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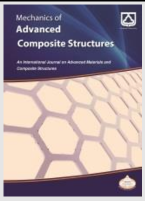

Mechanical Characterization and Wear Behavior of Nano TiO_2 Particulates Reinforced Al7075 Alloy Composites

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KEYWORDS

Al7075 Alloy
Nano TiO_2
Mechanical Behavior
Frcatography
Worn Morphology

ABSTRACT

In the current research work synthesis, characterization, mechanical and wear behavior of 5 and 10 wt. % of nano TiO_2 particulates reinforced Al7075 alloy composites are inspected. The Al7075 alloy and nano TiO_2 particle composites were provided by melt stir system. After the preparation, the prepared composites were analyzed by SEM, EDS, and XRD for inquiring the microstructures and chemical elements. Furthermore, mechanical and wear behavior of as cast Al7075 alloy and Al7075 -5 and 10 wt. % of nano TiO_2 composites were examined. Mechanical properties like hardness, UTS, yield quality, and ductility were assessed pursuant to ASTM measures. Pin on disc contraption was applied in order to lead the dry sliding wear tests. The analyses were led by differing loads and sliding speeds for a sliding distance of 3000 m. From the examination, it was discovered that the hardness, extreme strength and yield quality of composites were expanded because of nano TiO_2 particles in the Al7075 amalgam grid. In nano TiO_2 fortified composites the rate extension was diminished. Moreover, there was an expansion in the volumetric wear misfortune concerning the load, speed and sliding distance for all the readied materials. In order to inspect the fractography and dissimilar wear mechanisms for various test conditions of different compositions, tensile fractured surfaces and the worn surface morphology were analyzed by scanning electron microscope.

1. Introduction

Nano metal composites play an exceptionally essential role in cutting-edge innovation. As a rule, in order to enhance a definitive quality or better yield of the metals the nano scale particles are applied. In any case, the flexibility of MMCs crumbles as for quality by the ingestion of high ceramic particles. In accordance with these lines the nano clay particles can be fundamentally substituted in the place of micro scale particles [1].

When contrasted with different compounds and customary metals, aluminum composites as a matrix stage are broadly applied in various scope of spaces like aviation, vehicle and marine businesses because of their different properties like better resistance to corrosion, low density, great mechanical properties, and low warm coefficient of extension lastly the expense of production is generally low [2, 3]. Because of these characteristics' aluminum alloy forms a very strong and good contender in a wide range of applications. Despite that, some of the mechanical properties such as strength, elastic modulus and wear resistance are not very much enough for industrial applications yet; consequently, these are reinforced by various ceramic reinforcements such as B_4C, SiC, graphite, etc., therefore, as contrasted with other smaller scale particles, nano TiO_2 particles applied as fortification as settled on a superior noteworthy decision and have as of late been utilized in aluminum lattice composites by offering to a great degree high hardness, better quality, stability in chemical and thermal properties [4, 5].

Nano metal matrix composites are gradually getting to be distinctly appealing materials for cutting edge aviation applications, and yet their properties can be custom-made by the proper chose of reinforcement. Among three different composites, particulate strengthened MMCs as of late discovered unique intrigue on account of

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their particular quality and particular firmness at a room and elevated temperatures. It is noteworthy to mention that the flexible properties of the nano metal matrix are unequivocally affected by secondary parameters of the reinforcement, for example, shape, size, introduction, circulation, and volume.

Nano TiO_2 is known as one of the hard-ceramic reinforcement materials which tend to possess excellent hardness, low specific gravity, and high melting point; as a result of these properties one can choose nano TiO_2 particles. The Al–TiO_2 nano composites are applied in different applications like pulleys, linkages in automobiles, and because of the hard-nano particles it acts as interface for wear resistant applications [6]. For the preparing of nano metal network composites, different creation strategies are regularly accessible, as instance, powder metallurgy, mechanical alloying, high-vitality ball processing, stir cast method, nano-sintering, and spray technique. Despite that, the mechanical stir cast process by the development of vortex strategy is deliberated as outstanding amongst another system with generally minimal effort, and furthermore it very well may be applied to scatter nano measured TiO_2 particles in liquid aluminum without shaping grouping and agglomeration.

