

Competency of Natural Fiber Based Eco-Friendly Friction Lining Composites Over the Conventional Friction Material

Sandip S. Shirsath^{1*}, R.N. Yerrawar²

Abstract

The Braking system is important system of automobiles and is responsible for providing better performance and safety. A Millions of automobiles are frequently decelerated and stopped at heavy traffic zone. Overall performance of vehicle braking system depends on braking conditions and brake material. All friction based application releases wear products; either gaseous form or particulate matter form and braking system is prime source of non exhaust particulate matter emission. The Friction lining material is composed of various ingredients and its selection is based on experimental trials and fundamental understanding. The number of ingredients decided to achieve best braking performance at different working environments and loading conditions, in terms of the wear rate, friction level and noise level, At present, braking system facing technical challenges related to thermal stability, fade, abnormal noise, wear rate & environmental issues with existing semi metallic, low metallic material and asbestos based friction material. The present work aims to explore the influence of non exhaust particulate matter on human health; environment and focuses on featured eco-friendly friction lining composite materials (FLM) prepared from organic farm waste with desired percentage. This helps to understand the depth of natural fiber in FLM tested with best possible combinations and this found effective through comparative studies. It helps in reducing the load of natural waste disposal and reduces toxic elements at source.

Keywords: Friction lining composite material (FLM), Non-Asbestos Organic (NAO), Environmental impact

INTRODUCTION

Braking system is an important automobile system used to stop the moving vehicle within small distance. Braking system controls the vehicle speed and saves occupants. Brakes are of mainly two types i.e. parking brake and service brake. Parking brakes are used to hold the vehicle stationary where as service brakes reduces speed of vehicle by rubbing friction pads against rotating drum or disc as shown in Figure 1 [1, 3].

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Nowadays, Low metallic, semi- metallic and non asbestos based organic material can be seen in vehicles. In Low-metallic brake pads, small amount of metal ranging from 10-25% by mass is added with organic compounds, Whereas Semi-metallic brake pads have metal content up to 65% [1]. Non asbestos based organic brake pad consists of binders, abrasives, reinforcing fibers, solid lubricants, fillers, and friction modifiers [2]. Brake pads were previously made from asbestos organic material but as it is carcinogenic, it has serious

effects on environment and human health reported by many researchers. Hence it was substituted by fibrous materials and semi metallic brake pads [3]. Although copper based brake pads contributed to improve the brake performance but due to its serious effect on aquatic lives [4–8], U.S. Automotive industry and U.S. Environmental Protection Agency [EPA] decided to reduce the Cu use in brake pads [9]. The fibrous materials used as asbestos substitutes also shown health hazard [10].

The Particulate matter emitted during the road traffic is significant source of pollution affecting the environment and human health. There are various sources of particulate matter emission and based on that PM differentiated as exhaust related particles, non-exhaust related particles and re-suspended particles due to turbulence created by road traffic [11]. Exhaust related particulate matter is produced due to incomplete combustion of fuel and lubricant volatilization. Non exhaust related particles are generated due to tyre wear, brake wear, clutch wear, engine wear in heavy traffic region. These wear out particles remains in atmosphere and re-suspended due to traffic induced air turbulence [12]. Using technological improvements, exhaust related fine particulate matters are reduced as it was area of more interest. Non exhaust related particles are coarse compared with exhaust related emissions, so gets settle down and flow with water in rainy season. Brake wear is significant source of non exhaust emission but its effect on environment and human health is yet not studied in depth. So many questions remain unanswered.

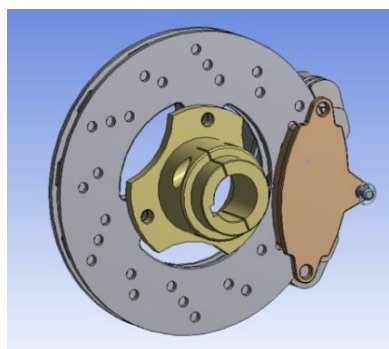


Figure 1. Braking system.

Due to the growing human awareness about environment, new rules are imposed on friction material industries by various regulatory bodies to develop eco- friendly materials [13, 16–17]. It reduces the environmental burden and non exhaust emission too. A friction material consisting of number of ingredients used to achieve good brake performance at different temperature, pressure and working conditions, in terms of the wear rate, friction level and noise level [15].

Since last few years, many efforts are made to develop brake pads from naturally available resources. Apart from braking strength of material, Cost, availability of material and effect on environment are essential properties of friction materials.

