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DEVELOPMENT OF ASBESTOS FREE BRAKE FRICTION MATERIALS FOR AUTOMOTIVE APPLICATION

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ABSTRACT

Composites are the combination of two or more materials which are different in form and chemical constituents. These materials are gaining more importance as structural material in the preset day engineering applications; because they offer very elegant properties such as high strength to weight ratio, higher thermal, corrosive and wear resistance.

Early to 1980's asbestos materials are largely used in automobile industries because of the positive characteristics of asbestos. From the medical research it is found that continuous use of asbestos cause cancer to human being because of its carcinogenic nature due this reason in 1986 the environmental protection agency announced ban on asbestos. Further, an attempt is made to develop semi-metallic copper based brake pads which contain 30- 40% of copper and other ingredients which include fillers binders and lubricants. During 2010 substitute Senate Bill 6557 (SSB 6557) adopted in Washington State to limit the use of copper in the brake friction materials which leads to the development of new materials to manufacture brake pads in automotive industry. Hence in this paper attempts are made to develop asbestos free brake pad materials using natural fillers.

Keywords: *Brake pad, asbestos, compression moulding.*

INTRODUCTION

A brake is a mechanical device which inhibits motion, slowing or stopping a moving object or preventing its motion. Most brakes commonly use friction between two surfaces pressed together to convert the kinetic energy of the moving object into heat. Modern automobile brakes evolved from the relatively crude brakes of horse-drawn vehicles. By the end of the first decade of the twentieth century, automobiles were using either external-contracting band brakes or internal-expanding drum brakes. Hydraulic brakes started to appear on lower-priced cars in the mid-1920s with hydraulic actuation, four-wheel drum brakes remain the standard braking system for most cars, in the middle and late 1960s. During 1967 Federal Motor Vehicle Safety Standards (FMVSS) 105 act specified that the brake systems had to pass specific performance tests that made to develop disc brakes. Hence disc brakes become the universal choice for automobiles since 1970.

The most common brake pad materials for today's vehicles are semi-metallic and are composed of metals such as copper, brass, and steel which are held together with resin. These brake pads are durable and relatively inexpensive but they are noisier, due to these reasons many researchers are trying develop non metallic brake pad materials. Further, non metallic brake pad liners were developed using asbestos which is thermally stable and regenerate the friction surface, flexible and also available at reasonable cost. The fibrous character remains intact until 14000C.

However, organic brake pads create dust when going through the process of stopping a vehicle, and it was noticed that asbestos dust can be very dangerous to the human beings because it causes carcinogenic diseases. Hence in 1986 the environmental protection agency announced ban on asbestos.

After the phasing-out of asbestos the evolution of new materials for automotive brake applications are developed by many researchers using organic asbestos-free brake pads.

Ceramic brake pads are some of the most expensive available on the market. They are comprised primarily by ceramic fibers with filling agents, but may also have small amounts of other materials, such as copper, as well. They dissipate heat very well, making them an excellent choice for high-performance vehicles. Ceramic brake pads break down very slowly, which may or may not mean they need replacement less often, depending on how harshly they are used. The material is also incredibly lightweight, making it perfect for racing applications.

Friction materials for automotive brake systems typically contain metallic ingredients to improve their wear resistance, thermal diffusivity, and strength. Various metals such as copper, steel, iron, brass, bronze, and aluminum have been used in the form of fibers or particles in the friction material, and it is known that the type, morphology, and hardness of the metallic ingredients can affect the friction and wear of friction materials. This is due to the friction materials which are designed to keep stable friction force, reliable strength, and good wear resistance over a wide range of braking conditions.

It has been progressively substituted in most brake linings and pads by fibers like synthetic aramids. The additive effects of different kinds of non-asbestos materials on friction linings. As a result of these efforts, asbestos-free organic, semi-metallic and metallic friction lining materials are now increasingly being utilized. Non-asbestos organic (NAO) based friction materials are contain many ingredients intermixed to achieve expected combination of performance properties. They are classified into four major categories, namely; binder, fibers, friction modifiers and fillers. The central part of a system which binds the ingredients firmly so that they can perform the desired function in the friction materials is called binder. Friction modifiers are used to control the desired range of friction while fibers in amalgamation are included usually for strength. The two types of fillers available include; functional fillers for enhancing specific characteristic feature of composites such as resistance to fade, etc; and space/non-reactive fillers employed mainly to cut cost.

