DEVELOPMENT OF CARBON FIBRE REINFORCED NATURAL RUBBER COMPOSITE FOR VIBRATION ISOLATION

BY

EYO, Richard Ekpenyong
MEng/SEET/2017/6908

DEPARTMENT OF MECHANICAL ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

SEPTEMBER, 2021

DEVELOPMENT OF CARBON FIBRE REINFORCED NATURAL RUBBER COMPOSITE FOR VIBRATION ISOLATION

BY

EYO, Richard Ekpenyong
MEng/SEET/2017/6908

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN MECHANICAL ENGINEERING

SEPTEMBER, 2021

ABSTRACT

The study "Development of Carbon Fibre Reinforced Natural Rubber for Vibration Isolation**"** is based on readily available materials within the locality. Carbon fibre was extracted from periwinkle shell to reduce the high cost of processing carbon fibre from petroleum pitch and to serve as reinforcement to the natural rubber resin. The fibre was then activated using potassium hydroxide (KOH) followed by various characterization through XRF, tensile test, hardness and impact test. The composite was formed, with the reinforced material based on calculated percentages of 10 %, 20 % and 30 % and added differently to 220 g of natural rubber resin. The samples were then prepared for various test analysis based on ISO and ASTM standard, (ISO 527 for tensile test, ISO 179 for impact test and ASTM D2240 for hardness test) to determine the composite strength in comparison with the natural rubber for vibration isolation. The basis for this comparison is because natural rubber is widely used as a vibration isolator. The result analysed shows an increased in tensile strength of the composite to 0.20 MPa as against 0.09 MPa of natural rubber resin, indicating an increased in strength of 45 %, with good strain rate for improved isolator life and high resistance to thermal expansion. The result also shows 10 % fibre reinforcement as the most effective proportion for high impact test in reducing the brittle nature of the carbon fibre with improved strength of 22 %. The 10 % fibre reinforcement also shows high resilience in energy absorption than both the 20 % and 30 % reinforcement respectively.

TABLE OF CONTENTS

Contents **Page**

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

Symbols	Meaning	Units
V0	Initial test rate	mm/min
V1	Final test rate	mm/min
a	Test piece height	mm
b	Test piece width	mm
F0	Switch point rate	N
FH	Maximum force (tensile or compression)	N
RH	Tensile or Compression force	N
AH	Overall extension of maximum force	%
dLH	Elongation at maximum force	mm
FB	Breaking force	N
RB	Stress at break	N/mm^2
AB	Overall extension at sample break	%
dLB	Elongation at sample break	mm

CHAPTER ONE

1.0: INTRODUCTION

1.1 Background to the Study

Vibration isolation deals with separation of unwanted vibrations, originating from machines and other forms of transmission (rotating, reciprocating or impacting equipment) into their support system (foundation). If a rotating machine and equipment are not properly balanced, it may generate centrifugal forces by creating a steady and random vibration. Equipment such as centrifugal pumps, forging presses; impact testers, hammers, injection mouldingand compressors generate pulses or impacts which are the predominant source of vibration (Fabreeka International, Inc. 2016).

Vibration can be controlled with the use of absorbent processed from activated carbon either found in coal, wood, coconut shell, peat, periwinkle shell, snail shell, palm kernel shell or fibre. It is a composition of carbon atoms produced from any materials with high carbon content and can be readily used as the best absorbent in absorption application (Akpa *et al.,* 2018). Activated carbon fibre are carbon with porous structure with high absorption capacity (Lee *et al.,* 2013) usually prepared by heat treatment in order to attain the high porosity required for specific applications. Its mechanical properties include high tensile strength, high stiffness, light weight, high chemical resistance, high temperature tolerance and low thermal expansion. These excellent properties of carbon fibreattract interest in the areas of vibration and shock control.

However, in most cases where shock and vibration are present, the environment often becomes undesirable and generally intolerable. In this case a discrete analysis can be used to address these changes in order to make the environment acceptable. If this is still not possible, the integration of special hardware such as dampers, shock absorbers, vibration isolators and shock transmitting unit is then used as a mitigation to control vibration. A machine can both act as a source and recipient of unwanted vibration. If the equipment needed to be isolated is the source of unwanted vibration, then the isolation is aimed at reducing the vibration that transmits from the source to its support structure. Conversely if the equipment that require isolation is the recipient of unwanted vibration, then the main purpose of isolation is to reduce the vibration transmitted from the support structure to the recipient in order to maintain high machine performance (Fabreeka International Inc, 2016) There are different types of isolators including pneumatic mounts, metal spring and rubber mounts. Vibration isolators are usually applied at the base of a vibrating system to protect a large transmitted force due to harmonic excitation or unbalanced rotating mass. The vibrating system may be a delicate device that needs to be protected from floor vibration; some produces a large dynamic force during operation and double the disturbance to other nearby precision equipment. While most machine tools may neither be sensitive or prone to vibration nor produce large dynamic forces and as a result may or may not require isolation.

The use of composite materials in isolating vibration is because of its relative stiffness, weight saving and strength. For example, carbon fibre reinforced composite may be five times stronger than 1020 grade steel and up to seven times the strength and still maintain one fifth of the weight (Essay, 2018). A composite material is composition of two or more constituent materials combined to give a superior characteristic. For instance, a fibre reinforced polymer usually with natural fibre (periwinkle and coconut shell) embedded in a polymer matrix (natural rubber) can form a versatile and efficient composites that can result in more durable solutions to vibration.

High levels vibration causes machine failure and undesirable effects on the surroundings (Lozano *et al*., 2000). A common example is the vibration of machine mounted on floors or walls. The most useful and economical way of reducing vibration is through elastic mounting, with the purpose of separating the propagation path between the source and the receiver; this hinders the spread of structural vibration, and stands as the most effective approach to noise and vibration mitigation. Highly vibrating machines in factories and offices can be placed on this elastic element for its efficient and proper performance. In the case of a vibrating vehicle, the passenger compartment is being separated from the wheel – roadway contact by incorporating the springs between the wheel axles and the chassis. It is also possible for mechanical vibration to transmit for a long distance routes, sometimes resurfacing hundreds of feet far away from the source. Regarding the location of the vibration, two extreme cases can be considered, the first is placement near the source of vibration in which the source must be isolated from the surroundings (source isolation). And in the second case, the receiver is isolated (shielding isolation). Both shielding and source isolation can be combined if there are demanding requirements for a very low vibration level. It is naturally ideal to isolate both the source and the receiver.

Most designers of machines have employed different methods to isolate vibrations which tend to work at lower frequency of about 100Hz, beyond this frequency, the system tends to fail or collapse to the high vibrating frequencies. In order to achieve good vibration isolation by design, the entire frequency range must be analysed using advance theoretical and experimental techniques. Since vibration isolators are mainly specified through their static deflection, and how they can deflect vibration when the weight of the machine is placed on them.

Spring elements are generally used to isolate vibration in heavy or industrial machinery. This reduced to a high extent the transfer of dynamic loads into the foundation, so that fewer vibrations are transferred to the surrounding and damages such as cracks in the foundation and bearing damages can also be avoided. In many applications, spring elements are equipped with a viscous – elastic damper to absorb sufficiently the vibration energy during the process of operation. By so doing resonance can be avoided and no unwanted movements will be seen of the equipment, especially in the case of forging hammer and presses where rapid dissipation of the movement is effectively ensured. The natural spring frequency is design specifically as a damper to isolate vibration effect over a wide frequency range.

This study will be focused mainly on the use of carbon fibre activated from periwinkle shell and natural rubber as viscous elastic materials to isolate vibration.

1.2 Statements of the Research Problems

Vibration over the years has led to machinery failure and undesirable disturbance to the surroundings. The effects are devastating and depend largely on the frequency of vibration. The higher the vibrating forces exert, the greater the effect it has on the working environment. Natural rubber is commonly used materials in reducing the severe effects of vibration, due to its viscoelastic ability. However, viscoelastic is not the only mechanism for damping, as some mechanical properties such as high stiffness, tensile modulus, and high resistance are also needed for effective vibration isolation.

Natural rubber suffers from low stiffness that results to low strength and low modulus of elasticity (Sorbothane, 2017). Rubber also has low resistance to solvent or liquid, which causes material swelling, softening, mold, rot, discoloration and total failure. Another concern is the vulnerability it has to sunlight, high temperature and oxygen, these causes stickiness and material deformation. Natural rubber needs to be reinforced in other to improve its mechanical properties to effectively subdue vibration.

1.3 Significance of Study

Based on the above listed problems, this study shall focus on the following areas;

1. Characterisation of periwinkle shell
2. Mechanical properties of natural rubber
3. Development of carbon fibre reinforced natural rubber composite
4. Mechanical properties of carbon fibre reinforced natural rubber composite

1.4 Justification of Study

Vibration emanating from machinery during operation is a normal phenomenon that occurs in all equipment, ranging from high precision machine to the least electronic components. Vibrational effects are quite disastrous if not controlled. It accelerates wear and tear in machine components, degrades and cause sudden breakdown of machine equipment and renders the environment unfavourable for habitation and intolerable.

5. The use of carbon fibre activated from periwinkle, with natural rubber is to control excessive effects of vibration on equipment and environment. The composition of these materials is based on their bonding nature and good mechanical properties. Carbon fibre on the other hand has good tensile strength, high stiffness and high resistance to fracture. While natural rubber is widely used as damping material, owing to its high resilience (elasticity) and resistance to corrosion.

6. The focus of this research is to design a strong and viable viscoelastic damper, to sufficiently absorb the vibration energy that causes large movement in machinery, unwanted noise and to reduce the effects of vibration in the surroundings. This will also add to the existing body of knowledge particularly in the industrial application where vibration isolation becomes important in protecting sensitive machinery parts from wear and tear, prevent movement by heavy machinery caused by excessive vibration, stop

vibration that may interfere with the quality of products produce and reduce the sound generated by the machinery.

1.5 Aims and Objectives of Study

This study is aimed at using carbon from periwinkle shell as reinforcement to the natural rubber to isolate vibration in a small generator.

The objectives of the study are:

1. characterisation of periwinkle shell.
2. to determine the mechanical properties (tensile strength, resilience and hardness) of natural rubber.
3. to develop carbon fibre reinforced natural rubber composite using periwinkle shell.
4. to determine the mechanical properties (tensile strength, resilience and hardness) of the composite.

1.6 Research Gap

Carbon fibre reinforced natural rubber composites is a composition of resins and fibre. The stiffening agent is the carbon fibre activated from periwinkle shell, while the resins are the natural rubber matrix. Periwinkle shell is used in this study because they are cheap and readily available. The shell contains volatile matter and moisture that are removed through heat treatment (Sanni *et al.,* 2017). Periwinkle shells are waste materials that have no competing demands and environmental concerns. The high carbon content of periwinkle shell has necessitated the use of it for the production of activated carbon (Akpa *et al.,* 2018).

Carbon fibre on the other hand has good mechanical properties such as high stiffness, good tensile strength, fatigue resistance, corrosion resistance, wear resistance and environmental stability (Rahmani *et al.,* 2014). The formation of composites arising from the interface between reinforced fibre and matrix tends to increase the damping capacity and also increases the stiffness effects. Traditionally, isolators are manufactured using natural rubber, to meet functional requirements such as vibration isolation and durability, carbon fibre is added into the rubber matrix as reinforcement which further increases the strength of vulcanized rubber more than tenfold (Khan *et al.*, 2013).

The damping strength of any vibration isolator depends largely on the composite used (the fibre and resin). The resin being the natural rubber matrix has low stiffness that result to low strength and loose modulus (Kumar *et al.*, 2019), low resistance to solvent that causes material swelling, softening and failure. Another major concern of natural rubber matrix is its vulnerability to high temperature, sunlight and oxygen, which cause stickiness that result to deformation. The rubber matrixes need reinforcement to improve its mechanical properties to effectively subdue vibration.

To overcome vibration, a material composite must combine high strength with high stiffness whichis the properties of a reinforcing fibre. The carbon fibres which act as a reinforcement carry most of the load. The resin helps to maintain the relative position of the fibre within the composite, and transfer load from the bottom fibre to the innerfibre (Mitra, 2014). These strengthen the interfacial properties of the fibre/resin composites.

This study is aimed at increasing the low stiffness of natural rubber to increase its damping ability, to cure the deterioration of natural rubber to withstand solvent, petroleum derivatives and to increase/improve the low resistivity of rubber matrix to harsh weather condition.

1.7 The Scope of Study

The scope of this study is limited only to the activated carbon from periwinkle shellused as reinforcement to natural rubber to isolate vibration.

The activation process is simply the thermal treatment under oxidizing atmosphere on the carbon fibre with temperature range of 700 - 1000 ˚C (Lee *et al.*, 2013). The traditional term for activated carbon is activated charcoal prepared in particulate form, either as powder or granules.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Vibration

Vibration is a continuous or repetitive movement of a body displaced from a position of equilibrium, (McGraw-Hill, 2020). Vibration causes serious effects on machine with high stresses that generates to fatigue, deformation and general malfunctioning of apparatus. These are undesirable for machine equipment leading to failure in machines.

Vibration isolation is a means of separating a piece of equipment from the source of vibration. The separating equipment can either be a rubber pads, or mechanical spring. Other methods of separation are sensors, actuators, control system or electronic force cancellation.

There's a need for the integration of special hardware application that can serve as a damper to mitigate vibration. This will be achieved through appropriate analysis by predicting its strength, physical properties, mechanical properties, effects, uses and the choice of the materials.

2.1.1 Causes of vibration

The major causes of machine vibration are imbalance; (caused by manufacturing defects, machining errors or casting flaws), maintenance issues; (missing balance weight, deformed or dirty fan blade), misalignment; (during assembly or development over time due to thermal expansion, shifting of components and improper re-assembly during and after maintenance), wear; (as a result of worn out gear, drive belts and bearing travelling repeatedly over a damage area), and looseness; caused as a result of loose bearings, or loosely attached to its mount (Wright, 2010).

The sources of vibration in centrifugal pump are divided into three major types; mechanical, hydraulic and peripheral causes, (Birajdar and Patil, 2009).While the main causes of piping vibration are excessive pulsation, mechanical resonance and inadequate support structure, (Rishab Engineering, 2021).

Occasional vibration in the airplane during flight is also linked to various causesto include landing gear extension and retraction, extension of speed brakes, free play in movable surfaces and system malfunctions. Others are external factors such as atmospheric turbulence. (Istec International, 2018) listed different errors to include misalignment, unbalance, resonance, loose parts and bearing damage as the root causes of vibration. An error in machine alignment could result to parallel misalignment, angular misalignment or combined parallel-angular misalignment. Unbalance is divided into static and coupled unbalance, while bearing damage can either be damage in the inner ring, damage in outer ring, damage in the cage or damage in rolling elements.

2.1.2 Effects of vibration

Vibrational effects are usually associated to damage in sensitive equipment, nuisance to human health, comfort and structural components, (Proenca and Fernando, 2005). These mechanical vibrations may result to damage in an entire or some elements of the equipment which shortened the service life of a machine. The effects can be devastating and depends largely on the frequency of vibration. Shock emanating from vibration can lead to fracture damage, separated or weakened connections, detonating explosives materials, machines instability, and mechanical failure, (Alrashdan *et al*., 2017).

Alshabi *et al.*, (2016) carried out a research on the effects of mechanical vibration on human body and concluded that, mechanical vibration causes forces that affect human bodies. The most affected area of the human body is the seated position. And two types of force were used to test the whole seated human body under low frequency citation, which are the sinusoidal wave signal and the impulse function.

The effects of sinusoidal vibration on seed germination of Arabidopsis thaliana was examined by Uchida and Yamamoto, (2002) which shows that vibration with frequencies higher than 70Hz increased the rate of seed germination. Also, there are little effects of vibration on seed germination in a starch deficient mutant.

The effect of vibration is very abnormal; this often leads to malfunctioning of mechanical equipment and friction. In airplane, there are two types of vibration. The first is the high frequency vibration typically more than 25Hz and the other type are of a lower frequency, less than 20Hz. These types of vibration are usually related to a large mass components acting on the airframe such as elevator, rudder with small mass components like access panel and loose door.