A. Health and environmental issues

While thinking about health and environmental impact, several prime factors like particle size and its distribution, chemical composition, surface area, durability, toxicity, agglomeration state need to be considered during investigation [14]. Out of all factors, chemical composition and particle size are more severe as Coarse particles deposits in the upper respiratory tract (nose and throat), and ultrafine particles enters into the lungs [51, 52], this causes oxidative stress, inflammation and causes atherosclerosis[53]. Literature also proved that fine particles may become blood-borne and moves to the brain, liver and kidneys [54]. Asbestos was the most commonly used friction material because of its desirable physical, chemical and tribological properties but health reports and many researches stated that it is non bio-degradable, carcinogenic and hazardous to human life [13, 25, 26]. Brake wear emissions having size smaller than 100 nm which is inhalable PM causes lungs cancer, asbestosis, mesothelioma and other respiratory diseases so, it is banned [14, 27, 33].

A study reported on health hazards of fibrous material on human being, which are considered as a replacement for asbestos [10]. The fiber size, type and its life span decides the level of toxicity of the material [22]. Splitting and fragmentation of fibers increases surface area and becomes more harmful. If considering type of fiber, amphibole asbestos remains in the Lungs more time than the serpentine chrysotile. As per the WHO and International Agency for Research on Cancer (IARC) health hazard assessment result, severity of fibrous material decided based on durability, carcinogenicity and on same basis it is classified as group 1, group 2B, group 3 [23, 24]. Group 1 includes fibers carcinogenic to humans like Erionite fiber which causes malignant mesothelioma. Group 2B contains possibly carcinogenic fibers to humans like refractory ceramics fibers. Group 3 includes shorter fibers which are not classifiable as to its carcinogenicity.

The particulate matter released from brake wear are remains suspended in the atmosphere and then settle down on the ground, can be transferred to creeks, rivers and marine waters [19]. The Copper is a neurobehavioral toxicant in fish. The copper based particulate matters are toxic to the fish's olfactory system as it disrupts the normal functioning of olfactory system [20]. With regards of human health, the reported toxicity is relatively low compared with other metals, such as cadmium, lead, mercury and chromium. Cu particles are inhaled as a PM or via copper-contaminated water and generate reactive oxygen species (ROS) in tissues [21].

Chemical composition of particles can also be an important factor causing adverse effects on human health. Particulate matter constituents attached to black carbon responsible for adverse impacts, (WHO 2013). Some Transition metals like Cu, Ni, Fe, Cr having ability to produce reactive oxygen species (ROS) and creates oxidative stress in biological tissues. The semi-quinone radicals of organic compounds adsorbed on the particles result from redox cycling, these reactive oxygen species produced by activated macrophages. The Metals like Pb, Al and Zn also affects the toxic effects of transition metals either lessening their activity or by enhancing [22].

Fe and Cu are main elements of the Brake wear emissions. Cu and S is associated with increased mortality rate [23]. Some elements have negative responses proved by Epidemiology studies. It revealed a high correlation between blood Pb and cardiovascular mortality and morbidity [24]. The neutrophilic inflammation is reported in the lungs with Fe and Se by the toxicology studies in healthy volunteers. Fe particle based agglomerates have been linked to inflammatory responses. The High concentration of Fe, Cu, Ni, Pd and Zn leads to pulmonary injury and inflammation. Sb_2O_3 is possible human lung carcinogen by the International Agency for Research on Cancer [25] the most of the research studies shown that high concentrations of most of the airborne metals are brake wear particles [26] therefore; it is possible that such particles leads to adverse health impacts.

Brake wear emissions from full stop braking cause pro-inflammatory responses in lung cells, through a organic compounds and black carbon mechanism. Riediker et al. reported that ultrafine particles emitted from speed-enhancing traffic modulates the autonomic control of the heart rhythm and rises the frequency of premature supra-ventricular beats in young, healthy, non-smoking men. It also rises elicits pro-inflammatory and pro-thrombotic responses. The Cu emission rises during traffic conditions due to speed-change which is associated with brake abrasion. The past studies shown that long-term cardiovascular risk can't be ignored, especially when the reported rise in myocardial infarction among professional drivers and the increased mortality in people living near major roadways [23].

Competency of friction material

The Friction materials are selected based on required characteristics like high coefficient of friction, high heat dissipation rate, low wear rate, good resistance to water swell, high tensile strength, dimensional stability at high temperature, high compressive strength, moderate shear strength and low absorption rate to water and oil etc.[28] Non asbestos material mainly consists of following ingredients given in Table 1.

