Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

The Impact of Friction Material on Disc Brake Performance: A Review

Ganesh Chandane[1], Dr. Sham Kulkarni[2]
[1]P.G Scholar [2] HOD & Professor
Department of Mechanical Engineering, SKN Sinhgad College of Engineering,
Pandharpur- 413304, Maharashtra, India

Abstract- The most crucial elements of an automobile's braking system are the brake pad and disc. It transformskinetic energy in heat energy in order to smoothly Delay the vehicle. Efficiency between brake pad with disc diminishes due to repetitive or tough braking on steep gradient coefficient of friction as well as wear rate. In this study, the impacts of Aluminum Titanium Nitride covering the disc area upon The use of a pin on disc machine, the braking system's tribological behavior is examined. Physical vapor deposition (PVD) technology is used to coat the disc in Aluminum Titanium Nitride (ALTiN) . For pins and discs, there are two options: gray cast iron and low metallic friction substance. Load, time, and sliding speed are the input factors considerered in this test. Additionally, Regression analysis includes in this work to look at coefficient of friction and rate of wear. Wear rate and coefficient of friction were used to compare the results of numerical and experimental studies. Keywords: Pin on Disc, Aluminum Titanium Nitride, Physical vapor deposition , coefficient of friction, delay.

I. INTRODUCTION

The most crucial safety feature of an automobile is its brakes. Fig(1). Brakes are necessary to bring a vehicle to a complete stop in the shortest amount of time, and they accomplish this through the transformation of the Thermal energy is created from kinetic energy and released into the surrounding environment. [1] [2]. A vehicle's component weight on the wheel and the coefficient of interaction between the road and tire surfaces determine the maximum hindering force that can be applied by the brake at the wheels. The disc combined brake pad between the interfaces that slide determines how well the disc braking system works. The friction between the brake pad and the disc causes braking torque to be applied to the wheel's rotor, which in turn causes the automobile to slow down due to friction between the tire and the road. Both the pad and the rotor wear throughout this operation, and some of that wear will result in particle emission. Experience or a trial-and-error procedure is required for the proper material selection for the disc and pad at the necessary ingredient quantities. Cast iron, composite, and aluminum composite materials are only a few of the materials used to makerotors. Most rotors are made of grey cast iron, which is robust and has a high carbon content. The pad material, which is made up of a few components, is used to increase strength and rigidity, lengthen life, reduce porosity, and reduce noise, as well as to improve friction qualities at low and high temperatures. The various categories of components in friction materials include additives, fillers, binders, and reinforcing fires. The typical commercial brake lining consists of almost ten different parts [3]. Brake rotors along with drums can absorb heat during protracted periods of hard braking more quickly than they can dissipate it into the surrounding air. The temperature increase in the braking components can have a big impact on how well a vehicle brakes. High temperatures during braking may result in thermally excited vibration, bearing failure, brake fluid vaporization, brake fade, and premature wear. As a result, it's crucial to forecast the temperature increase of a specific brake system and evaluate its capacity for heating early in the design process.

The maximum temperature can be caused by carrying heavy loads, halting from high speeds, braking in traffic, and frequent downhillstops on mountain paths. Due to issues with the brakes, the lining is more susceptible to external factors like temperature, pressure, sliding speed, and humidity. With high temperatures, the value of the coefficient for friction for brakes decreases. It is known as brakefade. The three types of brake fade are gas fade, mechanical fade, and lining fade. Additionally, brake-induced issues like judder (vibration caused by rotor warping with uneven disc thickness), fading (loss of braking efficacy due to frictional heat), and noise can be influenced by the shape plus physical characteristics of the brake rotors [3] [4] [5].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

