EXPERIMENTAL EVALUATION OF TRIBOLOGICAL PROPERTIES OF DISC BRAKE PAD MATERIAL

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ABSTRACT

The automobile car disc brakes are safety critical components whose performance depend strongly on contact condition at the pad to disc interface. During braking both brake pad and disc surfaces worn, affecting the useful life of brake as well as its behavior. From the literature, it is found that asbestos is widely used in automobile disc brake pads. But it is found that it may cause cancer to human being because of its carcinogenic nature. Therefore aim of this study is to analyze the effect of different material composition on friction & wear of brake pad. In this study two commercial brake pad materials were considered for investigation i.e. metallic based material and organic based material. The wear test is performed using pin on disk machine by varying the sliding speed, applied load and sliding distance. Full factorial design of three factor-three levels and analysis of variance is used in the study of the wear test. The influence of factors has been identified which can play a key role in wear rate and temperature at the interface of brake disc and brake pad. The wear rate of both metallic and organic pad depends upon load and sliding distance while temperature depends upon load and sliding velocity. The wear rate of metallic pad is more than organic brake pad while temperature developed in organic pad is more than metallic.

Keyword - *Tribological Properties, Carcinogenic, Disc Brake, Friction, Performance, Sliding, Wear. Etc*

1. INTRODUCTION

The main purpose of a brake system is to slow down the vehicle or to stop it completely within a reasonable amount of time. A brake system must be reliable in order to provide the operator with a better control. Any moving vehicle contains kinetic energy by virtue of its motion. The faster the vehicle moves the higher is its momentum or kinetic energy. Most brakes use the principle of friction to convert this kinetic energy into heat energy. The brakes must be store and dissipate all this heat into the surroundings. Over the past centuries as the technology of transportation has increased, the brake systems have also started becoming more reliable and at the same time more complex. During the early 19th century When animal carriages were used for transportation, the animal‘s power was used for both acceleration and deceleration. Slowly, this was replaced by manually applied friction surfaces that were directly applied to the wheel. These friction surfaces were generally made of wood as shown in that it was very difficult to operate in wet conditions.

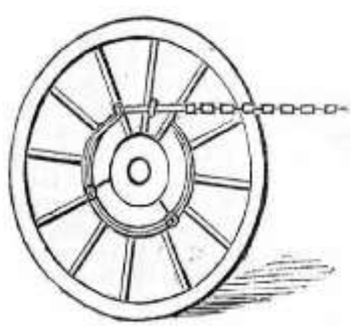


Fig-1: Brake system of a horse-carriage

1.1 Drum Brake System

A drum brake system is consists of hydraulic wheel cylinders, brake shoes and a brake drum. When the brake pedal applied the two curved brake shoes, which have a friction material lining are forced by the hydraulic wheel cylinders against the inner surface of a rotating brake drum. The result of this contact produces friction which enables the vehicle to slow down or stop as shown in following Figure 2.

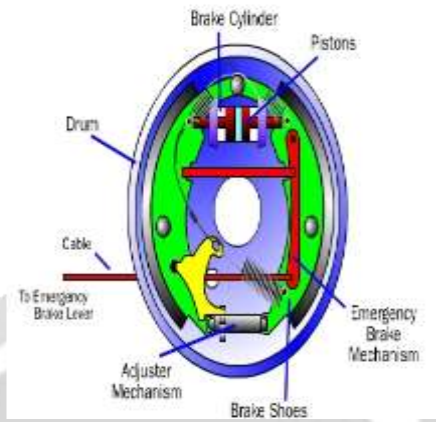


Fig-2: A Drum Brake System

1.2 Disc Brakes

Disc brakes were patented by Frederick William Lanchester in 1902 but the commercially use of these brakes started in the early 1950s. The brake system consists of a rotor made of cast iron or ceramic mounted on to the wheel (Figure 3). To achieve the braking action, the some form of friction material called brake pads is forced onto the disc brake rotor. Piston which moves inside a cylinder pushes the brake pad onto the rotor. This movement of the piston is achieved by the means of a hydraulic fluid. The whole piston-cylinder assembly is machined inside a heavy casting called a caliper.

