REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

Cutting-Edge Research: Analysing The Tribological Aspects Of Brake Pad Materials With Natural Fibres

Shital Gunjate[1*], Sanjay Khot[2]

[1*, 2] Department of Technology, Shivaji University Kolhapur, India *E-mail: shital.gunjate@gmail.com

Abstract
The developments in brake pad material are continuously advancing due to new automotive technologies that have been introduced in the last few decades. Currently, replacing asbestos-based brake pad materials with safer, eco-friendly, non-toxic and reliable materials is the objective of the researchers. The study of the performance of brake pad materials in different conditions is a challenging research area. The current study is focused on the comparative study of performance parameters of different organic materials. The experimental investigation is carried out on brake pads fabricated with three fibres namely, coconut, agave and sisal fibres. The brake pads are fabricated using these fibres and their tribological behaviour is investigated. During this investigation, the pads are subjected to a variable load with a volume or wear test to assess the characteristics of the surface. This study evaluated the tribological performance of brake pads made from coconut, agave, and sisal fibres, examining brake torque, brake power, and fade volume under varying loads and speeds. Coconut fibre brake pads showed the best overall performance with the lowest fade volume and best wear resistance, while agave fibres offered moderate performance, and sisal fibres had the highest fade volume and poorest wear resistance, making them less suitable for heavy applications.

Keywords: Brake pad, Organic brake pad, wear, natural fibres, Tribological aspects

1. Introduction

The evolution of the modern economy is a result of faster transportation means that have made current supply chain mechanisms possible. Land transportation facilitated by automobiles is a significant contributor to the overall supply chains. Engines, though considered the heart of automobile vehicles, all the supporting systems are equally important. The braking system is one of the supporting systems in automobiles that stop and decelerate the vehicle. A vehicle braking system is equipped with friction materials and an actuator; when the actuator is actuated, the kinetic energy is converted into heat, and speed is reduced. This friction causes lagging and rubbing of the materials in brake pads, which increases temperature and thermal fatigue; abrasive wear & glazed surface also lead to a deep cracked surface of the material [1]. The principal application of friction material in automobiles is to control the speed; for this, they must have good friction and wear properties. These properties should be constant in wet, rainy seasons and muddy and dusty conditions. This reliability of properties is crucial in engineering applications, and it is highly dependent on material composition and microstructures. Hence, the materials of the brake pad are of prime importance in the braking system design.

Brake pad material should be sufficiently flexible and adapt to moulding scenarios, and it should also possess comparable durability and heat dissipation characteristics. The brake liner should have a great extent of coefficient of friction with the brake disc. The brake liner substance must comply with extreme temperatures and not readily fade off under heavy loads [2]. Kalhapure and Khairnar [3] studied the role of different operating parameters on the wear rates of brake pads. They found that the applied load is the parameter most influencing wear rate, having a 48.07% contribution. Hence pad material should resist the wear under applied loads. This requirement can be met using brake pad materials like ceramics, low metallic, organic, non-asbestos, and semi-metallic materials. Asbestos-based friction materials were largely used as friction liner materials in braking systems. As asbestos can be dangerous if breathed, automakers and aftermarket manufacturers have had to come up with suitable alternative linings with a high friction coefficient. Few of the conventional brake pad materials as they generate toxic gases during friction [4]. Non-asbestos organic [NAO] frictional constituents are primarily multi-ingredient systems that produce the appropriate combination of performance properties. Though non-asbestos materials have a higher wear rate than asbestos materials [5], their properties can be tailored by adjusting the constituents like fibres and bonding agents. The fibre exhibits good bonding properties to form brake pads, thereby serving as an excellent choice for brake pads. Natural fibres have a minimal environmental impact and have the capacity to meet market demand [6]. Natural fibres serve to strengthen composite structures; these biological fibres can be derived from an extensive range of plants, including cereal strains [rice wheat, rye, and barley], fabric plants [cotton hemp and rapeseed], and plants with tough fibres [cane, rush, rape, coconut, bamboo, banana, sisal, etc.]. Several research studies have been published in the systematic literature on the use of organic fibres in the development of composite materials, such as jute, sisal, hazelnut shell, and coconut shell. These fibres can deliver comparable and sometimes even better properties than asbestos. Ashok [7] discussed that incorporating betel nut skin fibre up to a concentration of 30 vol% can enhance the tensile strength to a range of 17 MPa to 33 MPa. Senthilkumar et al. [8] found that incorporating pineapple leaf fibres into polymer composites can enhance tensile strength by 23% to 25% at a fibre volume fraction of 35 vol%. Additionally, the modulus of elasticity increases with fibre weights ranging from 25 wt% to 45 wt%. Pujar et al. [9] investigated reinforcing low-cost agricultural residue fibres in an epoxy matrix to create new material and studied

