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Hemp Fiber-Reinforced 1-Pentene/Polypropylene Copolymer: The Effect of Fiber Loading on the Mechanical and Thermal Characteristics of the Composites

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ABSTRACT: One of the recent developments in composite technology in South Africa is the increasing use of natural fiber materials in the manufacture of plastic products. Most of the previous work on natural fiber-reinforced composites has focused on sisal fiber as it was commercially available. In this study, the mechanical and thermal properties of composites made with locally produced hemp fibers, were compared with composites made with hemp fibers produced in France. New commercial polypropylene random copolymer was used as matrix because it can be processed at lower temperatures when compared with other commercial propylene copolymers. The composites were produced by extrusion compounding and were further processed into tensile test bars by injection molding. Up to 30% fiber loading could be achieved. It was observed in all composites that increasing the amount of fiber resulted in an increase in tensile strength, elastic modulus, and flexural strength and a decrease in impact strength. The thermal properties of the composites were analyzed by the thermogravimetric method. It was found that the fiber/PP composites showed excellent properties when compared to fiber and the matrix separately. The addition of hemp fibers shifted the start of the degradation process towards higher temperatures. The results obtained show that the mechanical and thermal properties of South African long hemp fiber composites compare favorably well with the French bleached and unbleached hemp fibers.

KEY WORDS: hemp fibers, polypropylene/1-pentene random copolymer, hemp fiber composites.

INTRODUCTION

THE COMPOSITE TECHNOLOGY of a polymeric matrix reinforced with man-made fibers such as glass, Kevlar and carbon, has raised great interest amongst researchers with the advances in automotive and aerospace applications. The drawback is that these fibers have the disadvantage that they impart properties to both manufacturing and post consumer waste products that result in recycled products with unpredictable properties. Glass fibers are relatively expensive and do not burn during thermal recycling and remain as solid waste that has to be land-filled.

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Figures 2–12 appear in color online: http://jrp.sagepub.com

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In recent years, there has been a renewed interest in the use of natural fiber as a substitute for glass fiber because of the potential advantages of weight saving, lower raw material price, recyclable, and renewable [1–12]. Natural fibers have always found wide applications from the time they gained commercial prominence. However, natural fibers exhibit high moisture absorption, which can be a major problem for many applications [13–15]. The quality of a fiber-reinforced composite depends considerably on the fiber/matrix interface because the interface acts as a binder and transfers stress between the matrix and the reinforcing fibers. However, studies have indicated that maleic anhydride can serve as an effective compatibilizer for natural fibers and polyolefin matrices resulting in the improvement of the mechanical properties [5,10,16–18]. Keller [19] reported that the tensile strength of the ductile hemp/PP composites was almost doubled (to 30 MPa) by the addition of 27%. Wambua et al. [7] studied the mechanical properties of different natural fiber composites. They found that hemp composites showed the highest tensile strength (52 MPa), flexural strength (54 MPa), and tensile modulus (6.2 GPa) when compared to the other natural fiber composites.

Thermal analysis is a useful technique that can be employed to determine the thermal stability and to quantify the amount of moisture and volatile products, which can cause deterioration and degradation in the natural fiber/PP composites. Thomas et al. [11] studied the thermal and crystallization behavior of short sisal fiber-reinforced polypropylene composites, while Wielage et al. [20] studied the thermogravimetric and differential scanning calorimetric analysis of natural fibers and polypropylene. In both studies, it was observed that the thermal stability of fiber/matrix composite is higher than that of the fiber and the matrix.

In South Africa, considerable attention has been given to the investigation of the mechanical and thermal properties of hemp fiber-reinforced composites because of the growing trials of hemp fibers in the Eastern Cape of the country. From an economical point of view, the government has realized that if cultivated and processed for the international market, hemp can solve many of the problems facing the economy, unemployment, and rural underdevelopment and poverty. It is believed that little or no work has been published on hemp fiber-reinforced polypropylene/1-pentene random copolymers, hence the essence of this investigation.

EXPERIMENTAL

Materials

The South African long hemp and the French unbleached and bleached slivers used in this study were supplied by the CSIR, Textile Technology Division in Port Elizabeth, South Africa. The South African (S.A.) long hemp fibers were produced by CSIR whereas the French unbleached and bleached hemp slivers were imported from France. The unbleached hemp slivers were locally cottonized for further applications.

