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Influence of alumina percentage on microstructure, mechanical and wear behaviour of 2014 aluminium-alumina metal matrix composites

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KEYWORDS

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Wear
Worn morphology

ABSTRACT

In this study, Al2014 matrix alloy reinforced with 9, 12 and 15 wt. % of Al_2O_3 (88μm) particulate by novel two stage melt stirring (stir casting) practice is used to synthesize, describe and analyze mechanical and wear behavior. Level of ceramic Al_2O_3 is maintained at 9, 12 and 15 wt. % additionally. For each wt. %, the preheated (i.e., 250°C) Al_2O_3 particles were introduced in to the molten Al2014 alloy in steps of two. Produced composite is examined by SEM and XRD analysis in support of investigation for the microstructure and chemical components. Characterization of mechanical and wear studies of cast Al2014 matrix alloy and Al2014-Al_2O_3 particulate composites were analyzed. With increase in wt. % of Al_2O_3 particles, it has been observed that there is an improvement in the hardness and tensile behaviour of the prepared composites meanwhile; decrease in percentage elongation is also observed. Also, the wear rate of all composites prepared decreases with increase in sliding distance while the wear rate of the composites prepared increases with increase in load. By using Scanning Electron Microscope (SEM) the fractured surface and diverse wear mechanism for different test states of various compositions were examined.

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1.0 INTRODUCTION

Metal matrix composites (MMCs) are a range of materials used to accomplish re-energized convergence of properties in the field of composites. While the cross portion can be of any metal or composite, most intrigue lies in the lighter metals, where, change in properties is the fundamental objective. Yet, the achievement of advanced gauge and excellence is the most important aspiration at the back of the movement of MMCs (Hariprasad et al., 2014; and Yuvaraj et al., 2015). In the middle of the evidently identifiable matrix materials nearby, aluminum mixes are capable materials because of their high explicit superiority and robustness. In any case, their relevance's are constrained due to their reduced wear obstruction. Particulate reinforced metal matrix composites are currently being considered over the regular blends for their improved wear and ductile properties, and the composites have expanded their broad uses in vehicle and avionics fields along these lines.

Significance has been given on conveying practical aluminum-based MMCs with different hardness and brittle fortifications like graphite, B4C SiC, and Al_2O_3 (Blugan et al., 2014; Khakbiz et al.,2009; Sarada et al., 2015; and Ajay Singh et al., 2015). In addition, in MMCs the mechanical properties are delicate to the preparing method used to create the materials. Impressive enhancements might be accomplished by applying science-based demonstrating strategies to improve the preparing methodology. A couple of strategies have been used to associate the composites together with powder metallurgy, liquefy procedures and squeeze casting (Yung and Chan, 2004; Sajjadi et al., 2010; Sajjidi and Zebarjad, 2010). Nonetheless, powder metallurgy has all the earmarks of being the preferential course of action in perspective on its capacity to give progressively uniform scatterings. At the same time, hot expulsion is commonly utilized as post-treatment to take the upsides of applying compressive forces and high temperatures (Mazahery et al., 2009). MMC's fluid state development uses two techniques that depend on the temperature at which the particles are melted into the liquid. The particles are added over the liquid temperature of the mixture of liquids in the melt stirring phase, whereas in the compo-casting procedure, the particles are inserted when the molten alloy enters semi-solid state. In both procedures, for introducing the reinforcement particles, vortex is used. In any case, the liquefying procedure has two huge issues i.e., (i) the ceramic particles are for the most part not wetted with a fluid metal lattice, and (ii) the particles will in general go down or drift as indicated by their density comparative with the fluid metal. Subsequently, the scattering of the ceramic particles is not uniform. The pressure casting such as die and squeeze casting techniques are required to diminish the porosity in the composite material (Sajjadi et al., 2011). Despite the fact that in MMC's better mechanical properties are obtained by powder metallurgy process. The disadvantage of using powder metallurgy process is that one cannot produce fully dense composite samples (Dobrzanski et al., 2006; Mazen et al., 1998; and Rahimian et al., 2009) and high cost of metal powders. Liquid stirring has some important advantages i.e., closer net form and the broad choice of materials, uniform dispersion of particles, simpler control of grid structure, ease of preparing (Yung and Chan, 2004; Sajjadi et al., 2010; Vencil et al., 2010; and Chawla and Shen, 2001) very large sized components can be fabricated and cost of production is economic in nature compared with powder metallurgy process.

In the present work Al2014 alloy-alumina composites have been studied and synthesized by novel two stage reinforcement addition method. In this study, Al2014alloy is used as the matrix material; this material is widely used for aerospace applications. The components are usually subjected to mechanical and wear conditions. As cast Al2014 is not sufficient to withstand the applied load in critical components like wing root fittings and landing gear mounting brackets.

Also, several components are subjected to the wear. It is essential to enhance these mechanical and wear properties of Al2014 alloy. Ceramic materials like TiC, Al_2O_3, SiC, TiB_2 etc are used in industries for their high hardness and wear resistance applications (Ramesh et al., 2018; and Vijaykumar Subramani et al., 2019). So in the current research Al2014 alloy strength and wear resistance is improved by adding Al_2O_3 particles in steps of 9, 12 and 15 weight percent. To know the significance of the addition of weight percentage of reinforcement on the strength and wear behaviour of Al alloy, mechanical and wear studies have been carried out as per ASTM standards.

2.0 INVESTIGATION DETAILS

2.1 Resources Utilized

In the existing examination Al2014 alloy was utilized as a matrix material and hard ceramic Al_2O_3 (88µm) particles were utilized as reinforcement material. Table 1 presents an understanding of the chemical composition of the Alloy 2014.

