A Review on Material, Wear Indication and Wear Analysis of Automotive Brake Pad

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Abstract - *Brake pads are the most significant element in the automobile, which helps to retard the vehicle and bringing to rest position. The needs enhanced on the mechanical and tribological properties of the material for brake pads. Studying various materials for the brake friction materials for replacement of asbestos, which causes harmful effects to the environment and the wear indication of the brake pads with various methods. Natural composite material plays a major role in friction coefficient and environment-friendly. Non-asbestos containing friction materials like those that palm kernel shell, bagasse, coconut shell, rice husk, banana peel, periwinkle shell, etc. are studied. Filler materials like copper powder, calcium carbonate, etc. are used. Different binders like phenolic resin and epoxy resin used to manufacture ecological brake pads. The metal matrix composites is a major concern for weight reduction and improved in strength. The researchers examined different types of materials made by varying compositions of various materials, fillers, binders, fibers, etc. which effects on tribological and physical properties of brake pads are examined.*

Key Words: Brake, Brake Pad Material, Wear Rate, Wear Indication, Friction Coefficient

1. INTRODUCTION

The researchers are investigating on different materials from the past few decades to innovate a new brake pad material. From a wide range of literature, few articles found interesting and innovative material used in their research work. Here a proper selection of materials for brake pad is required to make new formulations [1]. Asbestos-based brake pads are carcinogenic and producing airborne particle and environmental hazardous [2]. The material should be heterogeneous and ingredients used to improve the strength, rigidity and improve frictional properties. Generally, complex composites are made of 10-25 ingredients to make new friction materials [3]. Copper is a soft material and ductile in nature but environmental concerns recent research proves harmful to aquatic life [3]. Addition of filler materials influence the coefficient of friction, in non-asbestos material 12% steel wool and 8% brass fiber showed the best results [4]. By varying amounts of powders and fiber, materials like copper various percentages of samples were taken into consideration for eg. 0,10,20 wt% added to composite [5]. In friction materials, the size and shape of the ingredients are important which affects the thermal and physical properties [6]. Phenolic resin is used as a binder to hold multiple ingredients all together [7]. The brake pad material should withstand the counterpart grey cast iron and friction depends on the size of the ingredient, small size great friction [8]. In Al-MMC disk with copper as friction material shows best fade resistance same as steel fiber shows huge material transfer to disc was observed. Alumina matrix composite is known for strength to weight, which is developed by squeeze casting extensively used in automobile and aerospace. [9,10]. Iron has a high melting point, strength, and heat resistant properties than aluminum and copper, which performs well at high speeds and loads [11]. Because of low density and wear resistance, carbon carbon composite is used in racecars brake pads [12]. The brake pads split into various contact plateaus, which is nearby lowlands. The plateaus have a long life while real contact moving due to wear. With the size and properties of the composition shows variation in contact pressure between the pad and disc [13]. While testing the brake pads the materials detaching from the matrix, which can be seen in primary plateaus, during contact pressure, and sliding the microwear particles attach to pad and form secondary plateau [14]. Pin on disc test was carried out at room temperature load and speed concerns as per ASTMG-99 standard the pin size of 12 mm dia cylindrical shape [14]. For a large number of samples calculating random mixing ratios wt% is difficult so that, Taguchi method is used for the composition of brake pads [15]. Barium sulphate provides thermal stability to the friction material [1]. Ball milling is used to make the granules to powder form for making a composite material. The frictional behavior is tested on a pin on a disc [16, 17]. Bagasse is used to asbestos-free brake pad with different sieve grades of 100, 150, 250, 350, 710 µm is tested and microstructure analysis, water, and oil absorption are made [18]. Cashew nut shell liquid used as resin shows good toughness and thermal resistance [19]. Scanning Electron Microscope is used to examine microstructure and EDX analysis used to find an elemental composition.

The main aim of the brake pads is to slow down the vehicle by changing kinetic energy to heat through friction. Normally the problems on brake not only depends on brake pad but also on pedal pressure, speed environmental condition, wet-dry road condition. The shape and size of the brake pad matters, which is related to life, temperature, friction, etc. The organic material composite is difficult to develop because it requires more ingredients and each determined by trial and error method. With the help of powder metallurgy, a new formulation of brake pads were produced and compared with existing pads, so it can be used as alternate for the present using pads [1].

