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Wear Rate Investigation of Aluminium Based Silicon Carbide Metal Matrix Composite Embedded with Copper

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***Abstract*—**
The applications of Metal Matrix Composites (MMCs) are being increasing day by day in the aerospace, automobile and many more industries, because of their improved properties compared to uniform metals. Presently several grades of Aluminium Matrix Composites (AMCs) have been utilized in high-tech structural and functional applications including aerospace, defence, automotive, and thermal management areas, as well as in sports and recreation. This trend has been attributed to their superior specific strength and specific stiffness, high temperature capability, lower coefficient of thermal expansion, better wear resistance, improved dimensional stability, and responsiveness to conventional metal forming techniques. This report is concerned with Aluminium Matrix Composites and more specifically on the Aluminium (Al) based Silicon Carbide (SiC) metal matrix composite Embedded with Copper. The main aim of this project is to check feasibility of the Aluminium based Silicon Carbide metal matrix composite for passenger vehicle brake lining. Through this dissertation an attempt is made to test the tribological behavior of the Aluminium based Silicon Carbide metal matrix composite. The composite is formed by powder metallurgy route followed by hot extrusion. Two composites are prepared for the testing, one is composite of Al + 25% SiC while other is composite of Al + 25% SiC embedded with 5% Copper. The wear test is carried out for these composites both at ambient and elevated temperature by using pin on disc method. Pins are made of composite and tested against cast iron disc. The wear affecting parameters such as normal load, sliding speed and temperature are varied and tribological properties are observed. Also the results of the composite are compared with the results of conventional brake lining material. The results reveals that the addition of silicon carbide and copper reduces wear of the composite.

Index Terms*— *Metal Matrix Composite, Silicon Carbide, Wear

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I. INTRODUCTION

WEAR is a mechanism of removal of material from one surface body with respect to other surface. Factors governing the wear are material properties such as hardness, strength, ductility, surface finish, work hardening, lubrication, load, speed, corrosion, temperature. Types of wear are Adhesive Wear, Abrasive Wear, Erosive Wear, Cavitation Wear etc. It is possible to investigate on inappropriate friction material to get coefficient of friction within limits for the automobile applications. The friction material properties have to be like good resistance to severe temperatures, low compressibility and good resistance to wear [3]. The term “composite” broadly denotes a material system which is poised of a discrete constituent (the reinforcement) dispersed in a continuous phase (the matrix). Particle reinforced composites are light metals & already attracting the attention of materials producers and end users because of their admirable mechanical and physical properties. The major attractions for the use of metal matrix composites in the automotive industry are reduction in mass especially in engine parts, improved wear resistance or lubrication characteristics, improved material properties, particularly stiffness and strength, providing either increased component strength or allowing more extreme service conditions, minimized thermal expansion coefficient. The silicon carbide reinforced Aluminium composites are used as alternative materials for pistons, cylinder heads, brake rotors & calibers in automobile industry [2].

This review is concerned with Aluminium matrix composites (AMCs). The composite is formed by powder metallurgy route followed by hot extrusion. Two composites are prepared for the testing, one is composite of Al + 25% SiC while other is composite of Al + 25% SiC embedded with 5% Copper. The wear test is carried out for these composites both at ambient and elevated temperature by using pin on disc method. Pins are made of composite and tested against cast iron disc. The wear affecting parameters such as normal load, sliding speed and temperature are varied and tribological properties are observed. Also the results of the composite are compared with the results of conventional brake lining material.

II. LITERATURE SURVEY

Presently several grades of AMCs are manufactured and have been utilised in high-tech structural and functional applications such as defence, aerospace, automotive etc. This chapter covers research statistics carried out by various authors.

