Silicon (2022) 14:1083–1092
https://doi.org/10.1007/s12633-020-00885-5

ORIGINAL PAPER

Effect of SiC Weight Percentage on Tribological Characteristics of Al7075/SiC Composites

Mulugundam Siva Surya [1] · **G. Prasanthi** [1]

Received: 21 September 2020 / Accepted: 3 December 2020 / Published online: 6 January 2021

Abstract

In aerospace and automobile industries, because of high strength and excellent anti-wear properties, aluminium silicon carbide composites are widely used. Hence, the current work investigates the tribological characteristics of powder metallurgy processed Al7075-x wt.% SiC (x = 10,15 and 20) composites using pin-on-disc equipment. Taguchi's orthogonal array and analysis of variance are employed to study the effects of input parameters and their levels on output responses. The current study reveals that the wear loss decreases and increases when the reinforcement Wt.% changes from 10 to 20. It is also observed that the wear loss increases with an increase in load. The coefficient of friction increases with an increase in wt.% of reinforcement and sliding distance. The composite with 15 Wt.% SiC exhibits less coefficient of friction and wear loss. The wear effect was determined through morphological studies of worn out surface and worn out debris. The major influencing factors that control wear loss are sliding distance and load. The major influencing factors for coefficient of friction are % reinforcement and sliding distance. SEM analysis revealed that delamination and abrasion are the two-prominent wear mechanisms observed on worn-out surfaces of the specimens.

Keywords Aluminium7075 · SiC · Composite · Powder metallurgy · Pin on disc · Wear loss and coefficient of friction(COF)

1 Introduction

The Aluminium alloys are used to produce the components with combined features like high performance, lightweight and environmental resistance in automotive, space and mineral processing applications. Among many aluminium alloys, because of superior thermal, electrical and mechanical properties Al7075 is recommended [1–3]. Metal matrix composites with ceramic reinforcement have shown tremendous enhancement in mechanical and tribological characteristics like higher strength, stiffness and including resistance to wear because of the presence of solid phases in the metal matrix compared over monolithic materials. Ceramic reinforcement is done to monolithic counterparts to improve their tribological properties, which replaced them, mainly in the automotive and aerospace sector. Aluminium based composite materials offer an excellent combination of properties that differ from the original base materials and also are lighter in weight [4–7]. Usage of various hard-ceramic particles like aluminium oxide, boron carbide, titanium carbide, silicon carbide and rice husk as reinforcement has resulted in enhanced mechanical and tribological characteristics of composites. Many researchers are working on SiC-based metal matrix composites because of their attractive features [8–11]. Compared to stir casting, metal infiltration, spray decomposition and mechanical alloying, one of the widely-used technique to develop composites is Powder metallurgy technique. Ability to process any powders into its final part makes powder metallurgy most accepted method. P/M has replaced other methods in producing MMCs because of less power utilization, superior grade, less wastage of material, low initial price and its capability to manufacture complex components economically has discovered vast applications in aerospace, defence laboratories, automotive, structural and other manufacturing industries [12, 13]. Coefficient of friction and wear loss depends considerably on load, sliding distance, sliding speed, dimensions, surface roughness, type of metal and heat generation. In altering both wear and coefficient of friction, reinforcement wt.%,

✉ Mulugundam Siva Surya
sivasurya.mtech@gmail.com

G. Prasanthi
dr.smt.g.prasanthi@gmail.com

[1] Mechanical Department, JNTUA, Ananthapuramu, AP, India

sliding speed, sliding distance and average load play a considerable role [14–17]. Powder metallurgy has an advantage of distributing reinforcements uniformly which enhances structural, mechanical and anti-wear characteristics. Existing research stressed the importance of tribological characteristics, considering one or two factors in their study but very few researches considered multiple factors93 and beyond). Also, very few works have been reported on Al7075 and the studies beyond 15% reinforcement are even less. This work aims at addressing this gap by studying the wear behaviour of the powder metallurgy processed Al7075/SiC composites with 10,15 & 20 wt.% reinforcements and the effect of input factors, viz., sliding distance, sliding speed, load and Wt.% SiC on output responses are studied using Taguchi's experimental design. Influential factors and their interactions were determined using analysis of variance. Through SEM and EDX analysis wear mechanism of the composites were studied.

2 Experimental Details

The base material used in this investigation is aluminium 7075 alloy powder of size 40 µm, procured from Parshwamani metals, Mumbai, India. Matrix material composition is shown in Table 1. SiC powder of size 20 µm supplied by Nice chemicals Pvt. Ltd., Kochi, Kerala is considered as reinforcement. The study is carried out on three different composites processed by powder metallurgy.

Initially, the powders were preheated at 110 °C to remove the moisture. Ball mill is used to mix the powder. To achieve the uniformity in mixing, the preferred ball to powder proportion is 10:1 [18]. At an average speed of 100 rpm for 60 min, both the powders are mixed and poured in a die and compacted at 450 MPa to get a specimen of 10 mm diameter and 25 mm height. The die walls are lubricated using zinc stearate before each run. The specimens are sintered at 510 °C for two hours [18]. Rockwell hardness testing machine was used to determine hardness of the sintered composites with a loading of 100 kgf applied for 20s. The Rockwell B-scale test was use for hardness characterization as it is commonly applied for determining the hardness of composites. In order to minimize variation in the hardness results, the actual hardness of each composite was taken as an average of three measurements.