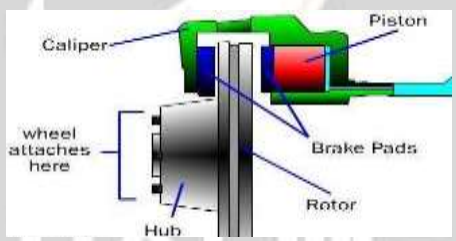


Fig- 3: Disc Brake System

2. OBJECTIVE OF RESEARCH

The objective of this study is to investigate the tribological behavior of brake pad under varying condition for evolving the performance.

- To identify which factors affect the pad material & wear of brake.
- To select the best pair material for brake disc and brake pad.
- To introduce a new alternative for NAO material for brake pad.
- To minimize the wear rate and increase the life of braking pad and disc rotor.
- To experimentally investigate the tribological behavior of brake pad for evolving the coefficient of friction, wear rate and contact temperature.
- To determine significant parameter affecting wear and temperature.
- Comparative study of developed composite material with commercial asbestos based brake pad material

3. METHODOLOGY

The literature review of various research papers related to disc brake pad materials and their effect on friction & wear properties has been done. Then depending upon this literature review the proper material is to be selected. Then next step is to prepare the composite material of selected composition. After preparation of composite material, the specimens of the will be prepared. The experimentation will be done on the basis of Taguchi Array. The results of this experimentation will be analyzed. The specimens of existing brake pad materials are to be prepared and experimentation will be done. The samples of composite will be tested under SEM. The results will be validated by the comparison of developed composite material with existing. Then conclusions will be made depending upon the results.

Factors are selected as per the literature survey i.e. by analyzing the effect of parameters on wear rate and interface temperature. Levels of factors are decided after conducting some pilot experiments for load and sliding distance. Load was varied from 5N to 50N and sliding distance from 1000m to 2000m. The Society of Automotive Engineers (SAE) Handbook contains requirements and testing procedures for automotive braking systems. Without elaborating on the details of every test, the deceleration requirements for in- service brake performance of passenger vehicles and light duty trucks up to 4500 kg is between 1 $m/s^2$and 5 m/s^2 not to exceed 6 m/s^2.The variation in parameters increases with increase in wear rate and temperature at contact point of disc. Full factorial systematically plans for experiments and investigates the wear rate and temperature output response with respect to input factors. Levels and coding for full factorial design of experiments are described in TABLE I

TABLE- I: Input Parameters

Factor Level ↓	Applied Load (N)	Sliding Velocity (m/s)	Sliding Distance (m)
High	50	5	2000
Medium	25	2.5	1500
Low	5	1	1000

3.1 Metallic based brake pad

Metallic based brake pad material was purchased from COMPO-ADVICS, an Aurangabad based brake material provider. It is an asbestos brake material of metallic type which consists of phenolic resin, chemigum rubber, Kaolin clay, Friction dust, tyre peels, iron oxide, Synthetic MgO and barites powder. The applications of these brake pads are in four wheel types automobile and in light trucks. The COMPO- ADVICS have no provision to make a brake pad in the form of pin because that requires special type of mould, so the commercially available brake pad material in its available normal shape is taken and machined to create the material in pin shape.

Fig-4: Commercial metallic brake pad (Full shape)

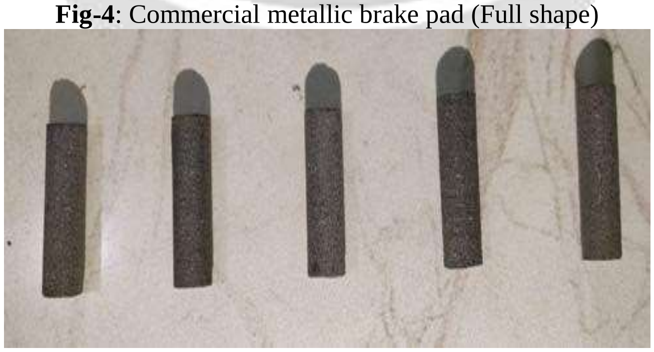


Fig-5: Metallic brake pad in Pin shape

TABLE- II: Physical Properties of Metallic brake pad

Sr. No.	Technical Data	Measured values	Unit
1	Sp. Gravity	2.10	g/cm^3
2	Compressive Strength	200	N/mm^2
3	Hardness	82	Shore D
4	Young's modulus	0.89	GPa
5	Poisons ratio	0.25	-

Commercial metallic brake pad as shown in following Fig 2. First the back plate of pad was removed and then the pad is cut in the rectangular bar. Then rectangular bar was transformed into circular pin of diameter 8 mm and height 25 mm on lathe machine. The end surfaces were finished on grinding wheel to ensure the smooth contact with disc.

