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Mechanical and Physical Properties of Silicon Carbide, Aluminum Oxide and Epoxy Hybrid Composite: An Overview

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- Evaluation and Characterization of Epoxy Reinforced Coconut Shell/SiC/Al2O3 for Super-capacitor Applications
- Design and fabrication of an artificial rocks from bio-wastes composite for mini carbon capture and sequestration systems

Overview

Mechanical and Physical Properties of Silicon Carbide, Aluminum Oxide, and Epoxy Hybrid Composite: An Overview

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Abstract: Very tellingly, hybrid epoxy based composite are used in various branches of engineering and other solid material systems because of their sustainable and effective mechanical strength, thermal efficiency, resistant to environmental and chemical conditions, cost, low specific gravity for their light weight applications, however, the introduction of hybrid fibers was due to the shortfalls in natural fibers which have lower engineering properties compare to organic or inorganic types of synthetic or manmade type of fibers, however, cost and availability of raw materials via natural fibers are the chief profit of vegetable and animal natural type of fibers over synthetic fibers whereas in other hand, good mechanical strengths, chemical and thermal properties are the advantages of synthetic fiber over natural fibers. Moreover, another material involve in composite application is the use of epoxy matrix which aid in hybridization fine formation to the layers of reinforcing fibers in the form of laminates, another factor that influences the application of composite is the preparation techniques which includes resin transfer-molding , vacuum assisted resin transfer-molding , cold/hot pressing, hand-layup and others. This paper work presented in this material showcases an overview of some natural fibers and synthetic fibers mainly silicon carbide and aluminum oxides which the focus area are the composite manufacturing techniques, physical and mechanical properties using experimental apparatus and their applications.

Key words: Natural fibers, synthetic fibers, silicon carbide, aluminum oxide, epoxy, thermoset, thermoplastic, hybridization, mechanical and physical properties.

1. Introduction

Minimal cost and quality performance have been the desire of every manufacturer both in engineering or otherwise which however composite material have made vast effective applications especially on the light weight, material availability and mass production, interestingly, composite materials penetrated in the evolution of engineering products and material development such as in mechanical systems like pressure vessel (1), hydraulic cylinder (2), turbine blades (3), automobile parts (4-6), aerospace systems like in aircraft wing box (7), airspace ablatives (8), aircraft brakes (9) marine engineering systems like marine propeller (10), ship vessel (11) and in structural systems like fire safety proof (12), bridges/ tunnels (13-14),earthquake resistance columns (15). Composite material which are made up natural or synthetic fibers have different or relatively sources such as natural fibers extracted from bio-wastes or biodegradables which causes environmental pollution attributing to global warming and climate change however characterizes in term of minimal material cost, minimum density, more specific mechanical strength and stiffness value, minimum wear rate to the processing device during manufacturing, always available due to its environmental activities on waste, renewability, sustainability and environmental friendly (16-19). However, despite natural fiber characteristics mostly on ecological friendly, economic benefits, good physical and mechanical qualities they still have some shortcomings including incompatible with hydrophobic polymer compounds, cohesive and destructible properties due to environmental and soil conditions, inflammable, low chemical/mechanical properties, poor resistivity to moisture/thermal degradation at high processing temperature (20-22).

Table 1. Characteristics and Researched Applications of Natural-Fibers

Natural fiber	Properties	Applications	Ref. no.

Bamboo	Density (g/cm^3) = 1.25 Moisture content (%) = 9 Young modulus in GPa=11-17 Tensile strength in MPa=290	Automobile bumper, beams, impact, flexural, tensile mechanical strength improvement	(23-24)
Periwinkle shell	Density = 1.01 Hardness values (HRB)=116.7 Compressive st.(N/mm^2)=147 Coefficient Friction=0.35-0.41	Wear material improvement such as brake pad, medical applications, mechanical strength improvement	(25-26)
Corncob	Density = 0.8 – 1.2 Tensile mod. N/mm^2= 500.2 Flexural mod. N/mm^2=11000 Moisture content = 6.38	Thermal insulation material, light weight concrete purposes, and concrete masonry unit	(27)
Sisal	Density= 1.3 – 1.4 Tensile strength = 390-450 Young's modulus = 12-14 Elongation (%) = 2.3-2.5 Moisture content = 11	Automotive interiors and upholstery in furniture	(28-30)
Coconut shell	Density= 1.29 Tensile strength=306 Mod. of elasticity =856 Elongation = 25.44	Seats parts such as bottoms, head restraints and wooden cushion design, interior trim and seat, seat surfaces/ backrests making.	(31-32)
Palm tree fiber (kernel)	Density = 1.65 Hardness value = 92.0 Compressive strength =103.5 Coefficient friction=0.440	Brake pads, furniture, surface finishing, mechanical properties improvements, light weight applications, water absorption products.	(33-34)

The limited mechanical properties of natural fiber and technology improvement requirement attracted the hybridization and reinforcement of natural fiber with synthetic fibers, synthetic composites are of two types organic and inorganic, organic synthetic involving carbon which are known as manmade synthetic due to their natural fiber related characteristics which includes flexibility, dielectric, ductility and process-ability, organic synthetic includes polymers like polyethylene, aromatic polyester, aramid etc, whereas inorganic synthetics involves the presence of oxygen, and its characteristics involves rigidity and thermal stability which glass, carbon, boron, silicon carbide, aluminum oxide etc are types of it kind. Moreover, the properties of synthetic fiber which made it superior over natural fiber includes electrical insulator property, high thermal conductivity, insoluble in water, resistance to weathering, stiffness, strength, interfacial adhesion and recyclability which is effective in both conventional and current engineering applications (35-37).

2. Silicon carbide as a synthetic fiber have good properties of a synthetic material which have proven by many researchers to be effective in solid material and productions due to their relatively good interfacial fiber-matrix adhesion and high endurance strength in automobile, aerospace, structural marine and other solid systems (38)

Silicon carbide

(https://images.app.goo.gl/LHLguBY47AFbGX9)

Table 2. Properties and Applications of Silicon Carbide

Properties	Applications	Ref. no.
Density in g/cm^3= 3.10 White color in nature Elastic value of modulus in Gpa= 410 Flexural strength in Mpa = 550 Fracture toughness in Mpa= 4.61 Hardness in kg/mm^2=2800 Poisson's ratio = 0.142 Max. temperature= 1650 ^{0}C Compressive strength in Mpa= 3900	Jet engines Thermal protection for space-craft and rockets Automotive parts such as brake pad systems Etc	(39-41)

3. Aluminum oxide synthetic fiber are mostly used when strength and durability are required, it is essential in sunscreen applications due to their white solid nature, moreover, they form good mechanical properties when used as a reinforcement in composite which is vast in research in engineering systems. (42)

Aluminum oxide

(https://images.app.goo.gl/dmnsWH3UaSDfCxHQ9)

Table 3. Properties and Applications of Aluminum Oxide

Properties	Applications	Ref. no.
Density (g/cm^3) = 3.89 Color = white Flexural strength (Mpa) = 330 Elastic value modulus in Gpa= 300 Fracture toughness in Mpa=3.50 Hardness (kg/mm^2) = 2100	Mechanical strength improvement Water absorbent Aerospace parts Structural systems Machine tools Refractory	(43-44)

Compressive strength in Mpa=2100 Max. temperature= 1700^0C Poisson’s ratio =0.21	Insulator etc.	

4. Hybridization of composites came to practice due to different or relatively characteristics of fibers both natural or synthetic thereby a particular fiber having more strength or properties than other, also the effect was fascinated due to increase in need of engineering material development with good strength which attracted the use of more than two reinforcing fibers in one composite matrix including the use of ceramics, steel or polymer defined as combination of more than one fillers (either synthetic or natural) into a common matrix (45). The process of hybrid fibers exhibits good characteristics such as reduced cost, good modulus and high strength, resistance to corrosion and thermal stability (46).

5. Epoxy as a type of thermoset resin that is used for composite adhesion thereby the presence of epoxy matrix as a bonding agent mainly leads to an improvement in the hybridization, specifically, composite fibers are used when reduced to tiny size including recent Nano size applications, so in other to bond the tiny fibers together strong epoxy material which are made of hardener is used, moreover, when selecting epoxy for composite material bonding some factors like chemical resistivity, cure time, sag, load time, gel time and nozzle time are considered due to the fact all fibers are not the same in characteristics, form, and properties. Resin materials are generally classified as thermoplastic and thermoset, thermoplastic generally plastic in form which softens when heated and hardens when cooled are essential in composite application and the essential advantage of thermoplastic over thermoset is due to its moldability. Thermoset resin being a polymer material that becomes permanently hard or solidify when heated which because of this property it is often used in advanced composite application such as in wind turbine in electric power generations, aircrafts and automobiles due to its mechanical strength properties, type of thermoset resins includes epoxy and they are of three type pure, polyester epoxy and acrylate epoxy (47-49).

