Development of Asbestos Free Brake-Pad Using Banana Peel Hybrid Composite

By

Sheferaw Tensaye Nisro

A Thesis Submitted to

The Department of Mechanical Systems and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

A Thesis Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Automotive Engineering

Program: M.Sc. in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Sheferaw Tensaye Nisro have read and evaluated his thesis entitled “Development of Asbestos Free Brake-Pad Using Banana Peel Hybrid Composite” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master’s in Automotive Engineering.

______________________	______________________	______________________
Advisor	Signature	Date
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ADVISOR'S APPROVAL SHEET

To: Mechanical Systems and Vehicle Engineering department

Subject: Thesis Submission

This is to certify that the thesis entitled "Development of Asbestos Free Brake-Pad Using Banana Peel Hybrid Composite" submitted in partial fulfillment of the requirements for the degree of Master's in Automotive Engineering, the Graduate Program of the Department of Mechanical Systems and Vehicle Engineering and has been carried out by Sheferaw Tensaye Nisro Id. No A/PE16415/10, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Dr. Ramesh Babu Nallamothu	_______________	_____________
Name of major advisor	Signature	Date

DECLARATION

I hereby declare that this MSc Thesis entitled "Development of Asbestos Free Brake-Pad Using Banana Peel Hybrid Composite" is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name:

Sheferaw Tensaye Nisro

Signature: ________________________________

This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

Name:

Dr. Ramesh Babu Nallamothu

Signature: _________________________________

Date of submission: ________________________

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ABSTRACT

Brakes are the most important mechanism on a vehicle. Even though there are two types of brakes available in the vehicle (disc type and drum type); disc brakes are widely used for reducing velocity, with their characteristics of braking stability, controllability and their ability to provide a wide ranging torques. Disc brakes have different components like; brake pad, brake disc, caliper, brake lining etc. During braking both the brake pad lining and disc surface get worn. The conventional material used in brake pad lining is asbestos which is dangerous for human health because of its carcinogenic nature. So to reduce these negative effects, there is a need to use eco-friendly materials in place of asbestos in brake pad lining. In this work a new brake pad was produced using banana peels waste to replace asbestos. The activities involved in this work are like, preparation of composite, testing its characteristics and preparing brake pad lining with banana peel composite. Banana peels were collected, dried and milled in to powder form. Then composite was prepared by mixing with carbon powder and predetermined epoxy-hardener. The percentage of carbon powder was varied in the composite and mechanical and wear properties of the brake pad were studied. As the result the developed banana peel brake pad has 0.021 mg/m wear rate, 110MPa amount of Compressive strength and 2.06 amount of Tensile strength, so the commercial brake pad has high wear rate and very high compressive and Tensile strength than that of the developed brake pad. Generally the developed brake pad is better than the existing brake pad.

Keywords: Banana peel, Brake pad, Disc brake, Hybrid composite

Abbreviations

PKS……………………………..Palm kernel shell

HRB ……………………………Values compressive

ASTM …………………………American Society for Testing and Materials

PMC…………………………… Polymer matrix composites

CTE……………………………..Coefficient of thermal expansion

CBS …………………………..…Cocoa beans shells

MH …………………………….Maize husks

BUNCp…………………………Un-carbonized banana peels

BCp …………………………….Carbonized banana peels

NAO ……………………………Non-Asbestos Organic

PR-51510i ………………………phenolic resin polymer

PMC …………………………….Polymer–matrix composites

MMC ……………………………Metal–matrix composites

CMC …………………………….Ceramic–matrix composites

ABS …………………………….Antilock braking systems

ROM ……………………………Rule of mixtures

PVA …………………………….Polyvinyl Alcohol

UTS …………………………….Ultimate tensile strength

MOENCO ……………………...Motor and Engineering Company of Ethiopia

CHAPTER ONE
INTRODUCTION

1.1 Background

The braking system is one of the active safety systems in the motor vehicles. If the brake fail, the result can be disastrous to the vehicle as well as to the users. Brake performance depends on the operating variables, mating members, environment, material characteristics, surface geometry, microstructure, design, type and mechanical properties (Jaafar et al., 2018).

Brake is a supreme part of all the automobiles and machineries without which we cannot imagine them to be completed. They are exploiting to reduce the speed and to control the motion of so many things around the globe. Brakes are framed with leverage, some moving parts and important one is lining material to have frictional effect those are utilized to absorb kinetic energy and transform it in to other forms (Shinde & Mistry, 2017).

Braking is the process of partially or completely decreases traveling speed of a vehicle. During braking, part of the kinetic energy gained by the vehicle turns into heat through friction. Other part is consumed for overcoming resistance to rolling and air resistance, which opposing the movement. The large amount of heat that is generated during braking contributes to the worsening of the vehicle braking qualities, hastens wear and friction linings and other brake system components. In recent years, the continued growth of the dynamic qualities of the vehicle and traffic, stressed the importance of braking systems. A braking system must have the following qualities: effectiveness, stability, fidelity and comfort. The effectiveness of the braking system ensures enhancement of the performance speed of the vehicles. A high efficiency of the braking system leads to obtaining higher speeds, in which case the vehicle's performances are elevated. Stability of the braking system, involves conservation of braking qualities of the vehicle. This is achieved if the braking force applied is maintained constantly in all operating conditions. In the case of brakes with friction; this depends on the stability of the friction coefficient of the brake pads. In normal use, the brake thermal regime should not exceed 300°C, to ensure this constant friction. In this scope, the brake pads must ensure evacuation of heat that occurs during braking, because in the event of excessive heating, noises and vibrations, the structure of material is change and the friction coefficient is reduced. All these leading to lower efficiency and decrease traffic safety. This is the reason why special attention is paid to the design and manufacture of braking systems components (Shinde & Mistry, 2017).

Brake pads are important parts of braking system for all types of vehicles that are equipped with disc brake. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc. Brake pads convert the kinetic energy of the vehicle to thermal energy by friction. Two brake pads are contained in the brake caliper with their friction surfaces facing the rotor. Brake pad materials are classified as belonging to one of the four principal categories such as: Non-metallic, semi-metallic, metallic, ceramic materials. Metallic and semi-metallic friction materials show better thermal stability and wear characteristics as compared to the non-asbestos organics but they generate more noise and degrade the disc material faster. Ceramic materials can withstand very high temperature and makes very less noise (Gowthaman & Rajesh, 2017).

Braking system can be broadly classified into two major categories such as drum brakes and disc brakes. A drum brake system has a set of shoes that press outward against a rotating cylinder-shaped part called brake drum. A disc brake system has calipers that squeeze a pair of brake pads against a rotating disc in order to create friction that will retard the motion of the disc (Gowthaman & Rajesh, 2017). It is an indispensable component of an automobile, and is composed of many parts including brake pads, master cylinder, wheel cylinders, and a hydraulic control system (Olele et al., 2016).

The disc brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or rotor in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon– carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade (R. Abhang & Bhaskar, 2014).

In disc brake applications, there are usually two brake pads per disc rotor, held in place and actuated by a caliper affixed to a wheel hub or suspension upright. Although almost all road-going vehicles have only two brake pads per caliper, racing vehicle calipers utilize up to six pads, with varying frictional properties in a staggered pattern for optimum performance. Depending on the properties of the material, disc wear rates may vary. The brake pads must usually be replaced regularly (depending on pad material), and most are equipped with a method of alerting the driver when this needs to take place (Shinde & Mistry, 2017).

A disc brake system consists of a brake disc, a brake caliper and brake pads as shown in Fig.1.1 When the brake pedal is applied, and master cylinder converts this force into hydraulic pressure. Brake pedal operation is based on the principle of the lever, and converting a small pedal force into large force acting on the master cylinder. Based on Pascal's law, the hydraulic force generated in the master cylinder is transmitted via brake line to individual wheel cylinders. It acts on brake linings and disc brake pads to generate a braking force. The result of this force produces friction which enables the vehicle to slow down or stop. If a vehicle design requires a larger braking force at the front wheels, for example, the designer will specify larger wheel cylinders for the front.

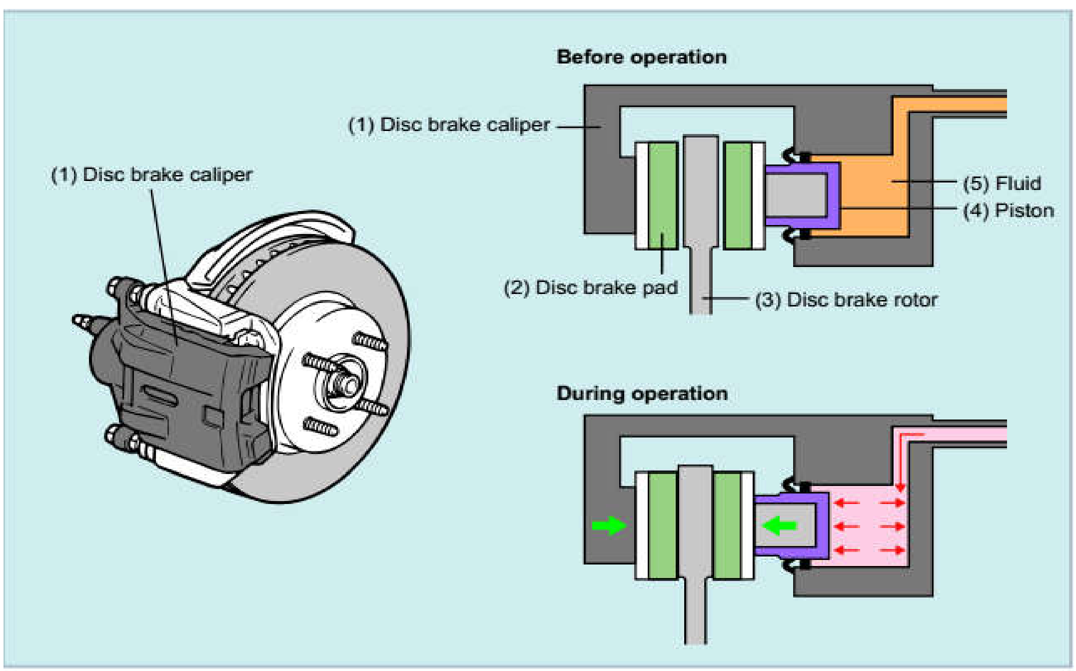


Figure 1.1: Components of Disc Brake[Chandgude& Ganiger, 2015].

Disc brakes are fairly simple to work. Typically, there are four main parts of a disc brake system as given below:

1. Mounting Bracket: Mounting Brackets are used to hold the caliper in place.

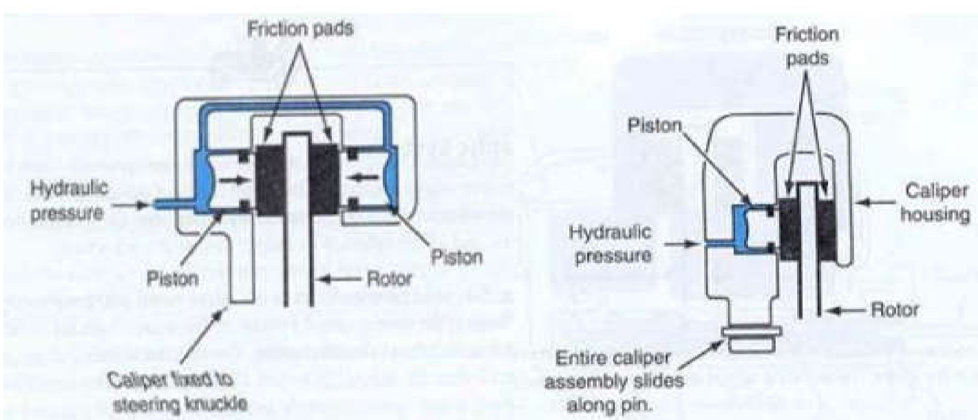
2. Rotors are metal discs supported by the suspension. The calipers clamp onto them to slow their rotation, and then slow or stop the car. Vented rotors have fins in the spaces between their machine d surfaces. These spaces allow air to pass through, which helps carry heat away. Non-vented rotors are used on smaller vehicles, and have no cooling fins.

3. Calipers are the housings that contain the pistons and the brake pads. The calipers are connected to the hydraulic system, and hold the brake pads to the rotor.

There are two types of calipers:

a) Fixed Caliper - Applies two pistons to opposite sides of rotor. Fixed calipers are as shown Fig. 1.2a, are disc brakes that use a caliper, which is fixed in position and does not slide. They have pistons on both sides of the disc. There may be two or four pistons per caliper. Motorcycles and some import trucks and cars use this type.

b) Sliding Caliper - There are two pistons between which fluid under pressure is sent which passes one friction pad directly onto the disc whereas the other pad is passed in directly via caliper as shown in Fig. 1.2b (Chandgude& Ganiger, 2015).



a).Fixed caliper b). sliding caliper

Figure 1.2: Caliper types [Chandgude& Ganiger, 2015].

Brake pads are important parts of braking system for all types of vehicles that are equipped with disc brake. The kinetic energy of the vehicle is converted into thermal energy by the friction produced by brake pads. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc. Different types of brake materials are used in different machines. The brake pads generally consist of asbestos fibers embedded in polymeric matrix along with several other ingredients. The use of asbestos fiber has been avoided due to its carcinogenic nature. Therefore, anew asbestos free friction material and brake pads have been developed.

Several researches have been carried out in the area of development of asbestos-free brake pads. The use of coconut shell, palm kernel shell (PKS) etc. has been investigated. Researches all over the world are focusing on ways of utilizing either industrial or agricultural wastes as a source of raw materials in the industry. These wastes utilization will not only be economically, but may also result to foreign exchange earnings and environmental control (Aigbodio et al., 2010).

Much of the brake pads industry is moving away from asbestos brake pads because of concerns regarding airborne particles in the factories and disposal of wastes containing asbestos. There are several patents for asbestos free organic friction materials.

Changes in brake pads formulation were also driven by the promulgation of the corporate average fuel efficiency requirements in the late 1970's and mid 1980's. These requirements led the automobile industry to switch from rear wheel drive cars to front wheel drive cars. This switch required more front braking which resulted in higher temperatures and a preference for semi-metallic brakes. A lot of researches have been carried out in the area of development of asbestos-free brake pads. All forms of asbestos are carcinogenic. This ban was overruled in 1991 due to widespread complaints of the difficulty of finding asbestos replacements; existing uses of asbestos are still permitted, while new applications and uses (of asbestos) are banned. The need to develop a new material for asbestos replacement as friction material and yet maintaining the same mechanical properties, still remains a bone of contention (Adeyemi et al., 2016).

The purpose of this proposal is to develop a new asbestos-free brake pads using agricultural waste (Banana peels). Since banana peels is readily available and very cheap to obtain (Idris et al., 2015).

Brake lining requirements

The following are the requirements of brake linings for efficient braking operations:

- The brake lining having a higher coefficient of friction contributes to more efficient braking.
- Lining materials should have less wear rate to increase the life of the brake lining and thus reducing the frequent changing of the brake lining – saving the time and money.
- Brake lining materials must have the capability to work at high temperatures without much change in the coefficient of friction and wear rate. High speed vehicles generate more heat during braking
- The brake lining material should have a high thermal conductivity to dissipate the heat produced.
- The brake lining material should not be hazardous and should be free from asbestos. Asbestos dust can cause serious health problems if inhaled. Breathing asbestos dust can cause upper and lower respiratory and gastrointestinal diseases (Darius et al., 2005).

Table 1-1: Comparative properties of brake lining materials(Shinde & Mistry, 2017)

Properties	Asbestos Bases	Palm kar-nel shell base	Peri-winkle Shell base	Banana peels base	Zir-cosil base	$Zrsio_4$ base
Specific gravity(gm./cm^3)	1.6	1.12	1.01-1.89	1.26	2.54	1.96
Coefficient hardness	0.2	0.41	0.3-0.4	0.4	0.46	1.96
Values compressive (HRB)	110	92	101-116	98.8	95	73
Strength(N/mm^2)	108	103	110	95.6	100	105

1.2 Statement of the problem

Asbestos which is used as frictional material in brake pad lining causes health problem to human beings. It is a big challenge to develop friction materials for brake pads which are asbestos free. While ferodo and metallic brake pad lining is used, it will damage the brake disc due to its iron, copper, steel and graphite content.

