Journal of Mechanical Engineering and Sciences
ISSN (Print): 2289-4659; e-ISSN: 2231-8380
Volume 13, Issue 1, pp. 4623-4635, March 2019

DOI: https://doi.org/10.15282/jmes.13.1.2019.19.0389

Investigations on mechanical and wear behavior of nano Al_2O_3 particulates reinforced AA7475 alloy composites

Madeva Nagaral[1*], V. Auradi[2], S. A. Kori[3], Vijaykumar Hiremath[4]

[1]Research Scholar, SIT, Tumkur & Design Engineer, Aircraft Research and Design Centre, HAL, Bangalore-560037, Karnataka, India
Phone: +91 9845452018
*E-mail: madev.nagaral@gmail.com
[2,4]R&D Centre, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India
[3]Professor, Department of Mechanical Engineering, Basaveshwar Engineering College, Bagalkot-587102, Karnataka, India

ABSTRACT

In the present investigation synthesis, microstructure, mechanical and wear behavior of 5 weight percentage of nano Al_2O_3 particulate reinforced AA7475 alloy composites has been reported. AA7475 matrix composite containing nano Al_2O_3 were fabricated by conventional stir casting method. The microstructures of the composites were examined by scanning electron microscopy. Further, mechanical and wear behavior of as cast AA7475 alloy and AA7475 - 5 wt. % nano Al_2O_3 composites were studied. Mechanical properties like hardness, ultimate, yield strength and percentage elongation were evaluated as per ASTM standards. Pin on disc apparatus was used to conduct the dry sliding wear tests. The experiments were conducted by varying loads and constant sliding speed of 300rpm for sliding distance of 4000m. Microstructural observation revealed the uniform distribution of particles in the AA7475 alloy matrix. From the analysis, it was found that the hardness, ultimate tensile strength and yield strength of composites were increased due to addition of nano Al_2O_3 particle in the AA7475 alloy matrix. Percentage elongation of the composite decreased in 5 wt. % nano Al_2O_3 reinforced composites. Further, the volumetric wear loss was found to increase with the load and sliding distance for all materials. Worn surface analysis made by using scanning electron micrographs to know the various mechanisms involved in the wear process.

Keywords: AA7475 Alloy; Nano Materials; Stir casting; Mechanical Behavior; Wear.

INTRODUCTION

The Metal Matrix Composite (MMC) is the one in which metals are matrix phase & the reinforcing phase may be a metal other than base metal/matrix metal or another material like organic compound or a ceramic. The reinforcing material may be in the form of particles or whiskers or fibers & the properties of the MMC's can be varied with variation of size of reinforcing material. Though MMCs are not widely used as the PMCs, but the properties like stiffness, high strength & fracture toughness are creating the trend towards MMCs [1, 2]. The MMCs can withstand high temperature, corrosive environment better than that of the composites made of PMCs. Most metals and alloys can be used as matrices which require reinforcement materials that are to be stable at high temperatures and are to be non-reactive too. It has to be kept in mind that if MMCs have to offer good strength then the reinforcing material used should have high modulus & high tensile strength.

Metal Matrix Composites (MMCs) are progressively getting to be distinctly appealing materials for cutting edge aviation applications yet their properties can be custom-made through the expansion of chose fortification. Specifically particulate strengthened MMCs have as of late discovered unique intrigue on account of their particular quality and particular firmness at room or raised temperatures. It is notable that the elastic properties of the metal matrix composite are unequivocally affected by small scale auxiliary parameters of the fortification, for example, shape, size, introduction, circulation and volume or weight [3-5].

Among the different matrix materials accessible, aluminum compounds are promising materials because of their high particular quality and firmness. Be that as it may, their applications are limited as a result of their poor wear resistance. Particulate strengthened aluminum lattice composites are currently being considered for their better mechanical and tribological properties over the customary compounds, and in this way, these composites have increased broad applications in car and aviation businesses. The accentuation has been given on creating reasonable Al-based MMCs with different hard and delicate fortifications like SiC, Al_2O_3, B_4C, Zircon, Tungsten Carbide, Graphite and Mica [6].

The essential capacity of the reinforcement in MMCs is to convey a large portion of the connected load, where the matrix ties the fortifications together, and transmits and circulates the outside loads to the individual support [7]. Great wetting is a fundamental condition for the bonding between particulate fortifications and fluid Al metal framework in stir casted composites, to permit exchange and appropriation of load from the lattice to the fortifications without disappointment [8]. It is demonstrated that the nano particles are viable fortification materials in aluminum compound to improve the mechanical and different properties. The support in MMCs is more often than not of earthenware materials; these fortifications can be partitioned into two categories, continuous and discontinuous.