G. Straffelini, M. Pellizzari, A. Molinari investigated effect of load & external heating on friction & wear behaviour of two Al based metal matrix composite (SiC10 & SiC20 containing 10 % & 20 % volume of reinforcement of silicon carbide particle) dry sliding against brake lining material. In actual brake systems, the nominal contact pressure typically varies between 0.3 and 2MPa and the sliding velocity between 1 m/s and above 10 m/s. External heating causes decrease in wear of both composite (negative wear) & decrease in friction coefficient & increase in wear of counter face friction material. As far as wear resistance of metal matrix composite disc is concerned external heating is advantageous since it allows formation of transfer layer. [2]

R. K. Uyyuru, M. K. Surappa, S. Brusethaug reported tribological behaviour of stir cast Al-SiC composite sliding against brake lining material on pin on disc apparatus. The coefficient of friction was about 0.3 & it decreases with increase in load. The coefficient of friction decreases with increase in sliding speed. With increase in sliding speed wear rate decreases for all composites. The presence of depressions in tribolayer was due to breaking of layer in trashes which may lead to abrasive wear. [5]

Rabindra Behera, S.Kayal, N.R. Mohanta, G.Sutradhar presented the effect of machining parameters such as cutting forces and surface roughness on the machinability of Al Alloy-SiCp metal matrix composites at different weight fraction of SiCp. Machining tests were carried out at various cutting speed and different depth of cuts at constant feed rate. It is observed that higher weight percentage of SiCp reinforcement imparts a higher surface roughness and needs high cutting forces. The surface roughness of MMCs increased on increasing the weight percentage of SiC pin the matrix metal and it increases on increasing the depth of cut at constant feed rate and different cutting speed. On increasing the cutting speed at constant feed rate and different depth of cut, the surface roughness decreases. [6]

Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas Chawla developed Aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain consistent dispersion of ceramic material. To accomplish these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made. Aluminium and SiC has been chosen as matrix and reinforcement material respectively. Experiments have been conducted by varying weight fraction of SiC (5%, 10%, 15%, 20%, 25%, and 30%), while keeping all other parameters constant. An increasing trend of hardness and impact strength with increase in weight percentage of SiC has been observed. The best results (maximum hardness 45.5 BHN & maximum impact strength of 36 N-m.) have been obtained at 25% weight fraction of SiC. [7]

Faramarz Talati, Salman Jalalifar carried out Analysis of heat conduction in a disk brake system. Variation of surface temperature of brake disc & brake pad is investigated for particular duration of braking. The maximum surface temperature obtained for brake disc was 200–250OC. The brake pad temperature was 800–900OC. [8]

S. Suresha, B.K. Sridhara investigated dry sliding wear behaviour of Al matrix composites reinforced with Gr & Sic particulate up to 10 % against EN31 steel disc. The increase in wear with increase of load in Al-SiC-Gr hybrid composite. At higher load it weakens tribolayer & lead to severe wear. [10]

A. Rehman, S. Das, G. Dixit reported the analysis of Aluminium alloy–Silicon Carbide MMC (Al–SiC MMC) in the automobile brake drum applications in comparison with cast iron (CI) brake drum. Al–SiC MMC was reinforced with 10% and 15% SiC particle by weight. The essence of this work is that Al–SiC MMC can be effectively used in brakes in automobiles due to its comparative coefficient of friction. It is of interest to note that brake drum and brake shoe interface temperatures with all composite material brake drum are lower than that observed with CI brake drums. Interface temperature has an important effect on the coefficient of friction of the braking surfaces which affects braking efficiency of the brake drums. Coefficient of friction with composite material is higher due to the existence of SiC particles in the aluminium alloy. [11]

III. PROBLEM STATEMENT

During braking action brake pad comes in contact with disc & with increase in braking leads to maximum wear of semi-metallic lining material, increase in temperature of brake pad, formation of hot spots on brake disc and formation of grooves on brake pads, brake fading, surface cracks, plastic deformation excessive wear leading to failure of brake system. This problem gives out a way for development of composite & evaluation of its tribological characteristics. The objective of this report is to compare friction & wear behaviour of semi-metallic lining material (brake pad), Al-25%SiC and Al-25%SiC-5%Cu Metal Matrix Composite as pin materials with Grey Cast Iron as disc material having chemical composition same as that of brake disc of actual passenger vehicle on pin on disc apparatus under ambient & elevated temperature by pin heating.

IV. METHODOLOGY

For the evaluation of tribological characteristic of materials under study is to be carried out on pin on disc apparatus TR20PHM400.

A. Specimen preparation

Specimens are used are as follows,

Pin: semi-metallic lining material (brake pad), Al-25%SiC and Al-25%SiC-5%Cu Metal Matrix Composite
Disc: Grey Cast Iron disc.

1) Semi-metallic lining material:
The Semi-Metallic Lining Material majorly consists of Phenolic resin, Asbestos fiber, copper, Zinc, Iron and other various binders and additives.

