American Journal of Engineering Research (AJER) ***2018***
American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-5, pp-384-388
www.ajer.org
Research Paper Open Access

Mechanical Properties Of Selected Natural Fiber Reinforced Composites For Automobile Application

[1*]Osoka, E.C., [2]Onukwuli, O.D. and [3]Kamalu, C.I.O
[1.3]Department of Chemical Engineering, Federal University of Technology, Owerri, Nigeria
[2]Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Nigeria
Corresponding Author: Osoka, E.C

ABSTRACT: *The mechanical properties of Composites formed from three selected natural fiber sources (Empty Plantain Bunch Fiber, Empty Palm Bunch Fiber and Rattan Palm Fiber), mercerized at optimum conditions, with two selected thermosetting resins (Polyester and Epoxy resins) have been studied for automobile application. Optimum conditions for mercerization of Empty Plantain Bunch fiber, Empty Palm Bunch fiber and Rattan Palm fiber are 4wt% NaOH for 120mins, 6wt% NaOH for 90mins and 4wt% NaOH for 120mins respectively. Composites from Polyester resin have the least Impact strength, about half of that obtained when Epoxy resin is used as matrix. The only exception is for Composites from Rattan Palm fibers which have relatively equal Impact Strength, the matrix of choice notwithstanding. All Composites formed from Epoxy resin have Impact Strength greater than 20kgfm/cm^2, which is about nine times the Impact Strength for mild steel used in auto body parts, with the maximum Impact Strength being for Rattan Palm-Epoxy Composite. Composites can be used as substitute for low carbon steel in auto body parts because of the good Impact Strength, while Empty Plantain Bunch-Polyester Composites will serve better for structural purposes.*
KEY WORDS: *Natural fiber, composites, automobile, mechanical properties*

Date of Submission: 05-05-2018 Date of acceptance: 21-05-2018

I INTRODUCTION

Composites are materials that comprise strong load bearing material (known as reinforcement) imbedded in weaker material (known as matrix), with the reinforcement providing strength and rigidity, helping to support the structural load, while the matrix or binder, which may be organic or inorganic, maintains the position and orientation of the reinforcement (Taj et al, 2007; Ku et al, 2011). Natural fibers have been used to reinforce materials for over 3500 years, but the emergence of polymers in the beginning of the 19th century ushered a new era of research with a new option of using the natural fibers in more diversified fields, but at the same time interest in synthetic fibers, like glass fiber - because of its superior dimensional and other properties - gained popularity and slowly replaced the natural fibers in different applications. However, change in the raw material and production of synthetic composites required a large quantum of energy and quality of environment suffered because of the pollution generated during the production and recycling of these synthetic materials. This has once again drawn the attention towards natural fibers due to their distinct advantages.

Natural fibers have advantages such as being abundantly available, low cost, low density (about half that of glass fibers), low weight, cheaper, renewable, non-irritation to skin, non-abrasive to equipment, high strength to weight ratio and interesting specific properties, producing composites that are environment friendly to a large extent. They also have some disadvantages such as moisture absorption, quality variations, low thermal stability and poor compatibility with the hydrophobic polymer matrix.

Though the high moisture absorption tendency of natural fibers would lead to composites with weak interface but pretreatments of natural fibers are aimed at improving the adhesion between fibers and matrix. In pretreatments, either hydroxyl groups get activated or new moieties are added that can effectively interlock with the matrix. This has been a subject of major research (Wang, 2004; Taj et al, 2007; Kalia et al, 2009; Ku et al, 2011; Odera et al, 2011a; Odera et al, 2011b; Odera et al, 2011c).

The renewed interest in the natural fibers has resulted in a large number of modifications to bring it at par and even superior to synthetic fibers. Due to such tremendous changes in the quality of natural fibers, they are fast emerging as a reinforcing material in composites, especially for packaging and automotive applications.