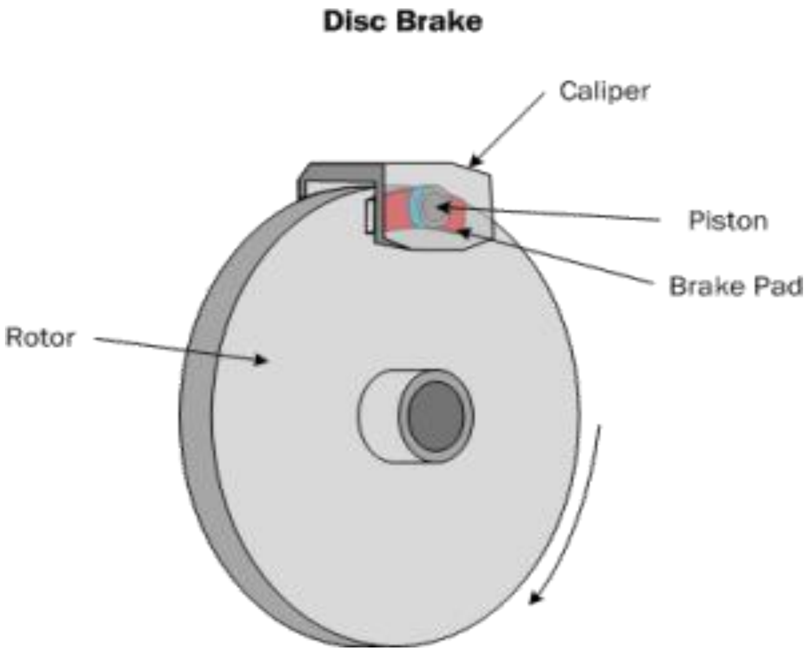

Fig.1 Disc Brake [2][4]

This is due to how the phases of grey iron affect the grey iron rotor's physical properties, including its thermal conductivity, damping ability, thermal expansion of coefficient, and specific heat. Beyond a certain degree, the temperature's impact on the coefficient of friction declines, making it harder to stop the car with the brakes. In fig (2) The graph demonstrates how the coefficient of friction of brake pads climbs modestly as temperature rises before dramatically declining as temperature rises. With the addition of more heat-stopping radius, the fade will get worse and eventually disappear. The pace at which brake linings and rotors were worn changed significantly in response to changes inrotor composition, demonstrating that rotors and brake liners were active chemically during braking.

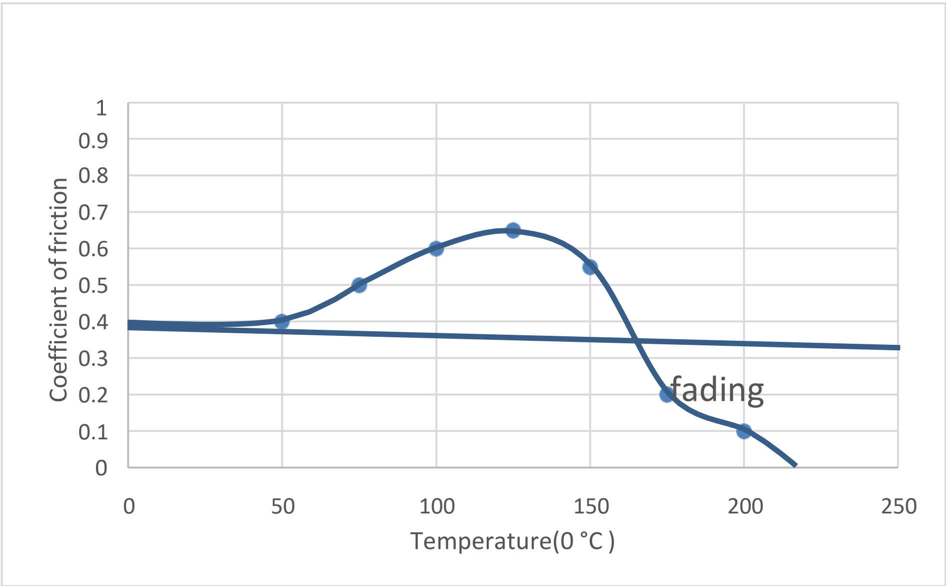

Fig. 2 Brake fading (coefficient of friction Drops) [3][5]

Only the brake drums experience mechanical brake fade. Drum as it enlarges as the temperature rises. As a result, before applying the brakes, the pedal is brought closer to the floor. A thin layer of hot gases might be released from organic material binding in the brake pads as a result of severe brake system overheating. As a result, as the pad hydroplanes, there is lower contact between the pad and the disc.

