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Evaluation of Fly Ash/ZrO_2 Reinforced AZ91E Hybrid Composites Based on Wear and Friction Characteristics

Surya Chandra Swamy Gari[1,]*, G. Murali[2], K.V. Durga Rajesh[3], S. Ramesh Kumar[4]

Abstract

In the current study the compo-casting Al alloy MMCs' wear resistance was examined under a variety of abrasive circumstances, including coefficient friction, wear rate and it's sliding distance. The AZ91E matrix composite was made by the liquid metallurgy process and reinforced with aluminum plated zirconium dioxide (ZrO_2) particles. Designers examined the characteristics of matrix alloys along with created composites. friction and wear from dry sliding experiments had been performed on a Pin-on-disk equipment throughout a load and velocities of sliding within the scope. The objective appertaining to the present study was to regulate the ramification of ZrO_2 and wear with fly ash properties of Al-Zn (AZ91E) and the weight % of hybrid complex. Investigation has done on Al-Zn alloy reinforced composite by ZrO_2-fly ash. The efficiency of incorporating ZrO_2 into the composite for the purpose of reducing wear was studied. Ceramic components were placed into an aluminum alloy matrix together with solid lubricants to enhance CoF and diminish wear resistance together with friction. Al-Zn/fly ash/ZrO_2 hybrid compound was synthesized using a weight proportion of ZrO_2 and fly ash particles of 5 and 10%, respectively. The wear attribute containing ZrO_2 demonstrated its improved resistance of wear. The results indicate that the Al-Zn coated ZrO_2 particles are dispersed equally throughout the matrix alloy.

Keywords: Pin on Disc; Frictional Force; Friction Coefficient; Volume fraction

INTRODUCTION

Composites made of metal matrix (MMC) grounded on Al alloys have gained wide spread acceptance in recent years, and are being used in a variety of intriguing applications, essentially parts for vibrator components, microwave filters, impellers, and space such as constructions. The better mechanical qualities of these composites, as compared to ordinary alloys, include high wear in conjunction with mechanical characteristics including strength, flexibility, and hardness [1–3]. AZ91E is a particularly popular choice on the point of a matrix material for construction of multi composites (MMCs) among due to its superior formability properties and the possibility of modifying the strength of composites by using the most appropriate heat treatment. It is noted from the literature that the greater part of attention was abstracted on the mechanism of MMCs as well as the characterization of their mechanical characteristics.

In this two decades, metal matrix composites based on aluminium alloy was investigated like possible contender of a variety of fascinating

***Author for Correspondence**
Surya Chandra Swamy Gari

[1]Research Scholar, Department of Mechanical, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India. Satya Institute of Technology And Management, Vizianagaram, Andhra Pradesh, India
[2]Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, Andhra Pradesh, India
[3]Associate Professor, Department of Mechanical, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India
[4]Assistant Professor, Department of Mechanical, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

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applications, including pistons, connecting rods, sliding is a critical integral of the design. Excessive wear caused by sliding eventually yields in the seizing of the components, which may lead to catastrophic failure in some cases [4, 5]. As a result, accurate forecasting the wear behavior of sliding components is critical in order to avoid significant economic depletion. The tribological features in regard to numerous MMC systems incorporating Al-Zn/fly ash/ZrO2 as discontinuous dispersoids was studied. These systems include When it comes to speculative behavior, however, there is a paucity of evidence available. Using a version of Archard's wear model, Yang has recently created a logical model that predicts wear behaviour [6–9]. According to the authors, the wear coefficient is a more accurate assessment of the materials since it considers material qualities and accomplishing circumstances.

Wear can be termed as steady loss related to material caused by relative motion between two surfaces. Wear-related damage might manifest itself as a localized plastic deformation or as microcracks in the material [10–12]. There are several factors that influence wear, including the engineering system's characteristics such as sliding speed, applied load, distance travelled between points, hardness, temperature, presence of foreign material, and the experimental conditions. Wear is a function of the manufacturing system's characteristics. With the reinforcement of hard particles at a materials surface, a major effect occurs, that takes place in metal matrix composites (MMCs), which will provide wear resistance and higher performance. Aluminum-based metal are extremely prominent in the field of materials, particularly in the field of high-performance tribology applications. The usage of aluminum-based composites in the maritime, aerospace, automobile, and mineral processing sectors is expanding as a result of their excellent wear resistance and specific strength. Assessment on wear characteristics in regard to magnesium AZ91E alloy nanocomposite, considering dry sliding circumstances with SiCnp using sliding wear tester results in the declining wear rate with respect to standard load at sliding speed [13–15].

In addition to highlighting the mechanical characteristics of metal composites such Fly ash, SiC, and AZ91D, the article explains how heat treatment procedures affect microstructures. In the past, several materials relying on stir casting and friction stir processing processes were used to reinforce the Mg and Al composites. Additionally, the maximum strength, low wear rate, and density were offered by hybrid composites and microstructures [16, 17]. The enhancement of wear resistance during fretting is nearly 3 to 10 times due to inclusion of AlN particles. By virtue of their high wear resistance and low cof, magnesium alloy composites containing 5 weight percent silicon carbide are suitable for use in automotive applications. An optical micrograph of a composite reinforced with 2 weight percent SiC reveals consistent distribution throughout the matrix. The mechanical and wear properties are improved. A further increase in SiC reveals the particle distribution of a necklace [18–20]. The SiC-graphite are potential candidate materials for applications requiring increased wear when light alloys pertaining to sliding motion [21]. With an increase in holding time, the coating's width grew. Additionally, when the holding period varied. The Al and Zn zone of solid solution in Mg served as a distinguishing feature of the region transitioning from the layer to the Mg. The layers consisting of A1/Zn displayed increased firmness compared to Mg substrate [22]. For improved interaction, Al-Zn powder mixture needed to be pressed down during the production process [23].

Pressing the Powdered AlZn combination down to assure greater association with the Mg substrate during manufacturing was a crucial step.Powder metallurgy and liquid casting procedures are typically imparted in fabrication of aluminum. The casting liquid process, particles are unreasoningly disseminated throughout the liquid metal prior to solidification and casting over the top of it. Typically, these solutions are both efficient and cost-effective. The primary objective of is to examine the wear rate of reinforcements made of fly ash and ZrO_2 combined with Aluminum AZ91E at various weight percentages to determine efficiency of reinforcements.

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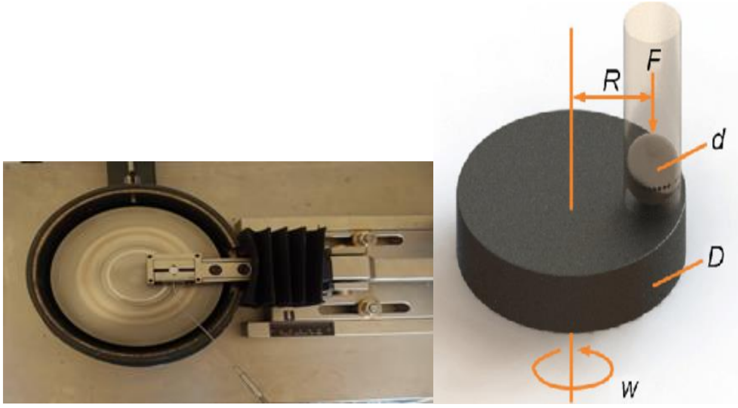

F = Normal Force on the Pin
d= pin or ball diameter
D= disk diameter
R = wear track radius
W= rotation velocity of the disk.

(a) Specimen with Pin-on-Disc (b) Arrangement Sample

Figure 1. (a) Pin-on-Disc Machine, (b) Arrangement of Sample.

PROPOSED METHODOLOGY

In general, quantity of wear in a system will rely on a variety of attributes, including the material properties, the sliding distance, and the sliding speed. Predicting relative ranking of material combinations is utility of any wear test technique [24–26]. As pin-on-disk test method does not replicate all constraints which might be encountered in process, there is no guarantee that apart from conditions specified in test, prediction of wear rate of given material will be accurate.