Global natural fiber composite market has grown from $1.086 Billion in 2005, to $2.1 Billion in 2010 and is expected to reach $3.8 Billion by 2016, with automotive and construction applications having the largest share. The demand in automotive application alone increased by 45% between 2009 and 2012, up to 40kg per car, and it is estimated that automotive application of natural fibers in Europe in 2010 is about 100,000 tons, especially as they show better crash behavior and are thus safer than glass fiber parts (Bledzki and Gassan, 1999; Bledzki et al, 2002; Mueller, 2004; Ceccarini and Angelini, 2010; Timmins et al, 2011; McIntyre, 2012). This is a market for developing nations like Nigeria, where most fibers are seen as agricultural wastes, to harness. Thus the essence of this work is to present optimal conditions for use of selected local natural fibers in automotive applications.

II MATERIALS AND METHODS

Composite Formation and Mechanical Properties Determination

Chemicals and Reagents

General Purpose-grade unsaturated polyester resin (HSR 8113M), commercial grade Epoxy Resin 103, amine hardener 301 (polyamine), methyl ethyl ketone peroxide (MEKP) and cobalt napthenate were supplied by Nycil Industrial Chemicals, Ota, Ogun State, Nigeria.

Composite Formation

Randomly oriented fiber composites containing fibers of varying lengths (10mm, 30mm and 50mm) and fiber volume fractions (10%, 30% and 50%) were prepared by hand lay-up method using a stainless steel sheet female mould with a marble tile male mould having dimensions 300x300x3mm^3 [Figure 1]. The fibers used were treated using the optimum NaOH concentration and time for mercerization (Osoka and Onukwuli, 2005a; Osoka and Onukwuli, 2005b; Osoka and Onukwuli, 2005c). Prior to the composite preparation, the mould surface was polished well and a mould-releasing agent (mirror-glaze) was applied on the surface of the mould. General unsaturated polyester resin was mixed well with 1 wt. % cobalt naphtenate accelerator and 1wt. % by MEKP catalyst, while the epoxy resin was mixed with amine hardener in a ratio of 2:1. The fiber mat was placed in the mould and the resin mixture was poured evenly on it. Using a metallic roller, the air bubbles were carefully removed and the mat was allowed to wet completely. The mould was closed and the excess resin was allowed to flow out as 'flash' by pressing in a hydraulic press. The pressure was held constant during the curing process at room temperature for 24 hours. The composite sheet was post cured at 80°C for 4 hours. Test specimens, according to ASTM standards, were cut from the sheet.

Fig. 1: Mould set-up for fiber-reinforced composites, CCRD, Nsukka

Mechanical Properties Determination

The standard mechanical properties are determined by the procedures found in ASTM standards for plastics.

Tensile properties

The tensile properties were determined at the Civil Engineering Laboratory, University of Nigeria, Nsukka (UNN), using a Hounsfield Monsanto Universal Tensometer Machine at a constant rate of traverse of the moving grip of 5mm.min^{-1} for randomly oriented fiber composites (ASTM D 638-99). The test specimens were rectangular in shape with dimensions 160 x 19 x 3 mm^3 for randomly oriented fiber composites.

The sides of test specimens were polished using emery paper prior to testing. One grip is attached to a fixed and the other to a movable (power-driven) member so that they will move freely into alignment as soon as any load is applied. The test specimen was held tight by the two grips, the lower grip being fixed. Load is applied by gradually increasing the distance between the clamps until failure occurs. The force is then recorded and the area of cross-section of test sample obtained from which the tensile strength is calculated. The output data in the form of stress-strain graph was used to obtain the modulus, elongation and energy absorbed (toughness).

Fig. 2: Hounsfield Monsanto Universal Tensometer

Impact Strength

Charpy impact testing specimen were prepared in accordance with ASTM D 6110-02M to measure the impact strength. The impact testing machine in the mechanical engineering laboratory at University of Nigeria, Nsukka was used for this test. The sharp file with included angle of 45^{O} was drawn cross the center of the same cut at 90° to the sample axis to obtain a consistent starter crack. The samples were fractured in a plastic impact testing machine and the net breaking energy and impact resistances were calculated.