2) Aluminium:
The strength and hardness of Aluminium at temperatures are high enough for use in such applications. The machinability of Aluminium is superior. Resistance to atmospheric corrosion is good. It may be anodized adequately by the sulphuric acid process. Anodizing, which produces an oil absorbing surface, is sometimes used to give improved bearing qualities to pistons. The particular characteristics which determine the applications of Al are its retention of strength and hardness at elevated temperatures, its low coefficient of thermal expansion and its high resistance to wear.

3) Silicon Carbide:
Silicon Carbide is the only chemical compound of carbon and silicon. Silicon carbide is an excellent abrasive. Today the material has been developed into a great quality technical grade ceramic with very decent mechanical properties. The melting point is 2700ºC with density 3.2 g/cm^3. It is used in refractories, abrasives, ceramics and numerous high-performance applications. Silicon carbide is hard and strong material. The high thermal conductivity coupled with low thermal expansion and high strength give this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600ºC with no strength loss. Some of the properties of Silicon Carbide are Low density, high strength, Low thermal expansion, High thermal conductivity, high hardness, High elastic modulus and excellent thermal shock resistance.

4) Copper:
Properties of Copper are Good thermal conductivity, Ductile, Easy to alloy, Nonmagnetic, Tough and Corrosion resistant

5) Grey Cast Iron:
The Grey Cast Iron material consists of Iron as a major constituent and additives as Carbon, Manganese, Phosphor, Sulphur and Silicon.

B. Experimental Procedure

In this experimental work wear characteristic of semi–metallic brake pad lining material, Al-25%SiC and Al-25%SiC-5%Cu MMC as pin are to be studied against disc which is having same chemical composition as that of actual brake disc used in vehicles i.e. Grey Cast Iron on pin on disc apparatus (TR20PHM400) at ambient & elevated temperature for duration of 20 minutes.

The semi-metallic brake pad lining material and Aluminium Silicon Carbide MMC as pins having circular cross section of diameter 8 mm & length 30 mm are selected.

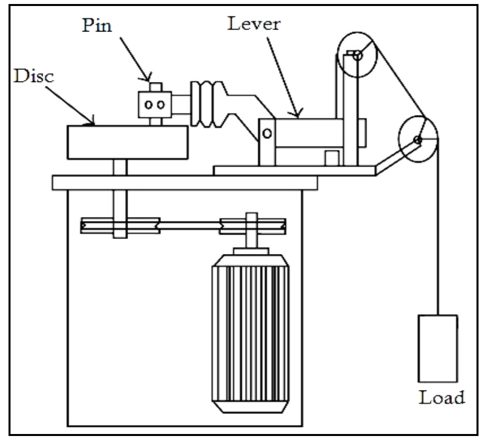

Fig. 1 Pin on disc apparatus

TABLE I
Technical Specification of TR20PHM400

Test Parameter	Values
Specimen pin size	3,6,8,10,12 mm dia. & 25–30 mm long
Wear Disc Size	Dia. 165 mm, 8 mm thick, 1.6 Ra surface roughness
Wear track diameter	Min: 50mm , Max: 100mm, In steps of 1mm
Disc rotation	Min: 200 rpm, Max: 2000 rpm, In steps of 1rpm
Sliding speed	0.5 to 10 m/s
Normal load	5N to 200N, In steps of 5N
Frictional force	0 to 200 N, L.C. of 0.1 N
Wear	Min:1 µm, Max: 2000 µm, L.C. of 1 µm
Temperature	Min: Ambient, Max:4000C, L.C. of 1^{O}C

C. Calculations

1) *Contact Pressure:* The nominal contact pressure acting between brake pad & brake disc is,

$$P = F_N / A$$

Where, P = Pressure acting on disc (MPa)
F_N = Normal load applied on disc (N)
A = Cross sectional area of pin (mm^2)

2) *Sliding Velocity:* For testing the sliding velocity is calculated,

$$V = (\pi * D * N) / 60$$

Where, V = Sliding Velocity (mm/s)
D = Wear Track Diameter (mm)
N = Rotational Speed of disc (rpm)

3) *Coefficient Of Friction:* The coefficient of friction is ratio of frictional force to normal load.

$$\mu = F / F_N$$

Where, μ = Coefficient of friction
F = Frictional force (N)
F_N = Normal load (N)

4) *Wear Volume:* Wear volume is given as

$$W = \Delta H * A$$

Where, W = Wear volume (mm^3)
ΔH = Change in length of pin (mm)
A = Cross sectional area of pin (mm^2)

As the contact pressure between brake pad and disc varies from 0.3 MPa to 2 MPa [2], for test three average values are considered as 0.3 MPa, 1.15 MPa and 2 MPa. By calculations based on cross section of pin the normal loads acting on disc are 15.07 N, 74 N & 100.53 N.

