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Tribological analysis of hybrid aluminum matrix composites for high temperature applications

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ABSTRACT

This research investigation explores the tribological performance of LM16 aluminum alloy-based Hybrid Aluminum matrix composite (HAMC). In this work is aimed to find optimum proportionality of the reinforced with Nickel coated Graphite (Ni-Gr.) and Silicon Carbide (SiC) of the Hybrid Aluminum matrix composite (HAMC) for the high-temperature applications. The stir casting technique is used for preparing the HAMC with reinforcement of Nickel coated Graphite (Ni-Gr) in weight of 2% and Silicon Carbide (SiC) varies 5% & 10% of weight into the LM16 aluminum alloy. The wear properties have been evaluated with the aid of a pin on disc apparatus and the L9 orthogonal array has been chosen for experimentation to know the impacts of process parameters like load, sliding distance, the weight percentage of hybrid reinforcements, and temperature. ANOVA is used to determine the optimum coefficient of friction (COF) and the loss of wear conditions of the HAMCs. It was found that temperature and applied load are the primary influence paraments in the tribological properties of LM 16 based Hybrid Aluminum matrix composites, the wear and coefficient of friction characteristics were studied with the help of SEM images.

1. Introduction

The current technologically sophisticated to the industrial system provides manufacturing a wide variety of components in some specific materials. The material can be used a broad variety of applications with extremely hard and inexpensive properties with the high-effectiveness in multipurpose. The researches are seeking to replace the alloys and metals with bright materials, the Metal Matrix Composites (MMC) are well established to provide such suitable property. The aluminium alloys show vulnerable tribological and mechanical characteristics in accordance with the adverse conditions like the absence of lubrication, higher temperature, and so on. The Aluminium Metal Matric Composites (AMCs) are limited in quantities for their lightweight, rigidity, and strength once strengthened with ceramic particles [1]. A new material with a greater resistance to wear with intended mechanical and tribology characteristics to be determined efficiently are basic requirements [2]. The recent new grade of Hybrid Aluminum matrix composites (HAMCs) becomes the most important material in various industrial applications like defence, aviation industry, automobiles, and other special-purpose usages. The usage of HAMCs can give a significant characteristic such as lesser in weight and low cost [3]. In HAMCs, the solid lubricant materials like graphite may also be utilized to reduce the wear rate and the friction coefficient of composite materials. It has been investigating very few researchers in various applications, which leads to adding the reinforcements and the treatments are playing a vital role to improve the mechanical properties.

2. Literature review

The improvement of tribological properties for the hybrid aluminum matrix composites consists of primary and secondary reinforcements [4]. The primary reinforcements such as ceramic particulate of Aluminium nitride (AlN), Silica (SiO_2), aluminum oxide (Al_2O_3) are used [5]. Industrial wastages like fly ash, red mud is used as secondary reinforcements and such as MoS_2, graphite is also used as reinforcement to improve the HAMC's [6]. HAMC's were prepared different methods but wisely mostly they were produced by powder metallurgical and casting techniques [7]. The AMC's reinforced Silicon Carbide (SiC) is chosen over

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traditional aluminum alloys due to their wear resistance and high strength [8,9]. The wear rate of Al.6061/SiCp composites was decreased by improving the size and volume fraction of Silicon Carbide (SiC) particles [10]. The elevated characteristics such as mechanical strength and wear resistance have been detected with an improvement in the volume fraction by using Silicon Carbide (SiC) particulates [11]. However, an improvement in rigidity was also discovered, which influences the workability of composite material. If the strong lubricant particles such as Molybdenum disulfide (MoS2) and graphite (Gr.) have been added beside with ceramic particles such as B4C, TiB2 sliding wear characteristics of composites have been increased [12,13]. In addition to that, the characteristics such as mechanical strength and wear resistance have been enhancing by adding hard particles such as Silicon Carbide (SiC) with a decrease of frictional coefficient because of the occurrence of lubrication film have been described [14,15]. For resistance stir welded Al-Mg2-Si metal matrix cast composite increase in Gr. level declines both wear resistance and fracture strength of the composite materials [16]. In certain experiments, the rise in Gr. proportion diminishes the toughness of the material with permeability difficulties limits augment on the level of consistent lubricants [17,18]. Additionally, the negative impact of additional Gr. level has been removed by the adding aluminum oxide particle also have been described [19,20]. Hard particles such as mica and carbon-reinforced AMCs with enhanced hardness have been indicated. It also described the impact of operational variables like reinforcing ratio on wear and frictional characteristics, sliding distance, and load applied to utilize arithmetical techniques [21]. Therefore, it can be stated that the optimum grade inclusion of solid lubricant is desirable, and can be combined with additional ceramic particles like TiB2, TiC, B4C, SiC, and so on. Additionally, because of its self-lubricating nature, most instances of Gr. are utilized as reinforcement to enhance the characteristics like friction and wear rate [22,23]. But extremely few researchers were performed on Ni.-Gr.(nickel-coated graphite) as a convergence of the component to the aluminum matrix composite materials, that also have the better-wet ability and self-lubricating characteristics.

