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Evaluation of Mechanical and Wear Assessment of Al-1.2Si-0.75Fe/Mullite MMCs for Industrial Applications

Raghavendra Govind Galgali[1], B. M. Satish[2], B. M. Girish[3], Mahesh B. Davanagere[4], L. Girisha[5], E. R. Babu[6], Nagaraja C. Reddy[6] and Chithirai Pon Selvan[7]

[1]*Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Bangalore - 560064, Karnataka, India*

[2]*School of Engineering, Department of Mechanical Engineering, Mohan Babu University, Tirupati - 517102, Andhra Pradesh, India*

[3]*Department of Mechanical Engineering, Alliance College of Engineering and Design, Alliance University, Bangalore - 562106, India*

[4]*Department of Mechanical Engineering, Graphic Era (Deemed to be University), Dehradun - 248002, Uttarakhand, India*

[5]*Department of Mechanical Engineering, PES Institute of Technology and Management, Shivamogga - 577204, Karnataka, India*

[6]*Department of Mechanical Engineering, Bangalore Institute of Technology, Bengaluru - 560004, Karnataka, India; cnraaja@gmail.com*

[7]*School of Science and Engineering, Curtin University Dubai - 345031, United Arab Emirates*

Abstract

The outline idea is based on saddling the high quality and wear capacities of eminent engineered fortifications, for example with the lightweight and minimal effort of preparing or squandering fiery remains. There is almost no writing which has considered the outline of Aluminium Matrix Composites (AMCs) with the utilization of fortifications of agro squander slag. The Scanning Electron Microscope (SEM) images of gleaming samples, the subsequent were examined. The distribution of strengthening flecks (Mullite (Al_2O_3-SiO_2)) is recovered to be steady. Mullite specks are not confined to the grain frontiers. From the wear studies of Al4006 alloy, it was observed that there was more wear out of the surface when compared to Al4006/ Al_2O_3-SiO_2 composites. Wear tracks of Al4006 alloy show a tough face with extra grooves and ridges associated with wear tracks of Al4006/Al_2O_3-SiO_2 composites dispersion and binding of the Al_2O_3-SiO_2 in the composite could indeed be explained by the reduced wear rate. Also, the addition of cenospheres acts as a load-bearing material which protects the matrix from more wear out. Wear track investigation described more wear out and deep abrasive trenches in as-cast contrasted to that of composites which may be due to the lack of load-bearing reinforcing material (mullite) which worsens the material strength leading to more tear or wear out. Overall, from the current studies, it can observed that as the mullite particle reinforcement increases the matrix hardness, strength, and density increase. This study highlights the essential characteristics of the technique of liquid metallurgy and its application to Al4006 MMCs reinforced with mullite..

Keywords: *Al4006 Alloy, Fracture Surface, Density, Hardness, MMCs, Mullite, Tensile Strength, Wear*

**Author for correspondence*

1.0 Overview

Aluminium composites are broadly used for food storage in place of customary glass jars, bottles, and steel cans. This trend is shaped by aluminium's unique mechanical properties, which include nimble bulk, ductility, and decay resistance[1]. Contemporary cans are 40% lighter than cans used in 1972. Agro squander fiery remains gotten by the controlled consumption of agro-squandered items, for example, bagasse, upsides of low masses and preparing budget contrasted and basic manufactured strengthening pottery, for example, SiC and Al_2O_3. Squander fiery debris has been effectively used to create Al framework mixtures with property levels which can be enhanced with the supplement of manufactured fortifications, for example, SiC and Al_2O_3[2]. The outline idea is based on saddling the high quality and wear capacities of eminent engineered fortifications, for example with the lightweight and minimal effort of preparing or squandering fiery remains. There is almost no writing which has considered the outline of Aluminium Matrix Composites (AMCs) with the utilization of fortifications of agro squander slag[3]. Around three forms of metal matrix mixes are Metal, Polymer and Ceramic Matrix Composites (MMCs, PMCs and CMCs). These 3 sorts may also be sorted as intermittently bolstered MMCs and unendingly bolstered amalgams. While not going into any detail on the last 2 sorts, particle-bolstered amalgams are enlightened in rapports of their use and[4]. Whereas recitation the process strategies of amalgams, the most focus is on the process of sporadically bolstered amalgams that are expounded in the present study. Sporadically bolstered amalgams have some benefits over unendingly bolstered amalgams. Initial of all, they're cheap compared to unendingly bolstered amalgams. As an example, monofilament fibre-bolstered amalgams square measure high-ticket because of the creation of those yarns. Second, unendingly bolstered MMCs will be salvaged best of the period[5]. This can be tough in the case of fibre-bolstered composites. Conjointly in several cases, similar to internet form casting will be performed throughout the process of discontinuously bolstered amalgams. Additionally, to all or any of those, once the speck extent dispersal of the bolstering is unvarying and acceptable, though this will increase the price, machining of made elements is feasible. Finally, continuously resistant aggregates are far beyond isotropous than fiber-durable blends[6]. Overall, in the current studies, mullite is fortified with Al4006 matrix using a liquified metallurgy route to develop composites and studied for microstructure, hardness, strength, density, and wear studies.

2.0 Materials and Procedure Details

Due to the appropriate level of strength, corrosion resistance, and durability thanks to its chemical composition, which is listed in Table 1. Due to its robust casting capabilities and desirable casting properties, this alloy was chosen. The strongest aluminium alloy currently in use is Al4006. Typically, mullite is kept in landfills. To increase the mechanical properties of aluminium composites, a study was done to look at the athratic effects of mullite content in the environment. Mullite, a silicate mineral with the formula $3Al_2O_3{\cdot}2SiO_2$ (or $Al6Si_2O_{13}$), exhibits several physical properties that make it a valuable material in various industrial applications, particularly in high-temperature environments. Mullite has an orthorhombic crystal structure It typically exhibits a colour range from colourless to pale yellow or pale brown with density ranging from approximately 3.0 to 3.2 g/cm^3 and a high melting point, typically around 1810°C to 1850°C. Also, it exhibits a low thermal expansion coefficient, around 4.5 to 5.5 x 10^{-6}/K. Mullite has moderate thermal conductivity, which is beneficial in applications where heat insulation or gradual heat distribution is required.

