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Investigation on Mechanical Properties and Wear Behaviour of Titanium Diboride Reinforced Composites

Aluminium Metal Matrix Composites (AMMCs) are popular materials for aviation and automotive sectors due to their enhanced strength to weight ratio, increased resistance to corrosion and better tribological properties. In this work, the AA7075 alloy was reinforced with Titanium Boride (TiB2) particles (0, 4, 8, 12 wt. %) via stir casting process. In this process, the preheated TiB2 powder is dispersed into molten AA7075 at 850 to improve wettability and distribution. The tensile strength, hardness, wear resistance, and microstructural studies were conducted for the proposed composites. Pin- on- Disc set up was used to study the wear behaviour of the proposed composites. The results revealed that the addition of TiB2 particulates to AL7075 matrix improved all the properties when compared to AL7075 matrix. Worn surface of the abraded surface was analysed using Scanning Electron Microscope.

Keywords: *AA7075, Metal matrix composites, TiB_2, Stir Casting, Corrosion, Properties.*

1. INTRODUCTION

The AMMCs have excellent properties which finds the applications in the field of automotive, aerospace, etc. due to their improved strength and increased resistance to wear [1,2]. The mechanical and tribological properties of AMMC's are enhanced by the addition of reinforcements like Al_2O_3, SiC, TiC, TiB_2, ZrO_2 B_4C etc., [2]. The AMMCs can be manufactured by spray deposition, powder metallurgy, squeeze-casting, compocasting, and stir-casting. Several investigators had adopted stir-casting process for fabrication of AMMCs due to higher metal yield, lesser damage to the particulate reinforcement and cost-effective [3-8]. Among the various ceramic reinforcements, TiB2 particulates have high stiffness, superior hardness and good thermal stability and it emerges as a better reinforcement [7]. The exothermic nature of TiB2 – Al reaction and its reduced oxidation during the merging of reinforcement has been a potential wear resistant for composite. Concerning applications of metal matrix composites containing carbide, oxide, boride and nitride are in due choice with good wear resistance. Addition of ceramic particulates in various aluminium matrixes had markedly increased the wear performance of the matrix as stated by many researchers [9-16]. The mutual interactions between the matrix-reinforcement interfaces, the volume, the size or wt. fraction of reinforcement in matrix are the factors which influence the mechanical properties of the composite [11]. Jianxin et al. have emphasized that the reinforcement of Al_2O_3 – TiB_2 / SiC composites have increased the resistance to wear property even up to 800°C. The mode of wear was found to be oxidative wear up to 800°C, it's found that at higher temperatures the oxidative wear dominates and this oxidation plays a crucial role in evaluating the wear rate [12-14]. Many researchers found that the inhomogeneous distribution of reinforcement particulates on the molten matrix, poor wettability, surface tension and high interfacial energy had reduced the mechanical properties [15, 16]. The properties of the composites can be increased by preheating the reinforcement for removal of absorbed gas and moisture, usage of surface coatings and addition of alloying elements with inert gas atmosphere, the injection of particles to prevent or reduce the formation of agglomeration and clustering of particles and improve the wettability and distribution in homogeneous form. [17-18].

From the previous literatures, it was found that there were no works related to characterisation and adhesive wear studies of AA7075- xTiB2. In this work, the AA7075- xTiB2 composites through stir-casting process with varying percentages (0, 4, 8 & 12 wt. %) of TiB2 were synthesised, and the fabricated composites were characterized for porosity, mechanical, microstructure and wear behaviour. The scope of this present work is to understand and analyse the correlation between mechanical, wear behaviour and microstructure of AA7075-xTiB2 composites.

2. EXPERIMENTAL DETAILS

In this study, AA7075 alloy was used as a matrix material, and its chemical composition is shown in Table 1. It was reinforced by different amounts of TiB2 particles (4, 8, 12 wt.%) via an in-situ reaction. In synthesis process of the composite, the Al7075 ingot was machined and cut into small blocks. The quantity of matrix to be melted is measured with added 25% slag, evaluated through trial and error method. Aluminium 7075 alloy was melted using an induction furnace with a graphite crucible at the centre for 850°C for 20 mins.

