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Thermal and Chemical Performance Evaluation of Thevetia peruviana Oil-Based Composites Reinforced with Short Sisal Fibers

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Abstract: Thermal properties and chemical performance of newly developed *Thevetia peruviana* oil-based (TPO) bio-composites with short sisal fibers reinforcement were studied in this research, with the aim of producing materials derived from renewable resources for engineering applications. Three sets of TPO composites (5C, 10C and 15C) reinforced with sisal fibers 5, 10 and 15 wt% respectively were produced by compression moulding method. Thermographic analyser (TGA) was used to determine the thermal behavior of the new composites and the results showed that the composites thermal stability behavior increase with fiber loading. 5% degradation temperature (T5) and 10% degradation temperature (T10) of the new composites increased from 300 to 312 ^{0}C and from 338 to 419 ^{0}C, respectively. The char value of 8.264 of the unreinforced resin reduced on the addition of 5 wt% of fiber while there were enhancements in the char values of composites reinforced with 10 wt% and 15 wt% fiber. The chemical resistance and water absorption tests showed that the percentage gain/loss of the composites in all the reagents are negligible, with composite 5C showing superior resistance in all the media. The results showed that the newly produced bio-composites is a potential material for storage vessels production.

Keywords: Char; chemical; sisal fiber; renewable

I. Introduction

The increase in number of human population on earth has increased the production of consumption goods, unavoidably generated millions of tons of wastes that are not friendly to the environment. Conceivably, most of these wastes are plastics originated from fossil resources and are not environmental friendly. To mitigate their effects on the environment**,** there is a necessity for innovative, renewable and sustainable materials that would be alternatives to fossil-fuel derived materials and would safely and easily decompose in the environment [1, 2].

Researchers have focused their e**ff**orts on the development of new, cost-e**ff**ective and eco-friendly polymers/composites from renewable, natural sources, pursuing the replacement of petroleum-based products in the last decades [3-6]. Mechanical, thermal and morphological properties of biocomposites filled with derived waste biochar were investigated and the result showed that the mechanical and thermal properties of the studied biocomposites were enhanced, also the water absorption and rigidity of the composites were high. It was concluded that the studied biocomposites found application in production of plants' clips and

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supports [7]. Thermal degradation of polylactic acid (PLA) based composite reinforced with photografted pineapple leaf fibre (PALF) was studied by [8] who found that photografted PALF/PLA had significantly better thermal stability than the untreated composite. It was further shown that the composites have better serviceability and can be used for diversified applications [8].

The superior qualities such as renewability, light weight, good mechanical strength, comparable specific strengths, cost effectiveness, acoustics, CO_2 absorption and thermal insulation properties are projecting biodegradable composites at its peak; replacing synthetic ones [9]. While the problems of synthetic composites, such as environmental problems, excess strength in specific applications or over strength, require expensive costs, these problems are solved by green composites or natural composites [9, 10].

II. Materials and Methods

A. Materials used and composite development

Thevetia peruviana Oil (TPO) was extracted from its fruits picked from Federal University Oye-Ekiti. Purification and characterization of the extracted oil was done in accordance with [11]. The divinylbenzene (DVB), styrene (ST), distilled grade boron trifluoride etherate (BF3E), glacial acetic acid, toluene and benzene used were obtained from Bayer AG, Leverkusen Germany. The nitric acid, hydrocloric acid, ammonium hydroxide, sodium hydroxide, carbon tetrachloride and polytetrafluoro-ethylene (PTFE) used as releasing agent were bought from Pascal Chemicals Nigeria Limited, Akure, Nigeria while sisal leaves were harvested from Federal University Oye-Ekiti Farm. The fiber was extracted and treated as described by [12].

The composite was developed using our previous method [13], as shown in the Figure 1 while the nomenclature used for composite samples produced is shown in Table 1.