Liquid phase materialisation technique is often more ecologically friendly because it typically takes less time than solid stage distribution. Stir casting was not only the simplest and most efficient production method accessible to MMC, but it was also the most inexpensive. The correct wetting of the molten metal and the particle reinforcement is essential. An interface change between the liquid and solid must also result in difficulty with strengthening propagation in cast aggregates at some point during the solidification process. MMCs can significantly lower their fees by employing this technique[7-9]. Casting has been done by Liquid Metallurgy route (Stir Casting Technique). The Stir Casting technique is a widely used method for producing Aluminum Metal Matrix

Table 1. Chemical composition of an Al4006 alloy (Wt %.)

Si	Fe	Cr	Cu	Mn	Zn	Mg	Others	Balance
1.2	0.75	0.18	0.08	0.045	0.045	0.008	0.047	97.64

Table 2. Designation of Al4006/Mullite composite

S/No	Alloy/Composite Label	Representation
1	Al4006 alloy	Al4006
2	Al4006 alloy + 5 % Mullite	Al4006-5 MuL
3	Al4006 alloy + 7 % Mullite	Al4006-7 MuL
4	Al4006 alloy + 9 % Mullite	Al4006-9 MuL

Composites (MMCs). It involves the incorporation of reinforcing materials, such as ceramic particles, into a molten aluminium matrix. Melting the Matrix Material. Al4006 alloy is melted in a furnace, reaching a temperature slightly above its melting point to ensure good fluidity. The reinforcing material, i.e., Mullite, is preheated to remove moisture and improve wettability. The preheated reinforcement particles are gradually introduced into the molten aluminium. The addition rate and method are controlled to prevent agglomeration and ensure uniform distribution. A mechanical stirrer is introduced into the melt to mix the reinforcement particles uniformly with the molten aluminium. Stirring parameters (speed, time, and blade design) are crucial for achieving a homogeneous mixture. The mixture is degassed to remove hydrogen and other impurities, which could lead to porosity in the final product. The composite material is then poured into preheated Molds and allowed to solidify. The mold type and cooling rate can affect the microstructure of the composite.

2.1 Investigational Features and Methodology Flow diagram

A carefully prepared specimen and magnifications are needed for microscopic examinations. Proper preparation of the specifications and materials surfaces requires a rigid step-by-step process. The sample is sliced into small pieces and polished using emery papers to get a scratchproof silvery surface. Later the polished surface is placed under SEM and images are captured. Hardness is the extent of imperviousness of strong material against indentation as a compressive push is employed. Macroscopical hardness is usually typified by tough entomb-molecular binds.

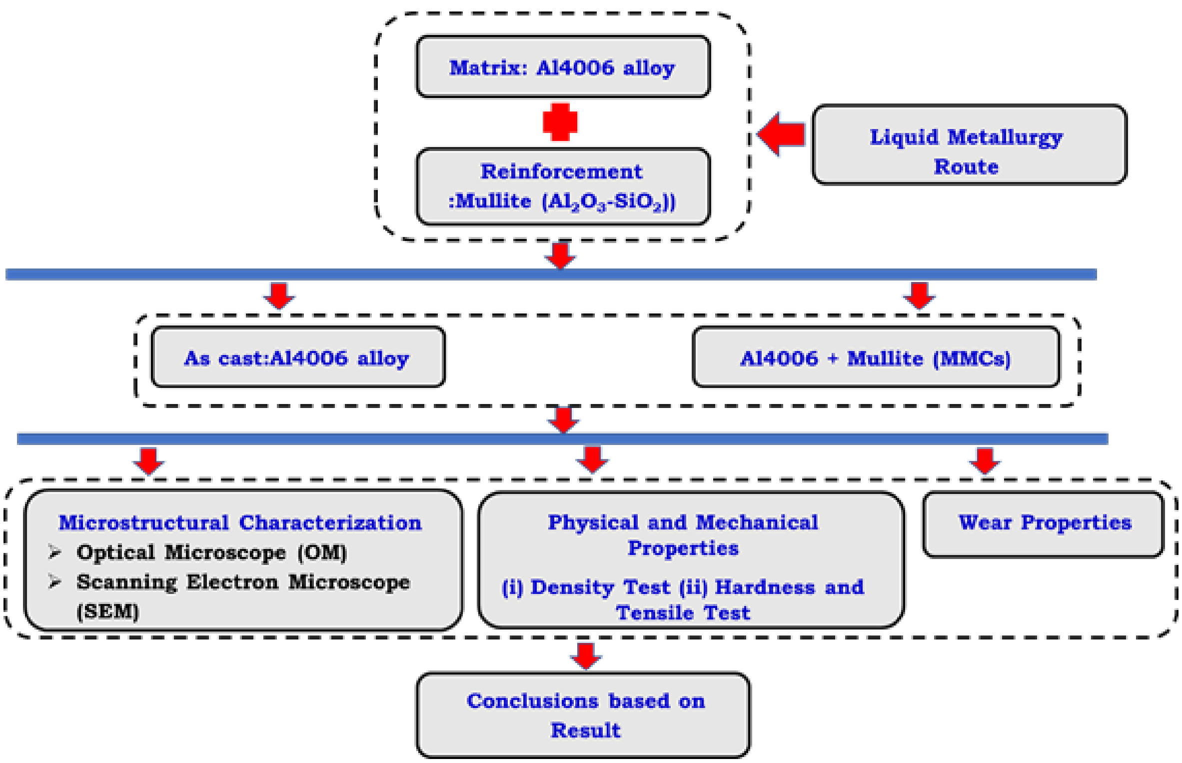


Figure 1. Methodology flowchart of work.

The hardness of a sturdy matter depends on its ductility, stretchy toughness, plasticity, toughness, and force.

Hardness is measured across the specimen according to ASTM standard procedure. In tensile testing the sample is placed between two jaws of tensile clamp and load is applied through the load cell. Slowly the material gets stretched and breaks and measured across the specimen according to ASTM standard procedure. Wear was measured across the specimen according to ASTM standard procedure. The sample was placed in the wear testing machine holder and the load was applied using a load cell. Speed was set and as the machine started running there was a wear out in samples and the wear tracks were captured using SEM.

3.0 Results and Discussions

This chapter explains the results and discussions of Al4006 alloy reinforced with mullite using the stir casting technique.