3.2 Organic Brake Pad

Organic based brake pad material was procured from CO-EFF friction bands Pune. The non-asbestos friction material is made with extremely high amount of organic and inorganic reinforcing fibres, fine brass fibres, non-ferrous organic binding, special synthetic rubber resins and NBR rubber. It exhibits high friction, mechanical stability, stable friction at high temperatures, excellent wear resistance and salt and water resistance. They are used in four wheel automobiles, hydro generators and wind turbines. Company provided the pad material in block shape as shown in following fig 6.

Fig-6: Organic brake pad

Fig 6**.** Organic brake pad the material was re-machined in pin shape with dimensions 8 mm diameter and 25 mm height on lathe machine. The end surfaces of pin were finished on grinding wheel to ensure the smooth contact with disc during sliding motion. The finished brake pad material in pin shape is shown in Fig.5

Fig-7: Pin of organic pad

TABLE- III: Physical Properties of Organic pad

Sr. No.	Technical Data	Measured values	Unit
1	Density	1.90	g/cm^3
2	Compressive Strength	190	N/mm^2
3	Hardness	85	Shore D
4	Young's Modulus	1	GPa
5	Poisons ratio	0.25	-

4. EXPERIMENTAL SETUP

Experimental work is carried out using a pin-on-disc Tribometer as shown schematically in Fig 6, this test equipment simulates a sliding contact. The pin- on-disc machine contains a horizontally rotating disc and a dead-loaded pin. A group of weights connecting the fulcrum through a beam provides the normal force on the pin. The rotation rate and radius of the disc are controllable so that a pure sliding contact is achievable at various speeds between the pin and disc. Experimental set up which is available in S.N.D College of engineering and research Centre, Yeola is as shown in following photograph. Using Pin-on-Disc Tribometer (TR-2OLE) reading is measured.

Fig-6: Pin on disc machine

Fig-7: Pin and disc setup

The TR-2OLE pin on disc wear testing is advanced regarding the simplicity and convenience of operation, ease of specimen clamping and accuracy of measurements both of wear and frictional force. The machine is designed to apply load up to 20 kg and is intended both for dry and lubricated test condition. It facilities the study of friction and wear characteristics in sliding contacts under desired test condition within machine specification. Sliding occurs between the stationary pin and rotating disc normal load; rotational speed and wear track diameter should vary to suit the test condition. Tangential frictional force and wear are monitored with electronic sensor and recorded on PC. These parameters are available as a function of load and speed. the machine consist of spindle assembly, loading lever assembly, sliding plate assembly and environmental chamber, all mounted on base plate over a structure made up of welded steel tube which absorbs entire force and load acting during testing, it is fitted with four member of adjustable anti vibration pad at the base. Some items like ac motor variable frequency drive and all electrical items refitted inside the structure and sides of it are covered with panels. the wear disc is mounted on the spindle top and driven by an ac motor through a time belt, which provides a high torque drive with low vibration.

The loading lever with specimen holder fitted at one end & at other end, it carries a wire rope for suspending dead weight to apply normal load on specimen. the frictional force produced between specimen pin and disc is directly measured by load cell at other end. the specimen pin placed at inside the hardened split jaw and clamped to specimen holder. to clamp different sizes of specimen, individual jaws are provided for different sizes of pin specimen. The oil for test (lubricated) is supplied by a lubrication unit fixed at the base of machine to leak proof lubrication chamber. The wear between specimen pin and disc is measured by lvdt and is sensed by a sensor mounted on lever the friction between pin & rotating disc is measured by stain gauge type load cell mounted on a bracket. During the test, friction force is measured by a transducer mounted on the loading arm and a microprocessor controlled data acquisition system is used. Metallic and organic brake pad used in this investigation and the specific test conditions, the output sent displays on controller and pc.

