International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-12 Issue-2, July 2023

A Review on Fabrication of Recent Novel Brake Friction Materials

Tarini Ranjan Pradhan, Santosh Kumar Shanti

***Abstract:** The primary means of mobility today are vehicles. For better braking system better materials are provided for tribo pairs. To reduce the cost of the tribo pairs instead of metals, composite materials are used recent days. This topic deals with the combination of brake disc and brake pad which is generally called tribo pair. As a consequence of its distinctive qualities like high fatigue strength, high hardness, high strength, high specific modulus, light weight and low density, the use of Al-SiC Metal Matrix Composites for brake disc & pad have been steadily expanding in recent years. The properties of the metal matrix composite like tensile and compression strength, as well as hardness, are investigated in order to identify the optimal carbide percent. For brake pad different material compositions are mixed together and in powder metallurgy method brake pad fabrication is developed. Previously Asbestos is commonly employ as a material for brake pads in automobiles. Brake pads are subjected to a great deal of friction, which generates a great deal of heat. Asbestos is a better heat absorber and dissipater than other materials. The main downside of asbestos is that it is extremely harmful to human's health. That's why asbestos can be replaced by other materials. This paper mainly covers recent advancement of composite brake friction materials along with comparison of every component with proper validation.*

***Keywords:** Brake disc, Brake pad, Solid lubricants, Wear, Friction, Al-Si C metal matrix composites, Composite materials, Tribometer: Pin on disc test*

I. INTRODUCTION

Asbestos was the most suited and frequently used brake lining material; however, it was banned due to its carcinogenic nature by health and environmental agencies. Researchers have been pushed to produce asbestos-free brake friction compounds as a result of the asbestos ban. Brake pads made of natural fibers or agricultural wastes are seen as the material of the future. Because of its reduced density and better braking stability, aluminium metal matrix composite (MMC) is investigated the future material for brake discs and drums. The braking mechanism is based on the notion of energy conservation. When all of the kinetic energy in the moving equipment is converted to frictional heat, the device comes to a halt. A braking disc or brake drum is an example of a revolving device.

Manuscript received on 23 May 2023 | Revised Manuscript received on 31 May 2023 | Manuscript Accepted on 15 July 2023 | Manuscript published on 30 July 2023.
*Correspondence Author(s)

Tarini Ranjan Pradhan*, Department of Mechanical Engineering, BITS Pilani Hyderabad Campus, Hyderabad (Telangana), India. E-mail: tarinivicky123@gmail.com, ORCID ID: 0000-0002-8012-4550

Er. Santosh Kumar Shanti, Senior Technical Officer, Department of Design & Project Engineering, CSIR-Institute of Minerals & Materials Technology, Bhubaneswar (Odisha), India.

Gray cast iron, carbon-based materials, steel, aluminum-based materials and ceramic-based materials are the five groups that these materials fall within. Poor braking dynamics are caused by a large amount of un-sprung mass. Because of the aforementioned issue, researchers have been working on the advancement of lightweight brake disc/drum materials from the start in order to improve brake dynamics. Another issue by using the grey cast iron disc is that the coefficient of friction decreases in damp situations. It might be what led to the accident. As a result, a brake material that works well in both dry and wet conditions must be developed [1].

Agricultural wastes such as banana peels, aramid fibres, flax fibres, palm wastes and other agricultural wastes are investigated. A bio supplied thermo set resin (When a solid bond is required, resins are frequently used in construction as adhesives, coatings, or building materials) was developed and experimented for a up to date use, as a resin matrix of automotive brake pads, employing bio source raw components such as condensed tannins and furfural alcohol. The developed production technique is quite simple [2], [3].

The main purpose of this study is to compare the frictional properties of asbestos based and asbestos free brake pad materials. The whole three friction materials were crushed and moulded into a sample: AF-22 (metallic based), DM-6 (asbestos based) and CL-3003 (fine brass based). Experiments were conducted with a specific test setup based on the Pin-on-Disc approach. Three materials' coefficients of friction were compared under various sliding velocity and pressure situations[4].

The demands on the material's mechanical and tribological qualities for brake pads grew. Examining alternative materials for brake friction materials as a replacement for asbestos, which has negative environmental consequences, as the wear indication of brake pads using various ways. Natural composite material contributes significantly to the friction coefficient and is environmentally benign. Friction materials containing no asbestos, such as palm kernel shell, rice husk, banana peel, bagasse, coconut shell, periwinkle shell, and others, are being investigated [5], [6].

Because of its very unusual crystalline structure, a synthetic hydrated calcium silicate (Binder) is utilized as one of the components in several friction materials. It has the potential to increase the porosity of the product. Five distinct types of copper-free brake pads were produced, each having the same composition but varied weight percentages of PD particles (0, 5, 10, 15, and 20) and barite, a space filler, to compensate for the variation. Because of its multifunctionality, copper appears to be an essential component of non-asbestos organic brake friction compounds.

However, new research has shown that it is a hazard to aquatic life, and attempts have been made around the world in recent years to find a replacement [7].

Due to its versatility in performance, copper (Cu) is an important component of friction materials (FMs). It is, however, prohibited due to its negative impact on aquatic life. Five different types of brake pads were created using a fixed parent composition and FA25 alloy percentage of 0, 5, 10, 15, and 20 weight percent. For the sake of comparison, another type of pad was produced that included Cu in a concentration of 10% by weight. Physical, tribological, noise-vibration (NV), mechanical, thermal properties of the brake pads were studied [8], [9].

Full-scale car brake dynamometer tests were performed on a model semi-metallic brake liner. The properties of emitted wear particles were also studied. The friction process was dominated by abrasive and adhesive wear, as well as oxidative reactions. The friction layer's properties are primarily determined by surface temperature, pressure, and sliding velocity [10].

The brake pad is a friction substance that is stationary and rubs against the revolving brake disc or brake drum. Lightweight, low wear rate, corrosion resistance, low noise, extended life, and low cost are some of the features necessary in a brake pad. Although asbestos is one of the greatest materials for brake drums, it does have some health risks. Asbestos is divided into two types: serpentine asbestos (chrysotile) and amphibole asbestos (crocidolite). Wear-out particles of chrysotile asbestos brake pads have been discovered to have a strong carcinogenic effect on vehicle mechanics who replace brake pads. correspondingly, the Environmental Protection Agency prohibited the employ of asbestos-based brake pads in 1986. Bernstein, a researcher, conducted a study comparing the health effects of two forms of asbestos (crocidolite and chrysotile). It was discovered that the results of earlier investigations contradicted each other. When chrysotile asbestos is inhaled for a short length of time, it does not induce lung infection. Crocidolite asbestos, on the other hand, had a half-life of almost 1000 days and triggered a significant inflammatory response. Other heavy metals released by brake pads, such as copper, iron, antimony is also detrimental to the environment, but Ceramic or carbon-carbon brake pads, non-asbestos organic (NAO) brake pads are not harmful to environment. Because of their low cost and environmental friendliness, NAO brake pads are the most popularly employ now a days. In the water spray scenario, the brake pad with a high percentage of steel fibers had a constant coefficient of friction. High metallic fiber content in the brake pad is beneficial from a safety standpoint, but a high steel percentage causes excessive disc wear. NAO brake pads account for over 80% of all brake pads used in autos. Organic brake pad contains binder, fibers, abrasives, lubricants, fire-resistant compounds, and other reinforcements, among other things. Low density, high plasticity, and ductility are only a few of the advantages of aluminium and its alloys. They have numerous uses in the realms of aeronautics, astronautics, automobiles, and high-speed trains. Due to their low cost of production, SiC particle reinforced with Al based MMCs are among the most familiar and widely obtainable MMCs [11].

To avoid complications caused by corrosion, vehicles with brake energy recuperation, such as Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) place significant expectations on the corrosion resistance of brake rotors. The lowering of rotor mass is important in general. Ford and Fagor Ederlan have collaborated to produce a whole aluminium brake rotor for passenger and SUV applications that is corrosion resistant and takes full advantage of aluminum's light weight. There are no ceramic or comparable reinforcements or coatings, in contrast to previous technology[12].