II. SUMMARY

Brakes are essential for a vehicle's safety, converting thermal energy from kinetic energy into braking force. The disc- combined brake pad and disc work together to prevent braking torque from being applied to the wheel's rotor. Proper material selection is crucial for the disc and pad, with grey cast iron being the most common. High temperatures during braking can cause vibration, bearing failure, fluid vaporization, brake fade, and premature wear. Forecasting temperature increases and evaluating heating capacity early in the design process is crucial. the characteristics of the friction materials and how they impact coefficient of friction and wear rate are used to select them for surveys. The rate of wear of the brake pad and the disc is influenced by the load, time, and sliding speed. Wear on the disc brakes is to blame for fifty percent of non-exhaust emissions from traffic and transportation on roads. To control coefficient of friction and the rate at which the brake pad and disc wear, several composite materials with varying percentages are used in brakes. Additionally, aluminum and materials based on aluminum can impact coefficient of friction and the rate at which a disc wears out due to its outstanding malleability, formability,ability to resist corrosion, and thermal conductivity. Up to sixty per cent of the disc material gets worn out when the brake is applied. To prevent wear, the disc has a covering. The layer on the disc also decreased the effects of rust and moisture. Future experiments canbe done while taking into account how moisture influences friction and wear. Additionally, taking into account different disc material coatings can impact coefficient of friction and wear characteristics.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

III. LITERATURE REVIEW

For a systematic review, disc brake-related literature from recent years was evaluated. Authors independently carried out a preliminary screening by carefully reading abstracts. The authors came to an agreement on which sources were appropriate for the reviews. The whole articles for those cite were consulted to determine their eligibility. The following information was taken from the papers that qualified: author and year, study design, input parameter, method/machine, and outcome measurements.

Author and Year	**Study Design**	**Input Parameters**	**Method/ Machine**	**Outcome Measures**
Blau , McLaughlin 2003	Effects of water films and sliding speed on the frictional behaviorof truck disc brake materials	Brake disc (127mm dia ,12mm thick) Brake pad (square faced specimen(12.7×12.7mm^2)) force - 161.N, contact pressure 1.0Mpa, velocities(2 and 11 m/s),sliding speed	Sub Scale,flat-on- flat Testing System	Friction force, disc temperature, Ave. COF, Std.Dev,(friction force vs time , friction coefficient vs drag number) friction coefficient(ave) vssliding speed
, Ferreira2011	Contribution to perform high temperature tests (fading) on a laboratory- scale tribometer	Disk (160mm dia, 12mm thick)Brake pad(two) inertia- 6.15kg m2, sliding speed(m/s), temperature(°C), area (mm^2), braking energy (j), braking torque(N m), braking time(s)	Brake dynamometer, tribometer	Thermal analysis,friction analysis

Author and Year	**Study Design**	**Input Parameters**	**Method/ Machine**	**Outcome Measures**
Kilic , Misirli2020	Investigation of tribological behavior of 20NiCrBSi- WC12Co coated brake disc by HVOFmethod	Cast iron Disc(280mm dia),Brake Liner, 20NiCrBSi-WC12Co Cermet Coating , Speed, Pressure.	Full scale Brake dynamometer, HVOF Method.	Wear rate,COF, (Coated and Uncoated Disc)
Bashir2015	Friction And Wear Behavior Of Disc Brake pad MaterialUsing Banana PeelPowder.	Brake Pad, Banana Peel Powder , Phenolic Resin , Frequency (40HZ) ,Stroke (2mm), Load(60N,120N,180N) Time (10min),Temp.	Reciprocating Friction Monitor machine.	COF (μ), Frictionalforce (N), Wear (g)
, Xu Ma2018	Design and optimization of oxidation resistant coating for C/C aircraft brake materials	C/C brake disk, SiCN/borosilicate glass coating, (B4C), temperature -(800°C) , time - 10 hour	Chemical vapor infiltration process, SEM ,EDS , analysis	Weight loss (%) vs Oxidation time (h)'anti oxidation properties, oxidationresistance property
torm , Lyu2017	A pin on disc tribometer study ofdisc brake contact pair with respect towear and Airborne particle emissions	Three novel rotors , Three novel pad , pindia (10 mm), rotor (dia 60mm , thick 6mm), normal forces, rotational speed	Pin-on-disc tribometer, air velocity transducer model8455.	particle concentration ,massconcentration measured using OPS, EPLI+ , CPC, mean specific wearrate , Mean COF, disc temperature, flow rate, mass losses