4.1 Working procedure

1. Connect the power input cable to 230V, 50Hz and I5 Amps supply. Switch on controller; allow 5 minutes for normalizing all electrical items. Thorough clean specimen pins remove burs from the circumference using empery paper. Clean the wear disc through with solvent and clamp it on folder and screw. With the help of dial indicator, clamp disc within 10µm run out.
2. Inserts specimen pin inside the hardened jaws and clamp to specimen holder. Set the height of specimen pin above the wear disc using height adjustment block ensuring the load arm always horizontal. Tighten clamping screw on jaw to clamp specimen pin firmly. Swivel off the height adjustment block away from

loading arm.

3. Set the required wear track radius (50 mm, 100 mm and 120 mm) by moving the sliding plate over graduated scale on base plate. Tighten all 6 clamping screws to ensure assembly is clamped firmly.
4. Wear display loosen LVDT lock screw, rotate thumb screw to bring LVDT plunger visually to mid position, the wear reading display on controller should be as near tozero, initialize wear display to O by pressing _ZERO‘ push button on controller.
5. Frictional force display more loading are away from frictional force load cell button to 0 by pressing _ZERO‘ push button on controller.
6. Pressed required weights on loading pan to apply normal load.
7. Setting disc speed: set time on controller, press test start push button &rotate. Set rpm knob on controller in clockwise direction till required test speed is display. Continue to run for the remaining time to observe for any fluctuation. Press
8. _STOP‘ button on controller.
9. Setting test duration on controller test duration is set either in time mode or counter mode selection is by toggle switch.

Setting of computer for data acquisition:

- Connect the data acquisition cable from controller to PC.
- Open the software winducom 2008 on PC.
- Click on mode run continuously icon on software screen to activate screen.
- Click on ACQUIRE tool bar at scene top to open acquiring screen.
- Enter the file name on window.
- In the sale for sample ID enter the material of the specimen and its dimension.
- Fill the remaining empty cells for speed, load, wear track and data sampling rate.
- In the remark cell, enter dry test, duration of test, speed etc.
- Click START button in the PC window.
- Press START push button on the controller front panel to commence the test & send data to PC.
- Set the required rpm by rotating slowly the rpm knob in clockwise direction.
- Measured rpm is displayed on the SPEED window of the controller front panel.
- Click zero buttons on PC screen and initialized all sensor values to zero.

On the controller acquired test parameter like wear, frictional force, speed and temperature are displayed, the same value are displayed on the PC graph

TABLE- IV: Specification of pin on disc tribometer (TR-20LE)

Overall size	660×630×860 mm (L×B×H)
Pin size	4, 6, 8, 10 and 12 mm diameter
Disc size	165 diameter × 8 mm thick
Wear track diameter	10mm to 150 mm
oading lever length	394 mm
Sliding speed range	0.05m/s to 10m/s
Disc rotation speed	20-200 RPM with least count 1 RPM
Normal load	5N to 200N
Frictional force	0 to 200 N digital recorded output
Wear measurement	± 2 mm LC 0.1μ digital recorded output

Power	1.5 kw, 230V, 15A, 1Phase, 50Hz

TABLE-V: Experimental Readings of Metallic pad

Sr. No.	Lo ad (N)	Sliding velocity (m/s)	Sliding distance (meter)	Wear (micron)	Coefficient of friction	Temper ature (Celsius)
1	5	1	1000	46	0.06	23
2	5	1	2000	59	0.045	24
3	25	1	1000	39	0.161	25
4	25	1	2000	80	0188	26
5	5	2.5	2000	19	0.02	25
6	5	2.5	1000	12	0.051	24
7	25	5	2000	57	0.168	31
8	50	2.5	1000	59	0.2	32
9	50	5	1000	77	0.179	36
10	5	1	1500	14	0.08	26
11	25	2.5	1000	22	0.234	22
12	25	2.5	2000	61	0.131	28
13	50	5	1000	36	0.252	37
14	25	2.5	1500	50	0.21	27
15	5	5	2000	28	0.047	35
16	50	2.5	2000	98	0.203	29
17	25	5	1500	36	0.177	35
18	5	5	1000	10	0.078	31
19	50	5	1500	98	0.236	44
20	25	1	1500	65	0.224	29
21	5	5	1500	10	0.103	35
22	50	2.5	1500	70	0.175	33
23	25	2.5	1500	13	0.047	28
24	50	1	2000	96	0.144	37
25	25	5	1000	18	0.167	34
26	50	1	1500	80	0.214	34
27	50	5	2000	116	0.205	38

