Impact of Alumina Particulates Addition on Hardness and Wear Behaviour of 2014Al Metal Matrix Composites by Vortex Method

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Abstract:- In this study, 2014Al matrix alloy reinforced with a 9 wt% of alumina (20 μm) particulates composites by novel two stage melt stirring (stir casting) practice used to synthesize, describe and analyze wear behaviour. Adding up of reinforcement was kept at 0 and 9wt%. For each wt. % preheated (i.e., 250°C) alumina particles were introduced in to the molten 2014Al alloy in steps of two by creating a vortex to overcome the clustering effects. Produced composite was examined by SEM analysis in support of exploring the microstructures and chemical components. Additionally characterization of wear studies of cast 2014Al matrix alloy and 2014Al-Al2O3 particulate composites were analyzed. After the assessment, it had been seen that there is an improvement in the hardness of the composites prepared and this is due to the incorporation of Al2O3 particulates in 2014Al alloy matrix meanwhile. Additionally, the wear rate of all composites prepared diminishes with increase in sliding distance while the wear rate of the composites prepared enhances with increase in load. By using Scanning Electron Microscope (SEM) the diverse wear mechanism for different test states of various compositions were examined.

Key words- 2014Al Alloy; Alumina; Hardness; Wear; Metal Matrix Composites;

1. Introduction
Metal Matrix Composites (MMCs) are generally encouraging in accomplishing upgraded mechanical properties, for example, Young’s modulus, hardness, 0.2 percent yield quality strength and extreme elasticity because of the nearness of small scale measured fortification particles in the matrix. Generally, regards to the mechanical properties, the fortifications result in increased quality and hardness, even at the cost of some malleability [1]. On account of their improved mechanical and physical properties, aluminum matrix composites (AMCs) strengthened with particles and whiskers are broadly utilized for superior applications, particulate strengthened aluminum matrix composites and whiskers are broadly utilized for predominant applications, for example, in automobiles, military, aviations and power industries [2]. By adding mainly strong yet brittle particles such as Al2O3 and SiC, comparatively soft alloy such as aluminum can be rendered extremely resistant in the composites. Due to their high particular consistency and firmness, aluminum compounds are popular materials among the various accessible matrix materials. Nevertheless, their applications are constrained because of their poor wear opposition.
Within Al-alloys, 2014Al-alloy broadly utilized in various designing applications together with transportation and development, where exceptional mechanical properties, for example tensile, hardness, strength and so forth, are basically required [1]. Particulate reinforced aluminum matrix composites are as of now being considered for their good mechanical and tribological properties over the customary compounds, and along these lines, these composites have improved broad applications in vehicle and aviation industries. Hard particles, for example, Boron Carbide (B<sub>4</sub>C), Alumina (Al<sub>2</sub>O<sub>3</sub>), and Silicon Carbide (SiC) are normally used in the composites as reinforcement phases. In the automotive and aircraft industries, the application of Al<sub>2</sub>O<sub>3</sub> or SiC particle strengthened aluminum matrix alloy composites is increasingly for cylinder heads, connecting rods, pistons and so forth. Meanwhile, the materials properties of tribology are significant [1–4]. MMC’s mechanical properties are also delicate to the manufacturing method utilized to produce the products. By making use of science-based modeling practices to automate the manufacturing cycle will make significant improvements. A few systems have been utilized for the composite preparation, involving powder metallurgy; squeeze casting and melting practice [2, 3]. Be that as it may, powder metallurgy gives off an impression of being the favoured procedure taking into account its capacity to give progressively uniform scatterings. In general, hot extrusion will be used as post treatment to take benefits from simultaneous compressive force and high temperature application [5].

MMC’s liquid state production involves two approaches relying upon the temperature, where the particles are brought into the melt. The particles are incorporated in the melt stirring phase over the temperature of the liquid molten metal, although the particles are introduced in compo-casting system at the metal’s semi-solid slurry temperature. The vortex is used for injection of reinforcement particles in both systems. Moreover, the melting procedure has two significant issues (i) the liquid metal matrix usually does not wet the ceramic particles and (ii) the particles appear to drift or descend as per their relative density to the metal liquid. Therefore ceramic particle scattering is not uniform. The pressure casting such as die and squeeze casting practices are required to reduce the composite material porosity [6]. While powder metallurgy delivers enhanced properties of mechanical in MMCs, there are several major improvements to melt processing i.e., better matrix–particle bonding, simpler matrix structure control, flexibility, low processing cost, closer net shape and large material selection [1–4].

Be that as it may, small data is accessible as respects to the microstructure, friction and wear behaviour of 2014Al strengthened with Al<sub>2</sub>O<sub>3</sub> particulates treated by two-stage stir casting technique. The aluminum–Al<sub>2</sub>O<sub>3</sub> composites play an important role with the growing competition for light weight materials applications in evolving industries. Keeping the above perceptions in seen, it is recommended to develop 2014Al-Al<sub>2</sub>O<sub>3</sub> composites with 9 wt. % of Al<sub>2</sub>O<sub>3</sub> particulates. The core aim of this study is to explore the impact of alumina on various factors such as processing method on the microstructure, hardness and wear behavior of 2014Al combination based composites with Al<sub>2</sub>O<sub>3</sub> particulates by utilizing two stage stir casting technique.