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

the abrasive wear behavior of pigeon pea stalk fibre composites. Treated composites demonstrated better abrasive resistance than untreated, with alkali-treated fibres showing improved adhesion and reduced wear. Most of these natural fibres require pretreatment before their use: treated fibres can give better performance with an increase in surface roughness. In an instance, it was demonstrated initially that the acetylation process enhanced the fibber thermal stability from 340°C to 378°C [10]. Naidu et al. [11] wear behavior of brake pad materials fabricated using hemp fibres. They also studied the friction characteristics of the braking pad and found that hemp fibres can provide a consistent friction performance with a low wear rate. Patil et al. [12] analyzed wear rate in brake pads fabricated using filler materials derived from pistachio shells aiming to replace asbestos material. Along with pistachio shell powder, they used phenolic resin, and copper for reinforcement in brake pads. They found that this new material can provide effective wear resistance till 30N load. Krishnan et al. [13] the properties of areca sheath fibres aiming to use them for braking systems. They observed that 5 wt% of Areca sheath fibre with 5 wt.% show optimal tribological proerties. Pujari and Srikiran [14] investigated the wear behavior of brake pad fabricated with Palm kernel reinforced composites. The phenolic resin was used for bonding palm kernel fibres, and it proved effective by providing excellent bonding strength. In this work, wear and hardness tests were performed at different speeds, and they found that at a 30% volume fraction of fibres, the brake pad shows the best wear performance. Ahmed et al. [15] used Areva javanica fibre to replace the synthetic fibre in brakes. Investigation showed that brake pads with Areva javanica fibres have cold and hot shear strengths of 44 and 27 kg/cm2. These properties are similar to synthetic acrylic fibres, and hence, they can be effectively used for their replacement.

Along with material, the orientation of fibres also has a great impact on the properties of brake pads. Madnasri et al. [16] studied the use of natural fibres as a substitute for asbestos fibres in brake pad. They used pineapple leaf, coconut, and areca fibres for fabricating brake pads; in this brake pad composite, they used different volume fractions and orientations. Results showed that the composite with fibres oriented at a 45° angle had the highest tensile strength, while the specimen with 2 vol% fibres had the highest hardness, and the sample with 10 vol% fibres had the lowest wear rate. Yun et al [17] formulated eco-friendly brake friction material and studied these materials using SEM, profilometry, and thermogravimetry, and ranked them with a multi-parameter extension evaluation method. They showed that Nitrile rubber powder material show stable friction and high fade resistance. Madnasri et al. [18] investigated the use of natural fibers as composite reinforcement for brake composites to replace asbestos fibers. Various natural fibers, such as pineapple leaf, coconut, and areca, were processed and incorporated in different volume fractions and orientations. Testing revealed that the specimen with fibers oriented at 45° had the highest tensile strength, while the specimen with 2 vol% fibers had the highest hardness, and the sample with 10 vol% fibers exhibited the lowest wear. Bashir et al. [19] developed a new brake pad material using banana peel powder as a modified binder to improve the binding ability of phenolic resin at high temperatures. Friction and wear tests were conducted under different loads and temperatures using a reciprocating friction monitor. The results demonstrated that the new material increased the coefficient of friction at higher temperatures, showing that banana peel powder effectively enhances the binding ability of resin. Karthikeyan et al. [20] focused on developing new brake pad materials using natural fibers [jute, kenaf, aloe vera] and additives [epoxy resin and hardener] to replace harmful asbestos fibers. The research aimed to address health risks associated with asbestos dust released during braking and brake housing maintenance. Results showed that these natural fibers, combined with appropriate additives, could effectively be used in manufacturing safer and efficient brake pads for future applications. Idris et al. [2] developed a new brake pad using banana peel waste and varying percentages of phenolic resin to replace asbestos. Results indicated that increasing resin content improved compressive strength, hardness, and specific gravity, while reducing oil soak, water soak, wear rate, and charring, with the best properties observed at 25 wt% uncarbonized and 30 wt% carbonized banana peels.