The polypropylene random copolymer granules used have a melt flow index of 8.5 g/10 min and were of propylene/1-pentene random copolymers (PP1) and manufactured in South Africa by Sasol Polymers. The compatibilizer used to promote the adhesion between the fiber and the polypropylene was a polypropylene-grafted-maleic anhydride (MAPP) wax, known as Permanol 603 supplied by Dick Peters (The Netherlands).

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Preparation of PP/Hemp Composites

The composite consisted of fiber, matrix, and compatibilizer mixtures. The amount of the compatibilizer was kept constant at 2% weight of the total fiber, while the fiber content was varied and is given in Table 1. The quantity of granulated hemp fiber was calculated on dry basis in order to obtain the correct reading. The hemp fiber contents were set at 0, 5, 10, 20, and 30% weight of the matrix. The balance of the mixture was made up of the polypropylene/1-pentene random copolymer granules, always to give a total weight batch size of 100%. A comparative control (matrix without fiber) was included which did not contain any compatibilizer.

The hemp fibers were dried overnight in an air-circulating oven at 60°C before being chopped into the desired length for the preparation of composites. It is important to dry them because they absorb moisture from the atmosphere and tend to swell [10]. The hemp fibers were chopped to a length of approximately 10 cm by guillotine machine. The fibers were then fed into the granulator (Type S10/9) having an 8 mm screen (manufactured by H. Dreher Maschinenbau from Aachen, Germany). However, since much longer (than 8 mm) fibers can pass through the 8 mm holes in the screen, a wide fiber length distribution was observed.

Compounding and Extrusion

The mixture was compounded with a small single screw laboratory extruder (Cavity Transfer Mixer-(CTM)) from Rapra Technology Ltd. The temperatures used during the compounding process were kept relatively low to prevent thermal degradation of the hemp fiber. The zones' set temperature, depending on the fiber content are as shown in Figure 1.

Table 1. Overview of hemp fiber composite mixtures.

Fiber/matrix/compatibilizer composition		
Fiber (g)	**Matrix (g)**	**Compatibilizer (g)**
0	1000	0
50	931	19
100	882	18
200	784	16
300	686	14

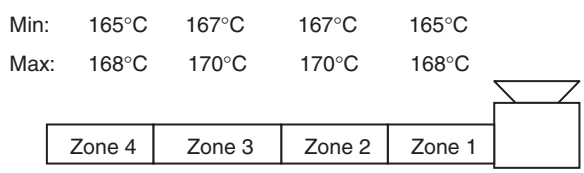

Figure 1. *Schematic diagram of temperature zones of extruder.*

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The screw speed was varied between 50 and 60 rev/min. The extrudate was cooled in a water bath. The compounded and extruded materials were collected as strands and pelletized in a standard strand pelletizer used in plastics compounding. The material was fed into the machine by rotating rollers. The blades of a large rotating cylinder cut the material. This resulted in cylindrical pellets approximately 3 mm long.

Injection Molding

Since water was absorbed during the cooling process, the pellets were dried in an oven at 60°C for 48 h before injection molding. This was to reduce the moisture content in the samples because it could lead to formation of air bubbles in the specimens that can result in poor mechanical properties. The compounded granules were injection molded for tensile test specimens, using a Mannesmann Demag Injection molding machine (Type D60 NC III-K). Table 2 shows the molding variables set on the injection molding machine.

MATERIAL CHARACTERIZATION

Tensile Behavior

Specimens were conditioned for 3 days at 23°C and 50% relative humidity. The tensile properties of the composites were measured with an Instron Model 4302 testing machine (ASTM D-638M). The width and the thickness of each sample were approximately 10 mm and 4 mm, respectively. The crosshead speed was 10 mm/min at a strain rate of 10 points/s. An average of six test specimens was used for the tensile strength determination.

Flexural Strength

Rectangular test pieces for flexural test were cut from the injection molded tensile test specimens. The flexural tests were performed on the same machine as tensile tests using the three-point bending method according to ASTM D-790M. The specimen was freely supported by a beam and the maximum load was applied in the middle of the specimen.

Table 2. Operating parameters set on the injection molding machine.