3.1 Microstructure Analysis

3.1.1 Microstructural Characterization of Results of Al4006-Mullite MMC'S using Optical Micrographs

Figure 2 depicts the optical micrographs of Al4006/ Mullite (Al_2O_3-SiO_2) MMCs, where (a) As-cast Aluminium 4006

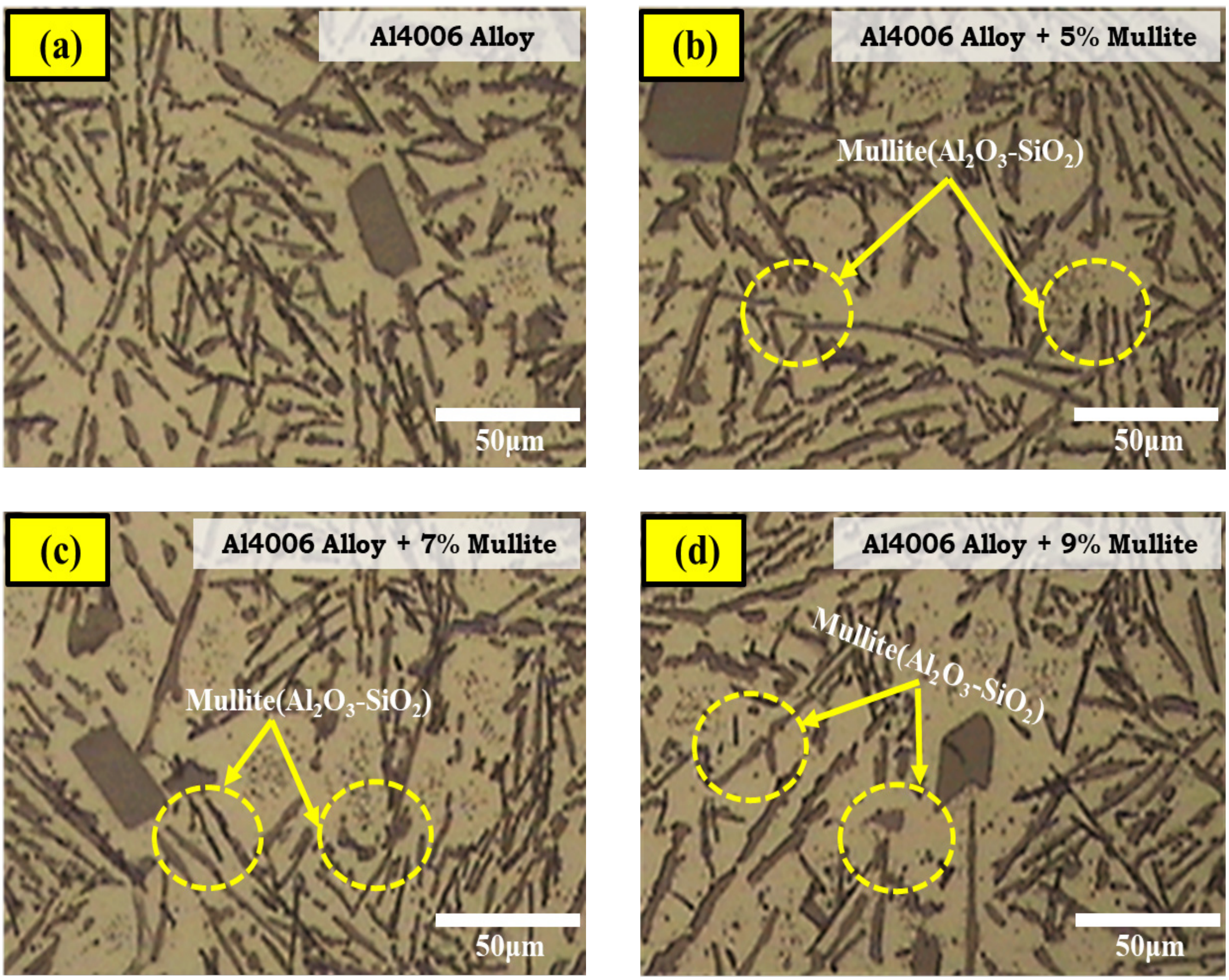


Figure 2. Microstructural characterization of Al4006 alloy and its mullite composites using optical micrographs.

alloy (b) Al4006 alloy + 5% Mullite (c) Al4006 alloy + 7% Mullite (d) Al4006 alloy + 9% Mullite. From Figure 2 (b to d), we can witness the consistency of mullite and the absence of casting flaws or porosity in the Al4006 alloy and its composites. In Figure 2 (b) we see a few mullite particles distributed in the Al4006 matrix. Contrasted to Figures 2 (b, d), Figure 2 (c) shows more mullite specks disseminated in the Al4006 matrix. This comment is in accord with several examinations[10,11].

3.1.2 Microstructural Characterization of Results of Al4006-Mullite MMC'S using Scanning Electron Micrographs

Figure 3 depicts the SEM images of Al4006/ Mullite (Al_2O_3-SiO_2) MMCs, where (a) As-cast Aluminium 4006 alloy (b) Al4006 alloy + 5% Mullite (c) Al4006 alloy + 7% Mullite (d) Al4006 alloy + 9% Mullite. From Figure 3 (b to d), we can witness the consistency of mullite and the absence of casting flaws or porosity in the Al4006 alloy