TABLE-VI: Experimental Reading of organic pad

Sr. No.	Lo ad (N)	Sliding velocity (m/s)	Sliding distance (meter)	Wear (micron)	Coefficient of friction	Temper-ature (Celsius)
1	5	1	1000	10	0.056	30
2	5	1	2000	32	0.012	28
3	25	1	1000	12	0.012	33
4	25	1	2000	38	0.244	31
5	5	2.5	2000	39	0.034	29
6	5	2.5	1000	14	0.033	33
7	25	5	2000	17	0.124	34
8	50	2.5	1000	45	0.171	35
9	50	5	1000	49	0.237	48
10	5	1	1500	19	0.145	26
11	25	2.5	1000	12	0.153	33
12	25	2.5	2000	65	0.142	32
13	50	5	1000	40	0.144	32
14	25	2.5	1500	22	0.172	32
15	5	5	2000	39	0.072	35

16	50	2.5	2000	80	0.125	32
17	25	5	1500	27	0.237	38
18	5	5	1000	12	0.108	43
19	50	5	1500	98	0.189	39
20	25	1	1500	38	0.163	47
21	5	5	1500	24	0.082	35
22	50	2.5	1500	72	0.184	40
23	25	2.5	1500	20	0.146	33
24	50	1	2000	94	0.21	33
25	25	5	1000	24	0.125	38
26	50	1	1500	43	0.134	36
27	50	5	2000	108	0.21	42

5. NUMERICAL ANALYSIS

The RPM is calculated according to wear track diameter and sliding velocity. Wear track diameter is fixed for particular velocity. The time of duration for particular rpm and velocity is calculated by simple velocity formulae i.e.

$$\text{Sliding velocity} = \frac{\pi \times \text{wear track diameter} \times \text{RPM}}{60000}$$

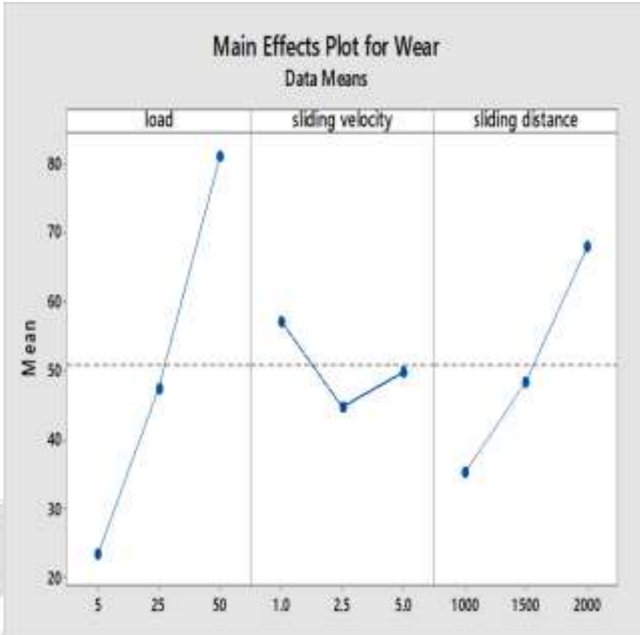
$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}}$$

The wear track diameter, velocity and RPM is constant for a set of varying distances, the time required for different sets of wear track diameter, velocity and RPM is given.

ANOVA FOR METALLIC PAD
ANOVA FOR FOR WEAR

TABLE-VII: General Linear Model for wear

Source	**Degree of freed om**	**Adjacent sum of square**	**Adjacent mean of square**	**F-Value**	**P-Value**	
Load	2	15098 .3	7549.1	30.50	0.00 0	Significant
Sliding velocity	2	691.2	345.6	1.40	0.27 1	
Sliding distance	2	4903. 6	2451.8	9.91	0.00 1	Significant
Error	20	4950. 5	247.5			
Total	26	25643 .6				
Model Summary						
S	R-sq	R- sq(adj)	R sq(pred)			
15.7330	80.69%	74.90 %	64.82%			