Table 1: Al2014 alloy elements chemical composition in weight %.

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Contents	0.7	0.2	4.5	0.83	0.63	0.01	0.19	0.06	Balance

2.2 Preparation of Al2014-Al_2O_3 Particulate Composites

The melt stirring (Stir casting) technique has been implemented to set up the composites as explained below. Preheated Al_2O_3 (88µm) particles were passed into the vortex of the liquefy subsequent to compelling degassing utilizing solid hexachloroethane (C_2Cl_6) in order to get rid of the gases from the molten alloy. Pre-heated (temperature of 250^0C) Al_2O_3 particles were introduced into the matrix Al2014 alloy and was accomplished in 2-steps i.e., total measure of essential strengthening particles was determined and brought into the liquefy for multiple (two) times as opposed to presenting at the same time there by improving the wettability. At each stage, when introducing Al_2O_3 particles, mechanical mixing of the liquid composite for a time of 10 minutes was accomplished by utilizing Zirconia-covered steel impeller. The stirrer was preheated prior to drenching into liquefy, found roughly to a depth of 2/3 stature of the liquid metal from the base and at a steady speed of 400 rpm. A driving temperature of 750^0C was received and the liquid composite was discharged into an eternal cast iron molds. In this manner composites containing particles 0, 9, 12 and 15 wt. % were obtained in the cylindrical form of 12.5 mm diameter and 125 mm length.

2.3 Testing of the Composites

By means of an automatic cutter the central portion of the casting was cut in order to examine the microstructure of the prepared specimens. Surface of the specimens were set up by granulating, using an emery paper of grit size 300, 600 and 1000 and afterward by cleaning with a diamond paste of 3µm. Infinitesimal assessment of the composites was done by SEM. To investigate the mechanical conduct of the composites Vickers hardness and ductile trial was completed utilizing Zwick and universal testing machine according to ASTEM E384 and E8 benchmarks separately. By means of diamond cone indenter with a load of 20N the micro-vickers hardness values of the samples were measured on the polished specimen. Hardness esteem detailed is the normal estimation of 50 interpretations noted down at various areas on the polished specimen. For pliable and wear results, test was rehearsed multiple (three) times to get an exact normal value.

3.0 RESULTS AND DISCUSSION

3.1 Microstructural Study

SEM images of Al2014-Al_2O_{3p} (9, 12 and 15 wt %) reinforced composites were produced by stir casting are revealed in Figure 1(a-d). The main intention in the preparation of Al2014-Al_2O_{3p} composites is to achieve uniform distribution of Al_2O_{3p}. The uniform distribution of strengthening particles conquered in the ready composite is the end result of two stages stirring. In view of the fact that, the whole weight of the reinforcing particles is added in 2-steps which ensure uniform dispersion conquering the viscosity divergence. As revealed in Figure 1(b-d) homogeneous dispersion of the Al_2O_{3p} was accomplished in the composites reinforced with 88μm Al_2O_{3p}. Figure 1(a) shows the SEM images of as cast Al2014 alloy and Figure 1(c) reveals the SEM images of the clustering or agglomeration of the 12 wt. % of Al_2O_{3p} at some area probably due to the porosity presence (Chaudhary et al., 2015; and Kok, 2005) and Figure 1(b-d) shows more amount of uniform dispersion as the weight percentage of alumina particles increases from 9-15 wt. %.

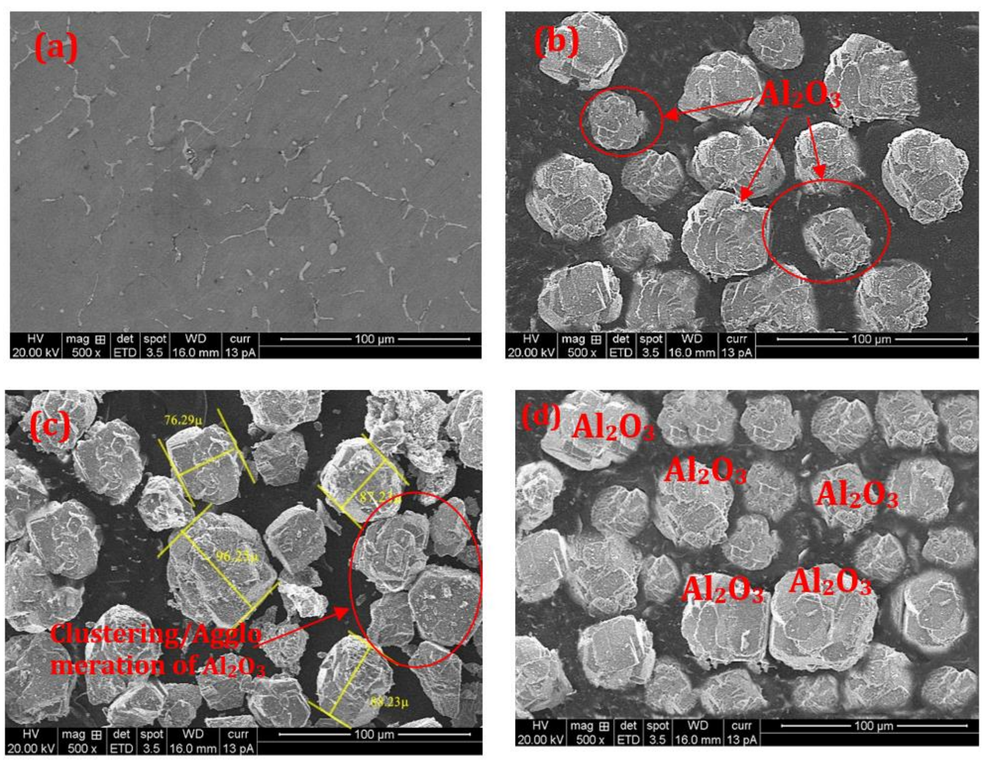


Figure 1: SEM images of (a) as cast Al2014 alloy, (b) Al2014 alloy with 9 wt. % Al_2O_{3p}, (c) Al2014 alloy with 12 wt. % Al_2O_{3p} and (d) Al2014 alloy with 15 wt. % Al_2O_{3p}.