However, insufficient information is available regarding the mechanical and tribological properties of nano TiO_2 particulates reinforced with Al7075, which is processed by two stage stir casting method. The aluminum–nano TiO_2 composites play an important role in the industry because of the increasing demand for advanced lightweight materials in different industrial applications. Considering observations above, it is proposed to develop Al7075 composites with 5 and 10 wt. % of nano TiO_2 particulates.

2. Experimental Details

2.1. Materials Used

The aluminum alloys are basically classified into two categories; these are cast aluminum and wrought aluminum. In the present research work Al7075 alloy is applied as the matrix material which is one type of wrought aluminum alloy designated by 4 numbers, having zinc as the primary element and combined with various other elements like copper, magnesium, silicon and many more elements which are presented in chemical composition of Table 1. 660°C is the melting point of Al7075 alloy is, and the density is 2.84 g/cc.

The main advantage of integrating the ceramic reinforcement material to the matrix material is to enhance dissimilar mechanical and tribological properties. In the current research, nano TiO_2 ceramic particulates have been applied which is causing a density of 4.69 g/cm^3 that is slightly higher than that of base alloy [8]. Pursuant to this reason the nano reinforcement material is added in steps of two stages during the preparation of the nano composites in order to gain proper bonding between matrix and reinforcement and to avoid agglomeration difficulty. The nano TiO_2 particles also have high hardness, good dimensional, phase stability, which makes the nano composite materials to ameliorate fracture toughness, creep resistance and fatigue resistance. Fig. 1 is revealing the SEM photograph of 150 nm to 200 nm sized nano TiO_2 particles used in the study, which were procured from Bioaid Scientific Industries, Bangalore.

2.2. Preparation of Nano Composites

In the present research work, the stir casting fabrication method was used for the preparation nano composite by using Al7075 alloy in accordance with 5 and 10 wt. % of nano TiO_2 particulates. The graphite crucible is located in the electrical furnace by introducing the pre-weighed Al billet which was cut into small chunks. The Electrical resistance furnace is heated to a temperature of 750°C. The nano TiO_2 reinforcement particulates were preheated to a maximum temperature of 600°C in small graphite crucible.

Table 1. Chemical composition of Al7075 alloy by weight %

Elements	Weight %
Zn	6.1
Mg	2.0
Si	5
Fe	0.5
Cu	1.5
Ti	0.1
Mn	0.3
Cr	0.1
Al	Balance

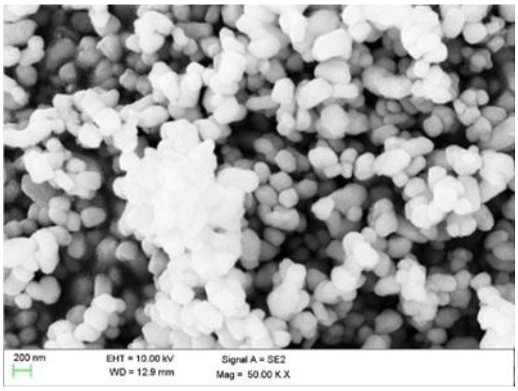


Fig. 1. SEM photograph of nano TiO_2 Particles used in the study

The digital temperature controller was used to check the temperature of the aluminum molten melt inside the graphite crucible which was located in an electrical resistance furnace. In order to eliminate the unwanted gases, present in the molten melt a degassing agent known as solid hexachloro-ethane (C_2Cl_6) was added [9]. Furthermore, to increase the wettability between nano reinforced particulate to the metal matrix 5 to 10 grams of magnesium was added. By applying zirconium coated stirrer, the mechanical stirring was demonstrated for the molten metal to the speed of 400 rpm for about 2 minutes before adding the reinforced particles to carry out a vortex. Once the vortex is achieved consequently the preheated nano TiO_2 particles were added with a constant feed of 1 gram/sec at equal intervals into the molten metal in two step addition process. The prepared molten melt is poured into a pre heated cast iron die at a temperature of 730°C and finally allowed to cool to acquire the required samples for further process as depicted in Fig.2 with 120 mm in length and 15mm diameter.

