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Dry Sliding Wear Behaviour of Al-Si-TiB_2 In-Situ Composites

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Abstract

The most rapidly growing area of composites is that of Aluminium Matrix Composites (AMCs) as a result of their improved specific strength and wear characteristics. Amongst different Aluminium alloys as matrix phase Al-Si alloys are widely used as engineering materials due to their good castability and reasonable cost. Addition of ceramic particles like TiB_2 to the Al-Si matrix phase does not increase the density of the composite considerably but ensures remarkable rise in the specific strength, modulus and wear resistance. Al-Si-TiB_2 composite exhibits some useful and unique characteristics pertaining to its properties and processing route. In the in-situ synthesis of salt-metal reaction the exothermic reaction between Potassium Hexa Fluoro Titanate (K_2TiF_6) and Potassium Tetra Fluoro Borate (KBF_4) halide salts yields TiB_2 particles within the matrix phase resulting cleaner interface. In the present work an attempt is made in order to study, synthesize and characterize the Al-Si alloys dispersed with TiB_2 through stir casting route. Effect of TiB_2 in-situ particles in the Al-Si base alloy has been investigated from the results obtained from optical microscopy as well as SEM study and wear analysis with a pin on disc wear testing machine. Improved hardness and wear properties were observed with addition of TiB_2.

Keywords: TiB_2, K_2TiF_6, KBF_4, in-situ composites, wear, microstructure

Introduction:

Aluminium based Metal Matrix Composites (AMCs) have appeared as a significant class of materials for various applications. The Al-Si alloys, among different Aluminium alloys as matrix phase, are broadly used as engineering materials due to their light weight, good castability, high specific strength, amplified wear resistance and reasonable cost. Mechanical properties of the alloy can be enhanced by the simultaneous refinement and transformation of the eutectic silicon with reinforcement of TiB_2. Reinforcement of ceramic particles like TiB_2, SiC or Al_2O_3 to the aluminium based matrix phase does not elevate the density noticeably but ensures substantial rise in the strength to weight ratio, modulus and wear properties. The presence of grain refiner and or modifier increases the toughness and strength of the alloys due to change in microstructure, which leads to reduce in wear rate as compared to the absence of grain refiner and or modifier [2-5].

Al- TiB_2 composites reveal convenient and unique features with respect to its properties and synthesis route. TiB_2, being a refractory compound, exhibits special characteristics such as high melting point (2790°C), high hardness (86 HRA or 960 HV) and high modulus (530 x 10^3GPa). Its obstruction to plastic deformation even at high temperatures illustrates it to be a fine inherent reinforcing contender in an Aluminium matrix. The difference in the coefficient of thermal expansion between TiB_2 ($7 \times 10^{-6}K^{-1}$) and Al ($23.5 \times 10^{-6}K^{-1}$) originates the development of strain field at the interface between the matrix and the reinforced particle, which leads to an increase in the dislocation density. These dislocations can also act as nucleating sites. Moreover, the exothermic nature of TiB_2 with Aluminium delivers a conducive condition for constructing the Al– TiB_2 composite using the in situ method. The obstacle in the development of ex situ particulate metal matrix composites such as poor wettability, inhomogeneous distribution of reinforcement particles, formation of unwanted reaction products at the interface between the reinforcement and matrix, etc., have led to the attempts to integrate new in situ composites. For the Al-Si alloy, the TiB_2 particles are liable for pining of dislocation line, grain refinement, and grain boundary strengthening and also creation of Orowan dislocation loops [6-13].