2.1.3 Control of vibration

Vibrational response is very common to all mechanical systems, especially when exposed to external disturbances. They are undesirable with harmful effects. Naucler, 2005 outlines two control strategies for active structures to include feedback control and feedforward control. A design and analysis of positive dissipative and passive system can be applied to beams with collocated actuator and sensor pairs. If a dissipative system is brought under control through a strictly positive controller (isolators) then the closed loop system will be brought back to stability due to spillover dynamics (Lozano *et al.*, 2000).

The Dynamic Vibration Absorbers (DVAs) is a widely used principle to control vibration in structures, Torres-Perez *et al.*,(2016). Being extensively studied under building structures, the DVAs are used as a defence mechanism against earthquakes to counter seismic movements and wind forces. Passive control and active control are the typical mitigating methods for undesired vibrations (Gohari and Tahmasebi, 2015). Active control requires sensors, actuators and electronic control systems to reduce vibrational levels.

To counteract negative effects of vibration (Barcik *et al.*, 1998) identified two methods which are passive and active methods. The active methods are structural modifications of vibration system with the use of additional energy source like the elastic and damping forces. This method actually controls external power source and absorb energy due to determined algorithm. The passive method is restricted due to small effectiveness in the range of low frequency, sensitive dependent on exploitation conditions(Engie *et al.*, 2015). This method dissipates a great deal of vibration energy in the range of high frequency (Kowal and Ornacki, 2002). Better result may be achieved with the use of active methods which consists of additional energy supply to the system.

Passive vibration controls are mostly limited to tackle a single structural resonance or a specific frequency disturbance. While active vibration control systems can overcome these limitations but required a continuous energy for a sufficient performance (Meyer *et al*., 2006).

2.1.4 Types of vibration

Kasula, (2018) broadly analyses four different types of vibration in an aircraft which are vibration, flutter, buffet and noise. When a body is forcibly moved from its position of equilibrium, it creates a motion known as vibration in oscillatory, reciprocating or periodic motion. Flutter vibration in aircraft is rather dangerous in a magnitude of causing failures in aircraft; it is as a result of unsteady aerodynamics exciting the natural occurring frequencies of an aircraft, as air flows over it. Buffet on the other hand is the most familiar type of vibration occurring during air turbulence. When the aircraft speed brakes, it extends and disrupts the air flow around it. While the noise is simply the vibration that excites the air in a whistling drain sound.

Vibration can be categorized into three classifications; free vibration, forced vibration and self-excited vibration. Free vibration of a system occurs due to the absence of external force. The sources of free vibration are initial displacement of system from equilibrium.

Forced vibration on the other hand is caused by an external force that acts on the system. The exciting force act continuously, by supplying energy to the system.

Self-excited vibration is a deterministic oscillation (Vladimir and Dae-seung, 2012), such that the system becomes unstable and any disturbance may further cause the perturbations energy to grow. The depletion of energy is known as damped vibration. When a vibrating system is damped the energy is loss. Damping can be through dry friction interfaces, mechanical devices and other viscous damping arrangements.

The major types of vibration that occurs in helicopter are low to high frequency, ground resonance, lateral and vertical vibrations (Mathew *et al*., 2022). The frequency of vibration ranges between low to high, is a typical vibration that occur when the revolution of a rotor is disturbed, due to loose components of the aircraft. The ground resonance is very dangerous and can destroy helicopter in seconds. It is as a result of unbalanced forces in rotor system that caused the rocking of the aircraft on the landing gear, incorrect tire pressure, and incorrect adjustments to landing gear. The lateral and vertical vibrations are as a result of worn, loose, cracked parts or imbalance rotor blade.

2.1.5 Application of mechanical vibration

One of the industrial applications of vibration is sieving. Mechanical sieve works with the use of vibration, and most industries filter their raw materials with the use of mechanical sieving machine, (Figure 2.1). There are many applications for mechanical vibration in industries. Mechanical vibration can be used in mixing two items which can either be solid or liquid. Vibration can be measured and data obtained from it is used in checking the condition of a machine, if those machines run perfectly fine.

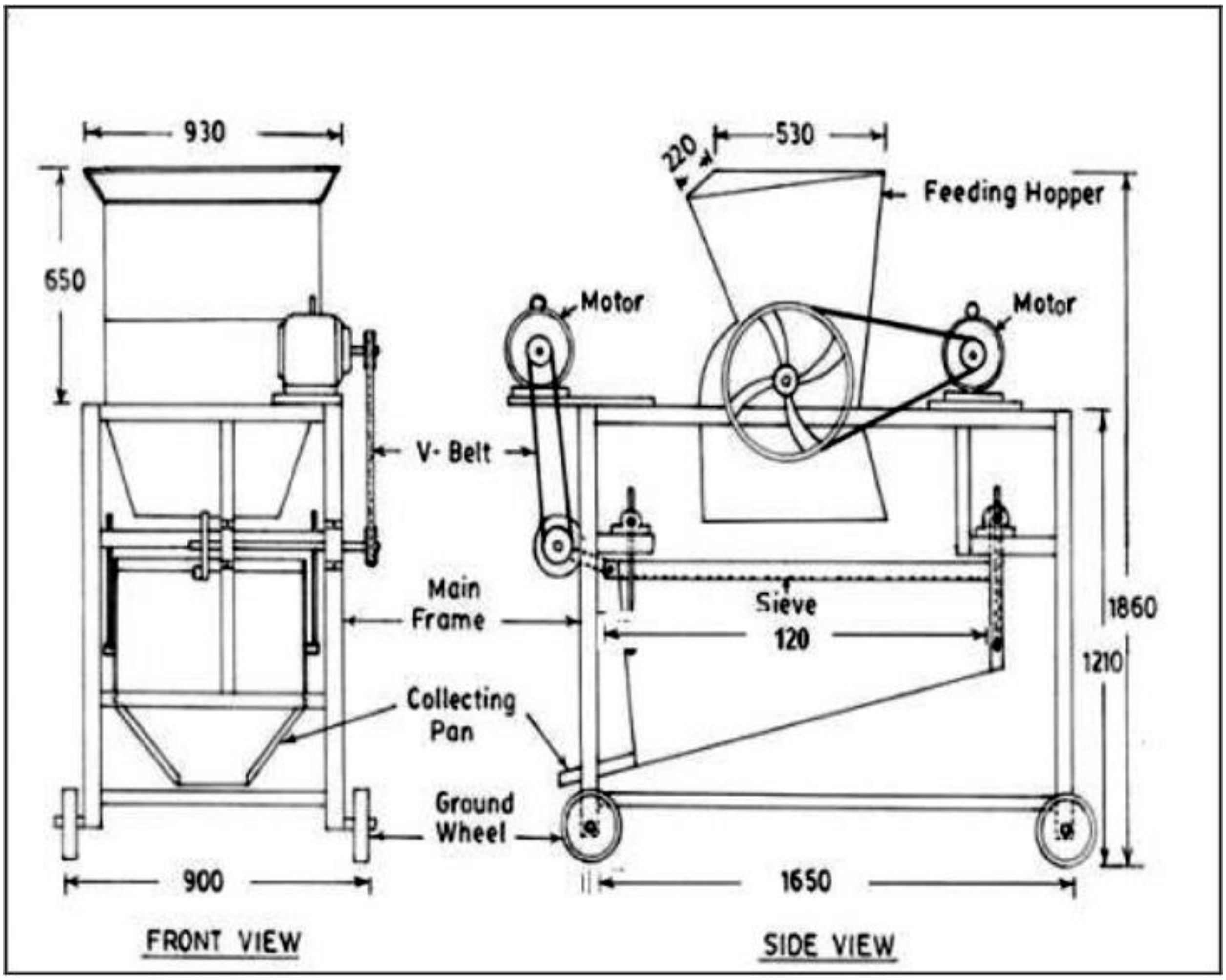

Figure 2.1: A Schematic Diagram of Mechanical Sieving Equipment (Geology Department, 2019)

Vibration Gyroscope and Dynamic Vibration Absorbers are few vibration applications in which when a mass is tuned to vibrate at a specific frequency, it absorbs energy from some of other oscillating components (Ekeocha, 2018). Such a system is used to reduce the vibration in electric hair clippers and also installed in the top of tall buildings to attenuate them from swaying. In the case of crack presence, ultrasonic vibrations are sent into the mechanical component. The vibration signatures are therefore collected and are compared with or without the crack signatures (Singh and Kumar, 2017), through this method the extent position and crack growth rate can be determine. This technique is extensively use in detecting small cracks in turbine blades.

Mechanical vibrations could be desirable in most cases, as in a mobile phone or the motion of a turning fork, but are largely undesirable in operations such as engines, electric motors or any mechanical device in operation. Such vibration causes imbalances and uneven frictions (Osvaldo *et al.*, 2011). Applications for electric and pneumatic industrial vibrators and vibratory equipment are used in almost all stages of production processes, by industries relying on bulk materials. Industrial vibrators and vibratory equipment can be effectively used in reducing cost and to improve quality of production.

In healing, vibration is an alternative therapy that involves the use of mechanical vibration administered through specialized equipment in treating some health problems and injuries. Vibration healing is also used in a variety of health care settings such as physical therapy, massage therapy, rehabilitation and sports medicine (Wong *et al*., 2019). A number of health professionals use vibration healing in their practice. While massage therapists, occupational therapists, physical therapists and body work practitioners all use vibration therapy.

In medicine, the use of vibration is not new. It can be locally applied through the means of vibrating support rolls, cushions, vibrating dumbbells or cables or applied to the whole body by means of a vibrating platform (Chwala *et al.*, 2021). During the whole body vibration, the transmissibility and impedance response of the human spine shows an increase at their resonant frequency. The greatest motion throughout the spine, indicates that the greatest effect would be achieved at resonant frequency be it beneficial or detrimental.

Vibration remains one of the earliest indicators of a machine's health which can identify problems earlier before other symptoms like heat, sound, electrical consumption, and lubricant impurities (Fluke Corporation, 2013). More than half of unplanned downtime is attributed to mechanical failures. While so many things can as well impact the life of a machine. Once a machine shows some sign of failure, it takes a little or shorter time before it completely fails. Vibration testing provides a means to determine where the machine is on the failure curve and react appropriately.

The use of vibration stimulation enhances athletic performance. It is used as a therapy for muscle, bone and cartilage tissues (Musumeci, 2017). Current evidence shows that vibration can effectively enhance musculoskeletal strength, power capacity and to improve physical conditions of patients with disorder cases as osteoporosis and osteoarthritis (Issurin, 2005). In rehabilitation medicine, the therapeutic application of vibrational energy is used in specific treatment. More so in sport rehabilitation, clinical application of vibrations exists in the following forms; mechanical vibrations, ultrasound therapy, extra corporal shock wave therapy and extremely low frequency magnetic field therapy (Saggini *et al*., 2017).

2.2 Vibration Isolators

Vibration isolation is a technique commonly used in reducing unwanted vibrations in structures and machines (Yang *et al.*, 2008). It is the separation of vibratory forces or motion in a system. This is accomplished by inserting a resilient material in the driving object. Vibration isolators with little damping capacity are well able to reduce transmission at a higher frequency and permit a great transmission of vibration at a resonant frequency. While additional damping level will reduce the response at the resonant frequency and limit the isolation capability at a higher frequency (Harris *et al.*, 1991).

An isolator is a resilient support which decouples an object from steady state or forced vibration (Fabreeka International Inc. 2016). To reduce the transmitted vibration, isolators in the form of springs, elastomers, shock absorbers are used. Vibration occurs when a system is displaced from a stable state of equilibrium, and the system tends to return back to its equilibrium position under the action of restoring forces like elastic force and spring.

Vibration is undesirable in so many ways, it propagates through mechanical waves, and high vibration level can cause machinery failure as well as objectionable noise levels, (Harris *et al.,* 1991). Vibration isolator is brought about by a developed method in preventing the transfer of mechanical vibration in engineering system.

2.2.1 Types of vibration isolator

There are different types of vibration isolators made from various materials, depending on their functions. Some of these materials include rubber, metals alloys, fibre glass and neoprene, (Meyer *et al.,* 2006). Most vibration isolators can be classified as either passive or active vibration isolation system.

The most utilized materials in isolating vibrations are elastomers, cork, glass fibre and felt. The major differences between these materials are their stiffness, natural frequency and their damping abilities.

2.2.1.1 Passive isolation

A passive isolation system such as shock mount is generally made up of Mass (M), Spring (K) and Damper (C), (Figure 2.2).Mass stores kinetic energy, spring stores potential energy and support load while damper dissipates energy and cannot support load. To dictate the natural frequency of a system, a conventional passive vibration isolator is composed of a resilient member and viscous damper (Lee *et al.,* 2013).

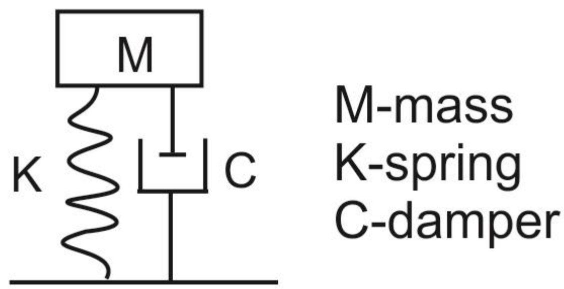

Figure 2.2: Conventional Vibration Isolator (Lee *et al.,* 2013)

Passive mechanism system can be typically altered using an electro mechanical system. The mode of vibration removal itself is passive and it includes springs, elastomers, pneumatic, tuned mass damper, wire rope isolators. Passive mechanisms are less expensive compared to active mechanisms with better reliability and safety.

Examples of Passive Isolation System

2.2.1.2 *Pneumatic Isolators*

Pneumatic or air isolators are canisters of compressed air. It provides damping as well as isolation in large trucks and industrial equipment. It can attain low resonant frequencies, (Mistry, 2013). Pneumatic isolator contains a sealed and pressurized air volume with movable piston. Compressed air pushes against the piston to support the static load of the system. And damping is provided by forcing the air to move in between the chamber through the orifices or a pendulum rod within the viscous damper.

2.2.1.3 *Spring isolators*

These isolators provide up to 98 % vibration isolation (Minus Technology, 2019). It is suitable for all applications. In choosing the spring type of isolation, the model must as well match with the generator weight to avoid overly compression of the spring.

Spring isolators, as shown in Plate 1 are used in reducing the transmission of noise, shock and equipment within a building structure. The isolated equipment includes boilers, compressors, cooling towers, pumps.


Plate I: Spring Isolator (MinusTechnology, 2019)

2.2.1.4 *Elastomeric isolators*

An elastomer is any elastic polymer be it silicon, rubber, fluoro-silicone rubber or butyl rubber to meet a specific application like internal dampening and modulus of elasticity (Galindo *et al*., 2015). The materials selection is dependent on ultimate loading, internal properties and sensitivity to environment.

For an elastomer, spring rates is determined by shape factor, loading shear, compression, tension and materials properties like bulk, shear and young modulus. Elastomers are used in between the set's base and pad to isolate generator components as controls. This provides 90 % isolation efficiency and is sufficient for most installations at or below grades level. Neoprene mounts are integral mounts fitted by the manufacturer between the engine and generator.

2.2.1.5 *Wire rope isolators*

The wire rope isolators have stainless steel cable and aluminium retaining bars (Plate II) that provides excellent vibration isolation. The isolators are corrosion resistant with high performance in a variety of applications, and can absorbed shock and vibration in small spaces, (ITT Enidine Inc. 2019). Wire rope isolators are useful on gallery components where equipment and fans produce vibrations onto surrounding structures. It can be used in controlling vibration and thermal expansion.

Plate II: Wire Rope Isolator (ITT Enidine Inc, 2019)

2.2.1.6 *Tuned mass damper*

A tuned mass damper is a harmonic absorber or seismic damper mounted in structures to reduce the amplitude of mechanical vibration. They are normally used in power transmission, automobiles and building to prevent damage or outright failure in structures (Lin *et al.,* 2000) Tuned mass dampers stabilize against a violent motion caused as a result of harmonic vibration. It practically reduces the vibration of a system.

2.2.2.7 *Active isolation*

Active isolation system comprises of a feedback circuit, sensor, actuator and a controller. The control circuit processes the vibration signal to feed the electro-magnetic actuator which then sets a stronger suppression of vibrations, (Mizuno *et al*., 2007). For photonic applications, active vibration isolation system uses a combination of sensors and actuators, whose functioning is controlled by articulated algorithms to attenuate vibrations. This algorithm is stored in external or internal controller as a central command for the system.