2. Experimental details

2.1 Selection of Materials

For the present experiment 2014Al alloy is used as matrix material whereas, alumina is used as a reinforcing material. 2014Al matrix alloy chemical composition is shown in Table 1 and matrix properties and reinforcement properties are shown in Table 2. Alumina (Al<sub>2</sub>O<sub>3</sub>) particle with a size 20 µm is used for synthesis of composites.

| Table 1. Chemical composition of 2014Al alloy in weight percentage |
|-------------------|---|---|---|---|---|---|---|---|---|
| Elements | Si | Fe | Cu | Mg | Cr | Zn | Ti | Mn | Al |
| Contents | 0.7 | 0.2 | 0.45 | 0.63 | 0.01 | 0.19 | 0.06 | 0.83 | Balance |
Table 2. Chemical composition of 2014Al alloy in weight percentage [7]

| Material/Properties | Density (gm/cc) | Hardness (HB500) | Strength (Tensile/Compressive) (MPa) | Elastic modulus (GPa) |
|---------------------|----------------|------------------|-------------------------------------|---------------------|
| Matrix-2014Al       |                |                  |                                     |                     |
|                     | 2.8            | 135              | 483                                 | 70-80               |

2.2 Preparation of composites

To manufacture the casted composites as mentioned below, the 2-stir casting practice has been used. After successful degassing with solid hexa-chloro ethane (C₂Cl₆), preheated 20 μm size of alumina particle are inserted into the vortex of the molten alloy. Before transferring into the melt, alumina particles were preheated (250°C). In steps of 2 the degree to which Al₂O₃ particles were integrated in the matrix alloy was accomplished. i.e., the overall quantity of reinforcement needed has been determined and is transferred into the melt two stages instead of presenting it at once. Mechanical stirring is carried out for a period of 10 minutes for the molten alloy and it was accomplished by the use of steel impeller coated with zirconia at either point of before and after the adding of strengthening particles. Until plunging into the melt, the stirrer was preheated, positioned roughly at a depth of 2/3 height from the bottom of the molten metal and worked at a 200 rpm. Once the pouring temperature (750°C) is accomplished, the liquid molten composite is poured into the cast iron molds and allowed for complete solidification for some time. Thus, composites containing 0, and 9 wt. percent alumina particles were accomplished as chambers of distance across 12.5mm and length 125mm.

2.3 Evaluation of produced composites

Obtained samples were subjected to machining operation i.e., samples were cut to suitable size of 5 mm thickness and 15 mm diameter then processed for polishing in order to examine the microstructure of the produced samples. At first, the cut examples were cleaned with emery paper up to 1000 grit size followed by cleaning with Al₂O₃ suspension on a cleaning plate utilizing velvet material. This was trailed by cleaning with a diamond paste (0.3 microns). The cleaned surface of the samples was engraved with Keller's reagent lastly exposed to microstructure concentrate under the examining electron magnifying instrument. Micro-hardness tests were conducted on the cleaned surface of the specimens utilizing micro-vickers hardness measuring system with a load of 2N for a dwelling time of 30 seconds, ten sets of measurements were taken at various locations of the cleaned surface of the specimen and the average was taken according to ASTM E10. As per ASTM G99 standard [8] wear test is carryout by the utilization of pin on disc machine (DUCOM, TR-20LE). Dry sliding wear tests were executed on samples of 8 mm diameter and 30 mm height. The counter circle material was of EN31 steel. Previous to testing, the pin and surface disc was dirt free with acetone. The examinations were driven at a consistent sliding speed of 1.25m/s and total time is 40 minute under room temperature over a varying load of 10N, 20N and 30N and a sliding distance of 500 m to 3000 m. In the midst of testing the pin samples was kept fixed and opposite to the disc while the indirect plate was rotated. Electronic estimating machine with the precision of 0.0001 g., was used to quantify the fundamental load of the models. During every single test, the circle counter face was dirt free with acetone. Test is followed by weight loss method.

3. Results and Discussions

3.1 Microstructural studies

Fig. 1a and b demonstrates the SEM micrographs of as-cast 2014Al matrix alloy and 9 wt. % of alumina strengthened with 2014Al alloy composite. These two analyzed samples were obtained from the middle segment from the cylindrical specimens. The microstructure of as cast 2014Al combination involves fine grains of aluminum strong arrangement with an adequate scattering of between metallic precipitates. Besides the standardized uniform scattering of estimated alumina particles with absence of agglomeration and bunching in the composites, it also shows the great holding between the structure and the fortification. This is due in part to the viable mixing operation that was achieved through two phases of expanding the fortification. All over the grain limit of the lattice the alumina particles hinder
the grain improvement and resist the grain separation production in the midst of stacking.

