Iranian Journal of Materials Science and Engineering, Vol. 19, Number 4, December 2022
RESEARCH PAPER

Mechanical and Tribological Behavior of Aluminum Alloy LM13 Reinforced with Titanium Dioxide Metal Matrix Composites

Gantasala Sreenivasulu[1], C B Mohan[2], Veeresh Kumar G B[3,*], M. G Ananthaprasad[4]

* *veereshkumargb@nitandhra.ac.in*

[1] Research scholar, Visvesvaraya Technological University, Belagavi, India
[2] Department of Mechanical Engineering, CIIRC, Jyothy Institute of Technology, Bengaluru, India
[3] Mechanical Engineering Department, National Institute of Technology, Andhra Pradesh, Tadepalligudem, Andhra Pradesh, India
[4] AIC, Jyothy Institute of Technology, Bengaluru, India

Received: February 2022 Revised: June 2022 Accepted: August 2022
DOI: 10.22068/ijmse.2688

Abstract: *The physical, mechanical and tribological behavior of Aluminum (Al) alloy LM13 reinforced with Nano-sized Titanium Dioxide (TiO_2) particulates were investigated in this study. The amount of nano TiO_2 particulates in the composite was varied from 0.5 to 2% in 0.5 weight percent (wt.%) increments. The Al-LM13-TiO_2 Metal Matrix Composites (MMCs) were prepared through the liquid metallurgical method by following the stir casting process. The different types of Al LM13-TiO_2 specimens were prepared for examining the physical, mechanical, and tribological characteristics by conducting ASTM standards tests. Microstructural images, hardness, tensile, and wear test results were used to evaluate the effect of TiO_2 addition on Al LM13 samples. Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS), and X-Ray Diffractometer (XRD) were used to examine the microstructure and distribution of particulates in the matrix alloy. In the Al LM13 matrix, microstructure analysis indicated a consistent distribution of reinforced nanoparticles. The attributes of the MMCs, including density, hardness, tensile strength, and wear resistance, were improved by adding up to 1 wt.% TiO_2. Fractured surfaces of tensile test specimens were examined by SEM studies. The standard pin-on-disc tribometer device was used to conduct the wear experiments; the tribological characteristics of unreinforced matrix and TiO_2 reinforced composites were investigated. The composites' wear resistance was increased by adding up to 1 wt.% of TiO_2. The wear height loss of Al LM13-TiO_2 composite increased when the sliding distance and applied load were increased. Overall, the Al LM13 with one wt.% of TiO_2 MMCs showed excellent physical, mechanical and tribological characteristics in all the percentages considered in the present study.*

Keywords: *Aluminum alloy LM13, TiO_2, Density, Hardness, Strength, Wear.*

1. INTRODUCTION

The utilization of Al alloys in the automobile industry is increasing day by day because of their lightweight and strength. However, they suffer from lower wear resistance and stiffness. Earlier studies show that Al alloys' performance was enhanced by incorporating ceramic supplements like Aluminum Oxide, Silicon Carbide, Zirconium Oxide, etc., and by using different ways of fabrication methods [1]. Lightweight, high strength, high hardness, high wear resistance, high corrosion resistance, and design freedom are advantages of employing Al-MMCs. Because of their capacity to endure high temperatures and pressures, particulate reinforced composites have been widely used in the automobile industry [2]. The final properties of Al-MMCs are governed by fabrication method, size, orientation, percentage of reinforced particles, bonding between reinforcement and matrix materials. Several manufacturing techniques are available to fabricate MMCs, like liquid metallurgy, powder metallurgy, and metal addition processes. Some of the liquid metallurgy methods, are Squeeze-casting, Compo-casting, stir casting, etc., are widely used concerning the ease with which the MMCs were fabricated successfully. The usage of other manufacturing techniques like Centrifugal, metallic foams manufacturing, and Directional solidification methods is very less. Particularly, the liquid metallurgy process is preferable for producing Al-MMCs due to its low cost, availability, and ease of manufacturing [3]. When coming to high-temperature situations, Al alloy with ceramic reinforcement shows excellent properties and performance [4]. The Al LM13 alloy was used as a basic material in creating or tailoring MMCs because of its low price, low density, strong corrosion resistance, good mechanical properties, ease of casting, and machining. The Al LM13 alloy is mostly used for pistons and other applications involving high thermal stresses and forces [5]. The TiO_2 is a single crystalline structure in the metal oxide surface science, and TiO_2 particles have high tensile strength, hardness, great wear resistance, outstanding dimensional stability, improved fracture toughness, creep resistance, and fatigue resistance in composite materials [6]. Continuous recrystallization occurs in the plastic zone at high temperatures. As a result, grain refinement and development occurred and subsequent deformation [7]. The density of the composite increases as the TiO_2 filler content increases and the findings were near to the theoretical values obtained from the rule of mixture. The amount of reinforcement, microstructure, bonding, load, sliding velocity, and distance influence the rate of wear of Al-TiO_2 composites. The Al6061-TiO_2 had superior resistance against wear than Al6061 in tribological tests, and Al6061-TiO_2 with more filler content had better physical, mechanical, and tribological properties [8]. Similarly, the results of Al6061-TiO_2 composite confirm that the highest mechanical and wear characteristics were achieved at one wt% of TiO_2 [9]. The A356-TiB_2 composite with 1.5% reinforcement had the maximum hardness, wear-resistance, and lowest friction coefficient [10]. The direct and indirect strength of composite will be enhanced by reducing reinforcement size [11]. The tensile, compressive, and torsional strength of MMCs increases with the volume fraction of TiO_2 [12]. The composites' enhanced hardness and tensile strength were owing to their finer grain structure and homogeneous dispersion of TiO_2 particles [13]. AA6063T_4-TiO_2 composite exhibited better electrical conductivity, magnetic properties, and fatigue strength than the matrix [14]. The rate of cooling influences the microstructure, and microstructure influences the mechanical characteristics [15]. The strength of the composite is greatly reliant on the reinforcement content and its proximity to the cold end. Increased Ultimate Tensile Strength (UTS) and fracture toughness result from increased chilling rate and reinforcing content. The composites' fracture behavior shifted from ductile inter-granular mode to cleavage mode [16]. The surface of the fracture has tiny cavities because of strain localization [17]. Magnesium (Mg) granules were refined as TiO_2 content was increased [18]. Increases in reinforcements resulted in increases in tensile strength and hardness until a certain point was reached, after which the mechanical aspect was found to decline [19]. The wear rate initially dropped with lower sliding velocity due to the development of mechanically mixed layers but eventually increased. In addition, the wear rate was reduced under low loading and sliding distance conditions [20]. In the case of Al7025-TiO_2 composite, the highest wear resistance occurred at 4 wt% of TiO_2. It was also discovered that the volume wear loss and wear rate increase when the applied stress increases [21]. According to the analysis of variance, the applied load and reinforcement wt% are the most influential parameters on specific wear rate and friction coefficient during sliding conditions [22]. In the case of Al5052-TiO_2 composite, it was observed that wear rate decreases as volume percentage of hard inclusions increases [23]. Both load and sliding distance increases the volumetric wear loss but decreases wear coefficient [24, 25]. In view of above, the main goal of this research is to make composites comprising Al LM13 matrix reinforced with nano-sized TiO_2 and evaluation of physical, mechanical and tribological characterization of the fabricated MMCs.

2. EXPERIMENTAL PROCEDURES

2.1. Matrix and Reinforcement Materials

Al alloy LM13 ingots selected as the matrix material in the present investigation were arranged by FENFE Metallurgical, Bengaluru, India. The Al LM13 alloy composition is mentioned in Table-1 and the TiO_2 with 50 to100 ηm average size was used as reinforcement material and was procured from LOBA chemie Pvt Ltd, India. Table-2 contains information about the properties of the matrix and reinforcement materials that were chosen.

Table 1. Chemical composition of Al alloy LM13.

Constituent	Al	Mg	Si	Mn	Zn	Cu	Ni	Fe	Ti	Pb	Sn
Wt%	Balance	1	11.6	0.2	0.08	1.1	1	0.5	0.12	0.03	0.04

Table 2. Properties of Al LM13 and TiO_2.