2.3. Testing of Samples

The prepared samples acquired from casting were cut to an appropriate size of 5 mm thickness and 15 mm diameter which is consequently subjected to mirror polishing at different levels for microstructure study. Initially, with 1000 grit size emery paper the cut samples were polished and then succeeded by polishing with Al_2O_3 suspension on a polishing disc by applying soft cloth, which consists of velvet. Further the diamond paste of 0.3 microns was applied for polishing. At last, Keller's reagent was used for etching of the polished surface and at lastly subjected to microstructure study by applying the scanning electron microscope (SEM).

The hardness test is done on the polished surface of the specimens by using Brinell hardness for both reinforced of unreinforced materials. The examination machine applied for conducting a hardness test as a ball indenter of 5 mm diameter and 250 kg load for a dwell period of 30 seconds, and 5 sets of readings were taken at various locations on the cleaned surface of the specimen, and the average reading was considered. As per the ASTM E8 [10] the tensile study was carried out on the cut specimens by applying electronic universal examination machine at room temperature to study different properties like UTS, yield strength, and percentage of elongation. Fig. 3 illustrates the dimensions of tensile specimen applied for examining as per ASTM standards.

The wear behavior was examined by conducting a wear test by applying pin on disc machine (DUCOM, TR-20LE). The dry sliding wear tests were employed on both reinforced and unreinforced materials by having a diameter of 8 mm and height of 30 mm as per ASTM G99 standards. The counter disc of wear machine was of EN32 steel material. Before the start of the testing process, the acetone liquid is used for cleaning the disc and test pin surface. The various investigations were led at 3000 m sliding distance and 400 rpm steady sliding velocity through varying loads of 20 N, 30 N, and 40 N. Similarly, tests were conducted at 40 N constant load through varying speeds of 200, 300 and 400 rpm. While operating the examinations, the test pin was kept opposite and stationary to the spherical steel disc while the circular plate was pivoted. The fundamental weight of the test pins samples was measured by applying digital electronic machines by measuring the accuracy of 0.0001 g. After each test, the acetone liquid was used for cleaning of the worned surface. The test pin was weighed prior, and consequently after the surface is worned, to know the measure of wear misfortune. The measured information as weight reduction was changed and calculated into volumetric wear misfortune. Fig. 4 reveals the wear specimens utilized for the wear investigation.