1.3 Objectives

1.3.1 General Objective

The general objective of this thesis work is to develop asbestos free brake pad using banana peel hybrid composite.

1.3.2 Specific Objectives

The specific objectives are:

- To develop banana peel composite.
- To test property of banana peel composite.
- To manufacture brake pad lining from banana peel composite.
- To compare and contrast with conventional brake pad lining.

1.4 Significance of the thesis

Significance of this thesis work is as follows;

- It eliminates health problem occurred due to usage of asbestos brake pad lining.
- It reduces service time due to unavailability of brake pad.
- It saves foreign currency for our country.
- It encourages the development of small-scale industries in Ethiopia. Small scale industries play a vital role in the socio- economic development of any country.

1.5 Beneficiaries

Automotive industries, vehicle owners, researchers, society and country as a whole get benefitted with this work.

1.6 Delimitation (Scope)

This work includes the study of the characteristics of the brake pad lining material, preparation of composite material brake pad lining for HZJ78L-RJMRS vehicle model (Toyota Land cruiser) and other type of vehicles are not considered, characterization as per ASTM standards and preparation of the prototype will be included in this work.

1.7 Limitations

During the execution of this thesis work many challenges were encountered. Some of the major limitations are given below.

a) Suitable standard test sample preparing machine is also not found which is specifically designed for natural composite application.

b) It was a big challenge to find testing machine to test the composite sample as per the requirement.

1.8 Organization of thesis

This thesis consists of the following five chapters. Chapter one: it gives information about the vehicle brake system, working principle, materials, statement of problem, objective, scope, limitation, significances and organization of the study are parts of this chapter. Chapter two: it reviews the previous research works that were conducted by other people and identifying the problem. Chapter three: it is the methodology. This chapter described the method and the material used to develop brake pad lining. Chapter four: this chapter includes the processes and techniques applied to prepare composite material from banana peel powder, software analysis; testing and results are also discussed in this chapter. Chapter five: which is the last chapter includes a summary of findings, conclusion, and recommendation for future works.

CHAPTER TWO
LITERATURE REVIEW

2.1 Previous Research

There are so many literatures review based on replacing of asbestos brake lining with eco-friendly natural composite materials.

Ilanko & Vijayaraghavan, (2016) said that the first generation of composites used in modern brake friction materials relied on asbestos reinforced composites. Asbestos fiber reinforced polymeric composites are used in brake pads, brake linings and brake couplings; however, asbestos has been found to be hazardous to the environment and to human health. Therefore, in recent years, non-asbestos reinforcements like Kevlar (aramid fiber), glass fiber, graphite and natural fibers have been used as replacements for asbestos. Conventional materials are being replaced by modern composite materials in many fields because of their many advantages such as light weight and easy processing. Reinforcing friction materials with natural and mineral fibers has provided significant enhancement in their mechanical and tribological properties. Although these fibers exhibit fairly good mechanical and friction properties, there are some serious drawbacks such as poor affinity with resin and susceptibility to friction-induced noise. However, because of their excellent mechanical properties, low cost, and low environmental impact, these fibers have recently become increasingly attractive material candidates. In automotive applications, polymer matrix composites (PMC) are used as brake pads with cast iron or steel discs as counterparts. It is impossible to avoid the wear of the brake pads, but wear should be minimized as far as possible without compromising on the functional performance of the component

Gowthaman & Rajesh, (2017) said Pollution is the adverse effect humanity has to suffer due to the technological advancement. Being engineer’s objective is to design the machine elements based on sustainable, eco-friendly concepts. Due to wear in brake pad, abrasive particles come to environment. So, the material selection of brake pad is an important criterion. In a braking system brake pad comes in contact with the disc and due to heavy friction, the kinetic energy of the vehicle reduces and it comes to rest. Generally, in this process a lot of wear occurs in brake pad and the abrasive particles comes out of the brake pad. In the brake pad composites asbestos has been used as reinforcement for a very long period of time. In the few years before it was found that asbestos particles having carcinogenic effect on the skin. So, a lot of research is going on for finding a suitable replacement for asbestos.

Olele et al., (2016) carried out in the area of development of asbestos free brake pads. The use of bagasse, palm kernel shell, coconut shell, banana peels, periwinkle shell, and palm oil clinker have been investigated. Friction materials and especially brake pads are made up of essentially four groups of material which include binders, fillers, reinforcing fibers and friction modifiers. Combined together, these groups of materials provide the developed brake pads with the necessary properties needed for it to perform effectively. Therefore, in the choice of materials for brake pads, the following should be considered; stable friction coefficient and a lower wear rate at various operating speeds, pressures, temperatures and environmental conditions.

Abutu, Lawal, Ndaliman, & Araga, (2018) studied with the aim of finding a possible replacement for asbestos, used coconut shell powder to develop brake pad material. This material was mixed with other ingredients such as catalyst, epoxy resin, cast iron fillings, silica, and accelerator. The coconut shell was dried in the sun for some days in order to get rid of the shell moisture and then reduced into smaller sizes using anvil and hammer and then pounded using mortar and pestle. Finally, a grinding machine was used to ground it into powder and sieved with a mesh size of 710 µm.

In the study, the weights of epoxy resin and the coconut shell powder were varied while the weight of the other ingredients remained unchanged. Mechanical (tensile, hardness, compressive, wear and impact) and corrosion tests were conducted to study the effect of process on the products. The results show that as the percentage of the coconut shell powder increases, the hardness, breaking strength, compressive and impact strength reduces.

Chandgude & Ganiger, (2015) has introduced carbon fibers as reinforcement and graphite powder as friction modifier in the brake pad material; he concluded that the brake pad material can play a vital role in this direction. The study reports the influence of these modifications on the thermal properties like coefficient of thermal expansion (CTE) and thermal conductivity along with the mechanical properties of non-asbestos brake pad composites samples developed in the laboratory. He also concluded that composition also helps in controlling the hardness of the brake pad to desired level. Reinforcement of carbon fibers at the present level does not influence the properties as much as the steel wool.

Aigbodio et al., (2010) developed composite brake pad using bagasse, it was sun dried for about one week after extracting the juice. The dried bagasse was ground into powder using a milling machine and then sieved into different sieve sizes of aperture 710µm, 350µm, 250µm, 150µm and 100µm. A different particle size of bagasse was collected as powder. The samples were produced using a compression moulding machine. With compression moulding, the counter mould was used to close the mould after impregnated. Different composition and sieve grades (i.e. 710µm, 350µm, 250µm, 150µm and100µm) of bagasse and phenolic powder were added together in the ratio 70%bagasse and 30% resin respectively. The combination were properly dry mixed in a mixer, almost achieving a homogenous state and transferred to a mould kept in a hot platen press at temperature of 140^{o}C at 100kN/cm^{2} pressure for 2 minutes. After removing from hot press, the brake pad was cured in an oven at a temperature of 120^{0}C for 8 hours.

Adeyemi et al., (2016) developed automotive brake pads from composite made of intermixed agro waste materials (cocoa beans shells - CBS, maize husks – MH and palm kernel shells – PKS). Prior to 1935, asbestos friction material has been in use, but its usage is now discouraged because it was confirmed carcinogenic. Hence there is need to develop alternative friction materials that are eco-friendly. Fillers particulate size considered is300µm and the binder is epoxy resin.

Test specimens were analyzed to evaluate their physical, mechanical and tribological properties. Properties of the intermixed (CBS+MH+PKS) based specimen pads were compared with those made of single filler materials like CBS based specimen pads and MH based specimen pads. The results obtained compared favourably with that of conventional brake pad and others produced from similar researches. Analysis of specimens showed that abrasion resistance, friction coefficient and water soak decrease, while tensile strength and compressive strength increase as matrix wt% increases in the formulation. But, hardness, density, thermal conductivity and oil soak varied non-uniformly with matrix content. The results showed that intermixed (CBS+MH+PKS) particles of the selected agro-wastes could be effectively used as replacement for asbestos in friction materials.

Ramanathan et al., (2017) investigated that, the usage of lemon peel powder as one of the composites for asbestos free-brake pad has-been studied. The usage of asbestos fibre in brake pad is avoided, as it causes health hazards such as cancer due to its carcinogenic nature. The lemon peels are sun dried at an atmospheric temperature of 32°C for 24 hours and then finely powdered. The percentage of lemon peel powder, aluminum oxide and iron oxide are varied and two samples are made by using hand moulding technique. Epoxy resin is used as the binding material and hardener is mixed with epoxy resin at a ratio of 1:4. The moulding die is made for 30mm diameter and 25mm thickness using mild steel. Both the samples are subjected to hardness test, wear test, water absorption test, oil absorption test and specific gravity test. From the result, it can be seen that the hardness and density of sample 1 is higher than that of sample 2. And the wear loss, oil absorption and water absorption of sample 1 is lower than that of sample 2. The sample 1 with the composition of 40% epoxy resin, 12.5% Al_2O_3, 12.5 % iron oxide, 15% graphite, 10% calcium hydroxide and 10% lemon peel powder has better properties than sample 2. The results clearly show that lemon peel powder can be effectively used as a replacement for asbestos in brake pad manufacture.

Idris et al., (2015) developed new brake pad using banana peels waste to replace asbestos and Phenolic resin (phenol formaldehyde), as a binder was investigated. The resin was varying from 5 to30 wt% with interval of 5 wt%. Morphology, physical, mechanical and wear properties of the brake pad were studied.

The results shown 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 un-carbonized banana peels (BUNCp) and 30 wt% carbonized (BCp) gave the better properties in all. The result of this research indicates that banana peels particles can be effectively used as a replacement for asbestos in brake pad manufacture.

Ademoh & Olabisi, (2015) studied that maize husks as asbestos-free friction material for the production of automotive brake pad. Asbestos friction material that has been used for over 80 years was found to be carcinogenic in nature and has prompted several research efforts for its replacement from brake pads.

Three sets of composite compositions were made using maize husks as filler material to impart friction properties with varied epoxy resin contents as the matrix that bonded the particles in the mix. Brake pad specimens were made out of the composites and subjected to mechanical, physical and tribological analyses to ascertain their possible performance in service using standard test procedures, materials and equipment. The particulate size of the MH filler material was 300µm and epoxy resin was in slurry. The result showed that specimen composite 3 with 30% MH filler content having coefficient of friction, abrasion resistance, water absorption, oil absorption, density, hardness, tensile strength, compressive strength, and thermal conductivity of0.37, 4.470E-6g/m, 0.725%, 0.660%, 0.852g/cm^3, 99.34MPa, 14.407MPa, 6.779MPa and 0.330W/mk respectively was optimum in performance. It was observed that reducing the filler content increased hardness, wear rate, tensile strength, compressive strength and thermal conductivity of the composite brake pad, while density, coefficient of friction water and oil absorption got increased with increased MH filler content. The result when compared with those of conventional brake pad made of asbestos and other friction materials of past researches showed that MH particles are an effective replacement for asbestos in automotive brake pad manufacture.

Aysal, (2016) developed car disc linings reinforced with carbon fiber, the prohibition of the asbestos in the manufacture of vehicle brake linings due to its effects on human health and the environment has led to the production and development of Non-Asbestos Organic (NAO)brake lining. The variety of materials used in Non-asbestos brake linings provided a positive effect in creating new lining compositions. In this study, the effect of car disc linings reinforced with carbon fiber on the friction performance has been examined. The mass ratio was used to determine the rate of materials contents. Test results obtained with using the Friction Assessment and Screening Test (FAST) machine showed that carbon fibers and carbon powder reinforced linings were suitable for use in vehicles.

Ikpambese et al., (2016) investigated asbestos-free automotive brake pads produced from palm kernel fibers with epoxy-resin binder. Resins varied in formulations and properties such as friction coefficient, wear rate, hardness test, porosity, noise level, temperature, specific gravity, stopping time, moisture effects, surface roughness, oil and water absorptions rates, and microstructure examination were investigated. Other basic engineering properties of mechanical overload, thermal deformation, fading behavior, shear, strength, cracking resistance, over-heat recovery, and effect on rotor disc, caliper pressure, pad grip effect and pad dusting effect were also investigated. The results obtained indicated that the wear rate, coefficient of friction, noise level, temperature, and stopping time of the produced brake pads increased as the speed increases. The results also show that porosity, hardness, moisture content, specific gravity, surface roughness, and oil and water absorption rates remained constant with increase in speed. The result indicated that palm kernel fibers can be effectively used as a replacement for asbestos in brake pad production.

Elakhame et al., (2014) studied that Palm Kernel Shell (PKS) is recovered as by-product in palm oil production. Large quantities of PKS are generated annually and only some fractions are used for fuel and other applications such as palliative for un-tarred road and in producing activated carbon. The unused PKS are dumped around the processing mill, constituting environmental and economic liability for the mill. Although, PKS must be ground into fine particles to be suitable for inclusion in brake lining, available information in the literature are on the ungrounded shell particles.

Adi Atmika et al., (2019) investigated hybrid composite reinforced basalt brake pads that have good mechanical and structural properties and are environmentally friendly. Brake lining pads material is made from hybrid composite reinforced basalt, shells, alumina and bound using phenolic resin polymer (PR-51510i). This brake pads material is produced through a sintering process with an emphasis of 2000 kg for 30 minutes at a fixed temperature of 160°C. This hybrid composite is made in as many as five variations, each of which is tested for wear resistance using a pin on disc test based on ASTM G 99-95a standards, while distilled water absorption test was based on ASTM D 570-98. The greatest wear rate is 0.000090 g/cm, which is still lower than wear rate of asbestos brake pad materials, and the highest distilled water absorption of the brake pads specimens obtained was 0.041558 still lower than the distilled water absorption of asbestos brake pads.

Amaren et al., (2013) investigated that periwinkle shell particle size on the wear behavior of asbestos free brake pad. The asbestos free brake pad produced by varying the periwinkle shell particles was from +125 to +710μmwith phenolic resin as the binder. The wear test was performed using pin on disk machine by varying the sliding speed, applied load, temperatures and periwinkle shell particle size. Full factorial design of four factor-two levels and analysis of variance were used in the study of the wear test.

The results shown that wear rate increases with increasing the sliding speed, load, temperatures and periwinkle particle size.

The co-efficient of friction obtained is within the recommended standard for automobile brake pad. The +125μm particles of periwinkles gave the best wear resistance.

Factorial design of the experiment can be successfully employed to describe the wear behavior of the samples and developed linear equation for predicting wear rate within selected experimental conditions. The results of this research indicate that periwinkle shell particles can be effectively used as a replacement for asbestos in brake pad manufacture.

Pradhan & Sivasaravanan, (2018) investigted a curved thin strip of an asbestos composition riveted to a brake shoe to provide it with a renewable surface. The brake liner is the part which results to bring to rest or slow down a moving body. Safe operation of vehicle demands dependable brakes is required to absorb the kinetic energy of the moving parts or the potential energy of the object being lowered by host when the rate of descent is controlled. The energy absorbed by brakes is dissipated in the form of heat.

This heat is dissipated in the surrounding atmosphere to stop the vehicle. Due to the friction between the brake drum and brake lining the brake lining will lose its life soon. In order to increase its life, it must be designed a new brake lining and to use different composite for brake liner.

Based on the above literatures it can be concluded that the conventional brake pad lining materials (asbestos) have its own side effect on human life, where as its production cost also higher when compare with composite material brake pad lining.

Bahrom et al., (2016) studied that the manufacturing of brake pads includes five primaries of materials composition with a different function. In addition, the ratios of these compositions vary widely in the different formulations and applications and will contribute to the improvement of braking performances. The five primaries of materials composition and its application are shown in Table 2.1.