Most sensors found within active isolation systems can detect parameters as displacement, velocity, and acceleration. Signals in active isolation are acquired through high sensitive detectors, and are analysed by electronic circuit, which drives electro-dynamic actuators. A counter force is immediately produced to counteract the vibration.

There are two main types of active isolation system; feedback and feed forward control systems. The feed forward control system is used to attenuate on-board vibrations. While in the feedback active control, the force that is causing the vibrations are measured, and the out of phase signals are sent to the transducers to reduce amplitudes, (Lee *et al.*, 2013).

2.2.3: Failures in isolators

The quality and performance of isolators may vary based on their variation, sensitivity and installation. All isolator products are not equally created and their quality and performance varies considerably from time to time. Generally, failure do not just happen, it might begin from product design, manufacturing, assembling, screening, testing, installation, operation or maintenance. The classes of failure in mechanism include overstress mechanism and wear out mechanism, as presented in Figure 2.3

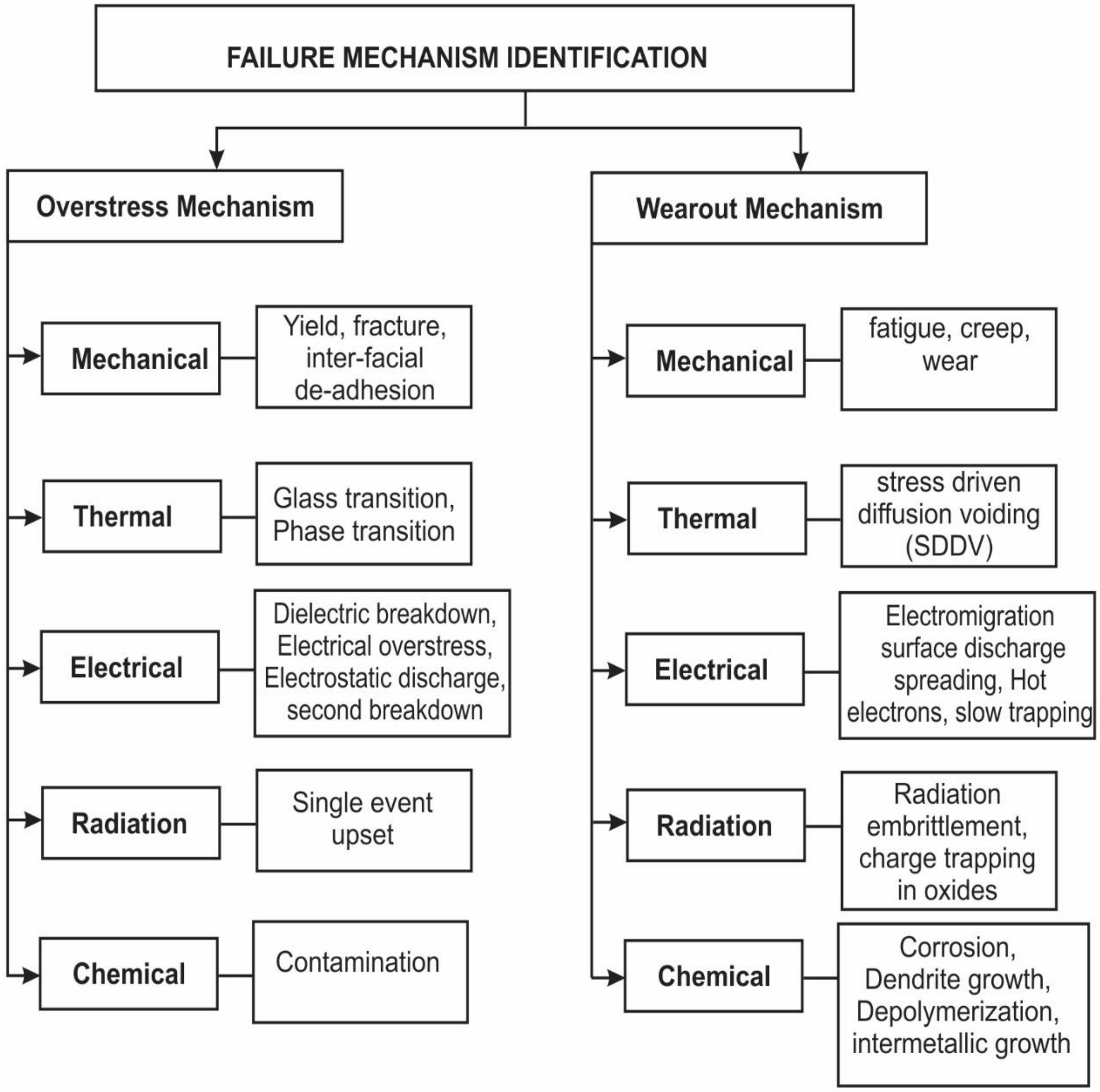

Figure 2.3: Classes of Mechanism Failure. (Schenkelberg, 2020)

There are many failure modes that exist in the isolation of a rotating system, and these are poor system design, inappropriate isolator selection and fabrication/installation failure. Isolator selection has more to do by choosing an element with enough static deflection to provide a suitably low natural frequency. Most times the best conceptual design and isolator selection can be undermined during implementation. And most errors during installations are always around alignment.

Torsional vibration is a vibration that involves shaft twisting during the machine rotation. And excessive torsional vibration can result to failure of crankshaft, couplings, engine dampers and compressor oil pumps (Issurin, 2005). These failures occur at an angle of 45 degrees to shaft axis. However, the problem of torsional vibration is simultaneously experienced in reciprocating and rotatory machinery. And the major causes include improper application and maintenance of viscous dampers and couplings. There are so many factors that tends to affect the life of insulation, these factors include; misapplication, vibration, high operating temperature, fatigue, improper lubrication, careless or negligent operation.

Without damping effect, vibration will result to premature failure. Also when a vibration damper has fully reached the end of its service life, it is advised that all the wear parts should be replaced at the same time to ensure long term solution (Gates Techzone Corporation, 2019). In a torsional vibration damper, the signs of failure are summarized in Table 2.1

Table 2.1: Failure Signs in Vibration Isolators. (Gates Techzone Corporation, 2019)

S/N	Failure Mode	Appearance	Cause	Solution
1	Micro cracks	There are fine	Hardening of the	Replace the

	in the rubber damping element	cracks in the rubber	surface due to aging that result to failure in damper.	torsional vibration damper
2	Deformation of the rubber damping element	The ring of the elastomeric materials is clearly deformed. The deformation is visible on the rear side of the damper	The rear side of the damper is situated closer to the engine, subjecting it to more heat and contamination	Replace the torsional vibration damper
3	Rubber separation	The rubber loosens and get stuck between the pulleys and the belt	The harsh working condition (vibration, shock, heat and contamination) affect the damping device	Replace the torsional vibration damper
4	Damaged slotted holes	Clear contact marks from the metal wear tabs in the slotted holes	The metal wear tab is prevented from contacting the slotted hole until the rubber damping elements has severely worn out. Once worn out the tab repeatedly hits the slotted hole leaving clear contact marks	Replace the torsional vibration damper
5	Damaged bushes	Cracked or split bushes which will result in strong vibration	Wrong torque settings at installation	Replace the torsional vibration damper
6	Total failure	The torsional vibration damper physically falls apart. It can also come off the engine	Excessive vibration due to lack of maintenance	Replace the torsional vibration damper and check all components

Common failure occurring from insufficient vibration dampening are solder joint failure, through hole pin lead cracking and lead wire fatigue (Lee *et al.*, 2013). These failure modes can greatly reduce product life, cause intermittent signalling and result in a complete failure of device. There are other failure modes that described the characteristics of a physical damage of isolators; these are overload, bending fatigue, wear, cracking. In most cases failed parts and inspection don't yield enough information in determining the root cause of failure.

2.2.4 Prevention of failure in isolator

Poor design is one of the root causes of failure in isolators (Alrashdan *et al.*, 2017). A good design and analysis is more effective for the safe and reliable functioning of isolators. The analyses require thorough knowledge of the materials properties, the boundary conditions, thermal and structural analyses. A crucial way of improving the equipment design is through accurate prediction of vibrational response. The weight of a damper is enough to dent it for failure (Ekeocha, 2018). Dampers weight about 44pounds looks much sturdier than they are, and if a damper is dented it definitely need to be replaced. Machine vibration without a good isolator can result to failure of many other components like the camshaft, flywheel bolts and flywheel housing.

For particular isolator that handles hazardous compounds, a routine maintenance can occur every six months or annually, depending on its use (Barcik *et al.*, 1998). If the isolator has not been used in the past months, then the routine performance monitoring may not be required. However, the isolator will need the routine monitoring before being used again. The routine performance monitoring assessment, checks the overall condition of the isolator to determine if the isolator has deteriorated since the last routine maintenance. It checks for discoloration, pitting, staining, agent residues, wear and tear. The most reliable and reactive indication of isolator health is routine assessment and replacement. Isolators can last longer as long as solvents are not involved and the isolator is not overdue in its integrity testing or the isolator is not inerted.

Damper with longer usage are bound to fail with time. At about 500,000 miles, silicone tends to harden, and the harder the silicone, the less functioning of the damper (Ekeocha, 2018). The durability of a damper, shock absorbers and struts depends on the miles a vehicle is being driven, the kinds of road it is driven and whether it is driven gently or recklessly. However, rough roads with large cracks, portholes, sharp ridges bump and frequently carrying of heavy loads will cause faster wear in shocks. It is quite unusual for shocks and struts to last up to ten years before it can be replaced, but with a thorough inspection at 40,000 to 50,000 miles can enhances their durability.

Most isolators fail before their design life span, as a result of wear particles, dirt and other contaminated debris that enter the isolator housings through openings and vents. Solvents are one of the common sources of contamination in isolators (Fabreeka International Inc 2016). A way of protecting the isolators from close contact with solvents is far easier in safeguarding the system failure. Modern bearing isolators are designed to provide a reliable protection against solvent and other particles contact and can last for many years when properly maintained. In humid weather, there is an increasing incident of isolation failure, and tracking down such failure is only possible at that time it occurs.

There are many failure modes present in the isolation of a rotating system, which are; poor system design, inappropriate isolator selection and installation/fabrication failure (Hopkins, 2009). These problems of design selection and installation can undermine optimal performance of isolator. Rubber shock, vibration isolators and dampers fails due to either excessive creep or mechanical fracture due to fatigue. Mechanical fractures occur when a rubber part is subjected to a cyclic stress and strain. The crack always starts in an area of high stress concentration and grows until total fracture occurs. Failure in isolators may also arise due to overheating, caused by high operating temperature or environment. For every 10 degree Celsius rise in temperature, the life of isolator is reduced by 50 percent.

2.3 Natural Rubbers

A natural rubber is obtained from a milky secretion known as latex, which comes out from a species of trees called *Heveabrasiliensis* (Woodford, 2022), commonly known as rubber tree (Plate III). The latex is very rich in rubber and can be preserved with addition of ammonia. The preserved latex can be transported to places where it can be processed in a liquid form as latex concentrate. This latex is about one third water and one third rubber particles held in a colloidal suspension. The latex can be filter and coagulated with the use of substance as acetic acid or through electrophoresis. These separate the raw natural rubber from the water to form a solid mass (coagulation), which can further be processed.

Plate III: A Natural Rubber Tree

When the water is squeezed out of the coagulum of rubber, the resulting thin sheets are dried over a wooden rack in smokehouses. The resulting dark brown rubber is folded into bales for shipping where it can be processed (Blaettler, 2018). Coagulation is the commonest method of extracting rubber from latex, the process is achieved by adding formic acid to the latex, and the coagulation process takes about 12 h.

Natural rubber has low modulus of elasticity which in turn results to deformation. After such deformation, it forcibly retracts to its original shape and size. Rubber is resilient with internal damping ability; the load deflection curve of a natural rubber can be altered with a change in shape. The application of natural rubber includes tyres, sport equipment, flippers, shoe soles, gloves, eraser, machinery equipment, abrasion or wear resistance, damping or for shock absorbing properties. It requires no lubrication neither do natural rubber corrodes.

2.3.1 Mechanical properties of natural rubber

Natural rubber is a commonly used material for vibration isolation due to its viscoelastic ability. It provides high elasticity with good tensile strength, high stretch recovery and good resistance to creep. This makes it an optimal material for a wide application of items that required repeated stretch recovery and compression.

Natural rubber is widely used as shock and vibration isolators because of its high resilience and tear properties. Traditionally, isolators are manufactured using natural rubber in other to meet functional requirements such as durability, fatigue and creep. It also possesses an inherent strength and strain crystallizes with or without the addition of a particulate reinforcement.

Natural rubber shows better properties as compared to other rubber produced synthetically, it is used as an improved property to expand applications of other rubber materials through blending (Ginting *et al.*, 2016). All rubber-like materials are polymers consisting of different molecules such as monomers. Rubbers are water repellent with high resistant to alkali and weak acid. The elasticity, toughness, impermeability, and electrical resistance of rubber make it a useful adhesive and coating composition for a wide variety of application.

2.3.2 Uses of natural rubber

Natural rubber is commonly used material in applications requiring wear resistance, elastic resistance and shock absorbing properties (Mente and Tshwafo, 2016). The most important use of natural rubber is in a vehicle tyres, machinery components, elastic band and sport equipment.

Natural rubber is used in everyday life ranging from pencil erasers to protective gloves, birthday balloons, condoms, paints and adhesives. Rubber can be made soft or hard depending on its applications. Harder rubbers are needed for tougher applications like roofing membranes and for rigid inflatable boats used by divers. It is an abrasive resistant material used in areas where other materials would wear out.

Natural rubber is an ideal polymer for dynamic and static engineering applications. Its strength and flexibility placed it as the best options to be used as electrical cables, fire-optic and heat pipes. The ranges of natural rubber applications are vast; medically it is used in several applications as birth control products, infusion and transfusion set, surgical implants, rubber bulb syringe, andin rubber diaphragms for artificial heart to pump blood (Guerra, 2021).

2.4 Reinforced Fibres

Reinforced fibre is a composite material which can be glass (fibreglass), carbon (carbon fibre), aramid or basalt. Other fibres such as paper, wood and asbestos are not commonly used as reinforcement. A fibre composite that is used as reinforcement is to strengthen the matrix which is usually weak in other to yield a final product with a desired mechanical property.

A reinforced fibre composite is naturally occurring materials, made from two or more constituent materials with different mechanical properties. Some of these composite are strong and stiff fibres in a matrix that is weak and less stiff (Bhatt and Goe, 2017). The main aim of adding a fibre to a matrix is for an improvement in strength, creep, thermal stability and toughness of the material that will result in high performance. A reinforced fibre whether carbon or glass fibre has some advantages such as corrosion resistance, non-magnetic properties, and high tensile strength and are light in weight.

A reinforced fibre is relatively light in weight with an increased strength, good fatigue and compression properties. This makes it so relevant in the automobiles industry with the aim of replacing the metals with a lightweight material of strength. Owing to its strength, a reinforced fibre can be used in a wide application of industry such as the automotive, aerospace, construction and marine sectors (Kumar, *et al.,* 2019). They also demonstrate good electrical properties, thermal insulation, structural integrity, fire- hardiness, ultra-violet radiation stability and resistance to chemical corrosives.

2.4.1 Carbon fibre

Carbon fibres are carbonaceous materials in fibrous shape with diameter of 5 to 10 micrometres (0.005 – 0.010 μm), and mainly composed of carbon atoms (Lee *et al.,* 2013). The carbon atoms are being bonded in a microscopic crystal, aligned parallel to the long axis of the fibre. The crystal alignment makes the fibre incredible strong for its size.

Carbon fibre is made of thin, strong crystalline filaments of carbon that is used in strengthening a material. It is tough and lightweight material. Carbon fibre is five times stronger than steel and as twice in stiffness. Carbon fibre is also lighter than steel irrespective of its strength and stiffness. This makes it very ideal and useful in several applications such as in the aerospace, automotive, military and recreational industries, (Innovative Composite Engineering, 2015).