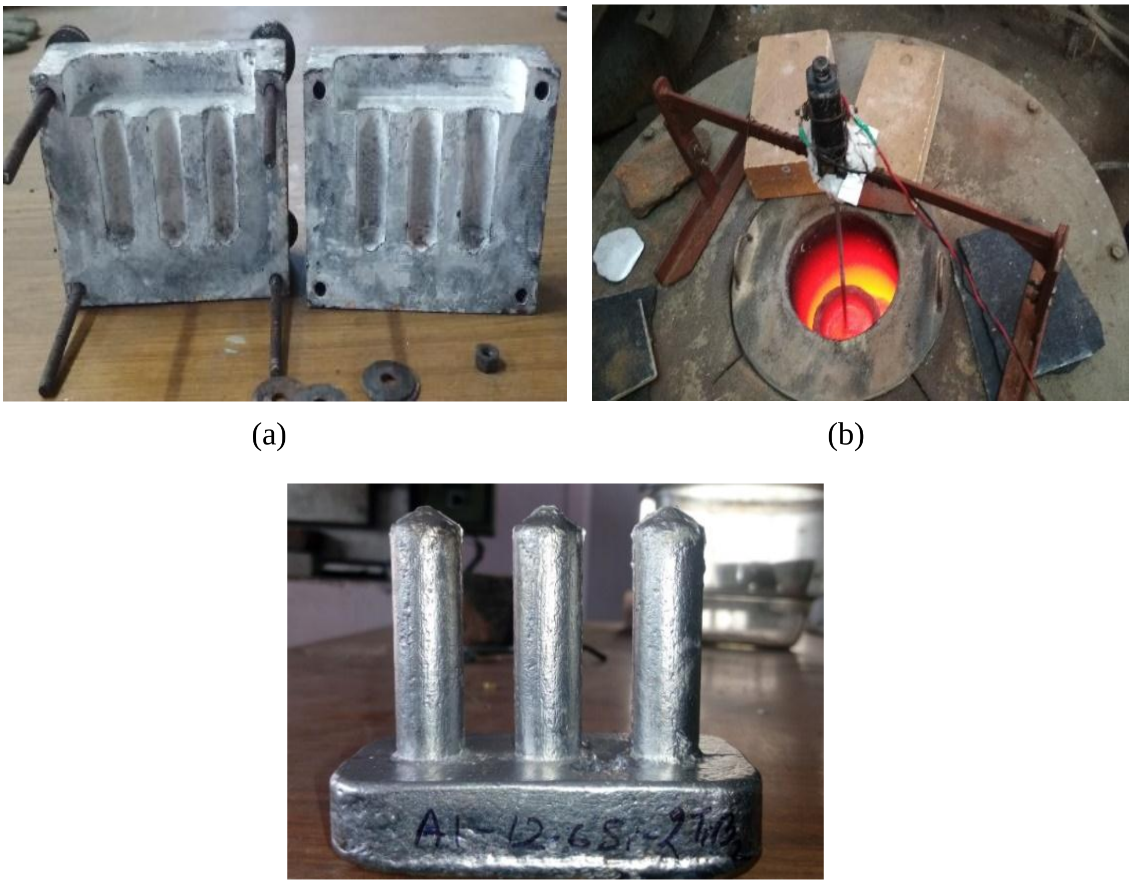
In this present work an attempt has been made to dissect the synthesis and characterization of Al- Si eutectic alloys with 2, 3 and 5wt. % in-situ TiB_2 through salt metal reaction using stir casting method.

2. Materials and Methods

The overall experimental procedure can be divided into two categories. In the first category, Al-12.6Si-xTiB_2 (x=2, 3, 5) composite samples have been synthesized by salt metal reaction. The second category illustrates the characterization of the samples for their physical and mechanical properties.

2.1 Synthesis of in-situ Al- 12.6Si-xTiB_2 composites

Commercially pure Aluminium and Al-50 wt% Si master alloy was melted in a graphite crucible in a pit type melting furnace at 800°C to prepare Al-12.6Si alloy. The Al-12.6Si- $xTiB_2$ (x = 2, 3, 5) composites were produced by exothermic salt metal reaction which made up of adding K_2TiF_6 and KBF_4 halide salts together to molten Al-Si alloy and assigned for 30 minutes of reaction time. As a result of chemical reactions of the salts, Titanium Diboride (TiB_2) particles are formed in the molten base alloy. Periodic stirring was performed for complete reaction of salts and uniform distribution of TiB_2 particles within molten Aluminium alloy. Before casting, all the lighter dross was discharged to synthesize sound casting. The essential composites specimens were casted by pouring into a preheated (at 450°C) cast iron mould [10].