3. Materials & methods

3.1. Material Preparation

The LM15 alloy is selected as a matrix material and Ni.-Gr. of size 93 μm, and Silicon Carbide (SiC) particulate matter of size 41 μm has been chosen as a reinforcing material. In this experiment, the matrix materials utilized have been LM-26 alloy, whose chemical arrangement is demonstrated in Table 1. The elements of Hybrid Aluminum Matrix Composite Materials (HAMC) are shown in Fig. 1.

LM16 alloy ingots are located in a graphite crucible and meltdown in an electric furnace at 725 °C when a corrosion agent and with a blending for 10 m in a closed chamber with a nitrogen gas cleansing at the speed of 380 rpm. Then the preheated SiC powder has flowed into the liquefied mixture with the predetermined 2% of Ni.-Gr. (fixed) quantity is supplied to the crucible. The Fig. 2 shows the fabrication of LM 16 based Hybrid Aluminum Matrix Composite Materials in the Stir Casting setup. The molten HAMC mix is flowed into the die to achieve the required samples. In the similar technique is used to fabricate other combination of composite material by varying the SiC weight proportion (10%, 15%) with the specified Ni.- Gr. (2%) amount. The wear test specimens have been fabricated through the CNC machine; the emery of various sizes is utilized to refine the samples to achieve a reliable surface.

3.2. Experimentation

The Pin on disc apparatus has been utilized to find the perform of wear tests of the HAMC's. According to ASTM G99 – 95, The samples have been manufactured with 10 mm of diameter and a sample size of 30 mm length. The Fig. 3 shows the Pin on Disk Apparatus with the specimen; the wear tests have been performed at three constant reinforcing blends of 0, 5, and 10 wt%, of SiC with 2% wt. of Ni.-Gr. (fixed), the sliding distances (0.5 m, 0.15 m, and 0.25 m), at temperatures (200 °C, 150 °C, and 100 °C), and three separate loads (10 N, 20 N, and 30 N) were considered for the testing. The sliding velocity was remaining at constant (1.57 m/s) for all the test trials. The pins have been slid against a rotatory EN32 steel disk strengthened to 65 HRC. Each test has been carried out repeatedly in three times for all the sets of tests to accomplish accurate standards of the wear loss. Following every experiment, acetone has been added towards the disk surface to counteract corruption and the merging of pieces. The weight loss has been established with a precise of 0.001 g weighing device and the proportion of regular normal and tangential force ($\mu = Ft / Fn$) was projected for the COF.

3.3. Design of experiments

This study examines the effect on friction coefficients and loss of wear from formulated hybrid composite experiments, the weight proportion of hybrid reinforcement, sliding distance, and temperature. L9 orthogonal array has been selected with the help of Minitab 18 software and the Taguchi method has been chosen for designing experimental methods. The variations of rates, variables, and the outcomes worried depend on the set of arrays. Table 2 shows all perceived variables with their rates.

Table 3 consists of the resultant data of L9 orthogonal array; the Signal/Noise ratio merges a variety of data and evaluates them based on attributes of the data. Additionally, three kinds of assessment standards have been chosen as "nominal the best", "bigger the better," and "smaller the better,". "Smaller the better" feature of the Signal/Noise ratio was deemed for the minimal COF and rate of wear among these three standards. Additionally, the ANOVA method has been utilized to determine the ratio consequence of every variable on COF and wear.

4. Results and discussion

4.1. Study of microstructure

Microstructure study of the LM16alloy and established composite materials have been approved by SEM. Fig. 4a displays the microstructure of LM16 alloy and Fig. 4b displays the LM16 + 10% SiC + 2%Ni.-Gr.hybrid composite. The constant weight proportion

Table 1
Chemical composition of LM16 alloy.