Table 1. Ingredients of brake pad composites.

Ingredients	Functions	Materials available
Binder	Matrix material to hold structural element and provides physical and chemical properties	Phenolic resin, epoxy resin, modified resin, Cashew net shell liquid, NBR, melamine resin (MR) [12, 36]
Filler	Improve the manufacturability thermal stability and compatibility	Mullite, bagasse, banana fibers, fly ash, palm karnel, Vermiculite, cashew powder, calcium carbonate and Barium Sulfate [12, 36, 46]
Friction modifier	To control the operating coefficient of friction stability and low wear rate	Aluminum oxide, Zirconium oxide, MgO , Quartz [12–40]
Lubricants	Heat dissipation and to maintain the temp	Graphite and hexagonal boron nitride [14, 38, 39]
Reinforcement fibers	To improve the manufacturability and to reduce the noise level	Fibers of metals, carbon, synthetic fiber, Kevlar, minerals, ceramics, natural fibers like Jute fiber, Aramid fiber, Pine fiber, coconut fiber, Bamboo fiber, Aramid and acrylic fiber, kevlar fiber, hemp fiber

Single fiber incorporation into friction composites does not improve a performance of brake pads. So the hybrid friction materials prospects as a beneficial approach [31]. The aim of the majority of recent studies has been to combine variety of fibers and improve the overall performance of friction composites. Today, various naturally available fibers used in friction composite claimed an improvement in the energy absorption and fracture properties of friction composites [66–71].

Effect of various naturally available fibers on the performance of friction material is discussed in the Table 2.

Table 2. Ingredients of brake pad composites.

Types of Fibers	Ingredients and Conclusions	Ref
Hemp fiber	sample with 5 wt% hemp fiber is effective to enhance Coefficient of friction, frictional stability, fade performance, wear resistance	[13, 34, 35]
Coconut Fiber	composition with 29 % coconut fibers, 6% MgO, 25% Al ₂ O ₃ and 40% Epoxy resin having minimum deformation of 0.51 mm, maximum equivalent stress of 129 MPa, frictional coefficient of 0.454, hardness of 37.14 HRB and wear rate of 0.323mm ³ /N.mm	[12, 36]
Bamboo Fibers	Sample prepared using 29% bamboo fibers, 40% Epoxy, 6% MgO, 25% Al ₂ O ₃ . composite with 3% bamboo fiber shown best performance	[37]
Palm karnel fiber	Varying percentage of Palm kernel (0-50%), Wheat (0-10%) and Nile roses (0-15%), aluminum oxide (5%-20%) as a friction modifier, graphite powder (10%-35%), Phenolic resin (35%) shown best result	[38, 39]
Kenaf fiber	kenaf fiber 25%, phenolic resin 40%, graphite 8%, alumina 3%, zirconium 2% , aerosol 10% and aramid fiber 12% composition shown best performance	[14]
periwinkle shell	periwinkle shell 710–125 µm size and 35% resin, particles with sieve size 125 µm shown best coefficient of friction and wear resistance	[41, 42].
Sisal Fiber	resin and sisal fiber combined with 3:4 proportion, has given optimum frictional and wear properties	[3, 43]
Coir Fiber	Coir Fiber 0-20 %, silicon carbide, graphite, zirconium oxide, resin. 5 % volume fraction of coir fiber reinforced composite exhibits higher density, better wear properties and higher compressive strength	[44, 45]
Banana Peel	Carbonized and un-carbonized Banana peels resin. Proper bonding is achieved at 20 wt % in un-carbonized samples and 30 wt % in carbonized samples. Samples containing 25 wt% in un-carbonized banana peels and 30 wt% in carbonized banana peels shown best results	[46]
Sugar Cane Fiber (Bagasse)	Bagasse with size 100-710 µm and resin in 70:30 proportions. Experimental result revealed that finer the sieve size the better the properties and 100 µm size shown best performance	[47]

MANUFACTURING OF FRICTION LINING MATERIAL

As friction material is made up of different ingredients so bonding between them decides properties of friction composite. The proper bonding between all particles is ensured by using most suitable

manufacturing process. The metal matrix based friction material is manufactured casting and powder metallurgy route. During this proper mixing of the constituents must be ensured [53, 54]. In All the manufacturing processes, the said ingredients are mixed with each other and blended to form a homogeneous uniform mixture. During mixing and blending, particle size of the fillers must be same and carefully controlled. It further decides properties of final product. The Compression molding carried out at higher temperature to shape the friction material and pressure gradually increased to avoid pores. [55] The naturally available materials cannot be directly used for final application in brake pad formulation. It requires some mechanical and chemical treatments before using them in brake pad composition [50–52]. Heat treatment can also be employed as per the requirement to refine the structure and to improve properties.