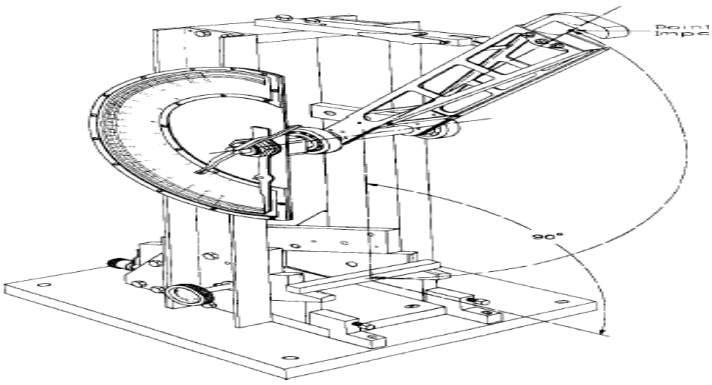

Fig. 3: Simple beam (Charpy Type) impact machine

III THE AUTOMOTIVE INDUSTRY

The automotive industry began its adventure with composites in 1953 to provide weight savings, reduced fuel consumption and CO_2 emission and due to challenges of high weight to volume ratio and corrosion with steel. Presently up to 15% of the weight of cars is made of composites and the automobile body accounts for about 30% of this weight.

In consideration of material strength in automobile application, the most useful term is specific strength, which is the ratio of force per unit area at failure to density of the material. It is also known as strength to weight ratio. While replacing existing materials used for auto body parts with new materials, the main aspect to be considered is its crashworthiness. Crashworthiness is the ability of vehicle components to protect an occupant from serious injuries at a time of accident. Selecting materials with high energy absorption capability is the base of crashworthiness design. The amount of energy or impact absorbed (Energy Absorption (EA)) by a material is the area under the load versus displacement curve. While comparing the performance of materials, the useful property considered is the specific energy absorption (SEA) which is the energy absorbed per unit mass of crushed structure expressed in J/g. This ability to absorb rapidly applied energy is impact resistance measured by impact tests like Izod, Charpy impact tests among others (Wagmare and Deshmukh, 2014).

The properties of steel used for auto body parts is compared below with glass fiber reinforced polyester (GFRP), carbon fiber reinforced polyester (CFRP), plantain bunch fiber reinforced polyester (PBFRP), plantain bunch fiber reinforced epoxy (PBFRE), oil palm bunch fiber reinforced polyester (OPBRP), oil palm bunch fiber reinforced epoxy (OPBRE), rattan palm fiber reinforced polyester (RPFRP) and rattan palm fiber reinforced epoxy (RPFRE).

It can be observed from Table 1 and Fig. 4 that the tensile strength of steel is more than ten times that of PBFRP, which has the highest tensile strength of the six composites studied. It also has higher yield strength, modulus and flexural strength, but PBFRP has impact strength more than four times that of steel, while all the composites of rattan palm or epoxy matrix have impact strength about nine times that of steel. This is close to the observation of Henry Ford, that his hemp based composite was ten times stronger than steel. Impact strength, is about the most important single parameter in choice of materials for auto body parts and in consideration of crashworthiness.

Table 1: Comparison of the properties of steel with fiber reinforced composites

Material Property	Steel	GFRP	CFRP	PBFRP	PBFRE	OPBRP	OPBRE	RPFRP	RPFRE
Tensile strength (MPa)	440	1490	110	34.87	8.43	30.15	10.75	14.80	12.06
Yield Strength (MPa)	180	-	-	31.71	6.79	18.10	7.89	11.44	8.90
Tensile Modulus (GPa)	210	35	37.5	5.61	2.97	4.46	2.46	3.24	3.41
Flexural Strength (MPa)	450	1150	250	54.65	37.60	50.72	28.13	37.35	31.36
Impact Strength (J/cm^2)	21.36	46.36	0.55	103.95	198.1	104.74	202.02	198.1	204.97
Density (g/cm^3)	7.85	2.50	1.325	1.315	1.245	1.248	1.178	1.360	1.290