Components	Copper	Magnesium	Silicon	Iron	Manganese	Nickel	Zinc	Lead	Tin	Titanium	Aluminium	Others: each	Others: total
Content (wt. %)	1.0–1.5	04–0.6	4.5–5.5	0.6 max	0.5 max	0.25 max	0.1 max	0.1 max.	0.05 max	0.2 max.	Remainder	0.05 max.	0.15 max.

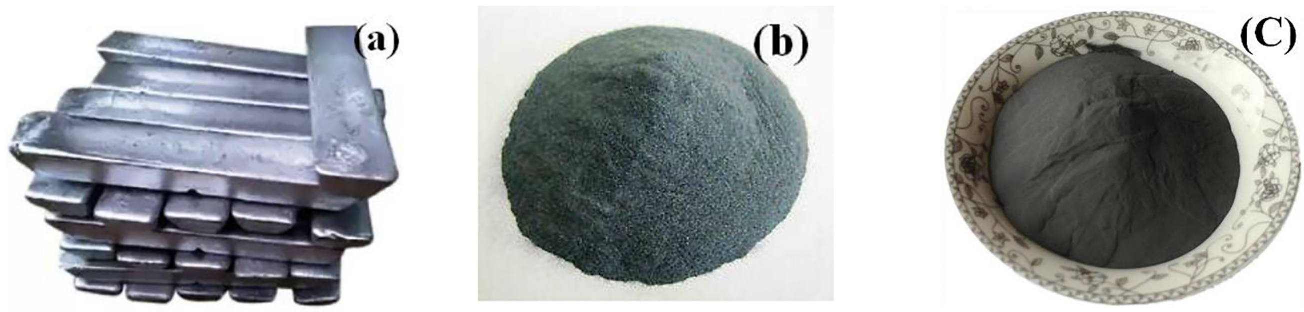

Fig. 1. Hybrid Aluminum matrix composite Materials elements (a) LM 16 alloy ingots, (b) Sic Particles and (c) Nickel-coated Graphite.

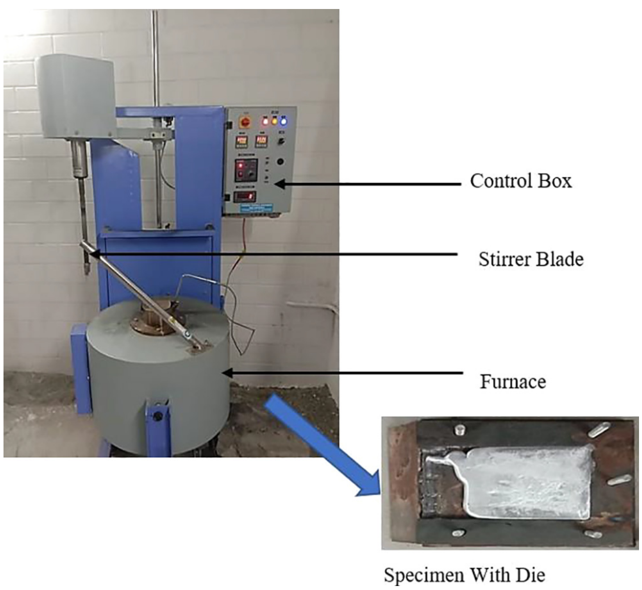

Fig. 2. Stir Casting Configuration for Specimen Preparation.

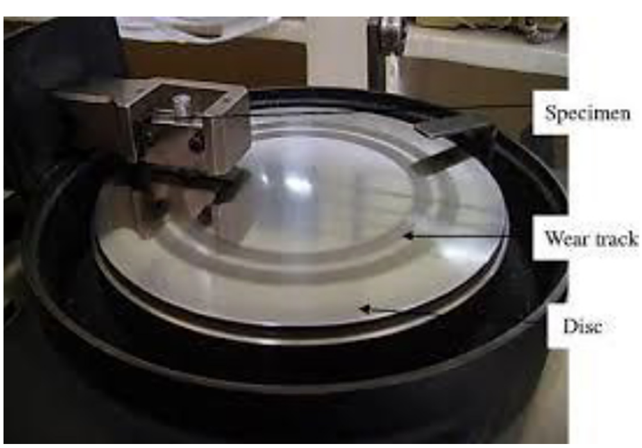

Fig. 3. Pin on Disk Apparatus with samples.

of Ni.-Gr and dissemination of reinforcing particles in LM16 alloy with Silicon Carbide (SiC) suggests their homogeneous dissemination (Fig. 4c) in the matrix composite.

