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Thermal Degradation and Viscometric Analysis of Sugarcane Fiber-Filled Biodegradable Polymer Composites

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Abstract— *This study examines the production and description of biodegradable polymer composites using sugarcane fiber and sweet potato starch. It is centered on assessing the thermal and flow behavior of the composites. It starts with a comprehensive analysis of the biodegradability of polymers as well as their environmental and economic effects, in particular against conventional plastics. The procedure includes the starch extraction, sugarcane fiber preparation, and creation of composite samples with different compositions. The methods used to analyze the samples include FTIR, viscometric analysis, and thermogravimetric analysis (TGA). The sample lacking fiber was proven to be more thermally stable (350°C to 500°C at 70 to 75%), and in the case of viscosity, the sample with fiber shows a far steeper rise. In the case of samples containing fiber, it can be seen that viscosity decreases rapidly to approximately 2.6-3.0 units of concentration, and then a slight plateau occurs. The green line (sample without fiber) indicates a visible jump at the range of 3.2-3.4 concentration units. It was found that sugarcane fiber can help in raising thermal stability and elevating the viscosity of the polymer matrix, which proves it to be an effective reinforcing material in biodegradable composites.*

Keywords— *Biodegradable composites, sugarcane fiber, thermal degradation, viscometric analysis, sustainability.*

I. INTRODUCTION

The creation of chemical reactions to produce synthetic polymers (plastics) using crude oil was a major breakthrough in the fields of chemistry and material sciences and led to one of the most versatile families of materials ever made. These polymers brought together the best qualities of strength, flexibility, light weight and low-cost production. But this made them one of the most non-biodegradable synthetic materials, which, however, made them so durable, and that is why they found extensive use in industrial and agricultural as well as domestic areas. This is because polyethylene (PE), the most consumed synthetic polymer, is produced globally at an approximate rate of 140 million Mg/year, out of the total of over 180 million Mg of plastics generated annually [34]. These plastics eventually turn into solid waste at the end of their life cycles, and this has become a source of great concern to the environment because of their persistence.

Traditional petroleum-based plastics cannot be biodegraded due to their good stability and hydrophobic properties [29]. Being inert, strong, lightweight, hygienic, and affordable, they cannot easily decompose in nature which leads to pollution and ecological imbalance. As a result, studies have turned into creating degradable plastics out of renewable agricultural products or altered petroleum plastics with degradable additives. Biodegradation plays a key role in transforming the polymer substrates into environmentally friendly elements, including carbon dioxide, water and humid substances, which can be applied as high quality farming fertilisers [34]. However, not every degradable plastic is completely decomposed in the natural environment, which casts doubts on the meaning and actual environmental advantages of "biodegradability" [34].

Bio plastics According to ASTM and ISO, biodegradable plastics are those that experience substantial chemical transformations in response to selected environmental conditions, leading to the loss of both physical and mechanical properties. This degradation is normally either by the effect of microorganisms such as bacteria, fungi, and alga or by photodegradation, oxidation and hydrolysis (Narayan et al., 1999). The biodegradable polymers are broadly divided into synthetic and natural polymers. PLA, poly(glycolic acid) (PGA), and polybutylene succinate (PBS) are synthetic biodegradable polymers that have been used in the fields of medicine and packaging [12]. Renewable resource-based natural biodegradable polymers such as starch, cellulose, and proteins are also becoming more and more popular concerning their environmental benefits and biodegradation [4].

Agricultural wastes such as rice husk, wheat straw, and sugarcane bagasse are gaining increasing popularity as a reinforcement to biodegradable composites among natural fillers. A significant part of the bagasse, a fibrous by-product of sugar production, is usually underutilized, and a significant proportion is burned as an energy source, leading to air pollution [9]. Bagasse, with almost half of fiber content is a renewable, inexpensive, and biodegradable resource that can be used to strengthen polymer [22]. Sugarcane fiber improves mechanical properties of composite, is biodegradable and minimizes carbon footprint of polymer production. Nevertheless, moisture absorption, low thermal resistance, and problems with processing also need to be overcome to leverage its usage to its fullest capacity [15].

The addition of sugarcane fiber to biodegradable polymer matrices enhances the mechanical strengthening of the polymer, as well as, promotes sustainable development, through the valorization of agricultural waste. Uses of sugarcane fiber composites include packaging, vehicle, biomedical equipment, and materials used in construction [48]. Having knowledge of their thermal stability and degradation characteristics will help forecast their performance in the real world, whereas viscometric analysis will be important to understand how they will behave in flow and how their molecules interact.

