Experimental and Simulation Study of Drum Brake Lining Made from Oxen Horn Particulate Composite for Minibus Taxi

Daniel Hayile Kaba

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Automotive Engineering

Office of Graduate Studies
Adama Science and Technology University

May, 2023

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Experimental and Simulation Study of Drum Brake Lining Made from Oxen Horn Particulate Composite for Minibus Taxi**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Experimental and Simulation Study of Drum Brake Lining Made from Oxen Horn Particulate Composite for Minibus Taxi**" was prepared under my guidance by **Daniel Hayile Kaba** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Automotive Engineering.

Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Major Advisor	Signature	Date

APPROVAL

I, the advisors of the thesis entitled "**Experimental and Simulation Study of Drum Brake Lining Made from Oxen Horn Particulate Composite for Minibus Taxi**" and developed by **Daniel Hayile Kaba** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by "Daniel Hayile Kaba have read and evaluated the thesis entitled "**Experimental and Simulation Study of Drum Brake Lining Made from Oxen Horn Particulate Composite for Minibus Taxi**" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Automotive engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
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Finally, approval and acceptance of the thesis are contingent upon the submission of its final Copy to the Office of Postgraduate Studies (OPGS) through the Department of Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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ACRONYMS

ASTM	American society of testing material
BPF	Banana peduncle fiber
CHAp	Cow horn ash particles
FRC	Fiber-reinforced composites
HF	Horn fiber
HP	Horn particles
IFs	Intermediate filaments
PP	Polypropylene
RVE	Representative volume element
SAE	Society of automotive engineering
SHC	Specific heat capacity
ABCBL	Asbestos based commercial brake lining
PKBBP	Palm kernel-based brake pad
PWSBL	Periwinkle shell-based lining
CHpBL	Cow horn-based brake lining
BPBP	Banana peel brake pad

NOMENCLATURES and SYMBOLS

μ_a	road adhesion factor
ρ_c	density of composite
ρ_m	density of matrix
ρ_p	density of particle
ρ_{water}	density of water
ΔL	change in gage
ΔW	weight loss
μ	coefficient of friction between lining and drum
A	area of brake lining
A_m	Cross-sectional
Cr	cross sectional the area of rear piston
a_x	average deceleration
b	specimen width
CS	compression strength
E	kinetic energy
e	nominal strain
E_{cupper}	upper elastic modulus of composite
E_m	elastic modulus of the matrix
E_p	elastic modulus of particle
F	force load at point of failure
F_{fr}	frictional force at the rear
F_l	leading force
F_t	tangential force
F_{tr}	total force rear brake
g	gravitational acceleration
h	specimen thickness

k	wear rate coefficient
K_c	thermal conductivity of composite
K_m	thermal conductivity of matrix
K_p	thermal conductivity of particle
Lp	pedal leverage ratio
L	specimen length
L_o	initial length of gage
M	mass of the vehicle
N	radial force
N	speed in revolution per minute
P	pressure in pipe line
Q	heat generated during braking
r	drum radius
R	wheel rolling radius
T	time taken
T_b	brake torque
T_w	wheel torque
v	Velocity
v_c	volume of particle
v_m	volume of matrix
v_p	volume fraction of particle
v_x	velocity of the vehicle
W	weight of the vehicle
W_1	weight of the sample after immersion
W_o	weight of the sample before immersion
W_r	wear rate
σ	nominal stress
σ_{UF}	flexural strength

ABSTRACT

Due to its advantageous thermal conductivity characteristics, asbestos has been utilized as a brake lining material for vehicles for a very long time. However, it has been banned and fallen out of use because of the health risk connected to its handling, and a number of substitute materials are being utilized more frequently. The objective of this study was, to make brake lining from oxen horn particulate composite through simulation and experimental study. Epoxy resin, graphite, and silicon oxide were combined with oxen horn particles to create an asbestos-free drum brake lining for a minibus taxi 5L model. By hand layup molding, three different sample composite brake linings were created. Composite one was developed with oxen horn particle 40%, Epoxy 30%, and Gr and SiO2 at 15%. In composite two, oxen horn particle was 30%, epoxy is 40%, and Gr and SiO_2 *are 15%. Composite three is prepared by reducing the oxen horn particle to 25% and epoxy to 35%, Gr, and* SiO_2 *to 25%. Modeling of the representative volume element of the brake lining was conducted in MSc Digimats 2017 with different percentage and imported to ANSYS 2022R1 for mechanical and thermal analysis. The physical and mechanical characteristics of the samples were investigated according to American Society of Material Testing. Accordingly, the average compressive, flexural, and tensile strengths were obtained to be 171.8, 6.3, and 92.5 MPa, respectively. The coefficient of friction, wear rate, and relative density were, 0.32, 0.000042 mg/m, and 1.5* g/cm^3 *respectively, while water and oil absorption tests were below 1% for 24 hours. From the simulation result, it was obtained that, the maximum principal stress was less than the ultimate strength of the sample obtained from the experimental result. These test results were compared with available asbestos-based commercial brake lining. Due to better mechanical properties of oxen horn particle, better result was obtained. Sample two was found to be best composition which has better mechanical and tribological properties among the other composites. The result indicates that cow horn particles can be used as reinforcement in brake lining material for automobiles.*

Keywords: *Asbestos, brake lining, oxen horn, epoxy, hand layup molding, MSc Digimats, RVE, wear rate.*

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

The brake system of car is its most crucial safety component**s.** The secret to drive safely is having brake system that can deliver predictable and safe stops. When braking force is applied, friction develops, and friction is the resistance to motion between two surfaces. As a result, by bringing a stationary surface into contact with a moving surface, the resistance to the relative motion or the rubbing action between the two surfaces will low down the vehicle. Energy conversion is the fundamental tenet of brake action. In starter, chemical energies are the battery is converted to electrical energy. The engine is turned by the starter. The heat energy that generated by the combustion of hydrocarbon and oxygen cannot destroyed; it can only be changed to another form of energy. As the vehicle is propelled the heat energy is converted to kinetic energy. The energy of mass in motion, or kinetic energy, is fundamental type of mechanical energy. When weights grow, kinetic energy rises directly and when speed rises it rises four times.

To operate properly the brake system should have the following requirements:

- The brakes must be strong enough to stop the vehicle within a minimum distance in an emergency.
- The driver must have proper control over the vehicle during braking and the vehicle must not skid.
- The brakes must have well anti-fade characteristics widely used than any other brake design (i.e. their effectiveness should not decrease with the constant prolonged application).
- The brakes should have well anti-wear properties.

The braking system has many types such as regenerative, hydraulic, pneumatic, and mechanical braking. The most widely used brake system in Ethiopia at present are the foot operated main brake and manual-type parking brake. Drum brakes are used mainly for the rear wheels of passenger cars and trucks while disc brakes are used exclusively for front brake because of their directional stability. The contact area between the shoes and drum is large, much larger than the contact area between brake pads and the rotor.

Requirements of the brake drum

- It should provide a surface having well anti-wear qualities.
- It should be able to be accommodated within the wheel space available.
- Accurately balanced
- Sufficiently rigid
- It should allow the optimum rate of heat transfer.

Every time the brakes are applied, heat is produced, and it must to be released into the atmosphere right away to prevent it from building up again during the next application. Particularly in passenger cars like city cabs and public transportation vehicles/buses, brakes are frequently used at numerous stop places. Any excessive brake heating would result in the drum expanding, which would reduce the effective pedal travel and deteriorate the brake lining. It should have sufficient strength but minimum weight.

The most popular passenger vehicle in Adama City is a minibus taxi 5L model, which operates from day to night. According to data obtained from Oromia Transport Authority, around 1000 taxis are working in Adama City daily. Due to the crowdedness, there are numerous stopping locations throughout the city, and each time a driver applies the brakes, a lot of heat is produced, which worsens the vehicle's braking capabilities and speeds up the wear rate of the friction linings and other brake system components.

1.1.2. Composite material

Composite materials are created by mixing two or more materials that are very different from one another in terms of their physical and chemical makeup. The composite's distinctive features are a result of the interaction between the various constituents. For thousands of years, people have used composite materials in many contexts. In order to build sturdy and long-lasting structures, early Egyptians and Mesopotamian settlers utilized a mixture of mud and straw as early as 1500 BC. Bricks made with mud and straw have a strong resistance to bending, tearing, and compression due to the combination of these two materials. Ancient composite items like pottery and boats continued to be reinforced by the straw. The first composite bow was created by the Mongols in 1200 AD using a combination of "animal glue, bone, and wood." Figure1.1 shows the standard classification scheme for composite materials.

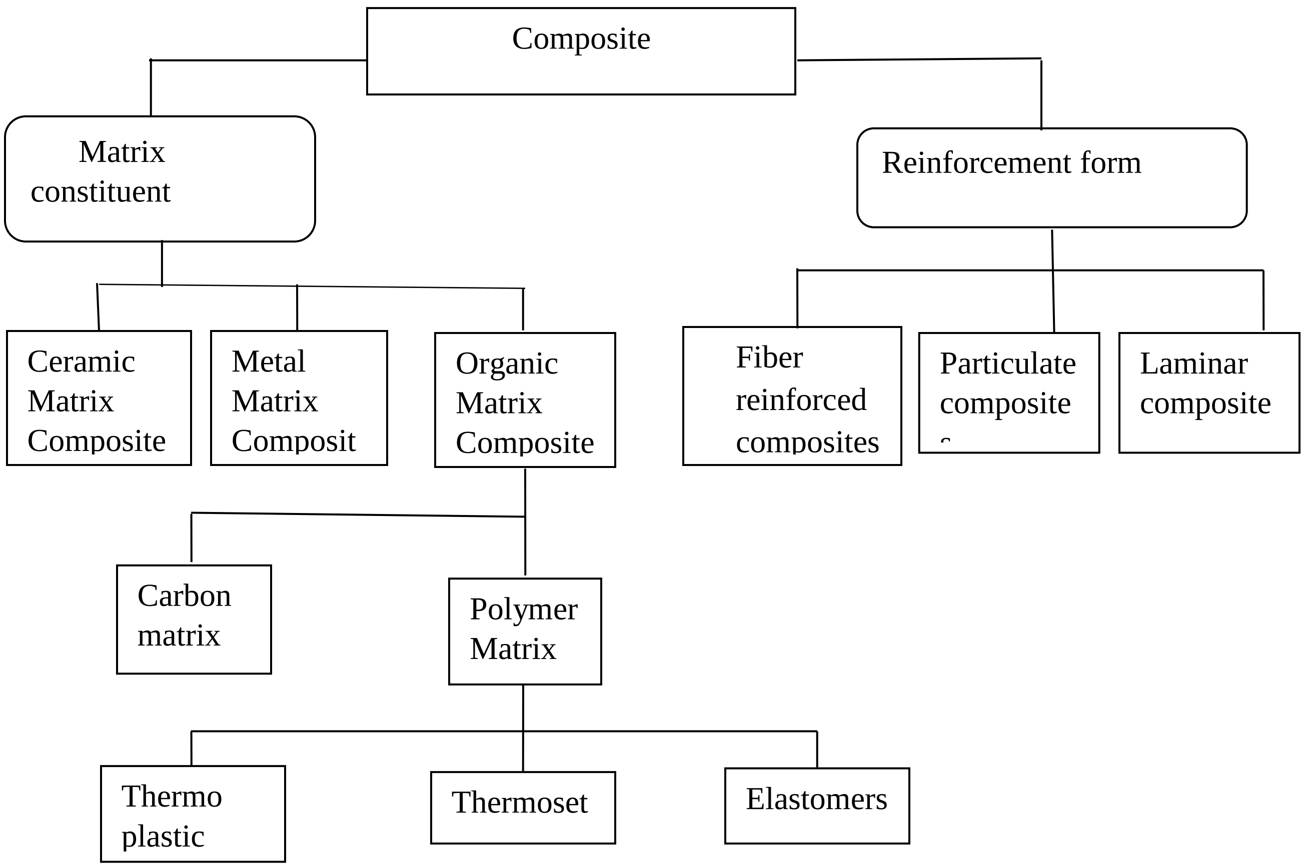


Figure 1.1. Classification of composites

Fiber-reinforced composites (FRP) can be further divided into those containing continuous fibers. These fibers must be supported to keep individual fibers from bending and buckling.

Laminar composites are composed of layers of materials held together by a matrix. Sandwich structures fall under this category.

Particulate composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder forms. Concrete and wood particle boards are examples of this category.

Thermoset Materials is direct condensation polymerization followed by rearrangement reactions to form heterocyclic entities is the method generally used to produce thermoset resins. Water, a product of the reaction, in both methods, hinders the production of void-free composites. These voids have a negative effect on the properties of the composites in terms of strength and dielectric properties. The two most significant classes of thermoset resins are polyesters and phenolic and epoxy resins. Epoxy resins are used in filament-wound composites and are appropriate for prepress molding. They are excellent adherents with slow shrinkage during curing and no release of volatile gases, and they are reasonably resistant to chemical attacks. However, because of these benefits, using epoxies is rather expensive.

1.2. Statement of the problem

For a long time, asbestos was used in brake lining to increase wear and friction at extremely high temperatures. According to research, asbestos particles can get trapped in the lungs and cause lung cancer. It is also expensive and scarce. Oxen horn is one of the by- product of the slaughter house. These chips and the horns that cannot be used for the production of useful items become landfills and pose huge problems causing environmental pollution. One of the vehicles frequently utilized in Adama to carry passengers in urban and rural areas is the minibus taxi 5L model. These passenger automobiles mostly use drum brakes on their rear wheels. At every stop, heat is produced when the brakes are applied, and this heat must be quickly released into the atmosphere to prevent it from building up again when the brakes are applied. Any excessive brake heating would result in the drum expanding, which would reduce the effective pedal travel and cause the brake to fade. Brake lining with strong heat resistance, heat transfer, and environmental friendliness is required to address these issues.

1.3. Objectives

It encompasses of general and specific objectives.

1.3.1. General objective

The general objective of this thesis is to develop/make drum brake lining from cow horn particle composite.

1.3.2. Specific objectives

The specific objectives are:

- To prepare composite material from oxen horn powder.
- To develop brake lining samples

- To test the engineering characteristics of a developed sample.
- To model and simulate representative volume element of brake lining using MSC Digitmat 2017 and ANSYS2022R1.
- To compare and contrast the properties of developed brake lining with available asbestos based commercial brake lining.

1.4. Scope of the study

The scope of this thesis encompasses, preparation of composite material, the development of brake lining samples by hand layup process for characterization purposes. Characterizations are density, water and oil absorption, flexural/bending, tensile, compression, and wear properties test. Characterization such as wear property test is at the laboratory level not on vehicle. During characterization, parameters such as load, speed and temperatures are not varied. To validate the result, it is compared with conventional brake lining. Simulation is conducted on MSc Digimats for modeling the representative volume element of the sample and analysis is done on ANSYS2022R1.

1.5. Limitation

During doing this thesis, some of the area and tests to be studied are limited due to different factors. The parameter such as age, growing environment and feeding type of cow is not considered due to its time taking. Development of the composite is made by hand layup process; since another method such as plasma sintering molding process which is recommended method for most particulate composites is not available. Casting is ignored due to less quality of final product. Matrix (adhesive) used in the synthesis of the composite is epoxy resin which is suspect able at higher temperature. Thermo- gravimetric analysis (TGA) of the sample is also not conducted due to unavailability. Since the composite is developed from different ingredient, dynamic analysis on software is not suitable.

1.6. Significance

The significance of this study is.

- To introduce alternative re-enforcement material for the friction material or drum brake lining which is cow horn particle since it has good mechanical and thermal properties.

- Reduces the environmental pollution due to cow horn disposal.
- It solves the problem of brake fade due to overheating of brake drum lining of passenger cars and also eliminates the health risk related to current asbestos-based brake lining.
- It also reduces the cost of importing brake lining from abroad.
- It creates job opportunities when mass production begins.
- Even though this study is for the application of drum brake, it could be applicable for another vehicle part.

1.7. Organization of the thesis

This section shows the framework how the thesis is prepared. It encompasses five chapters. Chapter one contains the background, a statement of the problem, objectives, the significance of the study and the scope. Chapter two focuses on previous literature related to on- hand study and research gaps. Chapter three shows the material and methods used to conduct the research work. Also, it contains the experimental set up, simulation and brake lining analysis. Chapter four is about the results of the conducted experiment, finite element analysis, and discussion of the results. Chapter five consists of a conclusion, recommendation and future work. Non-chapter parts such as references and appendixes are also found at the end.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter mainly focuses on previous works that provide background information to support and encourage the production of brake lining. There are many literatures about natural composite material as particle re-enforcement for different application. Especially, natural composite material is recently widely applied for vehicle part such as roof, fire wall, seat, vehicle inner part, brake friction material or brake lining. A lot of researches have been carried out in the area of the development of asbestos-free brake linings. Recent development in brake lining industry focuses on a search for a non-asbestos substitute for brake lining. This has motivated researchers to explore the potential of some agricultural wastes to be used in brake lining development. Some of these agricultural wastes pose an environmental hazard as their disposal is often a thing of concern.

2.2. Basic Braking system

Braking is the process of partially or completely decreases the traveling speed of a vehicle. The braking system has many types such as regenerative, hydraulic, pneumatic, and mechanical braking the most widely used brake system in Ethiopia at present are the foot operated main brake and manual-type parking brake. The main brake actuates the brake assemblies at each wheel simultaneously using hydraulic pressure. Fluid pressure created is transmitted to each of the wheel cylinders through brake tubing. The wheel cylinders force the shoes and pads into contact with a drum (fig 2.1) or rotor spinning with the wheels generating friction and converting kinetic energy to heat energy. Large amounts of heat are created resulting in short distance stopping and vehicle control. The converted energy is absorbed primarily by the brake drum and dissipated to the surrounding air.

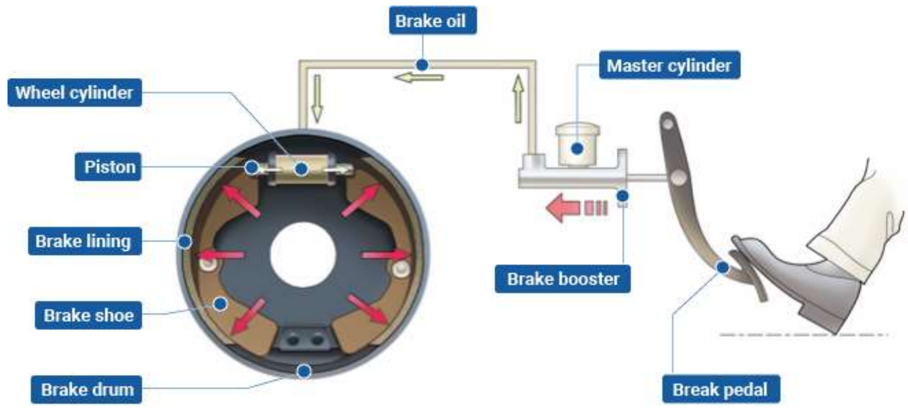


Figure 2.1. Drum brake (Jariwala & Kevadiya, 2019)

2.2.1. Various Phases of Brake Working

During the braking process, velocity and deceleration vary with time. Figure 2.2 describes the variation of deceleration as a function of time as a general pattern. The four phases in the braking process are described as follows.

Initial Response Phase: This phase starts from the inception of the actuation force to the onset of braking force and it is represented by the line O-P

Pressure Buildup Phase: The second phase begins at the point of onset of braking force to the moment until it reaches its stable value and is represented by P-Q.

Active Braking Phase: Third phase Q-R starts at the point of stable braking force till it ceases.

Final Response Phase: The final phase takes place at the point of deactivation to the disappearance of the braking force, represented by R-S.

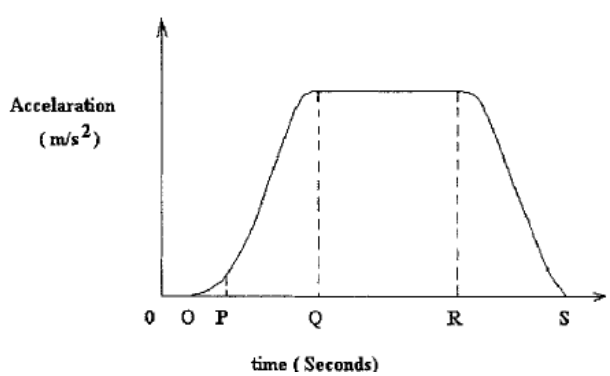


Figure 2.2. The four phases occurring in the braking process (Kavitha & Prakash, 2019)

2.2.2. Drum brake

The drum brake has been more widely used than any other brake design. Braking power is obtained when the brake shoe is pushed against the inner surface of the drum which rotates together with the axle (fig 2.3). Drum brakes are used mainly for the rear wheels of passenger cars and trucks while disc brakes are used exclusively for front brake because of their directional stability. The contact area between the shoes and drum is large, much larger than the contact area between brake pads and the rotor.

The following key elements are used by the majority of current drum braking systems.

Brake drum: The shoes brush on the inside surface of the drum that creates friction. Typically, drums are made of cast iron, however, some vehicles employ an outer shell made of composite aluminum and a friction surface made of iron to reduce weight.
Brake shoes: Are the metal backings that have lining materials attached to them.

Brake lining: Is frictional material linked to the brake shoe. Although the composition of the brake shoe lining varies, it frequently includes abrasives like aluminum, iron, and silica, friction-reducing agents like graphite and ceramic compounds, fillers, and binders. Asbestos was used in linings for a long time to increase wear and friction at extremely high temperatures.

Backing plate: the plate, attached to the axle assembly, holds the components of the drum brake assembly.

Figure 2.3. Main components of drum brake (https://www.fahadhvhassan.com/ drum-brake-function-components-working-principle-and-types)

2.3. Horns

Animal horns are mostly found in the Antilocapridae and Bovidae families, which include pronghorn, and are used as attack and defense weapons during intraspecific warfare (Wang et al, 2016). To suit the unique fighting behavior of their species, the horns, which serve as the primary combat weapons, must meet special mechanical requirements (impact resistance, energy absorption, high compressive and tensile strength (Blau, 2001). These weapons have evolved over millions of years into a variety of shapes and forms, but their basic structural component, a-keratin, a structural protein produced by keratinocytes, has remained constant (Pautard, 2019). One of the most prevalent biopolymers in nature, keratin is typically mineralized to less than 1% (for example, 0.05wt% in ox and rhino horns). It exhibits remarkable mechanical efficiency due to its relatively high fracture toughness and Young's modulus but is much lighter than other highly mineralized biological materials, such as bone and teeth (Wegst & Ashby, 2004).

To create bio-inspired materials with superior mechanical qualities and endurance, it is possible to learn design ideas from the study of the hierarchical structure and mechanical characteristics of keratinous horns (table 2.1).

Table 2.1. Mechanical properties of some animal horns (Issa et al, 2020)

No	Horn type	Young modulus (GPa)	Tensile strength (MPa)
1	Horn (big sheep)	1.5	127
2	Horn (Cattle)	2.2	39
3	Horn (Oxen)	0.81	60-159.5

2.3.1. Oxen horn

The majority of castles are found in Ethiopia, which is the first country in Africa. Oxen horn is one of the by-products of the slaughterhouse. According to the laws established by several nations, these horns may be used to create "technical products" such as organic fertilizers and soil that are not meant for human or animal use. The central core of the horn, which makes up a relatively small portion of the total horn, is used to make useful products. In these circumstances, the outer layers of the horn are chipped away, revealing the cylindrical internal core of the raw horn. When these chips and horns can't be used to make usable products, they end up in landfills, which is a major issue because it causes environmental contamination. The principal elements detected are discovered to be Carbon, Oxygen, Nitrogen, and Molybdenum, with a maximum

Carbon weight percentage of 59.03. Iron, Sodium, Chloride, and Calcium are additional elements that are present in lower concentrations (table 2.2).

Table 2.2. The content of cow/oxen horn shavings (Kumar and Boopathy, 2019)

No	Material Content	Percentage (%)
1	Dry matter	86.62
2	Organic mater	99.16
3	Organic carbon	39.91
4	Nitrogen	15.54
5	Phosphorus	0.165
6	Calcium	0.396
7	Potassium	0.09
8	Sulfur	0.049
8	Magnesium	0.014
9	Copper	6.68 mg/kg
10	Zink, chromium and cadmium	118.0mg/kg

These horns with high strength, high rigidity, nonabrasive behavior, excellent acoustic properties, excellent hydrophobic properties, low density, and very good ductility, that possesses highly resistant to impact and resistant to high temperature with its reasonable amount of carbon present can be used as reinforcing particle for the manufacture of composite materials (Kumar and Boopathy, 2019).

2.3.2. Cow horn particles in different composite

Using horn particles (HP) and epoxy resin with fillers of various percentage weights and particle sizes of 100 and 150µm, a particle-reinforced composite was created. Tensile, flexural, and impact tests were used to analyze the created composites' properties. The findings demonstrated that adding the cow horn temperature lowered the tensile characteristics of the polymers. However, a superior strength was attained at higher curing temperatures. In the meantime, the addition of the fiber boosted the polymers' flexural and impact properties without regard to order. The tensile (37.58 MPa) and impact properties of the composite materials with a particle size of 100µm and a curing temperature of 80^0C were higher than those of the lower particles (74J). According to its mechanical qualities, cow horn was generally determined to be a good potential filler in the composite, if manufactured utilizing a higher curing temperature. The use of cow horns as a reinforcing material has been advocated. It is a strong, resilient, lightweight material with good hydrophobic, acoustic, and ductile qualities that is also highly resistant to impact and high temperatures because of the reasonable quantity of carbon present in it and it can be applicable for automotive industry (Ambali et al, 2019).

Figure 2.4. Oxen horn

Composite of oxen/cow horn particles in the Aluminum matrix was developed with stir casting method in 2 different weight percentages of 5% and 10%. After mechanical properties test, three samples are compared and it is concluded that, as cow horn weight percentage increases, the mechanical properties such as impact energy, ultimate tensile stress, more elongation and ultimate compression of the composite is increased (Abeens & Shibu, 2019).

Cow horn ash particles are used as a novel flame-retardant additive for polyester/cow horn ash particles (CHAp)/Banana peduncle fiber (BPF) hybrid composites to enhance the fire resistance of natural fibers. After thermal and fire properties were tested, the result shows that the addition of CHAp improved the thermal stability of the composite by acting physical barrier against the thermal degradation of the polymer composite. It can be observed clearly that the addition of CHAp reduced the THR of the polyester. The suggested mechanism by which expanded CHAp acted as a fire retardant reducing thermal heat release (THR) involved the formation of a char that served as a potential barrier to both mass and energy transport between the flame and the burning polymer. (Ezeh et al, 2020).

To create composite materials with varying weight percentages, defatted horn fibers are employed as the particle reinforcement, and polypropylene as the matrix (5, 10, 15, and 20). A description of the material's physical, mechanical, thermal, and microstructural characteristics is given, and they are contrasted with those of pure PP and pure HF. When compared to the properties of pure raw materials, composites exhibit increased tensile yield strength, increased tensile modulus, increased flexural strength, increased flexural modulus, decreased ultimate tensile strength, decreased percentage elongation at break, and increased impact strength. Also, this research revealed that, from thermo-gravimetric analysis (TGA), cow horn can withstand maximum temperature of 371.38^{o}C (Kumar & Rajendra, 2019).

Research is conducted on the design analysis and optimization of cattle horn-plastic composite seat chairs. According to this study, the optimum thickness of the chair seat is evaluated based on the load and minimum weight requirement. The maximum stress experienced during loading was evaluated to be 1.148N/mm^2. The sensitivity study showed that the maximum stress reduces with an increase in the thickness of the chair seat. The optimum thickness required to sustain the load during usage is 4.148mm (Wegst & Ashby, 2004). Cow horn particle and Al 356 composite is developed using the plasma sintering molding process to study the effect of wear parameters. Tribo meter and scanning electron microscope are used to analyze the wear and worn scar of the composite respectively. According to the result obtained, the composite exhibited better dry sliding wear resistance than Al356 alloy. The optimum level of the factors with minimized wear loss was obtained at wt% CHP (20%), applied load (10 N), sliding velocity (3 m/s), and sliding distance (2000m). The wear resistance of the composite is greatly increased by incorporating cow horn particles as reinforcing material (Ochieze et al, 2017). 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 (Blau, 2001).

2.4. Brake lining material

The brake system's brake lining is a wearable, crucial component for safety. The majority of brake materials are composites of numerous different materials rather than single elements or compounds in order to attain the qualities needed for brakes. Commercial brake lining (fig 2.5) components today use more than 2000 distinct materials and variations on those materials. Wagon wheels and early automobiles both employed the first brake liner, which was made of a cotton-based material with a bitumen solution. Later, brake lining materials were woven, but in the 1920s, molded materials with chrysotile asbestos fibers and a wealth of minerals took their place. Asbestos was used in linings for a long time to increase wear and friction at extremely high temperatures. Magnesium silicate of hydrate, $MgSi_20_5$ (OH), makes up asbestos (table 2.3).

Table 2.3. Composition of chrysotile asbestos

Ingredient	Composition (%)
SiO_2	37-44
MgO	39-44
FeO	0.0-6.0
Fe_2O_3	0.1-5.0
Al_2O_3	0.2
H_2O	12.0-15.0
CaO	Tr -5.0

Six naturally occurring silicate minerals make up asbestos. According to research, breathing in asbestos dust can cause lung cancer. There have been persistent efforts to identify a replacement material for asbestos fibers in certain applications (Blau, 2001).

Figure 2.5. Brake shoe linings (https://www.chinagrtech.com)

The raw materials used to create disc brake pads and drum brake linings range from 10 to 20 different types. Following are some categories of brake lining materials based on expected uses.

1. Binder components

Resins are frequently utilized as binder materials. Only when they are added in precisely calculated amounts will they be able to perform their intended function. A pad's endurance is decreased if there is insufficient resin, and its hardness and temperature-reduced coefficient of friction are both potentially increased by excessive resin. One of the most crucial materials used in the production of brake pads is resin since it binds all the other parts of the pad and enables them to work together efficiently. However, the quality of the brake pad material may decrease if too much heat is produced during braking. This is due to resin degrading, which causes the material to lose its ability to attach (Borawski, 2020). The primary and most prevalent binder used in brake lining and pad materials are discussed as follows:

i) Phenolic resin

The most popular and reasonably priced resin binder used in brake friction material is probably phenolic resin. Phenol resin, a type of polymer created by the condensation reaction of phenol and formaldehyde, can serve as a matrix to bind various substrates together. These phenolic resins undergo a thermoplastic transformation into a densely cross-linked thermoset, which is also a matrix with comparatively high heat resistance when they are cured

ii) Epoxy-modified resin

High temperatures cannot be tolerated by a pure epoxy resin. Resin binders deteriorate at temperatures exceeding 260 °C. Epoxy resins require the use of specific curing agents to raise their operational temperature. As a result, epoxy is frequently used to alter phenolic resins, creating a synergistic effect that increases heat resistance and increases frictional stability (Chan & Stachowiak, 2004).

2. Fillers and Reinforcements

Fillers are used to maintain the overall composition of the friction material, and some have other functions as well. They can be metals, alloys, ceramics, or organic materials.

3. Frictional modifiers

Frictional additives are substances that are applied to friction-breaking materials to change the friction coefficients and wear rates. The two main divisions are lubricants, which reduce friction coefficients and wear rates, and abrasives, which raise friction coefficients and wear rates. Thus, it's crucial to strike a balance between the number of lubricants and abrasives in the brake friction compound.

i) Lubricant

The main purpose of a lubricant is to stabilize the friction materials to modify the developed friction coefficient during braking, particularly at high temperatures. Commonly used lubricants include graphite and various metal sulfides. Graphite is a crystalline form of the element carbon with its atoms arranged in a hexagonal structure. Graphite has Young's Modulus of Elasticity, Brinell hardness, Melting Point, thermal conductivity, 11.5GPa, 5 BHN, 3600°C, 0-450W/mK respectively. Its uncommon combination of properties is due to graphite's crystalline structure. Graphite is widely used as it is able to form a lubricant layer on the opposing counter friction material rapidly. This self-sustaining layer ensures a stable friction coefficient. The graphite used in brake friction materials can be of natural or synthetic origin and can exist in flake or powder form. Graphite in the flake form has improved lubrication properties, while graphite in the powder form is able to dissipate heat during braking more effectively (Piazza et al, 2013).

ii) Abrasives

Abrasives help maintain the cleanliness of mating surfaces and control the build-up of friction films. They also increase friction, particularly when initiating ’a stop (i.e., they increase “bite”). Glass fibers are available in different forms like continuous, chopped, and woven fabrics. The microstructure of any fiber plays a vital role in carrying heat. The glass fiber has an amorphous structure. It consists of SiO_2 molecules and forms a three-dimensional silica polyhedral network along the length of the fiber. It behaves nearly isotropic, resulting in nearly the same conductivity properties in any direction of the fiber (Mutnuri, 2006).

The brake shoe lining material varies and often contains abrasives, such as aluminum, iron, and silica. Reinforced polymer composite has found its applications in a variety of laces such as the automobile industry like the car bumper, among others. The automotive industry used 318 million pounds of composites. Because the automotive market is very cost-sensitive, carbon fiber composites are not yet accepted due to their higher material costs. So that it is advisable to use natural fiber composite for the purpose of environmental protection and the cost (American Chemistry Council, 2019).

Pollution is the adverse effect humanity has to suffer due to technological advancement. Being engineer's objective is to design the machine elements based on sustainable, eco-friendly concepts. 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 have a carcinogenic effect on the skin. So, a lot of research is going on for finding a suitable replacement for asbestos (Gowthaman & Rajesh, 2017).

Asbestos is a term that has been used to describe a group of six commercially available silicate minerals with fibers that are generally long, thin, and flexible when separated. Asbestos fibers are classified into two types: serpentine and amphiboles. Serpentine asbestos is curly, whereas amphibole fibers are straight. All forms of asbestos have been judged to be carcinogenic by the World Health Organization's International Program on Chemical Safety and International Agency for Research on Cancer and in the United States by the Environmental Protection Agency, the National Institute for Occupational Safety and Health and the National Toxicology Program (Stayner et al, 2013).

