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Wear Behaviour of Aluminium Metal Matrix Composite (AlMMC) for Brake Rotor Application

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Abstract- *Dry sliding tribological characterization of Al6063/Carbon fiber/boron nitride hybrid metal matrix composite (AlMMC) was investigated as per ASTM G99-05 using pin on disc experimental setup. At first, half breed composites were created through mix projecting procedure by shifting the wt%, and afterward the wear tests were completed dependent on Response Surface Methodology (RSM). Reaction surface approach has been utilized to design and break down the examination. The exploratory outcomes uncovered AlMMC demonstrated limit of 53% improved wear opposition thanAl6063. For all the composites, the coefficient of grating (CoF) increments and immerses with the applied burden and sliding separation, where 11 wt % AlMMC demonstrated limit of 40% expanded CoF than Al6063. Metallographic examination of destroyed AlMMC composite indicated that at most extreme applied burden, sliding rate, and sliding time, the wear instrument changes from grating to cement, yet including of fortified molecule demonstrated joined cement and rough wear components. The advanced tribological boundaries were gotten utilizing dim social examination which uncovered that AlMMC has improved tribological properties.*

Keywords: AL6063, BN, CF, Minitab, Stir casting, Pin-on-disc, GRG.

1. INTRODUCTION

Hybrid materials and composites form the key to successful development of next-generation aerospace propulsion and power systems. Metal-matrix composites play a significant role in the development of future aerospace components. These materials are not only resistant to high temperatures, but also provide significant improvements in weight specific mechanical and thermal properties. Aluminium is the most appealing non-ferrous grid material broadly utilized especially in the aeronautic trade where weight of basic segments is critical. The low thickness and high explicit mechanical properties of aluminum metal network composites (MMC) make these mixes one of the most charming material choices for the creation of lightweight parts for certain sorts of vehicles with wear obstruction and quality equivalent to project iron, 67% lower thickness and multiple times the warm conductivity, aluminum MMC amalgams are perfect materials for the assembling of lightweight car and other business parts. Most of exertion in aluminum framework composites has been coordinated toward improvement of elite composites, with exceptionally high qualities and module, for use in particular aviation applications. Be that as it may, there are various different applications in airplane motors and aviation structures where these extremely high properties may not be required, and where it could be monetarily sharp to use other metal framework composites. For instance cost, weight, and stiffness critical components, for example, motor static structures, don't require the high directional properties accessible with composites reinforced with adjusted consistent fibers. Therefore, efforts were started to survey the capability of applying minimal effort aluminium matrix composites to these structures, utilizing low cost reinforcement and low cost composite manufacture processes, including powder metallurgy, casting, and hot molding procedures. Cryogenically prepared car segments like brake rotors, gears, cylinder, associating poles, motors and machine parts, instruments and firearm barrels show huge expansion in the presentation and gainful life. The composite is fitting to the improvement of yachts, cruisers and bike outlines, brakes, angling reels, electrical fittings, couplings and valves. From the literature survey **[2]Anandha Moorthy A** and etc he is explained to Tribological Behaviour of Aluminium based MMC Subjected to Various Temperature and fabricated on MMC and calculate wear results and using optimization technique.**[5]Dr.S.V.S.NarayanMurty** and others are shows to fabricating on AL7075-CF reinforcement material and calculate the material chemical composition and wear tests, SEM test and X-ray diffraction on various heat treatment processes. The CF powder adding on above 3% that results is to reduce the hardness of materials. So CF content is using only below 3%. **[6]Megalingam A Kumar A** says that paper to fabricate on ALMMC and improve the hardness on ALMMC. Then to compare the raw material of AL6061 by using grey relation analysis and improve the wear resistance. **[7]Megalingam A Kumar A** explained (Effect of sliding distance on dry sliding tribological behaviour of Aluminium Hybrid Metal Matrix Composite (AlHMMC)) improve the wear resistance and show the results of SEM , X-ray diffraction and grey relation analysis. **[8]A.Lotfy A.Daoud** and etc to prepare the ALMMC and analysis the micro structure, thermal and mechanical properties. Hardness property is improved on ALMMC.

[10]Megalingam A Kumar A and etc to fabricate on AL6063/ Alumina/ Graphite/ Redmud are various weight %. Then calculate on wear and CoF on Taguchi L27 method and they improve on 90% of wear and 48% of CoF by using and improve the Redmud content. **[12] C. Velmurugan, R. Subramanian** and etc. are explained to calculate the wear and CoF by using various temperatures and improve the wear resistance and calculate the SEM test. Then the result is 8hours improve the life time of ALMMC and alloy material.

2. MATERIALS AND METHODS

1.1 Aluminium 6063

Aluminium, the second most plenteous metallic component on the earth, turned into a financial rival in building applications as of late. The metal grid chose for present investigation is Al 6063. Properties of al6063 are low weight, easily available, high corrosion resistance, heat treatable and semi smooth surface.

1.2 Boron nitride

BN particles are the most commonly used reinforcement materials in the reinforced metal-matrix composite system. Aluminium matrix composites strengthened with BN particulates accommodate a low cost, high-modulus material that can be handled by means of traditional powder metallurgy strategies with expanded augmentations of BN reinforcement, the modulus increments, and losses in strength, ductility, and toughness may happen. Likewise, the job of the interfacial bond between BN particulates and the aluminium grid may additionally take away from the mechanical properties when the composite is exposed to high temperatures. Molecule size and shape are significant factors in deciding materials properties. Fatigue strength is significantly improved with the utilization of fine particles. The BN particles, which were utilized to create the composite, had a normal molecule size of 5-11 microns and density of 2.1 g/cm3. The melting point of the BN is 2973 0C. Boron nitride has excellent thermal and chemical stability and also high hardness. Boron nitride powder determination was thermal conductivity 160-200 W/mK.