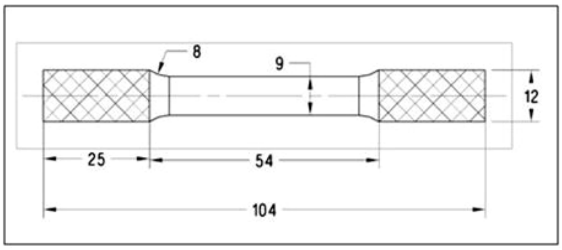


Fig. 2. Al7075- TiO_2 nano composites after casting

Fig. 3. Dimensions of tensile test specimen in mm

Fig. 4. Wear test specimens

3. Results and Discussion

3.1. Microstructural Study

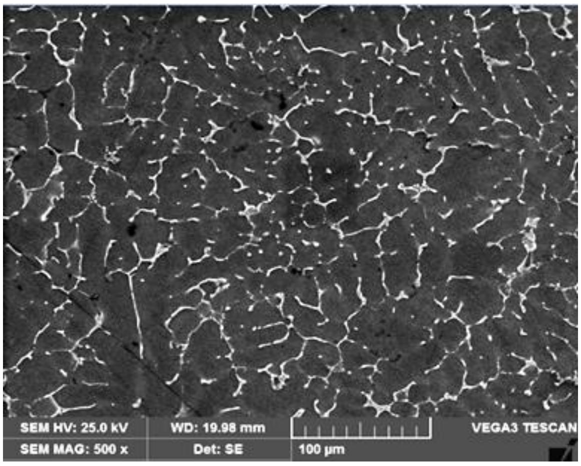
In order to examine SEM images, the samples were preferred from the middle segment from the cylindrical specimens. Fig. 5a and b depicted the SEM microstructure of as cast Al7075 alloy and the composite of 10 wt. % of nano TiO_2 reinforced with Al7075alloy. The microstructure of as cast Al7075 alloy comprises of fine grains of the solid solution of the aluminum in accordance with an ample distribution of inter-metallic precipitates. In additionally, the prepared nano composite indicates the significant bonding among the framework, and the reinforcement alongside the uniform homogenous circulation of nano estimated TiO_2 particulates without any agglomeration and bunching in the composites. This is essentially due to the practical mixing activity accomplished all through two stage addition process of nano TiO_2. By the uniform distribution of nano particle in matrix, the grain limit of the lattice obstructs the grain improvement and opposes the separation development of grains amid stacking.

Energy dispersive spectrum analysis (Fig.6) confirmed the presence of nano TiO_2 particulates in the form of T and O elements in the Al7075 alloy base matrix. EDS analysis applied in order to explicit the chemistry of the prepared composites. In the present study, Al7075-nano TiO_2 composites were studied by the EDS analysis to confirm the presence of TiO_2 particles in the base Al7075 alloy.

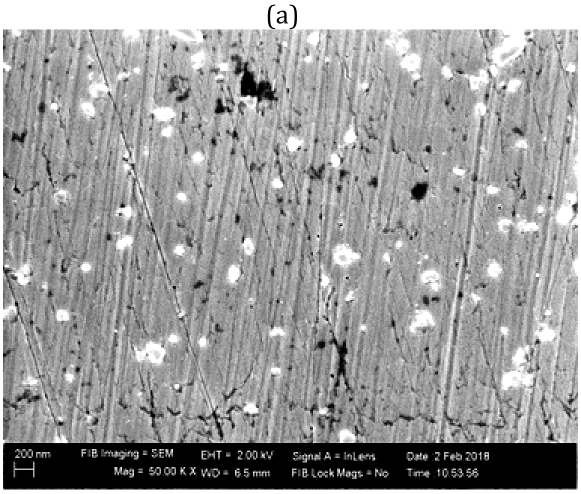
Figure 7 depicted the X-ray diffraction (XRD) pattern of the Al7075-10 wt. % nano TiO_2 and the occurrence of Al and nano TiO_2 phases are evidently seen. It can be observed that peak height increases and consequently decrease on the 2-theta scale indicating the presence of different phases of material. In Fig. 6 it is visible that X-ray intensities of peak are higher at 38°, 45°, 65° & 78° indicating the presence of aluminum phase. Similarly, it is observed the peaks for different phases of TiO_2 at 25°, 28° and 75°.

3.2. Hardness

The hardness is a mechanical parameter demonstrating the capability of resisting of prepared materials to indentation under a static load. The variation in the hardness can be observed from Fig. 8 with the addition of 5 and 10 wt. % of nano TiO_2 particulates to the Al7075 alloy with respect to unreinforced alloy. The increase is seen from 69.3 BHN to 99.7 BHN for Al composites. This can be credited to the because of the harder nano TiO_2 particles in the lattice than base alloy, and the higher constraint to the localized matrix deformation during indentation as an outcome of the presence of harder phase [11, 12]. Furthermore, the TiO_2, as other fortifications fortify the matrix by making of high-density dislocations amid cooling to room temperature because of the distinction of coefficients of thermal expansion developments between the nano TiO_2 and grid Al7075 compound.