Both modified and unmodified phenolic resins are always used as binders in friction materials because of low cost with good combination of mechanical properties. These resins are sensitive to heat and humidity, and have poor shelf life as a result of in-situ polymerization which starts even at ambient temperature.

Due to these reasons in this research work attempts are made to develop new composite material for brake friction liners using glass and carbon fibers filled with different volume fractions of phenolformdehyde and epoxy resin along with 10% of coconut shell powder as filler by compression molding technique.

LITERATURE REVIEW

A literature survey is the sources of background information which are relevant to a particular area of research. It provides a methodologies, description and critical assessment of each work. Present research mainly focused on the development, estimation of mechanical properties of slag and coconut shell powder filled glass fiber reinforced epoxy composites.

Suresha B et al., [1] studied three-body abrasive wear and mechanical behavior of poly methyl methacrlate and thermoplastic polyurethane. For all the samples, three-body abrasive wear results indicate that the wear volume increases with increase in abrading distance. A marginal reduction in tensile strength and tensile modulus and significant improvement in percentage elongation at break was noticed with an increase in the TPU content in the blends. Better correlation between selected mechanical properties and wear volume is obtained for neat PMMA and 95/5 PMMA/TPU blend. Scanning electron microscope (SEM) shows matrix cracking and deep furrows in PMMA/TPU blends.

Sutikno et al., [2] fabricated brake friction materials using carbonized coconut char powders to study its mechanical properties. Energy dispersive X-ray spectroscopy was used to find the chemical analysis. The amount of char used varied between 7–14% of total volume due to improved mechanical properties carbon made from coconut char powders can replace the role of graphite or coal powders as fillers for brake friction materials.

Husseinsyah et al., [3] analyzed the effect of coconut shell content on the mechanical, water absorption and morphological properties. A catalyst, butanox M-60 was used to initiate the polymerization reaction. SEM micrograph showed that the tendency of filler-matrix interaction increases with increase in the filler content. Tensile strength, young’s modulus and water absorption of Polyester/CS composites increased the increasing CS content.

Öztürk et al., [4] studied the variation infriction characteristics and mechanical properties of automotive brake materials with change in resin type and fiber length. Three series of friction composites composed of nine composites in the form of brake materials were manufactured. Physical, mechanical, and tribological properties of all composites were investigated. The results showed that both mechanical and tribological properties were influenced by resin type and fiber length. Wear resistance was found to increase with increase in the fiber length. To analyze the wear mechanism and frictional properties morphology of worn out surfaces were studied.

Olumuyiw.et.al.,[5] investigatedmechanical characterization of coconut shell reinforced polymer matrix composite. Coconut shell reinforced composite was prepared by compacting low density polyethylene matrix. The hardness of the composite increases with increase in coconut shell content though the impact energy, ductility, tensile strength and modulus of elasticity of the composite decreases with increase in the particle content .coconut shell particle and the polyethylene matrix showed poor interfacial interaction through SEM analysis. Due to non-uniform distribution of coconut shell particle there was decrease in strength when compared with the 0% coconut shell particles.

Shivamurthy et al., [6] fabricated multi-layered laminates of E-glass fabric/epoxy composites with the graphite particles as the fillers. Tensile, flexural behaviors, impact strength, hardness and density of these laminates were determined. Wear behaviors of these composites were investigated by a pin-on-disc wear test apparatus. The composite filled with 3 wt% of graphite exhibits the lowest specific wear rate and the best mechanical performance. Further increase in the graphite content increases the specific wear rate and deteriorates the mechanical behavior.