Friction is an entity that needs to reduce to a bare minimum in various areas in order to save energy, and also helps in savings lives. When it comes to driving safety, brake discs are quite important. The material selection is a crucial role in creating the target specification for a product development because there is such a vast variety of composites and ceramic materials available. Following a discussion on attributes and a market investigation, determined that AISI 1045 steel is the ideal material for our research. It is needed to complete product design phases with the support of CAD and CAE software such as Solid works and ANSYS [13]. The use of Aluminium & Silicon Carbide (SiC) Metal Matrix Composites has steadily increased in recent years. A centrifugal casting machine was used to make Al-SiC composites with varied carbide compositions. The microstructure-property relationship was investigated using scanning electron microscopy (SEM). It was discovered that when the aggregate of silicon carbide in the constituents rose, the compressive & tensile strength of the composites increased. It is vital to develop composite materials conducive to join the materials requirement and performance of car components. To satisfy industrial needs, aluminium metal matrix composites (AMMC) are used. AMMC is a combination of aluminium and silicon carbide with a small number of additional components such as aluminium oxide, magnesium and graphite that are precisely blended to improve the material's chemical, thermal & mechanical properties. The mechanical behaviors and characteristics of AMMC manufactured by stir casting technology, where silicon carbide (SiC) is reinforced with aluminium for use in disc brakes, are investigated in this work [14], [15].

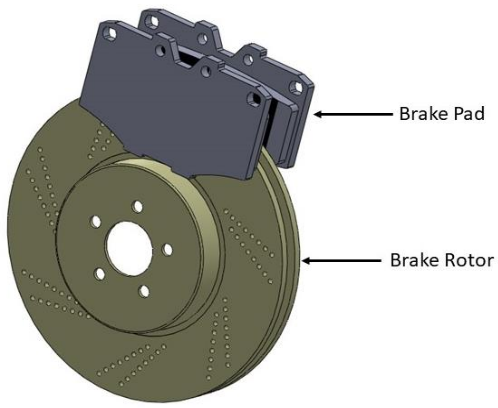

Fig. 1. 3D view of tribo pairs.

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

II. EVOLUTION OF BRAKE PAD MATERIALS

The three main kinds of brake pads are metallic, non-asbestos, and non-metallic organic brake pads. Process and element properties, such as moulding temperature, duration, pressure level, and heat treatment temperature, all influence the mechanical attributes of brake caliper materials [16]. Previously copper based and asbestos brake pads are used. But due to harmful effects like lungs diseases & cancer these are replaced by some fibres like materials. For brake disc cast iron may replace by Al-SIC brake disc. There are several compositions of materials which can overcome these problems. The future priority for automobiles will be decreased emissions and increased fuel efficiency for the best braking material [17].

2.1. Antiquity of brake pad or brake lining materials development

Table1. Development of brake lining materials throughout the years [18].

Brake Pad or Brake Lining Materials	Relative Year of First Use
Cast iron or steel	Before 1870
Cotton or hair belting	1897
Asbestos	1908
Other materials to replace steel or cast iron	1930
Flexible organic materials	1930
Materials like semi-metallic	1950
Non-asbestos organic (NAO)	1960
Carbon fibres	1991
Aluminium based compound	2002
Titanium based material	2008
Composite Materials along with solid lubricant Graphite	2012
Composite Materials along with solid lubricant MoS_2	2018

III. TYPES OF BRAKE PAD MATERIALS

The four basic varieties of brake pads are non-asbestos organic, metallic, non-metallic & composite.

3.1. 3.1. Metallic or semi-metallic composite friction materials

Metal or metal alloys are used to make metallic pads. Semi-metallic brake pads have a lot of metals or metallic fibres in them. The most often utilized metals are iron, copper, brass, and tin. Heavy-duty braking applications, such as trains and aircraft, commonly use cast iron or steel-based metallic pads. Semi-metallic brake pads are also more robust and heat-resistant than other types of brake pads, and they work in the largest temperature range. To finish the brake pad, these diverse metals are mixed with graphite lubricant and additional fillers. Semi-metallic pads are low-cost and offer great heat transfer away from the rotor. This helps to prevent rotor warping, which can happen if the rotor gets too hot. Semi-metallic brake pads are also durable and wear out slowly [1].

3.2. Copper-less ceramic friction materials

Copper has been used as an ingredient in non-asbestos friction compounds because copper free ceramics have a high thermal conductivity and can be operated as a solid lubricant at high temperatures. The employment of types of ceramic materials to provide a huge range of functionalities is referred to as the ceramic matrix formulation in friction materials. To boost the thermal conductivity of NAO-type brake pads, copper metal fibres (5 percent -10 percent) are typically used. Copper fibres also aid in the development of compact third body layers. However, there is potential health risks associated with the discharge of heavy metal copper. Graphite is a good substitute for copper since it has higher heat conductivity and a lower wear rate. However, at a greater temperature, graphite rapidly oxidized to carbon monoxide, which could be due to health concerns. Copper-free eco-friendly brake pads can also be made with natural fibres instead of copper. The Cu-free brake pads were found to emit higher airborne particulates [19], [20].

3.3. Non-asbestos organic friction materials (NAO)

Organic friction compounds come in two varieties that are commonly employed,

a) Organic compound containing asbestos

b) Organic material free of asbestos, 50 percent metallic components, phenolic resin, graphite, friction dust, and other elements are commonly found in them.

It was not long before; it was realized that a single fibre wasn't enough to do the function that asbestos did. Organic materials that are devoid of asbestos are the most typically utilized for brake pads. NAO brake pads account for over 80% of all brake pads used in autos. Organic brake pads contain a binder, fibres, abrasives, lubricants, fire-resistant compounds, and other reinforcements, among other things. For strength, binders are employed to keep fibres, organic & inorganic filler as base material together [21].

3.4. Composite friction materials

When compared to conventional brake pad materials, composite brake pad materials offer superior braking performance, less dust, and a longer lifespan, making them a popular option for high-performance applications. The following are some typical forms of composite brake pad materials:

- Ceramic Composites
- Kevlar Composites
- Carbon Fibre Composites
- Metallic Composites

Kevlar composites are a type of friction material that is commonly found in brake pads. It is a synthetic fibre with a high strength-to-weight ratio, making it an ideal material for high-performance applications in the aerospace, military, and automotive industries. Kevlar, when combined with other materials, can produce composites that are long-lasting, heat-resistant, and able to withstand high levels of friction.

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Comparing composite brake pad materials to traditional brake pad materials, they provide better braking performance, less dust production, and a longer lifespan.

3.4.1. Brake pad recent composite material compositions

Brake pads contain reinforcements, solid lubricants, abrasives, binders & fillers. These combinations are providing a good braking system for the vehicles.

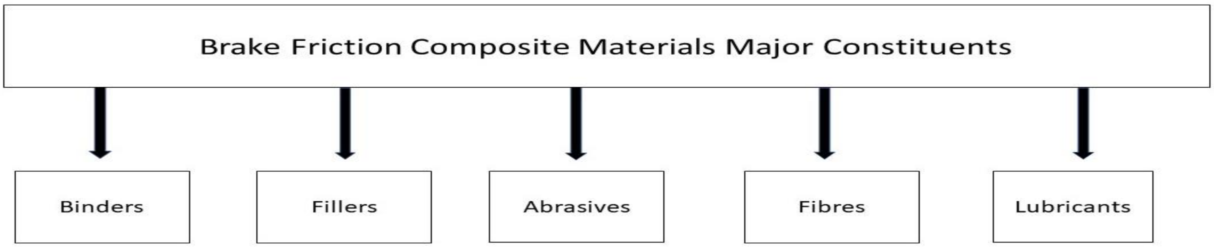

Fig. 2. Major Ingredients of brake friction composite materials.