Table 2-1: Materials Composition in Brake Pad Manufacturing[Bahrom et al., 2016]

Abrasive	Fillers	Lubricants	Reinforcing Fibers	Binders
• Improve stopping Performance • Modify friction wear	• Improve the manufacturing process • Reduce cost	• Counter the wear abrasives • Modify friction coefficient	• Improve mechanical strength	• Hold the various components together

Since there are many different types of brake pads sold in the market, the users now need to wisely choose the appropriate brake pads to be used in their vehicle not only limited to the pricing aspect but also to have the longer durability or life cycle as well as its effectiveness in improving the braking system of the vehicle. Non-asbestos friction materials use a blend of different fibers such as aramid, Kevlar, ceramic and glass as replacement for asbestos. These types of brake pads were usually softer and did not create much noise, but tend to wear faster and create a lot of dust. The road condition in city routes was the main factor for the wear rates of non-asbestos organic materials increased. The reason for this condition to be happened was due to the brake system application during traffic light, speed bump, pedestrians, junctions and the speed of other vehicles. Higher thickness loss means shorter brake pad life and thus, incurred more material and maintenance cost. This phenomenon is due to (i) the decomposition of organic materials, (ii) micro-structural changes, and (iii) transition of wear mechanism. The degradation of the organic components in the brake pad composition increased with surface temperature and this resulted in the reduction of composition bonding and structure integrity .This process may have increased the rate of surface failure, thus increasing wear rate exponentially.

Chandgude & Ganiger, (2015) said that in general, the main substances in friction materials consist of fibers, fillers and binder. The binder consists of various types of resins such as phenolic, epoxy, silicone and rubber. The resin serves to bind the various constituent substances in the friction material. Binder can form a matrix at relatively stable temperature.

(a) Fibers: these are used to provide mechanical strength. Steel wool, also known as wire wool or wire sponge, is a bundle of strands of very fine soft steel filaments. It is used as an abrasive in finishing and repair work for polishing wood or metal objects, cleaning household cookware, cleaning windows, and sanding in light painting. Steel wool is made from low-carbon steel. Steel wool is a metallic material which has an excellent structural reinforcement property and high thermal stability which are indeed required to improve the performance of the brake pad.

(b) Binders: it holds components of a brake pad together. Thermosetting phenolic resins are commonly used, often with the addition of rubber for improved damping properties. Phenolic resin is invariably used as binder in friction materials due to good combination of mechanical properties such as high hardness, compressive strength, moderate thermal resistance, creep resistance and very good wetting capability with most of the ingredient. The high hardness of the phenolic resin is attributed to the increase in the hardness during curing process.

(c) Frictional Modifiers: it determines the frictional properties of the brake pads and comprise a mixture of abrasives and lubricants. The literature shows that graphite powder when used as friction modifier helps in improving the thermal conductivity of the composite brake pad material. Zirconium silicate is also widely used material as friction modifiers in brake pads.

(d) Fillers: these are used to reduce the cost and improve the manufacturability of brake pads. Different minerals such as mica and vermiculite are often employed. Barium sulphate is another commonly used for filler.

Lafia-Araga, et al., (2018) studied theoretical densities obtained from rule of mixture theorem shows that seashell -reinforced composite has a theoretical density of 1.159 g/cm^3 respectively. This predicted value is in good agreement with recommended values of commercial brake pad whose densities fall between 1.01 and 2.06 g/cm^3

Darius et al., (2005) investigated and compared the physical and chemical characteristics of four commercial automotive brake shoe lining materials used in heavy vehicles. The swell resistance of the locally produced friction material compares favorably with that of the imported materials, but its bulk density was the lowest and its water absorption the highest. Complex mechano-chemical processes occurring on the friction interface of a composite friction material make it difficult to understand the correlation between the formulation of brake lining and the frictional performance. Analysis of their experimental results shows that the brake lining material containing potassium titanate significantly improved the stability of the friction coefficient, fade and wear resistance. The coefficients of friction of metals are related to the theoretical tensile, theoretical shear and actual shear strengths of metals. The higher strength of the metal relates to the lower the coefficient of friction.

Bashir, (2015) studied that the formulation of a brake pad material requires the optimization of multiple performance criteria. The brake pad material should achieve a stable and adequate coefficient of friction (μ) and should produce low fade and low wear. Resin is one of the most important ingredients of brake pad material because it binds all the other ingredients firmly and allows them to contribute effectively to the desired performance. However, when excessive frictional heat is generated during adverse braking, performance of the brake pad material deteriorates. This drop in performance may be related to the degradation of resin which is associated with loss of its binding ability. Therefore, the brake pad material's thermal stability, its ability to retain mechanical properties, and its ability to bind its ingredients together under adverse braking conditions all depend on the resin.

Ibhadode & Dagwa, (2008) studied that the comparisons for disk temperature rise and stopping time shows that the laboratory brake pad has about the same performance as the commercial pad. The average disk temperature rises and average stopping time for the laboratory pad are 11.6^0C and 4.1srespectively, while the corresponding values are 13.1 ^{0}C and 4.2s for the commercial pad.

Yang et al., (2012) said that composite materials provide design engineers with superior quality and long-life span. Higher strength, lower weight and less maintenance have led to many engineering applications, in particular in the transport sector for significantly reduced energy consumption and impact to the environment (CO_2). Generally speaking, three types of composite materials are developed and widely used in numerous kinds of engineering applications: polymer–matrix composites (PMC), metal–matrix composites (MMC), and ceramic–matrix composites (CMC). According to the reinforcement types, composite materials can be classified into particulate composites, fiber-reinforced composites, and structural composites.

On Natural Fiber and Natural Fiber Reinforced Composites

Das Geetanjali, (2016) said that fibers in polymer composites can be either synthetic/man-made fibers or natural fibers. Some commonly used synthetic fibers for composites are glass, aramid and carbon etc. If the fibers are derived from natural resources like plants or some other living species, they are called natural fibers. It is also known that natural fibers are non-uniform with irregular cross sections, which make their structures quite unique and much different from man-made fibers. Advantages of natural fibers over synthetic fibers include low density, high availability, low cost, recyclability and biodegradability. The natural fiber-based composites are classified into different categories according to their source of origin such as vegetable or plant fibers, animal or protein fibers and mineral fibers. Figure 2.2 shows the classification of the natural fibers.

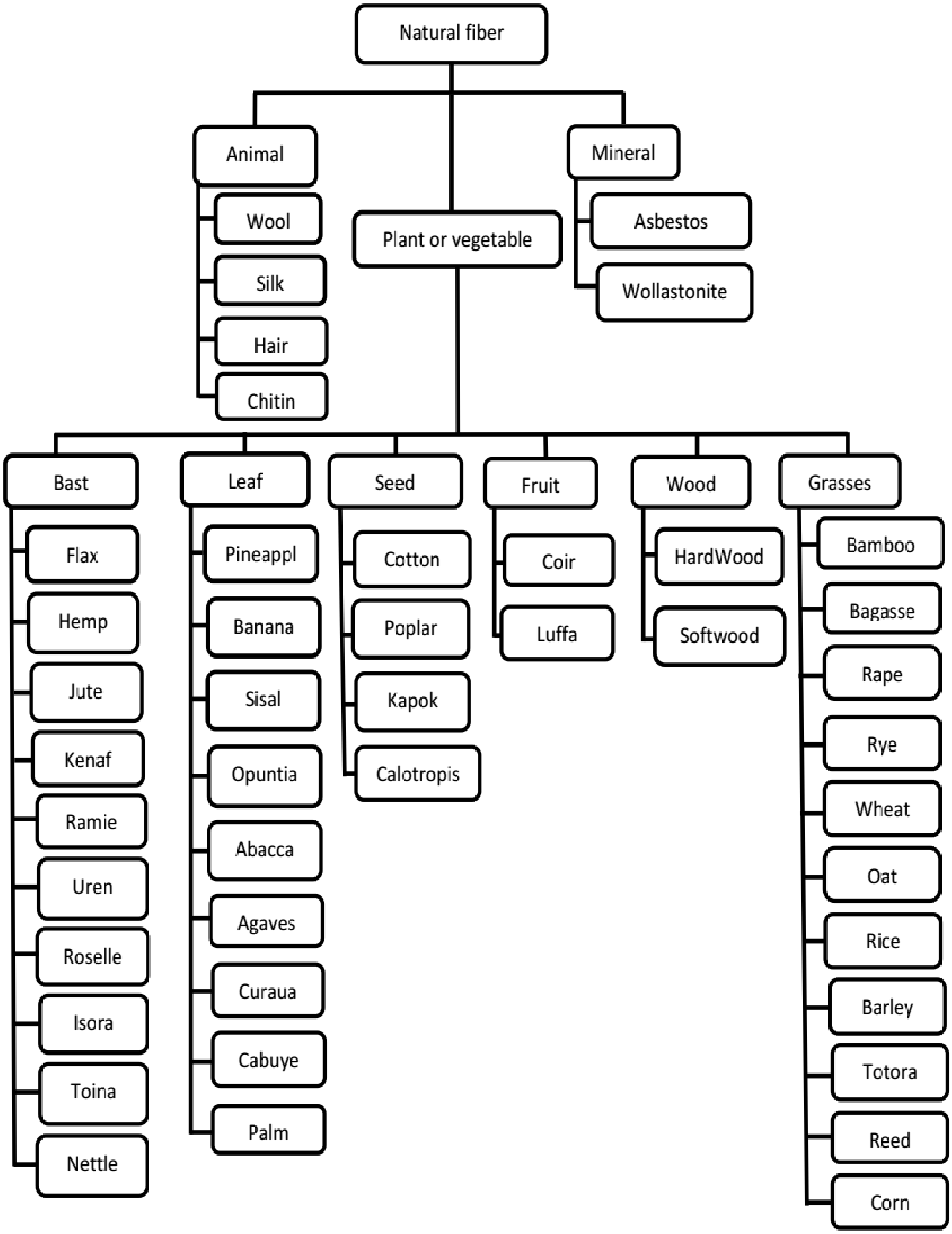


Figure 2.1: Classification of natural fibers [Das Geetanjali, 2016]

Properties of Natural Fiber Composites

Bongarde & Shinde, (2014) physical and mechanical properties of composites depend on the single fiber chemical composition (Cellulose, hemicelluloses, lignin, pectin, waxes, water content and other minors) according to grooving (soil features, climate, aging conditions) and extraction/ processing methods conditions. Grooving conditions is recognized as the most influent parameter for the variability of mechanical properties of the fibers. The chemical composition of several natural fibers is summarized in Table 2.2.

Table 2-2: Chemical composition of natural fibers [Bongarde & Shinde, (2014)]

Fiber	Cellulose %	Lignin %	Diameter (μm)	Hemi cellulose %	Elongation %
Coir	37	42	100-450	0.15	47
Banana	64	5	50-250	6-19	3.7
Sisal	70	12	50-200	10-14	5.1
Pineapple	85	12	28-80	16-19	2.8
Jute	71	13	15.9-20.7	13-20	3.0

Fundamentals of brake systems

Brakes are by far the most important mechanism on any vehicle because the safety and lives of those riding in the vehicle depend on proper operation of the braking system. It has been estimated that the brakes on the average vehicle are applied 50,000 times a year.

Brakes are an energy-absorbing mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. All braking systems are designed to reduce the speed and stop a moving vehicle and to keep it from moving if the vehicle is stationary.

Service brakes are the main driver-operated brakes of the vehicle. Service brakes are also called base brakes or foundation brakes.

2.2. Brake system parts

Most vehicles built since the late 1920s use a brake on each wheel. To stop a wheel, the driver exerts a force on a brake pedal. The force on the brake pedal pressurizes brake fluid in a master cylinder. This hydraulic force (liquid under pressure) is transferred through steel lines and flexible brake lines to a wheel cylinder or caliper at each wheel. Hydraulic pressure to each wheel cylinder or caliper is used to force friction materials against the brake drum or rotor. The friction between the stationary friction material and the rotating drum or rotor (disc) causes the rotating part to slow and eventually stop. Since the wheels are attached to the drums or rotors, the wheels of the vehicles also stop Halderman, (2012). Figure 2.3 represents the typical vehicle brake system.

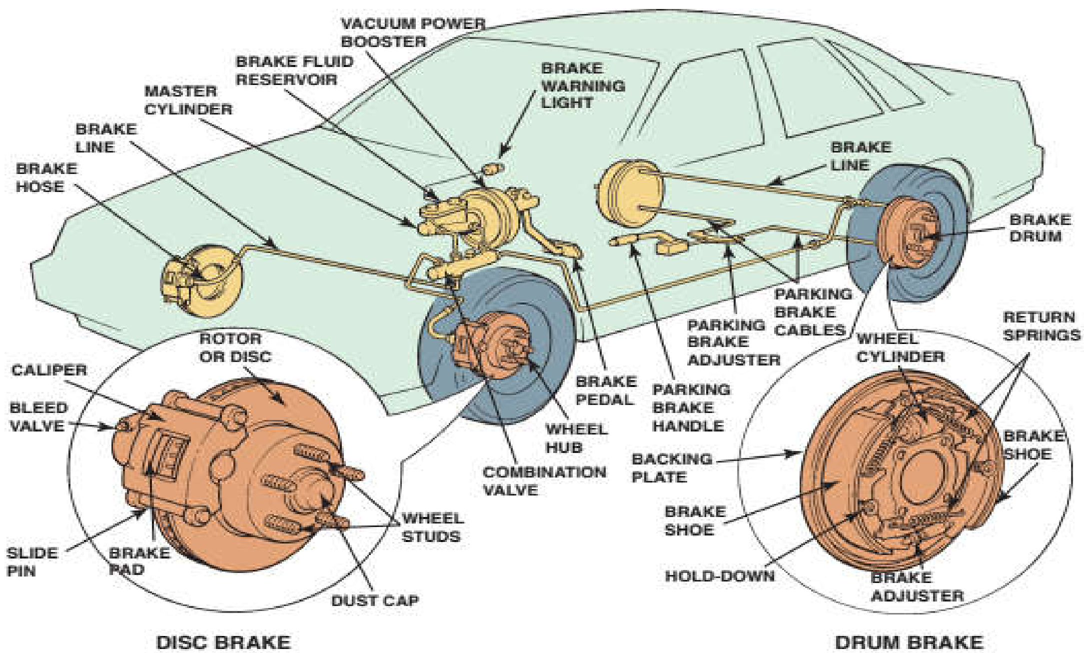


Figure 2.2: Typical vehicle brake system [Halderman, 2012]

Disc brakes: Disc brakes are used on the front of most vehicles built since the early 1970s and on the rear wheels of many vehicles. A disc brake operates by squeezing brake pads on both sides of a rotor or disc that is attached to the wheel. Figure 2.3 represents the photographic disc brake assembly.

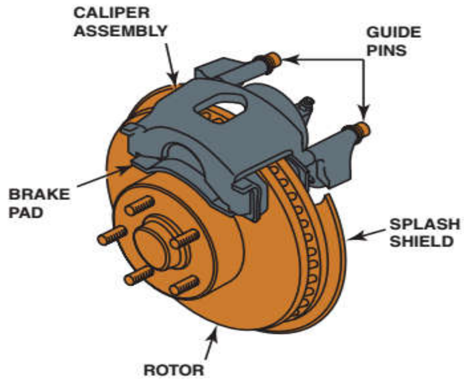


Figure 2.3: Typical disc brake assembly [Halderman, 2012]

Drum brakes: are used on the rear of many rear wheel-drive, front-wheel-drive, and four-wheel-drive vehicles. When drum brakes are applied, brake shoes are moved outward against a rotating brake drum. The wheel studs for the wheels are attached to the drum. When the drum slows and stops the wheels also slow and stop. The schematic representation drums brake assembly shown in Figure 2.4.