Dry sliding wear tests were performed on computerized pin-on-disk setup Ducom (2010) (model no ED-201, Bangalore India) at room temperature. As per the ASTM G99–05 test standards [1, 18]. Figure 1. shows the cylindrical pins of length 25 mm and diameter 10 mm were prepared from the sintered composites produced using powder metallurgy. All the sliding faces of pins were polished with 400, 600 and 1000 grit emery papers respectively. After every experiment, the disk EN 31 (60HRC) steel is wiped with acetone to remove the particles of composite specimens. The four parameters (SiC Wt.%, Load, sliding distance and sliding speed) with three different levels are shown in Table 2 are considered as input parameters in this study. The wear loss and coefficient of friction was determined after every experiment. The wear loss is calculated using Eq. (1).

Table 1 Al7075 composition

Composition of Al alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt. Percentage	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Bal

$$V = W_i - W_f \tag{1}$$

where,

V the volume loss,
W_i the weight of the pin before testing and.
W_f the weight of the pin after testing.

Taguchi's experimental design tool is used to design the total number of tests and to calculate the deviations between the experimental and expected values. The characteristic S/N ratio "smaller the better" is considered for calculating both wear loss and coefficient of friction. Smaller the better values are calculated using Eq. 2 [19].

$$\frac{S}{N} = -10 log \frac{1}{n} \left(\sum y^2\right) \tag{2}$$

3 Results and Discussion

3.1 Hardness

Figure 2 shows the hardness of the produced composites corresponding to the weight percentages of SiC. From Fig. 2, it is evident that, an increasing trend of hardness has been observed with an increment in the weight percentage of SiC up to 15%. Hardness enhancement can be ascribed to the reality that, SiC possess higher hardness and its existence in the composite increase the hardness. Further increase in SiC led to the formation of high porosity and micro cracks which is the

Table 2 Input parameters different levels

Input parameters	Level-1	Level-2	Level-3
SiC (Wt.%)	10	15	20
load(N)	10	15	20
sliding distance(m)	500	1000	1500
sliding Speed(m/s)	1	1.5	2

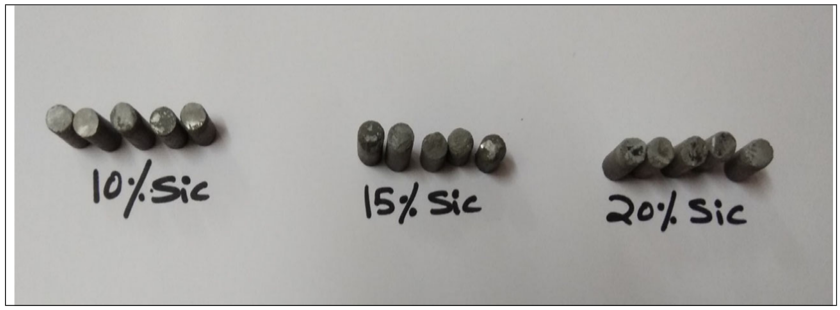


Fig. 1 Sintered composites for wear test

major reason for decrease in hardness when SiC content increased to 20%. Hardness of composite decreased from 72HRB at 15wt.%SiC to 67 HRB at 20wt.%SiC.

3.2 Wear Behaviour

Experimental wear loss and coefficient of friction results, together with their transformations into S/N ratio, are shown in Table 3.

The prominent wear mechanisms that are possible in Al/SiC composites are adhesive, abrasive, delamination and abrasion wears. This wears mechanisms occur due to change in reinforcement Wt.%, load, sliding speed and sliding distance [20]. Metallurgical characteristics, environmental conditions and nature of disc surface are the prominent causes of different types of wear mechanism [21].

Figure 3a and b shows worn out surface and worn out debris SEM morphology of Al-20%SiC specimens at 15 N load. It is evident from Fig. 3a that delamination and abrasion are the dominant reasons for wear mechanism [18, 22, 23]. Figure 3b shows the existence of deep craters and breakage of oxide layers in Al-20%SiC specimens, which resulted in increased wear loss and formation of extensive large worn out debris.

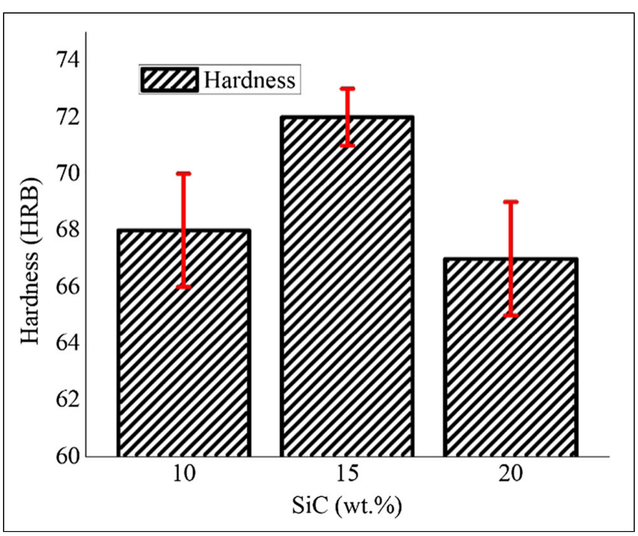


Fig. 2 Hardness of composites with respect to Wt.%SiC

Figure 4a and b shows worn out surface and worn out debris SEM morphology of Al-10%SiC specimens at 15 N load. It is evident from Fig. 4a that mostly abrasive and partly adhesion and plastic deformation are the dominant wear mechanisms [18, 24, 25]. The presence of parallel grooves and craters in the direction of sliding of the specimens is the indication of abrasive wear. Figure 4b shows the presence of small craters and fracture of oxide layers in Al-10%SiC specimens due to adhesive wear which resulted in wear loss and formation of small worn out debris.