3.2 XRD Studies

Illustration 2 shows the Al2014 alloy X-ray diffraction pattern and results with Al_2O_3 Metal matrix composites (MMC's) of 15 weight percent. Ten peaks were observed in the X-ray diffraction pattern (Figure 2), varying from 20 to 100 in the 2Θ. The peaks of 38.44°, 44.7°, and 65.32° belong to plain Al, with peaks of 26.23°, 37.46°, 44.67°, 58.2° and 66.2° belonging to Al_2O_3 and other minor peaks due to impurities and interfacial components.

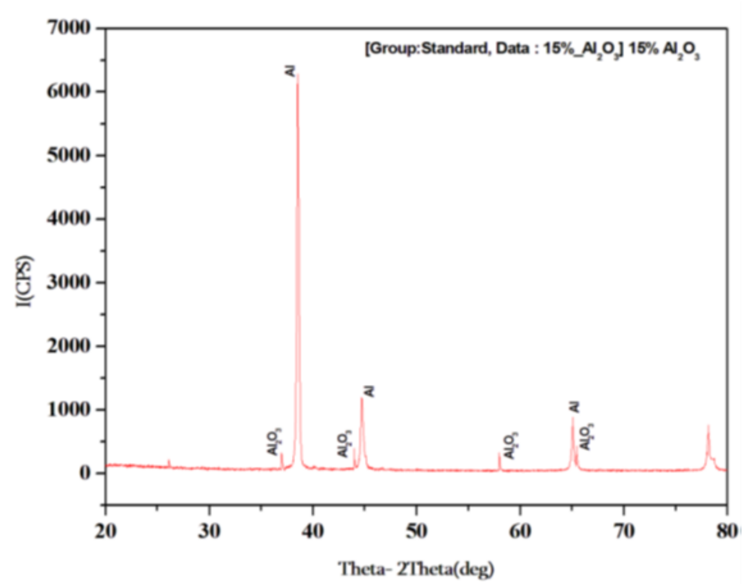


Figure 2: X-ray diffraction pattern of the Al2014 alloy with 15 wt. % Al_2O_3.

3.3 Hardness Test

Figure 3 illustrate the after effects of micro-vickers hardness tests directed on Al2014 framework and composite (Al2014-Al_2O_3) containing distinctive weight percent (9, 12 and 15wt. %) of Al_2O_3 particles. The hardness of micro-vickers was estimated on the cleaned tests utilizing precious stone cone indenter with a heap of 20N and value revealed is normal of 50 interpretations noted down at various areas. A critical increment in hardness of the amalgam lattice can be distinguished with adding up of Al_2O_{3p}. The larger estimation of hardness of composites shows that the presence of particulates in the lattice has enhanced the composites general hardness. It is valid because of the delicate nature of the matrix and hardness of the particle fortification, especially pottery material (Mittal, et al., 2016). The nearness of the stronger and more stable Al_2O_3 support prompts the expansion in imperative to plastic distortion of the lattice throughout the hardness test (Bharath, et al., 2014). Increasing composite hardness can be due to the increasingly elevated hardness of Al_2O_3 itself along these lines.

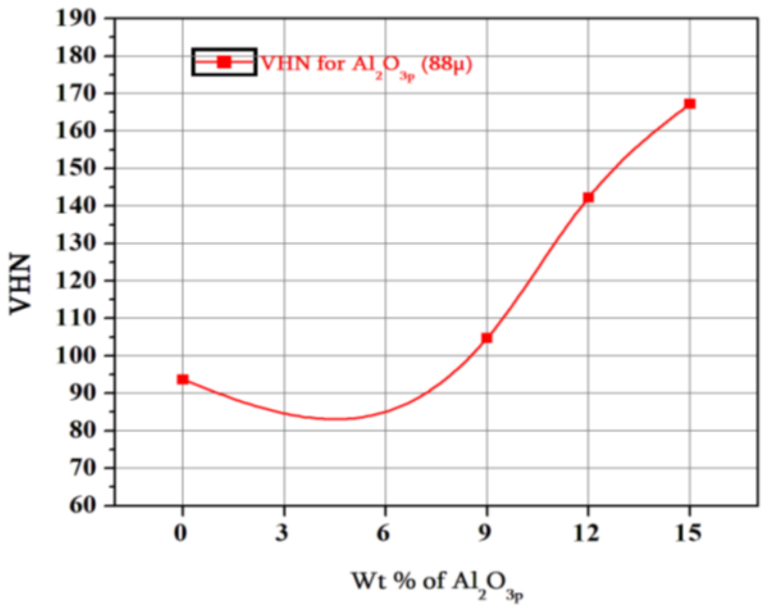


Figure 3: Discrepancies inAl2014 hardness prior and after addition of specific Al_2O_{3p} weight percent (88μ).