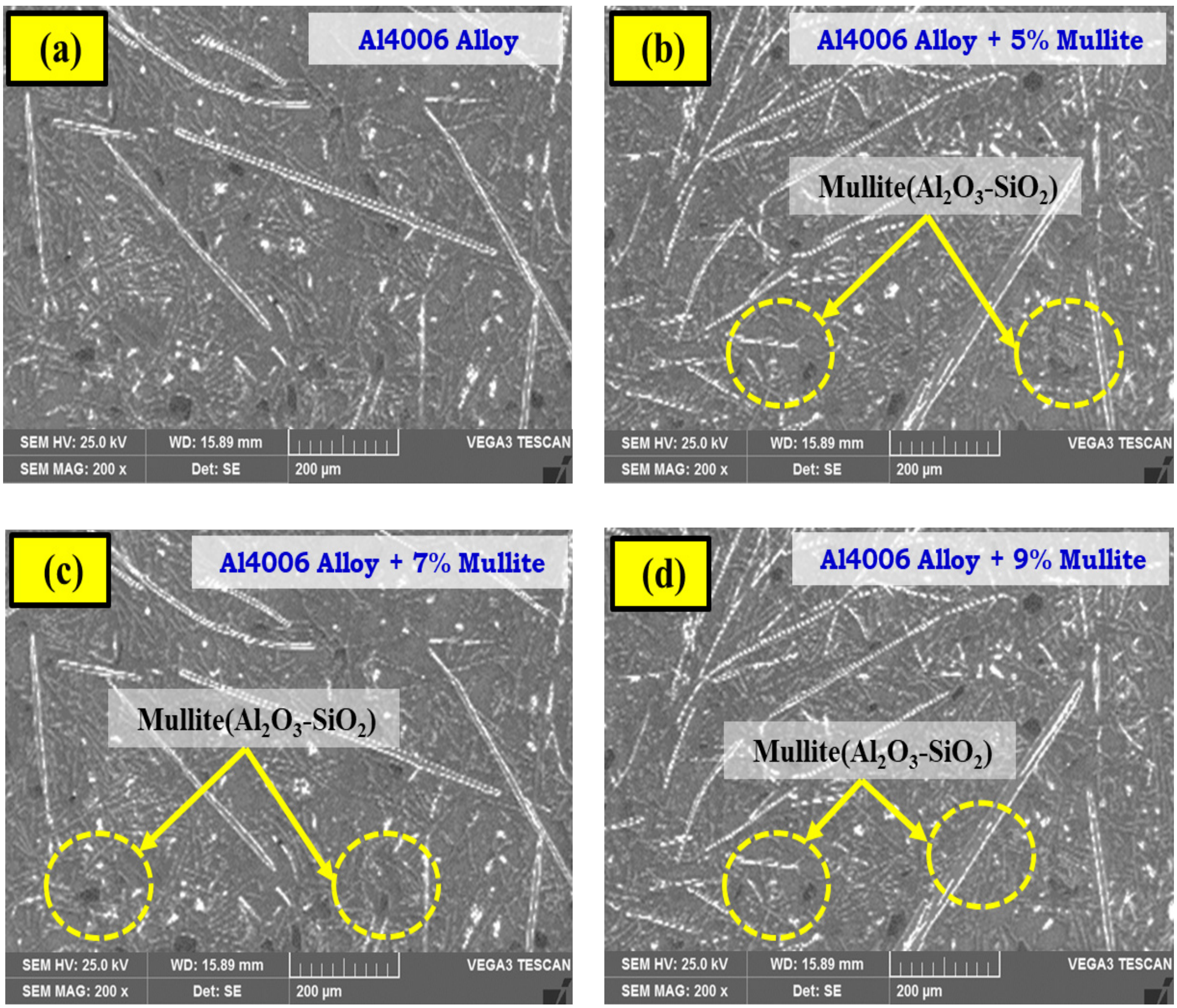


Figure 3. Microstructural characterization of Al4006 alloy and its mullite composites using Scanning Electron Micrographs.

and its composites. In Figure 3 (b) we see a few mullite particles distributed in the Al4006 matrix. Contrasted to Figures 3 (b, d), Figure 3 (c) shows more mullite specks disseminated in the Al4006 matrix. This comment is in accord with several examinations[12,13].

3.1.3 Hardness Test Results of Al4006-Mullite MMC'S

Figure 4 illustrates the hardness assessment results of Aluminium 4006-Mullite MMCs**.** Figure 4 depicts the hardness of the composite surges with mullite particles raise in A14006 matrix as likened to As-Cast (4006 alloy), Al4006 alloy + 5% mullite increase in hardness of 6.1 VHN (8.62%), Al4006 alloy + 7% mullite increase in hardness of 8.5 VHN (12.02%) and Al4006 alloy + 9% mullite increase in hardness of 1.7 VHN (2.40%). By the picture, it's observed that the strengthening proportion of mullite upsurges up to 7% here is a rise in hardness, once the reinforcement is increased further, i.e., from 7% to 9% there is a drastic decline in hardness. mullite clumping in the Al4006 tesseract may be to chastise for this. Look at that percentage on the chart[14,15].

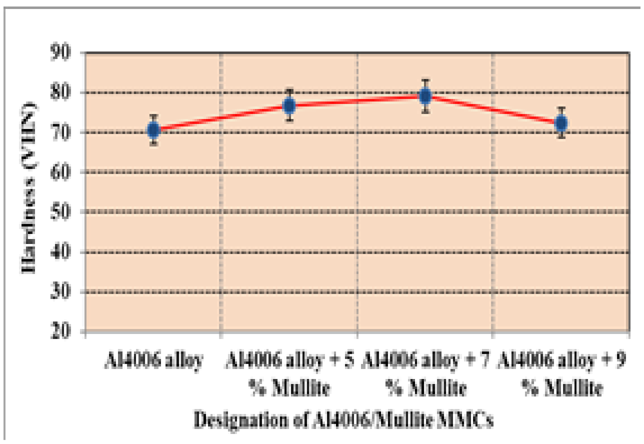
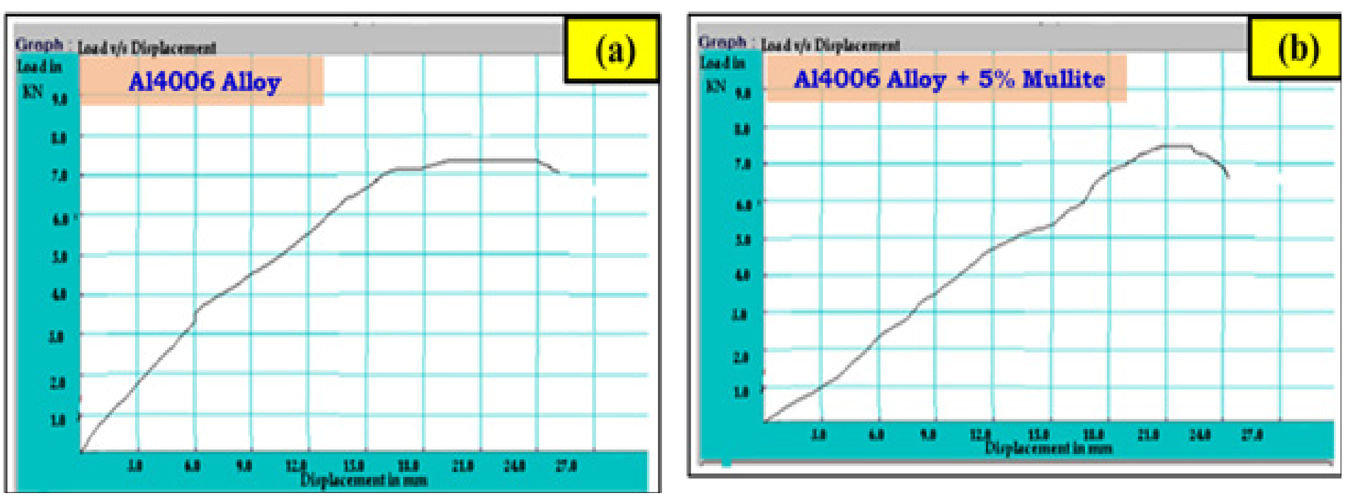