2. Materials used in brake pads

To increase the friction the metallic fillers like copper, aluminum, steel, brass, and iron are utilized so as to influence the wear behavior and frictional properties. The shape and amount of the material play a major role in wear [4, 6, 7]. Investigated on green resin over phenolic, which showed the best results in stability and COF under severe condition [7]. In addition to this Fe/Sic/graphite of hybrid composite tested under same sliding speed and Fe-20% and Sic-18% in the composite wear is controlled under sliding condition [3, 12]. Various amounts of nitrile rubber and boron replace with phenolic resin, the percentage 1:3 which effects on tribological properties and improved in thermal resistance. However, there is a drawback i.e difficult to maintain were resistance, friction, etc. So that resin modification is not a way to increase certain factors. Developed a Fe based metal matrix composite tested at a sliding speed of 25 to 35 m/s, reinforcement like silica and mullite with help of powder metallurgy. With an increase in sliding speed decrease in braking performance, so that high elastic modulus should be considered [11]. Actually, the brake pad material should maintain a high coefficient of friction, low temperature and humidity [7, 17]. The wear behavior of Cu/Sic+Gr hybrid composite investigated in two-layer and multi-layer alignment. With this composition, small size particle shows moderate braking and low wear at a sliding speed of 30-35 m/s. In multi-layer crack growth, protection is greater than the single-layer because of Cu in composition [17]. Here asbestos and formaldehyde resin is replaced with eggshell and gum Arabic as the binder. Gum Arabic with 3-18% proportion were tested and the best results show with 18% of GA with ES of compressive strength and density. This eco-friendly pad met the standard [18]. The carbon-carbon composite material used for brake pad material, which shows a low wear rate at a temperature of 300-400°c [20].

The ecofriendly material like banana peels used as an alternate material for asbestos and phenolic resin as a binder, which results from increase in percentage of resin addition the specific gravity, compressive strength, and hardness was increased with sample of 25 wt% in uncarbonized banana peels and 30 wt% in carbonized banana peel allows better properties. At higher temperatures, increase the binding ability of phenolic resin, Resins are sensitive to heat and humidity [2, 21, 22]. Copper is replaced with graphite and steel fibers because; it is harmful to aquatic life and in friction materials, this graphite acts as a lubricant at high temperature. 10 % of graphite results in optimum performance in fade and cracks were found with steel fibers due to the absence of copper but in steady state cracks disappeared [3, 23]. Copper replaced with barite 33.5 wt% and sample were prepared investigated on pin-on-disc at high temperature 300°c shows mild wear which is promising material. Barite is an environmentally friendly material [24]. Asbestos dust is harmful and carcinogenic which is replaced with bagasse in the brake pad material, which results 100μm sieve of bagasse gave better properties in compressive strength and hardness. The composition with 70% and rein with 30% brake pad is manufactured and compared with palm kernel shell-based composition [25]. Seashell particles that are a natural material used for brake pads act as polymer matrix composite. The small size 75μ shows best results due to small size particles and provides high strength to material [26]. PAN fiber shows moderate result than cellulose fiber, even though carbon fibers and aramid fibers show excellent results in wear [27]. Six samples were prepared with 0-10 wt% of aramid pulp added. Composites tested on full-scale inertia dynamometer according to Japanese standards (JASO C 406). With 10 wt% of aramid fiber proved the best result without fibers shows the worst results [28]. Rubber added to brake pad material with and without fiber reinforcement, cellulose and carbon fiber, aramid pulp used as reinforcing the material. In this experiment, rubber to glass transition occurs at a temperature of 300°c, by this came to know that does not influence critical sliding velocity [29]. Recycled rubber particles used to increase the frictional properties of the brake pad and smaller particle size shows high contact stiffness [30]. The brake lining made of palm kernel shell shows much better results than agro-waste material, rice husk, banana peels, sugar cane fiber, etc. which is eco-friendly and substitute for asbestos [21,31]. The wear performance is tested with Titanium-based coating sprayed on the specimen, physical and chemical vapor deposition process used to know thin films. The plasma spraying process is used when the multi-layer coating required [32]. Ceramics are the best material for friction application [33]. Functionally graded ductile iron is used for brake pads, which is wear-resistant and high COF 0.5 at all temperature when in contact. Further, it reaches to functional gradient zone then it became less sensitivity and stable [34]. Aluminum6063 added with clay varying volume 5-30% with a particle size of 250 microns composite for disc rotor application were made with help of stir casting. 4N and 10N loads were applied and tested at a speed of 200, 500, 1000 rpm. 15 wt% of clay showed best results less wear and which acts as a solid lubricant and load-bearing [35]. Friction mechanism in industrial brakes are tested with flywheel brake test bed. Piezoelectric sensors used in for measuring friction force and normal loads, after running a long time period friction layer extend to quasi-steady state condition. The temperature reaches up to 250°c from 30°c. The amount of iron particles dispersed into brake lining during friction process, which decides the COF small in mechanical braking under small load. Different types of 16 ingredients of NAO pad material made thirty-three specimens varying the vol% and different formulations were prepared. Materials like aramide pulp, rockwool, potassium titanate, phenolic resin, graphite, MoS_2, Sb_2S_3, $ZrSiO_4$ are used. Phenolic resin and MgO useful in increasing the friction coefficient and material like rockwool and zircon increased in wear resistance. Different resins like condensed poly-nuclear aromatic used as solid lubricant similar to graphite which gives higher shear strength than phenolic resin resists up to 400°c-500°c. Silicone modified resin have ability to stop water absorbing of friction layers. Cyanate ester resin are brittle in nature but having damping properties and maintains COF above 350°c.

