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An Extensive Study and Evaluation of Tribological Properties of FSW Plates using Linear Reciprocating Tribometer (LRT)

R. Shwethasree[1], J. T. Thirukrishna[1], M. Sadashiva[2]*, M. R. Srinivasa[2] and S. Praveen Kumar[3]

[1]*Department of Information Science and Engineering, DSATM, VTU, Belagavi - 590018, Karnataka, India*
[2]*Department of Mechanical Engineering, P.E.S.C.E, Mandya - 571401, Karnataka, India; sadashiva015@gmail.com*
[3]*Department of Mechanical Engineering, VTU, Belagavi - 590018, Karnataka, India*

Abstract

This study extensively focuses on analyzing the fretting wear characteristics of Aluminum-based hybrid Metal Matrix Composites (MMCs) under dry conditions, essential in understanding materials' tribological properties in mining environments. Aluminum-based MMCs offer improved wear resistance and durability, potentially enhancing mining equipment performance. The investigation targeted Aluminum 7075 alloy-based MMCs, comprising 7% fine greenish Silicon Carbide and 3% chopped E-glass fibers (2-3mm length, 10-14 micrometer diameters). Using traditional stir casting and Friction Stir Welding (FSW) techniques, composite plates meeting ASTM standards were fabricated. FSW parameters like rotation speed and tool feed rate were varied.Analyzing fretting wear on the welded zone, employing different loads through Linear Reciprocating Tribometer (LRT), provided insights into the tribological performance of these Aluminum-based hybrid MMCs. The lightweight and exceptional thermal properties of Aluminum have significantly expanded its use across various industries, enabling partial replacement of ferrous materials, especially in MMCs where Aluminum alloys offer distinct advantages over other materials.This research aids in determining the suitability of these MMCs for demanding mining conditions, where materials endure extreme stress. Understanding their tribological behavior is crucial for potential applications in mining equipment, contributing to longevity and improved performance.

Keywords: *Aluminium Alloy, Fretting, Friction Stir Welding, Stir Casting*

1.0 Introduction

Fretting is a small-amplitude (1-300 μm) relative motion that may accurse in between contact surfaces. Surface degradation by these movements is called fretting wear or fretting damage. Localized vibratory wear termed as fretting wear or fretting damage. The total damage can be described in term of fretting corrosion, fretting fatigue and fretting wear. There are certain examples in engineering application were you will have fretting contribute into total wear of the material component. So fretting can be divided into two categories, where the contact surface are not designed to move relative to each other, example riveted joints, shrink fits, bolted flanges keys, etc[1]. Other case where relative movement accurse for the part of the time. Example bearings, flexible couplings and reciprocating cams, etc. Figure 1 show some of the examples of fretting wear[2].

In understanding fretting wear there are 4 modes of fretting wear.

- Tangential fretting.
- Radial fretting.

*Author for correspondence

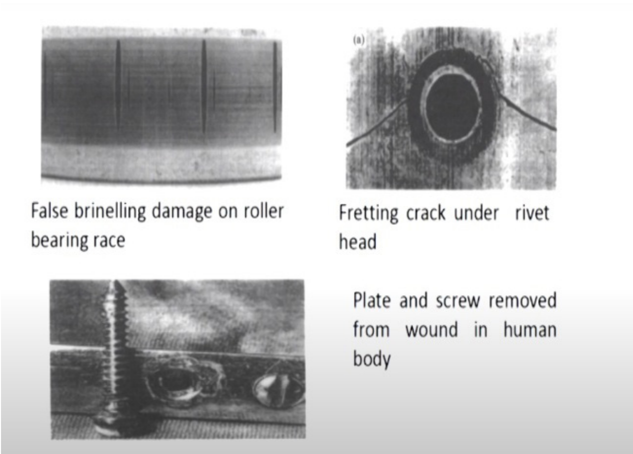


Figure 1. Fretting wear.