1.3 Carbon fiber

Carbon fiber powder is "Light in weight, Strong and Durable!" Carbon Fibers are only a 21st. century high development material. The fibers have low specific gravity, magnificent mechanical properties are high specific tensile strength, high specific elastic modulus, and etc. and attractive performances are heat resistance, electrical conductivity, low thermal expansion, chemical stability, self-lubrication property, high heat conductivity, and so on. Those highlights have been invigorating Carbon Fiber clients to build up various sorts of applications.Carbon fiber particle size is 5–10 microns. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers

Table1: Mechanical properties of Materials

Properties	AL6063	CF	BN
Melting point	600	1200	2973
Density (g/cm3)	2.7	1.7	3.45
Young's modulus(GPa)	70	70	19.5
Tensile strength (GPa)	0.195	230	27
Shear strength (GPa)	0.150	150-260	7.8

1.4 Composite preparation

The proposed AL6063/CF/BN composites required for the analysis are fabricated by stir casting. A group of 94% of aluminum composite was estimated and placed in the graphite cauldron and was liquefied at 600◦C utilizing an electric heater. To acquire homogeneous dissemination of fortification in the soften legitimate blending is required. The liquefy was mixed with the assistance of a mechanical stirrer to frame a fine vortex for 5 to 10 min. The 3% of CF and BN powder was preheated to a temperature of 600◦C with the goal that their surface oxidized; this pre-warmed earthenware powder was included at a consistent feed rate into vortex. Argon gas was provided into the soften during activity to give a latent air. In the wake of mixing the liquid blend, it was filled the shape of measurement 12 mm distance across and estimated mm length. Argon gas was provided until the whole dissolve was filled the preheated lasting mold at 2500C. The produced composite was permitted to set in air and was taken out from the form after cementing.

Table 2: Composition of Al6063 with Reinforcement (weight %)

Materials	Composition(A) in %	Composition(B) in %
Aluminium 6063	100	94
Carbon fiber	0	3
Boron nitride	0	3

Figure 1: Stir casting experimental setup & Stir casting Line diagram

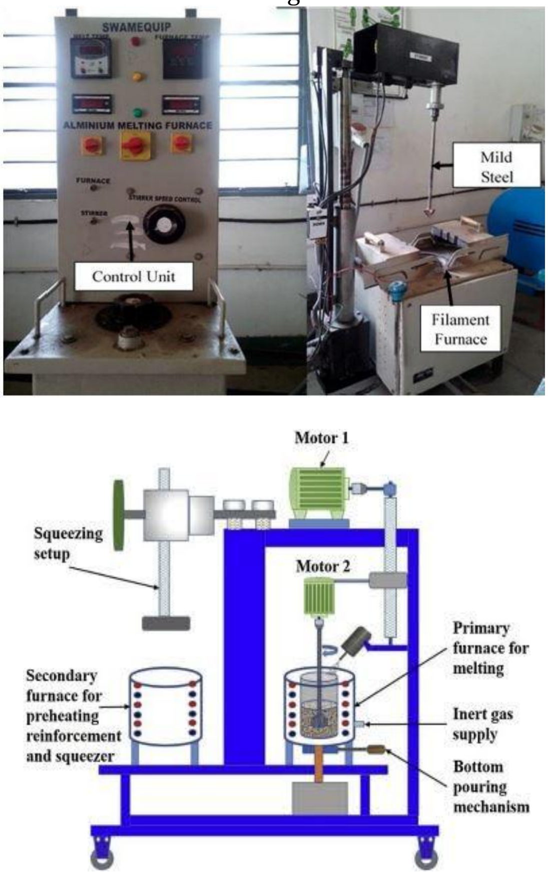
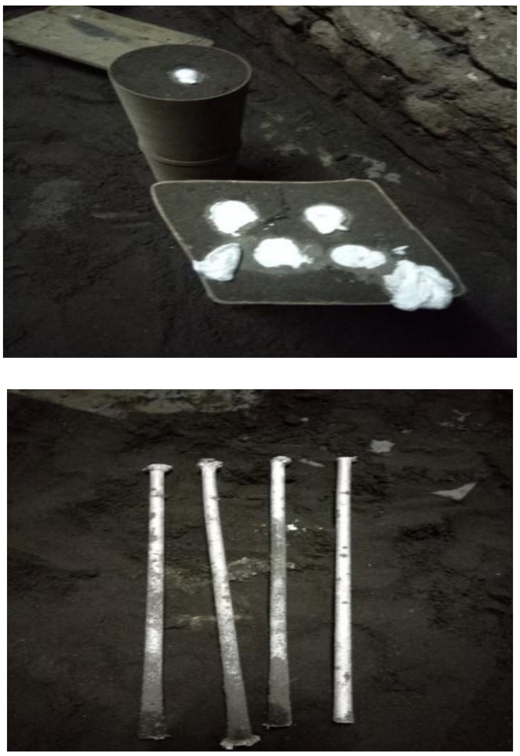


Figure 2: Die pattern & casting product



3. RESULT AND DISCUSSION

3.1 Wear testing

Reaction surface strategy (RSM) is a gathering of scientific techniques, factual surmising and trial systems, which are utilized for numerical displaying and inspecting designing issues, where a ton of factors, sway the reaction of concern [16, 17]. RSM is likewise characterized as a factual technique, which utilizes quantitative information from appropriate explores, to build up and simultaneously resolve multi-variable conditions. The exploratory structure related with RSM is utilized for delineating the assortment of the autonomous info factors, and the observational scientific model assists with researching a legitimate assessing relationship among the yield reactions and the information factors, and assess the impact of free factors on the ideal variable reaction and enhancement procedures for achieving the most ideal estimations of the procedure determinations, which creates the suitable estimation of the reactions. Wear test examples of measurement width 10 mm and length30 mm were readied. The end surfaces of the wear test examples were appropriately cleaned and afterward cleaned with grating paper of evaluation 400, 600 and 800, individually. The wear test has been performed on nail to plate mechanical assembly. The circle of the pin on plate is made of EN31 steel having surface unpleasantness 0.1. The pins and circle were cleaned appropriately with the assistance of CH3)2CO when wear test. The wear was estimated by weight reduction, taking load of the wear sticks when wear test.