Figure 1 (a) & (b) depicts a conventional Pin-on-Disc setup. The typical arrangement includes a lever-arm mechanism for holding the pin against the rotating disc specimen beside a predetermined weight. Other sort of mechanism rafts pin spinning around the centre of the disc onto a stationary disc. At any instance, disk's track is circular and involves several wear passes along the same surface [26–30]. The model may include a measuring the friction force apparatus, such as a cell load, for determining coefficient of friction.

This test procedure is applicable to numerous materials. The condition is that specimens with given measurements should be able to bear stress demanded during test without failing or bending excessively. Dimensions, surface quality, material type, form, makeup, microstructure, manufacturing techniques, and indentation hardness of the tested materials must be specified (if appropriate). The wear data must be recorded as the millimetres of cubic volume lost for both pin and disc. From the standard formulae given below, calculate volume losses where the initial end shape of the pin is spherical and the initial end shape of the disc is flat, [31–32]. and only one of the two parts wears significantly: it is assumed that there is no significant disk wear and no significant pin wear.The tests are controlled under ambient conditions by samples contrary to surface of a disc of hardened steel.

$$\text{Pin(spherical end) volume loss } (mm^3) = \frac{\pi(\textit{wear scar diameter})^4}{64(\textit{sphere radius})}$$

$$\text{Disk volume loss } (mm^3) = \frac{\pi(\textit{wear track radius})(\textit{track width})^3}{64(\textit{sphere radius})}$$

For each test, the disc is crushed to a flat surface and converted. Three levels and three factors are included during the dry sliding wear tests. This research will evaluate three independent parameters: sliding time, load, and reinforcement. Load and sliding time are the process parameters, while reinforcement is the material-dependent parameter.

EVALUATIONS AND RESULTS

The tests include reinforcement, load, and sliding time as three independent parameters at three levels. Amongst the parameters, former two were process parameters, and the latter was a parameters which are dependent on material. Table 1 represents Process parameters of Machine and sample specifications for the wear test.

Figure 2 & Figure 3 depict the wear behaviour of AZ91E and AZ91E-ZrO_2-fly ash particle composites. A load of 15 kg has been applied. On a counter disc with a track-radius of 40mm, a velocity of track 2.0 m/s at a sliding speed 318 rpm, a 12-minute wear test was conducted. All of the studies demonstrate that resistances grow as reinforcement content increases. Increasing the number of present particles, such as fly ash and SiC, makes the matrix more robust. As a result, the material exhibited greater wear resistance. The MMCs exhibited significant wear with decreasing weight fraction fly ash and ZrO_2 particle, and wear rises continuously with time. The basic metal displays greater wear, but MMCs with 10% reinforcements display the lowest wear. The presence of ZrO_2 particles and fly ash in Aluminum alloy is responsible to decreased wear losses of composites in comparison to base alloy. As normal load increases, so does the amount of wear. With increased typical load, MMCs transitioned from moderate to serious wear.

Table 1. Machine and sample specifications for the wear test

Material sample	**AZ91E, AZ91E + 2.5% ZrO_2 + 2.5% Fly ash, AZ91E + 5% ZrO_2 + 5% Fly ash**
Pin diameter	8 mm
Track radius	40 mm
Sliding speed	318 rpm
Applied load	15 kg, 20 kg, 25 kg
Time duration	12 mins

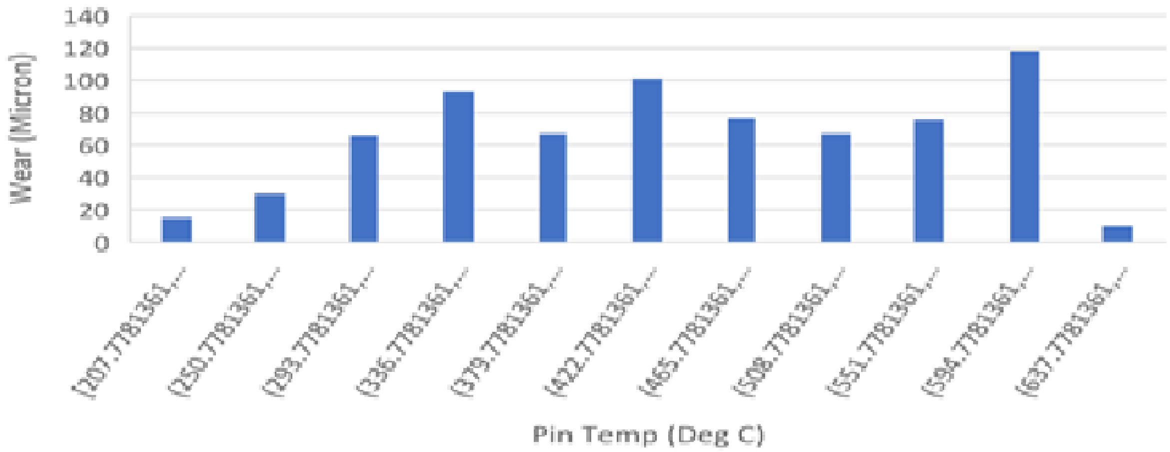

Figure 2. AZ91E Alloy Reinforced with 5% Fly Ash/ZrO_2 Particulates.

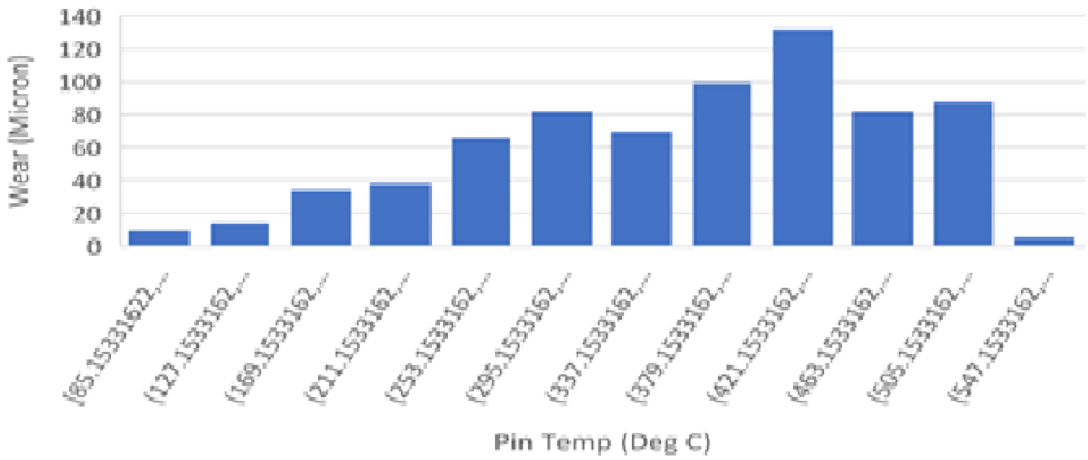

Figure 3. AZ91E Alloy Reinforced with 10 % Fly Ash/ZrO_2 Particulates.

Figure 4 depicts the frictional force with 318 rpm at a time of 12 min for 15 kg load of Pin diameter of 8mm for the 5% composite of AZ91E alloy is given. Alongside the buildup of fly ash/ZrO_2 particles in the base alloy, frictional force tends to decrease. It is clearly observed that the friction force is decreasing and increasing with time at 70 second friction force got the maximum valve of 5.7 N, after that starts decreased at 85 sec the friction force is 5.5 N and after some time slightly increased at 100 sec 5.9 N and as the time increasing at 720 sec friction force decreased to 4.9 N which is clearly shown in the Figure 4.