Asbestos and their composites have been used from several decades with varying compositions, which has good tribological and mechanical properties. Nevertheless, due to health hazards analogous with handling and application of asbestos, there is scope for development of alternative friction lining material (Shinde& Mistry, 2017).

Medical evidence has shown that four diseases can develop following exposure to asbestos dust:

Asbestosis - formation of scar tissue on the lung which often leads to premature death, one of the pneumoconiosis groups of diseases caused by mineral dust inhalation.

Mesothelioma - a relatively rare form of cancer of the outer surface of the lung or intestinal lining, which is fatal.

Lung cancer - increased susceptibility amongst those affected by asbestosis, particularly amongst those who smoke heavily (Pye, 1979).

The World Health Organization (WHO) estimates that about 125 million people are exposed to asbestos at worksites around the world, and more than 107,000 people die of asbestos-related diseases, including lung cancer, mesothelioma, or asbestosis, due to occupational exposure to asbestos (Baur et al, 2015).

Recent research has focused on the development of asbestos-free brake pads made of composite banana peel. According to his research, he carried out laboratory tests to evaluate the materials' tensile, compressive, bending, wear, water, and oil absorbability properties and discovered that the developed banana peel brake pad is superior to that of the existing brake pad by lowering the wear rate to 3.779mg/m. The outcome revealed that the designed banana peel brake pad has a tensile strength of 4.94MPa or higher than the currently used brake pad. The produced brake pad is much superior to the existing brake pad by wear rate and inferior to both compressive strength and tensile strength, as shown by the preceding result, which shows that the existing brake pad has a tensile strength greater than 108.38MPa (Shiferaw, 2021). Natural fibers are being considered as an alternative reinforcement in polymer composite due to their advantages over conventional glass and carbon. These advantages include low cost, comparable specific tensile properties, renewability, recyclability, biodegradability, less health risk, non-irritation to the skin, and non-abrasive to the equipment (Wegst & Ashby, 2004).

The majority of brake pad materials used now contain kevlar (aramid), which has emerged as the most effective material after asbestos. But current research and reports from the WHO show that Kevlar has the same effects as asbestos. Natural fiber's superior mechanical qualities give it the potential to replace asbestos. A unique natural fiber from Pinus rox burghii leaves used as reinforcement in friction materials has good mechanical properties and can replace asbestos (Kumar et al, 2022).

Hybrid composite reinforced basalt, shells, and mica are used to make the material for brake lining pads, and phenol resin polymer is used to bind them (PR-51510i). This brake pad material is made using a sintering process that uses an emphasis of 2000 kg for 30 minutes at a fixed temperature of 160°C. The ASTM G 99-95a pin-on-disc test is used to evaluate the wear resistance of up to five different versions of these hybrid composites, while the ASTM D 570-98 distilled water absorption test evaluates the composites' ability to withstand water absorption. The highest distilled water absorption of the brake pad specimens obtained was 0.041558 yet lower than the distilled water absorption of asbestos brake pads. The biggest wear rate is 0.000090 g/cm, which is still lower than the wear rate of asbestos brake pad materials (Atmika et al, 2019).

Palm kernel and coconut shell powder were used as the basic materials, Araldite and epoxy resin served as the binding agents, and carbon fiber was added for reinforcement to create the disc brake friction lining that meets the geometric requirements of the Audi 90 model. As abrasives and fillers, aluminum, copper, zinc, and cashew nut shells were employed, along with shoe rubber dust (Onyeneke, 2014).

Maize husks were used as fillers to add friction qualities to three different sets of composite compositions, and different amounts of epoxy resin were used as the matrix to bind the parts together. The composites were used to create brake pad specimens, which were then tested utilizing industry-standard test methods, supplies, and tools to determine their potential performance in service. The MH filler material's particle size was 300 µm, and epoxy resin was in a slurry. The results demonstrated that specimen composite 3 with 30% MH filler content had the best combination of coefficient of friction, abrasion resistance, water absorption, oil absorption, density, hardness, tensile strength, and compressive strength, as well as thermal conductivity, with values of 0.37, 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 found that decreasing the filler content increased the composite brake pad's hardness, wear rate, tensile strength, compressive strength, and thermal conductivity, whereas increasing the MH filler content increased the pad's density, coefficient of friction, water absorption, and oil absorption. The results of previous studies demonstrated that MH particles are an effective substitute for asbestos in the production of vehicle brake pads when compared to those of traditional brake pads composed of asbestos and other friction materials (Ademoh & Olabisi, 2015).

Using powder metallurgy, an asbestos-free friction material was created using agricultural waste (cocoa bean shells, or CBS) as a filler element and other additives. The filler material under consideration had 300µm-long particles, and epoxy resin served as the binding agent. The mechanical, physical, and tribological characteristics of the generated brake pad samples were assessed. Reducing the filler content improved the wear rate, tensile strength, and compressive strength of the produced brake pad, whereas hardness, density, water absorption, oil absorption, and thermal conductivity varied (Olabisi et al, 2016).

A natural fiber known as palm kernel fibers (PKFs) is used to make brake pad material because of its environmentally favorable properties, together with CaCO3, graphite, and Al2O3. A binding agent is an epoxy resin. Better properties than other compositions were provided by a composition of 40% epoxy resin, 10% palm wastes, 6% Al2O3, 29% graphite, and 15% calcium carbonate. Palm kernel shells, a commercial form of asbestos, were used to compare the findings. Results indicated that using epoxy resin as a binder and PKF could be an appropriate replacement for asbestos brake pads (Ikpambese et al, 2016).

In this work, epoxy resin, barium sulfate, graphite, and aluminum oxide were used to create an asbestos-free brake lining. This was done to take advantage of cow hooves' qualities, which are typically dumped as garbage. Compressive molding was used to create samples of brake linings, and the samples' physical and mechanical characteristics were investigated. The findings demonstrated that appropriate bonding was accomplished as the proportion of epoxy resin by weight increased and the percentage of pulverized cow hooves by weight decreased. The brake linings' relative density, hardness, compressive strength, coefficient of friction, water, and oil absorption, and wear rate were measured and compared to those of existing brake linings. The outcome suggests that powdered cow hooves can be employed as an automotive brake lining material (Bala et al, 2016).

The raw materials chosen for brake lining fabrication by altering process parameters include coconut shell, epoxy resin (binding), graphite (friction modifier), and aluminum oxide (abrasive). Brake pad samples were created utilizing the rule of mixing, and for manufacture, weight percentages of 52% reinforcing material, 35% binder, 8% abrasive, and 5% friction modifier were used. According to grey relational analysis (GRA), 14MPa, 140°C, 8min, and 5h, respectively, are the ideal molding pressure, temperature, curing time, and heat treatment time to achieve the best process performance. The experimental findings demonstrated that the optimized coconut shell-reinforced brake pad's performance compared favorably with commercially available samples and was capable of generating reduced brake noise and vibration when applied. According to an analysis of variance, heat treatment time, with a contribution of 46.3%, has the most significant impact on the friction coefficient and wear rate of coconut shell-reinforced brake pads, respectively, while curing time, with a contribution of 30.38% and 31.40%, has the most significant impact on the hardness and ultimate tensile strength of the coconut shell-reinforced friction material (Abutu et al, 2019).

As a base material, the brake pad was made utilizing sawdust grades of 100 m, 355 m, and 710m in accordance with the producers' standard operating procedure. Using compression molding, brake pads were made from the sieved sawdust in the following proportions: 55% sawdust, 15% steel dust, 5% graphite, 10% silicon carbide, and 15% epoxy resin. Microstructure analysis, hardness, compressive strength, density, ash content, wear rate, and water absorption are the characteristics analyzed. The outcomes demonstrated that the characteristics were better the finer the sieve size. When the outcomes of this study were compared to those of commercial brake pads made of asbestos, a strong correlation was found. As a result, sawdust can be utilized to make brake pads without asbestos (Lawal et al, 2017).

An epoxy resin and hardener were mixed with palm kernel shell and cow bone at sieve grading of 100, 100, and 120, respectively. Based on the specifications for brake pad uses, the formulated brake pads were classified. All evaluated parameters were found to fall within the permissible range for brake pad operation. For PKS and cow bone, the impact tests yield results of 1.0 J and 1.5 J, respectively. For PKS and cow bone, respectively, the hardness test yields values of 55.7 HRB and 46.0 HRB. The PKS water absorption test result was 5.05%, and the cow bone result was 5.53%. For PKS, the oil absorption test result was 2.23%, while for cow bone, it was 4.16%.PKS had a thermo-gravimetric analysis (TGA) score of 57.14% and cow bone had a value of 63.24% for the largest percentage of weight loss (Afolabi et al, 2015).

2.5. Brake lining wear rate

Wear can take place when two or more bodies in frictional contact slide against each other. The more the wear, the sooner the friction material needs to be replaced. There are various wear laws established from experimental results. For instance, for a specific application such as brakes systems, Rhee developed an empirical wear equation at a fixed temperature where he expressed the mass loss of the polymer friction material in terms of the contact normal force F, the speed, v and the time t as follows.

$$\Delta W = kF^{a}v^{b} \quad 2.1$$

Where k is the wear rate coefficient obtained from experiments and a, b and c are the set of parameters that are specific to the friction material and the environmental conditions. He stated that a, b and c could be unity in a special case but suggested that for a commercial friction material a and b = 0.42 and c = 1.0 (Abubakar et al, 2019).

For composite friction materials, Pavelescu and Musat proposed that the wear intensity without temperature effect could be in the following form.

$$I_u = kLF^a v^b \quad 2.2$$

Where L is the sliding distance and k, a and b are the constant. Those constants vary for different materials.

2.6. Rule of Mixture for Composites

'Rules of Mixtures' are mathematical expressions that give some property of the composite in terms of the properties, quantity and arrangement of its constituents.

Volume fraction: Volume fraction of composite and particles are always numbers less than one given by:

Volume fraction of particle, v_p = volume of particles/ volume of composite

The volume of composite,

$$V_c = v_p + v_m \quad 2.3$$

For the unit volume of composite,

$$1 = v_p + v_m \quad 2.4$$

The volume fraction of the matrix,

$$v_m = 1 - v_p \quad 2.5$$

Mechanical properties of composites depend on the volume fraction of reinforcement and matrix. The basic properties can be calculated using the rule-of-mixture principle with some assumptions

The type of reinforcement (fiber, particle or whiskers) and their orientation play a major role in determining the strength of composites

In particle reinforced composites, distribution of particle throughout the component is key to provide uniform material property.

Given the volume fractions of fiber, V_p, and matrix, V_m, the density of composites, ρ_c, can be calculated by the following equation (Tam et al, 2012).

$$\rho_c = \sum \rho_p v_p + \rho_m v_m \quad 2.6$$

For a general composite, total volume V, containing masses of constituents Ma, Mb, Mc, the composite density is given by

$$\rho = \frac{Ma + Mb + Mc}{V} \quad 2.8$$

2.7. Summary of reviews

At present, since natural composites have low density and are widely available at lower cost, natural composites are the area in which many researchers are participating for different applications. Cow horns are one of the natural materials that have good mechanical properties and are used in different composites for different applications. For example, it is used to produce home materials like tables and other utensils. It is shown that cow horn particles are used as a novel flame-retardant additive and it can be used in a material which operates at high temperatures. A cow horn particle and Al 356 composite are developed using the plasma sintering molding process to study the effect of wear parameters. The wear resistance is increased as cow horn particle incorporation increases. Another area in which most of the engineering researchers are participating is brake lining materials. One of the ingredients used in brake lining is asbestos, which has good thermal properties. But, it has been revealed that exposure to asbestos causes health problems such as asbestosis, mesothelioma, and lung cancer. The good news is that researchers are developing another material that can replace it. In some work, epoxy resin, barium sulfate, graphite, and aluminum oxide were used to create an asbestos-free brake lining. Banana peel, palm kernel, and coconut shell powder were used as the basic materials in manufacturing brake pads. Maize husks, agricultural waste (cocoa bean shells, or CBS), and other additives are used as a filler element. A natural fiber known as palm kernel fibers (PKFs) is used to make brake pad material because of its environmentally favorable properties. An epoxy resin and hardener were mixed with palm kernel shell and cow bone to produce a brake lining.

2.8. Research gap

From previous studies, researchers have been working on the natural composite material for different applications. This research work is still ongoing to solve the problems of fuel economy, environmental pollution, health matters, cost of the material, unavailability, etc. To solve the above problems, different methods are used. Among their efforts, replacing the existing materials with composite materials is one of the most widely adopted methods. A drum brake is a type of brake which is used at the rear wheels of passenger cars and trucks. Brake lining material is one of the areas where much research has been done to replace asbestos material with different materials such as carbon powder, graphite, glass etc. Because the automotive market is very cost-sensitive, carbon fiber composites are not yet accepted due to their higher material costs. Although a lot of work is done on drum brake lining, a material that can withstand high temperatures and high wear, low cost and availability are rare. Depending on the literature and review done before, the wear resistance of the composite is greatly increased by incorporating cow horn particles as reinforcing material (Ochieze et al, 2017). The use of cow horns as a reinforcing material has been advocated. It is a strong, resilient, lightweight material with good hydrophobic, acoustic, and ductile qualities that is also highly resistant to impact and high temperatures because of the reasonable quantity of carbon present in it and it can be applicable for automotive industry (Ambali et al, 2019). It is shown that cow horn has good mechanical and thermal properties, due to high content of carbon content and can be applied for automotive applications. But, it is not shown which automotive parts can be manufactured from the cow horn particle composite. Therefore, this thesis tries to improve the brake lining by introducing cow horn particles.

CHAPTER THREE

MATERIALS AND METHOD

3.1. Introduction

This chapter is a section in which the materials of the thesis are selected, the methodology used is identified, a composite is produced, and experimental work and simulation are done. Each topic is explained as follows.

3.2. Materials

Materials are the core of any thesis work and selected after many literatures are reviewed. In this thesis, materials used to develop the composite are grouped in phases. The four phases are re-enforcement, matrix, abrasive and lubricant which explained below.

i) Re-enforcement

It provides strength and stiffness to the composite, also used to reduce the cost of material to produce composite. Cow horn powder is used as re-enforcement/filler in this thesis.

ii) Matrix

The matrix bears the major portion of an applied load; the small dispersed particles hinder or impede the motion of dislocations. Thus, plastic deformation is restricted such that yield and tensile strengths, as well as hardness, improve. Epoxy resins are thermosetting polymers with good chemical resistance, high mechanical properties, thermal stability, high adhesive strength as well as high electrical insulation (Agarwal et al, 2017). For high performance applications in aerospace and marine structures, epoxy resins are used. This is a result of its ease of processing, hot and wet strength in conjunction with excellent mechanical properties in composites (Mukhopadhway, 2005).

iii) Lubricant

The main purpose of a lubricant is to stabilize the friction materials to modify the developed friction coefficient during braking, particularly at high temperatures. In this thesis two form of Graphite is used for two reasons. Graphite in the flake form has improved lubrication properties, while graphite in the powder form is able to dissipate heat during braking more effectively.

iv) Abrasive

Silicon dioxide has properties of high chemical purity and resistance, high softening temperature and thermal resistance, low thermal expansion with high resistance to thermal shocks, high transparency from the ultraviolet to the infrared spectral range, and high radiation resistance. So, it is selected as abrasive material in this thesis. The materials needed for preparation of the composite are given in table 3.1

Table 3.1. Materials

No	Material	Quantity
1	Cow horn powder	1.5kg
2	Epoxy resin 501 A	3L
3	Graphite	200g
4	Silicon oxide	500g
5	Release agent(wax)	500g
6	Polyethylene plastic	1x2 m
7	Hardener HY-951	1.5L
8	Distilled water	25L
9	Mold	3

Drum material is selected to be gray cast iron since it has good thermal properties. Properties of gray cast iron are given in table appendix C.

3.3. Method

Methodology is the mechanism used to do some work. In this thesis work some approach/method is used. Work flow flowchart is given in fig 3.1.

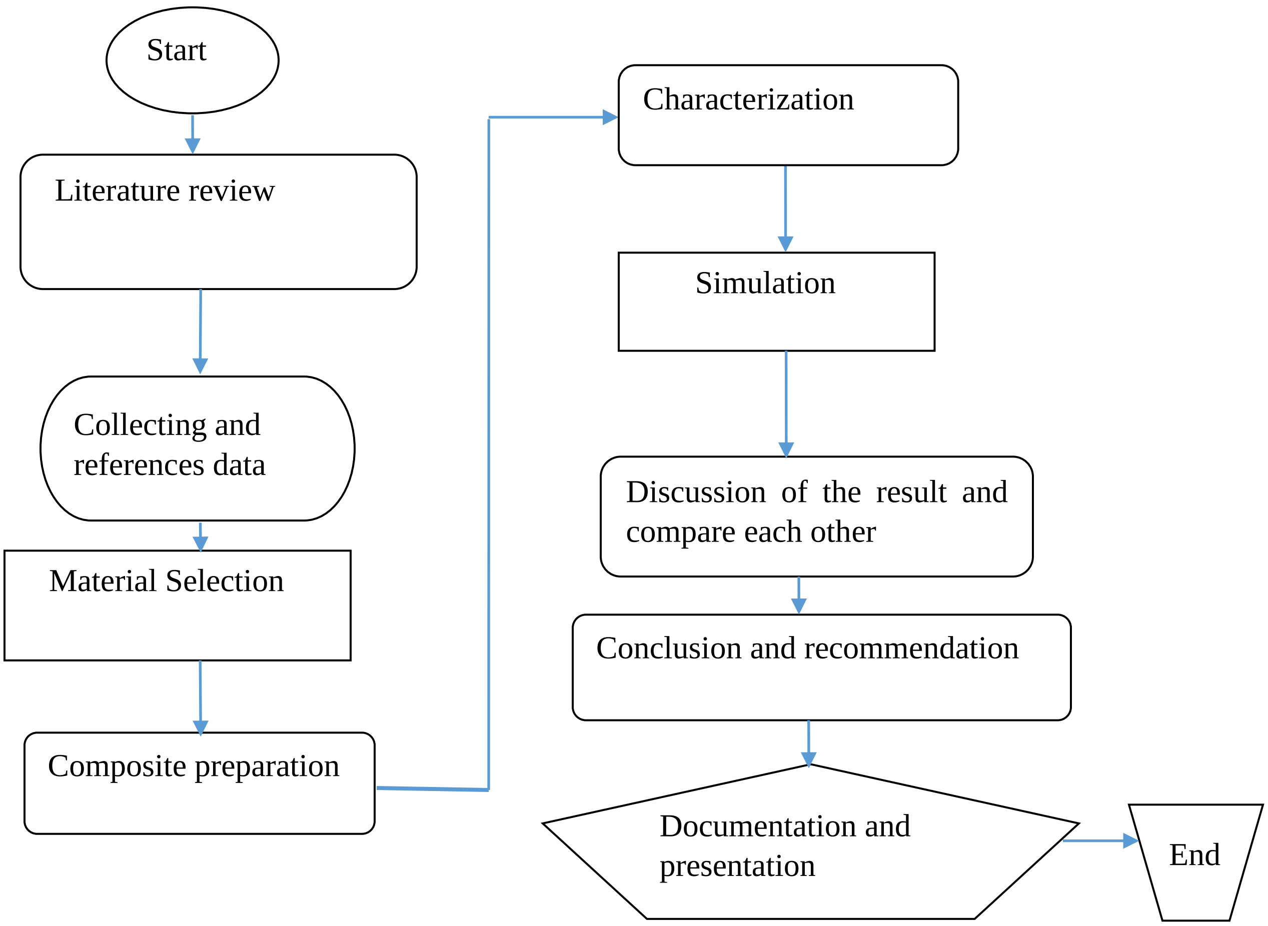


Figure 3.1. Work flow chart

3.3.1. Data collection

Data needed for this thesis was collected in two forms primary and secondary data collection. Primary data collection is used to get information about minibus taxi braking systems from different garages and companies such as Marta general garage and Moenco Company in Adama. Secondary data collection is used to collect data from the internet and different journals and the references are cited. Specifications of minibus KG-LH172V-RBMB (fig 3.2 & table 3.2) are collected from the internet and direct measuring the spare parts of the current vehicle since the arranged module is not available in the Toyota car selling company in Ethiopia.

Figure 3.2. Minibus KG-LH172V-RBMBS 5L model

Table 3.2. Specifications of minibus KG-LH172V-RBMBS

1	Car brand		TOYOTA
2	Model Code		KG-LH172V-RBMBS
3	Engine code		5L
4	Gross weight		2800kg
5	Maximum speed		105km/hrs.
6	Types of drive		2WD (rear)
7	Type of break		Front disc rear drum
8	Dimension(l×w×h) mm		4690 ×1690 ×1980
9	The size of rear tires		195R15−8PRLT
10	Master cylinder piston diameter (mm)		23.4
11	Rear wheel piston diameter (mm)		25.8
12	Drum dimension(mm)	Outer diameter	329
		Inner diameter	270
		Drum height	67
		Number of holes	6
		Bolt hole circle	139.7
		Bolt hole diameter	14.8
13	Drum material		Gray cast iron
14	Lining dimension (l× w× t)		50x6x149.5
15	Contact angle		120^o

3.3.2. Composite preparation

There are several methods for fabricating composite materials. Hand layup is one of the oldest and simplest methods which are shown in figure 3.3.

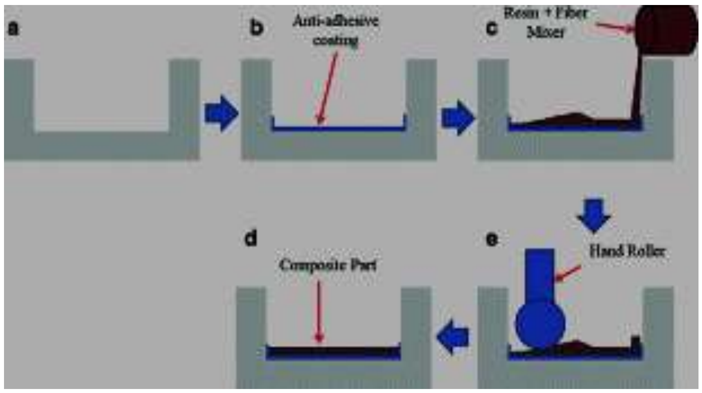


Figure 3.3. Hand layup molding process (Elkington et al, 2015)

Materials needed to prepare the composite given in table 3.1 were selected as explained next. Fresh cow horn was obtained from Adama Administrative City Kera and washed first with hot water and then with distilled water to remove the marrow and unwanted debris. Then, sun dried for one week and electric oven dried for four hours with 80^{o}C respectively (fig 3.4a). To get the powder, first crashed with a hammer on flat metal and the size is reduced with a hand coffee mill (fig3.4b). A mechanical ball mill machine was used to get the final powder. Sieve in the Material Science Engineering Laboratory was used to get 150µm mesh sizes (fig 3.4c). To get cow horn ashes powder, the chopped CH was heated in furnace to 250^{o}C for 40 minutes without presence of oxygen (Ezeh et al, 2019). Then it was milled with ball milling to 100µm. Epoxy resin and Hardener HY-951 (501A) were obtained from Cadisco Paint and Adhesive Industry S.C that found in Addis Ababa city. Silicon dioxide (SiO2) was obtained from Awash Malka Sa'a and releaser (wax) was bought from the market.

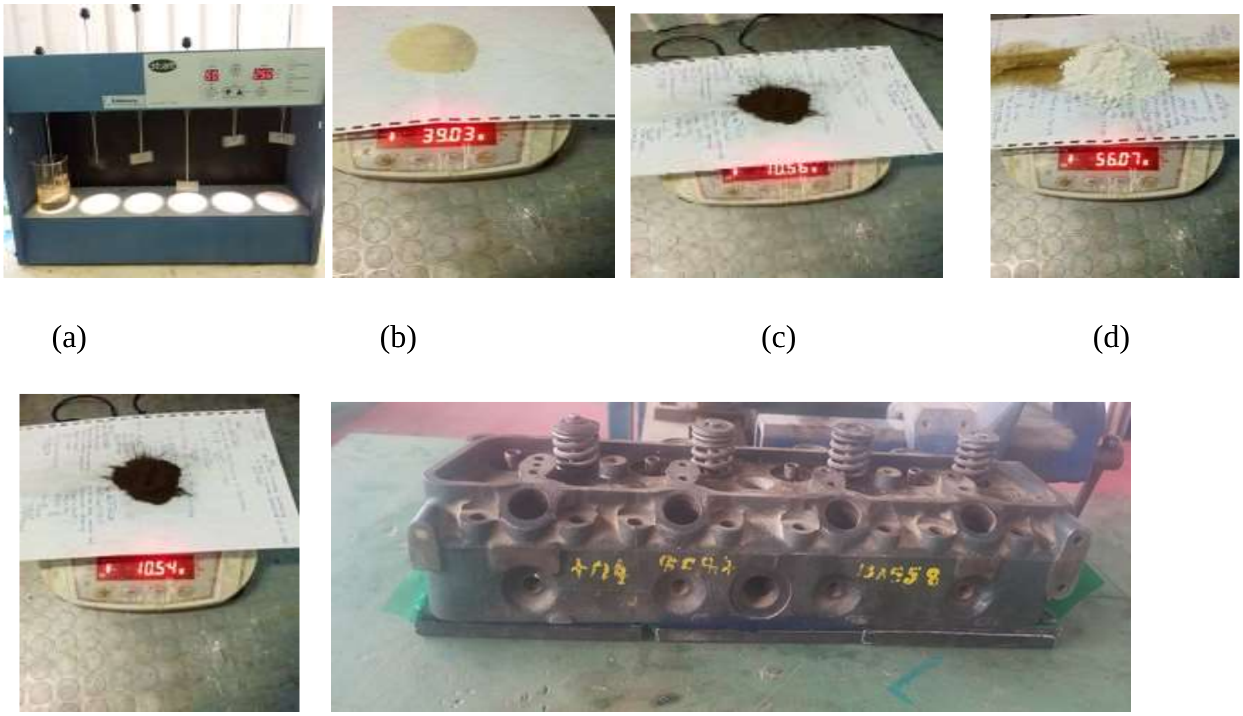
Three molds were prepared from sheet metal with 15×14×10cm. To prepare the composite each material was measured by electronic weight balance according to specified volume/weight fraction table 3.3 and fig3.5 b, c, and d. To find the volume/mass of the particles, equations 2.3, 2.4, and 2.5 in section two were used. Epoxy and hardener were mixed with the ratio of 2:1 by volume and with a magnetic mixer at 250rpm for15minutes to get a homogenous mixture (fig 3.5a). The measured powders were mixed until homogeneity was obtained. The mold was covered with plastics and the wax was used to eliminate sticking to it. The powder was poured into epoxy resin and mixed for 5 minutes by sticking in a beaker. The mixture was poured into a mold and punched with a roller to increase compatibility. Then the mold was kept covered with wood and loaded with around 500N for 72 hours at room temperature (fig 3.5f).

(a) (b) (c)

Figure 3.4. CH powder preparation set up (a) oven drying, (b) reducing with hand coffee mill and (c) ball milling

Table 3.3. Materials, volume fraction and volume/mass of samples composites

Sample s	Materials	Volume fraction	Volume/mass
Composite one	Epoxy resin	0.4	42ml
	CHp	0.3	29g
	SiO_2	0.15	42g
	Gr	0.15	36g
Composite two	Epoxy resin	0.3	31ml
	CHp	0.4	38.64g
	SiO_2	0.15	42g
	Gr	0.15	36g
Composite three	Epoxy resin	0.35	36.75ml
	CHp	0.25	24.15g
	SiO_2	0.2	55.83g
	Gr	0.2	47.58g



(a) (b) (c) (d)

(e) (f)

Figure 3.5. Composite preparation set up (a) mixer, (b) cow horn powder, (c) cow horn ashes powder (d) SiO2, (e) graphite and (f) loaded composite

After 72hours, the sample was took from mold and cured with 80 ^{0}C for 1hour (fig3.6 a and b). After curing the composite was kept on shelf for one week and cut in to specified dimension.

Figure 3.6. (a) Composite samples and (b) curing process

3.3.4. Dynamics and working principle of drum braking system

Some of the working principle and dynamics of shoe break are discussed below.

i) Pressure on brake lining

A hydraulic braking system converts the fluid pressure into useful work of braking at the wheels by transmitting brake pedal force through the pressured fluid to the wheel brakes. The master cylinder piston compresses the braking fluid by receiving input from the driver's foot through the brake pedal. Both the rear wheel cylinder pistons and the pistons in the front disc calipers get an identical amount of this fluid pressure. The ratio of the cross-sectional areas of the wheel cylinders for the disc or drum brakes and the master cylinder determines the amount of braking force in a hydraulic braking system. A straightforward analysis is provided in fig. 3.7 to demonstrate how an appropriate force ratio is obtained between the foot pedal and the wheel-cylinder pistons to understand the workings of the hydraulic braking system.

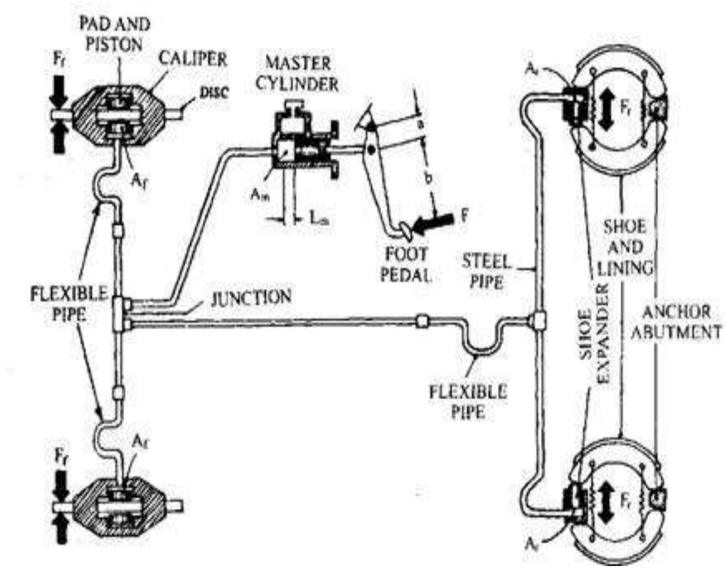


Figure 3.7. Hydraulic single-line braking system (Wang *et al, 2017*)

To analysis the force and pressure in brake lining, the following step is given.

Pressure on master cylinder piston

$$F_m = \text{FL} \qquad 3.1$$

Pressure in brake pipe line

$$P = \frac{F_m}{A_m} \quad 3.2$$

Force on each rear cylinder piston

$$F_r = P\,A_r \quad 3.3$$

Total force on rear brakes

$$Ft_r = 4PA_r \quad 3.4$$

Where, F_m= force on master cylinder, F = force on foot pedal, F_r = force on each rear cylinder piston, A_m = cross sectional area of master cylinder, A_r = cross sectional area of rear piston, L= pedal leverage ratio = b/a.

ii) Brake Shoe Self Energization

The two internal semicircular shoes that make up the drum-type brake are lined with friction material that matches the internal rubbing face of the drum. The shoes are attached to a back plate, also referred to as a torque plate, by a cam or hydraulic piston type expander at the upper shoe top end and a pivot anchor or wedge type abutment at the lower shoe end. The expander and shoe linings are easily depicted in fig3.8 by two opposing arrows and two little segmental blocks in the middle of the shoes, respectively. The expander force, Fe, pushes the upper tips of the shoes apart as the drum rotates counterclockwise, while a normal inward response force, N, generated by the drum, inhibits any shoe expansion. A tangential frictional force is created between each pair of rubbing surfaces as a result of the drum sliding over the shoe linings. The drag or friction force on the right-hand shoe (fig 3.8) often moves in the same direction as the force at the shoe tip, Fe. In turn, this aids in dragging the shoe onto the drum, effectively raising the shoe tip force above the initial expander force. Leading shoes are those that offer this self-energizing or servo action. Positive servo is the phrase used to describe this increase in shoe tip force over the input expander force. Therefore, the leading shoe tip resultant force is given by

$$FL = Fe + Ft \quad 3.5$$

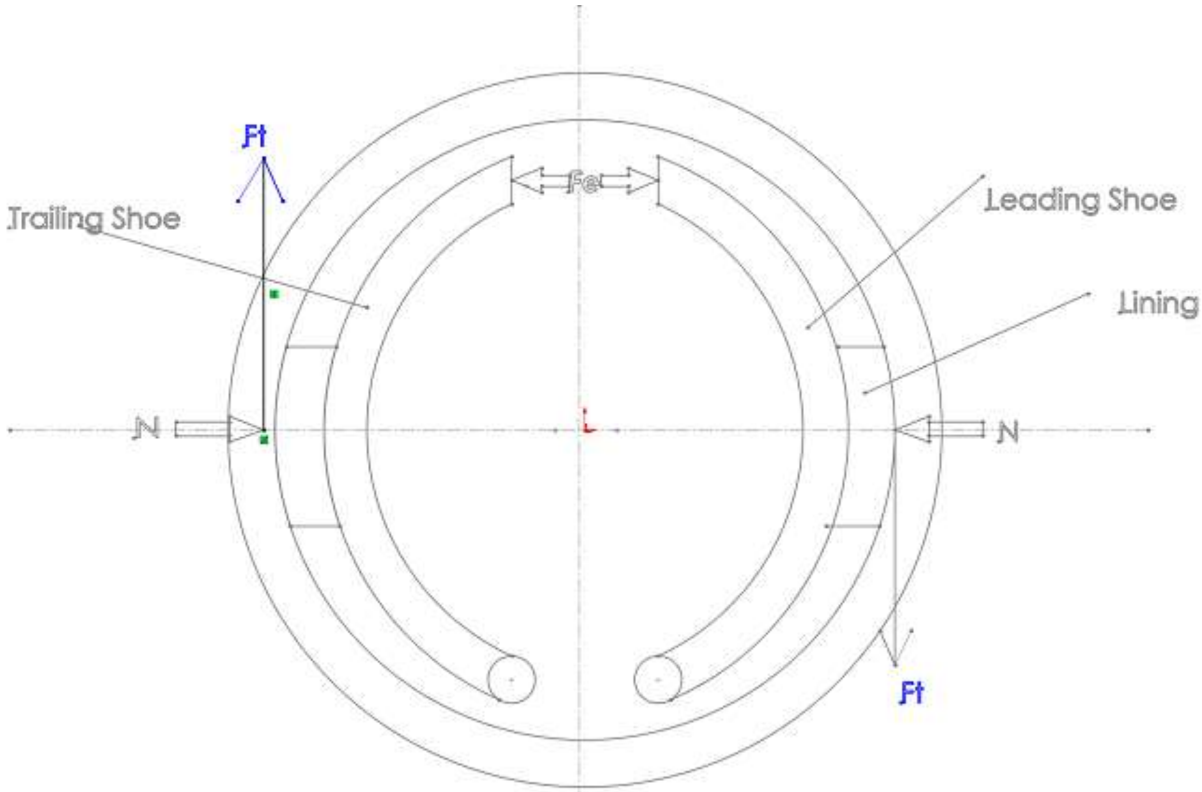


Figure 3.8. Drum and shoe

Likewise, in the left-hand shoe (Fig 3.8), the frictional force or drag, Ft, tends to oppose the shoe tip force, Fe, so that the effective shoe tip force becomes less than the expander input force. This reduction in shoe tip force below that of the initial input tip force is termed as negative servo, and shoes, which provide this de-energizing action are known as trailing shoes. Therefore, the trailing shoe tip resultant force is given by

$$F_t = \text{Fe} - F_l \qquad 3.6$$

The self-energizing action's amplitude is strongly influenced by the temperature of the rubbing surface, dampness, wetness, coefficient of friction, and speed of drum rotation. When the rotational orientation of the drum is altered, the original leading and trailing shoes turn into the new leading and trailing shoes, respectively, and their energizing effects are reversed. Drum brakes with leading-trailing shoes use the shoe arrangement shown in Fig. 3.8. A slightly higher level of self-energizing is attained if the shoe lining is firmly weighted toward the outer ends rather than the center.

iii) Retarding Wheel and Brake Drum Torques

The maximum retarding wheel torque is limited by wheel slip and is given by

$$\mathrm{T}w = \mu a W R \qquad 3.7$$

Where, $\mathrm{T}w$ is wheel retarding torque

μa is adhesion factor,

W is vertical load on wheel which is the load on rear wheel during braking

R is Wheel rolling radius

The torque produced at this brake drum caused by the frictional force between the lining and drum is required to bring the wheel to rest and is given by

$$\mathrm{Tb} = \mu \mathrm{Nr} \qquad 3.8$$

Where, $Tb$is brake torque,

μ is the coefficient of the friction between lining and drum.