Abhik et al. [21] examined the mechanical and wear behavior of aluminum metal matrix composites [MMC] reinforced with SiC, particularly for brake pads manufactured via powder metallurgy. Brake pads made from Aluminium 2014 alloy with 20% SiC reinforcement showed a 48% higher wear rate but a 30% higher hardness compared to those with 10% SiC reinforcement. Additionally, increased reinforcement resulted in higher porosity and a corresponding increase in wear rate by 48%, though hardness values were lower than pure aluminum due to insufficient sintering time and compaction pressure. Praveenkumar and Gnanaraj [22]. eviews global research on phenolic composites used in brake pads, focusing on replacing harmful materials with eco-friendly alternatives. Researchers from various countries explored different compositions, such as natural fibers and mineral fillers, to enhance the friction and wear properties of brake pads. Bagasse ash, Fly ash, palm kernel fibre, basalt fibre, natural fibre, shellfish powder, and flax fibre are valuable composites to remove potentially hazardous components like lead, asbestos, trisulphide, and antimony from the brake pad materials. Results indicate that natural fibers like fly ash and bagasse ash, and abrasives like SiC and Al2O3, improve performance. The findings provide valuable insights for developing eco-friendly, high-performance brake pads. Ruzaidi et al. [23] developed asbestose-free brake pads. Based on mechanical and wear properties, palm slag can be deployed successfully as an alternative ingredient for other fillers in brake pad composites. It has been seen in the factor of various mechanical properties that different organic materials place their properties similarly to that of Inorganic Brake pads. They proved the ability of palm slag to create better brake pads.

In the organic brake pad materials, Coconut fibre, Agave fibre, and Sisal fibre show potential for brake pad application. As these materials are available locally in enough quantity, they can be used to develop a novel, environmentally sustainable brake linear material. For developing a braking pad, a few important requirements of brake pad materials

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

should be considered to deliver an effective braking system. Due to initial wheel speed, braking speed, braking pressure and high temperature, brake pads are susceptible to a high wear rate. The heat emitted from chemical and physical reactions also becomes absorbed and dispersed in the braking system component. Newly proposed brake pad design or materials should prove their durability and performance under different working conditions, which can save cost and time and ensure better braking system performance. Natural fibres can provide materials that are resistant to wear, particularly in high temperatures, frictional, oxidizing & and corrosive environments.

2. **Methodology**

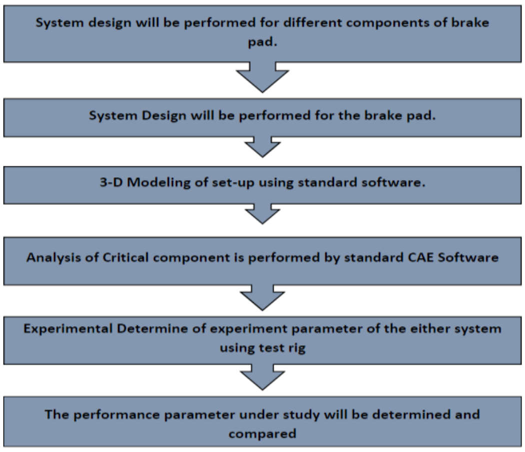

Figure 1. Methodology adopted for conducting this research

In this research, we designed and manufactured a testing rig to test different organic brake pads in various weather conditions. These Organic Brake Pads are tested by applying various loads to find out the durability, brake power absorbs and fade volume. The present work gives rise to analyzing the wear and depending on the frictional parameters of the brake pad's organic material. An actual brake pad has been manufactured and studied on the setup to note the efficiency wear-out criteria. An investigation has been carried out on different scenarios like speed and force. The motive of organic pad usage is the great extent of heat dissipation and decreased pad wear. Natural considerations have been a concern as the material is sisal fibre. Fig 1 shows the methodology used for conducting this research.

3. Materials and Methods

In this research work, Agave fibres (extracted from the agave plant), Coconut fibres (extracted from coconut shell), Sisal fibres (extracted from Sisal peel), calcium carbonate, graphite powder, epoxy resin, and silica oxide are used to manufacture brake pads. The sintering process is used to synthesise the brake pad as per the requirement, to achieve the required strength and structure sintering process is tuned by using the trial and error method [4]

The basic materials rewired for brake pad manufacturing, along with natural fibres, are selected based on availability, affordability, and suitability. Based on the literature, a mould is prepared, and after moulding, press fitting is done to fabricate the brake pad as shown in Figure 1. After manufacturing the brake pad, the experimental testing setup was used to carry out the testing. Here, the braking has been considered by adding the load on the other hand and absorbing the decelerating of the drum. Once the brake pad is fabricated, it is attached to metal support as shown in Figure 3.