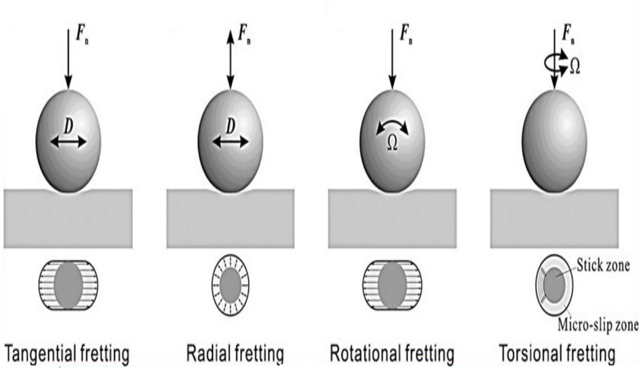


Figure 2. Types of fretting wear.

- Rotational fretting.
- Torsional fretting.

In general, according to the relative motion directions, for a contact of ball-on-flat, the fretting wear modes are composed of the tangential, radial, torsional and rotational modes, as noted in the above Figure 2. In our current work we focused only on tangential fretting mode to characterize the behavior of Al 7075 MMC at weld zone.

2.0 Materials and Methods

Current technology the advance engineering material has become more demand. To fulfill the current demand a lot of research has been carried out to get required properties of materials. Al is one of the materials which have huge number of engineering properties. In the current work, aluminum 7075 alloy is used as matrix and silicon carbide particulates and E-glass fibers are used as reinforcements, together the composites are fabricated called hybrid composites[3]. E glass fiber helps to improve higher shear strength and stiffness. Due to its good properties Al 7075 is widely used in automobile industries, aerospace, marine, rifles, turbine casting, missiles tail cone, bicycles components etc[4]. In the present work, research is done on aluminum AA 7075 base metal and AA 7075 reinforced with 7% of fine greenish 25 microns SiC and 3% of chopped E-glass fiber of 2 to 3 mm length and 10 to 14 micro diameter has been used. Stir casting process is used to fabricate the hybrid MMC of AA 7075 at 800°C. After casting the plats (100mm X 50mm X 6mm) and pin (Ø8mm x 15Lmm) were prepared according ASTM G-133-95 for fretting wear analysis. The Figure 3 shows

Figure 3. Cast of AA 7075 plates.

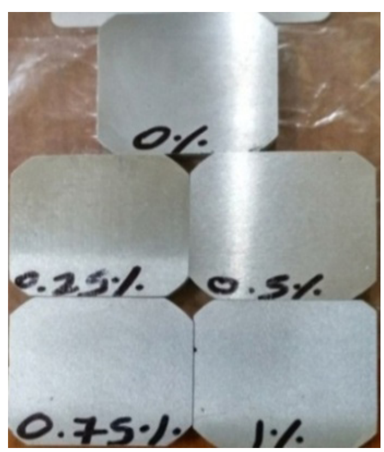


Figure 4. Specimen plate.

Figure 5. Pin.

the stir casted plats and Figures 4 and 5 shows standard plats and pin of required specification[5].

After casting, two plates were welded with the help of Friction Stir Welding process (FSW). Following points were outline the some advantages of FSW over other manufacturing methods.

- Solid state welding.
- No filler materials required.
- No melting of base materials.
- No formation of residual stresses.
- Clean process.
- Well suitable for non-ferrous metals.

Also FSW have some limitations like fume and hazardous form during welding. Thickness of welding plates was limited[6]. In current work, plates were brought

Figure 6. FSW operation.

Figure 7. Welded plates.

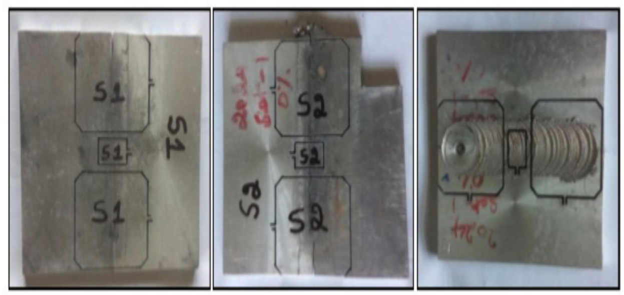


Figure 8. Dimensions of welded zone.