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

Author and Year	Study Design	Input Parameters	Method/ Machine	OutcomeMeasures
usubov2021	Wear Studies on Phenolic Brake- Pads Using TaguchiTechnique	Taguchi Technique,Pin on Disc (cy,pinDia 4.7mm , Hight 13mm) Steel Disc, ContactPressure, Sliding Velocity, Cycle	universal verticalMMW-1 tribometer, ANOVA Method.	Wear rate [g/hour], St Dev, S/N ratio [dB]
o , Kim2003	Tribological studyof (GCI)with automotive brake linings: Theeffect of rotor microstructure	Gray Iron Disk, Brake Lining ,Graphite, Ferrite(Flake), friction force, line pressure, rotation speed, disc temperature.	pad-on-disk type tribotester, infrared thermometer (3M Scotchtrak^tm IR- 16)	COF , graphite area(%)
tushenko,Kuciej 2017	Influence of thermal sensitivityof the material on temperature and thermal stresses ofthe brake disc with(TBC)	Steel DisC (UNS G51400), thetmal barrier coating and disc (constant thermal Properties)	Laplace transform method, Kirchhoff transformation method,quasi static thermal stresses in the strip (TBC)	dimensionless Temperature distribution, distribution of dimensionless normal thermal stresses in the ZrO2 strip
, Straffelini2017	P-O-D testing of low metallic friction material sliding against HVOF coated castiron: Modelling ofthe Contact Temperature Evolution	Discs (63 mm dia, 6 mm thick), two different Coatings(pearlitic cast iron discs) Pin (6 mm dia, 10mm height), roomtemperature (23°c) sliding speed (1.57m/s), angular velocity (52.36 rad/sec), contactpressure (1Mpa)	Eyre/Biceri pin on disc testing rig,(HVOF) Process, FEmodelling	Wear Parametersof the friction material, avg. Friction coefficient, temperature curves for Uncoated and coated discs.

Author and Year	Study Design	Input Parameters	Method/ Machine	Outcome Measures
Cueva2003	Wear resistance ofcast irons used in brake disc rotors	Gray cast iron disc,compact graphite iron disc, pressure(0.7,2, and4Mpa), time,cycle(300),	PLINT-TE67 Pin-on-disc wear testing	Disc Wear(g), Pin Wear(g)
.Kumar2019	Sliding wear performance of graphite reinforced AA6061 alloy composites for rotordrum/disk application	EN-31hardened disc(60-70 HRC),Pin Size(10mmx25mm), load(15N-55N), Sliding Speed (0.5m/s-2.5m/s),Sliding distance (200m-1000m)	Pin-on-disc Tribometer, TaguchiTechnique, ANOVA, SEM Analyses.	Specific wear rate (mm/N-m), S/N Ratio (db)
. Sinha2020	Experimental Characterization Protocols for Wear Products from DiscBrake Materials	Brake Pad and Disc Materials, Cast IronDisc , Coatings , Load , Speed , Pressure	pin-on-disc mchine, Dynamometer, SEM-EDXS, TEM-EDXS, SAED, XRD, RS Analysis.	the material characterisation techniques that were used for the analyses of the brake wear products are provided, paying particular attention to the airbornefraction
G.Bian ,Houzheng Wu2015	Friction And Surface Fracture of A (SiC) Brake Disc Tested Against A Steel Pad	SiC brake disc, Pad (Mild Steel), contactpressure (2.1) Mpa, Initial Braking Speeds (4000, 6500, 9000) rpm, sliding speed (8.5 , 14.0, 20.0) m/s	Laboratory- scale dynamometer testing, SEM/EDX,TEM Analysis	averaged COF for each braking stop, fraction of fracture surface