Factor	Levels for PP1
Dosing (mm)	65
Screw speed (rpm)	63
Back pressure (bar)	7
Barrel temperatures (°C)	180–185–185–185
Hold pressure (bar)	25
Injection time (s)	8
Injection speed (rpm)	15
Injection pressure (bar)	40
Cooling time (s)	20
Hold time (s)	15

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The tests were carried out at a temperature of 23°C and the relative humidity of 50%. The crosshead speed was 1.7 mm/min at a strain rate of 10 points/s.

Impact Strength

The impact strength of the samples was measured on the injection molded tensile test specimens using an Izod impact test machine. All test samples were notched. The method used for impact strength testing was according to ISO 180. The test specimen was supported as a vertical cantilever beam and broken by a single swing of a pendulum. The pendulum strikes the face of the notch.

Thermogravimetric Analysis

Thermogravimetric analysis was carried out on a Perkin Elmer TGS-2, coupled to a System-4 microprocessor and a TADS data station. Nitrogen gas at a flow rate of 20 ml/min was used to purge the furnace and the heating rate was 10°C/min.

RESULTS AND DISCUSSION

Mechanical Properties

The tensile strength, flexural strength, and impact strength are shown in Figures 2–5. It is clear that an increase in fiber content led to an increase in tensile strength in all