(a) (b)

(c)

Figure 1: (a) Mould for Casting of AMC (b) Stir casting setup (c) Al-12.6Si-2 TiB2 Cast Composite

2.2 Microstructural study

For microstructural observations, samples were prepared following standard procedures and etched with Keller’s reagent. The micrographs of the samples were analysed under computerized optical microscope (CARL ZEISS) with differing magnifications and Scanning Electron Microscope (SEM) as well.

Figure 2: ZEISS Optical Microscope

2.3 X-ray diffraction studies

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

2.4 Hardness & Density

In MicroVicker’s hardness tester the hardness values of the specimens were determined using square based diamond pyramid as indenter and 1kgf applied load for 15 seconds. The horizontal faces of the test sample must be made parallel by polishing. From the measured diagonals the VHN (Vickers Hardness values) of the samples were obtained from the indentions made at three locations of a sample. With the help of a density tester the density of the samples was measured turn by turn.

2.5 Wear test

To analyse the dry sliding wear behaviour of the cylindrical pins of the composite sample, a pin on disc wear testing machine was used with 10mm diameter and 30mm height. The load was varied from 10, 20 and 30N with 300, 400 and 500 rpm (track radius=40mm) at room temperature for 5 minutes without any lubricant. The wear testing machine controlled by the microprocessor provides simultaneous data for height loss (in micron), frictional force and co efficient of friction. After every test the mass loss due to wear of each specimen was noted. The role of applied load and Titanium Diboride (TiB_2) content on wear behaviour of the prepared composites was studied.

Figure 3: Pin on Disk Wear Testing apparatus

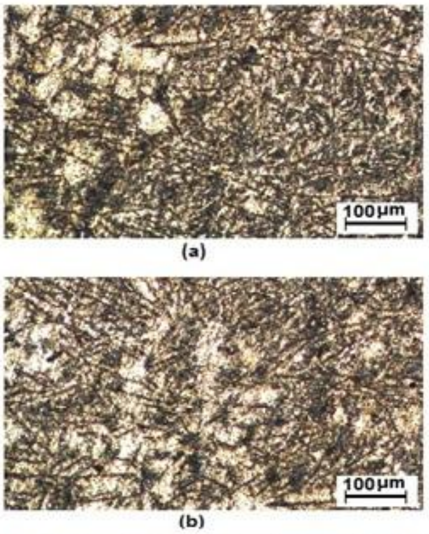
2.6. Worn surface analysis

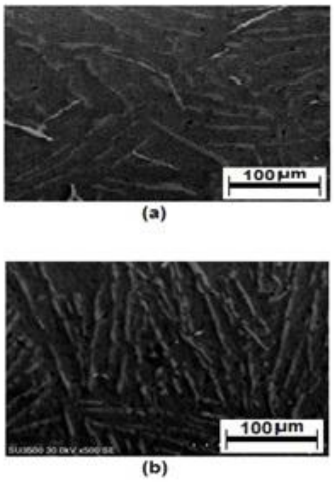
With the Field emission electron microscope (FESEM) the worn surfaces of the composite were studied.

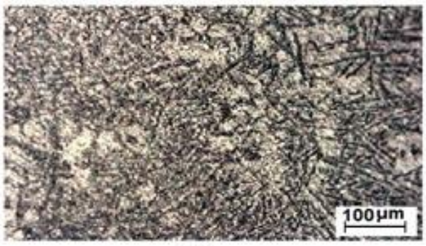
3. Results and Discussion

3.1. Microstructural study

The microstructures of Al-12.6Si-2 TiB_2, Al-12.6Si-3 TiB_2 and Al-12.6Si-5 TiB_2 in-situ composites are respectively shown the Figure-4.1 and 4.2. The composite with eutectic composition of the Al-Si binary alloy indicates needle form of Silicon uniformly scattered all over the matrix. TiB_2 particles act as nucleating sites and enhances the nucleation rate than the growth rate resulting fine eutectic structure.