As such, the current research explores the thermal degradation and viscometric characteristics of sugarcane fiber-based biodegradable polymer composites, in turn, providing further contributions to the development of eco-friendly materials that can be used widely in the industries.

II. MATERIALS AND METHODOLOGY

A. *Materials*

The apparatus used in this study included an analytical weighing balance, filter paper, funnel, measuring cylinder, stirring rods, spatula, hotplate, conical flask, glass mold, blender, sieve, Fourier-transform infrared (FTIR) spectrometer, and U-tube viscometer.

The materials and reagents employed were sugarcane rinds, sweet potatoes, distilled water, acetic acid, glycerol, sodium azide (NaN_3), and sodium hydroxide (NaOH). All reagents were of analytical grade and used without further purification.

B. *Sample collection*

Sweet potatoes and sugarcane rinds were sourced from local markets in Kabuga, Kano State, Nigeria.

C. *Preparation of 0.1M NaOH*

0.1M NaOH was prepared by weighing approximately 1g of NaOH pellets into a beaker. In a 250ml volumetric flask, about 200ml of distilled water was added, the NaOH was then added into the volumetric flask and shaked until the NaOH dissolved completely, then more distilled water was added to the 250ml mark.

D. *Preparation of 1% NaN_3*

0.1% NaN_3 was prepared by weighing approximately 2.5g of NaN_3 into a beaker. In a 250ml volumetric flask, about 200ml of distilled water was added, the NaN_3 was then added into the volumetric flask and shaked until the NaN_3 dissolved completely, then more distilled water was added to the 250ml mark.

E. *Preparation/extraction of starch*

Sweet potatoes were and soaked in a solution of distilled water and 0.1% sodium azide (NaN_3) at a 1:2 ratio for 24 hours to inhibit microbial growth. After thorough washing, excess water was drained, and the sweet potatoes were blended with sufficient water. The resulting slurry was filtered through a sieve, and any remaining solids were re-slurred with water to remove the germs and peels. This grinding, sieving, and regrinding process was repeated multiple times until the particles were free of residual fibers. The starch was then purified by repeated washing, redistributing in distilled water, and centrifuging until it appeared clean. Finally, the purified starch was air-dried on white paper for several days until fully dry, then blended again to obtain a fine, white powder [13].

F. *Preparation of sugarcane fiber*

Sugarcane bagasse was obtained as waste material from juice extractor, [3]. The sugarcane rind was first separated from the pith, and its nodal regions were removed due to their distinct physical properties. The rind pieces were then immersed in hot water to eliminate sugars. Following this, they were soaked in a 0.1 mol sodium hydroxide (NaOH) solution at atmospheric pressure for 1–2 hours. After treatment, the rinds were dried in a hot air oven at 121°C. Once fully dried, they were ground into fine particles using a mortar and pestle.

G. *Preparation of different composite materials*

20 samples of polymeric composites were prepared with varying compositions of glycerol, sugarcane fiber and starch in addition with distilled water and acetic acid presented in the table 1.0 below.

For each sample, 1mL of 5% acetic Acid solution was poured into a beaker and the starch was added followed by Glycerol and then the fiber. The resulting solution was heated on a hot plate for about 10 minutes until a sticky mixture was attained.

Foil paper was used to wrap the inner part of the glass mold and molten hot composite was added into the mold and allowed to solidify for a period of 2 to 3 days.

TABLE 1: Formulation of 20 Different Composites

Serial number	Starch content (g)	Glycerol content (mL)	Fiber content (g)
1	33.75	14.5	1.65
2	33.75	14.5	4.42
3	35.5	13.0	0
4	32	13.0	3.3
5	32	13	0
6	35.5	16	0
7	35.5	16	3.3
8	33.75	12	1.65
9	33.75	14.5	1.65
10	36.69	14.5	1.65
11	33.75	14.5	1
12	33.75	14.5	1.65
13	35.5	13	3.3
14	33.75	14.5	1.65
15	32	16	0
16	33.75	14.5	1.65
17	32	16	3.3
18	33.75	14.5	1.65
19	33.75	17	1.65
20	30.81	14.5	1.65

H. *Viscometric Measurement*

Four different polymer samples of varying composition of 1g, 0.8g, 0.6g and 0.4g were dissolved in 30ml of 5% NaOH. The dissolved solution was poured into U-tube viscometer, the time taken for the polymer solution to flow from mark A to mark B was recorded. The process was carried for all the dissolves samples and also the time was recorded [42].