As the sliding velocity for brake pad varies from 1 m/s to above 10 m/s [2], for test three average values are to be considered as 5 m/s, 7.5 m/s &10 m/s.

The temperature selected for elevated temperature condition is same as that of temperature attained by brake pad when brake pad & brake disc comes in contact during braking. The temperatures selected for testing are average temperatures and are 100^{O}C, 200^{O}C & 300 ^{O}C.

TABLE II
Wear Test Parameters

Load (N)	**Sliding Speed (m/s)**	**Temperature (oC)**
19.62	5	100
58.86	7.5	200
98.1	10	300

V. RESULTS

The results from wear test carried out on semi-metallic lining material (brake pad), Al-25%SiC and Al-25%SiC-5%Cu Metal Matrix Composite are as follows,

TABLE III
Result Table for varying Normal Load

Sr. No.	**Material**	**Normal Load (N)**	**Wear (µm)**	**Wear Volume (m3)**	**Friction Force (N)**	**Coefficient of Friction**
1	Semi Metallic pad	19.62	73	$3.67*10^{-09}$	5	0.25
		58.86	224	$1.13*10^{-08}$	11.8	0.20
		98.1	370	$1.86*10^{-08}$	21	0.21
2	Al + 25%SiC	19.62	17	$8.54*10^{-10}$	3.8	0.19
		58.86	109	$5.48*10^{-09}$	19.8	0.34
		98.1	245	$1.23*10^{-08}$	31.5	0.32
3	Al + 25%SiC +5%Cu	19.62	24	$1.21*10^{-09}$	3.7	0.19
		58.86	75	$3.77*10^{-09}$	15.6	0.27
		98.1	155	$7.79*10^{-09}$	25.2	0.26

TABLE IV
Result Table for varying Sliding Speed

Sr. No.	**Material**	**Sliding Speed (m/s)**	**Wear (µm)**	**Wear Volume (m3)**	**Friction Force (N)**	**Coefficient of Friction**
1	Semi Metallic Pad	5	234	$1.18*10^{-08}$	19.6	0.20
		7.5	216	$1.09*10^{-08}$	20.9	0.21
		10	370	$1.86*10^{-08}$	21	0.21
2	Al + 25% SiC	5	137	$6.88*10^{-09}$	32.3	0.33
		7.5	125	$6.28*10^{-09}$	32.6	0.33
		10	245	$1.23*10^{-08}$	31.5	0.32
3	Al + 25%SiC +5%Cu	5	93	$4.67*10^{-09}$	25.2	0.26
		7.5	96	$4.82*10^{-09}$	24.9	0.25
		10	155	$7.79*10^{-09}$	25.2	0.26

TABLE V
Result Table for varying Temperature

Sr. No.	**Material**	**Temperature (oC)**	**Wear (µm)**	**Wear Volume (m3)**	**Friction Force (N)**	**Coefficient of Friction**
1	**Semi Metallic Pad**	100	1136	$5.71*10^{-08}$	22.1	0.23
		200	977	$4.91*10^{-08}$	22.4	0.23
		300	1375	$6.91*10^{-08}$	21	0.21
4	**Al + 25%SiC**	100	291	$1.46*10^{-08}$	25.9	0.26
		200	850	$4.27*10^{-08}$	29.4	0.29
		300	812	$4.08*10^{-08}$	30.3	0.30
3	**Al + 25%SiC +5% Cu**	100	291	$1.46*10^{-08}$	23.2	0.24
		200	770	$3.87*10^{-08}$	24.1	0.25
		300	685	$3.44*10^{-08}$	21.9	0.22

