

# Wear behavior of Al-Si alloy based metal matrix composite reinforced with TiB<sub>2</sub>

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**Abstract:** Al-Si alloy based composites are widely used in automotive, aerospace and for structural application due to improved strength to weight ratio, low density, and better wear resistance. In the present work, Al-xSi-5TiB<sub>2</sub> (x=7, 11, 12.6) in-situ composite was synthesized successfully by stir casting method. Here the composites were prepared by the exothermic reaction of K<sub>2</sub>TiF<sub>6</sub> and KBF<sub>4</sub> salts with the molten Al-x Si alloy. The dry sliding wear behavior of Al-Si matrix composites reinforced with 5 % TiB<sub>2</sub> was studied using a pin-on-disc wear testing machine to study the effect of % Si, load (10, 20, 30 N), sliding speed (1.36, 1.82, 2.27 m.s<sup>-1</sup>) and sliding distance on stir cast Al-xSi-5TiB<sub>2</sub> composites. The Al-Si alloy and the reinforcement mixers were confirmed by the X-ray Diffraction analysis. The microstructure of Al-xSi-5TiB<sub>2</sub> composite was investigated by using Optical Microscope to determine the phases present in the prepared composites. The prepared AMC composites were tested for hardness using Vickers Hardness tester with the variation of Si. Wear rate (mm<sup>3</sup>/m), Wear resistance (m/mm<sup>3</sup>), Specific Wear rate (m<sup>3</sup>/N.m) and were analyzed with various conditions. The worn surfaces of the specimens were analyzed before and after wear testing by Scanning Electron Microscope (SEM) to determine the governing wear mechanisms in the composites. Wear rate and specific wear rate decreases at all the operating condition with increase in wt% Si. Wear resistance all most increases with increase in wt% Si. Hardness values are increased with increase in amount of Si.

## 1. Introduction

The most rapidly growing area of composites is that of Aluminium matrix composites as a result of their improved physical, chemical and mechanical properties. Amongst different Aluminium alloys as matrix phase Al-Si alloys are widely used as engineering materials due to their light weight, good castability, high specific strength, enhanced wear resistance and reasonable cost. Addition of ceramic particles like TiB<sub>2</sub>, SiC or Al<sub>2</sub>O<sub>3</sub> to the aluminium based matrix phase does not increase the density considerably but ensures significant rise in the specific strength, modulus and wear resistance [1-3]. Al-TiB<sub>2</sub> composite exhibits some useful and unique characteristics with respect to its properties and processing route. [4-5]

Synthesizing the ceramic particles within molten Aluminium alloys is called the in-situ method of preparing the AMCs. In the in-situ synthesis of salt-metal reaction the exothermic reaction between Potassium Hexa Fluoro Titanate (K<sub>2</sub>TiF<sub>6</sub>) and Potassium Tetra Fluoro Borate (KBF<sub>4</sub>) halide salts yields TiB<sub>2</sub> particles within the matrix phase. [6-8]

In the present work an attempt is to be made in order to study, synthesize and characterize the Al-varying amount of Si alloys dispersed with fixed amount of TiB<sub>2</sub> for different engineering applications.



## 2. Experimental Details

The overall experimental procedure can be divided into two stages. In the first stage, Al-xSi alloy (x=7, 11, 12.6) and Al-xSi-5TiB<sub>2</sub> composite samples are synthesized and casted. In the second stage, the samples were characterized for their microstructure, and wear behavior.

### 2.1 Synthesis of in-situ Al-axis alloy and Al- xSi-5TiB<sub>2</sub> composite

Initially Al-50Si master alloy and commercially pure aluminum (99 %) was melted in a graphite crucible in a non-ferrous melting furnace at 720°C to prepare Al-axis alloy. The Al-xSi-5TiB<sub>2</sub> composite was synthesized by Flux Assisted Synthesis (FAS) technique which consists of addition of halide salts, K<sub>2</sub>TiF<sub>6</sub> and KBF<sub>4</sub>, to molten Al-Si alloy at 800° C and a reaction time of one hour. The exothermic reaction within the melt results in formation of titanium diboride (TiB<sub>2</sub>) particles. The melt was stirred intermittently every 10 minutes to ensure complete reaction of salts with molten aluminium and homogeneous distribution of TiB<sub>2</sub> particles. After completion of reaction, the lighter dross was decanted. The molten composite was then poured into a preheated (450°C) cast iron mould for preparation of different specimen.