As revealed in the so far performed research, the particulates Al_2O_3 contributes to improvement of mechanical properties, also at elevated temperatures. The presence of nano Al_2O_3 could effectively prevent the matrix deformation, to carry the load and lock the micro cracks that often develop along the friction direction [9].

However, meager information is available as regards to the mechanical and tribological properties of AA7475 reinforced with nano Al_2O_3 particulates MMC’s processed by stir casting method. With the increasing demand of lightweight materials in the emerging industrial applications, the aluminum–Al_2O_3 composites play an important role. Keeping the above observations in view, it is proposed to develop Al 7475 nano Al_2O_3 composites with 5 wt. % of Al_2O_3 particulates. The aims of this work is to investigate mechanical and wear properties of AA7475 alloy based composites with nano sized Al_2O_3 particulates by using liquid metallurgy technique.

EXPERIMENTAL DETAILS

Materials

In the present experimental investigation aluminium alloy 7475 is used as the matrix material and its chemical composition is shown in Table 1. AA7475 alloy is one of the wrought aluminium alloy containing zinc as the major element and it is combined with copper and magnesium. The density of AA7475 is 2.81 g/cm^3 and the melting point is considered as 660°C.

Table 1- Chemical Composition of Al7475 alloy

Zn	Mg	Si	Fe	Cu	Ti	Mn	Cr	Al
6.2	2.6	0.1	0.12	1.9	0.06	0.06	0.18-0.25	Balance

The main benefit of introducing the reinforcement material to the matrix is to enhance both mechanical and tribological properties. In the current research 150 nm sized (procured from Bioaid Scientific Industries, Bangalore, India) nano Al_2O_3 particulates has been used because the nano-particles of aluminum oxide are water dispersion is having high hardness and good dimensional, phase stability and it is also used to improve fatigue resistance, smoothness, fracture toughness, and creep resistance. This Al_2O_3 is a compound of aluminum and potassium disulphate. The density of Al_2O_3 is 3.98 g/cm^3, is more than that of base alloy. So the reinforcement material is added in steps of two during the preparation of the composites to have proper mixing with the base matrix and to avoid the difficulty of agglomeration.

Preparation of Nano Composites

In this fabrication process, nano composites were prepared using AA7475 alloy along with 5 wt. % of nano Al_2O_3 particulates by stir casting method as per ASTM standards. The pre-weighed Al billet was cut into small chunks and introduced to the graphite crucible in the electrical resistance furnace. The Electrical resistance furnace is heated to the temperature of 750˚C. Reinforcement particulates of nano Al_2O_3 were preheated to a maximum temperature of 400˚C. A digital temperature controller is used to check the temperature of the melt in an electrical resistance furnace. Hexa chloro-ethane (C_2Cl_6) a degassing agent was added to remove unwanted gases present in the molten metal. 5 to 10 grams of magnesium was added to increase the wettability of the reinforced particles to the metal matrix. Mechanical stirring of the molten metal to the speed of 300 rpm for about 2 minutes was done before adding the reinforced particles to form vortex. Preheated reinforced particles were added in small increments at equal intervals into the molten metal in two step addition process. The cast iron die was preheated to a temperature of 200˚C to which melt is poured and allowed to cool to get the required samples.

Testing of Samples

The castings thus obtained were cut to appropriate size of 15 mm diameter and 5 mm thickness which is then subjected to different levels of polishing to get required sample piece for microstructure study. Initially, the sliced samples were polished with emery paper up to 1000grit size followed by polishing with Al_2O_3 suspension on a polishing disc using velvet cloth. This was followed by polishing with 0.3 microns diamond paste. The polished surface of the samples etched with Keller's reagent and finally subjected to microstructure study under the scanning electron microscope (Vega 3 Tescan equipment).

Hardness tests were performed on the polished surface of the specimens using Brinell hardness testing machine having a ball indenter of 5 mm diameter and 250 kg load for a dwell period of 30 seconds, five set of readings were taken at different places of the polished surface of the specimen and average was considered as per ASTM E10. The tensile study was carried out on the cut specimens as per ASTM E8 standards using Electronic Universal Testing machine at room temperature to study properties like tensile strength, yield stress and percentage of elongation. Figure 1 shows the dimensions of tensile test specimen used for the study.