Zhang Z et al., [7] investigated the wear resistance characteristics of epoxy using various fillers like short carbon fiber (CF), graphite, poly tetra fluoro ethylene (PTFE) and nano-TiO_2. Worn surfaces were investigated using a scanning electron microscope and an atomic force microscope. Results revealed that best wear-resistant composition was combination of nano-TiO_2 with conventional fillers. SEM and AFM worn surfaces of nano composites, showed that a nano scale rolling effect of nano particles which help to protect the worn surface of the composites from more severe wear mechanisms.

Sampathkumaran et al., [8] investigated the effect on slide wear and friction characteristics of epoxy–glass composite system. Coefficient of friction was determined to study the tribological behavior of the filled composites. Scanning electron microscope (SEM) was used to examine the worn surface. High wear loss was recorded for increased load and sliding velocity. Coefficient of friction values show an increasing trend with a rise in load and a decrease in their values for increase in velocity for rubber-bearing samples while Coefficient of friction increases with increase in load for a fixed velocity for graphite bearing samples. Lower coefficient of friction for any combination of load and velocity was recorded by higher graphite bearing G–E composite.

Hee et al., [9] studied the performance of wear and friction characteristics of brake lining material with the impact of potassium titanate. Friction Assessment and Screening Test (FAST) was used to determine the wear and friction characteristics of samples with and without potassium titanate. X-ray diffraction analysis, energy dispersive X-ray analysis, light microscopy, scanning and transmission electron microscopy were used to investigate the friction surfaces of the samples. Improvement in friction coefficient, wear resistance and fade was observed in brake lining material containing potassium titanate. Stabilized friction coefficient, fade reduction, and wear improvements were achieved by adding potassium titanate and its contribution to the friction layer formulation.

Suresha et al. [10] investigated the influence of silicon carbide particles (SiC) and graphite, on the wear characteristics of the glass fabric reinforced epoxy composites under dry sliding conditions. Pin-on-Disc wear tester was used to investigate the wear characteristics under varying load and sliding velocities. Higher wear loss was recorded for increased load and sliding velocity conditions. Graphite filled G-E composite shows lower coefficient of friction and SiC filled G-E composite exhibited the maximum wear resistance. Composites exhibited better wear resistant properties with the addition of Graphite and SiC particulate fillers. Wear change from adhesive wear to abrasive wear was evident from SEM analysis.

Srivastava et al. [11] investigated the effects of wheat starch on erosive wear of E-glass fibre reinforced epoxy resin composite materials. Erosive wear of wheat flour powder filled composites is evaluated at different velocities and different impingement angles. Value of hardness, tensile strength, and density was decreased with addition of wheat flour filler in GFRP composite. Highest erosion rate was showed by pure glass epoxy without

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any filler material. The impingement angle on erosive wear of all composites exhibited semi-ductile erosive wear behavior with maximum wear rate at 60^0.
Ranganathan et al. [12] investigated the effect of aramid fiber content on the friction coefficients and wear rates of friction materials containing phenolic resin binder used for brake pad applications. Aramid fiber reinforced phenolic matrix friction composite was developed with fiber content varying from 0 to 7 wt %. Coefficient of friction decreased linearly with increase in fiber content. Further the sliding velocity and the wear rate also decreased with increase in fiber content. Better tribological characteristics were shown by material containing aramid fiber compared to material without aramid fiber content. Improved wear resistance and friction stability was achieved by the incorporation of aramid fiber in the friction composite.

U.D. Idris et al. [13] investigated the effect of eco-friendly asbestos free brake-pad using banana peels by varying the resin (phenol formaldehyde) from 5 to 30 wt% with interval of 5 wt%. Morphology, physical, mechanical and wear properties of the brake pad were studied. The results showed that compressive strength, hardness and specific gravity of the produced samples were seen to be increasing with increased in wt% resin addition, while the oil soak, water soak, wear rate and percentage charred decreased as wt% resin increased. The samples, containing 25 wt% in uncarbonized banana peels (BUNCp) and 30 wt% carbonized (BCp) gave the better properties in all.