2.1 Blending of raw materials

Generally, agricultural waste cannot be used directly in a composite material. Some chemical and mechanical treatments required. Here some techniques used for natural fibers based upon the literature.

- Banana peel powder [2]: These peels were dried under the sun and ball-milled at 250 rpm to form a powder that is uncarbonized. With the help of graphite crucibles, the powder was packed in it and heated in an electric furnace at a temperature of 1200 °c to form ash, which is carbonized.
- Periwinkle shells [36]: Which is collected and sieved into grain size and mixed with 35% phenolic resin and with help of compression molding by varying size 125,250,335,500,710 at a 40 kg/cm^2 pressure at a temperature of 160°c. After that, the size decreases while oil and water absorption decrease. Which can be used as the replacement of asbestos.
- Cococa beans shells [36]: These shells were dried under the sun and mixed with calcium carbonate, silica sand, epoxy resin, graphite made into powder and sieved. The samples mixed with varying resin 50-60% and shell powder with 21-31 %. 60% epoxy with 21 % shell powder shown best results. Which can be used as the replacement of asbestos.
- Lemon peel powder: Lemon peels are dried under sun for 240 hours and finely powdered. By varying amount of vol% of lemon peel powder, graphite, calcium hydroxide, epoxy resin two samples were made with moulding technique. 10% of peel powder, 40% epoxy resin, 15% graphite, 12.5 % Al_2O_3 and iron oxide showed best results in wear, oil and water absorption which has high interfacial bonding. Which can be used as replacement of asbestos.

2.2 Preparation of brake pad composites

After completion of chemical and mechanical treatment for raw materials, the composition mixture is made of a lot of other ingredients like a binder, reinforcing the material, abrasive, fillers, etc. with different vol %. A mould required to make a desired shape of the brake pad. The mixtures are compacted with hydraulic and uniaxial hand press at a pressure of 15-17 MPa for green composite. Further hardening process should be done using a hot press of 150°c for 3 hrs. And with compressive molding pressure of 60 tons for 4-5 minutes. Allow the samples to cool down to room temperature and finishing operation were made with the grinding machine to remove excess material.

3. Indication and wear analysis of brake pad

- A squeaking noise while applying bakes which indicates the pads were not installed correctly.
- When the brakes are not applied even though the squealer noise comes out due to completion of pads material and hitting the rotor.
- When the pads are completely worn out grinding sound appears due to grinding the rotor.
- Dust building upon hubcaps and wheels near the brakes it is an indication of worn brakes.