N is the radial(normal) force between lining and drum

r is effective drum radius.

During braking, both these wheel and drum torques must be equal up to the point of wheel slip and they act in the opposite direction to each other, therefore

$$\mathrm{T}w = Tb, \mu a W R = \mu N r \qquad 3.9$$

Normal force

$$N = (\mu a W R)/(\mu r) \qquad 3.10$$

Tangential frictional force between lining and drum which is breaking force is given by

$$\mathrm{Ft} = \mu \mathrm{N} \qquad 3.11$$

Pressure on brake lining is given by

$$\mathrm{P} = \frac{\text{Normal force aplied on brake lining}}{\text{area of brake lining}} = \frac{\mathrm{N}}{\mathrm{A}} \qquad 3.12$$

iv) Kinetic energy of the vehicle

The brake system's objectives include immobilizing the stationary vehicle, reducing vehicle velocity more quickly or even coming to a safe stop, and maintaining a manageable pace. The kinetic energy that the car gains from maintaining its braking motion is first converted into heat (friction), which is subsequently released into the environment. Nevertheless, is used to overcome rolling and air resistance, which consistently oppose a vehicle's movement. The braking energy is as follows when a car brakes from a higher velocity v_1 to a lower velocityv_2.

$$E = \frac{m}{2}(v_1 - v_2)^2 \quad 3.13$$

Where m is the gross mass of the vehicle (i.e. mass of the vehicle and the passengers).

v) Braking force

To stop the vehicle in the shortest time, the maximum braking force cannot be larger than the maximum friction force between the tires and the ground, which can be transmitted to the ground. This maximum friction force on the rear tire is calculated as follows.

$$F_{fr} = \mu_a W \quad 3.14$$

The simple and fundamental relationships can be derived for the case where it is reasonable to assume that the force acting on the vehicle will be constant throughout a braking application.

The average deceleration during braking is given by

$$a_x = \frac{F_f}{m} \quad 3.15$$

Total time to stop the vehicle is

$$t = \frac{v_x}{a_x} \quad 3.16$$

vi) Temperature of brake lining

Due to the most heat being produced between the brake lining and drum, the temperature of the brake lining increases when braking. Maximum heat produced while braking is equal to the vehicle's maximum kinetic energy. Fourier's law of conduction, or the law of heat transfer, is used to determine the maximum temperature of the brake lining.

Fourier put forth the thermal conductivity theory in 1822. For a homogeneous material, the local heat flux is proportional to the negative local temperature gradient, according to Fourier's definition of the fundamental equation for heat conduction. For one dimensional steady state heat transfer, this statement can be represented by Equation 3.17.

$$q'' = -K\frac{dT}{dx} \quad 3.17$$

$$K = (Q/A)/(dT/dx) \quad 3.18$$

Where, k = Thermal conductivity, W/mm °C

$\Delta T/l$ = Temperature gradient

vii) Heat flux

Only calorific energy is transformed from mechanical energy in the case of the braking system. The area where the drum and lining make contact defines this energy. The drum's and lining's friction cause heat to be produced. In this instance, the brake lining absorbs the same amount of heat that is created. Heat flux into the contact area is obtained by first calculating heat flow into the drum and dividing it by the lining area. This heat flux given as equation 3.19 is then utilized as an input tool to begin the simulation (boundary condition).

$$q = \frac{Q}{A} \qquad 3.19$$

Where, q = heat flux

Q = amount of heat generated

A = contact area.

viii) Thermal conductivity of brake lining composite

Different materials with various volume fractions and thermal conductivity are used to create this composite brake liner sample. To forecast a composite's thermal conductivity, Caruso suggested a universal finite element analysis technique. This approach is based on fusing advanced finite element techniques with streamlined micromechanics equations. In deriving the equation to forecast thermal conductivity, the boundary conditions, and loading circumstances namely, temperature changes and thermal expansions were considered. The transverse and longitudinal conductivity equations were provided (Mutnuri, 2006).

$$\mathrm{Kc} = \sum[(\mathrm{Vp} \times \mathrm{Kp}) + (\mathrm{Vm} \times \mathrm{K\,m})] \qquad 3.20$$

Where $Vp, Kp, Vm, and\ Km$are volume fractions and thermal conductivity of particles and matrix respectively. The microstructure of any fiber plays a vital role in carrying heat. The glass fiber has an amorphous structure. It consists of SiO2 molecules and forms a three-dimensional silica polyhedral network along the length of the fiber. It behaves nearly isotopically, resulting in nearly the same conductivity properties in any direction of the fiber.

3.3.5. Characterization set up

It is the process of testing using different method to know the mechanical properties of the material. Numbers of tests are conducted on WP 300 material testing devices. The capacity of the tester is sufficient to carry out tests of an industrial nature up to 50kN. Simple operation and robust construction make the tester particularly suitable for student experiments. The tester is a vertical, hydraulically operated pillar tester with the direct generation of both tensile and compressive forces. The height of the lower cross-member can be adjusted in steps for coarse adjustment. Cylindrical receptacles on the cross-members make the different experimental setups easy to change. Force and displacement are recorded by sensors, displayed and can be processed on a PC.

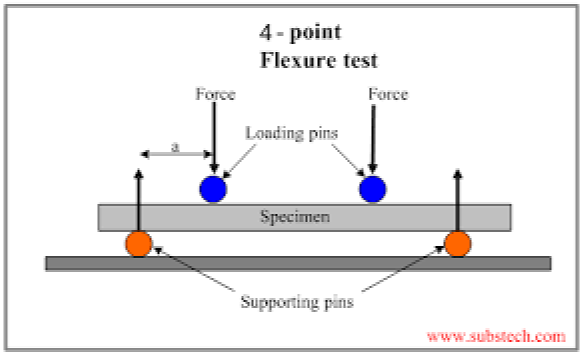
a) Flexural Strength Test

The degree to which a material is suitable for an application depends on a number of parameters, including its flexural strength and flexural modulus. Flexural strength and flexural modulus are measurements of how well a material can withstand bending stress without cracking or breaking. A substance with high flexural strength can withstand bending, stretching, twisting, and other forms of stress without deforming when force is applied in tension or compression. The flexural strength of a material is defined as the greatest fiber stress at failure on the tension side of a flexural specimen. WP 300 is used to gauge a material's stiffness or strength. Flexural strength can be evaluated using one of two techniques; three point and four point. In a four-point bending strength test, the sample's medium span is subjected to an increasing load until the material breaks or permanently bends, whichever comes first. A composite beam specimen with a rectangular cross-section is loaded in this test and bent in four directions (fig3.9 a). The flexural strength in a four-point flexural test is thus given by applying a homogeneous beam theory.

$$\sigma_{UF} = \frac{3PmaxL}{4bh^2} \qquad 3.21$$

Where P_{max}= maximum load at failure; b = specimen width; h = specimen thickness; L = specimen length between the two support points.

According to ASTM D790 the dimension of the sample is 127x12.7x5mm. Test machines for reinforced & unreinforced plastic generally require a force capacity of 2.2kN (500lb) with the potential of up to 25kN.



(a) (b)

Figure 3.9. (a) four-point flexural test diagram and (b) flexural test samples

b) Compression strength test

By inserting the compressive force into the specimen at wedge grip contacts, this approach calculates in-plane compressive characteristics. Although alternative materials may be tried, WP 300 is particularly suitable for composite materials reinforced by high-modulus fibers like tape and cloth. The specimen is strained till it breaks. The cross-section of the specimens should be uniformly rectangular, and different thicknesses can be permitted. Specimen dimensions, according to WP 300, are 50x50x5mm.

Compressive strength is given by

$$CS = \frac{F}{A} \qquad 3.21$$

c) Tensile test

Tensile testing is a destructive testing method that reveals details about the material's tensile strength, yield strength, and ductility. It assesses the amount of strain or elongation that must be applied in order for a composite specimen to break, as well as the force necessary to achieve that point. Installing the specimen in a machine (fig 3.11a) and applying tension to it is how a tensile test is conducted. According to the increase in gauge length, the tensile force is measured. Engineering stress or nominal stress is defined as

$$\sigma = \frac{F}{A} \tag{3.22}$$

Where F is the tensile force and A is the initial cross-sectional area of the gage section which is given by

A= gage length x gage width

Engineering strain, or nominal strain, e, is defined as

$$e = \frac{\Delta L}{L_o} \tag{3.23}$$

Where L_o is the initial gage length and ΔL is the change in gage length ($L - L_o$).

The size of the specimen for the composite material is given as 70×12.5×5mm (fig 3.10). The reduced gage section is 7mm.

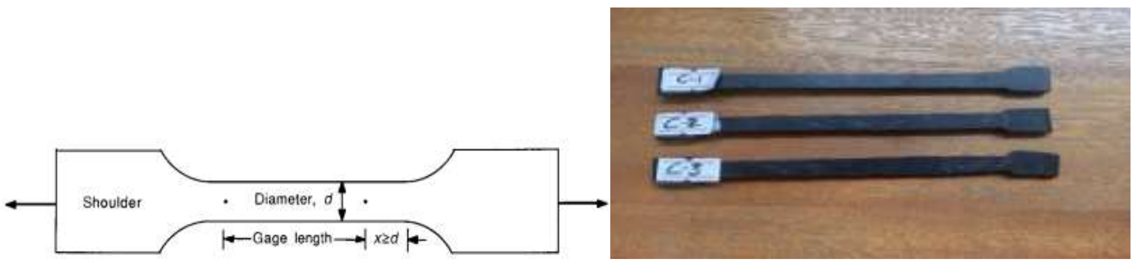


Figure 3.10. Typical tensile specimen, showing a reduced gage section and enlarged shoulders

(a) (b) (c)

Figure 3.11. (a) Tensile test set up, (b and c) samples after tensile test

d) Wear test

Pin-On-Disc wear testing equipment was used to prepare specimens in accordance with ASTM standards. The Pin-On-Disc machine is a multipurpose tool created to assess the wear and friction properties of various materials subjected to sliding contacts in dry or lubricated conditions. A stationary pin stylus and a revolving disk are used in the sliding friction test. The usual load is used. Electronic sensors keep track of abrasion and frictional force in relation to load, speed, lubrication, and environmental factors. Diagram for the pin-on-disc wear test is presented in Fig. 3.12.

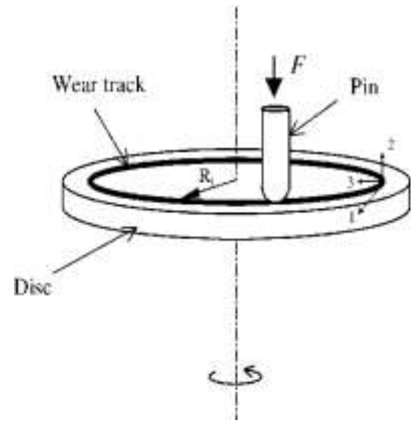


Figure 3.12. Pin on disc wear test layout (Bressan et al, 2008)

Wear rate is given by

$$Wr = \frac{\Delta W}{2\pi NRt} \qquad 3.24$$

Where ΔW = weight loss (weight difference before and after wear (g), R = radius of disc (m), N = speed in rpm, t = time it takes each sample on the grinding machine (min). The input parameters are the speed of the motor, elapsed time, and load. The sliding distance is calculated from the rpm of the motors, the track diameter of the disc, and elapsed time. The size of the sample is prepared according to the specifications of the machine, which are 5.8mm in diameter and 12.5mm in length. The effective track diameter of the disc is set to 100mm. For all samples, the motor speed is kept constant to 600rpm and the load 20N, and the time is kept constant at 15 minutes. The temperature and weight of each sample is measured just before and after test. The weight loss method is used to calculate the wear rate by equation 3.24 or it can be read from the data points given in the appendix A&B. The coefficient of friction is either calculated from frictional force and normal load or the output displayed automatically on the screen of the machine in appendix C.

A wear rate test is conducted on a pin on disc tester according to ASTM G99 at Addis Ababa Science and Technology University material laboratory (fig 3.13).

Figure 3.13. Wear rate test set up

e) Relative density test

The relative density of the brake linings samples was found using Archimedes principle. The buoyant force on a submerged object is equal to the weight of the fluid displaced. The samples were weighed in air and when fully immersed in a beaker of water by means of a thread without touching the walls of the beaker. The relative density of samples was calculated using equation.

$$\rho_{sample} = \rho_{water} \frac{\text{weight of sample in air}}{\text{weight of sample in air} - \text{weight of sample in water}} \quad 3.25$$

Density of water is taken to be 1000kg/m^3.

f) Water and oil absorption test

The water and oil (SAE DOT 3) absorption of the samples was determined by soaking the samples in water and oil for 24, 36 and 48 hours (fig 3.14). Before the test, the samples were oven dried and the weight measured. The samples were cleaned after 24 hours in water and oil and weighed.

(a) (b)

Figure 3.14. (a) Water and (b) Oil absorption test set up

The percentage absorption was calculated using the following equation.

$$\text{Absorption} = \left(\frac{W_1 - W_o}{W_o}\right) \times 100\% \qquad 3.26$$

Where, W_o = weight of the sample before immersion (g), W_1 = weight of the sample after immersion.

3.3.6. Software modeling of drum and brake lining RVE

Three different software are used to model and analysis in this thesis. To model drum brake, Solidworks2016 is used while for brake lining MSc Digimat2017 FE is used. To analysis both the mechanical and thermal properties of the drum and the lining (RVE), ANSYS 2022 R1 is used.

In this thesis, an RVE technique with incorporated particulate inclusions is developed to predict the characteristics of the composite. The Digimat2017-FE software is used to create a 3D microstructure RVE model of composite (fig3.15). The RVE microstructure model is comprised of epoxy resin as matrix and cow horn, graphite, and silica as particulate (with different shapes) inclusions with an assumed perfectly bonded interface. Through proper tuning of parameters, the size and dispersion of particulate inclusions in a composite material are precisely stated. Figure 3.16 shows that how particles are dispersed in epoxy matrix during RVE modeling. The RVE model was generated by assigning the volume fraction, shape, distribution of inclusion phase and the minimum relative distance between inclusions. The developed RVE drum are imported to ANSYS 2022R1 (fig3.17&18) and all the meshing and other analysis are conducted.

Table 3.4. Input parameters in Digimats FE

Material	Density(g/ cm^3)	Young. (Gpa)	P. R	Mass/volume fraction%			No of particle inclusion	Shape
				C_1	C_2	C_3		
Epoxy	1.1	3.42	0.3	0.4	0.3	0.35		Cubic
Cow horn	0.92	2.2	0.38	0.3	0.4	0.25	10000	Prism
Graphite	2.266	11.5	0.31	0.15	0.15	0.2	4000	Ellipsoid
Silica	2.65	70.55	0.15	0.15	0.15	0.2	4000	Sphero-cylindrical

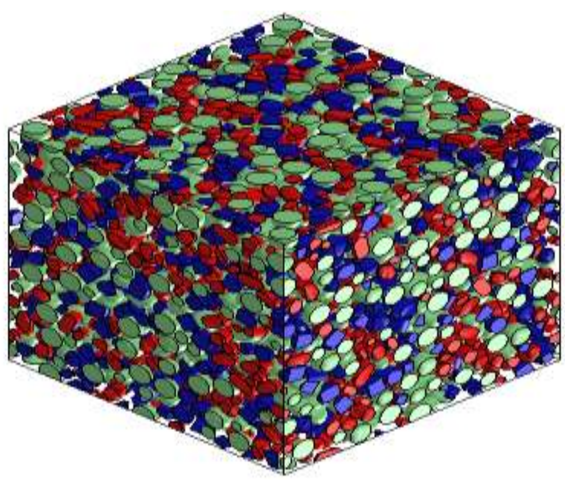
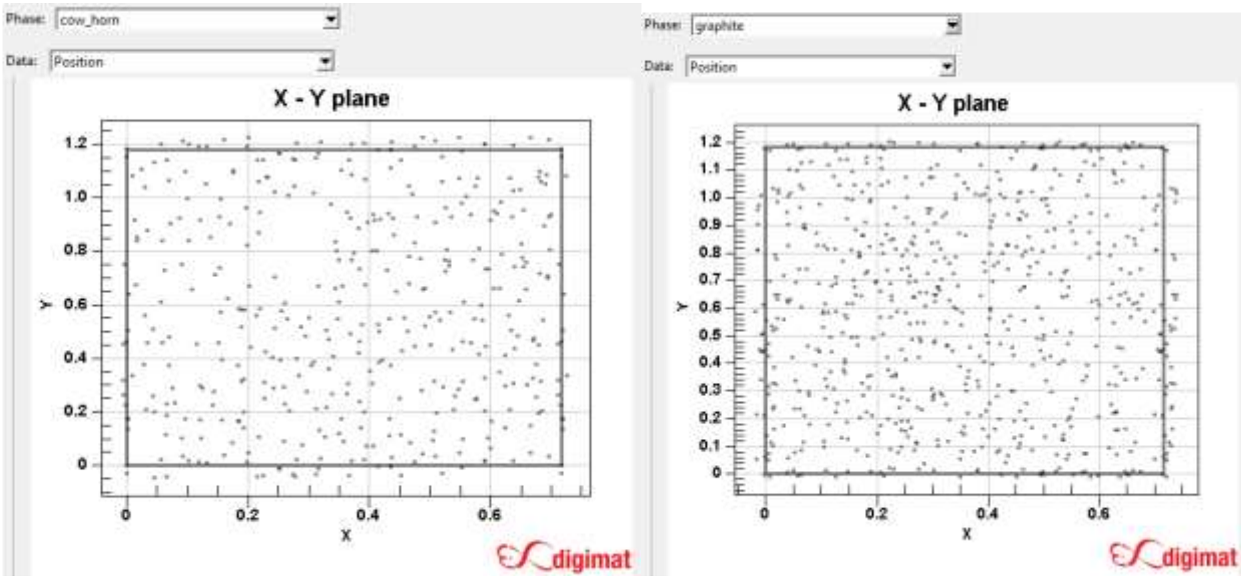
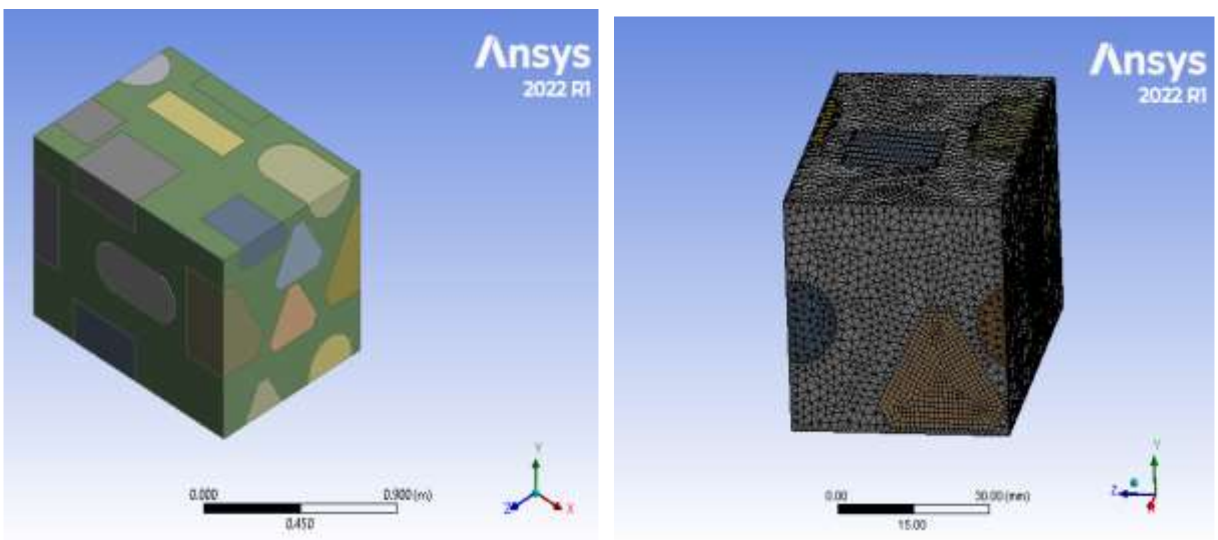


Figure 3.15. Generated 3D RVE model



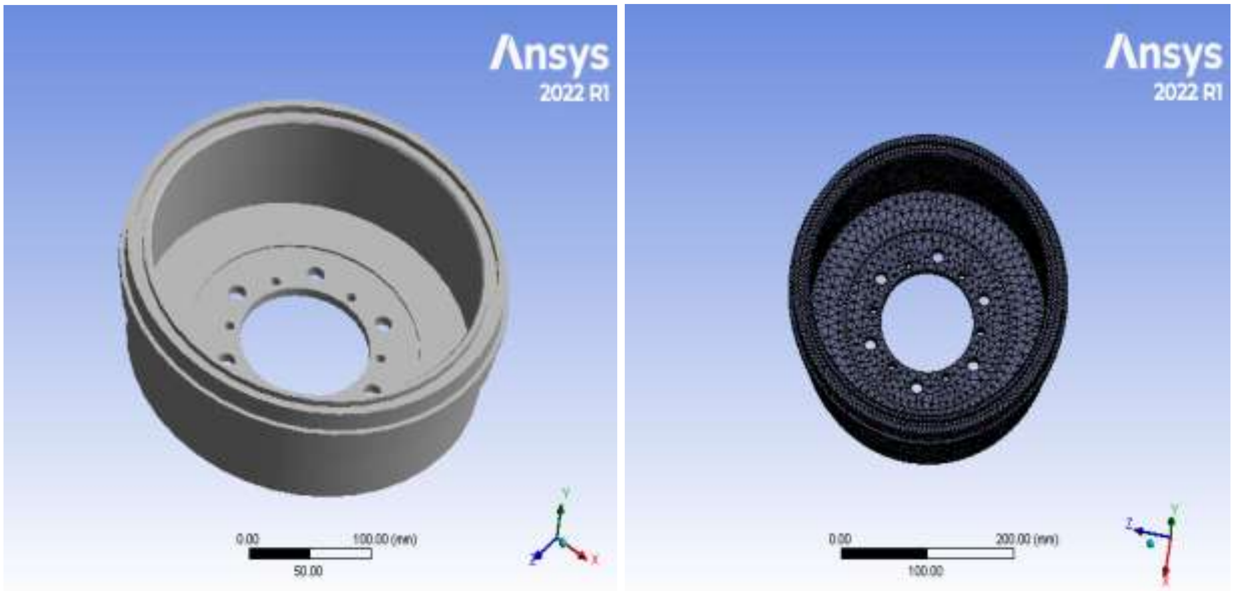
(a) (b)

Figure 3.16. Particles position of different phases (a) cow horn (b) graphite



(a) (b)

Figure 3.17. (a) RVE imported to ANSYS and (b) RVE meshed



(a) (b)

Figure 3.18. (a) Drum model (b) meshed

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

This chapter deals with the results of the experiment after different characterization and software simulation study. As explained in section three there are a number of characterizations that needed to define whether the developed composite fits for the application purpose or not. It also contains detail discussions of the result obtained.

4.2. Experimental Results

Experiment such as wear test is conducted at Addis Ababa Science and Technology University; while density test, water and oil absorption test are conducted at the Adama Science and Technology University Department of Material engineering. Experiments such as tensile, compression, and flexural are conducted at the Mechanical engineering department laboratory on WP 300 material testing devices.

4.2.1. Tensile test result

The tensile test is one of the destructive tests, as explained in section three. It measures the force required to break a composite specimen and the extent to which the specimen stretches or elongates to that breaking point. During the test, the testing machine records stress-elongation percentage data and force applied to stretch or break the specimen. The test results are explained below for each composite sample.

a) **Tensile test result for composite one (C1)** The composite one is created using the input parameters listed in table 3.4, which include epoxy 40%, cow horn particle 30%, and graphite and silica 15%. Figure 4.1 depicts the tensile test result of stresses versus elongation percentage.

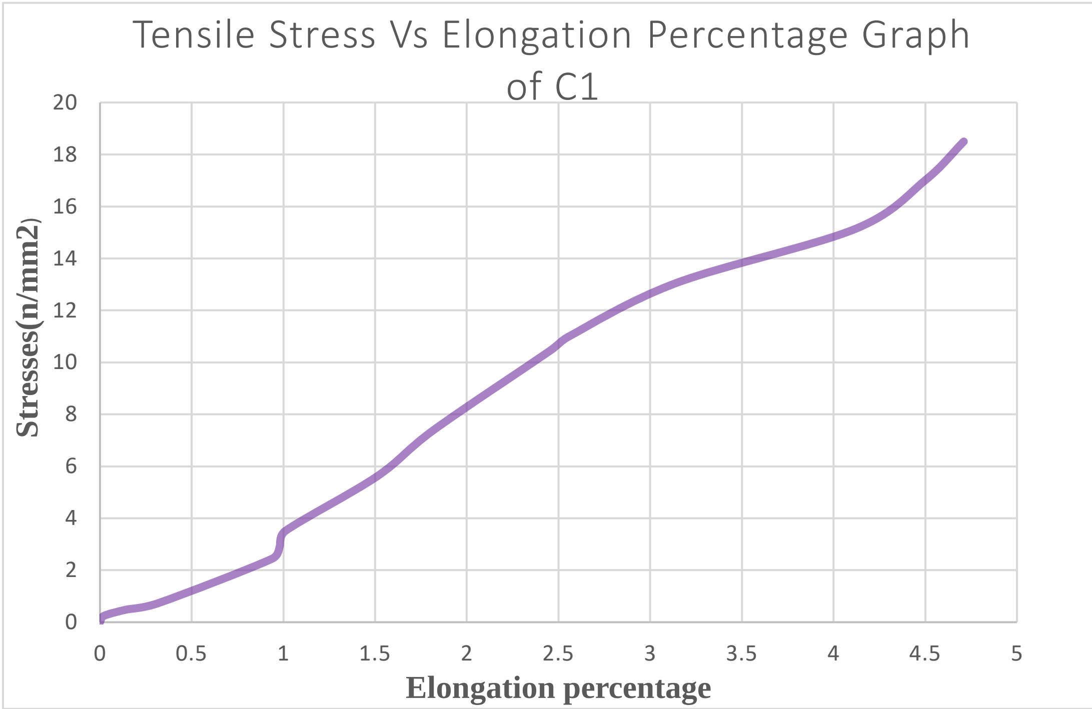


Figure 4.1. Stresses vs. elongation percentage graph of tensile test of C1

b) Tensile test result for composite two (C2)

Composite two is also made according to table 3.4 with epoxy 30%, cow horn particle 40%, and graphite and silica15%. Tensile stresses and elongation percentage is given in fig 4.2.

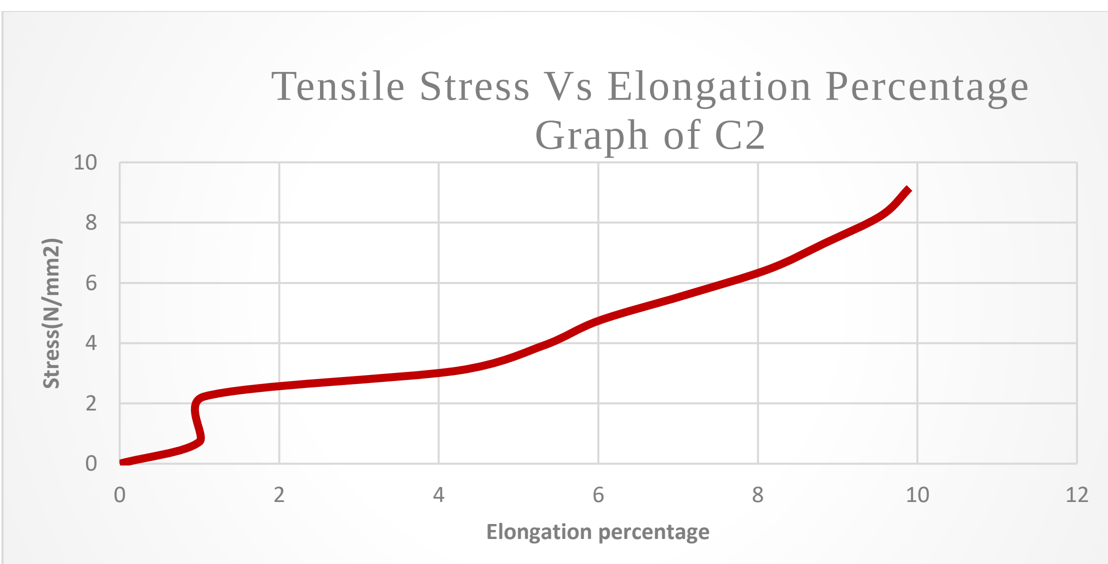


Figure 4.2. Stresses vs. elongation percentage graph of tensile test of C2

c) Tensile test result for composite three (C3)

In composite three, the percentage of both epoxy and cow horn particles has decreased to 35% and 25%, respectively. The percentage of silica and graphite is raised to 20%. Tensile stresses and elongation percentage is given in fig 4.3.

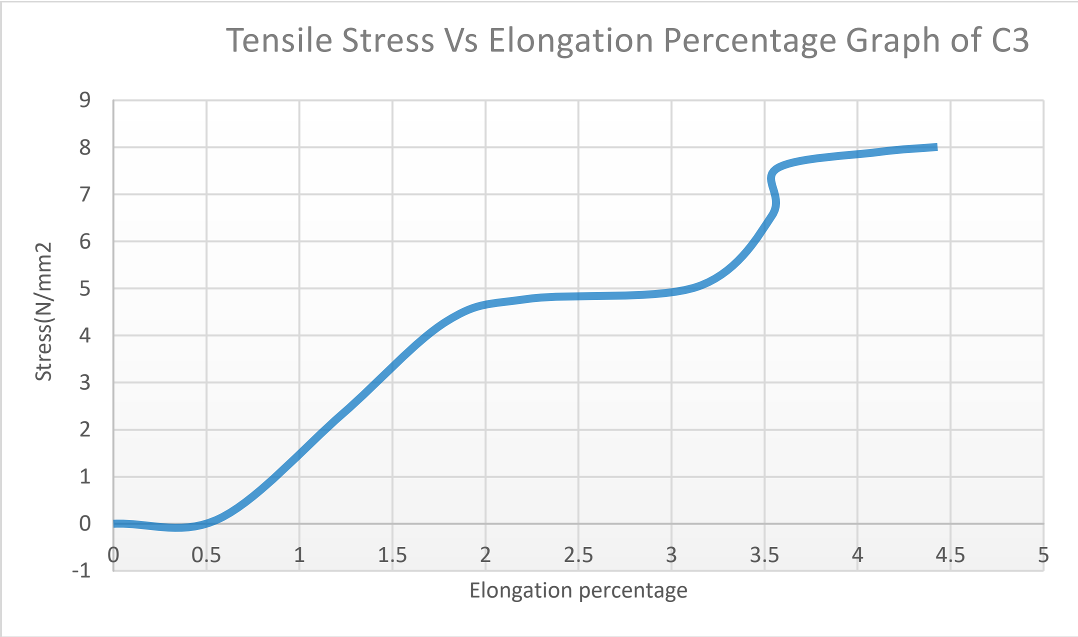


Figure 4.3. Stresses vs. elongation percentage graph of tensile test of C3

Summary of tensile test results

In composite one, the maximum tensile stress recoded is 4.71MPa. The maximum elongation percentage gained is 18.93. Composite two has a maximum tensile stress of 9.9MPa and the maximum elongation percentage gained is 8.25(Appendix D table 5.1). The maximum tensile strength obtained in composite three is 0.29MPa and the maximum elongation percentage is 12.54. The tensile stresses and percentage of elongation are given in figure 4.4. Brittle materials such as glass, particulate composites, and ceramics exhibit elastic behavior until they fail catastrophically, without warning. They do not deform plastically or yield, and therefore do not have a yield point. Composite two (C2) has maximum tensile stress of 9.9Mpa which is greater than the other two composites.

