

Study and Analysis of Silicon Carbide Particles Reinforced with Al 6061 Metal Matrix Composites of Brake Rotor using Pin-on-Disc

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Key words: Al6061, Silicon Carbide (SiC), Stir casting, pin on disc apparatus

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Page No.: 186-193 Volume: 16, Issue 5, 2021 ISSN: 1816-949x Journal of Engineering and Applied Sciences Copy Right: Medwell Publications

INTRODUCTION

The study has been carried on the use of aluminium metal matrix composite material for brake rotors which is expected to have less heat content due to high thermal dissipation of the heat generated due to braking $action^{[1,2]}$. Brake materials transform the kinetic energy of the vehicle into thermal energy by friction between the pad materials and metal disc or drum, usually cast iron^[3, 4]. It has been thought that aluminium material is not suitable for parts used under extremely severe frictional conditions and it cannot withstand higher temperatures. But it is found that Al-MMC can withstand higher temperatures^[5]. The most important condition is the ability of the brake rotor material to withstand high temperatures generated of the order of 300-800°C during a braking action, its resistance to abrasive wear. The performance of a braking action is affected by the rise in temperature during application in braking load which is known as brake fade. In general, wear occurs by five principal

Abstract: Aluminium Metal matrix Composites (AMC) is being extensively used in various field of life, especially in aerospace and automotive industries, because of its good thermal stability and excellent specific strength. AMCs are well known for high strength to weight ratio and high temperature applications. In the present study, wear behaviour of SiC particles reinforced with Aluminium Matrix composites have been investigated. Al 6061 discs were made with 10, 15 and 20% SiC particles by stir casting and machined to fit as a disc in pin on disc tribometer. Using Taguchi Design of Experiments, the experiments were carried out with 4 factorials and 3 levels based on L9 orthogonal array and the results are discussed.

processes: adhesive, abrasive wear, corrosion, surface fatigue and erosion. Earlier study^[6] for SiC particles reinforced composites showed that wear was strongly dependent on the contents of the reinforcement, sliding distance and speeds. In this study, the effects of mixture of aluminium and silicon carbide, i.e. (SiC) reinforced aluminium metal matrix composite on the wear of brake pad materials were studied and the results are discussed.

Composite materials are usually classified based on the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix, and ceramic composites. Aluminium metal matrix refers to the class of lightweight high performance aluminium centric material systems. The major advantages of Aluminium metal matrix compared to unreinforced materials are a greater strength, improved stiffness, reduced weight, improved high-temperature properties, controlled thermal expansion coefficient and improved abrasion and wear resistance^[7].

Table 1: Properties of Al6061 with 20%	SiC
Properties	Values
Ultimate tensile strength	370 (MPa)
Compressive strength	761 (MPa)
Hardness	80 (BHN)
Elastic modulus	103 (GPa)
Ductility	2.5 (%)
Coefficient of friction	0.44
Thermal conductivity	$5 (W m^{-1} K)$
Specific heat capacity	$0.92 (kJ kg^{-1} K)$
Heat transfer coefficient	$50 (W m^{-2} K)$

Al6061, an alloy of aluminium, magnesium and silicon is chosen in this work because of its mechanical and thermal stability. An in-depth investigation of literature shows that 20% SiC-reinforced aluminium alloy exhibits a significant reduction in the wear compared to other volumetric fraction of SiC in the aluminium matrix. The composite material also has lower thermal expansion than the matrix material due to the presence of SiC particles^[8]. The properties of Al6061 with 20% SiC is shown in Table 1.

MATERIALS AND METHODS

Material selection and procedure

Aluminium composite: The increase in weight percentage of SiC up to 25%, when added to Al 6061 matrix, increases both hardness and impact strength of the composite. Beyond this weight fraction, the hardness starts to decrease as SiC particles interact with each other leading to the clustering of particles and consequently settling down. Therefore, in the study, the SiC powder in weight percentages of 10, 15 and 20 were added to Al 6061 alloy to make wear discs to be fitted to pin on disc tribometer.

Fabrication process of the composite brake rotor

Stir casting: In stir casting, the reinforcement phase in powder form varying between 10 and 30 μ m size is added to molten matrix phase and it is mixed thoroughly using stirrer blades attached to an electric motor. The stirring time can vary from a minimum of 5 min to a maximum of 3 to 4 h depending upon the volume of the melt.

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized and chemical reactions between the reinforcement materials and the matrix alloy must be avoided. SiC reinforcement in an Al alloy matrix containing <7% Si may cause the following reaction^[9]:

$$4Al+3SiC \leftrightarrow Al_4C_3+3Si$$

Formation of Al_4C_3 affects the mechanical properties of the composite. In order to prevent the reaction, SiC



Fig. 1: CAD Model of disc



Fig. 2: Disc after machining

particulates should be heated to a temperature of 700°C, so that a thin coat of 2-µm-thick SiO₂ is formed over the SiC. This barrier coating prevents the migration of Al into SiC and hence prevents the reaction. The oxide layer also improves the wettability of SiC particles by aluminium^[10]. The molten Al 6061 with SiC powder thoroughly stirred was poured into the metal die made to the shape of the disc with machining allowances.

Specimen preparation for wear test: The disc on pin on disc apparatus has a diameter of 165 mm and thickness of 10 mm. The assembly holes and the outer profile of the disc were machined in a Vertical Machining Centre (VMC). The CAD Model of the disc for pin on disc, Disc after machining are shown in Fig. 1 and 2, respectively.