Material	Hardness (BHN)	Density (gm/cm^3)	Elastic Modulus (GPa)	Tensile Strength (MPa)
Al LM13	125	2.7	70	180
TiO_2	9330*	3.9	230	333

*MPa

2.2. Fabrication of Al LM13-TiO_2 MMCs

The Liquid metallurgical process is easy and cheapest way for fabricating MMCs. Presently, liquid metallurgical method was used to develop the Al LM13-TiO_2 composites. The required quantity of matrix alloy Al LM13 was accurately weighed and placed in electrical induction furnace Graphite (Gr) crucible and heated up to 750°C. The molten matrix was treated with Coverall as slag extraction agent and Hexachloroethane as a gas removal agent. A small amount of Mg chips was introduced into the molten alloy to improve wettability. A Gr-coated steel stirrer was used to mix the molten Al alloy at a steady speed of 400 rpm. To remove moisture and increase wettability, a weighed quantity of nano sized TiO_2 powder enclosed in Al foil and heated up to 450°C. The TiO_2 reinforced composite was made using a two-step stir casting procedure that took 20 minutes to complete. Each step of the mechanical stirring procedure took 10 minutes to accomplish proper reinforcement dispersion in liquid metal, with the first stage taking place at 650°C and the second at 750°C. By adopting the vortex method, warmed (450°C) TiO_2 was introduced to the Al metal pool with varied reinforcement wt% and mechanical stirring action was then conducted [26]. The molten material was transferred from crucible into preheated cast iron moulds and allowed to solidify naturally to ambient temperature. The amount of TiO_2 powder reinforcement was added from 0 to 2 wt% in the intervals of 0.5 wt%. Following solidification, cylinder-like samples of 24 mm diameter and 190 mm length were obtained.

2.3. Experimental Studies

The cast MMCs were machined to required dimensions according to ASTM standards using computerized lathe machine. Prepared standard specimens were used to investigate density, microstructure, hardness, tensile strength, ductility; fractography and wear resistance. The density was compared between rule of mixture values and practical values obtained from mass to volume ratios. To obtain excellent finish, different levels of emery sheets were applied on the samples before microstructure studies. Keller’s agent was used to etch the polished samples. Microstructure studies were carried out on fabricated composites using Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) at BMS College of Engineering, Bengaluru. To verify the presence and quantity of different constituents present in Al LM13 alloy and reinforced particles in Al LM13-TiO_2 composite EDS analysis was done. To identify phases and to validate the existence of TiO_2 particles, X-Ray Diffraction (XRD) analyses were carried out on Al LM13-TiO_2 composites. The Hardness test was done using MRB 250 Brinell cum Rockwell hardness testing machine. According to ASTM E8M standard the specimens were machined to conduct tensile test. The computerized UTM was used to perform tensile test in accordance with ASTM B557M-2015. The Fracture surface analysis was carried out on tensile strength tested specimens to study the nature of fracture. As per ASTM-G99 guidelines, computerized tribometer with pin-on-disc was employed for wear tests (Ducom, Bengaluru). A length of 30 mm X 10 mm diameter pins were used for wear test. A wear test was performed at a constant speed of 500 rpm and a constant track diameter of 120 mm with four different loads ranging from 10 to 40 N with an increment of 10 N and five sliding distances of 2500 m was adopted. To analyze the type of wear, worn surface SEM images were collected and analyzed.

3. RESULTS AND DISCUSSION

3.1. Density of Al LM13-TiO_2 MMCs

The analytical densities of Al LM13-TiO_2 composites with 0.5 to 2 wt% of TiO_2 were determined based on Rule of mixture and practical densities were determined based on mass to volume ratio. The figure-1 shows comparison between theoretical and practical values of density of Al LM13 alloy and its TiO_2 filled MMCs. From figure 1 it is evident that the practical densities were less than theoretical densities because of casting deficiencies like porosity.

The practical density of the Al LM13–TiO_2 MMCs was increased up to 1 wt% of TiO_2 addition and then decreased above 1 wt%. Due to the inclusion of TiO_2, in the Al LM13 matrix the density increased, and this is mainly due to the higher density values of TiO_2 further the decrease in practical density may be reasoned to the fact that the improper bonding between the matrix and reinforcement materials beyond 1 wt%, the existence of casting flaws, and reinforcement TiO_2 forming as slag. The findings are consistent with earlier research findings who also noticed the decrease in density values [27].

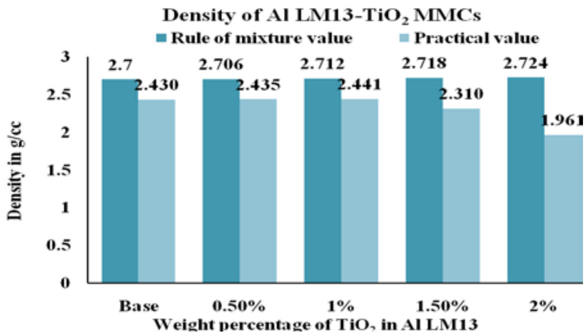


Fig. 1. Theoretical and practical densities of Al LM13-TiO_2 MMCs.

3.2. Microstructure Studies of Al LM13-TiO_2 MMCs

The morphology of procured TiO_2 powder is shown in Figure 2, which show that the mixture of round and angular grains with sharp cornered morphology. The TiO_2 particle size used in the current studies was 50 to 100 ηm as it is evident from the SEM image.

The SEM images were used to examine the microstructure and dispersion of TiO_2 in Al LM13 and are presented in the Figure 3. SEM microstructure of Al LM13 alloy is shown in figure 3a and from the SEM image, dendritic grains are plainly visible. Figures from 3b to 3e represent the SEM of Al LM13 alloy with 0.5, 1.0, 1.5 and 2.0 wt% of TiO_2 respectively.

According to the metallography, TiO_2 reinforcement was evenly dispersed in the Al LM13 matrix (no cracks in the SEM images). TiO_2 phases were formed from the Al LM13 melt and grain size of Al LM13 matrix was noticeably reduced. However, up on adding more than 1 wt% of TiO_2, the TiO_2 phases coarsened as the Ti content increased. The phase growth rate is proportional to the solute concentration. The faster the phase increases, the higher the solute concentration [28]. As a result, TiO_2 particles in the Al LM13 alloy with high Ti concentrations (>1 wt% TiO_2) tend to clump together and coarsen.

The inclusion of TiO_2 particles refines the microstructure effectively. This will aid in improvement of Al LM13-TiO_2 MMCs mechanical and tribological properties up to 1 wt% of TiO_2. Previously, identical findings had been discovered in another investigation that the uniform distribution of the reinforcement particulates in the matrix material with less porosity [29].

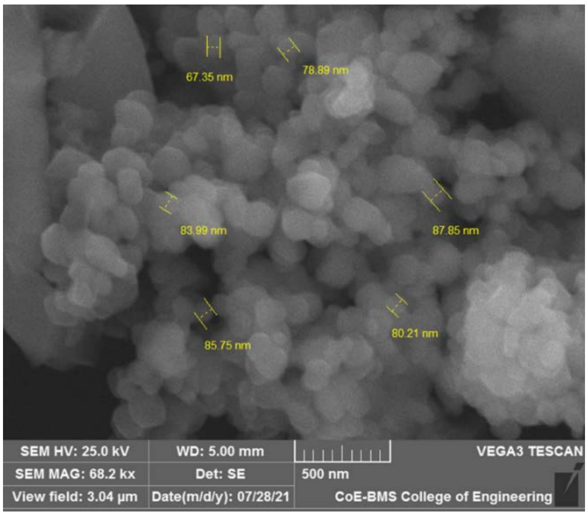
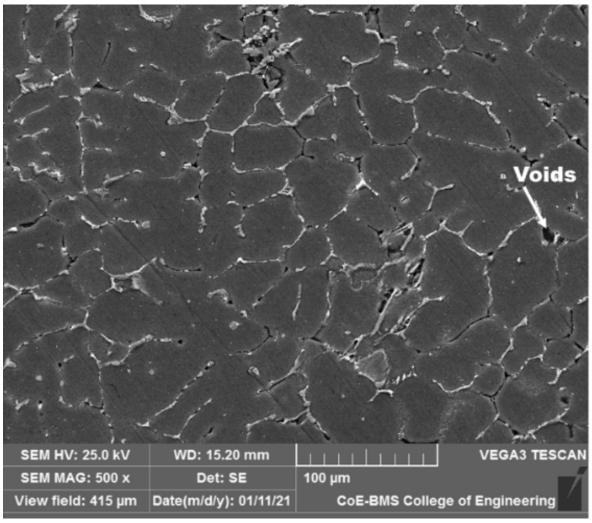


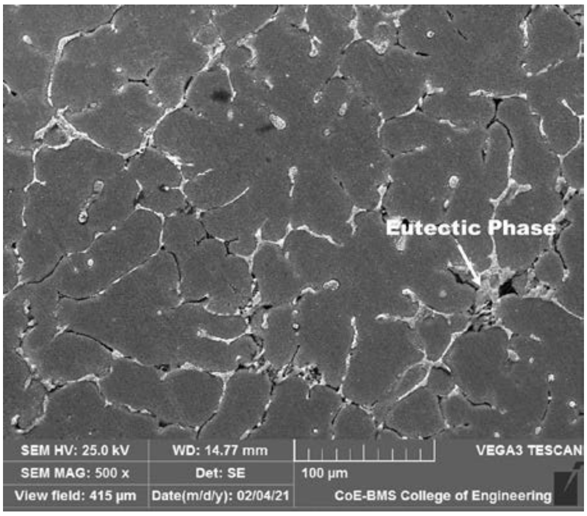
Fig. 2. SEM image of the obtained TiO_2 nano-particulates.