Figure 4. Findings of Al4006-mullite MMC's hardness trials.

3.1.4 Tensile Test Results of Al4006-Mullite MMC'S

Al4006-Mullite MMCs stress-strain curve can be seen in Figure 5. Figure 6 illustrates the strength assessment results of Al4006-mullite MMCs**.** Figure 6 depicts the strength of the composite surges with mullite particles raised in the A14006 matrix as likened to As-Cast (4006 alloy), Al 4006 alloy + 5% mullite surge in strength of 14.6 MPa (13.87%), Al 6061 alloy + 7% mullite increase in UTS of 37.3 MPa (35.45%) and Al 6061 alloy + 9% mullite upsurge in UTS of 32.9 MPa (31.27%). By the picture, it's observed that the strengthening proportion of mullite upsurges up to 7% here is a rise in UTS, when the reinforcement is enhanced further i.e., from 7% to 9% there is a drastic decline in UTS. mullite clumping in the Al4006 tesseract may be to chastise for this. Look at that percentage on the chart[16,17].

Figure 7 illustrates the strength assessment results of Al4006-mullite MMCs**.** Figure 7 depicts strength of the composite surges with mullite particles raise in A14006



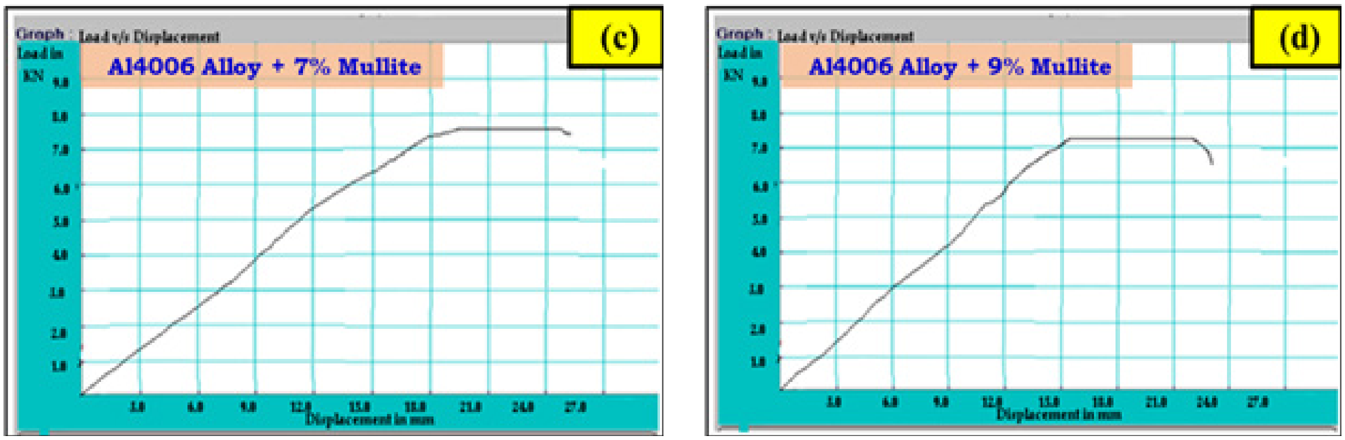


Figure 5. Stress-Strain curves of Al4006- Mullite MMCs.

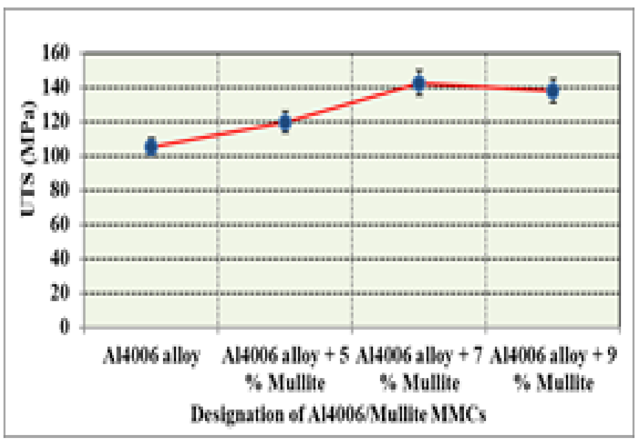


Figure 6. Findings of Al4006-mullite MMC's tensile (UTS) trials.

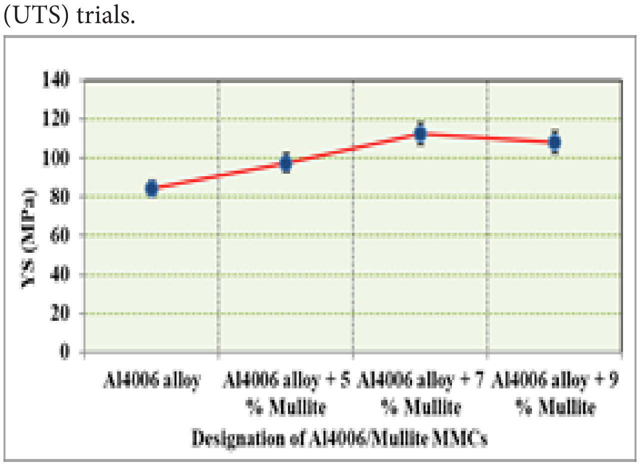


Figure 7. Findings of Al4006-Mullite MMC's Tensile (YS) trials.

matrix as likened to As-Cast (4006 alloy), Al 4006 alloy + 5% mullite surge in strength of 15.65 MPa (15.65%), Al 6061 alloy + 7% mullite increase in YS of 33.45 MPa (33.45%) and Al 6061 alloy + 9% mullite upsurge in YS of 28.11 MPa (28.11%). By the picture, it's observed that the strengthening proportion of mullite upsurges up to 7% here is a rise in YS, once the reinforcement is increased further i.e., from 7% to 9% there is a drastic decline in YS. mullite clumping in the Al4006 tesseract may be to chastise for this. Look at that percentage on the chart[18,19].