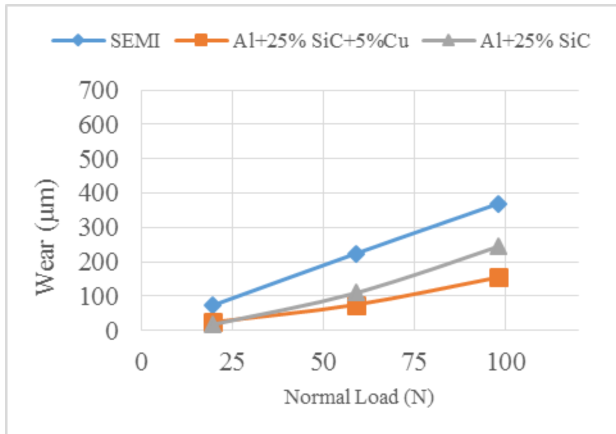

Fig. 2 Wear vs. Normal load

The three showed linear relationship between wear and normal load. The wear increased with increase in the normal load. The composite i.e. Al+25%SiC+5%Cu showed lowest wear.

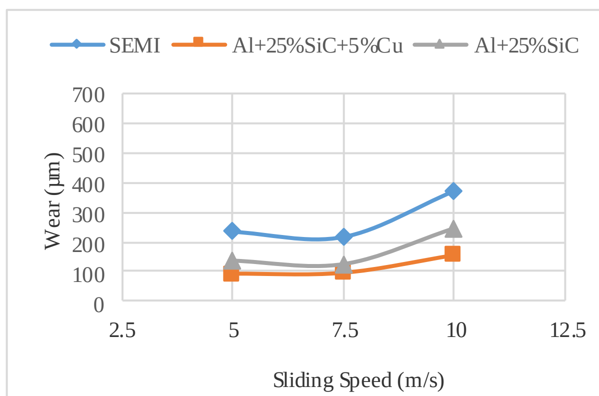

Fig. 3 Wear vs. sliding speed

The wear shown by composites is less than the semi metallic lining material. The composites showed first constant wear up to the sliding speed of 7.5 m/s and then further showed increase in wear.

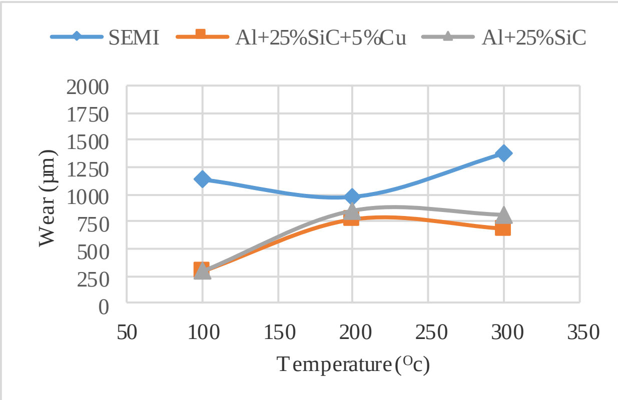

Fig. 4 Wear vs. Temperature

The wear of semi metallic lining material first decreased and then further increased. Among all the three temperatures the wear is maximum for the temperature of 300^{O}C. Wear of the composites first increased and then slightly decreased further.

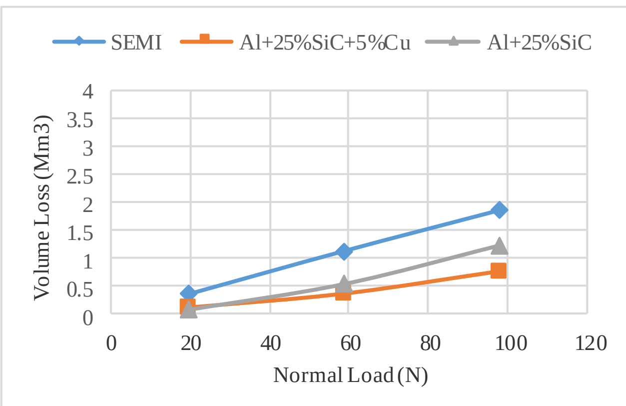

Fig. 5 Volume Loss vs. Normal Load

The three showed linear relationship between volume loss and normal load. The volume loss increased with increase in the normal load. The composite i.e. Al+25%SiC+5%Cu showed lowest volume loss.