3.4.1.1. Binders

It offers bonding strength and binds the brake pad's constituent together. At high temperatures, it is able to maintain excellent stability. To improve the damping qualities of phenolic resin, it is typically combined with rubber crumb. Traditional phenolic resins, which are utilized as binders in friction materials, are made from fossil fuels. Binders can be made of solid plastic or thick cardstock, although they are more usually made of a plastic or paper sheet wound around heavy paperboard [22]. More binder cannot be added to a recipe because excessive addition would cause brake pad fade and wear.

3.4.1.2. Friction modifiers

Single abrasive or solid lubricants are almost seldom utilized. To eliminate morning sickness and maintain optimal friction levels at high temperatures, a combination of abrasives including hard and soft abrasives is utilized instead.

3.4.1.3. Abrasives

Controlling the frictional characteristics is required to keep the brakes stable. Abrasives examples are included zircon ($ZrSiO4$), zirconium oxide, and alumina [23]. When dealing with lubricants, it is necessary for them to develop a suitable tribo-film at the friction pair interface, as well as the ability to regenerate the tribo film on a constant basis in order to maintain the friction coefficient. Typical solid lubricants include molybdenum disulfide, tin sulphide, antimony sulphide, iron sulphide, copper sulphide, and various types of graphite such as natural graphite, flake graphite, synthetic graphite, and polarized graphite, among others.

3.4.1.4. Lubricants

To lower friction and wear in tribo pairs, lubricants are added to the composite materials. They are playing crucial role in the boundary lubrication regime, where they can prevent solid surfaces from making direct contact, reducing friction and wear significantly. Due to their ability to withstand extreme heat and pressure without degrading or vaporizing, solid lubricants like graphite or molybdenum disulfide are frequently added to composite materials. The current study examines the tribological behaviour of solid lubricants, such as graphite, molybdenum disulfide and tungsten disulfide-based brake friction materials, in combination with other substances designed as brake pads [24].

3.4.1.5. Fillers

A filler in composite is a material that can simply fill the space or takes up a significant amount of space in a brake friction material. They are included to cut down on the costs of manufacturing and the end product. Instead of being abrasive or lubricant, the filler material should simply support the other components without affecting how well they work. By substituting a few of the more costly reinforcement fibres, filler materials can also help cut costs. For instance, incorporating glass microspheres into a composite can lessen the quantity of carbon fibre required without compromising strength. The role of filler is not as important as that of other components such as reinforcement, binder, and so on. Organic fillers and inorganic fillers are the two types of fillers available. In the brake pad, organic fillers such as cork, cashew friction dust, rubbers, and leather were used, as well as inorganic fillers such as vermiculite, petroleum coke, mica, calcium carbonate, carbon black, and molybdenum trioxide. These are used to reduce expenses while also increasing production capacity. Fillers, mostly to save money but also to enhance manufacturing efficiency. Mica and vermiculite are two minerals that are frequently used. Another popular filler is barium sulphate [16], [25].

3.4.1.6. Fibres

The goal of this study is to provide an environmentally friendly and sustainable composite material for brake pads. Coconut fibres, magnesium oxide, bamboo fibres and epoxy resin make up the composite. With increasing fibres content, the thermal stability of Coconut fibre composite improves [26].

IV. CLASSIFICATION OF FRICTION MATERIAL FORMULATIONS FOR BRAKE PAD

Friction material compositions are available in many different shapes and sizes. New materials have evolved as a result of the dangerous asbestos airborne particles. This type of metal is appropriate for autos that are utilized on city streets. Due to the increased amount of steel present, these do not fade away soon, but they do begin to fade as you down the slope, especially at a quicker speed. It makes a lot of noise when braking and corrodes in humid environments. In the below diagram some friction material formulation types are there. Those are

a) Semi metallic
b) Low metal & steel
c) Ceramics
d) Carbon-Carbon
e) Sintered metals
f) Non-Asbestos organics (NAO)

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

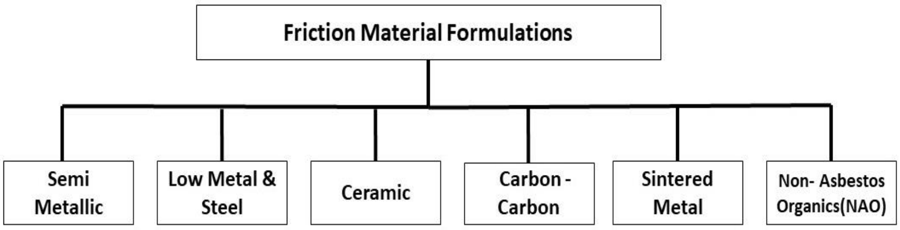

Fig. 3. Friction material formulations.

4.1. Low metal & steel

The amount of steel fibre and metal content merely differs, there is no substantial difference between the low metal and low steel brake friction material formulations. The weight percent of resin in low metal brake pad formulations is usually 1%–4% more than in semi-metallic formulations. They have a friction coefficient of 0.35–0.38 compared to 0.4 for semi-metallic. The shape of the abrasive affects the wear rate, round shaped tiny abrasive particles are typically employed in this sort of formulation. Low steels are utilized in front axles when there is a lot of braking force. When compared to low metal formulas, the abrasives employed are usually less [16], [25].

4.2. Ceramic formulation

The formation of ceramic materials to produce a huge range of functionalities is known as ceramic matrix formulation. Unlike semi-metallic formulations, they do not fade quickly. Steel fibre, in reality, has no place in this type of composition. This sort of composition also includes both hard and soft abrasives to reduce friction at both low and high temperatures. In a wet environment, Wang et al. tested the tribological characteristics of a carbon-based brake pad against a steel rotor. The friction coefficient decreased by roughly 30% in wet conditions compared to dry conditions, which could be a contributing factor in the disaster. Jiang et al. studied the tribological features of graphite/SiC brake pads in comparison to SiC/Al brake discs [1], [16], [25].

4.3. Sintered metal formulation

The bonding between constituents happens via the fusion of metal particles under the effect of heat and pressure in sintered metal brake friction material, also known as the metallic friction material.

There are two types of sintered friction material

a) Sintered metal based on copper.

b) Sintered metal based on iron.

The primary purpose of sintered metal is to disperse high energy densities. Matrix material must be able to transport heat without deteriorating. Due to their high thermal conductivity, wear resistance, and durability, sintered metal formulations are frequently used in brake lining materials. These mixtures typically include metal powders like copper, iron, and steel that are compressed under pressure and then sintered at high temperatures to create a solid substance. When the iron is added, it can be used for both dry and wet friction. The iron-based sintered material contains around 61 percent weight of iron in the finished product [1], [25], [27].

4.4. Carbon-Carbon formulation

Carbon is formed on the fibres surface using the carbonizing concept. They are employed in high-speed trains, aircraft, and racing automobiles because they have extreme thermal stability up to 1500 degrees celsius and where the requirement for braking performance is greater than the cost of production. They have various advantages, including 2.5 times the performance of steel, better strength at extreme temperatures, 40% less weight, and doubled service life [25], [28]. Carbon-carbon brake friction materials have a carbon matrix composed of carbon-carbon composite, which is formed by stacking layers of carbon fabric and then heating them in the absence of oxygen to form a solid block. This matrix gives the brake material its overall structure and toughness.

4.5. Category of friction material formulation in a brief summary

Table.2. Summary of friction material formulations [1], [2], [4], [5].