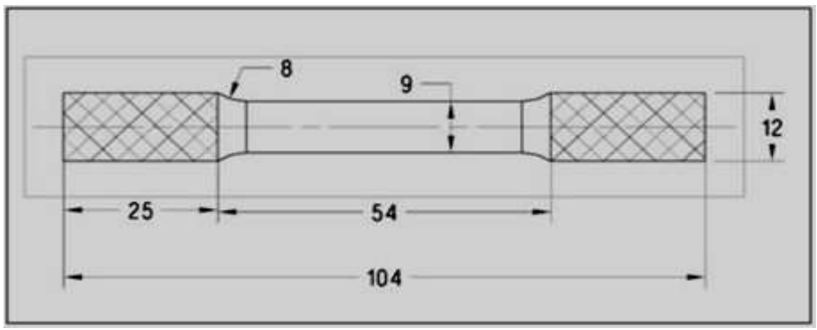


Figure 1. Dimensions of tensile test specimen in mm

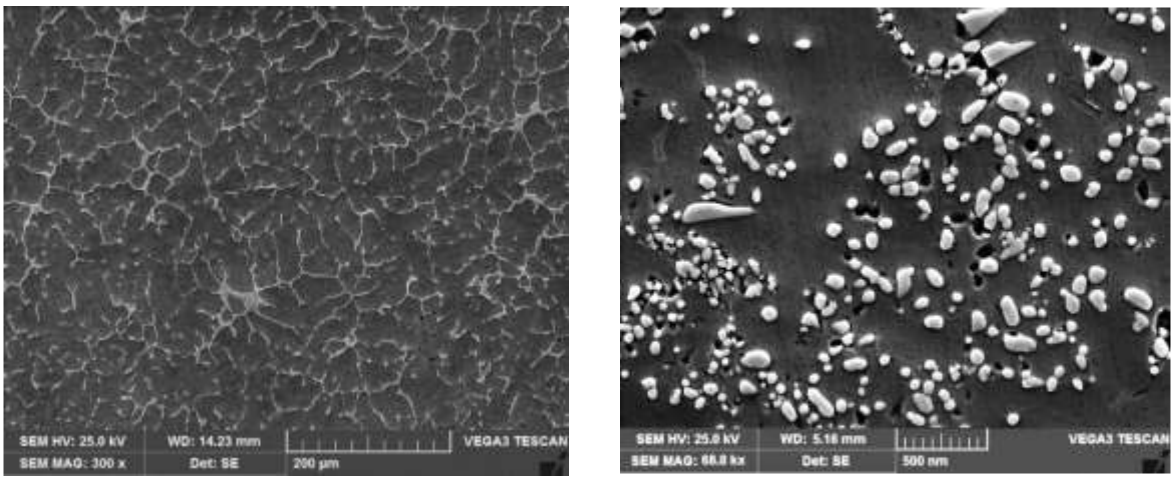
Pin on disc machine (DUCOM, TR-20LE) was utilized to convey wear tests according to ASTM G99 standard [10]. Dry sliding wear tests were performed on samples of diameter 8mm and height of 30mm. The counter circle material was of EN31 steel. Preceding testing, the pin and disc surface was cleaned with acetone. The investigations were led at a steady sliding rate of 300rpm and sliding distance of 4000m over a differing load of 10N, 20N and 30N. Amid testing the pin specimen was kept stationary and opposite to the disc while the roundabout plate was pivoted. Electronic measuring machine with the exactness of 0.0001 g., was utilized to measure the underlying weight of the examples. After each test, the counter face circle was cleaned with acetone. The pin was weighed prior and then afterward testing to decide the measure of wear misfortune. The information as weight reduction was changed over into volumetric wear misfortune as for their comparing thickness and from the wear volume. Figure 2 demonstrates the wear test specimen utilized for the examinations.

Figure 2. Wear test specimen

RESULTS AND DISCUSSION

Microstructural Study

Figure 3a and b shows the SEM micrographs of as cast alloy AA7475 and the composite of 5 wt. % of nano Al_2O_3 reinforced with AA7475. These two examined samples were chosen from the middle segment from the cylindrical specimens. The microstructure of as cast AA7475 alloy comprises of fine grains of aluminium solid solution with a sufficient dispersion of inter-metallic precipitates.



(a) (b)

Figure 3. Scanning electron micro photographs of (a) as cast AA7475 alloy (b) AA7475-5 wt. % Al_2O_3 composites

It additionally demonstrates the great holding between the framework and the fortification alongside the uniform homogenous circulation of nano estimated Al_2O_3 particulates with no agglomeration and bunching in the composites. This is essentially because of the viable mixing activity accomplished all through the expansion of the fortification by two phases. The nano particles everywhere throughout the grain limit of the lattice obstruct the grain improvement and oppose the separation development of grains amid stacking.