Carbon fibre has high tensile strength, high modulus and offer good resistance to high temperature. There are basically five categories of carbon fibre generally used in composites based on its tensile modulus; low modulus, standard modulus, intermediate modulus, high modulus, and ultra-high modulus (Baohui *et al*., 2020). As the modulus increased, the fibre tends to be more brittle, more expensive and harder to handle. However, the tensile strength of the fibre generally increased as the modulus increased from low to intermediate, and then falls off in the high and ultra-high modulus fibre. This shows that the intermediate modulus fibre gives the best overall performance to the composite.

Carbon fibre classified as low modulus has a tensile modulus below 34.8 million psi (240 million kPa), while ultra-high modulus carbon fibre has a tensile modulus of 72.5 – 145 million psi (500 million – 1 billion kPa). In comparison, steel has a tensile modulus of about 29 million psi (200 million kPa). However, the strongest carbon fibre is ten times stronger than steel and eight times stronger than aluminium, and much lighter in weight than both materials (Zoltek Corporation, 2019). In addition, the fatigue properties of carbon fibre are more superior as to compare with all metallic structures with a corrosion resistant when mixed with a proper resin.

2.4.2 Mechanical properties of carbon fibre

Carbon fibre are very useful to a wide range of engineering applications, owing to their excellent qualities such as strength, corrosion resistant, low weight and environmental friendly.. The property of carbon fibre varies based on the structure of the fibre. However, the most attractive properties of carbon fibre are; high tensile strength, high modulus, low density, low thermal expansion coefficient, excellent creep resistance, high thermal conductivity, availability in a continuous form, biocompatibility, chemical stability in strong acids (Rosszainily *et al.,* 1990).

The mechanical properties of carbon fibre as summarised in Table 2.2 include high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These make it more applicable in the aerospace, engineering, military, recreation and sports industries (Khan *et al.*, 2013). The key features of carbon fibre are excellent strength and light weight. The specific strength of carbon fibre is approximately ten times the specific strength of iron while its specific modulus of elasticity is approximately seven times that of iron. Other characteristics include non-rusting, non-failing due to fatigue, chemically and thermally stable.

Table 2.2: Mechanical Properties and Applications of Carbon Fibre. (Naucler, 2005)

S/N	Mechanical properties of carbon fibre	Applications of carbon fibre
1	Physical strength, specific toughness, light weight	In aerospace, road and marine transport.
2	Good vibrational damping strength and toughness	For audio equipment, loudspeaker for Hi-fi equipment, robot arms.
3	Fatigue resistance, self-lubrication, high damping ability	For textile machinery and general engineering.
4	Chemical inertness, high resistance to corrosion	In chemical industry, nuclear field, seals, valve. Pumps and components in processing plants.
5	Electrical conductivity	In automobiles, casing and

		bases for electronic equipment.
6	Biological inertness and X-ray permeability	In medical applications, surgery and X-ray equipment, implants, tendon and ligament repairs.
7	Electromagnetic properties	In large generator retaining rings, radiological equipment.
8	High dimensional stability, low coefficient of thermal expansion and low abrasion	For missiles, aircraft brakes, aerospace antenna and support structure, large telescope, optical benches, wave guides for stable high frequency (GHZ)

2.4.3 Activated carbon fibres

The activated carbon fibre is a fibre activated from carbon, processed to be extremely porous (small and low-volume pores) that increases the surface area for adsorption or chemical reaction. It is mainly composed of carbon atoms which can be produced from any materialswith high carbon content (Akpa *et al.*, 2018). Such materials include coconut shell, periwinkle shell, snail shell, waste bamboo, coal, palm kernel fibre and shell.

The activated carbon fibre is a micro porous material commonly produced from carbon fibre. The process of activation involves introduction of thermal treatment under oxidizing atmosphere on the carbon fibre in the range of temperature between 700 to 1000 ˚C (Lee *et al.*, 2013). The raw materials used in producing activated carbon fibre are natural and synthetic polymeric materials such as polyacrylonitrile (PAN), cellulose, phenolicresin, pitch, viscose, acetate and saran (Poly Vinylidene Chloride PVDC).

Activated carbon fibre is prepared by two stage process of carbonisation followed by activation. Carbonisation involves pyrolysis (temperature less than 650 degree Celsius) of the raw materials in a non – oxidative atmosphere. The resulting low – porosity char is then activated. The manufacturing method differs depending on the kinds of raw materials; however, the general method is similar to the manufacturing fibres for clothing (Figure 2.4).

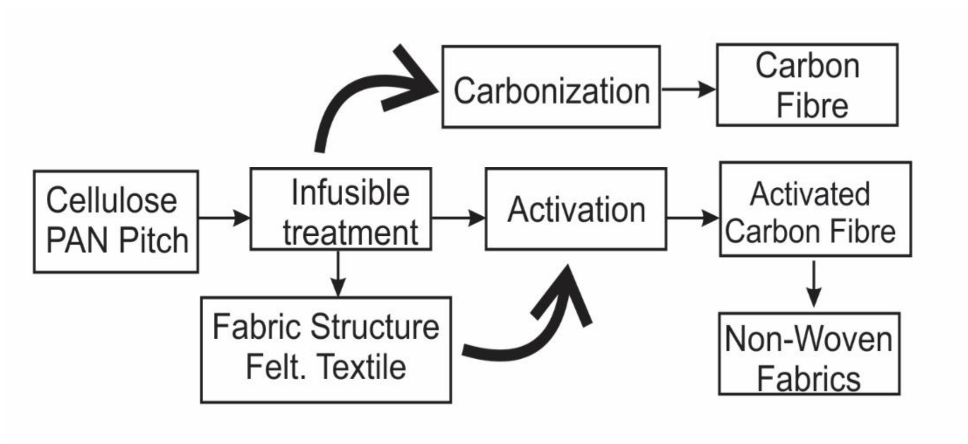

Figure 2.4: General Methods of Activating Carbon Fibre (Heidarinejad *et al.*, 2020)

Activated carbon fibre has some advantages over other forms of activated carbon (Figure 2.5) such as powder and granules, due to its excellent absorption to low concentrates substance, heat resistant, tensile strength, acid and alkaline resistant, rapid and efficient adsorption and desorption rates. The activated carbon fibre has unique shape (form-fitting property) which allows it to be fabricated into many available shapes. It is widely used for recovering organic compounds and solvent, anti-corrosive and heat insulating material, drinking water purification, military defence and clothing.

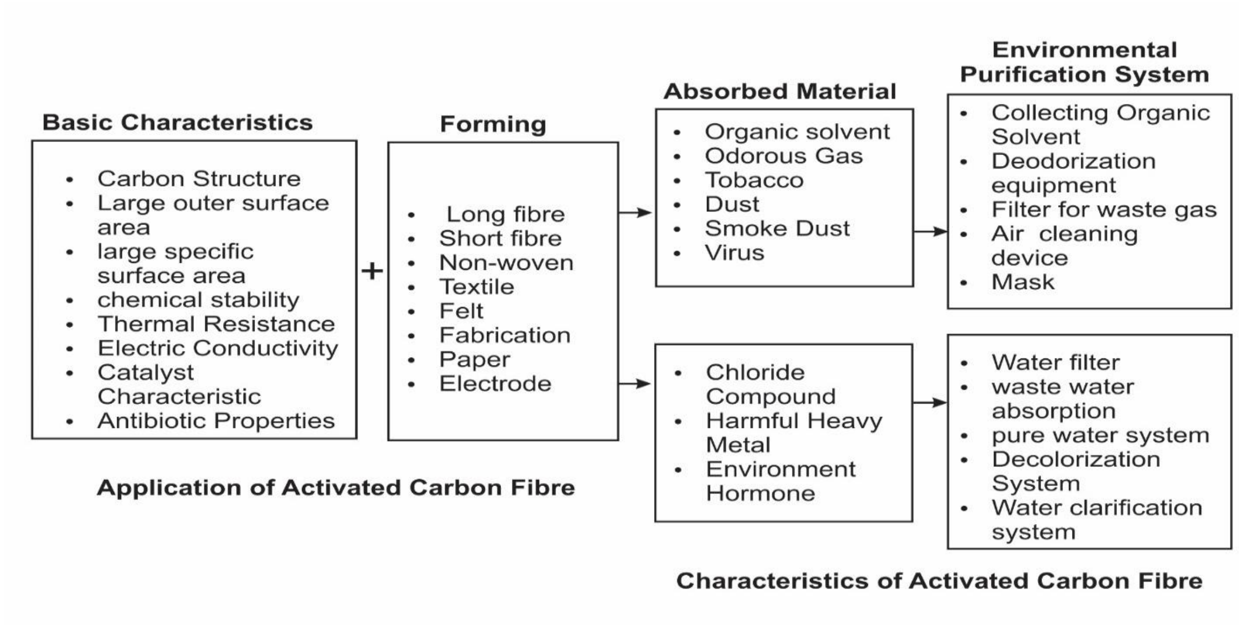

Figure 2.5: Application of Activated Carbon Fibre (Sharma *et al.*, 2022)

2.4.4 Other forms of reinforcement

As carbon fibre and fibreglass remains the most common forms of reinforcement in thermoplastic composites, there are other forms of fibre which can also be used to reinforced polymer matrix composites. For instance, the aramid and boron fibre offers good properties in terms of excellent toughness and compressive strength. While ceramic fibres like aluminium oxide are quite attractive in terms of compression, insulating or high-temperature properties.

Fibre reinforcement is a specific method of using fibre materials to mechanically augment the elasticity and strength of a matrix. The original matrixes are usually tough and weak which therefore need to be blended with a reinforcing material to yield a final product with the desired mechanical properties (Kumar *et al*., 2019).

2.4.4.1 *Carbon fibre*

Materials based on carbon fibres exhibits a high tensile strength, chemical resistance, stiffness and temperature tolerance. Carbon atoms form crystals which lie along the axis of the fibre, this strengthen the materials by increasing the strength to volume ratio

(Sandhanshiv and Petel, 2014). Carbon fibres are conductive with excellent combination of high modulus and tensile strength. As the modulus increase the fibre tends to get more brittle. Carbon fibre has incredible strength to weight properties. It is a very stiff material that remains close to rigid until failure. It is best used in constant loading conditions.

2.4.4.2 *Fibreglass*

Fibreglass is commonly used as a reinforcement material for moulded and laminated plastics. Although it is not as strong and stiff as carbon fibre, it does have a characteristic that makes it useful in several applications. Fibreglass is non-conductive (insulator) and is generally invisible to most types of transmission, which serves as a useful option in the electrical applications.

There are five major types of fibre glass which are; A-glass (Alkali glass), this has a good chemical resistance with lower electrical properties. C-glass (chemical glass) has very high chemical resistance. E-glass (electrical glass) has excellent insulator, and also resist water attack. S-glass (structural glass) it is optimized for mechanical properties. D-glass (dielectric glass) it has the best electrical properties but lacks in mechanical properties compared to S and E glass. E-glass and S-glass are the commonest type of glass found in composites. These types are good combination of mechanical properties, chemical resistance and insulating properties.

Glass fibre reinforcement are good options for the power industry since it is devoid of any magnetic field, and can offer good resistant to electric sparks (Craftech industries Inc. 2019).

2.4.4.3 *Aramids*

Aramids are class of synthetic polyamide formed from aromatic monomers (ring shaped molecules). It demonstrates robust heat resistance. They are used as bullet proof and fire resistant clothing (Zoltek Corporation, 2019). Aramid fibres are commonly known as

Kevlar, Nomex and Technora. Aramid fibres are manufactured with different grades of strength and rigidity, in other to meet a specific design requirement, such as cutting the tough material during manufacture.

2.4.4.4 *Carbon black*

Carbon blackare material produced by the incomplete combustion of petroleum products such as coal tar. It is widely used as a reinforcing agent in automobiles for various types of tyre, and in plastics for conductive packaging, films, fibres, pipes and semi conductive cable (ICBA, 2019).

Carbon black as illustrated below (Plate IV) is mainly used as a pigment in ink, coatings and plastic. It absorbs ultraviolet radiation to prevent a material from degradation. Carbon black particles are also used in some radar absorbent materials, in photocopier and laser printer toner, and in ink and paints. The high tinting strength and stability of carbon black has also made it useful in colouring of resins and films (Lee *et al.*, 2013). Carbon black are useful in a wide application of electronics, it is used as filler in plastics, elastomers, films, adhesives and paints.

Plate IV: Carbon Black

2.4.4.5 *Wood fibre*

Wood fibres are commonly used materials in the pulp and paper industry for the production of wide variety of products such as paper for printers, newsprint, paper for magazine, paper for tissues, fluff products for diapers, furniture board and corrugated board (Matuana and Stark, 2015). Wood fibres are also used as reinforcement in composite materials due to its mechanical properties.

Wood is a combination of cellulose fibre and lignin. The cellulose fibre provides strength and the lignin is the glue that bonds and stabilizes the fibre. Wood offers a considerable advantage as compared to synthetic fibres like glass and carbon. Wood is relatively not expensive andbeing derived from renewable resources makes itbiodegradable.

2.4.4.6 *Asbestos fibre*

Asbestos fibres are naturally occurring mineral fibres that are soft and flexible. They are resistant to heat, electricity and corrosion. Pure asbestos act as insulators and can be used in cloth, cement, papers, plastic and other materials.

2.4.4.7 *Organic fibre*

Organic fibres are fibres derived from plants and animal's origin. Examples of these include all plant fibres such as cotton, jute, hemp, kenaf, flax, coir, abaca, wool, silk, periwinkle and coconut (Mitra, 2014). Of the fibres, jute, flax, hemp and sisal are the most and commonly used fibres for polymer composite.

2.5 Periwinkles

Periwinkles are species of small edible sea-snailfood, found in coastal communities of Nigeria, stretching from Calabar in the south east to Badagry in the south-western part of Nigeria (Abdullahi and Sara, 2015). It is housed in v-shaped spiral shells which are waste products after consumption. The shell (Plate V) is used as coarse aggregate for concrete reinforcement.

Plate V: Periwinkle Shell

Periwinkle shell has several layers that are typically made of organic matrix, bonded with calcium carbonate precipitates. It is used in a wide application as fillers in places where there are neither stones nor granite for such purposes of paving water logged area.

The use of periwinkle shell as natural fillers is due to its high specific strength, relatively low density and biodegradability by reducing environmental pollution (Aku *et al.,* 2017). Other common used particulate fillers are calcium carbonate, silica, and carbon black. Most of these materials are not readily available, and so there arises a need to source for potential and suitable reinforcing constituents for polymer matrices.

2.5.1 Uses of periwinkle shell

Periwinkle shells is being used in the coastal areas of Cross River, Delta, Rivers and Bayelsa states as conglomerates in reinforcement of concrete. The shell are used for many purposes such as road construction, in homes soak-away, slabs and pillars, since the cost of periwinkle is ten times cheaper than gravels (Owabor and Iyaomoler, 2013).

Periwinkle shells can be used as a partial replacement for granite in a normal site construction. The additional development of strength in a periwinkle-granite concrete is similar to that of conventional granite concrete (Gumus and Apre, 2016). They have carbon content which when carbonized and activated can serve as absorbent in various applications such as medicine, environmental studies, chemical purification, distilled alcoholic purification and fuel storage.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The major materials for this study are natural rubber obtained from a species of trees known as *Hevea brasiliensis*and activated carbon fibre from periwinkle shell. The non-coagulated lumps of natural rubber were obtained in a liquid form from rubber plantation in Cross River State. While the periwinkle shell is a waste material collected from the coastal area of Creek town in western Calabar.

3:2 Methods

3.2.1 Preparation of periwinkle shell

The collected periwinkle shells were thoroughly washed in fresh water and allowed to dry in the sun for 48 h to drain off the water. It was further dried in a thermostatic drying oven at the Geology Department, University of Calabar at a regulated temperature of 150 ˚C for 24 h to completely remove water residue in the shell (Plate VI). The dried shell was then crushed into smaller sizes by a jaw crusher (Plate VII), and then pulverised (Plate VIII) in a rock pulverizing machine (Plate X), Geology Department, University of Calabar.