Serial no.	Types of pads	Assets	Liabilities	Limitations
1	Semi metallic	Semi-metallic brake pads are highly adaptable and developed for performance in harsh driving circumstances. They feature a longer brake pad life, great cold bite, and work well throughout a wide temperature range.	Create more noise & they produce more dust than other types of pads.	Semi-metallic pads may cause the rotor to wear out more quickly, so necessitating its replacement.
2	Low metal & steel	Low steel formulae are utilized in front axles when there is a lot of braking force.	The shape of the abrasive affects the wear rate, round shaped tiny abrasive particles are typically employed in this sort of formulation	When compared to low metal formulas, the abrasives employed in this type of articulation are usually less.
3	Ceramic	Unlike semi-metallic formulations, they do not fade quickly. Less sticky to wheels. The compounds in the friction material make them	Heat is not well absorbed by ceramic brake pads. The most expensive brake pads on the market are usually these. In	Higher in cost with respect to other brake pads.

		endure longer than organic or semi-metallic brake pads.	extreme cold, ceramic brake pads may not perform as well.	
4	Sintered metal	They're more resilient than organic pads and should last longer because they're better at handling dirt and moisture.	They cause rotor wear to increase. It might be costly to repair rotors as they wear out. Sintered brake pads are louder than other types.	Expensive as it wears out the brake rotor. The brakes generate more heat with sintered brake linings.
5	Carbon-Carbon	Carbon brakes can provide up to double the number of landings per overhaul as steel brakes. High performance: Compared to steel brakes, carbon brakes can absorb more energy. High thermal stability up to 1500 degree Celsius. 40% less weight compares to steel pad & double service life.	High cost with respect to others.	Limited to high-speed railways, fighting tanks, airships and racing automobiles. Not use in day-to-day automobiles.
6	Non-Asbestos organic	These brake pads are ideal for everyday automobiles and drivers who only need to get to work and the store. On brake rotors, organic brake pads are quiet and simple to use. To acquire the friction needed to stop properly, the brake pads don't need to generate a lot of heat.	For their compositions, organic brake pads may wash out more quickly.	Necessitating more frequent replacement of pads.

V. BRAKE PAD FABRICATION

The main steps in the Brake pad manufacturing process consist of the following:

(i) Raw material mixing
(ii) By proper composition (%)
(iii) Mixing with proper Temperature & Time
(iv) Manufacturing

- Preforming (pre-moulding)
- Moulding (press cure)
- Post-curing

The manufacturing of brake pads is divided into three stages: mixing, moulding, and curing. The manner in which these steps are carried out, as well as the technology used, result in products of varying quality and production rates. Until now, the importance of blending has been overlooked. However, understanding the electrostatic charging of powders in dry mixing will help to improve this critical phase, resulting in better blend mixing and homogeneity.

5.1. Fabrication process

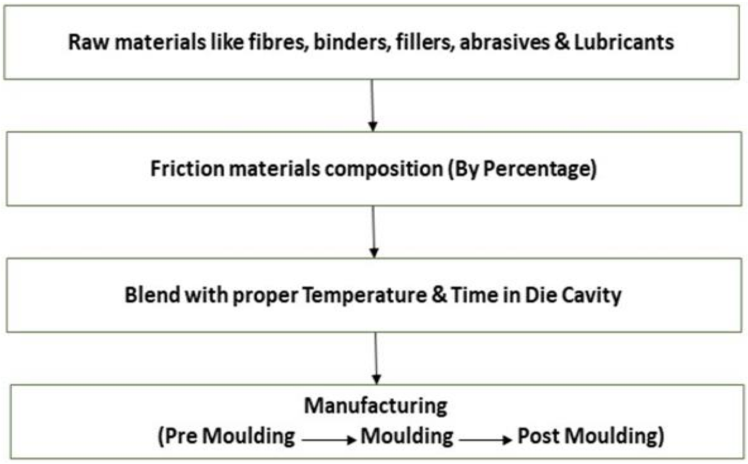

Fig.4. Brake pad fabrication process.

5.1.1. Asbestos free brake pad materials

Table. 3. Comparative study of brake lining materials [29].

Serial No.	Properties	Asbestos base	Palm kernel shell base	Peri-winkle shell base	Banana peels base	Zircosil base	ZrSiO4 base
1	Specific gravity (g/cm3)	1.6	1.1248	1.01-1.89	1.26	2.54	1.96
2	Friction coefficient	0.2	0.41	0.3-0.4	0.4	0.46	1.96
3	Hardness value (HRB)	110	92	101-116.7	98.8	95	73
4	Compressive strength (N/mm2)	108	103	110	95.6	100	105

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

There is potential for Asbestos replacement, and some analysts have proposed alternatives to replace asbestos as the basis material for brake linings. However, by varying the mix of these alternate materials, their tribological and mechanical capabilities may be carefully examined. ZrSiO4 had undergone tests to determine its friction-wear characteristics. The sample's hardness, density, friction coefficient, and wear behaviour were evaluated. SEM was used to perform a microstructural analysis of samples before and after sintering as well as worn surfaces, and the types of wear and relationships between the parameters were identified.

5.1.2. Saw dust brake pad materials

Table. 4. Saw dust-based brake pad materials [30].

Serial No.	Property	Brake Pad Commercial (Asbestos Based)	New Formulation Lab Brake-Pad (Sawdust) Recommended
1	Hardness (at 3000 KgH)	101	226-258
2	Density (ρ)	1.320	1.320-1.750
3	Compressive Strength	110	110-125
4	Porosity Measurement Water: Oil:	0.52 0.61	0.50-0.57 0.41-0.76
5	Assessment of Friction Materials and Wear/Microstructure MS 474:PART 10: 2003	(g/km*10-2) 3.800	(g/km*10-2) 1.887-2.359
6	Flame resistance test at 1 hour	Charmed with 69% ash	Charmed with 30- 40 ash

According to the findings of this study, samples containing 100m of formulation had better properties than samples containing 280m, 355m, and 1mm size particles from formulations evaluated. As a result, the better the qualities, the lower the sieve grades of sawdust. As indicated in Table 4, the findings of the 100m sieve size were compared to those of commercial brake pads (asbestos based) and new formulation brake pads (Sawdust) based, which were tested under identical conditions.

VI. FABRICATION OF BRAKE DISC MATERIALS

In this process firstly intermixing of metals or alloys or some additives with proper percentage wise are prepared. All the substituents are going through the compaction process by the application of high pressure. For this step an external force is provided by the means of some machine parts. After this process the product is going through the sintering process in which producing a solid substance without melting to the point of liquefaction using heat and pressure. Then secondary machining & secondary finishing operations are done. At last finished product is out from the die cavity. The main steps are shown below;

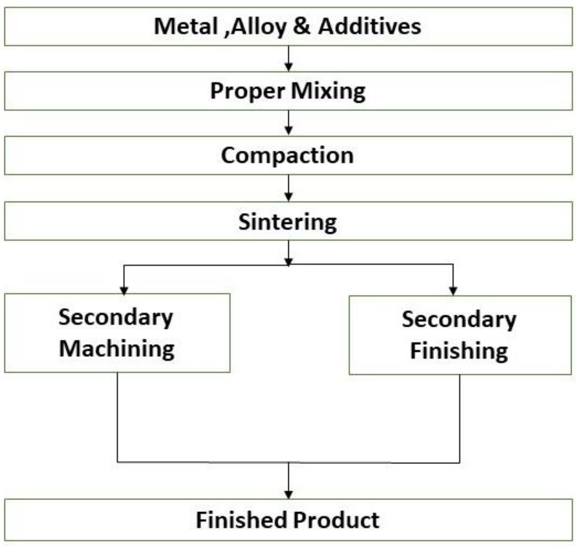

Fig. 5. Brake disc fabrication process.

6.1. Brake disc friction material formulations

It's important to note that the choice of brake disc material will depend on a variety of factors, including the intended use of the vehicle, driving conditions, and personal preferences. In the automotive industry, the following new brake disc materials are frequently used;

a) Cast Iron
b) Carbon-Ceramic
c) Ceramic
d) Steel
e) Aluminum
f) Copper
g) Composite

6.1.1. Cast Iron

The most typical substance used to make brake discs is cast iron. It has good thermal conductivity, wear resistance, ability to dissipate heat quickly and consistently performs well when it comes to braking. These are the several types of cast iron brake discs;

- Gray Cast Iron
- Ductile Iron
- High Carbon Cast Iron
- Composite Cast Iron

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

It is significant to note that depending on the specific application and performance requirements, the precise composition of the cast iron used for brake discs can change[31].