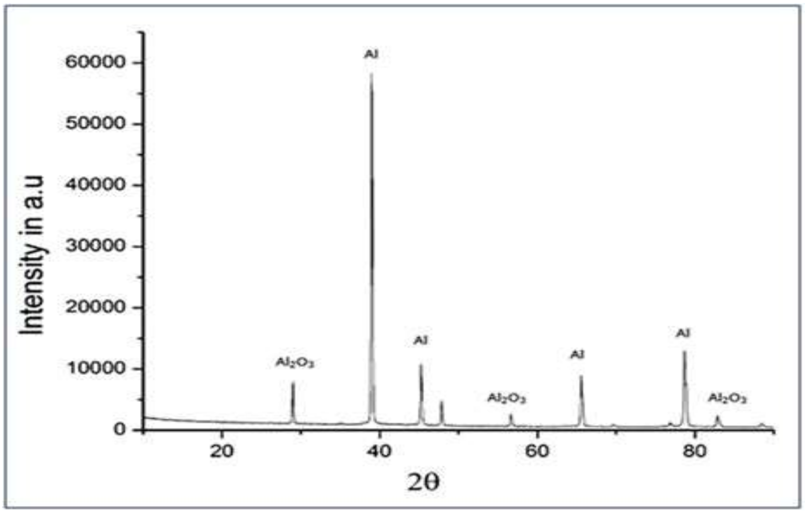


Figure 4. Showing XRD analysis of AA7475-5wt. % Al_2O_3 composite
X-ray diffraction (XRD) pattern of the AA7475-5 wt. % nano Al_2O_3 is shown in figure 4. The presence of Al and Al_2O_3 phase are clearly seen.

Hardness

Figure 5 shows the variation in hardness with the addition of 5wt. % of nano Al_2O_3 particulates to the AA7475 alloy. The hardness of a material is a mechanical parameter indicating the ability of resisting local plastic deformation. The hardness of Al-Al_2O_3 composite is found to increase with the addition of 5 wt. % nano Al_2O_3 particulates. This increase is observed from 71 BHN to 94 BHN for Al composites. This can be credited basically to the nearness of harder alumina particles in the lattice, and furthermore the higher constraint to the localized matrix deformation during indentation as a result of the presence of harder phase [11, 12]. Additionally, Al_2O_3, as like other fortifications fortifies 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 Al_2O_3 and grid AA7475 compound. Mismatch strains developed between the reinforcement and the matrix obstructs the movement of dislocations, resulting in improvement of the hardness of the composites.

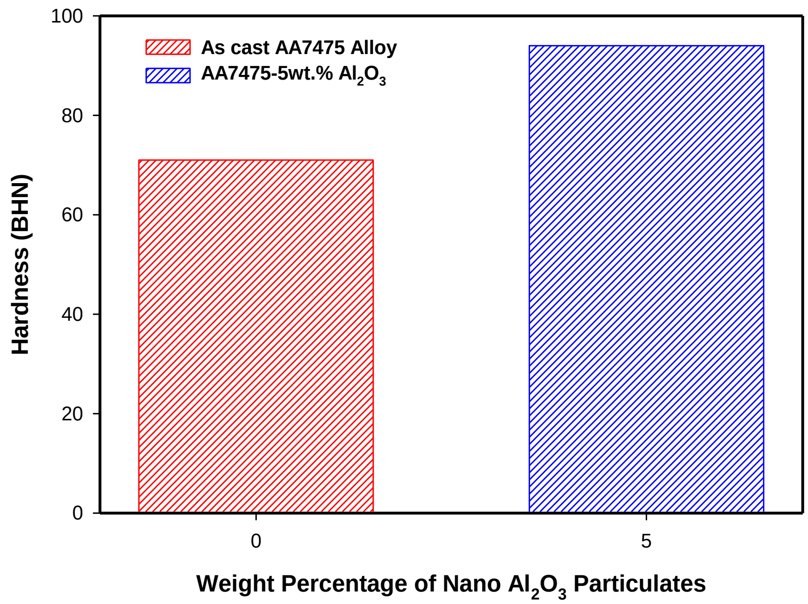


Figure 5. Hardness of AA7475 alloy and nano Al_2O_3 composites

Ultimate Tensile Strength and Yield Strength

The plot of ultimate tensile strength (UTS) with 5 wt. % of nano Al_2O_3 dispersoid in metal lattice composite has been introduced in figure 6. The deliberate estimations of UTS were plotted as a component of weight rate of nano alumina particles. There has been a change of 33% in UTS esteem when contrasted with base AA7475 alloy. The expansion in strength is credited because of legitimate contact between the framework and support materials. Better the grain estimate better is the hardness and quality of composites prompting to enhance the wear resistance moreover.

The improvement in UTS is credited to the nearness of hard nano Al_2O_3 particulates, which confers quality to the framework amalgam, in this way giving improved rigidity [13]. The expansion of these particles may have offered ascend to huge lingering compressive anxiety created amid cementing because of contrast in coefficient of development between flexible matrix and brittle particles. The improvements of quality are likewise ascribed to closer packing of fortification and thus little inter particle spacing in the lattice.