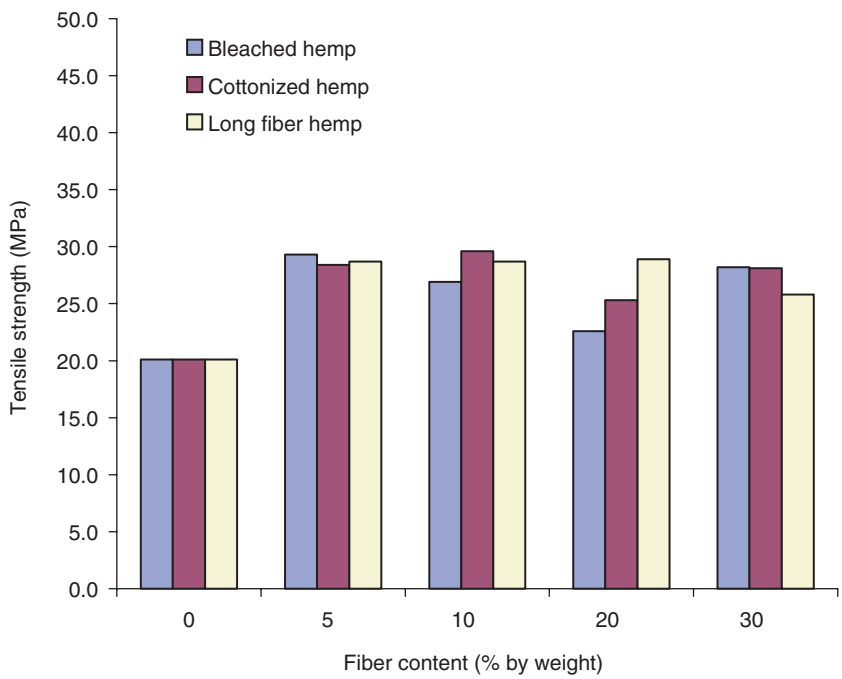

Figure 2. *Effect of fiber content in PP1 composites on tensile strength.*

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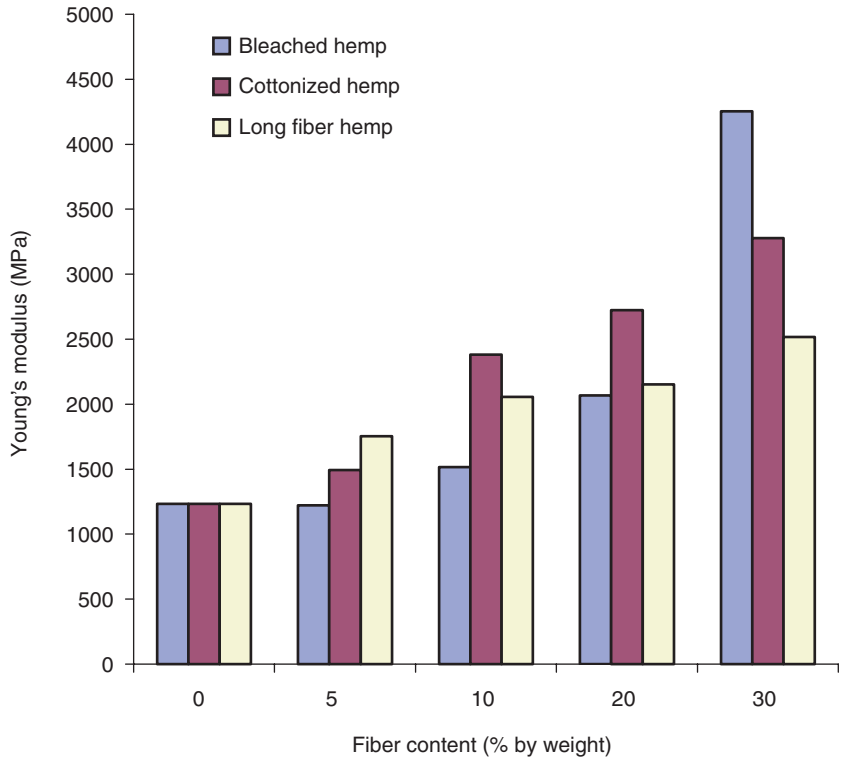

Figure 3. *Effect of fiber content in PP1 on Young's modulus.*

fiber composites. However, a decrease in tensile strength of bleached hemp/PP composite is noticed when fiber content increases from 10 to 20%.

In Figure 3, fiber reinforcements resulted in a significant increase in modulus. Bleached composites showed a higher modulus value (4252 MPa) at 30% fiber content while cottonized and long fiber composites showed the lowest modulus (3279 and 2518 MPa respectively). Generally, the bleached and cottonized fibers showed better reinforcements than long hemp fiber. As expected, it is clear from Figure 4 that the flexural strength of all hemp fiber composites increased with increasing fiber content. Long hemp fiber/PP composites compare well with bleached and cottonized hemp fiber composites at higher fiber content (>10% fiber content).

Figure 5 shows the measured impact strengths of the fiber/PP composites. Generally, the impact resistance was not improved by fiber reinforcement for all hemp fiber/PP composites. The low impact strength could be the result of weak interfacial bond strength between the hemp fibers and the PP matrix.

Thermogravimetric Analysis

Thermogravimetric curves within the temperature range of 30–650°C of PP1, hemp fibers, and hemp fiber/PP1 composites containing 30% fiber are shown in Figures 6–12. From Figure 6, PP1 decomposes at a temperature of about 503°C, which is higher than that of the hemp fibers in Figures 7–9. The slight drop in mass of all hemp fibers at the

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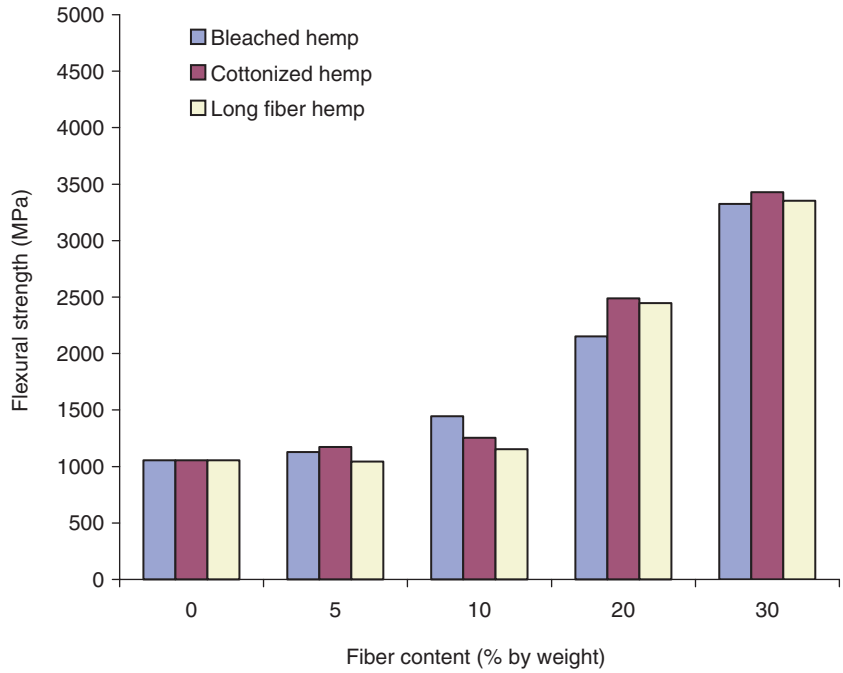