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Meanwhile, the TiB2 powder is preheated at 500°C and calcium globules (5 wt. %) were preheated to 150 °C. The molten Al7075 was allowed to cool down to 750 °C to form slurry. The stirring was carried for 10 mins at 500 rpm using four blade stirrer. A vortex is formed due to the stirring process. The preheated TiB_2 particles were fed through a hopper to the vortex with proper timing. The furnace temperature was controlled around 750 °C with continued stirring to give a homogeneous mixture. The molten mixture is formed into rods and plates by cooling the mould at room temperature. The tensile and hardness specimens were fabricated according to ASTM E08 and ASTM E384-11 standards. The sliding wear tests of Al7075- $xTiB_2$ were carried out according to ASTM G99 standards.

The microstructure and worn surface morphology of the abraded surface was studied in Scanning Electron Microscope (SEM), along with an Energy Dispersive Spectroscopy (EDS) to examine the particle distribution and interfaces of the composites. The specimens were prepared by grinding with 1000 and 2000 grit papers and then polished by standard metallographic procedure. Density plays a vital role in determining the weight of the components. The theoretical densities of the composite were obtained by the Rule of Mixture (ROM)

Table 1. Composition of Al7075 alloy

Component	Al	Cr	Cu	Mg	Fe	Si	Ti	Zn
wt. %	89.07	0.23	1.6	2.5	0.5	0.4	0.2	5.5

3. RESULTS AND DISCUSSIONS

3.1 Characterization of composites

Figure 1 shows the SEM image of 4 % of TiB_2 particulates reinforced Aluminium 7075 alloy matrix comosites.

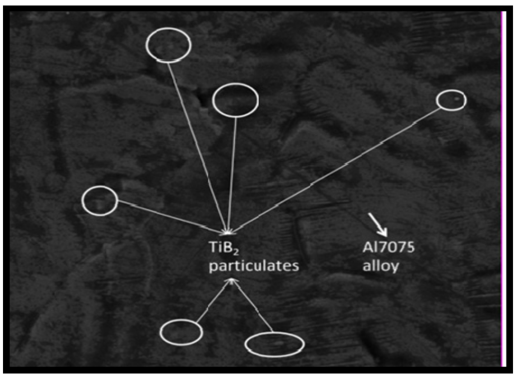


Figure 1. SEM images shows the presence of TiB2 particulates in the matrix Al7075 alloy.

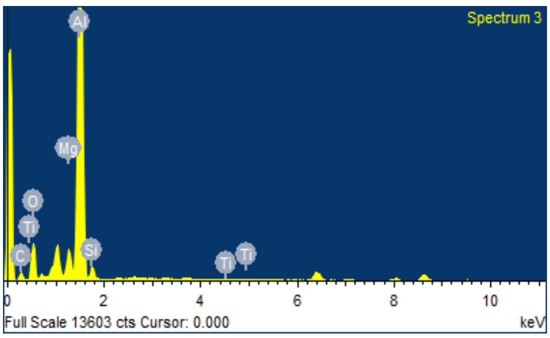


Figure 2. EDS image of Al7075 alloy

From the EDS image in figure 2, the peak values of Aluminium and Titanium have been seen, which shows the content of particulates of produced comosites. The EDS image of Al7075/4 % TiB_2 composite is shown in Figure 2 which confirms the presence of Aluminium and Titanium particulates.

3.2 Effect of reinforcement on density

Figure 3, shows the theoretical and experimental densities of various wt. % of TiB2 in Al 7075 composites. The density increases with increase in TiB2 in Al 7075 composites. From the Figure 3, it can be seen that there is an increase in values of density when TiB2 content was increased in Al7075 composites. The values of theoretical density values were higher because the theoretical density value does not consider porosity during the stir casting process. Thus the addition of 12wt. % TiB2 to Al 7075 resulted in better density values, and pure Al 7075 resulted in least density values.[19-21]. The presence of porosity is due to the mixing of TiB2 in Al7075 makes density difference between the matrix and reinforcement. The presence of porosity in the manufactured composites is due to (i) gas entrapment during the stir casting process, (ii) increase in air contact ratio with the surface area, (iii) shrinkage during the solidification process and (iv) pouring distance from the mould.