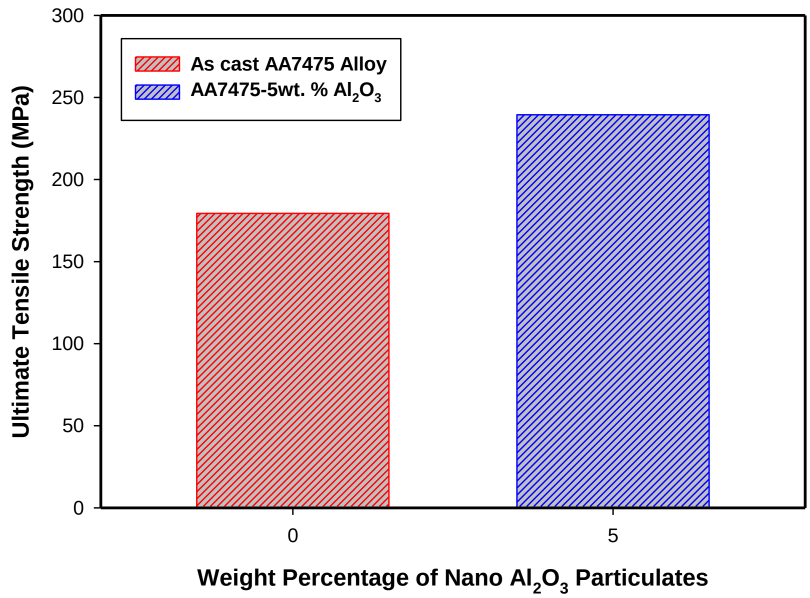


Figure 6. Ultimate tensile strength of AA7475 alloy and nano Al_2O_3 composites

Figure 7 shows variation of yield strength (YS) of AA7475 alloy matrix with 5 wt. % of nano Al_2O_3 particulate reinforced composite. It can be seen that by adding 5 wt. % of Al_2O_3 particulates yield strength of the Al alloy increased from 155 MPa to 215MPa.

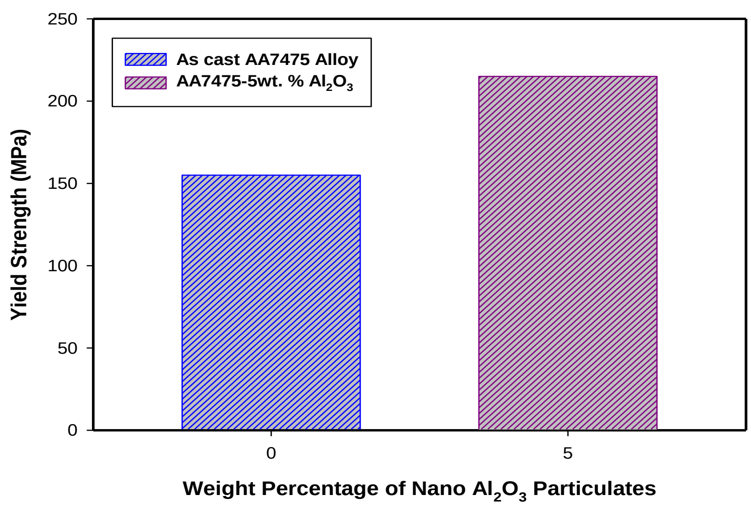


Figure 7. Yield strength of AA7475 alloy and nano Al_2O_3 composites

This expansion in yield quality is in concurrence with the outcomes got by a few specialists, who have detailed that the quality of the molecule fortified composites is exceedingly reliant on the weight or volume division of the fortification [14]. The expansion in YS of the composite is clearly because of nearness of hard Al_2O_3 particles which grant quality to the delicate aluminum network bringing about more prominent resistance of the composite against the connected ductile load. On account of molecule strengthened composites, the scattered hard particles in the grid make limitation to the plastic stream, in this way giving upgraded quality to the composite [15].