Figure 5a and b shows worn out surface and worn out debris SEM morphology of Al-15%SiC specimens at 15 N load. From Fig. 5a, it is evident that the wear mechanisms observed in Al-15%SiC composites are oxidation and adhesion. [22]. Figure 5b shows the presence of small craters in Al-15%SiC specimens which resulted in little wear loss and formation of small debris. In comparison to the above two composites, at 15 Wt.% SiC, a mechanically mixed layer (MML) is developed on the composite which acts as a protective layer and as a solid lubricant. Due to the formation of this tribo-layer or oxide layer, there is a decrease in wear loss [26–28].

3.3 Energy Dispersive X-Ray (EDX) Analyses

The EDX analysis performed on the wear surface of composites were subject to wear test. On all the specimens, a moderate-intensity oxygen peak was detected. This peak indicates the formation of oxide at the interacting surfaces. The collective action of huge temperature and environmental response can lead to the creation of oxide film on the interacting surfaces.

Figure 6 shows the EDX spectrum of wear surfaces of Al-10%SiC composite at 15 N load and 2 m/s speed. In Fig. 6a low-intensity Si peak and high-intensity Al peak are observed. The high-intensity Al peak represents the plastic deformation of Al-10%SiC composite [18], which must have prevailed while sliding wear.

Figure 7 shows the EDX spectrum of wear surfaces of Al-15%SiC composite at 15 N load and 2 m/s speed. In comparison to the EDX spectrum of wear surface of the other two composites (Al-10%SiC and Al-20%SiC), Al-15%SiC composite exhibits a low-intensity Al and Si peaks. It also shows a

Table 3 L_{27} orthogonal array by design of experiments

Expt. No	%SiC	Load	Sliding distance(m)	sliding speed(m/s)	Wear loss (gm)	S/N ratio(db)	COF	S/N ratio(db)
1	10	10	500	1	0.011	39.17215	0.151	16.42046
2	10	10	1000	1.5	0.0125	38.0618	0.164	15.70312
3	10	10	1500	2	0.0139	37.1397	0.192	14.33398
4	10	15	500	1.5	0.0118	38.56236	0.155	16.19337
5	10	15	1000	2	0.0127	37.92393	0.169	15.44227
6	10	15	1500	1	0.0198	34.0667	0.199	14.02294
7	10	20	500	2	0.0123	38.2019	0.173	15.23908
8	10	20	1000	1	0.0135	37.39332	0.185	14.65657
9	10	20	1500	1.5	0.024	32.39578	0.197	14.11068
10	15	10	500	1.5	0.0096	40.35458	0.147	16.65365
11	15	10	1000	2	0.012	38.41638	0.158	16.02686
12	15	10	1500	1	0.0136	37.32922	0.183	14.75098
13	15	15	500	2	0.0105	39.57621	0.151	16.42046
14	15	15	1000	1	0.0124	38.13157	0.162	15.8097
15	15	15	1500	1.5	0.019	34.42493	0.193	14.28885
16	15	20	500	1	0.0111	39.09354	0.161	15.86348
17	15	20	1000	1.5	0.0131	37.65457	0.176	15.08975
18	15	20	1500	2	0.02	33.9794	0.19	14.42493
19	20	10	500	2	0.0119	38.48906	0.172	15.28943
20	20	10	1000	1	0.0128	37.8558	0.188	14.51684
21	20	10	1500	1.5	0.014	37.07744	0.195	14.19931
22	20	15	500	1	0.0122	38.2728	0.199	14.02294
23	20	15	1000	1.5	0.013	37.72113	0.204	13.8074
24	20	15	1500	2	0.0221	33.11215	0.209	13.59707
25	20	20	500	1.5	0.0125	38.0618	0.215	13.35123
26	20	20	1000	2	0.0137	37.26559	0.219	13.19112
27	20	20	1500	1	0.026	31.70053	0.225	12.95635

high intensity Fe peak. Al and Si indicate a less plastic deformation and abrasive wear, which results in high resistance to wear. The high intensity Fe peak is the result of adhesive wear in which more material is transferred from counter disk to pin.

Figure 8 shows the EDX spectrum of wear surfaces of Al-20%SiC composite at 15 N load and 2 m/s speed. The intensity of Si peak is less because more number of SiC particles are pulled from the composite surface due

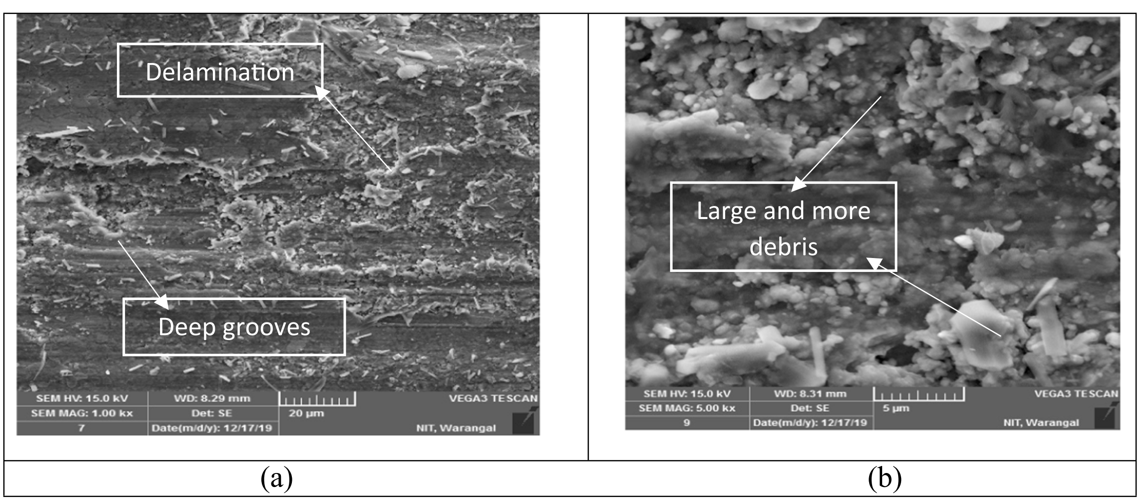


Fig. 3 **a** Worn out surface and **b** worn out debris SEM images of 20%SiC specimens

