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Physico-Mechanical Properties of Reinforced Bioresin from Mango (*Mangifera Indica*) Kernel Oil

Sadiq, A. S., Bawa, M. A. and Benjamin. A.
Department of Mechanical and Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

ABSTRACT: *The paper presents experimental report on physico-mechanical properties of composite material consisting of bioresin from mango kernel oil (MKO) as matrix and chopped strand mat E- glass fibre as reinforcement. It was centered on determination and analysis of void and moisture contents, tensile, compression and impact strengths of the composite laminates. The void content of the MKO bioresin composite was 6.0% while that of polyester resin composite produced in the same manner and compared with was 3.2%. The moisture content of the MKO bioresin composite was 1.1% while that of polyester resin composite was 0.5%. The tensile, compressive and impact strengths of the MKO bioresin composite laminates determined were, 177.00KN/m^2. 101.01KN/m^2 and 29.57KN/m^2 respectively while that of the polyester resin composite were 209.11KN/m^2, 131.68N/m^2 and 41.82KN/m^2 respectively. The moisture and void contents results showed that MKO bioresin composite laminates are more susceptibility to trap air or gas and absorb water than the polyester resin. The reason is unconnected with the inherent properties and the production method of the resins. These tend to weaken the cross linking bond strength between the matrix and reinforcement thereby reducing the magnitude of mechanical properties. The mechanical properties results showed the polyester resin composite can withstand more mechanical loads than the MKO resin composites. However, the overall results showed that bioresin from mango kernel oil has appreciable physico-mechanical properties close to that of polyester resin composites and thus can serve as alternative resin to the petrochemical one at lower stresses conditions.*

Keywords*: MKO bioresin, Polyester resin, Hand layup, Void content, Moisture content, Tensile strength, Compressive strength and Impact strength*

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I. INTRODUCTION

Composite material is one of the engineering materials widely used nowadays in the fields of Air, Land and Sea transportation among others for production of materials that have high strength to light weight ratio coupled with corrosion resistance, [1] and [2]. The materials are generally used for light weight and high strength structures of machine component without compromising its efficiency.

Composite materials generally consist of two major constituents, reinforcement (i.e. fibre) and matrix (commonly called resin). Resin (polymer matrix) is one of constituents of composite material that constitutes a significant volume fraction (above 50%) of any fibre reinforced composite material that requires proper impregnation of the reinforcement.

Despite the fact that the reinforcement (fibre) carries the bulk of the load that the composite is subjected to, it is hardly possible to use the reinforcement alone as a single entity in any load bearing structure without the resin (matrix), [4]. According to [5], resin in cast state may be used alone in a low load bearing structure without reinforcement. This indicates one of the importances of resin in composite material.

Resin, as defined by [1] and [3] separately, is a viscous and transparent liquid either from organic or inorganic source that will transform (cured and hardened) into solid when treated with suitable catalyst, accelerator with or without heat. Those from inorganic sources (petrochemicals) are commonly called synthetic resins while those from organic sources (such as plant or animal) are called bioresin or renewable resins. Going by [2], any type of resin has several functions: it is a binder that holds the reinforcement (fibre) in place, transfers external loads to the reinforcement and redistributes the load to surrounding fibers when an individual fiber fractures and laterally supports the fibers to prevent buckling in compression among others. It also gives the shape of the composite and protects it and reinforcement from adverse environmental effects and others.

Considering the problems associated with linear use of synthetic (petrochemical) resins for composite manufacturing activities despite the increasing global demand for composite materials, it was noted by [2] that concerted efforts were made by researchers across the globe to source for alternative materials that are renewable and sustainable either for resin or the reinforcement.

Going by the work of [4], Mango seed kernel oil is one of the renewable and sustainable sources of oils in Nigeria and many other countries for bioresin synthesis. Bioresin had been successfully produced from mango kernel oil by [4]. Another work centered on determination and analysis of Mechanical properties of cast neat resin from mango (*Mangifera indica*) kernel oil was also done by [5]. In that work neat resins without reinforcement were cast into solid and subjected to mechanical tests. The results of the tests showed that the mechanical properties can be improved upon by reinforcing the bioresin with suitable and available fibre reinforcement.