3.4 Tensile Properties

The tensile experiments were carried out using automatic UTM according to the principles of ASTM-E8 to analyze the mechanical behavior of the composites. Three samples were operated for every examination and normal value is accounted for. The elastic properties, for example, rigidity, and yield quality and % prolongation were obtained from the pressure strain bends and are illustrated in Figure 4 (a-b).

From Figure 4a plainly rupture effectiveness of composites (9, 12 and 15wt. %) is superior when contrasted with as cast Al2014, whereas from Figure 4b pliability of composite is lesser to as cast Al2014 alloy. Figure 4 also shows that the elasticity increments with rise in reinforcement measure, although there is a decrease in pliability with an expanding support measure. Increment in strength is most likely because of increment in disengagement density with adding up of particulates (Purazrang, et al., 1994). Further, support of α-Al dendrites after adding up of fortification particulates may have likewise contributed in improving strength. Be that as it may, the prepared composite materials displayed reduced prolongation than unreinforced samples. Perhaps plastic twisting of the blended soft metal matrix and non-deformable fortification is more troublesome than the base metal itself. In relation to that of as cast Al2014 alloy, however, the ductility of the prepared composite decreases. The decrease in percentage elongation is clear as ceramic reinforcement is having lower flexibility in examination with the matrix and furthermore, during tensile loading, the unformed Al_2O_3 particle could cause pressure focus around the particles. Consequently, particles collected at grain limits intensified the pressure focuses.

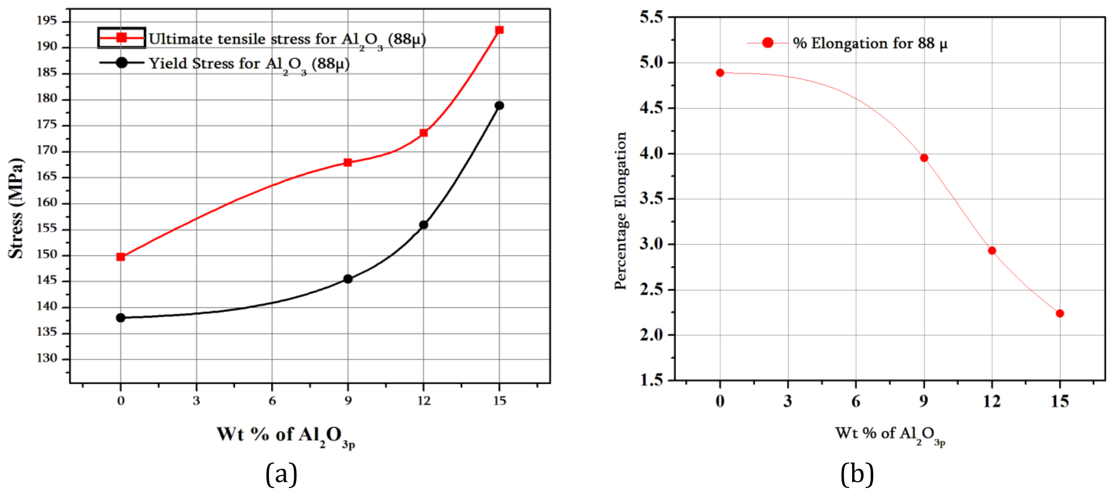


Figure 4: (a) Tensile test and (b) % elongation outcomes of Al2014-alloy before and after addition of different wt% of Al_2O_{3p} (88μ).

3.5 Fracture Studies

Figure 5 (a-b) illustrates the fractured surfaces of both as cast Al2014 alloy and the synthesized composites.

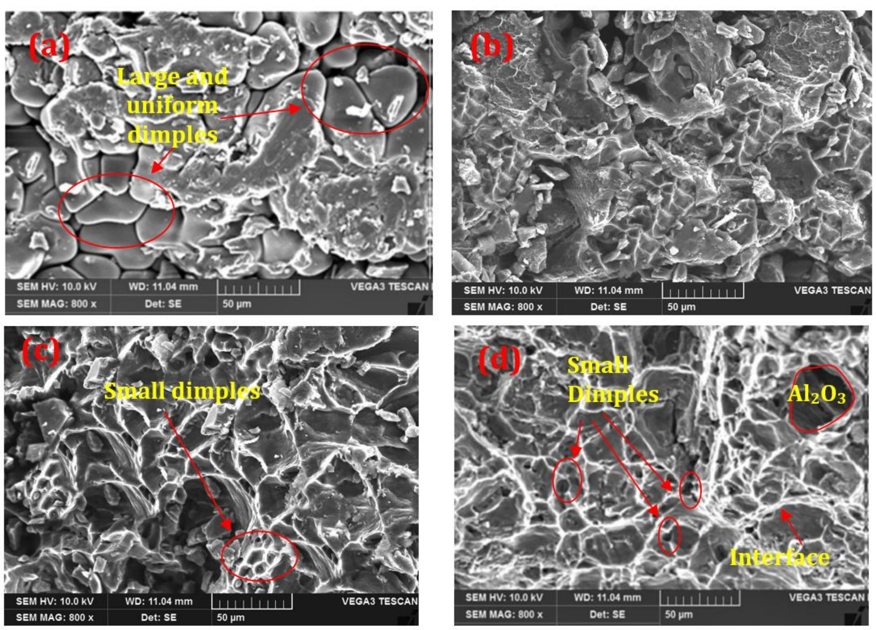


Figure 5: Fractured surfaces of samples of (a) Al2014 matrix alloy, (b) Al2014-9 wt. % of Al_2O_3, (c) Al2014-12wt. % of Al_2O_3 and (d) Al2014-15 wt.% of Al_2O_3 particulate composites.