Table 3: Input Parameters and their Levels

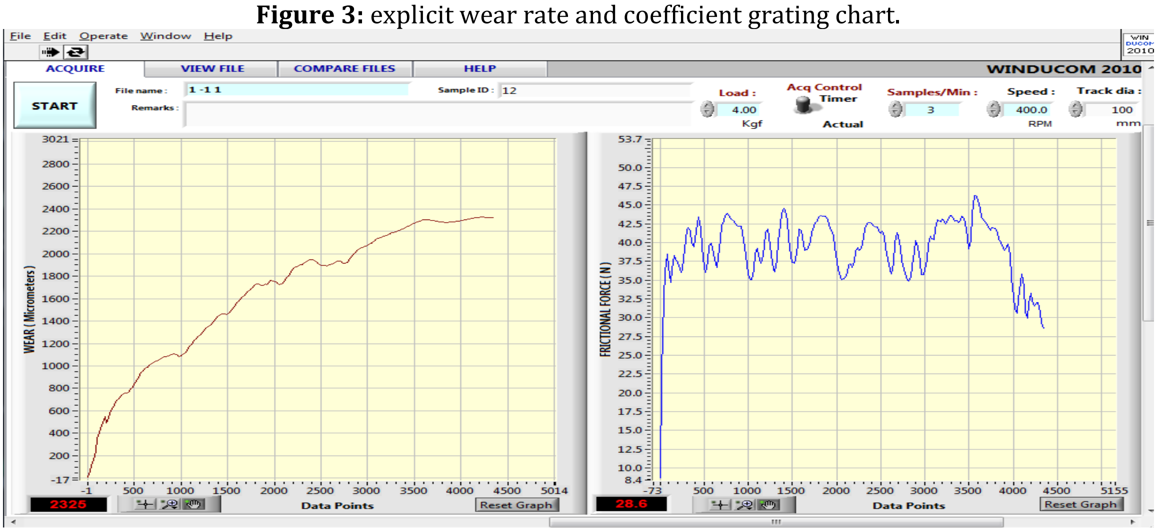
Parameters	Unit	Level		
		I	II	III
Applied Load (L)	Kg	2	3	4
Sliding Speed (S)	Rpm	400	600	800
Sliding Time (T)	Min	3.20	4.25	6.38

Table 4: Results of wear test

Ex .No	Load (L)	Speed (S)	Time (T)	Wear rate for AL6063	Wear rate for ALMMC	COF for AL6063	COF for ALMMC
1	20	400	6.38	0.3440	0.1203	0.35	0.24
2	40	400	6.38	0.4590	0.1066	0.45	0.23
3	20	800	6.38	0.5649	0.2359	0.52	0.33
4	40	800	6.38	0.6246	0.2748	0.56	0.34
5	20	400	3.20	0.1745	0.1530	0.33	0.18
6	40	400	3.20	0.2272	0.1306	0.37	0.24
7	20	800	3.20	0.3249	0.1861	0.40	0.26
8	40	800	3.20	0.4463	0.2325	0.52	0.29
9	20	600	4.25	0.3120	0.1296	0.48	0.23
10	40	600	4.25	0.3267	0.1766	0.49	0.20
11	30	400	4.25	0.2358	0.1508	0.38	0.20
12	30	600	4.25	0.2786	0.1510	0.42	0.18
13	30	600	6.38	0.3530	0.1493	0.49	0.39
14	30	600	3.20	0.2482	0.1268	0.39	0.24
15	30	600	4.25	0.2623	0.1363	0.36	0.24
16	30	600	4.25	0.2891	0.1343	0.37	0.26
17	30	600	4.25	0.3015	0.1389	0.33	0.21
18	30	600	4.25	0.3280	0.1370	0.35	0.20
19	30	600	4.25	0.3463	0.1343	0.39	0.23
20	30	600	4.25	0.3049	0.1308	0.38	0.25

It is evident from that, among these parameters, Load is a dominant factor on the specific wear rate and speed for coefficient of friction. The influences of controlled factors on specific wear rate and coefficient friction are graphically represented in the following figure

Figure 3: explicit wear rate and coefficient grating chart.



Over the diagrams clarified Specific wear rate and coefficient of contact regarding applied burden, sliding rate, sliding time and sliding separation.

3.2 Optimization results

The test results and determined qualities were gotten dependent on the arrangement of investigation and afterward the outcomes were dissected with the assistance of MINITAB 16 programming.

3.2.1 Specific wear rate-composition (A)

The specific wear rate in mm3/N-m is calculated as per Archard wear equation as given in equation WS = V/(W*L) Where V is the wear volume in mm^3, W is the applied load in N and L is the sliding distance in m. The following equation represents the regression equation corresponding to quadratic model for specific wear.

Wear (A) = 0.269- 0.0165 L- 0.001146 S+ 0.131 T+

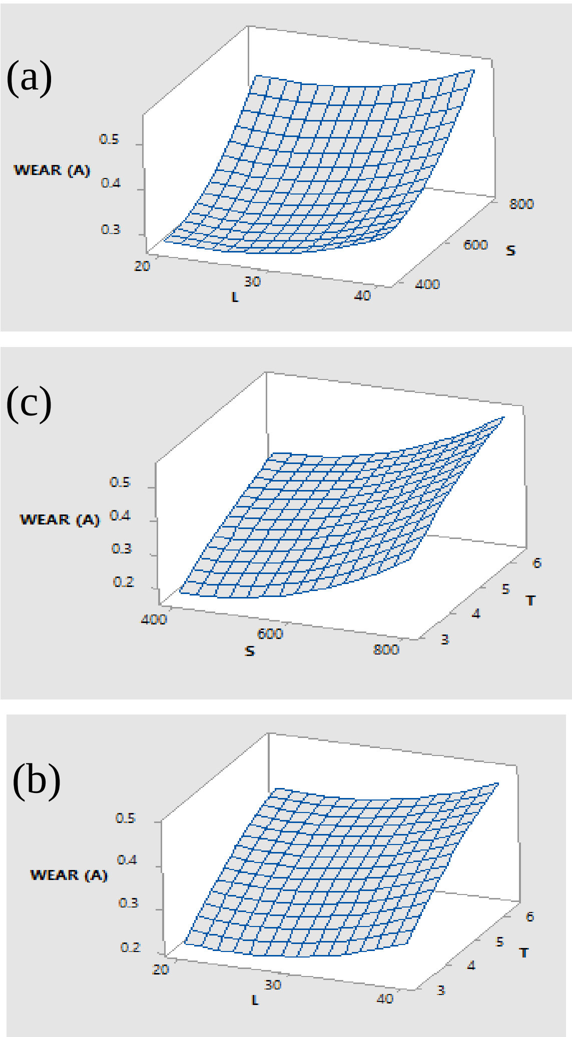
0.000315 L*L+ 0.000001 S*S-0.0084 T*T+0.000001 L*S+ 0.000156L*T+ 0.000004 S*T **(1)**