The crack propagation in the composite pad due to failure of the material. Small hairline like cracks can be observed through SEM images. Humidity can modify the pads adhesion surface and which can increase in contact area. In the brake pad, wear growing and destruction of the hard patches can be seen on the contact surface these patches adjust the COF. Frictional power is directly proportional to total area of the contact surface. For a sudden fading, which results in higher shattering than growth, rate. When the humidity is high on the pads surface, the wear decreases and vice versa, this varies in kinetic coefficient of friction and static coefficient of friction. Which is experimentally tested on pin on disc and brake dynamometer the stick slip amplitude was higher at high humidity due to water present on the surface of the sliding area. The friction and vibration is tested under dry and wet conditions, the low COF is proved in wet conditions in many investigations. High braking pressure is required for shorter braking distance. When it is in wet condition braking distance is longer than dry condition. Transition from wet to dry while braking increase COF can be seen slowly.

The COF compared with dry and wet condition at low speed, which shows 30% decrease rate. The water film rebuilt under fragile water flow is 0.30 m/s and under vigorous water flow is 0.45 m/s. The vigorous water flow leads lo more wear loss. The experimental errors made while testing the pads area of fraction, size and density of the plateaus in micrographs. Therefore, that analysis made border, center, distributed of the pads surface. Resulted that plateaus of the contacting surfaces increased towards border of the pad. The squeal noise is tested on different brake pads like semi metallic, low metallic, NAO and low metallic. Which is tested according to SAE J2521 procedure with different weights then, the squeal index noisiest to quietest are semi metallic > low metallic >NAO > low metallic, whih disclosed that high friction of coefficient from high noise. The break squeal noise analyzed with help of finite element model. FEM model is used to know the friction element steady state friction force acting on normal and interface of the pad. This model used to investigate the modes and natural frequencies. By this method elastic properties and contact stiffness of the friction, material is known. To compute thousands of degree of freedom FEM is used eigenvalue analysis for non zero matrix. ABLE developed to find any unstable modes within a specified frequency range which is based on lanczos tecchnique for unsymmetric matrix. Any positive eigenvalue is unsymmetric which is complex and unstable mode.

3. 1 Methods of Wear analysis

The airborne particulate matter, which is measured with brake dynamometer [16, 37]. Air removed isokinetically with the placement of probe around the brake hardware, which was surrounded by the system. Generally, the loss of brake pads determined with lining thickness calculation. The dust particles collected on filters and compared to the loss of brake lining and rotor. If it has a high volatile fraction then its collection efficiency was less [37]. The airborne pm ranged from 0.04 to 1.4 mg/k/vehicle for PM_{10} in urban driving condition and for $PM_{2.5}$ ranged from 0.04 to 1.2 mg/km/vehicle [38]. To suppress the squealing noise from brakes incorporated a piezo ceramic unit. The negative capacitance required for operation, which stabilizes and reduce the noise [39]. To know the problem of automotive troubleshooting ontology and SWRL language is used. It is a flexible engineering knowledge in OWL format. By this method, it is easy to troubleshoot the vehicle without any human intervention. Algorithms are required to obtain certain results [40]. The various approach to measure the wear is (i) gravimetric method, (ii) linear measuring touch probe, (iii) 3-D laser scanning. Touch probe leads to significant errors due to its sensitivity. In the gravimetric method, an error shows higher due to moisture absorption. The 3-D laser method proved best suitable for wear analysis. These methods were tested on semi-metallic and non-asbestos organic materials [41]. The optical microscope, micro indentation, and image segmentation and confocal laser scanning microscopy used to find various structures on the worn surface mainly to find secondary plateau and elastic high lands [42]. Railway wheel wear prediction is important to secure the locomotive with the help of archard's equation and local contact universal kriging is embedded. Construction of a wear coefficient map based on sliding speed, contact pressure. Simulation technology is required for more effective working [43].