From the SEM micrographs it is clear that Al2014 alloy combination shows bigger and uniform dimples demonstrating the malleable fracture (Figure 5a), whereas Figure 5(b-d) synthesized composites (Al2014-9,12 and 15wt. %Al_2O_{3p}) show dimples of size smaller than that of as cast Al2014 matrix alloy, showing perceptibly weak crack and infinitesimally ductile fracture. It is likewise seen that Al_2O_3 particles stay unblemished with the matrix because of a solid interfacial particle-matrix holding, which further directs flexible highlights showing substantial plastic progression of metals (Tjong et al., 2003). These fractographs obviously show a proof of good bond among matrix and the reinforcement prompting improved hardness and extreme elasticity of composites as talked about in the previous segments. Further particle fractures in many areas have not been seen.

3.6 Wear Studies

To carry out the wear studies a pin-on-disc tribometer is utilized. With the help of acetone, the alloy, prepared composite specimens and wear track are cleaned meticulously before carrying out the experiment. By utilizing a computerized equalization having a precision of ±0.0001 gm each prepared specimen is weighed before test. Following to this, specimen positioned on the tribometer pin holder is then fitted for the wear trial. For all trials, the sliding speed is changed in accordance with 400 rpm, 80mm track diameter, load of 30N and absolute time is 40 minutes under room temperature. ASTM-G99 benchmarks were used for this examination.

3.6.1 Consequence of Sliding Distance on Wear Rate Under Dry Sliding State

From the Figure 6 we can say that with increase in distance of sliding, the wear rate of unreinforced Al2014 alloy and the prepared composites diminishes. In any case, when contrasted with the as cast Al2014 matrix, Al2014 alloy with various weight percentage of Al_2O_{3p} (9, 12 and 15 wt. %) composites have demonstrated diminished wear rate. It is also seen from Figure 6 that with escalating option level of Al_2O_3 particulates, wear resistance of as cast Al2014 matrix increments at all distance of sliding contemplated. This obviously draws out the way that existence of the hard ceramic Al_2O_3 particles in Al2014 matrix advance the wear resistance of the matrix. Existence of hard Al_2O_3 particles in Al2014 alloy matrix confine ploughing activity of hard steel counterpart in this manner advances the wear resistance. Also more interfacial strength exits between the Al2014 matrix alloy and 88μm size Al_2O_{3p} owing to the great surface bonding which make it hard for the particle pull out from the Al2014 matrix. Hence, it is concluded that increase in weight percentage (9, 12 and 15 wt. %) provides reduced wear rate, thereby wear resistance of the MMC's increases.

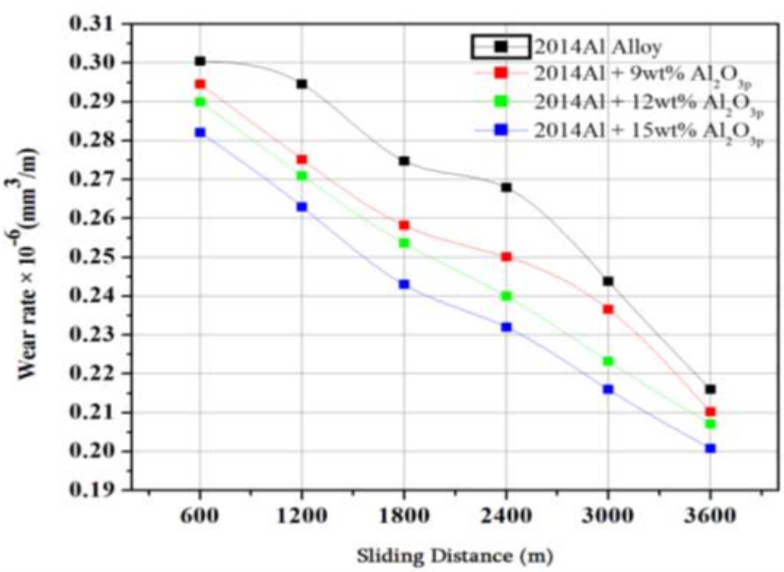


Figure 6: Effect of sliding distance on the Al2014 matrix wear rate before and after addition of Al_2O_3 particulates.

3.6.2 Consequence of Load On Wear Rate Under Dry Sliding State

Figure 7 illustrates the results of load versus wear rate of as cast Al2014 alloy and prepared composites (Al2014-Al_2O_{3p}) for sliding speed of 400 rpm and constant sliding distance of 3600m. For the test selected functional loads are 10N, 20N and 30N. By exposing every specimen to 3 constant loads at steady speed and sliding distance, wear rate was estimated. Figure 7 obviously shows that wear rate of the Al2014 alloy matrix and Al2014 alloy with different weight percentage of Al_2O_{3p} (9, 12 and 15 wt %) composites enhances with increase in load. This expansion in wear rate could be credited to the increase in temperature at pin-disc line with escalating load (Chawla and Shen Y L 2001). Notwithstanding, for the whole loads as cast Al2014 alloy matrix has demonstrated higher wear rate when contrasted with the reinforced Al2014 alloy matrix. Again among Al2014-Al_2O_{3p} composites wear rate diminished with expanding level of Al_2O_{3p} from 9 to 15wt. % i.e., Al2014 alloy matrix containing 15wt% of Al_2O_{3p} displayed utmost wear resistance among every one of the creations examined.

From the Figure 7 we can conclude that Al2014-15 wt. % Al_2O_{3p} composites provides better wear resistance for the most part because of higher contact region between Al_2O_3 particles and steel disc. In view of the fact that Al_2O_3 particles display better load carrying competence when contrasted with the as cast Al2014 alloy matrix alone. Higher contact zone in collection with load conveying capacity has brought about improved wear resistance.