Cho et.al.,[14] studied the tribological properties and morphological effects of potassium titanate in the brake friction material. To obtain thermal stability and wear resistance of the friction materialsKrauss type friction tester was used at elevated temperatures. Better friction stability and improved wear resistance was exhibited by friction material with splinter shape potassium titanate. Transfer films produced by the friction materials with platelet or whisker potassium titanate were not sustainable at elevated temperatures. The friction material containing potassium titanate whiskers and splinters showed good high temperature friction stability compared to that with platelets. By using splinter shape potassium titanate wear resistance at elevated temperatures was greatly improved. Wear resistance of the friction material was affected by the thickness of the transfer films.

Ferit Ficici et.al., [15] conducted weight loss of automotive brake using taguchi technique. Wear tests of the cast iron against brake pad disk were conducted in dry sliding condition using pad-on-disk rig method. The wear tests were conducted at the sliding speeds of 7, 9, and 11 m/s at of 0.5, 1, and 1.5 bars. The lowest weight loss consist copper flake volume fraction of 20 wt% under the test conditions. Interaction between volume fraction of copper flake and pressure exert a great effect on the weight loss at 58.11, 16.35, and 20.86 %, respectively. About 20.86% of wear was observed with interaction between pressure and volume fraction while about 2.25 % observed with sliding distance and volume fraction.

Shicheng Qi et.al., [16] Conducted experiment of 0–14.6 vol.% alkaline-treated walnut shell powders (WSPs) as a functional filler in the proposed eco-friendly brake friction materials. Components prepared using five non-asbestos friction material samples containing WSP and jute fibers along with natural resource such as basalt fibers, zircon, wollastonite, barite, and vermiculite. Also an extension evaluation method was implemented to prioritise the composites based on their overall friction-wear characteristics. The wear rate and coefficient of friction (COF) of the samples were effectively improved with a WSP content of 45.6 vol. %.

Yawas, D. S et. Al., [17] developed non asbestos automotive brake pad using periwinkle shell particles as frictional filler material using compressive moulding. This was done to determine the characteristics of the periwinkle shell, which is largely deposited as a waste. Brake pads with five sets and having different sieve size (710–125 lm) of periwinkle shell particles with 35% resin were produced using compressive moulding. The mechanical, physical and tribological properties of the periwinkle shell particle-based brake pads were evaluated against the values of the asbestos-based brake pads. The Hardness, compressive strength and density of the developed brake pad samples increased with decreasing the particle size of periwinkle shell from 710 to 125 lm, at the same time wear rate and oil soak decreased with decreasing the particle size of periwinkle shell. The results obtained at 125 lm of periwinkle shell particles compared with that of commercial brake pad.

Scieszka et.al., [18] conducted experiment on the brake disc surface temperature field measurements while applying emergency braking using thermo vision infra-red camera. The experimental part of the research also covers tribological testing on the coefficient of friction between steel (brake disc) and friction brake material (brake pad) in laboratory conditions. The tribological characteristic of the friction couple was calculated using finite element analysis. In the numerical part, the FEM technique was used to simulate the brake interface hot

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International Journal OF Engineering Sciences &Management Research

spotting and the axial disc distortion as a function of geometrical and material properties of the brake elements and the brake's operational conditions. The disc's material thermal expansion coecient has the strongest influence on the critical velocity. Increase of young's modulus and thermal expansion coefficient reduces the value of the critical velocity.

MATERIALS AND METHODS

Fibers are the major elements in FRP composites; the reinforcing fiber is most important load-transferring agents and occupies the largest volume fraction in a composite laminate. Different types of glass fibers used to manufacture fiber-reinforced plastics (FRP) are S-glass and E-glass in industry. Many components for air craft and missile components are developed using S-glass fibers because of its highest tensile strength among all fibers in use. It is noticed that E-glass has the least expensive fibers among all commercially available fibers, because of this reason they are widely used in the FRP industries. In the present work different volume fractions of glass fibres and carbon fibres are used as reinforcements.

Chopped glass fibers *Chopped carbon fibers*

Figure:1. Chopped Glass and Carbon fibers

The roles of the matrix in a fiber-reinforced composite is to keep the fibers in place, transfer stresses between the fibers. In general, Ceramics, thermoset, thermoplastic are used as common matrix materials. Epoxy resins are extensively used in the manufacture of fiber reinforced composites because of their flexibility, low contraction and exceptional adhesive properties with minimum cost. Hence in this research work phenol formaldehyde and epoxy VP 401 grade are used as matrix materials.

