ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)

https://doi.org/10.17559/TV-20220217173159
Preliminary communication

Investigation on Mechanical Properties of Aluminum 8011 Metal Matrix Compositewith Titanium Carbide Particulate Reinforcement

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Abstract: Aluminium metal matrix composites are the key material in engineering fields like aerospace, defense, automobiles and consumer goods. Aluminium matrix composite dominates the conventional materials due to its low economic rate, high wear resistance and strength to weight ratio. So, the present work considered Al 8011 alloy as the metal matrix and titanium carbide (TiC) particles as reinforced material for investigation. The composite was prepared by stir casting method. A digital pin on disc tester was used to measure the wear with EN32 steel disc as counter surface (72HRC) and cylindrical pin as the composite specimens. The present tests were conducted for various sliding velocity of 1,57 m/s, 2,62 m/s and 3,67 m/s. The normal load of 20 N, 40 N, 60 N and the filler content of 0%, 10%, 20% have been considered for the sliding distance of 1000, 3000 and 5000 m. The results of new composite show better wear resistance than matrix metal. The micro structural characterization of worn surface was investigated using De-wintor inverted trinocular metallurgical microscope. Prepared polished matrix shows the distribution of TiC particles in Al 8011 metal matrix based on the quantity added. The impact energy of the samples was found using Izod impact testing machine. Final results showed improved mechanical properties for Al 8011 with 7% TiC compared with other two samples.

Keywords: Al8011-TiC composite; impact; microstructure; tensile; wear

1 INTRODUCTION

In recent years, metal matrix composites have drawn the attention of many researchers and scientists due to their superior properties such as high specific strength, lower density with higher wear resistance [1, 2]. In addition to that, particular reinforced metal matrix composites are finding high volumes of commercial applications. Ease of fabrication methods, isotropic properties and improved mechanical properties are the basic reasons to select metal matrix composites [3, 4]. Recent researches have considered several reinforcement materials for aluminium metal matrix composites, but a special attention was created on TiCdue to its high hardness, wear resistance and stiffness [2, 5]. Hence, titanium carbide is used as reinforced particles since they are hard refractory substance with black appearance of sodium chloride crystal structure. Because of its good mechanical properties, titanium carbide is frequently used [6]. It is reported that electron density of TiC ceramics dispersed uniformly which provides a good metallic character of bonds. Also it can enable the chemical bonds in close proximity [7].To fabricate these composites, stir casting method is a common practice which produces discontinuous metal matrix laminates. The present study used stir casting technique which considers several factors such as proper reinforcement distribution inside the matrix, wettability between reinforcement and metal matrix, porosity, chemical compatibility during the process. The process and preparations of SiC particles reinforced aluminium metal matrix composites by stir casting method was studied [8, 9]. In some researches, fly ashes are used as reinforcement since availability is easierand dispersions discontinuous due to their low density and low reinforcement factors [10]. A comparative study on Al 7075 and the Al-7075metal matrix composites shows that hardness and the tensile strengths are increasing when they are reinforced with fly ashes [11]. The microstructure analysis of the Al-WC composite has been studied [4] along with a few manufacturing techniques. The results were found to be extraordinary because of their better interfacial bond between tungsten carbide particles with metal matrix. When compared to aluminium, it has a higher gain structure and impact resistance. Also, Al alloys were having high thermal elongation and poor wear resistance. To overcome this issue, silicon carbide has been reinforced with the Al alloys to improve the wear resistance, thereby reducing the thermal elongation [12, 13]. So, the addition of SiC will improve the wear resistance and hardness of heat treated composite materials [14]. Similarly, the influence of TiC reinforcement has been investigated on various parameters such as microstructure, wear resistance, hardness and kinetics [15-17]. Also, hardness value and tensile properties are reported for the reinforcement of TiC particles [18-19].A study reported the influence of TiC in aluminium metal matrix composite on relative density (R), formability stress index and stress ratio parameters [20]. The tribological properties of Al matrix composites strongly depend on carbon content [21, 22]. Also the influence of Ti addition on mechanical properties of matrix composites has been investigated [23, 24]. In recent researches, nanocomposites are considered in larger scale with the Al alloy matrix [25]. Hence, the literature survey showed that the addition of TiC particles to Al composites was providing possible and improved material properties for various applications.