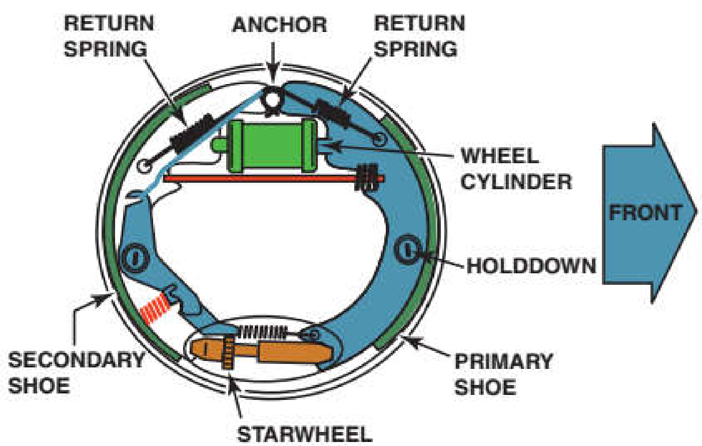


Figure 2.4: Typical drum brake assembly[Halderman, 2012]

The friction film, an intermediate product in braking, is greatly beneficial to protect friction materials from being seriously abraded. The braking conditions have complicated influences on friction and wear behaviors of brake. The friction coefficient tends to be fairly low while the wear rate increases rapidly under a condition with high temperature, braking pressure, or initial braking speed (Xiao et al., 2016). Due to the friction between the road surface and the tires, the vehicle stops. To summarize, the sequence of events necessary to stop a vehicle include the following:

i. The driver presses on the brake pedal.
ii. The brake pedal force is transferred hydraulically to a wheel cylinder or caliper at each wheel.
iii. Hydraulic pressure inside the wheel cylinder or caliper presses friction materials (brake shoes or pads) against rotating brake drums or rotors.
iv. The friction slows and stops the drum or rotor. Since the drum or rotor is bolted to the wheel of the vehicle, the wheel also stops.
v. When the wheels of the vehicle slow and stop, the tires must have friction (traction) with the road surface to stop the vehicle.

2.3. Brake design requirements

All braking forces must provide for the following:

- Equal forces must be applied to both the left and right sides of the vehicle to assure straight stops.
- Hydraulic systems must be properly designed and serviced to provide for changes as vehicle weight shifts forward during braking. Hydraulic valves must be used in the hydraulic system to permit the maximum possible braking forces but still prevent undesirable wheel lockup. Antilock braking systems (ABS) are specifically designed to prevent wheel lockup under all driving conditions, including wet or icy road conditions.
- The hydraulic system must use a fluid that will not evaporate or freeze. The fluid has to withstand extreme temperatures without boiling and must not damage rubber or metal parts of the braking system.
- The friction material (brake shoes or brake pads) must be designed to provide adequate friction between the stationary shoes or pads and the rotating drum or rotor. The friction material should be environmentally safe. Non-asbestos lining is generally considered to be safe for the environment and the technician.

- The design of the braking system should secure the brake lining solidly to prevent the movement of the friction material during braking. It is this movement of the friction material that causes brake noise (squeal).
- Most braking systems incorporate a power assist unit that reduces the driver's effort but does not reduce stopping distance. The most commonly used brake booster is vacuum operated (Halderman, 2012).

Disc brake pad: This is the friction material that is pushed against the rotating disc brake rotor. Maintenance items include the inspection of the disc brake pad thickness.

Anti-squeal shim: Prevents unusual noise as the brake pad vibrates at the time of braking.

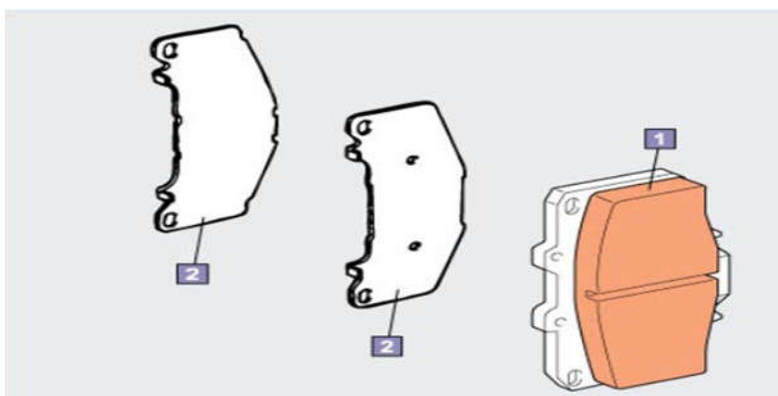


Figure 2.5: Brake pad (1) and Anti-squeal shim (2) [Halderman, 2012]

The brake pad developed uses the materials seashell, epoxy resin (binder), graphite (friction modifier) and aluminum oxide (abrasive) is analyzed. Composite component mixture was used for the formulation and a weight percent of 52% reinforcement, 35% binder, 8% abrasive and 5% friction modifier were used for production. Grey relational analysis was conducted in order to scale the multi-response performance to a single response. The results indicate that optimum performance can be achieved with 14 MPa molding pressure, 160^0C molding temperature, 12 minute curing time and 1h heat treatment time. Analysis of variance shows that curing time has the least significant effect on the mechanical properties, while curing time of 24.26% and 55.23% has the most significant effect on coefficient of friction and wear rate respectively on the brake pad developed(Abutu, et al., 2018).

The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in the surrounding atmosphere to stop the vehicle. Due to the friction between the brake drum and brake lining the brake lining will lose its life soon. In order to increase its life, we are going to design a new brake lining and to use different composite for brake liner. In this work the new brake lining is designed from a new composite material with 4 mm thickness. That composite material Al_60_{61} reinforced with Al_2O_3 and ZrO_2. This material of brake lining will give more strength and long life. While brake it will generate very less stress and deformation due different load and temperature. This research project shows the best mechanical properties of combination of Al_60_{61}, Al_2O_3 and ZrO_2 materials (Pradhan & Sivasaravanan, 2018).

The experimental results for longitudinal effective thermal conductivity were verified using rule of mixtures. According to the rule of mixtures (ROM), the overall thermal conductivity of a composite can be given by the following equation.

$$K_1 = k_f v_f + k_m v_m$$

Where $K_1$is the overall longitudinal thermal conductivity of the composite, K_f, $K_m$are the individual thermal conductivities of the fiber and matrix respectively and V_f, V_m are the fiber volume fraction and matrix volume fraction of the composite (Mutnuri & Virginia, 2006).

Summary of the review

Based on the above literatures it shows that different types of composite materials can be used to replace asbestos materials for brake pad lining production due to asbestos particles having carcinogenic effect on the skin these leads to cancer dieses. Due to this problem it must be enhanced or developed as well as replaced by another material to reduce or eliminate these problems. So the purpose of this project is replaced the asbestos material by banana peels and carbon powder to eradicate the highly healthy risk cancer dieses.

Research gap

There is no that much studies on banana peel which used for brake pad lining application. But the only one researcher tries to study the brake pad by using the banana peels and the epoxy risen varying only the amount of risen. Therefore this research is study and develops the brake pad by varying the banana peels and carbon powder as well as the risen.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes the methodology used to effectively achieve the specific objectives of the study by utilizing different materials and methods.

3.1. Materials

The materials and equipment required to carry out this work are listed in Table 3.1 and Table 3.2.

Table 3-1: Materials

No.	Item	Unit	Quantity
1	Banana peel powder	kg	1
2	Epoxy+hardner	Ltrs	4
3	Carbon powder	kg	1
4	Polyvinyl alcohol	Ltrs	0.25
5	Wax	pack	1

Table 3-2: Equipment

No.	Item	Unit	Quantity
1	Brake pad mould	Pc	1
2	Heater	Pc	1
3	Hydraulic press	Pc	1
4	Digital weighing balance	Pc	1
5	Glove	Pc	8
6	Test machine(WP 310 Universal Material Tester 50kN)	Pc	1
7	Sieve	Pc	1

3.2. Methods

The procedure followed in this work includes the following stages

- **Primary survey:** gather and collect data from the literature review in the previous works and collect and prepare materials for produced the spacemen like banana peel, carbon powder, and wax.
- **Secondary survey**: fabricate the brake pad lining sample with different spacemen for Toyota land cruiser HZJ78L-RJMRS vehicle modeling and finally experimental test is done.

Procedures for fabrication of the composite

- Preparation of the Banana powder
- Preparation of mould
- Post curing of the mould
- Removing specimen from mould & cleaning
- Cutting the laminate into standard size specimen for test.

3.2.1. Banana powder Composite Preparation

The banana peels were collected and dried by exposing to direct sunlight. As shown in Figure 3.1 due to the direct sun ray, its physical structure and color changes and becomes blue black color.

Figure 3.1: Banana peels.

The methodology to be followed is shown in Figure 3.2 in the form of flow chart.

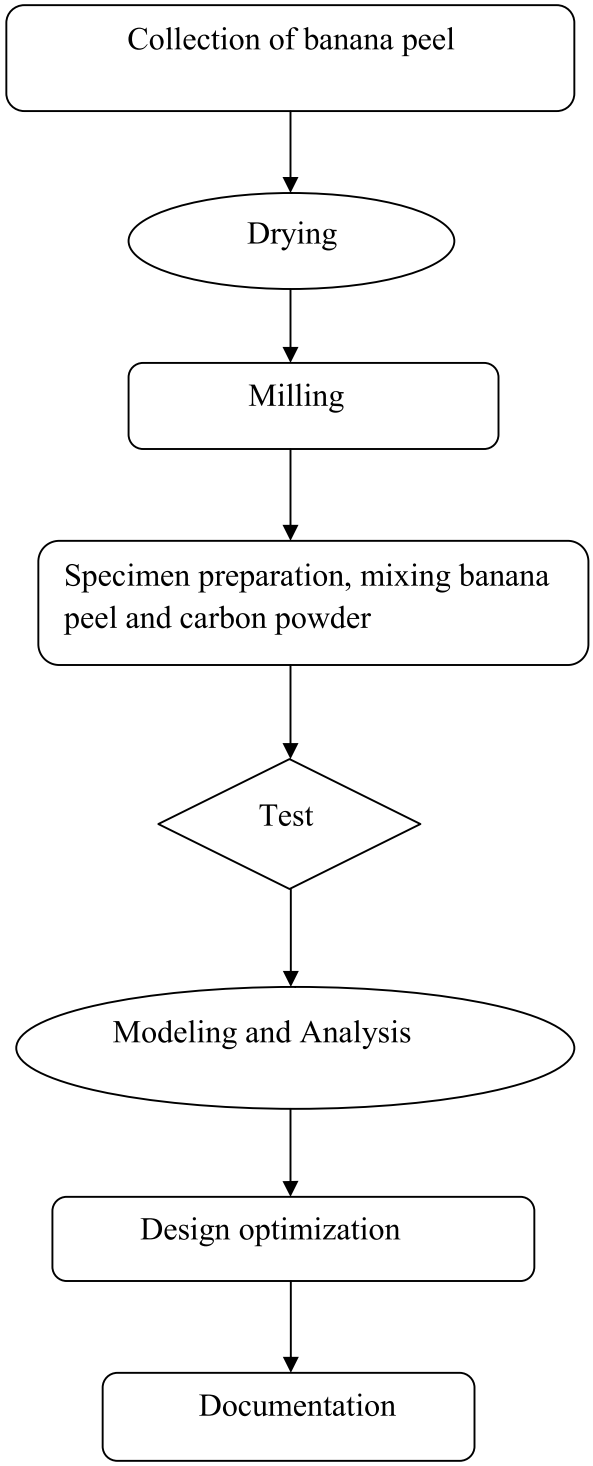


Figure 3.2: Methodology

While Figure 3.3 shows the ball mill banana peel powder were tried to form a fine one to mix with carbon powder easily otherwise it is difficult to form a homogeneous mixture.

Figure 3.3:Banana peels powder

3.2.2. Carbon powder Composite Preparation

The black carbon is a form of carbon processed to have small, low-volume pores that increase the surface area available for adsorption or chemical reactions and used in methane and hydrogen storage, air purification, and solvent recovery (as shown in figure 3.4), and the properties are shown in Table A1,in appendix.

Figure 3.4:Carbon powder

3.2.3. Sample Composition

The resin was varying from 5 to 30 wt% with interval of 5 wt% (Idris et al., 2015) .Based on the above research, these work was performed on the base of varying carbon powder and other components in order to investigate the effect of carbon powder in the entire composite properties. Three samples were produced by varying the banana and carbon powder from 30–40 wt% banana powder and from 25-35 wt% carbon powder particles (as shown in table 3.3).

Table 3-3:Composite's composition

	Composition	wt% (gm)
First ratio	Carbon powder	35
	Banana Powder	30
	Epoxy	22.75
	Hardener	12.25
	Bronze Powder	2
Second ratio	Carbon powder	30
	Banana Powder	35
	Epoxy	22.75
	Hardener	12.25
	Bronze Powder	2
Third ratio	Carbon powder	25
	Banana Powder	40
	Epoxy	24
	Hardener	14
	Bronze Powder	2

Measuring of carbon black powder and banana peel powder is to form the proper mixture as per the above proportion with digital weight measurement device (as shown in fig 3.5).

Figure 3.5:Measuring weight of carbon and banana peel powder

3. 2.4 Preparation of mould

First, the inner surfaces of the mould (the same size as the specimen) are coated with a thin layer of the release agent. The epoxy resin is mixed with 1wt percentage methyl ethyl ketone peroxide catalyst as hardener. The steps involved in preparation of the composite are discussed as followed.

3.2.4.1 Working Station preparation: An initial preparation of all the materials and tools that are going to be used is a fundamental standard procedure when working with composites. Prepared all materials and supplies available and set up before proceeding.

3.2.4.2 Cleaning and applying a release agent**:** Preparation consists of cleaning the mold and applying a release agent on the surface of it to avoid the resin to stick. The following are the steps.

- Clean the mold with a clean cloth.
- Apply release agent on the surface of the mold.
- Wait certain period of time to set up the release agent.
- Buff with clean cloth.

3.2.5 Mold Release Agents

Mold release is essential for preventing the polyester from sticking to the mold when the composite is apart. Even though, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this thesis work is paste wax (oil), and polyethylene plastic for better surface finish of the composite.

3.2.5.1 PVA (Polyvinyl Alcohol): To start directly into the process, coat the surface of the mold by PVA softly and uniformly. The purpose of this fluid was to facilitate the release process.

3.2.5.2 Apply Wax: Wax was first used as a release agent in the composites industry in the 1950's. Carnauba wax-based products are the most suitable for use with composite materials and these are widely employed, particularly in contact molding applications. Silicone modified products can be used but care has to be exercised as silicone can interfere with the release interface making separation difficult. Any silicone-based release agents should be thoroughly tested before use.

Wax release agents Figure 3.6 are available in several forms but those most commonly used are pastes or liquids. Among the advantages of wax release agents are their ease of use, convenience and economy. Waxes are used mostly in low volume contact molding applications, as the need for regular re-application can be time consuming.

Figure 3.6:Wax -release agent

3.2.6 Epoxy resin matrix preparation

Polyester resin preparation; the first step is to mix the resin and the hardener. The proportions are usually given by the supplier and can be found on the containers of the hardener or resin. But most researchers applied the ratio of resin and hardener 10:1 / 11:1 respectively.

Finally, as shown in Figure 3.7 epoxy resin and hardener are weighed for suitable mixing ratio and then manually mixed for 15 minutes to have good homogeneity between epoxy resin and hardener.

Figure 3.7:Mixing of Epoxy with hardener

3.2.7. Composite preparation and testing

Banana peel can be dried for about two weeks until it loses all water content, then mill the banana peel to form banana powder and mix with carbon powder. The test specimen was prepared by adding the epoxy resin to the banana peels particles. The formulation was properly mixed in a mixer, to achieve a homogenous mixture**.** After mixing, the mixture was compacted in a mould to get the required shape. A compressive force of 30-40kNwas applied through a punch, by a hydraulic press, for a period of 24hrs. The specimen was cured by heating in an electric oven at a temperature of 100°C for 1 hour shown in Figure 3.8.The specimen was tested for hardness, wear resistance, water and oil absorption.

Figure 3.8:Heat treatmenting oven

3.2.8. Software Modeling and Analysis

Using properties from the standard test and real brake pad; asbestos free brake pad is modeled by using Space claim, analyzed and optimized by using Ansys software.