Figure 4. *Effect of fiber content in PP1 on flexural strength.*

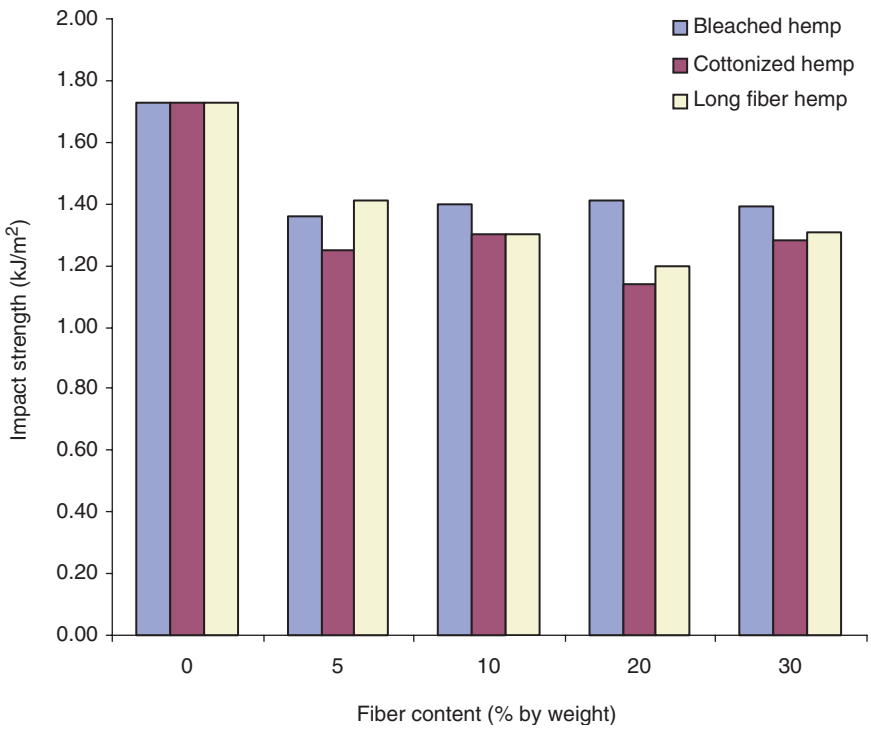

Figure 5. *Effect of fiber content in PP1 on impact strength.*

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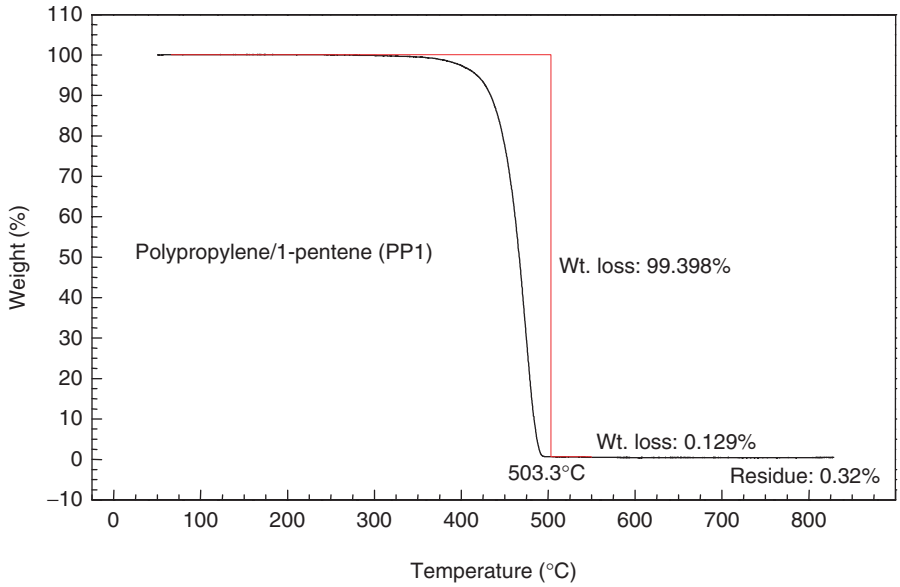