Figure 5 depicts the frictional force with 318 rpm at a time of 12 min for 15 kg load of Pin diameter of 8 mm for 10% composite of the AZ91E alloy is given below. It is observed that the friction force is decreasing and increasing with time at 70 second friction force got the maximum valve of 4.7 N, Which is less then 5% composition, after that starts decreased at 85 sec the friction force is 4.4 N and after some time slightly increased at 100 sec 4.6 N and as the time increasing at 720 sec, friction force decreased to 4.1 N which is clearly shown in the Figure 5. Friction force is high for 5% of ZrO_2 composite compared to 10% of ZrO_2 composite.

Figure 6 depicts the friction coefficient with 318 rpm at a time of 12 min for 15 kg load of Pin diameter of 8 mm for the 5 % composite of AZ91E alloy, the coefficient of friction depletes with inflation of time, at 125 sec coefficient of friction is 0.38 and after that decreased to 0.37 at 140 sec, and again increased to 0.38 at 160 sec. and finally it is decreased to 0.33 at 720 sec. For 5% alloy the composites, μ decreased with expanding applied load. Also, μ diminishes with increment of reinforcement content.

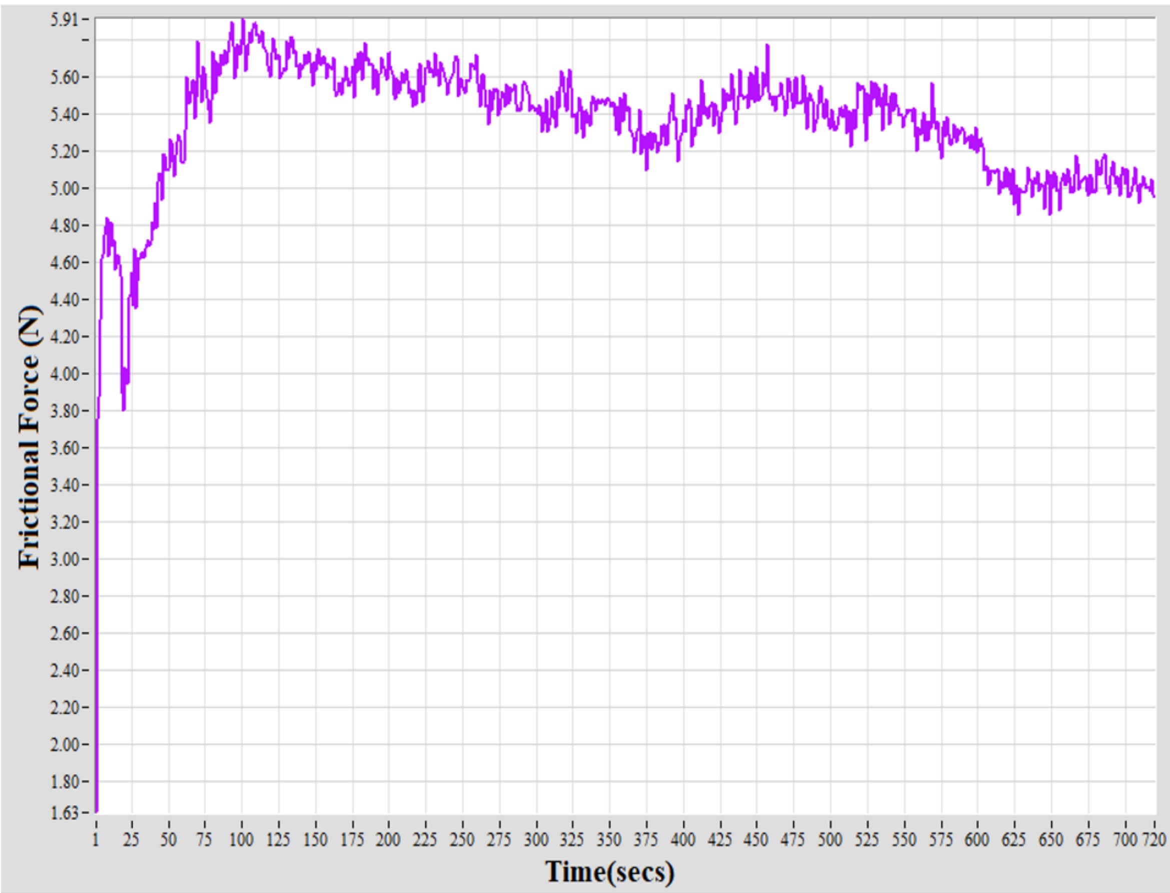

Figure 4. AZ91E Alloy Showing the Frictional Force as a Function of Sliding for 5% of ZrO_2

composite.

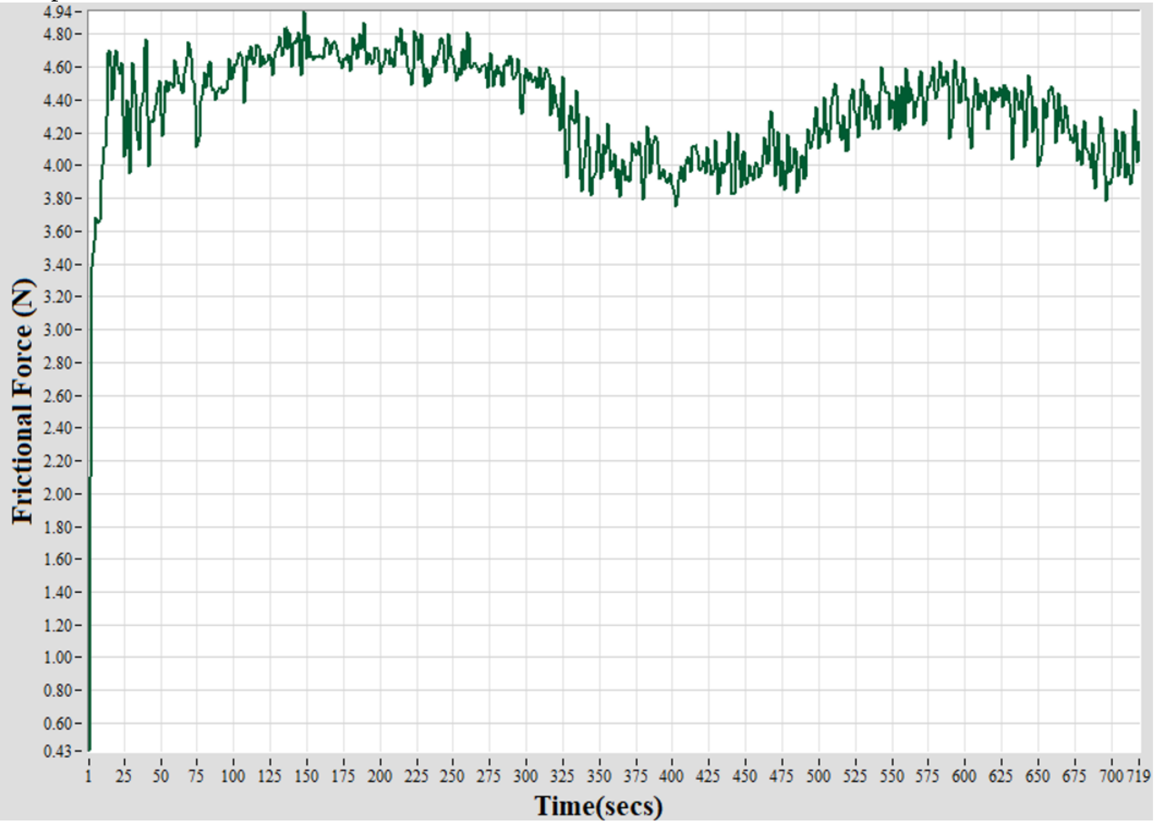

Figure 5. AZ91E Alloy Showing the Frictional Force as a Function of Sliding for 10% of ZrO_2 composite.