### 2.2 Characterization

#### 2.2.1 Optical Microscopy

Microstructures of the composite samples were observed under computerized optical microscope. The samples were polished using emery papers followed by disc polishing and etching with Keller's reagent (1 % HF-1.5 % HCl-2.5 % HNO<sub>3</sub>-95 % H<sub>2</sub>O). The micrographs of the samples were obtained.

#### 2.2.2 X-Ray Diffraction Analysis

X-ray diffraction analysis of the composite samples was performed with Co-K $\alpha$  target to identify different phases. Sample of size 10mm $\times$ 10 mm $\times$ 2mm were taken for x-ray diffraction. The diffraction pattern was then analyzed by matching the peaks with JCPDS data files to identify all the phases present in the sample.

#### 2.2.3 Hardness test

The microvicker's hardness test was conducted for measuring the hardness of the AMC in-situ composite with varying amounts of Si in the matrix. The samples to be tested were machined to require dimension and both their horizontal faces were made parallel by polishing .The square based diamond pyramid was used as indenter and 1kgf load applied for 15 seconds. The hardness values were measured in three locations over the sample and the average length of the diagonals of the indentation were calculated. Then the Vickers Hardness Number (VHN) of the samples was obtained.

#### 2.2.4 Wear Testing

Wear tests were conducted on a pin-on-disc wear testing machine. The cylindrical pins (10mm diameter and 30mm height) of the composite sample were cut by specimen cutter ,machined and then polished metallographically .Wear test are conducted by varying loads ranging from 10 to 30N ,and sliding speed 1.36,1.82,2.27 m.s<sup>-1</sup> for 300 sec and 600 sec. at room temperature without any lubricants . During the test the pin is pressed to the steel disc by applying normal load. The wear testing machine is microprocessor controlled where height loss and frictional force was monitored simultaneously. After the test completed the specimen are removed, cleaned through acetone, dried and weighed to determine weight loss due to wear. Difference in weight before and after testing was measured to determine weight loss (i.e. wear) in the composite specimen. The wear of the

composite specimen were studied as a function of weight percentage of silicon in the alloy matrix, sliding speed, applied load, and sliding distance.