Figure 6. *Thermogravimetric curve of polypropylene/1-pentene copolymer.*

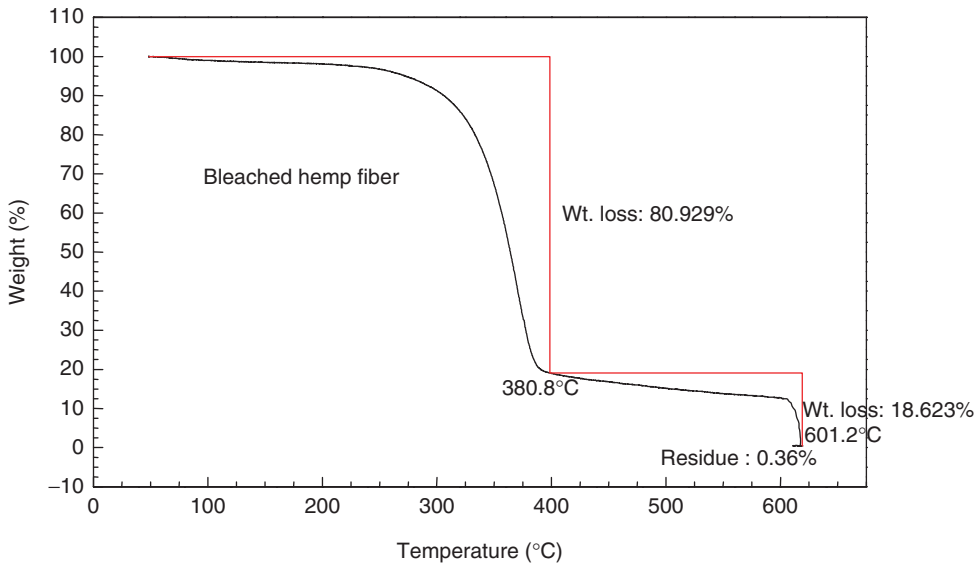

Figure 7. *Thermogravimetric curve of bleached hemp fiber.*

beginning of the curve is due to the heat of vaporization of water from the fiber [11]. The bleached, cottonized and long hemp fibers decomposed at relatively close temperatures (380, 382, and 385°C respectively). At these temperatures, similar mass loss of about 70% was observed for both cottonized and long hemp fibers, while bleached hemp fiber showed

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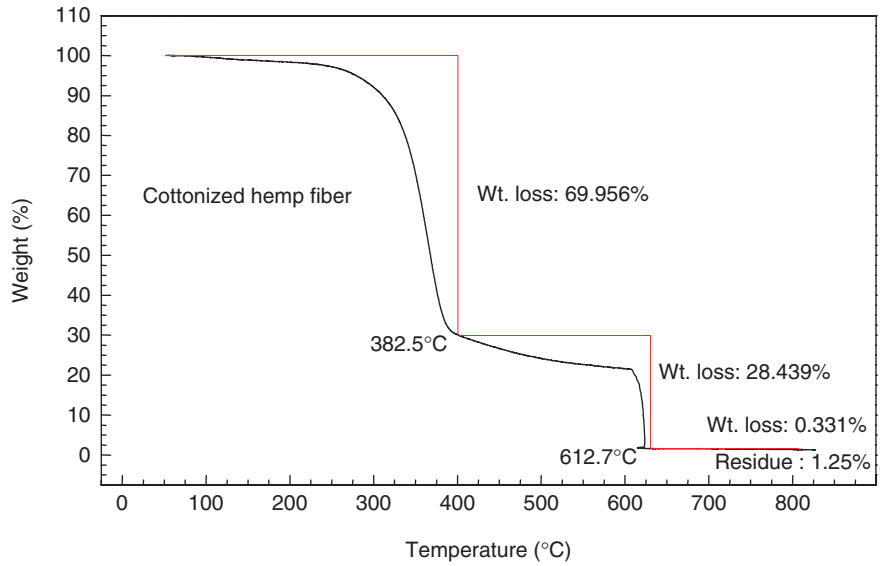