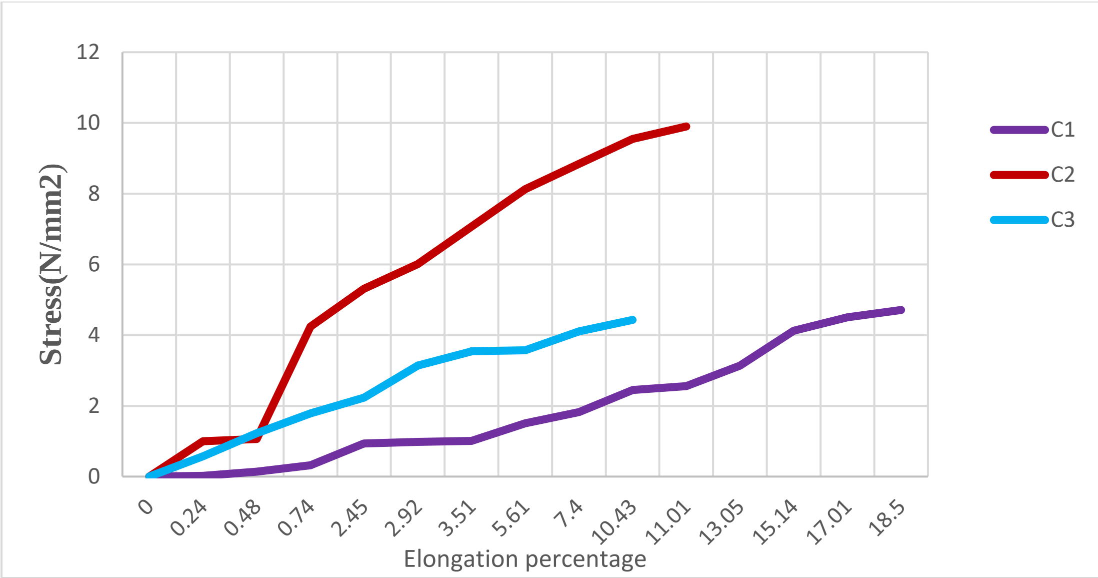


Figure 4.4. Tensile stress vs elongation percentage of three samples

4.2.2. Compression test results

The compression test is also one of the main destructive material tests that uses compressing force to failure. Each composite with a dimension of 50x50x5mm has two samples, and the average value is obtained. Figure 4.5 shows composite samples after compression testing.

Figure 4.5. Composite samples after compression test

a) Compression test result for composite one (C1)

Composite one is made according to specification on table 3.4 with epoxy 40%, cow horn particle 30%, and graphite and silica15%.

Force applied to the failure and stress (compression strength) elongation is given in table 5.2.

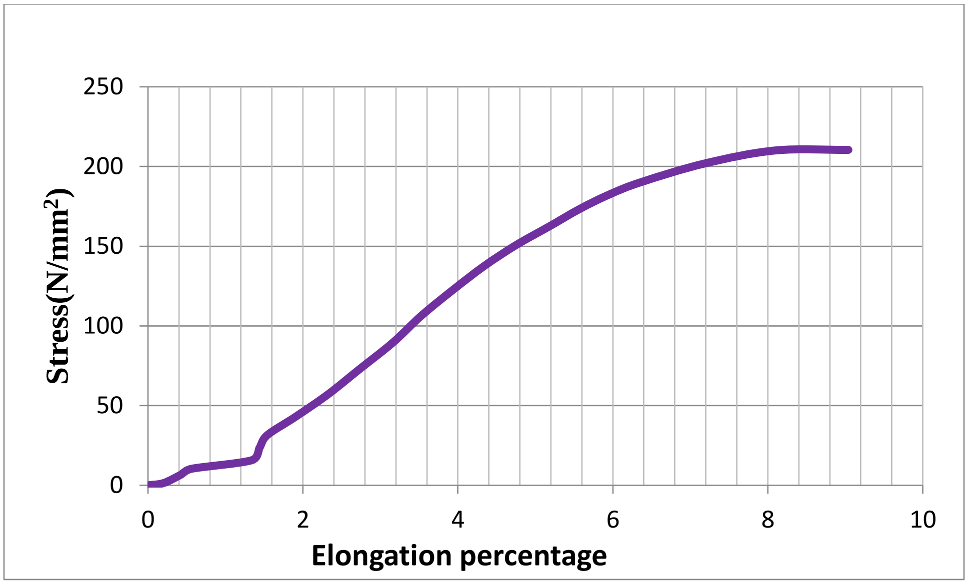


Figure 4.6. Stresses vs. elongation percentage graph of compression test of C1

b) Compression test result for composite one (C2)

Composite two is also made according to specification on table 3.3 with epoxy 30%, cow horn particle 40%, graphite and silica15%. Maximum applied force that causes the sample to the failure is 7.38kN. The maximum ultimate compressive stress obtained is 29.52MPa with elongation percentage of 3.2. Stress versus elongation percentage diagram is given in figure 4.7.

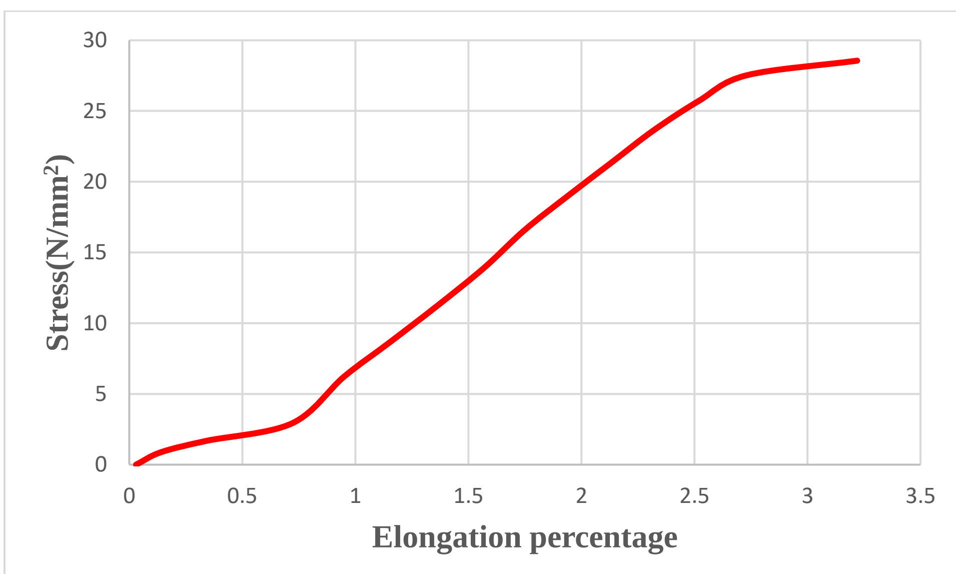


Figure 4.7. Stresses vs. elongation percentage graph of compression test of C2

c) Compression test result for composite three (C3)

In composite three, percentage of both epoxy and cow horn particle are decreased to 35% and 25% respectively. The percentage of silica and graphite is raised to 20%. Maximum ultimate compression stress obtained is 275.5MPa(fig4.8) and maximum elongation percentage is 24.75.

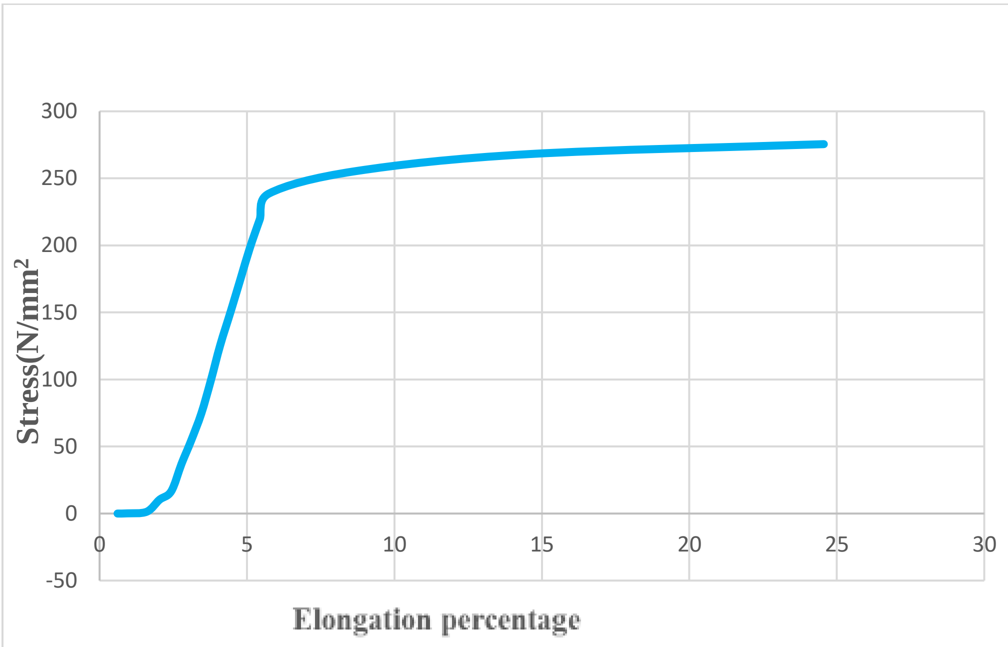


Figure 4.8. Stresses vs. elongation percentage graph of compression test of C3

Summary of compression test result

The maximum force to failure in composite one is 5.95kN, and the maximum compressive strength and elongation percentage are 210.44MPa and 9.04, respectively. The force applied to the failure and stress (compressive strength) elongation is given in table 4.5. In a composite two, the two maximum forces to failure are 7.38kN, with maximum compressive strength and elongation percentages of 29.52MPa and 3.2, respectively. The composite three has the force applied to the failure and the stress (compressive strength) elongation is given in table 4.6. Maximum force to failure is 7.79kN, with maximum compressive strength and elongation percentages of 275.52MPa and 24.75, respectively. The compression test results of three composites are summarized in figure 4.9.

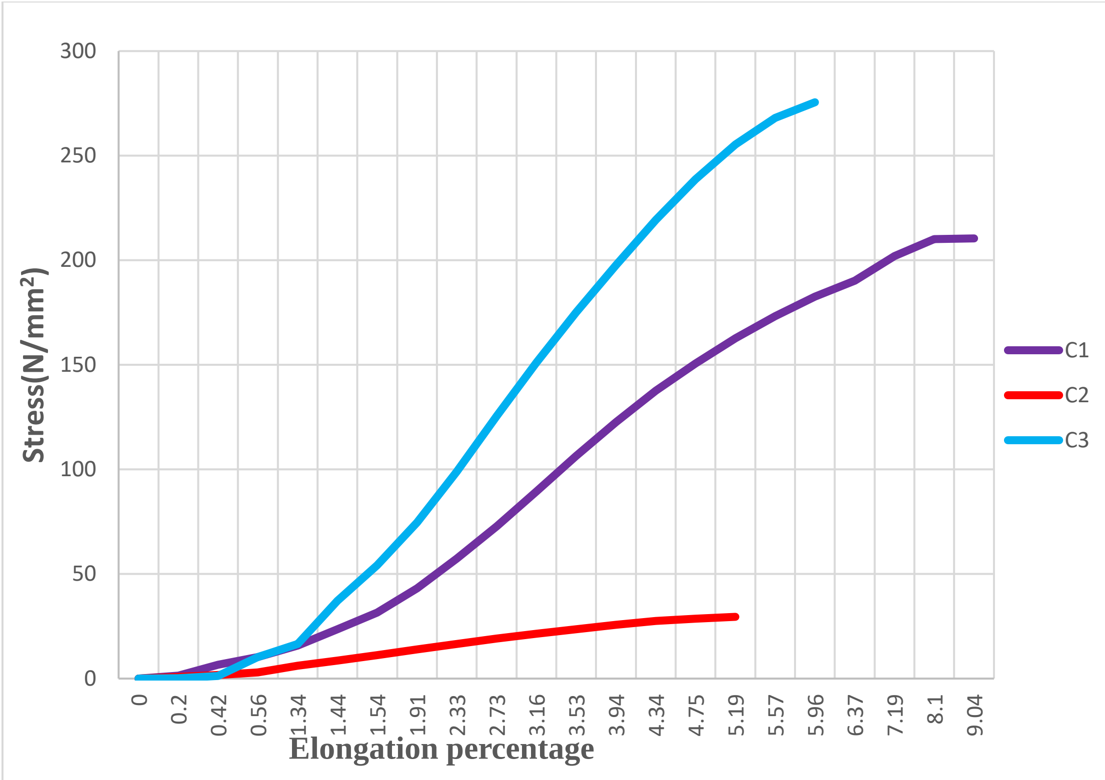


Figure 4.9. Average Compressive stress of three samples

4.2.3. Flexural test result

Flexural strength of each composite sample is done by four-point bending. During the test the maximum force brake point (fig4.10) is taken from force elongation table data.

Figure 4.10. Sample after flexural test

Average flexural strength is calculated according to equation 3.21 and the dimension of samples. The flexural strength in a four-point flexural test is given by $\sigma_{UF} = \frac{3PmaxL}{4bh^2}$. Flexural strength of each composite is calculated depending upon force elongation data as follows.

a) Flexural strength of composite one (C1)

Table 4.6 is obtained after two trial of flexural test and the average value of the two-maximum force at failure is obtained.

$$\sigma_{UF} = \frac{3PmaxL}{4bh^2}, P_{\max average} = 0.45kN + 0.41kN = 0.43kN, \text{L=140mm, b=12, h=5}$$

$$\sigma_{UF} = \frac{3\times 0.43kN\times 140mm}{4\times 12\times (5)^2} = 150.5\text{N/mm}^2(150.5\text{MPa})$$

Table 4.1. (a) Force elongation of C11 and (b) C12 of composite one

(a)

Force-elongation table of C11		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.32
3	0.02	0.35
4	0.09	0.41
5	0.12	0.65
6	0.14	0.74
7	0.15	0.81
8	0.25	0.84
9	0.26	0.88
10	0.35	0.91
11	0.41	0.94
12	0.42	1.12
13	0.45	1.24
14	0.23	2.25
15	0.05	3.54
16	0.02	4
17	0.01	4.67
18	0	5.67

(b)

Force-elongation table of C12		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.11
3	0.02	0.25
4	0.11	0.41
5	0.12	0.55
6	0.14	0.65
7	0.15	0.89
8	0.18	1.01
9	0.26	1.05
10	0.32	1.15
11	0.38	1.18
12	0.41	1.19
13	0.35	1.35
14	0.25	2.33
15	0.01	3.11
16	0	3.95

b) Flexural strength of composite two (C2)

Table 4.2. (a) Force elongation of C21 and (b) C22 of composite two

(a) (b)

Force-elongation table of C21		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.11
3	0.02	0.13
4	0.1	0.15
5	0.15	0.55
6	0.18	0.63
7	0.21	0.75
8	0.23	1.23
9	0.22	2.55
10	0.15	2.96
11	0.13	3.23
12	0.1	4.01
13	0	4.23

Force-elongation table of C22		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.11
3	0.03	0.14
4	0.08	0.18
5	0.18	0.55
6	0.22	2.55
7	0.21	2.96
8	0.15	3.12
9	0.12	3.78
10	0.11	4.56
11	0	4.93
12	0	4.98

$$P_{\max average} = \frac{0.23+0.22}{2} = 0.225\text{kN}$$

$$\sigma_{UF} = \frac{3\times 0.225kN\times 140mm}{4*\times 12\times(5)^2} = 78.75\text{N/mm}^2(78.75\text{Mpa})$$

c) Flexural strength of composite three (C3)

$$P_{\max average} = \frac{0.15+0.13}{2} = 0.14\text{kN}$$

$$\sigma_{UF} = \frac{3\times 0.14kN\times 140mm}{4\times 12\times(5)^2} = 49\text{N/mm}^2(49\text{MPa})$$

Table 4.3. (a) Force elongation of C31 and(b) C32 of composite three

(a)

Force-elongation table of C31		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.11
3	0.1	0.15
4	0.15	0.22
5	0.14	0.63
6	0.12	0.89
7	0.11	2.45
8	0.1	2.55
9	0.09	2.9
10	0.08	3.23
11	0.04	3.89
12	0	4.21

(b)

Force-elongation table of C32		
No.	F[kN]	dL[mm]
1	0	0
2	0.01	0.11
3	0.02	0.13
4	0.12	0.14
5	0.13	0.89
6	0.11	1.34
7	0.1	1.78
8	0.08	2.45
9	0.06	2.9
10	0.04	3.45
11	0.02	4.04
12	0	4.6

Summary of flexural test results

Flexural strength is the highest amount of stress in bending tension that a material can withstand before failing. The maximum bending tensile stress causes the composite material to break down before the maximum bending compressive stress. Accordingly, the ultimate flexural strength of composite one is 150.5MPa, composite two is 78.75MPa, and composite three is 49MPa. The highest value is reached in composite number three since there is the most epoxy present.

4.2.4. Wear rate test result

The results given in table 4.4 are summarized from appendices A and B.

Table 4.4. Wear rate test result

	C1	C2	C3
Weight before	0.4540	0.4597	0.5215
Weight after	0.4383	0.4460	0.5113
Temperature before	25	25	25
Temperature after(^{o}C)	82.6	84	87.5
Load(N)	20	20	20
Max. Frictional force	4.80	6.25	6.20
Wear rate(g/m)	0.000042	0.000036	0.000027
Coefficient of friction	0.24	0.32	0.31

The wear rate is minimum in composite three, which is 0.00027g/m due to the percentage of abrasive being increased. The maximum value is obtained in composite one, which has a value of 0.000042g/m. Composite three, falls between the two, which is 0.000036g/m. The maximum coefficient of friction is obtained in composite two, which is 0.32.

4.2.5. Density test result

This result is obtained experimentally according to Archimedes principle of equation 3.25. The results, measured weight of sample in air and water is given in table 4.5.

Table 4.5. Density results from Archimedes principle

No	Samples	Mass(g)		Density(g/cm^3)
		In air	In water	
1	C_1	23.51	7.70	1.48
2	C_2	13.83	5.05	1.57
3	C_3	19.88	7.48	1.60
4	Cow horn	100	8.81	0.91

By using equation 2.6 of section two and mass and volume from table 3.4, the density of each sample is calculated and the result is given in table 4.6.

Table 4.6. Density result from the rule of mixture of composites.

No	Samples	Mass(g)		Density(g/cm^3)
		Volume(cm^3)	Mass(g)	
1	C_1	105	149	1.419
2	C_2	105	147.64	1.406
3	C_3	105	164.31	1.564

According to the result obtained by theoretical and experimental approach, the composite one has minimum value of 1.48g/cm^3. Cow horn powder is tested for density to be 0.91g/cm^3.

4.2.6. Water and Oil absorption test result

These results are obtained after immersion of samples in oil and water for 24hrs, 36hrs and 48hrs and the weight of each sample is taken. Table 4.7 explains the weight of samples before and after immersion and percentage of absorption. The percentage absorption of each sample is calculated as equation 3.26.

Table 4.7. Water and Oil absorption test result

Samples		Mass before immersion(g)		Mass after immersion(g)		Absorption percentage	
		Oil	Water	Oil	Water	Oil	Water
For 24hrs	C_1	15.36g	19.22	15.44	19.32	0.4	0.60
	C_2	13.83g	20.29	13.89	20.36	0.4	0.50
	C_3	14.13g	20.43	14.16	20.57	0.2	0.30
For 36hrs	C_1	15.36g	19.22	15.56	19.51	1.3	1.5
	C_2	13.83g	20.29	13.99	20.55	1.1	1.2
	C_3	14.13g	20.43	14.28	20.63	0.9	0.9
For 48hrs	C_1	15.36g	19.22	16.09	20.44	4.7	6.3
	C_2	13.83g	20.29	14.33	21.23	3.6	4.6
	C_3	14.13g	20.43	14.54	21.25	2.9	4

Oil absorption increases as the staying time in oil are increasing (fig 4.11). For the first 24hrs, it is below 1% and below 5% for 48hrs tests.

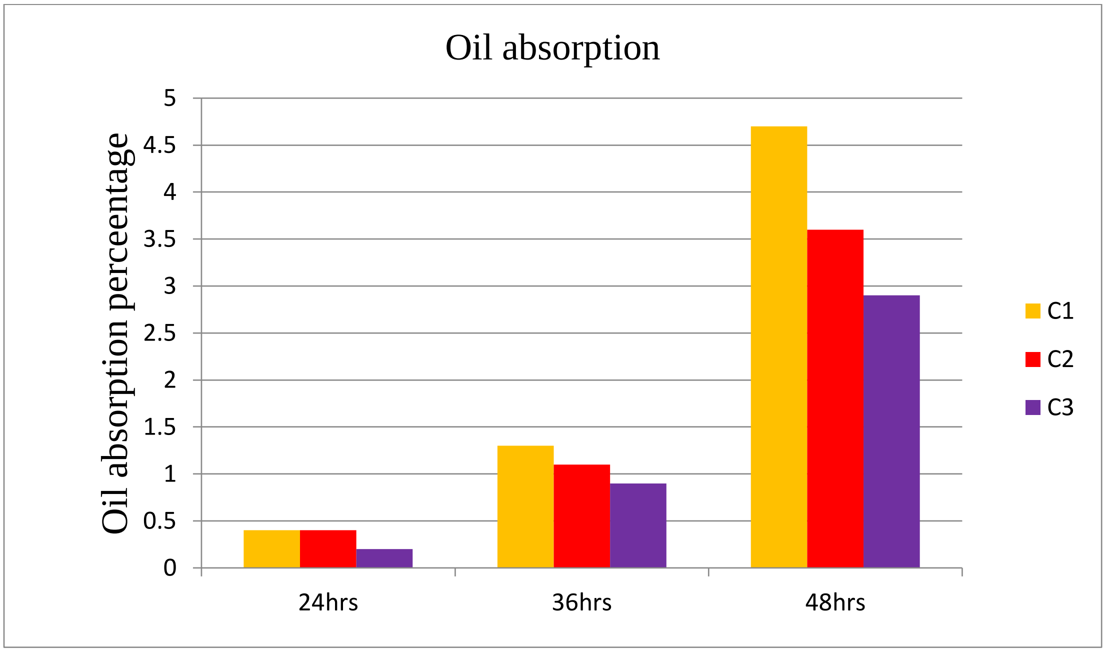


Figure 4.11. Comparison of oil absorption tests for different days

Water absorption percentage also increases as the time increases (fig4.12). The range is from 0.6% to 6.3%.

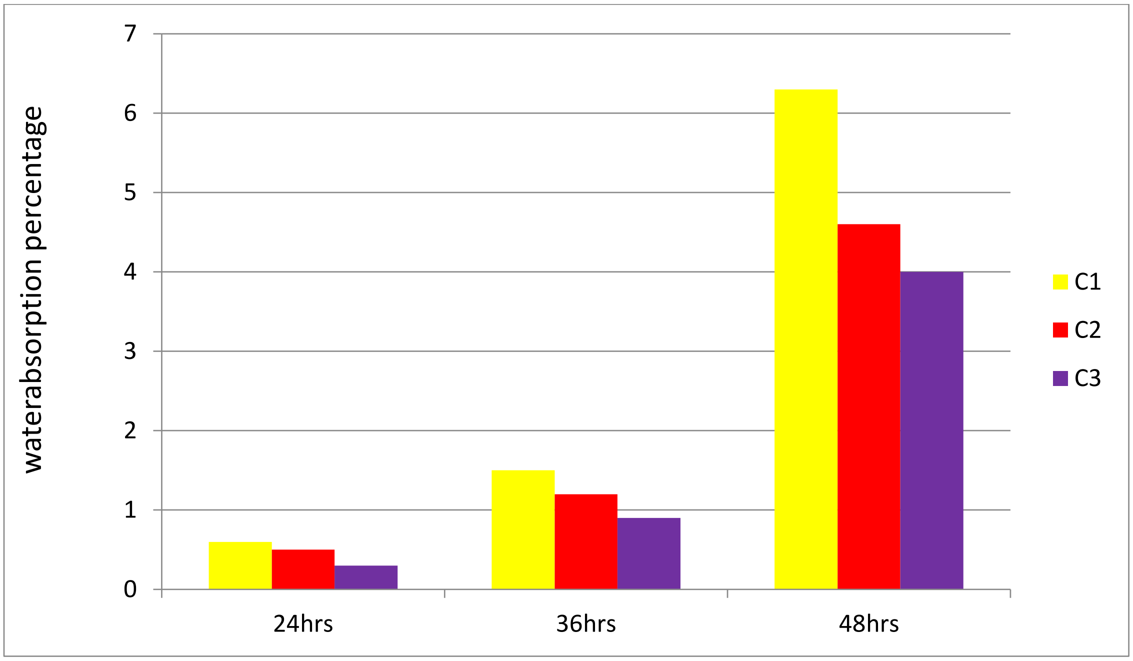


Figure 4.12. Water absorption test for different days

Experimental results are summarized in table 4.8.

Table 4.8. Summary of a composites sample experimental result

Properties		C1	C2	C3
Tensile strength (MPa)		4.71	9.9	4.43
Compressive (MPa)		210.44	29.52	275.5
Flexural (MPa)		150	78.75	49
Density (g/cm^3)		1.40	1.57	1.6
Wear rate(g/m)		0.000042	0.000036	0.000031
Coefficient of friction		0.24	0.32	0.31
	After 24hrs	0.2	0.4	0.4
Oil absorption (%)	after 36hrs	0.9	1.1	1.3
	After 48hrs	2.9	1.5	3.6
	After 24hrs	0.6	0.5	0.5
Water absorption (%)	After 36hrs	0.9	1.5	1.5
	after 48hrs	4	4.7	6.3

4.2.7. Rear wheel dynamics of minibus KG-LH172V-RBMBS

To calculate the load analysis of rear wheel of minibus tax 5L model, it is depended on specification of specified vehicle and given formula in section 3.3.

a) Force on rear brakes

This total force is in the force applied by the driver and reaches the rear wheel through the break lining line. For manual vehicle, pedal leverage ratio = b/a = 5:1, according to Federal Motor Vehicle Standard (FMVS) the force driver can apply on foot pedal is within the range of 136-387N. The average force applied on foot pedal is 261N.

Cross sectional area of master cylinder and rear piston is calculated as follows:

$$A_m = \pi r^2 = 3.14\times (11.7)^2 = 429.8mm^2$$

$$A_r = \pi r^2 = 3.14\times (12.9)^2 = 522.5mm^2$$

$$E_m = 260\times 5 = 1300N$$

$$P = 1300N/429.8mm^2 = 3.025N/mm^2$$, which is the same in the line.

$$F_r = 3.025N/mm^2\times 522.5mm^2 = 1580.5N$$

$F_{tr} = 4\times 1580.5 = 6322N$ this force (F_e) is applied on both two rear wheel.

b) Pressure on break lining

The pressure on break lining depends on the area of the lining and the normal force applied by the drum to the lining. Normal force is calculated from the equation 3.10 and coefficient of friction if the lining is from the wear test result, which is 0.32, and assumes the adhesion/coefficient of friction between road and tire is 0.7. The rolling radius of KG-LH172V-RBMBS is given by 195R15, which is 693mm, and the effective drum radius is 135mm (table 3.2). Assume 50% of the mass of the vehicle, which is 1400kg, is transferred to the front during hard braking. Therefore, the normal force is calculated as

$$N = (\mu a W R)/(\mu r)$$

$$N = \frac{0.7\times 1400kg\times 9.81\times 693mm}{0.32\times 135mm} = 154.2kN$$

Maximum pressure is calculated as equation 3.12. The area of brake lining is calculated from the dimension of break lining as follows.

$\text{Area of lining} = \text{width} \times \text{length} = 50\text{mm} \times 149.5\text{mm} = 7471.75mm^2$

$$P = \frac{\text{Normal force aplied on brake lining}}{\text{Area of brake lining}} = \frac{N}{A}$$

$$P = \frac{154.2\text{kN}}{7471.75mm^2} = 20.64\text{MPa}$$

iii) Kinetic energy of the vehicle

According to the specification of the current vehicle, three vehicle speeds 105km/hrs, 60km/hrs, and 30km/hr. are selected to analyze the amount of heat generated, braking force, and stopping time during braking. Assume the adhesion/coefficient of friction between road and tire is 0.7.

For vehicle speed=$\mathbf{105km/hr}(\mathbf{29.1m/sec})$

Assume that 50% of the mass of the vehicle is transferred to the front during hard braking. Therefore, the kinetic energy of the vehicle during hard braking is.

$$E = \frac{m}{2}{v_1}^2 = 1/2 \times 1400 \times (29.1)^2 = 592.76\text{kJ}$$

For vehicle speed 60km/hr (16.67m/sec)

$$\text{Kinetic energy, } E = 1/2 \times 1400 \times (16.67)^2 = 194.5\text{kJ}$$

For vehicle speed 30km/hr (8.3m/sec)

$$\text{Kinetic energy, } E = 1/2 \times 1400 \times (8.3)^2 = 48.2\text{kJ}$$

Braking force

To stop the vehicle in the shortest time, the maximum braking force cannot be larger than the maximum friction force between the tires and the ground, which can be transmitted to the ground. This maximum friction force on rear tire is calculated as follows. The adhesion coefficient of the road is taken 0.7.

$$F_{fr} = \mu_a W = F_b$$

$$F_b = 0.7 \times 1400 \times 9.81 = 9613.8\text{N}$$

Average deceleration

The simple and fundamental relationships can be derived for the case where it is reasonable to assume that the force acting on the vehicle will be constant throughout a braking application.

The average deceleration during braking is given by $a_x = \frac{F_f}{m}$

$$a_x = 9613.8N/1400 = 6.86m/sec^2$$

Stopping time

Total time to stop the vehicle is $t = \frac{v_x}{a_x}$

For vehicle speed=105km/hr(29.1m/sec)

$$t = \frac{29.1m/sec}{6.86m/sec2} = 4.2sec$$

For vehicle speed 60km/hr. (16.67m/sec)

$$\text{Stopping time, } t = \frac{16.86m/\sec}{6.86m/sec2} = 2.4sec$$

For vehicle speed 30km/hr. (8.3m/sec)

$$\text{Stopping time, } t = \frac{8.3m/sec}{6.86m/sec2} = 1.2sec$$

IV) Thermal analysis of break lining

a) Thermal conductivity

Total thermal conductivity of the composite is, $Kc = \sum Vp \times Kp + Vm \times K m$

$$Kc = (0.4 \times 0.165 + (0.15 \times 25) + (0.15 \times 0.112) + (0.3 \times 0.2)$$

$$Kc = 3.32W/mK$$

b) Temperature

Maximum heat generated during braking is equal with maximum kinetic energy of the vehicle. The maximum temperature of brake lining is calculated from Fourier's law of conduction, heat transfer given in equation 3.17.

Assume 7% of the heat generated is absorbed in 4sec by the brake lining and the left is absorbed by the brake drum. The thermal conductivity of the developed composite brake lining is known to be$\mathrm{Kc} = \frac{3.32\mathrm{W}}{\mathrm{mK}}$, the thickness and area of the 5L model minibus lining are dx=6mm and A=7471.75mm^2 respectively.

Heat absorbed by four brake lining=0.07*539.8kJ=37.78kJ/4sec=2.22kwatt

Using equation 3.18

$$\Delta\mathrm{T} = \frac{Ql}{kA} = \frac{2.22kwatt\times 6mm}{\frac{30.32w}{mk}\times 4\times 7471.75\mathrm{mm}2} = 62.5\mathrm{K}$$

Let the temperature of brake lining before brake applied is T_1 =27^{0}C (300.5K). Therefore, the temperature of the brake lining just after the vehicle stops is.

$$\Delta\mathrm{T} = T_2 - T_1,\ T_2 = \Delta\mathrm{T} + T_1 = 62.5 + 300.5 = 363\mathrm{K}\ (89.85^0\mathrm{C}).$$

c) Heat flux

Brake lining transfer 9.44kWatt to brake shoe which is 7% of the total heat generated between drum and lining. Therefore 93% of the heat generated flows to the drum if convection and radiation heat transfer is neglected.

Area of lining =7471.75mm^2

$$\text{Heat Flow for single drum in 4sec } = 0.93 \times 539.8\mathrm{kJ} = \frac{502\mathrm{kJ}}{4\mathrm{sec}} = 125.5\mathrm{kW}$$

$$\text{Heat flux into the drum is} = \frac{31.37\mathrm{kW}}{7471.75mm2} = 4.19\mathrm{W/mm}^2$$

4.3. Simulation results

Software simulation in this thesis is done by two approaches, which are static structural and Steady-state thermal analysis approaches.

4.3.1. Static structural analysis of drum and brake lining RVE

Principal stress is one of the evaluation criteria of brittle material. It is based on the value of compression and tensile strength value. In this the simulation, maximum value of 0.0047948MPa and minimum value -0.00096341MPa are obtained. Deformation is obtained after applying pressure in the x direction. Since the RVE of the sample is less than that of real brake lining, the pressure is scaled down to 0.000215MPa from the brake lining pressure obtained in section 4.2.7. Accordingly, the maximum total deformation is obtained to be 1.6226mm while the maximum directional deformation in the x-axis is 0.70802mm (fig4.14a&b).