Wear test

Pin on disc apparatus: Wear test was carried out for three different compositions of SiC in Al6061 alloy. The Silicon carbide particles were mixed at 10, 15 and 20% by



Fig. 3: Pin on disc test

Table 2	: Different di	iscs and brak	ke pads		
	Al6061 with		Al6061 with	Al6061 with	
Disc	10% SiC		15% SiC	20% SiC	
Pad	Non asbe	estos	Semi metallic	Cast iron	
	~				
Table 3	: Combinatio	ons of chang	ing parameter		
SiC in v	weight (%)	Load (N)	Speed (rpm)	Time (min)	
10		50	250	10	
10		100	500	15	
10		150	750	20	
15	5 50		500	20	
15 1		100	750	10	
15		150	250	15	
20	0 50		750	15	
20		100	250	20	
20		150	500	10	

weight with the aluminium alloy. The wear test was carried out using three different brake pads which are shown in Table 2.

The disc and the pin fitted with brake pad were fitted to the apparatus as shown in Fig. 3 and the experiments were carried out according to the Taguchi design combinations and the worn mass was found.

A Taguchi based design of experiments (L9 orthogonal array) was constructed a using commercial software and the experiments were conducted according to the combinations of the changing parameters given in Table 3.

RESULTS AND DISCUSSION

Wear analysis of disc: The worn mass was found for all the three discs using an electronic balance after conducting wear tests against three different brake pads. Similarly the worn mass for the three different brake pads were weighed and tabulated as shown in Table 4-6. The worn disc is shown in Fig. 4 and the worn out portion of the disc is clearly seen as a ring. The wear track may have tribo-oxidation and acts as a protective coating and provides a better wear resistance.



Fig. 4: Disc after wear test

Using the commercial software, the graphs were generated for analysis Al-SiC composite disc wear with semi metallic, CI and non-asbestos brake pad materials which are shown in Fig. 5a-c. It is observed that the wear loss in 20% Al-SiC disc is less in comparison with 10% and 15% Al-SiC disc for all the three brake pads tested. This is due to higher hardness attained in the case 20% SiC and the disc/components with higher hardness wear less as reported in many wear studies. Also, it is observed from Fig. 5a-c, the wear increases as the load and time increases which in line with Archard's wear model wherein wear depth is directly proportional to load and sliding distance.

Analysis of variance was carried using ANOVA considering only three factors viz. % SiC, Load and Time for all the brake pads and the results are shown hereunder. In the case of semi metallic brake pad, based on F and p-values, the order of significance is 1. Load, 2. SiC% and 3. Time. It is also observed that R^2 value is 99.15% and the results obtained for wear are in good agreement with the regression model, since, R^2 >0.8 (Table 7-11).

In the case of CI brake pad based on F and p-values, the order of significance is 1. SiC%, 2 Load and 3. Time. It is also observed that R^2 value is 97.68% and the results obtained for wear are in good agreement with the regression model, since, R^2 >0.8 (Table 12-15).

In the case of non asbestos brake pad based on F and p-values, the order of significance is 1. Load, 2. SiC% and 3. Time. It is also observed that R^2 value is 99.93% and the results obtained for wear are in good agreement with the regression model since R^2 >0.8.

Frictional force and coefficient of friction (μ) values: Similarly the effect of friction coefficient of the three brake pad materials, non-asbestos, CI and semi metallic brake pads on the three discs of 10% SiC, 15% SiC and 20% SiC Al6061 composite were studied and the results