6.1.2. Carbon Ceramic

Brake discs made of carbon-ceramic material are thin and have excellent heat resistance. High-performance vehicles frequently employ them. In high-end sports cars, racing vehicles, and aircraft, carbon ceramic brake discs also referred to as ceramic matrix composites are a type of high-performance brake disc material. Carbon fibre and ceramic materials are combined to create carbon ceramic brake discs, which are then reinforced with a resin binder. Excellent strength and stiffness are provided by the carbon fibres, and high thermal stability and wear resistance are provided by the ceramic materials [32].

6.1.3. Ceramic

The high-performance brake disc material known as ceramic brake discs is typically a composite of ceramic fibres and resins. It provides high temperature resistance, improve stopping power, longer life, reduced weight & reduce dust in the automotive. While ceramic brake discs have a number of benefits over cast iron discs, they are also more expensive and may be more vulnerable to damage from impacts and vigorous use. As a result, these are frequently employed in high-performance applications where the extra expense is justifiable given the advantages [33], [34].

6.1.4. Steel

Steel is frequently used for brake discs because of its low cost, long lifespan, and good thermal conductivity. There are different types of steel used in brake discs;

- Carbon Steel
- Stainless Steel
- High Performance Steel

Steel brake discs are superior to other materials in a number of ways, including durability, affordability, and ease of manufacturing. These are heavier than other materials, though, and this can increase unsprung weight and have a negative impact on how a vehicle handles and performs. Furthermore, they do not dissipate heat as well as other materials do, which can lower braking effectiveness and increase wear [35]–[37].

6.1.5. Aluminium

A type of lightweight, high-performance brake disc material that is gaining popularity in racing and high-performance applications is aluminium. Typically, high-strength fibres like carbon or ceramic are used to reinforce an aluminium alloy used to make aluminium brake discs. Excellent thermal conductivity of aluminium enables quick dissipation of heat produced during braking. As a result of the fibre's strength and stiffness, the brake disc can withstand the forces produced during braking. Although aluminium brake discs have a number of benefits, these are also more expensive than cast iron brake discs and may be more vulnerable to damage from impacts and vigorous use. As a result, it is frequently used in high-performance applications where the advantages outweigh the extra expense [38].

6.1.6. Copper

Due to its poor thermal conductivity and low melting point, copper is rarely utilized as a brake disc material. Brake discs must be capable of withstanding the high temperatures produced by braking without deteriorating or melting. In contrast, cast iron, carbon ceramic, and steel all have much higher melting points than copper, which has a relatively low melting point of about 1,083°C. Due to its capacity to dissipate heat and offer better braking performance, copper can be used to make brake pads, but it should not be used to make brake discs. Due to their high temperature resistance and durability, other materials like cast iron, carbon ceramic, steel, and aluminium alloys are frequently used for brake discs [39].

6.1.7. Composite

In high-performance and racing applications, composite materials are frequently used for brake discs because of their superior thermal conductivity, low weight, and durability. In order to create a strong and lightweight structure that can withstand high temperatures and offer superior braking performance, composite brake discs are typically made by combining two or more materials, such as carbon fibre and ceramic. The main benefits of composite materials for brake discs are improved braking performance, durability at high temperatures, and low weight [40].

- **Aluminium SiC brake disc**

For Brake disc, is made up of either cast iron or Al-Sic composite materials. Here both materials are going to test under some parameters. The stir casting process was used to create aluminium (Al-6061)/Sic (Silicon carbide) MMCs in this work. The reinforced particles in the MMC plates were varied by weight fractions of 5%, 10%, and 15%. SiC reinforced particles had an average mesh size of 325 mesh.

This experiment is going to perform on the powder metallurgy method. In which different proportion of materials are mixed and finally a new product is going to produce [41], [42].

Table. 5. Variation % in the SiC on aluminium [41].

Serial No	Aluminium (Grams)	SiC (Grams)	Al- % SiC	Hardness (Vickers) (HV10)	Wear Rate (Mm^3/M)
1	380	20	Al-5%SiC	36	0.732448
2	360	40	Al-10%SiC	45	0.632448
3	340	60	Al-15%SiC	50	0.405977

From the entire table if SiC percentage increases up to certain limit then hardness value increases and wear rate decreases which provide a lot of advantages regarding brake disc improvement. Cast iron brake disc has some good properties but some properties like density, specific heat capacity, over all heat transfer coefficient & thermal conductivity are not good for it.

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Al-SIC disc brake can replace the cast iron brake disc because it has very good properties just like mentioned above. SiC is a relatively pricey material, so increasing the SiC percentage above certain limit may increase the cost of manufacturing the brake disc. Furthermore, increasing the SiC content makes the brake disc more brittle, raising the possibility of cracking or breaking under specific circumstances.

- **For composition of samples Aluminium Sic + Fly Ash brake disc**

Table.6. Variation in the SiC & fly ash percentage on aluminium [17], [43].

Serial No	Combination	Tensile Strength(N/mm^2)	Hardness (BHN)
1	95% Al + 5% SiC	107	39
2	90% Al + 10% SiC	112	40
3	95% Al + 5% fly ash	125	55
4	90% Al + 10% fly ash	128	61
5	90% Al + 5% SiC + 5% fly ash	137	59

The above Analysis described that if SiC & fly ash percentage increases in Aluminium up to certain limit then hardness value increases also the tensile strength increases. It is observed that the serial number 4 & 5 gave nearly same values of hardness and tensile strength. The tensile strength of the five various weight percent composite samples gradually rises, and the addition of 5% SiC +5% fly ash sample resulted in a greater tensile strength of 137 N/mm^2 when compared to the other samples.

VII. BRAKE PAD FRICTION & WEAR RATE TESTING (TRIBOMETER)

Tribometers are available in a variety of types and configurations, depending on the application and testing requirements. Tribometers of various types are commonly used;

- **Pin-on-disc tribometer:** This type of tribometer measures the friction and wear of the contacting surfaces by pressing a pin or a ball against a rotating disc.
- **Reciprocating tribometer:** This type of tribometer moves the sample back and forth, simulating real-world conditions such as sliding contact between machine parts.
- **Ball-on-disc tribometer:** This type of tribometer measures the wear and friction of the contacting surfaces using a ball rather than a pin.

The wear rate can be calculated by using the below equations;

$$K = \frac{\Delta m}{\rho * \Delta s * P}$$

Where K = Wear Rate.

Δm = Specimen Mass.

ρ = Density of Specimen.

Δs = Sliding Distance

P = Normal Force

Now a days high temperature tribometer is used rapidly to perform the wear rate test at high & elevated temperature to provide more accuracy in the experiment. A tribological test known as the pin-on-disc test is deployed to gauge a material's resistance to wear and its frictional behaviour. Under precisely controlled loads, speeds, and temperatures, a tiny cylindrical pin is pressed opposed to a rotating disc in this process. The test simulates the sliding contact that happens in actual applications by using a pin and disc that are typically made of different materials

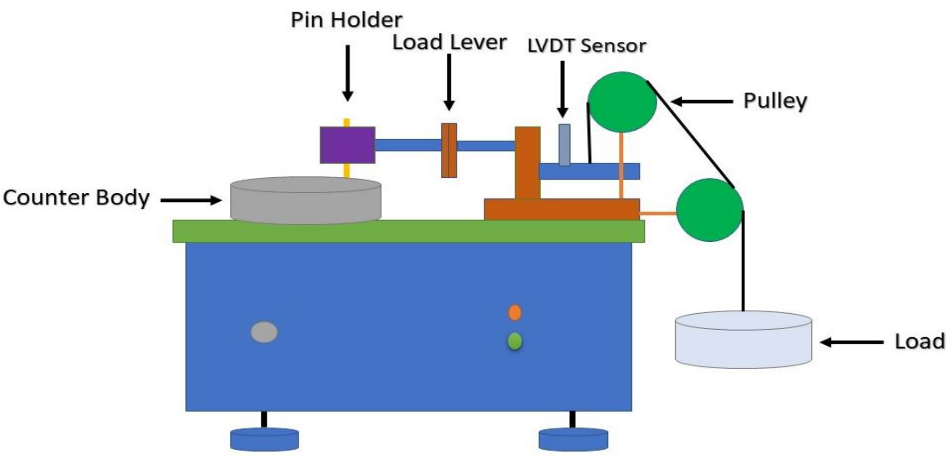

Fig. 6. Tribometer experimental set-up.