Epoxy VP 401 *Phenol formaldehyde*

Figure:2. Matrix materials used to manufacture friction material

Fillers are added to a polymer matrix to reduce cost, increase modulus, reduce mold shrinkage, controls the viscosity and to produce smoother surface.
Commonly used inorganic fillers are Barium sulphate, Calcium carbonate, Mica, Vermiculite, Alkali metal, and Molybdenum trioxide. During braking enormous amount of heat generated hence it is necessary to take away the heat generated.

From the statistics huge quantity of waste has formed and burning of the coconut shell leads to environmental pollution. Presently attempts are made to use Coconut shell powder as filler in many of the composites because of its inherent properties. Hence an effort has been made to manufacture friction material for brake pad using coconut shell powder as alternate filler and friction additive since it is cheaper and available in abundance as compared to cashew dust and rubber.

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Barium Sulphate

Calcium carbonate

Coconut shell powder

Figure: 3.Fillers

Frictional Additives

Frictional additives are added in order to alter the frictional coefficient as well as the wear rate. They are classified as abrasives and lubricants.

Graphite

Antimony sulphide

Figure: 4. Lubricants

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International Journal OF Engineering Sciences & Management Research

Abrasives are the hard particles of metal oxides and silicates, these abrasives increases friction coefficient and wear rate of the counter face material and they remove iron oxides from the counter friction material as well as other undesirable surface films formed during braking. Commonly used Abrasives are zirconium oxide, zirconium silicate, aluminium oxide and chromium oxide. From the literature it was noticed that physical, thermal and mechanical characteristics of Al_2O_3 is predominant as compared to other abrasives which can be metallizable composition with a purity of 94% hence in this research work Al_2O_3 is used as abrasive material.

Aluminum oxide
Figure: 5. Abrasive

Lubricants are mainly used to stabilize the developed friction coefficient during braking, especially at high temperatures. Commonly used lubricants include graphite and various metal sulphides.

Graphite is widely used as lubricant in friction material to form lubricant layer on the opposing counter friction surface. Heat generated during braking can be effectively dissipated if the graphite is used in powder form. Excessive use of graphite in phenolic resins leads to weak bonding which intern reduces shear strength.

To provide good lubrication as well as to lower the thermal conductivity, metal sulphides are popularly used in friction materials due to its high melting point. Hence antimony sulphide is used as lubricant along with graphite.

Formulation of Brake Pad Friction Lining Materials

The construction of the brake pad friction material requires fillers, binders, additives and reinforcements to obtain frictional characteristics. In the present study friction material was developed using different volume fractions of fillers, binders, additives and reinforcements listed in the above section

Figure 6 shows the different materials used to manufacture asbestos free brake pad friction liner by the varying volume fractions.

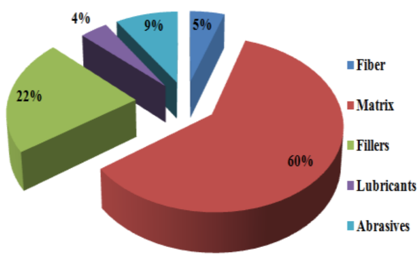

Figure: 6. Percentage composition of material categories for brake friction material

Attempts are made to manufacture composite with less than 50% volume fractions of matrix and more than 15% of the reinforcement and it is noticed that a poor bonding exists between fiber and matrix. Hence the present investigation focused to manufacture friction liners by considering minimum 50% volume fraction of matrix and maximum 15% volume fractions of fiber along with fixed volume fractions fillers and additives.

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PROCESS PLAN TO MANUFACTURE FRICTION LINERS

In the present work a composite sheet of 200 mm X 160 mm X 5 mm thick is fabricated using compression molding process for different volume fractions of fiber and the matrix. Mass of glass and carbon fibers, epoxy resin, phenol formaldehyde, mass of the fillers and frictional additives were calculated as per their volume and density. Calculated quantity of above ingredients is used to manufacture composite plates of required dimensions using compression molding machine as shown in figure 7.