Plate VI: Dried Periwinkle Shell

Plate VII: Crush Periwinkle Shell

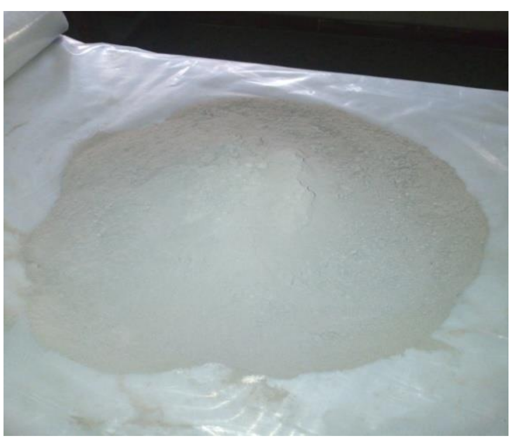

Plate VIII: Pulverize Periwinkle Shell

Plate IX: Sieve Periwinkle Shell

The pulverise particles of periwinkle shell were sieved (Plate IX) using a sieve shaker to pass 200 µm size of fine particle.

Plate X: Rock Pulverizing Machine

3:2:2 XRF analyses

The elemental composition of the sieve periwinkle shell was detected by X-ray Fluorescence (XRF) spectrometer (Plate XI) at Centre for Solid Minerals Research and Development, Kaduna Polytechnic.

The periwinkle sample was placed on the XRF machine and allowed to run for interval of 30 seconds to detect each elemental composition of the sample.

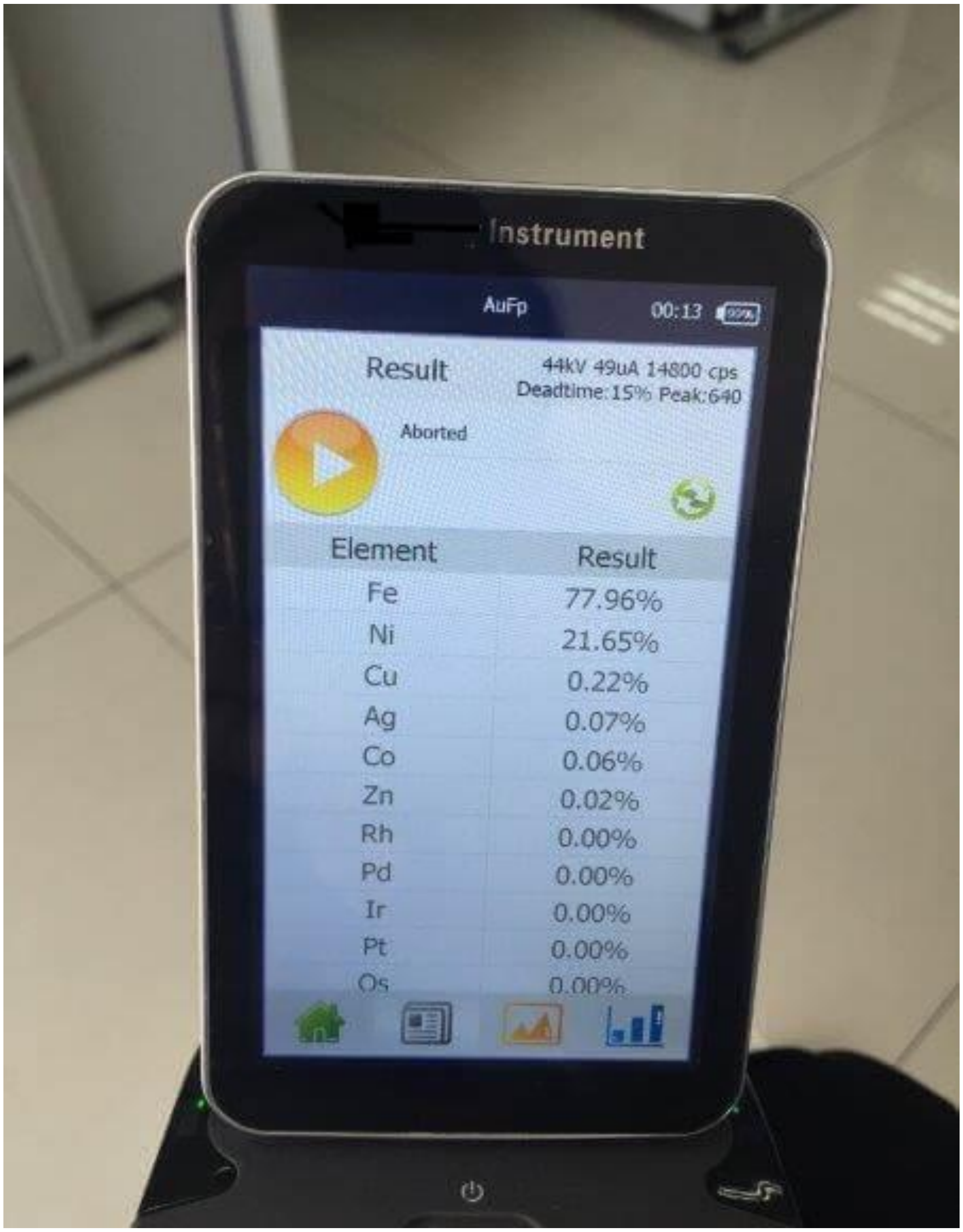

Plate XI: Handheld XRF Machine

3.2.3 Carbonization

420 grams of the sieved periwinkle shell were measured using a digital mass scale and placed in a vecster muffle furnace at a temperature of 300 ˚C for 2 h to have the char particles of the periwinkle shell. It was then cooled at a room temperature of 23 ˚C for activation.

3.2.4 Chemical activation

The carbonized periwinkle shell was then activated using Potassium Hydroxide (KOH) solution (Plate XII) as the oxidizing agent. 100grams of potassium hydroxide (KOH) were added to the 420 g of the carbonized samples of periwinkle shell inside a plastic container and was then mixed thoroughly with a distilled water to dissolve all the (KOH) solution (Owabor and Iyaomoler, 2013). The dissolve solution was placed under Bunsen burner to remove water residue and then transferred to furnace where it was further heated to a temperature of 800 $^\circ C$ for 2 h. The sample was collected and stored in an airtight container after being cooled at a room temperature of 23 $^\circ C$.

Plate XII: Potassium Hydroxide (KOH) **Plate XIII:** Natural Rubber Resin

3.2.5 Forming the composite

The activated carbon fibre obtained from the periwinkle shell was calculated mathematically at a different percentage range of (10 – 30 $^0/_0$) (as shown below) and added differently to 220 g of natural rubber resin and then stirred manually for 20 mins to minimize air or gas entrapment.

1. For 10 $^0/_0$

$\frac{10}{100} \times 220$ g = 22 grams of fibre

2. For 20 %

$\frac{20}{100} \times 220$ g = 44 grams of fibre

3. For 30 %

$\frac{30}{100} \times 220$ g = 66 grams of fibre

Table 3.1: Percentage of Calculation of Carbon Fibre and Natural Rubber Resin.

Calculated Percentage	**Carbon Fibre (g)**	**Natural Rubber Resin (g)**
10	22	220
20	44	220
30	66	220

The mixture was then allowed to cure for 72 h at room temperature, and then prepared for various characterisations according to their specific standard.

3.3 Preparation of Samples

Samples were prepared based on standard for different test analysis. The sample were divided into sample A, B, C and D. Sample A is the natural rubber while sample B, C and D is the reinforced natural rubber with activated carbon fibre at different percentages. The standard for the various test conducted was International Standard Organization (ISO 527) for tensile test, ISO 179 for impact test and American Society for Testing and Materials (ASTM D2240) for hardness test. Each sample was trim to sizes and dimension in regards to the International Organization of Standardization.

Plate XIV: Sample A (Natural Rubber) **Plate XV:**Sample B

(Composite of Carbon Fibre Reinforced Rubber)

3.3.1 Tensile test

The tensile test was done using a universal test machine, TIRA test 2810. The machine was set for test in an initial rate of 5mm/min. Each sample was aligned to a uniform size of 7mm × 17mm based on ISO 527 standard. The end of test criterion was 85 percent with a gauge length of 52mm across all samples. The test parameters are summarised in Table 3.2 as follows:

Table 3.2: Tensile Test Parameters

Test Parameters	
Test:	Universal Tensile/Compression Test
UTM type:	TIRA test 2810

Load cell:	1Kn
Clamping device:	-01-
Test area:	Lower test area
Sample dimensions:	a = 7mm; b = 17mm
Gauge length:	52mm
Test rates:	V0 = 5mm/min; V1 = 10mm/min
Rate switch points:	F0 = 0N
End of test criterions:	85 percent

Plate XVI: Universal Tensile/Compression Test Machine (TIRA test 2810)

3.3.2 Impact test for resilience

The impact test for resilience of all samples was done at a regulated temperature of 23 ˚C. The dimension of each samples were fixed at 4mm ×12.4mm based on ISO 179 standard.

The notched hammer was set at a free swing at an angle degree of 150. The pre-test condition is summarized below in Table 3.3 as follows:

Table 3.3: Pre-test Parameters for Impact Test for Resilience based on ISO 179 Standard

Testing temperature:		23^0C
Standard:		ISO179
Samples dimension		
Thickness (mm):		4.00
Width (mm):		12.40
Equipment type:		Pendulum
Serial number of equipment:		20008380
Serial number of hammer:		0232.060
Nominal values		Test values
Energy (J):	2.000	2.000
Speed (m/s):	2.900	2.885
Angle (degree):		150

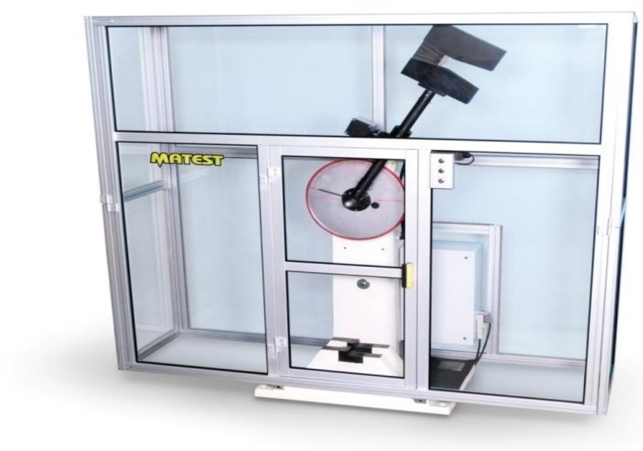

Plate XVII: Pendulum Impact Charpy Tester Motorised

3.3.3 Hardness test

This test was done using Shore D durometer scale to determine the hardness of the samples. The durometer scale has a scale values from 0 to 100 % , the higher the number, the higher the hardness of the materials. Shore D hardness test measures the depth of penetration of an indenter using ASTM D2240 test method. The sample was measured at 8mm radius and placed under the indenter foot of the durometer before pressure was applied. The pressure load used for the Shore D hardness test was 50N, positioned over an area with enough space to allow the pressure of the durometer's foot to easily come in contact with the specimen. Reading was taken at interval of three seconds each at varying test conducted. A total of eight reading was recorded at different intervals indicating four each from sample A and B. The indentation reading all show how flexible or hard each samples are.

Plate XVIII: Zwick Hardness Equipment **Plate XIX:** Shore D Durometer Scale

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Elemental Composition of Periwinkle Shell

The elemental composition of periwinkle shell using X-Ray Fluorescence (XRF) spectra is presented below:

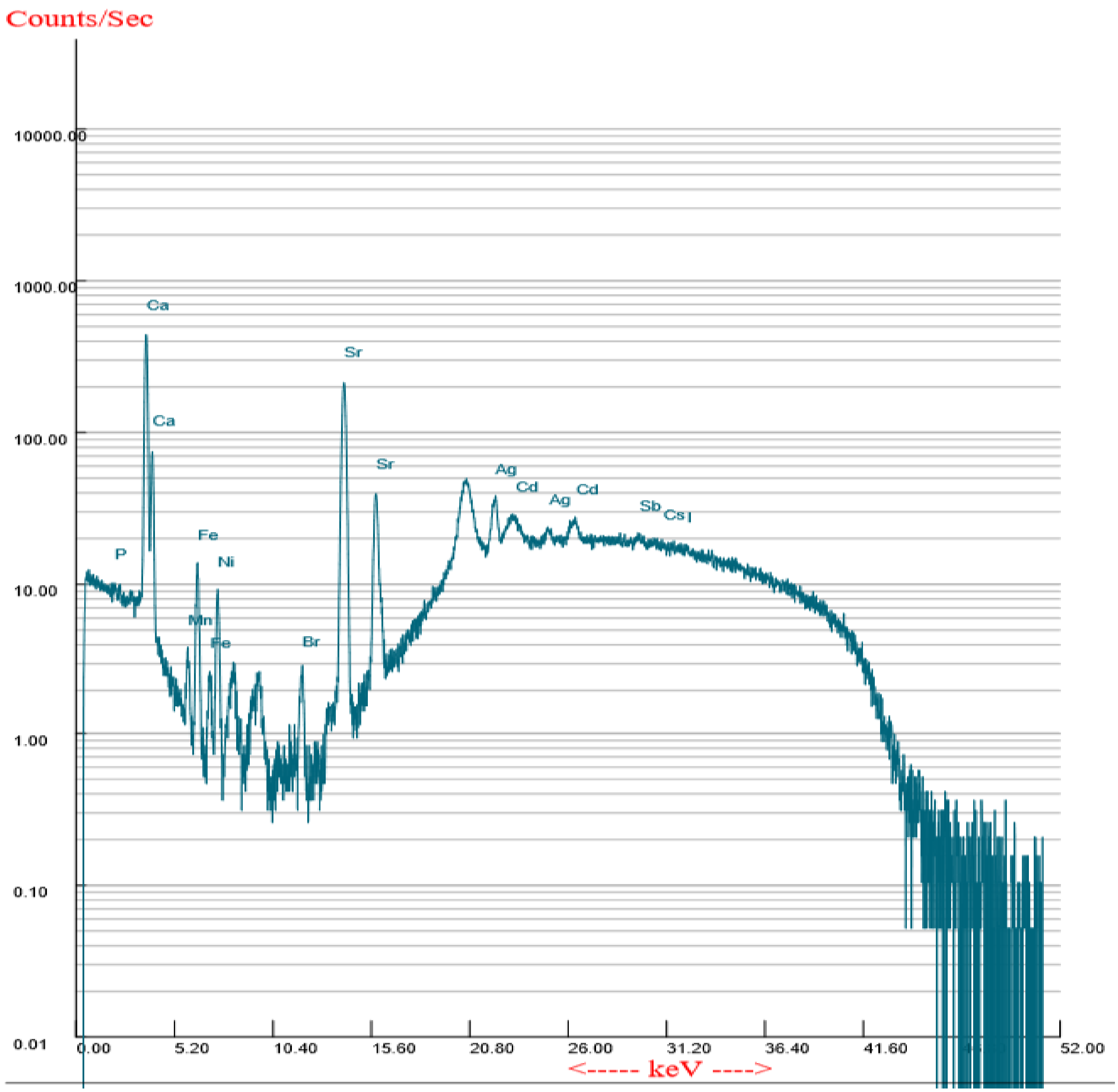

Figure 4.1: XRF Spectra of Periwinkle Shell Powder

Figure 4.1 shows the elemental composition of a periwinkle shell, indicating counts/sec on the vertical axis and KeV (energy) on the horizontal axis. The above figure shows calcium (Ca) as the dominant element with highest peak of 700 -750 counts/sec at a lesser energy of 3 to 4 KeV. Other traces of elements found are phosphorus, ferrous, nickel, manganese, bromine, strontium, cadmium, silica and antimony. Elements such as calcium, ferrous, silica, nickel and aluminium also have high content to give the shell the much needed strength it requires to withstand vibration. The high content of these elements in the shell develops an oxide compound.

4.1.1 Percentage of oxide composition in periwinkle shell

Periwinkle shell also form a compound of oxide with one or two elements, the percentage of each oxide it forms with other element is illustrated below;

Table 4.1: Oxide Composition of Periwinkle Shell Using X-Ray Fluorescence (XRF) Cu-Zn Method

Oxide	**Pulverised Periwinkle (%)**
CuO	0
NiO	0
Fe_2O_3	0.272
Mno	0.066
Cr_2O_3	0
TiO2	0
CaO	56.96
Al_2O_3	0.458
MgO	0
ZnO	0.001
SiO_2	0.931

Table 4.1shows that calcium oxide (CaO) has the highest percentage of concentration in periwinkle shell, with over 56 % of the total oxide composition. This is a clear indication that periwinkle shell is predominantly calcium oxide. This Calcium Oxide is form by the thermal decomposition of periwinkle shell to liberate a molecule of $C0_2$ (carbon dioxide).