Table 4. Epoxy matrix composite materials and preparation techniques

Matrix	**Reinforcement**	**Processing technique**	**Ref**
Epoxy resin	Kenaf fiber and palm ash (Nano size)	Compression molding	(50)
Epoxy resin	Oil Nano palm filler and kenaf fiber	Hand layups	(51)
Epoxy	Coconut coir/glass fiber	Hand layups	(52)
Epoxy	Kenaf/glass/carbon nanotubes	Hand layups	(53)
Epoxy	Jute & bamboo & E-glass (all weaved)	Hand layups	(54)
Epoxy	Flax/basalt	Vacuum bagging technique	(55)
Epoxy	Carbon reinforced with flax	Vacuum bag and in an autoclave	(56)
Epoxy	Jute fiber reinforced with glass fiber (woven)	Brushing/roller	(57)
Epoxy	Woven kenaf reinforced	(RTI) Resin transfer	(58)

	with Silicon and silica	infusion	
(Reformed Epoxy) Vinyl ester	Basal reinforced with Flax	Epoxy-resin infusion than by heat and autoclave	(59)
(Reformed epoxy)Vinyl-ester resin	Basalt reinforced with flax	Vacuum-infusion	(60)

6. Physical and Mechanical Properties of cross-breed Composite on *Natural fibers*/SILICON CARBIDE

The characteristics properties of natural or degradable fibers are more chosen compared to the silicon carbide and aluminum oxide fibers used in this article because it have been observed that few contributions likely towards significant differences between cost and stiffness of the natural fibers (61). However, the benefits of high strength, good impact behavior and better modulus which are of importance on applications were compressive strength couple with light weight is really needed (62). This part on this review denotes compositions, characteristics, techniques, experiments, results and applications of some natural fibers and silicon carbide hybrids.

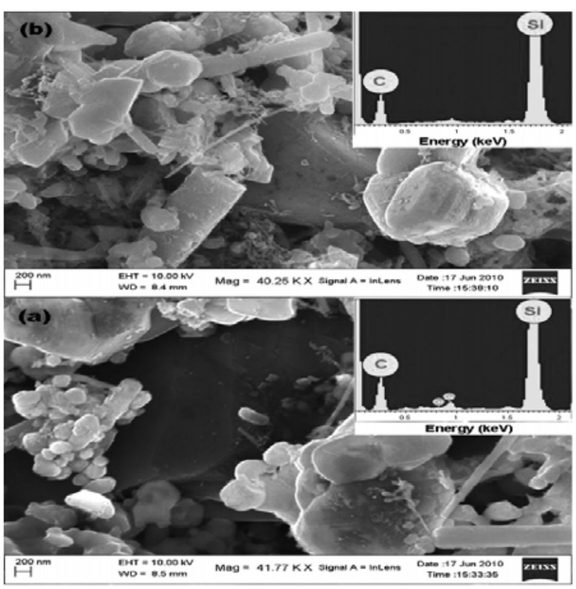
6.1 Silicon carbide/Bamboo fiber

Bamboo as a natural fiber are known as one of the strongest fiber used mostly in composite application in automotive, structural and other related systems, which however, their reinforcement with silicon carbide fiber generates composites with good damping and improved strength. Sandhyarani (63) traced the mechanical properties of silicon carbide fiber layer and bamboo-epoxy composite, proving the experiment suitable for structural application, the composites were subjected to flexural, hardness, tensile test by different weight percentage of silicon carbide but constant 45% weight of bamboo fiber. However, 15% of silicon carbide exhibited hardness of 57Hv, at 10% of silicon carbide tensile strength of 13.44Mpa was observed and 5wt% SiC had flexural strength 29.53Mpa, which are the maximum mechanical strength resulting the possible high strength and rigidity application such structural building (beams, bridges).

Praveenkumara et al (64) Studied using hand layup preparation method on the engineering properties of bamboo/carbon fiber and silicon carbide as a particulates including K-6 hardener and L-5 thermoset epoxy resin as the reinforcement matrix, tensile, flexural, hardness and water absorption tests was conducted, the result when silicon carbide was added indicated improved micro-hardness in the composite even possessed break load of 9423 N, tensile modulus of 1912.39 $N/mm^2$and ultimate tensile strength of 165.32 N/mm^2, generally from the result, the experimented composite could be suitable engineering high strength products such as in mechanical and structural systems.

Asif et al. (65) prepared and compared the characterization and development of hybrid composite using bamboo, silicon oxide and basalt, which was investigated of their characteristics such as hardness, flexural, impact and specific gravity, interestingly, 30wt% of silicon carbide had the highest mechanical strength composition on ASTM D-638 standard universal testing machine for mechanical strength analysis which indicated 146.56 Mpa and 5836 Mpa of peak tensile strength and young modulus respectively, moreover, flexural value of 351.56 Mpa and 11652.36 Mpa of highest bending value at highest load and young's modulus respectively, also on the same universal machine and same percentage of silicon carbide, 168.44 Kj/m^2 impact strength and 82 RHN hardness strength was observed. Finally, the specific gravity test conducted using general formula and $1.45 g/cm^3$was achieved which, the experiment was prepared using traditional technique of hand layup which from the results the composition can be used in light weight and high strength applications such as in aerospace, automobile, structural bridges and beams and material strength improvements.

Sankar et al. (66) quantified the mechanical properties of reinforced composite of bamboo and silicon carbide based on thermal conductivity of plasma reactor, through a single step manufacturing process, which the hybrid composite were subjected to power source of 50V and 300 amp introduced to produce to generate the required plasma which was further subjected to high temperature of 700^0C in a muffle furnace for about two hours, furthermore, the composites was immersed in an 40% HF and HCl acid to remove impurities such as silica and mineral oxides, which resulted to green color pigment. (DTA) Differential-thermal-analysis and (TGA) Thermo-gravimetric-analysis spectrum for composite weight analysis after subjecting to temperature, X-ray test with diffractometer machine was also conducted on the experiment to determine the structural changes and phase identification, (SEM) Scanning-electron-microscope was implemented in the test to determine the morphology mixture and finally, (EDX) energy dispersive X-ray and the final apparatus used is (FESEM) Field-emission-scanning-electron-microscope to observe the final elements present in the composite after the whole experiments, which the FESEM showed beta-Silicon carbide made up of lattice parameter (a = 4.295A) which is closed to the value accepted lattice parameter of 4.347 A, moreover, SEM and XPS test conducted also confirmed the formation of beta-SiC Phase in the final nature of the composite which can be used in engineering applications such as grinding, as a filler particle in composites and polishing agent.

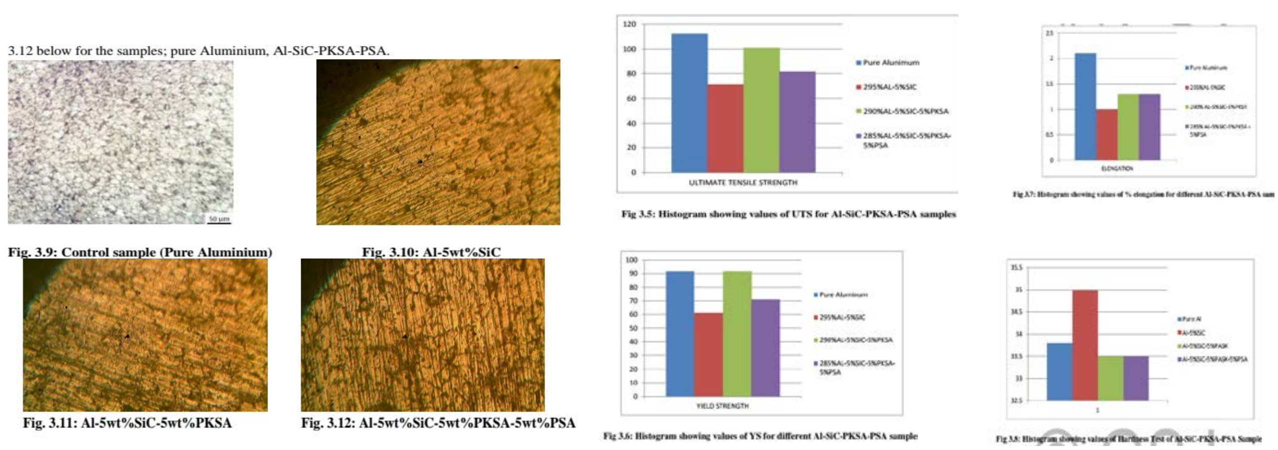


Adeolu et al. (67) investigated the presence of silicon in structural composition of bamboo fiber for carbothermal applications such as chemical vapor deposition, microwave plasma discharge, plasma and Acheson which requires excess energy processes which silicon carbide are used as one of the materials for these machine due to its high thermal strength. The experiment was conducted by subjecting the composites to high temperature ranging from 900-1900 ^{0}C in a muffle furnace, then for active phases of the Silica-based refractory elements was investigated using (FTIR) Fourier-transform-infrared-spectroscopy, also the features amorphous and crystalline were investigated using SEM apparatus and finally X-ray diffractometer (XRD) was introduced to investigate the morphologicalfeatures existing in the bamboo. The results from the analysis show some functional groups of silicon particulates in the bamboo which includes Si-c and Si-O-Si groups which the yield of Silicon Carbide poly types present is about 5-10 wt% and other percentage is silica.

6.2 Silicon carbide/Periwinkle shell fiber

Interestingly, periwinkle shell possessing relatively high mechanical strengths such coefficient of friction, compressive strength, water absorption, hardness, tensile, thermal conductivity and others, which are developed due to compounds of SiO_2, Fe_2O_3 and CaO in its chemical composition which is comparable with silicon carbide. In the sense the both serves almost the same purpose although different in some areas like sources which most times the research are mostly comparing.