2 MATERIALS

The experimental investigation on prepared metal matrix composite is carried out by considering the following materials, machines and standard preparation methods.

Aluminum 8011 (Al 8081) alloy is selected as metal matrix which is a wrought alloy. The following table will provide more details about aluminum 8011 alloy.

Titanium Carbide (TiC): TiC is used as reinforcing material for fabricating Al-TiC metal matrix composite. The properties of TiC are shown in Tab. 2.

Stir casting: Stir casting process has been selected to fabricate the composite which is a familiar method of composite production. Initially the reinforcement particles have been added to molten base metal and stirred continuously. The final mixture is taken in a specified die to let solidify for a certain period of time. Usually, the particles will get agglomerated in stir-casting process that can be dissolved by consistent stirring at high temperature.

Table 1 Properties of selected Al 8081

Elements	Specified value / %	Observed value / %
Silicon	0,4 - 0,8	0,598
Iron	0,5 - 1,0	0,774
Copper	0,1 Max	0,038
Maganese	0,1 Max	0,054
Magnesium	0,1 Max	0,009
Chromium	0,1 Max	0,007
Zinc	0,1 Max	0,002
Titanium	0,05 Max	0,021
Aluminium	Rest	98,473

Table 2 Properties of TiC

S.No	Parameter	Quantity
1	Formula	TiC
2	Appearance	Black powder
3	Elastic Modulus	400 GPa
4	Shear Modulus	188 GPa
5	Density	4.93 g/cm^3
6	Molar Mass	59.89 g/mol
7	Melting point	4300 °C

3 EXPERIMENTAL

Tensile test: The capability of material to withstand stress at maximum force before its failure is termed as tensile strength. To estimate the tensile strength, a standard test specimen is prepared with two shoulders (end) and a gage section in between them. The gage section is smaller whereas the shoulders are bigger in diameter to properly grip at the end. The deformation and failure will occur at the gage section during the test. The test has been carried out under the following specification:

- Tensile load range: Max 5 Ton.
- Make: Associate scientific engineering works, New Delhi.
- Digital encoder Make: Auto Instruments, Kholapur.
- Software details: FIE Make, India.
- Shape of the specimen: Cylindrical.
- Specimen diameter: 5,75 mm.
- Cross section area: 25,978 mm^2.
- Original gauge length: 40 mm.
- Final gauge length: 44,71 mm.
- Grip section: 20 mm.

Wear Test: For wear test, the cylindrical specimen is prepared with 10 mm diameter and 30 mm length. The sample was tested on a hardened ground steel disc (EN-32, hardness 72 HRC, surface roughness Ra = 0,07 μm). Here, the frictional force was monitored by the transducer which was mounted on the loading arm. The frictional force readings were noted for every 40 seconds time interval with 100 readings as average. The sliding velocity of 1,57; 2,62; 3,67 m/s, normal load of 20, 40, 60 N, filler content of 0, 10, 20% and the sliding distance of 1000, 3000 and 5000 m have been considered.

Impact test: To estimate the impact strength, an ASTM standard, called Izod impact testing was considered. A specimen with notched section was used to determine the impact energy and notch sensitivity. In this test, apendulum with constant potential energy is pulled to a specific height and then released. Hence, the pendulum travels down which hits the sample and tends to break the specimen. The impact energy absorbed by the specimen was calculated from the difference of the potential energy of the hammer at the beginning and end of the test:

- Model: XJJU-50.
- Impact energy: 5,5 J; 11 J; 22 J.
- Impact speed: 3,5 m/s.
- Display: Automated, Digital.
- Load model: Charpy and Izod.
- Shape of the specimen: Square.
- Size: 12 mm.
- Length: 60 mm.
- Wedge angle: V notch, 45°.
- Wedge depth: 5 mm.

Microstructure analysis: A specimen was prepared for microscopic examination by considering the following stages.