Table 4: Dis	se worn mas	ss values f	for semi-metallio	e brake pao	1	Weight loss (g)					
SiC (%)	Load (N)	Speed (rpm)	Time	(min)	Trial 1	Tı	rial 2	Trial 3	A	verage
10	50		250	10)	0.0082	0.	0085	0.0071	0.	.007933333
10	100		500	15	5	0.0101	0.	0106	0.0095	0	.0100666667
10	150		750	20)	0.0125	0.	0132	0.0139	0.	.0132
15	50		500	20)	0.0072	0.	0076	0.0065	0.	.00/1
15	100		/50	10)	0.0081	0.	0095	0.0089	0.	.0088333333
15	150		250	1.5	-	0.0095	0.	0095	0.0103	0.	.009766667
20	100		750	13	,)	0.0042	0.	003	0.0031	0.	.004/0000/
20 20	150		230 500	10	,)	0.0078	0. 0.	0082	0.0082	0.	.008466667
Table 5: Dis	sc worn mas	s values f	for cast iron								
						Weight loss (g)					
SiC (%)	Load (N)	Speed (rpm)	Time	(min)	Trial 1	Tı	rial 2	Trial 3	А	verage
10	50		250	10)	0.0125	0.	0145	0.0152	0.	.0140666667
10	100		500	15	5	0.0185	0.	0187	0.0184	0.	.0185333333
10	150		750	20)	0.0215	0.	0217	0.0214	0.	.0215333333
15	50		500	20)	0.0099	0.	0098	0.0097	0.	.0098
15	100		750	10)	0.0105	0.	0101	0.0109	0.	.0105
15	150		250	15) -	0.0125	0.	0122	0.0121	0.	.012266667
20	50		/50	13)	0.0081	0.	0078	0.0079	0.	.007933333
20 20	100		250 500	20)	0.0092	0. 0.	0089	0.009	0.	.009033333 .0100666667
Table 6: Dis	se worn mas	s values 1	for non- asbesto	8		Weight loss (g)					
SiC (%)	L oad (N)	Speed (rpm)	Time	(min)	 Trial 1	т	 rial 2	Trial 3	Δ	verage
10	50	11)	250	10)	0.0075	0	007	0.0062	0	0060
10	100		500	14	5	0.0073	0.	0111	0.0107	0.	010666667
10	150		750	20	,)	0.0126	0	0119	0.013	0	0125
15	50		500	20	,)	0.006	0.	0052	0.0059	0	0057
15	100		750	10)	0.0082	0	0076	0.0078	0	007866667
15	150		250	15	5	0.0099	0.	0105	0.0103	0.	.010233333
20	50		750	15	5	0.005	0.	0051	0.0045	0	.004866667
20	100		250	20)	0.0073	0.	0076	0.0083	0.	.007733333
20	150		500	10)	0.0083	0.	0089	0.0095	0.	.0089
Table 7: An	alvsis of va	riance wit	th semi metallic	brake pad		Table 11: A	nalysi	s of variance (ii	i)		
Factors	а <u>јулу от</u> та Т	Types	Levels	cruite put	Values	Source	df	Adj SS	Adj MS	F-value	p-values
SiC (%)	F	Fixed	3		10,15,20	SiC (%)	2	0.000137	0.000068	37.49	0.026
Load (N)	F	Fixed	3		50,100,150	Load (N)	2	0.000024	0.000012	6.660	0.131
Time (min)	F	Fixed	3		10,15,20	Time (min)	2	0.000006	0.000003	1.600	0.385
			-		-, -, -	Error	2	0.000004	0.000002		
Table 8: An	alysis of va	riance (i)				Total	8	0.000171			
Source	df A	dj SS	Adj MS	F-value	p-values	T-11-12-1	r	(!)			
SiC (%)	2 0	.000017	0.000009	48.14	0.020	Table 12: N	lodel s	summary (11)	52		52 (1)
Load (N)	2 0	.000023	0.000011	62.73	0.016	S		R ²	R^2 (ac	<u>1</u>])	R ² (pred)
Time (min)	2 0	.000002	0.000001	6.13	0.140	0.0013502		97.86%	91.44	.%	56.68%
Error	2 0	.000000	0.000000								
Total	8 0	.000042				Table 13: A	nalysi	s of variance w	ith non-asbest	os brake pa	nd Malaaa
T-1-1- 0- M-	4 - 1	(1)				Factors SiC (%)		Types Fixed	Levels		Values
Table 9: Mo		ry (1)	D ² (1)		52 (1)	$L \text{ ord } (\mathbf{N})$		Fixed	3		50 100 150
<u>s</u> 0.0004262	R ² 99	15%	R ² (adj) 96 61%		R ² (pred) 82 84%	Time (min)		Fixed	3		10,15,20
0.0004202		.1.5 /0	70.0170		02.0470	ara tahul	atad	and are a	hown in 7	Cabla 16	10 The
Table 10: A	nalysis of v	ariance w	ith CI brake pac	l		are tabul	ateu ntel	and are sl	ere carried	$a \cup e = 10$	rio. 116
Factors	1	ypes	Levels		Values	caperinte	11111	anarysis W			asing tilt
SiC (%)	F	Fixed	3		10,15,20	commerc	al so	Itware the real	sults were a	nalysed a	ind plotted
Load (N)	F	Fixed	3		50,100,150	as shown	in F	Fig. 6a-c. In	Fig. 6a-c,	it is obse	erved that
Time (min)	I	Fixed	3		10,15,20	there is no	o mu	ch variation	in coefficie	nt of fric	tion value

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Fig. 5(a-c): (a) Disc worn mass graph for Al-SiC disc using semi metallic brake pad, (b) Disc worn mass graph for Al-SiC disc using cast iron brake pad and (c) Disc worn mass graph for Al-SiC disc using non-asbestos brake pad

Table 14: Analysis of variance (iii)

Source	df	Adj SS	Adj MS	F-value	p-values
SiC (%)	2	0.000013	0.000007	399.07	0.002
Load (N)	2	0.000034	0.000017	1038.50	0.001
Time (min)	2	0.000001	0.000001	32.40	0.030
Error	2	0.000000	0.000000		
Total	8	0.000048			

Table	15: Model summary (iii)
a	P)

S	R ²	R^2 (adj)	R ² (pred)
0.0001281	99.93%	99.73%	98.62%

for 10, 15 and 20% Al-SiC composite but it is slightly lower in the case of 15% Al-SiC for semi metallic and non-asbestos brake pad materials. However, it is interesting to note that friction coefficient is higher in the case CI brake pad for 15% Al-SiC in comparison with the other two composites 10% Al-SiC and 20% Al-SiC. It is



Fig. 6(a-c): (a) Coefficient of friction graph for semi metallic brake pad, (b) Coefficient of friction graph for cast iron brake pad and (c) Coefficient of friction graph for non-asbestos brake pad

observed that as the load increases the friction coefficient gets reduced probably due to the formation of oxide layer on the surface of disc. The influence of running time duration on friction coefficient is much less compared to the load applied.