Figure: 7. Compression Molding Machine

Compression molding is closed molding process used to develop variety of composite material products for high pressure application. Compression molder consists of two matched metal molds in which base plate is stationary while upper plate is movable. Reinforcement and matrix are placed in the metallic mold and the whole assembly is kept in between the compression molder. Heat and pressure is applied as per the requirement of composite for a definite period of time. The material placed in between the molding plates flows due to application of pressure and heat it acquires the shape of the mold cavity with high dimensional accuracy. Curing of the composite may carried out either at room temperature or at some elevated temperature. After curing, mold is opened and composite product is removed for further processing. Mass of glass, carbon fiber, epoxy resin, Phenol Formaldehyde, different frictional additives and fillers were calculated as per their volume and density.
The process flow chart to prepare the asbestos free brake friction liners is as shown in Figure 8.

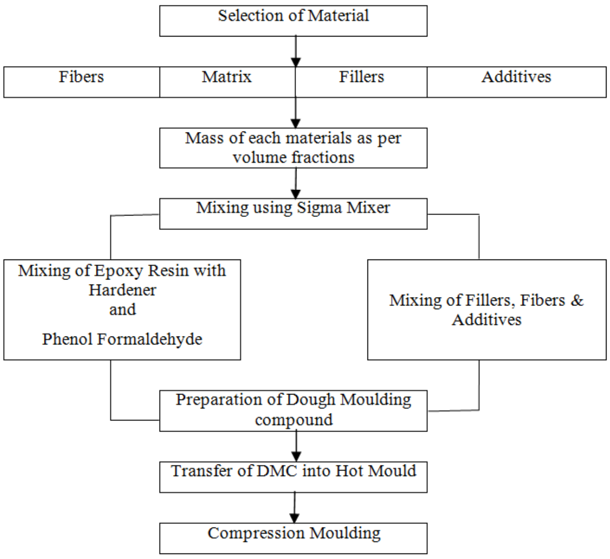

Figure 8: Process flow chart

In this stage, sequence of process used to manufacture friction liners are as shown in the process flow chart. Calculated mass of fiber, matrix, fillers and frictional additives are mixed using sigma mixture to get dough molding compound (DMC).

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The steel metal mould as shown in figure 9 pre heated to 135ºC to 145ºC using the platens of hydraulic type compression moulding press and DMC was charged into it.

The heated mould and the two platens of compression moulding press are closed with a maximum clamping pressure of 110 kg/cm² as shown in figure 7 and allowed to cure phenol formaldehyde based composite for 20 to 25 minutes. After curing, composite material was removed from the mould and post curing was done at 60ºC to 80ºC about 24 hours in a hot air oven to ensure the complete curing of friction liners.

Similar procedure was adopted to manufacture epoxy resin based friction liners with curing time 30 minutes. The cured composite laminates of different volume fractions of glass fiber and carbon fiber reinforced with phenol formaldehyde and epoxy resin are as shown in figure 10. Further these composites will be used to estimate wear and mechanical characteristics as per ASTM Standards.

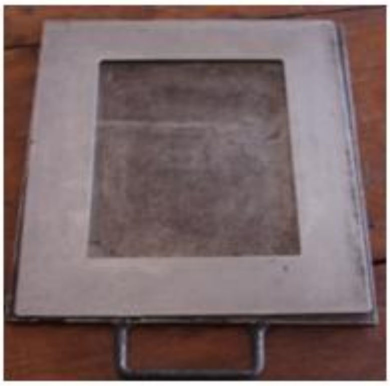

Figure: 9. Pre heated metal mold

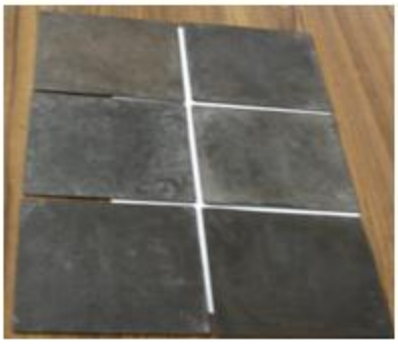

Figure: 10. Cured composite laminates.