Cutting: The cutting process may change the microstructure of a specimen material, since the heating and mechanical failures could happen during the cutting. So, for ceramics, low speed diamond wafer blades were used. Because the specimen's entire body may not be homogeneous, the specimen has been prepared by focusing on the region that represents the proper structure.

Mounting: Mounting is an essential step to ensure the protection of metallographic specimen edges and improvement of its irregular shape. Proper mounting enables both manual and automated grinding/polishing operation in easy way. Compression mounting is the familiar method for metal specimen.

Grinding: Surface damages are reduced by grinding. Initially, the rotation speed is 300 rpm and has to be reduced to 150 rpm in the course of grinding. Grinding process is carried out on different stages by applying grinding papers with ever smaller granulations of the abrasive, 240, 400, 600 and 1000. The consecutive grinding operation removed the unwanted marks, created in the previous operation. The specimen was washed thoroughly after each grinding stage to prevent the carry-over coarser grit to the grinding paper.

Polishing: This process removed the fine scratches developed during final grinding operation. A mixture of powder (Alumina 14 μm, magnesia 6 μm and diamond 1 μm) and water is spread over a rotating disc covered with polishing velvet cloth for successive polishing stages. To prevent the contamination in polishing cloth, the specimen is washed at every stage of polishing from the previous stage. Polishing process uses the rotary disc machines with variable rotation speed.

4 RESULTS AND DISCUSSIONS

Tensile test: Fig. 1 to Fig. 3 shows the graphical representation of stress-strain relationship. Here, the tensile strength of the specimen is plotted against relative change in length of the specimen during the test.

This shows various characteristics such as maximum yield point and ultimate tensile strength of material being tested. Tensile strength of Al 8011 is 140 N/mm^2. Fig. 1 to Fig. 3 show maximum tensile strength of 142 N/mm^2, 165 N/mm^2 and 148 N/mm^2, respectively. The composite improved the tensile strength in the range of 1,4% - 15,15%.

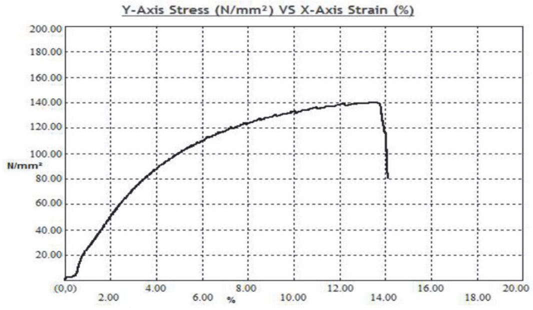

Figure 1 Stress versus strain at 5% TiC

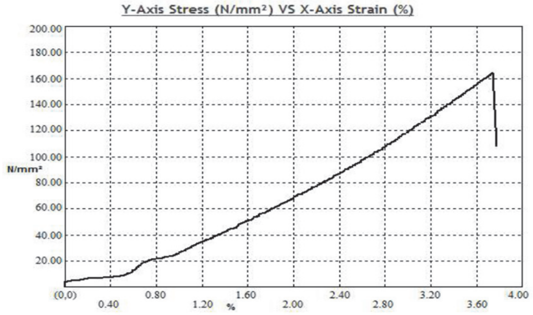

Figure 2 Stress versus strain at 7% TiC

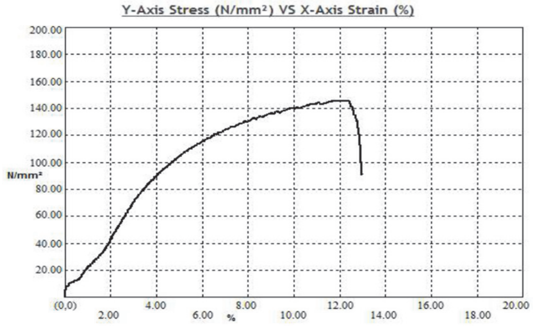

Figure 3 Stress versus strain at 10% TiC

Wear test: Fig. 4, Fig. 6 and Fig. 8 show the variation of wear rate with respect to time which is conducted at a sliding velocity of 1,57; 2,62 and 3,67 m/sec respectively. It was observed that increasing the sliding distance reduces the wear rate. Also it decreases while increasing the amount of TiC particulates. So, reinforcement of the titanium carbide in metal matrix is possibly increasing its wear strength.