to butt position and FSW were conducted on aluminum AA 7075 base metal and AA 7075 hybrid MMC by varying the different welding parameters and keeping the spindle rotation speed constant (600 RPM). During FSW considered process parameters like feed rate such as 40mm/min, 80mm/min, and 120mm/min for both base and composites[7]. For AA base metal S1 (70S1F1) for the feed rate of 40mm/min, S2 (70S1F2) for 80mm/min, S3 (70S1F3) for 120mm/min. similarly for hybrid MMC as S4 (7S1F1) for the feed rate of 40mm/min, S5 (7S1F2) for 80mm/min, S6 (7S1F3) for 120mm/min. Figure 6, shows FSW operation and Figure 7 shows the welded joint after FSW process[8].

After FSW, the welded zone was extract to required size using EDM to ASTM standards for fretting wear test[9]. The Figure 8 Shows the marked area of welded zone plates to be cut and examine. After machining, weld zone under gone through secondary operation like Grinding and Polishing was shown in Figure 9. The Al 7075 base plate and hybrid MMC square plates of 40mm x 40mm

Figure 9. Grinded and polished plate.

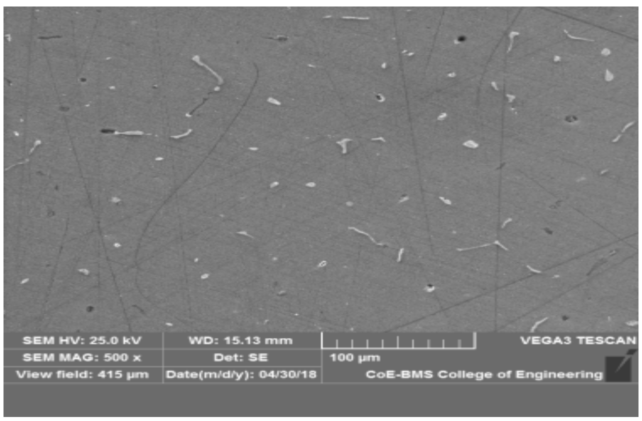


Figure 10. SEM image of Al base material.

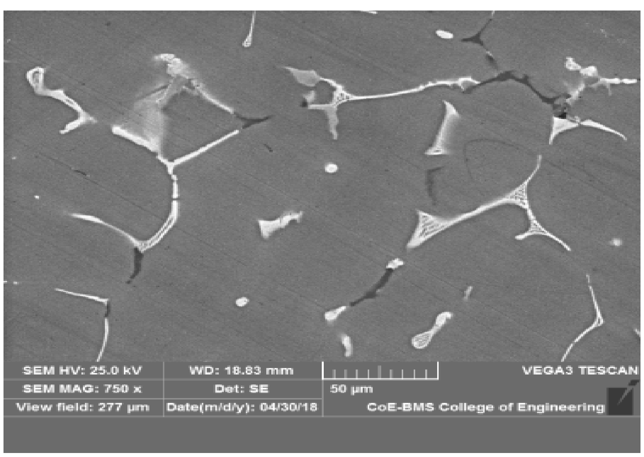


Figure 11. SEM image of Al MMC material.

and pins of dia 15x8 mm length were prepared by smooth grinding and polished surface exhibits well surface characteristics during test result. The polished specimens of both plates and pins were shown in the Figure 9.

Followed by carried out the micro structural characterization by using SEM. The Figures 10 and 11 shows the SEM image of both base metal and composite specimen. From the image concluded that distribution of ingredients in matrix is homogeneous and its results that fretting resistance significantly higher in the composites than base materials[10].

2.1 Experimentation

Machined ASTM Standard specimen subjected to the fretting wear analysis under dry condition for different sets of plates on the weld zone[11]. The LRT machine set up is as shown in Figure 12. The Al plates and pins are fixed in their position on LRT machine and both plate and pin are made contact with each other and the load is applied on the holder by means of metallic disc[12].