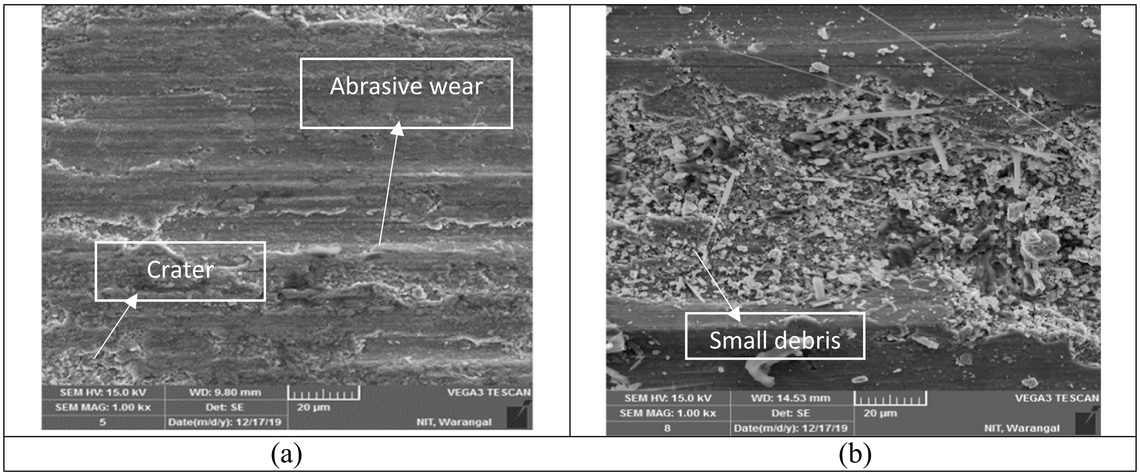


Fig. 4 **a** Worn out surface and **b** worn out debris SEM images of 10%SiC specimens

to less hardness and severe abrasive wear. The material transfer from the counter surface to the composite surface is less, which resulted in the low-intensity Fe peak. The high-intensity Al peak indicates the plastic deformation of the Al–20%SiC composite during sliding. [22].

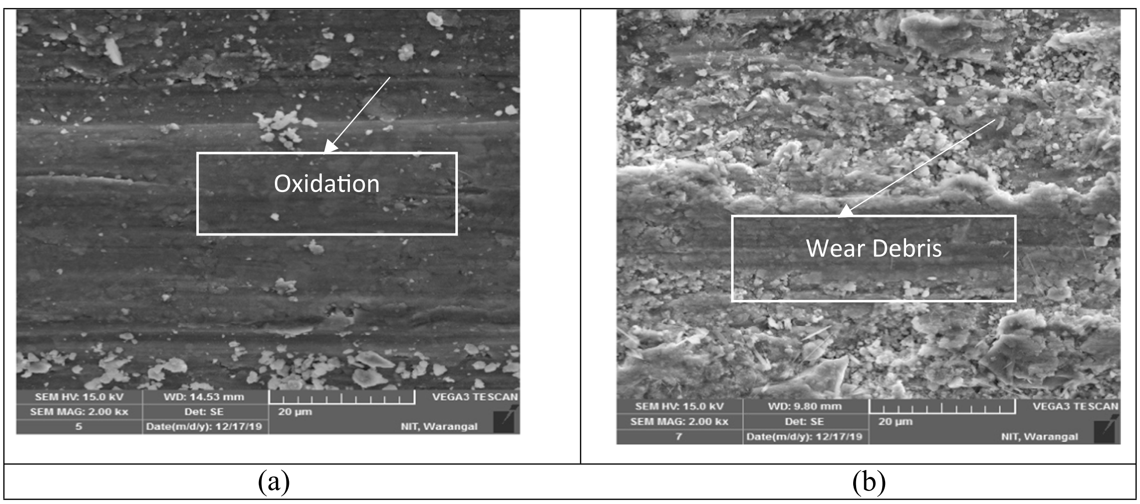


Fig. 5 **a** Worn out specimen and **b** worn out debris SEM images of 15%SiC specimens