I. Thermogravametric Analysis

TGA was performed using perkin Elmer TGA instrument. 10 ± 2 mg of the polymer composites was measured using analytical weighing balance and transferred into a TGA crucible.The TGA machine was calibrated to the temperature range of 30-800. The heating process was started, and the mass loss was recorded as the temperature increases [10].

III. RESULTS AND DISCUSSION

A. Results

Based on the methodology used above, several results were obtained, presented as follows.

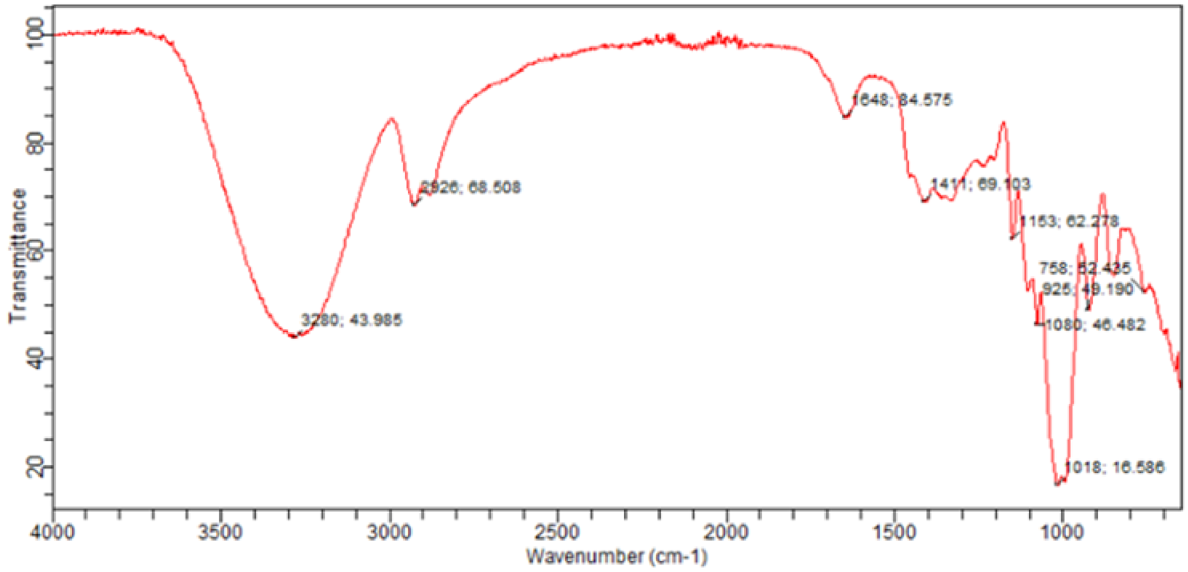

Figure 1: FTIR result of sample A

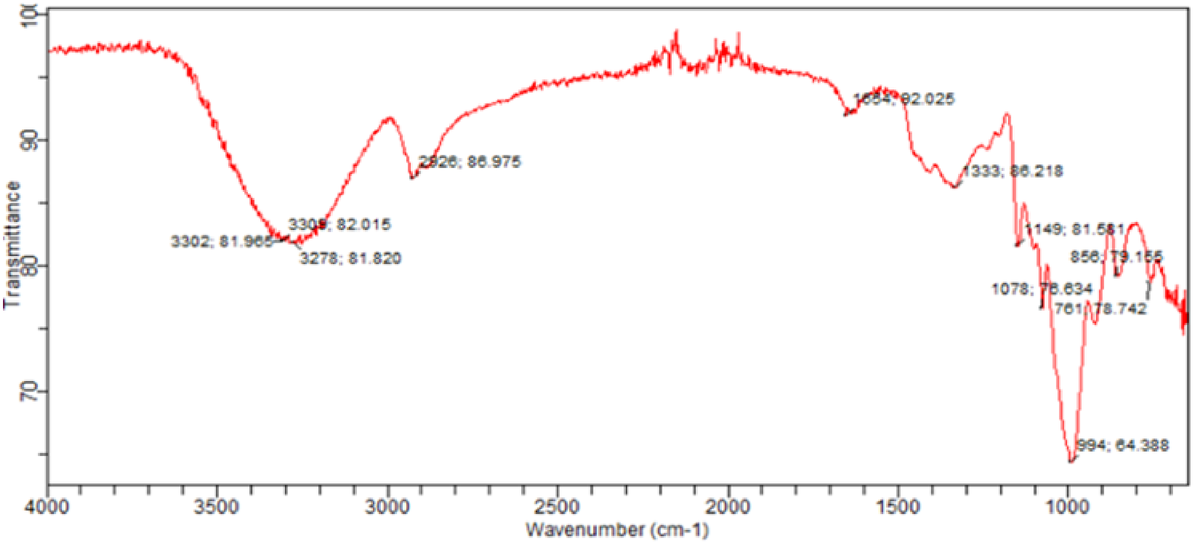

Figure 2: FTIR result of sample B