3.7 Study of Worn Out Surfaces of Produced Composites

For the above prepared composites, after wear test the worn-out surfaces are inspected using SEM in order know the mechanism of wear. SEM photographs of the worn-out surfaces of Al2014 alloy matrix and Al2014-Al_2O_{3p} composites at a functional load of 30N, speed of sliding of 400 rpm for a distance of sliding about 3600m is illustrated in Figure 8(a-f). Al2014 alloy and Al2014-Al_2O_{3p} composites wear rates are exceptionally impacted by various mechanisms of wear and they are constrained by load applied and sliding speeds. The following types of wear mechanisms are recognized depending on the in-depth observations made on the worn surfaces and wear debris. i.e., adhesion wear (Inem, 1995; Alpas and Zhang, 1994), abrasion wear (Jahanmir and Suh, 1977; Inem, 1995; Alpas and Zhang, 1994; Saka et al., 1985), delamination wear (Kwok and Lim, 1999; Modi and Prasad, 1992), amalgamation of delamination, adhesion and wear (Ren, 2008).

Usually, at low speeds and low loads the surface of intermittently reinforced aluminium composites are distinguished by existence of layers of oxide, which incorporates oxides of aluminum and iron rich exchange film (Suh, 1973). Such oxides formed when the surfaces slip against each other leading to plastic twisting and making contact with asperities at the interface. In this way, material exclusion is because of cohesive failure and adhesion of asperities, and is described as adhesive wear (Ramesh et al., 2010) (Figure 8a). The tiny scratches/grooves formed by the abrasive action of hard particles on eroded surfaces (Figure 8b) are the reasonable evidence of abrasive wear (Dutta Majumdar, et al., 2006; Alpas and Zhang, 1994). Furthermore, the microphotograph also shows some miniaturized scale cuts and ploughs (Figure 8f) brought about by abrasive particles. Be that as it may, with additional increment in load the material exclusion process is never again abrasive wear forms. Because of serious plastic distortion (Figure 8c) and shearing activity, the depth and size of the grooves increase and process material exclusion happens in the structure slender plates/strips as it is apparent from the wear debris (Zhang and Wang, 1998; Smith and Chung 1996). These perceptions are noticeable signs of delamination wear (Figures 8d and e). As anticipated by Suh et al., (1973); wear delamination is brought about by splits or voids created at the subsurface or surface area and their circulation towards sliding is because of broad plastic flow and the material expulsion at slight sheets/plates. In addition, at higher loads notwithstanding delamination wear, the micrographs also appear (Figures 8e and f) with many oxide layers and broad grooves demonstrating individually the complex closeness of the adhesive and abrasive wear phase as investigated before. It is therefore, advised that scraped region and delamination result in substance removal at higher load.

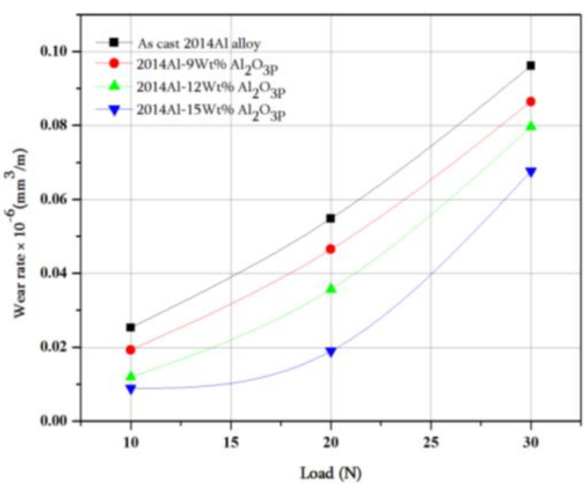


Figure 7: Comparison between wear rates of as cast Al2014 matrix and Al2014 composites reinforced with 9, 12 and 15wt. % of Al_2O_3 particulates.