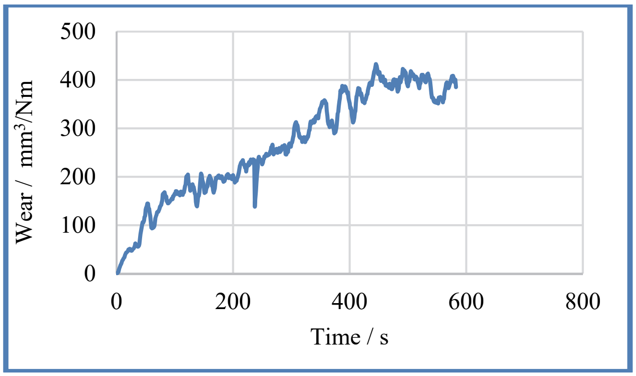

Figure 4 Wear rate versus time at 5%

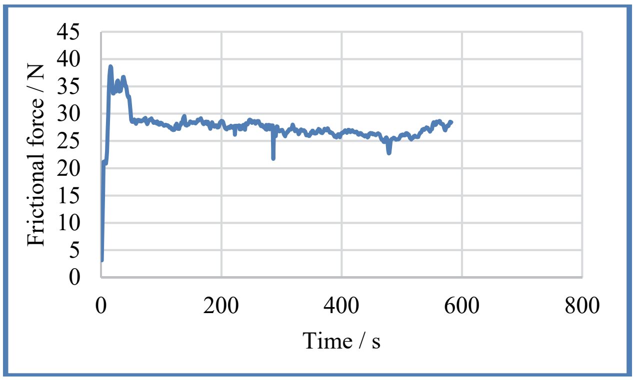

Figure 5 Frictional force versus time at 5%

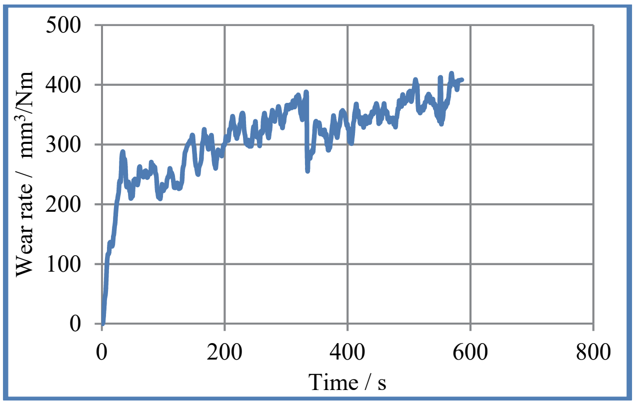

Figure 6 Wear rate versus time at 7%

Pre-experimentation results showed that the wear rate of reinforcement of base material (0% TiC) with 5% TiC and 7% TiCis high compared to 10% TiC reinforcement. The wear rate can be calculated by:

$$\mathit{Weare\ rate} = \frac{\Delta m \times 10^3}{\rho L F} \tag{1}$$

Wear rate in mm^3/Nm, ρ is density in gm/cm^3, F is load in N and L is sliding distance in the m.

Similarly Fig 5, Fig. 7 and Fig. 9 show the frictional force developed with respect to time. Here, 20, 40 and 60 N force was applied respectively during the test. It was noted that frictional force was gradually decreasing along with increasing the time.