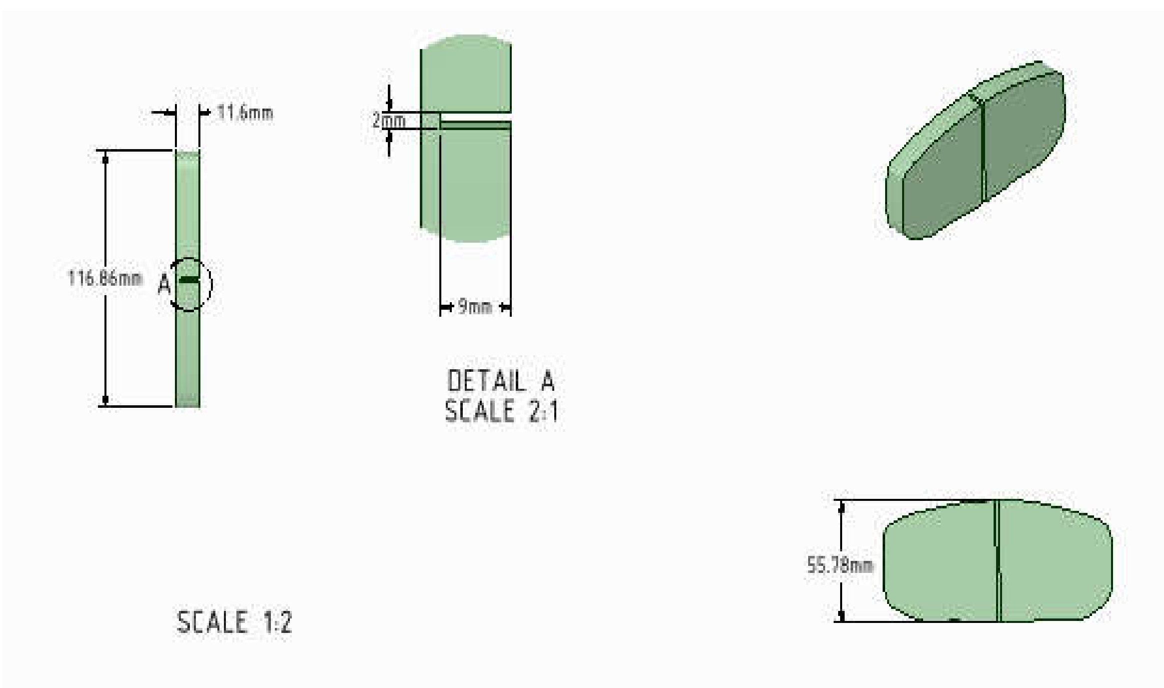


Figure 3.9:Ansys model of Brake Pad

Water and oil absorbiblity of the developed composite material is also prepared and implimented to have a best suited material for brake lining system.

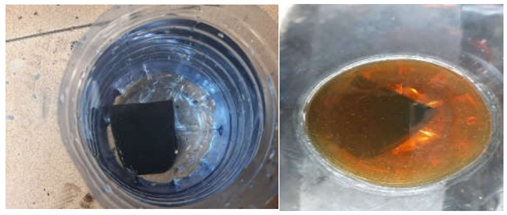


Figure 3.10:Water and oil absorbability Setup

Wear test is carried out to predict the wear performance and to investigate the wear mechanism. From a material point of view, the test is performed to evaluate the wear property of a material. By considering the application area of brake, performing wear test is the critical thing and it is performed using the setup shown in Figure 3.11.

Figure 3.11:Wear test setup

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Brake pad lining preparation

The commercial brake pad is manufactured from asbestos which has its own health impact. So, in this work, it is tried to replace conventional material with biocompatible composite. There are a number of reasons which lead researchers to prepare innovative new material to reduce the negative health impact. Out of those asbestoses' health impact takes the degree to be replaced with less harmless material.

Organic friction material was most widely used due to its simple preparation method, excellent tribological properties, and eco-friendliness. Generally, organic friction material consists of a binder, reinforced fibers, friction additives, and fillers.

Binder: The binder sticks all components together to form a thermo stable matrix. The phenolic resin is often selected as a binder because it possesses excellent heat resistance.

Reinforced fibers: The reinforced fibers are used to improve friction performance and strength. The metal fibers (iron, copper, etc.), glass fibers, carbon fibers, and organic fibers (kevlar, cotton, etc.) are commonly used as reinforced fibers.

Friction additives: The friction additives can adjust friction properties and control wear behaviors of brake's friction materials. Generally, the additives can be classified into two types: lubricant and abrasive. The lubricant is always used to reduce the wear of friction material. For example, as an excellent lubricant, graphite can decrease the wear rate effectively by reducing the direct contact between the surface of the friction material and brake disk. However, the abrasive (e.g. metal sulfide) is generally used to increase the friction coefficient and strengthen the wear resistance of friction material.

Fillers: The fillers are used to improve the process-ability and reduce the cost of friction material. Generally, the vermiculite, mica, and barium sulfate are often used as fillers

As it is tried to develop a biocompatible brake pad by using carbon powder, banana peel powder, and bronze powder as the main structure while epoxy and hardener were used as a matrix to bind those components. Initially, to specify the percentage composition of the specimen, written literature was used as a benchmark. So, in this work, only three compositions were analyzed by varying substrates percentage.

To determine the properties of the developed materials different tests like tensile strength, compressive strength, bending strength, wear, water, and oil absorbability were performed. Based on those properties additional on work analysis was performed using Ansys.

Actually, for the case of brake pad, tensile, bending and other properties are not that critical but the main materials property is wearing resistance and it is the main concern of this work.

a) Sample one b) Sample two c) Sample three

Figure 4.1: Prepared test samples

The first sample was developed with a composition of 35% Carbon powder, 30% Banana peel, 22.75% Epoxy, 12.25% Hardener, and 2% Bronze powder. For those samples, at least three tests were conducted to have best-suited properties by taking an average of each test result.

The second sample was prepared with a component materials proportion of carbon powder 30%, banana peel 35%, Epoxy 22.75%, hardener 12.25%, and bronze powder 2%.

The third sample was developed based on the following component composition: carbon powder 25%, banana peel 40%, epoxy 24%, hardener 14%, and bronze powder of 2%.

The proportion of epoxy is depending on the amount of banana peel powder, as the banana peel powder is increased the more amount of binding material is required.

Table 4-1: Composition of the composite

Sample	Carbon Powder	Banana Peel powder	Epoxy	Hardener	Bronze Powder
Sample 1	35	30	22.75	12.25	2
Sample 2	30	35	22.75	12.25	2
Sample 3	25	40	24	14	2

4.2. Tests and Its Setup

To determine the mechanical properties of the developed material, different tests were performed using WP 310 Universal Material Tester 50kN. Out of that its tensile strength, compressive strength, bending strength, wear rate, water, and oil absorbability were checked for those three compositions.

Except for the wear and absorbability test all others were performed in defense engineering university college and the rest were in MOENCO workshop. The Figure 4.2 given below shows the testing of the prepared samples.

Figure 4.2: Prepared test samples were under test

Tensile Strength Test

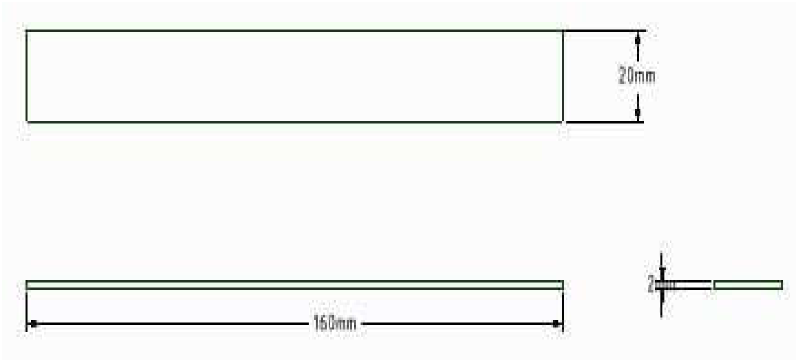


Figure 4.3: Tensile test specimen

The tensile test was performed considering a standard test specimen dimension approved by ASTM-D790 Shown in Figure 4.4. Those tests give tensile strength, stress versus elongation, applied force versus elongation, and other mechanical properties of a composite material. Basically, in this work, the wear property determines whether it is best suited for the intended application or not and for compression other properties were represented graphically.

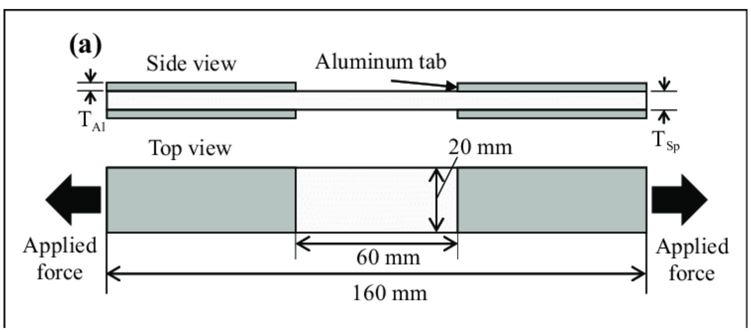
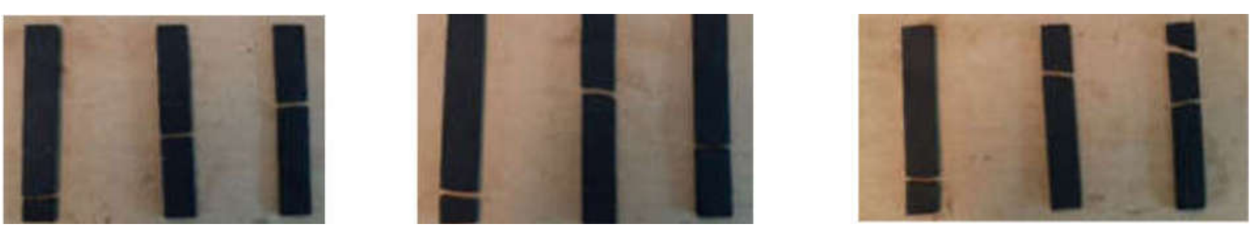


Figure 4.4: ASTM tensile test specimen[ASTM-D790]



a) Sample one tensile b) Sample two tensile c) Sample three tensile

Figure 4.5:Tensile Test Specimen

The specimens after tensile test are shown in Figure 4.5. Each test was accomplished by repeating three times (for the same composition) to have a more precise result and the average is taken as the final finding. So, the tensile strength of composite for the first composition (35% Carbon powder, 30% Banana peel, 22.75% Epoxy, 12.25% Hardener, and 2% Bronze powder) is 2.06MPa.

The first specimen's the stress-percentage elongation is shown in Figure 4.6 and its maximum stress is 2.06MPa at 12.95 percentage elongation. Where percentage elongation is the materials ability to stretch up to its breaking point and can be expressed as:

$$\text{Percentage (\%) elongation} = \frac{Elongation\ at\ brake(E)}{Initial\ Guage\ Length\ (l_o)} \text{ x } 100 = \frac{\Delta l}{lo} \text{ x } 100$$

Table 4-2:First composition average tensile stress

No.	S [N/mm²]	E [%]
0	0.00	0
1	0.25	1.55
2	0.41	3.45
3	0.58	4.29
4	1.07	7.12
5	1.24	8.06
6	1.40	9.04
7	1.73	10.99
8	1.90	11.96
9	2.06	12.95
10	1.31	13.93
11	0.90	14.92
12	0.49	15.83
13	0.08	16.09

Similarly, for the second (carbon powder 30%, banana peel 35%, Epoxy 22.75%, hardener 12.25% and bronze powder 2%) and third (carbon powder 25%, banana peel 40%, epoxy 24%, hardener 14%, and bronze powder of 2%.) composition the test gives a tensile strength of 1.76MPa and 1.39MPa respectively is shown in Figure 4.6.

Table 4-3: Second composition average tensile stress

No.	S [N/mm²]	E [%]
0	0.00	0
1	0.05	3.17
2	0.10	5.13
3	0.15	5.99
4	0.20	6.89
5	0.32	7.82
6	0.48	8.77
7	0.64	9.73
8	1.12	12.55
9	1.28	13.48
10	1.44	14.4
11	1.60	15.35
12	1.76	16.28
13	1.63	17.23
14	1.38	19.17
15	0.73	21.88
16	0.24	23.04

The last experimental investigation was performed with the component materials composition of carbon powder 25%, banana peel 40%, epoxy 24%, hardener 14%, and bronze powder of 2% is shown in Figure 4.6. With the maximum carbon powder component in the first sample composite and its amount is reduced to 25% in the third sample and as expected its strength becomes decreased in this test. The maximum tensile stress is 1.39MPa at the percentage elongation of 5.2.

Table 4-4: Third composition average tensile stress

No.	S [N/mm²]	E [%]
0	0.00	0
1	0.49	1.31
2	0.65	2.24
3	0.90	3.18
4	1.14	4.18
5	1.39	5.2
6	1.20	5.5
7	1.00	5.75

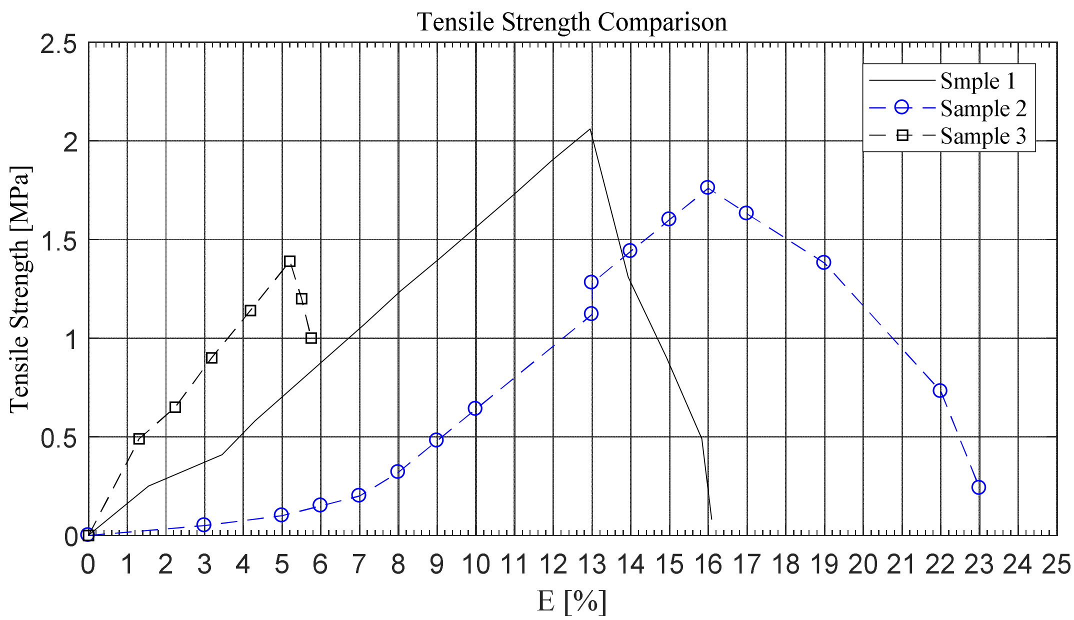


Figure 4.6:Average tensile stress (sample 1, sample 2 and sample 3)

For the graph's roughness, there are many reasons which can be mentioned, like machine efficiency, problems encountered while fixing the specimen, etc.

That is why tried to take an average of three tests per sample to minimize the deviation due to those expected factors.