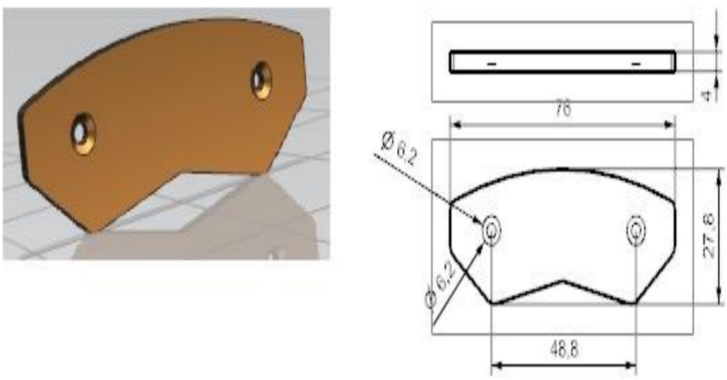

Fig. 2. Design of brake pad

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

3.1. MANUFACTURING OF COMPOSITE BRAKE PAD

Figure 3: Brake pads with a) Coconut fibres b) Agave fibres c) Sisal fibres

4. Experimental Test Rig

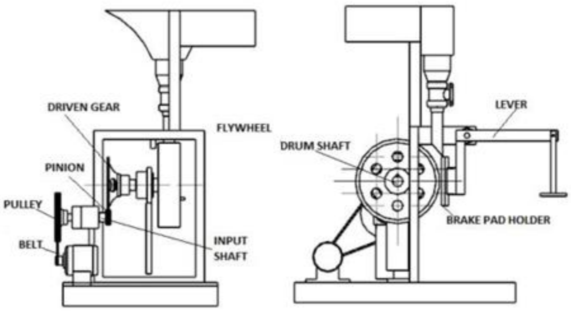

Fig 4: CAE model of test Rig

Fig 5: Experimental Test Rig

4. **Result and Discussion**

The table 1 showing the results of the experimental test conducted on coconut fiber, its seen that, From Figure 6 a), It can be seen that the brake torque and brake power absorbed increases linearly with the load, at an accelerating rate. The linear increase in brake torque with load is expected because higher loads generally require more braking force to decelerate the vehicle

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

TABLE 1. Performance evaluation of coconut fibre

Sr. No	Load (Kg)	Speed (RPM)	Brake Torque (N-m)	Brake power absorbed(Watt)	Fade Volume (mm3)
1	0.5	856	0.841	007.027	2.88
2	1.0	659	0.168	033.283	4.32
3	1.5	480	3.366	076.132	5.28
4	2.0	330	5.050	130.792	6.24
5	2.5	210	6.733	192.772	7.68

Similarly, the accelerating increase in brake power absorbed is due to power being a product of torque and rotational speed. As load increases, more torque is required, resulting in higher power absorption, especially at lower speeds. From this, it can be speculated that Coconut fibre provides a proportional increase in braking force with load, which is beneficial for predictable braking performance. Also, the accelerating increase in absorbed power indicates good energy dissipation properties of coconut fibre, although it also means higher thermal stress at higher loads.

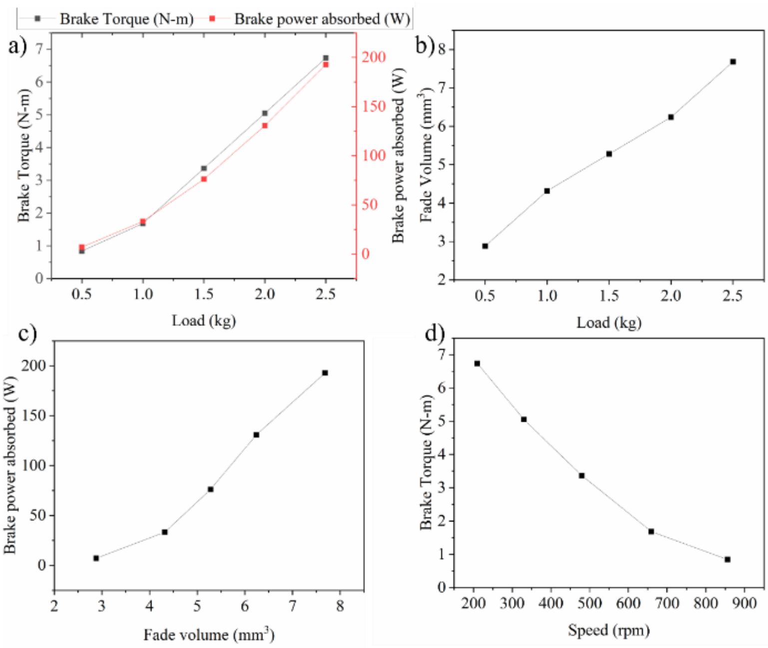

Figure 6: shows the performance analysis for the Coconut fibre brake pad.