4.2 Material Strength Analysis

The composite strength of the carbon fibre reinforced natural rubber are determined in comparison with natural rubber by the various test conducted. The basis of this comparison is because natural rubber is generally used in isolating vibration. The results of these comparisons between the two materials areanalysed as follows;

4.2.1 Tensile strength of natural rubber

Table 4.2: Tensile Test Results for SampleA (Natural Rubber)

Number Of test	**FH N**	**RH** N/mm^2	**AH %**	**dLH mm**	**FB N**	**RB** N/mm^2	**AB %**	**dLB mm**
1	8.19	0.06	75.33	39.20	4.14	0.03	125.80	65.46
2	11.31	0.09	88.53	46.04	5.69	0.05	148.85	77.41
3	8.56	0.07	69.48	36.13	4.35	0.04	113.25	58.89

Table 4.2 is the result for tensile test on natural rubber. The result obtain shows high percentage of deformation of natural rubber up to 88.53 per cent to a minimal load of 11.31 Newton. The result also show that natural rubber is highly elastic in nature (high elasticity), obeying Hooke's law. After being stretch beyond its elastic limit, it eventually lose its elasticity without regaining back its original size and shape.

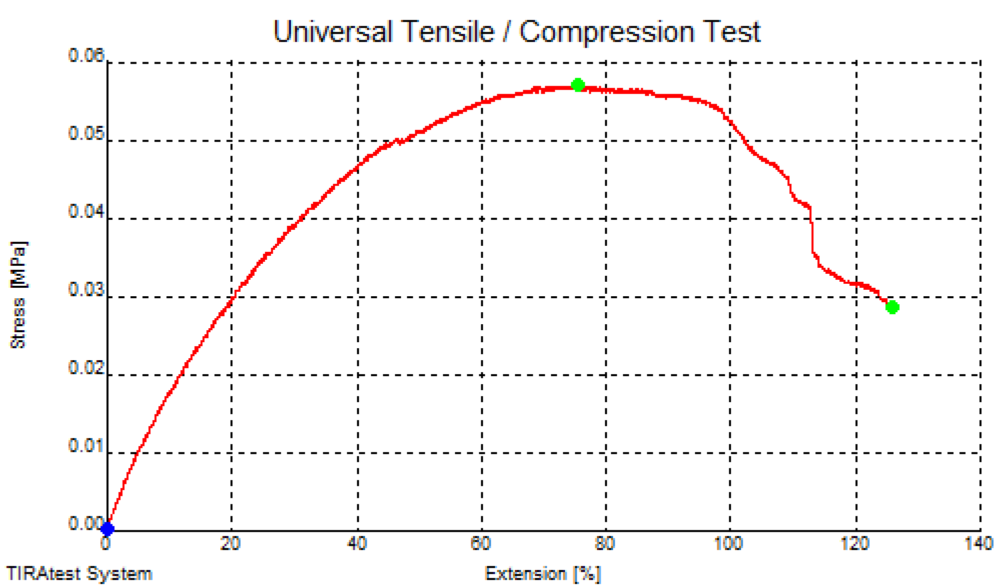

Figure 4.2: Universal Tensile Test of Natural Rubber (Test1)

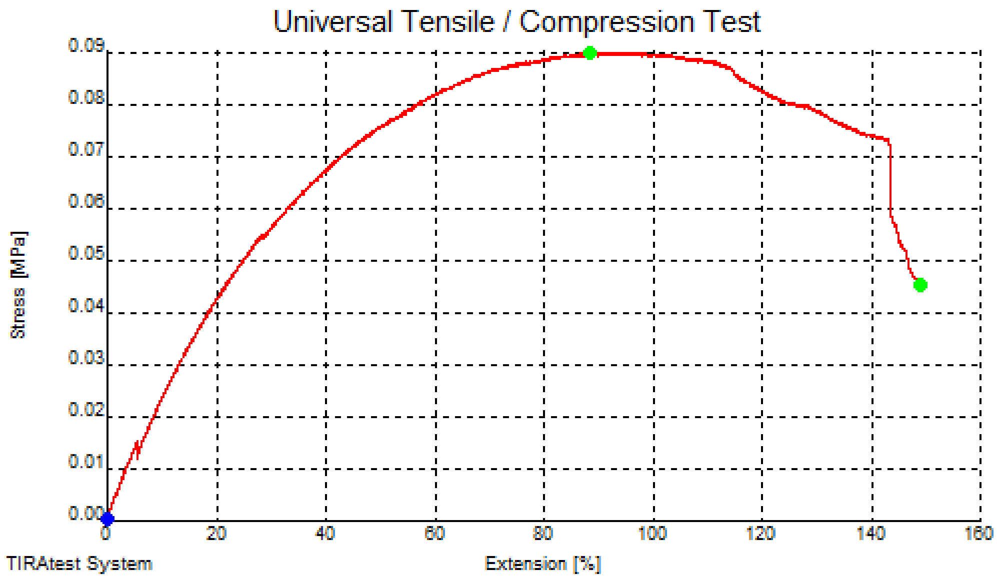

Figure 4.3: Universal Tensile Test of Natural Rubber (Test 2)

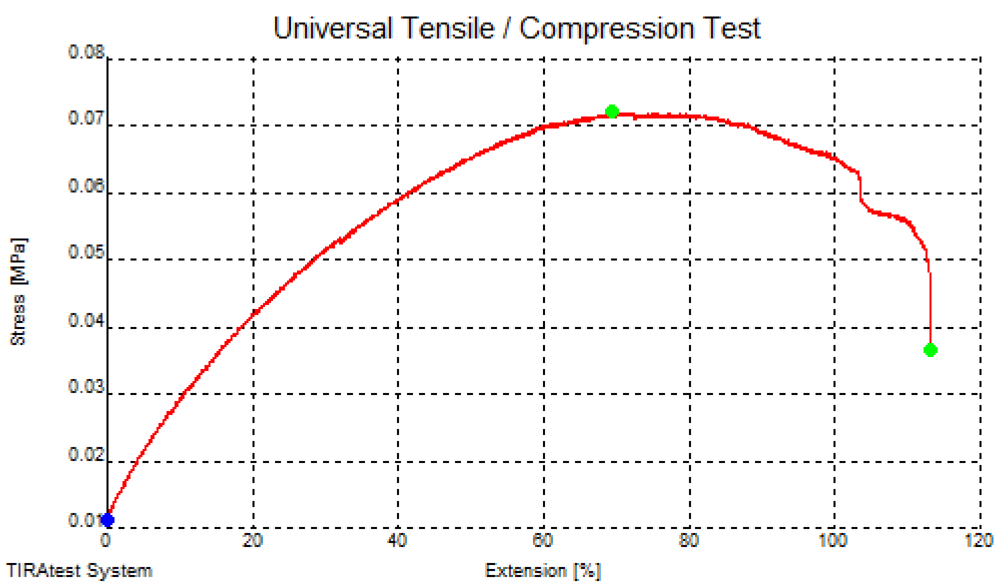

Figure 4.4: Universal Tensile Test of Natural Rubber (Test 3)

Figure 4.2, 4.3 and 4.4 is the stress-strain curve of a tensile test conducted on three samples of natural rubber. The result shows that natural rubber deforms easily at a minimal load, it is flexural and lack the strength to withstand stress. From the above diagram, the highest load it bears before deformation is 0.09 mega Pascal (Figure 4.3). Others are 0.06 and 0.07

mega Pascal respectively (Figure 4.2 and 4.4). Natural rubber has high extension rate, the highest in this category is 75 % strain rate (Figure 4.4). The entire figure shows a linear stress-strain curve up to a certain point where deformation begins, beyond this point, the curve decreases slightly as deformation continues.

4.2.2 Tensile strength of carbon fibre reinforce natural rubber

Table 4.3: Tensile Test Result of Carbon Fibre Reinforced Natural Rubber Composite

Percentage of Reinforcement (%)	**FH** N	**RH** N/mm^2	**AH** %	**dLH** mm	**FB** N	**RB** N/mm^2	**AB** %	**dLB** mm
10	11.38	0.11	5.97	3.58	8.18	0.08	7.17	4.30
20	19.94	0.18	7.52	4.51	0.00	0.00	0.00	0.00
30	22.30	0.21	18.73	11.24	15.65	0.14	32.23	19.64

The result of tensile test of carbon fibre reinforced natural rubber composite (Table 4.3) shows that the addition of carbon fibre in the natural rubber resin reduces the elasticity of natural rubber. The higher the percentage of carbon fibre added to natural rubber resin, the more ductile the materials become. However, the addition of carbon fibre as reinforcement cures the elasticity of natural rubber.

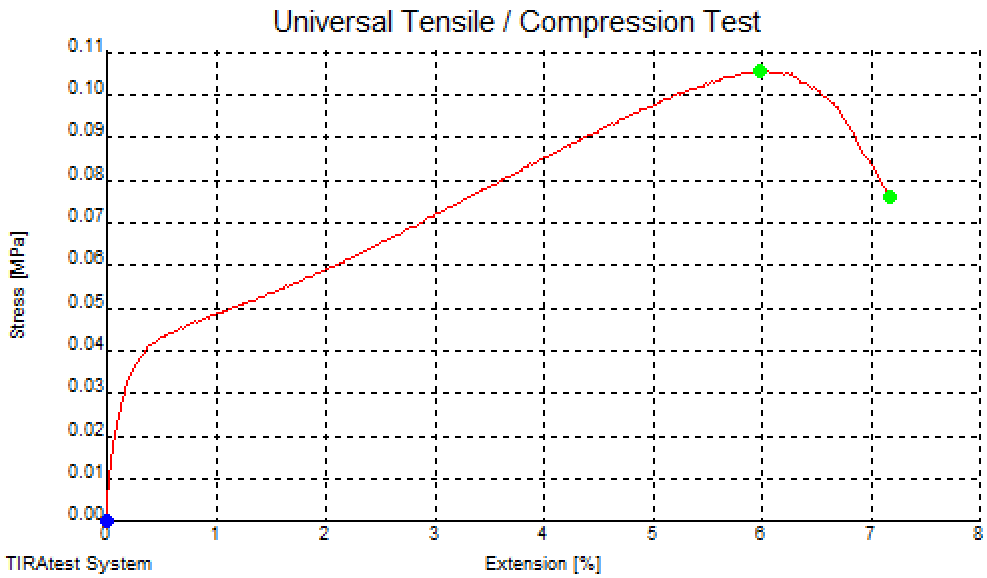

Figure 4.5: Universal Tensile Test of 10 % Carbon Fibre Reinforced

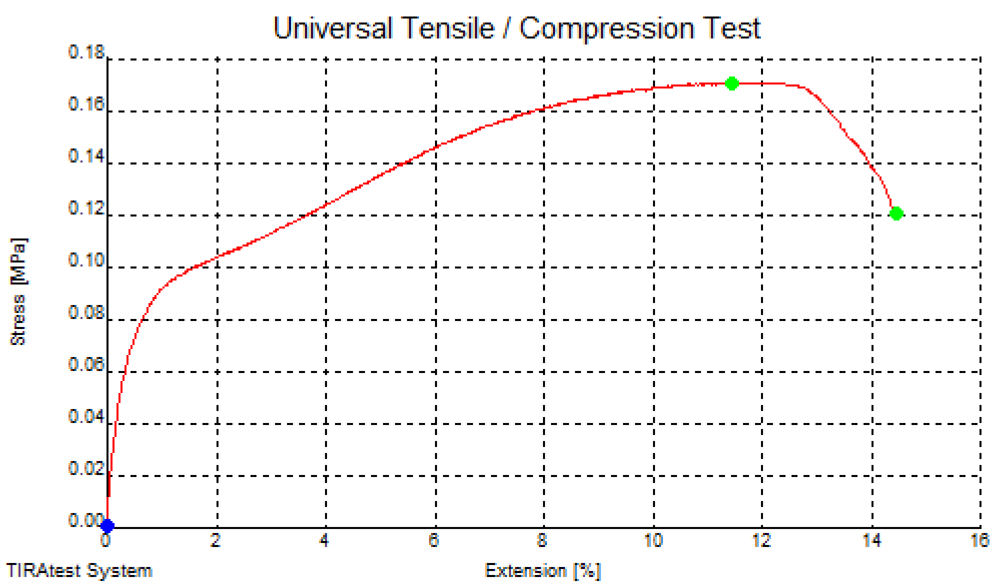

Figure 4.6: Universal Tensile Test of 20 % Carbon Fibre Reinforced

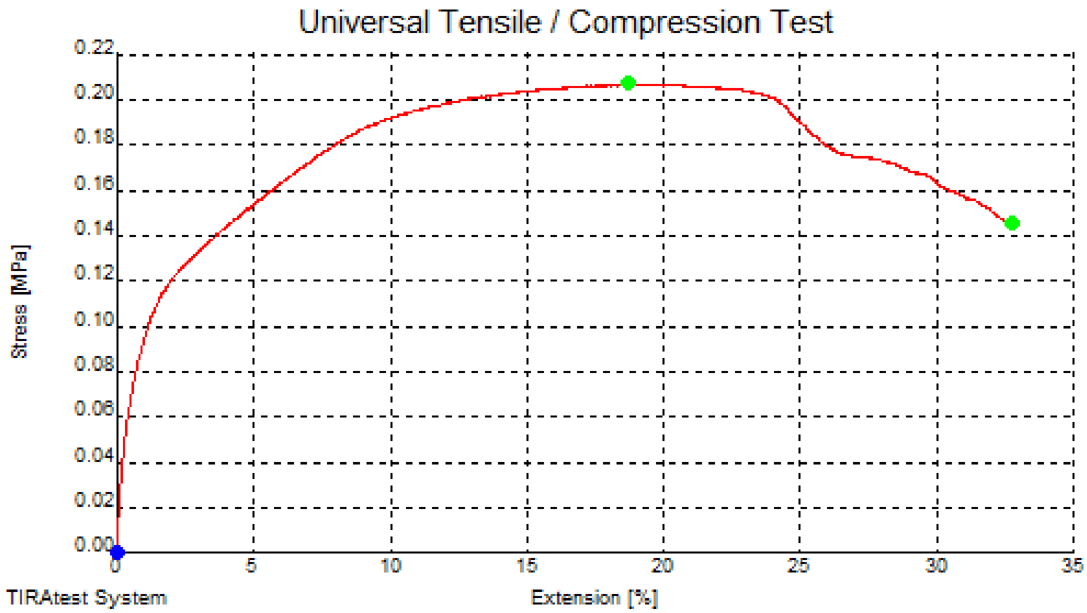

Figure 4.7: Universal Tensile Test of 30 % Carbon Fibre Reinforced

The Figure above (4.5, 4.6 and 4.7) is the stress-strain curve of a tensile strength conducted on the composite of carbon fibre reinforced natural rubber. The result of the test shows an improvement in the material strength. The addition of fibre in the rubber matrix gives the composite the strength it requires to withstand load. The highest load in this category before fracture is 0.20 MPa (Figure 4.7) as compare to 0.09 MPa (Figure 4.3) of natural rubber. The result shows 45 % increase in the hardness of the composite material to that of natural rubber. Carbon fibre is a brittle material; it breaks with no well-defined shape, and hasa low rate of deformation as compare to natural rubber. Lastly, the composite of carbon fibre reinforced natural rubber exhibits low strain rate (Figure 4.5, 4.6 and 4.7), which shows high resistance to thermal expansion to further extend the life of the isolator.

4.2.3 Resilience

Table 4.4: Impact Test Result of Resilience for Natural Rubber

Number Of test	Resilience kJ/m^2	Absorbed Energy %	J
1	39.698	98.5	1.969
2	39.652	98.4	1.967
3	39.617	98.3	1.965
4	39.597	98.2	1.964
Average	39.641	98.4	1.966

The result of resilience for impact test of natural rubber in Table 4.4 shows that natural rubber has a high energy percentage to rebound back to its original shape after a deformation. It has high ability to absorbed impact without any deformation.