In Figure 8, Al 4006/Mullite MMCs have good ductility characteristics. Figure 8 reveals that the ductility of the composite reduces with mullite particles raised in the A14006 matrix material. As contrasted to base alloy 4006 of as cast, Al 4006 alloy + 5% mullite reduces %

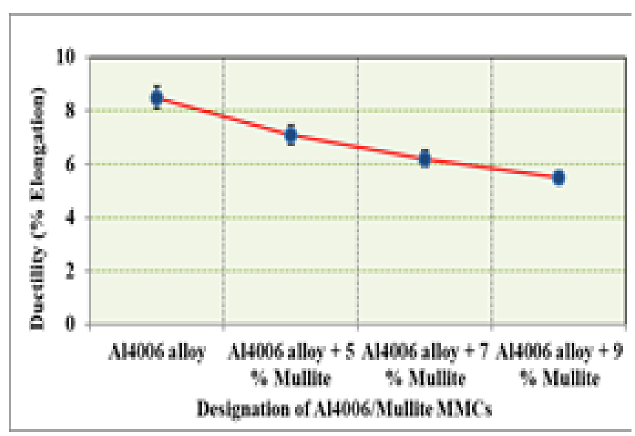


Figure 8. Findings of Al4006-mullite MMC's tensile (% Elongation) trials.

Elgn. by 1.4 times (16.47%), Al 4006 alloy + 7% mullite reduces % Elgn. by 2.3 times (27.05%), and Al 4006 alloy + 9% mullite reduces % Elgn. by 3 times (35.29%). The result illustrates as the reinforcing proportion of mullite climbs up the ductility keeps on reducing. As the reinforcement obstructs the matrix material leading to a decrease in ductility. This finding is supported by several studies[20,21].

3.1.5 Fractography Test Results of Al4006/ Mullite Composites

Figure 9 shows the Fractographs of A4006/Mullite Composites. Where Figure 9 (a) Fractograph of Aluminium 4006 alloy, Figure 9 (b) Fractograph of Al4006 alloy + 5 % Mullite, Figure 9 (c) Fractograph of Al4006 alloy + 7% Mullite and Figure 9 (d) Fractograph of Al4006 alloy + 9% Mullite. From Figure 9 (a, b) we

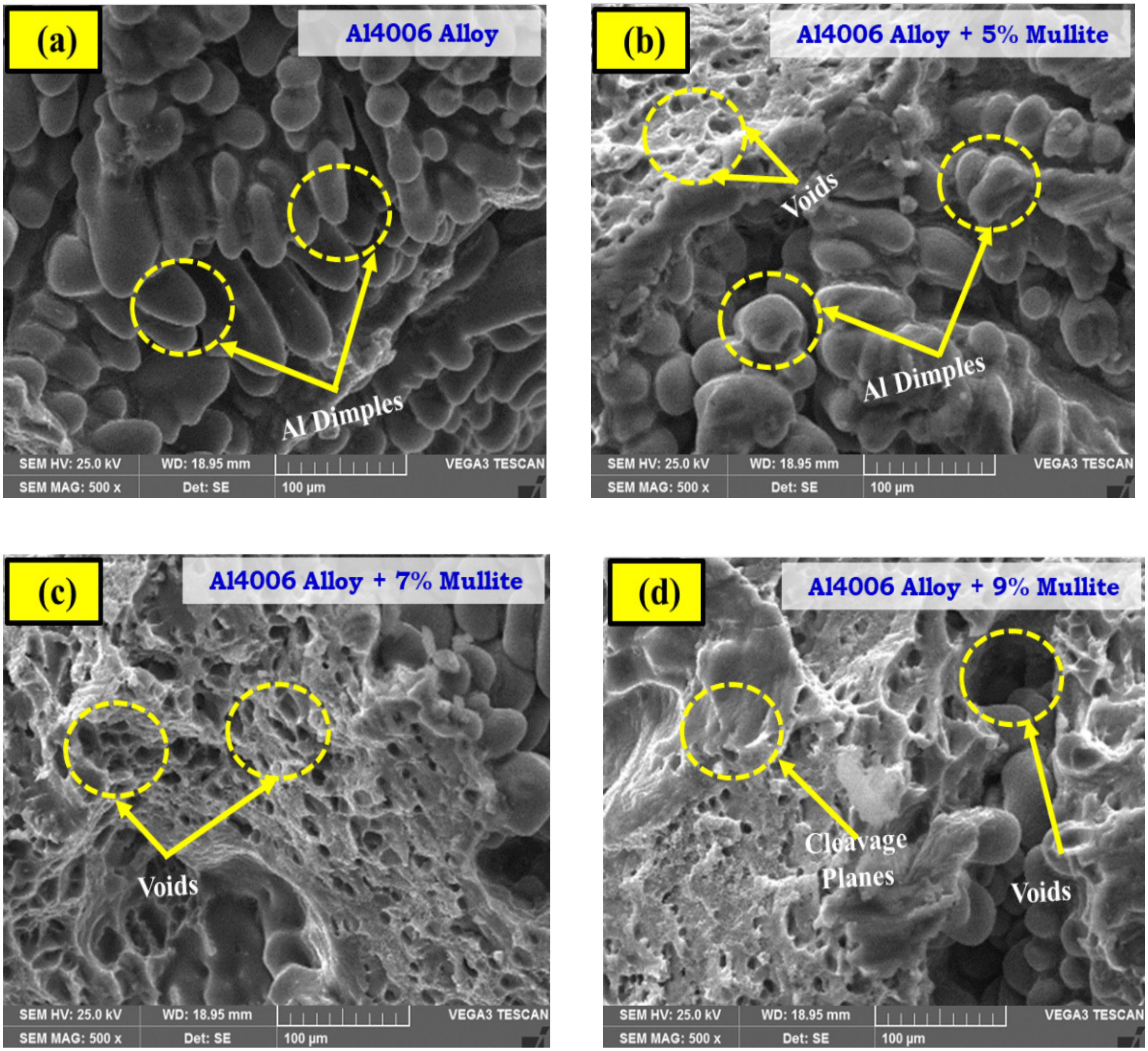


Figure 9. Fractography Analysis of Al4006 alloy and its mullite composites.

can observe a large number of dimples which indicate ductile fracture. From Figure 9 (c, d) we can observe the combination of dimples and voids which indicates brittle fracture[22,23].