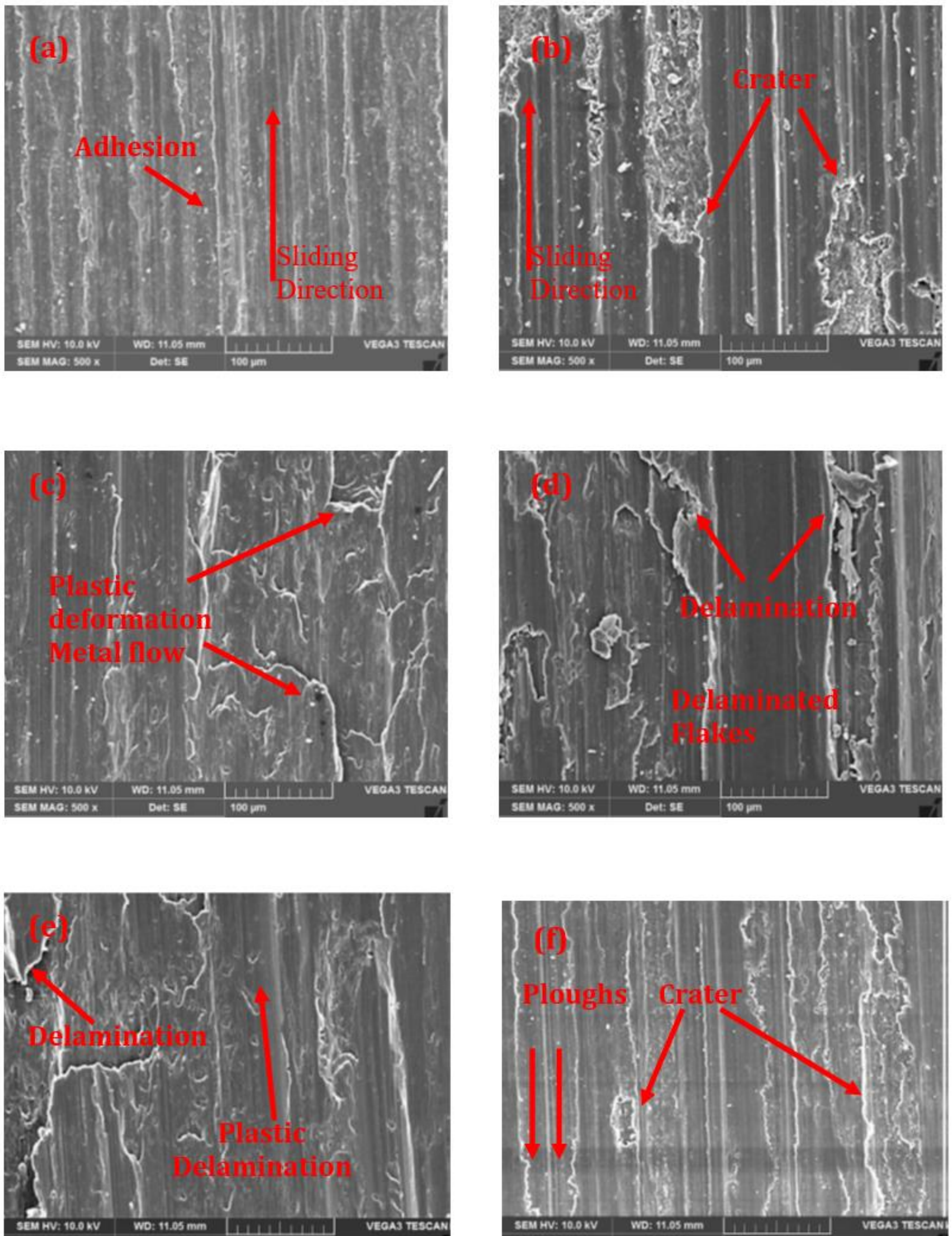
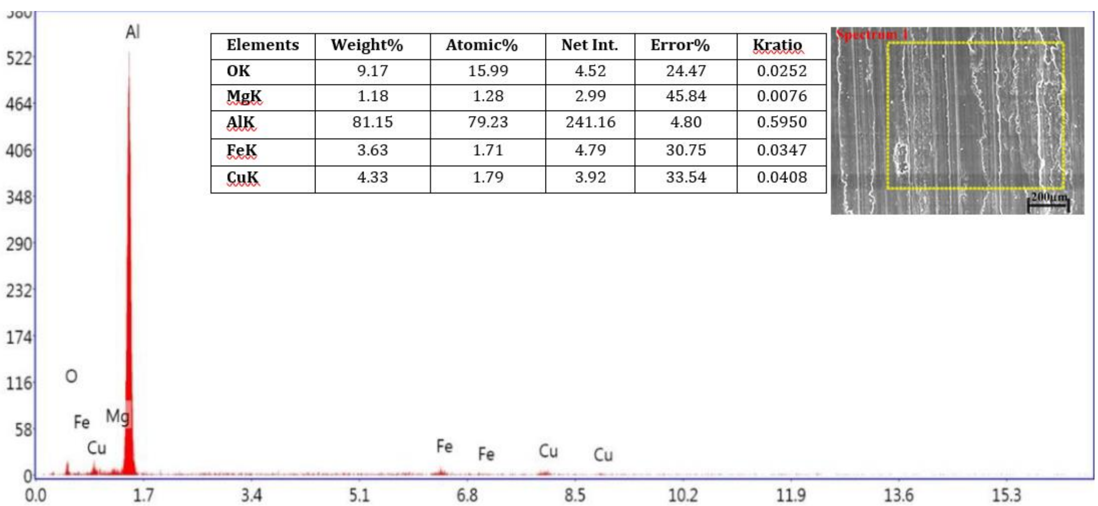


Figure 8 SEM Photographs of wear tracks of Al2014-Al_2O_{3p} composites showing different wear mechanisms.

The formation of oxide in the composite's worn surface after 3600 m of sliding is demonstrated by the identification of the peaks of O, Mg, Al, Cu and Fe in the selected zone (spectrum 1) through energy dispersive spectroscopic study as shown in Figure 9. The presence of oxygen and iron in the spectra helps to form the oxide layer at this load during the sliding. This low wear rate behavior for reinforced particles of fine size alumina is also recorded on various composites by Das et al., (2001); and Kumar et al., (2015).



Elements	Weight%	Atomic%	Net Int.	Error%	Kratio
OK	9.17	15.99	4.52	24.47	0.0252
MgK	1.18	1.28	2.99	45.84	0.0076
AlK	81.15	79.23	241.16	4.80	0.5950
FeK	3.63	1.71	4.79	30.75	0.0347
CuK	4.33	1.79	3.92	33.54	0.0408

Figure 9: EDS Analysis of worn surface of Al2014-15wt. % Al_2O_{3p}.

