Current Research Trends and Innovations on Asbestos Free Brake Pad Materials in Automotive Vehicle Applications

Dr S Karthikayan [1,*], Madhankumar D[2], P Kamalkumar[3], E.C. Prasad Nidumolu[3]

[1] Professor, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad-043, India.
[2] GET, Jai Krishnaa Auto Pvt.Ltd , Coimbatore-32, India.
[3] Assistant Professor, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad-043, India.
sskksmit@gmail.com[1,*], karthik.s@mlrinstitutions.ac.in[1,*], +91-9894457440*,[1]

Abstract. In present scenario the proliferation of the vehicles, the traffic conditions are worse in nook and corner of every city. This extreme traffic condition forces the driver to act in an engrossed manner. To ensure the safety of the pedestrians, passengers and goods, it is responsible for the brake manufacturers to produce the good quality brake pads. In earlier days asbestos fibre was used to manufacture these brake pads. But this fibre showed an adverse effect on human health likely respiratory problem, lung disorder and carcinogenic diseases. The composite material brake pads showed a good wear resistance than the regular asbestos fibre. This blemish in the asbestos fibre made researchers attract towards the composite brake pads as an alternative. Quite a large number of researches were made on the manufacturing of brake pads by using composite materials. This paper minutia the innovative trends in the materials used for the manufacture of brake pads. So, by implementing these researches, the manufacturers can guarantee their safety in the industry and the lifespan of the brake pads can be increased.

keywords: Asbestos-free brake pad; composite brake pads; Pin-on-disk test; Un-carbonized banana peel; Carbonized banana peel; Quebracho wood tannin.

1. Introduction

Owing to the ever-increasing population level, people are eager in acquiring own vehicles than public transport systems. This leads to the rise in pollution level all around the globe. Several researchers worked on the intake system [1-3] in IC engines, some tried biofuels [4, 5], and few studied the advanced combustion [6, 7] strategies to enhance the IC engine performance [8, 28-30]. Numerous researches have been made to ensure the safety of the driver, passengers, goods and the pedestrian. Among the many types of braking systems, the drum brakes and disc brakes are widely used. In drum brakes, brake shoes are used while in disc brakes, brake pads are used. At the end of 1960's brake manufacturers moved from drum brakes to disc brakes. Nowadays all the vehicles are equipped with disc brakes so that the vehicles can be stopped instantaneously. In the disc brake system, brake pads engage with the brake discs by creating friction and producing an enormous amount of heat. The asbestos fibre used in the manufacture of brake pads caused severe carcinogenic effects on human health. Due to these adverse effect researchers focus on the development of brake pads by using alternate and excluding asbestos fibre. Some researchers were made by using agricultural wastes [9] as raw materials for the manufacture of brake pads and many of them tried with several combinations of composite materials as raw materials. Abundant tests were made on these asbestos-free brake pads and proved that they have better wear properties in comparison with the brake pads made-up of asbestos.

2. Literature review

Idris et al. [9] experimented on an asbestos less, banana peel made brake pad. The banana peels were dried and milled to form un-carbonized banana peel. This powder was loaded in a crucible made of graphite and kept at a temperature of 1473 K to form carbonized form of banana peels. This peels results in proper bonding with the addition of higher resin which was more than 30 % weight during production. The brake pad prototype was undergone to various tests like hardness, compression, flame resistant and pin-on-disc test. When resin weight % increases, specific gravity, hardness and compressive strength of the produced samples increases.

Table 1. Properties of BUNCp and BCp [9]

Properties	BUNCp	BCp
Proper Bonding	Good (at 20 % weight)	Worse (at 30 % weight)
Flame Resistance	Lower (when compared)	Higher
Thermal stability	Enhanced	Demoted
Compressive Strength	Higher	Lower
Wear rate	Lower	Higher
Hardness value	Higher	Lower

Maleque et al. [10] experimented on automotive brake rotor system. In that, an attempt was made to reduce the weight of the rotor using an aluminium matrix composite. The study resulted in 50 % weight reduction due to the introduction of aluminium matrix composite which compensates 19 % energy savings in comparison with cast iron brake rotor.