The aim of this paper is to determine some physico-mechanical properties of reinforced bioresin from mango (*Mangifera indica*) kernel oil and to see the role played by the reinforcement when compared with the cast neat resins done by [5].

There are different types of tests that can be conducted on composite materials, however, going by [6], [7] and [8], the type of tests conducted on fibre reinforced composites are inclined towards intended applications. As the case with [5], the mechanical tests of interest in that work were tensile, compression and impact respectively. This was due to the fact that fibre reinforced composite materials that are to be used as components of Automobile or similar systems are mostly subjected to either one or combination of tensile, compression and impact forces in practical situations. The behaviour of the material before failure and the results of tests will enable one to have knowledge of the tensile, compressive and impact strengths of the composite and to a large extent give an insight into some other mechanical properties such as hardness, ductility, malleability, etc. In addition to the fact that the results of the tests will serve as data guide for selection of the material, it will also give idea about the expectation of the composite material when in service.

II. EXPERIMENTATION

2.1 Materials/devices/equipment and machines

The materials/devices/equipment and machines used for the work include:
Bioresin from MKO, Polyester resin, Catalyst (methyl ethyl Ketone peroxide, Accelerator (cobalt amine). Digital weighing machine, Measuring cylinder, Rollers and brush, Wooden moulds, Steel rule, Hacksaw, Hand files, Small plastic containers, wooden mallet, Universal testing and Impact testing machines

2.2 Production of specimens

All the composite laminates were produced by hand layup technique described by [1]. In this method, methyl ethyl Ketone peroxide (MEKP) catalyst and cobalt amine hardener (accelerator) were added to each of the resins (bioresin from MKO and polyester resin) and mixed thoroughly. The ratio of catalyst, accelerator and resin mixture depends on how quickly one wants the resin to harden. In this work the ratio was 1:2:100 (catalyst, hardener, resin) in ml.

After the application of release agent (waste engine oil in this case) on the inner surface of the produced wooden mould, an appropriate amount of the catalyzed and accelerated resin was applied and distributed on top of the mould release agent and the E-glass fibre was placed by hand on top of the resin. The reinforcement was then worked with a hand-held roller which also compact the laminate and helps to remove voids (trapped air or gases). After one reinforcement layer has been satisfactorily impregnated and compacted, more resin was applied and another E-glass fibre reinforcement layer was placed on top of the resin and the impregnation and compaction were repeated until the desired thickness of the laminate was reached. The ratio of mass of resin to fibre in each composite was 60:40.

Each of the moulded specimens was sun dried for five day to cure and harden fully before removing for finishing for mechanical tests.

Plate I: Materials for production of specimens from both MKO and Polyester resins.

2.3 Preparation of specimens

Prior to testing, the demoulded specimens were cut and finished to the dimensions suitable for each test.

(i). Tensile tests: 180mm length by 35mm breadth by 7mm thick. Three pieces for bioresin and three pieces for polyester resin. The bioresin specimens were labeled RTB_1, RTB_2 and RTB_3 while those of polyester resin were RTP_1, RTP_2 and RTP_3

(ii). Compression tests: 70mm height by 30mm breadth by 12mm thick. Three pieces for bioresin and three pieces for polyester resin. The bioresin specimens were labeled RCB_1, RCB_2 and RCB_3 while the polyester's were RCP_1, RCP_2 and RCP_3

(iii). Impact tests: 80mm length by 30mm breadth by 10mm thick with vee notch at the centre of the length. Three pieces for bioresin and three pieces for polyester resin. The bioresin specimens were labeled RIB_1, RIB_2 and RIB_3 while the polyester specimens were labeled RIP_1, RIP_2 and RIP_3.

Plate 1I: Some sample of reinforced polyester resin test specimens

Plate III: Some samples of reinforced MKO resin test specimens

2.4 Testing of specimens

2.4.1 Void and Moisture contents in the composite laminates

The void content in the composite laminates were estimated by comparing the theoretical density with its actual density as described by [9]. This work involves the use of experimental values in table 1.