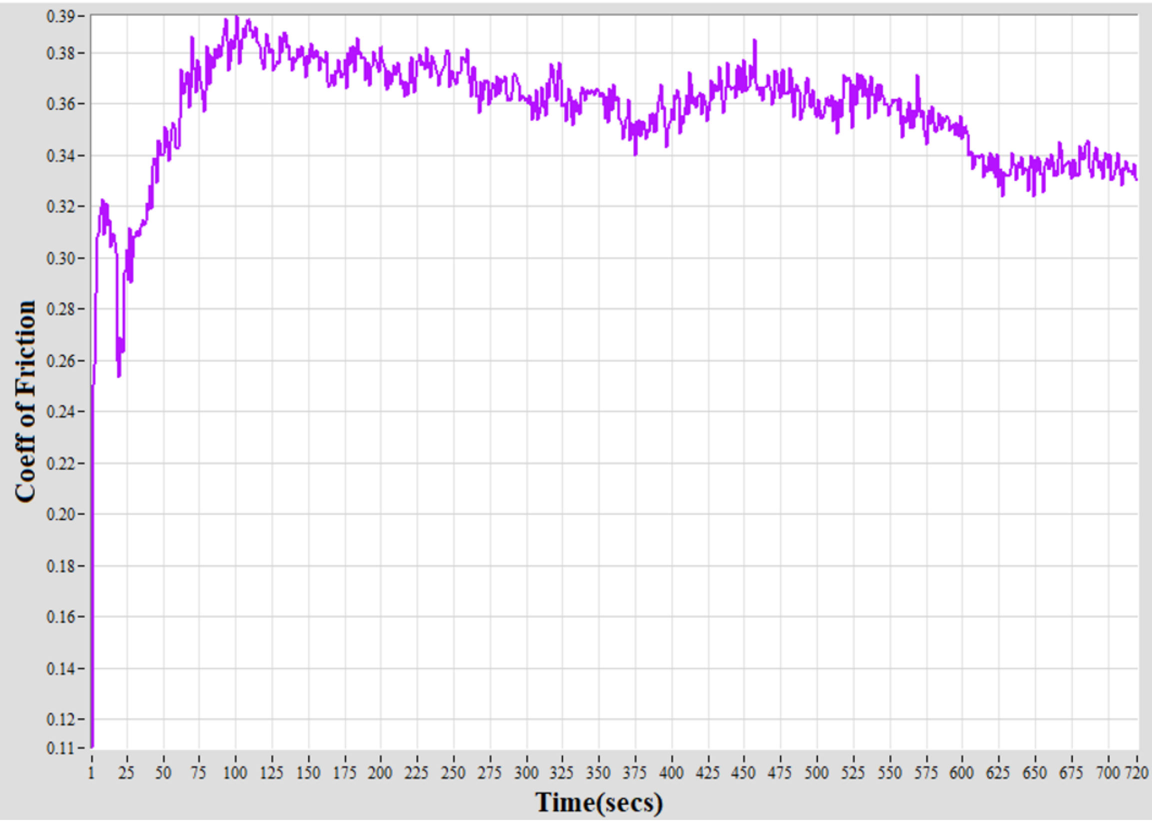

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Figure 6. AZ91E Alloy Showing the friction coefficient as 5% ZrO_2 composit*e.*

Figure 7 depicts the friction coefficient with 318 rpm at a time of 12 min for 15 kg load of Pin diameter of 8 mm for the 10% composite of AZ91E alloy at 125 sec coefficient of friction is 0.31 which is very less then 5% composite and after that decreased to 0.30 at 140 sec, and again increased to 0.31 at 160 sec. and finally it is decreased to 0.27 at 720 sec. For 10 % alloy the composites of µ decreased with raising applied load. Also, µ diminishes with increment of reinforcement content.

The change in the friction coefficient (µ) for alloy, composites under various loads. For both alloys and composites, friction coefficient decreased as applied weight enhanced. The value enhanced as the reinforcement content inflated.

The graphical representation of µ as a Function of Sliding for 5% ZrO_2, 10% ZrO_2 composite as the results obtained are explained.

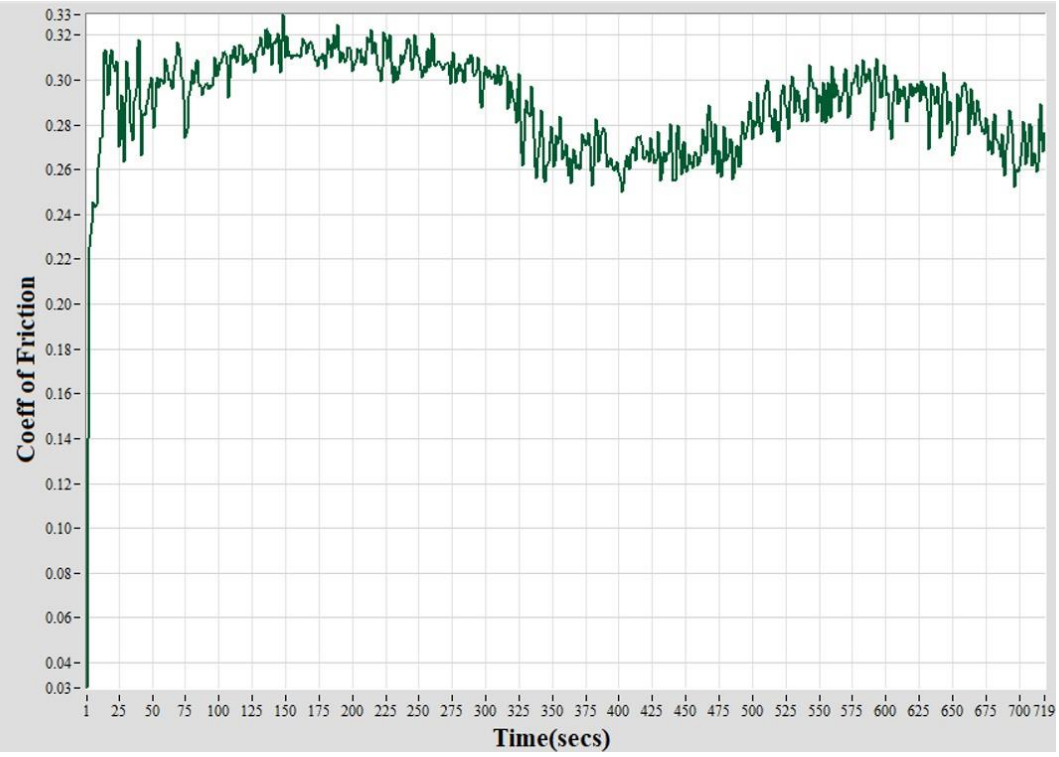

Figure 7. AZ91E Alloy Showing the friction coefficient as 10% ZrO_2 composite.

Table 2. Tribological properties for 15 kg load at 318 rpm

Material Sample	Wear(Micron)	Frictional Force(Newton)	Coefficient of Friction
AZ91E	710.656453	6.064909705	0.535239527
AZ91E + 2.5% ZrO_2 + 2.5% Fly ash	640.6095387	4.964882033	0.276651689
AZ91E + 5% ZrO_2 + 5% Fly ash	548.7938386	4.149775342	0.330992136
Tribological properties for 20 kg load at 318 rpm			
AZ91E	437.2565622	7.384422166	0.364545332
AZ91E + 2.5% ZrO_2 + 2.5% Fly ash	327.2982375	5.777891248	0.288894562
AZ91E + 5% ZrO_2 + 5% Fly ash	277.787176	5.753626482	0.287681324
AZ91E	387.254625	7.956466625	0.294655625
AZ91E + 2.5% ZrO_2 + 2.5% Fly ash	342.155416	7.605766482	0.304230659
AZ91E + 5% ZrO_2 + 5% Fly ash	313.1741317	7.758645503	0.31034582

From Table 2, Tribological properties for 15 kg load at 318 rpm, wear is maximum for base material and minimum for 10% composition alloy, friction force is minimum for 10% composition alloy, Coefficient Of Friction is minimum for 5% composition alloy. Also there is a large difference for 5% composition alloy and 10% composition alloy.