Percentage Elongation

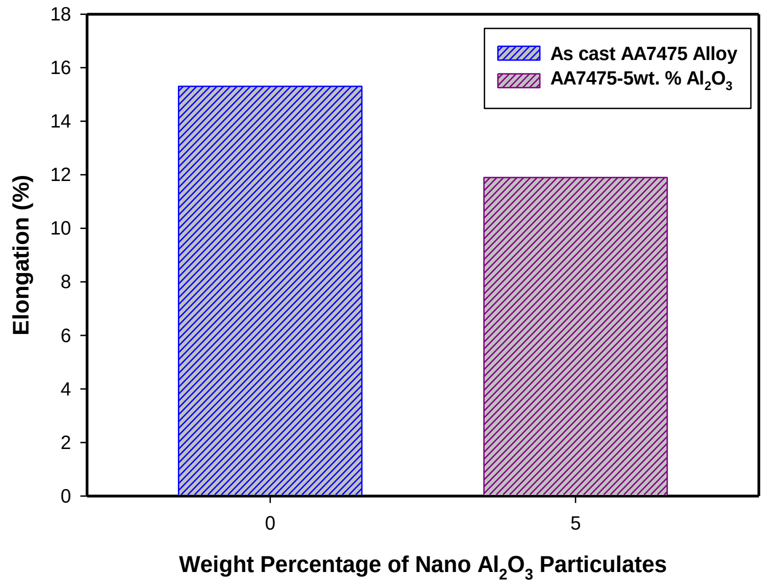
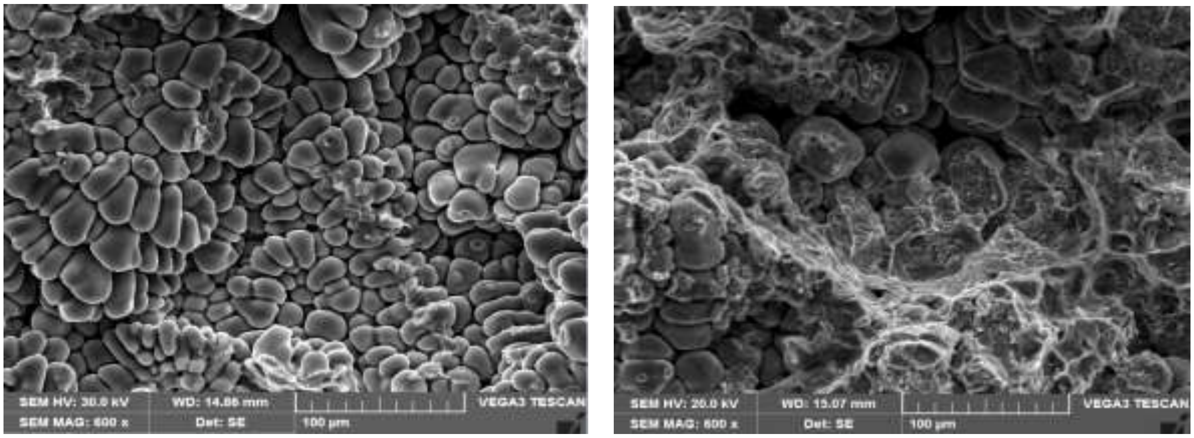


Figure 8. Percentage elongation of AA7475 alloy and nano Al_2O_3 composites

Figure 8 demonstrating the impact of nano Al_2O_3 content on the elongation (ductility) of the composites. It can be seen from the chart that the flexibility of the composites diminish essentially with the 5 wt. % Al_2O_3 fortified composites. This diminishing in rate prolongation in correlation with the base amalgam is a most usually happening detriment in particulate fortified metal lattice composites. The lessened pliability in composites can be ascribed to the nearness of Al_2O_3 particulates which may get broke and have sharp corners that make the composites inclined to restricted split start and proliferation.

Fracture Studies

Fracture mechanisms of as cast alloy and composite samples after tensile testing were studied by using SEM images of fracture surfaces (figure 9a-b). The as cast AA7475 alloy fracture mode is a ductile fracture mode as shown in figure 9-a, which has large number of dimple shaped structures, no crack can be seen.



(a) (b)

Figure 9. Fracture surfaces of samples tested for tensile test (a) AA7475 matrix alloy (b) AA7475-5wt. % nano Al_2O_3 composite

Figure 9b shows that 5wt. % Al_2O_3 reinforced MMCs fracture structures have less ductile failure. During tensile test it is accepted that particle cracking along with matrix material fracture, de-bonding between the alumina particles and Al matrix alloy interface are some of the reasons for failure MMCs. Small voids observed in the case of 5wt. % Al_2O_3 composites, fractured surfaces showed local stresses at the interfaces is more and so crack at reinforcement particles mechanism is observed.

Wear Behavior

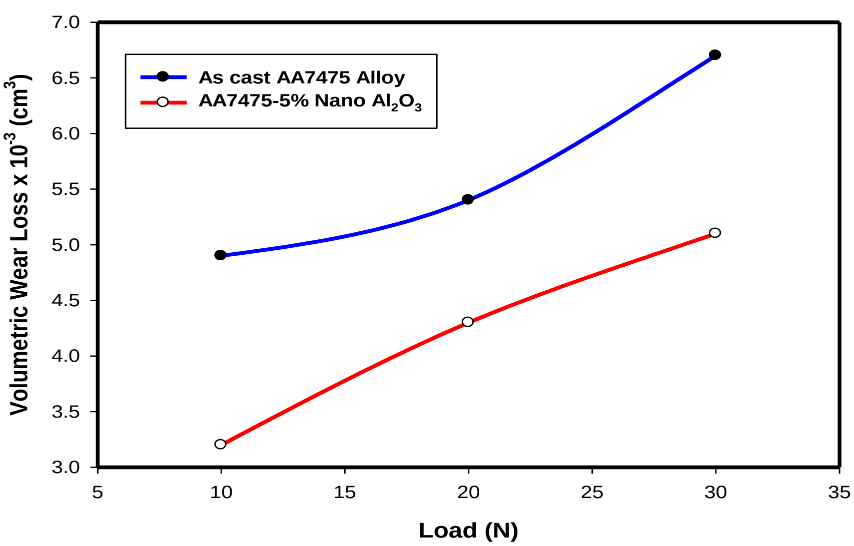


Figure 10. Volumetric wear loss of AA7475 alloy and nano Al_2O_3 composites at varying loads and 300rpm constant load