The obtained EDS images for the matrix and reinforcement materials were presented in the Figure 4 below. The Figure 4a represents the result of EDS analysis of as cast Al LM13 alloy and the peak of Al element is evident from EDS analysis. The result of EDS analysis of the fabricated Al LM13-0.5 wt% TiO_2 MMC was presented in the figure 4b and values were presented in the Table 3 that conforms the presence of TiO_2 reinforcement along with base alloy Al LM13.

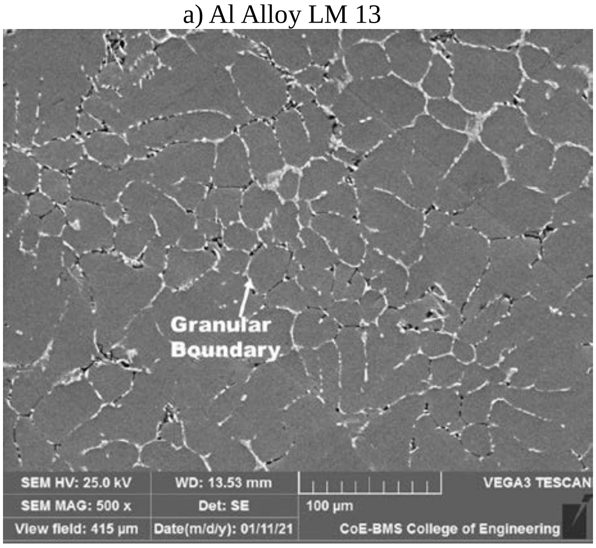
Figure 5 represents X-ray diffractogram of Al LM13-1% TiO_2 fabricated composites. There are strong peaks in the XRD graph that correlate to Al and TiO_2. Indicated the presence of reinforcement content in the matrix alloy confirms the successful fabrication of the Al LM13-TiO_2 composites.



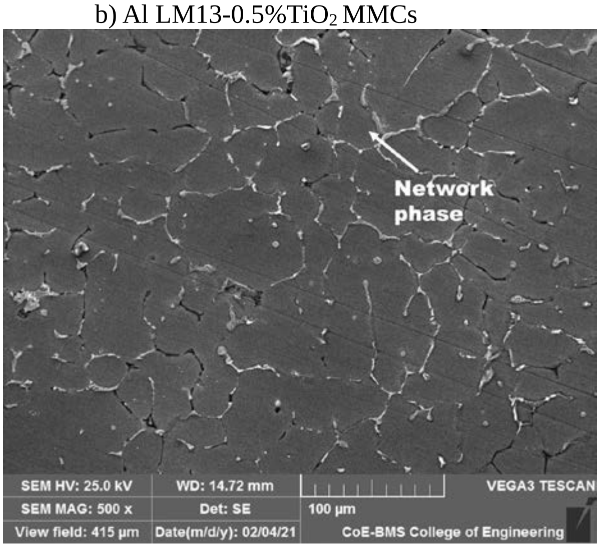
a) Al Alloy LM 13



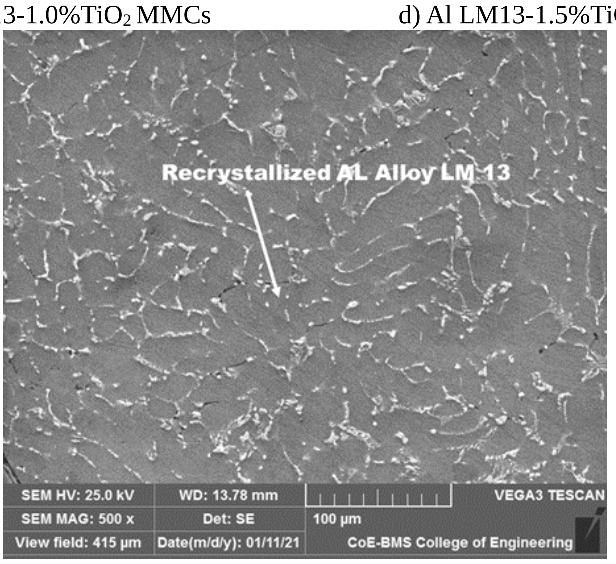
b) Al LM13-0.5%TiO_2 MMCs



c) Al LM13-1.0%TiO_2 MMCs



d) Al LM13-1.5%TiO_2 MMCs



e) Al LM13-2.0%TiO_2 MMCs

Fig. 3. Micrographs of Al LM13-TiO_2 MMCs with 500X magnification.

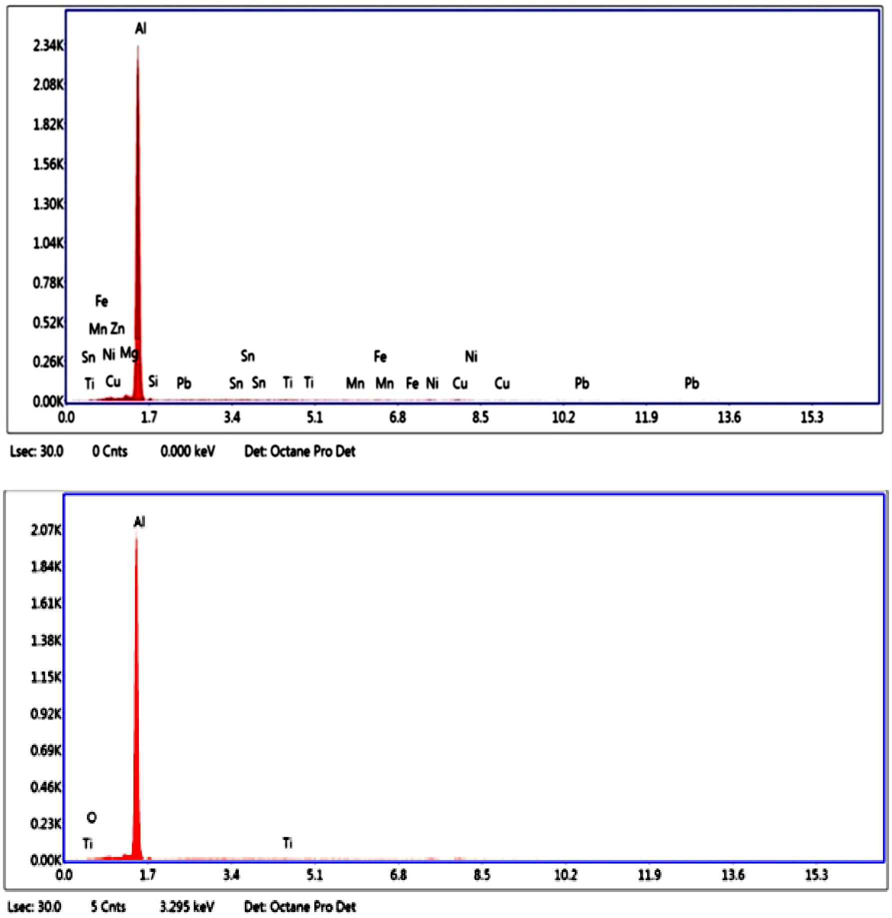


Fig. 4. a) Al LM13 alloy EDS image. b) Al LM13-0.5% TiO_2 Composite EDS image.

Table 3. Wt% & Atomic % of TiO_2 in Al LM13-0.5% TiO_2.