Bending / Flexural/ Strength

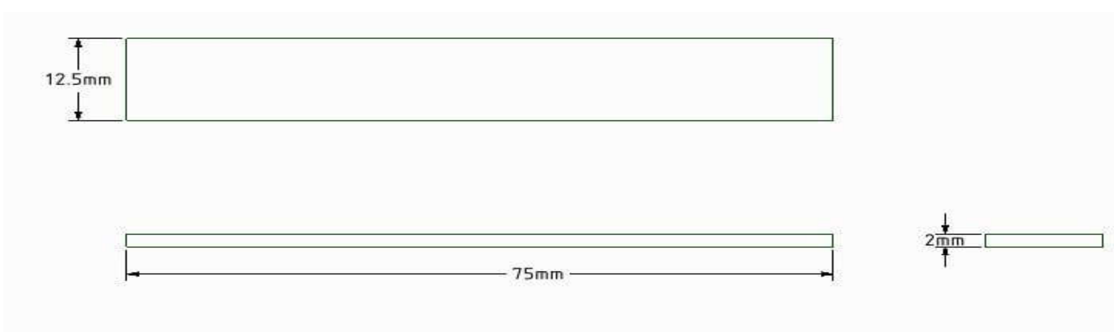


Figure 4.7:Flexural test specimen

The Flexural or Bending strength of the composite was determined by controlling through computer installed application with the corresponding graphical and mathematical representation shown in Figure 4.8.

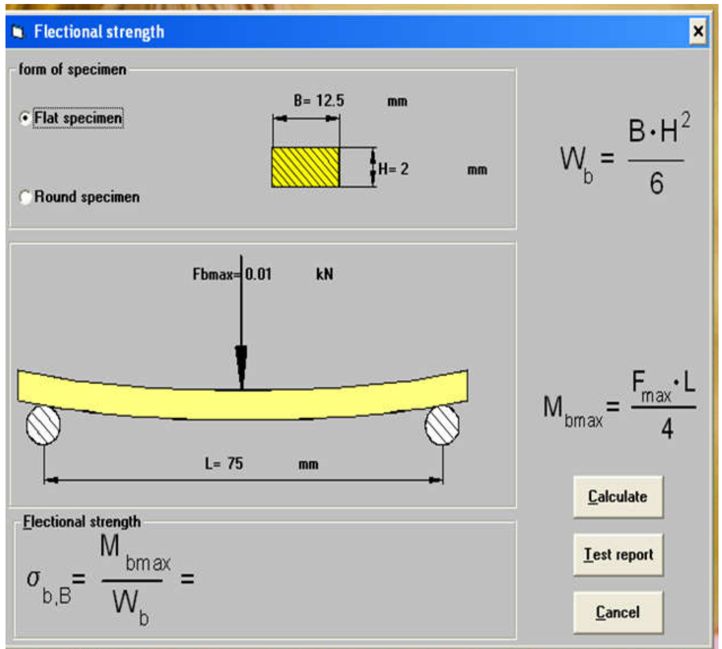
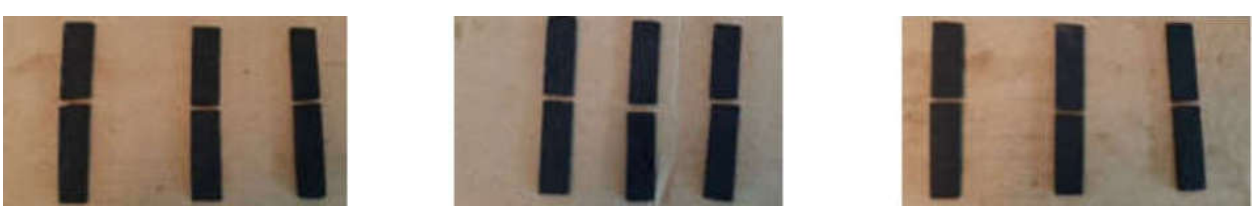


Figure 4.8:Flexural strength test computer setup

Based on the above description on the test equipment, the bending strength of the composite is shown in those three different compositions. So as the composition as described in the above on tensile strength result description, the first composite composition sample have an average bending strength of 30MPa with three independent trials. Similarly, for the second and the third samples as well the bending strengths were 23.5MPa and 23.5MPa respectively (both have the same flexural property).

In materials, mechanical properties test mode of failure gives different information, like that bending test specimen was failed almost in a predetermined manner, at the center of the specimen or equal distance from upper and lower jaws.



a) Sample one bending   b) Sample two bending   c) Sample three bending

Figure 4.9:Specimen samples after bending test

Compressive Strength

The other parameter or mechanical property that was used to characterize the brake pad composite material is its Compressive strength. Like others, this was also evaluated by taking the average of three tests for each sample for more accuracy of the study. Figure 4.10 below shows the stress-strain failure proportion for the first sample composite which is 35% Carbon powder, 30% Banana peel, 22.75% Epoxy, 12.25% Hardener, and 2% Bronze powder.

Table 4-5:First composition average compressive strength

No.	Compressive Stress (MPa)	E (%)
0	0.00	0.00
1	0.19	0.28
2	0.46	1.15
3	0.54	2.13
4	0.72	2.72
5	0.90	3.44
6	1.00	4.17
7	1.26	4.90
8	1.50	5.63
9	1.62	6.36
10	1.29	7.09
11	1.11	7.82
12	0.53	8.55

The first composition of brake composite material can overcome the maximum compressive stress of 1.62MPa at a percentage deformation of 6.36. This material can withstand for compressive strength of 1.62MPa, doesn’t mean that the brake pad is loaded with this much of compressive stress. Actually, for the brake pad materials wear resistance is the main pre-determinant property to design and select the best-suited one.

Figure 4.10 shows the average stress vs deformation graph of the brake pad composite material with a composition of carbon powder 30%, banana peel 35%, Epoxy 22.75%, hardener 12.25%, and bronze powder 2%. The test result indicates that the composite material has a compressive strength of 1.5MPa at a percentage deformation of 5.56. As it is expected from the amount of carbon in the composite, its strength is decreased accordingly.

Table 4-6: Second composition average compressive strength

No	Compressive Stress (MPa)	E (%)
1	0.00	0.00
2	0.16	0.47
3	0.33	1.41
4	0.55	2.04
5	0.66	2.74
6	0.82	3.45
7	0.99	4.15
8	1.30	4.86
9	1.50	5.56
10	1.48	6.27
11	0.24	6.97

The compression test results on sample 3 is expressed on the graph below 4.10. Its maximum stress is 0.443 MPa at a percentage deformation of 2.843 which is determined by taking the average of three test samples.

Out of those test result graphs, it is expected that the stress-strain graph

Table 4-7: Third composition average compressive strength

No.	Compressive Stress (MPa)	E [%]
1	0	0
2	0.13	0.4
3	0.24	0.84
4	0.24	1.83
5	0.36	2.25
6	0.443	2.843
7	0.08	3.436

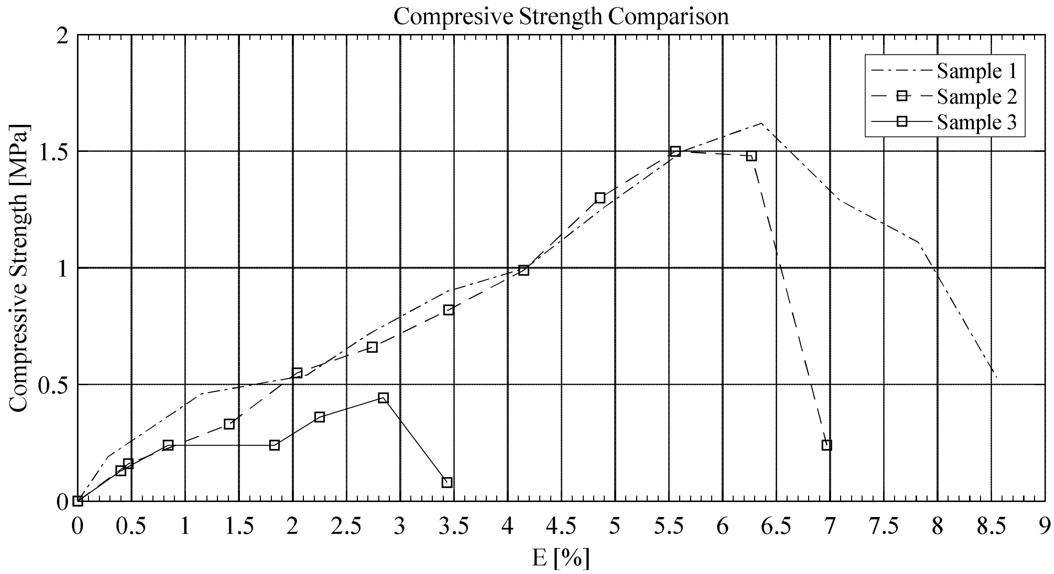


Figure 4.10:Average compressive strength (sample 1, sample 2 and sample 3)

Verification

The tensile test result comparison between sample 1, sample 2 , sample 3 and CBS is expressed and shown below in the stress-strain diagram on the graph 4.11 and the compression test result comparison between sample 1, sample 2 , sample 3 and CBS is expressed and shown below in the stress-strain diagram on the graph 4.12.

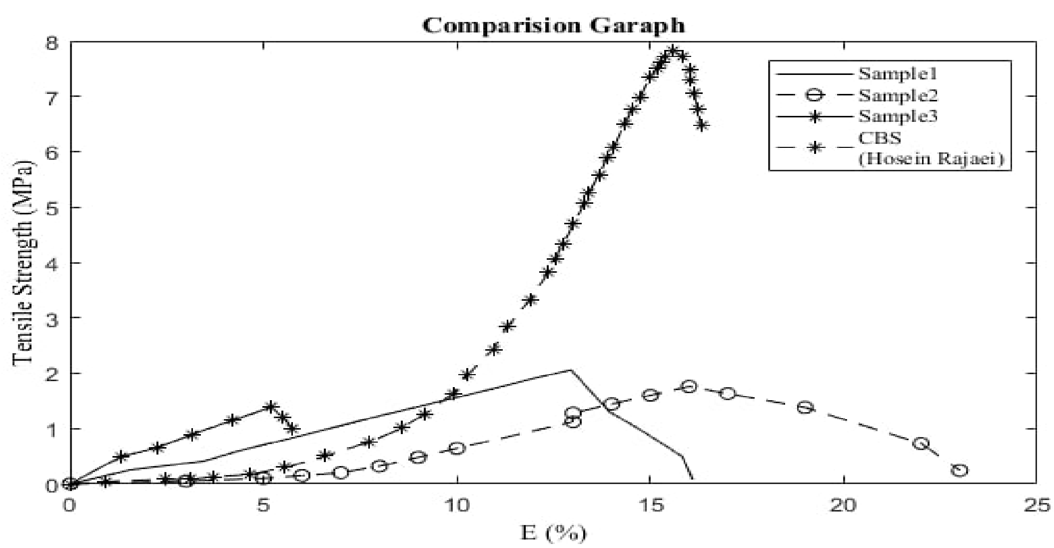


Figure 4.11:Verfication graph 1

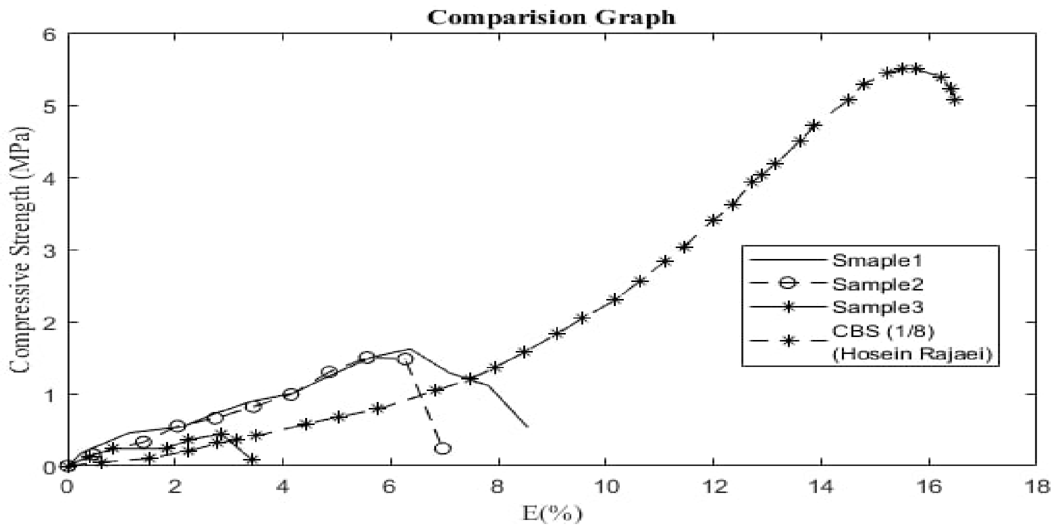


Figure 4.12:Verfication graph 2

The maximum stress of both the tensile and compression strength is smaller when compared to CBS due to machine efficiency (calibration error) or personal error.

4.3. Wear Test

Figure 4.13: Wear testing machine setup

The wear test was carried out using an adopted method with a specimen equal portion of a brake pad (75×12.5×2 mm) made from different the compositions. The method involves placing each sample (clamped rigidly in position) against the disc of grinding machine of a diameter of 210mm for 22 minutes. The force applied with this machine is determined from the applied force and the size of supporting component with a dimension of inner diameter is 14.5mm and outer diameter is 15.5mm hallow tube. From this, the area on which pressure is applied and the force exerted on the pad can be determined using Pascal's principle.

$$Effective\ Area = \pi\frac{(d_o^{\,2} - d_i^{\,2})}{4} = \pi\frac{(15.5^2 - 14.5^2)}{4} = 23.56mm^2$$

The applied pressure reading is taken from the compressor is 0.5bar (0.05N/mm^2) as shown in Figure 4.13 and the force can be calculated from it and two effective tube areas.

So, to express the fixing parameter in terms of force, the total force f_t,

$$\begin{aligned} total\ force\ applied\ (f_t)[N] &= pressure[N/mm^2] \times effective\ area[mm^2] \\ &= 0.05N/mm^2 \times (2 \times 23.56mm^2) \\ &= 2.356N \end{aligned}$$

While the steel wheel is running with a speed of 120 rpm for 22 minute to observe the weight difference by wearing effect of brake pad material.

The samples weights were taken before and after grinding. The weight difference from each sample indicates the loss in weight. Out of all samples, minimum weight loss is obtained for the first composition sample containing 35% Carbon powder, 30% Banana peel, 22.75% Epoxy, 12.25% Hardener, and 2% Bronze powder. For brake pad material, the less weight loss means best suited for the intended purpose. The test result gives that only a 0.1gm weight variation after applying 2.356N force on a disc running with a speed of 120rpm for 22minute. The second and the third compositions also have a weight loss of 0.25gm and 0.31gm respectively.

Therefore, wear rate is given by the following equation:

$Wear\ rate = \frac{\Delta w}{s} = \frac{\Delta w}{2\pi ND \times t}$ (g/m) Where, Δw = weight loss (weight difference before wear and after wear), S = sliding distance, D = diameter of disc, N = rpm and t = time it takes each sample (exposed) on the grinding machine.

$$Wear\ rate_1 = \frac{\Delta w}{2\pi ND \times t} = \frac{0.1gm}{(2\pi \times 120rpm \times 0.2855m \times 22\min)} = 0.000021\, {}^{g}\!/\!{}_{m}$$

$$Wear\ rate_2 = \frac{\Delta w}{2\pi ND \times t} = \frac{0.25gm}{(2\pi \times 120rpm \times 0.2855m \times 22\min)} = 0.000053\, {}^{g}\!/\!{}_{m}$$

$$Wear\ rate_3 = \frac{\Delta w}{2\pi ND \times t} = \frac{0.31gm}{(2\pi \times 120rpm \times 0.2855m \times 22\min)} = 0.000065\, {}^{g}\!/\!{}_{m}$$

Based on composite's mechanical properties like tensile strength, bending strength, compressive strength and rate of wear which is the main determinant in this case to select the best suited composition. First composition is used for further analysis and recommended for mass production. The results obtained through tests were used to calculate other parameters like young's modulus and friction coefficient from ultimate tensile strength (UTS) and the percentage elongation (%E) using the following equations.

$$Young\,Modulus(\gamma) = \frac{Tensile\,Stress\,(\sigma)}{Tensile\,Strain(\varepsilon)}, and\ \varepsilon = \frac{\Delta l}{l_o}$$

So, from the percentage (%) Elongation Equation,

$$Tensile\ Strain(\varepsilon) = \frac{Percentage\,(\%)Elongation}{100}$$

4.4. Water and Oil Absorption Tests

Water and oil absorption tests were conducted as shown in Table 4.8. The initial weight of each specimen was taken and recorded before soaking into water and engine oil separately. The oil used was automotive engine oil of rating 5W-40. The test took 72 hours. At an interval of 24 hours, specimens were brought out of water and oil, thoroughly cleaned to drain water and oil on their surfaces and reweighed to determine the new weights that were recorded and used later to determine the absorption rates, but there is no a significant change on the weight of the samples.