Lagel et al. [11] analyzed the bioresin matrix brake pads by means of Quebracho wood tannin. Aluminium trioxide (Al_2O_3): Alu 36 and Alu 60 were used as abrasive particles. The brake pads were developed by undergoing various processes, further, they were hot pressed and cooled. An emergency braking test was done at an average speed of 50 km/hr. The Brinell hardness test was done using Instron 4467 machine. Tannins resin was analysed by MALDI-ToF. A solid-state CP-MAS13C NMR was used to analyze the tannin resin and the Quebracho tannin. The mineral wool is sandwiched between the two layers of brake pad returns the better bonding by using Alu 60. The Brinell hardness value of 3.0, 4.2, 6.2 and 2.8 was obtained for the brake pads of 150 %, 100 %, 75 % and 50 % abrasive particles respectively. The BHN value thus obtained was smaller than that of commercial brake pads.

Table 2. Properties and Brinell Hardness Observation of Formulations [11]

Formulation	Wear resistant	Braking efficiency	Brinell Hardness Observation
1	-	-	Break

3	Less	-	Break
4	Good	-	/
5	Less	-	Break
7	Good	-	/
10	-	-	Break
11	-	-	Break
12	Good	-	/
13	Broken after testing	-	Break
16	Less	Better	Break
17	-	-	Break
18	-	Good	Break
19	-	Good	Break

Ikpambese et al. [12] evaluated the asbestos less palm kernel fibre by using the epoxy-resin binder. The Dried PKFs were prepared from the raw materials and pulverized, kept in the X-ray tube which was analyzed by Axil customized software. Mixing, cold and hot pressing, cooling, postcuring and finishing were the operations involved in the production of the brake pad. Inertia dynamometer was employed to measure several properties possessed by brake pads.

Table 3. Properties of various samples (S1 to S6) and Commercial brake pads [12]

Properties	**S1, S2, S3, S4, S5, S6, (when Speed increases)**	**Commercial (when Speed increases)**
Wear rate	Increases (S1*, S3*)	Increases
Coefficient of friction	Stable (S1*, S2*)	Stable
Porosity	Remains constant	Remains constant
Hardness	Stable	Stable
Noise level	Increases (excluding S5)	Increases
Moisture effect	Remained constant (S2*)	Remained constant
Water and oil absorption rates	Constant	Constant
Temperature	Rises linearly	Rises linearly

Stopping time	Increases	Increases
Specific gravity	Did not vary	Did not vary
Surface roughness	Remained constant	Remained constant

*= better than commercial brake pads

Rathod Abhik et al. [13] evaluated the properties of Al-SiC Reinforced MMC for Brake Pads. From Aluminium 2014 (raw material) the brake pads were produced by involving various processes such as material selection-mixing-weighing-compacting-sintering. According to the varying percentage of SiC two different (S1 was 20% reinforced) & (S2 was 10% reinforced), silicon carbide reinforced Al brake pad materials has been prepared.

Table 4. Properties of the samples S1 and S2 [13]

PROPERTIES	S1	S2
Density	Higher	Lower
Porosity	Lower	Higher
BHN	Higher	Lower
Cumulative wear rate	Higher	Lower

Increase in BHN leads to increase in wear rate. A 400x magnification microscope shows that Al 2014 properly mixed with the silicon carbide reinforcement. Higher wear rate of S1 was due to its lower density. S1 has a higher hardness than S2. The decrease in reinforcement increases porosity by 7%.

Tej Singh et al. [14] studied the assessment of the braking performance of lapinus –wollastonite fibre reinforced friction composite materials. In that, brake friction materials comprising of varying proportions of lapinus and wollastonite fibres were designed, fabricated and characterized for their chemical, physical, mechanical and tribological properties. Lapinus fibres intrinsically contain metal silicates, synergistically combined with other fibres that improved the tribo-performance and restrain the vibration, noise, judder in driving conditions. Wollastonite fibres having higher thermal resilience and inherent hardness, which stabilize the friction coefficient and maximize the recovery performance.

With an increase in lapinus content followed by a complementary decrease in wollastonite content, there was a decrease in density with the increase in void content. The density decrease may be accredited to the replacement of content of highly dense wollastonite content comparatively by low-density lapinus content. The dispersion ability is vulnerable to higher lapinus content and leads to an increase in the void. The extraction of Acetone denotes the quantity of uncured portion of resin in composites, is insignificant. The hardness rises abruptly as the wollastonite content increases which may be endorsed to the fact that wollastonite content results in composites' good mixing and curing cause mechanical compaction of the ingredients. The heat swelling, ability of absorption of water and compressibility of the friction composites investigation decrease simultaneously, in increase with wollastonite content. The shear strength remains still higher for LW-1/LW-2 (Lapinus fibre composition) indicating the role of fibre combination influencing the shear strength showing effective synergism.