Iyasele (87) investigated the mechanical strength of pure solid aluminum as the matrix reinforced with periwinkle shell ash, palm kernel shell and silicon carbide using, thereby the laminates were developed using stir casting technique after melting the solid aluminum, tensile strength, hardness and microstructure tests of the composition were carried out. The results after confidential tests using good apparatus indicted an even formation in phases of the reinforced fibers in the melted pure aluminum, the hardness property of the aluminum increased as the some percentage weight of periwinkle shell and silicon carbide was added, the ductility of aluminum oxide increases as periwinkle shell and palm kernel was added and the brittleness increases as silicon carbide was added, which archived the aim ofusing bio wastes as an material mechanical improvement applicable in automobile systems.



6.3 Silicon carbide/Corncob fiber

Okoronkwo et al. (88) observed how important silica is in the engineering applications including solar panels renewable energy, which was observed to be present in microstructure of some natural fibers like corncob in nano size using sol-gel method which involved the use of special

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apparatus to investigate the nature of the silica inside a specimen of corncob such XRD testing apparatus which indicates the forms (amorphous) nature of extracted silica in the corncob, the chemical composition of corncob specimen in the experiment was done using XRF, silica phase in the corncob ash was investigated and confirmed using (FTIR) Fourier transform infrared which the group of the silica included siloxane and silanol, SEM/dispersive-X-ray-spectroscopy was used in experiment which verified the grain boundaries that formed the microstructure of the corncob and analysis on the SEM indicated that 44nm-98nm sizes of the microstructural particles in diameter of 55nm and finally the EDS result shows the presence of silicon oxide (SiO_2) in the corncob specimen**.**

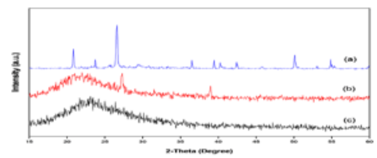
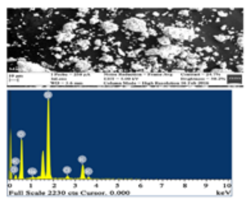


Figure 3. XRD pattern of (a) Corn con ash; (b) extracted silica and (c) Nano silica.



(a) (b)

Figure 4. SEM image of (a) Nano-structured silica and (b) EDS spectrum.

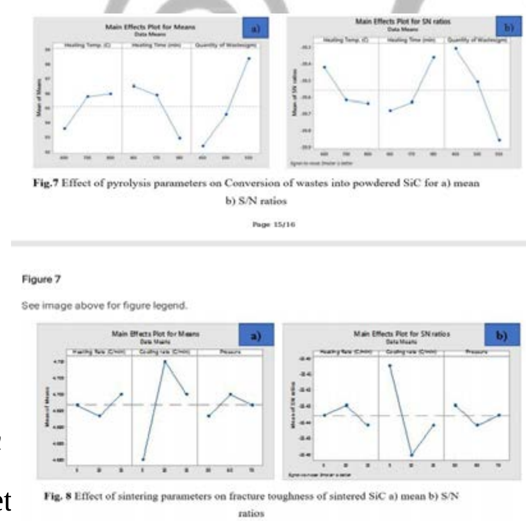
Chandee (89) also did a related job which he investigated the high thermal conductivity of Si-SiC also called self-propagating synthesis (SHS) which was extracted from corncob ash, carbon element and magnesium in an effective molar ratio of 2:1:4 respectively, the experiment was conducted using SEM and EDS apparatus for the chemical and microstructure of the composition, also the XRD analysis indicated the formation of the silica groups in phases, moreover, the high-thermal synthesis or rather the thermodynamic and formation of the extracted Si-Sic was investigated using ignition source of Fe_2O_3 and Al ignited through electric current by a tungsten wire for the in-situ SHS reaction under a stable argon environment, which was further leached to chemical composition in two steps reactions with $HCl:CH_3COOH$ and $HF:H_2O$ solutions at a particular time. The analysis proves not only the presence of silicon oxide in a bio waste but also indicated some percentage of thermal strength affordable for high strength application in engineering components.

Alfonso et al. (90) investigated the effectiveness of the extracted silicon oxide and activated carbon from corncob in electricity application such as in supercapacitor for electric energy storage. The process involved sol-gel and chemical activation techniques accordingly, thereby the composition of SiC activated carbon and magnesium powder was subjected to 600^0C then in the process the SiC acted as the catalyst, the SiC were further doped in an aluminum oxide in varying amount through solvothermal synthesis p-type semiconductor, the un-doped SiCand corncob fiber were subjected to SEM-EDX and FTIR analyses to determine the microstructure compositions and properties of the specimenswhich the following were observed

- P-doped and un-doped SiC indicated presence of Si-C laminates from the corncob when analyzed in SEM-EDX and FTIR analyzer

- That the p-doped SiC exhibited more energy in apparent region than un-doped
- The even formation of SiC when combined with Al was shown in FTIR
- Higher absorbance was observed in p-doped SiC than un-doped using UV-spectroscopy
- The doped SiC when doped in aluminum increases its absorption making the composition more suitable in photovoltaic application such as in solar because of the characteristic of decrease in band-up and increase in conductivity estimated value of 1.57-1.58 eV which can also be applicable to p-junction of solar cells.

Amit et al (91) combined bio-wastes (peanut shells, rice husks, sugar cane extract and corncob) to form Silicon carbide through some good approach including *characterization of synthesized SiC* present in waste which was conducted using SEM and XRD apparatus which shows the formation of different phases of SiC, the *pyrolysis analysis* which involved subjecting the wastes to 450-500g to high temperature of 600-800^{0}C at heating period of about 160-180 minutes so as to covert the wastes into powder SiC, the *sintering* a*nalysi*s which involved heating, cooling and pressure of the specimens inside a chamber which the sintering was done to archive fracture toughness of the extracted SiC from the wastes and the maximum fracture toughness was observed at 150C/min heating, cooling rate at 100/C and pressure rate of 60MPa, finally the *validation test* which was conducted using Taguchi for optimization values and the experiment indicated 88.4322g and 4.32MPa optimum powdered SiC fracture toughness value, furthermore, the Taguchi technique used in the experiment not only indicated a material for automotive application such as in bearings and water pump seals but also a cost reduction material source of extracting cleaner SiC.



6.4 Silicon

Kamaraj et cteristics of hybrid composition of Silicon carbide and sisal fiber reinforced in epoxy resin as matrix, the composites was prepared using hand layup method and bending/tensile/impact strengths tests was conducted using ASTM apparatus for a standard test after samples were developed in different fiber weights. However, the result from the analysis indicated that percentage of SiC increases as well as the elongation and tensile properties of the specimen increases but reduces the ultimate tensile strength when the SiC increases in weight, whereas the flexural strength increases when the SiC increases and finally the maximum compressive strength was optimum with an increase on SiC weight%.

Malla et al. (93) envisaged on the thermal/mechanical characteristics on sisal fiber when reinforced with silicon carbide, using polyester type of resin as the binder and hand layup composite preparation technique by 0%, 5% and 10% of silicon carbide. The mechanical tests conducted using ASTM D638-89 standard test apparatus includes tensile test which 10% SiC indicated higher (72.5MPa) than other samples, impact test conducted also showed highest impact strength of 14.25 J/m^2 at 10% weight of SiC and finally thermal experiments was conducted which includes thermal conductivity using ASTM E1530 when 500^0C was used in the experiment and the 10% SiC sample indicated highest thermal conductivity of about 0.38 W/mk, specific heat, thermal degradation and thermal diffusivity which was conducted using TGA testing apparatus, flash method and differential scanning calorimeter (DSC), indicated highest value at the 10% of added SiC fiber which from the result the reinforced composite can be used in high thermal applications in engineering tools.

