

PAPER 71 – ADVANCEMENTS IN COMPOSITE BRAKE PAD MATERIALS: A REVIEW OF THEIR TRIBOLOGICAL PROPERTIES AND PERFORMANCE.

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ABSTRACT

Composite brake pad materials have become increasingly popular due to their desirable properties; high strength, low weight, and excellent wear resistance. This review article provides a comprehensive overview of recent advances in composite materials for high-performance brake pads, focusing on their tribological properties and wear mechanisms. The article begins by introducing the importance of selecting suitable materials for brake pads. It then highlights the advantages and limitations of different composites used in brake pads, including ceramic matrix composites, carbon fiber-reinforced composites, and metal matrix composites. The article also discusses the mechanisms behind the wear and degradation of brake pads, such as abrasive wear, adhesion wear, and thermal degradation. Finally, the review concludes with a discussion of future research directions and potential improvements in the design of composite brake pads. This article provides a valuable resource for researchers and engineers in brake pad materials and tribology.

1 INTRODUCTION

A brake pad is the most crucial component of the disc braking system in which the life of the driver, passengers, and road users lies once the vehicle is set into motion [Borawski 2022]. A braking system's main function is to overcome the vehicle's momentum and stop the vehicle through friction [Milenković et. al. 2010]. The performance of the brake pad is greatly influenced by the friction material on the brake pad, which alters the vehicle's motion by converting the kinetic energy to thermal energy. Hence, this is achieved by the coefficient of friction, which accompanies the wear whenever the brake is engaged [Glisovic et. al. 2011]. These tribological properties are the most important to look into in the brake pad as a prerequisite to other properties because the lifespan of the brake is a function of how fast it fades during usage and how often the replacement will be done on the braking system. Figure 1 shows a typical automobile brake pad.



Figure 1: A typical brake pad [www.delphiautoparts.com. accessed 23/5/2023]

Tribology was coined from the Greek word *tribos*, which means “rubbing,” translating the word literally into the “science of rubbing” [Al-Samarai et. al. 2012]. Tribology refers to the science and technology guiding the interaction of surfaces in relative motion. It also encompasses the study and application of wear, friction, and lubrication of parts [Archard 1986]. Friction and wear involves two or more bodies in contact, sliding, rolling, with respect to each other depending on the geometrical configuration of the objects, and the interfacial force produced in the process is known to as friction [Aadarsh 2014]. Friction and wear, as two kinds of responses from one tribo-system and are directly proportional to each other in every state of contact in the system. However, there are no simple, comprehensive relationship between them [Hsun-Yu et. al 2020]. Literature shows the recommended successful means of controlling wear irrespective of wear mechanisms by tribologists including soft or hard film coating, multi-phase alloying, and composite structuring in addition to the traditional lubrication method [Ostermeyer 2001].

Interactions among heat, wear, and friction characterises the tribological interface between the brake friction material and the brake disc. This results in continuous growth and destruction of smooth and hard surface structures [Ostermeyer and Mueller 2006], which is also achieved via modern automated methods [Bode and Ostermeyer 2009]. These interactions are influenced by the external load parameters, including normal force and sliding velocity, which dictates the life cycle and average size of the contact patches and the coefficient of friction over a period [Österle and Dmitriev 2016].

On the other hand, lubrication is a means of reducing the effect of friction and wear by incorporating a regulating film between the moving surfaces in contact. This film, known as a lubricant, can be in the form of solid, fluid, or

plastic substance but the most commonly used is oil and grease [Perez and Echeberria 2019]. The functions of lubricants, includes reduction of friction, wear and tear, corrosion prevention, temperature control and contamination, power transmission, and reduction in squealing or screeching noise due to vibration [Adeyemi et. al. 2016]. The addition of solid lubricant in the brake friction material helps modifies the effectiveness and harshness of the brake when applied. Also, it helps reduce the noise/squeal during braking.

2. PROPERTIES OF MATERIALS USED FOR BRAKE PADS

Friction material plays an important role in the braking system since it's the crucial part of the brake pad that decelerates and stop the wheel's rotation by transforming its kinetic energy to heat energy and dissipating it to the surrounding [Adekunle et. al. 2022, Lawal et. al. 2017]. Friction material is made from a blend of several raw materials because no single material can give all the properties required of friction material. Several researchers have worked on replacing carcinogenic asbestos (base material) lined brake pads in the market with eco-friendly materials such as palm kernel shell, periwinkle, sawdust, cow hooves, cow horn, banana peels, eggshell, and other agro-residue, together with other additives [Lawal et. al. 2019, Uzochukwu et. al. 2019]. The brake pad has been designed and formulated to maintain a steady frictional coefficient and should not decompose at high temperatures [Dineshkumar et. al. 2017]. There are three types of brake pads available on the market. Asbestos, metallic, and ceramic brake pads are available. Asbestos brake pads have good friction properties and thermal resistance, but they are carcinogenic. Because of this carcinogenic effect, the manufacturer decided to look for a more environmentally friendly alternative material [Blau 2001]. Ceramic brake pads generate less vibration, dust, and adequate disc or drum wear, whereas metallic brake pads provide a long service life with a reduced rotor life span. Ceramic brake pads generate less vibration, dust, and adequate disc or drum wear, whereas metallic brake pads provide a long service life with a reduced rotor life span [Verma 2016, Xingming et. al. 2016].