Tribological properties of 15 kg, 20 kg, 25 kg of different loads, with 318 rpm, of different compositions. It was contemplated that due increase in loads, to wear rate increased. Wear rate of the AZ91E depletes constantly with accelerating sliding speed (4.608 m/s). It may be noted that in the case of 4.608, abrasive wear predominant wear mechanism. Wear mechanism may switch abrasive wear to beginning delamination wear as sliding speed is increased.

Wear

Figure 8 indicates Amount of sample specimen wear with a load and sliding speed. There is more wear at 5% of ZrO_2 & fly ash in comparison to 10% of ZrO_2 & fly ash, depletes as volume fraction of ZrO_2 & fly ash. Hybrid composite does not display any difference in wear property as the load increases from 15 to 25 kg with same speed of 318 rpm the wear value is 25 kg-318 rpm.> 20 kg-318 rpm > 15 kg-318 rpm for AZ91E + 2.5% ZrO_2 + 2.5% Fly ash.

COEFFICIENT OF FRICTION (COF)

Figure 9 CoF of AZ91E and various ZrO_2 and fly ash volume fractions and loads are 15 to 25 kg at 318 rpm. It disclosed that, at 10% volume fraction of ZrO_2 & fly ash the Compared to pure AZ91E, the coefficient of friction is relatively high in any load- speed condition. The graph demonstrates that coefficient of friction is high under 25 kg load at 318 rpm in contrast to load condition.

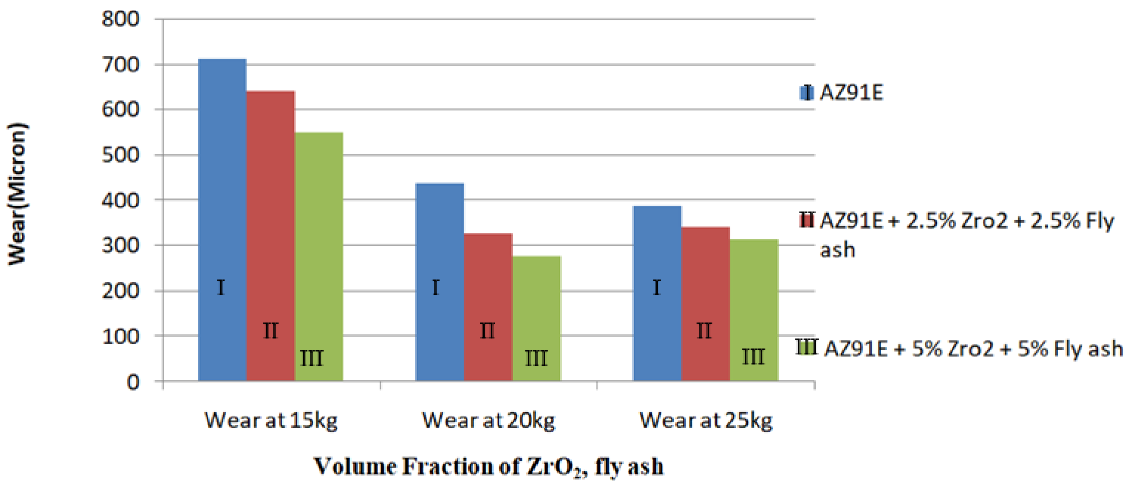

Figure 8. Variation in AZ91E wear as a function of fly ash and ZrO2 volume fraction.

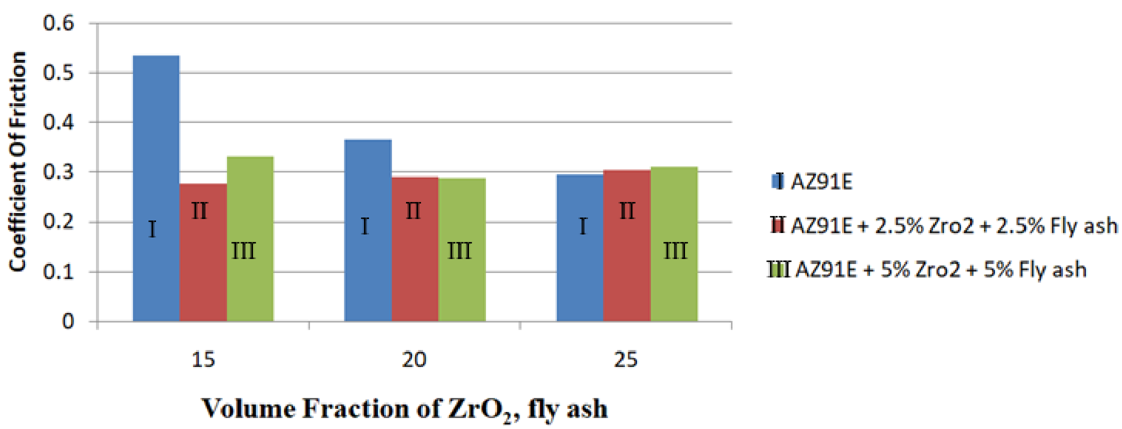

Figure 9. Variations in the coefficient of friction of AZ91E with various ZrO_2 and fly ash volume

fractions

Wear test were performed to analyze the influence of process parameters to find wear rate and coefficient of friction. The process parameters are shown in the below graphs. These below graphs help us in understanding the tribological behavior of the composites.

Figure 10 is the test data analysis of wear in microns vs. time in sec, for the sample AZ91E 2.5% ZrO_2 and 2.5% Fly ash. The final result is when the time increase the wear go on increasing, to know the complete details of wear rate of this material, the thing is, have to check for all the loads like 15 kg, 20 kg, 25 kg loads for the same sample after that, have to compare at which loading condition the wear is more, and how the wear differs from different loading condition.

The below figure depicts the wear analysis of AZ91E 2.5% ZrO_2 and 2.5% Fly ash composite under the loading conditions of 15 kg. below figure clearly illustrates that under the static loading, wear rate increases as the time increases. According to Archard's law, material loss from wear is directly related to the sliding distance and normally applied force rather than being indirectly proportional to the material's hardness. The Archard's timing Law, it is mostly applied to single-phase materials, but multiphase alloys and composites shall also performs brilliantly when it is used. This law has only been addressed to adhesion wear. It is also observed that increased contact pressure could lead in increase in temperature, resulting in higher rate of MRR. From Figure 10 the wear rate at the time of 720 sec is 640.9 microns.