Thus Void = $\frac{pt-pa}{pt}$ .....(1)

Where,

Pt = theoretical density of composite material

pa = actual density of composite material

The theoretical density of composite is calculated as: Pt or $Pc = P_f v_f + P_m v_m$ .....(2)

Where,

P_f and P_m are the densities of fibres and matrix respectively while v_f and v_m are the volume fractions of fibres and matrix respectively.

The moisture content of the composite laminates was determined by weight loss method reported by [10] and [11]. The average value was determined using experimental values in table 1.

Moisture content (Mc) = $\frac{Ww-Wd}{Ww}\ x100\%$ .....(3)

Where,

W_w = wet weight of material before drying in the sun.

W_d = dry weight of material after drying in the sun.

Table 1: Experimental data on Reinforced resins for Void and Moisture contents determinations.

Resin	Volume fraction	Dimension & mass	Density
MKO		44.1cm^3 = 64.5g after drying	Actual density = 1.46g/cm^3
Polyester		44.1cm^3 = 73.6g after drying	Actual density = 1.67g/cm^3
MKO	V_m = 60%	Theoretical density = 1.66 g/cm^3	
Polyester	V_m = 60%	Theoretical density = 1.78 g/cm^3	
Glass fibre	V_f = 40%	Theoretical density = 2.5 g/cm^3	
MKO		44.1cm^3 = 65.2g before drying	
Polyester		44.1cm^3 = 74.0g before drying	

2.4.2 Mechanical properties tests

All the tensile and compression specimens were tested on universal testing machine as described by [12] and [13]. The tensile force was gradually applied until failure occurred while the same procedure was adopted for compression tests. In each case the maximum applied (breaking) force was read from the machine after which the tensile and compression strengths were respectively calculated using the formula obtained from [12] and [13].

Tensile strength = $\frac{Breaking\ \ force}{Original\ \ area\ \ of\ \ specimen}$ or $\sigma = \frac{F}{A}$ ..... (4)

Where,

σ = Tensile Stress

F = Force at failure

A = Original cross sectional area of specimen

The compressive strength = $\frac{Crushing\ \ force}{Original\ \ area\ \ of\ \ specimen}$ or $\sigma = \frac{F}{A}$ ..... (5)

Where,

σ = Compressive Stress

F = Crushing force

A = Original cross sectional area of specimen

The impact tests were conducted on Charpy impact testing machine. The impact strength of the specimens was calculated using the relation obtained from [12].

Impact strength = $\frac{Energy\ \ absorbed}{Original\ \ area\ \ of\ \ specimen}$ or $\sigma = \frac{WR\ (\cos\beta - \cos\alpha)}{A}$ .....(6)

Where,

σ = Impact Stress

WR (cosβ - cosα) = Energy absorbed or required to rupture specimen

A = Original cross sectional area of specimen W = weight of the Charpy impact testing pendulum

R = Length of pendulum or pendulum arm

β = angle of rise and α = angle of fall

III. RESULTS AND DISCUSSIONS

Moisture contents results.

The moisture and the void contents of the composites are shown in table 2.

Table 2. Results of moisture and void contents of MKO bioresin and Polyester resins composites

Parameters	Specimen	Determined value (%)
Moisture content	MKO bioresin	1.1
	Polyester resin	0.5
Void content	MKO bioresin	6.0
	Polyester resin	3.2

Moisture as defined by [10] and [11], is simply water diffused in a relatively small quantity in a material or substance. The amount of this water in the material constitutes its moisture content. Nearly all materials contain at least a diminutive volume of moisture as a component of the molecular makeup. In this work, the moisture content of MKO bioresin was 1.1% while that of the polyester resin was 0.5%. Although, these values are low with non noticeable shrinkage of the specimens, however the results show that MKO bioresin specimens are susceptible to absorb water than the polyester specimens. This will advertently affect the binding force of the bulk material and of course the mechanical properties as shown in the results.

The void contents of the composite laminates were 6.0% for MKO bioresin and 3.2% for polyester resin. The results showed that MKO bioresin composite is more susceptibility to trap air or gas than the polyester resin. The reason is unconnected with the chemical makeup of the resin and the degree of crystalinity and molecular weight differences. Going by [12], resin with high molecular weight tends to have better compact structure than the low one and thus low value void content.