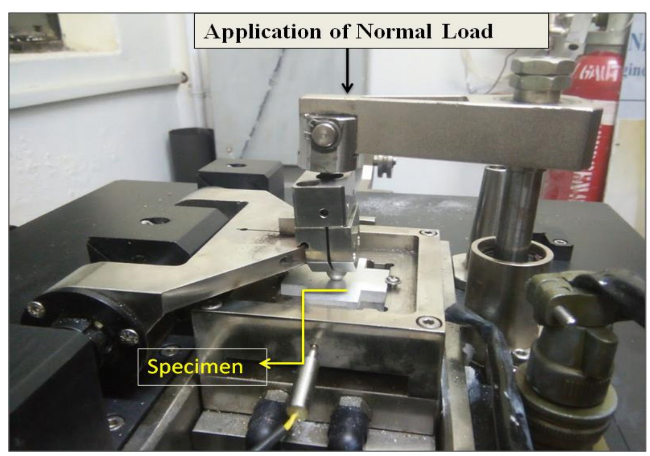


Figure 12. LRT m/c set up.

Figure 13. Fretting wear sample (before and after).

All the inputs data were given through computer system using 'WINDUCOM' software. Once the all the set up was done the experiment is carried out for desired number of cycle of oscillations. The obtained data were recorded and results analyzed. The results are shown in the table below.

In the current study, friction stir welded AA 7075 metal plates were machined as fretting specimen such as S1, S2, S3, S4, S5 and S5. Each set subjected to under three different load conditions like 20N, 40N and 60N. The following Figure 13 shows the experimental sample before and fretting test.

3.0 Result and Discussion

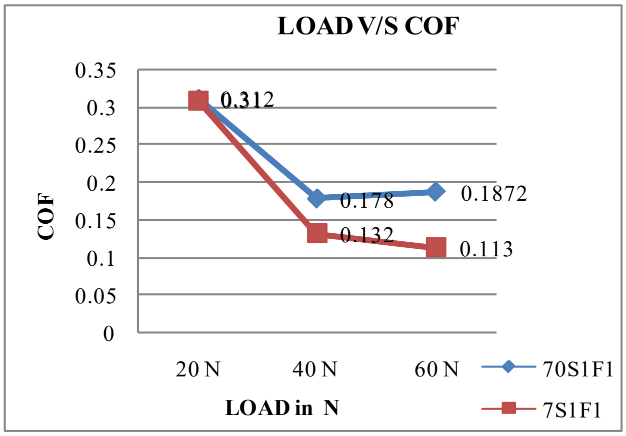
The output of test were recorded and cumulative results for base plates (S1 Conditions) and composite plates (S4 conditions) for different parameter shown in the following Table 1.

From the Graphs 1 and 2 found that COF was decreases in both set of specimen as load is increased but

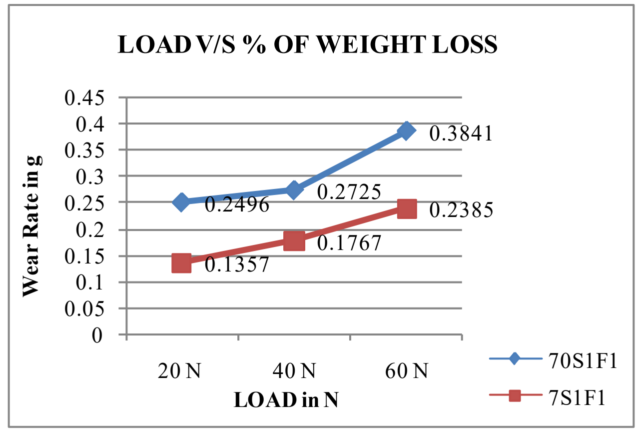
Table 1. Cumulative results of specimen S1 (70S1F1) and S4 (7S1F1)