B. Methods

i. Thermo-Gravimetric Analysis

Thermogravimetric analyser TGA (Model Q500, TA Instrument, USA) was used to determine the thermal stability of the new composites. It was operated in air from room temperature to 600 ^{o}C at a heating rate of 10 ^{o}C/min on approximately 10 mg of the composite samples. The composites chemical resistance was studied in accordance with [14]. Test specimens with 150 x 15 x 3 mm dimensions from composites were used. The samples for resin (matrix material) were also prepared to serve as control.

ii. Chemical Resistance Test

Nine reagents were used for chemical resistance test of the produced TPO composites and the matrix. Glacial Acetic acid (8 %), concentrated Nitric acid (40 %), concentrated Hydrochloric acid (10 %); concentrated Ammonium hydroxide (10 %), aqueous Sodium carbonate (20 %), aqueous Sodium hydroxide (10 %); Toluene (250 ml), Benzene (250 ml), and Carbon tetrachloride (250 ml) were used after purification. The produced biocomposite samples were pre-weighed before dipping into the appropriate reagents. The composites were removed after 24 hrs and instantly washed in distilled water and dried by pressing them on both sides with the filter paper at room temperature. The samples were re-weighed and the percentage weight loss/gain was calculated with Eq. 1. The new composites water

absorption was investigated, following the same procedure used for chemical test.

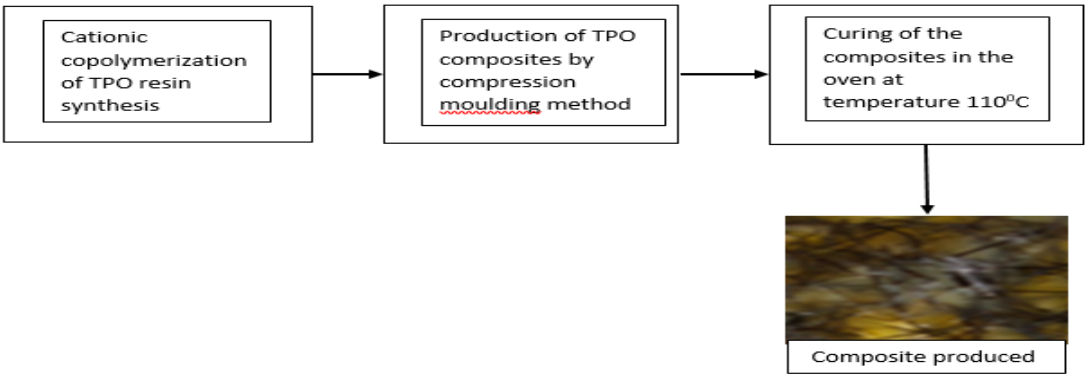

Figure 1: Flow diagram for composite production.

Table 1: Nomenclature used for the composite samples produced

Sample	Matrix wt% composition	Fiber wt% composition
Polymer 1 (Neat)	100	0
Composite 1 (5C)	95	5
Composite 2 (10C)	90	10
Composite 3 (15C)	85	15

$$\%Gain/Loss = \frac{Final\,Weight - Initial\,Weight\,(g)}{Initial\,Weight\,(g)} \times 100 \quad (1)$$

III Results and Discussion

Figure 2 shows the thermal properties of TPO polymer resin and the composites and the TGA curves, respectively. From Figure 2, weight loss in three stages was exhibited by the TPO polymer resin. Between 200 to 400 °C, the resin underwent the initial loss due to decomposition, evaporation of soluble components and unreacted oil in the resin. The second loss was exhibited between 400 to 450 °C and it is indicative of thermal degradation of the crosslinked polymer resin. Around 450 to 500 °C, the resin underwent the final loss; believed to be caused by oxidation of the carbon residue and complete decomposition of the smaller fragments. This is in agreement with the findings of [15].

Figure 3 shows the profile of 5 % weight degradation temperature of the composites and neat. It was observed that the 5 % degradation temperature T_5 is highly influenced by the sisal fibre loading. The T_5 witnessed an increase from 229.151 °C for the polymer resin (Neat) to 312.398 °C for composite 15C which is an indication that the developed composites are more thermally stable than the polymer resin.

Figure 4 shows the temperature T_{10} of 10% degradation of TPO composites and the neat.