Figure 6 b) shows that the fade volume increases with the increasing load. As the load increases, the brake pad has higher resistance and friction, which results in higher material wear. This trend shows a minor acceleration with an increase in load; this might be the result of higher temperatures, the weakening of material and more intense contact stresses. This highlights the ability of coconut fibre to maintain a predictable wear rate, which is important for maintenance scheduling. Figure 6 c) shows the brake power absorbed Vs fade volume behaviour of the brake pad with coconut fibres. The fade volume increases with brake power absorbed, following a near-linear trend with a slight upward curvature. Higher brake power absorption shows higher energy conversion into heat; this increases the wear rate of the brake pad material. Also, higher wear rates lead to higher brake power absorption due to higher temperatures and possibly more aggressive abrasion. It suggests that enhanced material bonding and cooling mechanisms are needed for high-power applications to control wear. It highlights a thinned thermal management of the braking system for the longer life of the brake pads. Figure 6 d) shows that brake torque decreases with increasing speed. At higher speeds, the braking system needs to apply a higher torque to reduce speed due to greater kinetic energy. The brake torque decreases with speed due to high-temperature material fade, where the braking efficiency reduces due to thermal losses. The reducing torque with speed suggests that coconut fibre may experience thermal fade, where its efficiency decreases as it heats up at higher speeds. This indicates that while coconut fibre is effective at lower speeds, high-speed braking performance might be improved with additional cooling or advanced formulations to mitigate thermal effects.
In Figure 7 a), it is shown that with an increase in load, the brake torque and brake power absorbed also increase with linear behaviour. Table 2 shows the performance evaluation conducted through experimental analysis. It is a result of requirement of higher braking force at higher loads to reduce the vehicle speed. Similarly, the increase in brake power absorbed is due to the combined effect of increasing torque.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

TABLE 2. Performance evaluation of Agave fibre

Sr. No	Load (Kg)	Speed (RPM)	Brake Torque (N-m)	Brake power absorbed (Watt)	Fade Volume (mm3)
1	0.5	746	0.841	012.395	03.84
2	1.0	610	1.683	038.066	06.24
3	1.5	410	3.366	086.381	08.16
4	2.0	272	5.050	142.110	10.08
5	2.5	183	6.733	199.360	11.52

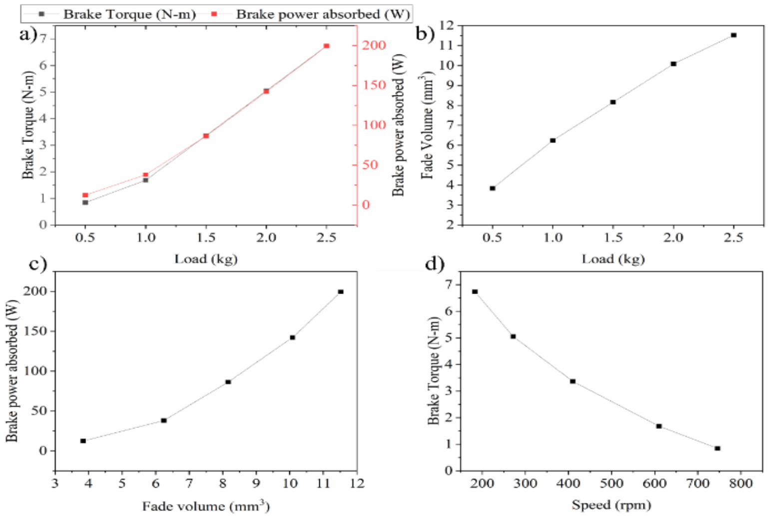

Figure 7: Comprehensive Performance Analysis of Agave Fibre Brake Pads

As the lad increases, the frictional force and hence fade volume between the brake pad and the rotor increases, showing increased wear as seen in Figure 7 b). This observation highlights the need for lower life of Agave fibre brake pads if used for heavy-duty applications. The relative behaviour of fade volume with brake power absorbed can be seen in Figure 7 c) it shows the increase in fade volume with brake power absorbed. It indicates that due to high brake power absorption fade volume increases due to thermal erosion. This trend also shows that higher brake power absorption will increase heat generation which can subsequently lead to high erosion, highlighting the need of brake cooling system and material replacement if brake is continuously used at high loads. Figure 7 d) shows that the brake torque continuously decreases with an increase in speed. It shows that, at low speeds brake system is more effective and can apply higher torque. As the braking system has a dynamic working and at higher speeds, the need for braking torque itself is increased; hence, this decrease in braking torque should not be interpreted as a reduction in effectiveness. It shows that the agave fibre provides reliable braking performance at varying speeds. This stable braking performance proves the reliability of Agave fibres for braking applications. This section shows that brake pads with Agave fibre can deliver a reliable, stable and effective braking performance. Though high wear rates are observed at higher loads, this limitation can be addressed by using more effective binding materials or limiting its use for light applications. This behaviour of the agave fibres in the form of different performance characteristics shows good potential as a brake pad material.