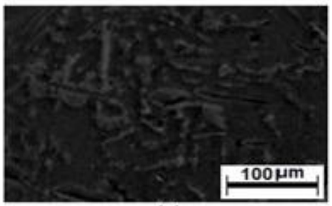






(c)

Figure 4.1: Optical Micrograph at (50X) of (a) Al-12.6Si-2TiB2 (b) Al-12.6Si- 3TiB2 (c) Al-12.6Si-5TiB2



(c)

Figure 4.2: SEM Micrograph at (500X) of (a) Al-12.6Si-2TiB2 (b) Al-12.6Si-3 TiB2 (c) Al-12.6Si-5 TiB2

3.2. XRD analysis of in-situ composite

The largest peaks in the obtained XRD results describe the presence of Aluminium and smaller peaks signify the existence of Silicon in synthesized composite. Very small peaks confirm formation of in-situ TiB_2 particles in the base alloy. The intensity of the peaks of TiB_2 in the XRD pattern was very low in Al-12.6Si-2TiB_2 composites but clearly distinguish in the composite with 5 wt. % TiB_2.

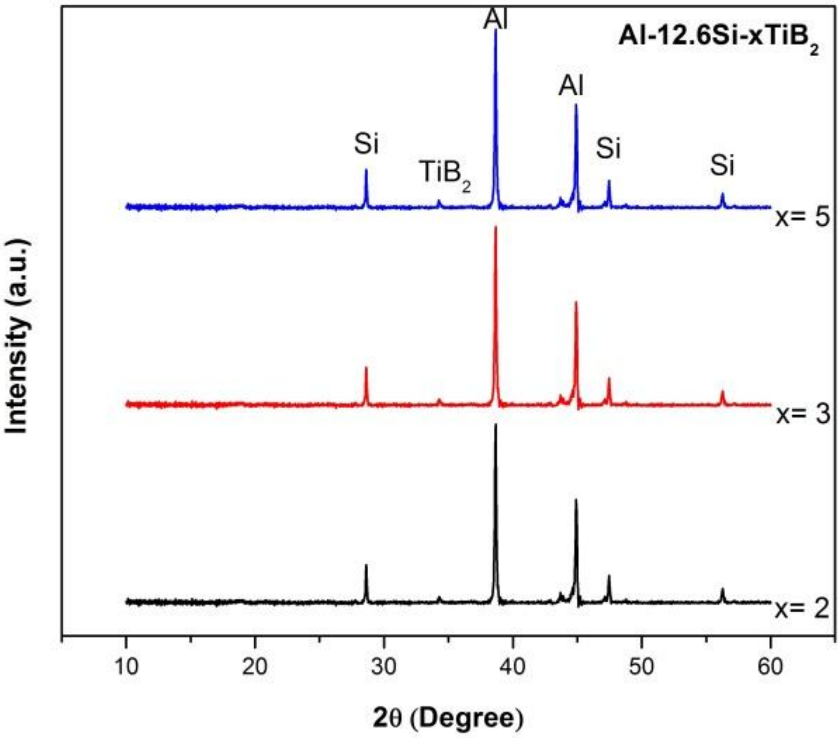
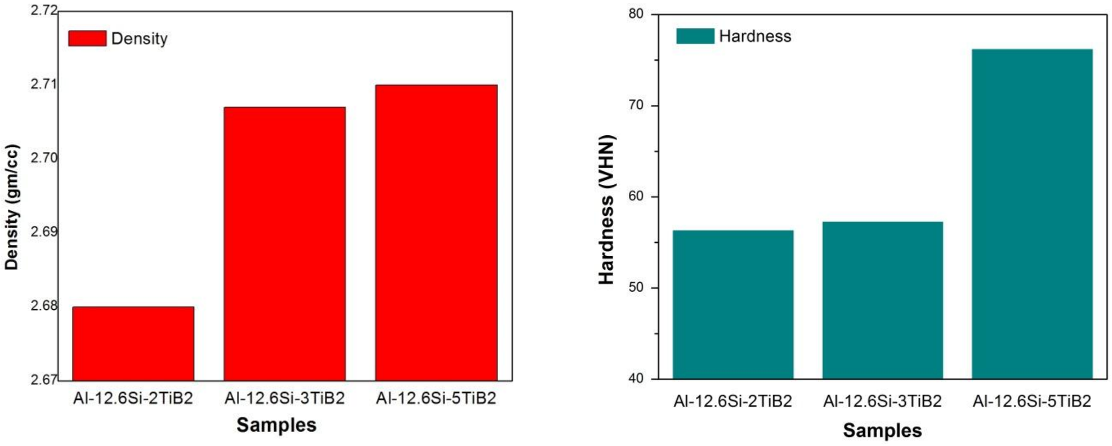