4. Results and discussion

The result shows that in banana peel powder there is good interfacial bonding with 20% resin, which is uncarbonized. According to industrial standards, the COF is 0.3-0.45 for brake pad. The sample with 25 wt% in BUNCP and 30 wt% BCP gave better properties which can be used as alternate material for asbestos [2]. In semi-metallic brake pad investigation debris collected after friction test, variation between dynamometer and ball-milled samples. In dynamometer test high metal content in amorphous structure and in ball milling nanocrystal line metals with the high carbonaceous matter. These differences due to different load, speed and temperature [16]. In palm kernel shells properties compared with commercial brake pads show results that temperature rise of the disc is 10.7°c and stopping time 5.3s for PKS pad and 13.1°c,4.2s respectively for the commercial brake pad [17]. Bagasse replaced with asbestos shown that effectively used in brake pad with 70% bagasse and 30% resin with best results [25]. Rubber particles size of 75 and 450μm effects on friction material investigated on brake dynamometer. The smaller particle size shows higher friction and large contact plateau. Whereas large particle size destroys the secondary plateau and stopping the development of contact plateau [30]. The friction material reinforced with potassium titanate with high crystallinity improves in COF and fade resistance [44]. A mixture of Potassium titanate and copper fiber exhibits Stable COF up to 250°c beyond that unstable. Potassium titanate with copper fiber and steel fiber shows both primary and secondary plateaus [45]. Cu-MMC material showed the best results with static COF 0.400 with highest disc temperature 566°c that is an excellent material for brake pads especially for trains [46]. Silica acts as solid lubricants which decides the wear resistance of composite at high-speed 3m/s and load 300N [47]. Formation of film and destruction of films plays a major role in wear and friction, which is elevated at 40-120°c [48]. Al_2O_3-Nb composite is better than containing Mo, shows more wear resistance. Nb particles are heavily bonded to matrix investigated with different loads sliding against WC disc [49]. Brass material is added to parent composition with varying the volume 0, 4, 8, 12 wt% and barite varying volume with 35,31,27,23 wt%. Two tests were carried out fade and recovery by using Krauss machine and another test with reduced scale prototype to examine friction sensitivity. 8% of brass demonstrates the best performance. Increase in brass shows increases in friction performance [50, 51]. Usage of milled short glass fibers as a friction material the COF and wear rate higher because of smoother topology and more adherent contact areas. Well-arranged fibers can reduce the noise of friction material and improves mechanical properties [51]. The train brake pads are tribological analyzed with sub-scale friction machine. The friction is directly proportional to velocity and pressure. The wear loss of the shoe rings increases with increasing pressure and velocity while for wheel rings wear rate decreases with increase in pressure [52]. Both Semi-metallic and non-asbestos organic brake pads were tested at 600 N and 1200 N to find contact pressure, resulted in heterogeneous friction layer. A higher normal force led to an increase in the area of the fraction of the contacting region found more in NAO than SM [53]. Stick-slip test investigated with small grain size, which effects on friction stability of the contact plateau. The sample with a large area of contact which impacts on energy transferred to the system which produces squeal noise in the same way smaller contact plateaus no squeal noise. By this method, reduce noise and vibration [54]. Tribo test rig is used to test the performance of brakes. At higher loads, the intense heat generated while contacting the disc and pad surface hard material protrude leads to the formation of a secondary plateau. Low wear responsible when the carbon present in the composition of the pad [55]. Low metallic brake pads tested on cast iron disc using full-scale inertia dynamometer and airborne particles collected and measured using ELPI+. The Fe and Cu pads emission were PM10, Fe/Cu composite shows stabilized friction. These investigations are used to decrease particulate matter emission and developing advanced material properties [56]. These days the same level of frictional force is the major concern of drivers. It is a vital importance to change the COF of brake pads of sliding speed under the wet condition and dry condition. Silicon carbide ceramic composite brake samples were tested in air and water spray method. Which showed the coefficient of friction 0.52 for 53.1 % high fraction of Sic/Si composite and 0.4 for low fraction of Sic/Si. Hydrodynamic friction is vigorously connected to SiC of friction area.

5. Conclusion

In this review, studied various agricultural wastes and metals as an alternative for asbestos brake pads and the wear indication. The results of natural fibers and non-asbestos compositions are free from environment and health effects. To gain better frictional properties, brake pads with palm kernel shells, cocoa beans shells, banana peels, rice husk, and bagasse, etc. used as a replacement of asbestos. The replacement of phenolic resin can be epoxy resin or newly developed resin etc. are studied. Brake pad, which made of agricultural waste, shows equal and better properties than metallic pads and usage of these natural fiber materials does not harm the environment.

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