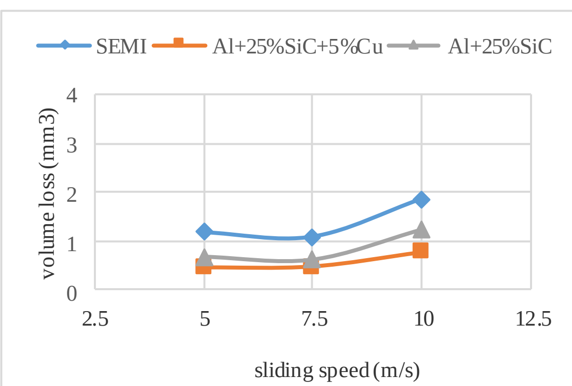

Fig. 6 Volume Loss vs. sliding speed

The Volume Loss shown by composites is less than the semi metallic lining material. The composites showed first constant Volume Loss up to the sliding speed of 7.5 m/s and then further showed increase in Volume Loss.

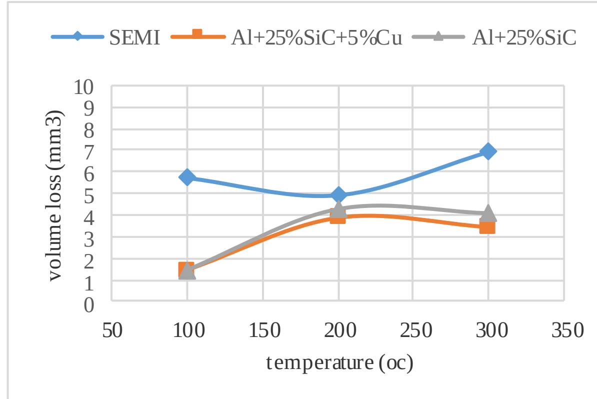

Fig. 7 Volume Loss vs. temperature

The Volume Loss of semi metallic lining material first decreased and then further increased. Among all the three temperatures the Volume Loss is maximum for the temperature of 300^{O}C. Volume Loss of the composites first increased and then slightly decreased further.

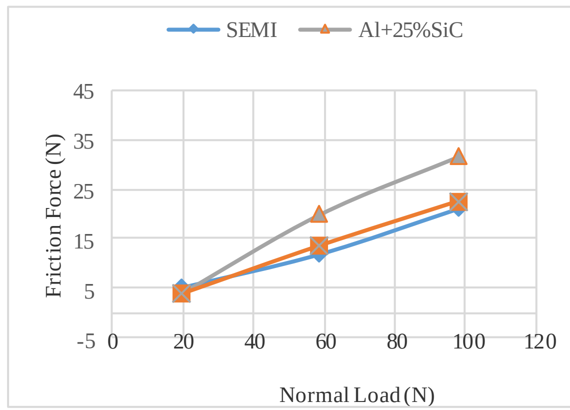

Fig. 8 Frictional Force vs. Normal Load

The Frictional Force increased linearly with increase in the normal load. In this the semi metallic lining material showed less Frictional Force compared to the Composites.

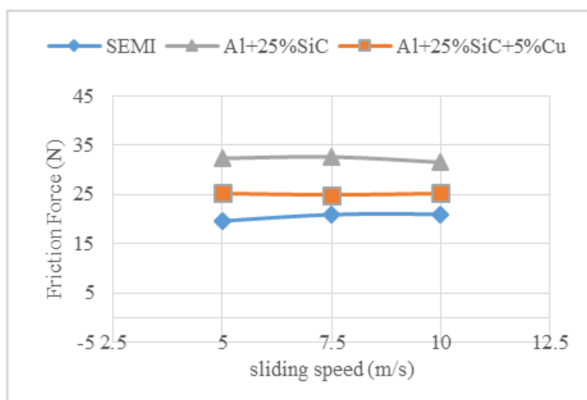

Fig. 9 Frictional Force vs. sliding speed

In this the both materials showed constant Frictional Force over the wide range of the sliding speed. But the friction force for the composite is more than semi metallic lining material.