Under various velocities, frictional heat, and operating conditions such as mud, oil, and water, good friction material for brake pads maintains a coefficient of friction ranging from 0.2 to 0.4 [Yuji and Takashi 1998, Dineshkumar et. al. 2017]. The friction material for brake pad consists of more than ten elements in which solid lubricant is not left behind to increase the stability of the brake pad frictional coefficient and improve the thermal conductivity of the friction material.



Figure 2: Brake friction material [www.hella.com. accessed 23/5/2023]

Brake pads should be inspected every six months or every 16,000 to 80,000 kilometers drives for replacement, depending on the type of pad, weight of the vehicle, and driving terrain [Engberg 1995].

Recent Advances in Composite Materials for High-Performance Brake Pads: Eco-Friendly Materials Used for Brake Pads

Composite materials have been extensively used in manufacturing high-performance brake pads due to their superior mechanical and thermal properties. In recent years, several advancements have been made in composite materials for high-performance brake pads. Asbestos has been removed from brake pads, and there have been researches that have demonstrated that the removal can be replaced by eco-friendly composites such as seashells (base material), sawdust (fillers), and other additives such as Palm kernel shell (abrasive), charcoal (lubricant), metal chips (reinforcement) and epoxy resin (binder) [Adekunle et. al. 2022]. Agro-based materials have also demonstrated a promising prospect, as they have been used for production of brake pad. Lawal et. al. 2019 examined the production of automobile brake pads as well as the potential of agro-based composites of cashew nut shells and Nigerian gum Arabic binder. Steel dust, silicon carbide, and graphite were also used as additives. The produced friction material showed some favourable properties, such as improved hardness, compressive strength, frictional coefficient, wear rate, and good thermal capacity, in line with the work of Adekunle et al. 2022. Furthermore, agro-based materials, particularly plants fibers, are good replacements for asbestos for brake pad production as their coefficient of friction is reported to be 0.4848 and wear rate of 1.16mg/m. The tribological properties of the agro-based materials were in agreement with the commercial brake pads. They followed the trend in literature such as that of Adekunle et al. 2022, which had a 0.315 frictional coefficient and wear rate of 0.0614 mm³/Nm. Other agro-based materials which have also been used as friction material is a coconut shell (base material), aluminum oxide (abrasive), graphite (friction modifier), and epoxy resin (binders). The coefficient of friction of 0.614 and the wear rate were found to be 0.03156 mg/m [Lawal et. al. 2019]. As a result, the developed friction material performs satisfactorily in terms of reduced brake noise and vibration during braking, as well as a low wear rate and stable frictional coefficient. The high wear resistance of the developed composite resulted

from the higher tensile strength leading to resistance of abrasive effect more than the reference sample with higher brittleness. Consequently, agro-based friction materials have substituted for asbestos in the production of brake pad friction material [Abutu et. al. 2018].

Metallic materials have also been used as friction materials, which produces improved performances compared to asbestos-based brake pads. Princa-Bretotean et al. 2018 replaced asbestos and its additives for brake friction material production with Aluminium, graphite, zirconium oxide, silicon carbide, titanium oxide, phenolic resin, Hexamethyl-tetramine, and coconut fibre. The coefficient of friction was determined to be 0.35; thus, the friction material with a wear value of 0.06 g is a good alternative to be used for small and medium vehicles, which is in accordance with technical literature on the tribological characteristic of the friction material produced from eco-friendly composite [Adeyemi et. al. 2016]. Similarly, Lawal et al. 2017 developed friction material from a blend of sawdust, steel dust, silicon carbide, graphite, and epoxy resin. The tribological property reported a wear rate of 3.23mg/m for the best sample produced. The composite brake friction material's higher wear resistance was attributed to the sample's higher compressive strength which indicates that there is proper bonding between the composite's particle arrangement and the intermolecular relation are firmly bonded with little pour spaces, which gives rise to low moisture absorption during the percolation test.