Fig. 6 Al-10%SiC worn out surface EDX spectrum

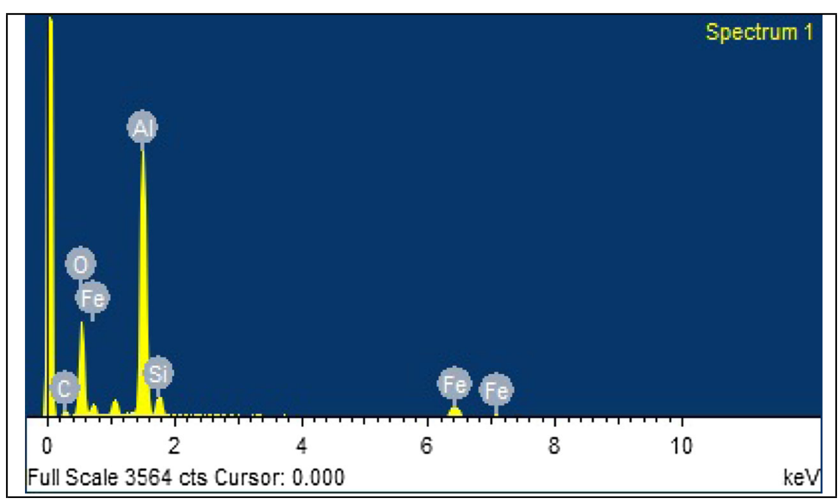


Fig. 7 Al-15%SiC worn out surface EDX spectrum

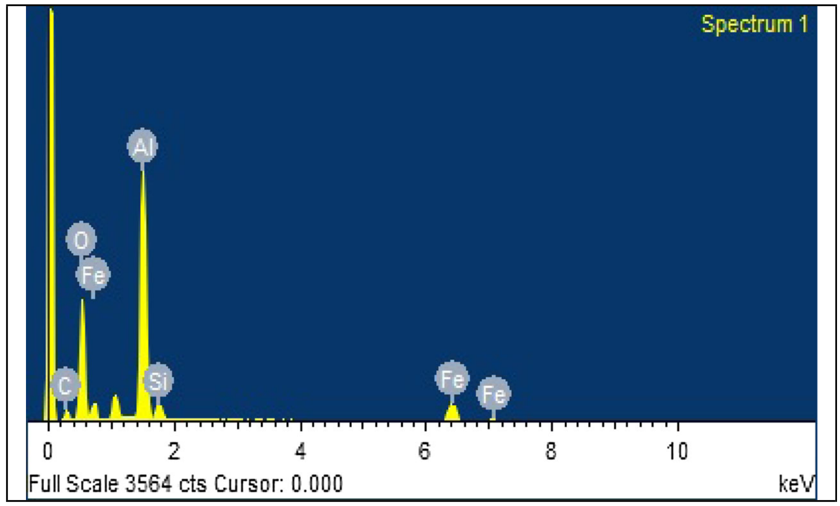
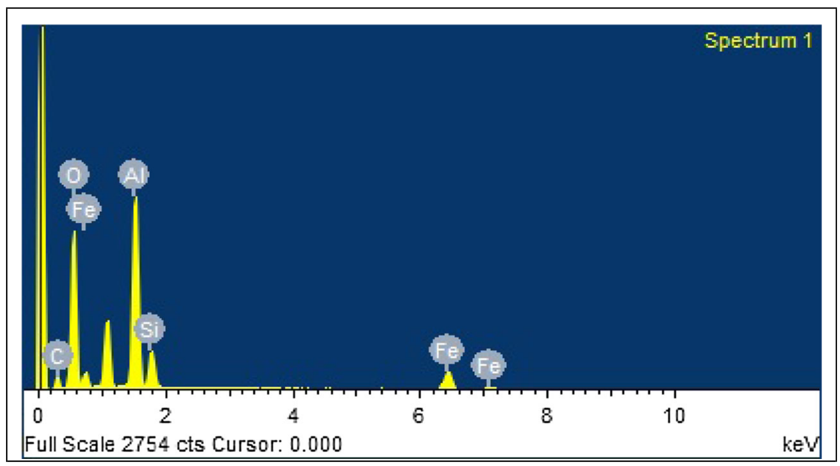


Fig. 8 Al-20%SiC worn out surface EDX spectrum



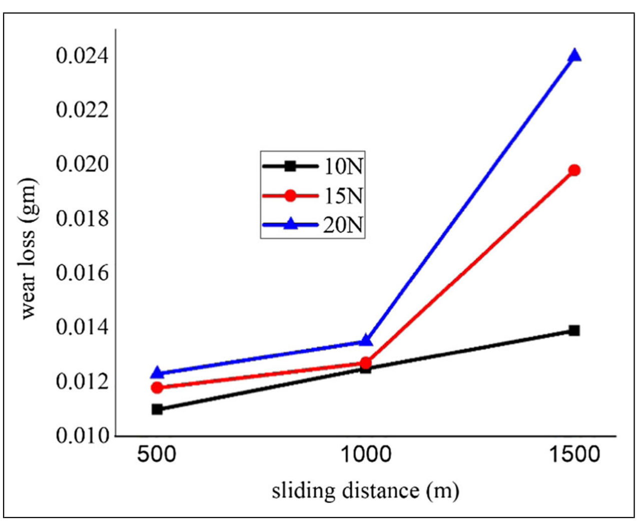


Fig. 9 Variation of wear loss with respect to sliding distance and load at constant reinforcement 10%SiC

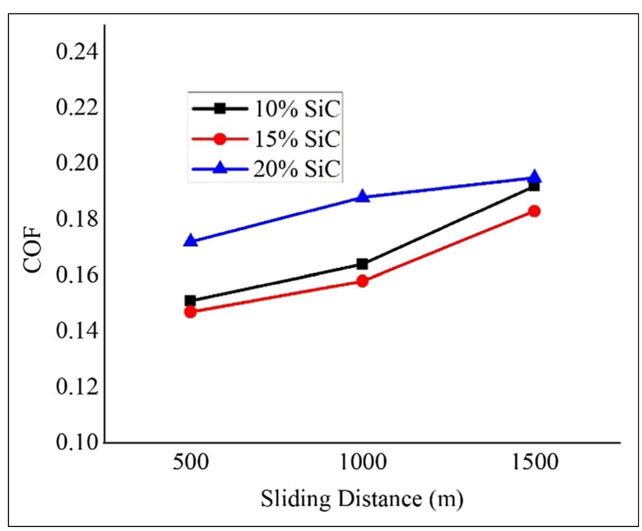


Fig. 10 Variation of COF with respect to sliding distance and Wt.%SiC at constant load 10 N