(a)



(b)

Fig. 5. SEM micro-photographs of (a) Al7075 alloy & (b) Al7075 with 10 wt. % nano TiO_2 composite

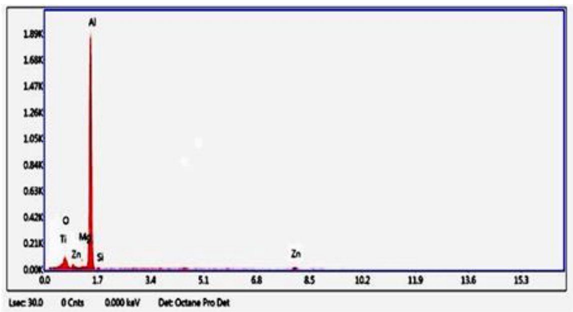


Fig. 6. Showing the energy dispersive spectrum analysis of Al7075-10wt. % nano TiO_2 composite

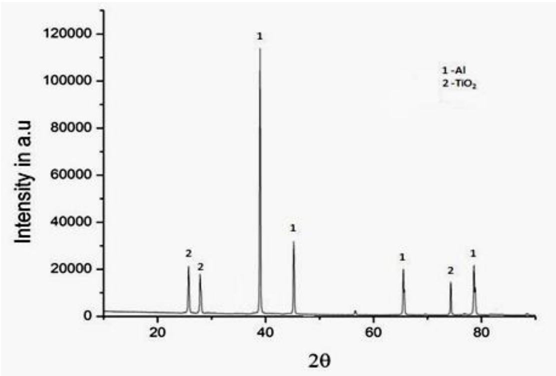


Fig. 7. Showing XRD analysis of Al7075 alloy with 10wt. % nano TiO_2 composite

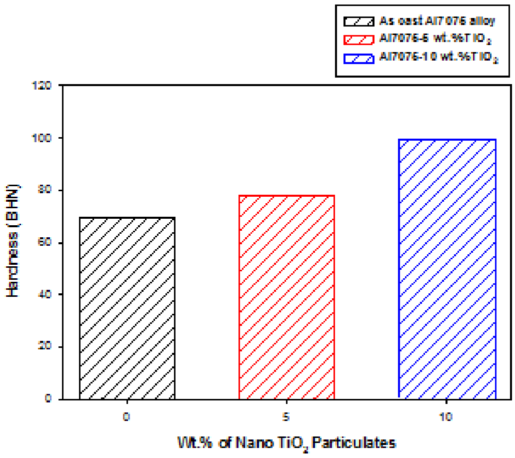


Fig. 8. The hardness of Al7075 alloy and nano TiO_2 composites

3.3. Ultimate Tensile and Yield Strength

Figure 9 represents the plot of ultimate tensile and yield strength (UTS) with 5 and 10 wt. % of nano TiO_2 dispersions in metal lattice composite. As a component of the weight rate of nano TiO_2 particles the computed estimations of ultimate tensile strength were plotted. When compared to base Al7075 alloy with 10 wt.% of nano composites, there has been an increase of 39.7% in UTS. The major increase in strength is credited due to the legal contact between the framework mixture and the supporting materials. Better the grains estimate better is the hardness and additionally the better quality of composites prompting to enhance the wear resistance [13]. The improvement in UTS is credited by the hard nano ceramic TiO_2 particulates, which confers quality to the framework mixture, in this way, giving improved solid rigidity. The expansion of these hard-nano particles may have offered rise to huge lasting compressive unease generated in accordance with cementing because of contrast in coefficient of developed between flexible matrix and brittle nano particles. The improvements of quality are likewise attributed to closer packing of reinforcement and thus little inter particle spacing in the lattice.

By realizing that the nature of the prepared composites is extremely dependent on the weight or volume division of the reinforcement leads to an increase in yield quality. Fig. 8 illustrating the variation in yield strength (YS) of Al7075 alloy matrix with 5and 10 wt. % of nano TiO_2 particulates reinforced composites. It is realized that by adding 10 wt. % of nano TiO_2 particles the yield strength is ameliorated from 172.3 MPa to 253.5 MPa. The expansion in yield strength of the nano composite is clear due to the hard nano TiO_2 ceramic particles that contribute to the quality by delectating the aluminum network and bringing about more quality resistance of the composite against the connected ductile load. On account of nano particle strengthened composites, the uniformly distributed hard ceramic particles in the grid make limitation till the plastic stream, in this way giving upgraded quality to the composite [14].