4.2. Mechanical characteristics

The density and hardness of unreinforced LM16 alloy and various hybrid composite materials formulated by differing weight proportion of Ni.-Gr and SiC. were demonstrated in Table 4. A better hardness value of improved Silicon Carbide (SiC) with reinforcement applied because of an enhancement in the hardness of the HAMCs. The composite strength is observed to rise when the reinforcing ratio rises, the composite strengthened with 10% SiC has the desired hardness quality among all HAMCs established.

4.3. Sound impacts of control factors (Wear loss)

Sound impacts of control factors exhibit the COF and loss of wear which is estimated for the different mixtures of control factors. The response variables have been converted as per the Taguchi rule to the Signal/Noise ratio concentrated on three principles: "nominal the best", "greater the better," and "lesser the better". The value of the Signal/Noise ratio is deemed as "lesser the better", as the unbiassed is to decrease COF and loss of wear. Major effect plots were established (Fig. 5 & Fig. 6).

The impact of each factor around response variables was set up with the computed SN ratio. Wear loss in the HAMCs diminishes, with a wt.% rise in hybrid reinforcement, because better resistance to wear is frequently observed to stronger materials with enhanced microstructure than weaker substances. Furthermore, the extent of soft matrix (pin) severities in the relationship with a difficult counter face enhances the strength of wear when the ratio of hybrid reinforcement is reduced [11]. The distribution of Ni.-Gr and SiC reduces hybrid composite wear loss which is a strong adsorbing link that forms in the aluminium matrix. Because of cereal refining and increased strength, and spread of HAMCs and reduced precipitation, the rate of wear is lower in comparison to unreinforced LM16 alloy for HAMCs at all temperatures [12]. The loss of wear increases when the sliding and load range increase and interaction among the counter body and the hybrid composite also rises. Additionally, because of material relaxation alterations in loss of wear is observed when temperature rises [13]. From the major impact plot, LM16 + 10% SiC + 2% Ni.-Gr., 800 m sliding distance, 212°F temperature, and 10 N load are the best possible conditions for the reduced loss of wear.

4.4. ANOVA for wear loss

The experiment results have been assessed by utilizing ANOVA to examine the impacts of the wear factors, particularly: temperature, reinforcing ratio, sliding distance, and load applied. The assessment was carried out at a point of 5% significance and 95% confidence and Table 5 demonstrates the results.

Conclusions contained in the report are reasonable. The alpha factor value is 0.05Pr. which shows the proportion of wear loss level and involvement of the impact of every variable. ANOVA has been described as the most significant component on the level of P. It must be stated that for the load the value of P is approximately zero, therefore it has a better impact on the loss of wear (45.51%) followed by sliding distance, reinforcing rate, and

Table 2
Various Empirical factors together with their levels.

Level of the factor for investigational test				
Factor	Unit	Level		
		1	2	3
Sliding distance	m	0.5	0.15	0.25
Weight %	wt.	1.5	2.5	3.5
Temperature	0C	303	303	303
Load	N	150	250	350

Table 3
L9 Orthogonal array for experimentations.

Investigational No.	Sliding distance (m)	Wt. % of reinforcement	Temperature (0c)	Applied load (N)
1	0.5	1.5	303	150
2	0.5	2.5	303	250
3	0.5	3.5	303	350
4	0.15	1.5	303	150
5	0.15	2.5	303	250
6	0.15	3.5	303	350
7	0.25	1.5	303	150
8	0.25	2.5	303	250
9	0.25	3.5	303	350