Table 4 Response table for wear loss: smaller is better

Level	%SiC	load(N)	Sliding Distance(m)	Sliding Speed (m/s)
1	36.99	38.21	38.86	37.00
2	37.66	36.87	37.82	37.15
3	36.62	36.19	34.58	37.12
Delta	1.04	2.02	4.28	0.14
Rank	3	2	1	4

3.4 Effect of Sliding Distance and Load on Wear Loss

Two major contributing factors for wear loss are sliding distance followed by the load. From Fig. 9 it is clear that wear loss increases with an increase in load and the sliding distance. As the sliding distance increases from 500 m to 1500 m, high temperatures are generated on the sliding surfaces are unavoidable. This results in softening of the matrix and composite pin surfaces, leading to heavy deformation at higher sliding distances. This contributes to higher volumetric wear loss of matrix and the composite. As load increases from 10 N to 20 N, the number of grooves formed on the specimen surface increased. This grooves are large and led to severe plastic deformation, which in turn led to rigorous wear loss. With the increase in SiC (Wt.%), the formation of grooves reduced due to higher hardness of composites and provided good interfacial bonding which resulted in lower wear loss [1, 21, 24].

3.5 Effect of SiC (Wt.%) and Sliding Distance on Coefficient of Friction

Two major contributing factors for the coefficient of friction are reinforcement percentage and sliding distance. From Fig. 10 it is clear that 15% of SiC composites exhibited a smaller coefficient of friction than 10% and 20% SiC composites. As the wt.% of SiC increases, the coefficient of friction increased. This is due to high surface roughness and separation of hard SiC particles from Al-Matrix [22]. With the increase in sliding distance from 500 m to 1500 m, the coefficient of friction increases. The contact time of surfaces increases with the increase in the sliding distance, which leads to a higher coefficient of friction.

4 Analysis of Variance for Wear and Coefficient of Friction

The analysis based on Taguchi methods was carried out using MINITAB 17. In order to determine the main factors effects the wear loss and coefficient of friction, analysis of variance (ANOVA) is applied. The optimal combination of factors for minimum wear loss and coefficient of friction are determined using Taguchi's S/N rations. Delta values are the average difference among the highest and the lowest for each factor, based on Delta values grades are allocated. Category one is assigned to the highest delta value, and so on [20].

4.1 Analysis of Variance Results for Wear

Based on the S/N ratio results it can be determined which factors has the greatest impact on the wear loss. Optimal combination of controlled factors for minimum wear loss can be determined based on the S/N ratios shown in Table 4 and Fig. 11.

The Sliding distance and load has the greatest impact on the wear loss. Figure 11 shows the optimized set of parameters for minimizing wear loss. The combination of control factors for minimized wear loss are wt.%SiC at level-2, load at level-1, sliding distance at level-1 and sliding speed at level-2. Experimental results were processed by the analysis of

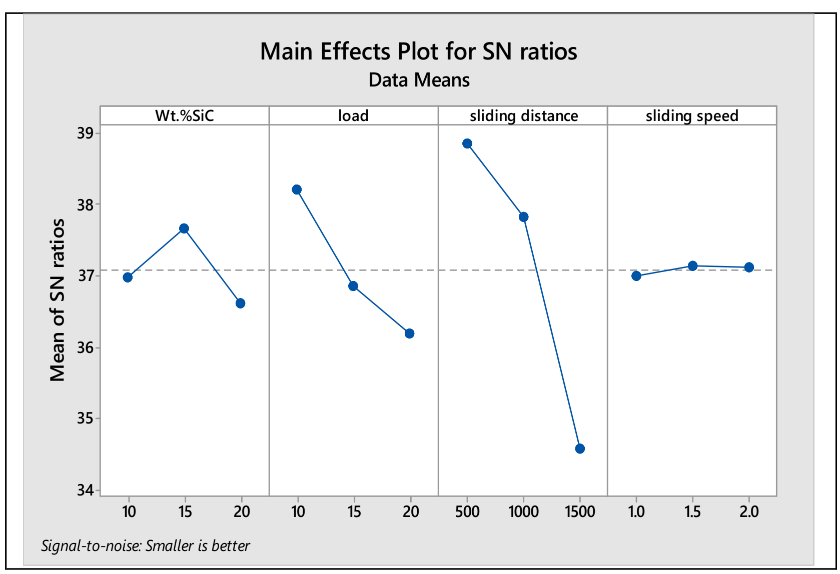


Fig. 11 Main effects plots for wear loss

Table 5 ANOVA analysis for wear loss

Source	Degrees of freedom	Adj Sum of squares	Adj Mean of squares	F-Value	%Contribution
%SiC	2	0.000016	0.000008	1.63	4.12
load(N)	2	0.000069	0.000035	7.03	17.76
Sliding Distance(m)	2	0.000304	0.000152	30.85	77.94
Sliding Speed(m/s)	2	0.000001	0.000000	0.07	0.18
Error	18	0.000089	0.000005		
Total	26	0.000479			

variance(ANOVA), which is used for the identification factors that can have an impact on the wear loss. The ANOVA results are shown in Table 5. The last column in Table 5 shows the percentage contribution of each of these factors. Table 5 shows that sliding distance and load have significant percentage of contribution were as %SiC and sliding speed have insignificant contribution towards wear loss.