Element	Al	TiO_2
Wt%	99.59	0.41
Atomic%	99.48	0.52

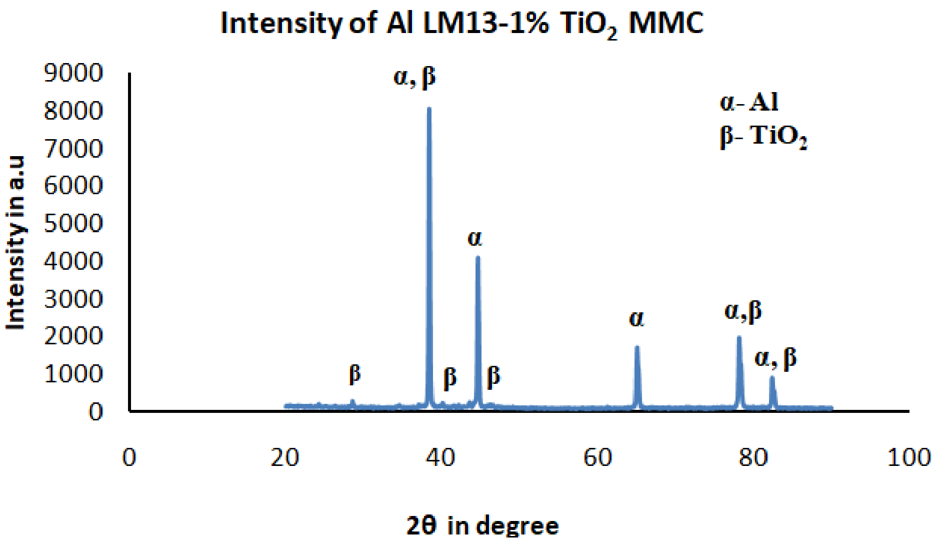


Fig. 5. XRD of Al LM13-1 wt% TiO_2 MMC.

3.3. Hardness of Al LM13-TiO_2 MMCs

Hardness is an important component in materials performance since it has a direct impact on strength and wear resistance. The hardness test was conducted on non-reinforced Al LM13 alloy and Al LM13-TiO_2 composite with wt% varying from 0.5 to 2 wt% of TiO_2 in steps of 0.5%. Figure 6 explains the influence of TiO_2 on the hardness of Al LM13 alloy. The hardness value of Al LM13-TiO_2 is greater than that of Al LM13. As reinforcement TiO_2 increases up to 1 wt% the hardness of Al LM13-TiO_2 MMCs also increased. Various factors are expected to influence the hardness of composites. The Matrix strength can be enhanced by the grain refinement initiated due to the presence of TiO_2 reinforcement [30]. The enhancement of mechanical characteristics of composites can't be explained just by grain boundary strengthening [31]. Overall hardness of composite was enhanced due to the existence of high hardness TiO_2. The Orowan strengthening process recognized as a strengthening mechanism generated due to resistance offered by the closely spaced hard particles to the movement of dislocations. From Figure 6 it is evident that hardness of the Al LM13-TiO_2 MMC was hike by 46.71% when TiO_2 reinforcement was 1%. This demonstrates that the introduction of TiO_2 with a higher hardness can significantly improve the Al LM13 properties.

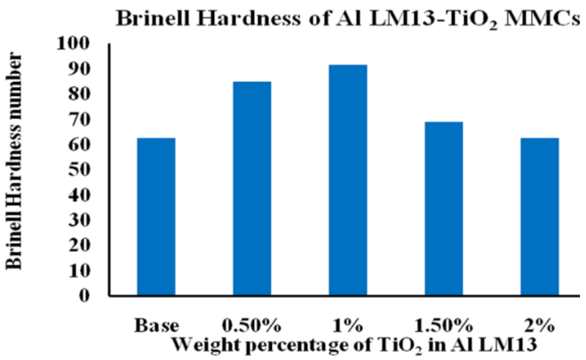


Fig. 6. Hardness of Al LM13-TiO_2 MMCs.

These findings are consistent with those of earlier researchers [32]. Any more addition above 1 wt% of TiO_2 results in a decrease in strength. This could be attributed to the composites' greater porosity due to reinforcement along with improper bonding between the matrix and reinforcement particulates. Up on adding more than 1 wt% of TiO_2 to Al LM13 alloy, stress concentration happens at the tips of TiO_2 phases. The existence of these stresses will cause particle interface debonding, micro crack nucleation, propagation, and eventually brittle rupture. Meanwhile, TiO_2 phases reduce the potency of liquid Al heterogeneous nucleation. The large matrix grains also obtained reason for the composites brittle fracture [33].

3.4. Tensile strength of Al LM13-TiO_2 MMCs

The variation in tensile strength of Al LM13 with varying TiO_2 wt% is shown in Figure 7. The outcome indicates that increasing TiO_2 content up to 1 wt% improves tensile strength and increasing TiO_2 content above this percentage degrades tensile strength. The Al LM13-TiO_2 composite with 1 wt% of TiO_2 have a maximum strength of 147.5 N/mm^2. As per present research studies, the tensile strength of Al LM13-TiO_2 composite increases by increasing TiO_2 percentage till 1 wt% of TiO_2 addition and there is a noticeable improvement in tensile strength when 1 wt% TiO_2 is added. In metals with polycrystalline structures, preference of dislocation glide, differences in phase crystal structure and stress condition causes permanent deformation. As a result, the lack of uniformity in microstructures may cause alloys to deform ineffectively [34].

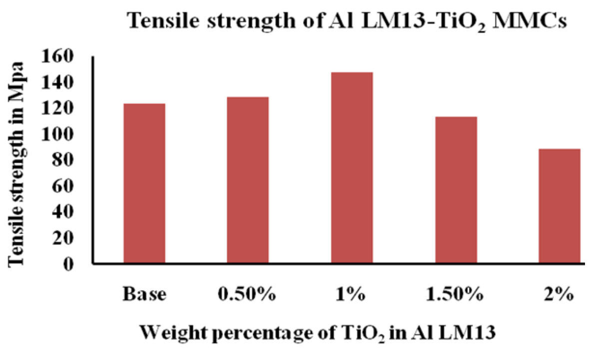


Fig. 7. Tensile strength of Al LM13-TiO_2 MMCs.

Due to TiO_2 particles, grain refinement of as cast alloys occurs and the grain refinement served as a potential site for alpha-grain nucleation and uniform dispersion of second phases. This is brought about by vigorous stirring; vigorous stirring could also help to increase microstructure uniformity with the dispersion of TiO_2 particulates. So that the plastic deformation of grains is well coordinated at the time tensile load applied. Cracks will be formed at the interface due to non-coordinated deformation between Al

LM13 and TiO_2. Hence coordinated deformation dislocations are created to prevent cracks at the interface. These TiO_2 particles function as a barrier to dislocation migration when the applied load increases, resulting in pile-ups. The grain refinement increases grain boundary area that will reduce dislocation length within the grain. This alone is insufficient to trigger dislocation glide in the adjacent grains. As a result, additional shear stress on the composites is required to induce additional distortion of the plastic. The composites' strength increases because of the combined effect of these two hurdles. Any more addition of TiO_2 above 1 wt% results decrement in tensile strength. This is because of stress concentration happened at the tips of TiO_2 phases. The existence of these stresses will cause particle interface debonding, micro crack nucleation, propagation, and eventually brittle rupture. Meanwhile, TiO_2 phases reduce the potency of liquid Al heterogeneous nucleation. The large matrix grains also obtained reason for the composites brittle fracture [33]. The volume proportion of reinforcement has a major impact on the tensile strength of reinforced composites. Brittleness will be imparted by increasing the volume percentage of TiO_2 particles, which will impair ductility due to micro particle segregation. Hence, it's critical to use the right quantity of TiO_2 reinforcement particle to ensure that the composite has balanced mechanical and tribological qualities. With the addition of 1 wt% TiO_2, tensile strength increased by 19.5%. These findings are in line with those of previous studies [35]. As more TiO_2 is added, the tensile strength decreases beyond 1 wt% in the current studies which is mainly attributed to the improper bonding between the matrix and reinforcement materials beyond 1 wt% which is also evident from the reduction in the hardness.