Wear analysis of brake pad: The wear of brake pads were measured during experimentation and using the commercial software the results were analysed and plotted as shown in Fig. 7a-c. From Fig. 7a-c, it is clearly understood that CI pad wear is less in comparison with semi metallic and non-asbestos brake pad. This may be due to the presence of graphite flakes which acts as a lubricant thereby reducing the wear of pad (Table 19-21).

From Fig. 7a-c, it is noted that the pad wear increases with increase in percentage of SiC in Al-SiC composites. This is due to the presence of higher percentage of SiC

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1 4010 1	o. Frictional force va	nues for senii metanii	c brake pau					
SiC	Load (N)	Speed (rpm)	Time (min)	Trial 1	Trial 2	Trial 3	Average	Average/Load (u)
10	50	250	10	46	54	5.8	5.26	0 1052
10	100	500	15	5.2	4.5	4.5	173	0.0473
10	150	750	20	2.2	4.5	4.5	4.75	0.0475
10	150	730	20	2.3	4.1	4.9	3.70	0.023007
15	50	500	20	4.2	4.1	2.9	3./3	0.0746
15	100	750	10	4.4	4.8	3.1	4.1	0.041
15	150	250	15	3.4	4.7	5	4.36	0.029067
20	50	750	15	4.2	3.8	4.6	4.2	0.084
20	100	250	20	3.1	4.8	4.2	4.0	0.04
20	150	500	10	4.1	3.8	39	3.93	0.0262
<u> </u>								
Table 17	7: Frictional force va	alues for cast iron						
SiC	Load (N)	Speed (rpm)	Time (min)	Trial 1	Trial 2	Trial 3	Average	Average/Load (µ)
10	50	250	10	4.2	4.7	3.9	4.266	0.08532
10	100	500	15	3.7	3.9	2.2	3.266	0.03266
10	150	750	20	4.2	3.6	4.9	4.233	0.02822
15	50	500	20	4.9	4.7	4.6	4.733	0.09466
15	100	750	10	4.5	3.7	3.8	4.0	0.04
15	150	250	15	5.1	4.2	37	4 33	0.028867
20	50	250	15	3.1	57	3.0	4.35	0.020007
20	100	250	20	2.2	J./	5.9	4.5	0.000
20	100	250	20	3.8	4.8	4.3	4.3	0.043
20	150	500	10	3.3	3.8	3.7	3.6	0.024
Table 19	8: Frictional force va	dues for non asbestos						
SiC	Load (N)	Speed (rpm)	Time (min)	Trial 1	Trial 2	Trial 3	Average	Average/Load (II)
10	50	250	10	13	1.2	41	43	0.086
10	100	500	10	4.5	4.2	4.2	4.5	0.000
10	100	500	15	4.0	4./	4.2	4.5	0.045
10	150	750	20	3.3	5.1	4.2	4.2	0.028
15	50	500	20	3.2	4.4	4.2	3.933	0.07866
15	100	750	10	5.1	4.2	3.2	4.166	0.04166
15	150	250	15	2.6	4.1	5.2	3.966	0.02644
20	50	750	15	4.2	4 1	4.1	4 1 3 3	0.08266
20	100	250	20	7.5	5.1	4.2	56	0.056
20	150	500	10	5.2	4.1	4.4	1.56	0.0304
20	150	500	10	5.2	7.1		4.50	0.0504
Table 19	9: Brake pad worn m	hass values for semi m	netallic brake	pad				
SiC		G 1 ()		- (!)	$T_{-1} = 1 + 1 - 1$	$T_{-1} = 10(-)$	Trial 2(a)	
	Load (N)	Speed (rpm)) Tim	e (min)	Irial I(g)	1 rial Z(g)	111a1 J(g)	Average
10	Load (N) 50	Speed (rpm) 250) Tim	10	$\frac{1 \operatorname{Hal} 1(g)}{0.012}$	$\frac{1 \text{ fial } 2(g)}{0.012}$	0.011	Average 0.011667
10	Load (N) 50	250 500) Tim	10 15	0.012 0.013	0.012 0.015	0.011	0.011667
10 10	Load (N) 50 100	Speed (rpm) 250 500 750) Tim	10 15 20	0.012 0.013	0.012 0.015 0.018	0.011 0.014 0.021	Average 0.011667 0.014 0.010222
10 10 10	50 100 150	Speed (rpm) 250 500 750) Tim	10 15 20	0.012 0.013 0.019	0.012 0.015 0.018	0.011 0.014 0.021	0.011667 0.014 0.019333
10 10 10 15	50 100 150 50	Speed (rpm) 250 500 750 500) Tim	10 15 20 20	0.012 0.013 0.019 0.015	0.012 0.015 0.018 0.014	0.011 0.014 0.021 0.016	0.011667 0.014 0.019333 0.015
10 10 10 15 15	50 100 150 50 100	Speed (rpm) 250 500 750 500 750) Tim	10 15 20 20 10	0.012 0.013 0.019 0.015 0.022	0.012 0.015 0.018 0.014 0.020	0.011 0.014 0.021 0.016 0.019	Average 0.011667 0.014 0.019333 0.015 0.020333
10 10 10 15 15 15	Load (N) 50 100 150 50 100 150	Speed (rpm) 250 500 750 500 750 250) Tim	10 15 20 20 10 15	0.012 0.013 0.019 0.015 0.022 0.025	0.012 0.015 0.018 0.014 0.020 0.029	0.011 0.014 0.021 0.016 0.019 0.024	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026
10 10 10 15 15 15 20	Load (N) 50 100 150 50 100 150 50	Speed (rpm) 250 500 750 500 750 250 750) <u> </u>	10 15 20 20 10 15 15	0.012 0.013 0.019 0.015 0.022 0.025 0.023	0.012 0.015 0.018 0.014 0.020 0.029 0.026	0.011 0.014 0.021 0.016 0.019 0.024 0.024	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333
10 10 15 15 15 20 20	Load (N) 50 100 150 50 100 150 50 100	Speed (rpm) 250 500 750 500 750 250 750 250 250	<u>) 11m</u>	10 15 20 20 10 15 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 20 15 20 20 20 20 15 20 20 20 20 20 20 20 20 20 20	0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029	0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033	0.011 0.014 0.021 0.016 0.019 0.024 0.024 0.035	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333