Amaren et al. [15] studied the consequence of periwinkles shells size of a particle on the wear characteristics in asbestos less brake pad with binder phenolic resin. The Periwinkle shell was dried in sun and oven, crushed in a ball mill and mixed with phenolic resin. The sliding wear characteristics were measured using pin-on-disk test apparatus. The rate of wear of samples increases when sliding speed, load and temperatures increases. The higher wear rate was attained by +710 μm sample. The rate of wear decreases when the periwinkle shell particle size decreases which was determined by ANOVA [16]. The coefficient of friction for the given sample decreases when applied load, sliding speed and temperatures increases, while it increases with a decrease in periwinkle shell particle size. The actual values were nearer to the predicted values and periwinkle shell particle can be efficiently used as the substitute for asbestos in brake pad manufacture.

S.Y. Zhang et al. [17] analyzed the two-body abrasive behaviour of brake pad by using interpenetrating network ceramics/Al-alloy composites. The Al- alloy and ceramic foam frameworks were heated. When melted Aluminium alloy was cast in the ceramic frameworks, composites were made at a pressure of 700 bar with the specific wt percentage of compositions were chosen for investigation. In load sensitivity test and wear, tests were carried out at different temperatures. The coefficient of friction decreases with increase in temperature and it increases with increasing load. The specific wear increases with increase in temperature. When observed through Scanning Electron Microscope, deeper grooves, larger recess and some microcracks were found. The value of specific wear rate for Al-alloy composites was $1x10^{14}$ nm^3 per Nm. Friction fade occurs at high temperatures.

Table 5. Properties of interpenetrating network ceramics/Al-alloy composites [17]

LOAD	Wear (373 K and 523 K)	Friction (373 K and 523 K)
Load (32 N to 128 N)	Increases	Increases

A. Almaslow et al. [18] studied the behaviour of epoxidized natural rubber with alumina nanoparticles composites in semi-metallic brake pad materials. In that, semi-metallic friction composites consisted of ENRAN, graphite, benzoxazine and steel wool, were prepared by a melt-mixing technology.

The Al_2O_3-nanoparticles polymer composites like thermoplastics elastomers and polymer blends enhanced tribology, mechanical wear, optical, electrical and other properties [19-21]. Alumina has a very high melting point (2323 K), supreme hardness and capability of taking on various shapes, functions etc [22].

The presence of nanoparticles of Al_2O_3 increased the curing process by 40 %, Young's modulus by cent percentage and linear elongation by 300% in comparison with the unfilled epoxidized natural rubber in the epoxidized natural rubber with alumina nanoparticles formulation [23, 24]. It increases the crosslink density, thereby increasing Young's modulus, hardness and with a trade-off in stiffness and impact strength. The Al_2O_3 particles also formed the agglomerates structure in the matrix and effected in the high filler-matrix interaction, hence enhancing the material properties. The iron oxide formation has been found in the friction surfaces which implied the incidence of contacting surfaces and the environment.

The cross-linking of induced radiation improved the cross-linking degree between the Al_2O_3 and epoxidized natural rubber, thus the epoxidized natural rubber with alumina nanoparticles resulted in the rise in hardness in the SMFC. The porosity was improved with the greater additions of ENRAN. In the wear of the rough surface, primary plateaus were formed which increased with an increase in friction. Since the relations between the exposing surfaces of the pad and brake drum, the deformed steel fibres containing epoxidized natural rubber with alumina nanoparticles formed a Fe_2O_3 film on the sample friction surfaces with 29 volume percentage of ENRAN.

T. Ram Prabhu et al. [25] studied the material and tribological characteristics of multilayer Cu / SiC + Gr hybrid-composites applied for the brake pad. Since friction material was very good, which is having high friction coefficient, wear resistance, toughness, thermomechanical stability, thermal conductivity and a low thermal expansion coefficient and these properties are obtained in Cu / SiC MMC. Composites should provide high crack resistance to avoid catastrophic failure in the emergency conditions.

Erdogan [26] and Hunt et al. [27] proposed the existence of unreinforced sections along with reinforced sections in the multi-layer composites decreased the force in crack propagation and hence improved the toughness. The braking performance and resistance to wear were increased when composite layer is present. Small size particles provided low wear rate and better braking behaviour. The abrasive wear was the major one at low speed and a combined mode wear mechanism of abrasive wear, the addition of oxygen, de-lamination, thermal fatigue wear, was operative at slightly increased speed. The compression and flexural strengths of MLC were considerably greater than SLC. Low porosity and strain hardening of the Copper layer and the residual compressive stress in the composite layer resulted in higher strength. The fracture surface of the composite shows the quasi-cleavage intergranular fracture and Cu layers show the pure ductile fracture of the multi-layer composite.