From the ANOVA table 5, it is evident that the interaction effect of time (T) has the most significant influence on the wear resistance and with quadratic term of speed (S) contributing 43.97and 35.29% respectively. The linear term of load (L), interaction square of load, speed and time has the further reasonable influence on specific wear contributing 5.67, 6.95, 1.82 and 0.35% respectively. The 2-way interaction of load-speed (L*S) load-time (L*T) and speed-time (S*T) have the least significance on specific wear. The model presents high determination coefficient of R^2=94.09% and adjusted R^2=88.77% value is higher than the predicted R^2.

Table 5: Anova table for Wear test Composition (A)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.219219	94.09%	0.219219	0.024358	17.69	0.000
Linear	3	0.197880	84.93%	0.176919	0.058973	42.82	0.000
Square	3	0.021251	9.12%	0.021224	0.007075	5.14	0.021
2-Way Interaction	3	0.000088	0.04%	0.000088	0.000029	0.02	0.995
Error	10	0.013772	5.91%	0.013772	0.001377		
Lack-of-Fit	4	0.008836	3.79%	0.008836	0.002209	2.69	0.135
Pure Error	6	0.004936	2.12%	0.004936	0.000823		
Total	19	0.232991	100.00%				
S = 0.03711016 , R-sq=94.09% , R-sq(adj)=88.77% , R-sq(pred) =44.90% , Press= 0.128388							

Fig 4: 3D surface plot for Wear (A) versus (a) Load - Speed (b) Time - Load (c) Time – Speed for Wear (A)



From the 3D surface plots shown in figures 4 it is observed that the time is most significant parameter influencing the specific wear rate followed by load and speed. From in at low time surface would have low wear rate further increase of time from 3.20 to 6.38min tends to increase of wear rate. Thus, for more investigation, the effect of time on wear resistance was also studied. By increasing the time, the wear rate value of the composite material increases, it revealing their better wear resistance at lower time. The wear rate was gradually decreases with increase of time from 3.20 to 6.38min due to composite materials weight percentage increase after that increase of wear rate from increase time from 3.20 to 6.38min due to composite materials weight percentage decrease. In this study the reasonable wear rate was achieved at time 3.20min this result in more deposition of composite materials this leads to high wear resistance.

3.2.2 Co-efficient of friction-composition (A)

The regression equation for the co-efficient of friction is given by the equation

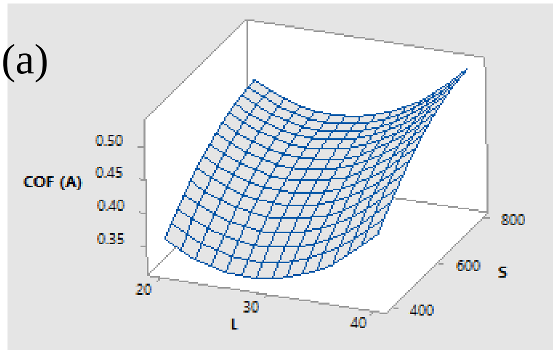
CoF (A) = 0.547- 0.0350 L+ 0.00081S- 0.018 T+ 0.000624 L*L- 0.000001 S*S+ 0.0023 T*T+ 0.000001 L*S- 0.00002 L*T+0.000032 S*T **(2)**

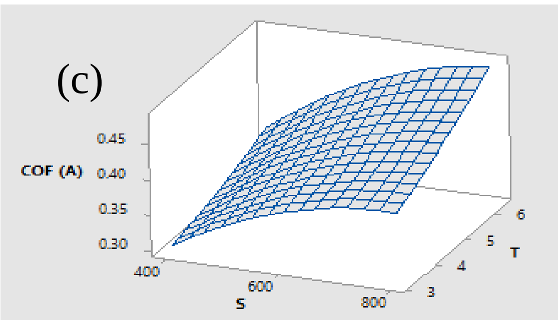
Table 6: Anova table for CoF composition (A)

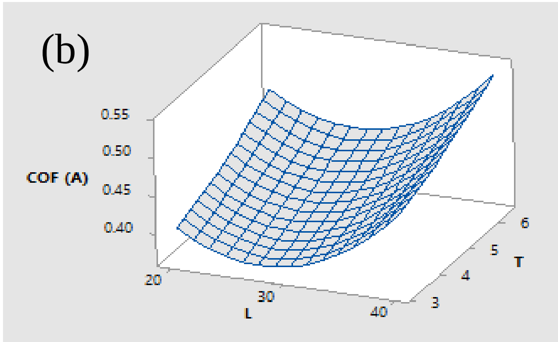
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.071874	76.74%	0.071874	0.007986	3.67	0.028
Linear	3	0.058680	62.66%	0.047237	0.015746	7.23	0.007
Square	3	0.012297	13.13%	0.012556	0.004185	1.92	0.190
2-Way Interaction	3	0.000898	0.96%	0.000898	0.000299	0.14	0.935
Error	10	0.021781	23.26%	0.021781	0.002178		
Lack-of-Fit	4	0.016695	17.83%	0.016695	0.004174	4.92	0.042
Pure Error	6	0.005086	5.43%	0.005086	0.000848		
Total	19	0.093655	100.00%				
S= 0.0466702 , R-sq = 76.74% , R-sq(adj) =55.81% , R-sq(pred)= 0.00% , Press =0.186342							