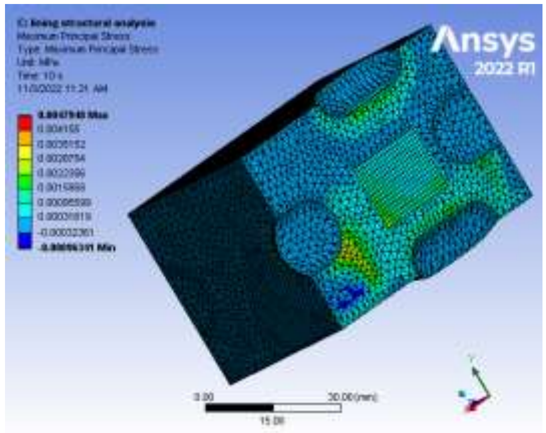
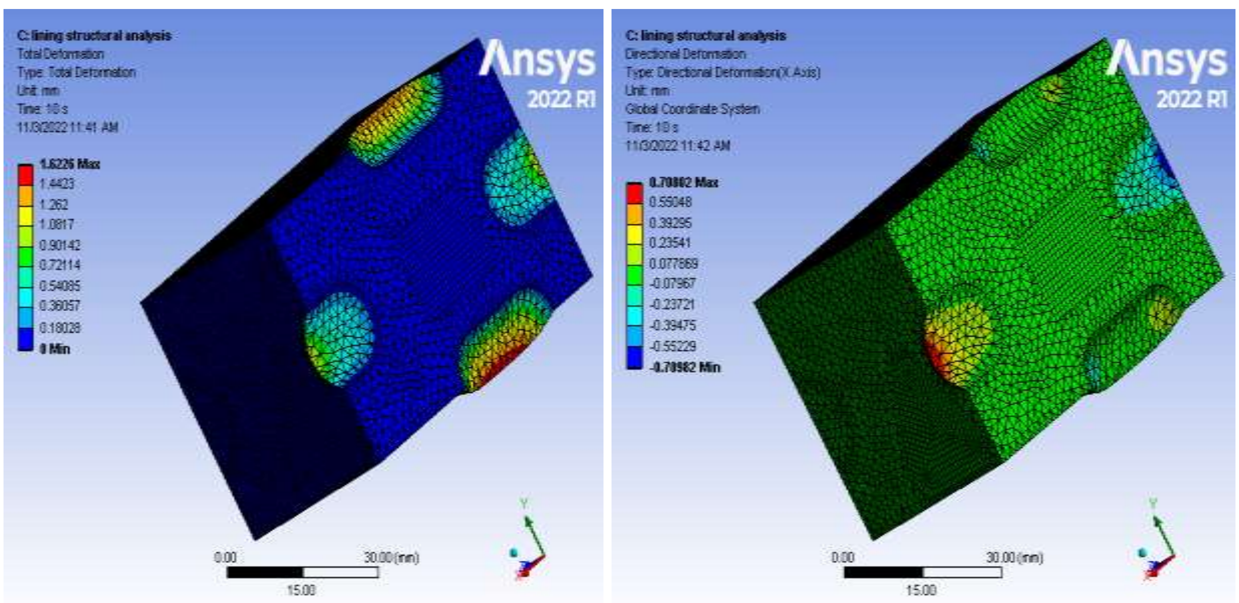
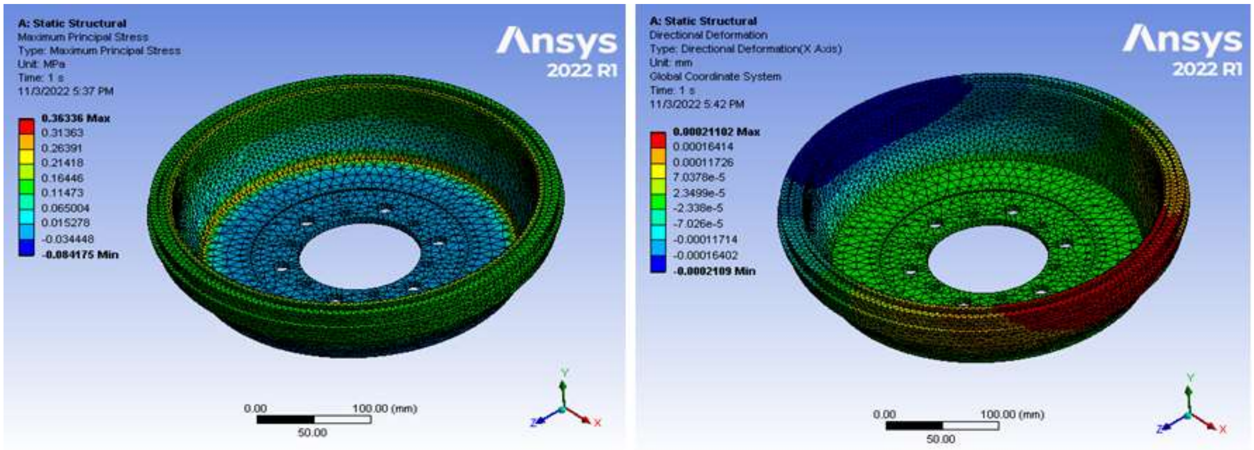


Figure 4.13. Maximum principal stress of RVE



(a) (b)

Figure 4.14. (a) Total deformation (b) directional deformation of RVE

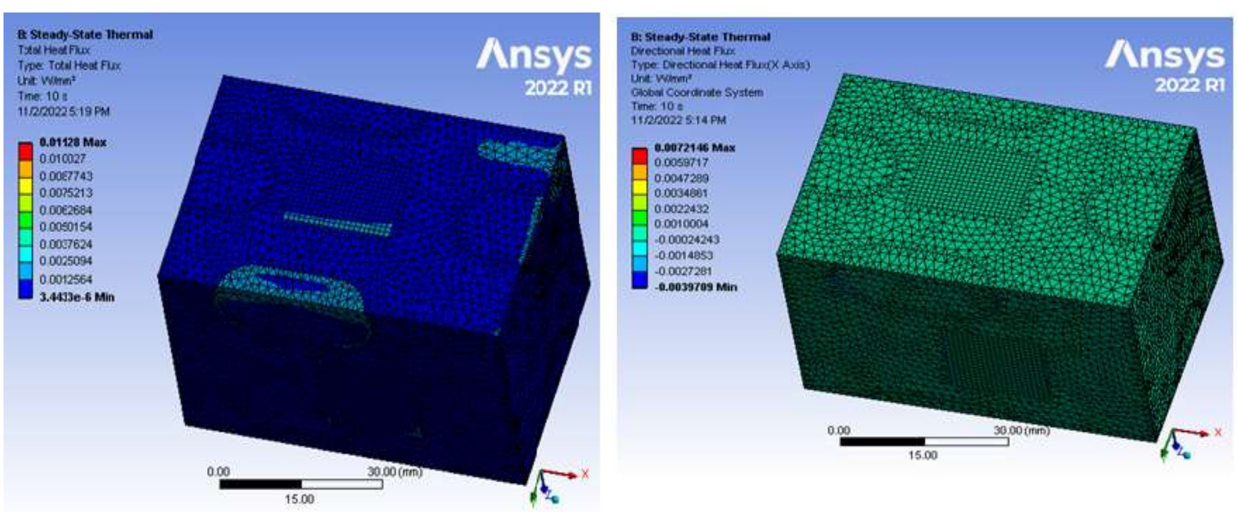


(a) (b)

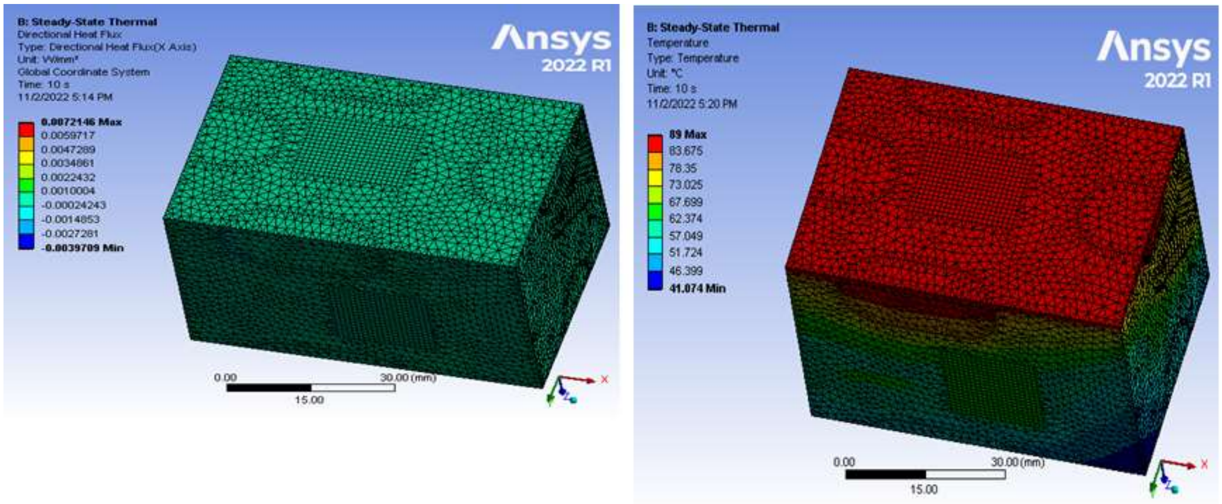
Figure 3.15. Static structural analysis of drum (a) maximum principal stress (b) directional deformation

Gray cast iron is the mostly used for drum brake. It is brittle type material which has no defined yielding point, so that ultimate strength is selected for evaluation criteria. The maximum principal stress obtained is 0.36336MPa while maximum directional deformation is 0.00021102mm (fig 3.15 a & b).

4.3.2. Steady state thermal simulation results of drum and brake lining RVE

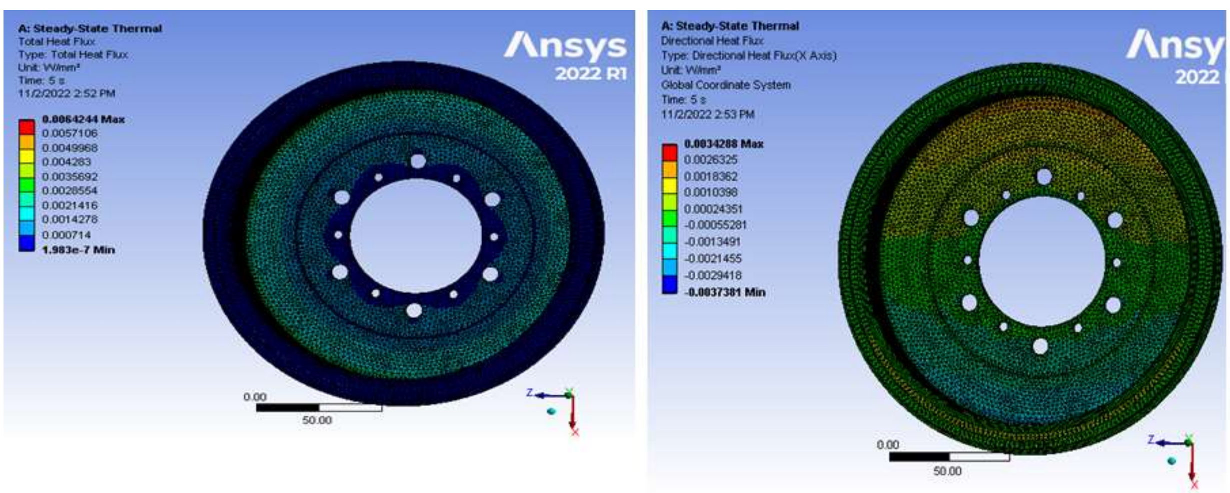


(a) (b)



(b) (c)

Figure 4.16. Steady-state thermal simulation result of RVE (a) total (b) directional heat flux (c) maximum temperature



(a) (b)

Figure 4.17. Steady-state thermal simulation result of drum (a) total (b) directional heat flux

Heat flux is the rate of heat energy that passes through a surface. In lining RVE, maximum total heat flux is 0.01128W/mm^2 (fig4.17a) and maximum directional heat flux is 0.0072146 W/mm^2 (fig 4.13b). In brake drum, maximum heat flux is 0.006424 and directional heat flux is 0.003428 W/mm^2 (fig4.17 a&b). During this simulation process, it is seen that directional flux of lining is near to the drum heat flux. But, the total heat flux of lining exceeds of drum by small amount.

4.3.3. Validation (Comparing and contrast)

The aim of this thesis study is to develop a brake lining that substitutes an asbestos-based commercial brake pad. Ademoh, N. A., & Olabisi, A. I. (2015) compared some of the brake linings developed from different natural reinforcements to asbestos-based commercial brake linings. The average result value of cow horn particle-based lining is also compared with asbestos based lining (table 4.9). Material mechanical properties are one of the criteria to decide the fitness of that material for different applications. Accordingly, the brake lining developed from cow horn particles is compared against different commercial brake linings. For instance, the properties of asbestos-based brake lining are taken to be compared since the purpose of this thesis study is to eliminate it. The compressive strength of ABCBL is 110.0MPa while that of CHpBL is 171.8 MPa. The tensile strength of ABCBL is 7.0 MPa and that of CHpBL is 6.3MPa. The other essential properties are thermal conductivity, which is 0.53W/mK in ABCBL and 3.2W/mK in CHpBL(obtained by numerical calculation). The density of CHpBL is also less than the ABCBL.

Table 4.9. Comparison of different brake lining

Properties	ABCBL	CHpBL
Density(g/cm^3)	1.89	1.5
Thermal con.	0.53	3.2
Wear rate(g/m)	3.80×10^{-5}	3.1×10^{-5}
Coe. of friction	0.3-0.4	0.32
Water abs. (%)	0.9	0.6
Oil absorption (%)	0.3	0.4
Comp. strength	110.0	171.8
Tensile strength	7.0	6.3
Flexural strength	-	92.5

From table 4.9 it is seen that density of CHpBL is less than that of ABCBL by 0.39. Thermal conductivity of CHpBL is greater than that of ABCBL by 2.68. Wear rate of CHpBL is less than that of ABCBL by 0.7 and water absorption by 0.3. Oil absorption test is given in percentage for this thesis, while for ABCBL is given by thickness change. Similarly, it could be seen that other properties from figure 4.9. CHPBL has better average compressive strength than that of ABCBL.

4.3.4. Comparison of experimental test with simulation study

Deformation is one of the experimental and simulation results. In characterization, deformation and stresses are the simultaneously obtained. In this section, maximum deformation with maximum stress is obtained from tensile, compression and bending test result. The deformation from simulation result is obtained from lining analysis. The comparison of both results is given in graph figure 4.17. Tensile test has maximum deformation value; because of axial tension load is applied. At maximum ultimate tensile stress (at the fracture point), maximum value of deformation is obtained which is 0.0825mm. Similarly, at maximum ultimate compression and flexural stress, maximum deformation obtained are, 0.0575 and 0.0124mm respectively. Deformation in simulation study is the lowest value when compared with the all experimental value.

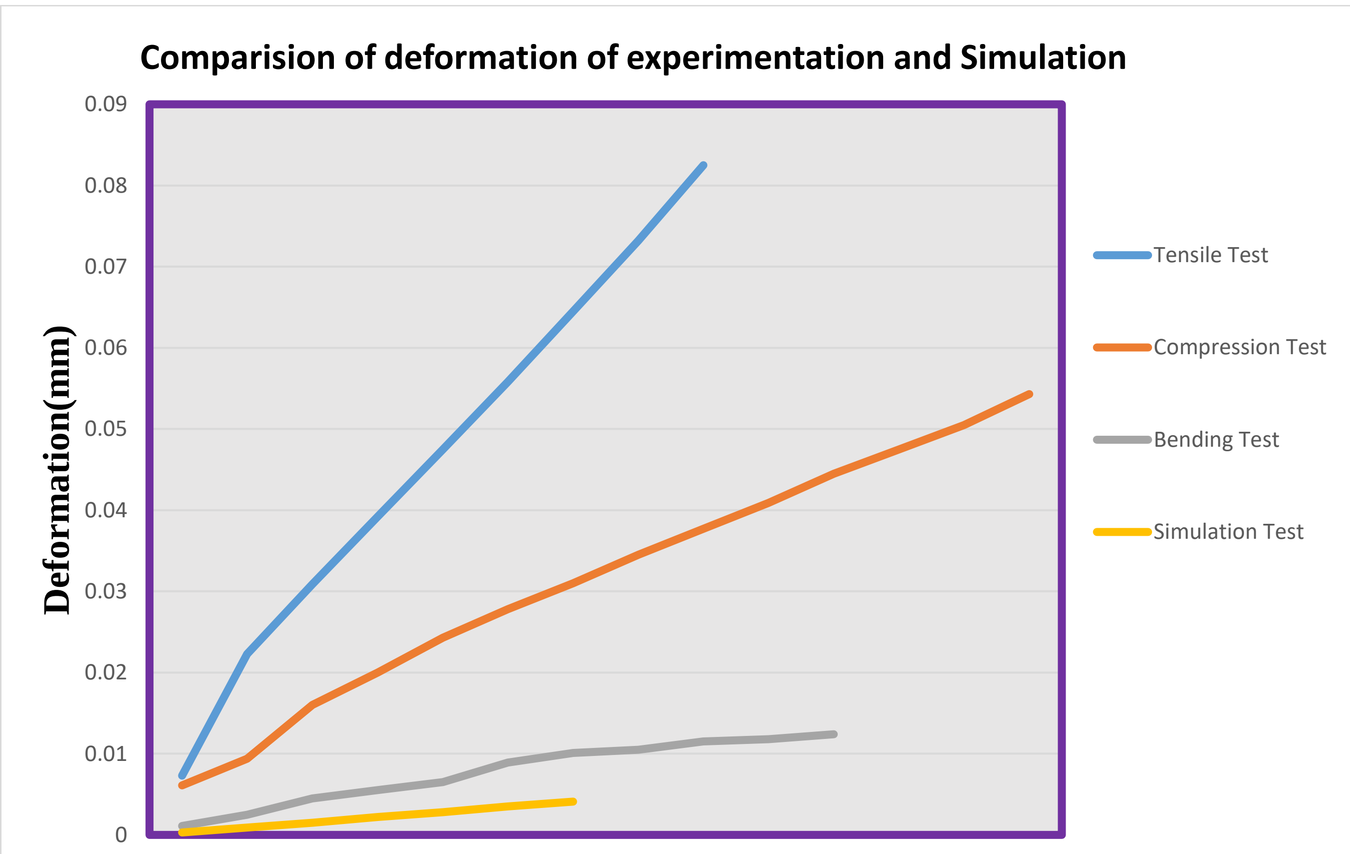


Figure 4.18. Comparison of experimental and simulation result

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Summary

Methods and procedures are employed to arrive at the final conclusion. First, a review of the relevant literature is conducted. To develop the samples, materials are then either chosen or prepared. Samples are characterized in accordance with each material test's requirements. The given vehicle is the subject of a theoretical investigation. Software simulation is another technique for assessing the content. The findings are verified and contrasted with commercial brake linings.

5.2. Conclusion

The braking system is the fundamental vehicle system. The drum brake lining is the one part of the braking system that plays a crucial role in controlling the vehicle. These linings are made up of different materials from time to time. Asbestos is the main ingredient as filler because of its good thermal properties. The core aim of this thesis is to develop an eco-friendly brake lining using cow horn particles as a reinforcement and epoxy resin as an adhesive. The composite is prepared with different percentages and different mechanical properties are characterized along with software simulation. The results obtained are compared with the pre-existing brake lining to identify the fitness of the developed lining. Depending on the result obtained, the conclusion is given as follows.

- The density of the developed lining is obtained at 1.5 g/cm^3, which is still lower than that of asbestos-based brake lining. In automobiles, the density of the material should be as low as possible.
- For the first 24 hours, water and oil absorption percentage tests are 0.5 and 0.3, respectively. As the days are lengthening, the absorption percentage for both water and oil is increasing.
- The average compression strength is 171.8MPa, which is greater than that of ABCBL. In the brake lining, compressive force resistance should be high. Because if resistance to compressive force is low, the lining compresses and the pedal moving distance increases.

- The average tensile strength is 6.3MPa. Tensile strength in composite two is obtained at its maximum due to an unknown factor. This could be due to the maximum incorporation of CHp.
- The flexural strength obtained is to be the maximum value of 92.5MPa. It is shown that as the number of cow horn particles decreases, flexural strength also decreases.
- The most crucial properties of the brake lining are its tribological and thermal properties. From the wear rate test, it is obtained that the maximum wear rate is 0.000042g/m, 0.000036g/m, and 0.000027g/m in C1, C2, and C3 respectively. From these results, it is concluded that incorporation of the abrasive and lubricant has a major effect on wear rate. As the percentages of abrasive and lubricant increase, the wear rate decreases, but this decrements also have an effect of sliding between the drum and the lining. Therefore, the content of abrasives and lubricants should be kept at an optimum level.
- Obtained coefficient of friction is 0.32. As the content of abrasive/ silica increases the coefficient of friction increases.
- From simulation result it is shown that, principal stresses of developed brake lining are less than ultimate strength (tensile and compressive strength obtained from the experimental results). Average ultimate tensile strength in three samples is 6.3MPa, while average ultimate compressive strength is 171.8MPa. Maximum principal stress obtained in simulation is 0.0047948MPa.
- Experimental and simulation results of deformation is compared with each other and deformation in simulation study is lower than that of experimental study.
- Sample two (C2) was found to be best composition which has better mechanical and tribological properties among the other composites.
- Generally, depending up on experimental and simulation analysis, cow horn particles can be used as one of the re-enforcement materials in brake lining.

5.3. Recommendation for the future work

This thesis study focused on the material of brake lining that can substitute asbestos. For the long-time asbestos is used as main ingredient in friction material. Due to its health matter, it is banned out of market not to use. So that, researchers are innovating natural material which replace it with many advantages such as availability, low production cost, low density, ecofriendly, better physical and mechanical properties. In this thesis, cow horn particle is found to be re-enforcement material in brake lining after experimental and simulation analysis. For the future work, the following points are recommended in the aspect of brake lining developed from the CHp as re-enforcement material.

- In this thesis study, the cow horns are obtained from slaughter house without considering the ages of oxen/bulls, feeding and growing environment. For further study, these factors and which part of cow horn contains more carbon may be studied.
- Since cow horn is organic material, it may have bad aroma when heated to high temperature. So that, mechanisms of removing this bad smell should be used or material which can reduce it should be added during production.
- Epoxy resin has good mechanical and adhesion properties with natural re-enforcement material. However, it is suspected at higher temperature in baking system. Phenolic resin is also another type of matrix mostly used in brake pad manufacturing. Even though it has good thermal resistance at higher temperature, it has low adhesion property with natural filler material. Therefore, to compromise the properties of adhesivity and thermal resistance, modified phenolic resin should be used to overcome those problem.
- Thermal conductivity of the sample is analyzed only by theoretical approach. This is due to unavailability of device that tests material thermal conductivity. For the future work, it should be tested with material testing device according to ASTM.
- Characterization only at laboratory level is not enough to decide the application of the material to specified purpose. So that, it is recommended that characterization on the vehicle gives good results.
- The performance of the product may be improved by using more precise composite manufacturing techniques, such as vacuum bagging and resin transfer.
- Since cow horns have good mechanical properties, any researcher can do on it for different application in automotive industry.

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APPENDIX A: Wear rate test result data point of C1

Time; FF (N); NL (N); SPEED (rpm); Wear (Microns); Pin Temp (Deg C); Heater Temp (Deg C)

0.000; -0.005; 18.000; 0.000 0.790; 180.586; 20.776; 0.000; 0.000; 0.00000;
0.997; -0.001; 18.000; 1.000 -0.530; 180.156; 20.947; 0.001; 0.002; 0.00000;
2.050; -0.000; 18.000; 1.000 -0.446; 180.535; 21.050; 0.003; 0.002; 0.00000;
3.100; 0.024; 18.000; 1.000 0.009; 180.408; 20.981; 0.005; 0.002; 0.00000;
0.000; -0.745; 18.000; 0.000-1100.549; 180.551; 20.974; 0.000; 0.000; 0.00000;
0.254; -0.918; 18.000; 1.000-1104.262; 180.349; 21.138; 0.000; 0.002; 0.00000;
1.304; -1.552; 18.000; 1.000-1106.318; 180.495; 21.040; 0.002; 0.002; 0.00000;
2.351; -1.509; 18.000; 1.000-1106.877; 180.648; 21.116; 0.004; 0.002; 0.00000;
3.409; -2.300; 18.000; 1.000-1106.715; 180.643; 21.172; 0.005; 0.002; 0.00000;
4.457; -2.709; 18.000; 1.000-1106.751; 180.523; 21.101; 0.007; 0.002; 0.00000;
5.557; -1.532; 18.000; 1.000-1106.692; 180.458; 21.178; 0.009; 0.002; 0.00000;
0.000; -0.047; 18.000; 0.000 -973.837; 180.678; 20.946; 0.000; 0.000; 0.00000;
0.602; 0.000; 18.000; 1.000-1104.366; 180.491; 21.081; 0.001; 0.002; 0.00000;
1.653; 0.023; 18.000; 1.000-1113.863; 180.792; 21.053; 0.003; 0.002; 0.00000;
2.704; 0.015; 18.000; 1.000-1113.453; 180.789; 21.121; 0.004; 0.002; 0.00000;
3.752; 0.032; 18.000; 1.000-1035.820; 180.735; 21.186; 0.006; 0.002; 0.00000;
4.848; 0.003; 18.000; 1.000 -758.673; 180.640; 21.135; 0.008; 0.002; 0.00000;
0.000; 4.539; 18.000; 0.000 -413.323; -2.132; -6.058; 0.000; 0.000; 0.00000;
0.000; 0.167; 18.000; 0.000-1121.350; 180.622; 21.001; 0.000; 0.000; 0.00000;
0.847; 0.066; 18.000; 0.000-1121.308; 180.499; 20.938; 0.000; 0.000; 0.00000;
1.944; 0.076; 18.000; 0.000-1119.021; 180.499; 20.981; 0.000; 0.000; 0.00000;
0.000; 0.018; 18.000; 1.000 0.380; 180.959; 21.121; 0.000; 0.002; 0.00000;
0.654; 1.430; 18.000; 3.307 0.403; 180.969; 21.068; 0.003; 0.005; 0.00000;
1.746; 2.566; 18.000; 66.360 0.358; 180.400; 21.048; 0.177; 0.104; 0.00002;
2.851; 3.027; 18.000; 126.307 0.446; 180.488; 21.218; 0.556; 0.198; 0.00003;
3.955; 2.909; 18.000; 192.757 1.197; 180.578; 21.450; 1.180; 0.303; 0.00005;
5.050; 2.985; 18.000; 252.580 3.546; 180.767; 21.358; 1.984; 0.397; 0.00007;
6.151; 3.109; 18.000; 312.260 4.491; 180.963; 21.290; 2.992; 0.490; 0.00009;
7.204; 3.137; 18.000; 372.206 5.613; 180.802; 21.206; 4.181; 0.585; 0.00010;
39.613; 3.439; 18.000; 399.673 6.626; 180.816; 21.200; 4.645; 0.628; 0.00011;
40.706; 4.461; 18.000; 399.807 9.351; 180.652; 21.303; 25.530; 0.628; 0.00011;
41.761; 4.391; 18.000; 399.757 9.648; 180.891; 21.332; 26.190; 0.628; 0.00011;
42.810; 4.430; 18.000; 399.487 9.920; 180.865; 21.326; 26.830; 0.628; 0.00011;
43.901; 4.456; 18.000; 399.569 10.665; 180.631; 21.252; 27.523; 0.628; 0.00011;
44.955; 4.528; 18.000; 399.697 9.529; 180.987; 21.282; 28.193; 0.628; 0.00011;

46.057;	4.439;	18.000;	399.740	9.556;	180.724;	21.318;	28.885;	0.628;	0.00011;
47.105;	4.326;	18.000;	399.632	10.042;	180.962;	21.343;	29.534;	0.628;	0.00011;
48.201;	4.368;	18.000;	399.457	10.044;	180.729;	21.354;	30.217;	0.627;	0.00011;
49.302;	4.356;	18.000;	399.695	9.877;	181.055;	21.320;	30.925;	0.628;	0.00011;
50.355;	4.394;	18.000;	399.673	10.268;	180.675;	21.310;	31.582;	0.628;	0.00011;
51.408;	4.413;	18.000;	399.579	10.962;	180.690;	21.246;	32.233;	0.628;	0.00011;
52.459;	4.384;	18.000;	399.695	10.224;	180.683;	21.276;	32.902;	0.628;	0.00011;
53.506;	4.415;	18.000;	399.635	10.427;	181.297;	21.297;	33.550;	0.628;	0.00011;
54.602;	4.393;	18.000;	399.414	10.431;	180.688;	21.341;	34.228;	0.627;	0.00011;
55.657;	4.295;	18.000;	399.440	10.098;	181.085;	21.373;	34.891;	0.627;	0.00011;
56.704;	4.312;	18.000;	399.576	10.873;	180.954;	21.343;	35.560;	0.628;	0.00011;
57.805;	4.390;	18.000;	399.698	11.137;	180.979;	21.232;	36.263;	0.628;	0.00011;
58.858;	4.455;	18.000;	399.414	10.971;	180.865;	21.248;	36.895;	0.627;	0.00011;
59.908;	4.480;	18.000;	399.498	10.950;	181.114;	21.261;	37.559;	0.628;	0.00011;
61.005;	4.455;	18.000;	399.443	10.610;	180.880;	21.315;	38.245;	0.627;	0.00011;
62.055;	4.307;	18.000;	399.712	10.537;	180.868;	21.370;	38.934;	0.628;	0.00011;
63.152;	4.278;	18.000;	399.540	11.008;	180.803;	21.297;	39.602;	0.628;	0.00011;
64.253;	4.320;	18.000;	399.674	11.023;	180.779;	21.309;	40.307;	0.628;	0.00011;
65.306;	4.376;	18.000;	399.800	11.886;	180.537;	21.208;	40.979;	0.628;	0.00011;
66.357;	4.365;	18.000;	400.056	11.129;	180.780;	21.326;	41.663;	0.628;	0.00011;
67.408;	4.315;	18.000;	399.943	11.181;	181.103;	21.348;	42.313;	0.628;	0.00011;
68.457;	4.286;	18.000;	400.079	11.152;	181.127;	21.366;	42.989;	0.628;	0.00011;
69.552;	4.172;	18.000;	400.076	11.655;	181.280;	21.340;	43.678;	0.628;	0.00011;
70.657;	4.213;	18.000;	400.197	11.656;	180.822;	21.344;	44.376;	0.629;	0.00011;
71.758;	4.190;	18.000;	400.198	11.471;	180.819;	21.380;	45.077;	0.629;	0.00011;
72.802;	4.241;	18.000;	400.107	11.599;	180.857;	21.339;	45.726;	0.628;	0.00011;
73.859;	4.290;	18.000;	399.669	11.220;	180.841;	21.326;	46.337;	0.628;	0.00011;
74.910;	4.279;	18.000;	399.676	11.603;	180.459;	21.381;	46.998;	0.628;	0.00011;
75.955;	4.268;	18.000;	399.617	11.427;	180.600;	21.432;	47.647;	0.628;	0.00011;
77.009;	4.306;	18.000;	399.622	11.580;	181.058;	21.365;	48.305;	0.628;	0.00011;
78.057;	4.230;	18.000;	399.528	12.074;	181.108;	21.461;	48.954;	0.628;	0.00011;
79.105;	4.285;	18.000;	399.412	12.242;	181.108;	21.366;	49.603;	0.627;	0.00011;
80.156;	4.348;	18.000;	399.647	12.167;	181.009;	21.369;	50.278;	0.628;	0.00011;
81.201;	4.340;	18.000;	400.127	11.733;	181.048;	21.448;	51.006;	0.629;	0.00011;
82.258;	4.236;	18.000;	400.280	12.423;	181.036;	21.495;	51.691;	0.629;	0.00011;
83.308;	4.347;	18.000;	400.218	11.692;	181.084;	21.407;	52.339;	0.629;	0.00011;
84.352;	4.297;	18.000;	400.052	12.523;	181.237;	21.417;	52.977;	0.628;	0.00011;