3.4. Percentage Elongation

Figure 10 displays the effect of nano titanium oxide content on the ductility of the Al7075 alloy and the flexibility of the composites decreases essentially with the 10 wt. % nano TiO_2 composites, which can be realized from the chart. This diminishing in rate prolongation in association with the matrix and reinforcement is a most commonly occurring disadvantage in particulate prepared metal matrix composites. The reduced malleability in nano composites can be attributed to the closeness of nano TiO_2 ceramic particulates, which may get broke by stirring process and have sharp corners that make the composites distorted to limited part initiate and enhance [15]. The delicate impact that happens because of the contact of the hard particles bringing on expanded locality stretch focus locales may like manner be the reason.

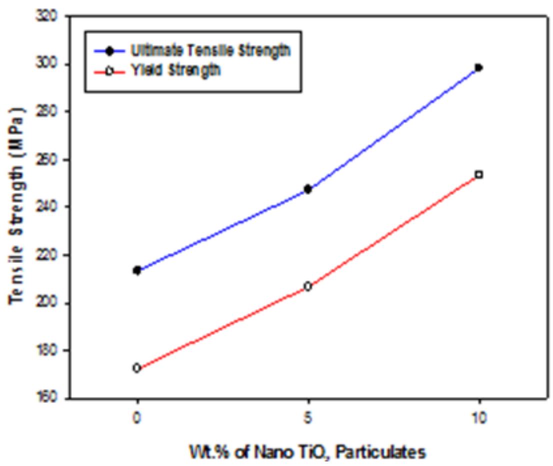


Fig. 9. Ultimate tensile and yield strength of Al7075 alloy and nano TiO_2 composites

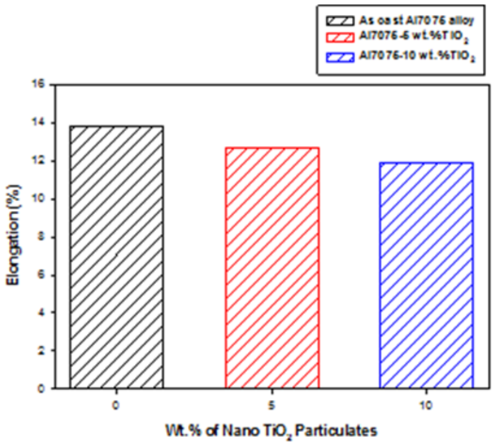


Fig. 10. Percentage elongation of Al7075 alloy and nano TiO_2 composites

3.5. Fracture Studies

After tensile testing the fracture mechanisms of as cast alloy and nano composite samples were examined by applying SEM images of fracture surfaces (Fig. 11a-b). The as cast Al7075 alloy fracture mode is a ductile fracture mode, which can be observed in Fig. 11-a, and has a large number of hollow shaped structures and also grains are visible. Fig. 10b reveals that structures have less ductile failure because of reinforcing the 10wt. % nano TiO_2. Small voids are observed in the case of 10wt. % TiO_2 nano composites, fractured surfaces showed limited stresses at the interfaces is more, and small crack at reinforcement particles mechanism is observed.

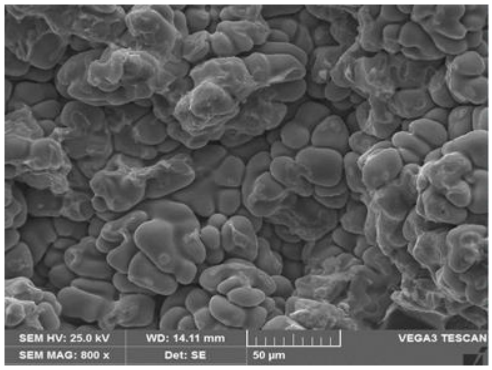
3.6. Wear Behavior

Figure 12 illustrates the varying load at 400 rpm along the x axis for Al7075 alloy, and nano TiO_2 composites **v**olumetric wear loss along y axis**.** As the load increases from 20 N to 40 N the volumetric wear loss is enhanced, and relatively it is less in the case of nano TiO_2 reinforced composites.