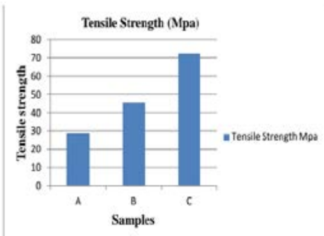


Figure 2. variation of tensile strength of 0%, 5%, 10% SiC in sisal fiber composite

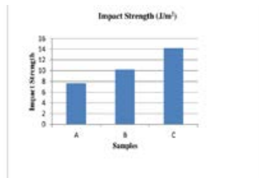


Figure 3. variation of impact strength of 0%, 5%, 10% SiC in sisal fiber composite

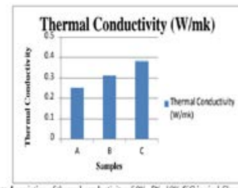


Figure 4. variation of thermal conductivity of 0%, 5%, 10% SiC in sisal fiber composite

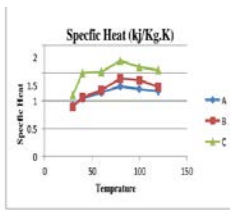


Figure 5. variation of specific heat of 0%, 5%, 10% SiC in sisal fiber composite with temperature

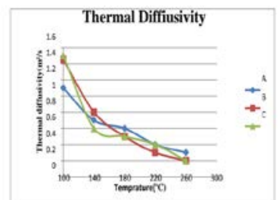


Figure 7. variation of thermal diffusivity of 0%, 5%, 10% SiC in sisal fiber composite with temperature

Arpitha et al. (94) researched on sustainable low cost alternative material for heavy engineering products such as aerospace and automobile manufacturing thereby using sisal natural fiber from wastes, silicon carbide and glass as synthetic fibers reinforced with epoxy thereby subjecting them to mechanical test such as impact strength, tensile, and flexural value using universal testing machine (UTM) after preparing the specimens in different weight percentage comparing sisal/glass and sisal/glass/SiC using hand layup processing method and it was found that composite of sisal/glass possessed more mechanical properties than when reinforced with SiC

Table 5. Results on the mechanical experiments on the composites

Samples in fiber weight (%)	compressive strength in KJ/m^2	Flexural strength in Mpa	Tensile modulus in N/mm^2	Tensile strength in N/mm^2
Sisal/Glass fiber	33.71	414.87	2747.42	158.167
Sisal/glass/3%SiC	32.00	558.6	3620.66	156.882
Sisal/glass/6%SiC	28.25	404.06	1882.03	114.81
Sisal/glass/7%SiC	31.85	467.75	1619.9	91.331

Dilip et al. (95) orchestrated and executed an experiment on the mechanical characterization of a fabricated sisal fiber as a biodegradable agent, silicon carbide (SiC) and epoxy. The experiment involved epoxy as the matrix element treated with 18% weight of NaOH alkaline base compound whereas the sisal fiber was treated with heat, however, SiC was used as the filler material in the composition, it was observed from the tests result that the alkali and heat treatment on the epoxy and sisal fiber on the composition with SiC affected mechanical characteristics such as maximum tensile strength value, flexural impact, shear and compressive strength of the composites and the science behind these properties is that the alkali removed the organic particles in the microstructural form of the composites and the heat treated sisal fiber filled in the voids and the combination of the SiC in the composition added to the improvement of the microstructure, the results from the experiment indicates that the material can be used in high mechanical strength applications.

6.5 Silicon carbide/Coconut fiber

Poornesh et al. (96) added SiC and coconut shell ash to pure aluminum metal to investigate the mechanical properties effects on it. The process includes stir casting technique then base pouring at a preset at high temperature of $750^{O}C$ and mechanical stirring speed of 600 rpm for good bonding of the composites, the prepared specimens in different fiber weight of the reinforced composites (coconut shell ash (CSA) and SiC) was examined to mechanical property tests such as hardness, impact and tensile strength likewise density. The results from the tests such as hardness test from Vickers test apparatus indicated highest hardness value of 44 HV from 10% CSA and 5% SiC added fiber weight of the reinforced composites likewise the tensile strength, but the highest impact strength was observed at the pure aluminum without reinforcements and the lowest impact strength at the 10% CSA and 5% SiC added reinforced composite, finally the lowest density was observed at 10% and 5% of CSA and SiC respectively, which from experiment it is observed that the composites possess brittle properties for engineering applications.

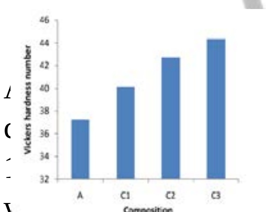


Figure 1. Comparison of hardness for different composition of coconut shell ash and silicon carbide

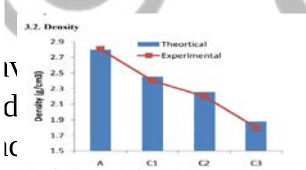


Figure 2. Comparison of density for different composition of coconut shell ash and silicon carbide

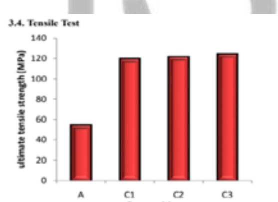
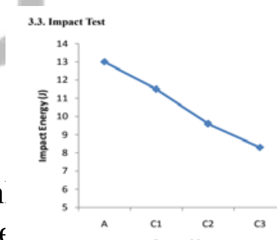


Figure 4. Comparison of Impact Energy for different composition of coconut shell ash and silicon carbide



A[illegible] tv[illegible] e of [illegible] oconut c[illegible] d[illegible] tre[illegible] rature 1[illegible] ic[illegible] g ra[illegible] es, the V[illegible] ted using XRD to investiga[illegible] crysta[illegible] the fiber, FTIR analyzer used to verify the dominant elements in the heat tre[illegible] the during the experiment which verified the presence of Si-C and Si-O-Si groups, moreover, the XRD also indicated alpha-SiC indicating a precipitate as six edge (hexagonal 6H-SiC and 4H-SiC) formations. Finally, the investigation showed 11-40 wt.% of SiC present in the heat treated coconut shell which is extracted for synthesized SiC replacement in high mechanical strength and thermal efficient applications in engineering.

Lakshmi et al. (98) conducted a designed and fabricated experiment to produced more efficient aluminum based automobile clutch by reinforced using biodegradable material from coconut fiber and SiC, which the composite was processed with stir-casting by 92% Al, 5% SiC and 3% CSA, the composites was then subjected to mechanical tests to certify the essential properties of the existing clutch such as hardness test using Rockwell hardness tester, wear test result was investigated using pin-on-disc apparatus, bending test and microstructural test using optical metallurgical microscope including the coefficient of friction and density of the composites was calculated, interestingly, a modelled mechanical clutch was designed using ANSYS 15.0 software using the more effective results from the analysis.

6.6 Silicon carbide/Palm kernel shell

Voon et al. (99) used microwave medium of heating to prepare a process to investigate green synthesis of silicon carbide nanowhiskersinside compositions of silica and palm kernel.

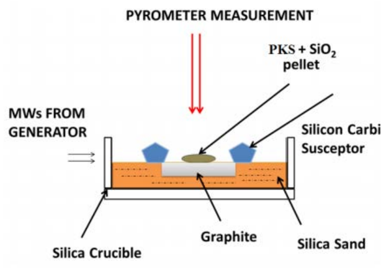


Figure 1. Schematic Diagram of Setup Within Microwave Cavity.

The test was conducted with the aid of field emission(FE)-SEM) and (XRD) analysis after the composites of palm kernel shell (PKS) and SiO_2 was blended in different ratios, however, the results from the tests indicated beta-SiC elements in the microstructure of the composites from the XRD analysis from the ratio of 5:1 of PSK and SiO_2respectively and SEM analysis showed an average diameter of 70 nm of silicon carbide nanowhiskers (SiCNWs) when applied ratio of 7:1 of PSK and SiO_2 which is concluded to possess thermal strength, chemical resistivity and electrical characteristics.

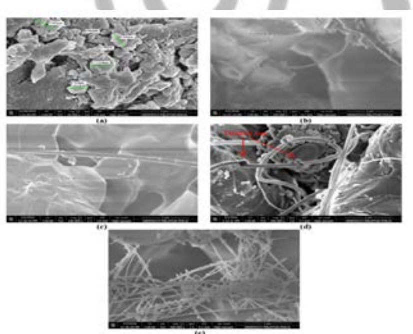


Figure 3. FE-SEM Images of the (a) PKS Powder and the Mixture of PKS:SiO_2 Subjected to Microwave Heating in the Ratio of (b) 1:1, (c) 3:1, (d) 5:1 and (e) 7:1.

Ikubanni et al. (100) researched on the changes on microstructural and chemical properties of palm kernel shell pyrolysis (pyrolysis process of converting fiber to ash by heat) when subjected to high temperature, the process of the investigation Involved subjecting the shell to different high temperature of 900, 1000 and 1100^{O}Cwhich turned the color of the pyrolysis to shades of brown then the specimen was analyzed by the application of XRF, FTIR, SEM_EDX and XRD apparatus which indicated silicon oxides as the highest composition of the palm kernel ash and other compounds present in microstructure of the heat treated palm kernel shell which makes the material suit for metal reinforcement fiber for engineering applications.

7. Mechanical and Physical Characteristics of Hybrid Composite on *Natural fibers/*ALUMINUM OXIDE

7.1 Aluminum oxide/ Coconut fiber

Abutu et al. (68) experimented on composite materials using coconut shell fiber reinforced with aluminum oxide and graphite as friction modifier to develop mechanical brake pad which can replace the asbestos material form of brake pad which have proven not good for human health. Epoxy resin was used in the experiment for strong bond between the hybrid composites, grey relational analysis (GRA) was used in the preparation which involves the evidence of optimal process performance thereby 52% coconut shell fiber, 35% of binder, 8% of aluminum oxide and 5% of friction modifier composite were subjected to heat treatment time of about 5 hours, 5mins of curing time and mold pressure of 14MPa which the result obtained indicated a good and affordable brake pad comparable to commercial brake pads which also are capable of producing less vibration and less noise after standard tests.

Table 6. Investigated Outcomes from the Test Relating it with Commercial Product.