![Fig. 1 SEM photographs of (a) as-cast 2014Al alloy (b) 2014Al-9 wt. % Al₂O₃ composites.](image)

3.2 Hardness measurement

Fig. 2 demonstrates the difference in hardness when 9 weight percent of alumina is added to the 2014Al alloy. A material's hardness is a mechanical parameter showing the capacity to withstand nearby plastic deformation. With the incorporation of 9 wt. % of alumina particles, the hardness of 2014Al-Al₂O₃ composite is found to increase. This rise is observed for Al composites, from 93.67 VHN to 104.7 VHN. This can be traced essentially to the closeness of tougher alumina particles in the lattice and also to the maximum constraints of localized deformation of matrix throughout the indentation, due to the presence of tougher phase [9, 10 and 11]. Moreover, alumina, like different fortifications, reinforces the matrix by making of high dislocation density between cooling and room temperature, because of the differentiation of coefficient of thermal expansion among the alumina and the 2014Al compound. Disparity strains formed involving the reinforcement and the matrix inhibits the development of dislocations, thus improving the composite hardness.

![Fig. 2 Hardness of 2014Al alloy and Al₂O₃ composites](image)

3.3 Wear behaviour of the produced composites:

Fig.3 displays the wear rate of as-cast 2014Al compound and 2014Al-9 wt. % Al₂O₃ composites. Wear rate diminishes after incorporation of alumina particles contrasted with 2014Al matrix with increment in distance of sliding varied from 500 m to 3000 m. The wear rate reduction with increment
in the distance of sliding is because of (i) the improved hardness of the scattered alumina particulates as a load-bearing part (ii) the proximity of alumina particulates as a solid lubricant [12], (iii) Alumina particulates released on the erode surface keeps from the prompt metal to metal contact and serves as a lubricant consequently decreasing the coefficient of friction among the steel disk and the arranged composite pin [12], (iv) Rigid alumina particulates in the 2014Al matrix resist these rigid steel plugging operation and increases wear resistance [13]. The wear opposition of the produced composites altogether upgraded due to the presence of the alumina particulates. The outcomes as showed from Fig. 3 shows the diminishing pattern of wear rate after the introduction of 9 wt. % of alumina particles.

![Fig. 3 Variation of wear rate with respect to distance of sliding (As-cast 2014Al matrix alloy and 2014Al-9 wt% Al2O3 composites)](image)

Fig. 4 shows the impact of load applied on 2014Al alloy wear behavior and its composites. As the usual load rises from 10N to 30N the wear rate is increased and is lower for composites that are strengthened with alumina. Maximum wear rates are identified at higher loads for 2014Al matrix alloy and the composites. The temperature of the sliding surface and pin is greater than the critical value at optimum loads and as the load increases on the plate, the wear rate of both the matrix alloy and the alumina composites eventually increases. Wear rate of the produced composites is observed to decrease with 9 wt. % of alumina additions in alloy matrix. Enhancement in the wear opposition of the produced composites with 9 wt. % of fortification can be credited to the high hardness of alumina particulates which serves as the hindrance for the material misfortune [14].

![Fig. 4 Wear rate of 2014Al alloy and 2014Al-9 wt. % Al2O3 composites at different loads](image)
3.4 Worn Morphology

Using scanning electron micro-photographs wear surface analysis of 2014Al alloy and Al$_2$O$_3$ reinforced composites are studied. Figure 5 displays the wear worn surfaces of matrix material 2014Al alloy and 9 wt. % of Al2O3 particles strengthened composite at a load of 30N and a sliding speed of 1.25 m / sec.

Fig. 5 SEM microphotographs of worn surfaces of (a) as-cast 2014Al matrix alloy (b) 2014Al-9% Al$_2$O$_3$ at a load of 30N and 1.25m/sec

Fig. 5a displays specific depressions and edges moving in sliding direction parallel to one other. From the micrograph it can be seen that the furrows in the grid combination 2014Al are more significant and deeper as compared with the composites tried with practically identical conditions. Furrowing on the worn out surface of the 2014Al-9 wt. % of alumina can also be seen in fig. 5b, which may be due to slipping of the composite oxide molecule. A thick layer could be seen due to the composites, which shields the basic matrix from being in contact with the sliding partner and diminishes the volumetric wear misfortune along those lines. This trade layer surrounded on the composites gives the protective cover to hidden material and thus suppresses the metal- metal contact.

4. Conclusions

In this study, composites 2014Al/Al$_2$O$_3$ were manufactured using a process of 2-stage stir casting by taking 9 wt. % of alumina reinforcement. The microstructure, hardness, and wear conduct of prepared samples are examined. The matrix is nearly pore-free and uniform dispersion of alumina particle which is clear from SEM microphotographs. The micro- hardness estimation of 2014Al-9 wt. % alumina composite is better than those of unreinforced material. The wear obstruction of 2014Al-9 wt. % alumina composite is extensively higher than that of the 2014Al alloy. In addition, the wear rate of 2014Al matrix alloy and 2014Al-9 wt. % alumina composites diminished with increment in distance of sliding and wear rate of the composite produced is less as contrasted to as-cast 2014Al matrix alloy with increment in load and further, these composites can be utilized for aviation basic applications and furthermore can be utilized as a high load transfer components.

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