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

Author and Year	Study Design	Input Parameters	Method/ Machine	Outcome Measures
A. Belhocine, M. Bouchetara 2012	Thermal analysis ofa solid brake disc	Total time simulation=45s Increment initial time=0.25[s] Increment minimal initial time=0.125[s] Increment maximal initial time= 0.5[s] Initial disc Temperature = 60 [°C] Materials: three types of Cast iron(FG 25 AL,FG 20, FG 15)	implement the finite element method in ANSYS	Temperature distribution for a cast iron disc that is fully filled and ventilated (FG 15) Temperature variation for both designs using the same material acrossthe thickness (FG15)
. Talati2009	Analysis of heat conduction in a disk brake system	duration of braking, vehicle velocity, geometries, dimensions ofthe brake components, materials of the disk brake rotor pad, contact pressure distribution	governing heat equations, Green's function	Thermal resistance constituted by wear particles accumulating at thepad-disc contact interface, Disc surface Temp vs time, Pad surfaceTemp vs time
Aranke2019	Coatings for Automotive GrayCast Iron Brake Disc: A Review	Gray cast iron disc, Coating Technologies (Non-Thermal Spray process , Thermal Spray process) , coating process, coating material,(oxides, carbides, alternative material)	Pin on disc dynamometer, XRD,SEM analysis	Brake wear emissions, spray process- coating material , wear rate,COF .
K. Hendre2021	Tribological behaviour of non- asbestos brake padmaterial	Steel disc (15mm thick, 150mm dia),cylindrical sample pin of CL-3003 brake pad material of 10 mm diameter. Temperature (T) (°C). Sliding Velocity (V) m/s Pressure (P) N/mm2 Sliding Distance (D) m	DUCOM (TR-20LE) Pin on disc test rig. Taguchi's analysis technique,Thermal analysis, EDS, SEM analysis	ANOVA wear rate,COF , SN ratio

Author andYear	Study Design	Input Parameters	Method/ Machine	OutcomeMeasures
S. Zhao2020	The braking behaviors of Cu-Based powder metallurgy brakepads mated withC/C-SiC disk forhigh-speed train	P/M pads, C/C SiC ceramic disc outer dia 350 mm, thick 30mm) sliding speed (m/s), braking pressure= 1.27 MPa, brake inertia=19.4 kgm², mass= (12.3) tons	sub-scale inertial braking dynamometer (TM-I, Shaanxi, China), EDS analysis , thermal analyser (LFA-427, NETZSCH)	COF, wear rate,highest temperature
M.H Cho2005	Effects of ingredients on tribological characteristics of a brake lining: an experimentalcase study	Gray Iron Disk(12cm dia 2.5 cm thick),Initial brake temperature(IBT)=°C, speed=m/s, Pressure=Mpa, time = s	small scale frictiontester, Rockwell hardness tester, mercury porosimeter, JURID compression tester.	friction coefficient, fade,wear resistance, noise propensity.
Djafari , Bouchetara 2014	Effect of humidityand corrosion on the tribological behavior of disc brake materials	Three brake disc material cast iron (type FG25), chromium bearing steel (type 100Cr6), an aluminium-based composite Al MMC (type A359/SiCp), Brake pad (Resin Based), sliding speed (1.57 m/s to 5.79 m/s), load (10Nto 200N), relative humidity (20%to 90%) speed (500 rpm to 1800 rpm)	P-O-D machine(SRV4), Salt SprayTest, SEM-EDX analysis	Effect of normal load, sliding speed,relative humidity On the Friction coefficient and wear rate, Compared Al MMC A359/SiCp to other brake disc materials, it exhibits better tribological behavior
nganathan ,Mahale 2016	Effects of aramid fiber concentrationon the friction andwear characteristics of non-asbestos organic friction composites using standardized braking tests	Maruti® Alto ™ rotor disc, Six friction material (brake pads form) , varying aramid fibers (0, 2, 4, 6, 8, 10 wt.%),braking speeds (50, 80 100) kmph eight different decelerations(0.1–0.8 g)	full scale brake inertia dynamometer, SEM, energy-dispersive X-ray analysis	Physical properties, Friction performance, Wear performance , Worn SurfaceAnalysis

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

IV. INFLUENCING INPUT PARAMETERS ON PERFORMANCE OF DISC BRAKE

In this describing the different parameters which impact of friction material on disc brake performance. This influencing parameteras follows