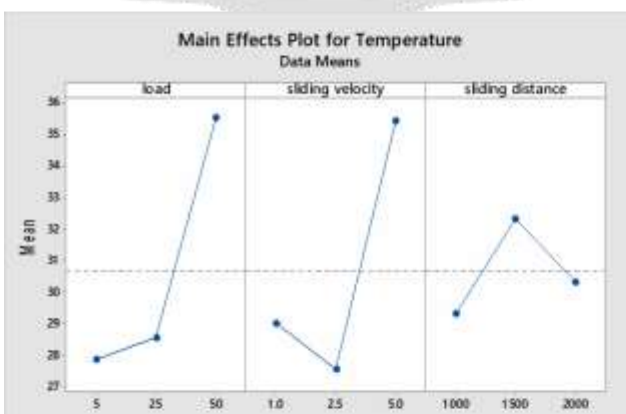


Graph-1: Main effect plot for wear

ANOVA FOR TEMPERATURE

TABLE-VIII: General Linear Model for temperature

Sr. No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value	
1	Load	2	324.67	162.333	30.69	0.000	Significant
2	Sliding Velocity	2	317.56	158.778	30.02	0.000	Significant
3	Sliding distance	2	42.00	21.000	3.97	0.035	
4	Error	20	105.78	5.289			
5	Total	26	790.00				
		Model Summary					
6	S	R-sq	R-Sq(adj)	R-sq(pred)			
7	2.29976	86.6%	82.59%	75.60%			



Graph-2: Main effect plot for temperature

ANOVA FOR ORGANIC PAD
ANOVA FOR FOR WEAR

TABLE-IX: General Linear Model for wear

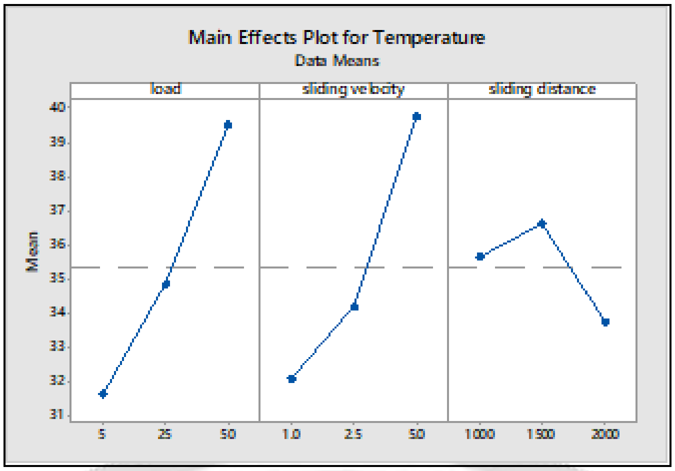
ANOVA - General linear model							
Sr.No	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	-
1	Load	2	11792.3	5896.1	31.43	0.000	Significant
2	Sliding velocity	2	291.6	145.8	0.78	0.473	-
3	Sliding distance	2	4802.3	2401.1	12.80	0.000	Significant
4	Error	20	3752.5	187.6	-	-	-
5	Total	26	26	20638.7	-	-	-
	Model summary						
6	S	R-sq	R-sq(Adj)	R-sq(pred)	-	-	-
7	13.6977	81.82%	76.36%	66.86%	-	-	-

Graph- 3: Main effect plot for wear

ANOVA FOR TEMPERATURE

TABLE –X: General Linear Model for temperature

ANOVA - General linear model							
Sr. No	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	
1	Load	2	283.19	141.593	20.51	0.000	Significant
2	Sliding velocity	2	282.30	141.148	20.45	0.000	Significant
3	Sliding Distance	2	38.74	19.370	2.81	0.084	-
4	Error	20	138.07	6.904	-	-	-
5	Total	26	742.30	-	-	-	-
	Model Summary						
6	S	R-sq	R-sq (adj)	R-sq(pred)	-	-	-
7	2.62749	81.40%	75.82%	66.10%	-	-	-



Graph- 4: Main effect plot for temperature

6. RESULT AND DISCUSSION

6.1 Result from ANOVA

A) Wear

- Load

The load is the most significant factor and it is directly proportional to wear. Interaction plot shows that wear rate faintly increased with the load till 25N. However wear rate rapidly increased when the
load is increased from 25N. Because at high load, the deformation is more in pad and this promotes to higher wear rate.