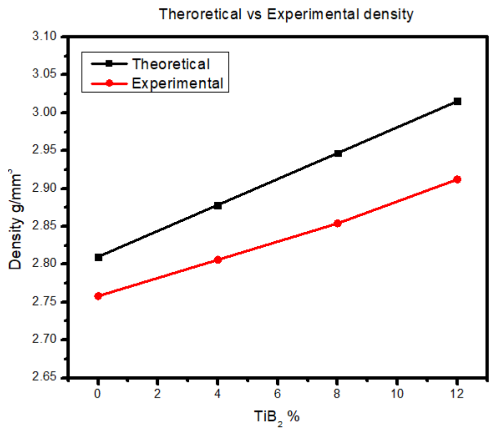


Figure 3. Theoretical and Experimental density for various weight percentage of TiB2 reinforcement

3.3 Effect of reinforcement on tensile strength

Figure 4 shows the Al7075 and Al7075 composites with various wt. % of TiB2. The tensile load is provided to develop strong internal stresses, which may fail when it increases above the strength of the material. The internal stress distribution will be based on the reinforcement particles bonding [22]

From Figure 4, it can be inferred that the tensile strength increases when TiB2 was increased in Al7075 composites. The tensile strength of Al7075 is 198 MPa and the tensile strength increases as the increasing reinforcement percentage of TiB_2, where it obtains a 17% increase on 4 wt. % of TiB_2 further it reached up to 29 % for the 12 wt. % of TiB_2 reinforcement, but the percentage difference of UTS between 8 and 12 wt. % of reinforcement is minimum. The increase in tensile strength at 12 wt. % is due to better bonding between TiB2 and Al7075 matrix [7, 24].

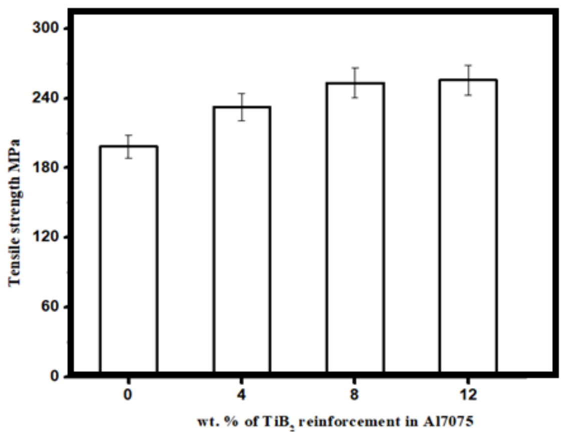


Figure 4. Tensile strength for various weight percentage of TiB2 reinforcement

3.4 Effect of reinforcement on hardness

In general, hardness can be viewed as the resistance to indentation. The hardness of Al7075 and Al7075 composites are shown in Figure 5. This is evident as shown in Figure 5, where the micro-hardness values of the samples show a pronounced improvement when TiB2 content was increased. When TiB2 was added at 4wt. % the hardness values improved by 19.5 % compared to pure Al 7075. Furthermore, it increased by 32.6 % and 42.4% from the base matrix with 8 wt. % and 12wt. % of added reinforcement. The higher hardness and stiffness of TiB2 particles gives a good resistance to plastic deformation on Al7075 matrix; the TiB2 particles form preferable sites of heterogeneous nucleation of grains when added in melt matrix. Therefore, the microstructure of matrix is refined, and bonding improves, which is a major factor for improving hardness. Similarly, many researchers reported the improvement in Vickers hardness value when TiB2 particles was added through in-situ process in any metallic matrix [22, 25,26].