Mechanical tests results

The results of the mechanical tests results are shown in tables 3-5 while figures 1-3 are histograms showing the variations of the average strengths of polyester resin composites compared with MKO resin composites.

Table 3: Tensile tests results of glass fibre reinforced resins

Specimen	Breaking Force (N)	Tensile strength (KN/m^2)	Average(KN/m^2)
RTB_1	242.9	991.4	987.3
RTB_2	241.6	986.1	
RTB_3	241.3	984.9	
RTP_1	244.1	996.4	995.9
RTP_2	243.3	993.1	
RTP_3	244.5	998.3	

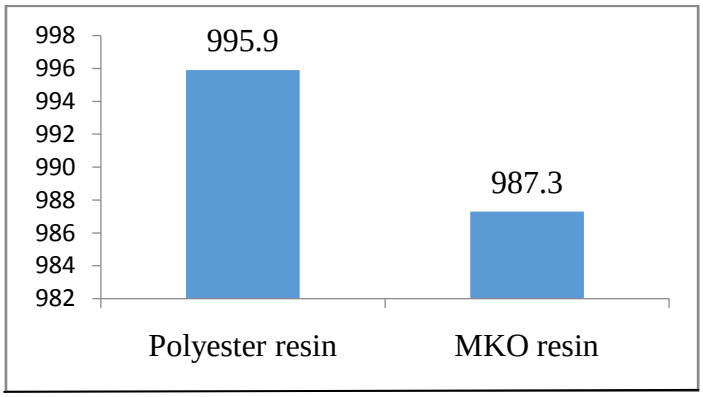

Figure 1: Histogram showing the variation of Tensile strengths of the reinforced Polyester and MKO resin composites

As shown in table 3 and figure 1, the average tensile strength of reinforced MKO bioresin composite was 987.3KN/m^2 while that of reinforced polyester resin composite was 995.8KN/m^2. Despite the fact that the polyester resin composite has higher value, the results showed that MKO bioresin can be used as alternative to polyester resin in a situation where the percentage tensile load tolerated is either 1% or more of that of the polyester resin composite.

Comparing these results with the cast resins reported by [5], there was a large disparity between them. The percentage different between the cast and reinforced MKO resin was 81.74% while that of the Polyester resin was 79%. These large disparities between the reinforced and cast resins were brought about by the important role played by reinforcement in composite material. This is due to fact that the reinforcement (i.e. fibre) has much more strength and stiffness than the matrix material and this characteristic is displayed when used to produce composite material.
The results of compression tests are shown in table 4 and figure 2

Table 4: Compression tests results of glass fibre reinforced resins

Specimen	Breaking Force (N)	Compressive strength (KN/m^2)	Average(KN/m^2)
RCB_1	37.1	123.7	123.8
RCB_2	37.0	123.3	
RCB_3	37.3	124.3	
RCP_1	47.1	157.0	156.3
RCP_2	45.9	153.0	
RCP_3	47.7	159.0	

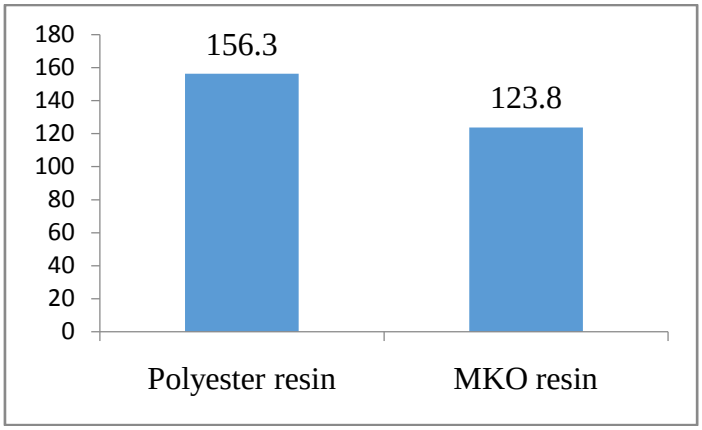

Figure 2: Histogram showing the variation of Compressive strengths of the reinforced Polyester and MKO resin composites

The average compressive strength of reinforced MKO resin composite was 123.9KN/m^2 while that of the reinforced polyester resin composite was 156.3KN/m^2. These results also showed that the compressive strengths of the two materials are not too far from each other. Although polyester resin composite like the tensile strength has higher value, there is that possibility of using the MKO bioresin as alternative to polyester resin at lower stress level (about 21% less of the polyester resin composite value).