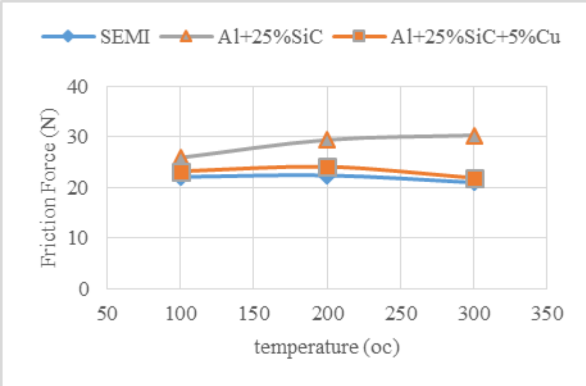

Fig. 10 Frictional Force vs. temperature

The Frictional Force shown by semi metallic lining material is constant with temperature. The composites showed more frictional force than semi metallic lining material.

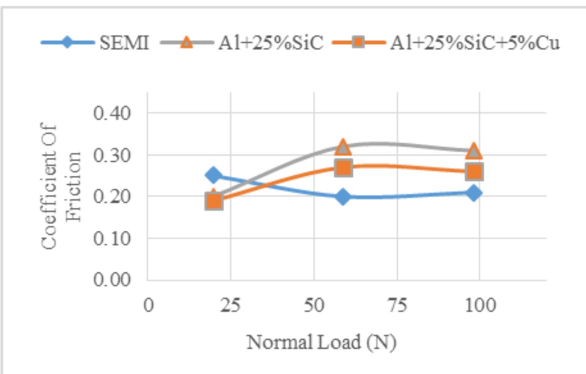

Fig. 11 Coefficient Of Friction vs. Normal Load

For the semi metallic lining material Coefficient Of Friction decreased with Normal Load up to 60N and then it nearly remains constant. The composite showed more Coefficient Of Friction as compared to semi metallic lining material.

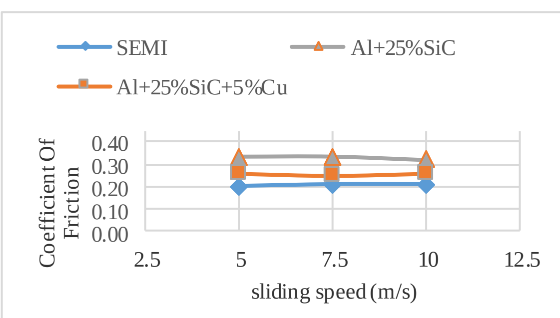

Fig. 12 Coefficient Of Friction vs. sliding speed

In this the semi metallic lining material showed constant Coefficient Of Friction over the wide range of the sliding speed. The composite also showed similar relationship between Coefficient Of Friction and sliding speed as that of semi metallic lining material. But the Coefficient Of Friction for these composites is more than semi metallic lining material.

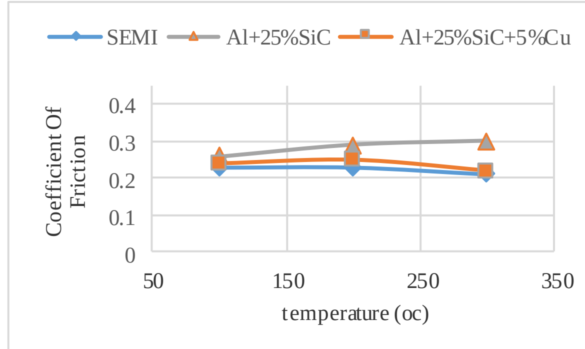

Fig. 13 Coefficient Of Friction vs. temperature

All three materials showed constant Coefficient Of Friction over the wide range of the temperature. The Coefficient Of Friction for the composites is more than semi metallic lining material.

CONCLUSION

The wear and volume loss increases with increase in normal load, sliding speed and temperature. The wear observed is lowest for the composite containing copper as compared to other two materials. This is due to formation of tribolayer at the mating interface which reduces the wear. At extreme conditions of normal load and sliding speed the temperature increases so that there is plastic deformation of copper particles which helps in formation of tribological layer and reducing the wear. The friction force increases with increase in Normal Load. The frictional force for the composite containing copper is lower as compared with composite without copper. But it is more than semi metallic brake lining material. The Coefficient of friction nearly remains constant for all materials. The composite containing copper shows Coefficient of friction lower as compared to composite without copper. This is due to formation of tribolayer which acts as a lubricant in the interface of pin and disc.

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