Thermal conductivity of friction material decides tribological performance as lower thermal conductivity accumulates frictional heat on the working surface and leads excessive fade, similarly higher thermal conductivity Results in excessive heat flow towards back-plate leads to spongy brakes. Thermal conductivity must be increased along length of brake instead of into the brake. This can be achieved by providing conductive thin plate [67–74].

CURRENT CHALLENGES IN FRICTION MATERIAL DEVELOPMENT AND FUTURE TREND

In any automotive industries, friction materials based on asbestos, copper and few fibrous materials are phasing out. Now, the research and development is heading towards safer, eco friendly friction material from naturally available resources with design changes. But NAO based material has poor thermal stability, wear rate and particle emission issue. So fiction material required to be designed by considering requirements such as stable coefficient of friction, lower wear rate, temperatures, pressures and working environment. Another challenge is investigation and development on non-phenolic base binders as presently choices are limited [53].

Following Figure 2 displays India's commercial vehicle manufacturing from 2007-08 to 2018-19. During whole period of 2018-19, reported about 1.1 million commercial vehicles were manufactured. These vehicles include commercially registered passenger and goods vehicles [75].

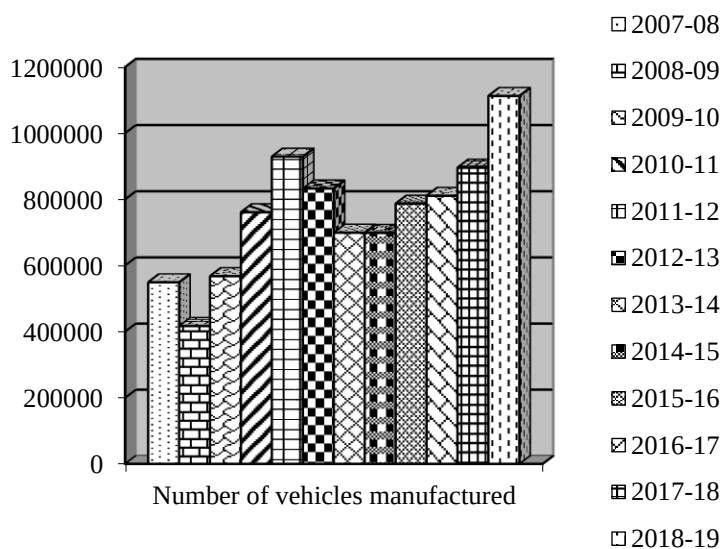


Figure 2. Commercial vehicle production rate in India from 2007-08 to 2018-19.

The future trend in development of friction materials is somehow related with the current trends of the automotive industry. Due to newly adopted environmental regulations, future vehicles will be on

lower emissions, electric operated and fuel efficient. All changes will be made to reduce exhaust as well as non exhaust emissions. In future, brake requirement will be lighter and eco friendly friction material. Also, friction base industries will be more dependent on development of regenerative braking system. When this technique reaches the affordable level then place of friction brakes might be taken by regenerative braking and brakes would be limited up to parking brake system only. The development in autonomous vehicles can increase importance of friction material due to more frequent engagement of friction brakes [61–65].

SUMMARY

The braking system is contributing to air born particulate matter released during friction of materials. In last few years, new generation vehicles have entered in the market so market geared up with high quality parts. In this paper, various human health and environmental related issues created by friction materials are discussed and several alternative naturally available materials are reviewed for the required function of a friction material. Exhaust and non-exhaust sources contribute almost to total traffic-related emissions and Brake wear has been recognized as important non-exhaust traffic-related source, with its relative contribution from 16 -55 %. The Estimated value of brake wear emitted as airborne PM 10 is approximately 50 % of total. Several factors affect the brake wear particle generation rate and making it difficult to understand the phenomenon of wear generation and study the properties of brake wear particles. Wear particles released from brake pad have been recognized as dangerous for the human health. The natural fiber based friction material can have improved friction properties compared with commercial brake pads. There is scope for finding out the direct relationship between mechanical and tribological properties as well as correlation between process controlling parameters and wear rate is essential. With growing market, novel friction material may have huge scope in automotive industry with some modifications.

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