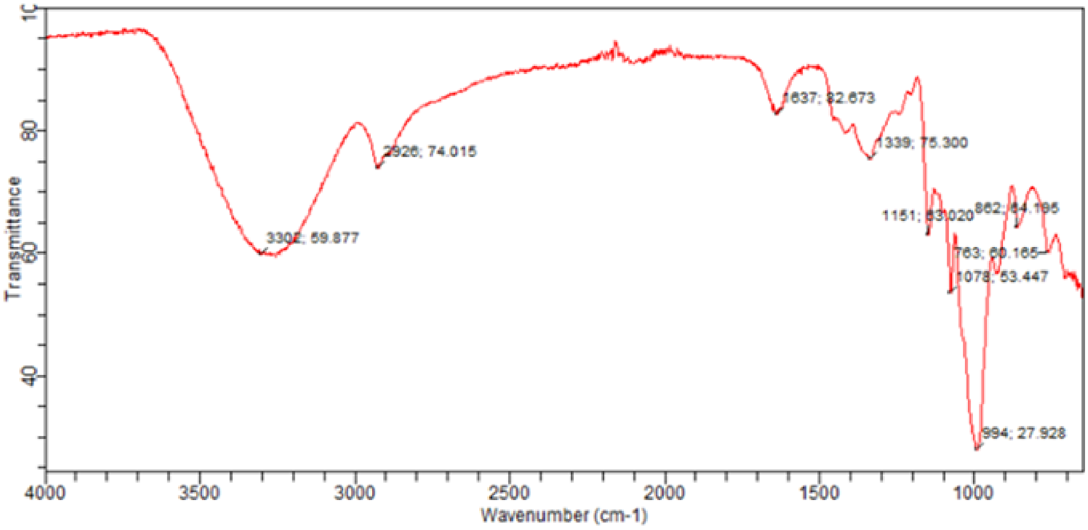

Figure 3: FTIR result of sample C

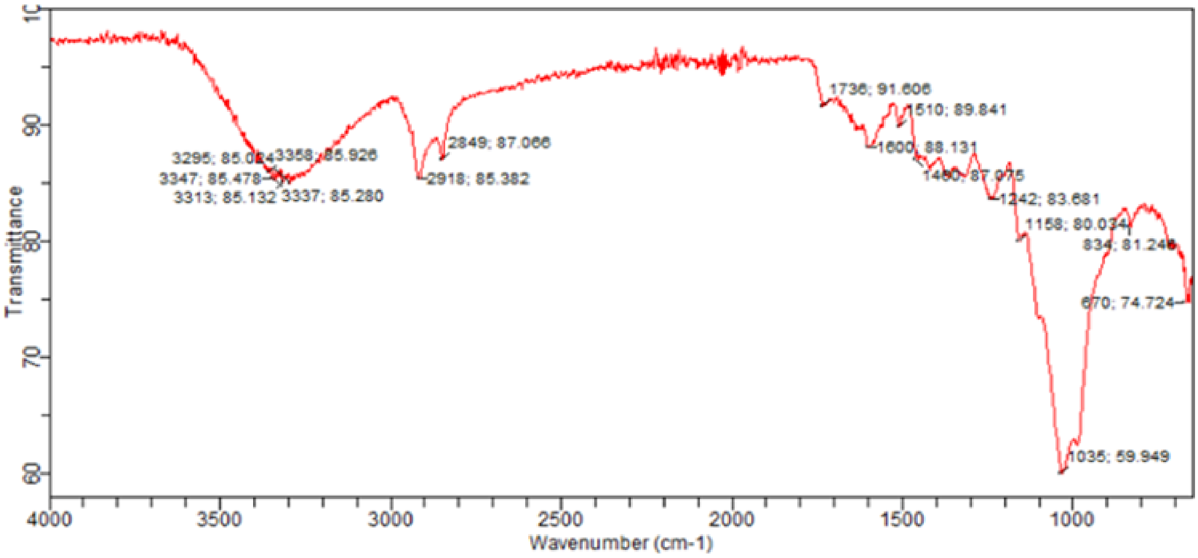

Figure 4: FTIR result of sample D

TABLE 2: Viscosity data for the polymeric materials at 30°C

Sample	Samples Weigh (g)	Concentration gdL^{-1}	t (s)	η_{rel}	η_{sp}	η_{red}	η_{inh}
A	1.0	3.33	14.84	4.216	3.216	0.996	0.432
	0.8	2.67	11.55	3.281	2.281	0.854	0.332
	0.6	2.00	8.01	2.281	1.281	0.688	0.411
	0.4	1.33	6.43	1.827	0.827	0.622	0.453
B	1.0	3.33	32.41	9.207	8.207	2.465	0.667
	0.8	2.67	27.00	7.670	6.670	2.498	0.763
	0.6	2.00	19.83	5.634	4.634	2.317	0.864
	0.4	1.33	9.11	2.588	1.588	1.194	0.715
C	1.0	3.33	20.72	5.886	4.886	1.467	0.532