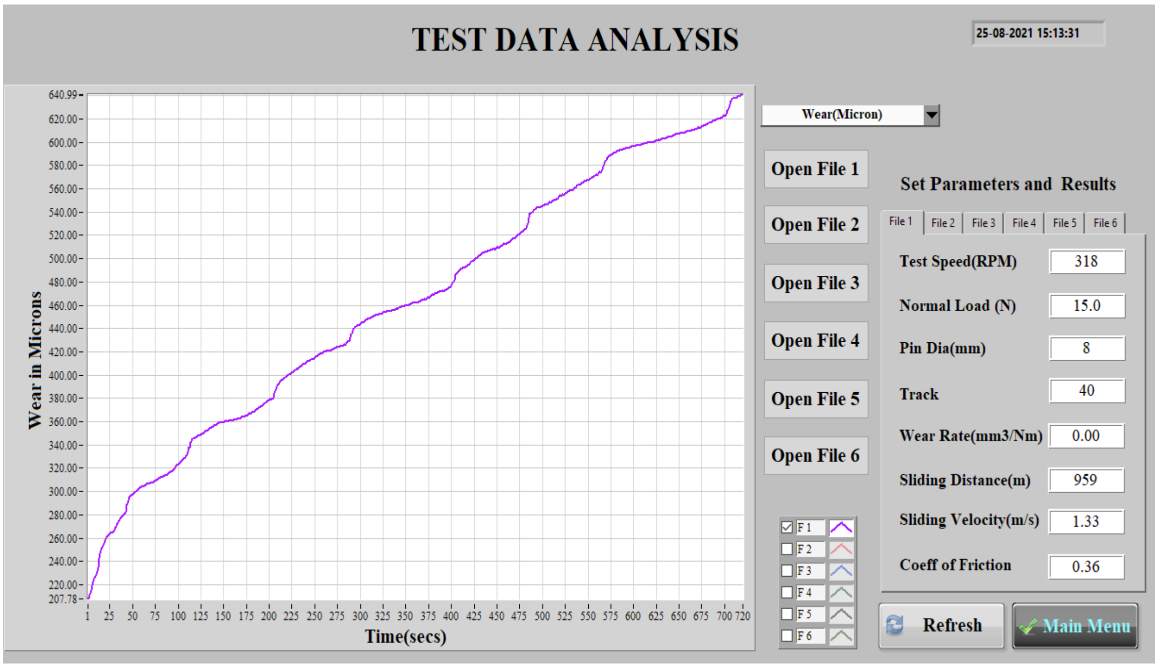

Figure 10. Analysis of wear in Microns vs. Time in sec for 2.5% ZrO_2 and 2.5% Fly ash for 15 kg load.

Figure 11 indicates the sample analysis of 2.5% ZrO_2 and 2.5% Fly ash for 20 kg load it is represented by red colour line and the graph is drawn between wear and time, at a sliding velocity of 1.33 m/s, and at the time of 720 sec, the wear rate is 327.56 microns

Figure 12 indicates the sample analysis of 2.5% ZrO_2 and 2.5% Fly ash for 25 kg load it is represented by blue colour line at a sliding distance of 959 m, and at the time of 720 sec, the wear rate is 342.16 microns.

Figure 13 is the combination of 15 kg load, 20 kg load, 25 kg load. By the analysis it is clearly seen that the wear rate for 20 kg load is much suitable, when compared to 15 kg and 25 kg load.

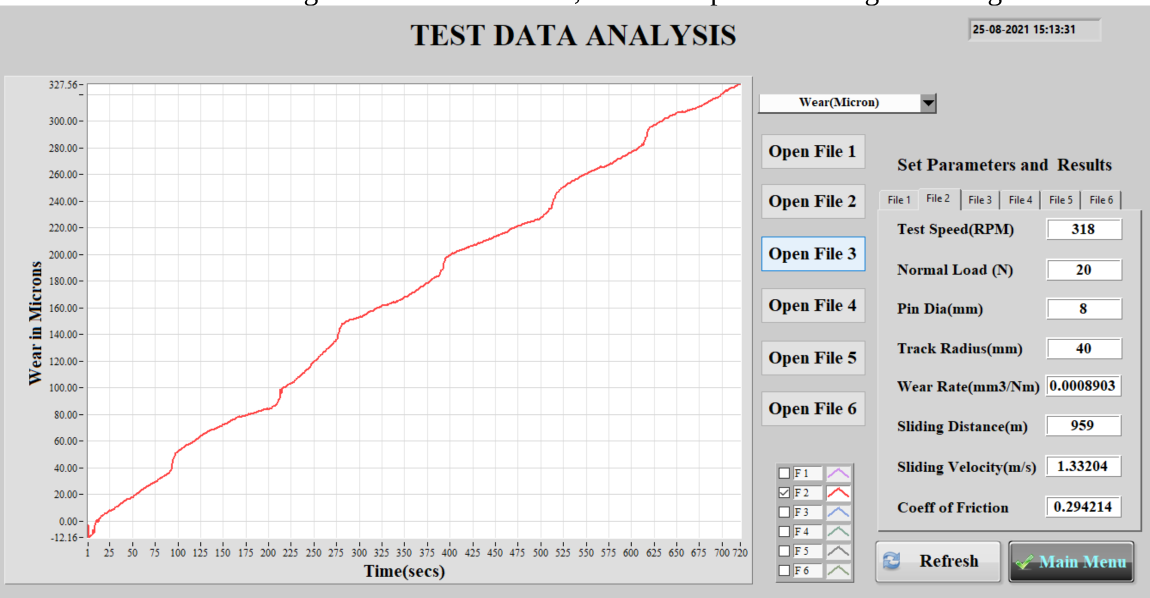

Figure 11. Analysis of wear in Microns vs. Time in sec for 2.5% ZrO_2 and 2.5% Fly ash for 20 kg load.

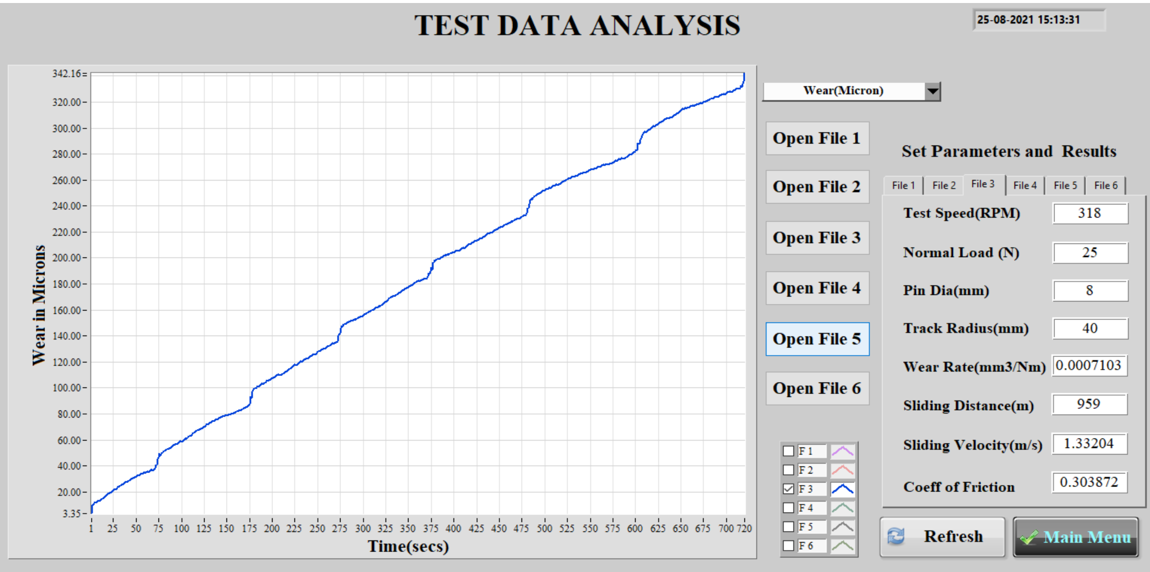

Figure 12. Analysis of wear in Microns vs. Time in sec for 2.5% ZrO_2 and 2.5% Fly ash for 25 kg load.

The above graph represents wear analysis for the AZ91E with 2.5% ZrO_2 and 2.5% Fly ash at a load of 15 kgs, 20 kg, 25 kg. It was found that as the time increases, wear rate had significantly increased linearly. Increasing the weight fraction of ZrO_2 and Fly ash leads to wear rate reduction, owing to the high hardness of alloy content, and leads to significant wear resistance.

Wear test were performed to analyze the influence of process parameters to find wear rate and coefficient of friction. The process parameters are shown in the below graphs. These below graphs help us in understanding the tribological behavior of the composites. Figure 14, Figure 15 and Figure 16 explains the test data analysis of wear in microns versus time in sec, for the sample AZ91E 5% ZrO_2 and 5% Fly ash. Wear analysis has been conducted in different loading conditions (15 kg, 20 kg and 25 kg). This helps us in understanding how the manufactured composite behaves under different dynamic conditions.