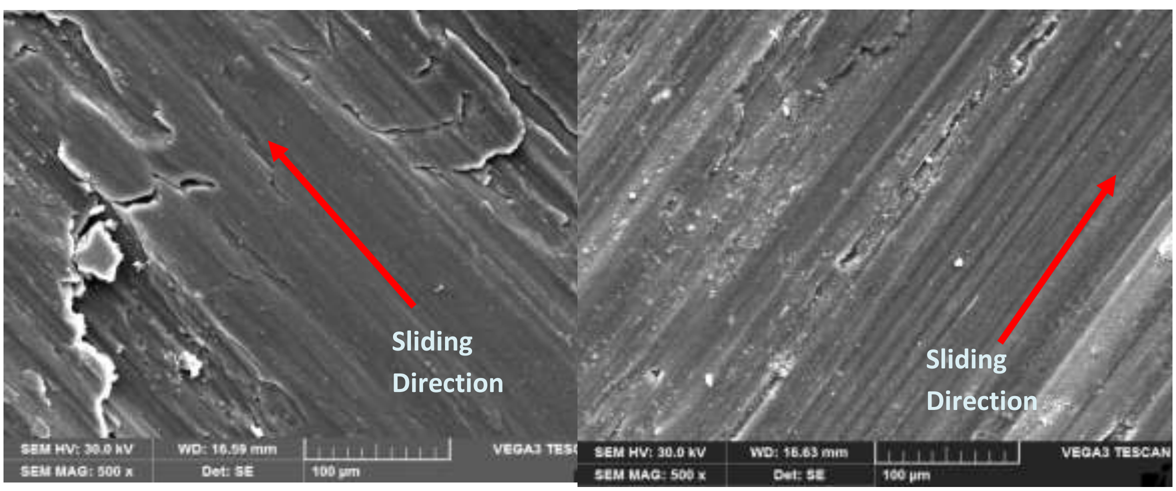
The volumetric wear loss of AA7475 alloy and its composites are as shown in figure 10 and 11. The effect of applied load on the wear behavior of AA7475 alloy and its composites are shown in the figure 10. The volumetric wear loss is increased as the normal load increases from 10N to 30N and is lower in case of nano Al_2O_3 reinforced composites.

Higher volumetric wear loss is observed for matrix alloy and the composites at higher loads. At maximum loads the temperature of sliding surface and pin exceeds the critical value. So as load increases on the pin ultimately there is an increase in the volumetric wear loss of both the matrix alloy and Al_2O_3 composites.

It is observed that the volumetric wear loss of the composites decrease with 5 wt. % Al_2O_3 reinforcements in the matrix alloy. The improvement in the wear resistance of the composites with 5 wt. % of reinforcement can be attributed to the high hardness of alumina particulates which acts as the barrier for the material loss [16].

Worn Morphology

Wear surface analysis of AA7475 alloy and nano Al_2O_3 reinforced composites are studied by using scanning electron micro-photographs. Figure 11 represents the wear worn surfaces of matrix material AA7475 alloy (fig. 11a) and its composites 5 wt. % of Al_2O_3 particles reinforced composite at 30N load and 300rpm sliding speed.



(a) (b)

Figure 11. Shows the SEM microphotographs of worn surfaces of (a) as cast AA7475 alloy (b) AA7475-5% Al_2O_3 3kg load and 300rpm

In figure 11a shows particular depressions and edges running parallel to each other in the sliding direction. It can be seen from the micrograph that the furrows are more extensive and more profound in grid combination AA7475 when contrasted with the composites tried under comparable conditions. In figure 11b furrowing can likewise be seen on the well-used out surface of the AA7475-5wt. % Al_2O_3 composite, which might be because of sliding of oxide molecule in the composite. On account of composites, a thick layer could be seen, which shields the basic matrix from being in contact with the sliding partner and along these lines diminishing the volumetric wear misfortune. This exchange layer framed on the composites gives a defensive cover to the hidden material therefore repressing the metal-metal contact.