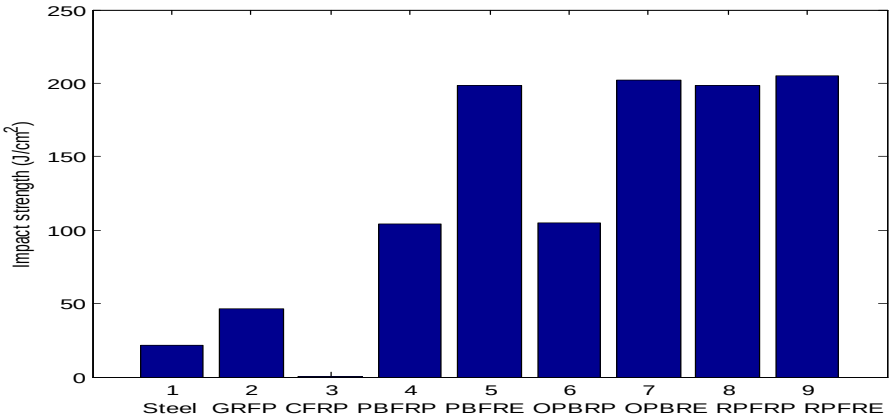

Figure 4: Comparison of Impact strength of steel with all composites

Table 2 and Fig. 5 show specific strength and energy absorption of steel and all composites. It can be observed that specific strength of steel is less than twice that of PBFRP while the specific energy absorption of the composites studied are from 29-50 times that of steel.

Table 2: Comparison of the specific properties of steel with fiber reinforced composites

Material Property	Steel	GFRP	CFRP	PBFRP	PBFRE	OPBRP	OPBRE	RPFRP	RPFRE
Specific Strength (KNm/kg)	50	587.5	75	26.5171	6.7711	24.1587	9.1256	10.8824	9.3488
Specific Energy Absorption (J/g)	2.72	18.54	0.42	79.05	159.12	83.93	171.49	145.66	158.89

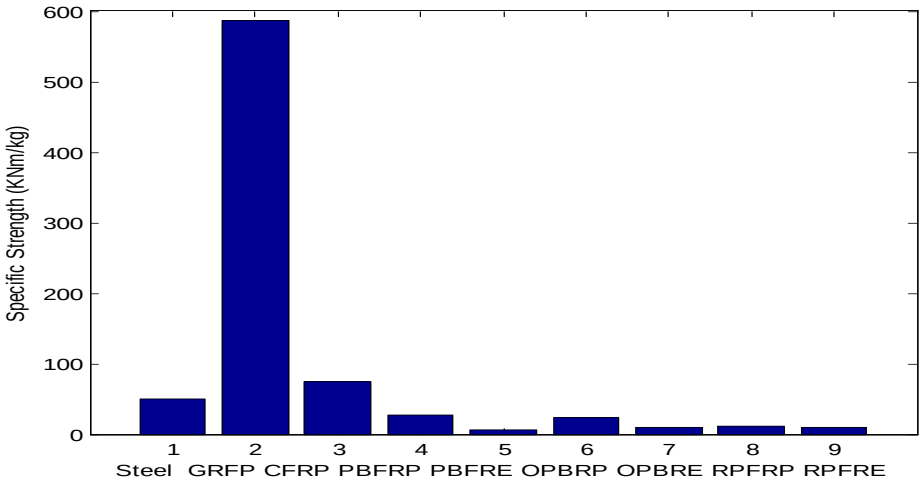

Figure 5: Comparison of Specific strength of steel with all composites

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Osoka, E.C., Onukwuli, O.D., Kamalu, C.I.O. " Mechanical Properties Of Selected Natural Fiber Reinforced Composites For Automobile Application"American Journal Of Engineering Research (AJER), Vol. 7, No. 5, 2018, Pp.384-388.