Table 6. Composite materials and its wear properties [9-18, 25]

Composite materials		Wear properties
Uncarbonized banana peels particles		Lower
Carbonized banana peels particles		Higher
Quebracho wood tannin		Combination of less and good
Palm kernel fibres		Increases
Al-SiC Reinforced Metal Matrix	S1	Higher
	S2	Lower
Periwinkle shell	Decreases (size)	Decreases
	Increases (size)	Increases
Wollastonite fibre		Higher
Interpenetrating network ceramics/Al-alloy composites (with applied load)		Increases
Epoxidized natural rubber–alumina nanoparticles (aENRAN)		Lower
Cu/SiC+ Gr hybrid composites		Decreased

3. Conclusion

- The inferences of the study of composite brake pads are bulleted below:

- Better properties were obtained when 25 wt percentage in BUNCp and 30 wt percentage BCp are used. In BUNCp at 20 wt percentage resin addition, proper bonding was attained. BUNCp is better than BCp in the formulation of interfacial bonding.
- NMR and MALDI-ToF analysis show that tannins react with furfuryl alcohol to facilitate the formation of a resistant thermoset matrix. During an emergency braking, these new asbestos less brake pads are more effective than commercial brake pads.
- The values obtained from various parameters by PKFs were within and even better than commercial brake performance pad. S2 has a higher coefficient of friction and a higher rate of wear with a shorter lifespan. S6 gave better properties than other samples.
- Asbestos can be suitably replaced by Palm kernel fibre (PKFs) for brake pad production.
- In Al-alloy composites BHN increases the wear rate by 48 percentage. The hardness value obtained was much lower than the pure aluminium specimen due to lower sintering time and compaction pressure.
- A higher wear resistance and recovery response were listed when wollastonite fibre increases in formulation mix.
- The periwinkle shell particle size of +125 μm from developed brake pads provided a greater friction coefficient than the +710 μm periwinkle shell particle size.
- For interpenetrating network ceramics/Al-alloy composites, the SEM examination revealed that the two-body abrasion competed with its three body abrasion.
- The finest friction coefficient (0.437) was exhibited by samples with 29% of ENRAN which also had low specific wear rates of 0.27×10^{-7} cm^3/ Nm.
- For Cu/SiC + Gr hybrid composites, the presence of the ductile copper layer deflects and obtuse the crack which results in higher crack growth resistance.

4. Abbrevations and Acronyms

ANOVA	-	Analysis of variance
BCp	-	Carbonized banana peels particles
BHN	-	Brinell Hardness Number
BUNCp	-	Uncarbonized banana peels particles
CTE	-	Coefficient of Thermal Expansion
ENRAN	-	Epoxidized Natural Rubber – Alumina Nanoparticles
MALDI – ToF	-	Matrix-Assisted Laser
MLC	-	Multi-Layer Composites
MMC	-	Metal Matrix Composite
PKFs	-	Palm kernel fibres
SEM	-	Scanning Electron Microscope
SLC	-	Single Layer Composites
SMFC	-	Semi-Metallic Friction Composites
wt %	-	Weight percentage

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PROFILE OF AUTHOR

Professor, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad-043, India completed his Research in IC Engines. He has 16 years of experience in industry and teaching.

He has published 28 papers in various reputed journals and conferences in international and national level and a textbook for Anna University first-year engineering students. He received DR&DO grant twice. He has received "Best Faculty Advisor Award" for the year of 2010 – 2011, from SAE India. Received ***"Best Champion Award"*** for the Recognition of my Extraordinary Contributions to SAEIndia Southern Section in the year **2016 – 2017,** from **SAE International President,** ***Mr. Doug Patton,*** Executive Vice President, and chief technical officer, DENSO International America, Inc. (DIAM).

He led the team for SAE Supra, SAE BAJA, SAEISS Tractor Design Competition and effi-cycle.

He is a management committee member of SAE India Southern Section, Chennai, Champion for SAE Trek, SKIP, Factory visit. He is also an active member of Combustion Institute (Indian Chapter), ISTE & NIQR.

Contact Details: sskksmit@gmail.com, +91-8838918273.