TABLE 3. Performance evaluation of Sisal fibre

Sr. No	Load (Kg)	Speed (RPM)	Brake Torque (N-m)	Brake power absorbed (Watt)	Fade Volume (mm3)
1	0.5	728	0.841	013.274	04.32
2	1.0	593	1.683	039.725	07.20
3	1.5	387	3.366	089.748	09.12
4	2.0	251	5.050	146.214	11.04
5	2.5	164	6.733	203.997	13.44

Figure 8 shows the performance characteristics of the Sisal fibre brake pads. Sisal fibre brake pads have similar trends as that of coconut and agave fibre brake pads.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1s (2024)
http://www.veterinaria.org
Article Received: Revised: Accepted:

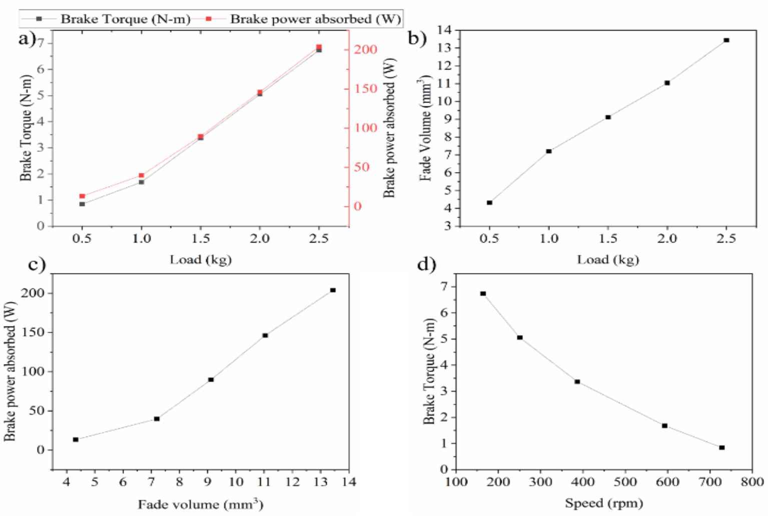

Figure 8: Comprehensive Performance Analysis of Agave Fibre Brake Pads

Figure 8 a) shows that brake torque and brake power absorbed increases with the load, showing consistency and predictability in braking force as the load increases. Figure 8 b) depicts the increase in fade volume with the load, with a slightly steeper slope compared to coconut and agave fibres. This shows higher wear of Sisal fibre brake pads at higher loads compared to coconut and Agave fibre brake pads. The variation of loads and respective behaviour has been presented in Table 3.

The fade volume increases with brake power absorbed, as can be seen in Figure 8 c). It suggests that sisal fibre has a predictable wear pattern with energy absorption. Figure 8 d) shows that the brake torque decreases with increasing speed. The braking system needs to apply a higher force at higher speeds to achieve the same deceleration due to greater kinetic energy. However, the brake torque itself decreases with speed due to thermal fade, whereas the braking efficiency reduces due to thermal loss. A decrease in brake torque at higher speed shows that sisal fibre may undergo thermal fade. Higher wear rater and thermal fade show that at higher speeds and loads, the performance of sisal fibre brake pads may deteriorate. The comparative fade volume of three fibres, namely, Coconut, Agave and Sisal fibres, is presented in Figure 9. All the brake pads with different fibres show similar trends, and fade volume linearly increases with load.

This linearity in all three fibres' fade volumes vs load indicates predictable performance, but their different slopes show varying degrees of wear resistance.

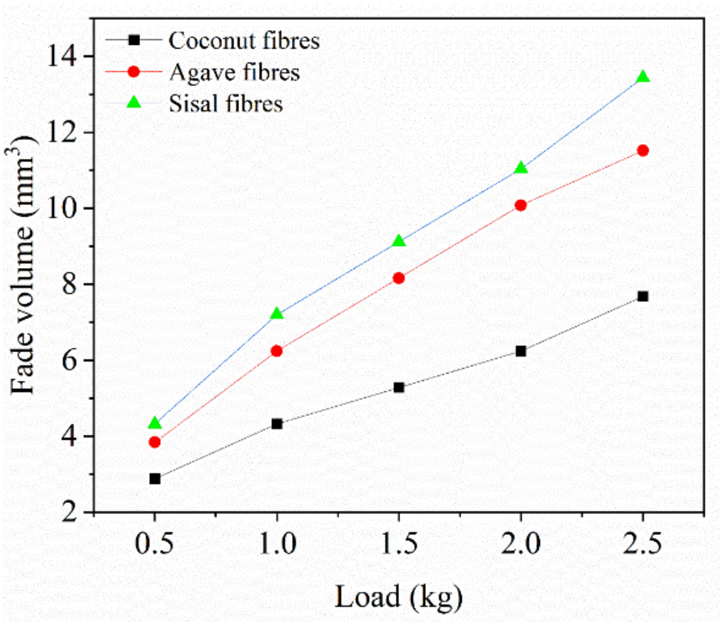

Figure 9: Comparative wear behaviour of fibres at varying load

It can be observed that the brake pads fabricated with coconut fibre have the highest wear resistance, and it shows that brake pads with coconut fibre have a maximum of 38% lower fade volume than brake pads with agave fibre while 43.47%