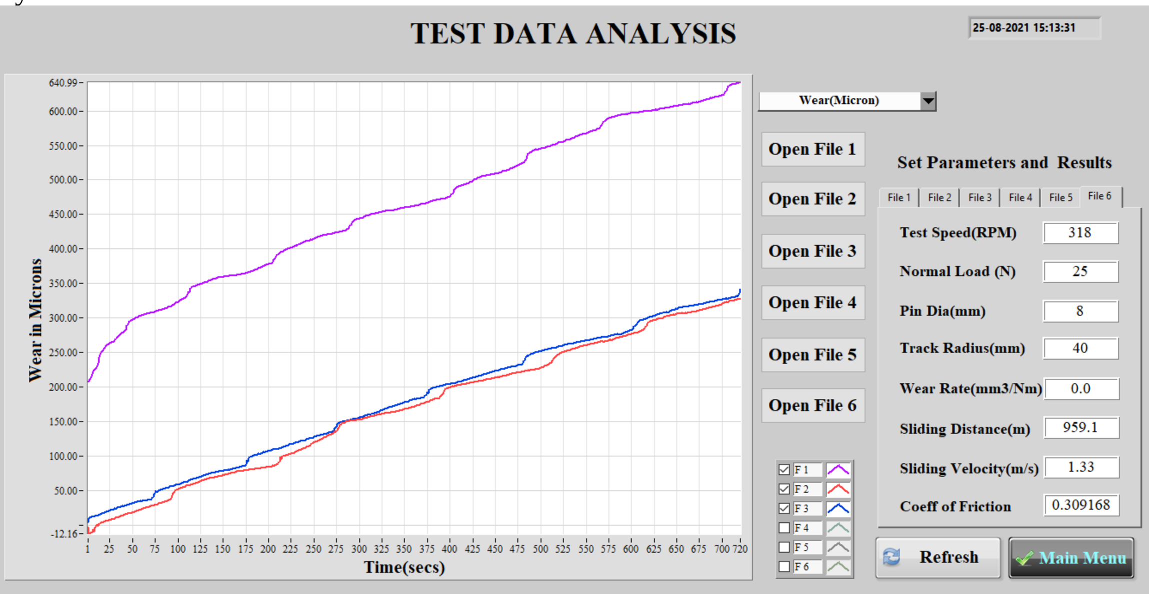

Figure 13. Analysis of wear in Microns vs. Time in sec for 2.5% ZrO_2 and 2.5% Fly ash for all the 3 loads(15 kg, 20 kg, 25 kg).

The Figure 14 depicts the wear analysis of AZ91E 5% ZrO_2 and 5% Fly ash composite under the loading conditions of 15 kg. Above figure clearly illustrates that under the static loading, wear rate increases as the time increases. According to Archard's law, material loss from wear is directly related to the sliding distance and normally applied force rather than being indirectly proportional to the material's hardness. The Archard's timing Law, it is mostly applied to single-phase materials, but multiphase alloys and composites shall also performs brilliantly when it is used. This law has only been addressed to adhesion wear. It is also observed that increased contact pressure could lead in increase in temperature, resulting in higher rate of MRR.

Figure 14 indicates that 5% ZrO_2 and 5% Fly ash for 15 kg load of sample 2, by the following data it is observed that at the time of 719 sec the wear rate is 548.79 microns

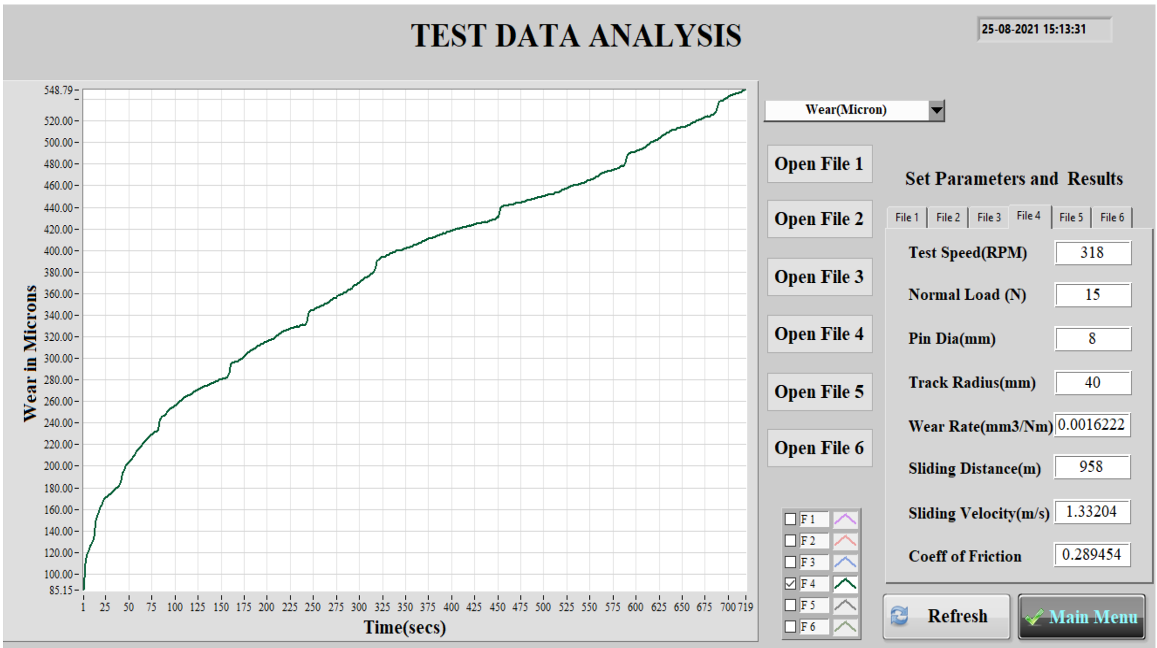

Figure 14. Analysis of wear in Microns vs. Time in sec for 5% ZrO_2 and 5% Fly ash for 15 kg load.

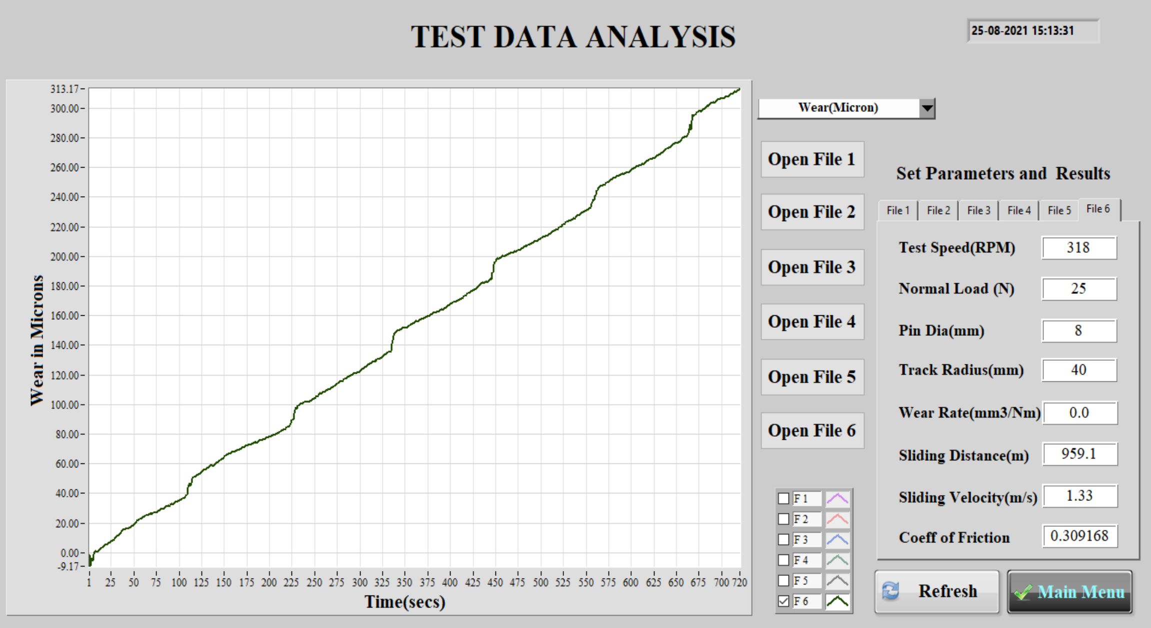

Figure 15. Analysis of wear in Microns vs. Time in sec for 5% ZrO_2 and 5% Fly ash for 25 kg load.