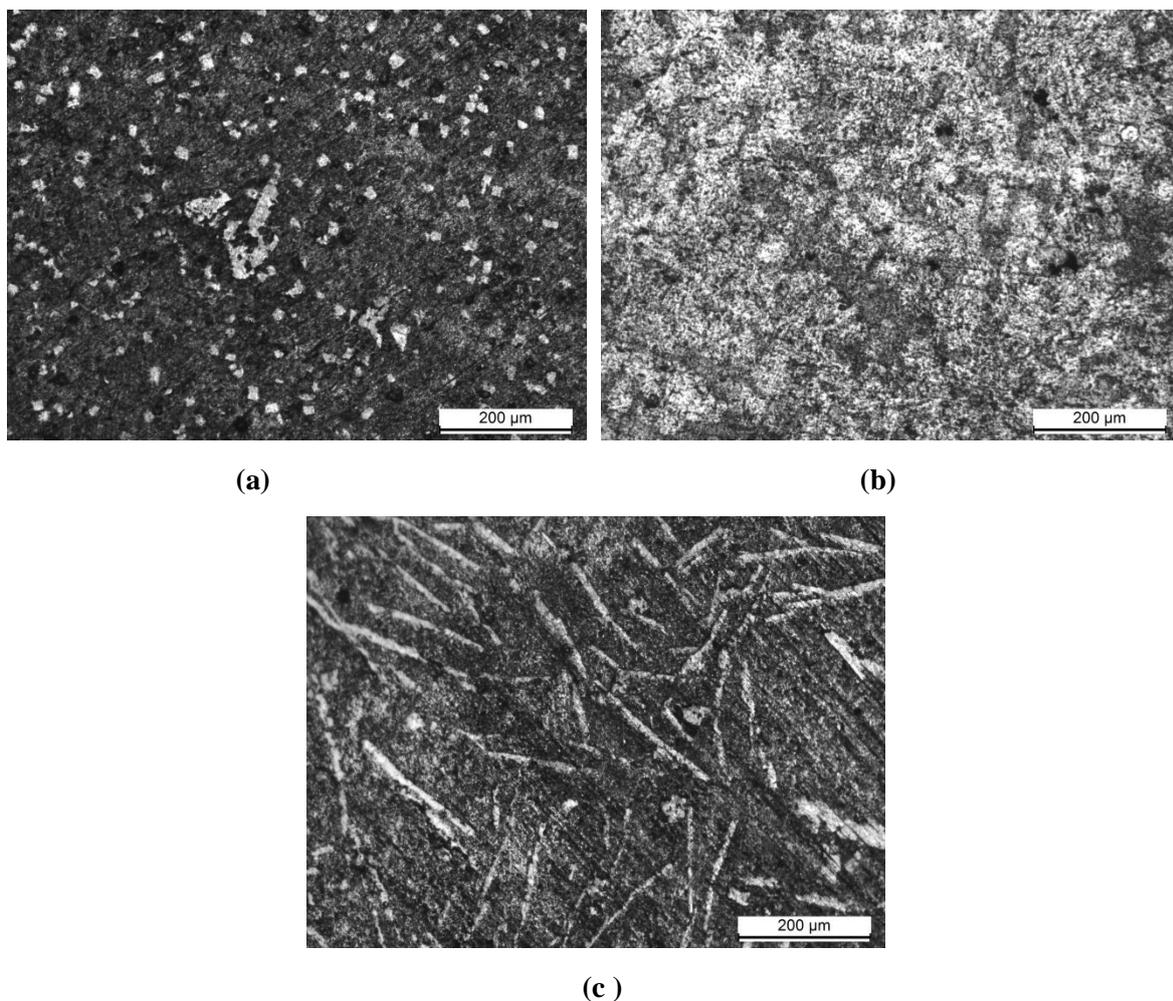
### 2.2.5 Scanning electron microscopy

Worn surfaces of the composite were examined with Field emission electron microscope (FESEM).

## 3. Results and discussion

### 3.1 Microstructure

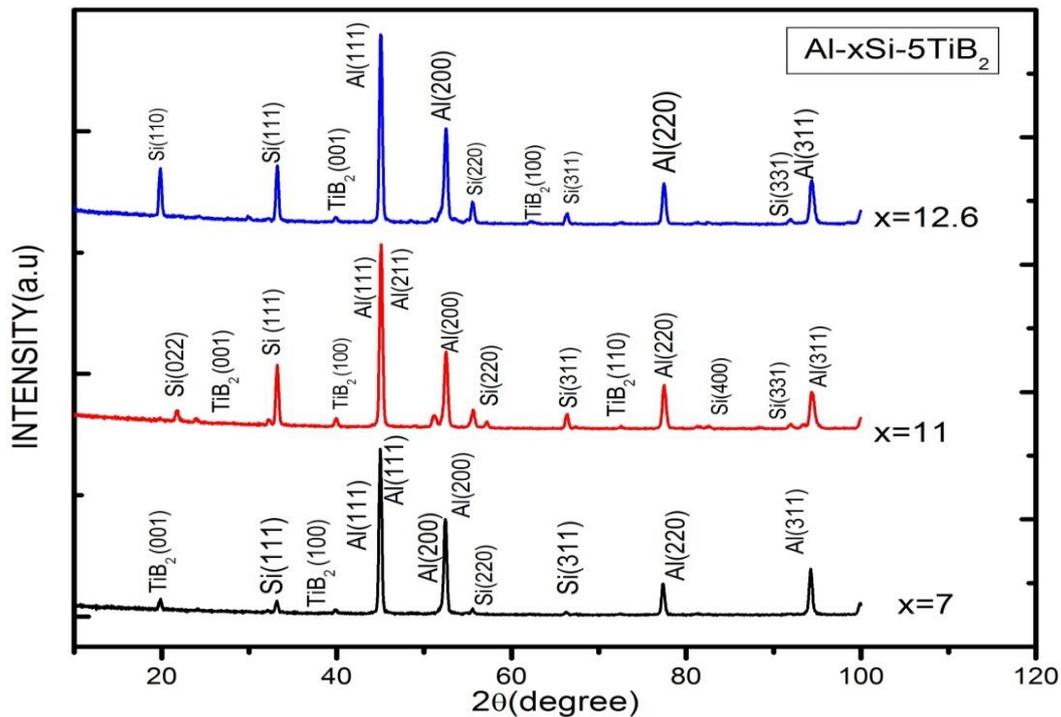
The optical microstructure of Al-7Si-5TiB<sub>2</sub>, Al-11Si-5TiB<sub>2</sub> and Al-12.6Si-5TiB<sub>2</sub> in situ composite are respectively shown the fig-1. it is observed from the figure that the Si particles are distributed with the  $\alpha$ -Al in the Al-7Si-5TiB<sub>2</sub>. Al-12.6Si is the eutectic composition of Al-Si binary alloy which exhibit niddle shaped Si well dispersed throughout aluminium matrix but in the formation of TiB<sub>2</sub> particles in the melt , the space available for the growth of Si decreases. TiB<sub>2</sub> particles thus restrict the growth of Si during the solidification.