3.1.6 Density Test Results of Al4006-Mullite MMC'S

Figure 10 illustrates the density test results of Al 4006/ Mullite MMCs**.** Figure 10 reveals that the density of the composite improves with mullite particle raises in the A14006 matrix material. As contrasted to base alloy 4006 of as cast, Al 4006 alloy + 5% mullite enhances density by 1.87%, Al 4006 alloy + 7% mullite raises density to 6.74%, and Al 4006 alloy + 9% mullite enhances raises density by 4.49%. The result illustrates as the reinforcing proportion of mullite ascends to 7%, the density rises; nevertheless, even as the reinforcing ratio is raised higher, i.e., from 5% to 7%, the density falls slightly. It could be due to the Al4006 matrix's clumping of mullite. According noticed in this diagram, that's the ratio. Eventually, this can be assumed that reliable reinforcement spreading leads to superior density. This finding is supported by several studies[24,25].

3.1.7 Wear Test Results of Al4006-Cenosphere MMC'S

Figure 11 illustrates the wear test results of Al 4006/ CNS MMCs**.** Figure 11 reveals that the wear rate of the composite improves with mullite particle raises in the A14006 matrix material. It could be owing to the Al4006 matrix's clumping of mullite. According noticed in this diagram, that's the ratio. The Al4006 alloy has the highest wear rate, which is 0.5342 x 10^{-3} mm^3/m for 30N, and for 10N the value is 0.5312 x 10^{-3} mm^3/m. Al4006 alloy + 3% mullite i.e., for 10N the value is 0.4381 x 10^{-3} mm^3/m and for 30N the value is 0.4348 x 10^{-3} mm^3/m and these both are the medium wear rate. Followed by Al4006 alloy + 7% mullite, i.e., for 30N the occurred value is 0.3272 x 10^{-3} mm^3/m, and for 10 N the occurred value is 0.4311 x 10^{-3} mm^3/m. Resulting the wear rate is 2.528 x 10^{-3} mm^3/m for a 10N alloy + 9% mullite, and 0.2115 x 10^{-3} mm^3/m for a 30N alloy, the minimum wear rate is 0.2247 x 10^{-3} mm^3/m. mullite functions as a load bearers to avoid the wearing out of the matrix. Ultimately, this can be concluded that consistent augmentation dispersal leads to a lower wear rate. This finding is supported by several studies[26,27].

3.1.8 Wear Surface Morphology Results of Al4006 Alloy and its Mullite Composites

Where Figure 12 (a) WSM of Al4006 alloy, Figure 12 (b) WT of Al4006 matrix alloy + 5% mullite, Figure 12 (c) WT of Al4006 matrix alloy + 7% mullite, Figure 12 (d) WT of Al4006 matrix alloy + 9% mullite. WT is taken at a Parameter of Load: 30N, Slithering Velocity: 1.5 m/sec, Slithering Distance: 1200 meters. The wear development occurring here concerned the brim formation and

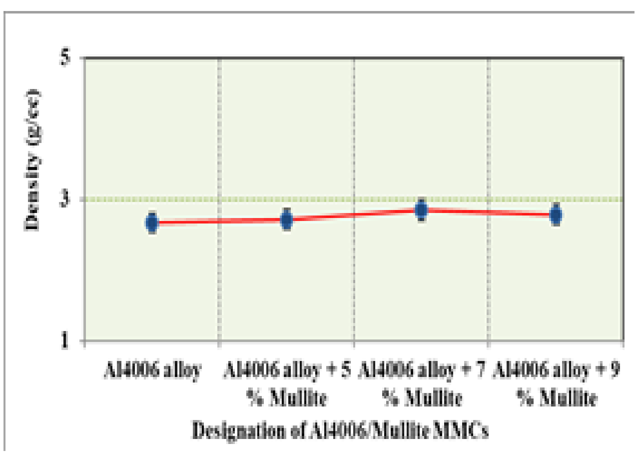


Figure 10. Findings of Al4006-mullite MMC's density trials.

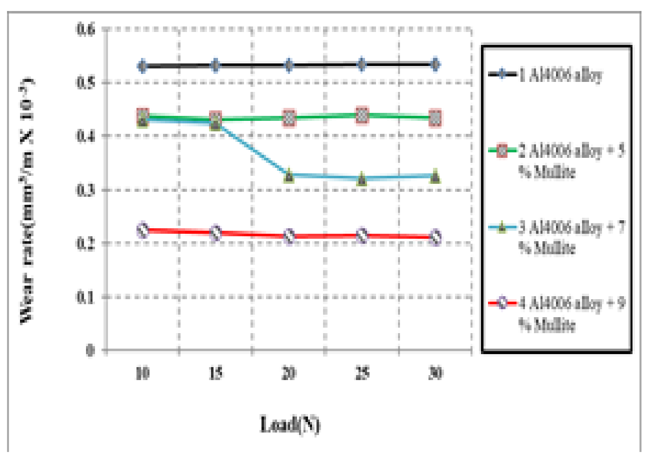


Figure 11. Wear test values Al4006 alloy and its mullite composites.