VIII. MODERN ADVANCEMENTS IN FRICTION MATERIALS FOR BRAKE PAD-DISC

Continuous research and developments are being done to enhance the performance, sustainability, and durability of brake pads and discs, which are essential parts of the braking system in automobiles. Here are some recent advancements in friction materials for brake pads and discs,

- **Non-metallic materials**

The use of non-metallic materials is one trend in the development of brake pad and disc friction materials. These substances, like organic compounds and ceramic, can offer excellent stopping power while also lowering noise, dust, and wear. Due to their high strength and heat resistance, materials based on aramid fibres are frequently used in high-performance brake pads. These materials are perfect for high-speed driving and racing applications because they can withstand extreme temperatures without losing their effectiveness. Additionally, ceramic particles are used in brake pads to give them superior thermal stability, low noise levels, and a longer lifespan than metallic pads. To increase their resistance to heat and wear, brake discs frequently use high-temperature resins like phenolic and melamine resins. These materials are appropriate for high-performance and heavy-duty applications because they can withstand temperatures of up to 700 degrees Celsius[44], [45]. Compared to conventional metallic brake materials, non-metallic brake friction materials have a number of advantages. These are a preferred option for luxury and performance vehicles because it produces less dust. Additionally, it doesn't contain heavy metals like copper and lead, which can be bad for the environment, hence consider as environmentally friendly material

- **Composite materials**

Utilizing composite materials, which combine various materials to improve performance, is another trend. For instance, some brake pads use a blend of ceramic and carbon fibres to reduce weight and noise while still offering excellent stopping power. Depending on the specific application and performance requirements, the exact composition of the composite materials may vary [46]–[48]. For example, brake pads for powerful sports cars may contain more carbon fibres and ceramic fibres for increased durability and heat resistance, whereas brake pads for everyday commuter vehicles may contain more organic materials for enhanced comfort and noise reduction. Even different solid lubricants are also used according to the requirements of the vehicle.

- **High-performance materials**

For racing and other demanding applications, there is also rising interest in the development of high-performance brake pad and disc friction materials. For excellent braking and heat dissipation, these materials may be based on carbon fibre or other high-strength materials. Ceramic brake pads are made of a composite material that includes ceramic fibers, fillers, and resins [49], [50]. They have high stopping power, low dust output, and a long life. Semi-metallic brake pads are composed of metallic fibers, filler materials, and resins but it produces more dust and noise than ceramic.

- **Sustainable materials**

Similar to friction materials, sustainable brake pad and disc friction materials are also on the rise. The environmental impact of brake dust and other byproducts may be reduced by using materials that are recyclable or made from renewable resources. Natural materials such as rubber, Kevlar, and other fibres are used to make organic brake pads. Because they are biodegradable and produce less dust and noise than other types of brake pads, these are the popular choice among environmentally conscious consumers [51]. Organic brake pads, on the other hand, may not provide the same level of stopping power as other types of brake pads.

- **Integrated sensors materials**

Some scientists are investigating the use of built-in sensors in brake discs and pads. These sensors enable more accurate control and enhanced performance by continuously monitoring the temperature, wear, and other friction material properties. These brake pads' integrated sensors are typically made up of a metal strip embedded within the friction material [52]. The metal strip is exposed as the brake pad wears down, completing an electrical circuit and triggering a warning light on the vehicle's dashboard. This early warning allows drivers to plan maintenance before the brakes completely fail.

- **Carbon fibre-based materials**

The use of materials based on carbon fibre is another trend now. High strength and stiffness, as well as excellent thermal conductivity and heat dissipation, are all characteristics of carbon fibre. Friction materials made of carbon fibre are frequently used in high-performance settings, like racing [53]. Carbon fibre-based brake friction materials have a high coefficient of friction, which provides strong braking performance even in wet or slippery conditions, in addition to their thermal properties. They are also less prone to fading, which occurs when brake pads lose their effectiveness as a result of excessive heat buildup [54]–[56]. The high thermal conductivity of carbon fibre allows heat to dissipate quickly, hindering the brake pads from overheating and losing braking power.

- **Hybrid materials**

Organic and ceramic materials are commonly used in modern hybrid brake friction materials for brake pads and discs. Organic materials, like rubber and resin, are well-known for their excellent stopping power and quiet ride. These are, however, prone to wear and can produce a lot of dust [57]. Ceramic materials, on the other hand, are extremely long-lasting and resistant to wear, but they can be noisy and take longer to warm up, which can reduce their stopping power. Ceramic-carbon, ceramic- kevlar, and ceramic-organic composites are some examples of hybrid brake friction materials [58].

IX. CONCLUSION

The entire review has focused on the detrimental effects of non-exhaust emissions on persons and the environment. Its harmful impact on the ecosystem has also been studied by researchers. The results of brake pads created with various compositions are examined in the review papers. Brake pads are made by many scientists using compression moulding and powder metallurgy.

Retrieval Number: 100.1/ijrte.B77590712223
DOI: 10.35940/ijrte.B7759.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

The wear rate & coefficient of friction (Cof) of the tribo pairs are calculated using a pin on the disc experiment method. The analysis presented above leads to the following conclusions.

- Asbestos is an excellent material for friction products like brake pads and linings. However, it has been banned by environmental and health agencies due to its carcinogenic characteristics. As a result, researchers are focusing on the creation of asbestos-free braking materials. The most frequent substance utilized to make brake pads is non-asbestos organic compounds. Ceramic brake pads are better suitable for high-speed racing cars, railways and aero planes.
- The atmosphere is also harmed by the emission of copper and other heavy metals from tribo pairs during braking. As a result, scientists are striving to produce environmentally acceptable braking materials made from agricultural waste or natural fibers. For brake pad in recent days composite materials along with different solid lubricants are also used to provide stability, less wear & light weight. Solid lubricants play a very essential role in the compositions. Recent days MoS_2 lubricant gives more better results than graphite lubricant.
- For brake disc cast iron can be replaced by Aluminium silicon carbide or Aluminium silicon carbide with Fly ash. The brake disc is made of silicon carbide, which makes it extremely durable and resistant. It's what gives the discs their unique characteristics. Carbon fibres added strength and reinforcement to the material, as well as the requisite fracture toughness.
- Increasing percentage of silicon carbide in aluminium gives a good result as mention in the fabrication of brake disc part. In design point of view disc should contain small holes for proper hear transfer rate & for light weight to increase fuel efficiency.
- In recent advancements more focus is on composite materials as it provides better stability & desired effect for both Tribo pairs. Composite materials are an appealing option for high-performance applications because, overall, their use in the fabrication of brake discs has improved braking functionality, decreased weight, and increased durability.
- Hybrid materials are used in which different compositions of materials being mixed up with proper ratio to improve the braking system & performance.
- Integrated sensor materials are deployed in tribo pairs so that it will control the wear rate, temperature & other frictional attributes.

DECLARATION

Funding/ Grants/ Financial Support	No, We did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence
Availability of Data and Material/ Data Access Statement	Not relevant
Authors Contributions	All authors having equal contribution for this article.