Table 4.5: Impact Test Result of Resilience for 10 % Carbon Fibre Reinforced Natural Rubber

Number Of test	Resilience kJ/m^2	Absorbed Energy %	J
1	28.576	72.4	1.068
2	28.728	72.5	1.064
3	28.704	72.0	1.066
4	28.785	72.2	1.062
Average	28.698	72.3	1.065

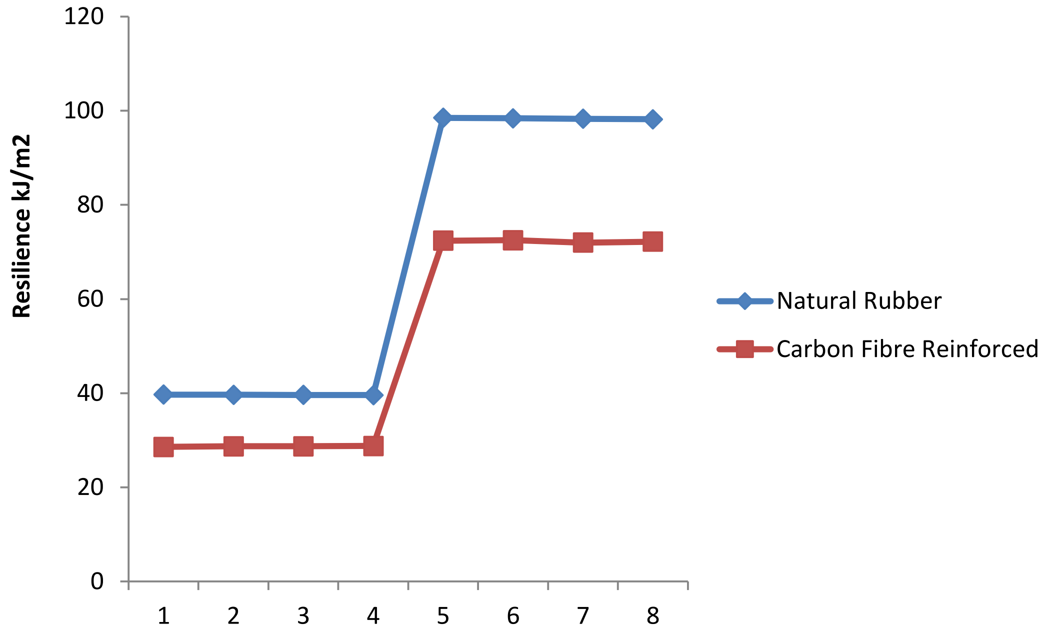

Figure 4.8: Resilience Result on 10 % Carbon Fibre Reinforced Natural Rubber

Table 4.6: Impact Test Result of Resilience for 20 % Carbon Fibre Reinforced Natural Rubber

Number Of test	**Resilience $\mathbf{kJ}/m^2$**	**Absorbed Energy %**	**J**
1	15.627	31.4	0.651
2	15.531	31.1	0.653
3	15.658	31.3	0.650
4	15.625	31.5	0.654
Average	15.610	31.3	0.652

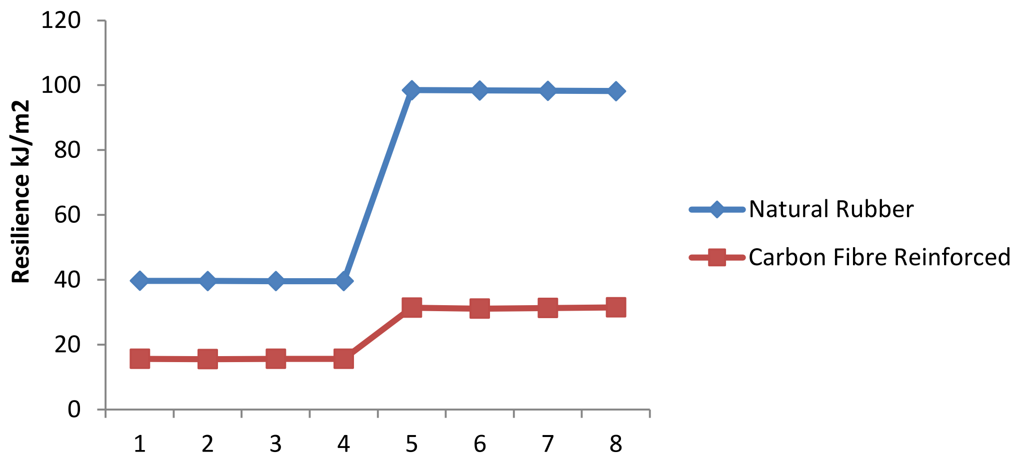

Figure 4.9: Resilience Result on 20 % Carbon Fibre Reinforced Natural Rubber

Table 4.7: Impact Test Result of Resilience for 30 % Carbon Fibre Reinforced Natural Rubber

Number of test	Resilience $\mathbf{kJ}/m^2$	Absorbed %	Energy J
1	7.325	16.5	0.231
2	7.517	16.0	0.230
3	7.468	16.8	0.236
4	7.386	16.1	0.234
Average	7.424	16.4	0.233

Table 4.5, 4.6 and 4.7 shows the 10 %, 20 % and 30 % test for impact of resilience for carbon fibre reinforced natural rubber. The test indicates that carbon fibre is a brittle material, it lack the energy to withstand impact. Carbon fibre breaks easily at high impact test.

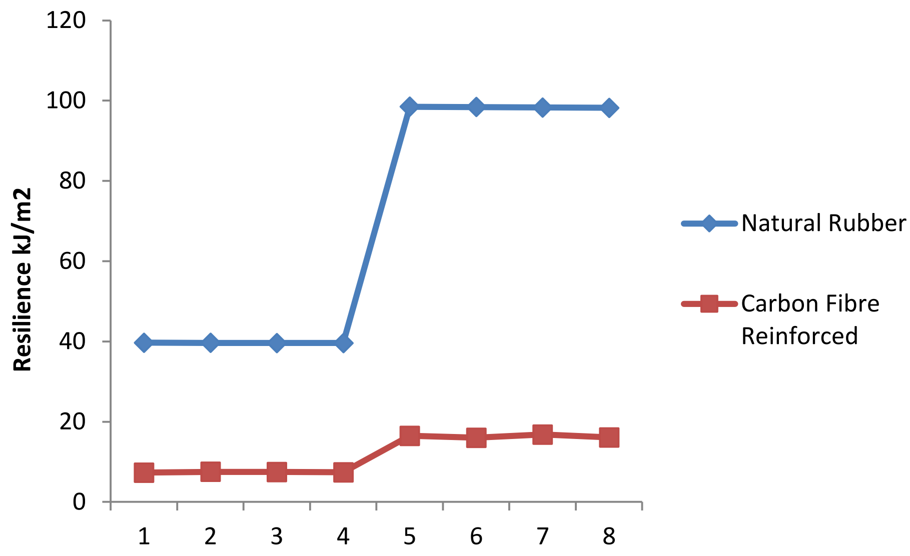

Figure 4.10: Resilience Result on 30 % Carbon Fibre Reinforced Natural Rubber

Figure 4.8, 4.9 and 4.10 shows the resilience of natural rubber and the composite of carbon fibre reinforced natural rubber. From the result it shows that natural rubber has high resilience to impact and can absorbed more energy than carbon fibre. The 30 % carbon fibre reinforcement shows very poor resilience (Figure 4.10) and being a brittle material; it shatters easily on high impact. Its energy absorption during impact is poor. The 10 % fibre reinforcement on the other hand gives the materials the much needed strength to high resilience on impact (toughness) and cannot shatter easily as compared to 30 % fibre reinforcement. Figure 4.9 shows 20 % carbon fibre reinforcement, its energy absorption is poor as compared to 10 % reinforcement and can shatter on high impact test. The results analysed indicates that carbon fibre reinforced natural rubber composite is a brittle material with high strength rate and improved hardness to withstand vibration. The composite of carbon fibre reinforced natural rubber also shows low strain rate to failure that posed high resistance to thermal expansion, this is more sufficient in extending the isolator life for effective use. The result analysed also show 10 % fibre reinforcement as the most effective proportion for high impact test in reducing the brittle nature of the carbon fibre with improved strength of 22 % (Figure 4.5). The percentage of energy absorption in 10 % fibre reinforcement is 72.3 % (Table 4.5) which is higher than both the 20 % and 30 % respectively.

4.2.4 Hardness

Table 4.8: Test of Hardness for Natural Rubber

Number of Test	Reading
1	15
2	18
3	16
4	15
Average	16

Table 4.8 summarize the hardness test conducted on a natural rubber of four different sample of the same size, length and weight. The result of the test shows that natural rubber in its original form is flexural in nature, as compared to natural rubber reinforce composite. The result from the hardness test of natural rubber show low percentage of 15, 16 and 18 respectively.

Table 4.9: Test of Hardness for 10 % Fibre Reinforced Natural Rubber

Number of Test	Reading
1	23
2	26
3	25
4	28
Average	25.5

Table 4.9 summarizes the hardness test of a 10 % carbon fibre addition to a natural rubber resin. The addition of carbon fibre as reinforcement to natural rubber increased the hardness of natural rubber from 15 % to 23 %, 25 per cent, 26 % and 28 % respectively.

Table 4.10: Test of Hardness for 20 % Fibre Reinforced Natural Rubber

Number of Test	Reading
1	38
2	35
3	34
4	37
Average	36

Table 4.10 is the result for 20 per cent hardness test of carbon fibre reinforced natural rubber. The result shows an increased percentage of hardness of natural rubber resin. The result of the test indicates that the higher the percentage of fibre in natural rubber resin, the higher the percentage of hardness of the natural rubber resin.

Table 4.11: Test of Hardness for 30 % Fibre Reinforced Natural Rubber

Number of Test	Reading

1	55
2	51
3	53
4	57
Average	54

The result from table 4.11 shows a high hardness per cent of natural rubber as compared to 10 % and 20 % respectively (Table 4.9 and 4.10). The hardness of the natural rubber is higher in proportion to the high percentage of carbon fibre in the natural rubber matrix.

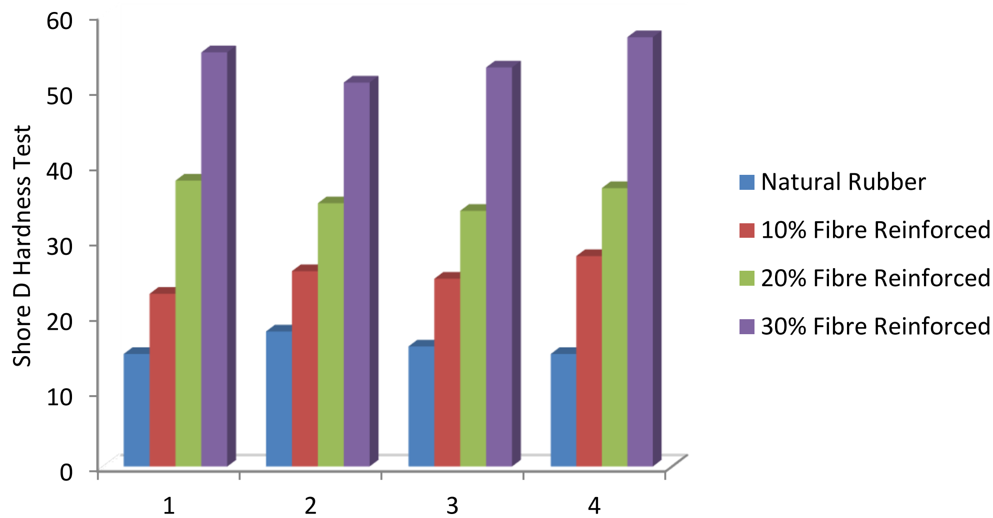

Figure 4.11: Hardness of Natural Rubber/Carbon Fibre Reinforced Natural Rubber Composite

Figure 4.11 shows that, the addition of fibre into the natural rubber matrix cures the flexibility of rubber and improved the material strength of the composite. The hardness of the material depends largely on the reinforced fibre. The figure above shows an increased in the hardness of materials in relation to an increased percentage of reinforced material. The higher the percentage of fibre in the natural rubber matrix, the higher the hardness of the composite. From figure 4.11, the 30 % fibre reinforcement is harder than the 10 % and 20 % respectively.

4.3 Cost Analysis

The cost analysis for the composite; carbon fibre reinforced natural rubber for effective control of vibration is to reduce the high cost of producing a viable and lasting vibration isolator through available materials within the locality. The cost is analysedin Figure 4.12

4.3.1 Raw materials

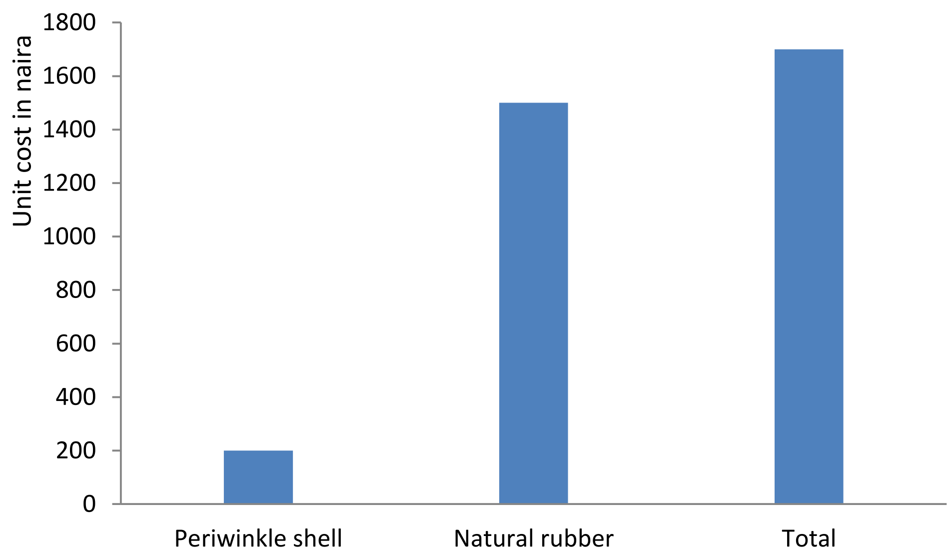

Figure 4.12: Unit cost of raw materials

Figure 4.12 shows the unit cost of raw materials, which indicates the abundant of each material in respect to cost. The low cost of periwinkle shows that it is readily available likewise natural rubber. The cost of manufacturing a composite for a specific purpose is dependent on the method of production, cost and availability of the materials. Generally a high modulus carbon fibre with high stiffness and low strain to failure are produced from natural and synthetic polymeric materials such as polyacrylonitrile (PAN), cellulose, pitch and rayon at a high temperature of 2000 degree Celsius (Lee*et al.*, 2013).

Carbon fibre composites used for a high performance application such as spacecraft, racing cars, jet fighters, racing yachts, oil and gas and exotic sports car are comparatively more expensive than metals because of the cost and performance.

The use of carbon fibre from periwinkle shell in this study is to serve as reinforcing agents to the natural rubber matrix. The carbon fibre by being activated possesses similar properties to the conventional fibre produced from petroleum pitch, PAN and rayon. In addition, the carbon fibre reinforced natural rubber composite has been shown to performed well in terms of their combine strength and hardness by the various test conducted.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Carbon fibre reinforced natural rubber composite was developed and used as a vibration isolator. The developed isolator shows an improvement in the material strength of the composite over that of natural rubber to withstand vibration. This assessment was done in comparison with natural rubber owing to the fact that natural rubber is widely used as a vibration isolator. Natural rubber has high resilience to impact but can easily deform when subjected to high tensile test, it lacks strength to bear the much needed load require to isolate vibration. Carbon fibre was used as a reinforcing agent to further strengthen the composite for vibration isolation. Based on the result of characterisation, it shows that carbon fibre as a reinforcing agent increases the physical, mechanical and the strength of the isolator. The analysed result shows;

i. The characterisation of the periwinkle shell

ii. The mechanical properties (tensile test, impact test for resilience and hardness) of a natural rubber

iii. The developed carbon fibre reinforced natural rubber composite using periwinkle shell

iv. The mechanical properties (tensile strength, resilience and hardness) of the composite.