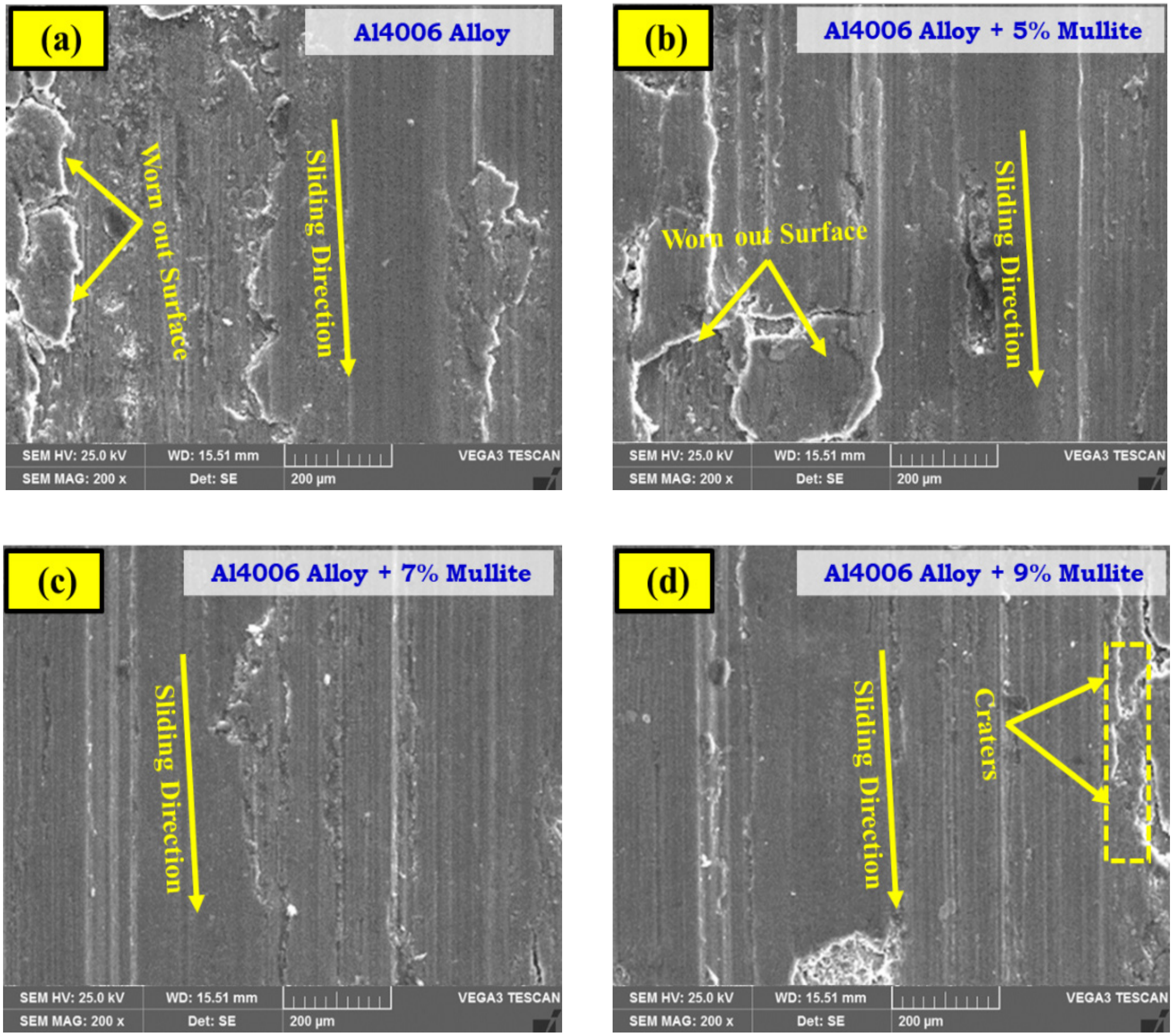


Figure 12. Wear Track (WT) analysis of Al4006 alloy and its mullite composites using SEM.

material removal materialized by plastic deformation thanks to a high load of 30N. The wear and tear surface morphology of Al4006 alloy is suave with fewer cracks. The examination of the wear surfaces of the Al4006 and the different wt. % of mullite composites at higher magnification reveals discrete configuration of trenches seriatim parallel to one another in the slithering direction witnessed in Figure 12 (b, d). This finding is supported by several studies[28,30].

4.0 Conclusions

Al4046/Mullite MMC's analysis shows the following inferences which were illustrated:

1. From the OM and SEM images of gleaming samples, the subsequent was examined:
    - Distribution of strengthening flecks (Mullite (Al_2O_3-SiO_2)) is recovered to be steady.
    - Alumina specks are not confined to the grain frontiers.

- Alumina Flakes have affected nice soaking with matrix which is beneficial in the enhancements of the mechanical properties.

2. From the studies we can observe that as the mullite particle reinforcement increases the matrix hardness, strength, and density increase.
3. Also, the liquefied metallurgy route, i.e., stir casting is an efficient approach of creating Al4006/ Mullite MMC's.
4. Mullite-fortified composites demonstrated an elevation in hardness on a margin of 7.68% when compared to Al4006 alloy. Mullite serves as a load-bearing constituent when added, boosting hardness.
5. Mullite-fortified composites demonstrated an elevation in tensile strength on a margin of 26.86 % when compared to Al4006 alloy. Mullite serves as a load-bearing constituent when added, boosting strength (UTS).
6. Mullite-fortified composites demonstrated an elevation in yield strength on a margin of 25.73% when compared to Al4006 alloy. Mullite serves as a load-bearing constituent when added, boosting strength (YS).
7. Contrasted to Al4006 alloy, its composites bolstered with mullite indicated decline in ductility (i.e., %Elgn) on a means of 26.27% respectively. The addition of mullite leads to brittleness in material due to ductility reduction.
8. Associated to Al4006 alloy, its composites reinforced with mullite displayed an enhancement in density on an average of 4.36% correspondingly. Impenetrable microstructure with the least porosity has led to increase in density.
9. Mullite-composite is more resistant to wear than as-cast 4006 alloys, according to a comparison. The increase in hardness was achieved due to mullite's consistent scattering and adherence within the composite, which lowered the rate of wear. Furthermore, the inclusion of mullite serves as a load-bearing ingredient, avoiding further wear on the matrix.
10. Wear track findings indicate steeper abrasion pits and more wear out in as-cast than in composites, which may be linked to the omission of load-bearing reinforcement (mullite), that weakens the mechanical performance and creates severe shred or wear out.

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