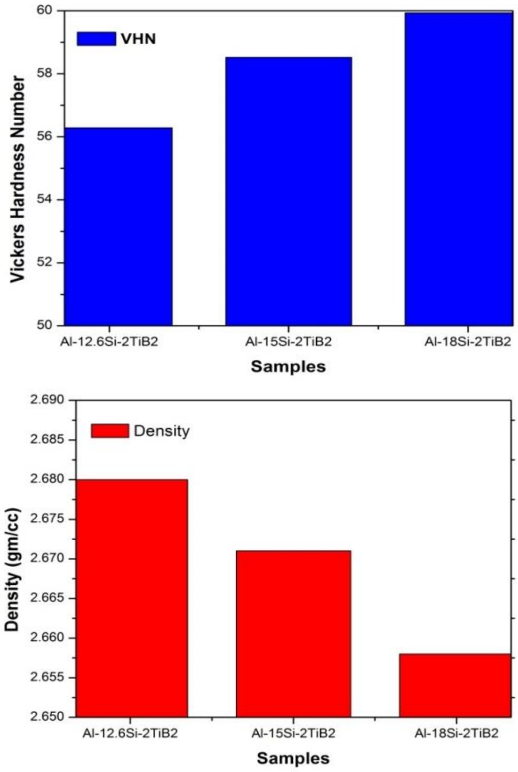

Figure 3.4. (a) Variation of hardness with Silicon content (b) Variation of density with Silicon content of the prepared in-situ composites.

The VHN and density histograms illustrate that AMC with 18 % Si possesses maximum hardness with lowest density. Increase in amount of silicon increases the hard primary Silicon and eutectic Al-Si phases that resist the indentation and provide high hardness values for the composites.

3.4 Wear Analysis

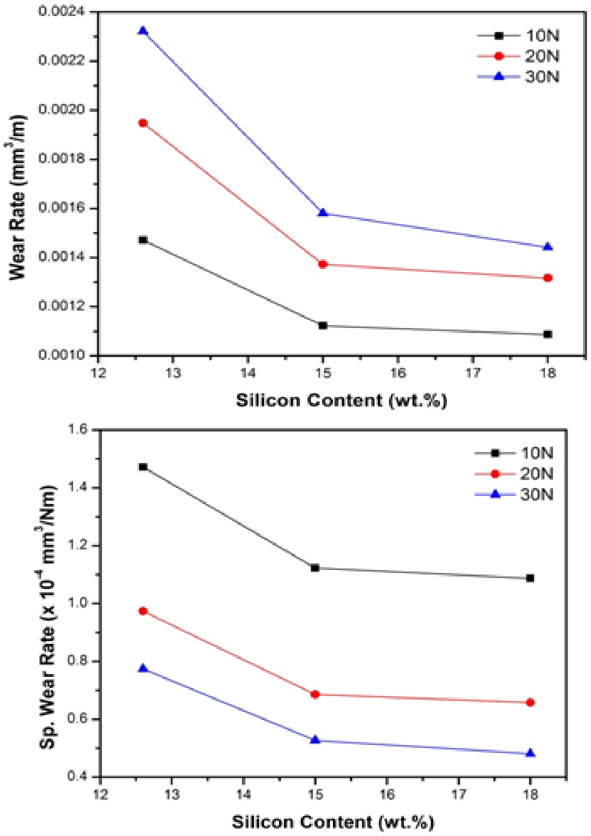

Figure 3.5. (a)Wear rate of the composite as a function of wt% of Si and load, (b) Specific Wear rate of the composite as a function of wt% of Si and load.

Figure 3.5 (a) shows wear rate of in-situ composites with three varying wt% of Si, as at different applied load. The wear rate found to decrease with increase in wt% of Si because of improvement in hardness, refining and modification of primary Silicon but the wear rate was brought up with higher applied load and found to be maximum at 30N load.

Figure 3.5 (b) shows specific wear rate of the composite and a similar trend was observed for varying wt% of Si and indicates the minimum specific wear rate in higher Silicon content in all condition. Uniform dispersion of the TiB$_2$ particles due to stir casting method and control in growth of primary Silicon due to TiB$_2$ particles contributes to lower specific wear rate in Al-18Si-2TiB$_2$ composite samples.

4. Conclusions

Present investigation leads to the conclusions as follows:

1)Al-Si-TiB$_2$ in-situ composites were successfully synthesized by salt metal reaction using K_2TiF_6 and KBF_4 salts through stir casting method.

2)Presence of TiB$_2$ in the Al-Si matrix was confirmed by XRD analysis.

3)Density test observations are in corroboration with presence of different constituents of the prepared composite samples.

4)Higher hardness values were observed in composites with higher amount of Silicon.

5) Wear rate and specific wear rate found to decrease at all the operating condition with higher Silicon content.

6) Microstructure study revealed the effect of TiB_2 in modification and growth restriction of primary Silicon in hyper-eutectic Al-Si alloy.

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