	0.8	2.67	14.41	4.094	3.094	1.159	0.528
	0.6	2.00	9.57	2.727	1.724	0.862	0.501
	0.4	1.33	5.11	1.452	0.452	0.339	0.280
D	1.0	3.33	36.67	10.418	9.418	2.828	0.704
	0.8	2.67	12.75	3.622	2.622	0.982	0.482
	0.6	2.00	9.64	2.739	1.739	0.869	0.504
	0.4	1.33	6.81	1.935	0.935	0.703	0.496

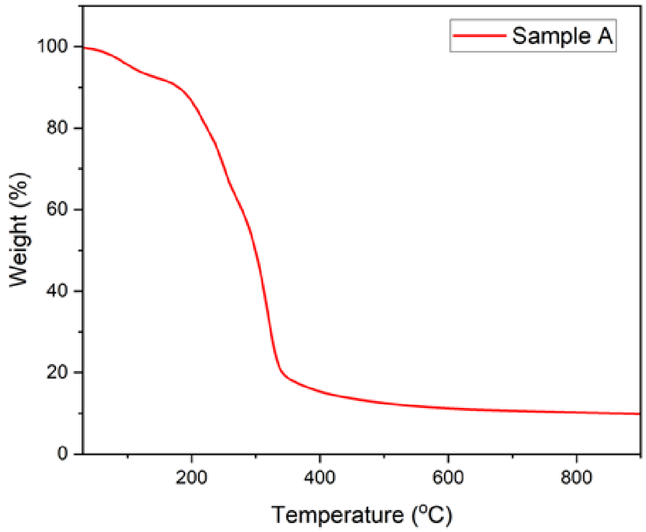

Figure 5: TGA results of sample without fiber

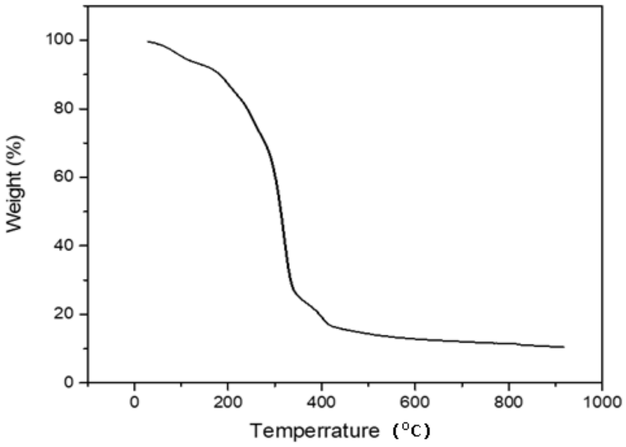

Figure 6: TGA results of sample with fiber

B. *Discussion*

I. FTIR Analysis

As shown in Figures 1-5, the infrared spectroscopy of the four samples demonstrated that several functional groups existed in the chemical structures of these samples [36].