**Figure1.** Optical micrograph at (100X) of (a) Al-7Si-5TiB<sub>2</sub> (b) Al-11Si-5TiB<sub>2</sub>(c ) Al-12.6Si- 5TiB<sub>2</sub> in-situ AMC composite

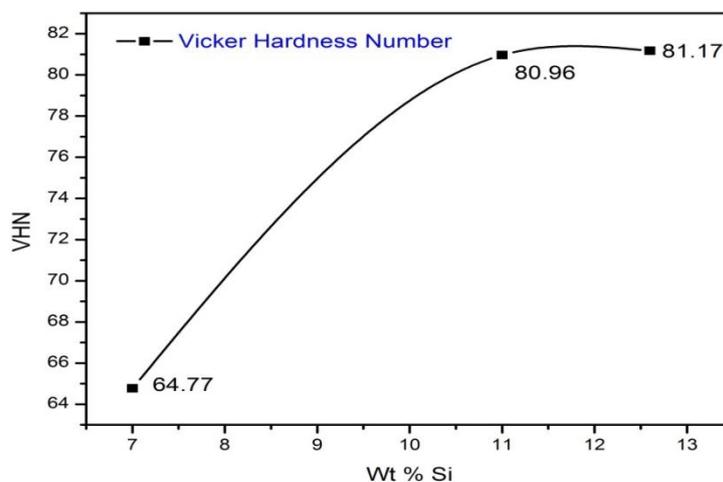
### 3.2 XRD Analysis of in-situ Composite

In XRD result that has been obtained reveals that the presence of Aluminium is in the form of the largest peaks. Minor peaks indicate the presence of Silicon and Titanium diboride particles. It is evident that there is an increase in the weight percentage of the Silicon the peaks of Si also increases. The peaks of  $TiB_2$  in the XRD pattern confirms the formation of  $TiB_2$  in the Al-Si alloy matrix.



**Figure.2** XRD results for the prepared in-situ composites

### 3.3 Hardness test results



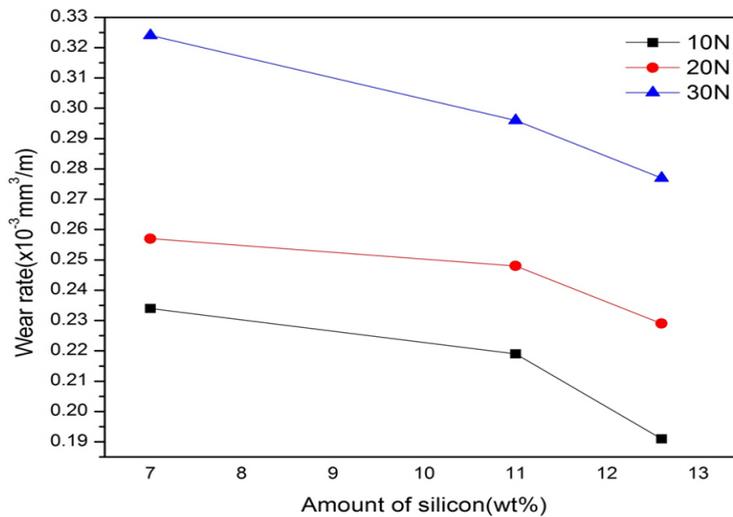
**Figure.3** Hardness test results of the prepared in-situ composites

From the above graph it can be observed that AMC material having 12.6 % Si is showing maximum hardness and AMC having 7% Si is showing the least hardness. Increase in amount of silicon increases the eutectic Al-Si phase which resists the plastic deformation which leads to in the hardness of the composites.