It is evident from the ANOVA table 6 of co-efficient of friction (CoF) that the linear term of speed (S), quadratic term of load (L^2) and linear term of time (T) have significant influence on co-efficient of friction contributing 34.34, 18.06 and 12.06% respectively. The linear terms of load (L), quadratic term of speed (S^2) and 2-way interaction effect of speed-time (S*T), has reasonable influence on the co-efficient of friction contributing 10.26, 1.03 and 0.90% respectively. The quadratic term of time (T^2), 2-way interaction effect of load-speed (L*S) and 2-way interaction effect of load-time (L*T) has the least contribution, indicating their insignificance on CoF. The model presents high determination coefficient value, R^2=76.74%, indicating good model and its significance. It shows that there exists high correlation between the experimental and the predicted values. Also, the adjusted R^2value is 55.81%.

Fig 5: 3D surface plot for Wear (A) versus (a) Load - Speed (b) Time - Load (c) Time – Speed for CoF (A)







The 3D surface plots as shown in figures 5, it is observed That average friction co-efficient was less in low speed, load and time after that increases with increase of speed, load and time. The average friction co-efficient increases with increasing of speed load and time due to composite particle content. In this study the reasonable CoF was achieved at speed 400rpm this result in more deposition of composite materials this leads to high Coefficient of friction.

3.2.3 Specific wear rate-composition (B)

The specific wear rate in mm3/N-m is calculated as per Archard wear equation as given in equation WS = V/(W*L) Where V is the wear volume in mm^3, W is the applied load in N and L is the sliding distance in m. The following equation represents the regression equation corresponding to quadratic model for specific wear.

$$\text{WEAR (B)} = 0.5798 - 0.00716\,L - 0.001543\,S + 0.0148\,T + 0.000064\,L*L + 0.000001\,S*S - 0.00473\,T*T + 0.000008\,L*S - 0.000063\,L*T + 0.000060\,S*T \quad \textbf{(3)}$$

From the ANOVA table 7, it is evident that the interaction effect of speed (S) has the most significant influence on the wear resistance and with quadratic term of (L, S, T) contributing 22.78% respectively. The linear term of (L, S, T), reasonable influence on specific wear contributing 60.70% respectively. The 2-way interaction of load-speed (L*S) load-time (L*T) and time (T*T) have the least significance on specific wear. The model presents high determination coefficient of R^2=96.65% and adjusted R^2=93.64% value is close to the predicted R^2.

From the 3D surface plots shown in figures 6 it is observed that the speed is most significant parameter influencing the specific wear rate followed by load and time. From in at low speed surface would have low wear rate further increase of speed from 400-800rpm tends to increase of wear rate.

Table 7: Anova table for Wear test composition (B)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.035086	96.65%	0.035086	0.003898	32.07	0.000
Linear	3	0.022034	60.70%	0.022922	0.007641	62.85	0.000
Square	3	0.008270	22.78%	0.007938	0.002646	21.76	0.000
2-Way Interaction	3	0.004782	13.17%	0.004782	0.001594	13.11	0.001
Error	10	0.001216	3.35%	0.001216	0.000122		
Lack-of-Fit	4	0.000964	2.66%	0.000964	0.000241	5.76	0.030
Pure Error	6	0.000251	0.69%	0.000251	0.000042		
Total	19	0.036302	100.00%				
S=0.0110258 , R-sq =96.65%, R-sq(adj)= 93.64%, R-sq(pred)= 75.33%, Press=0.0089562							

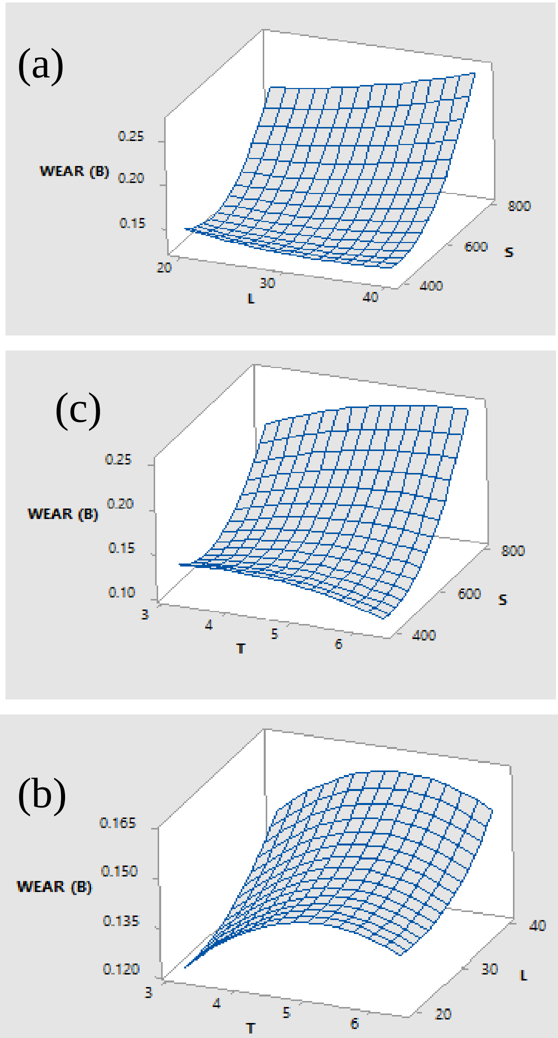


Fig 6: 3D surface plot for Wear (A) versus (a) Load - Speed (b) Time - Load (c) Time – Speed for Wear (B)

The results discussed above represent that plating parameters significantly influence the particles content and the hardness of the reinforced materials. Thus, for more investigation, the effect of speed on wear resistance was also studied. By increasing the duty speed, the wear rate value of the composite material increases, it revealing their better wear resistance at lower speed. The wear rate was gradually decreases with increase of speed from 400-600rpm due to composite materials weight percentage increase after that increase of wear rate from increase speed from 400-600 rpm due to composite materials weight percentage decrease. In this study the reasonable wear rate was achieved at speed 400rpm this result in more deposition of composite materials this leads to high wear resistance.