CONCLUSIONS

In this research, nano Al_2O_3/AA7475 composites have been fabricated by stir casting method by taking 5 wt. % of reinforcement. The microstructure, hardness, ultimate tensile strength, yield strength, percentage elongation, fractography and wear behavior of prepared samples are studied. The matrix is almost pore free and uniform distribution of nano particles, which is evident from SEM microphotographs. The XRD analysis confirms the presence of Al_2O_3 particles in the Al alloy matrix. The mechanical properties of AA7475-5wt. % nano Al_2O_3 composite is superior to those of unreinforced material. The fracture surface of the composite material consists of voids which formed by the strain localization. These voids were then coalesced during tensile loading, resulting in the formation of dimple appearance at the fracture surface. The wear resistance of AA7475-5 wt. % Al_2O_3 composite is considerably higher than that of the unreinforced material. Further, the volumetric wear loss of matrix and composites increased with increase in load. Further, these composites can be used for aerospace structural applications and also can be used as a high load transfer members.

REFERENCES

[1] Palanivel R, Dinaharan I, Laubscher RF, Paulo Davim J. Influence of boron nitride nano particles on microstructure and wear behavior of AA6082/TiB_2 hybrid aluminium composites synthesized by friction stir processing. Materials and Design 2016; 106:195-204.

[2] Xian Zhu, Yu-Guang Zhao, Min Wu, Hui-Yuan Wang, Qi-Chuan Jiang. Fabrication of 2014 aluminium matrix composites reinforced with untreated and carboxyl-functionalized carbon nano tubes. Journal of Alloys and Compounds 2016; 674:145-152.

[3] Narendra Kumar, Rakesh Kumar Gautum, Sunil Mohan. In-situ development of ZrB_2 particles and their effect on microstructure and mechanical properties of AA5052 metal matrix composites. Materials and Design 2015; 80:129-136.

[4] Xiao Hui Chen, Hong Yan. Solid liquid interface dynamics during solidification of Al 7075-Al_2O_3 based metal matrix composites. Materials and Design 2016; 94:148-158.

[5] Jaswinder Singh, Amith Chauhan. Overview of wear performance of aluminium matrix composites reinforced with ceramic materials under the influence of controllable variables, Ceramics International 2016; 42:56-81.

[6] Meijuan Li, Kaka Ma, Lin Jiang, Hanry Yang, Enrique J, Lavernia, Lianmeng Zhang, Julie MS, Synthesis and mechanical behavior of nanostructured Al5083/n-TiB_2 metal matrix composites. Materials Science & Engineering A 2016; 256:241-248.

[7] Garces G, Mathis, Perez J, Capek P. Adeva, Effect of reinforcing shape on twinning in extruded magnesium matrix composites. Materials Science & Engineering A 2016; 666: 48-53.

[8] Sathyashankara Sharma, Achuta Kini, Gowri Shankar, Rakesh TC, Raja H. Tensile fractography of artificially aged Al6061-B_4C composites. Journal of Mechanical Engineering and Sciences 2018; 12:3866-3875.

[9] Kenneth Kanayo Alaneme, Michel Oluwatosin Bodunrin, Adebimpe, Awe A. Microstructure, mechanical and fracture properties of ground nut shell ash and silicon carbide dispersion strengthened aluminium matrix composites. Journal of King Saud University-Engineering Sciences 2018; 30:96-103.

[10] Sekar K, Allesu K, Joseph MA, Effect of heat treatment in tribological properties of A356 aluminium alloy reinforced with Al_2O_3 nano particles by combination effect of stir and squeeze casting method. Applied Mechanics and Materials 2014; 592:968-971.

[11] Bhaskar Chandra Kandpal, Jatinder Kumar, Hari Singh. Fabrication and characterization of Al_2O_3-aluminium alloy 6061 composites fabricated by stir casting. Materials Today Proceedings 2017; 4:2783-2792.

[12] Marcin, Pietrzak Katarzyna. Processing, microstructure and mechanical properties of Al_2O_3-Cr nanocomposites. Journal of European Ceramic Society 2007; 27:1273-1279.

[13] Chandrashekar A. Ajaykumar BS, Reddappa HN. Mechanical, structural and corrosion behavior of AlMg4.5-nano Al_2O_3 metal matrix composites. Materials Today Proceedings 2018; 5:2811-2817.

[14] Sammer Kumar, Suman KNS.Tara Sasanka C. Ravindra, Palash Poddar, Venkta Siva SB. Microstructure, mechanical response and fractography of AZ91E-Al_2O_3 nano composite fabricated by semi solid stir casting method. Journal of Magnesium and Alloys 2017; 5: 48-55.

[15] Yaping Bai, Yongchun Guo, Jianping Li, Zhong Yang, Jia Tian. Effect of Al_2O_3 nano particle reinforcement on the mechanical and high temperature tribological behavior of Al-7075 alloy. Journal of Engineering Tribology 2017; 231:900-909.

[16] Kaveh Edalati, Maki Ashida, Zenji Horita, Toshaiki Mastui, Hirotaka Kato. Wear resistance and tribological features of pure aluminium and Al-Al_2O_3 composites consolidated by high pressure torsion. Wear 2014; 310:83-89.