Figure 5: XRD analysis of in-situ composites

3.3 *Hardness and Density*

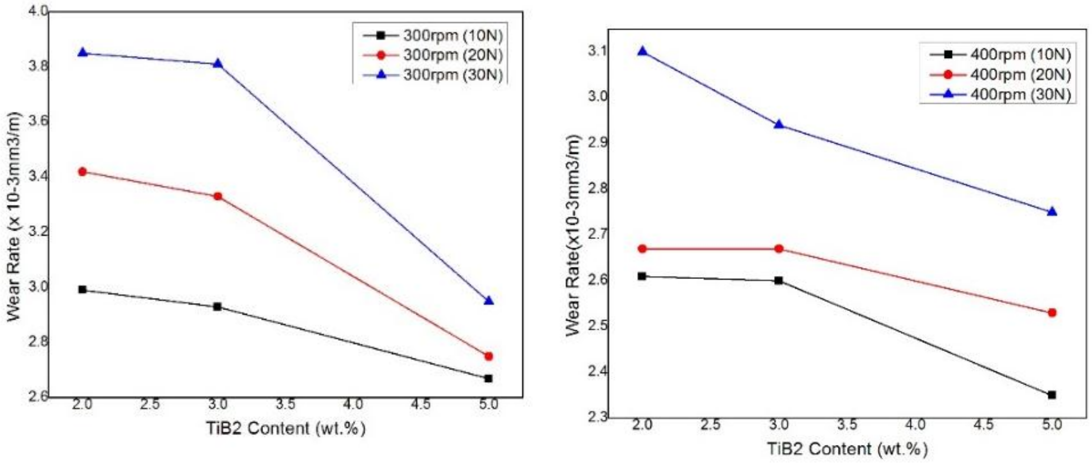


(a) (b)

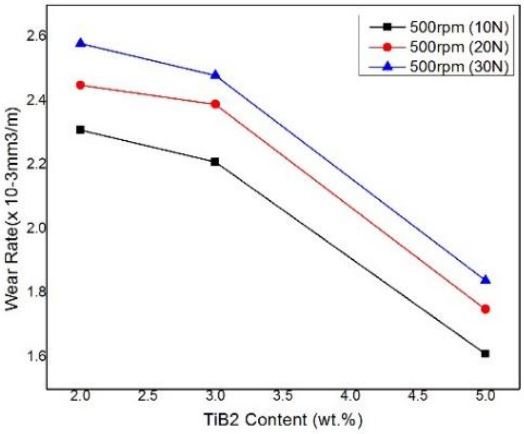
Figure 6: (a) Variation of density with TiB_2 content (b) Variation of hardness with TiB_2 content of the prepared in-situ composites

The VHN and density histograms explain that AMC with 5 wt. % TiB_2 possesses maximum hardness and density. There was found marginal increase in density with addition of the ceramic particle in the base alloy. Further hard ceramic particles resist the indentation and provide high hardness values for the composites.