lower than sisal fibre at 2 kg load. Considering the average values, coconut fibre has 32.5% and 40.35%% lower fade volume compared to agave and sisal fibre brake pads, respectively. In the context of this study, the worst wear performance is observed with sisal fibre; it exhibits the highest initial percentage increase and maintains higher increases compared to the coconut fibre brake pad, making it the least resistant to fading. These findings show that each fibre delivers different performance behaviours to the brake pad. The brake pads with coconut fibre have high resistance to wear, and hence, brake pads have high durability and low maintenance needs. using coconut fibre can deliver brake pads with longer life, higher braking performance, reliability and low maintenance needs. The coconut fibre has the lowest fade volume (7.68) at the highest load (2.5 kg), indicating its superior durability and resistance to fading under stress compared to agave and sisal fibres. This suggests that coco fibre is the best choice for applications requiring high load resistance and minimal fading. The agave fibre brake pads showed a modest and balanced performance with moderate durability. Sisal fibre brake pads have a higher wear rate; hence, for applications where higher wear is acceptable, sisal fibre brake pads can be employed.

5. Conclusion

The study comprehensively examines the tribological performance of brake pads fabricated using coconut, agave, and sisal fibres. In this study, brake torque, brake power absorbed, fade volume, and their relationships are studied at varying loads and speeds. Brake pads with coconut fibre showed the best overall performance, exhibiting the lowest fade volume at all loads and showing the best wear resistance among studied fibres. Coconut fibres can deliver good braking in applications where durability and long-term performance are prime considerations. Brake pads with agave fibre showed moderate wear resistance with a steeper fade volume increase compared to coconut fibre; however, their performance is better than that of sisal fibre. Brake pads with agave fibre have modest and balanced braking performance and can be used where a balance between durability and cost is a consideration.

Sisal fibre showed a consistent brake torque but had the highest fade volume, which indicated the worst wear performance in this study. This highlights the limitations of sisal fibre to be used in heavy applications and having a lower life. This study showed the importance of selecting appropriate brake pad materials based on specific application requirements. This study also provides strengths and weaknesses for each brake pad material so that each material can be selected for specific applications.

6. Authors Contributions

First Author: Conceptualization, analysis, Experimentation, writing
Second Author : Conceptualization, writing-editing

Conflict Of Intrest

The authors declare no conflict of interest.

Funding

No funding is available for this research

Acknowledgements

This is an opportunity to convey my gratitude to the Department of Technology (Shivaji University Kolhapur) and to thank P.V.P.I.T. Budhgaon for giving me the experimentation facilities.

REFERENCES

[1] N. Elzayady and R. Elsoeudy, "Microstructure and wear mechanisms investigation on the brake pad," J. Mater. Res. Technol., vol. 11, no. February, pp. 2314–2335,
[2] U. D. Idris, V. S. Aigbodion, I. J. Abubakar, and C. I. Nwoye, "Eco-friendly asbestos free brake-pad: Using banana peels," J. King Saud Univ. - Eng. Sci., vol. 27, no. 2, pp. 185–192, 2015, doi: 10.1016/j.jksues.2013.06.006.
[3] Kalhapure, V.A.; Khairnar, H. Taguchi Method Optimization of Operating Parameters for Automotive Disc Brake Pad Wear. Appl. Eng. Lett. J. Eng. Appl. Sci. 2021, 6, 47–53.
[4] Papon, E.A., Haque, A. and Spear, S.K., 2020. Effects of functionalization and annealing in enhancing the interfacial bonding and mechanical properties of 3D printed fibre-reinforced composites. *Materials Today Communications*, 25, p.101365. https://doi.org/10.1016/j.mtcomm.2020.101365.
[5] S. H. Gawande, A. S. Banait, and K. Balashowry, "Study on wear analysis of substitute automotive brake pad materials," Aust. J. Mech. Eng., vol. 00, no. 00, pp. 1–10, 2020, doi: 10.1080/14484846.2020.1831133.
[6] H. Wang, G. Zhuang, C. Wang, and S. Zheng, "Practical application study of hybrid fibres reinforced organic brake pad for railroad passenger-coach braking," J. Macromol. Sci. Part A Pure Appl. Chem., vol. 48, no. 7, pp. 531–537, 2011, doi: 10.1080/10601325.2011.579814.
[7] Ashok, R. B., Srinivasa, C. V., & Basavaraju, B. (2018). A review on the mechanical properties of areca fibre reinforced composites. Science and Technology of Materials. doi:10.1016/j.stmat.2018.05.004