MECHANICAL CHARACTERISTCS	Commercial Brake-pad (a)	Brake-pad from coconut composites (b)
Wear value in Mg/m	0.04184	0.03156
Coefficient of friction	0.634	0.614
Impact strength in J/mm	0.082	0.032
Compressive strength in Mpa	5.451	3.817
Hardness (shore D scale)	62.14	63.31
Bending strength in Mpa	8.41	8.34
Ultimate tensile strength in Mpa	5.071	7.38

Simon et al. (69) used hybrid natural fibers of coconut shell and kyanite particles reinforced with aluminum oxide to investigate the possibilities in invention of local waste based automobile brake disc, the process involved reducing the sizes of the waste fibers (coconut shell and kyanite) to 3.074 um then prepare the specimens with SiO_2, Fe_2O_3 and Al_2O_3 to investigate the best combination. XRF, XRD and SEM apparatus was used to investigate the structural compositions, also density of the composite was calculated using formula

$$\frac{W_2 - W_I}{(W_4 - W_1) - (W_3 - W_2)}$$

(W is the weight of the fibers), and thermal conductive (K) of the specimens was conducted using

$$\frac{Q.L}{A\,(T_2 - T_1)}$$

Given that thickness or length (L) of the specimens, area of the specimen (A), Temperature change of the composite T_1 and T_2 and Q=heat. The XRD analysis indicated some essential elements in the composites such as quartz, hematite, andorite, and gualtite in the coconut shell and kyanite particles element includes quartz and beryl at 26.72^0C and 20.19^0C (angles) was as $638.28A^0$ and $789.38A^0$ respectively, the SEM machine indicated 26.24um and 3.074um microstructure of coconut shell and kyanite particles, EDX (energy dispersive X-ray) apparatus indicated crystalline phases in the composition which proves a good strengthening materials with the combination of aluminum oxide for engineering applications.

Aku et al. (70) showcased an application that indicated the essential need for light material in engineering tool and machines manufacturing using hybrid composites of coconut shell ash and Al-Si-Fe particulates by evaluating the density, microstructure and hardness of the composition using double stir-casting method. However, from the experiment it was observed when the fiber weight of coconut fiber increases the density of the specimens decreased and also hardness value on the specimen test increases as the coconut fiber weight is increased. Furthermore, result from SEM analysis indicated the evenness in the microstructure of the composition due to the fine distribution property of coconut shell particles reacting with aluminum alloy which also indicated in the low result of pore in the experimented composites which from the analysis indicated the composite can be used in light weight manufacturing like in aerospace, automobiles and other engineering applications.

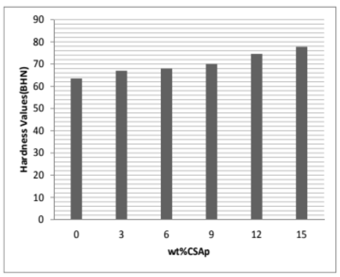


Figure 7. Variation of Hardness values with wt% coconut shell ash.

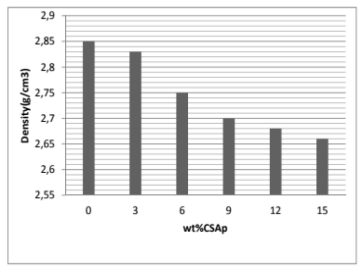


Figure 2. Variation of Density with wt% of Coconut shell ash.

Siva e ... ium machi ... operties of pure
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special method or software applied to verify maximum efficiency, incorporating maximum control factor stage of mixture and conduct experiment so as to verify the results for consistent performance, the composite was prepared using stir casting technique then subjected to furnace heat (920^{0}C) after moreover the particle size (60 um) of the coconut ash used in this experiment was reduced using harmer mill and from the result the experiments indicates that coconut shell ash present in the material reduces the rough surface when combined with pure aluminum and can be used in structural improvement and material strength.

Table 7. Results from the pure Al and coconut ash experiments

TEST ONE

Material/s	Model eq.	Result	% error
Al	3.052	2.745	2.153
Al and CS_A	2.105	2.089	1.11

TEST TWO

Material/s	Model eq.	Result	% error
Al	1.487	1.275	-4.953
Al and CS_A	1.84	1.925	-4.619

Al = Pure Aluminum and CS_A = Coconut shell ash

Himansu et al. (72) also used tanguchi special approach to investigate the mechanical properties under theability of a component to be made or modified by a machine (machinability), physical and microstructure of hybrid composite of aluminum and coconut shell (60 um) using stir casting processing technique and high temperature using furnace which the following results were obtained

- As the coconut shell increases in the composition the hardness property of the composite increases
- When subjected to cutting machine (rpm) for machinability analysis, feed rate has the maximum influence on the outer body roughness of aluminum when machined and coconut shell composite including the test on depth of cut and cutting speed.

7.2 Aluminum oxide/Bamboo

Anu Gupta (73) used bamboo reinforced with aluminum oxide and some percentage weight of silicon carbide to improve the physiochemical characteristics of bamboo including epoxy material for effective adhesion of the composites so as to suit the application qualities of bamboo in engineering products. The improvement experiments was carried out by investigating the liquids (H_2O) and chemical resistivity of the composition and the material preparation technique used in this investigation was hand lay-up method which the chemical resistivity test on the composites was conducted by subjecting it to chemical compounds such as carbon tetrachloride, benzene toluene, acetic acid, sodium hydroxide, sodium carbonates, ammonium hydroxide solutions, moreover, the H_2O absorption experiment was conducted by subjecting the specimens in alkaline water, normal water, distilled water and salt water, which the test was conducted based on different sets of composite samples by percentage weight, however, the treated set of the composites on alkaline indicated improved resistance to chemicals and water when evaluated with the untreated hybrid composite which further indicated that the application of the synthetic fibers (Al2O3 and SiC) on the bamboo increases the chemical and water resistance significantly and can be used in engineering application that requires chemical and water proof.

Junjie et al. (74) did a good job in sewage systems of engineering by using bio-waste material (bamboo) and synthetic fiber (aluminum nitrate) for the wastewater treatment application through the process of extracting the ammonia nitrogen pollutant from the domestic wastewater. The design involves introduction of carbon precursor which is the major component prepared for novel adsorbent for ammonia nitrogen removal which was developed by treating the bamboo fiber with alkaline solution to convert the bio-waste (bamboo fiber) to biomass fiber then react the bio fiber and aluminum nitrate Nano-hydrate and copper nitrate hydrate to form the compound that reacts on the surface layer of the wastewater the compound formed by this mixtures is called Cu-Al composite oxide. The experiment was carried out using SEM. XRD and BET techniques which involved in testing the time, pH (acid-alkaline tests), temperature and dosage when reacted on the ammonia nitrate in the wastewater. However, the results from the analysis shows minimum absorption of ammonia nitrate of about 18.29 mg/g from model of Langmuir isotherms.

7.3 Aluminum oxide/ periwinkle

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Periwinkle *(Turritella communis)* being a sea base food commonly more available in Calabar south-south of Nigeria, having dark banded shell with very hard and rough texture, shell width within 10-12 (mm) in mature form mean size of16-38 (mm) and up to 30, 43, or 52 (mm) shell height. periwinkle as a waste material have been proven very useful in engineering application by many researchers such as in automobile parts, structural applications even in material mechanical properties improvement due to the chemical composition (fe_2O_3, CaO and SiO_2) in periwinkle shell (75).

Abdulkareem et al. (76) conducted hardness and tensile test on aluminum alloy (Al 6063), periwinkle shell and cow bone as a reinforcement, which the bio-waste fibers were subjected to treatments to remove impurities and to get a desired sizes for the tests, like the cow bones were washed and sundried for weeks then crushed to 75 micro-meters in ball mill also the periwinkle shell was treated in an oven at 110 degrees temperature for 30 minutes so as to dry up the moisture content inside the shell then the experiment on density, tensile and hardness tests was carried out by combining aluminum alloy/periwinkle shell and aluminum alloy/cow bone which the result from density using Archimedes principle shows 2.68 g/cm^3 for cow bone composite and 2.60 g/cm^{3}for periwinkle shell composite, the tensile strength result conducted using universal testing machine and ASTM E10 machine for hardness test standards using also Brinell hardness showed by average summary of 41.18 BHN (hardness strength) and 135.88 Mpa (tensile strength) for periwinkle composition, whereas, an encouraging engineering material properties such as hardness strength (40.45 BHN) and tensile strength (134.63 Mpa) was observed when cow bone was added, which indicates a good properties for engineering applications and material improvement**.**

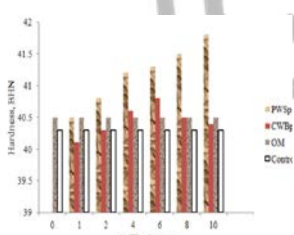

Figure 6: Hardness values for Al/Ps and Al/Cb with Control and OM

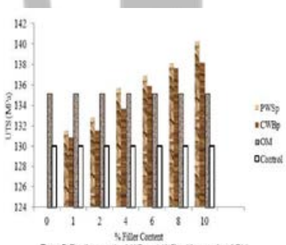

Figure 7: Tensile strength of Al/Ps and Al/Cb with control and OM

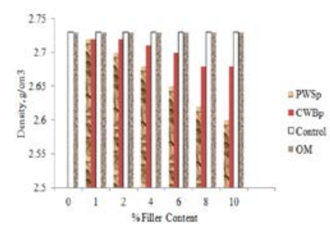

Figure 5: Density of the Al/Ps and Al/Cb composites Vs control sample and OM

Umunakwe et al. (77) applied two-step casting manufacturing technique to form a composite of aluminum alloy and periwinkle shell as a particulate fiber to investigate the mechanical properties and microstructural effects and the process involved milling of the periwinkle shell to 75 and 150 micro miters in sizesthen mix it with 1,5,10 and 15wt% of the aluminum alloy and was subjected to chemical analysis, tensile test, hardness test and metallography analysis which involved x-ray fluorescence, ASTM machine, vicker hardness tester and software driven optical metallurgical microscope respectively for the experiments, however, the result indicated that periwinkle shell distributes uniformly when reinforced with aluminum alloy (AA6063) which creates a fine grains bond from coarse grains at a smaller particles size, in addition to this fine grains result which also improves the mechanical and microstructural arrangement of the composites such as strength, elastic modulus, ductility and hardness which can be applicable where light weight and higher strength are required such as in aerospace, electronic industries and power electronic modules**.**