Table 4-8:Water and oil absorbability test result

Sample	For oil absorbability				For water absorbability			
	Initial Weight g/m	After 24 hour g/m	After 48 hour g/m	After 72 hour g/m	Initial Weight g/m	After 24 hour g/m	After 48 hour g/m	After 72 hour g/m
1	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
2	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

Table 4-9: Mechanical Properties

Property / **Composition**	Tensile Strength (MPa)	Bending Strength (MPa)	Compressive Strength (MPa)	Wear rate mg/m
First Composition	2.06	30	1.62	0.021
Second Composition	1.76	23.5	1.5	0.053
Third Composition	1.39	23.5	0.443	0.065

The obtained mechanical properties of all different samples are given in Table 4.9. The tensile strain of the composite having 35% Carbon powder, 30% Banana peel, 22.75% Epoxy, 12.25% Hardener, and 2% Bronze powder have a percentage elongation of 12.95 with a corresponding strength of 2.06MPa.

$$Tensile\,Strain\,(\varepsilon) = \frac{12.95}{100} = 0.1295$$

$$Young's\,Modulus = \frac{2.06MPa}{0.1295} = 15.91MPa$$

4.5. Vehicles Braking Force

The brake pad's braking force numerical value is to be determined to use as an input to software analysis. The brake system multiplies the force applied by the driver and helps in stopping the rotating wheel with minimum effort. The force passes through the pedal lever, master cylinder, wheel cylinder, and finally to the piston which quizzes brake pad against the rotation of the wheel.

So, the force calculation and analysis were carried out based on vehicles specification as shown below in Figure 4.14 and Table 4.10.

Figure 4.14:Vehicle specification

Table 4-10: Master cylinder and Wheel cylinder specification

<table>
<tr><td colspan="3">Type</td><td colspan="2">Ventilated Disc</td></tr>
<tr><td colspan="3">Caliper Type</td><td colspan="2">S12 + 12</td></tr>
<tr><td colspan="3">Wheel Cylinder Diameter</td><td colspan="2">42.85 mm (1.69 in.) x 2</td></tr>
<tr><td colspan="3">Rotor Size (Diameter x Thickness)</td><td colspan="2">322.0 mm x 32.0 mm (12.6 in. x 1.10 in.)</td></tr>
<tr><td colspan="2">Engine Type</td><td colspan="2">Gasoline</td><td>Diesel</td></tr>
<tr><td rowspan="2">Brake Booster</td><td>Type</td><td colspan="2">Tandem Diaphragm</td><td>Single Diaphragm</td></tr>
<tr><td>Size</td><td colspan="2">8.5 + 8.5 in.</td><td>9 in.</td></tr>
<tr><td rowspan="2">Brake Master Cylinder</td><td>Type</td><td colspan="2">Lockheed + Lockheed*1
Portless + Lockheed*2</td><td>←</td></tr>
<tr><td>Diameter</td><td colspan="2">23.81 mm (0.94 in.)</td><td>←</td></tr>
</table>

Table 4-11: Speed specification

Body Type				Double Cab Pick-up	Single Cab Pick-up		Double Cab Pick-up
Vehicle Grade				Standard			
Model Code				HZJ79R-DKMRS	HZJ79L-TJMRS	HZJ79L-TJMRS3	HZJ79L-DKMRS
Max. Speed			km/h (mph)	140 (87)	140 (87)	140 (87)	140 (87)
Max. Permissible Speed	1st Gear	Transfer in low	km/h (mph)	15 (10)	15 (10)	15 (10)	15 (10)
		Transfer in high	km/h (mph)	34 (21)	34 (21)	34 (21)	34 (21)
	2nd Gear	Transfer in low	km/h (mph)	27 (17)	27 (17)	27 (17)	27 (17)
		Transfer in high	km/h (mph)	63 (39)	63 (39)	63 (39)	63 (39)
	3rd Gear	Transfer in low	km/h (mph)	44 (27)	44 (27)	44 (27)	44 (27)
		Transfer in high	km/h (mph)	102 (63)	102 (63)	102 (63)	102 (63)
	4th Gear		km/h (mph)	-	-	-	-
Turning Radius (Outside Front)	Tire		m (ft.)	7.2 (23.6)	7.2 (23.6)	7.2 (23.6)	7.2 (23.6)
	Body		m (ft.)	7.5 (24.6)	7.5 (24.6)	7.5 (24.6)	7.5 (24.6)

The Geometrical correlation between braking system linkages is shown below in Figure 4.15. The size of the master cylinder and wheel cylinder (two-wheel cylinder is used) is represented in the above-listed tables from the vehicle's specification (23.81mm and (42.85x2) mm respectively) which means that the size of the wheel cylinder (it have two wheel cylinders) and the master cylinder can be related as ($z \approx 3.6y$) which means that force is multiplied by three-point six times as transferred from master cylinder to the wheel cylinder piston. The brake pedal lever dimensions are measured directly from the vehicle as to the length from the pivot point to the master cylinder support, x = 115mm, and the total length of the brake lever, w = 460mm.

Based on different studies drivers can apply a force of up to 250N on the brake pedal. As stated early this force can be multiplied through different components and the analysis is stated here like this.

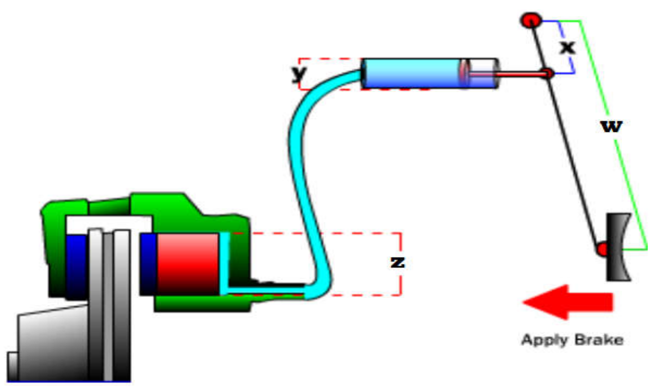


Figure 4.15:linkage of the brake system[Automotive Industry Training,2008]

First, let us determine the force that can be available at the master cylinder connection by using the dimension correlation.

1. **Force on The Master Cylinder:**

$$Fp \times w = \mathrm{Fm} \times x$$

$$\mathrm{F}m = Fp \times \frac{w}{x}$$

$$F_m = 250N \times (\frac{460}{115})$$

$$F_m = 1000N = 1KN$$

Where, F_p the force applied on the brake pedal, F_m is the force developed in the master cylinder and w and x are the distance shown in the Figure 4.15 Still, this force is multiplied through the master cylinder and wheel cylinder arrangement as follows

The master cylinder:

$$Diameter\ of\ the\ master\ cylinder\ \left(d_m\right)\ =\ 23.81mm$$

$$Area\ of\ master\ cylinder(A_m) = \frac{\pi(d_m)^2}{4} = \frac{\pi(23.81mm)^2}{4} = 445.25mm^2$$

The pressure generated by the master cylinder (P_m) can be derived from the force applied and its area

$$P_m = \frac{F_m}{A_m} = \frac{1000N}{445.25mm^2} = 2.249MPa$$

The wheel cylinders:

A single wheel cylinder diameter parameter is shown and its area is determined as follows while the system has a two-wheel cylinder mechanism finally its area was multiplied by two.

$$Diameter\ of\ the\ wheel\ cylinder\ \left(d_{wc}\right)\ =\ 42.85mm$$

$$Area\ of\ wheel\ cylinder(A_{wc}) = \frac{\pi(d_{wc})^2}{4} = \frac{\pi(42.85mm)^2}{4} = 1442.1mm^2$$

Pressure transmitted to the wheel cylinder (P_{wc}) equals with the pressure generated by the master cylinder; $P_{wc} = P_m = 2.249MPa$

Where; F_{wc} = is the force on the wheel cylinder

$$F_{wc} = P_{wc} \times A_{wc} = 2.249MPa \times 1442.1mm^2$$

$$F_{wc} = 3243.28N = 3.243kN$$

This force is applied on one side of the brake pad due to both wheel cylinders and the over whole clamping force will be equal to twice the linear mechanical force developed by the wheel cylinder as follows:

$$F_{clamping} = 2 \times F_{wc} = 2 \times 3243.28N = 6486.566N = 6.486kN$$

Brake Pad:

The frictional force is related to the caliper clamp force as follows:

$$F_{frictional} = F_{clamping} \times \mu_{bp} \text{ Where } \mu_{bp} = \text{brake pad coefficient of friction}$$

$$F_{frictional} = 6486.566N \times 0.3$$
$$=1945.97N$$

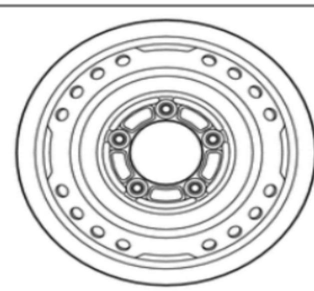
The torque is related to the brake pad frictional force as follows by using effective rotor radius

R_{eff} = (322/2-42.85/2) = 139.575mm=0.1396m

1945.97N×0.1396m = 271.66Nm

The angular speed of the axle which drives the wheel can be determined as follows; by using the vehicles maximum speed determined in the vehicle's specification Table 4.11. As shown the maximum speed is 140km/h, can be converted to the angular speed at the wheel or axle.

Table 4-12: Tire and Wheel Type System General

Wheel Design	
Tire Size	7.50R16 or 225/95R16
Disc Wheel Size	16 x $5^1/_2$F
Pitch Circle Diameter	150 mm (5.91 in.)
Offset (Inset)	20 mm (0.787 in.)
Material	Steel

From the above table 4.12 tire's specification 225/95R16 means tire width is 225mm with the aspect ratio of 95%, from this its height is determined like this:

$$height = \frac{aspecr\ ratio}{100} \times width$$
$$0.95 \times 225 = 213.75mm$$

Tire rolling radius is the sum of rim radius (25.4*16/2 mm = 203.2mm) and tire height (213.75mm) so, its value is 416.95mm.

Once the vehicle's maximum linear velocity is known tire's maximum angular velocity is determined using kinematics relations, $\omega = \frac{v}{r} rad/_{\sec} = \frac{140\ ^{km}/_{h}}{0.41695m} = \frac{38.89\ ^{m}/_{s}}{0.41695m} = 93.3\ rad/_{\sec}$. This angular speed is also equal with the speed at the wheel part of the transmission system.

The brake pad's property is depending on different parameters in the overall performance, so to determine pads strength and other mechanical properties first the thermal property should be specified. Some properties are taken from references based on some other related properties. The higher the coefficient of friction for the pad, the more brake power will be generated coefficient of friction can vary depending on the type of material used for the brake rotor. If the value of the coefficient of friction is increased, the disc is slowed down by friction forces which are opposed to its movement, and the maximum deformation that it undergoes is less significant (Belhocine et al., 2016).The bolt holes and outer side of the fins could first damage due to high stress concentration for single and double piston cases, respectively. Contact pressure is predicted higher at the leading side compared to the trailing side and its value slightly increases with an increase in the disc rotation speeds.

4.6. Brake Pad Finite Element Analysis

The analysis process is proceeding after determining the real working boundary conditions, like the mesh properties, supports, applied external parameters and others.

Figure 4.16:Developed composite brake pad

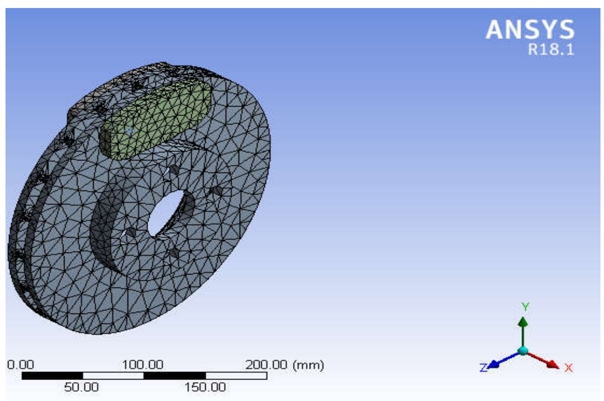


Figure 4.17:Meshed assembly

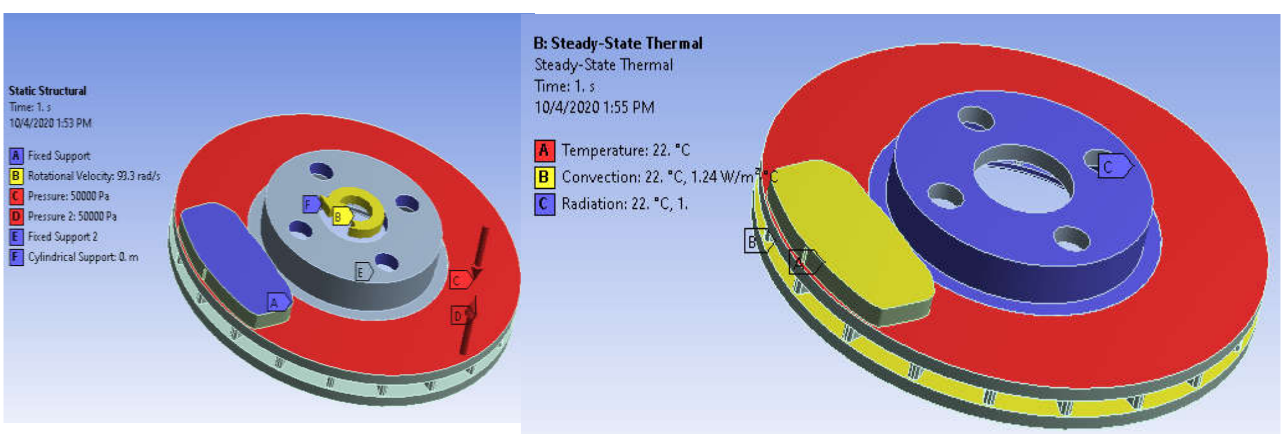


Figure 4.18:Boundary Conditions

Thermal analysis

All this analysis is conducted based on the test obtained result in the workshop. The thermal conductivity of the composite material can be determined from the corresponding volumetric fraction and individual components thermal property. The respective property is shown in Table 4.13.

Table 4-13: compositions proportion and thermal conductivity

Composition	**Proportion (%)**	**Thermal conductivity (w/m^{o}k)**	**(%) ×(w/m^{o}k)**
Carbon powder	0.35	1.7	0.595
Banana Peel	0.3	0.32	0.096
Epoxy	0.2275	0.2617	0.0595
Hardener	0.1225	0.816	0.09996
	1		0.8505
Subtotal	0.98	0.8505	0.83349
Bronze	0.02	50	1
Total thermal conductivity of the composite			**1.83349**

$$From\ the\ thermal\ relation\ for\ composite\ material,$$
$$K_{Brake\,Pad} = k_c v_c + k_b v_b + k_e v_e + k_h v_h + k_{br} v_{br}$$
$$So, K_{Brake\,Pad} = 1.8335 w/m^o K$$

4.6.1.1 Temperature

As the test setup shown in Figure 4.13 the brake pad operates for 22 minutes in a load of 0.5bar braking pressure. The temperature of the pad is measured before the test is conducted with a radar thermometer and reads 22^{o}C. Finally, just as the brake is released the pads temperature is raised to28.6^{o}C with a wear rate of 0.00001mg/m. The temperature distribution is mainly based on the materials conductivity property and the distribution on the pad and disk is shown in the Figure 4.19.