4.2 Analysis of Variance Results for Coefficient of Friction

Similar to the wear loss, based on the S/N ratios, it can be determined which factors has the greatest impact on the coefficient of friction. Optimal combination of controlled factors for minimum coefficient of friction can be determined based on the S/N ratios shown in Table 6 and Fig. 12.

Table 6 Response table for COF: smaller is better

Level	%SiC	load(N)	Sliding Distance(m)	Sliding Speed (m/s)
1	15.12	15.32	15.49	14.78
2	15.48	14.84	14.92	14.82
3	13.88	14.32	14.08	14.89
Delta	1.60	1.00	1.42	0.10
Rank	1	3	2	4

The Wt.%SiC and sliding distance has the greatest impact on the COF. Figure 12 shows the optimized set of parameters for minimizing coefficient of friction. The combination of control factors for minimized coefficient of friction are Wt.%SiC at level-2, load at level-1, sliding distance at level-1, and sliding speed at level-3. Experimental results were processed by the analysis of variance(ANOVA), which is used for the identification factors that can have an impact on the coefficient of friction. The ANOVA results are shown in Table 7. The last column in Table 7 shows the percentage contribution of each of these factors. Table 7 shows that SiC and sliding distance have significant percentage of contribution were as load and sliding speed have insignificant contribution towards COF.

5 Conclusions

In this study, aluminium7075/SiC metal matrix composites with different weight percentage (10, 15 & 20) are processed by powder metallurgy technique. Composites with 15 weight

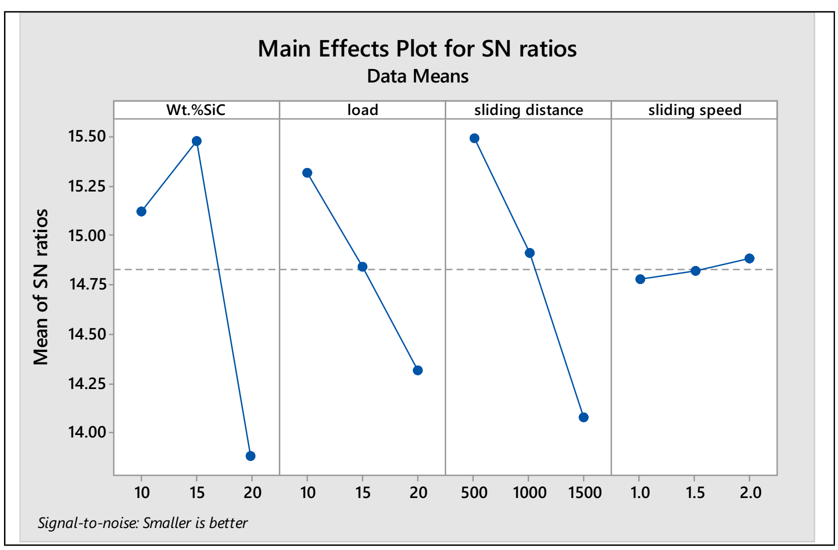


Fig. 12 Main effects plots for COF

Table 7 ANOVA analysis for coefficient of friction

Source	Degrees of freedom	Adj Sum of squares	Adj Mean of square	F-Value	%Contribution
%SiC	2	0.005748	0.002874	42.14	49.61
load(N)	2	0.002028	0.001014	14.87	17.51
Sliding Distance(m)	2	0.003787	0.001893	27.76	32.68
Sliding Speed(m/s)	2	0.000023	0.000011	0.17	0.20
Error	18	0.001228	0.000068		
Total	26	0.012814			

percentage of SiC exhibited high resistance to coefficient of friction and wear loss. The Al/15wt.%SiC composite exhibited higher hardness because of strong interfacial bonding between the matrix and reinforcement.

The SEM analysis of the worn-out surface's revealed that the fracture of oxide layers with severe plastic deformation was observed for 10 Wt.%SiC composites, which indicates that the wear mechanism is abrasion. Delamination and abrasion wear mechanism was observed in 20% of SiC composites as deep grooves and large craters were observed on these surfaces. The small craters and small debris observed on worn out surface and wear debris in 15% of SiC composites represent a strong bonding between Al7075/SiC particles which is the prime reason for higher wear resistance.

From the ANOVA investigation, it is evident that the most influential factors affecting the wear loss of the composites are sliding distance (77.94) and load (17.94). ANOVA investigation also provides the most influential factors affecting the coefficient of friction are Wt.% of SiC (49.61) and sliding distance (32.68). From Taguchi's analysis, the optimized combination of factors for minimization of wear loss is (15wt.%SiC, 10 N load, 500 m sliding distance and 1.5 m/s sliding speed). Similarly, the optimized combination of factors for the minimization of coefficient of friction is (15%SiC, 10 N load, 500 m sliding distance and 2 m/s sliding speed). Sliding distance is a prominent factor which has a significant effect on both wear loss and coefficient of friction. Moreover, %SiC and load also play a significant role, but sliding speed has a little influence.

Author Contributions Mulugundam Siva Surya: Conceptualization, Methodology, Experimentation, Result Analysis, Writing- Original draft preparation., G. Prasanthi: Supervision.

Data Availability All data generated or analyzed during this study are included in this article.

Compliance with Ethical Standards

The present study work was not conducted on human or experimental animals where national or international guidelines are used for the protection of human subjects and animal welfare.

Conflict of Interest No Potential conflict of interest was reported by the authors.

Consent to Participate Not Applicable.

Consent for Publication We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that all the authors listed in the manuscript has been approved by all of us.