3.5. Percentage of Elongation of Al LM13-TiO_2 MMCs

All the qualities of the composite will improve as the degree of reinforcement increases, except for ductility, which has gradually reduced [36]. Figure 8 demonstrates the percentage elongation characteristics of the fabricated MMCs and a decrease in Al LM13-TiO_2 composite elongation when the reinforcing TiO_2 content was raised from 0% to 2%. This decrease in ductility is because of increment in the hardness. The percentage of elongation of Al LM13-TiO_2 was reduced by 52.69% when compared with Al LM13.

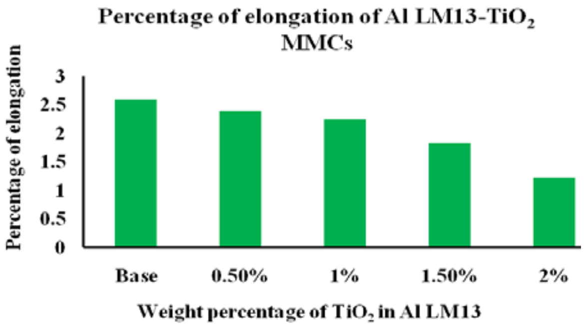
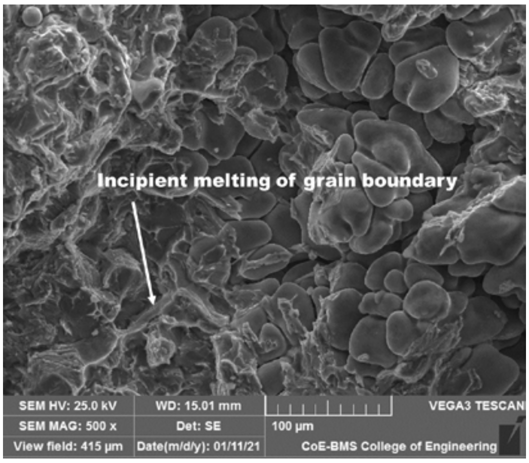


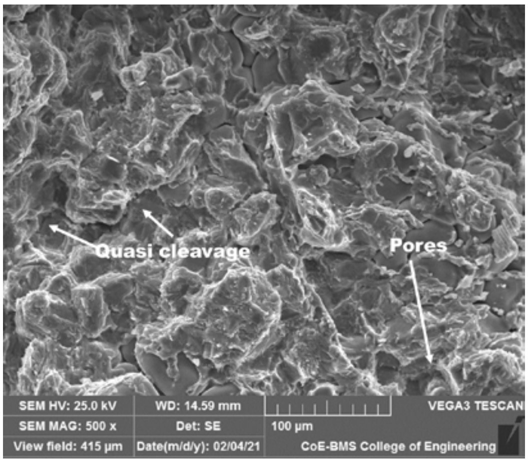
Fig. 8. Percentage of elongation of Al LM13-TiO_2 MMCs.

3.6. Fracture Surface Studies

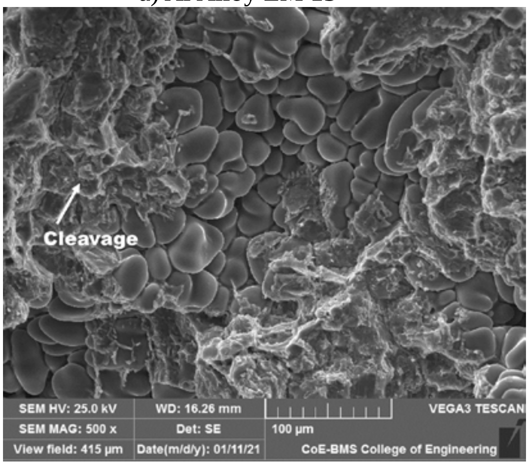
The Figure 9 is presented with the fractured SEM surfaces of Al LM13-TiO_2 MMCs with 500X magnification and figures 9a to 9e show the broken surfaces of tensile test specimens of as cast Al LM13 and Al LM13-TiO_2. The purpose of the fracture analysis was to investigate the impact of TiO_2 on the fracture behavior of composite. Figure 9a demonstrates that the fracture of Al LM13 alloy comprises of both transgranular and intergranular areas, indicating brittle fracture. The SEM image of Al LM13-TiO_2 composite containing 1 wt% of TiO_2 is shown in figures 9c. In the fracture zones, there are torn edges and cleavage facets, as well as some plastic deformation. Again, multiple dimples in the matrix can be found in some sections of composite fracture surfaces which could be the result of void nucleation and subsequent coalescence caused by significant shear deformation, fragmentation and decohesion of TiO_2 particles. The matrix could be the source of the crack. Figure 9c shows that micro cracks did not cross the TiO_2 particle but did travel to the matrix via the Al LM13-TiO_2 interface, implying that the particle-matrix interface is functioning properly. Stress concentration can occur when dislocations pile up at the interface under applied stress [37]. If the stress exceeds the interfacial binding forces, the reinforcement-matrix interface will debond, resulting in crack formation and dimple formation. The cleavage fracture is indicated by Walnor line and is used to characterize some fracture areas. As a result, the quasi-cleavage and tough mixed fracture modes of the as cast composite with 1 wt% TiO_2 exist [33]. Higher addition of TiO_2 above 1 wt% results decrement in hardness and tensile strength. This is because of stress concentration happened at the tips of TiO_2 phases. The existence of these stresses will cause particle interface debonding, micro crack nucleation, propagation, and eventually brittle rupture. Meanwhile, TiO_2 phases reduce the potency of liquid Al heterogeneous nucleation. The large matrix grains also obtained reason for the composites brittle fracture [33].



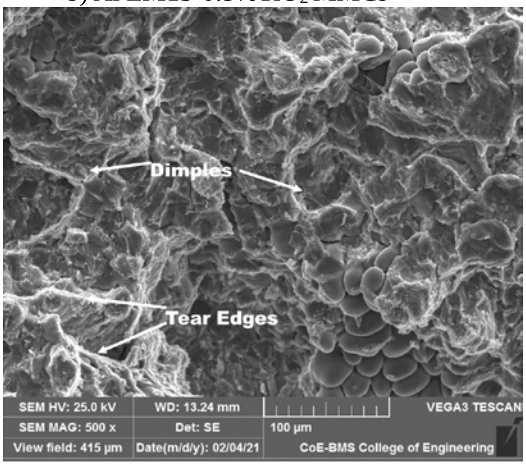
a) Al Alloy LM 13



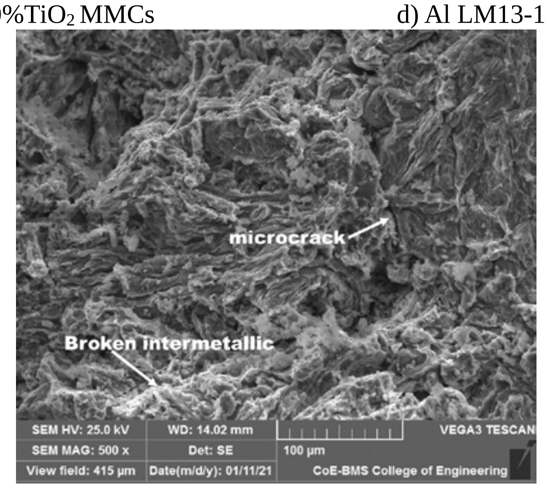
b) Al LM13-0.5%TiO_2 MMCs



c) Al LM13-1.0%TiO_2 MMCs



d) Al LM13-1.5%TiO_2 MMCs



e) Al LM13-2.0%TiO_2 MMCs

Fig. 9. Fractured surfaces of Al LM13-TiO_2 MMCs with 500X magnification.

3.7. Sliding Wear Resistance of Al LM13-TiO_2 MMCs.

Figure 10 depicts the variation in wear height loss over a range of sliding distances. As the sliding distance rises, the wear height loss increases as well. The Adhesive wear mechanisms may occur at initially, but as the sliding distance increases, adherent particles may emerge from the specimen and act as an abrasive between the specimen and disc, causing abrasive wear. The Abrasive wear increases the frictional force causing the Al LM13-TiO_2 composites to heat up. As the temperature rises, the material softens, resulting in higher wear loss. Figure 10a to d, explains that the wear loss of AlLM13-TiO_2 composites was less than wear loss of Al LM13 for any sliding distance and dropped as the TiO_2 wt% rose. This can be attributed to the composite materials' improved hardness and enhanced hardness raises material resistance to wear. Further as the applied load increase from 10 to 40 N the amount of wear loss has increased proportionally this is because as the load on the pin increases the friction also increases with temperature hence the higher the wear loss.