Nwabufoh (78) developed and characterized the mechanical and physical properties for engineering material improvement applications using aluminum alloy and other synthetic fibers cupper and magnesium reinforced with periwinkle ash as a particulate composite which was subjected to double stir casting manufacturing technique. However, the periwinkle was first subjected to x-ray fluorescence which proved the presence of CaO, SiO_2, Al_2O_3, MgO and TiO_2inside periwinkle fiber,then the following mechanical and physical tests were carried out including density test using Archimedean principle which exhibit 2.82g/cm^3 at 5wt% of periwinkle ash to 2.60g/cm^3 at 30% of periwinkle ash addition,porosity test which was conducted on the seven different samples after subjecting them to high temperature and water reactions was then calculated using general apparent formula (A.P)

A.P= W-D/W-S X 100 (%)………where D is constant weight, weight of the dried sample = W and weight of saturated sample is denoted as S, howevere, the experiment indicated increase from 0.11% at 5wt% of periwinkle ash addition to 0.33% at 30wt% of periwinkle ash addition, the hardness test was determined using Rockwell hardness machine and 5wt% of periwinkle ash showed 57.15 hardness increase and when the periwinkle ash was further increased to 30wt% , 87.75 hardness was observed, furthermore, tensile strength values (ultimate and yield) of composition increased as the percentage of periwinkle ash increases which attained addition maximum value of 151.60 and 202.45 N/mm^2 observed using house field tensometer machine for tensile test, charpy impact machine which was implemented in the research to investigated the impact mechanical strength of the specimens which decreases as the fiber weight (%) of periwinkle ash increases in the aluminum alloy signaling brittle material. However, this experiment indicates that the composition is good in material property improvement and lightweight applications.

7.4 Aluminum oxide/ Corncob

Theoretically, corncob is a part of corn plant which is made up of cylindrical core of an ear on which the kernels or corn seeds are attached in row, it is made up 35-40% of hemicellulose, 17-20% of lignin and 32-36% of cellulose with low amount of organic composition, some good research have proven corncob fiber good in engineering application, for instance, Liu et al. (79) used corncob fiber in preparation of corncob fiber plastic which exhibited mechanical strength used in material improvements also, the chemical and thermal degradation of corncob which indicated a good applicable characteristic was investigated by Panthapulakkal and Sain (80).

Odoni et al. (81) researched the mechanical and physical analyses such as tensile-impact strengths, wear index rate, hardness, porosity and density using corncob ash and aluminum oxide composite subjected stir casting manufacturing technique. During the process, the corncob ash was mixed with aluminum 6063 alloy in 2.5, 5, 7.5, 10, 12.5 and 15 weight percentage which was compared with the characterized properties of the aluminum alloy, which exhibited homogenous reinforcement with the aluminum alloy and the result obtained after test showed that reinforced corncob ash and aluminum alloy possess more mechanical strength and density compared to aluminum alloy, furthermore, statistical evaluation and optimization test was conducted on the composites using design-expert software which informed optimal concentration on corncob-aluminum alloy composite compared to aluminum alloy alone, also regression model was used in this experiment to indicate the optimal physical properties and mechanical strengths of the compared composites which resulted to 7.919% and 92.081 reinforcement respectively.

However, from the result it shows that these two composites can be used were lightweight materials are applicable such as in automobile, aerospace, load-bearing and wear resistant materials.

7.5 Aluminum oxide/Palm kernel

Satish and Srikiran (82) experimented on improvement of automotive brake pads from asbest**os** base materialwhich is generally harmful to human health, so they investigated the possibility of producing brake pad with palm kernel, Nile rose (for coefficient of friction improvement), wheat powder (for wear rate reduction) reinforced with aluminum, graphite and phenolic resin for proper adhesionall were in but different percentage then subjected it to different tests such as wear test with pin-on-disc machine, hardness test with Rockwell machine, and oil absorption test, which the result indicated a good application of both composite in automobile brake pad comparable to asbestos type.

7.6 Aluminum oxide/ Sisal

Sisal fiber (Agave sisalana) being an natural fiber extracted from tree is made up of some chemical constituents include lignin, cellulose and hemicellulose which attributed to the engineering physical and mechanical characteristics of the fiber having density that ranges from 1.33-1.5 g/cm^3, 400-700 MPa tensile strength and other properties like low weight, cost, high specific strength ability to stretch (rope production), thermal stability and specific stiffness which have found a way in engineering applications such as automobile, marine, and aircraft structures (83-84)

Pinheiro et al. (85) used two surface treatment to investigate the water absorption rate of sisal fiber and aluminum oxide which they used acetylation and then modify the hybrid composite with aluminum oxide hydrate then the properties characteristics of the composition was investigated with FTIR, EDS, SEM spectrums, moreover, manual rolling processing technique was used in mixing the composites for proper bonding, however, FTIR analyzing machine showed that the double treatment conducted on the composites promoted decrease in water absorption which after treated with acetylated fiber yield water absorption decrease by 33% and afterward decreased further to 28% when subjected to hydrated aluminum oxide which proves its application in water resistance equipment, machine and tools in engineering.

Asif (86) used chemically treated aluminum nitrate reinforced with sisal fiber to investigate their effect in dielectric application by applying sintering process technique, thereby aluminum nitrate was treated first with ammonium chloride in a distilled water then added sisal fiber with an affective stir for good adhesion which then was subjected to high temperature of about 1000 degrees in a furnace so as to dry the composites which forms white color solid crystals in appearance observed to be aluminum oxide then finally the resulted specimen was analyzed in impedance analyzer which was observed that the composites after the experiment has a good electrical applications of an dielectric due to the cellulose, hemicelluloses, lignin and pectin present in the chemical constituent in the sisal fiber.

References

1. Schakel, M,;Jansseen, H,; Brecher, C. ‘’Increased reliability for the manufacturing of composite pressure vessels’’ *Lightweight Des. Worldw*. **2019**, 12, 10-17.
2. Solazzi, L.; Buffoli, A.‘’Telescopic hydraulic cylinder made of composite material’’ *Appl. Compos. Mater*. **2019**, 26, 1189-1206.
3. Lu, Z.L.; Lu, F,; Cao, J.W.; Li, D.C ‘’Manufacturing properties of turbine blades of carbon fiber-reinforced SiC composite based on Stereolithography’’. *Mater. Manuf. Process*. **2014.**
4. Wagh, P.H.; Pagar, D.D. “Investigation of mechanical and tribological behavior of composite material filled with black epoxy resin and aluminum tri-hydroxide using reinforcement of glass fiber”*AIP Conf. Proc.***2018.**
5. Zhang, J.; Khatibi, A.A.; Castanet, E.; Baum, T.; Komeily-Nia, Z.;Vroman, P.; Wang, X. “Effect of natural fiber reinforcement on the sound and vibration damping properties of bio-composites compression moulded by nonwoven” *mats. Compos. Commun*. **2019.**
6. Forintos, N.; Czigany, T. “Multifunctional application of carbon fiber reinforced polymer composites: Electrical properties of reinforcing carbon fiber- A short review”*Compos. Part. B.Eng*. **2019**
7. Boegler, O.; Kling, U.; Empl, D.; Isikveren, A. “Potential of sustainable material in wing structural design”*In proceedings of the DueuscherLuft-und Raumfahrtkongress, Munchen, Germany, UK,* **2018.**
8. Zou, Z.; Qin, Y.; Tian, Q.; Huang, Z, Zhao, Z. “The influence of zirconia fiber on ablative composite materials”*Plast. Rubber Compos*. **2019.**
9. Fan, S.; Yang, C.; He, L.; Du, Y.; Krenkel, W.; Greil, P.; Travitzky, N. “Progress of ceramic matrix composites brake materials for aircraft application” **2016**
10. Kumar, A.; Lai, K.G.; Anantha, S.V “Design and analysis of a carbon composition propeller for podded propulsion”**2019.**
11. Mouritz, A.P. “Manufacturing of fiber-polymer composite materials. In introduction to Aerospace Materials*” WoodheadPulblishing: Sawston, UK;* **2012.**
12. Ding, Z.; Xu, M.R.; J.G.; Dong, B.Q.; Zhang, M.J.; Hong, S.X.; Xing, F. “Strengthening concrete using phosphate cement-based fiber-reinforced inorganic composites for improved fire resistance”**2019.**
13. Cheng, L.; Karbhari, V.M. “New bridge systems using FRP composites and concrete: A state-of-the-art review”**2006.**
14. Pham, T.M.; H. “Review of concrete structures strengthened with FRP against impact loading”*Structures***2016**, 7, 59-70.
15. Ozbakkaloglu, T.; Lim, J.C.; Vincent, T. “FRP-confined concrete in circular sections: Review and assessment of stress-strain models”*Eng. Struct*. **2013**, 49, 1068-1088.
16. Pickering, K.L.; Efendy, M.G.A.; Le, T.M. “A review of recent developments in natural fiber composites and their mechanical performance”*Comp. Part. A.Appl. S*. **2016,** 83, 98-112.
17. Alves Fidelis, M.E.; Pereira, T.V.C.; Gomes, O.F.M.; de Andrade Silva, F.; TeledoFilho, R.D. The effect of fiber morphology on the tensile strength of natural fibers. *J. Mater. Res. Technol*. **2013,** 2, 149-157.
18. Nair, A.B.; Joseph, R. “Eco-friendly bio-composites using natural rubber (NR) matrices and natural fiber reinforcements. In Chemistry Manufacture and Applications of Natural Rubber” *Woodhead Publishing: Sawston, UK; Cambridge, UK,* **2014.**