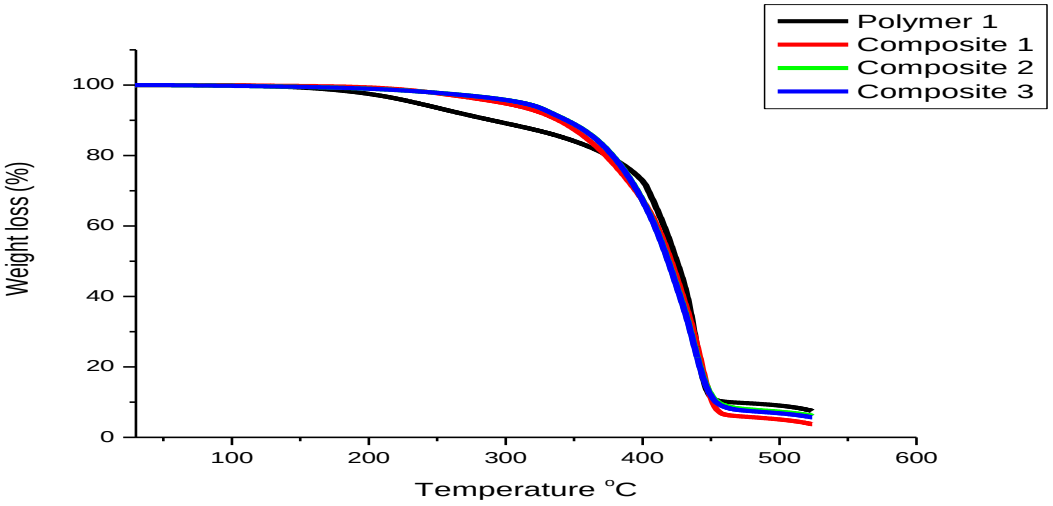

Figure 2: Plot of TGA Curves for TPO Polymer Resin and the Composites

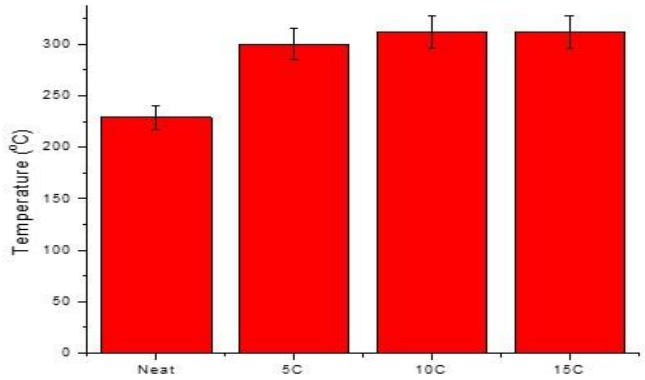

Figure 3: Plot of 5% Degradation Temperature of TPO composites and the Neat

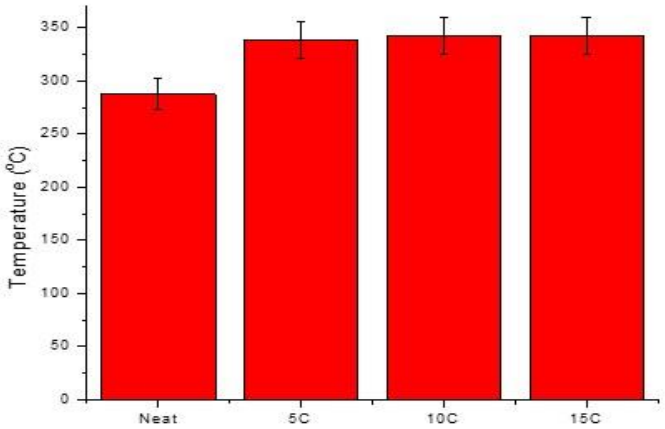

Figure 4: Plot of 10% Degradation Temperature of TPO composites and the Neat

It was shown that composites 10C and 15C; have the highest T_{10} value of 342.801 °C, followed by composite 1 (5C) with a value of 338.692 °C and these are higher than that of the polymer resin with a value of 287.416 °C. This is due to the increase of the weight percent of the sisal fibre content of the composites.

Figure 5 shows the temperature T_{max} of 50 % degradation of TPO polymer resin and composites produced. It was revealed that the percentage content of the sisal fibre has slight influence on the composites, because the T_{max} of composite 5C with value 423.886 °C is little above that of the polymer resin with a value of 423.636 °C, while composites 10C and 15C have the same value of 419.769 °C.