REFERENCES

1. N. Kumar, A. Bharti, H. S. Goyal, and K. K. Patel, “THE EVOLUTION of BRAKE FRICTION MATERIALS: A REVIEW,” Materials Physics and Mechanics, vol. 47, no. 5, pp. 796–815, 2021, doi: 10.18149/MPM.4752021_13.
2. M. Arman, S. Singhal, P. Chopra, and M. Sarkar, “A review on material and wear analysis of automotive Break Pad ,” 2018. [Online]. Available: www.sciencedirect.comwww.materialstoday.com/proceedings [CrossRef]
3. D. Bacche, “Influence of Temperature on the Plant Fiber Reinforced Brake Pad Materials: A Review.” [Online]. Available: www.solidstatetechnology.us
4. K. N. Hendre, B. D. Bachchhav, and H. H. Bagchi, “Frictional Characteristics of Brake Pad Materials Alternate to Asbestos,” Int J Eng Adv Technol, vol. 9, no. 2, pp. 694–698, Dec. 2019, doi: 10.35940/ijeat.B3170.129219. [CrossRef]
5. A. Kumar Kankanala and M. Sarkar, “A Review on Material, Wear Indication and Wear Analysis of Automotive Brake Pad,” International Research Journal of Engineering and Technology, 2020, [Online]. Available: www.irjet.net
6. W. Song, J. Park, J. Choi, J. J. Lee, and H. Jang, “Effects of reinforcing fibers on airborne particle emissions from brake pads,” Wear, vol. 484–485, p. 203996, Nov. 2021, doi: 10.1016/J.WEAR.2021.203996. [CrossRef]
7. B. Bhatt, N. Kalel, A. Darpe, and J. Bijwe, “Promaxon-D reinforced brake-pads to ameliorate the noise-vibration performance,” Wear, vol. 477, Jul. 2021, doi: 10.1016/j.wear.2021.203808. [CrossRef]
8. B. Bhatt, N. Kalel, S. Ameta, S. Mittal, and J. Bijwe, “Fe–Al alloy for eco-friendly copper-free brake-pads,” Tribol Int, vol. 163, Nov. 2021, doi: 10.1016/j.triboint.2021.107156. [CrossRef]
9. N. Kalel, B. Bhatt, A. Darpe, and J. Bijwe, “Copper-free brake-pads: A break-through by selection of the right kind of stainless steel particles,” Wear, vol. 464–465, p. 203537, Jan. 2021, doi: 10.1016/J.WEAR.2020.203537. [CrossRef]
10. J. Kukutschová et al., “Wear mechanism in automotive brake materials, wear debris and its potential environmental impact,” Wear, vol. 267, no. 5–8, pp. 807–817, Jun. 2009, doi: 10.1016/j.wear.2009.01.034. [CrossRef]
11. R. Agnihotri, “Mechanical Properties of Al-SiC Metal Matrix Composites Fabricated by Stir Casting Route,” Research in Medical & Engineering Sciences, vol. 2, no. 5, Dec. 2017, doi: 10.31031/rmes.2017.02.000549. [CrossRef]
12. D. Tan et al., “Evaluation of the wear resistance of aluminium-based hybrid composite brake discs under relevant city rail environments,” Mater Des, vol. 215, p. 110504, Mar. 2022, doi: 10.1016/J.MATDES.2022.110504. [CrossRef]
13. D. Mathur, A. Maheshwari, A. Sharma, C. Kumar, A. Nayyar, and R. Chundawat, “Engineering and Technology (A High Impact Factor,” International Journal of Innovative Research in Science, vol. 7, 2018, doi: 10.15680/IJIRSET.2018.0708042.
14. K. Karthikeyan, K. K. Naga Chandrika, A. Deepan Raj Kumar, S. Thiagarajan, and V. Vishnukumar, “Research on mechanical behavior of AMMC (Al-SiC) composite in disc brake,” Int J Eng Adv Technol, vol. 8, no. 6 Special Issue 3, pp. 1432–1437, Sep. 2019, doi: 10.35940/ijeat.F1255.0986S319. [CrossRef]
15. S. Nandhakumar, W. E. Santhkumar, and V. K. Shunmughanaathan, “Experimental analysis of aluminium matrix composite material for braking application,” Mater Today Proc, vol. 37, no. Part 2, pp. 2517–2520, Jan. 2021, doi: 10.1016/J.MATPR.2020.08.375. [CrossRef]
16. S. M. Mulani, A. Kumar, H. N. E. A. Shaikh, A. Saurabh, P. K. Singh, and P. C. Verma, “A review on recent development and challenges in automotive brake pad-disc system,” Mater Today Proc, Feb. 2022, doi: 10.1016/j.matpr.2022.01.410. [CrossRef]
17. S. SMukadam, S. RWankhade, and B. Road, “EVALUTION OF MECHANICAL PROPERTIES OF ALUMINIUM/ SILICON CARBIDE /FLY ASH BRAKE ROTOR,” International Research Journal of Engineering and Technology, 2017, [Online]. Available: www.irjet.net