85.406;	4.378;	18.000;	399.982	12.974;	180.869;	21.303;	53.626;	0.628;	0.00011;
86.504;	4.444;	18.000;	400.156	12.368;	180.944;	21.365;	54.341;	0.629;	0.00011;
87.556;	4.452;	18.000;	399.980	12.520;	180.584;	21.410;	54.986;	0.628;	0.00011;
88.604;	4.505;	18.000;	399.726	12.836;	181.162;	21.433;	55.601;	0.628;	0.00011;
89.651;	4.393;	18.000;	399.788	12.634;	181.053;	21.384;	56.270;	0.628;	0.00011;
90.704;	4.357;	18.000;	400.013	12.615;	180.924;	21.437;	56.957;	0.628;	0.00011;
91.756;	4.283;	18.000;	400.079	13.181;	180.950;	21.378;	57.627;	0.628;	0.00011;
92.806;	4.447;	18.000;	400.020	12.533;	180.924;	21.356;	58.281;	0.628;	0.00011;
93.856;	4.437;	18.000;	399.698	12.695;	180.822;	21.368;	58.904;	0.628;	0.00011;
94.904;	4.430;	18.000;	399.653	12.731;	180.725;	21.372;	59.548;	0.628;	0.00011;
95.957;	4.343;	18.000;	399.797	12.866;	180.963;	21.349;	60.227;	0.628;	0.00011;
97.006;	4.252;	18.000;	399.862	13.237;	181.192;	21.406;	60.902;	0.628;	0.00011;
98.056;	4.236;	18.000;	399.925	12.767;	180.943;	21.462;	61.562;	0.628;	0.00011;
99.101;	4.383;	18.000;	399.905	12.763;	181.166;	21.346;	62.225;	0.628;	0.00011;
100.155;	4.334;	18.000;	400.191	13.174;	181.273;	21.413;	62.929;	0.629;	0.00011;
101.259;	4.270;	18.000;	400.551	13.208;	181.242;	21.409;	63.672;	0.629;	0.00011;
102.308;	4.237;	18.000;	400.378	13.902;	181.168;	21.333;	64.312;	0.629;	0.00011;
103.357;	4.213;	18.000;	400.450	13.326;	181.209;	21.482;	64.981;	0.629;	0.00011;
104.404;	4.160;	18.000;	400.402	13.083;	180.834;	21.464;	65.631;	0.629;	0.00011;
105.455;	4.257;	18.000;	400.047	13.289;	180.791;	21.344;	66.235;	0.628;	0.00011;
106.507;	4.215;	18.000;	399.811	13.320;	180.509;	21.428;	66.852;	0.628;	0.00011;
107.553;	4.195;	18.000;	399.691	13.870;	181.269;	21.316;	67.492;	0.628;	0.00011;
108.657;	4.147;	18.000;	399.820	14.421;	181.116;	21.378;	68.205;	0.628;	0.00011;
109.708;	4.108;	18.000;	399.632	13.884;	181.227;	21.523;	68.834;	0.628;	0.00011;
110.752;	4.141;	18.000;	399.609	13.609;	180.800;	21.360;	69.490;	0.628;	0.00011;
111.853;	4.165;	18.000;	399.834	13.083;	180.797;	21.379;	70.208;	0.628;	0.00011;
112.901;	4.171;	18.000;	400.081	13.754;	180.668;	21.415;	70.922;	0.628;	0.00011;
113.951;	4.174;	18.000;	400.096	14.362;	180.989;	21.306;	71.584;	0.628;	0.00011;
115.050;	4.124;	18.000;	400.004	14.466;	180.972;	21.415;	72.257;	0.628;	0.00011;
116.158;	4.126;	18.000;	399.985	14.505;	181.246;	21.514;	72.944;	0.628;	0.00011;
117.208;	4.124;	18.000;	400.284	13.919;	181.169;	21.468;	73.661;	0.629;	0.00011;
118.262;	4.212;	18.000;	399.957	13.580;	181.093;	21.422;	74.261;	0.628;	0.00011;
119.303;	4.184;	18.000;	399.914	13.876;	181.090;	21.386;	74.912;	0.628;	0.00011;
120.351;	4.231;	18.000;	399.809	14.935;	180.631;	21.357;	75.553;	0.628;	0.00011;
121.399;	4.182;	18.000;	399.652	14.361;	181.101;	21.477;	76.184;	0.628;	0.00011;
122.452;	4.117;	18.000;	399.832	14.789;	181.123;	21.529;	76.877;	0.628;	0.00011;
123.507;	4.156;	18.000;	399.743	13.703;	180.833;	21.426;	77.517;	0.628;	0.00011;

124.556;	4.253;	18.000;	399.696	13.847;	180.856;	21.443;	78.171;	0.628;	0.00011;
125.602;	4.251;	18.000;	399.841	14.672;	181.077;	21.387;	78.858;	0.628;	0.00011;
126.658;	4.315;	18.000;	399.585	14.864;	180.875;	21.366;	79.464;	0.628;	0.00011;
127.703;	4.201;	18.000;	399.682	14.566;	181.489;	21.551;	80.145;	0.628;	0.00011;
128.757;	4.192;	18.000;	399.750	14.587;	181.257;	21.454;	80.815;	0.628;	0.00011;
129.808;	4.230;	18.000;	399.791	13.789;	181.145;	21.402;	81.485;	0.628;	0.00011;
130.855;	4.255;	18.000;	399.786	14.057;	181.353;	21.415;	82.144;	0.628;	0.00011;
131.907;	4.278;	18.000;	399.804	14.682;	181.361;	21.345;	82.808;	0.628;	0.00011;
132.957;	4.230;	18.000;	399.756	14.464;	181.650;	21.469;	83.457;	0.628;	0.00011;
134.009;	4.150;	18.000;	399.946	15.171;	181.019;	21.611;	84.155;	0.628;	0.00011;
135.052;	4.187;	18.000;	399.917	13.593;	180.887;	21.448;	84.808;	0.628;	0.00011;
136.102;	4.137;	18.000;	399.950	13.323;	180.981;	21.456;	85.478;	0.628;	0.00011;
137.156;	4.174;	18.000;	399.780	14.176;	180.975;	21.391;	86.099;	0.628;	0.00011;
138.203;	4.251;	18.000;	399.737	14.807;	181.640;	21.359;	86.748;	0.628;	0.00011;
139.254;	4.228;	18.000;	399.637	14.368;	181.038;	21.466;	87.388;	0.628;	0.00011;
140.307;	4.165;	18.000;	399.426	14.667;	181.136;	21.542;	87.997;	0.627;	0.00011;
141.354;	4.142;	18.000;	399.579	14.136;	180.939;	21.443;	88.689;	0.628;	0.00011;
142.402;	4.258;	18.000;	399.432	13.851;	181.215;	21.480;	89.319;	0.627;	0.00011;
143.454;	4.157;	18.000;	399.305	14.369;	181.047;	21.395;	89.949;	0.627;	0.00011;
144.507;	4.321;	18.000;	399.502	15.262;	181.276;	21.322;	90.651;	0.628;	0.00011;
145.606;	4.316;	18.000;	399.904	15.229;	181.130;	21.391;	91.432;	0.628;	0.00011;
146.652;	4.208;	18.000;	400.079	14.258;	180.955;	21.470;	92.133;	0.628;	0.00011;
147.702;	4.272;	18.000;	400.282	14.585;	181.100;	21.510;	92.839;	0.629;	0.00011;
148.755;	4.259;	18.000;	400.294	14.320;	180.963;	21.459;	93.502;	0.629;	0.00011;
149.805;	4.172;	18.000;	400.579	14.690;	180.695;	21.470;	94.232;	0.629;	0.00011;
150.857;	4.261;	18.000;	400.428	15.208;	181.391;	21.386;	94.856;	0.629;	0.00011;
151.905;	4.332;	18.000;	400.602	15.320;	181.187;	21.342;	95.557;	0.629;	0.00011;
152.958;	4.165;	18.000;	400.357	14.869;	181.254;	21.433;	96.163;	0.629;	0.00011;
154.005;	4.036;	18.000;	400.320	14.892;	180.728;	21.564;	96.809;	0.629;	0.00011;
155.106;	4.114;	18.000;	400.520	14.816;	180.878;	21.526;	97.549;	0.629;	0.00011;
156.152;	4.084;	18.000;	400.374	14.535;	181.322;	21.506;	98.174;	0.629;	0.00011;
157.204;	4.014;	18.000;	400.545	15.085;	181.112;	21.466;	98.877;	0.629;	0.00011;
158.256;	3.981;	18.000;	400.516	15.112;	181.166;	21.428;	99.529;	0.629;	0.00011;
159.304;	3.910;	18.000;	400.429	15.682;	181.367;	21.387;	100.168;	0.629;	0.00011;
160.351;	3.827;	18.000;	400.327	14.862;	181.110;	21.477;	100.804;	0.629;	0.00011;
161.403;	3.744;	18.000;	400.055	14.704;	181.157;	21.569;	101.397;	0.628;	0.00011;
162.456;	3.824;	18.000;	399.842	14.712;	180.966;	21.501;	102.005;	0.628;	0.00011;

163.507;	3.803;	18.000;	399.887	14.905;	181.114;	21.543;	102.671;	0.628;	0.00011;
164.556;	3.754;	18.000;	399.849	15.195;	180.944;	21.491;	103.321;	0.628;	0.00011;
165.605;	3.928;	18.000;	399.784	15.322;	181.064;	21.383;	103.967;	0.628;	0.00011;
166.656;	3.941;	18.000;	399.888	15.508;	181.006;	21.410;	104.651;	0.628;	0.00011;
167.705;	3.871;	18.000;	400.132	14.730;	181.419;	21.531;	105.378;	0.629;	0.00011;
168.756;	3.834;	18.000;	400.209	14.855;	180.928;	21.621;	106.055;	0.629;	0.00011;
169.804;	3.740;	18.000;	400.219	15.177;	180.991;	21.564;	106.719;	0.629;	0.00011;
170.858;	3.716;	18.000;	400.242	15.280;	181.108;	21.504;	107.383;	0.629;	0.00011;
171.907;	3.735;	18.000;	399.931	15.730;	181.005;	21.468;	107.960;	0.628;	0.00011;
172.955;	3.725;	18.000;	399.800	15.893;	180.965;	21.412;	108.584;	0.628;	0.00011;
174.004;	3.779;	18.000;	399.856	16.147;	181.111;	21.433;	109.255;	0.628;	0.00011;
175.052;	3.711;	18.000;	399.957	15.367;	181.303;	21.544;	109.949;	0.628;	0.00011;
176.157;	3.810;	18.000;	399.990	15.483;	181.065;	21.612;	110.646;	0.628;	0.00011;
177.250;	3.779;	18.000;	400.165	15.752;	181.232;	21.600;	111.398;	0.629;	0.00011;
178.306;	3.671;	18.000;	400.029	15.888;	181.211;	21.585;	112.010;	0.628;	0.00011;
179.357;	3.767;	18.000;	400.199	16.073;	181.212;	21.536;	112.717;	0.629;	0.00011;
180.402;	3.724;	18.000;	400.088	16.454;	180.762;	21.492;	113.344;	0.628;	0.00011;
181.454;	3.705;	18.000;	399.875	16.717;	180.993;	21.439;	113.946;	0.628;	0.00011;
182.503;	3.701;	18.000;	399.617	16.294;	180.938;	21.501;	114.530;	0.628;	0.00011;
183.555;	3.742;	18.000;	399.341	15.837;	181.484;	21.600;	115.108;	0.627;	0.00011;
184.607;	3.641;	18.000;	399.553	16.029;	181.282;	21.636;	115.828;	0.628;	0.00011;
185.708;	3.662;	18.000;	399.617	16.191;	181.126;	21.637;	116.536;	0.628;	0.00011;
186.754;	3.626;	18.000;	399.691	16.541;	181.317;	21.639;	117.218;	0.628;	0.00011;
187.803;	3.607;	18.000;	399.532	16.942;	181.159;	21.533;	117.834;	0.628;	0.00011;
188.857;	3.739;	18.000;	399.403	16.975;	181.075;	21.559;	118.451;	0.627;	0.00011;
189.902;	3.624;	18.000;	399.547	17.108;	180.660;	21.509;	119.152;	0.628;	0.00011;
190.957;	3.737;	18.000;	399.838	16.486;	181.343;	21.512;	119.900;	0.628;	0.00011;
192.008;	3.719;	18.000;	399.649	16.190;	181.167;	21.616;	120.502;	0.628;	0.00011;
193.057;	3.664;	18.000;	399.623	16.202;	181.087;	21.621;	121.152;	0.628;	0.00011;
194.105;	3.603;	18.000;	399.714	16.859;	181.248;	21.644;	121.839;	0.628;	0.00011;
195.156;	3.669;	18.000;	399.819	17.011;	181.398;	21.567;	122.531;	0.628;	0.00011;
196.204;	3.685;	18.000;	399.715	17.088;	181.241;	21.557;	123.159;	0.628;	0.00011;
197.258;	3.665;	18.000;	399.757	16.969;	181.096;	21.529;	123.835;	0.628;	0.00011;
198.303;	3.788;	18.000;	399.614	16.690;	181.425;	21.553;	124.445;	0.628;	0.00011;
199.405;	3.662;	18.000;	399.560	16.259;	181.297;	21.617;	125.120;	0.628;	0.00011;
200.453;	3.637;	18.000;	399.419	16.342;	181.090;	21.633;	125.733;	0.627;	0.00011;
201.501;	3.599;	18.000;	399.454	16.712;	180.907;	21.652;	126.403;	0.627;	0.00011;

202.552;	3.600;	18.000;	399.790	17.087;	181.323;	21.575;	127.173;	0.628;	0.00011;
203.602;	3.643;	18.000;	399.793	16.966;	180.999;	21.570;	127.833;	0.628;	0.00011;
204.707;	3.702;	18.000;	399.850	16.825;	180.870;	21.574;	128.538;	0.628;	0.00011;
205.755;	3.734;	18.000;	399.924	16.915;	181.151;	21.551;	129.225;	0.628;	0.00011;
206.802;	3.762;	18.000;	400.027	16.536;	181.498;	21.641;	129.918;	0.628;	0.00011;
207.854;	3.736;	18.000;	400.019	16.567;	181.393;	21.637;	130.574;	0.628;	0.00011;
208.907;	3.642;	18.000;	399.890	16.524;	181.154;	21.667;	131.204;	0.628;	0.00011;
209.952;	3.661;	18.000;	399.980	16.989;	181.384;	21.625;	131.879;	0.628;	0.00011;
211.005;	3.778;	18.000;	400.213	17.033;	181.193;	21.608;	132.617;	0.629;	0.00011;
212.055;	3.747;	18.000;	399.921	16.803;	181.073;	21.598;	133.182;	0.628;	0.00011;
213.106;	3.765;	18.000;	399.852	16.596;	181.135;	21.633;	133.819;	0.628;	0.00011;
214.154;	3.742;	18.000;	399.665	16.672;	181.241;	21.694;	134.415;	0.628;	0.00011;
215.208;	3.720;	18.000;	399.734	16.912;	181.115;	21.695;	135.096;	0.628;	0.00011;
216.257;	3.596;	18.000;	399.718	17.099;	181.182;	21.686;	135.748;	0.628;	0.00011;
217.306;	3.672;	18.000;	399.622	17.326;	181.312;	21.637;	136.376;	0.628;	0.00011;
218.356;	3.689;	18.000;	399.527	16.605;	180.930;	21.682;	137.002;	0.628;	0.00011;
219.401;	3.672;	18.000;	399.656	17.170;	181.333;	21.621;	137.705;	0.628;	0.00011;
220.455;	3.675;	18.000;	399.585	16.711;	181.362;	21.706;	138.340;	0.628;	0.00011;
221.502;	3.548;	18.000;	399.874	16.811;	181.432;	21.721;	139.101;	0.628;	0.00011;
222.556;	3.602;	18.000;	400.027	17.136;	181.263;	21.711;	139.814;	0.628;	0.00011;
223.609;	3.549;	18.000;	399.925	17.097;	181.326;	21.642;	140.437;	0.628;	0.00011;
224.655;	3.614;	18.000;	399.907	17.082;	181.400;	21.670;	141.092;	0.628;	0.00011;
225.704;	3.682;	18.000;	400.036	16.703;	181.123;	21.641;	141.794;	0.628;	0.00011;
226.752;	3.745;	18.000;	400.391	16.874;	181.439;	21.589;	142.582;	0.629;	0.00011;
227.805;	3.723;	18.000;	400.492	16.474;	181.380;	21.704;	143.281;	0.629;	0.00011;
228.854;	3.663;	18.000;	400.541	16.899;	181.225;	21.730;	143.961;	0.629;	0.00011;
229.907;	3.534;	18.000;	400.423	16.780;	181.483;	21.680;	144.575;	0.629;	0.00011;
230.955;	3.628;	18.000;	400.562	17.011;	181.157;	21.684;	145.285;	0.629;	0.00011;
232.057;	3.597;	18.000;	400.197	17.005;	181.157;	21.687;	145.844;	0.629;	0.00011;
233.104;	3.902;	18.000;	400.237	16.716;	181.431;	21.636;	146.519;	0.629;	0.00011;
234.153;	3.998;	18.000;	400.015	16.492;	181.293;	21.669;	147.099;	0.628;	0.00011;
235.203;	3.761;	18.000;	400.015	16.993;	181.406;	21.740;	147.759;	0.628;	0.00011;
236.252;	3.645;	18.000;	399.784	17.055;	181.360;	21.759;	148.330;	0.628;	0.00011;
237.307;	3.572;	18.000;	399.759	17.377;	181.716;	21.676;	148.982;	0.628;	0.00011;
238.358;	3.802;	18.000;	399.730	17.006;	180.957;	21.674;	149.628;	0.628;	0.00011;
239.401;	3.696;	18.000;	399.697	16.966;	181.163;	21.658;	150.280;	0.628;	0.00011;
240.455;	3.761;	18.000;	399.678	17.294;	181.420;	21.586;	150.932;	0.628;	0.00011;

241.502;	3.752;	18.000;	399.764	16.809;	181.195;	21.766;	151.620;	0.628;	0.00011;
242.553;	3.657;	18.000;	399.595	17.211;	181.303;	21.760;	152.214;	0.628;	0.00011;
243.606;	3.701;	18.000;	399.790	17.162;	181.035;	21.734;	152.951;	0.628;	0.00011;
244.654;	3.732;	18.000;	399.744	17.027;	181.411;	21.749;	153.591;	0.628;	0.00011;
245.706;	3.777;	18.000;	399.917	16.840;	181.111;	21.744;	154.317;	0.628;	0.00011;
246.757;	3.904;	18.000;	399.899	17.239;	181.484;	21.666;	154.972;	0.628;	0.00011;
247.802;	3.932;	18.000;	400.040	16.757;	181.457;	21.788;	155.683;	0.628;	0.00011;
248.853;	3.696;	18.000;	399.983	17.253;	181.242;	21.790;	156.322;	0.628;	0.00011;
249.906;	3.743;	18.000;	400.013	17.206;	181.504;	21.753;	156.996;	0.628;	0.00011;
250.954;	3.740;	18.000;	400.066	16.845;	181.355;	21.739;	157.674;	0.628;	0.00011;
252.054;	3.743;	18.000;	400.244	17.043;	181.352;	21.739;	158.434;	0.629;	0.00011;
253.102;	3.833;	18.000;	400.219	16.987;	181.069;	21.719;	159.087;	0.629;	0.00011;
254.155;	3.971;	18.000;	400.178	17.084;	181.445;	21.763;	159.732;	0.629;	0.00011;
255.202;	3.837;	18.000;	400.105	17.094;	181.280;	21.827;	160.359;	0.628;	0.00011;
256.257;	3.674;	18.000;	400.093	17.482;	181.180;	21.793;	161.017;	0.628;	0.00011;
257.305;	3.689;	18.000;	400.073	17.481;	181.365;	21.777;	161.669;	0.628;	0.00011;
258.355;	3.854;	18.000;	400.116	17.198;	181.126;	21.737;	162.347;	0.629;	0.00011;
259.404;	3.758;	18.000;	400.033	17.357;	181.264;	21.700;	162.969;	0.628;	0.00011;
260.456;	3.748;	18.000;	400.074	17.369;	181.372;	21.715;	163.650;	0.628;	0.00011;
261.505;	3.782;	18.000;	400.176	17.685;	180.991;	21.780;	164.348;	0.629;	0.00011;
262.555;	3.825;	18.000;	400.275	17.077;	181.426;	21.804;	165.052;	0.629;	0.00011;
263.652;	3.850;	18.000;	400.287	17.583;	181.239;	21.786;	165.745;	0.629;	0.00011;
264.705;	3.808;	18.000;	400.229	17.219;	181.753;	21.760;	166.384;	0.629;	0.00011;
265.755;	4.058;	18.000;	400.186	17.404;	181.747;	21.730;	167.026;	0.629;	0.00011;
266.810;	3.936;	18.000;	400.204	17.101;	181.760;	21.729;	167.693;	0.629;	0.00011;
267.861;	3.918;	18.000;	400.272	17.467;	181.333;	21.825;	168.380;	0.629;	0.00011;
268.903;	3.731;	18.000;	400.461	17.615;	181.676;	21.798;	169.119;	0.629;	0.00011;
269.958;	3.619;	18.000;	400.267	17.614;	181.079;	21.779;	169.699;	0.629;	0.00011;
271.003;	3.880;	18.000;	400.176	17.138;	181.153;	21.807;	170.323;	0.629;	0.00011;
272.054;	3.932;	18.000;	400.032	17.443;	181.331;	21.767;	170.919;	0.628;	0.00011;
273.104;	3.917;	18.000;	399.835	17.196;	181.292;	21.770;	171.515;	0.628;	0.00011;
274.155;	3.827;	18.000;	399.587	17.476;	181.314;	21.833;	172.047;	0.628;	0.00011;
275.208;	3.843;	18.000;	399.438	17.417;	181.363;	21.833;	172.640;	0.627;	0.00011;
276.255;	3.914;	18.000;	399.322	17.268;	181.303;	21.828;	173.252;	0.627;	0.00011;
277.305;	3.995;	18.000;	399.680	16.988;	181.477;	21.848;	174.065;	0.628;	0.00011;
278.358;	3.930;	18.000;	399.815	17.636;	181.221;	21.738;	174.782;	0.628;	0.00011;
279.409;	3.907;	18.000;	399.771	16.682;	181.279;	21.838;	175.424;	0.628;	0.00011;

280.505; 3.825; 18.000; 400.015 17.458; 181.257; 21.848; 176.220; 0.628; 0.00011;

281.553; 3.873; 18.000; 399.849 17.220; 181.635; 21.852; 176.808; 0.628; 0.00011;

282.656; 3.913; 18.000; 399.753 17.391; 181.613; 21.851; 177.455; 0.628; 0.00011;

283.703; 3.912; 18.000; 399.493 16.804; 181.428; 21.865; 178.006; 0.628; 0.00011;

284.757; 3.911; 18.000; 399.587 17.354; 181.546; 21.776; 178.701; 0.628; 0.00011;

285.809; 3.973; 18.000; 399.699 17.271; 181.525; 21.742; 179.408; 0.628; 0.00011;

286.901; 3.932; 18.000; 399.805 17.639; 181.637; 21.841; 180.147; 0.628; 0.00011;

287.952; 3.855; 18.000; 399.901 17.581; 181.352; 21.811; 180.850; 0.628; 0.00011;

289.006; 3.955; 18.000; 400.042 17.160; 181.138; 21.802; 181.577; 0.628; 0.00011;

290.058; 3.942; 18.000; 400.344 17.045; 181.262; 21.802; 182.375; 0.629; 0.00011;

291.108; 3.914; 18.000; 400.226 17.215; 181.254; 21.786; 182.977; 0.629; 0.00011;

292.159; 3.844; 18.000; 400.054 17.387; 181.541; 21.717; 183.559; 0.628; 0.00011;

293.209; 3.824; 18.000; 399.815 17.649; 181.262; 21.847; 184.110; 0.628; 0.00011;

294.254; 3.716; 18.000; 399.841 17.204; 181.356; 21.853; 184.782; 0.628; 0.00011;

295.308; 3.781; 18.000; 399.503 16.972; 181.431; 21.872; 185.282; 0.628; 0.00011;

296.355; 3.905; 18.000; 399.578 16.996; 181.501; 21.879; 185.979; 0.628; 0.00011;

297.405; 3.814; 18.000; 399.479 18.146; 181.278; 21.785; 186.593; 0.628; 0.00011;

298.457; 3.760; 18.000; 399.598 17.200; 181.485; 21.902; 187.304; 0.628; 0.00011;

299.552; 3.685; 18.000; 399.808 17.785; 181.186; 21.909; 188.092; 0.628; 0.00011;

300.051; 3.769; 18.000; 399.992 17.359; 181.449; 21.898; 188.497; 0.628; 0.00011;

Appendex B: Wear rate test result data point of C2

Time; FF (N); NL (N); SPEED (rpm); Wear (Microns); Pin Temp (Deg C); Heater Temp (Deg C)

0.000; 0.328; 30.000; 0.000 21.287; 182.077; 22.540; 0.000; 0.000; 0.00000;

0.058; 0.333; 30.000; 1.000 21.337; 182.086; 22.546; 0.000; 0.000; 0.00000;

1.134; 5.685; 30.000; 1.835 1.819; 182.070; 22.597; 0.003; 0.003; 0.00000;

2.182; 7.310; 30.000; 61.731 1.908; 182.079; 22.534; 0.206; 0.097; 0.00001;

3.231; 7.801; 30.000; 136.394 2.213; 182.123; 22.639; 0.683; 0.214; 0.00002;

4.274; 7.981; 30.000; 211.214 2.275; 182.090; 22.629; 1.406; 0.332; 0.00003;

5.374; 8.004; 30.000; 285.812 2.550; 182.100; 22.651; 2.392; 0.449; 0.00005;

6.431; 8.201; 30.000; 360.646 2.725; 182.046; 22.593; 3.611; 0.567; 0.00006;

7.530; 8.352; 30.000; 435.553 2.880; 182.073; 22.599; 5.113; 0.684; 0.00007;

8.577; 8.376; 30.000; 500.156 3.234; 182.079; 22.632; 6.702; 0.786; 0.00008;

9.623; 8.568; 30.000; 499.626 3.170; 182.126; 22.669; 7.515; 0.785; 0.00008;

10.681; 8.639; 30.000; 499.852 3.235; 182.097; 22.664; 8.342; 0.785; 0.00008;

11.725; 8.660; 30.000; 500.193 3.437; 182.088; 22.588; 9.172; 0.786; 0.00008;

12.824; 8.666; 30.000; 500.151 3.715; 182.145; 22.620; 10.036; 0.786; 0.00008;

13.874;	8.922;	30.000;	499.911	3.392;	182.119;	22.638;	10.856;	0.785;	0.00008;
14.931;	9.068;	30.000;	500.062	3.173;	182.086;	22.671;	11.687;	0.785;	0.00008;
15.975;	9.062;	30.000;	499.950	3.730;	182.060;	22.591;	12.509;	0.785;	0.00008;
17.025;	9.143;	30.000;	499.924	3.699;	182.141;	22.609;	13.334;	0.785;	0.00008;
18.125;	9.081;	30.000;	499.710	4.509;	182.085;	22.652;	14.186;	0.785;	0.00008;
19.178;	9.194;	30.000;	499.659	3.823;	182.078;	22.706;	15.010;	0.785;	0.00008;
20.230;	9.188;	30.000;	499.718	4.263;	182.104;	22.674;	15.836;	0.785;	0.00008;
21.273;	9.239;	30.000;	499.642	4.101;	182.121;	22.587;	16.662;	0.785;	0.00008;
22.374;	9.102;	30.000;	499.659	4.892;	182.138;	22.653;	17.522;	0.785;	0.00008;
23.473;	9.164;	30.000;	499.451	5.029;	182.098;	22.669;	18.379;	0.785;	0.00008;
24.523;	9.142;	30.000;	499.114	4.527;	182.080;	22.714;	19.188;	0.784;	0.00008;
25.575;	9.138;	30.000;	499.069	4.968;	182.064;	22.661;	20.010;	0.784;	0.00008;
26.630;	9.226;	30.000;	499.279	4.779;	182.111;	22.609;	20.841;	0.784;	0.00008;
27.724;	9.173;	30.000;	499.414	5.652;	182.099;	22.647;	21.710;	0.784;	0.00008;
28.772;	9.194;	30.000;	499.650	5.047;	182.111;	22.692;	22.545;	0.785;	0.00008;
29.827;	9.200;	30.000;	499.866	5.513;	182.162;	22.638;	23.381;	0.785;	0.00008;
30.881;	9.340;	30.000;	500.011	5.245;	182.133;	22.580;	24.209;	0.785;	0.00008;
31.928;	9.229;	30.000;	500.117	5.986;	182.100;	22.636;	25.040;	0.786;	0.00008;
32.977;	9.266;	30.000;	500.365	5.574;	182.110;	22.659;	25.880;	0.786;	0.00008;
34.025;	9.281;	30.000;	500.432	5.271;	182.140;	22.656;	26.709;	0.786;	0.00008;
35.074;	9.311;	30.000;	500.234	5.665;	182.095;	22.591;	27.523;	0.786;	0.00008;
36.127;	9.237;	30.000;	500.135	6.119;	182.176;	22.626;	28.343;	0.786;	0.00008;
37.228;	9.263;	30.000;	499.908	6.359;	182.091;	22.651;	29.193;	0.785;	0.00008;
38.280;	9.345;	30.000;	500.153	5.943;	182.080;	22.719;	30.032;	0.786;	0.00008;
39.328;	9.375;	30.000;	500.179	6.092;	182.071;	22.642;	30.858;	0.786;	0.00008;
40.377;	9.448;	30.000;	499.949	5.803;	182.128;	22.622;	31.671;	0.785;	0.00008;
41.426;	9.382;	30.000;	499.912	6.356;	182.091;	22.653;	32.492;	0.785;	0.00008;
42.479;	9.456;	30.000;	500.018	6.300;	182.082;	22.666;	33.320;	0.785;	0.00008;
43.576;	9.410;	30.000;	499.896	6.239;	182.135;	22.618;	34.180;	0.785;	0.00008;
44.628;	9.472;	30.000;	500.092	6.587;	182.137;	22.568;	35.015;	0.786;	0.00008;
45.721;	9.398;	30.000;	499.947	6.895;	182.117;	22.637;	35.868;	0.785;	0.00008;
46.776;	9.401;	30.000;	499.999	6.723;	182.137;	22.668;	36.697;	0.785;	0.00008;
47.875;	9.340;	30.000;	500.109	6.952;	182.136;	22.665;	37.571;	0.786;	0.00008;
48.923;	9.462;	30.000;	500.186	6.887;	182.127;	22.611;	38.401;	0.786;	0.00008;
49.975;	9.403;	30.000;	500.131	6.961;	182.132;	22.637;	39.222;	0.786;	0.00008;
51.028;	9.361;	30.000;	500.262	7.377;	182.081;	22.633;	40.058;	0.786;	0.00008;
52.077;	9.343;	30.000;	500.144	7.045;	182.136;	22.690;	40.872;	0.786;	0.00008;

53.173;	9.404;	30.000;	499.917	7.161;	182.121;	22.654;	41.716;	0.785;	0.00008;
54.232;	9.377;	30.000;	500.025	7.255;	182.163;	22.599;	42.549;	0.785;	0.00008;
55.276;	9.293;	30.000;	500.147	7.928;	182.079;	22.665;	43.386;	0.786;	0.00008;
56.331;	9.300;	30.000;	500.359	7.688;	182.097;	22.680;	44.232;	0.786;	0.00008;
57.423;	9.492;	30.000;	500.112	7.042;	182.182;	22.637;	45.073;	0.786;	0.00008;
58.480;	9.488;	30.000;	500.335	7.376;	182.124;	22.637;	45.919;	0.786;	0.00008;
59.528;	9.399;	30.000;	500.539	8.024;	182.094;	22.675;	46.765;	0.786;	0.00008;
60.578;	9.404;	30.000;	500.414	7.920;	182.117;	22.663;	47.576;	0.786;	0.00008;
61.630;	9.542;	30.000;	500.296	7.535;	182.129;	22.687;	48.389;	0.786;	0.00008;
62.677;	9.572;	30.000;	500.131	7.521;	182.138;	22.591;	49.199;	0.786;	0.00008;
63.776;	9.434;	30.000;	499.822	7.788;	182.145;	22.662;	50.034;	0.785;	0.00008;
64.828;	9.534;	30.000;	500.106	8.953;	182.079;	22.665;	50.883;	0.786;	0.00008;
65.924;	9.438;	30.000;	500.192	8.089;	182.063;	22.700;	51.757;	0.786;	0.00008;
67.031;	9.541;	30.000;	499.981	7.973;	182.161;	22.664;	52.600;	0.785;	0.00008;
68.077;	9.705;	30.000;	500.054	7.674;	182.162;	22.566;	53.432;	0.785;	0.00008;
69.130;	9.386;	30.000;	500.363	8.565;	182.107;	22.679;	54.292;	0.786;	0.00008;
70.225;	9.413;	30.000;	500.445	8.741;	182.087;	22.694;	55.164;	0.786;	0.00008;
71.324;	9.316;	30.000;	500.481	8.586;	182.114;	22.738;	56.033;	0.786;	0.00008;
72.379;	9.498;	30.000;	500.439	8.378;	182.141;	22.656;	56.853;	0.786;	0.00008;
73.430;	9.489;	30.000;	500.536	8.330;	182.112;	22.655;	57.690;	0.786;	0.00008;
74.482;	9.302;	30.000;	500.618	8.862;	182.077;	22.666;	58.528;	0.786;	0.00008;
75.578;	9.304;	30.000;	500.479	9.110;	182.113;	22.660;	59.373;	0.786;	0.00008;
76.631;	9.482;	30.000;	500.192	8.831;	182.187;	22.678;	60.168;	0.786;	0.00008;
77.724;	9.335;	30.000;	500.435	8.886;	182.114;	22.605;	61.060;	0.786;	0.00008;
78.829;	9.349;	30.000;	499.759	9.163;	182.146;	22.668;	61.841;	0.785;	0.00008;
79.880;	9.416;	30.000;	499.691	9.279;	182.066;	22.688;	62.656;	0.785;	0.00008;
80.973;	9.401;	30.000;	499.394	8.829;	182.122;	22.744;	63.480;	0.784;	0.00008;
82.025;	9.460;	30.000;	499.399	9.137;	182.165;	22.673;	64.307;	0.784;	0.00008;
83.123;	9.300;	30.000;	499.714	9.004;	182.195;	22.621;	65.209;	0.785;	0.00008;
84.175;	9.206;	30.000;	499.574	10.041;	182.108;	22.702;	66.019;	0.785;	0.00008;
85.231;	9.276;	30.000;	499.932	9.530;	182.149;	22.726;	66.888;	0.785;	0.00008;
86.282;	9.313;	30.000;	500.081	9.218;	182.199;	22.676;	67.731;	0.786;	0.00008;
87.377;	9.217;	30.000;	500.348	9.328;	182.110;	22.675;	68.634;	0.786;	0.00008;
88.425;	9.069;	30.000;	500.519	10.076;	182.116;	22.689;	69.484;	0.786;	0.00008;
89.484;	9.158;	30.000;	500.007	10.120;	182.057;	22.725;	70.238;	0.785;	0.00008;
90.528;	9.259;	30.000;	499.788	9.535;	182.152;	22.726;	71.033;	0.785;	0.00008;
91.580;	9.275;	30.000;	499.830	9.811;	182.146;	22.664;	71.864;	0.785;	0.00008;