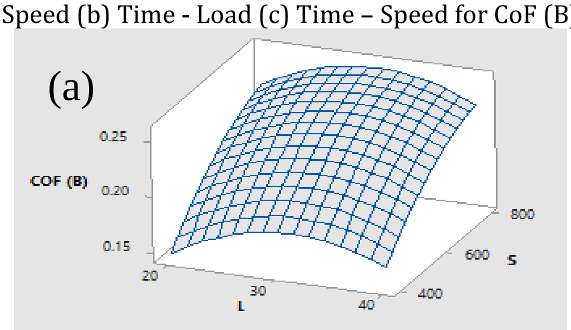
3.2.4 Co-efficient of friction-composition (B)

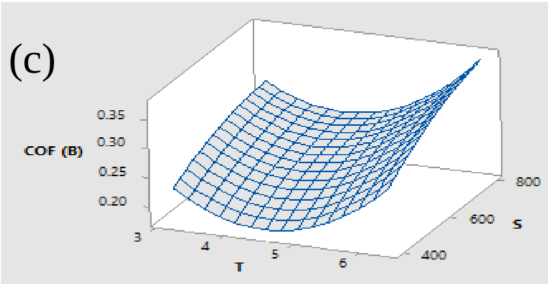
The regression equation for the co-efficient of friction is given by the equation

COF (B) = 0.305 + 0.0186 L + 0.000492 S - 0.256 T - 0.000248 L*L – 0.000000 S*S +0.0288 T*T- 0.000001 L*S- 0.000582 L*T + 0.000030 S*T **(4)**

It is evident from the ANOVA table 8 of co-efficient of friction (CoF) it is evident that the interaction effect of speed (S) has the most significant influence on the CoF and with quadratic term of (L, S, T) contributing 18.90% respectively. The linear term of (L, S, T), reasonable influence on CoF contributing 56.42% respectively.The 2-way interaction of load-speed (L*S) load-time (L*T) and time (T*T) have the least significance on specific wear.

Fig 7: 3D surface plot for Wear (A) versus (a) Load - Speed (b) Time - Load (c) Time – Speed for CoF (B)





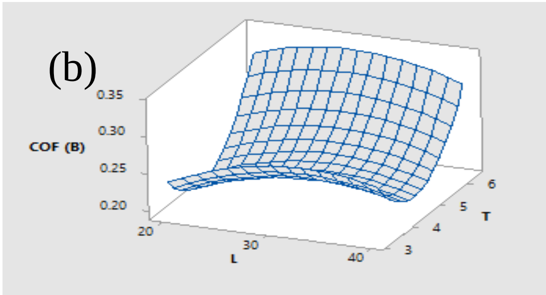


Table 8: Anova table for CoF composition (B)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.043795	77.90%	0.043795	0.004866	3.92	0.022
Linear	3	0.031718	56.42%	0.023115	0.007705	6.20	0.012
Square	3	0.010624	18.90%	0.010765	0.003588	2.89	0.089
2-Way Interaction	3	0.001452	2.58%	0.001452	0.000484	0.39	0.763
Error	10	0.012425	22.10%	0.012425	0.001242		
Lack-of-Fit	4	0.007453	13.26%	0.007453	0.001863	2.25	0.179
Pure Error	6	0.004971	8.84%	0.004971	0.000829		
Total	19	0.056220	100.00%				
S= 0.0352488, R-sq =77.90%, R-sq(adj) = 58.01%, R-sq(pred) = 0.00%, Press = 0.0807599							

The model presents high determination coefficient value, R^2=77.90%, indicating good model and its significance. It shows that there exists high correlation between the experimental and the predicted values. Also, the adjusted R^2value is 58.01%. The 3D surface plots as shown in figures 7, it is observed That average friction co-efficient was less in low speed, load and time after that increases with increase of speed, load and time. The average friction co-efficient increases with increasing of speed load and time due to composite particle content. In this study the reasonable CoF was achieved at speed 400rpm this result in more deposition of composite materials this leads to high Coefficient of friction.

3.3 Multi objective optimization by grey relation grade

The AL6063 composite material Wear rate & Co-efficient of friction was investigated on multi objective optimization. That is to minimize the Ws & COF. The input parameters are Load (L), Speed(S), and Time (T). Grey relation grade is used the multi objective problem is converted to single objective problem. The RSM is used to measure the influence of process parameters on experimental result of single response. In this problem two responses considered are Ws and COF. Using GRG different units of measurement responses converted into single objective problem. For the data processing from the table 4, the minimum and maximum values of each response are considered. Wear and co-efficient of friction is dominant characteristics for which 'larger-the-better' characteristic relation is used. This can be normalized by equation (5),

$$Y^*_{i\,(k)} = \frac{\max Yi(k) - Yi(k)}{\max Yi(k) - \min Yi(k)} \quad \textbf{(5)}$$

After the data processing using above equation, the sequences are given in the tables.

Now, the deviation sequence $\delta_{0i\ (k)}$ is for the corresponding reference sequence $Y^*_{0(k)}$ and the comparability sequence $Y^*_{i\,(k)}$, is found by, equation (5),

$$\delta 0i\ (k) = |Y^*0(k) - Y^*i\ (k)\ | \quad \textbf{(6)}$$

The results of all δ_{0i} for i=1–20 are listed in below tables.