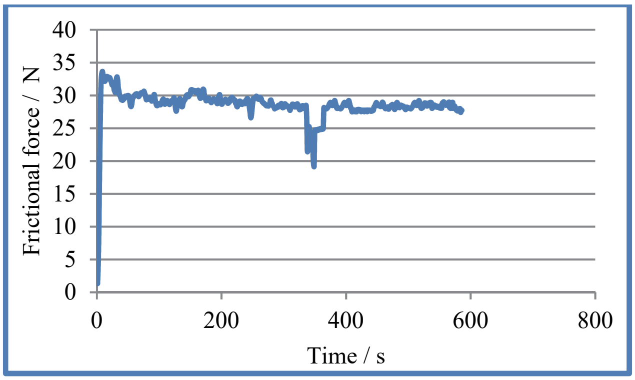

Figure 7 Frictional forceversus time at 7%

Impact test: Impact tests are used to study the toughness of material and energy absorption during plastic deformation.

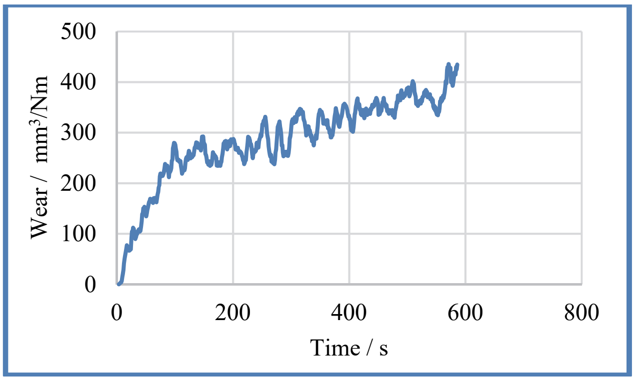

Figure 8 Wear rate versus time at 10%

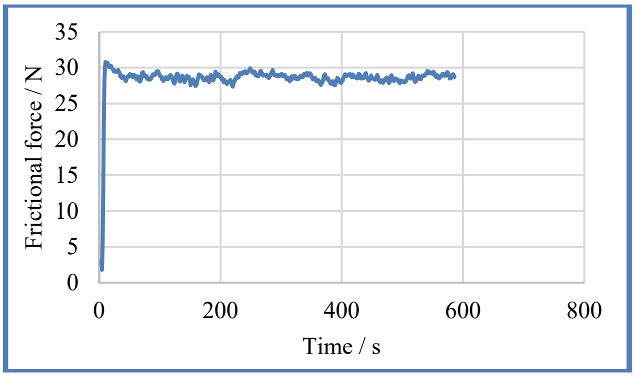

Figure 9 Frictional force versus time at 10%

Generally, the specimen size influences the output of the Izod impact test, since it may lead to the various imperfections in the material. Tab. 3 shows the energy absorbed at different weight percentage of TiC during the test. The composition of 10% TiC has absorbed maximum energy in comparison with the other two which shows the higher impact energy involved.

Table 3 Impact energy values

Trail No	Sample	Impact energy / J
1	Al + 5% TiC	12
2	Al + 5% TiC	11
1	Al + 7% TiC	16
2	Al + 7% TiC	15
1	Al + 10% TiC	17
2	Al + 10% TiC	17

Micro structural analysis: The purpose of micro examination is to show the evidence on TiC particle distribution over the metal matrix composites and the bonding characteristics. Fig. 10a to Fig. 10d, shows the stir cast metal matrix composite of Al 8011 with 5% TiC. The polished matrix shows the distribution of composite particles in Al 8011 metal matrix. But, Fig. 13b shows uniform and lean distribution of TiC in metal matrix.

Fig. 11 shows the microstructure of metal matrix composite under chemical etching with 2,5% HNO_3, 2% HCl, 1% HF, and 94,5% H_2O solution. Fig. 12a to Fig. 12d shows the stir cast metal matrix composite of Al 8011 with 7% TiC. The distribution of TiC composite particles in Al 8011 metal matrix is higher than 5% because of increased quantity. TiC particles filled the pores or cavities available on the surface of Al metal. Fig. 12c indicates uniform distribution of TiC in metal matrix.