10 10 15 15 15 20 20 20	Load (N) 50 100 50 100 150 50 100 150 100	Speed (rpm) 250 500 750 500 750 250 750 250 500	<u>) 11m</u>	e (mn) 10 15 20 10 15 20 10 15 20 10 15 15 20 10 15 10	0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	0.012 0.015 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036	0.011 0.014 0.021 0.016 0.019 0.024 0.024 0.024 0.035 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.0326667
10 10 15 15 20 20 20	Load (N) 50 100 150 50 100 150 50 100 150	Speed (rpm) 250 500 750 500 750 250 750 250 750 250 750 500 750 250 750 250 500) 11m	e (mn) 10 15 20 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 20 10 15 15 20 20 15 15 15 15 15 15 15 15 15 15	0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036	$\begin{array}{c} 0.011\\ 0.014\\ 0.021\\ 0.016\\ 0.019\\ 0.024\\ 0.024\\ 0.035\\ 0.039\\ \end{array}$	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667
10 10 15 15 20 20 Table 20	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m	Speed (rpm) 250 500 750 500 750 250 750 250 500 ass values for non as) 1 im	e (mn) 10 15 20 20 10 15 15 20 10 20 10 20 20 10 20 20 20 10 20 20 20 20 20 20 20 20 20 2	0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036	0.011 0.014 0.021 0.016 0.019 0.024 0.024 0.024 0.035 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667
10 10 15 15 20 20 <u>Table 20</u> <u>SiC</u>	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N)	Speed (rpm) 250 500 750 500 750 250 750 250 500 mass values for non as Speed (rpm)) 11m bestos brake p) Tim	e (min) 10 15 20 20 10 15 15 20 10 10 bad e (min)	Intal 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	0.012 0.015 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036 Trial 2(g)	0.011 0.014 0.021 0.016 0.019 0.024 0.024 0.035 0.039 Trial 3(g)	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667
10 10 10 15 15 20 20 20 <u>Table 20</u> <u>SiC</u> 10	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50	Speed (rpm) 250 500 750 500 750 250 750 250 750 250 500 500 750 250 500 300 ass values for non as Speed (rpm) 250) 11m bestos brake [) Tim	e (mn) 10 15 20 20 10 15 15 20 10 15 15 20 10 10 10 10 10 10 10 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 15 20 20 10 15 15 20 10 10 10 10 10 10 10 10 10 1	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Inal 2(g) 0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036 Trial 2(g) 0.018	0.011 0.014 0.021 0.016 0.024 0.024 0.024 0.024 0.035 0.039 Trial 3(g) 0.016	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032667
10 10 10 15 15 20 20 <u>Table 20</u> <u>SiC</u> 10 10	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100	Speed (rpm) 250 500 500 750 250 750 250 750 250 750 250 500 750 250 500 ass values for non as Speed (rpm) 250 500) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 10 \\ 15 \\ 15 \\ 15 \\ 10 \\ 10$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036	0.011 0.014 0.021 0.016 0.024 0.024 0.024 0.024 0.035 0.039 Trial 3(g) 0.016 0.018	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 Average 0.015 0.015667
10 10 10 15 15 15 20 20 20 Table 20 SiC 10 10	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150	Speed (rpm) 250 500 750 500 750 250 750 250 750 250 750 250 750 250 500 ass values for non as Speed (rpm) 250 500 750) 1im bestos brake p) Tim	$\begin{array}{c} e(min) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ nad \\ e(min) \\ 10 \\ 15 \\ 20 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021	Trial 3(g) 0.011 0.014 0.021 0.016 0.024 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667 Average 0.015 0.015 0.015667 0.023
10 10 10 15 15 20 20 <u>Table 20</u> <u>SiC</u> 10 10 15	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150	Speed (rpm) 250 500 750 250 750 250 500 mass values for non as Speed (rpm) 250 500 750 250 500) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ pad \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 20 \\ 20 \\ \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.018 0.018 0.016 0.024	0.011 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667 Average 0.015 0.015 0.016667 0.023 0.026333
10 10 10 15 15 20 20 20 <u>Table 20</u> <u>SiC</u> 10 10 15 15 15 15 20 20 20 20 20 20 10 10 15 15 15 15 15 15 15 15 15 15	<u>Load (N)</u> 50 100 150 50 100 150 0: Brake pad worn m <u>Load (N)</u> 50 100 150 50	Speed (rpm) 250 500 750 500 750 250 500 ass values for non as Speed (rpm) 250 500 750 250 500 750 250 500 750 250 500 750 250 500 750 250 500 500 750 250 500 500 750 250 500 500 500 750 250 500 500 500 500 500 500 5) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ \hline \\ n \\ 10 \\ 15 \\ 20 \\ 20 \\ 20 \\ 10 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.018 0.016 0.021	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.025 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 Average 0.015 0.015667 0.023 0.026333 0.026333 0.026333