$\delta_{max\ (k)}$ and $\delta_{min\ (k)}$ are obtained as follows, equation (7),

$$\eta\ i\ (k) = \frac{\delta min + \lambda * \delta max}{\delta 0i(k) + \lambda * \delta max} \quad \textbf{(7)}$$

Where, δ_{min} and δ_{max} is the deviation sequence of minimum and maximum value $\delta_{0i\ (k)}$. The limit of identification coefficient λ is 0 $\underline{<}$ λ $\underline{>}$ 1. The λ value is assumed 0.5.Final GRG value is calculated on below equation (8),

$$\gamma i = \frac{1}{N} \sum_{N=0}^{N} \eta i(k) \quad \textbf{(8)}$$

3.3.1 GRG on Composition A

Table 9: The Grey relational coefficients and Grey relation grade for Composition (A)

Ex. No	Wear $Y^*_{i(k)}$	COF $Y^*_{i(k)}$	Wear δ_{0i}	COF δ_{0i}	Wear $\eta_{i(k)}$	COF $\eta_{i(k)}$	WGRG γ_i	Rank
1	0.6234170	0.91	0.376582	0.086956	0.570396	0.851851	0.711124	7
2	0.367918	0.48	0.632081	0.52173	0.441664	0.489361	0.465512	17
3	0.1326371	0.17	0.867362	0.82608	0.365667	0.377049	0.371358	19
4	0	0.00	1	1	0.333333	0.333333	0.333333	**20**
5	1	1.00	0	0	1	1	1	**1**
6	0.8829149	0.83	0.117085	0.17391	0.810261	0.741935	0.776098	3
7	0.6658520	0.70	0.334147	0.304347	0.599414	0.621621	0.610517	13
8	0.3961341	0.17	0.603865	0.826086	0.452953	0.377049	0.415001	18
9	0.6945123	0.35	0.305487	0.652173	0.620741	0.433962	0.527352	14
10	0.6618529	0.30	0.338147	0.695652	0.596554	0.418181	0.507367	15
11	0.8638080	0.78	0.136191	0.217391	0.785926	0.696969	0.741448	5
12	0.7687180	0.61	0.231281	0.391304	0.683730	0.560975	0.622353	11
13	0.6034214	0.30	0.396578	0.695652	0.557675	0.418188	0.487928	16
14	0.8362586	0.74	0.163741	0.260869	0.753305	0.657142	0.705224	8
15	0.804932	0.87	0.195067	0.130434	0.719354	0.793103	0.756228	4
16	0.745389	0.83	0.254610	0.173913	0.662593	0.741935	0.702264	9
17	0.717840	1.00	0.282159	0	0.639255	1	0.819627	2
18	0.658964	0.91	0.341035	0.086956	0.594505	0.851851	0.723178	6
19	0.618307	0.74	0.381692	0.260869	0.567090	0.657142	0.612116	12
20	0.710286	0.78	0.289713	0.217391	0.633141	0.696969	0.665055	10

Where the γ_i is highest value of wear and COF and number of experiments in N. The highest value of GRG is 1 for the experiment number 5 from the tables.

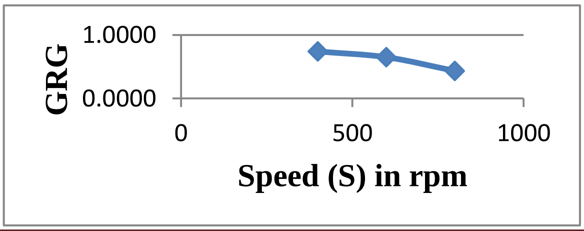
The higher GRG values indicate multiple output responses characteristics for the corresponding input parameters. In the present work, AL6063 composite multiple response result has been converted into optimization of a GRG. Thus, the multi-response optimization problem is reduced to a single objective function. The mean value of the GRG for each level of input parameters, and the total mean value of the GRG is showed in below table.

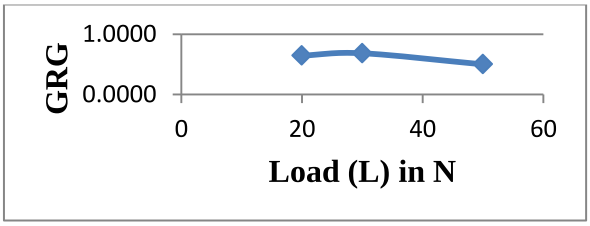
Table 10: Ranking of Composition A input parameters

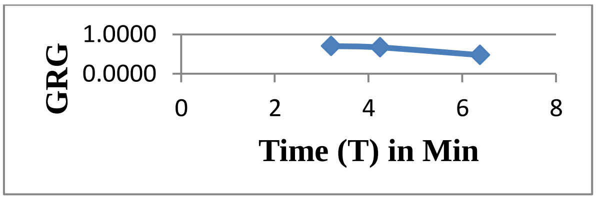
	Levels	Load	Speed	Time
Composition A	-1	0.6441	**0.7388**	**0.7014**
	0	**0.6835**	0.6481	0.6677
	1	0.4995	0.4326	0.4739
	Mean	0.6090	0.6065	0.6143
	Ranking	**2**	**1**	**3**

From the larger value of the GRG are the optimal value and its selected. In addition to this, the total mean of GRG for all the experiments is calculated to find influence of input parameters which are denoted by rank.

Figure8. Mean effective Plot of GRG in Composition A







Figures 8 graphically represent the grey relational grades (GRGs) for Composition A in mean effect plot. From the GRGs and figures 8, the input parameters are found to be L (0)-S (-1)-T (-1), i.e. Load: 30 N, Speed 400rpm, and Time: 3.20 Min.