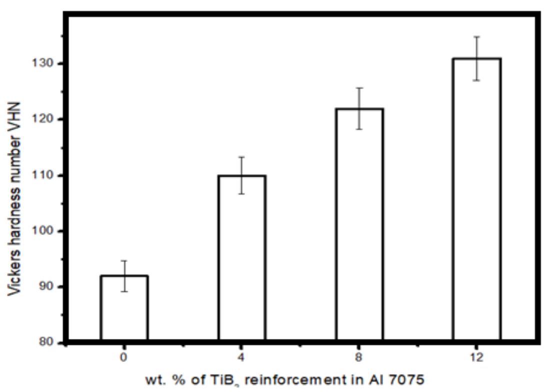


Figure 5. Peak Hardness values of Al7075 cast alloy with 4%, 8% and 12% TiB2 reinforcement

3.5 Effect reinforcement on wear properties

Figures 6 (a-c), 7(a-c), and 8(a-c) show the wear rate of Al7075 composites as a function of weight percentage of TiB2, load, and speed. Figure 6 (a-c) shows the wear rate of various percentage of TiB_2 reinforcements in Al 7075 matrix at constant sliding speed. Generally, the wear rate increases when the load applied is increased. The wear rate of pure Al 7075 composite is higher when compared to other composites produced. The values of wear rate started to decrease when the amount of TiB_2 reinforcements in Al 7075 matrix was increased, which can be seen from the figure. The same trend was noted for all sliding speeds.[25, 27,28].

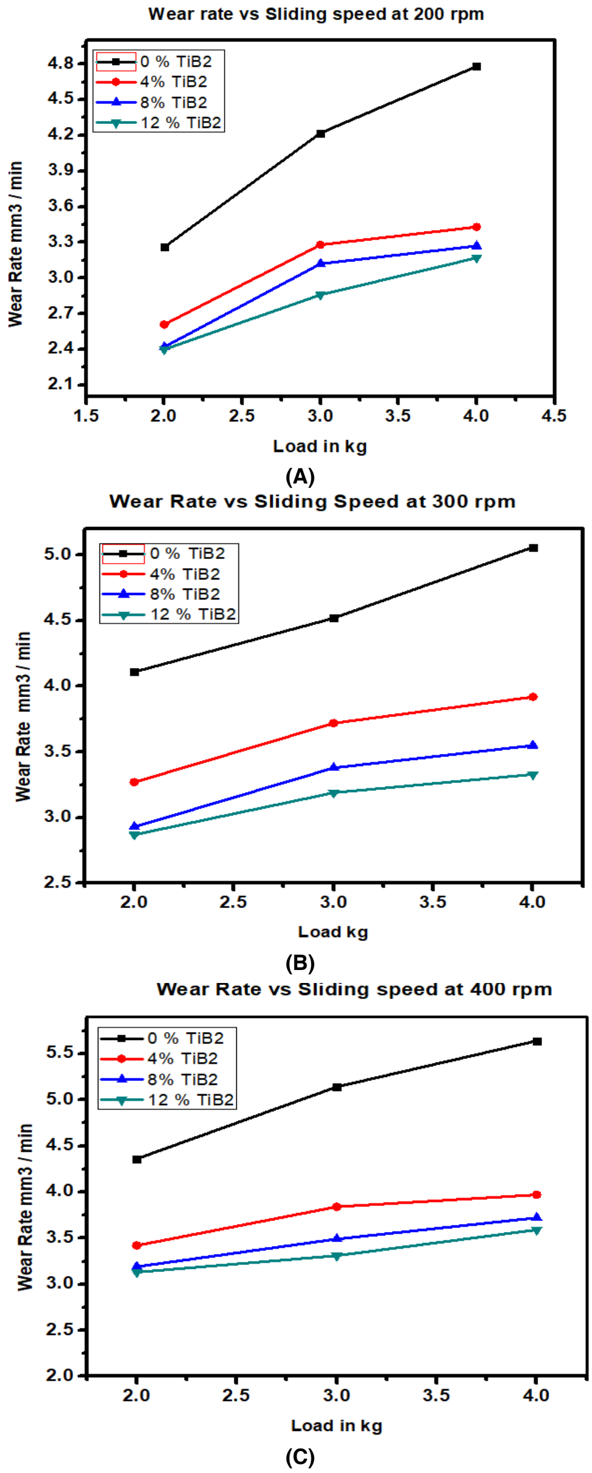
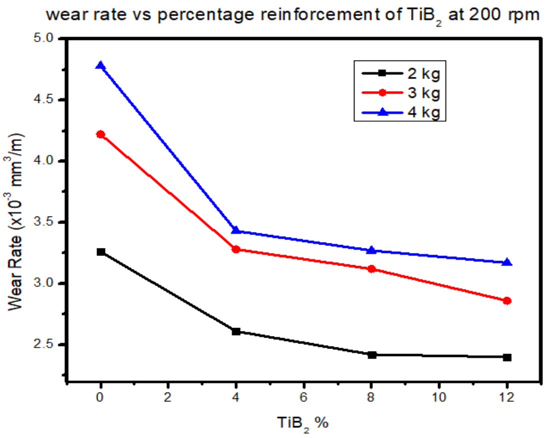