Figure 11 depicts the variation in wear loss as a function of load. The load, which is one of the essential elements influencing wear behavior, influences the wear rate of matrix and composite [38]. The wear rate changes in proportion to the force applied, according to Archard's principle, and this is usually lower in composites.

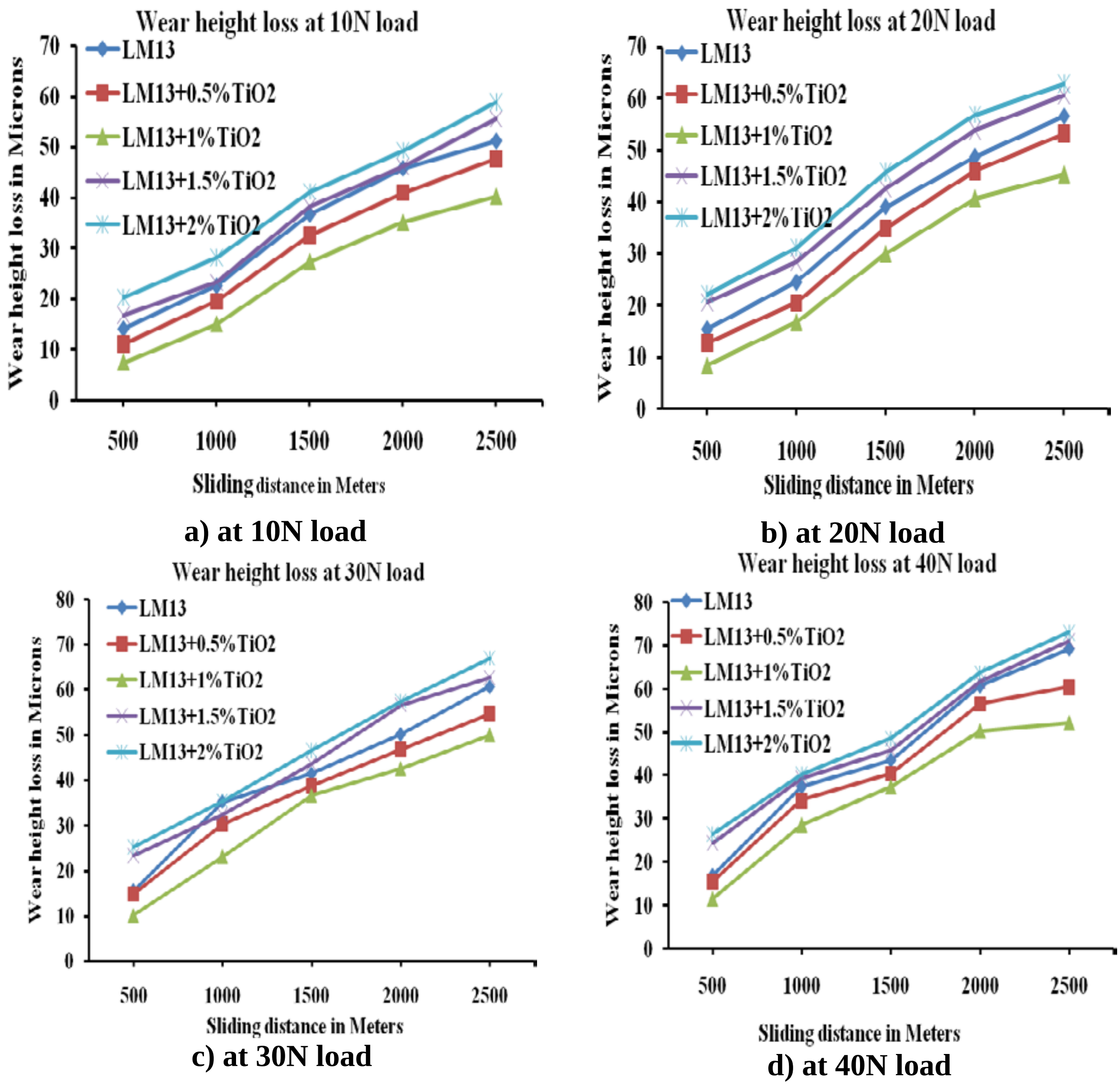


Fig. 10. Influence of sliding distance on wear height loss.

The matrix and composite wear will be more with greater forces. Nonetheless, the composites outperformed the matrix in terms of wear resistance for all the loads studied. Increased loads cause more delamination, resulting in increased matrix and composite wear [39].

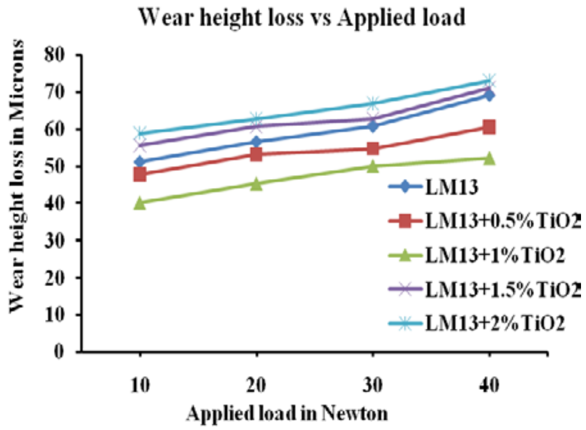


Fig. 11. Influence of applied load.

Figure 12 depicts the influence of TiO_2 quantity on Al LM13 wear resistance. Al LM13-TiO_2 MMCs have a higher wear resistance than the Al LM13 alloy.

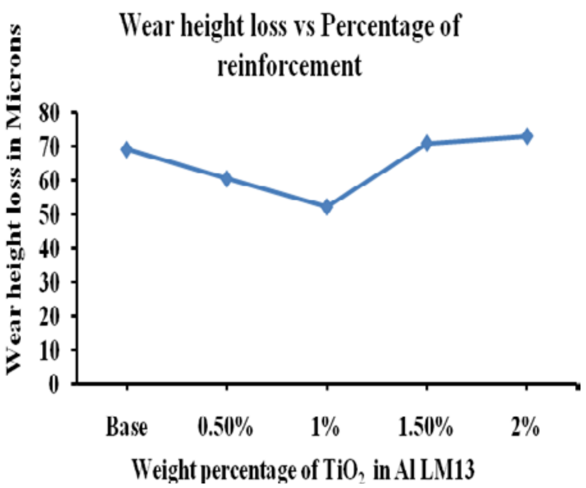


Fig. 12. Effect of percentage of on wear height loss.

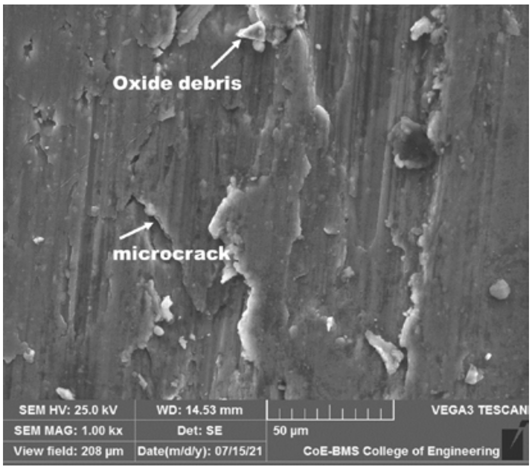
According to the findings of the current research, the resistance to wear of the Al LM13-TiO_2 increases as the amount of TiO_2 increases. When 1 wt% TiO_2 particle was introduced to the samples, they showed a significant benefit with respect to wear resistance. The TiO_2 particles may avoid direct contact of load with Al LM13 matrix. Furthermore, some of the subsurface strains of shear type were relieved due to the presence of reinforcing material present at the surface [40, 41].

The improvement in composite hardness is also responsible for the decrease in wear loss. Furthermore, increasing TiO_2 concentration reduces the extent of grooving in the composites' worn surfaces, resulting in low grooving. The wear resistance decreases as the TiO_2 particle content rises above 1 wt% TiO_2. The effects of matrix-reinforcement bond quality, particles pileup, localized material deformation, and porosity are all negative aspects that reduce wear resistance. The porosity content appears to be one of the primary elements affecting wear resistance of composite. These findings are in line with those of previous studies [42].