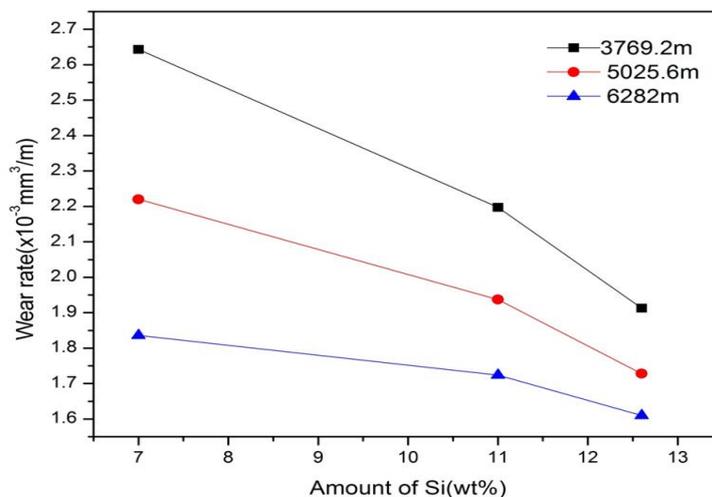
### 3.4 Analysis of wear test results

#### 3.4.1 Wear rate of the composite as a function of wt% of Si and load, speed, sliding distance

Figures 4-6 indicates the wear rate of the prepared composite as a function of amount of Si and load, sliding distance, sliding speed. The wear rate of three varying wt% of Si of the in-situ composites were compared with different controlling condition. The wear rate was decreased along with the increasing wt% of Si. The higher wt% of Si has the minimum wear rate in all the conditions of the experiment. Figure. 4 shows that the wear rate decreases with increase in load. Fig 4.2 confirms the minimum wear rate achieved to the various sliding distances.