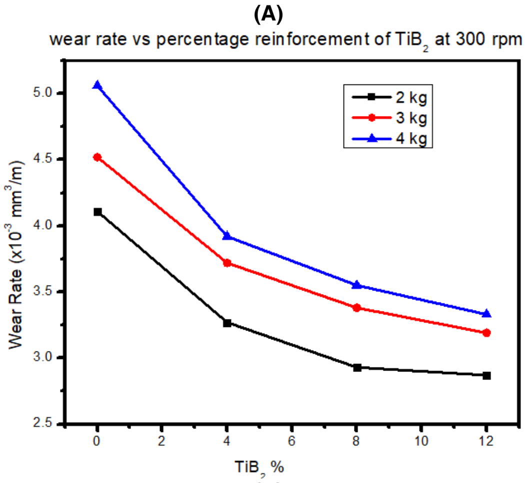
Figure 6. (a-c) Effect of Wear Rate at different loading conditions with different sliding speed for various composition of composites

The wear rate difference of 30-35% is shown in the graphs of base alloy and 12% TiB_2 addition of all loads. The wear rate graph is not linear with the increase in reinforcement of TiB_2, which is stated in Mandal et al.

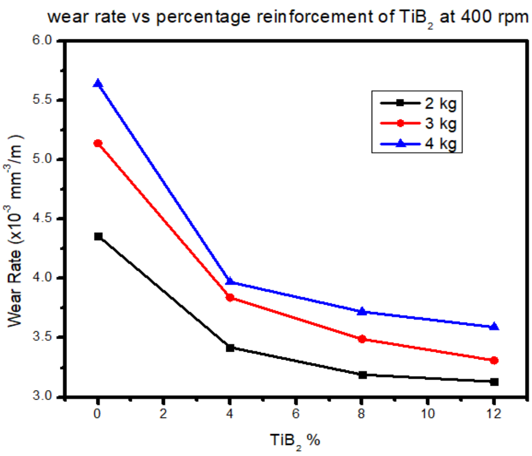
due to complex processes that occurred during wear of the composites. At 200 rpm sliding speed, the wear rate at different loads depicts that wear at lower loads is less, when compared at higher loads. The wear rate interaction between the counterface and matrix will be attributed based on the reinforcement. The phenomena of adhesion are created between the asperity to asperity contact of the hard counterface (disc) and the soft surface (pin). This contact undergoes deformation due to the results of cold welding and is termed as adhesion. This process results in metal loss as asperities are detached from the surface during sliding and is termed as adhesive wear.