Polymer composites have also found their usefulness in producing friction material for brake pads. Afolabi et al. 2015 reinforced polymer with palm kernel shell and cow bone. The experimental matrix was palm kernel shell/epoxy resin and cow bone/epoxy resin at 30:70 formulation. A proper combination of PKS and cow bone as reinforced material showed excellent thermal resilience enough not to decompose at braking temperatures for long durations. The coefficient of friction test was performed with the aid of horizontal plane apparatus with a recorded value of 0.735 for palm kernel and 0.677 for cow bone with the wear rate of 9.57×10^{-7} and 1.44×10^{-6} g/m, respectively [Afolabi et al. 2015]. Table 1 gives the summary of the results of the tribological properties of friction material for brake pads reported in works of literature.

Table 1: Summary of works of literatures on tribological properties of brake pads.

Author (s)	Base Material	COF Produced/ control	Wear Produced/ control
Adekunle et. al. 2022	Seashell	0.315/ 0.318	0.0614/0.0812 mm ³ /Nm
Lawal et. al. 2019	Cashew Nut Shells	0.4848/ (0.3-0.4)	1.16/3.80 (mg/m)
Abutu et. al. 2018	coconut shell	0.634/0.634	0.03156/ 0.04184 (mg/m)
Lawal et. al. 2017	Saw dust	-----	3.23 (mg/m)
Adeyemi et al. 2016	Palm kernel shell	0.37	3.040×10^{-6} (g/m)
Adeyemi et al. 2016	Cocoa beans shells	0.35	0.715×10^{-6} (g/m)
Adeyemi et al. 2016	Palm kernel shell	0.37–0.40/0.30–0.40	2.146/3.80 (mg/m)
Egeonu et. al. 2015	Palm kernel shell	0.349 /0.359	$4.2547/3.2864 (\times 10^{-10}) (m^3 /m)$
Bashir et. al. 2015	Banana peel	0.39/ (0.3-0.4)	0.038 /----- g
Afolabi et. al. 2015	Palm kernel shell	0.73/ (0.3-0.4)	$9.57E^{-7}/ 1.85E^{-6}$ (g/m)
Afolabi et. al. 2015	Cow bone	0.677/ (0.3-0.4)	$1.44E^{-6}/1.85E^{-6}$ (g/m)
Mgbemena et. al. 2014	Palm kernel shell	-----	0.24/0.16 μ m
Onyeneke et. al. 2014	Periwinkle	(0.4-.65)/ 0.45-0.65	0.025-0.06 (mm/min)
Aigbodion et. al. 2010	Bagasse	0.42/ (0.3-0.4)	4.20/3.80 (mg/m)

Wear and Degradation of Brake Pads

Figure 3a shows a typical brake pad without wear degradations. Figure 3b shows the wear tracks of the brake pad. Wear occurs as a result of interaction between brake pad and the rotating disc of the automobile's wheel. The material with less hardness, the brake pad, shows severe degradation with time. The disc's lifespan depends on the pad's aggressivity, determined by the friction material composition. A brake disc is majorly made of grey cast iron, and the brake pad should be made from lesser properties materials to promote long-term disc usage.

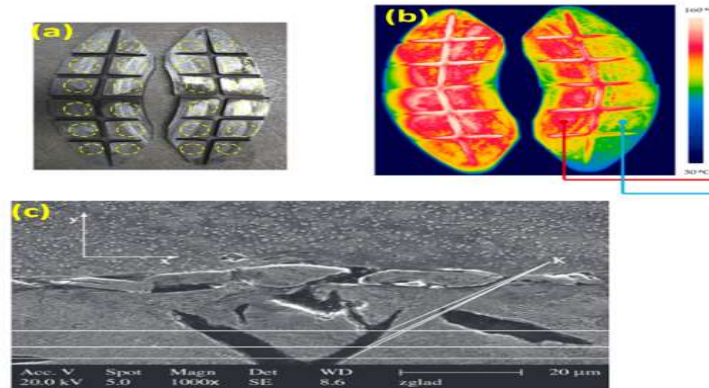


Figure 3: (a) A typical brake pad (b) worn brake pad (c) SEM image of worn brake pad [Polak and Grzybek 2005, Sawczuk et. al.2022]