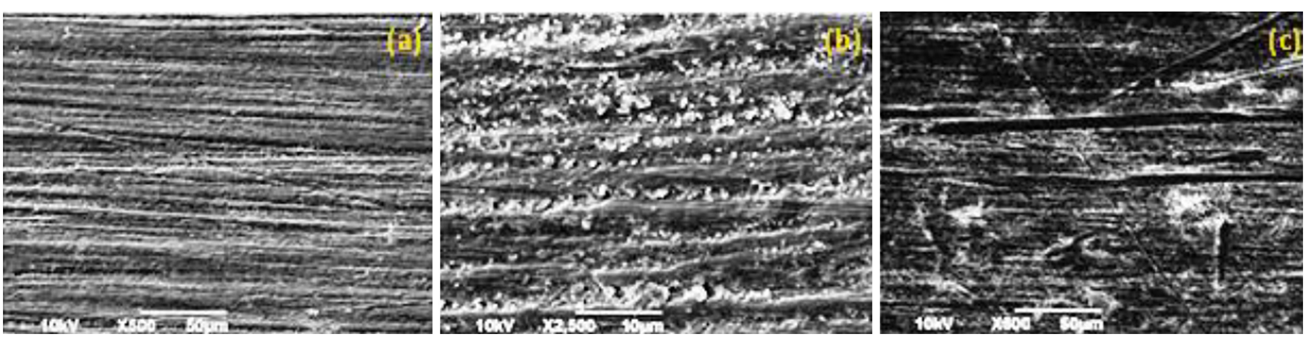

Fig. 4. Sample SEM images of (a) of LM16 alloy, (b) LM16 + 10% SiC + 2%Ni-Gr and (c) Enlarged view of LM16 + 10% SiC + 2%Ni-Gr.

Table 4
Mechanical characteristics of the specimens.

Specimen No.	Wt.% of Hybrid Reinforcement	Hardness (BHN)	Density (g/cm3)
1	Pure	80	2.70
2	5%SiC + 2%Ni.Gr.	78	2.87
3	10%SiC + 2%Ni.Gr.	85	2.91

temperature impacting 0.29%, 17.94%, and 29.79%. The factor nearest to the horizontal field has a less important impact and the factors away from the parallel row in the signal to noise ratio chart have the most important impact on the response variables. The major impact plot demonstrates that the temperature and load applied to remain away from the parallel row and is therefore the most considerable factor of wear loss. The S / N response table has been established by using MINITAB 18 software. A load factor with the maximum delta value is the most significant factor of wear loss as presented in Table 6. The evaluation of each variable has been calculated based on the delta value, which is the difference between the S/N ratio minimum and maximum value.

4.5. Impact of control factors on COF

The COF of the LM16 alloy rises with an increase in the temperature and load because of the solid shifting of pin material to the counter side [15]. Fig. 7 & Fig. 8 shows the impact of control factors on COF. Additionally, COF values rise at elevated loads, the same as the roughness with fortifying blows was established [14]. COF declines with an increase in wt% of hybrid reinforcement. The hybrid reinforcing rate has been postponed by the counter disc interaction and the intensity of the composite pin, as hard abrasive reinforcing particles appear on the surface of the composite. The structure of the coating and heat stability among the boundary surfaces of hybrid composite materials are distinctly revealed. Consequently, a smaller amount of energy is necessary to come off severities whereas sliding for HAMCs as in comparison with the unreinforced LM16 alloy [13,14].

4.6. ANOVA for COF

The ANOVA method is utilized to analyze an experimental result to test the effect of the different factors on COF: temperature, reinforcing ratio, sliding distance, and load applied. ANOVA was designated to find the most essential component by P-value; the P-value of the strengthening ratio is nearly zero. Consequently, it possesses a better impact on COF of 59.12%, temperature, and the load of 2.27% and 10.06% with a sliding distance of 16.70%. The S / N table has been determined by using MINITAB 18; the assessment of each component was concentrated based on the delta value and which is the difference between the high and low S/N ratio values.