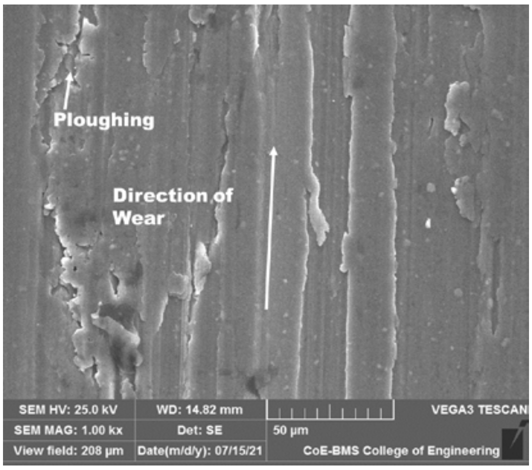
Figures 13a-e represent worn-out surfaces of Al LM13 and Al LM13-TiO_2 composites images with 40 N applied load, 2500 m sliding distance, and 500 rpm speed. When compared to an Al LM13 matrix, the worn surface images of Al LM13-TiO_2 show a different wear profile. The Al LM13 worn surface is fully smooth, level, and contains wear tracks that go in the direction of sliding. With the addition of TiO_2 percentage, the depth of groove in the composites' worn surface is reduced, indicating a reduction in wear loss. The lack of grooves suggests that very little material is removed. As the TiO_2 content increased in the matrix material, the amount of wear grooves formed decreased, which is the evidence of higher wear resistance property shown by the MMCs and is up to 1 wt% in the current study. Also, from figures 13d-e, the deeper grooves were noticed compared to the figures 13b-c, which indicates higher wear and improper bonding between the matrix and reinforcement materials in the current studies. Further is evident from the decrease in the density and hardness values beyond 1 wt% TiO_2 in the Al LM13 matrix.

4. CONCLUSIONS

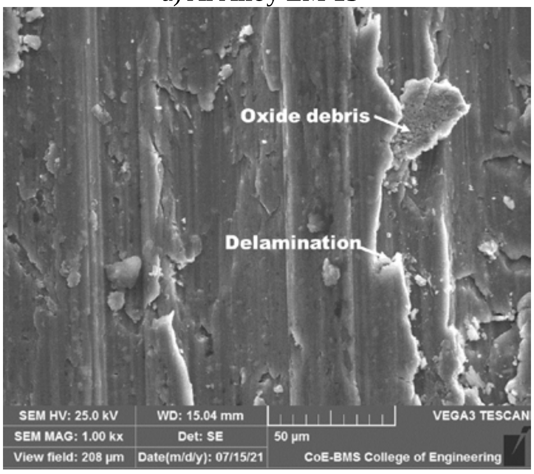
The liquid metallurgical process can be employed to distribute the TiO_2 reinforcement uniformly throughout the Al LM13 matrix. When 1 wt.% TiO_2 is added, the density, hardness, tensile strength, and wear resistance values all were improved significantly; however, as the TiO_2 increases above 1 wt%, the density, hardness, tensile strength, and wear resistance values all were decreasd.



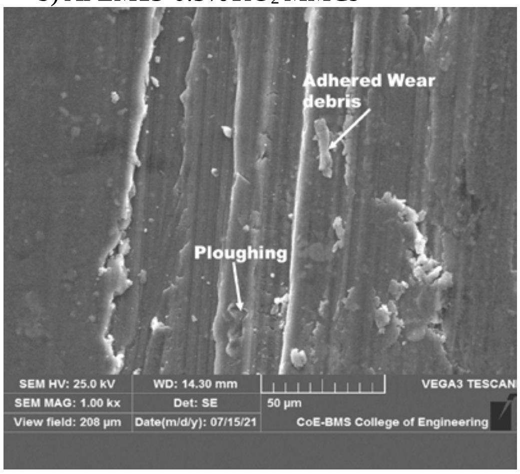
a) Al Alloy LM 13



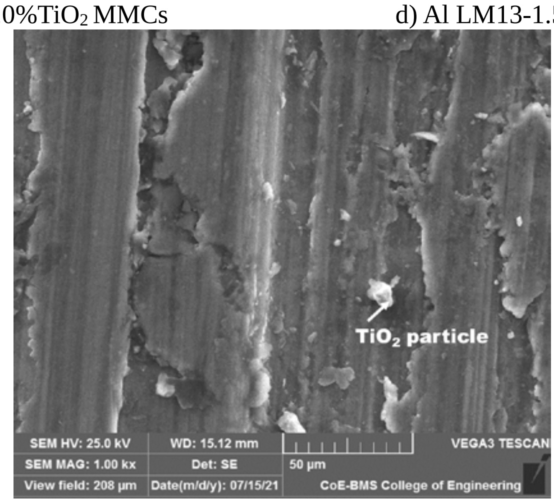
b) Al LM13-0.5%TiO_2 MMCs



c) Al LM13-1.0%TiO_2 MMCs



d) Al LM13-1.5%TiO_2 MMCs



e) Al LM13-2.0%TiO_2 MMCs

Fig. 13. SEM images of worn out surfaces of Al LM13-TiO_2 MMCs.

The SEM images represented dendritic regions confirming the even dispersion of TiO_2 in the Al LM13 matrix. The morphological studies like EDS and XRD studies validated the presence and quantity of TiO_2 in fabricated composites. The fracture surface indicated that the brittleness of the Al LM13-TiO_2 composites was improved with the addition of TiO_2 reinforcement. Al LM13-

TiO_2 composites were shown to have a greater wear resistance than the Al LM13. The wear loss of Al LM13-TiO_2 composites increased as the applied force and sliding distance increased. In contrast to the soft Al LM13 matrix alloy, the worn-out surface of Al LM13-TiO_2 was hard, and showed higher wear resistance.

REFERENCES

[1] Gajanan M Naik, B Sachin, Ravindra I Badiger, Ajit M Hebbale, "Microstructure and mechanical properties of TiO_2 reinforced AA22 MMCs", Elsevier's Materials today: Proceedings, 2021, 35, 303-307.

[2] Sajjad Arif, Basharat Jamil, Mohd Bilal Naim Shaikh, Tariq Aziz, Akhter H. Ansari, Mahfoozurrahman Khan, "Characterization of surface morphology, wear performance and modeling of graphite reinforced aluminium hybrid composites", Engineering Science and Technology, an International Journal, 2020, 23, 674-690.

[3] A. Vencl, A. Rac, I. Bobic, "Tribological behavior of Al-based MMCs and Their Application in Automotive Industry", Tribology in industry, 2004, 26, 31-38.

[4] G B Veeresh Kumar, R Pramod, Ch Guna Sekhar, G.Pradeep Kumar, T.Bhanumurthy, "Investigation of physical, mechanical and tribological properties of Al6061-ZrO_2 nano-composites", Elsevier's Heliyon, 2019, 5, e02858.

[5] Puneeth Arora, Rajesh Kanda and Ranvir singh panwar, "Effects of reinforcement on the properties of aluminium matrix composite", International Journal of Technical Innovation and Modern Engineering and Science (IJTIMES), 2018, 4, 464-475.

[6] Levent Ulvi Gezici, Burak Gul, Ugur Cavdar, "The Mechanical and tribological characteristic of Aluminum-Titanium dioxide composites", Revista De Metalurgia, 2018, 54, 1-9.

[7] K. Anil kumar, S. Natarajan, Muthukannan duraiselvam and S. Ramachandra, "Effect of Titanium dioxide particles on the morphology, mechanical and wear properties of the Aluminum Alloy 3003 based composites", Arabian Journal for Science and Engineering, 2019, 44, 10207–10217.

[8] G B Veeresh Kumar, P. S Shivakumar Gouda, R Pramod and C S P Rao, "Synthesis and characterization of TiO_2 Reinforced Al6061 Composites", Advanced Composites Letters, 2017, 26, 18-23.

[9] K. R. Padmavathi and R Ramakrishnan, "Tribological and Mechanical characterization of Aluminum Metal Matrix Composites", Indian journal of Science and Technology, 2016, 9, 1-6.

[10] M Karbalaei Akbari, S. Rajabi, K. Shirvanimoghaddam and HR Baharvandi, "Wear and friction behavior of nanosized TiB_2 and TiO_2 particle-reinforced Casting A356 Aluminum Nano Composites: A comparative study focusing on particle capture in matrix", Journal of composite materials, 2015, 49, 3665-3681.