10 10 10 10 10 15 15 20 20 20 20 20 20 10 10 10 15 15	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150	Speed (rpm) 250 500 750 250 750 250 750 250 500 ass values for non as <u>Speed (rpm)</u> 250 500 750 500 50) 11m bestos brake p) Tim	$\begin{array}{c} e(min) \\ 10 \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ pad \\ e(min) \\ 10 \\ 15 \\ 20 \\ 20 \\ 20 \\ 10 \\ \hline \\ \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036 Trial 2(g) 0.016 0.021 0.024 0.031	Trial 3(g) 0.011 0.014 0.021 0.016 0.024 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029 0.033	Average 0.011667 0.014 0.019333 0.015 0.026 0.024333 0.032333 0.036667 Average 0.015 0.015 0.015 0.02333 0.023 0.026333 0.026333 0.026333 0.026333 0.026333
10 10 10 10 15 15 20 20 20 SiC 10 10 15 15 16 17 18 15 15 15 15 15	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150	Speed (rpm) 250 500 750 250 750 250 500 1ass values for non as Speed (rpm) 250 500 750 250) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.016 0.021 0.024 0.031 0.040	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.029 0.033 0.04	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667 Average 0.015 0.015 0.015 0.015 0.015667 0.02333 0.026333 0.031333 0.039667
10 10 10 15 15 20 20 <u>Table 20</u> <u>SiC</u> 10 10 15 15 20 20 <u>SiC</u> 10 10 15 20 20 20 20 20 20 20 20 20 20	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 50	Speed (rpm) 250 500 750 250 750 250 500 mass values for non as Speed (rpm) 250 500 750 500 750 250 500 750 250 500 750 500 750 250 500 750 750 250 500 750 750 250 500 750 750 250 500 750 750 750 750 750 750 7) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ \hline \\ pad \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.018 0.016 0.021 0.024 0.031 0.040	0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.018 0.029 0.033 0.04 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667 0.015 0.015667 0.023 0.026333 0.031333 0.039667 0.035333
10 10 10 10 10 15 15 20 20 20 20 20 20 10 10 10 15 15 20 20	<u>Load (N)</u> 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100	Speed (rpm) 250 500 750 500 750 250 750 250 500 300 ass values for non as Speed (rpm) 250 500 750 250 500 750 500 750 500 750 250 750 250 750 250 750 250 750 250 750 250) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ nd \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021 0.024 0.031 0.040 0.032 0.042	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.023 0.033 0.04 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015 0.015 0.015667 0.023 0.026333 0.036637 0.035333 0.036667
10 10 10 10 10 15 20 20 20 20 20 20 10 10 10 10 15 15 20 20	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150	Speed (rpm) 250 500 750 500 750 250 750 250 500 300 ass values for non as Speed (rpm) 250 500 750 250 500 750 500 750 500 750 250 750 250 750 250 750 250 750 250 750 250 750 250 500) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ nd \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035 Trial 1(g) 0.011 0.013 0.022 0.035 0.036 0.037	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021 0.024 0.031 0.040 0.032 0.042	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029 0.033 0.04 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015 0.015 0.01667 0.02333 0.026333 0.031333 0.039667 0.035333 0.042667 0.042667
10 10 10 10 10 15 15 20 20 20 20 20 20 10 10 10 15 15 20 20	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150	Speed (rpm) 250 500 750 500 750 250 750 250 500 ass values for non as Speed (rpm) 250 500 750 250 500 750 500 750 500 750 250 750 250 750 250 750 250 750 250 750 250 750 250 500) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ nd \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \end{array}$	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.029 0.035 Trial 1(g) 0.011 0.012 0.022 0.035 0.030 0.035 0.035 0.035 0.041 0.049	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021 0.024 0.031 0.040 0.032 0.042	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029 0.033 0.04 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015 0.0155 0.015667 0.02333 0.026333 0.031333 0.039667 0.035333 0.042667 0.042667