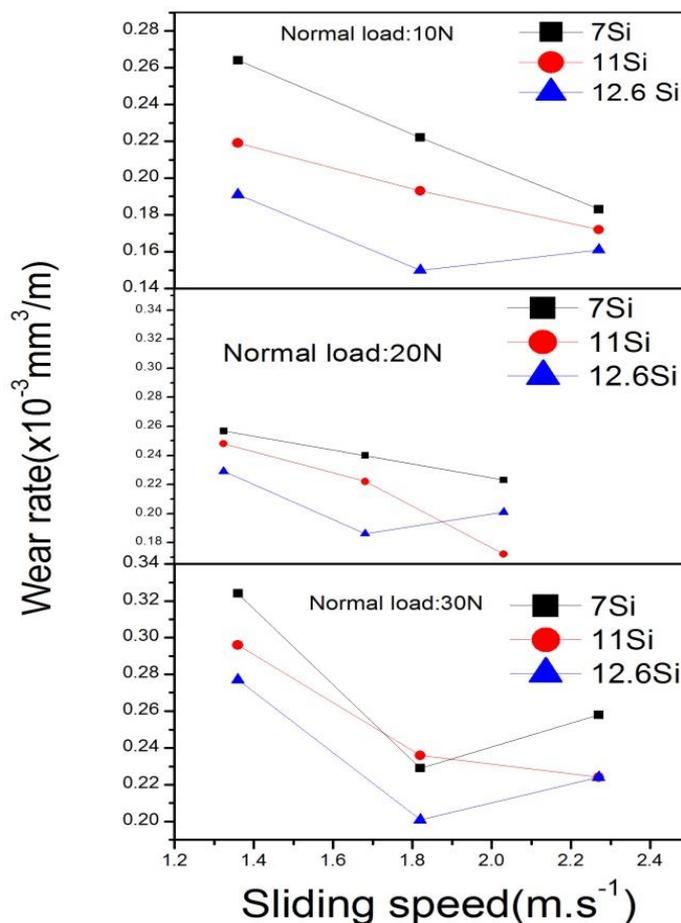


**Figure.4** Wear rate of the in-situ composites as a function of amount of Si(wt%) and sliding distance



**Figure.5** Wear rate of the in-situ composites as a function of amount of Si(wt%) and sliding distance

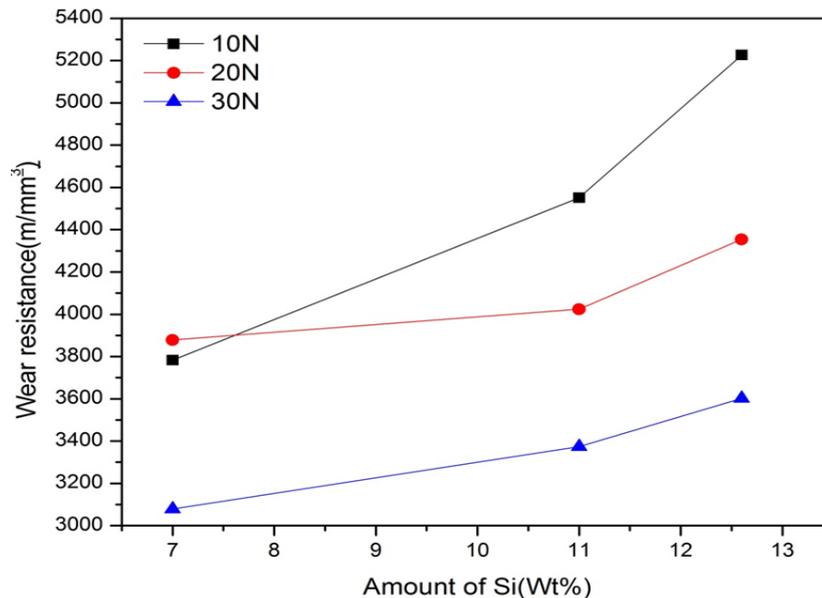
The effect of sliding speed on wear rate is shown in Figure.6 for the AMC's tested for different loads of 10, 20, 30N respectively. Wear rate was decreased with increase in sliding speed in all most the three cases ,one of the possible causes for the reduced wear rate at the start could be the surface oxidation which may increase the local hardness and strength at the interface .The drop of wear rate which causes the AMC to have increased wear resistance, i.e. the effect of oxidation increases gradually. Another thing that during wear process two opposing processes acted such as softening and hardening that took place simultaneously. The softening of surface material occurs with the increase of temperature and strength, and the hardening occurs with the formation of metal oxides .The oxidation is a continuous process at all rotational speeds .The metal oxide film thickness would possibly grow at faster rate than the rate of material removal. It means that only the strengthened and hardened metal oxide would be present at the interface and it would mask the softer matrix material underneath. But in case of 12.6 wt % Si AMC the wear rate decreases first then increases with increasing the sliding speed. This is due to severe wear for that material at higher speed. At loads of 10N, 20N, and 30N, wear rate of all samples were increases respectively. However, a large difference in wear rate was observed at 30N loads.



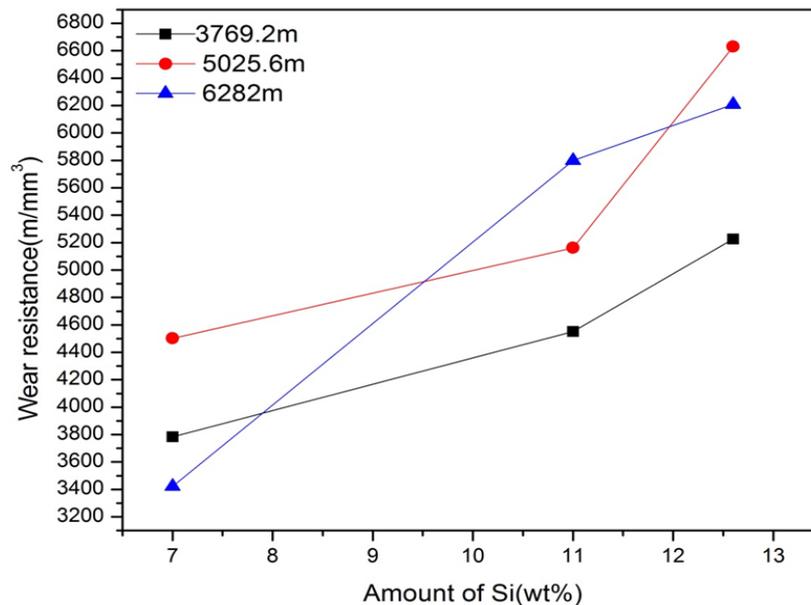
**Figure.6** Wear rate of the in-situ composites as a function of sliding speed and amount of Si (wt%) in different load

### 3.4.2 Wear resistance of the composite as a function of wt % of Si and load, sliding distance

The wear resistance of the prepared composites with various parameters is shown in the Figure 7-8. The composites with the higher wt % of the Si have the higher wear resistance. Similarly as the sliding distance increases the wear resistance increases.