A. IMPACT OF LOAD

The Impact of load on the frictional behaviour of the pad material was studied for coefficient of friction and wear rate with load for various sliding speeds. The normal load exerted a strong force against the stationary pin against the rotating disc. the load that a pin is subjected to virtually always determines how much wear it experiences. A reduction in material strength occurs as a result of frictional heat generated at the contact surface when the normal load rises. The quantity of friction force is influenced by the weight and sliding speed. As the load is increased, the wear rate immediately increases. However, the behaviour of the load and sliding speed combination has an impact on the amount of friction force. The most important factors impacting the rate of wear for brake pads are normal load, followed by sliding velocity and sliding distance. [8],[13],[16],[18]

B. IMPACT OF SLIDING VELOCITY

The primary element is how sliding velocity impacts the friction and wear behaviour of the braking system. The contact between the friction surface and the rate at which the friction material is removed is affected by sliding velocity. The distance (radius) of the pin from the rotation axis multiplied by the speed of the rotating disc determines the relative velocity between the pin and rotating disc. No of the temperature outside, an increase in sliding velocity raises the temperature at the siding interface. In brake performance The impact of sliding velocity on coefficient of friction and wear rate investigated at loads and sliding distances. If sliding Velocity increases wear rate increases due to without coated layer on the disc. But sliding Velocity increases wear rate decreases due to coated discs. [1],[3],[6],[11],[13],[15]

C. IMPACT OF TIME

Pin on disc machines were used in experimental research to look into variations in the coefficient of friction and wear rate. Several braking applications at various velocities with regard to time were investigated using brake discs and Non-asbestos organic (NAO) pad material. Many variables impact the operating conditions of brakes during their operating time, which causes changes in their tribological properties.The goal of the investigation was to extend the working time till failure.
The major variations in friction coefficient and wear rate in braking performance are caused by time. The friction surfaces' structure vary with time, load, the quantity of applications, the distance travelled, and the rate of wear.[2],[5],[8],[9][19]

D. IMPACT OF COATINGS

The brake discs in modern automobiles perform under demanding braking circumstances and at very high speeds. Therefore, for the safety of both people and vehicles, high braking performance is crucial. The goal of vehicle braking performance is to safely manage the vehicle's speed without resulting in a mechanical failure. In a moving vehicle, significant abrasion happens during braking. Less surface contact temperature and stable braking performance were displayed by the coated disc. Additionally, this coating extends the service life of the brake system by lowering the rate of lining wear and abrasive wear on the brake disc surface, both of which result in decreased emissions of particulate matter into the atmosphere. Under the various wear processes at high temperatures, the coated disc demonstrated better wear resistance than the uncoated disc. According to the measured coefficient of friction, the coated disc provided superior braking capability. [7],[9],[10],[11],[20]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 09, September-2023

V. CONCLUSION

From this review papers we can conclude that

1. This investigation will contribute to the understanding of why friction material wears out at minimum load and slidingvelocity.
2. This investigation will also assist in identifying stable frictional forces and coefficient of friction under various load circumstances.
3. This investigation will also help to find out the coefficient of friction of the coated disc and wears of friction material pinwith applied load and minimum duration.

VI. REFERENCES

[1] Wahlström, Jens, Yezhe Lyu, Vlastimil Matjeka, and Anders Söderberg. "A pin-on-disc tribometer study of disc brakecontact pairs with respect to wear and airborne particle emissions." *Wear* 384 (2017): 124-130.

[2] Belhocine, Ali, and Mostefa Bouchetara. "Thermal analysis of a solid brake disc." Applied thermal engineering32(2012): 59-67.

[3] Cho, Min Hyung, Seong Jin Kim, Daehwan Kim, and Ho Jang. "Effects of ingredients on tribological characteristics ofabrake lining: an experimental case study." Wear 258, no. 11-12 (2005): 1682-1687.

[4] Talati, Faramarz, and Salman Jalalifar. "Analysis of heat conduction in a disk brake system." Heat and mass transfer45, no. 8 (2009): 1047-1059.