92.631;	9.231;	30.000;	499.887	9.793;	182.181;	22.654;	72.694;	0.785;	0.00008;
93.680;	9.132;	30.000;	499.923	10.378;	182.092;	22.719;	73.523;	0.785;	0.00008;
94.724;	9.152;	30.000;	499.822	10.021;	182.095;	22.751;	74.332;	0.785;	0.00008;
95.778;	9.157;	30.000;	499.744	9.962;	182.129;	22.697;	75.144;	0.785;	0.00008;
96.827;	9.196;	30.000;	500.263	9.771;	182.158;	22.625;	76.048;	0.786;	0.00008;
97.882;	9.072;	30.000;	500.392	10.604;	182.086;	22.717;	76.894;	0.786;	0.00008;
98.928;	9.019;	30.000;	500.273	10.671;	182.144;	22.721;	77.703;	0.786;	0.00008;
99.980;	9.029;	30.000;	500.343	10.287;	182.173;	22.719;	78.536;	0.786;	0.00008;
101.030;	9.224;	30.000;	500.237	10.025;	182.147;	22.633;	79.348;	0.786;	0.00008;
102.081;	9.089;	30.000;	500.114	10.576;	182.109;	22.706;	80.156;	0.786;	0.00008;
103.131;	9.032;	30.000;	499.957	10.747;	182.115;	22.739;	80.951;	0.785;	0.00008;
104.178;	9.022;	30.000;	499.832	10.653;	182.213;	22.722;	81.756;	0.785;	0.00008;
105.233;	9.154;	30.000;	499.391	10.602;	182.122;	22.686;	82.509;	0.784;	0.00008;
106.284;	9.033;	30.000;	498.841	11.025;	182.158;	22.716;	83.240;	0.784;	0.00008;
107.331;	9.021;	30.000;	498.769	11.084;	182.125;	22.723;	84.050;	0.783;	0.00008;
108.380;	9.063;	30.000;	498.525	10.672;	182.213;	22.718;	84.830;	0.783;	0.00008;
109.427;	8.961;	30.000;	498.832	10.897;	182.144;	22.730;	85.695;	0.784;	0.00008;
110.477;	8.945;	30.000;	498.839	10.883;	182.171;	22.690;	86.529;	0.784;	0.00008;
111.523;	8.886;	30.000;	498.915	11.680;	182.104;	22.703;	87.363;	0.784;	0.00008;
112.578;	8.783;	30.000;	498.986	11.224;	182.157;	22.749;	88.200;	0.784;	0.00008;
113.629;	8.895;	30.000;	499.558	11.083;	182.198;	22.717;	89.124;	0.785;	0.00008;
114.673;	8.902;	30.000;	499.488	11.136;	182.187;	22.660;	89.937;	0.785;	0.00008;
115.725;	8.810;	30.000;	499.557	11.783;	182.070;	22.702;	90.774;	0.785;	0.00008;
116.781;	8.816;	30.000;	499.128	11.724;	182.108;	22.755;	91.517;	0.784;	0.00008;
117.828;	8.947;	30.000;	498.965	11.461;	182.193;	22.723;	92.309;	0.784;	0.00008;
118.879;	9.033;	30.000;	498.979	11.259;	182.183;	22.660;	93.133;	0.784;	0.00008;
119.930;	8.865;	30.000;	499.000	11.901;	182.126;	22.711;	93.961;	0.784;	0.00008;
120.977;	8.862;	30.000;	499.285	11.831;	182.106;	22.738;	94.842;	0.784;	0.00008;
122.026;	8.972;	30.000;	499.293	11.534;	182.239;	22.712;	95.665;	0.784;	0.00008;
123.074;	9.003;	30.000;	499.483	11.278;	182.146;	22.692;	96.522;	0.785;	0.00008;
124.131;	8.856;	30.000;	499.779	12.264;	182.161;	22.739;	97.404;	0.785;	0.00008;
125.177;	8.984;	30.000;	500.023	12.163;	182.111;	22.739;	98.279;	0.785;	0.00008;
126.224;	8.938;	30.000;	499.920	11.679;	182.172;	22.754;	99.083;	0.785;	0.00008;
127.278;	8.942;	30.000;	500.016	11.843;	182.144;	22.734;	99.924;	0.785;	0.00008;
128.324;	8.993;	30.000;	499.795	11.854;	182.166;	22.705;	100.704;	0.785;	0.00008;
129.377;	8.877;	30.000;	499.935	12.271;	182.066;	22.758;	101.559;	0.785;	0.00008;
130.424;	8.898;	30.000;	499.707	12.132;	182.133;	22.780;	102.337;	0.785;	0.00008;

131.528;	9.004;	30.000;	499.778	11.813;	182.210;	22.730;	103.214;	0.785;	0.00008;
132.577;	9.009;	30.000;	499.735	12.288;	182.187;	22.670;	104.029;	0.785;	0.00008;
133.628;	8.940;	30.000;	499.851	12.535;	182.108;	22.754;	104.880;	0.785;	0.00008;
134.676;	8.948;	30.000;	499.765	12.451;	182.115;	22.764;	105.683;	0.785;	0.00008;
135.726;	8.871;	30.000;	499.637	11.954;	182.254;	22.702;	106.485;	0.785;	0.00008;
136.780;	8.989;	30.000;	499.605	12.194;	182.145;	22.701;	107.302;	0.785;	0.00008;
137.825;	8.855;	30.000;	499.881	12.199;	182.162;	22.721;	108.188;	0.785;	0.00008;
138.879;	8.821;	30.000;	499.861	12.629;	182.082;	22.756;	109.006;	0.785;	0.00008;
139.925;	8.842;	30.000;	499.739	12.338;	182.173;	22.772;	109.804;	0.785;	0.00008;
140.975;	8.976;	30.000;	499.752	12.306;	182.187;	22.727;	110.627;	0.785;	0.00008;
142.024;	9.020;	30.000;	499.784	12.422;	182.159;	22.739;	111.462;	0.785;	0.00008;
143.079;	8.885;	30.000;	500.003	12.790;	182.102;	22.733;	112.336;	0.785;	0.00008;
144.130;	9.062;	30.000;	500.125	12.283;	182.144;	22.794;	113.187;	0.786;	0.00008;
145.176;	9.068;	30.000;	499.893	12.642;	182.155;	22.758;	113.957;	0.785;	0.00008;
146.229;	9.105;	30.000;	499.908	12.585;	182.177;	22.717;	114.788;	0.785;	0.00008;
147.278;	8.888;	30.000;	499.773	13.230;	182.127;	22.731;	115.582;	0.785;	0.00008;
148.329;	8.891;	30.000;	500.052	12.902;	182.150;	22.745;	116.467;	0.785;	0.00008;
149.425;	8.968;	30.000;	499.799	12.853;	182.232;	22.750;	117.274;	0.785;	0.00008;
150.475;	9.102;	30.000;	499.701	13.030;	182.172;	22.690;	118.076;	0.785;	0.00008;
151.526;	8.922;	30.000;	499.476	13.278;	182.152;	22.715;	118.847;	0.785;	0.00008;
152.577;	8.851;	30.000;	499.786	13.126;	182.147;	22.784;	119.744;	0.785;	0.00008;
153.626;	8.828;	30.000;	499.911	12.977;	182.266;	22.734;	120.596;	0.785;	0.00008;
154.680;	8.790;	30.000;	500.107	13.300;	182.192;	22.742;	121.464;	0.786;	0.00008;
155.728;	8.775;	30.000;	500.263	13.470;	182.202;	22.729;	122.335;	0.786;	0.00008;
156.777;	8.683;	30.000;	500.297	13.967;	182.084;	22.748;	123.164;	0.786;	0.00008;
157.826;	8.588;	30.000;	500.192	13.174;	182.169;	22.800;	123.967;	0.786;	0.00008;
158.875;	8.667;	30.000;	500.456	13.770;	182.212;	22.727;	124.856;	0.786;	0.00008;
159.924;	8.716;	30.000;	500.265	13.737;	182.182;	22.718;	125.634;	0.786;	0.00008;
160.977;	8.566;	30.000;	499.997	13.970;	182.121;	22.801;	126.393;	0.785;	0.00008;
162.024;	8.608;	30.000;	499.901	13.870;	182.153;	22.782;	127.190;	0.785;	0.00008;
163.079;	8.645;	30.000;	499.987	14.006;	182.192;	22.771;	128.035;	0.785;	0.00008;
164.126;	8.719;	30.000;	499.972	13.937;	182.194;	22.700;	128.856;	0.785;	0.00008;
165.174;	8.620;	30.000;	499.922	14.214;	182.161;	22.732;	129.669;	0.785;	0.00008;
166.223;	8.593;	30.000;	499.672	14.277;	182.145;	22.765;	130.427;	0.785;	0.00008;
167.278;	8.579;	30.000;	499.827	14.138;	182.256;	22.745;	131.292;	0.785;	0.00008;
168.325;	8.682;	30.000;	499.903	13.956;	182.199;	22.757;	132.140;	0.785;	0.00008;
169.374;	8.608;	30.000;	499.758	14.353;	182.175;	22.754;	132.922;	0.785;	0.00008;

170.433;	8.594;	30.000;	499.427	14.499;	182.168;	22.793;	133.658;	0.784;	0.00008;
171.489;	8.623;	30.000;	499.350	14.049;	182.228;	22.787;	134.477;	0.784;	0.00008;
172.541;	8.751;	30.000;	499.600	14.034;	182.198;	22.738;	135.368;	0.785;	0.00008;
173.995;	8.721;	30.000;	499.666	14.315;	182.161;	22.750;	136.171;	0.785;	0.00008;
175.122;	8.819;	30.000;	499.674	14.531;	182.151;	22.739;	137.412;	0.785;	0.00008;
176.177;	8.621;	30.000;	499.859	14.753;	182.180;	22.760;	138.289;	0.785;	0.00008;
177.223;	8.605;	30.000;	500.092	14.399;	182.205;	22.830;	139.178;	0.786;	0.00008;
178.278;	8.636;	30.000;	500.240	14.269;	182.246;	22.808;	140.043;	0.786;	0.00008;
179.326;	8.701;	30.000;	500.320	14.392;	182.172;	22.777;	140.892;	0.786;	0.00008;
180.404;	8.562;	30.000;	500.392	14.777;	182.212;	22.827;	141.612;	0.786;	0.00008;
181.439;	8.566;	30.000;	500.293	14.938;	182.147;	22.814;	142.547;	0.786;	0.00008;
182.484;	8.510;	30.000;	500.172	14.762;	182.170;	22.839;	143.300;	0.786;	0.00008;
183.559;	8.699;	30.000;	500.039	14.898;	182.201;	22.782;	144.138;	0.785;	0.00008;
184.606;	8.922;	30.000;	500.022	14.675;	182.134;	22.771;	144.959;	0.785;	0.00008;
185.710;	8.724;	30.000;	499.908	15.371;	182.144;	22.814;	145.787;	0.785;	0.00008;
186.759;	8.744;	30.000;	499.647	14.902;	182.211;	22.807;	146.535;	0.785;	0.00008;
187.831;	8.790;	30.000;	499.466	14.965;	182.189;	22.788;	147.330;	0.785;	0.00008;
188.883;	8.850;	30.000;	499.704	14.773;	182.193;	22.770;	148.221;	0.785;	0.00008;
189.989;	8.899;	30.000;	499.877	14.978;	182.189;	22.793;	149.136;	0.785;	0.00008;
191.034;	8.697;	30.000;	499.897	15.415;	182.170;	22.825;	149.970;	0.785;	0.00008;
192.086;	8.712;	30.000;	499.834	14.899;	182.195;	22.874;	150.776;	0.785;	0.00008;
193.138;	8.856;	30.000;	499.771	15.149;	182.212;	22.789;	151.578;	0.785;	0.00008;
194.184;	8.933;	30.000;	499.876	14.983;	182.144;	22.786;	152.435;	0.785;	0.00008;
195.233;	8.838;	30.000;	499.992	15.402;	182.160;	22.804;	153.296;	0.785;	0.00008;
196.286;	8.731;	30.000;	499.957	15.627;	182.136;	22.831;	154.096;	0.785;	0.00008;
197.371;	8.748;	30.000;	499.910	15.209;	182.261;	22.767;	154.940;	0.785;	0.00008;
198.417;	8.743;	30.000;	499.780	15.292;	182.154;	22.768;	155.730;	0.785;	0.00008;
199.467;	8.711;	30.000;	499.893	15.628;	182.215;	22.776;	156.586;	0.785;	0.00008;
200.568;	8.701;	30.000;	499.908	15.670;	182.142;	22.810;	157.454;	0.785;	0.00008;
201.615;	8.619;	30.000;	500.004	15.741;	182.209;	22.837;	158.312;	0.785;	0.00008;
202.665;	8.805;	30.000;	499.921	15.462;	182.176;	22.795;	159.111;	0.785;	0.00008;
203.771;	8.857;	30.000;	499.759	15.307;	182.166;	22.787;	159.920;	0.785;	0.00008;
204.816;	8.790;	30.000;	499.784	15.612;	182.192;	22.821;	160.756;	0.785;	0.00008;
205.863;	8.638;	30.000;	499.859	15.779;	182.135;	22.861;	161.605;	0.785;	0.00008;
206.914;	8.672;	30.000;	499.771	15.922;	182.219;	22.800;	162.399;	0.785;	0.00008;
207.965;	8.831;	30.000;	499.730	15.488;	182.153;	22.801;	163.210;	0.785;	0.00008;
209.019;	8.763;	30.000;	499.618	15.686;	182.184;	22.768;	163.995;	0.785;	0.00008;

210.069;	8.636;	30.000;	499.730	15.924;	182.125;	22.829;	164.856;	0.785;	0.00008;
211.118;	8.640;	30.000;	500.374	15.882;	182.202;	22.816;	165.893;	0.786;	0.00008;
212.167;	8.661;	30.000;	500.127	15.814;	182.192;	22.811;	166.639;	0.786;	0.00008;
213.219;	8.746;	30.000;	499.975	15.554;	182.207;	22.810;	167.413;	0.785;	0.00008;
214.265;	8.650;	30.000;	499.928	16.075;	182.146;	22.830;	168.220;	0.785;	0.00008;
215.367;	8.589;	30.000;	499.783	15.948;	182.122;	22.838;	169.035;	0.785;	0.00008;
216.414;	8.665;	30.000;	499.646	16.075;	182.220;	22.787;	169.815;	0.785;	0.00008;
217.473;	8.641;	30.000;	499.406	15.736;	182.127;	22.803;	170.557;	0.784;	0.00008;
218.566;	8.665;	30.000;	499.282	16.287;	182.136;	22.784;	171.376;	0.784;	0.00008;
219.621;	8.669;	30.000;	499.299	16.190;	182.132;	22.842;	172.204;	0.784;	0.00008;
220.715;	8.621;	30.000;	499.571	16.044;	182.205;	22.811;	173.165;	0.785;	0.00008;
221.771;	8.662;	30.000;	499.594	15.921;	182.193;	22.795;	173.984;	0.785;	0.00008;
222.868;	8.699;	30.000;	499.783	16.058;	182.165;	22.826;	174.922;	0.785;	0.00008;
223.969;	8.672;	30.000;	499.916	16.367;	182.184;	22.821;	175.831;	0.785;	0.00008;
225.021;	8.609;	30.000;	499.773	16.325;	182.149;	22.876;	176.609;	0.785;	0.00008;
226.072;	8.660;	30.000;	499.916	16.434;	182.235;	22.772;	177.489;	0.785;	0.00008;
227.171;	8.692;	30.000;	499.872	15.983;	182.185;	22.820;	178.322;	0.785;	0.00008;
228.219;	8.660;	30.000;	499.677	16.497;	182.196;	22.819;	179.083;	0.785;	0.00008;
229.268;	8.617;	30.000;	499.629	16.393;	182.182;	22.809;	179.896;	0.785;	0.00008;
230.364;	8.550;	30.000;	499.559	16.286;	182.179;	22.854;	180.715;	0.785;	0.00008;
231.471;	8.631;	30.000;	499.764	16.431;	182.248;	22.798;	181.666;	0.785;	0.00008;
232.570;	8.665;	30.000;	499.757	16.416;	182.132;	22.833;	182.537;	0.785;	0.00008;
233.616;	8.633;	30.000;	499.757	16.531;	182.162;	22.830;	183.355;	0.785;	0.00008;
234.670;	8.603;	30.000;	499.589	16.363;	182.132;	22.856;	184.116;	0.785;	0.00008;
235.719;	8.642;	30.000;	499.751	16.506;	182.209;	22.789;	185.002;	0.785;	0.00008;
236.767;	8.654;	30.000;	499.805	16.428;	182.201;	22.822;	185.848;	0.785;	0.00008;
237.819;	8.557;	30.000;	499.725	16.608;	182.209;	22.797;	186.639;	0.785;	0.00008;
238.867;	8.533;	30.000;	499.469	16.439;	182.184;	22.858;	187.367;	0.785;	0.00008;
239.920;	8.557;	30.000;	499.485	16.399;	182.179;	22.862;	188.199;	0.785;	0.00008;
240.964;	8.641;	30.000;	499.339	16.556;	182.243;	22.829;	188.965;	0.784;	0.00008;
242.021;	8.614;	30.000;	499.771	16.477;	182.173;	22.832;	189.953;	0.785;	0.00008;
243.071;	8.661;	30.000;	499.932	16.914;	182.192;	22.831;	190.842;	0.785;	0.00008;
244.115;	8.536;	30.000;	499.884	16.444;	182.150;	22.886;	191.647;	0.785;	0.00008;
245.171;	8.631;	30.000;	499.956	16.758;	182.271;	22.806;	192.501;	0.785;	0.00008;
246.269;	8.739;	30.000;	500.285	16.462;	182.150;	22.811;	193.486;	0.786;	0.00008;
247.319;	8.578;	30.000;	500.392	17.206;	182.160;	22.821;	194.357;	0.786;	0.00008;
248.418;	8.600;	30.000;	500.430	16.650;	182.160;	22.870;	195.235;	0.786;	0.00008;

249.471; 8.642; 30.000; 500.223 16.827; 182.237; 22.815; 195.981; 0.786; 0.00008;
250.520; 8.655; 30.000; 500.257 16.692; 182.203; 22.818; 196.821; 0.786; 0.00008;
251.570; 8.653; 30.000; 500.001 16.808; 182.221; 22.816; 197.540; 0.785; 0.00008;
252.618; 8.552; 30.000; 500.190 17.013; 182.154; 22.836; 198.446; 0.786; 0.00008;
253.672; 8.621; 30.000; 500.248 16.683; 182.223; 22.900; 199.288; 0.786; 0.00008;
254.719; 8.578; 30.000; 500.263 17.040; 182.242; 22.824; 200.119; 0.786; 0.00008;
255.764; 8.627; 30.000; 500.360 17.020; 182.209; 22.811; 200.983; 0.786; 0.00008;
256.818; 8.800; 30.000; 500.104 17.390; 182.145; 22.857; 201.709; 0.786; 0.00008;
257.870; 8.642; 30.000; 500.131 17.112; 182.163; 22.883; 202.544; 0.786; 0.00008;
258.920; 8.580; 30.000; 500.529 17.300; 182.231; 22.806; 203.529; 0.786; 0.00008;
260.020; 8.639; 30.000; 499.953 16.838; 182.197; 22.842; 204.160; 0.785; 0.00008;
261.068; 8.639; 30.000; 500.134 17.160; 182.198; 22.842; 205.057; 0.786; 0.00008;
262.118; 8.699; 30.000; 499.961 17.209; 182.199; 22.884; 205.810; 0.785; 0.00008;
263.214; 8.666; 30.000; 499.901 17.323; 182.230; 22.866; 206.649; 0.785; 0.00008;
264.321; 8.768; 30.000; 500.005 16.885; 182.224; 22.822; 207.555; 0.785; 0.00008;
265.416; 8.785; 30.000; 499.738 16.934; 182.205; 22.841; 208.309; 0.785; 0.00008;
266.470; 8.700; 30.000; 499.519 17.573; 182.204; 22.866; 209.044; 0.785; 0.00008;
267.522; 8.661; 30.000; 499.870 17.381; 182.199; 22.918; 210.017; 0.785; 0.00008;
268.566; 8.614; 30.000; 499.845 17.519; 182.288; 22.803; 210.826; 0.785; 0.00008;
269.613; 8.689; 30.000; 499.820 17.035; 182.211; 22.859; 211.639; 0.785; 0.00008;

APPENDIX B: Wear rate test result data point of C2

Time; FF (N); NL (N); SPEED (rpm); Wear (Microns); Pin Temp (Deg C); Heater Temp (Deg C)

0.000; 0.328; 30.000; 0.000 21.287; 182.077; 22.540; 0.000; 0.000; 0.00000;
0.058; 0.333; 30.000; 1.000 21.337; 182.086; 22.546; 0.000; 0.000; 0.00000;
1.134; 5.685; 30.000; 1.835 1.819; 182.070; 22.597; 0.003; 0.003; 0.00000;
2.182; 7.310; 30.000; 61.731 1.908; 182.079; 22.534; 0.206; 0.097; 0.00001;
3.231; 7.801; 30.000; 136.394 2.213; 182.123; 22.639; 0.683; 0.214; 0.00002;
4.274; 7.981; 30.000; 211.214 2.275; 182.090; 22.629; 1.406; 0.332; 0.00003;
5.374; 8.004; 30.000; 285.812 2.550; 182.100; 22.651; 2.392; 0.449; 0.00005;
6.431; 8.201; 30.000; 360.646 2.725; 182.046; 22.593; 3.611; 0.567; 0.00006;
7.530; 8.352; 30.000; 435.553 2.880; 182.073; 22.599; 5.113; 0.684; 0.00007;
8.577; 8.376; 30.000; 500.156 3.234; 182.079; 22.632; 6.702; 0.786; 0.00008;
9.623; 8.568; 30.000; 499.626 3.170; 182.126; 22.669; 7.515; 0.785; 0.00008;
10.681; 8.639; 30.000; 499.852 3.235; 182.097; 22.664; 8.342; 0.785; 0.00008;
11.725; 8.660; 30.000; 500.193 3.437; 182.088; 22.588; 9.172; 0.786; 0.00008;
12.824; 8.666; 30.000; 500.151 3.715; 182.145; 22.620; 10.036; 0.786; 0.00008;
13.874; 8.922; 30.000; 499.911 3.392; 182.119; 22.638; 10.856; 0.785; 0.00008;
14.931; 9.068; 30.000; 500.062 3.173; 182.086; 22.671; 11.687; 0.785; 0.00008;
15.975; 9.062; 30.000; 499.950 3.730; 182.060; 22.591; 12.509; 0.785; 0.00008;
17.025; 9.143; 30.000; 499.924 3.699; 182.141; 22.609; 13.334; 0.785; 0.00008;
18.125; 9.081; 30.000; 499.710 4.509; 182.085; 22.652; 14.186; 0.785; 0.00008;
19.178; 9.194; 30.000; 499.659 3.823; 182.078; 22.706; 15.010; 0.785; 0.00008;

20.230;	9.188;	30.000;	499.718	4.263;	182.104;	22.674;	15.836;	0.785;	0.00008;
21.273;	9.239;	30.000;	499.642	4.101;	182.121;	22.587;	16.662;	0.785;	0.00008;
22.374;	9.102;	30.000;	499.659	4.892;	182.138;	22.653;	17.522;	0.785;	0.00008;
23.473;	9.164;	30.000;	499.451	5.029;	182.098;	22.669;	18.379;	0.785;	0.00008;
24.523;	9.142;	30.000;	499.114	4.527;	182.080;	22.714;	19.188;	0.784;	0.00008;
25.575;	9.138;	30.000;	499.069	4.968;	182.064;	22.661;	20.010;	0.784;	0.00008;
26.630;	9.226;	30.000;	499.279	4.779;	182.111;	22.609;	20.841;	0.784;	0.00008;
27.724;	9.173;	30.000;	499.414	5.652;	182.099;	22.647;	21.710;	0.784;	0.00008;
28.772;	9.194;	30.000;	499.650	5.047;	182.111;	22.692;	22.545;	0.785;	0.00008;
29.827;	9.200;	30.000;	499.866	5.513;	182.162;	22.638;	23.381;	0.785;	0.00008;
30.881;	9.340;	30.000;	500.011	5.245;	182.133;	22.580;	24.209;	0.785;	0.00008;
31.928;	9.229;	30.000;	500.117	5.986;	182.100;	22.636;	25.040;	0.786;	0.00008;
32.977;	9.266;	30.000;	500.365	5.574;	182.110;	22.659;	25.880;	0.786;	0.00008;
34.025;	9.281;	30.000;	500.432	5.271;	182.140;	22.656;	26.709;	0.786;	0.00008;
35.074;	9.311;	30.000;	500.234	5.665;	182.095;	22.591;	27.523;	0.786;	0.00008;
36.127;	9.237;	30.000;	500.135	6.119;	182.176;	22.626;	28.343;	0.786;	0.00008;
37.228;	9.263;	30.000;	499.908	6.359;	182.091;	22.651;	29.193;	0.785;	0.00008;
38.280;	9.345;	30.000;	500.153	5.943;	182.080;	22.719;	30.032;	0.786;	0.00008;
39.328;	9.375;	30.000;	500.179	6.092;	182.071;	22.642;	30.858;	0.786;	0.00008;
40.377;	9.448;	30.000;	499.949	5.803;	182.128;	22.622;	31.671;	0.785;	0.00008;
41.426;	9.382;	30.000;	499.912	6.356;	182.091;	22.653;	32.492;	0.785;	0.00008;
42.479;	9.456;	30.000;	500.018	6.300;	182.082;	22.666;	33.320;	0.785;	0.00008;
43.576;	9.410;	30.000;	499.896	6.239;	182.135;	22.618;	34.180;	0.785;	0.00008;
44.628;	9.472;	30.000;	500.092	6.587;	182.137;	22.568;	35.015;	0.786;	0.00008;
45.721;	9.398;	30.000;	499.947	6.895;	182.117;	22.637;	35.868;	0.785;	0.00008;
46.776;	9.401;	30.000;	499.999	6.723;	182.137;	22.668;	36.697;	0.785;	0.00008;
47.875;	9.340;	30.000;	500.109	6.952;	182.136;	22.665;	37.571;	0.786;	0.00008;
48.923;	9.462;	30.000;	500.186	6.887;	182.127;	22.611;	38.401;	0.786;	0.00008;
49.975;	9.403;	30.000;	500.131	6.961;	182.132;	22.637;	39.222;	0.786;	0.00008;
51.028;	9.361;	30.000;	500.262	7.377;	182.081;	22.633;	40.058;	0.786;	0.00008;
52.077;	9.343;	30.000;	500.144	7.045;	182.136;	22.690;	40.872;	0.786;	0.00008;
53.173;	9.404;	30.000;	499.917	7.161;	182.121;	22.654;	41.716;	0.785;	0.00008;
54.232;	9.377;	30.000;	500.025	7.255;	182.163;	22.599;	42.549;	0.785;	0.00008;
55.276;	9.293;	30.000;	500.147	7.928;	182.079;	22.665;	43.386;	0.786;	0.00008;
56.331;	9.300;	30.000;	500.359	7.688;	182.097;	22.680;	44.232;	0.786;	0.00008;
57.423;	9.492;	30.000;	500.112	7.042;	182.182;	22.637;	45.073;	0.786;	0.00008;
58.480;	9.488;	30.000;	500.335	7.376;	182.124;	22.637;	45.919;	0.786;	0.00008;
59.528;	9.399;	30.000;	500.539	8.024;	182.094;	22.675;	46.765;	0.786;	0.00008;
60.578;	9.404;	30.000;	500.414	7.920;	182.117;	22.663;	47.576;	0.786;	0.00008;
61.630;	9.542;	30.000;	500.296	7.535;	182.129;	22.687;	48.389;	0.786;	0.00008;
62.677;	9.572;	30.000;	500.131	7.521;	182.138;	22.591;	49.199;	0.786;	0.00008;
63.776;	9.434;	30.000;	499.822	7.788;	182.145;	22.662;	50.034;	0.785;	0.00008;
64.828;	9.534;	30.000;	500.106	8.953;	182.079;	22.665;	50.883;	0.786;	0.00008;
65.924;	9.438;	30.000;	500.192	8.089;	182.063;	22.700;	51.757;	0.786;	0.00008;
67.031;	9.541;	30.000;	499.981	7.973;	182.161;	22.664;	52.600;	0.785;	0.00008;
68.077;	9.705;	30.000;	500.054	7.674;	182.162;	22.566;	53.432;	0.785;	0.00008;
69.130;	9.386;	30.000;	500.363	8.565;	182.107;	22.679;	54.292;	0.786;	0.00008;
70.225;	9.413;	30.000;	500.445	8.741;	182.087;	22.694;	55.164;	0.786;	0.00008;
71.324;	9.316;	30.000;	500.481	8.586;	182.114;	22.738;	56.033;	0.786;	0.00008;
72.379;	9.498;	30.000;	500.439	8.378;	182.141;	22.656;	56.853;	0.786;	0.00008;
73.430;	9.489;	30.000;	500.536	8.330;	182.112;	22.655;	57.690;	0.786;	0.00008;
74.482;	9.302;	30.000;	500.618	8.862;	182.077;	22.666;	58.528;	0.786;	0.00008;
75.578;	9.304;	30.000;	500.479	9.110;	182.113;	22.660;	59.373;	0.786;	0.00008;
76.631;	9.482;	30.000;	500.192	8.831;	182.187;	22.678;	60.168;	0.786;	0.00008;
77.724;	9.335;	30.000;	500.435	8.886;	182.114;	22.605;	61.060;	0.786;	0.00008;
78.829;	9.349;	30.000;	499.759	9.163;	182.146;	22.668;	61.841;	0.785;	0.00008;

79.880;	9.416;	30.000;	499.691	9.279;	182.066;	22.688;	62.656;	0.785;	0.00008;
80.973;	9.401;	30.000;	499.394	8.829;	182.122;	22.744;	63.480;	0.784;	0.00008;
82.025;	9.460;	30.000;	499.399	9.137;	182.165;	22.673;	64.307;	0.784;	0.00008;
83.123;	9.300;	30.000;	499.714	9.004;	182.195;	22.621;	65.209;	0.785;	0.00008;
84.175;	9.206;	30.000;	499.574	10.041;	182.108;	22.702;	66.019;	0.785;	0.00008;
85.231;	9.276;	30.000;	499.932	9.530;	182.149;	22.726;	66.888;	0.785;	0.00008;
86.282;	9.313;	30.000;	500.081	9.218;	182.199;	22.676;	67.731;	0.786;	0.00008;
87.377;	9.217;	30.000;	500.348	9.328;	182.110;	22.675;	68.634;	0.786;	0.00008;
88.425;	9.069;	30.000;	500.519	10.076;	182.116;	22.689;	69.484;	0.786;	0.00008;
89.484;	9.158;	30.000;	500.007	10.120;	182.057;	22.725;	70.238;	0.785;	0.00008;
90.528;	9.259;	30.000;	499.788	9.535;	182.152;	22.726;	71.033;	0.785;	0.00008;
91.580;	9.275;	30.000;	499.830	9.811;	182.146;	22.664;	71.864;	0.785;	0.00008;
92.631;	9.231;	30.000;	499.887	9.793;	182.181;	22.654;	72.694;	0.785;	0.00008;
93.680;	9.132;	30.000;	499.923	10.378;	182.092;	22.719;	73.523;	0.785;	0.00008;
94.724;	9.152;	30.000;	499.822	10.021;	182.095;	22.751;	74.332;	0.785;	0.00008;
95.778;	9.157;	30.000;	499.744	9.962;	182.129;	22.697;	75.144;	0.785;	0.00008;
96.827;	9.196;	30.000;	500.263	9.771;	182.158;	22.625;	76.048;	0.786;	0.00008;
97.882;	9.072;	30.000;	500.392	10.604;	182.086;	22.717;	76.894;	0.786;	0.00008;
98.928;	9.019;	30.000;	500.273	10.671;	182.144;	22.721;	77.703;	0.786;	0.00008;
99.980;	9.029;	30.000;	500.343	10.287;	182.173;	22.719;	78.536;	0.786;	0.00008;
101.030;	9.224;	30.000;	500.237	10.025;	182.147;	22.633;	79.348;	0.786;	0.00008;
102.081;	9.089;	30.000;	500.114	10.576;	182.109;	22.706;	80.156;	0.786;	0.00008;
103.131;	9.032;	30.000;	499.957	10.747;	182.115;	22.739;	80.951;	0.785;	0.00008;
104.178;	9.022;	30.000;	499.832	10.653;	182.213;	22.722;	81.756;	0.785;	0.00008;
105.233;	9.154;	30.000;	499.391	10.602;	182.122;	22.686;	82.509;	0.784;	0.00008;
106.284;	9.033;	30.000;	498.841	11.025;	182.158;	22.716;	83.240;	0.784;	0.00008;
107.331;	9.021;	30.000;	498.769	11.084;	182.125;	22.723;	84.050;	0.783;	0.00008;
108.380;	9.063;	30.000;	498.525	10.672;	182.213;	22.718;	84.830;	0.783;	0.00008;
109.427;	8.961;	30.000;	498.832	10.897;	182.144;	22.730;	85.695;	0.784;	0.00008;
110.477;	8.945;	30.000;	498.839	10.883;	182.171;	22.690;	86.529;	0.784;	0.00008;
111.523;	8.886;	30.000;	498.915	11.680;	182.104;	22.703;	87.363;	0.784;	0.00008;
112.578;	8.783;	30.000;	498.986	11.224;	182.157;	22.749;	88.200;	0.784;	0.00008;
113.629;	8.895;	30.000;	499.558	11.083;	182.198;	22.717;	89.124;	0.785;	0.00008;
114.673;	8.902;	30.000;	499.488	11.136;	182.187;	22.660;	89.937;	0.785;	0.00008;
115.725;	8.810;	30.000;	499.557	11.783;	182.070;	22.702;	90.774;	0.785;	0.00008;
116.781;	8.816;	30.000;	499.128	11.724;	182.108;	22.755;	91.517;	0.784;	0.00008;
117.828;	8.947;	30.000;	498.965	11.461;	182.193;	22.723;	92.309;	0.784;	0.00008;
118.879;	9.033;	30.000;	498.979	11.259;	182.183;	22.660;	93.133;	0.784;	0.00008;
119.930;	8.865;	30.000;	499.000	11.901;	182.126;	22.711;	93.961;	0.784;	0.00008;
120.977;	8.862;	30.000;	499.285	11.831;	182.106;	22.738;	94.842;	0.784;	0.00008;
122.026;	8.972;	30.000;	499.293	11.534;	182.239;	22.712;	95.665;	0.784;	0.00008;
123.074;	9.003;	30.000;	499.483	11.278;	182.146;	22.692;	96.522;	0.785;	0.00008;
124.131;	8.856;	30.000;	499.779	12.264;	182.161;	22.739;	97.404;	0.785;	0.00008;
125.177;	8.984;	30.000;	500.023	12.163;	182.111;	22.739;	98.279;	0.785;	0.00008;
126.224;	8.938;	30.000;	499.920	11.679;	182.172;	22.754;	99.083;	0.785;	0.00008;
127.278;	8.942;	30.000;	500.016	11.843;	182.144;	22.734;	99.924;	0.785;	0.00008;
128.324;	8.993;	30.000;	499.795	11.854;	182.166;	22.705;	100.704;	0.785;	0.00008;
129.377;	8.877;	30.000;	499.935	12.271;	182.066;	22.758;	101.559;	0.785;	0.00008;
130.424;	8.898;	30.000;	499.707	12.132;	182.133;	22.780;	102.337;	0.785;	0.00008;
131.528;	9.004;	30.000;	499.778	11.813;	182.210;	22.730;	103.214;	0.785;	0.00008;
132.577;	9.009;	30.000;	499.735	12.288;	182.187;	22.670;	104.029;	0.785;	0.00008;
133.628;	8.940;	30.000;	499.851	12.535;	182.108;	22.754;	104.880;	0.785;	0.00008;
134.676;	8.948;	30.000;	499.765	12.451;	182.115;	22.764;	105.683;	0.785;	0.00008;
135.726;	8.871;	30.000;	499.637	11.954;	182.254;	22.702;	106.485;	0.785;	0.00008;
136.780;	8.989;	30.000;	499.605	12.194;	182.145;	22.701;	107.302;	0.785;	0.00008;
137.825;	8.855;	30.000;	499.881	12.199;	182.162;	22.721;	108.188;	0.785;	0.00008;