[11] Raghu S, H. M Nanjundaswamy and M Sreenivasa, "Synthesis and Mechanical Characterization of Aluminum Reinforced with Various Nano-sized TiO_2 Particulate Composite", International journal of Advance Research in science and Engineering, 2018, 7, 281-292.

[12] Mithilesh Kumar Tiwari, A. K. Jain and Pranjal Sharma, "Evaluation in Mechanical Properties of aluminum metal matrix reinforced with Titanium dioxide (TiO_2) composite via Stir casting", Journal of Emerging Technologies and Innovative Research (JETIR), 2018, 5, 393-400.

[13] Vidit Mathur, Subramanya R. Prabhu B and Manjuanath Patel G. C and A. K Shettigar, "Reinforcement of Titanium Dioxide Nanoparticles in Aluminum Alloy AA5052 through Friction Stir Process", Advances in Materials and Processing and Technologies, 2019, 5, 29-337.

[14] Manal Hadi jaber, Ghada Adel Aziz, Alia Jasim Mohammed & Hussain J.AL-Alkawi, "Electrical Conductivity, Magnetic & Fatigue Properties of Al MMCs Reinforced with Nano-Titanium Dioxide", Nanocomposites, 2020, 6, 47-55.

[15] H. S Harshith and Joel Hemanth,

"Evaluation of Mechanical properties and characterization of LM13 reinforced with fused SiO_2", International Journal of Current Engineering and Technology, 2017, 7, 1105-1108.

[16] G. Balakumar, "Development and Property Evaluation of Copper-Chilled Aluminum Alloy Reinforced with Nano-ZrO_2 Metal Matrix Composites (NMMCs)", International Journal of Networks and Applications, 2013, 4, 1-11.

[17] M. Nagaral, V. Auradi, S. A Kori and V. Shivaprasad, "Mechanical characterization and Wear Behaviour of Nano TiO_2 Particulates Reinforced Al7075 Alloy Composites", Mechanics of Advanced Composite Structures, 2020, 7, 71-78.

[18] P C Elumalai and R Ganesh, "Synthesis and Characterization of Magnesium Matrix Composite Reinforced with Titanium Dioxide Nano-Particulates", Materials Research Express, 2020, 7, 015093.

[19] C Rajaganapathy, D Vasudevan and N Selvakumar, "Investigation on Tribological and Mechanical behavior of AA6082-Graphene based composites with Ti particles" Materials Research Express, 2020, 7, 076514.

[20] C. Aravind, S. Gopalakrishnan and N. Radhika, "Investigating the Adhesive Wear Properties of Aluminum Hybrid Metal Matrix Composites at Elevated Temperatures using RSM Technique", Journal of Nano Composites, 2019, 41, 604-612.

[21] Asaad Khudhair Hamzah, Talib Abdulameer Jasim, Bahaa Sami Mahdi and Hussain J. M. Al-alkawi, "Tribological Characterization of 7025/TiO_2 Nanocomposite at A Various amount of Nanoreinforcement", Journal of Mechanical Engineering Research and Development, 2020, 43, 178-184.

[22] S. V., A. and M., R., "Investigations on Tribological Behaviour of AA7075-TiO_2 Composites under Dry Sliding Conditions", Industrial Lubrication and Tribology, 2019, 71, 1064-1071.

[23] F. Khodabakhshi, A. Simchi and A. H Kokabi, "Surface Modifications of an Aluminum-Magnesium Alloy Through Reactive Stir Friction Processing with Titanium Oxide Nano Particles For Enhanced Sliding Wear Resistance", Journal of Surface and Coatings Technology, 2017, 309, 114-123.

[24] C. S. Ramesh, A. R. Anwar Khan, N. Ravikumar and P. Savanprabhu, "Prediction of Wear Coefficient of Al6061-TiO_2 Composites", Wear, 2005, 259, 602-608.

[25] Sumod Daniel and Dr G.Harish, "Sliding wear behavior of Aluminum Alloy (LM-13) Reinforced with Nano-ZrO_2 Matrix Composites", International Journal of Innovations in Engineering research and Technology [IJIERT], 2015, 2, 1-7.

[26] Pagidi Madhukar, N. Selvaraj, G. B. Veeresh Kumar, C. S. P.Rao, Faruq Mohammad, Murthy Chavali, "Effect of TiCnp on microstructure and mechanical behaviour of high-performance Al7150-TiC nanocomposites", Materials Science and Engineering: B, 2021, 265, 115034.

[27] G B Veeresh Kumar, Pinaki Prasad Panigrahy, Nithika Suresh, Pramod R, C S P Rao, "Assessment of Mechanical and Tribological Characteristics of Silicon Nitride Reinforced Aluminum Metal Matrix Composites", Journal of Composites: Part-B Engineering, 2019, 175, 107138.

[28] G. Y Yuan, Y. S Sun and Z. Wang, "Effect of antimony on microstructure and mechanical properties of Mg_9Al based alloy", Chinese Journal of Nonferrous Metals (China), 1999, 9, 779-784.

[29] G B Veeresh Kumar, Pramod R, Gude Venkatesh Chowdary, Mandadi Surya Vamsi, K Jayarami Reddy, Madeva Nagaral, K Naresh, "Effects of addition of Titanium Diboride and Graphite Particulate Reinforcements on physical, mechanical and tribological properties of Al6061 Alloy based Hybrid Metal Matrix Composites", Journal of Advances in Materials and Processing Technologies, 2021. https://doi.org/10.1080/2374068X.2021.1904370.

[30] Srivatsan TS, Al-Hajri M, Smith C et al., "The tensile response and fracture behavior of 2009 Al alloy metal matrix composite", Material Science Engineering: A, 2003,

346, 91-100.

[31] Aghababaei R and Joshi SP, “Grain size-inclusion size interaction in metal matrix composites using mechanism based gradient crystal plasticity”, International Journal of Solids and Structures, 2011, 48, 2585-2594.

[32] G B Veeresh Kumar, P S Shivakumar Gouda, Pramod R, U Srinivas Kumar Chowdary, Tammila Subash, Mandadi Surya Vamsi, K Naresh, “Development and Experimental Evaluation of Titanium Diboride Particulate Reinforcements on the Al6061 Alloy Composites Properties Advances in Materials and Processing Technologies” Journal of Advances in Materials and Processing Technologies, 2020, DOI: 10.1080/2374068X.2020.1855399.

[33] X. H Chen, H. Yan and X. P. Jie, “Effects of Ti addition on microstructure and mechanical properties of 7075 alloy”, International Journal of Cast Metals Research, 2015, 28, 151-157.

[34] C. Z Wang, “Material performance”, Beijing Industrial University press, Beijing, 2006, 103-156.

[35] G. B. Veeresh Kumar, D. Gopinath Reddy, C. Vineeth Reddy, C. Sriteja, and R. Pramod, “Investigation of Mechanical and Tribological Properties of Al6061–TiB2 Metal Matrix Composites,” Materials Performance and Characterization, 2020, 9, 1–12.

[36] G. B. Veeresh Kumar, R. Pramod, P. S. Shivakumar Gouda, and C. S. P. Rao, “Effect of Tungsten Carbide Reinforcement on the Aluminum 6061 Alloy,” Journal of Testing and Evaluation, 2019, 47, 2613–2629.

[37] Q. P Zhong and Z. H Zhao, “Fractography”, Book Higher education press, Beijing, 2006, 74-109.

[38] Praveen kumar Bannaravuri, Anil Kumar Birru, "Strengthening of Mechanical and Tribological Properties of Al-4.5%Cu Matrix Alloy with The Addition of Bamboo Leaf Ash", Results in Physics, 2018, 10, 360-373.

[39] C. S Ramesh, S. K. Seshadri, “Tribological characteristics of nickel composite coatings”, Wear, 2003, 255, 893–902.

[40] Kok M and Ozdin K, “Wear resistance of aluminum alloy and its composites reinforced by Al_2O_3 particles”, Journal of Materials Processing Technology, 2007, 183, 301-309.

[41] Mandal A, Chakraborty M and Murty BS, “Effect of TiB_2 particles on sliding wear behavior of Al-4Cu alloy”, Wear, 2007, 262, 160-166

[42] P Madhukar, N Selvaraj, CSP Rao, Veeresh Kumar G B “Tribological Behaviour of Ultrasonic Assisted Double Stir Casted Novel Nano-Composite Material (AA7150-hBN) using Taguchi Technique”, Journal of Composites: Part-B Engineering, 2019, 107136.