Figure 8. *Thermogravimetric curve of cottonized hemp fiber.*

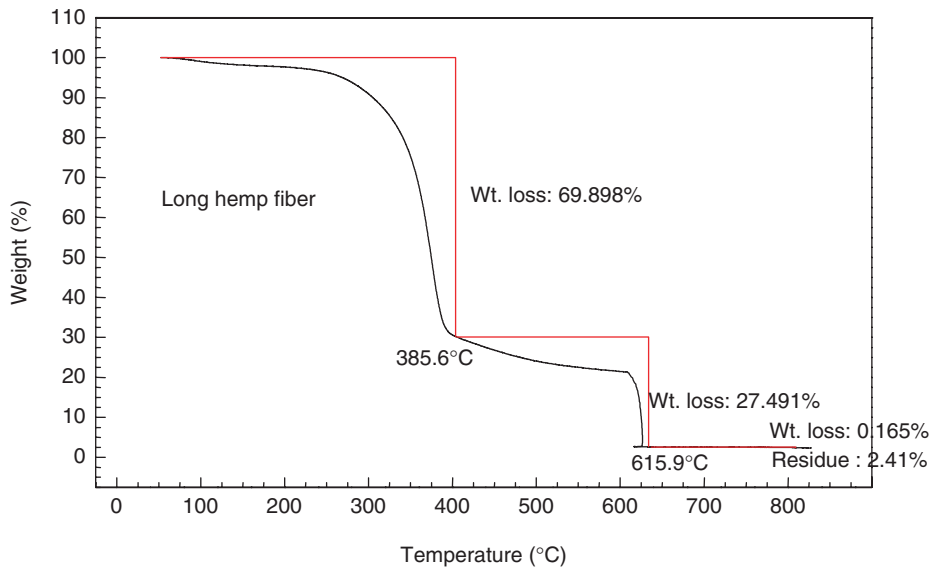

Figure 9. *Thermogravimetric curve of long hemp fiber.*

a higher mass loss of 80%. This could be due to the bleaching agent weakening the bonds in the hemp fiber.

In all the thermogravimetric curves for all hemp fiber/PP1 composites, two curves are observed: a minor curve corresponds to the degradation of cellulose and a major curve corresponds to the degradation of hydro cellulose [11]. From Figure 10, it is clear that the

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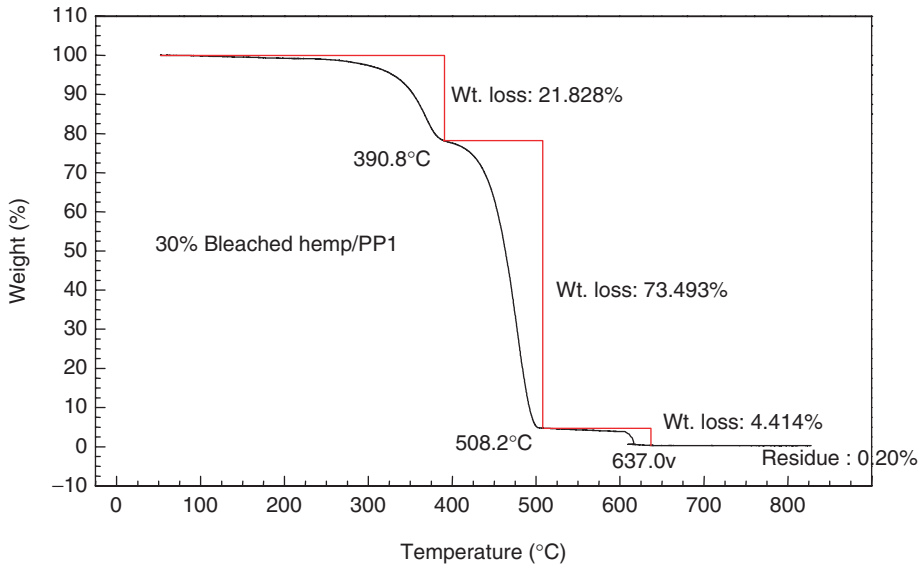