138.879;	8.821;	30.000;	499.861	12.629;	182.082;	22.756;	109.006;	0.785;	0.00008;
139.925;	8.842;	30.000;	499.739	12.338;	182.173;	22.772;	109.804;	0.785;	0.00008;
140.975;	8.976;	30.000;	499.752	12.306;	182.187;	22.727;	110.627;	0.785;	0.00008;
142.024;	9.020;	30.000;	499.784	12.422;	182.159;	22.739;	111.462;	0.785;	0.00008;
143.079;	8.885;	30.000;	500.003	12.790;	182.102;	22.733;	112.336;	0.785;	0.00008;
144.130;	9.062;	30.000;	500.125	12.283;	182.144;	22.794;	113.187;	0.786;	0.00008;
145.176;	9.068;	30.000;	499.893	12.642;	182.155;	22.758;	113.957;	0.785;	0.00008;
146.229;	9.105;	30.000;	499.908	12.585;	182.177;	22.717;	114.788;	0.785;	0.00008;
147.278;	8.888;	30.000;	499.773	13.230;	182.127;	22.731;	115.582;	0.785;	0.00008;
148.329;	8.891;	30.000;	500.052	12.902;	182.150;	22.745;	116.467;	0.785;	0.00008;
149.425;	8.968;	30.000;	499.799	12.853;	182.232;	22.750;	117.274;	0.785;	0.00008;
150.475;	9.102;	30.000;	499.701	13.030;	182.172;	22.690;	118.076;	0.785;	0.00008;
151.526;	8.922;	30.000;	499.476	13.278;	182.152;	22.715;	118.847;	0.785;	0.00008;
152.577;	8.851;	30.000;	499.786	13.126;	182.147;	22.784;	119.744;	0.785;	0.00008;
153.626;	8.828;	30.000;	499.911	12.977;	182.266;	22.734;	120.596;	0.785;	0.00008;
154.680;	8.790;	30.000;	500.107	13.300;	182.192;	22.742;	121.464;	0.786;	0.00008;
155.728;	8.775;	30.000;	500.263	13.470;	182.202;	22.729;	122.335;	0.786;	0.00008;
156.777;	8.683;	30.000;	500.297	13.967;	182.084;	22.748;	123.164;	0.786;	0.00008;
157.826;	8.588;	30.000;	500.192	13.174;	182.169;	22.800;	123.967;	0.786;	0.00008;
158.875;	8.667;	30.000;	500.456	13.770;	182.212;	22.727;	124.856;	0.786;	0.00008;
159.924;	8.716;	30.000;	500.265	13.737;	182.182;	22.718;	125.634;	0.786;	0.00008;
160.977;	8.566;	30.000;	499.997	13.970;	182.121;	22.801;	126.393;	0.785;	0.00008;
162.024;	8.608;	30.000;	499.901	13.870;	182.153;	22.782;	127.190;	0.785;	0.00008;
163.079;	8.645;	30.000;	499.987	14.006;	182.192;	22.771;	128.035;	0.785;	0.00008;
164.126;	8.719;	30.000;	499.972	13.937;	182.194;	22.700;	128.856;	0.785;	0.00008;
165.174;	8.620;	30.000;	499.922	14.214;	182.161;	22.732;	129.669;	0.785;	0.00008;
166.223;	8.593;	30.000;	499.672	14.277;	182.145;	22.765;	130.427;	0.785;	0.00008;
167.278;	8.579;	30.000;	499.827	14.138;	182.256;	22.745;	131.292;	0.785;	0.00008;
168.325;	8.682;	30.000;	499.903	13.956;	182.199;	22.757;	132.140;	0.785;	0.00008;
169.374;	8.608;	30.000;	499.758	14.353;	182.175;	22.754;	132.922;	0.785;	0.00008;
170.433;	8.594;	30.000;	499.427	14.499;	182.168;	22.793;	133.658;	0.784;	0.00008;
171.489;	8.623;	30.000;	499.350	14.049;	182.228;	22.787;	134.477;	0.784;	0.00008;
172.541;	8.751;	30.000;	499.600	14.034;	182.198;	22.738;	135.368;	0.785;	0.00008;
173.995;	8.721;	30.000;	499.666	14.315;	182.161;	22.750;	136.171;	0.785;	0.00008;
175.122;	8.819;	30.000;	499.674	14.531;	182.151;	22.739;	137.412;	0.785;	0.00008;
176.177;	8.621;	30.000;	499.859	14.753;	182.180;	22.760;	138.289;	0.785;	0.00008;
177.223;	8.605;	30.000;	500.092	14.399;	182.205;	22.830;	139.178;	0.786;	0.00008;
178.278;	8.636;	30.000;	500.240	14.269;	182.246;	22.808;	140.043;	0.786;	0.00008;
179.326;	8.701;	30.000;	500.320	14.392;	182.172;	22.777;	140.892;	0.786;	0.00008;
180.404;	8.562;	30.000;	500.392	14.777;	182.212;	22.827;	141.612;	0.786;	0.00008;
181.439;	8.566;	30.000;	500.293	14.938;	182.147;	22.814;	142.547;	0.786;	0.00008;
182.484;	8.510;	30.000;	500.172	14.762;	182.170;	22.839;	143.300;	0.786;	0.00008;
183.559;	8.699;	30.000;	500.039	14.898;	182.201;	22.782;	144.138;	0.785;	0.00008;
184.606;	8.922;	30.000;	500.022	14.675;	182.134;	22.771;	144.959;	0.785;	0.00008;
185.710;	8.724;	30.000;	499.908	15.371;	182.144;	22.814;	145.787;	0.785;	0.00008;
186.759;	8.744;	30.000;	499.647	14.902;	182.211;	22.807;	146.535;	0.785;	0.00008;
187.831;	8.790;	30.000;	499.466	14.965;	182.189;	22.788;	147.330;	0.785;	0.00008;
188.883;	8.850;	30.000;	499.704	14.773;	182.193;	22.770;	148.221;	0.785;	0.00008;
189.989;	8.899;	30.000;	499.877	14.978;	182.189;	22.793;	149.136;	0.785;	0.00008;
191.034;	8.697;	30.000;	499.897	15.415;	182.170;	22.825;	149.970;	0.785;	0.00008;
192.086;	8.712;	30.000;	499.834	14.899;	182.195;	22.874;	150.776;	0.785;	0.00008;
193.138;	8.856;	30.000;	499.771	15.149;	182.212;	22.789;	151.578;	0.785;	0.00008;
194.184;	8.933;	30.000;	499.876	14.983;	182.144;	22.786;	152.435;	0.785;	0.00008;
195.233;	8.838;	30.000;	499.992	15.402;	182.160;	22.804;	153.296;	0.785;	0.00008;
196.286;	8.731;	30.000;	499.957	15.627;	182.136;	22.831;	154.096;	0.785;	0.00008;
197.371;	8.748;	30.000;	499.910	15.209;	182.261;	22.767;	154.940;	0.785;	0.00008;

198.417;	8.743;	30.000;	499.780	15.292;	182.154;	22.768;	155.730;	0.785;	0.00008;
199.467;	8.711;	30.000;	499.893	15.628;	182.215;	22.776;	156.586;	0.785;	0.00008;
200.568;	8.701;	30.000;	499.908	15.670;	182.142;	22.810;	157.454;	0.785;	0.00008;
201.615;	8.619;	30.000;	500.004	15.741;	182.209;	22.837;	158.312;	0.785;	0.00008;
202.665;	8.805;	30.000;	499.921	15.462;	182.176;	22.795;	159.111;	0.785;	0.00008;
203.771;	8.857;	30.000;	499.759	15.307;	182.166;	22.787;	159.920;	0.785;	0.00008;
204.816;	8.790;	30.000;	499.784	15.612;	182.192;	22.821;	160.756;	0.785;	0.00008;
205.863;	8.638;	30.000;	499.859	15.779;	182.135;	22.861;	161.605;	0.785;	0.00008;
206.914;	8.672;	30.000;	499.771	15.922;	182.219;	22.800;	162.399;	0.785;	0.00008;
207.965;	8.831;	30.000;	499.730	15.488;	182.153;	22.801;	163.210;	0.785;	0.00008;
209.019;	8.763;	30.000;	499.618	15.686;	182.184;	22.768;	163.995;	0.785;	0.00008;
210.069;	8.636;	30.000;	499.730	15.924;	182.125;	22.829;	164.856;	0.785;	0.00008;
211.118;	8.640;	30.000;	500.374	15.882;	182.202;	22.816;	165.893;	0.786;	0.00008;
212.167;	8.661;	30.000;	500.127	15.814;	182.192;	22.811;	166.639;	0.786;	0.00008;
213.219;	8.746;	30.000;	499.975	15.554;	182.207;	22.810;	167.413;	0.785;	0.00008;
214.265;	8.650;	30.000;	499.928	16.075;	182.146;	22.830;	168.220;	0.785;	0.00008;
215.367;	8.589;	30.000;	499.783	15.948;	182.122;	22.838;	169.035;	0.785;	0.00008;
216.414;	8.665;	30.000;	499.646	16.075;	182.220;	22.787;	169.815;	0.785;	0.00008;
217.473;	8.641;	30.000;	499.406	15.736;	182.127;	22.803;	170.557;	0.784;	0.00008;
218.566;	8.665;	30.000;	499.282	16.287;	182.136;	22.784;	171.376;	0.784;	0.00008;
219.621;	8.669;	30.000;	499.299	16.190;	182.132;	22.842;	172.204;	0.784;	0.00008;
220.715;	8.621;	30.000;	499.571	16.044;	182.205;	22.811;	173.165;	0.785;	0.00008;
221.771;	8.662;	30.000;	499.594	15.921;	182.193;	22.795;	173.984;	0.785;	0.00008;
222.868;	8.699;	30.000;	499.783	16.058;	182.165;	22.826;	174.922;	0.785;	0.00008;
223.969;	8.672;	30.000;	499.916	16.367;	182.184;	22.821;	175.831;	0.785;	0.00008;
225.021;	8.609;	30.000;	499.773	16.325;	182.149;	22.876;	176.609;	0.785;	0.00008;
226.072;	8.660;	30.000;	499.916	16.434;	182.235;	22.772;	177.489;	0.785;	0.00008;
227.171;	8.692;	30.000;	499.872	15.983;	182.185;	22.820;	178.322;	0.785;	0.00008;
228.219;	8.660;	30.000;	499.677	16.497;	182.196;	22.819;	179.083;	0.785;	0.00008;
229.268;	8.617;	30.000;	499.629	16.393;	182.182;	22.809;	179.896;	0.785;	0.00008;
230.364;	8.550;	30.000;	499.559	16.286;	182.179;	22.854;	180.715;	0.785;	0.00008;
231.471;	8.631;	30.000;	499.764	16.431;	182.248;	22.798;	181.666;	0.785;	0.00008;
232.570;	8.665;	30.000;	499.757	16.416;	182.132;	22.833;	182.537;	0.785;	0.00008;
233.616;	8.633;	30.000;	499.757	16.531;	182.162;	22.830;	183.355;	0.785;	0.00008;
234.670;	8.603;	30.000;	499.589	16.363;	182.132;	22.856;	184.116;	0.785;	0.00008;
235.719;	8.642;	30.000;	499.751	16.506;	182.209;	22.789;	185.002;	0.785;	0.00008;
236.767;	8.654;	30.000;	499.805	16.428;	182.201;	22.822;	185.848;	0.785;	0.00008;
237.819;	8.557;	30.000;	499.725	16.608;	182.209;	22.797;	186.639;	0.785;	0.00008;
238.867;	8.533;	30.000;	499.469	16.439;	182.184;	22.858;	187.367;	0.785;	0.00008;
239.920;	8.557;	30.000;	499.485	16.399;	182.179;	22.862;	188.199;	0.785;	0.00008;
240.964;	8.641;	30.000;	499.339	16.556;	182.243;	22.829;	188.965;	0.784;	0.00008;
242.021;	8.614;	30.000;	499.771	16.477;	182.173;	22.832;	189.953;	0.785;	0.00008;
243.071;	8.661;	30.000;	499.932	16.914;	182.192;	22.831;	190.842;	0.785;	0.00008;
244.115;	8.536;	30.000;	499.884	16.444;	182.150;	22.886;	191.647;	0.785;	0.00008;
245.171;	8.631;	30.000;	499.956	16.758;	182.271;	22.806;	192.501;	0.785;	0.00008;
246.269;	8.739;	30.000;	500.285	16.462;	182.150;	22.811;	193.486;	0.786;	0.00008;
247.319;	8.578;	30.000;	500.392	17.206;	182.160;	22.821;	194.357;	0.786;	0.00008;
248.418;	8.600;	30.000;	500.430	16.650;	182.160;	22.870;	195.235;	0.786;	0.00008;
249.471;	8.642;	30.000;	500.223	16.827;	182.237;	22.815;	195.981;	0.786;	0.00008;
250.520;	8.655;	30.000;	500.257	16.692;	182.203;	22.818;	196.821;	0.786;	0.00008;
251.570;	8.653;	30.000;	500.001	16.808;	182.221;	22.816;	197.540;	0.785;	0.00008;
252.618;	8.552;	30.000;	500.190	17.013;	182.154;	22.836;	198.446;	0.786;	0.00008;
253.672;	8.621;	30.000;	500.248	16.683;	182.223;	22.900;	199.288;	0.786;	0.00008;
254.719;	8.578;	30.000;	500.263	17.040;	182.242;	22.824;	200.119;	0.786;	0.00008;
255.764;	8.627;	30.000;	500.360	17.020;	182.209;	22.811;	200.983;	0.786;	0.00008;
256.818;	8.800;	30.000;	500.104	17.390;	182.145;	22.857;	201.709;	0.786;	0.00008;

257.870;	8.642;	30.000;	500.131	17.112;	182.163;	22.883;	202.544;	0.786;	0.00008;
258.920;	8.580;	30.000;	500.529	17.300;	182.231;	22.806;	203.529;	0.786;	0.00008;
260.020;	8.639;	30.000;	499.953	16.838;	182.197;	22.842;	204.160;	0.785;	0.00008;
261.068;	8.639;	30.000;	500.134	17.160;	182.198;	22.842;	205.057;	0.786;	0.00008;
262.118;	8.699;	30.000;	499.961	17.209;	182.199;	22.884;	205.810;	0.785;	0.00008;
263.214;	8.666;	30.000;	499.901	17.323;	182.230;	22.866;	206.649;	0.785;	0.00008;
264.321;	8.768;	30.000;	500.005	16.885;	182.224;	22.822;	207.555;	0.785;	0.00008;
265.416;	8.785;	30.000;	499.738	16.934;	182.205;	22.841;	208.309;	0.785;	0.00008;
266.470;	8.700;	30.000;	499.519	17.573;	182.204;	22.866;	209.044;	0.785;	0.00008;
267.522;	8.661;	30.000;	499.870	17.381;	182.199;	22.918;	210.017;	0.785;	0.00008;
268.566;	8.614;	30.000;	499.845	17.519;	182.288;	22.803;	210.826;	0.785;	0.00008;
269.613;	8.689;	30.000;	499.820	17.035;	182.211;	22.859;	211.639;	0.785;	0.00008;
270.673;	8.619;	30.000;	499.955	17.539;	182.218;	22.837;	212.536;	0.785;	0.00008;
271.715;	8.689;	30.000;	500.095	17.178;	182.184;	22.908;	213.409;	0.786;	0.00008;
272.772;	8.660;	30.000;	500.157	17.414;	182.235;	22.839;	214.261;	0.786;	0.00008;
273.871;	8.724;	30.000;	500.050	17.411;	182.229;	22.881;	215.076;	0.785;	0.00008;
274.968;	8.769;	30.000;	499.664	17.451;	182.189;	22.880;	215.773;	0.785;	0.00008;
276.020;	8.710;	30.000;	499.887	17.682;	182.210;	22.844;	216.673;	0.785;	0.00008;
277.071;	8.571;	30.000;	499.861	17.143;	182.186;	22.976;	217.512;	0.785;	0.00008;
278.121;	8.719;	30.000;	499.957	17.569;	182.287;	22.798;	218.373;	0.785;	0.00008;
279.223;	8.723;	30.000;	499.933	17.415;	182.190;	22.878;	219.229;	0.785;	0.00008;
280.266;	8.802;	30.000;	499.906	17.881;	182.214;	22.855;	220.045;	0.785;	0.00008;
281.320;	8.715;	30.000;	499.925	17.407;	182.217;	22.935;	220.873;	0.785;	0.00008;
282.418;	8.675;	30.000;	499.770	17.704;	182.247;	22.886;	221.667;	0.785;	0.00008;
283.468;	8.907;	30.000;	499.716	17.407;	182.238;	22.831;	222.469;	0.785;	0.00008;
284.523;	8.778;	30.000;	499.406	17.694;	182.231;	22.843;	223.154;	0.784;	0.00008;
285.567;	8.749;	30.000;	499.225	17.735;	182.165;	22.884;	223.899;	0.784;	0.00008;
286.665;	8.552;	30.000;	499.307	16.988;	182.221;	23.011;	224.794;	0.784;	0.00008;
287.722;	8.726;	30.000;	499.477	17.761;	182.296;	22.837;	225.698;	0.785;	0.00008;
288.821;	8.766;	30.000;	499.581	17.571;	182.197;	22.879;	226.607;	0.785;	0.00008;
289.868;	8.725;	30.000;	499.431	17.898;	182.169;	22.867;	227.385;	0.785;	0.00008;
290.918;	8.729;	30.000;	499.224	18.039;	182.148;	22.905;	228.093;	0.784;	0.00008;
291.969;	8.688;	30.000;	499.482	17.968;	182.251;	22.854;	229.032;	0.785;	0.00008;
293.021;	8.732;	30.000;	499.634	17.868;	182.214;	22.895;	229.926;	0.785;	0.00008;
294.069;	8.779;	30.000;	499.684	17.911;	182.213;	22.839;	230.778;	0.785;	0.00008;
295.124;	8.755;	30.000;	499.457	18.175;	182.198;	22.905;	231.494;	0.785;	0.00008;
296.166;	8.728;	30.000;	499.740	17.974;	182.196;	22.930;	232.448;	0.785;	0.00008;
297.222;	8.849;	30.000;	499.682	17.972;	182.249;	22.903;	233.249;	0.785;	0.00008;
298.271;	8.751;	30.000;	499.818	18.339;	182.226;	22.895;	234.132;	0.785;	0.00008;
299.315;	8.806;	30.000;	499.602	18.080;	182.177;	22.898;	234.858;	0.785;	0.00008;
270.673;	8.619;	30.000;	499.955	17.539;	182.218;	22.837;	212.536;	0.785;	0.00008;
271.715;	8.689;	30.000;	500.095	17.178;	182.184;	22.908;	213.409;	0.786;	0.00008;
272.772;	8.660;	30.000;	500.157	17.414;	182.235;	22.839;	214.261;	0.786;	0.00008;
273.871;	8.724;	30.000;	500.050	17.411;	182.229;	22.881;	215.076;	0.785;	0.00008;
274.968;	8.769;	30.000;	499.664	17.451;	182.189;	22.880;	215.773;	0.785;	0.00008;
276.020;	8.710;	30.000;	499.887	17.682;	182.210;	22.844;	216.673;	0.785;	0.00008;
277.071;	8.571;	30.000;	499.861	17.143;	182.186;	22.976;	217.512;	0.785;	0.00008;
278.121;	8.719;	30.000;	499.957	17.569;	182.287;	22.798;	218.373;	0.785;	0.00008;
279.223;	8.723;	30.000;	499.933	17.415;	182.190;	22.878;	219.229;	0.785;	0.00008;
280.266;	8.802;	30.000;	499.906	17.881;	182.214;	22.855;	220.045;	0.785;	0.00008;
281.320;	8.715;	30.000;	499.925	17.407;	182.217;	22.935;	220.873;	0.785;	0.00008;
282.418;	8.675;	30.000;	499.770	17.704;	182.247;	22.886;	221.667;	0.785;	0.00008;
283.468;	8.907;	30.000;	499.716	17.407;	182.238;	22.831;	222.469;	0.785;	0.00008;
284.523;	8.778;	30.000;	499.406	17.694;	182.231;	22.843;	223.154;	0.784;	0.00008;
285.567;	8.749;	30.000;	499.225	17.735;	182.165;	22.884;	223.899;	0.784;	0.00008;
286.665;	8.552;	30.000;	499.307	16.988;	182.221;	23.011;	224.794;	0.784;	0.00008;

287.722;	8.726;	30.000;	499.477	17.761;	182.296;	22.837;	225.698;	0.785;	0.00008;
288.821;	8.766;	30.000;	499.581	17.571;	182.197;	22.879;	226.607;	0.785;	0.00008;
289.868;	8.725;	30.000;	499.431	17.898;	182.169;	22.867;	227.385;	0.785;	0.00008;
290.918;	8.729;	30.000;	499.224	18.039;	182.148;	22.905;	228.093;	0.784;	0.00008;
291.969;	8.688;	30.000;	499.482	17.968;	182.251;	22.854;	229.032;	0.785;	0.00008;
293.021;	8.732;	30.000;	499.634	17.868;	182.214;	22.895;	229.926;	0.785;	0.00008;
294.069;	8.779;	30.000;	499.684	17.911;	182.213;	22.839;	230.778;	0.785;	0.00008;

APPENDIX C: Mechanical and thermal properties of Gray Cast Iron

Material properties	Value	Unit
Density	7200	kg/m^3
Young modulus	1.1e+5	MPa
Poison ratio	0.28	MPa
Shear modulus	4.2969 e+4	MPa
Bulk modulus	8.33e+4	MPa
Tensile ultimate strength	2400	MPa
Compressive ultimate strength	8200	MPa
Melting temperature	1127-1204	^oC
Specific heat conductivity	447	J/kg^oC
Thermal conductivity	52	W/m^oC

APPENDIX D: Experimental results

Table 5.1. (a) Force- elongation and (b) tensile stress-elongation of composite two

(a)

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.03	0.22
2	0.12	0.67
3	0.15	0.93
4	0.17	1.18
5	0.20	1.43
6	0.23	1.68
7	0.25	1.94
8	0.27	2.19
9	0.28	2.47
10	0.26	2.74
11	0.23	3.02
12	0.21	3.30
13	0.21	3.58
14	0.15	3.95
15	0.00	4.16

(b)

C2 Stress- elongation table

No	S[N/mm^2]	E[%]
1	0	0
2	1	0.73
3	1.06	2.23
4	4.24	2.23
5	5.31	3.09
6	6.01	3.92
7	7.07	4.75
8	8.13	5.58
9	8.84	6.45
10	9.55	7.32
11	9.9	8.25
12	9.2	9.15
13	8.13	10.05
14	7.43	11.92

(c)

C3 Stress- elongation table

No	S[N/mm^2]	E[%]
1	0	0
2	0.57	0.11
3	1.23	2.33
4	1.79	4.3
5	2.33	4.78
6	3.14	5.04
7	4.11	6.55
8	4.43	7.56
9	3.57	7.9
10	3.09	8.01
11	2.34	8.55
12	2.01	9
13	1.23	10.45
14	1.04	11.33
15	0.11	11.45

Table 5.2. (a) Force- elongation and (b) stress (compressive strength)-elongation of composite one

(a)

Force-elongation-table

No.	F [kN]	dL [mm]
5	1.62	0.70
6	2.06	0.82
7	2.53	0.95
8	3.01	1.06
9	3.47	1.18
10	3.89	1.30
11	4.26	1.42
12	4.60	1.56
13	4.90	1.67
14	5.16	1.79
15	5.38	1.91
16	5.71	2.16
17	5.94	2.43
18	5.95	2.71
19	5.74	2.97
20	2.79	3.75
21	0.04	4.07

(b)

C1 Stress-elongation table

No	S[N/mm^2]	E[%]
1	0	0
2	1.4	0.2
3	6.54	0.42
4	10.34	0.56
5	15.75	1.34
6	23.56	1.44
7	31.48	1.54
8	43.15	1.91
9	57.3	2.33
10	72.86	2.73
11	89.48	3.16
12	106.46	3.53
13	122.73	3.94
14	137.57	4.34
15	150.67	4.75
16	162.69	5.19
17	173.3	5.57
18	182.56	5.96
19	190.28	6.37
20	201.95	7.19
21	210.08	8.1
22	210.44	9.04
23	203.01	9.88

Table 5.3. (a) Force- elongation and (b) stress (compressive strength)-elongation of composite two

(a)

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.22	0.02
2	0.42	0.07
3	0.73	0.16
4	1.55	0.36
5	2.15	0.48
6	2.80	0.57
7	3.48	0.68
8	4.15	0.79
9	4.78	0.87
10	5.36	0.97
11	5.91	1.07
12	6.43	1.16
13	6.88	1.26
14	7.14	1.37
15	7.38	1.60
16	7.29	1.96

(b)

C2 Stress-elongation table

No	S[N/mm^	E[%]
1	0	0
2	0.88	0.03
3	1.68	0.14
4	2.92	0.34
5	6.2	0.72
6	8.6	0.95
7	11.2	1.15
8	13.92	1.36
9	16.6	1.57
10	19.12	1.75
11	21.44	1.95
12	23.64	2.14
13	25.72	2.32
14	27.52	2.52
15	28.56	2.73
16	29.52	3.2
17	29.16	3.93
18	29.01	4.02
19	28.02	4.12
20	25.42	4.19
21	20.11	4.5
22	14.45	4.95

Table 5.4. Force- elongation (a) and stress (compressive strength)-elongation (b) of composite three

(a)

Force-elongation-table

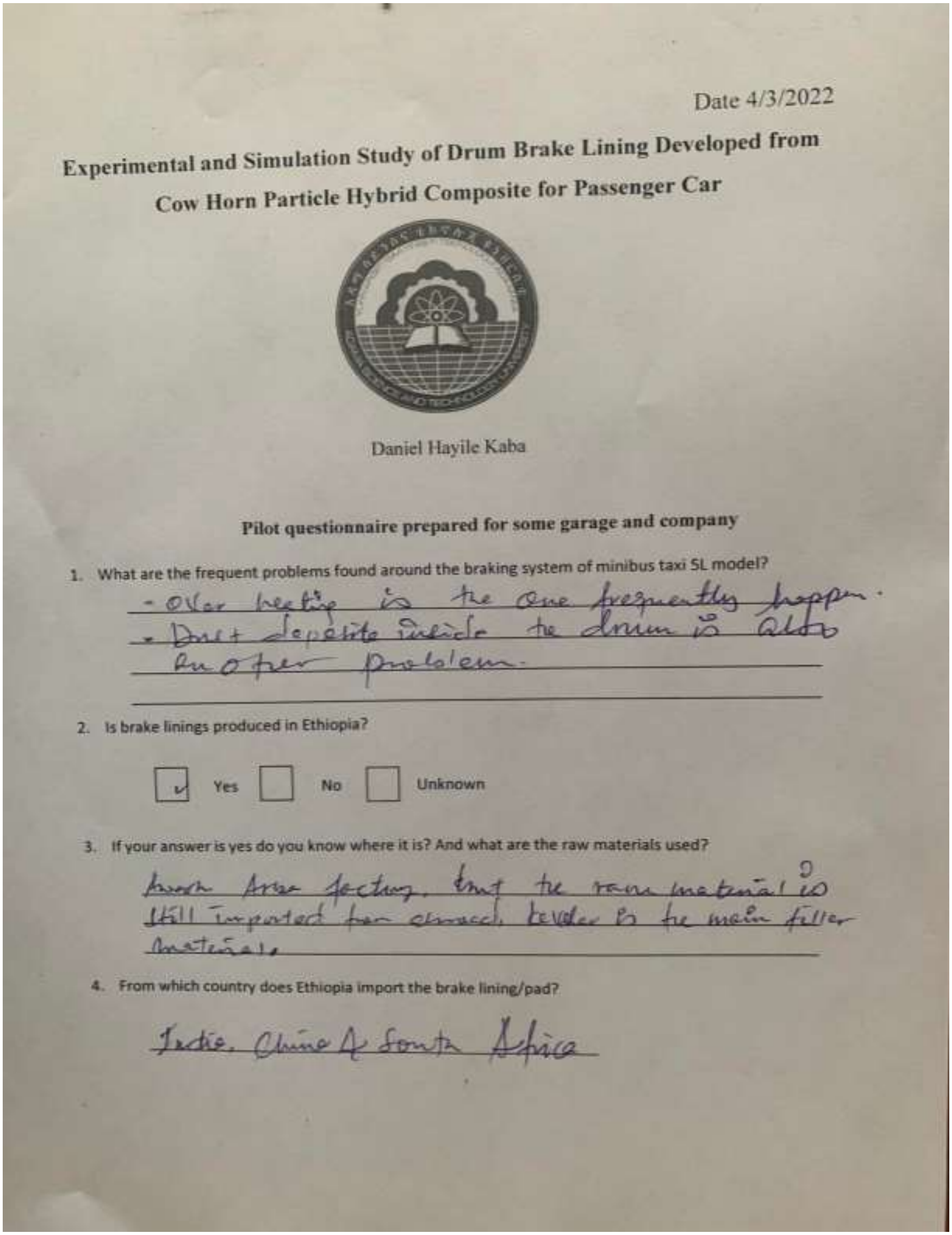
No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.29	0.18
2	0.47	0.28
3	1.05	0.48
4	1.53	0.60
5	2.11	0.73
6	2.80	0.83
7	3.55	0.93
8	4.27	1.03
9	4.95	1.13
10	5.59	1.23
11	6.20	1.34
12	6.75	1.44
13	7.22	1.53
14	7.58	1.63
15	7.79	1.72
16	3.84	2.60

(b)

C3 Stress-elongation table

No	S[N/mm^2]	E[%]
	0	0
1	10.26	0.61
2	16.62	0.94
3	37.14	1.6
4	54.11	2
5	74.63	2.43
6	99.03	2.78
7	125.56	3.1
8	151.02	3.45
9	175.07	3.77
10	197.71	4.09
11	219.28	4.45
12	238.73	4.78
13	255.36	5.09
14	268.09	5.43
15	275.52	5.75
16	135.81	8.68
17	102.45	14.56
18	50.43	24.56

APPENDIX E: Pilot questionnaire



Date 4/3/2022

Experimental and Simulation Study of Drum Brake Lining Developed from Cow Horn Particle Hybrid Composite for Passenger Car

Daniel Hayile Kaba

Pilot questionnaire prepared for some garage and company

1. What are the frequent problems found around the braking system of minibus taxi 5L model?

   - Over heating is the one frequently happen.
   - Dust deposite inside the drum is also another problem.

2. Is brake linings produced in Ethiopia?

   ☑ Yes ☐ No ☐ Unknown

3. If your answer is yes do you know where it is? And what are the raw materials used?

   Awash Arsa factory, but the raw material is still imported from abroad, bevder is the main filler materials.

4. From which country does Ethiopia import the brake lining/pad?

   India, China & South Africa

5. Is it possible to know whether the lining contains asbestos or not?

☐ Yes ☑ No

6. Do you know that, asbestos is hazardous material?

☑ Yes ☑ No

7. If you answer for no 6 is yes what protective method do you use during repairing or changing brake lining?

for the drum brake we use hand glove some times but not always. some of the worker operate by their hand without using protective material

8. How long is the drum brake lining uses in the passenger car?

for house vehicle around 25000 km, for taxi around 10000 km

9. How long hours minibus taxi works per day?

at least for 14hrs per day

10. How is the disposal of used pad?

simply disposed, but some time sold to the buyers

11. How many of you are cancer patient?

even the cause is unknown, some of the has TB desease