References

1. Veeresh GB, Rao CSP, Selvaraj N (2012) Mechanical and dry sliding wear behavior of Al7075 alloy-reinforced with SiC particles. J Compos Mater 46(10):1201–1209
2. Vishwakarma P, Soni S, Mishra PM (2018) An effect of reinforcement and heat treatment on AA7075 metal matrix composite – a review. Int J Mechanic Product Eng Res Develop 8:275–288
3. Srinivasa R, Upadhyaya GS (1995) 2014 and 6061 aluminium alloy-based powder metallurgy composites containing silicon carbide particles/fibers. Mater Des 16(6):359–366
4. Khathun AS, Srinivas PNS, Babu R (2018) Experimental investigation of mechanical and Tribological properties of aluminum metal matrix composite (MMC) reinforced with alumina (Al_2O_3) using powder metallurgical process. Int J Adv Res Sci Eng Technol 5(5): 5822–5828
5. Anil Kumar G, Sateesh J, Shivanand (2016) Experimental study of Wear and mechanical properties of Al7075/SiC MMC processed by powder metallurgy. Int Res J Eng Technol 03(07):1339–1345
6. Singh J, Chauhan A (2014) A review on sliding Wear behaviour of Aluminium matrix composites with hybrid reinforcements for automotive applications. Tribol Online 9(3):121–134
7. Sultan S, Bisht S, Arya S (2016) Mechanical properties of 7075 Aluminium matrix composites reinforced by Nanometric silicon carbide particulates. Int J Adv Res Innov 4(2):576–582
8. Surya MS, Prasanthi G (2019) Manufacturing and mechanical behavior of (Al/SiC) functionally graded material using powder metallurgy technique. Int J Innov Technol Explor Eng 8(9):1835–1839
9. Verma S, Rao S (2018) Study on mechanical behavior of aluminum alloy 6061 based composites a review. IOSR J Mechanic Civil Eng 15(4):16–20
10. Surya MS, Nilesh TV (2019) Synthesis and mechanical behaviour of (Al/SiC) functionally graded material using powder metallurgy technique. Materials Today: Proceedings 18(7):3501–3506
11. Kati S, Halesh SB (2016) Microstructure and tensile behavior of AA7475-B4C composites. Int J Eng Res 5(6):1129–1254
12. Bodukuri AK, Eswaraiah K, Katla R, Sampath V (2016) Fabrication of Al–SiC–B4C metal matrix composite by powder

metallurgy technique and evaluating mechanical properties. Perspect Sci 8:428–431
13. Singh J (2016) Fabrication characteristics and tribological behavior of Al/SiC/gr hybrid aluminum matrix composites: a review. Friction 4(3):191–207
14. Baradeswaran A, Perumal A (2013) Influence of B4C on the tribological and mechanical properties of Al 7075–B4C composites. Compos Part B 54:146–152
15. Uvaraja V, Nanjappan N, Sivakumar K, Jegadheeshwaran S, Sudhakar S (2015) Tribological behavior of heat treated A1 7075 aluminium metal matrix composites. Indian J Eng Mater Sci 22:51–61
16. Surya MS, Prasanthi G (2018) Tribological behaviour of aluminum silicon carbide functionally graded material. Tribol Industry 40(2): 247–253
17. Veličković S, Mladenovic S (2018) Influence of load and reinforcement content on selected tribological properties of Al/SiC/Gr hybrid composites. Product Eng Arch 18:18–23
18. Ravindran P, Manisekar K (2013) Tribological behaviour of powder metallurgy-processed Aluminium hybrid composites with the addition of graphite solid lubricant. Ceram Int 39(2):1169–1182
19. Dey D, Biswas A (2020) Comparative study of physical, mechanical and Tribological properties of Al2024 alloy and SiC-TiB_2 composites. Silicon. https://doi.org/10.1007/s12633-020-00560-9
20. Karakoc H, Ovali I, Dundar S, Citak R (2019) Wear and mechanical properties of Al6061/SiC/B_4C hybrid composites produced with powder metallurgy technique. J Mater Res Technol 8(6): 5348–5361
21. Idusuyi N, Olayinka JI (2019) Dry sliding wear characteristics of aluminium metal matrix composites: a brief overview. J Mater Res Technol 8(3):3338–3346
22. Majzoobi GH, Atrian A, Enayati MH (2015) Tribological properties of Al7075-SiC nanocomposite prepared by hot dynamic compaction. Compos Interf 22(7):579–593
23. Dey D, Bhowmik A, Biswas A (2020) Effect of SiC content on mechanical and Tribological properties of Al2024-SiC composites. Silicon. https://doi.org/10.1007/s12633-020-00757-y
24. Savaskan T, Bican O (2010) Dry sliding friction and Wear properties of Al–25Zn–3Cu– (0–5) Si alloys in the as-cast and heat-treated conditions. Tribol Lett 40:327–336
25. Mazahery A, Shabani MO (2012) Study on microstructure and abrasive wear behavior of sintered Al matrix composites. Ceram Int 38:4263–4269
26. Venkatraman B, Sundararajan G (2000) Correlation between the characteristics of the mechanically mixed layer and wear behaviour of aluminium, Al-7075 alloy and Al-MMCs. Wear 245(1–2):22–38
27. Reddy, A Prasad & Krishna, Vamsi & Rao, R., (2019) Two body abrasive wear behaviour of AA6061-2SiC-2Gr hybrid nanocomposite fabricated through ultrasonically assisted stir casting. J Compos Mater 53(15):1–16
28. Douglas C (2007) Montgomery, Design and Analysis of Experiments, Wiley India (P) Ltd.