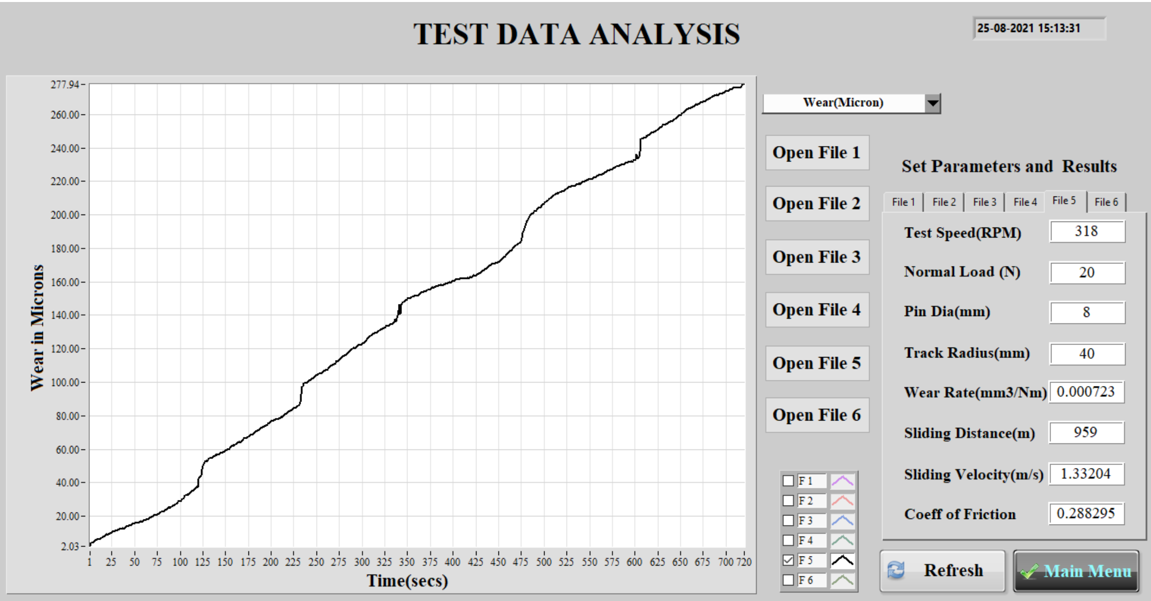

Figure 16. Analysis of wear in Microns vs. Time in sec for 5% ZrO_2 and 5% Fly ash for 20 kg load.

Figure 15 indicates that 5% ZrO_2 and 5% Fly ash for 20 kg load, by the following data it is observed that at the time of 720 sec the wear rate is 277.94 microns.

Figure 16 indicates that 5% ZrO_2 and 5% Fly ash for 25 kg load, by the following data it is observed that at the time of 720 sec the wear rate is 313.17 microns.

Figure 17 As it said earlier when the time increase the wear rate is increasing with respect to time, but have to check in which way the wear increased for different loading condition, what are the different aspects involved in that for increasing or decreasing of load. So that have to draw all the three different loading conditioning in a single test data analysis helps to analysis upon which load the wear is suitable of withstanding the load. It is found that from sample 2 also for 20 kg load only the wear rate is better.

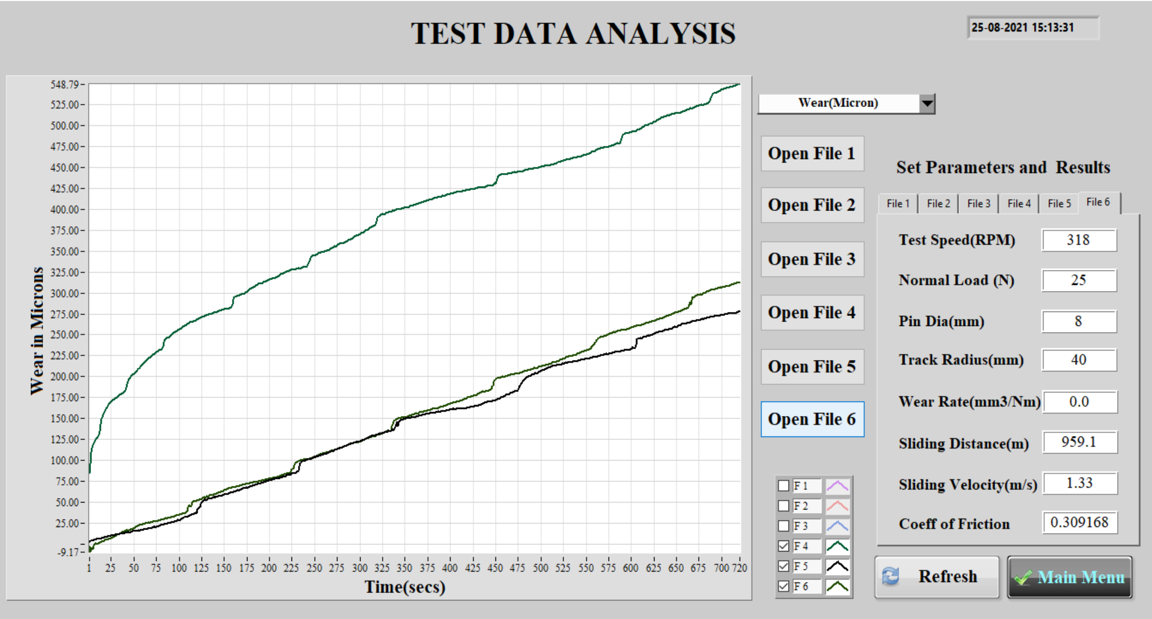

Figure 17. Analysis of wear in Microns vs. Time in sec for 5% ZrO_2 and 5% Fly ash for all the 3 loads(15 kg, 20 kg, 25 kg).

CONCLUSION

- Dry sliding tests were been conducted at room temperature for composite (AZ91E 2.5% ZrO_2 and 2.5% Fly ash) as well as for the composite (AZ91E 5% ZrO_2 and 5% Fly ash) under different static conditions such as 15 kg, 20 kg and 25 kg. It has been observed that as the sliding distance and time increases, the wear rate has been increased linearly. It has also been found that there was decreased wear rate for both the composites under the static load condition of 20 kgs.
- Due to substantial increase in time/ the wear rate, the sliding distance drops, indicating that matrix has expanded and that particles are bearing the load, resulting in a smaller contact area and providing more wear. This is true as µ values decrease with increasing reinforcement concentration. Figured is there in for cement banding nature demonstrating unceasing rein for cements supply to the connection area, even when the particle that was connected to the rotating disc has either fallen off or become worn.
- Due to the enlarged area of reinforcement and the decreased wear rate at the contact area, this conversation extends considerably. Likewise, the same description is applicable to increasing descending distance.
- Wear test was conducted considering various loads and sliding rates for steel counter face. In consideration of less accuracy in surface of pin with non-uniformity, the accomplished data and graphs project random results.
- On considering all possible conditions, Durability in composite is much greater for 10% volume fraction of ZrO_2 & fly ash. Beneath high sliding speed conditions (normal load: 20 kg).

Author Contribution

1. Conception – P.V. Elumalai, Design of the work – Gari Surya Chandra Swamy, the acquisition – G. Murali, analysis – M. Murugan, interpretation of data for the work – Nasim Hasam
2. Drafting the work-K. V. Durga Rajesh
3. Final approval of the version to be published – Vinay Kumar

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