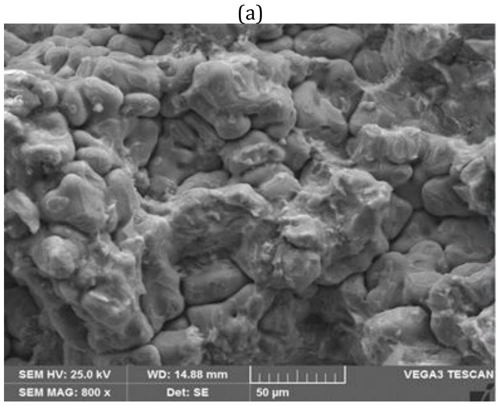
At higher loads, higher volumetric wear loss is observed for matrix alloy and the composites. At maximum loads the temperature of sliding surface and the pin exceeds the critical value. As ultimately load increases on the pin there is an increase in the volumetric wear loss of both the matrix alloy and nano TiO_2 composites. However, it is observed that the volumetric wear loss of the composites reduces with 5 and 10 wt. % nano TiO_2 reinforcements in the matrix alloy. This improvement in the resistance of the composites with respect to wear is mainly with wt. % of reinforcement and as a result of the high hardness of titanium oxide particulates, which works as the obstacle for the material loss.

Fig. 13 indicates the dependence of all the wear loss of Al7075 matrix alloy along with TiO_2 composites on sliding speed. As the sliding speed is increased from 200 rpm to 400 rpm, the loss as a result of wear is increased for both Al7075 aluminum matrix alloy and its constituent composites.

The increased wear loss in Al7075 alloy is due to delamination occurred in the alloy with fragments from the pin being transferred to the disc and larger fragments being thrown out [16]. The introduction of TiO_2 phase in the Al7075 reduces the wear loss. The TiO_2 particles provide ameliorated wear resistance to the Al composites than Al7075 alloy by the formation of mechanically mixed layers at the interface of the composite specimen and the steel disc.



(a)



(b)

Fig. 11. Fracture surfaces of samples tested for the tensile test (a) Al7075 matrix alloy (b) Al7075-10wt. % nano TiO_2 composite

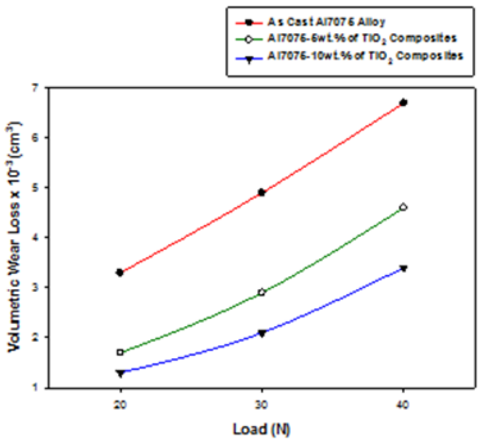


Fig. 12. Volumetric wear loss of Al7075 alloy and nano TiO_2 composites at varying loads and 400 rpm constant speed