(A)



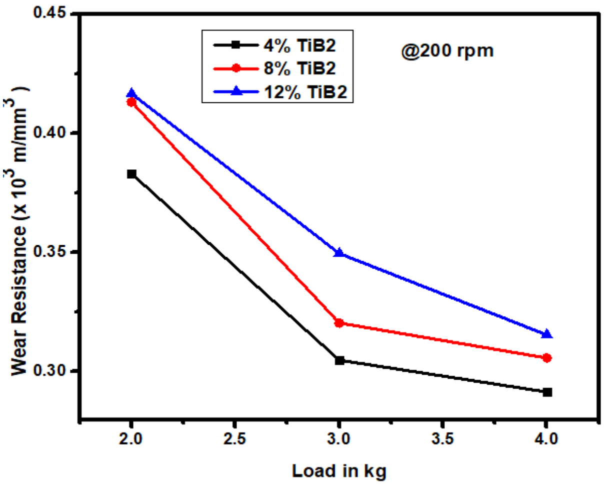
(B)



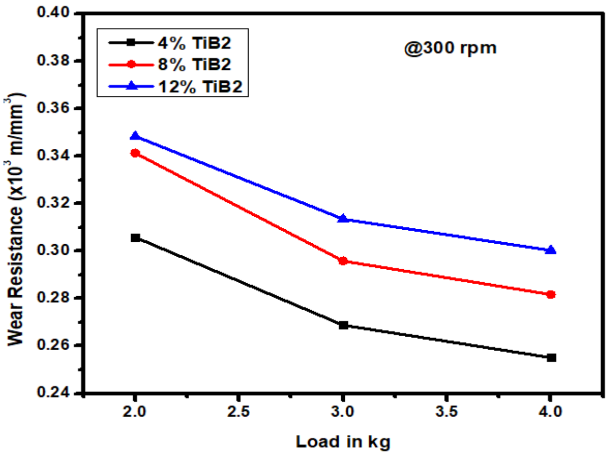
(C)

Figure 7 (a-c) Effect of Wear Rate at different composition of TiB2 particulate reinforcement and at different loading conditions for different sliding speed

The resistance to wear is termed by the reciprocal of wear rate of the composites. It is based on the function of load applied, and TiB2 particulates present for a constant sliding speed for 20 mins. From the Figures 8 a, b & c, the influence of TiB_2 on the part of wear resistance at lower load is more significant, and the wear resistance drops as the applied load is increased to 4 kg. The obtained graph is also not linear as the variation of processing and adhesion properties influences the composites wear resistance.



(A)



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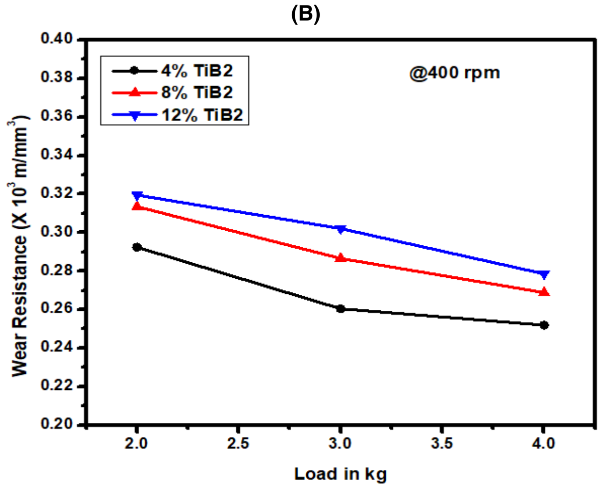
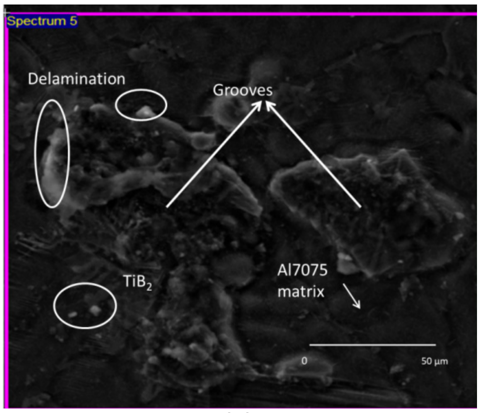