There are various types of brake pad wear, which aids in the identification of the causes and the precise measurement toward accuracy in repairs, allowing for effective management of user time and money [Elzayady and Elsoeudy 2021, Li Xuewu et. al. 2020]. The wear on brake pads can be in any form; outer, inner, tapered, over-lapping pad wear, and a glazed or cracked pad surface with lifted edges. The glazed or cracked brake pad wear exhibits signs of physical damage and thermal tribulation to the friction material. Improper braking application of new pads and overuse are the common causes of this type of wear in brake pads [www.delphiautoparts.com. accessed 23/5/2023]. The major wear mechanisms, as shown in Figure 3c, occur as a result of delamination [Laguna-Camacho et. al. 2001 of filler particles from the organic binder and degradation of the phenolic resin during asperity heating [Manoharan et. al. 2019]. The primary dependants on the deformation of the friction pair parts are local friction intensity and heat due to thermal contact resistance [JIANG et. al. 2019]. Furthermore, braking force and brake pad vibrations [Perez and Echeberria 2019] Its wear was influenced by demonstrating that high weather temperatures result in rapid wear. The dominant wear modes were high sliding abrasion wear and fatigue cracks, and the friction behavior of automotive brakes is determined by the friction layers and friction films formed on the surface of the brake assembly [Bashir et. al. 2015, Elzayady and Elsoeudy 2021].

Based on the investigation conducted on a specific automotive vehicle's actual brake pad surface before and after the pad was subjected to usage for its wear mechanisms determination [Elzayady and Elsoeudy 2021]. Fiber delamination, as shown in Figure 4a, and fragmental wear, as shown by the large hole induced by particle removal from the material's surface in Figure 4b, are two possible wear mechanisms in brake pads. The most common type of wear that occurs during frictional motions between the brake lining and the disc surface is abrasive wear. The hole in the surface, as shown in Figure 4b, caused microcracks in the radial directions of the hole's circumference [Elzayady and Elsoeudy 2021, JIANG et. al. 2019], indicating non-uniformity of particle size in the sample. These cracks almost always appear when there is too much pressure applied to the pad, resulting in more working actions and stress. Other wear modes can be seen in large cracks in two perpendicular directions. Figure 4c depicts these cracks. They are most likely initiated in the sliding direction and then propagated, resulting in transverse sub-crack incidence. Thermal fatigue on the surface caused by working at a temperature range is the most common cause of these cracks. These wear modes occur in different ways and could be as result of mechanical damage due to friction action in the form of a glazed surface. It could also be wear due to abrasive which resulted in eroded phases. Furthermore, thermal fatigue which occurs due to thermo-mechanical (fatigue) wear and resulted to the formation of a large cracked surface. Finally, physical degradation by the rust layer formation and corroded surfaces which gives rise to diffused iron, oxygen, and carbon compounds, and could be thermo-chemical wear (phases pyrolysis) leading to phases fading [Elzayady and Elsoeudy 2021].

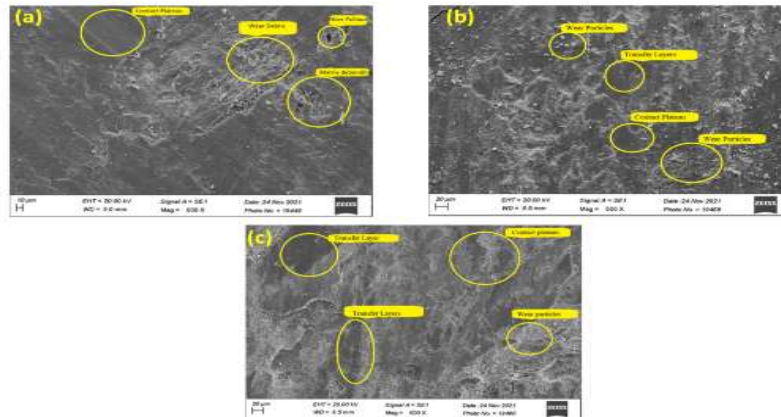


Figure 4: SEM images showing (a) voids (b) wear tracks (c) cracks of brake pad [Naidu et. al. 2022]

3 FUTURE RESEARCH DIRECTIONS

With the close correlation in the performance of the brake friction material produced from agro-waste, locally sourced eco-friendly composites, and conventional carcinogenic asbestos-lined ones, it is of great necessity to encourage the production of eco-friendly brake pads in replacement of asbestos-lined to provide a safe environment.

In determining the wear rate of the brake pad, the area of contact, the weight of the vehicle, and the sliding distance should be considered. Those are the parameters on which the braking performance depends.

4 CONCLUSION

Brake friction material should possess a moderately high coefficient of friction ranging between 0.2 to 0.4 for a lightweight vehicle, good thermal conductivity, good strength, and relatively high wear resistance under variable load and speed conditions. The Pin-on-disc apparatus is the most suitable, accurate, and mostly used method of determining the tribological properties (friction and wear) of friction material for brake pads. The velocity of sliding, sliding distance, and load acting on materials are the parameters on which the wear rate of friction material for brake pad depends. The tribological properties (friction coefficient and wear rate) of the brake pad are greatly influenced by the material composition and quantity of binder present in the composition, i.e., the higher the percentage of binder in the friction material composition led to corresponding higher hardness and wear resistance of the brake friction material.

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