The spectrum in Figure 1 indicates the existence of some absorption peaks in it, with a broad peak of about 3280 cm-1, which is related to the O-H bond vibrations and implies the existence of hydroxyl groups. The presence of a clear peak at 2926 cm-1 is an indication of the C-H bond stretching, whereas the presence of a peak at about 1648 cm-1 is the indication of conjugated double bonds, which are usually related to aromatic rings. Equally, Figure 2 indicates wide absorption peaks of 3278-3302 cm-1, associated with O-H stretching vibration, which indicates the existence of hydroxyl groups. Moreover, at 2926 cm-1, there is a peak relating to the C-H bond stretching and at 1654, there was an absorption that relates to conjugated pair bond and thus indicated aromatic ring structures.

To figure 3, the spectrum once more shows a wide absorption peak at 3302 cm-1 of O-H bond-stretching vibrations and the existence of hydroxyl groups. This is supported by a peak at 2926 cm-1 attributed to C-H stretching with the absorption at 1637 cm-1 typical of aromatic rings. Lastly, as seen in Figure 4, there are several large peaks at 3295, 3313 and 3347 cm-1 which are all O-H bond stretching vibrations, thus confirming the presence of hydroxyl groups. Two, unlike the prior spectra, distinct peaks emerge at 2849 and 2918 cm-1 which are attributed to C-H vibrations of hydrogens in varying environments. Further, the high rate of absorption at 1736 cm-1 implies that there are C=O stretching vibrations, which implies the presence of carbonyl groups.

II. Viscosity Measurement

Addition of fibers greatly augments the diminished viscosity of the polymer solution in all concentrations. This is predicted due to the fact that fibers not only limit the movement of polymer chains, but also amplify intermolecular interactions and enhance the solution viscosity [6].

In both samples, the steeper increase in viscosity is observed with concentration, although the fiber-filled sample rises much steeper because of extra physical barriers (fibers) and greater hydrodynamic volume in the solution.

The fact that the curve of fiber samples levels off at high concentrations indicate the creation of a pseudo-network or entangled structure, in which the increase in concentration no longer creates a proportional increase in viscosity [6].

III. Thermogravametric Analysis (TGA)

To test the stability of the samples under heat and the decomposition process, thermogravimetric analysis (TGA) was used. According to Glusac et al. (2018), the significant loss of weight at temperatures ranging 300°C-500°C is attributed to the decomposition of organic substances, and the mass not lost after 500°C is the inorganic fillers and char or ash contents that are stable even at 800°C.

The thermal degradation occurred in distinct stages. In the first stage (0-100/150degC), a slight weight loss was observed, which can be attributed to the evaporation of absorbed moisture. As the temperature increased to ~150-350degC, a second stage of degradation took place, accounting for approximately 5-10% weight loss, and was likely due to the decomposition of low molecular weight compounds, plasticizers, or additives. The third and most significant stage (350-500degC) corresponded to the breakdown of the polymer backbone, resulting in the major decomposition of the material.

A comparative analysis between the fiber-reinforced and non-reinforced samples further highlights the impact of fiber addition on thermal stability. Weight loss in the sample without fiber was about 70-75 thus resulting to 20-25 percent remaining mass, which slowly leveled off to zero. Conversely, fiber showed a lesser weight loss of 50-55% with a greater residual mass of 30-40% that corresponds to a better thermal resistance.

IV. CONCLUSION

This research highlights the potential of sugarcane fiber as a reinforcing fiber in biodegradable polymer composite made of sweet potato starch. The findings show that the addition of sugarcane fiber serves to improve thermal stability and viscometric properties of the composites. FTIR analysis showed the presence of major functional groups and viscosity measurements indicated that fiber addition increased resistance to flow significantly with an indication of more intermolecular interactions and pseudo-network formation at increased concentrations. The thermogravimetric analysis further revealed that fiber-filled composites maintained a higher residual mass and weight loss was less than that of fiber-free samples which proved the increased thermal stability.

In general, the research confirms that the sugarcane fiber does not only offer a sustainable application of the agricultural byproducts, but also enhances the functionality of the starch-based biodegradable polymers. These discoveries highlight the promise of sugarcane fiber-based composites as promising alternatives to traditional plastics, and they have potential uses in packaging, building and construction, automobile, and other highly sensitive industries to environmental needs.

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