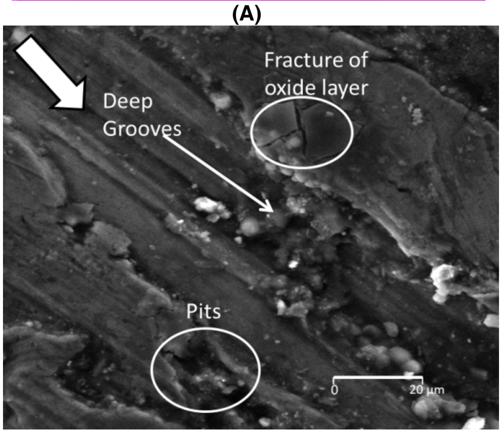
(C)

Figure 8 (a-c) Effect of Wear Resistance at different composition of TiB2 particulate reinforcement and at different loading conditions for different sliding speeds.

As said in Archard's law of sliding wear, "the hardness is directly proportional to the volumetric wear resistance of the composites". The wear resistance of the 8wt.% TiB_2 and 12wt. % TiB_2 was similar with significant increase at 2 kg of applied load, but the resistance came down at 3 kg of load. The wear rate obtained per unit wt. % of TiB_2 particulate reinforcement is a vital factor in wear analysis due to its drastic changes as there is an increase in the amount of reinforcement. A study of worn surface morphology and surface is important for better understanding of the non-linear graphs observed in these specimens [27].



(A)



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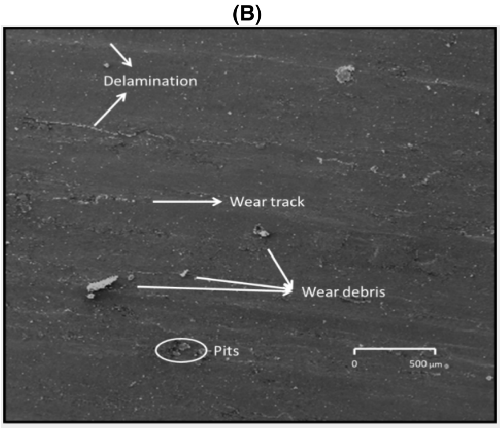
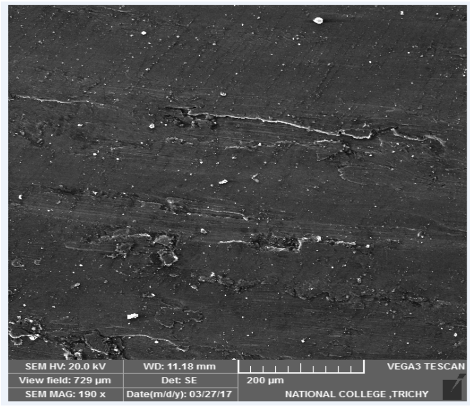


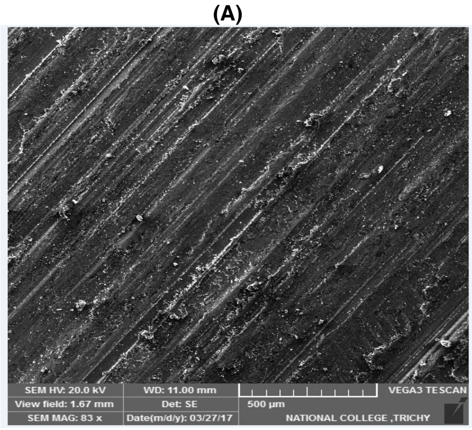
(C)

Figure 9 (a) SEM image of the wear surface of 12% reinforcement of TiB2 (b) SEM image of the wear surface for the specimen at 4Kg Load, (c) SEM image of the wear surface for the specimen at 2Kg Load

Figures 9 a - 9 c show SEM image of the worn surface of TiB_2 reinforced Al7075 alloy, the specimen samples. The samples were made to slide under room temperature with different loads of 2, 3 and 4 Kg. Initially, the specimens were cleaned with chemical acetone to remove loose particles like debris, and many scratches were seen on the wear surface. This scratch indicates the abrasive wear's primary wear mechanism. The wear mechanism depicts the plastic deformation of surfaces, due to the relative motion of contact surface, pressure, the asperities and surface projections present.