- Sliding distance

The sliding distance is the second most significant factor after load. It has comparatively lesser effect on wear as compared to load. Linear relationship is observed between sliding distance and wear.

B) Temperature

Load and sliding velocity are the significant factors during braking operation. The sliding distance has not any significant effect. The details of significant factors are as follows.

- Load

The applied load also has a linear relationship with temperature. During testing at heavy loads development of frictional force is high and as the load increases there is increase in friction forces which will emit more heat. Ultimately higher the load and higher the temperature at contact.

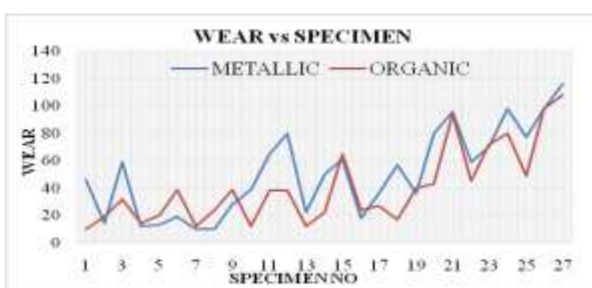
- Sliding velocity

The sliding velocity is a significant factor for temperature. Observations of main effect plot shows that at velocity till 2.5 m/s the temperature is less but as the velocity increases above 2.5 m/s there is stagnant increase in temperature.

6.2 Comparative Analysis

The comparative analysis between metallic and organic brake pad is based on wear, temperature and coefficient of friction.

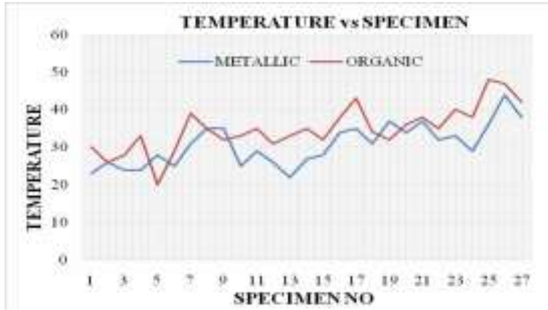
- **Wear**



Graph- 5: Wear vs specimen no

The wear rate of metallic material is more than organic material at the same loading condition, sliding velocity and sliding distance. The presence of large amount of metallic reinforcing fibres in metallic material causes excessive wear rate.

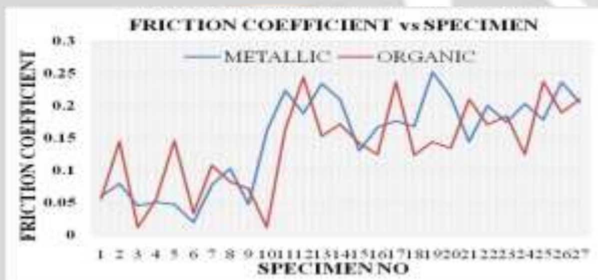
- **Temperature**



Graph- 6: Temperature vs specimen no

The temperature developed at the interface of pin and disc in organic material is more than metallic material. The metallic material contains more amounts of metallic chips and granules as compare to inorganic material, which promotes higher heat transfer rate.

- **Friction coefficient**



Graph- 7: Friction coefficient vs specimen no

The coefficient of friction depends upon the contact of two materials. For the safe braking, the coefficient of friction should be constant but as in testing the conditions are varying the coefficient of friction is also continuously varying which is not in favor of safe braking

7. CONCLUSIONS

In present work, experimental investigation has been reported on metallic brake pad material and organic material under dry sliding condition. Full factorial methodology has been utilized to obtain the various combinations of the load, sliding velocity and sliding distance at different levels of factor. Analysis of variance investigate the influence of three important input parameters – Load, sliding velocity and sliding distance on two performance characteristics- wear and temperature. The analysis of experimental work is performed using MINITAB 18 statistical software. The important conclusions that can be drawn from the present research work are:

1. The influence of factors has been identified which can play a key role in wear rate and temperature at the interface of brake disc and brake pad.
2. The wear rate of both metallic and organic pad depends upon load and sliding distance while temperature depends upon load and sliding velocity.
3. The wear rate of metallic pad is more than organic brake pad while temperature developed in organic pad is more than metallic.