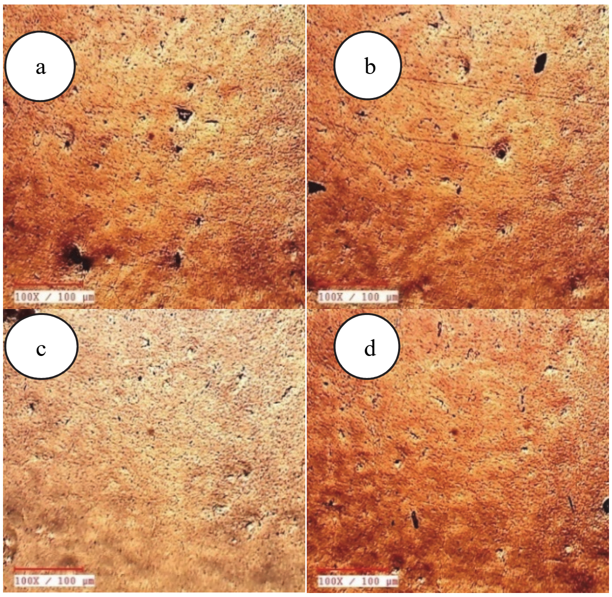

Figure 10 Structure in polished state (at 5% TiC)

Fig. 13a to Fig. 13d represents the microstructure of the same composite in etched condition. Here, the black particles are observed over the grain boundaries and they could be the TiC particles.

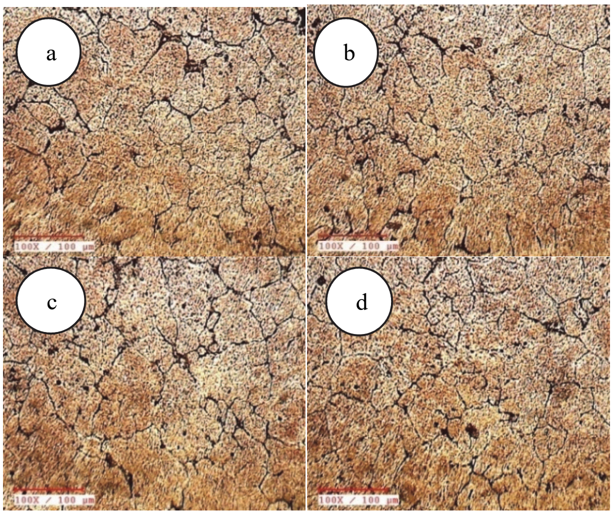

Figure 11 Etched microstructure (at 5% TiC)

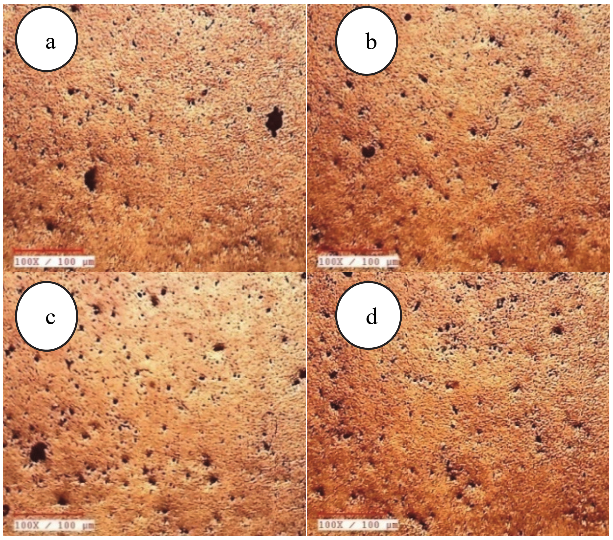

Figure 12 Structure in polished state (at 7% TiC)

Fig. 14a to Fig. 14d shows the stir cast metal matrix composite of Al 8011 with 10% TiC. The polished matrix is observed with uniform distribution of TiC composite particles in Al 8011 metal matrix. Fig. 14c shows the lean distribution of TiC in metal matrix.

The inclusion of TiC has been separated into the material's voids, providing the base metal with the necessary strength. Fig. 15a to Fig. 15d indicates the definite boundaries of grain structure under etched condition. TiC particles usually will have an ability to concentrate more on the grain boundaries of a matrix.