Specimen	Load in N	Specimen Weight(g)		Indentor Weight(g)		Total Initial Weight(g) $(W_I) = (W_{IS}+W_{II})$	Total Final Weight(g) $(W_F) = (W_{FS}+W_{FI})$	Reduction In Weight(g) $(W_I - W_F)$	of Reduction Of Wt.	Coefficient of Friction	Frictional Force (N)
		Initial Weight (W_{IS})g	Final Weight (W_{FS})g	Initial Weight (W_{II})g	Final Weight (W_{IF})g						
AA 7075 Base plate welded by FSW with the tool rotational speed of 600rpm and feed of 40mm/min											
S1	20	18.483	18.457	2.148	2.123	20.631	20.580	0.051	0.2496	0.3120	6.2001
	40	20.489	20.459	2.114	2.083	22.60	22.542	0.0616	0.2725	0.1783	7.1321
	60	20.427	20.383	2.038	1.995	22.465	22.379	0.0863	0.3841	0.1872	11.232
AA 7075 Composite plate welded by FSW with the tool rotational speed of 600rpm and feed of 40mm/min											
S4	20	22.058	22.042	2.402	2.385	24.461	24.427	0.0332	0.1357	0.3100	6.2001
	40	23.050	23.029	2.357	2.335	25.408	25.365	0.0430	0.1767	0.1329	5.3133
	60	23.022	22.992	2.252	2.222	25.275	25.214	0.0603	0.2385	0.1134	6.7864

COF is much lesser in the Al 7075 hybrid MMC compared with Al-7075 base metal due to Sic and glass fiber which increases the mechanical properties of the material and even composite plates shows excellent fretting resistance over base plate[13]. Its evidently observed from SEM images. Specimen subjected to S1 condition shows higher fretting forces and also high wear rate at 60N Load. In case of composites, S4 condition with load 40 N shows excellent fretting wear resistance due to homogenous mixing and strong bond exist between matrix and reinforcements in composites[14].



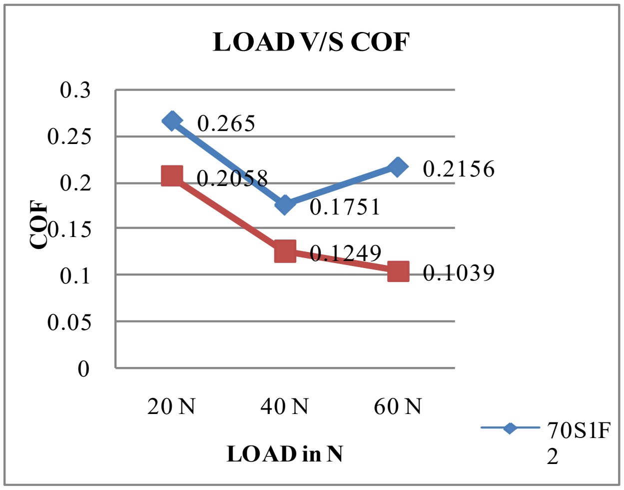
Graph 1. Load v/s COF.



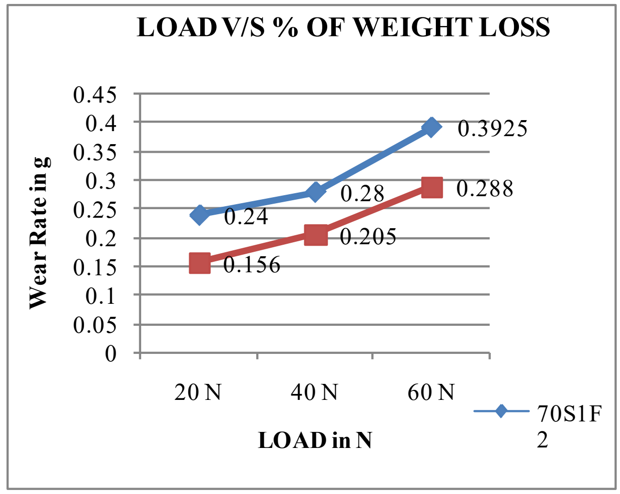
Graph 2. Load v/s Percentage of weight loss.