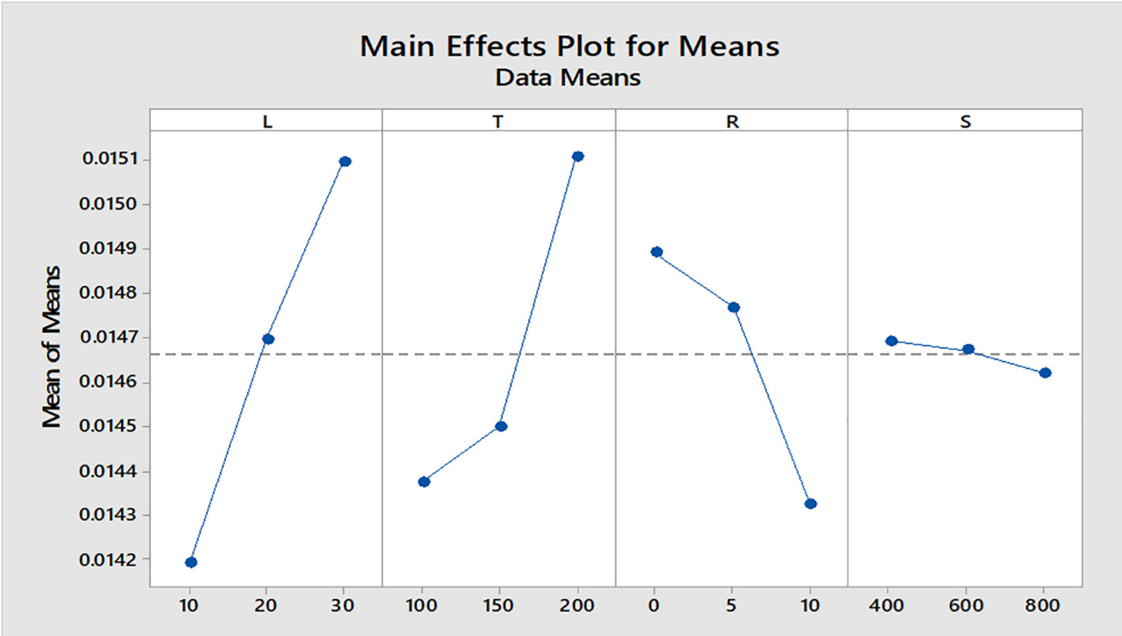

Fig. 5. Wear loss major impacts plot for means.

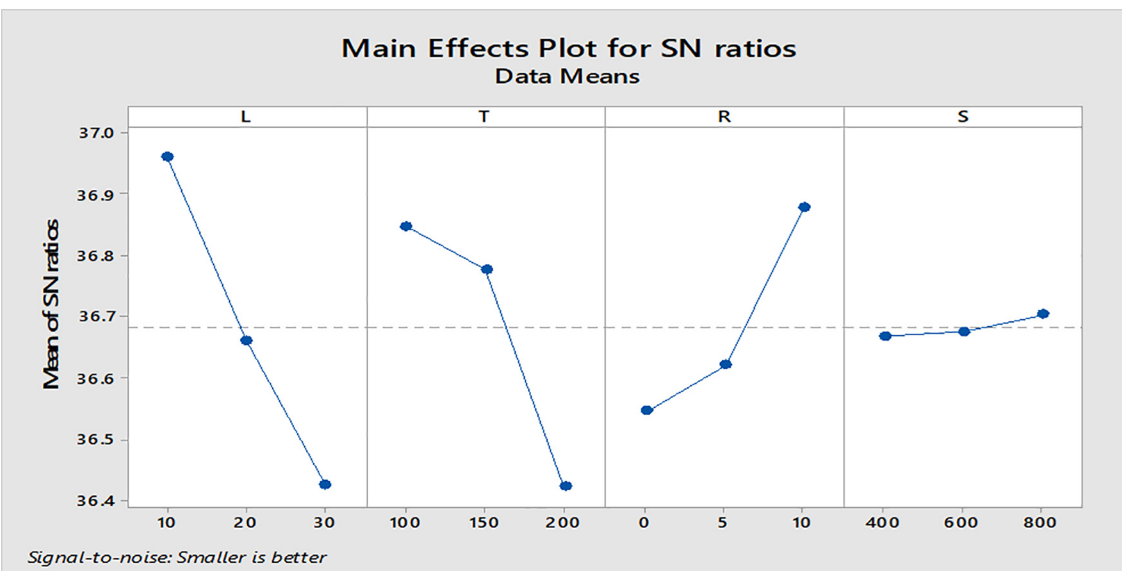

Fig. 6. S/N ratio major impacts plot (wear loss).

Table 5
ANOVA Results (wear loss).

Source	DOF	Adj. MS	Adj. SS	F Value	P-Value	Contribution (%)
Error	4	0.210	0.232	0.12	0.343	6.47
Sliding Distance	1	0.219	0.221	0.18	0.695	0.29
% Reinforcement	1	21.9	22.1	11.09	0.029	17.94
Temperature	1	302	302	18.41	0.013	29.79
Load	1	1.2	1.2	28.13	0.006	45.51
Regression	4	0.3	0.4	14.45	0.017	96.53
Total	8					100

Table 6
S/N ratio response (wear loss).