3.8 Debris Analysis

Figure 10 shows the SEM micrographs of wear debris of Al2014 as cast matrix alloy and Al2014-9, 12 and 15 wt. % Al_2O_{3p} composites at a functional load of 30N, speed of sliding 400 rpm for a distance of sliding about 3600m. It is seen that there is an increase in the size of the wear debris collected in the Al2014 matrix alloy (Fig. a) at a practical load of 30N, where, as in the case of composites produced (Fig. b-d), there is a decrease in the size of the wear debris collected due to the increased fragility of the composites, which describes the lower wear rate in the composites produced compared to the Al2014 as-cast matrix alloy at higher load condition. This is very well illustrated by the results of the wear rate, as stated above. This is further found that the debris is a mixture of fine and coarse particles at higher loads, leading to the breakdown of large particles due to increased sliding activity. Furthermore, it is stated that at higher loads (Levy et. al., 1972), because the strength of the surface contact is very high, the stresses surpass the fracture stress of the reinforced particles, resulting in the reinforced phase fractures.

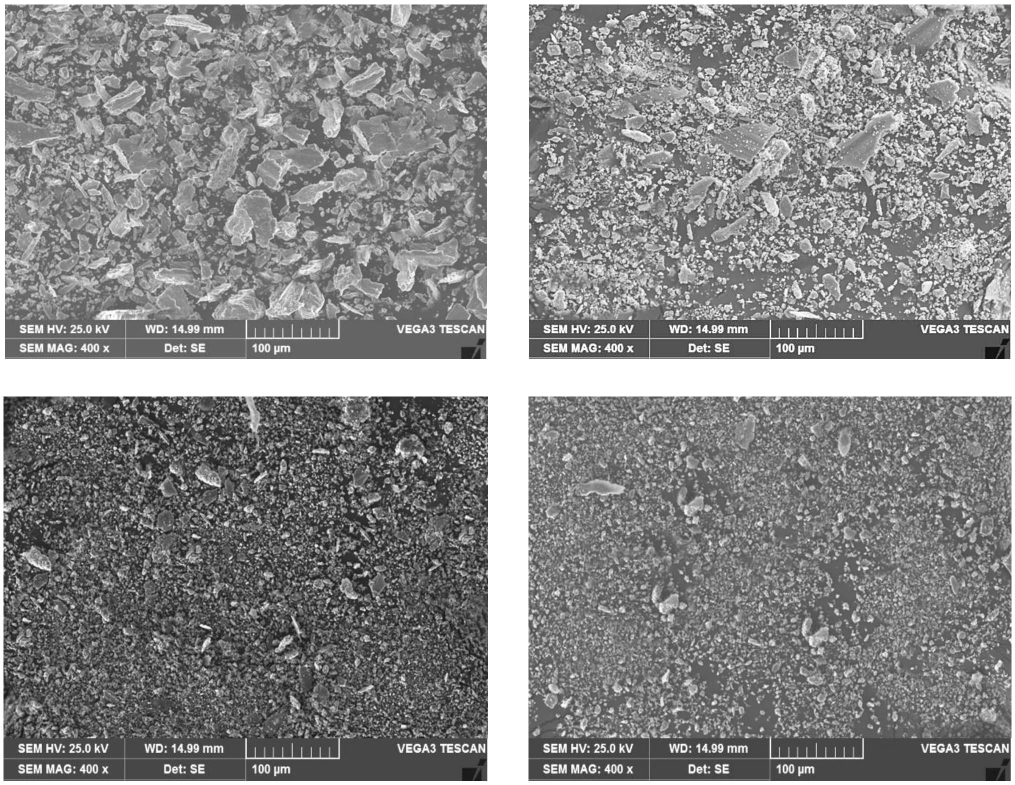


Figure 10: Wear debris morphology of (a) as cast Al2014 alloy, b Al2014 alloy with 9 wt. % Al_2O_{3p}, (c) Al2014 alloy with 12 wt. % Al_2O_{3p} and (d) Al2014 alloy with 15 wt. % Al_2O_{3p}.

CONCLUSION

An effort is being made in the present work to examine the mechanical and wear behaviour aspects of Al2014 and Al2014-Al_2O_{3p} composite formed by melt stirring process. The influence of addition of alumina percentage on mechanical and wear behaviour is studied experimentally. The work has led to following conclusions:

(a) By a novel two stage melt stirring technique, synthesis of Al2014-Al_2O_{3p} (9, 12 and 15wt. %) composite was produced effectively.
(b) The SEM images of liquid stirring technique composites display a fairly uniform distribution of Al_2O_{3p} in the Al2014 MMC's with less agglomeration.
(c) Al2014 alloy tensile and yield strength increased after addition of 9, 12 and 15 weight percent Al_2O_{3p} given the limited plastic deformation and load transfer among Al_2O_{3p} and Al2014 matrix under standard testing conditions.
(d) On SEM fractures of as cast Al2014 alloy, fine shallow and uniform dimples were found, while composites displayed two-way dimple distribution, i.e., strengthening particles held the wider dimples although smaller dimples were at normal temperature due to ductile failure of the matrix suggesting ductile to brittle failure.

(e) For Al2014, a minimum wear rate was established, which is reinforced with a 15 weight percent Al_2O_{3p} at a continuous load of 29.43N, a sliding speed of 400rpm and a sliding distance of 3600 m compared to the Al2014 alloy cast and with increase in load, minimum wear rate was observed in case of Al2014-15wt. % of Al_2O_{3p} composite compared to as cast Al2014 there by resulting in better wear resistance of the above prepared composites.

(f) Formation of protecting compound layer at an intermediate slippery distance of 3600m were seen that confirms the minimum wear rate of the composite and disclosed from the worn surface microphotographs. The deteriorated surface showed that during sliding material removal, delamination, abrasion and adhesion and their variation are the primary wear processes. At higher loads, metallic debris undergoes melting leading spherical to elliptical shaped debris.

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