Table 2. Cumulative results of specimen S2 (70S1F2) and S5 (7S1F2)

Specimen	Load in N	Specimen Weight (g)		Indentor Weight (g)		Total Initial Weight(g) $(W_I)=(W_{IS}+W_{II})$	Total Final Weight(g) $(W_F)=(W_{FS}+W_{FI})$	Reduction In Weight(g) $(W_I - W_F)$	% of Reduction Of Wt.	Coefficient of Friction	Frictional Force (N)
		Initial Weight (W_{IS})g	Final Weight (W_{FS})g	Initia Weight (W_{II})g	Final Weight (W_{IF})g						
AA 7075 Base plate welded by FSW with the tool rotational speed of 600rpm and feed of 80mm /min.											
S2	20	19.967	19.940	2.258	2.231	22.225	22.172	0.0534	0.2402	0.2652	5.3034
	40	21.052	21.019	2.258	2.225	23.310	23.245	0.0653	0.2801	0.1751	7.0021
	60	21.011	20.967	2.145	2.099	23.157	23.066	0.0909	0.3925	0.2156	14.174
AA 7075 Composite plate welded by FSW with the tool rotational speed of 600rpm and feed of 80mm /min.											
S5	20	20.524	20.506	2.286	2.268	22.810	22.775	0.0356	0.1560	0.2058	4.1161
	40	20.562	20.539	2.250	2.226	22.813	22.766	0.0469	0.2055	0.1249	4.6391
	60	20.532	20.499	2.157	2.124	22.689	22.624	0.0655	0.2886	0.1039	6.2435



Graph 3. Load v/s COF.

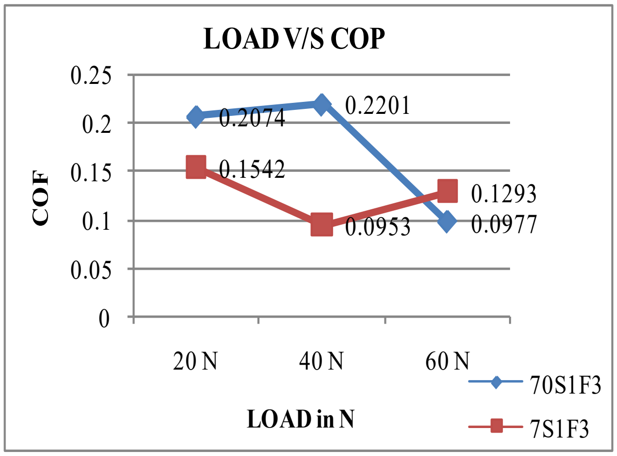


Graph 4. Load v/s % percentage of weight loss.

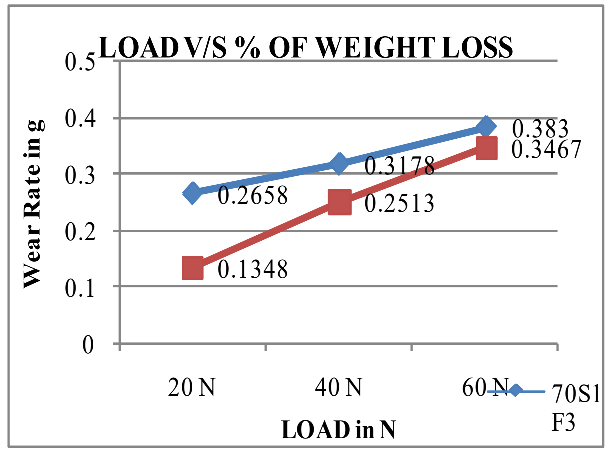
Table 3. Cumulative results of specimen S3 (70S1F3) and S6 (7S1F3)