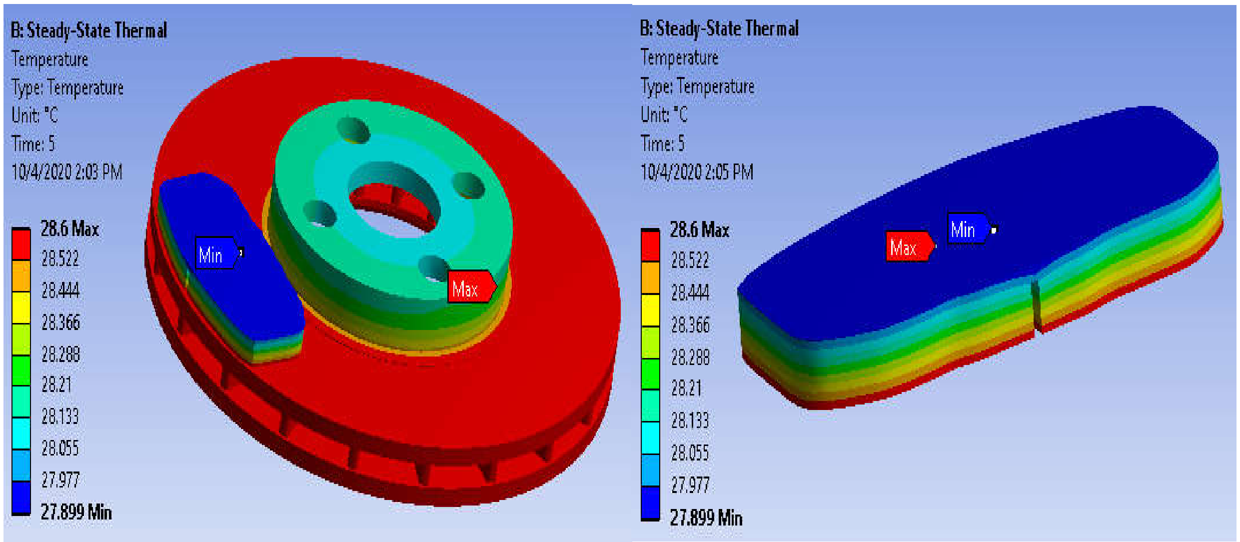


Figure 4.19:Temperature distribution

4.6.1.2 Directional Heat flux

The amount of heat transferred per unit area per unit time to or from a surface of the composite is shown in the Figure 4.20. Those values are correlated with the previously investigated natural composite materials for brake pad application. At fifth time of iteration the maximum directional heat flux of 604.24W/m^2 is developed through the indicated areas.

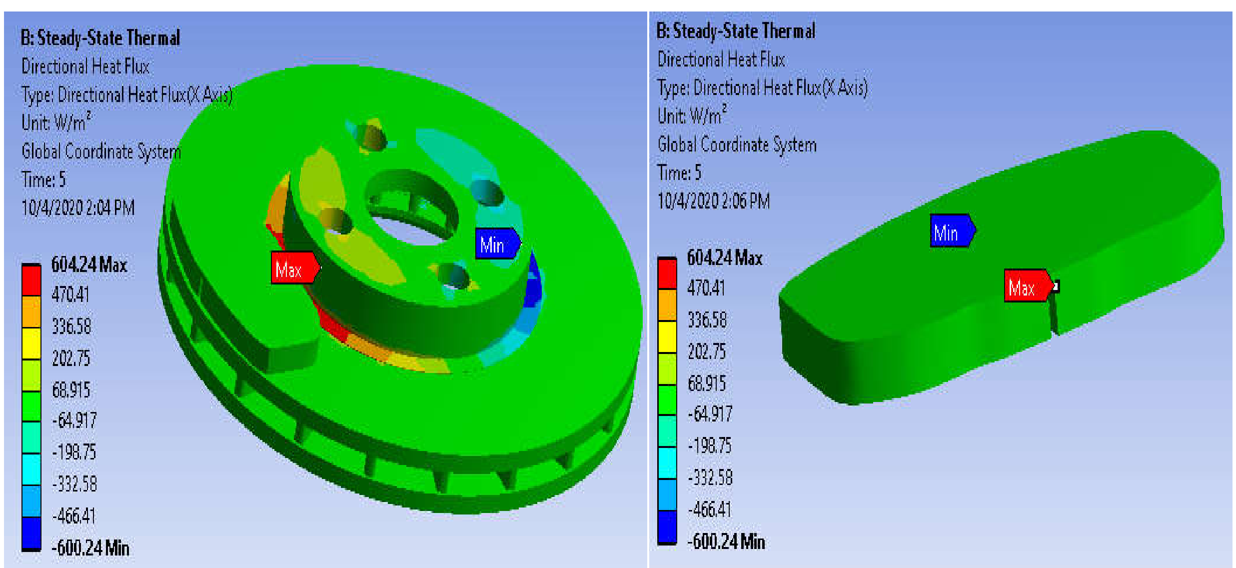


Figure 4.20:Directional heat flux distribution

4.6.2 Structural Analysis

4.6.2.1 Total deformation

The total deformation simulation of the pad and the disc is shown in the figure 4.21. Due to the wear of the friction pad the maximum deformation is observed at the contacting surface of the pad. These simulated results are obtained based on the pad testing variables, like a pressure of 0.5MPa and speed of 120 rpm for 22 minute. So, the maximum deformation is shown first for the disk 0.07727mm which, is expected due to its material strength.

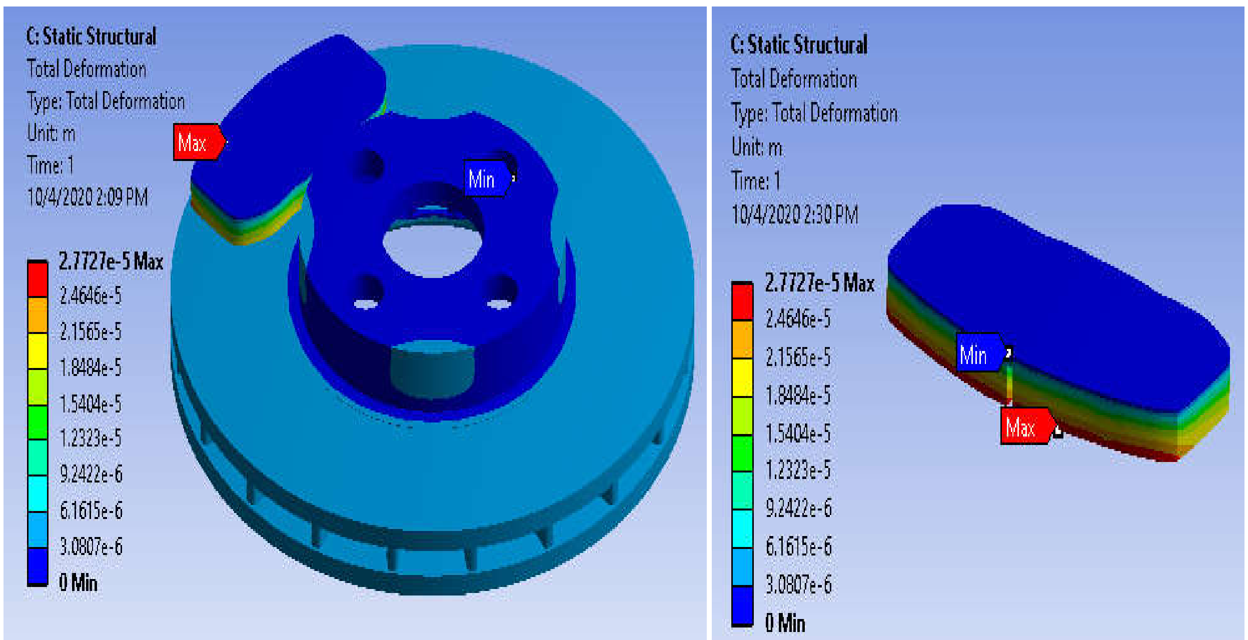


Figure 4.21:Total deformation

4.6.2.2 Equivalent Elastic Strain

The maximum limit for the values of strain up to which the pad will rebound and come back to the original shape upon the removal of the braking load. So the location of this point is shown in the Figure 4.22. highlited with red color. The numerical value of 0.003174m/m equivalent strain is measured with those boundary conditions.

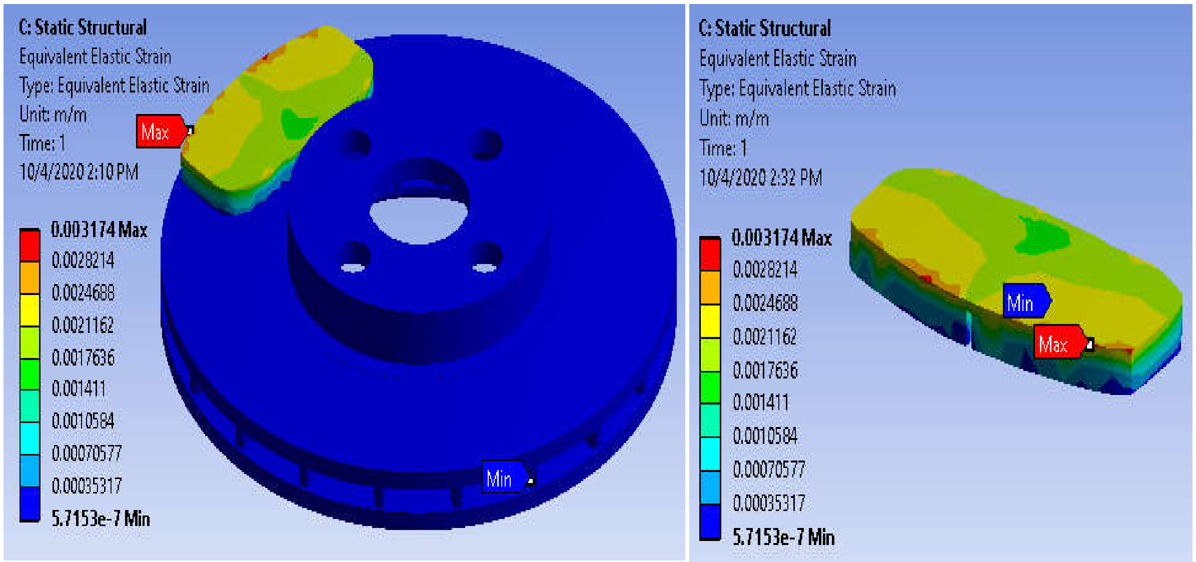


Figure 4.22:Equivalent elastic strain

4.6.2.3 Equivalent Stress

The maximum equivalent stress developed in the system is located around the rigidly fixing areas with load transferring system. The maximum equivalent stress is 1.429×10^{-7}Pa is around the bolt fixing regions and the remaining part is less stressed.

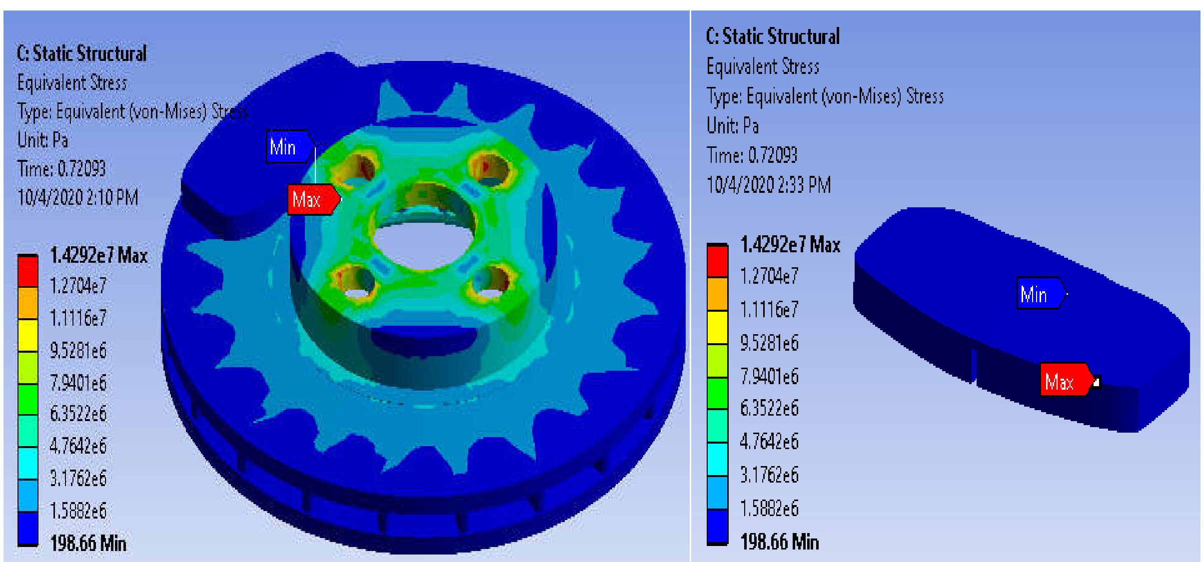


Figure 4.23:Equivalent stress

4.7. Compare and contrast

From the above test got the developed banana peel brake pad result and from the Adeyemi et al., (2016) the commericial brake pad results as shown below in table 4.14.

Table 4.14 comparing of the developed brake pad with the existing brake pad

Properties	Commercial brake pad (asbestos based)	Developed banana peel brake pad
Wear rate (mg/m)	3.8	0.021
Compressive strength (MPa)	110	1.62
Tensile strength (MPa)	7	2.06

As the result from the above table the commercial brake pad has 3.8 mg/m wear rate and the developed banana peel brake has 0.021 mg/m wear rate, so the commercial brake pad is wear rapidly than that of the developed brake pad.

As the comparisons from the above table the commercial brake pad has 110MPa amount of Compressive strength and the developed banana peel brake has 110MPa amount of Compressive strength, so the commercial brake pad has very high Compressive strength than that of the developed brake pad.

As the comparisons from the above table the commercial brake pad has 7MPa amount of Tensile strength and the developed banana peel brake has 2.06 amount of Tensile strength, so the commercial brake pad has high Tensile strength than that of the developed brake pad.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1. Summary

Brake pads are designed for: friction stability, durability, minimization of noise and vibration. Materials used for brake pads should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature and high durability. Asbestos was a favorite material in the manufacture of brake pads because it has a good ability to dissipate heat, but it has proved to be harmful to human health. Currently, the brake pads are made from mineral fibers, aramid fibers, cellulose, glass fiber, steel fibers and copper. Each material has its advantages and disadvantages related to: environmental conditions, wear, noise, braking capacity, but the final properties of each type of brake pads are influenced by the abrasive material. On this study a composite material made up of asbestos free brake lining material, banana peel powder with carbon powder and other filling materials were developed and analyzed through ANSYS for real working situation.

5.2. Conclusion

The result of this research indicates that banana peels particles with carbon powder can be effectively used as a replacement for asbestos in brake pad.

- The developed banana peel brake pad is better than that of the existing brake pad; by reducing 3.779mg/m wear rate.
- The result has shown that the existing brake pad is more than 4.94MPa tensile strength than the developed banana peel brake pad.
- The above result proves that the existing brake pad is more than 108.38MPa tensile strength than the developed banana peel brake pad.
- Therefore the developed brake pad is much better than the existing brake pad by wear rate and lesser than by both compressive strength and tensile strength.

5.3. Recommendation

- Banana peel processing is performed manual but using better banana peel processing mechanism can gives more accurate result.
- Using more accurate composite manufacturing techniques may increase the performance of output like resin transfer method, Vacuum Bagging etc.
- Conducting tests with newly calibrated test machine can also increase newly formulated composite material.

5.4. Future work

- Develop brake pad from oven dried banana peel powder (without exposing to sun light) for better strength and performance.
- By using varying the ratio of between the carbon powder and banana peel powder increasing the strength of the brake pad.

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APPENDICES A

https://en.wikipedia.org/wiki/Carbon_black

Table A1: Carbon Black specification

Properties	
Chemical formula	C
Molar Mass	12.011g.mol^{-1}
Appearance	Black Solid
Density	1.8-2.1g/cm^3(20°c)[1]
Solubility in water	Practically insoluble[1]