[8] Senthilkumar, K., N. Saba, M. Chandrasekar, M. Jawaid, N. Rajini, and O. Y. Alothman. 2019. Evaluation of mechanical and free vibration properties of the pineapple. Construction and Building Materials 195:423–31. doi:10.1016/j.conbuildmat.2018.11.081.
[9] Pujar, N.M., Mani, Y., and Mouleeswaran, S., 2022. Experimental investigation on three-body abrasive wear behaviour of novel natural cellulosic pigeon pea stalk fibre reinforced epoxy biocomposites. *Materials Research Express*, 9(8), 085501. doi: 10.1088/2053-1591/ac85a0.
[10] V. Vineeth Kumar and S. Senthil Kumaran, "Characterization of Various Properties of Chemically Treated Allium sativum Fibre for Brake Pad Application," J. Nat. Fibres, vol. 19, no. 2, pp. 523–535, 2022, doi: 10.1080/15440478.2020.1745130.
[11] Naidu, M.; Bhosale, A.; Munde, Y.; Salunkhe, S.; Hussein, H.M.A.Wear and Friction Analysis of Brake Pad Material Using Natural Hemp Fibres. Polymers 2022, 15, 188. https://doi.org/10.3390/polym15010188
[12] Patil, R.S.; Shete, H.V.; Miraje, A.A. DAAM Analyse wear behaviour of brake friction lining manufactured from pistachio shell composite. Int. J. Creat. Res. Thoughts 2020, 8, 3472–3475.
[13] Sai Krishnan, G., Balaji, M.A.S., Kumar, S.S. and Sanjay, M.R., 2019. Investigation on the physical, mechanical and tribological properties of areca sheath fibres for brake pad applications. Materials Research Express, 6(8), 085109
[14] Pujari S, Srikiran S, Experimental investigations on wear properties of Palm kernel reinforced composites for brake pad applications, Defence Technology (2018), https://doi.org/10.1016/j.dt.2018.11.006.
[15] Ahmed, M.J., Balaji, M.A.S., Saravanakumar, S.S., Sanjay, M.R. and Senthamaraikannan, P., 2018. Characterization of Areva javanica fibre – A possible replacement for synthetic acrylic fibre in the disc brake pad. Journal of Industrial Textiles. https://doi.org/10.1177/1528083718779446.
[16] Sutikno Madnasri, Gudel Astika & Putut Marwoto (2020): The Effects of Natural Fibre Orientations on the Mechanical Properties of Brake Composites, Journal of Natural Fibres, DOI: 10.1080/15440478.2020.1838989
[17] Yun R, Filip P and Lu Y 2010 Performance and evaluation of eco-friendly brake friction materials Tribol. Int. 43 2010–9
[18] S. Madnasri, G. Astika, and P. Marwoto, "The Effects of Natural Fibre Orientations on the Mechanical Properties of Brake Composites," J. Nat. Fibres, vol. 00, no. 00, pp. 1–12, 2020, doi: 10.1080/15440478.2020.1838989.
[19] Masrat Bashir, , Sheikh Shahid Saleem, , Owais Bashir, "Friction and Wear Behavior of Disc Brake Pad Material Using Banana Peel Powder," Int. J. Res. Eng. Technol., vol. 04, no. 02, pp. 650–659, 2015, doi: 10.15623/ijret.2015.0402091.
[20] S. Sri Karthikeyan, E. Balakrishnan, S. Meganathan, M. Balachander, and A. Ponshanmugakumar, "Elemental analysis of brake pad using natural fibres," Mater. Today Proc., vol. 16, pp. 1067–1074, 2019, doi: 10.1016/j.matpr.2019.05.197.
[21] R. Abhik, V. Umasankar, and M. A. Xavior, "Evaluation of properties for Al-SiC reinforced metal matrix composite for brake pads," Procedia Eng., vol. 97, pp. 941–950, 2014, doi: 10.1016/j.proeng.2014.12.370.
[22] B. Praveenkumar and S. Darius Gnanaraj, "Case Studies on the Applications of Phenolic Resin-Based Composite Materials for Developing Eco-Friendly Brake Pads," J. Inst. Eng. Ser. D, vol. 101, no. 2, pp. 327–334, 2020, doi: 10.1007/s40033-020-00231-4.
[23] C. M. Ruzaidi, H. Kamarudin, J. B. Shamsul, and M. M. A. Abdullah Rafiza, "Mechanical properties and wear behavior of brake pads produced from palm slag," Adv. Mater. Res., vol. 341–342, pp. 26–30, 2012, doi: 10.4028/www.scientific.net/AMR.341-342.26.