REFERENCES

1. *Suresha, B., and Joong-Hee Lee. "Mechanical and three-body abrasive wear behavior of PMMA/TPU blends." Materials Science and Engineering: A492.1 (2008): 486-490.*
2. *Sutikno, M., P. Marwoto, and S. Rustad. "The mechanical properties of carbonized coconut char powder-based friction materials." Carbon 48.12 (2010): 3616-3620.*
3. *Husseinsyah, Salmah, and M. Mostapha. "The effect of filler content on properties of coconut shell filled polyester composites." Malaysian polymer journal 6.1 (2011): 87-97.*
4. *Öztürk, Bülent, and Sultan Öztürk. "Effects of resin type and fiber length on the mechanical and tribological properties of brake friction materials."Tribology Letters 42.3 (2011): 339-350.*
5. *Olumuyiwa, Agunsoye J., Talabi S. Isaac, and Sanni O. Samuel. "Study of mechanical behaviour of coconut shell reinforced polymer matrix composite."Journal of Minerals and Materials Characterization and Engineering 11.08 (2012): 774.*
6. *Shivamurthy, B., K. Udaya Bhat, and S. Anandhan. "Mechanical and sliding wear properties of multi-layered laminates from glass fabric/graphite/epoxy composites." Materials & Design 44 (2013): 136-143.*

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International Journal OF Engineering Sciences &Management Research

7. *Zhang, Z., et al. "Enhancement of the wear resistance of epoxy: short carbon fibre, graphite, PTFE and nano-TiO 2." Composites Part A: Applied Science and Manufacturing 35.12 (2004): 1385-1392.*
8. *Sampathkumaran, P., et al. "A study on the effect of the type and content of filler in epoxy–glass composite system on the friction and slide wear characteristics." Wear 259.1 (2005): 634-641.*
9. *Hee, K. W., and P. Filip. "Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings." Wear 259.7 (2005): 1088-1096.*
10. *Suresha, B., et al. "The role of fillers on friction and slide wear characteristics in glass-epoxy composite systems." Journal of Minerals and Materials Characterization and Engineering 5.01 (2006): 87.*
11. *Srivastava, V. K. "Effects of wheat starch on erosive wear of E-glass fibre reinforced epoxy resin composite materials." Materials Science and Engineering: A 435 (2006): 282-287.*
12. *Srivastava, V. K. "Effects of wheat starch on erosive wear of E-glass fibre reinforced epoxy resin composite materials." Materials Science and Engineering: A 435 (2006): 282-287.*
13. *Tudu, Prakash. Processing and characterization of natural fiber reinforced polymer composites. Diss. National Institute of Technology Rourkela, 2009.*
14. *Tomášek, Vladimír, et al. "Effects of alumina in nonmetallic brake friction materials on friction performance." Journal of materials science 44.1 (2009): 266-273.*
15. *Suresha, B., et al. "Influence of graphite filler on two-body abrasive wear behavior of carbon fabric reinforced epoxy composites." Materials & Design31.4 (2010): 1833-1841.*
16. *Cho, Keun Hyung, et al. "Tribological properties of potassium titanate in the brake friction material; morphological effects." Tribology Letters 32.1 (2008): 59-66.*
17. *Qi, Shicheng, Zhezhen Fu, Rongping Yun, Shengling Jiang, Xiaoa Zheng, Yafei Lu, Vlastimil Matejka, Jana Kukutschova, Veroslava Peknikova, and Martin Prikasky. "Effects of walnut shells on friction and wear performance of eco-friendly brake friction composites." Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 228, no. 5 (2014): 511-520.*
18. *Ma, Yun Hai, Sheng Sheng Ma, Sheng Long Shen, Jin Tong, and Li Guo. "Hybrid biological fiber-reinforced resin-based friction materials friction and wear performance test." In Applied Mechanics and Materials, vol. 461, pp. 388-396. Trans Tech Publications, 2014.*