19. Lotfi, A.; Li, H.; Dao, D.V.; Prusty, G. "Natural fiber-reinforced composites A review on material, manufacturing, and machinability"**2019.**
20. Wintayakran, S.; Smithipong, W.; Wangpradid, R.; Chollakup R.; Clouston, P.L, "Natural fiber composites; Review of current trends. In Reference module in materials science and materials engineering"*Elsevier publishing; Amherst, MA, USA, Z* **2017**; *ISBN 9780128035818.*
21. Huda, MS; Drzal, LT; Ray, D; Mohanty, AK; Mishra, M, "Natural-fiber composite in the automotive sector, in properties and performance of natural-fiber composites" *Woodhead publishing; Oxford, UK,***2008**; *ISBN 9781845692*
22. M.J. Mohane, T.C Mokhena, T.H. Mokhothu, A. Mtibe, E.R. Sadiku, S.S. Ray, I.D. Ibrahim, O.O Daramola. "Recent progress on natural fiber hybrid composites for advanced applications"*A review*.**2018**.
23. Kim, D-H; Kim, H-G; Kim, H-S. "Design optimization and manufacture of hybrid glass/carbon fiber reinforced composite bumper beam for automobile vehicle"**2015.**
24. Tang, Q; Wang, Y; Ren, Y; Zhang, W.; Guo, W.A "Novel strategy for the extraction and preparation of bamboo fiber-reinforced polypropylene composites" *Polym. Compos*. **2019**, 40, 2178-2186.
25. M.C. Menkiti, C.R. Ndaji, I.G. Ezemagu & V. Uddameri, "Application of periwinkle shell coagulant (PSC) for the remediation of petroleum produced water (PPW) by coag-flucculation"**2016.**
26. Timothy Soneye, Anthony Nkem Ede, Gidion Olukunle Bamigboye, David Olatunde Olukanni, "The study of periwinkle shells as fine and coarse aggregate in concrete works"**2016.**
27. Jorge Pinto, Ana Briga Sa, Sandra Pereira, Isabel Bentes and Anabel Paiva, "Possible Application of corncob as a raw insulation material"**2016.**
28. Chand, N; Fahim, M. "Sisal reinforced polymer composite" *Tribol. Nat. Fiber Polym. Compos***2008.**
29. Senthilkumar, K; Saba, N; Rajini, N; Chandrasekar, M; Jawaid, M; Siengchin, S; Alontman, O.Y. "Mechanical properties evaluation of sisal fiber reinforced polymer composites"*A review. Constr. Build. Mater.* **2018**, 174, 713-729
30. Sexena, M; Pappu, A; Haque, R; Sharma, A. "Sisal fiber based polymer composites and their applications. In cellulose fibers; Bio- and Nano-polymer composite"**2011.**
31. Kadir, A.A., Zulkifly, SN. M,; Abdullah, M.M.A.B; Sarani, N.A. "The utilization of coconut fiber into fired clay brick" *Key Eng. Mater***2016.**
32. J. Bhaskar and V.K Singh, "Physical and mechanical properties of coconut shell particle reinforced-epoxy composites" **2012.**
33. Osita Obiukwu, Francis Alo, Christongonus Onukwube, "Investigation of mechanical properties of palm kernel fiber reinforced with waste water sachet (polyethylene) composite material"**2019.**
34. J.O Agunsoye, J.E Anyanwu, S.A. Bello, S.B Hassan, "study of breakage tendencies of palm shells using ball-milling process"**2019.**
35. Notta-Cuvier, D.; Lauro. F.; Bennani, B.; Nciri, "Impact of natural variability of flax fibers properties on mechanical behaviour of short-flax-fiber-reinforced polypropylene" *J. Mater. Sci.***2016.**

36. Rajak, D.K.; Pagar, D.D.; Kumar, R.; Pruncu, C. "Recent progress of reinforcement materialsA comprehensive overview of composite materials"*J. Mater. Res. Technol*. **2019.**
37. Sathishkumar, T.; Naveed, J.; Satheeshkumar, S. "Hybrid fiber reinforced polymer composites"- A review *J. Reinf. Plast. Comp*. **2014.**
38. https://www.accuratus.com/articles/aluminumoxide-siliconcarbide engineering properties **2021.**
39. Walter Krenkel, "Applications of fiber reinforced C/C-SiC ceramics"**2003.**
40. Stefan Flauder, Nico Langh of, Walter Krekel. "Tailored macro-press during the formation of C/C-SiC via liquid phase pyrolysis"**2020.**
41. Walter Krenkel, R. Renz, Bernhard Heidenreich, "Lightweight and wear resistant CMC brakes"**2000.**
42. Ruba Fahmi Abbas, Emad Mahmoud Eltayef, Neda Ibrahem, "Applications of aluminum oxide and Nano aluminum oxide as adsorbents: review"**2020.**
43. K.N. Yathish Narayana Rao, K. Mohamed Kaleemulla, "Mechanical characterization of pure aluminum oxide"**2018.**
44. Pertti Auerkari, "Mechanical and physical properties of engineering alumina ceramics"**1996.**
45. Swolfts, Y.; Gorbatikh, L.; Verpoest, I. "Fiber hybridization in polymer composites" *A review. Compos. Part A-Appl*. S. 67, 181-200, **2014.**
46. Swolfts, Y.; Verpoest, I.; Gorbatikh, L."Recent advances in fiber-hybrid composites: Material selection, opportunities and applications"*Int. Mater. Rev. 64, 181-215*, **2018.**
47. Martin Rush and Jim Collins, "Epoxy Types: A guide for specific selection"**2015.**
48. Sophia Dankus. "What are epoxy hardeners and why are they used?"**2018.**
49. Aeromarine products (BLOG) "polyester resin vs epoxy resin"**2018**.
50. Saba N., Paridah M. T., Abdan K., Ibrahim N.A."Dynamic mechanical properties of oil palm nano filler/kenak/epoxy hybrid nanocomposites''*Construction and Building Materials, 124, 133-138,* **2016.**
51. Saba N., Parida M. T., Abdan K., Ibrahim N. A."Physical, structural and thermomechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites''*Materials Chemistry and Physics, 184, 64-71*, **2016.**
52. Karikalan L., Chandrasekran M., Ramsubramanian S., Baskar S."Hybridization of composites using natural and synthetic fibers for automotive application'' *International Journal of Scientific research in science and technology, 7, 916-920,* **2017.**
53. Sapiai N., Jumahat A., Mahmud J. "Flexural and tensile properties of kenaf/glass fibers hybrid composites filled with carbon nanotubes'' *Journal Teknologi, 76, 115-120,* **2015.**
54. Samanta S., Muralidhar M., Signh T.J., Sarkar S. ''Characterization of mechanical properties of hybrid bamboo/GFRP and jute/GFRP composites'' *Materials Today: Proceedings, 2, 1398-1405*, **2015.**
55. Alexander J., Churchill S. J. E, "Mechanical characterization of basalt based natural hybrid composites for aerospace applications''*IOP Conference Series: Materials Science and Engineering, 197, 012008/1-012008/8,* **2017.**
56. Sarasina F., Tirillo J., D' Altilia S., Valente T., Santulli C., Touchard F., Chocinski-Arnault L., Mellier D., Lampani L., Gaudenzi P. "Damage tolerance of carbon/flax hybrid composites subjected to low velocity impact" *Composites Part B: Engineering, 93, 35-42*,**2016**.