Level	Sliding Distance	Reinforcement %	Temp.	Load
I	0.5	56	303	150
II	1.5	67	303	250
III	2.5	98	303	350
Delta	0.75	76	303	250
Rank	II			

Fig. 7. COF major impacts plot for means.

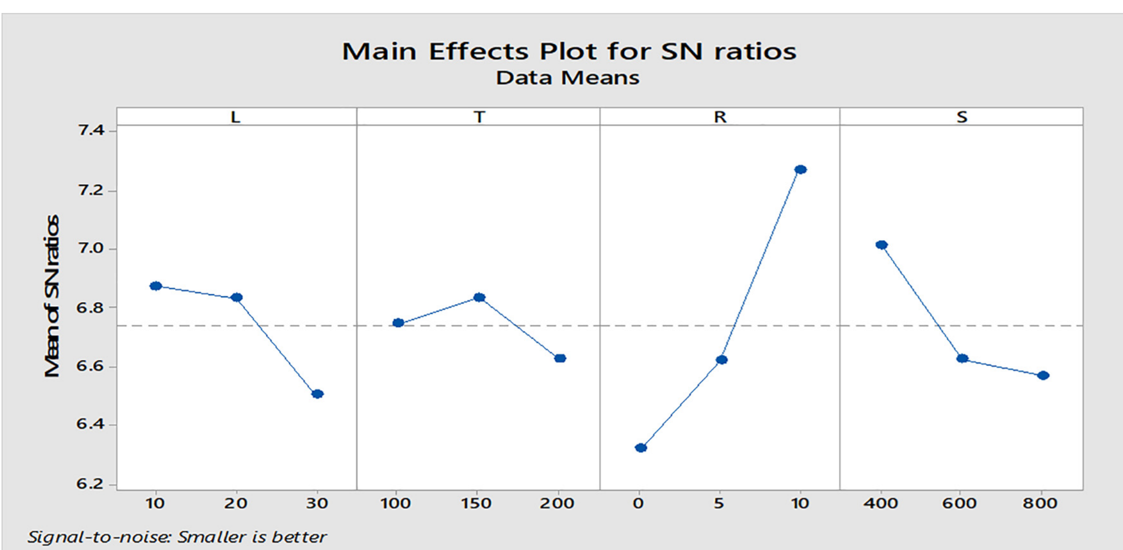

Fig. 8. S/N ratio the primary impacts plot (COF).

Fig. 6 and Fig. 7 are showing COF of the S/N ratio of reinforcing factors and which has the maximum delta value.

5. Conclusion

In this study, the stir casting method has been utilized to prepare the LM16 / SiC / Ni.-Gr. Hybrid Aluminum matrix composite (HAMC) by the reinforcing blends of 0, 5, and 10 wt%, of SiC with 2% wt. of Ni.-Gr. (fixed) various compositions of the material were prepared. In the Hybrid Aluminum matrix composite, the combination of 10 wt%, of SiC with 2% wt. of Ni.-Gr. is superior in the Hardness value (85) and Density (291). The Pin on disc apparatus has been utilized to find the wear performance of the HAMC's the sliding distances of 0.5 m, 0.15 m, and 0.25, in the temperatures of 200 °C, 150 °C, and 100 °C, and three separate loads of 10 N, 20 N, and 30 N were considered for the testing with 1.57 m/s constant sliding velocity is used for all the test trials. Micro-structural results suggest that resistance to wear of HAMCs is enhanced at elevated and room temperature by adding Ni-Gr and SiC. The following are outcomes of the research;

- The ANOVA indicates that the applied load (45.51%) is the most powerful component tracked by the reinforcement ratio (17.94%) at the temperature in 29.79% for the wear loss.
- In the Taguchi method is precise in determining COF and loss of wear with the minimum error, which discovers that the reinforcement ratio (59.12%) is the most prominent factor for the tracked load (10.06%) and sliding distance (16.70%) for COF of the LM16/Ni-Gr/SiC HAMCs.
- The S/N ratio analysis suggests that optimum operational condition; of 400 m sliding distance, 10% hybrid reinforcement at the temperature of 212○F with the 10 N load.
- The HAMCs alloys have a lesser frictional coefficient than the parent alloy (LM16), The results show that the reinforcement of Ni.-Gr. and SiC is strengthening the HAMC in the wear resistance characteristics and withstand the elevated temperature, which could be utilized for the high-temperature applications..

Authorship statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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