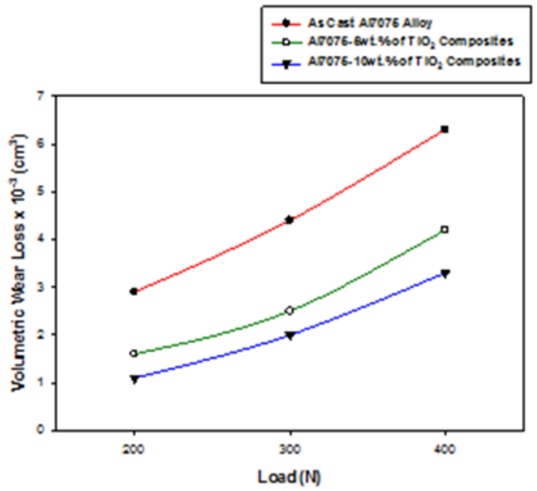


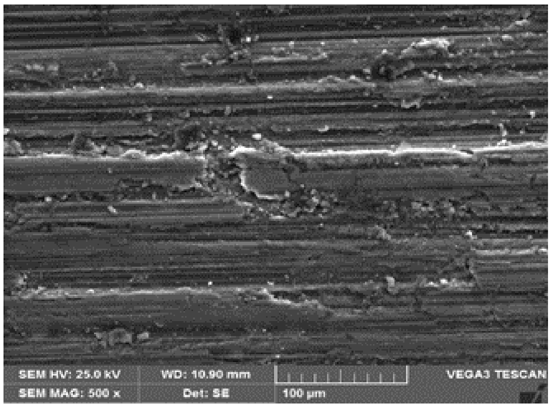
Fig. 13. Volumetric wear loss of Al7075 alloy and nano TiO_2 composites at varying speeds and 40 N constant load

Furthermore, as sliding speed is kept increasing there is increase in wear loss also because of the softening of the composite at increased temperature due to rubbing action. The increase in temperature resulting due to higher sliding speeds also leads to plastic deformation of the test piece [17]. Consequently, an increased delamination contributing exists to enhanced wear loss [18].

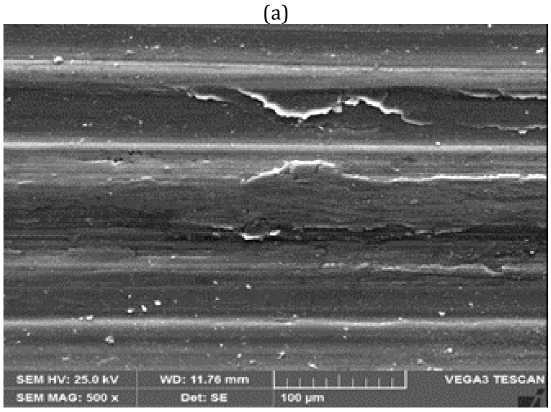
3.7. Worn Morphology

Worn surface studies of as cast Al7075 alloy and nano TiO_2 reinforced composites are investigated by applying SEM microphotographs. Fig. 14 characterizes the wear worn surfaces of matrix material Al7075 alloy (Fig. 14a) and the nano composite, which is examined at 40 N load and 400 rpm sliding speed by reinforcing of 10 wt. % of nano TiO_2 (Fig. 14b) particles in the base material.

From Fig. 14a, it indicates in the sliding direction the particular edges and depressions running parallel to each other. It can be observed from the micrograph the cracks are deeper and more widespread in lattice combination Al7075 when compared with the nano composites under comparable conditions. Due to the sliding of oxide molecule in the reinforced composite it might be seen from Fig.14b that a break likewise on the well-used outer surface of the Al7075-10wt. % TiO_2 nano composite. On account of nano composites, a thick layer could be seen, which shields the basic matrix from being in contact with the sliding partner and along these lines minimizing the volumetric wear misfortune. Therefore, the layer framed on the nano composites gives a self-protective cover to the hidden material as a result of repressing the metal-metal contact.



(a)



(b)

Fig. 14. Shows the SEM microphotographs of worn surfaces of (a) as cast Al7075 alloy (b) Al7075-10 wt.% TiO_2 composites at 40 N load and 400 rpm speed

4. Conclusions

In this research, through applying stir casting fabrication technique the nano TiO_2 /Al7075 nano composites have been fabricated by deliberating 5 and 10 wt. % of reinforcement. The micro-structural analysis, major mechanical behaviors like hardness, ultimate and yield strength, percentage elongation, and fractography and wear behavior of prepared samples are examined as per ASTM standards. The matrix is almost free from pores in as cast alloy and uniformly distributed of nano particles in the prepared composite, which is evident from SEM microphotographs. The EDS and XRD analysis confirmed the presence of nano TiO_2 particles in the Al alloy matrix. Compared to unreinforced material the mechanical properties of Al7075-10wt. % nano TiO_2 composite is superior and enhanced. As a result of strain localization, the fracture surface of the composite material consists of small voids. Moreover, the volumetric wear loss of matrix and TiO_2 particles reinforced nano composites increased with increase in applied load and speed.

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