(A)



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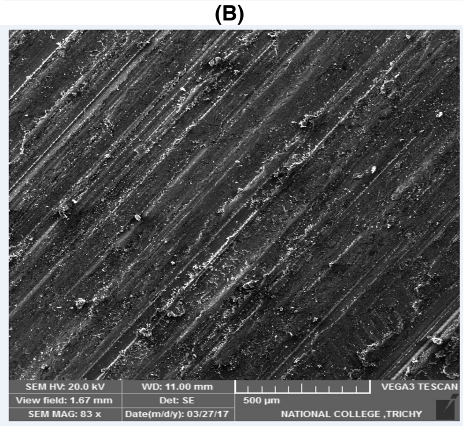

(C)

Figure 10 (a) SEM image of the wear track for specimen with 4% TiB2 reinforcement at 4 Kg load condition, (b) specimen with 8% TiB2 reinforcement at 4 Kg load condition, (c) wear track for specimen with 12% TiB2 reinforcement at 4 Kg load condition

The wear rate examination reveals the pattern of grooves, tracks, asperities and ridges running parallel on the surface along the sliding direction, as shown in Figure 10 a to 10 c. The aggressiveness of grooves is larger and deeper in lower amount of reinforced composite than the higher reinforcement as the factor of loading increases [25, 26]. The grooves formed on the low TiB_2 reinforcement matrix are coarser than the grooves which are smoother, found on the 12 % TiB_2

addition. The presence of thin oxide film near the wear tracks was seen and reveals the layer of oxide debris present on the wear surfaces. There were not many fractured micro cracks seen in these SEM images as stated by Degnan et al. [7,8]. Large craters were formed in the specimen due to the tearing of larger debris during sliding condition, and in the process, the reinforcement TiB_2 particles adhere to the larger debris.

4. CONCLUSION

In the current research work, various percentage of reinforcements of TiB_2 added to Al7075 were synthesised by stir casting technique. The tensile, hardness and tribological properties were studied. The following conclusions were reported.

1. The preheating of the TiB_2 particles before the melt stirring has some significant effect. The porosity is at reduced level, which shows the bonding was fairly better.
2. The values of microhardness increased when the addition of TiB_2 particles increased in the Al7075 matrix.
3. The highest wear resistance and lowest wear rate was obtained by the samples processed in 2Kg load and at 200 rpm speed with 12% addition of reinforcement.
4. There was an increase in wear resistance at 12 wt. % TiB2 in Al7075 composites irrespective of applied load, sliding velocity and sliding distance.
5. The worn surface morphology reveals more wear grooves during high load irrespective of sliding distance and wt. % of TiB2 reinforcement.

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ИСТРАЖИВАЊЕ МЕХАНИЧКИХ СВОЈСТАВА И ХАБАЊА КОД КОМПОЗИТА ОЈАЧАНИХ ТИТАНДИБОРИДОМ

М. Рамеш, Ј. Данијел Д., М. Равичандран

Композити са матрицом од алуминијума су материјали који се све више користе у авио и аутомобилској индустрији због побољшаног односа снаге и тежине, боље отпорности на корозију и бољих триболошких својстава. У овом раду је легура АА7075 ојачана честицама титанборида (0, 4, 8, 12 теж. %) процесом изливања мешањем. Претходно загрејани прах титандиборида је распршен у истопљени АА7075 на температури од 850^0Ц да би се побољшала влажност и дистрибуција честица. Затезна чврстоћа, тврдоћа, отпорност на хабање и микроструктурна испитивања су извршена код композитног материјала. Трибометар пин-он-диск је коришћен за испитивање пнашања хабања. Резултати су показали да се додавањем честица титандиборида композиту са матрицом од алуминијума побољшавају његова својства. Скенирајућим електронским микроскопом извршена је анализа похабане површине.