Figure 6 reveals TPO polymer resin and composites weight percent char. The residual weight percent was observed to reduce at the addition of 5% sisal fibres into the polymer matrix to a value of 4.871 from 8.264, and the addition of more sisal fibres increases the residual weight of the composite from 7.032 to 7.806 for composite 10C and 15C, respectively. This trend can be attributed to the fact that the fibres must have burnt off at 500 °C; leaving the

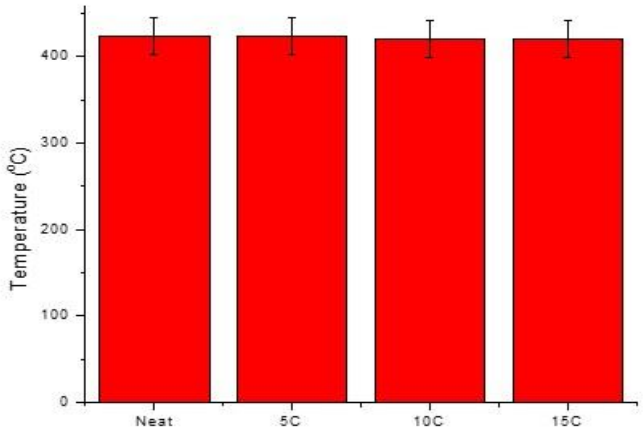

Figure 5: Plot of 50 % Degradation Temperature of TPO composites and the Neat

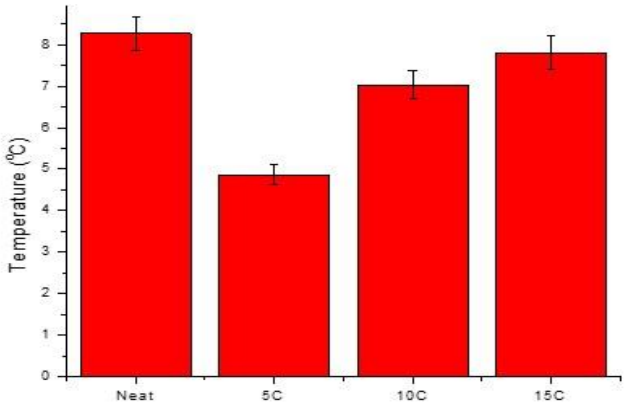

Figure 6: Char profile of TPO composites and the Neat

complete decomposed and oxidized carbon residue. The char increase observed in composites 10C and 15C is due to the increase of percentage weight of fibres content from 10 % and 15 %, respectively.

The result reveals weight gain was recorded in nitric acid, hydrochloric acid, acetic acid and sodium hydroxide reagents, while erosion was noticed in ammonium hydroxide, sodium carbonate, benzene, toluene and carbon tetrachloride reagents. The percentage gain/loss in all the reagents are negligible; with composite 5C showing superior resistance in all the media compared with the other two composites, as shown in Table 2.

From Table 3, it can be deduced that TPO composites have low percentage of water absorption, composite 5C absorbed least water with 0.0323 % value; followed by composite 10C with 0.0330 % value, and the highest water absorption value was exhibited by composite 15C. It was shown that the quantity of fibre loading is directly proportional to the corresponding water absorption value of the new composite and this can be attributed to the water affinity of natural fibres. It was also observed that the values of water absorption for TPO composites are negligible.

Table 2: Resistance of TPO Composites to Chemical Reagents

Chemicals	**5C**	**10C**	**15C**
	% gain/loss	**% gain/loss**	**% gain/loss**
40% Nitric acid (HNO_3)	+0.3095	+0.3148	+0.3200
10% Hydrochloric acid (HCl)	+0.2193	+0.2348	+0.2567
8% Acetic acid (CH_3CHOOH)	+0.0900	+0.1097	+0.1400
10% Sodium hydroxide (NaOH)	+0.1000	+0.1333	+0.1699
10% Ammonium hydroxide (NH_4OH)	-0.4499	-0.4151	-0.3300
20% Sodium carbonate (Na_2CO_3)	-0.1233	-0.0828	-0.0631
Benzene (C_6H_6)	-0.2867	-0.2610	-0.2131
Toluene (C_7H_8)	-0.0933	-0.0667	-0.0367
Carbon tetrachloride (CCl_4)	-0.3533	-0.2600	-0.1833

Table 3: Water absorption of TPO Composites

Sample	**5C**	**10C**	**15C**
Water (H_2O)	0.0323	0.0330	0.0339

IV Conclusion

Conclusion was drawn on the discussion of the above data that;

1. The newly bio-composites developed, possessed enhanced thermal and chemical resistance properties compared to the polymer resin.
2. The composites can be used in production of storage tanks because of the chemical resistance exhibited by the composites.

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