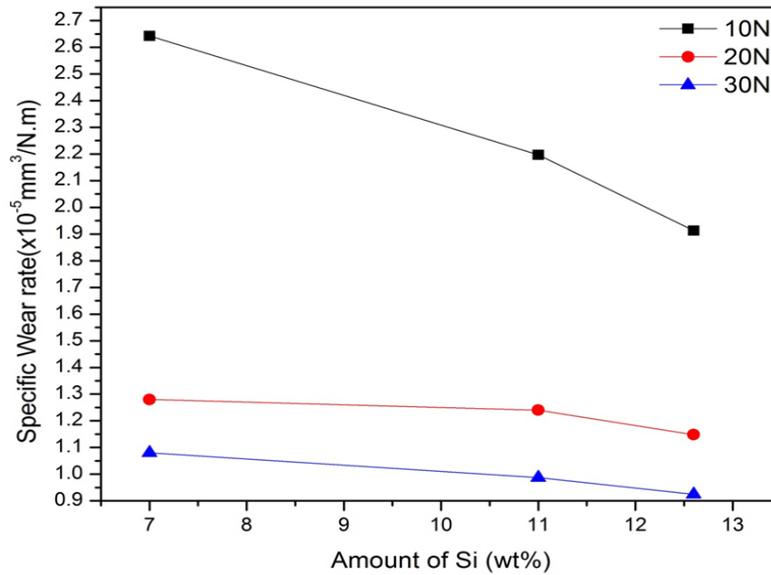
**Figure.7** Wear resistance of the in-situ composites as a function of amount of Si (wt%) and load



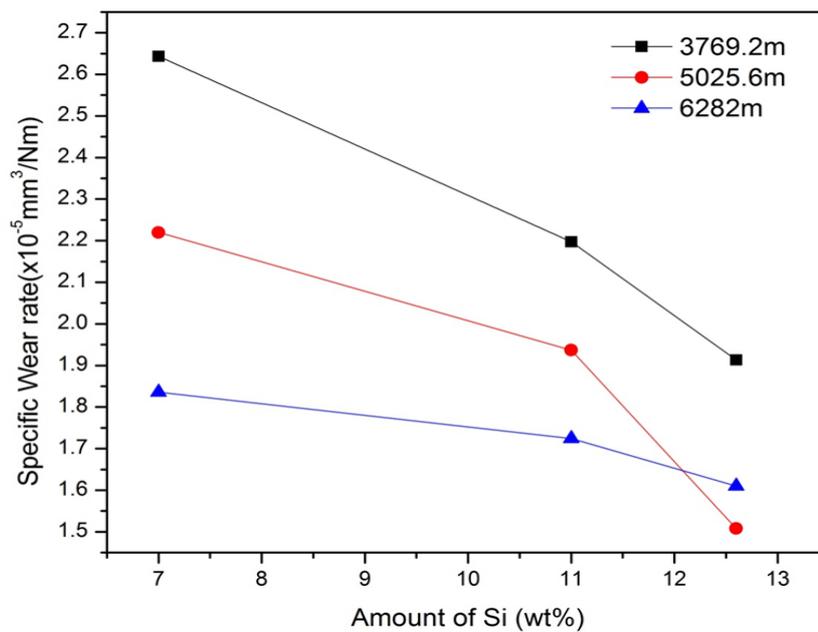
**Figure.8** Wear resistance of the in-situ composites as a function of amount of Si (wt%) and sliding distance

### 3.4.3 Specific wear rate of the composite as a function of wt% of Si and load, sliding distance

Specific wear rate was compared with various wear testing condition such as load and sliding distance of the composite with various wt % of Si contents. Figure.9-10 proves the minimum specific wear rate in all condition. By the stir casting method the reinforcements and the Si were mixed successfully and achieved the uniform distribution to improve the wear properties. The various testing conditions were performed to observe the specific wear rate, the silicon contents were increased and the specific wear rate was decreased simultaneously.