The results of the compression tests were compared with the compression tests results conducted on neat cast resins reported by [5]. There was a wide disparity between the two results. The percentage disparity between the reinforced and neat cast MKO resins was 18.4% while that of reinforced and neat cast Polyester resins is 15.8%. These disparities were brought about by the role played by reinforcement in composite material. It helps to improve the load carrying capacity of neat cast resin.

Table 5: Impact tests results of glass fibre reinforced resins

Specimen	Breaking Force (N)	Impact strength (KN/m^2)	Average(KN/m^2)
RIB_1	27.9	93.0	95.3
RIB_2	29.3	97.7	
RIB_3	28.7	95.7	
RIP_1	41.3	137.7	140.3
RIP_2	42.2	140.7	
RIP_3	42.8	142.7	

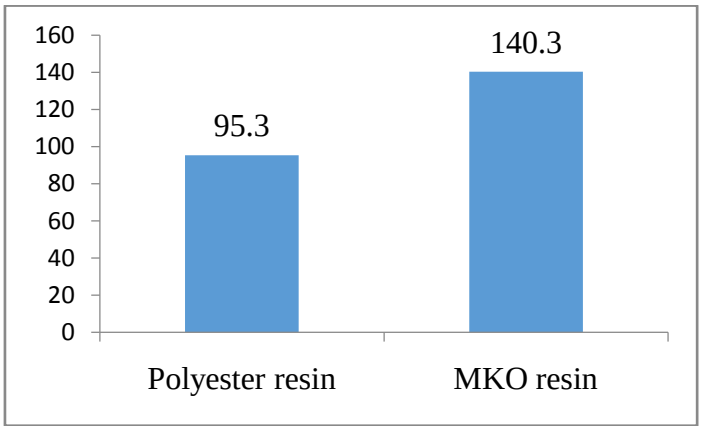

Figure 3: Histogram showing the variation of Impact strengths of the reinforced Polyester and MKO resin composites

The results of Impact tests results are shown in table 4 and figure 2. The average Impact strength of reinforced MKO resin was 95.3KN/m^2 while that of reinforced polyester resin was 140.3KN/m^2. Despite the fact that both composites can withstand impact load, polyester resin composite can withstand 32.1% more impact load than the MKO resin composite.

The impact tests results were compared with the impact tests results conducted on neat cast resins reported by [5]. The percentage disparity between the reinforced MKO bioresin and neat cast bioresins was 69.0% while that of reinforced Polyester resin and neat cast resin was 70.2%. The large disparities between the results of neat cast and reinforced resins in each in case were brought about by the role played by reinforcing material in composite.

IV. CONCLUSIONS

The following conclusions are made based on the outcome of the study:

(i). The results of tensile, compression and impact tests of the reinforced MKO bioresin composite and reinforced polyester resin (synthetic resin) composite showed that polyester resin (synthetic resin) composite can withstand more loads than the MKO bioresin composite.

(ii) Comparism of the results of reinforced composites with unreinforced (cast neat resin) composites showed that reinforced composites can withstand much higher loads than the unreinforced (cast neat resin) composites. The large disparities between the two composites were brought about by the role played by reinforcement in composite material. The reinforcement (i.e. fibre) has much more strength and stiffness than the matrix material and this characteristic is displayed when used.

(iii) The results of moisture and void contents revealed that MKO bioresin composites are more susceptible to absorb water and trap air or gas than the polyester resin composites. This is due to the chemical makeup of the resins. The moisture and void contents in the specimens tend to weaken the bond strength of the composite and thus the mechanical properties of the materials as shown in the tests results.

(iv) The overall results revealed that composite produced from MKO bioresin has appreciable mechanical and physical properties close to the polyester (synthetic) resin composite both in cast and reinforced states and thus can serve as alternative resin at lower stress applications when the need arises.

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