3.4 *Wear Analysis*

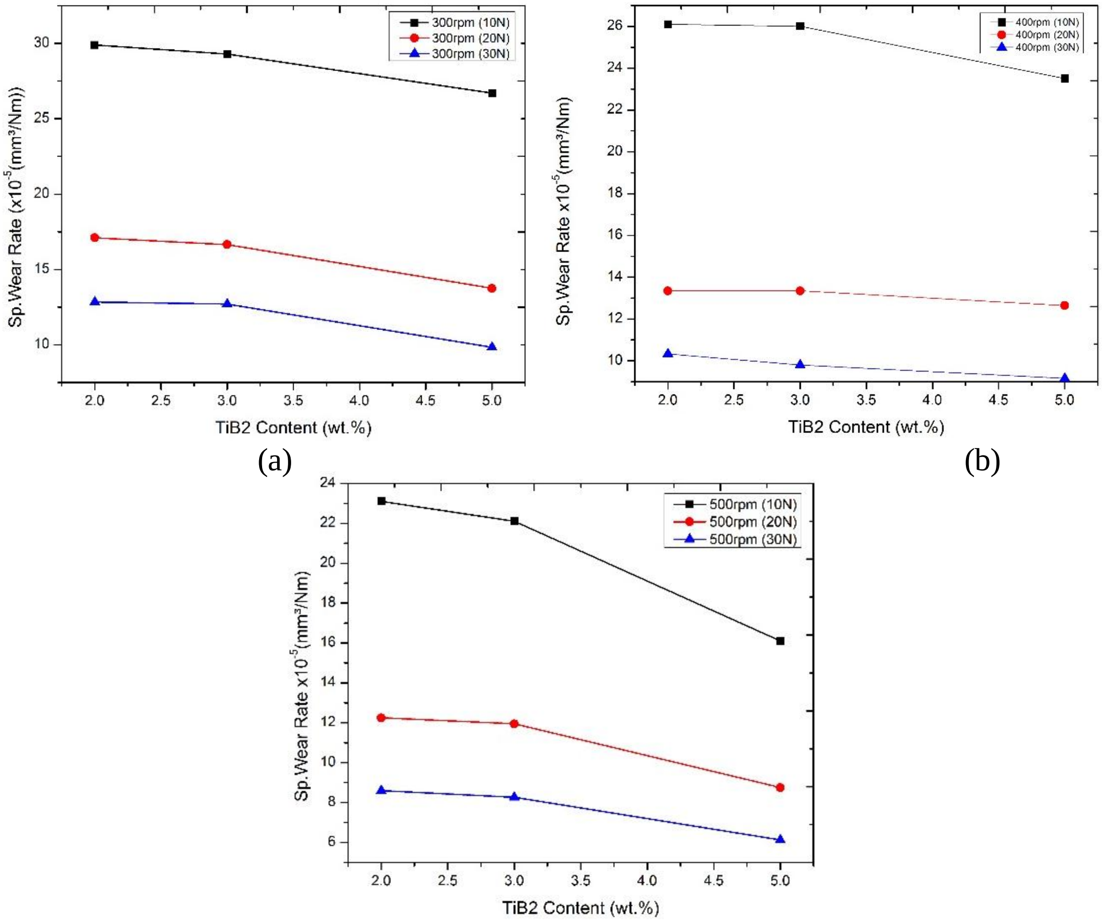


(a) (b)



(c)

Figure 7: Wear rate of the composite as a function of wt. % of TiB_2 and load at (a) 300 rpm (b) 400rpm (c) 500rpm



(a) (b)

(c)