10 10 10 10 10 15 15 20 20 20 20 20 20 10 10 10 15 15 20 20 10 10 15 20 20 20 20 20 20 20 20 20 20 20 20	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 100 150 100 150	Speed (rpm) 250 500 750 500 750 250 750 250 500 250 500 250 500 hass values for non as Speed (rpm) 250 500 750 500 750 250 750 250 750 250 750 250 750 250 750 250 500) 11m bestos brake p) Tim	$\begin{array}{c} e(mn) \\ 10 \\ 10 \\ 15 \\ 20 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ pad \\ e(mn) \\ 10 \\ 15 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ \hline \\ 15 \\ 15 \\ 20 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 15 \\ 15 \\ 20 \\ 10 \\ 10 \\ 10 \\ 10 \\ 10 \\ 10 \\ 10$	1111 (g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.018 0.016 0.021 0.024 0.031 0.040 0.032 0.042 0.046	Trial 3(g) 0.011 0.014 0.021 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.018 0.026 0.029 0.033 0.04 0.039	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015 0.015667 0.023 0.026333 0.036633 0.039667 0.035333 0.039667 0.035333 0.042667 0.047667
10 10 10 10 15 15 20 20 20 20 20 20 20 10 10 15 15 20 20 20 20 20 20 20 20 20 20 20 20 20 20 SiC	Load (N) 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 0: Brake pad worn m 100 150 50 100 150 50 100 150 50 100 150 100 150 100 150 1: Brake pad worn m Load (N)	Speed (rpm) 250 500 750 500 750 250 750 250 750 250 750 250 750 250 500 ass values for non as Speed (rpm) 250 500 750 250 750 250 750 250 500 750 250 500 250 500 250 500 250 500 ass values for cast incomponent for cast inco) 1im bestos brake p) Tim) Tim on	e (min) 10 10 10 15 20 20 10 15 15 20 10 0 e (min) 10 15 20 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 15 20 10 15 15 15 15 15 15 15 15 15 15 15 15 15	1111 (g) 0.012 0.013 0.019 0.022 0.023 0.029 0.035 Trial 1(g) 0.011 0.013 0.022 0.035 Trial 1(g) Trial 1(g) Trial 1(g)	Trial 2(g) 0.012 0.015 0.018 0.014 0.020 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021 0.024 0.031 0.040 0.032 0.046 Trial 2(g)	Trial 3(g) 0.011 0.014 0.021 0.016 0.024 0.024 0.035 0.039 Trial 3(g) 0.016 0.029 0.033 0.04 0.035 0.048 Trial 3(g)	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015 0.015667 0.026333 0.039667 0.035333 0.042667 0.047667
10 10 10 10 15 15 20 20 20 20 20 20 10 10 15 15 20 20 10 15 15 20 20 20 20 20 20 20 20 20 20 20 20 20 20 21 310	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 50	Speed (rpm) 250 500 750 500 750 250 750 250 500 750 250 500 3500 hass values for non as Speed (rpm) 250 500 750 250 750 250 750 250 750 250 500 750 250 500 250 500 250 500 250 500 250 500) Tim bestos brake p) Tim) Tim) Tim	e (min) 10 10 15 20 20 10 15 15 20 10 10 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 15 20 20 10 15 15 20 20 10 15 15 20 10 15 20 20 10 15 15 20 10 15 15 20 20 10 15 15 20 10 15 20 10 15 20 20 10 15 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 20 20 10 15 15 20 20 10 15 15 20 20 10 15 15 20 20 10 15 15 20 20 10 15 15 20 20 10 15 15 20 10 15 15 20 10 10 15 15 10 10 10 10 10 10 10 10 10 10	1111 (g) 0.012 0.013 0.019 0.015 0.022 0.023 0.029 0.035	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.016 0.021 0.024 0.032 0.042 0.046 Trial 2(g) 0.002	0.011 0.014 0.014 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.017 0.035 0.039 0.016 0.018 0.029 0.033 0.04 0.039 0.045 0.048 Trial 3(g) 0.001	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.032333 0.036667 Average 0.015 0.036667 0.015 0.015667 0.023 0.026333 0.035333 0.035333 0.042667 0.047667 Average 0.001333
10 10 10 10 10 15 15 20 20 <u>Table 20</u> <u>SiC</u> 10 10 15 15 20 20 <u>Table 20</u> 20 20 20 20 20 20 20 20 20 20 20 20 20 10 10	Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 0: Brake pad worn m Load (N) 50 100 150 50 100 150 50 100 150 50 100 150 50 100 150 100 150 100	Speed (rpm) 250 500 750 500 750 250 750 250 750 250 500 3500 nass values for non as Speed (rpm) 250 500 750 250 500 750 250 750 250 750 250 500 nass values for cast into Speed (rpm) 250 500) 11m bestos brake p) Tim) Tim	e (min) 10 15 20 20 10 15 15 20 10 10 15 20 10 10 15 20 20 10 15 20 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 20 10 15 15 15 15 15 15 15 15 15 15	Trial 1(g) 0.012 0.013 0.019 0.015 0.022 0.025 0.023 0.029 0.035 Trial 1(g) 0.011 0.013 0.022 0.035 0.030 0.039 0.035 0.041 0.049 Trial 1(g) 0.001 0.002	Trial 2(g) 0.012 0.015 0.018 0.014 0.029 0.026 0.033 0.036 Trial 2(g) 0.018 0.018 0.016 0.021 0.040 0.032 0.042 0.046 Trial 2(g) 0.002	0.011 0.014 0.014 0.016 0.019 0.024 0.035 0.039 Trial 3(g) 0.016 0.019 0.039 0.016 0.018 0.029 0.033 0.04 0.039 0.045 0.045 0.048 Trial 3(g) 0.001	Average 0.011667 0.014 0.019333 0.015 0.020333 0.026 0.024333 0.032333 0.036667 0.015667 0.023 0.026333 0.035333 0.039667 0.035333 0.042667 0.042667 0.047667
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Table 16: Frictional force values for semi metallic brake pad