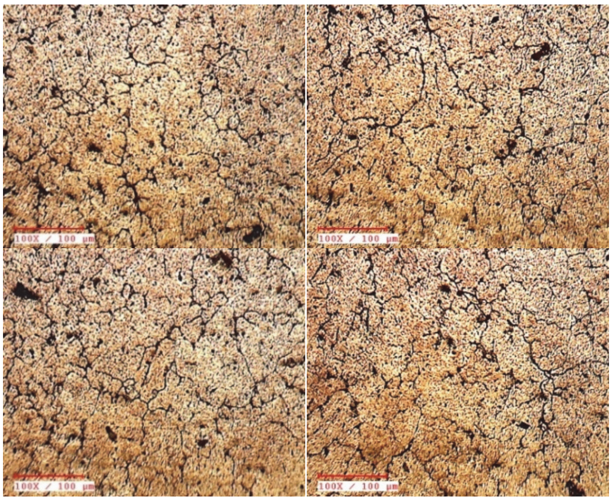

Figure 13 Etched microstructure (at 7% TiC)

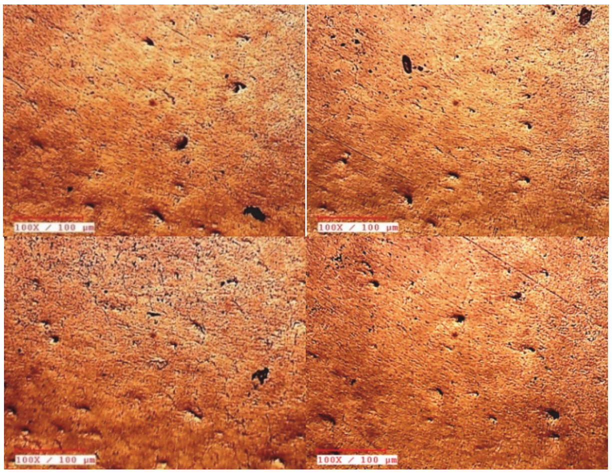

Figure 14 Structure in polished state (at 10% TiC)

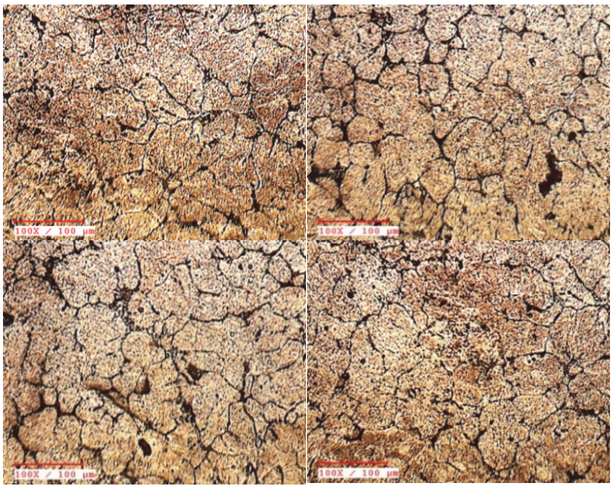

Figure 15 Etched microstructure (at 10% TiC)

However, when the quantity ofTiCincreased, the flow of reinforcement particles inside the grain boundaries also increased. Hence, the continuity of their presence has been noticed on the surface of the matrix composites.

5 CONCLUSION

The experimental study on reinforcing TiC particles in Al 8011 metal matrix has been conducted as per the standard devices and formulations. The study observed the following points.

Addition of TiC particles significantly improves the tensile strength of composite material. This is because of distribution of hard TiC particles in soft Al8011 aluminium alloy.

When the percentage of TiC becomes high, the material loosesits improved mechanical properties. Comparatively 7% of TiC composition provides better mechanical properties than 10% of TiC.

Impact energy is increasing along with TiC addition.

Wear rate is not consistent for all three samples and depends on the frictional force developed. But maximum wear rate is observed on 10% TiC addition

Micro examination reveals the uniform distribution and proper segregation of TiC particles on the boundaries under selected operating conditions.

The entire study observed the improved mechanical properties in metal matrix with 7% TiC reinforcement.

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