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REFERENCES

[1] Nagesh S. N, Siddarju C, PrakashS. V and Ramesh, Characterization of brake pads by varition of composition of frictional material, Procedia materials science 5 (2014), pp. 295 – 302.

[2] EL-Tayeb N. S. M. and Liew K.W, On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry, Wear 266 (2009), pp. 275–287.

[3] Maleque M. A, Dyuti S and Rahman M. M, Material selection method in design of automotive brake disc, Proceedings of the world congress on engineering, volume- 3, 2010, june 30 - july 2.

[4] Omar Maluf, Mauricio Angeloni, Marcelo Tadeu Milan, Dirceu Spinelli and Waldek Wladimir Bose Filho, Development of materials for automotive disc brakes, Minerva 4(2010), pp. 149-158.

[5] Peter J. Blau, Compositions, functions, and testing of friction brake materials and their additives, Wear 263 (2007), pp. 1202–1211.

[6] Chan D and StachowiakG. W, Review of automotive brake friction materials, Journal of automobile engineering, september 1, 2004, volume. 218, pp. 953-966.

[7] Idris U. D, AigbodionV. S, AbobakrI.J and Nwoye C. I, Eco-friendly asbestos free brake pad:using banana peels, Journal of king saud university – engineering sciences (2015) 27 pp. 185–192.

[8] Djafri M, Bouchetara M, BuschC. and Weber S, Effects of humidity and corrosion on the tribological behaviour of the brake disc materials, Wear 321(2014), pp. 8–15.

[9] Andrzej Wojciechowski, Artur Gołowicz and Ryszard Michalski, Influence of the form of copper in the friction material of disc brakes on the coefficient of friction and wear in rig tests, Publishing scientific industrial research institute of automotive industry, 2013, volume-4, pp. 77-88.

[10] Radhika N, Vaishnavi A and ChandranG. K, Optimisation of dry sliding wear process parameters for aluminium hybrid metal matrix composites, Journal of engineering tribology, july (2013), volume. 227, issue no-7, pp. 749-760.

[11] Sanatore. A, AgostinoV.D, GiudaR. D and Petrone V, Exprimental investigation and neural network prediction of brakes and clutch material frictional considering the sliding accelaration influence, Tribology international 44 (2011), pp. 1199–1207

[12] Mukesh Kumar and Jayashree Bijwe, Studies on reduce scale tribometer to investigate the effects of metal additives on friction coefficient-temperature sensitivity in brake material, Wear 269 (2010), pp. 838–846.

[13] UyyuruR. K, Surappa M.K and Brusethaug S, Tribiological behavior of al-si-sicp composite automobile brakepad system under dry sliding condition, Tribology international 40 (2007), pp. 365–373.

[14] BezzaziM, Khamlichi A,Jabbouri A, Reis P and Davim J. P, Experimental charactorizational of frictional behaviour of clutch facings using pin on disk machine, Materials and design 28 (2007), pp. 2148–2153.

[15] Cueva G, Sinatora. A, Guesser. W. Land Tschiptschin A. P, Wear resistance of cast irons used in brake disc rotors, Wear 255 (2003), pp. 1256–1260.

[16] Kennedy D. M and HashmiM.S. J, Methods of wear testing for advanced surface coatings and bulk materials, Journal of materials processing technology 77 (1998), pp. 246–253.

[17] Tavoosi H, Ziaei-Rad, Karimzadeh F and Akbarzadeh S, Experimental and finite element simulation of wear in nanostructured NiAl coating, Journal of tribology (2005), volume.137 (4), pp. 1-6.

[18] Prasanna Chowdary, Strength analysis of disc brake assembly & dynamic pad pressure distribution, Altair technology conference 2015, pp. 1-6.

[19] Ali Belhocineb and Wan Zaidi Wan Omar, Three-dimensional finite element modeling and analysis of the mechanical behavior of dry contact slipping between the disc and the brake pads, International journal of advanced manufacturing technology, may-2015, pp. 1-17.

[20] Kulkarni S.S, KurkuteV. K and Chavan S. T, Experimental and finite element analysis of tribological behaviour of heat treated 40 c 8 steel in dry sliding test using pin on disc apparatus, international journal of advanced research (2015), volumeume 3, issue 8, pp. 684 – 690.