Fig. 7(a-c): (a) Brake pad worn mass values for semi metallic brake pad, (b) Brake pad worn mass values for non-asbestos brake pad and (c) Brake pad worn mass values for cast iron

abrasives in Al matrix disc. Pad wear in all the pad materials increased due to the increase in load and there is no much influence on it due to the change in time duration of testing.

Analysis of variance was carried using ANOVA considering only three factors SiC%, Load and time for all the brake pads and the results are shown hereunder. In the case of semi metallic brake pad based on F and P value, the order of significance is 1. SiC%, 2. Load and 3. Time. It is also observed that R^2 value is 98.88% and the results obtained for wear are in good agreement with the regression model, since, R^2 >0.8 (Table 22-24).

In the case of non-asbestos brake pad based on F and p-value, the order of significance is 1. SiC%, 2. Load and 3. Time. It is also observed that R^2 value is 98.79% and the results obtained for wear are in good agreement with the regression model, since, R^2 >0.8 (Table 25-27).

Table 22: An	nalysis	of variance w	ith semi metal	lic brake pa	ad			
Factors		Types	Leve	ls	Values			
SiC (%)		Fixed	3	10,15,20				
Load (N)		Fixed	3		50,100,150			
Time (min)		Fixed	3		10,15,20			
Table 23: An	nalysis	of variance (in	v)					
Source	df	Adj SS	Adj MS	F-values	p-values			
SiC (%)	2	0.000403	0.000201	63.00	0.016			
Load (N)	2	0.000160	0.000080	25.04	0.038			
Time (min)	2	0.000003	0.000002	0.49	0.671			
Error	2	0.000006	0.000003					
Total	8	0.000572						
Table 24: Mo	odel su	ummary (iv)						
S		\mathbb{R}^2	R ² (adj)		R ² (pred)			
0.0017884		98.88%	95.53%		77.38%			
Table 25: An	nalysis	of variance w	ith non-asbest	os brake pa	ıd			
Factors		Types	Levels	3	Values			
SiC (%)		Fixed	3		10,15,20			
Load (N)		Fixed	3		50,100,150			
Time (min)		Fixed	3		10,15,20			
Table 26: An	nalysis	of variance (v	·)					
Source	df	Adj SS	Adj MS	F-values	p-values			
SiC (%)	2	0.000877	0.000439	67.13	0.015			
Load (N)	2	0.000192	0.000096	14.71	0.064			
Time (min)	2	0.000002	0.000001	0.14	0.874			
Error	2	0.000013	0.000007					
Total	8	0.001084						
Table 27: Mo	odel su	ummary (v)						
S		\mathbb{R}^2	R ² (adj)		R ² (pred)			
0.0025558		98.79%	95.18%		75.60%			
Table 28: An	nalysis	of variance w	ith CI brake pa	ıd				
Factors		Types	Levels	3	Values			
SiC (%)		Fixed	3		10,15,20			
Load (N)		Fixed	3		50,100,150			
Time (min)		Fixed	3		10,15,20			
Table 29: An	alysis	of variance (v	(1)					
Source	df	Adj SS	Adj MS	F-values	p-values			
SiC (%)	2	0.000041	0.000021	46.64	0.021			
Load (N)	2	0.000007	0.000003	7.59	0.116			
Time (min)	2	0.000001	0.000000	0.58	0.632			
Error	2	0.000001	0.000000					
Total	8	0.000050						
T 11 20 34		<i>/</i> •						
Table 30: Mo	odel su	$\frac{1}{2}$ mmary (v1)	D2 (11)		D ² (1)			
5		K ²	<u>K² (adj)</u>		R ² (pred)			
0.0006663		98.21%	92.83%		63.72%			
In the	case	of CI brak	e pad based	on F an	d p-value.			
the order of significance is 1 SiC% 2 Load and 3 Time								

In the case of CI brake pad based on F and p-value, the order of significance is 1. SiC%, 2. Load and 3. Time. It is also observed that R^2 value is 98.21% and the results obtained for wear are in good agreement with the regression model, since, R^2 >0.8 (Table 28-30).

The SEM images of non asbestos brake pad are shown in Fig. 8a, b. From the images; it is found that there are large quantities of Al particle embedded on the surface of the pad. Moreover, the flaking of the pad material is also seen.



Fig. 8(a, b): SEM images of non-asbestos brake pad after wear test



Fig. 9(a, b): SEM images of semi metallic brake pad after wear test



Fig. 10(a, b): SEM images of cast iron after wear test

The SEM images of semi metallic brake pad are shown in Fig 9a, b. From the images it is found that there are large quantities of Al particle embedded on the surface of the pads. Moreover, the ploughing of the surface of pads are also seen that may be due to abrasive action of SiC.

The SEM images of CI brake pad are shown in Fig. 10a, b. From the images; it is found that there are few quantity of Al particle embedded on the surface of the pads. Moreover, the ploughing of the surface of pad is also seen due to the presence of SiC abrasives in the disc.

CONCLUSION

Al-SiC with 10, 15 and 20% silicon carbide-reinforced Al 6061 metal matrix composite discs were cast using stir casting and machined to fit in the pin on disc tribometer. The disc made of 20% of the SiC particles with Al 6061 matrix worn less in comparison with the other two percentages of SiC viz. 10 and 15%

discs. The wear rate varied directly with the applied normal load and the sliding speed and the load has a major effect on the wear of the Al-SiC disc in comparison with time. Of the three brake pad materials used in this study, CI brake pad has given a better wear characteristic with 20% Al-SiC disc.

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