Table 11: Result of confirmation test

Ex. No	Optimum value of ALMMC		
	Initial	**Experimental**	**Error %**
Wear	0.2482	0.24	3.303787
COF	0.39	0.40	-2.5641

3.3.2 GRG on Composition B

Table 12: The Grey relational coefficients and Grey relation grade for Composition (B)

Ex. No	Wear $Y^*_{i(k)}$	COF $Y^*_{i(k)}$	Wear δ_{0i}	COF δ_{0i}	Wear $\eta_{i(k)}$	COF $\eta_{i(k)}$	WGRG γ_i	Rank
1	0.91854	0.71	0.08145	0.28571	0.85991	0.63636	0.748140	6
2	1	0.76	0	0.23809	1	0.67741935	0.838709	**1**
3	0.23127	0.29	0.76872	0.71428	0.39409	0.41176470	0.402930	19
4	0	0.24	1	0.76190	0.33333	0.39622641	0.364779	**20**
5	0.72413	1.00	0.27586	0.00000	0.64444	1	0.822222	3
6	0.85731	0.71	0.14268	0.28571	0.77798	0.63636363	0.707173	11
7	0.52734	0.62	0.47265	0.38095	0.51405	0.56756756	0.540813	16
8	0.25148	0.48	0.74851	0.52380	0.40047	0.48837209	0.44442	18
9	0.86325	0.76	0.13674	0.23809	0.78524	0.67741935	0.73133	8
10	0.58382	0.90	0.41617	0.09523	0.54574	0.84	0.69287	12
11	0.73721	0.90	0.26278	0.09523	0.65549	0.84	0.74774	7
12	0.73602	1.00	0.26397	0.00000	0.65447	1	0.82723	2
13	0.74613	0.00	0.25386	1.00000	0.66324	0.33333333	0.49829	17
14	0.87990	0.71	0.12009	0.28571	0.80632	0.63636363	0.72134	9
15	0.82342	0.71	0.17657	0.28571	0.73901	0.63636363	0.68768	14
16	0.83531	0.62	0.16468	0.38095	0.75223	0.56756756	0.65990	15
17	0.80796	0.86	0.19203	0.14285	0.72250	0.7777777	0.75014	5
18	0.81926	0.90	0.18073	0.09523	0.73449	0.84	0.78724	4
19	0.83531	0.76	0.16468	0.23809	0.75223	0.67741935	0.71482	10
20	0.85612	0.67	0.14387	0.33333	0.77654	0.6	0.68827	13

Where the γ_i is highest value of wear and COF and number of experiments in N. The highest value of GRG is 0.838709677for the experiment number 2 from the tables.

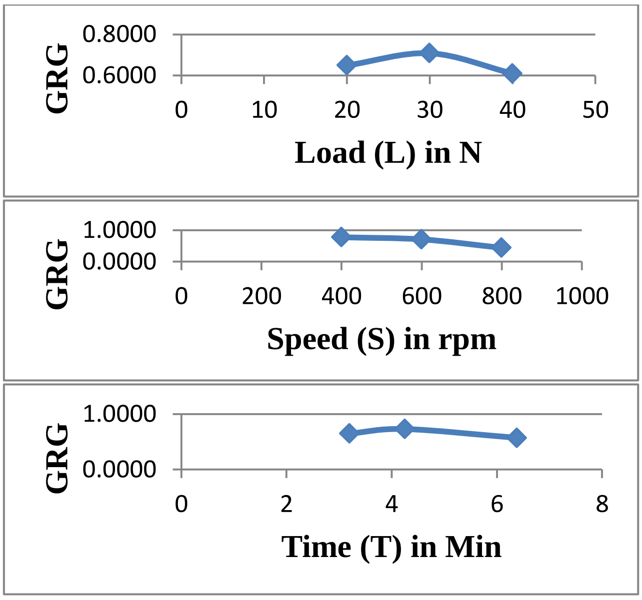
The higher GRG values indicate multiple output responses characteristics for the corresponding input parameters. In the present work, AL6063 composite multiple response result has been converted into optimization of a GRG. Thus, the multi-response optimization problem is reduced to a single objective function. The mean value of the GRG for each level of input parameters, and the total mean value of the GRG is showed in tables 13.

Table 13: Ranking of Composition B input parameters

	Levels	Load	Speed	Time
Composition B	-1	0.6491	**0.7728**	0.6472
	0	**0.7083**	0.7054	**0.7287**
	1	0.6096	0.4382	0.5706
	Mean	0.6557	0.6388	0.6488
	Ranking	**3**	**1**	**2**

From the larger value of the GRG are the optimal value and its selected. In addition to this, the total mean of GRG for all the experiments is calculated to find influence of input parameters which are denoted by rank.

Figure9: Mean effective Plot of Composition B in ALMMC



Figures 9 graphically represent the grey relational grades (GRGs) for Composition B in mean effect plot. From the GRGs and figures 9, the input parameters are found to be L (0)-S (-1)-T (0), i.e. Load: 30 N, Speed 400rpm, and Time: 4.25Min.

Table 14- Result of confirmation test

Ex. No	Optimum value of ALMMC		
	Initial	Experimental	Error %
Wear	0.1508	0.15	3.627321
COF	0.20	0.19	5

4. CONCLUSIONS

Dry sliding wear trial of aluminum half and half composites were completed. GRG—an advancement method was utilized to locate the ideal info boundary mixes. From the outcomes, the accompanying ends are drawn.

- Due to the consideration of CF and BN molecule as a fortification, the wear opposition of AlMMCs speeds up to the limit of 53% than Al6063 regardless of applied loads in this way, the proposed AlMMC can be utilized as another for cast iron and solid aluminum brake rotors in autos.
- The increment in wt% of strengthened molecule increments and soaks the CoF of AlMMCs to the limit of 40% than Al6063, and this moderate COF is required for the brake rotor application.
- AlMMC uncovered extreme glue wear system as the applied burden, sliding pace, and sliding time increment.
- As the wt % of strengthened particles expands, the joined cement and rough wear components were related to increment in applied burden, sliding speed, and sliding separation.
- For the ideal boundaries mix of 30 N applied burden, 400rpm speed, and 4.25 min sliding time. ANOVA was additionally applied to check the competence of the developed model and there was a good agreement subsists between the experimental and predicted outcomes. GRG–ANOVA results reveal that SWR is significantly influenced by sliding speed followed by applied load later by sliding time for all composites.
- GRG–ANOVA results show that the CoF is affected by applied load then by sliding speed and finally by sliding time for all composites. The developed model in the present study had good capability such that it can be used to predict the results with minimum error
- Pilot studies were carried out in various percentage of reinforcement's among that the 3% BN, 3% carbon fiber produce better results compare to AL6063. The wear resistance has 53% and COF has 40% improved with adding boron nitride and carbon fiber content in the matrix.

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