57. Braga R. A., Magalhaes Jr. P.A.A. ''Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites'' *Materials Science and Engineering: C, 56, 269-273,* **2015.**
58. Hua C., Mazlan N. ''Investigation on the flexural properties and glass transition temperature of kenaf/epoxy composite filled with mesoporous silica for wind turbine applications''*Pertanika Journal of science and technology,* 25, 1261-1274, **2017.**
59. Fagassa C., Pavlovic A., Santilli C. ''Mechanical and impact characterization of flax and basalt fiber vinylester composites and their hybrids''*Composites Part B Engineering, 137, 247-259,* **2018.**
60. Almansour F. A., Dhakal H. N., Zhang Z. Y.''Effect of water absorption on mode interlaminar fracture toughness of flax/basalt reinforced vinyl ester hybrid composites''*Composite Structures, 168, 813-825,***2017.**
61. Santulli, C. ''Mechanical impact damage analysis of carbon/natural fibers hybrid composites''*A Review. Material***2019.**
62. John, M.J.; Francis, B.; Varughese, K.T.; Thomas, S. ''Effect of chemical modification on properties of hybrid fiber biocomposites'' *Comp. Part A Appl. Sci. Manuf.***2008**, 39, 352-363.
63. Sandhyarani Biswas, "Mechanical properties of bamboo-epoxy composites a structural application" **2012.**
64. Praveenkumara J, Madhu P, Yashas Gowda TG and Pradeep S. ''Studies on mechanical properties of Bamboo/Carbon fiber reinforced epoxy hybrid composites filled with SiC particulates'' **2018.**
65. Asif Ahmed. A, Dr. Keerthiprasad K.S, ''Development and characterization of natural hybrid composite using basal and bamboo fibers''**2018.**
66. Sankar Mohapatra, R. Sakthivel, G.S Roy, ShikhaVarma, S.K Singh & Dilip Kumar Mishra, ''Synthesis of B-SiC powder from bamboo leaf in a DC extended thermal plasma reactor''**2011.**
67. Adeolu Adesoji Adediran, Kenneth Kanayo Alaneme, Isiaka Oluwole Oladele, Esther Titilayo Akinlabi, ''Processing and structural characterization of Si-based carbothermal derivatives of bamboo leaf''**2019.**
68. J. Abutu, S. A. Lawal, M.B Ndaliman, R.A. Lafia-Araga, O. Adedipe. A.I. Choudhury, ''Production and characterization of brake pad developed from coconut shell reinforcement material using central composite design''**2018.**
69. Simon Godenaan Dantua, Muhammed Ahmed Bawa, Jacob Shekwonudu Jatua, Muhammad Hamisu Muhammad, Adekunle Safiu Bello, ''The potentials of kyanite particles and coconut shell ash as strengthener in aluminum alloy composite for automobile brake disc''**2020.**
70. S.Y. Aku, D.S. Yawas, A. Apasi, ''Evaluation of cast Al-Si-Fe alloy/coconut shell ash particulate composites''**2013.**
71. Siva SankarRaju R, G. Srinivasa Rao, M. Muralidhrar Rao, ''Optimization of machinability properties of aluminum metal matrix composite prepared by insitu ceramic mixture using coconut shell ash- Tangushi Approach'' **2015.**
72. Himansu Mohanty, Subhankar Chowdhury, Bikash Kumar Rout, Suraj Kumar Panda, Swarup Sampad Biswal, Siva Sankar Raju R, ''Study on mechanical and machinability properties of aluminum coconut shell ash by Tangushi Approach''**2019**.

73. Anu Gupta, ‘’Improvement of physiochemical properties of short bamboo fiber-reinforced composites using ceramic fillers’’**2019.**
74. Junjie Yuan, Yao Zhu, F.Qiu, ‘’Agricultural bamboo leaf waste as carbon precursor for the preparation of Cu-Al/biomass fiber adsorption and its application in the removal of ammonia nitrogen pollutants from domestic wastewater’’**2021.**
75. Aku, S.Y., D.S. Yawas, P.B. Madakson, and S.G. Amaren, ‘’characterization of periwinkle shell as asbestos-free brake pad materials’’*Pacific journal of science and technology*. *13(2) 57-63*. **2012.**
76. Abdulkareem Sulaiman, Adekaye Timothy Adeniyi, Abdulrahim Abdulbaqi Toyin, Shuaibu Yusuf Lanre, Ajiboye Tajudeen Kolawole, Ahmed Ismail Idowu, Ibrahim Hassan Kobe, Adebisi Jelil Adekunle and Yahaya Taiwo, ‘’Hardness and tensile properties of prophylactic knee brake produced from cow bone and periwinkle shell composites’’**2019.**
77. R. Umunakwe, D,J. Olaleye, A. Oyetunji, O.C Okoye and I.J. Umunakwe, ‘’Assessment of some mechanical properties and microstructure of particulate periwinkle shell-aluminum 6063 metal matrix composite (PPS-ALMMC) produced by two-step casting’’**2017.**
78. Micheal Nebolisa Nwabufoh, ‘’Development and characterization of Al-3.7% Cu-1.4% Mg Alloy/Periwinkle ash (Turritella Communis) particulate composites’’**2015.**
79. Lui, Q.Y. Yang, F., Sun, X.F., Lui, Z.H. and Li, G., ‘’Presentation of biochar catalyst with saccharide and lignocellulose residues of corncob degradation for corncob hydrolysis into furfural’’ *J. Mater. Cycles Waste Manage,* **2017.**
80. Panthapulakkal, S., and Sain, M.‘’Agro-residue reinforced high-density polyethylene composites: Fiber characterization and analysis of composite properties’’ Composites part A Applied science & manufacturing, **2007.**
81. B. Odoni, Edoziuno F.O, R.O Akaluzia, ‘’Experimental analysis, predictive modelling and optimization of some physical and mechanical properties of aluminum 6063 alloy based composites reinforced with corncob ash’’**2020**.
82. SatishPujari, S. Srikiran, ‘’Experimental investigations on wear properties of palm kernel reinforced composites for brake pad applications’’ 2018.
83. Adriana R. Martin, Maria Alice Martins, Odilon R.R.F. Da silva, Luiz H.C. Mattoso, ‘’Studies on thermal properties of sisal and its constituents’’**2010.**
84. J. Naveen, M. Jawaid, P. Amuthakkannan, M. Chandrasekar, ‘’Mechanical and physical properties of sisal and hybrid sisal fiber-reinforced polymer composites’’**2019.**
85. Pinheiro C.H., Pelluci L.A, Da Silva M.L.C.P, ‘’Water absorption study in composites of epoxy matrix using as reinforcement fiber, sisal natural, acetylated and modified with aluminum oxide hydrated’’**2018.**
86. Asif Jehan, ‘’Effect on chemically treated aluminum nitrate: its dielectric studies of sisal fiber composite’’**2015.**
87. Iyasele, Edgar Omondiale,‘’Comparative analysis on the mechanical properties of a metal-matrix composite (MMC) reinforced with palm kernel/periwinkle shall ash’’**2018.**
88. Elvis A. Okonronkwo, Patrick EhiImoisili, Smart A. Olubayode, Samuel O. O. Olusunle,‘’Development of silica nanoparticle from corn cob ask’’**2016.**
89. T. Chanadee ‘‘Experimental studies on self-propagating high-temperature synthesis composite from reactants of SiO_2 derived from corn cob ash/C/Mg,’’**2017.**

90. Arwil Nathaniel R. Alfonso, Joel R. Salazar, Juvy J. Monserate & Marilou M. Sarong, ‘’Potential for photovoltaic cell material by green synthesis of silicon carbide from corn cob through magnesiothermic reduction’’ **2020.**
91. Amit Kumar Thakur, Ajay Kumar Kaviti, Mohd Tariq Siddiqi, J. Ronald Singh and Anita Gehlot, ‘’Taguchi optimization of fracture toughness of silicon carbide extracted from agricultural wastes’’ **2012.**
92. M Kamaraj, R Santhanakrishnan, E Muthu, ‘’An experimental investigation on mechanical properties of SiC particles and sisal fibre reinforced epoxy matrix composites’’ **2018**.
93. Malla Surya Teja, M V Ramana, D Sriramulu and C J Rao, ‘’Experimental investigation of mechanical and thermal properties of sisal fiber reinforced composite and effect of SiC filler material’’ **2016.**
94. Arpitha G R, Sanjay M R, L Laxmana Naik, B Yogesha, ‘’Mechanical properties of epoxy based hybrid composites reinforced with sisal/SiC/glass fibers’’, **2014.**
95. Dilip Sen, Chitresh Nayak, K.G Sudhakar & Shyam Birla, ‘’Mechanical properties of fabricated hybrid composites infused with heat-treated alkali sisal fiber and SiC particles: a quantitative analysis’’ **2020.**
96. Poornesh M., Johnson Xavier Saldanha, Jevy Singh, Gavin Manuel Pinto, Gaurav, ‘’Effect of coconut shell ash and SiC particles on mechanical properties of aluminum based composites’’ **2017**.
97. Adeolu Adesoji Adediran, Kenneth Kanayo Alaneme, Isiaka Oladele, ‘’Synthesis of refractory compounds from coconut shell by carbothermal method’’ **2019.**
98. Lakshimi Rajan P, Mohamed Said U.Y, Amruth T.M, ‘’Design and analysis of composites of aluminum, coconut shell ash and SiC based clutch plate facing’’ **2019.**
99. C H Voon, B Y Li, S C B Gopinath, H H Tan, V C S Tony, M K Md Arshad, K L Foo and U Hashim, ‘’Green synthesis of silicon carbide nanowhiskers by microwave heating of blends of palm kernel shell and silica’’ **2016.**
100. P. PIkubanni, M. Oki, A.A. Adeleke, A.A. Adediran, O.S Adesina, ‘’Influence of temperature on the chemical composition and microstructural changes of ash formed from palm kernel shell’’ **2020.**