Specimen	Load in N	Specimen Weight(g)		Indentor Weight(g)		Total Initial Weight(g) (W_I)=(W_{IS}+W_{II})	Total Final Weight(g) (W_F)=(W_{FS}+W_{FI})	Reduction In Weight(g) (W_I - W_F)	of Reduction Of Wt.	Coefficient of Friction	Frictional Force (N)
		Initial Weight (W_{IS})g	Final Weight (W_{FS})g	Initia Weight (W_{II})g	Final Weight (W_{IF})g						
AA 7075 Base plate welded by FSW with the tool rotational speed of 600rpm and feed of 120 mm/min											
S3	20	18.387	18.359	2.035	2.008	20.422	20.368	0.0543	0.2658	0.2074	4.1482
	40	19.950	19.916	1.980	1.946	21.930	21.862	0.0679	0.3178	0.2201	8.8013
	60	20.536	20.495	2.174	2.127	22.710	22.623	0.0870	0.3830	0.0977	5.8577
AA 7075 Composite plate welded by FSW with the tool rotational speed of 600rpm and feed of 120mm/min											
S6	20	20.534	20.516	2.295	2.286	22.830	22.803	0.0272	0.1348	0.1542	3.0873
	40	17.486	17.461	2.286	2.261	19.772	19.724	0.0480	0.2513	0.0953	3.3854
	60	17.459	17.424	2.209	2.175	19.663	19.600	0.0632	0.3467	0.1293	7.7680

The output of test were recorded and cumulative results for base plates (S2 Conditions) and composite plates (S5 conditions) for different parameter shown in the following Table 2. And from the Graph 3 and 4, it was observed that wear rate at the weld zone for the base metal as well as hybrid MMC is increases with increasing applied load.



Graph 5. Load v/s COF.



Graph 6. Load v/s % Percentage of weight loss.

But wear rate is more at base metal compared with hybrid MMC at increasing in load conditions. From the Graph 3 conclude that decreasing fretting wear at the load 20N due to excellent bonding between atoms during friction stir welding makes localized compaction, results weld zone undergone work hardening condition causes wear resistance in base material[15]. In case of composites, S5 condition under 20N load observed that wear resistance is excellent shown in from Graph 4.

The output of test were recorded and cumulative results for base plates (S3 Conditions) and composite plates (S6 conditions) for different parameter shown in the following Table 3. And from the Graphs 5 and 6, it was observed that wear rate at the weld zone for the base metal as well as hybrid MMC is increases with increasing applied load. But wear rate is more at base metal compared with hybrid MMC at increasing in load conditions due to resistance was setup in composite ingredients during fretting.

E-glass fiber acts as barrier for wearing due periodic sliding of tool over work. Sic particulates becomes compaction and acts as self lubricating agent results resistance setup in the weld zone. From the Graph 3 conclude that decreasing fretting wear at the load 60N due to excellent bonding between atoms during friction stir welding makes localized compaction, results weld zone undergone work hardening condition causes wear resistance in base material. In case of composites, S6 condition under 20N load observed that wear resistance is excellent shown in from Graph 6.

4.0 Conclusions

This comprehensive of current research work explains detailed analysis of tribological process parameters, specifically focusing on the coefficient of friction and fretting wear. The research successfully demonstrated the production of AA7075 aluminum alloy reinforced with 7.0% SiC and 3.0% E-glass fiber through the stir casting method, effectively enhancing the material's mechanical properties. Subsequently, various experiments were conducted to examine the wear characteristics within the weld zone.The efficient joints were obtained between the plates by the FSW process. The output of the experiment was listed below.

- Optimizing welding parameters based on the study's findings can significantly improve the durability of mining equipment, reducing wear and frictional forces because The coefficient of friction was observed considerably less in MMC than in base metal shown in the above graphs.
- The Coefficient of friction decreased as the load increased and vice versa it will help to exploration of reinforced plates suggests potential advancements in material composition, offering opportunities to develop wear-resistant components crucial for the harsh conditions in mining.
- The outcome of fretting wear test experimentation concludes that the AA7075 base metal has more wear rate compared to that of the hybrid AA7075 reinforced with SiC and E-glass fiber, These

research conclusions provide a practical pathway for enhancing the reliability and longevity of mining machinery, addressing key challenges in the industry and contributing to overall operational efficiency.

- The wear rate was increased concerning increases in the load on specimens in both bases as well as composites and more in the base metal than the composite metal because of the presence of Sic and e-glass which decreases the wear rate. The fretting wear was increased with the increased welding feed rate and the wear was found to be maximum at the feed rate of 120mm/min and minimum at 40mm/min.

5.0 Acknowledgement

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