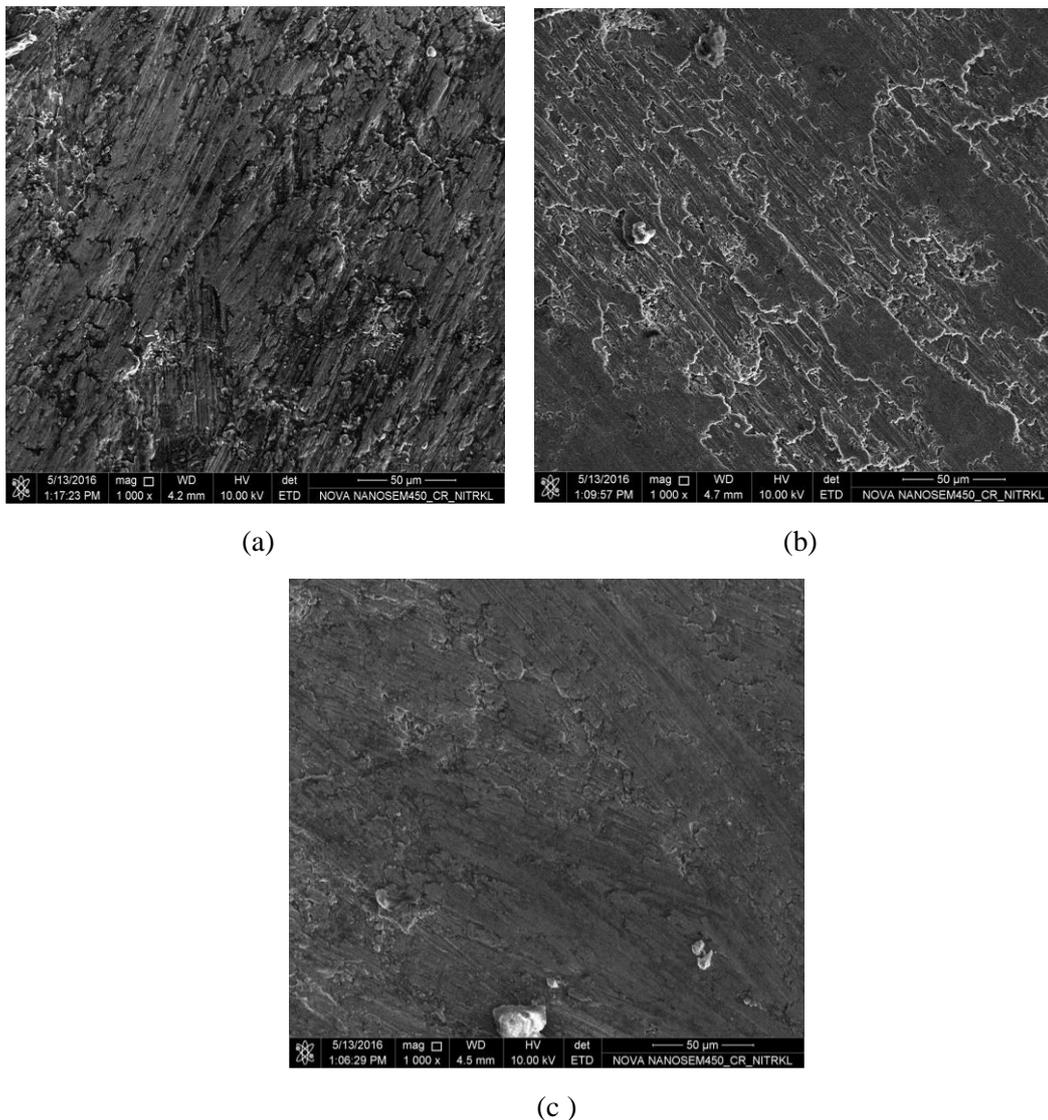


**Figure.9** Specific wear rate of the in-situ composites as a function of amount of Si (wt%) and load



**Figure.10** Specific wear rate of the in-situ composites as a function of amount of Si (wt%) and sliding distance

### 3.5 Worn surface analysis



**Figure.11** FESEM micrographs of worn surfaces of Al-xSi-5TiB<sub>2</sub> in-situ composite (a) 7 wt% Si (b) 11% Si (c) 12.6% Si

Figure.11 shows the morphology of the worn surfaces of the AMCs with varying amounts of Si (wt %). The wear mechanism is characterized by the flow of material in wavy form and deep grooves on the wear surface. However, the material flow was less in SEM images of the worn surface of "12.6%" Si AMC. But larger grooves were clearly visible in the "7 % Si" micrographs. In all the three cases the grooves are formed on the wear surface due to ploughing action of the hard asperities of Si. This increases the temperature of the wear surface of the composite. Further, the yield strength of the composite is decreased, which results in softening of wear surface and starting of adhesive wear. It is noticed that the Si is a hard material. This may plough out from the composite during sliding of the counter face of the disc. It has also found that the hard Si improves resistance of composite against plastic deformation and material flow there by increasing the load bearing capacity. The probability of adhesive wear is less in these composite and the dominant mechanism is abrasion and de-lamination.

#### 4. Conclusions

From the present investigations the following conclusions were obtained:

- 1) The Al-xSi-5TiB<sub>2</sub> in-situ composite was synthesized successfully by stir melt casting.
- 2) XRD analysis confirmed that the required phases are present in the in-situ AMCs.
- 3) Hardness values are increases with increase in amount of Si (wt %).
- 4) Wear rate (mm<sup>3</sup>/m) and specific wear rate (mm<sup>3</sup>/Nm) decreases at all the operating condition with increase in wt % Si.
- 5) Wear resistance all most increases with increase in wt%Si.
- 6) Wear mechanism was studied from the SEM micrograph of the worn surface of the in-situ AMCs.

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