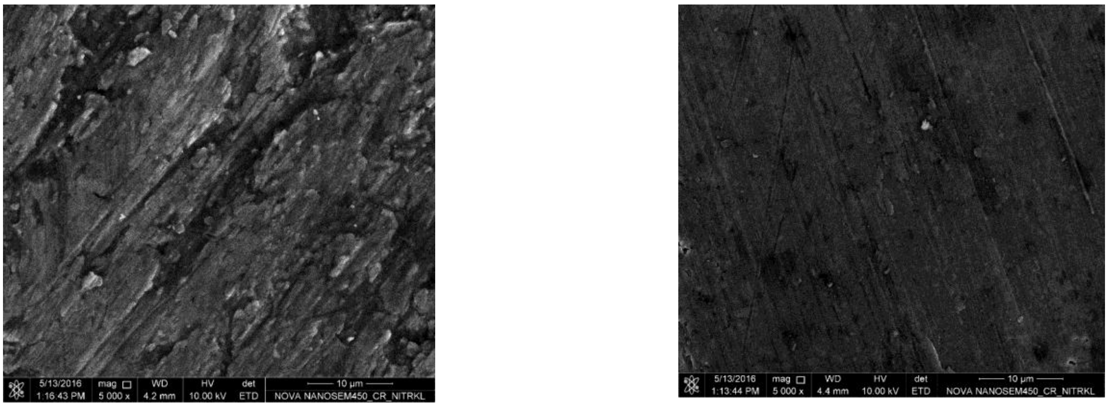
Figure 8: Specific Wear rate of the composite as a function of wt. % of TiB_2 and load at (a) 300 rpm (b) 400rpm (c) 500rpm

Figure 7 shows wear rate of in-situ composites with three varying wt. % of TiB_2, at different applied load and rpm. The wear rate found to decrease with increase in wt. % of TiB_2 because of improvement in refining of eutectic structure but the wear rate was brought up with higher applied load and found to be maximum at 30N load.

Figure 8 shows specific wear rate of the composite and a similar trend was observed for varying wt. % of TiB_2 and describes the minimum specific wear rate in higher TiB_2 content in all conditions. Due to stir casting method uniform dispersion of the TiB_2 particles and grain refinement affinity of these particles account for lower specific wear rate in Al-12.6Si-5TiB_2 composite samples.

In general, at constant sliding distance the specific wear rate is proportional inversely to the normal pressure; this could be due to the work hardening effect at the wear surface during sliding. However, addition of grain refiner to Al–Si alloys shows less specific wear rate as compared to the base matrix. The change in microstructure from plate like eutectic Si to fine particles restriction resulted in high wear resistance of Al–Si alloys. With increase in sliding speed there was a decrease both in wear rate and specific wear rate due to the fact that, at low sliding speeds, more time is available for formation and growth of micro welds, which rises the force required to shear off the micro welds to retain the relative motion, due to which specific wear rate increases which verify the results of S.A. Kori , T.M. Chandrashekharaiah [14].

3.5 Worn surface analysis



(a) (b)

Figure.9 FESEM micrographs of worn surfaces of Al-12.6Si-xTiB_2 in-situ composite (a) 2 wt. % TiB_2 (b) 5 wt. % TiB_2

Figure.9 shows the morphology of the worn surfaces of the AMCs with different amounts of TiB_2. Deep grooves on the wear surface of the composite with 2 wt. % TiB_2 indicate more flow of material than the composite with 5 wt. % TiB_2 corroborating the wear data. It has also been noticed that the hard Si improves resistance of composite against plastic deformations and material flow. The probability of adhesive wear is limited in these composite and the dominant mechanism is abrasion and de-lamination.

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) The XRD analysis showed the presence of TiB_2 in the Al-Si matrix.
3) Density test observations and hardness values were in affirmation with presence of different constituents of the prepared composite samples.
4) Wear rate and specific wear rate found to decrease at all the operating conditions with higher TiB_2 content.
5) Microstructure study revealed the effect of TiB_2 in growth limitation in eutectic Al-Si alloy.

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