5.2 Recommendations

Carbon fibre obtained from periwinkle shell shows high contents of calcium oxide at 56.96 % which is evidence of the material strength for vibration absorption. This oxide is also useful in cement production and so more research can focus on this aspect by annexing the abundant calcium contents found in periwinkle shell as:

1. Alternative methods of reducing sulphur dioxide ($S0_2$) emission.
2. Alkaline for water treatment.
3. Animal feeds.
4. Exhaust gas cleaning system.

5.3 Contribution to Knowledge

The models analysed from this study was very useful in the industrial application where vibration isolation becomes important in protecting sensitive machinery parts from wear and tear.

The developed carbon fibre obtained from carbonised periwinkle shell, contains 56 % Calcium Oxide (CaO), 10 % fibre loading with an improved strength of 22 % composite. The vibration isolator was successfully developed to serve as a source of increased in damping ability, aimed at solving the deterioration of natural rubber to withstand solvent, petroleum derivatives and low resistivity to harsh weather condition.

REFERENCES

Abdullahi, I., and Sara, S. G. (2015). Assessment of periwinkle shells ash as composite materials for particle board production. *International Conference on African Development Issues (CU-ICADI) 2015:* Material Technology Track.

Akpa, J. G., Nduka, and C. N. (2018). Kinetics, equilibrium and thermo- dynamics studies of Fe^{3+} ion removal from aqueous solution using periwinkle shell activated carbon. *Advance in Chemical Engineering and Sciences.*8: 49-66.

Aku, S. Y., Yawas, D. S., Madakson, P. B., and Amaren, S. G. (2017). Characterization of periwinkle shell as asbestos- free brake pad materials.*The Pacific Journal of Science and Technology.*

Alshabi, M., Araydah, W. S., Elshatarat, H. L., Othman, M., Younis, M. B., and Gadsden, S. A. (2016). Effects of mechanical vibration on human body. *World Journal of Mechanics* 06(09): 273-304.

Alrashdan, A., Alsumait, A., and Es-said, O. S. (2017). Material selection of an elastomer capable of absorbing vibrations actuated by a 4D movie theatre.*Journal of Failure Analysis and Prevention.*17: 374-384.

Baohui, S., Yuanguan, S., Ping, Z., Angela, P., Cuadro, Jing, Q., Baozhong, S., Bohang, G., Tsu-Wei,C., and Kun, F. (2020). Dynamic capillary driven additive manufacturing of continuous carbon fibre composites. 2(6).Pp 1594-1604. https://doi.org/10.1016/j.matt.2020.04.010.

Barcik, M., Konieczny, J., Kowal, J., and Sapinski, J. (1998). Vibration control of mechanical systems- introduction to problem. Actamontanisticaslovaca 3, 504-509

Bhatt, P., and Goe, A. (2017). Carbon fibers production, properties and potential use. *Material Science Research, India*. 14(1):52-57. https://doi.org/10.13005/msri/140109

Blaettler, K. G. (2018). The manufacturing process. Retrieved from https://sciencing.com

Birajdar, R. S., & Patil, R. V. (2009). Vibration and noise in centrifugal pumps – sources and diagnosis method. *3rd International Conference on Integrity, Reliability and Failure, Porto/Portugal*.20-24.

Chwala, W., Pogwizd, P., Rydzik, and Ambrozy, T. (2021). Effect of vibration massage and passive rest on recovery of muscle strength after short-term exercise. *International Journal of Environmental Research and Public Health*. https://doi/10.3390/ijerph182111680

Craftech Industries Inc. (2019). Types of fiber glass. Retrieved from www.craftechindustries/fiberglass/types.com

Ekeocha, R. J. O. (2018). Vibration in systems.*Journal of Mechanical Engineering Research.* 10(1): 1-6.

Engie, T., Mahmoud, H., and Chulahwat, A. (2015). Hybrid tuned mass damper and isolation floor slab system optimized for vibration control.Journal of Earthquake Engineering.1197-1221.

Essay, U. K. (2018). Carbon fibre reinforced polymer (CFRP) uses and properties. Retrieved from https://www.ukessays.com/essays/chemistry/carbon-fibre-reinforced-polymer-cfrp-5854.php?vref=1

Fabreeka International, Inc. (2016). Vibration and shock control solutions for industries. Retrieved from www.fabreeka.com/product.compliance

Fluke Corporation (2013). Vibration testing equipment; calibration policies. Retrieved from www.fiukecorporation.com

Gates Techzone Corporation (2019). Torsional vibration damper failure signs. Retrieved from www.gatestech-zone.com/problems-diagnosis/accessory-drive-system/tvd-failure-signs

Galindo, C. M., Majumdar, S., and Das, A. (2015). Advances in elastomeric isolators.ABSE-JSCE *Joint Conference on Advance in Bridge Engineering III*. https://doi/10.13140/RG.2.1.4821.128

Geology Department, (2019). University of Calabar , Nigeria. September 18, ASTM D2240, ISO 179, ISO 529

Ginting, E. M., Bukit, N., Muliana., and Frida, E. (2016). Mechanical properties and morphology natural rubber blend with benlonit and carbon black innovation in polymer science and technology. *Material Science and Engineering.* 223(2017). https://doi:10.1088/1757-899x/223/1/012003

Gohari, M., and Tahmasebi, M. (2015). Active off-road seat suspension system using intelligent active force control. *Journal of Low Frequency Noise, Vibration and Active Control.* https://doi.org/10.1260/0263-0923.34.4.475

Guerra, N. B. (2021). Biomedical application of natural rubber latex from the rubber tree heveabrasiliensis.Material Science and Engineering Materials for Biological Application. 126(11) 21-26. https://doi.org/10.1016/j.msec

Gumus, R. H.,and Apre, L. (2016). Kinetic studies of methylene blue adsorption to activated carbon from sea snail shell waste.(Bithynia Tentaculata). International Journal of Advances in Materials Science and Engineering(IJAMSE) 5, (1)

Harris, A. L., Rethberg, L., Dhar, Levinos, N. J., and Dubois, L. H. (1991). Vibrational energy relaxation of a polyatomic adsorbate on a metal surface: methyl thiolate (CH_3S) on Ag (III). *The Journal of Chemical Physics.*94(4). https://doi.org/10.1063/1.4598

Heidarinejad, Z., Dehghani, M. H., Heidari, M., Javedan, G., Ali, I., and Sillanpaa, M. (2020). Methods for preparation and activation of activated carbon: a review. *Environmental Chemistry Letters*. 18(2):1-23. https://doi:10.1007/s10311-019-00955-0

Hopkins, C. (2009). Introduction to designing elastomeric vibration isolators. OPTI 51208. Retrieved from www.slidetodoc.com/introduction-to-designing-elastomeric-vibration-isolators

Innovative Composite Engineering. (2015). Retrieved from www.Innovativecomposite.com/carbonfibermanufacturer

International Carbon Black Association (2019). Uses and production of carbon black. Retrieved from www.carbon-black.org.

Istec International (2018). Common causes of machine vibration. Retrieved from www.istec.com/vibration-analysis

Issurin, V. B. (2005). Vibration and their application in sport; a review.*Journal of sports, Medicine and Physical Fitness; Turin*.45(3).324-326.

ITT Eniding Inc. (2019). Wire rope isolators/vibration isolation. Retrieved from www.enidine.com-wireropeisolator.com

Kasula, S., (2018). The common signs and causes of vibration in aircraft. *Published by aces systems*. www.acessystems.com.blog

Khan, T. A., Gupta, A., Shima, S., Jose, R., Nasir, M., and Kumar, A., (2013). Synthesis and characterization of carbon fibres and their application in wood composites. *Journal of Bioresources*.8(3); 4171-4184.

Kowal, J., and Ornacki, R., (2002). Analysis of properties of actuators used in vibration control systems. *International Carpathian Control Conference,* (ICCC). Malenovice, Czech Republic.

Kumar, R., Hag, M. I., Raina, A., and Anand, A. (2019).Industrial application of natural fibre-reinforced polymer composites – challenges and opportunities. International Journal of Sustainable Engineering.12:3, 212- 220. Doi:10.1080/19397038.2018.15.

Lee, T.,Chee-Heong O., Radzali O., and Fei-Yee Yeoh (2013).Activated carbon fibre- the hybrid of carbon fibre and activated carbon.Advance Material Science. 36: 118 - 136

Lin, C., Ueng, I., and Huang, T. (2000). Siesmic response reduction of irregular building using passive tuned mass dampers.*Journals of Engineering Structures*. 22(5), 513-524.

Lozano, R., Brogliato, B., Ejeland, O., and Maschke, B. (2000). Dissipative systems in dissipative systems analysis and control communications and control engineering springer, London. https://doi.org/10.1260/0263-0923.34.4.475

Mathew, B., Banerjee, P., and Fawaz, M. (2022).A review on vibration analysis of helicopter rotor blade. https://doi:10.22214/ijraset.2022.40533

Matuana, L. M., and Stark, N. M. (2015). Biofiber reinforcement in composite materials. https://doi.org/10.1533/9781782421276.5.648

McGraw-Hill, E. (2020). Engineering vibrations: with applications to structures and machinery.

Mente, P., and Tshwafo, M. (2016). Natural rubber and reclaimed rubber composites – A systematic review. *Polymer Science USSR*. 2(1).Doi:10.4172/2471- 9935.100015

Meyer, H., Frederick, L., Celine, L., and Fabien, G. (2006). Calculation and selective population of vibrational levels with the multi-configuration time-dependent hartree (MCTDH).*Algorithm Chemical Physics*.329(1-3), 179-192.

Minus K. Technology (2019). Vibration isolation case studies. Retrieved from https://www.minusk.com/content/technology
Mistry, H. (2013). Fundamentals of pneumatic engineering.*Create Space e-publication 2013*. ISBN 1-49_372755-3.
Mitra, B. C. (2014). Environment friendly composite materials.*Journal of Bicomposite and Green Composites Defence Science*. 64 (3): 244-261. https://doi:10:14429/dsj.64.7323
Mizuno, T., Takasak, M., Kishita, D., and Hirakawa, K. (2007). Vibration isolation system combining zero power magnetic suspension with spring.*Control Engineering Practice.* 15(2), 187-196.
Musumeci, G. (2017). The use of vibration as physical exercise and therapy.*Journal of Functional Morphology and Kinesiology.* 2(2),17. https://doi.org/10.3390/jfmk2020017
Naucler, P. (2005). Modelling and control of vibration in mechanical structures, division of systems and control, department of information technology, Uppsala University Uppsala, Sweden. https://www.it.uu.se
Osvaldo, C., Hartono, S., and Bhavesh, K. P. (2011).The use of vibration principles to characterize the mechanical properties of biomaterials. https://doi:10.5772/22858
Owabor, C. N., and Iyaomoler, A. I. (2013). Evaluation of the influence of salt treatment on the structure of pyrolyzed periwinkle shell. JASEM ISSN1119-8362. *Journal of Applied Science Environmental Management.*17(2), 321-327.
Proenca, J. M., and Fernando, B. (2005). Case studies of vibrations in structures. *Revue Euro Penne de Genie Civil*, 9: 1-2, 159-186, https://doi:10.1080/17747120.2005.9692749
Rishab Engineering (2021) .Common causes of piping vibration and its effects on piping systems. Retrieved from https://www.rishabheng.com
Rahmani, H., Najafi, S. H., and Ashori, A. (2014). Mechanical performance of epoxy/carbon fibre laminated composites. *Journal of reinforced plastics and composites*. 2014, vol. 33 (8) 733-740. https://doi:10.1177/0731684413518255.jrp.sagepub.com
Rosszainily, I. R. A., Salim, M. A., Mansor, M. R., Akop, M. A., Putra, A., Musthafah, M. T., Hassan, M. Z., Abdulrahman, M. N., and Sadin, M. N. (2016). Effects of carbon black fillers on tensile stress of vulcanized natural rubber compound. *Journal of mechanical engineering and sciences (JMES).*10, (2), 2043-2052, e-ISSN: 2231-8380
Saggini, R., Bellomo, R., and Cosen, L. (2017). Vibration in neurorehabilitation; a narrative review. Medical Research Archives. 5(11). https://doi:10.18103/mra.v5:11.1563
Sandhanshiv, R. D., and Petel, D. M. (2014). Carbon fibre reinforced composite material: review of properties and processing for various metal matrix materials. *Material Science and Engineering.* 8(10). https://doi.10.1088/1757-899x/8101/1/012014
Sanni, E. S., Emetere, M. E., Odigure, J. O., Efenovbokhan, V. E., Agboola, O., and Sadiku, E. R. (2017). Determination of optimum conditions for the production of activated carbon derived from separate varieties of coconut shells. *International Journal of chemical engineering2017*. https://doi.org/10.1155/2017/2801359
Schenkelberg, F. (2020). Failure modes and mechanism.Accendo Reliability. Illuminated reliability engineering knowledge
Sharma, S., Kumar, A., Lai, C., Naushad, M., Shehnaz, Iqbal, J., and Stadler, F. J. (2022).Activated carbon as superadsorbent and sustainable material for diverse applications. Adsorption Science and Technology. https://doi.org/10.1155/2022/4184809

Singh, S., and Kumar, N. (2017). Detection of bearing faults in mechanical systems using stator current monitoring in IEEE transactions on industrial informatics. 13(3): 1341-1349. https://doi:10.1109/T11.2016-2641070.

Sorbothane, (2017). An introduction to shock, impact and the action of viscos-elastic materials.

Torres-Perez, H., A., Kaczmarczy, K. S., & Picton, P. (2016). Active vibration control using mechanical and electrical analogies. J*ournal of physics; conference series,* 721.012013.The University of Northampton, St. Georges Avenue, Northampton, NN26JD, United Kingdom. https://doi:10.1088/1742-6596/721/1/012013

Uchida, A., and Yamamoto, K. T. (2002).Effects of mechanical vibration on seed germination of arabidopsis thaliana (L) heynh. *Plant and cell physiology.* 43(6): 647-651.

Vladimir, N., and Dae-Seung, C. (2012). Approximate natural vibration analysis of rectangular plates with openings using assumed mode method. *International Journal of naval architecture and ocean engineering.* 5(3). https://doi:10.3744/JNADE.2013.5.3.478

Woodford, C. (2022). Rubber. Retrieved from https://www.explainthatstuff.com/rubber.html

Wong, A., Pigueroa, A., and Kalfon, R. (2019). Effects of whole body vibration exercise training on aortic wave reflection and muscle strength in postmenopausal women with prehypertension and hypertension. Journal of human hypertension, 28, 118-122. https://doi.org/10.1038/jhh.2013-59

Wright, J. (2010). Machinery Lubrication Published by Noria Corporation.

Yang, C., Fang, B., Tianzhi, Y., and Wenhu, H. (2008). Study of whole-spacecraft vibration isolators based on reliability method. Chinese Journal of Aeronautics. 22(2009). 153-159. www.elsevier.com/locate/cja

Zoltek Corporation, (2019). Industrial carbon fibre, absolute superiority in strength to weight performance. Retrieved from www.zoltek.com

APPENDIX 1

The Developed Vibration Isolator Based on10 % Fibre Reinforcement

Appendix I: Side View of the Developed lsolator

Appendix II: Top View of the Isolator

Appendix III: Back View

APPENDIX 2

Elemental composition of periwinkle shell using X-Ray Fluorescence (XRF) Cu-Zn method

Element	Pulverized Periwinkle (%)
Mg	< LOD
Al	0.242
Bal	58.139
Si	0.435
P	< LOD
S	0.021
Cl	0.05
K	0.022
Ca	40.686
Ti	< LOD
V	< LOD
Cr	< LOD
Mn	0.051
Fe	0.19
Co	< LOD
Ni	< LOD
Cu	< LOD
Zn	< LOD
As	< LOD
Se	< LOD
Rb	< LOD
Sr	0.123
Zr	< LOD
Nb	< LOD
Mo	< LOD
Pd	< LOD
Ag	< LOD
Cd	< LOD
Sn	< LOD
Sb	0.015
Ba	0.018
W	< LOD
Au	< LOD
Pb	< LOD
Bi	< LOD
TOTAL	99.992

LOD: Low Detection