[5] Cho, M. H., S. J. Kim, R. H. Basch, J. W. Fash, and H. Jang. "Tribological study of gray cast iron with automotive brakelinings: The effect of rotor microstructure." Tribology International 36, no. 7 (2003): 537-545.

[6] Yusubov, F. F. "Wear studies on phenolic brake-pads using Taguchi technique." *Tribology in Industry* 43, no.3(2021): 489.

[7] Kılıç, Halil, and Cenk Mısırlı. "Investigation of tribological behavior of 20NiCrBSi-WC12Co coated brake disc by HVOFmethod." *Materials Research Express* 7, no. 1 (2020): 016560.

[8] Bashir, Masrat, Sheikh Shahid Saleem, and Owais Bashir. "Friction and wear behavior of disc brake pad material using banana peel powder." *International Journal of Research in Engineering and Technology* 4, no. 2 (2015): 650-659.

[9] Fan, Shangwu, Xu Ma, Zuo Li, Jing Hu, Zan Xie, Juanli Deng, Litong Zhang, and Laifei Cheng. "Design and optimization of oxidation resistant coating for C/C aircraft brake materials." Ceramics International 44, no. 1 (2018):175-182

[10] Yevtushenko, Aleksander, Michal Kuciej, and Ewa Och. "Influence of thermal sensitivity of the materials on temperature and thermal stresses of the brake disc with thermal barrier coating." *International Communications in Heatand Mass Transfer* 87 (2017): 288-294.

[11] Federici, Matteo, Giovanni Straffelini, and Stefano Gialanella. "Pin-on-disc testing of low-metallic friction material sliding against HVOF coated cast iron: Modelling of the contact temperature evolution." *Tribology Letters* 65 (2017): 1- 12.

[12] Cueva, G., Amilton Sinatora, Wilson Luiz Guesser, and André Paulo Tschiptschin. "Wear resistance of cast irons usedin brake disc rotors." *Wear* 255, no. 7-12 (2003): 1256-1260.

[13] Kumar, Mukesh, and Ashiwani Kumar. "Sliding wear performance of graphite reinforced AA6061 alloy composites forrotor drum/disk application." *Materials Today: Proceedings* 27 (2020): 1972-1976.

[14] Sinha, Ankur, Gloria Ischia, Cinzia Menapace, and Stefano Gialanella. "Experimental characterization protocols forwear products from disc brake materials." *Atmosphere* 11, no. 10 (2020): 1102.

[15] Bian, Guangyu, and Houzheng Wu. "Friction and surface fracture of a silicon carbide ceramic brake disc testedagainst a steel pad." *Journal of the European Ceramic Society* 35, no. 14 (2015): 3797-3807.

[16] Djafri, M., M. Bouchetara, C. Busch, and S. Weber. "Effects of humidity and corrosion on the tribological behaviourofthe brake disc materials." *Wear* 321 (2014): 8-15.

[17] Aranganathan, N., Vishal Mahale, and Jayashree Bijwe. "Effects of aramid fiber concentration on the friction and wearcharacteristics of non-asbestos organic friction composites using standardized braking tests." *Wear* 354 (2016): 69- 77.

[18] Blau, P. J., and J. C. McLaughlin. "Effects of water films and sliding speed on the frictional behavior of truck discbrake materials." *Tribology international* 36, no. 10 (2003): 709-715.

[19] Neis, P. D., N. F. Ferreira, and F. J. Lorini. "Contribution to perform high temperature tests (fading) on a laboratory-scale tribometer." *Wear* 271, no. 9-10 (2011): 2660-2664.

[20] Aranke, Omkar, Wael Algenaid, Samuel Awe, and Shrikant Joshi. "Coatings for automotive gray cast iron brake discs:A review." *Coatings* 9, no. 9 (2019): 552.

[21] Hendre, Kishor, and Bhanudas Bachchhav. "Tribological behaviour of non-asbestos brake pad material."

[22] *MaterialsToday: Proceedings* 38 (2021): 2549-2554.

[23] Zhao, Sanqing, Qingzhi Yan, Tao Peng, Xiaolu Zhang, and Yuying Wen. "The braking behaviors of Cu-Based powdermetallurgy brake pads mated with C/C–SiC disk for high-speed train." *Wear* 448 (2020): 203237.