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

18. N. Kumar, A. Bharti, H. S. Goyal, and K. K. Patel, "THE EVOLUTION of BRAKE FRICTION MATERIALS: A REVIEW," Materials Physics and Mechanics, vol. 47, no. 5, pp. 796–815, 2021, doi: 10.18149/MPM.4752021_13.
19. N. Aranganathan and J. Bijwe, "Development of copper-free eco-friendly brake-friction material using novel ingredients," Wear, vol. 352–353, pp. 79–91, Apr. 2016, doi: 10.1016/j.wear.2016.01.023. [CrossRef]
20. X. Ma et al., "Investigation on braking performance and wear mechanism of full-carbon/ceramic braking pairs," Tribol Int, vol. 142, p. 105981, Feb. 2020, doi: 10.1016/J.TRIBOINT.2019.105981. [CrossRef]
21. C. Pinca-Bretotean, A. Josan, and V. Putan, "Testing of brake pads made of non asbestos organic friction composite on specialized station," in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. 4183–4188. doi: 10.1016/j.matpr.2020.12.039. [CrossRef]
22. B. S. Joo, Y. H. Chang, H. J. Seo, and H. Jang, "Effects of binder resin on tribological properties and particle emission of brake linings," Wear, vol. 434–435, p. 202995, Sep. 2019, doi: 10.1016/J.WEAR.2019.202995. [CrossRef]
23. H. Z. Harraz, "Abrasive and Abrasion Minerals", doi: 10.13140/RG.2.1.2903.6403.
24. I. J. Antonyraj and D. L. Singaravelu, "Tribological characterization of various solid lubricants based copper-free brake friction materials – A comprehensive study," Mater Today Proc, vol. 27, pp. 2650–2656, Jan. 2020, doi: 10.1016/J.MATPR.2019.11.088. [CrossRef]
25. V. V. Kumar and S. S. Kumaran, "Friction material composite: Types of brake friction material formulations and effects of various ingredients on brake performance-a review," Materials Research Express, vol. 6, no. 8. Institute of Physics Publishing, May 31, 2019. doi: 10.1088/2053-1591/ab2404. [CrossRef]
26. Q. Lei, J. P. Latham, and C. F. Tsang, "The use of discrete fracture networks for modelling coupled geomechanical and hydrological behaviour of fractured rocks," Computers and Geotechnics, vol. 85. Elsevier Ltd, pp. 151–176, May 01, 2017. doi: 10.1016/j.compgeo.2016.12.024. [CrossRef]
27. L. Kukati, K. Chittimalli, N. B. Shaik, and S. Thoudoju, "Formulation and evaluation of sintered floating tablets of cefpodoxime proxetil," Turk J Pharm Sci, vol. 15, no. 3, pp. 278–290, Dec. 2018, doi: 10.4274/tjps.59454. [CrossRef]
28. T. Lee et al., "ACTIVATED CARBON FIBER-THE HYBRID OF CARBON FIBER AND ACTIVATED CARBON," 2014.
29. D. Shinde and K. N. Mistry, "Asbestos base and asbestos free brake lining materials : comparative study," International Journal of Scientific World, vol. 5, no. 1, p. 47, Jan. 2017, doi: 10.14419/ijsw.v5i1.7082. [CrossRef]
30. Z. U. Elakhame et al., "Manufacture of Automotive Brake Pads from Sawdust Composites," 2017. [Online]. Available: http://www.ijser.org
31. O. Aranke, W. Algenaid, S. Awe, and S. Joshi, "Coatings for automotive gray cast iron brake discs: A review," Coatings, vol. 9, no. 9. MDPI AG, Sep. 01, 2019. doi: 10.3390/coatings9090552. [CrossRef]
32. S. Shahrukh, S. Mubarak, P. N. Borse, and P. G. Student, "Improvement in Performance Characteristics of Brake Disc by Design & Analysis," 2020. [Online]. Available: http://ijesc.org/
33. M. Indrajeet, B. Jadhav, M. Firdos, and I. Pirjade, "Ceramic Disc Brakes," 2018. [Online]. Available: www.ijsrd.com
34. S. Manavalan, A. Gopi, J. Arivarasu, A. A. Ahi, and S. Chandru, "Review on Ceramic Disc Brake System," 2019.
35. P. Hazarathaiah and A. Professor, "Issue 3 IJRAR19J2368 International Journal of Research and Analytical Reviews (IJRAR) www.ijrar," vol. 5, p. 1313, 2018, [Online]. Available: www.ijrar.org
36. D. Chelopo and K. Gupta, "Structural analysis on mild-steel and aluminium brake disk for application on belt conveyor," in IOP Conference Series: Materials Science and Engineering, IOP Publishing Ltd, Nov. 2020. doi: 10.1088/1757-899X/971/4/042056. [CrossRef]
37. D. Ch, U. C. kiran, and V. Y. kumar, "Design, Analysis and Manufacturing of Disc Brake Rotor," 2017.
38. A. A. Agbeleye, D. E. Esezobor, S. A. Balogun, J. O. Agunsoye, J. Solis, and A. Neville, "Tribological properties of aluminium-clay composites for brake disc rotor applications," J King Saud Univ Sci, vol. 32, no. 1, pp. 21–28, Jan. 2020, doi: 10.1016/j.jksus.2017.09.002. [CrossRef]
39. W. Sterle, C. Prietzel, H. Kloß, and A. I. Dmitriev, "On the role of copper in brake friction materials," Tribol Int, vol. 43, no. 12, pp. 2317–2326, Dec. 2010, doi: 10.1016/j.triboint.2010.08.005. [CrossRef]
40. A. Bharambe, "Modelling and Analysis of Disc Brake with Composite Material," 2013. [Online]. Available: www.ijsr.net
41. R. Agnihotri, "Mechanical Properties of Al-SiC Metal Matrix Composites Fabricated by Stir Casting Route," Research in Medical & Engineering Sciences, vol. 2, no. 5, Dec. 2017, doi: 10.31031/rmes.2017.02.000549. [CrossRef]
42. L. JIANG et al., "Fabrication, microstructure, friction and wear properties of SiC3D/Al brake disc−graphite/SiC pad tribo-couple for high-speed train," Transactions of Nonferrous Metals Society of China, vol. 29, no. 9, pp. 1889–1902, Sep. 2019, doi: 10.1016/S1003-6326(19)65097-1. [CrossRef]
43. S. Mohanty and Y. P. Chugh, "Development of fly ash-based automotive brake lining," Tribol Int, vol. 40, no. 7, pp. 1217–1224, Jul. 2007, doi: 10.1016/J.TRIBOINT.2007.01.005. [CrossRef]
44. G. S. Darius, M. N. Berhan, N. V David, A. A. Shahrul, and M. B. Zaki, "Characterization of brake pad friction materials," 2005. [Online]. Available: www.witpress.com,
45. V. Tomášek, G. Kratošová, R. Yun, Y. Fan, and Y. Lu, "Effects of alumina in nonmetallic brake friction materials on friction performance," J Mater Sci, vol. 44, no. 1, pp. 266–273, Jan. 2009, doi: 10.1007/s10853-008-3041-z. [CrossRef]
46. B. K. Satapathy and J. Bijwe, "Composite friction materials based on organic fibres: Sensitivity of friction and wear to operating variables," Compos Part A Appl Sci Manuf, vol. 37, no. 10, pp. 1557–1567, Oct. 2006, doi: 10.1016/j.compositesa.2005.11.002. [CrossRef]
47. F. Yusubov, "Optimum design of brake friction composites." [Online]. Available: https://www.researchgate.net/publication/355978322
48. F. Ahmadijokani, Y. Alaei, A. Shojaei, M. Arjmand, and N. Yan, "Frictional behavior of resin-based brake composites: Effect of carbon fibre reinforcement," Wear, vol. 420–421, pp. 108–115, Feb. 2019, doi: 10.1016/j.wear.2018.12.098. [CrossRef]
49. G. Bian and H. Wu, "Friction performance of carbon/silicon carbide ceramic composite brakes in ambient air and water spray environment," Tribol Int, vol. 92, pp. 1–11, Jun. 2015, doi: 10.1016/j.triboint.2015.05.023. [CrossRef]
50. W. Österle, H. Kloß, I. Urban, and A. I. Dmitriev, "Towards a better understanding of brake friction materials," Wear, vol. 263, no. 7-12 SPEC. ISS., pp. 1189–1201, Sep. 2007, doi: 10.1016/j.wear.2006.12.020. [CrossRef]
51. A. Bonfanti, "Low-impact friction materials for brake pads," 2016.
52. H. Burde, M. Mandaokar, S. Dhad, D. Tidke, and S. Jaiswal, "DESIGN AND WORKING OF BRAKE PAD WEAR INDICATING SYSTEM," International Research Journal of Engineering and Technology, 2021, [Online]. Available: www.irjet.net
53. T. R. Jaafar, A. M. Zaharudin, A. Pahmi, R. Kasiran, and E. Abu Othman, "Effect of Carbon in Brake Friction Materials on Friction Characteristics," Journal of Engineering Science, vol. 14, pp. 47–59, 2018, doi: 10.21315/jes2018.14.4. [CrossRef]
54. Z. Ma, C. Zheng, C. Xiong, L. Yu, Y. Liu, and C. Zhang, "Friction-Wear Characteristics of Carbon Fiber Reinforced Paper-Based Friction Materials under Different Working Conditions," Materials, vol. 15, no. 10, May 2022, doi: 10.3390/ma15103682. [CrossRef]
55. F. Ahmadijokani, A. Shojaei, M. Arjmand, Y. Alaei, and N. Yan, "Effect of short carbon fiber on thermal, mechanical and tribological behavior of phenolic-based brake friction materials," Compos B Eng, vol. 168, pp. 98–105, Jul. 2019, doi: 10.1016/j.compositesb.2018.12.038. [CrossRef]
56. U. V. Saindane, S. Soni, and J. V. Menghani, "Dry sliding behavior of carbon-based brake pad materials," International Journal of Engineering, Transactions B: Applications, vol. 34, no. 11, pp. 2517–2524, Nov. 2021, doi: 10.5829/IJE.2021.34.11B.14. [CrossRef]
57. S. M. Mullaikodi, P. Sethuvelappan, M. Kamaraj, E. Naveen, and N. Ramanan, "Development of Hybrid Friction Material for Brake Pad Application," in IOP Conference Series: Materials Science and Engineering, IOP Publishing Ltd, Oct. 2020. doi: 10.1088/1757-899X/923/1/012039. [CrossRef]

58. O. J. Gbadeyan and T. P. Mohan, "LOW FRICTION HYBRID NANOCOMPOSITE MATERIAL FOR BRAKE PAD APPLICATION," 2017.

AUTHORS PROFILE

Mr. Tarini Ranjan Pradhan working as a MTech Student in the department of Mechanical Engineering, BITS PILANI, Hyderabad Campus (2021-2023). His area of research interests includes Mechanical Engineering, Tribology, Composite Materials, Material Science & Design Engineering.

Er. Santosh Kumar Shanti working as Senior Technical Officer in Design & Project Engineering Department of CSIR-Institute of Minerals & Materials Technology, Bhubaneswar, Odisha, India-751013. He has more than 12 years of R&D experience in the field of Mechanical Engineering, Mechanical Design, Hydraulic Transportation & Tribology.