Figure 10. *Thermogravimetric curve of 30% bleached hemp fiber/PP1.*

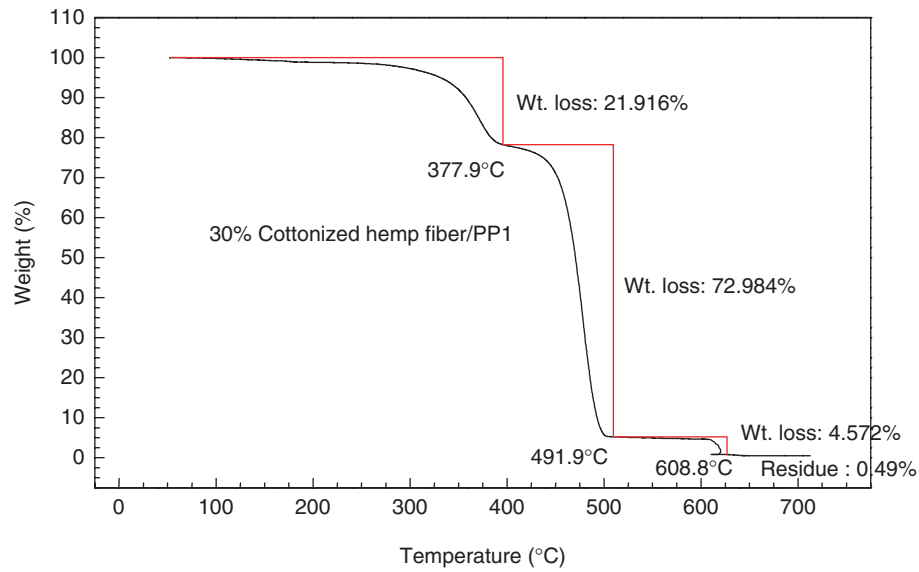

Figure 11. *Thermogravimetric curve of 30% cottonized hemp fiber/PP1.*

degradation of bleached hemp/PP1 composite shifted to a higher temperature region (508°C) when compared to the cottonized (491.9°C) and long hemp fiber (489°C) composites (Figures 11 and 12). The thermal stability of fiber/PP composites is better than that of the fibers and/or matrix. This is attributed to the improved fiber/matrix adhesion resulting from the treatment of the composite with the MAPP compatibilizer.

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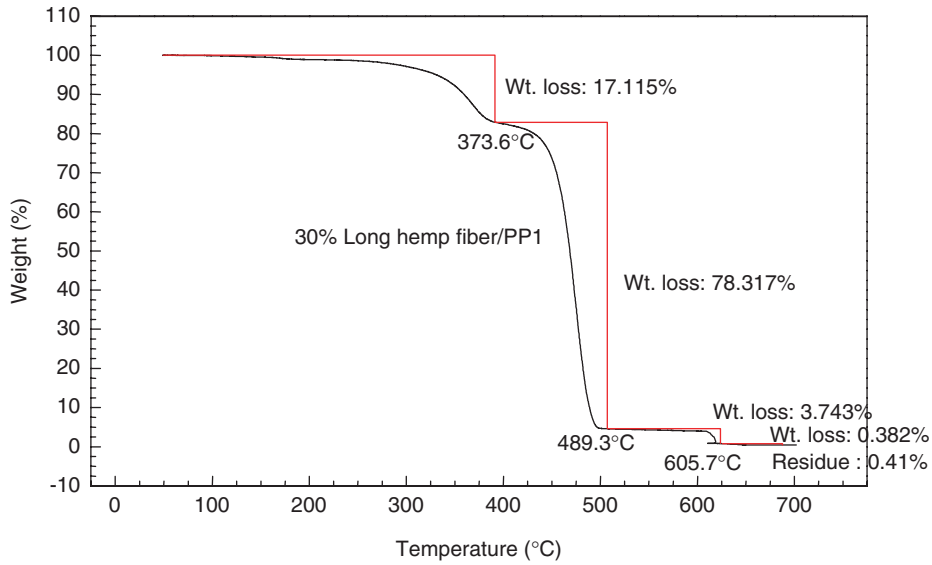

Figure 12. *Thermogravimetric curve of 30% long hemp fiber/PP1.*

CONCLUSIONS

The hemp fiber content has an influence on the mechanical properties. It was observed in all fiber/matrix composites that increasing the amount of fiber resulted in an increase in the tensile strength, elastic modulus, and flexural strength. On the other hand, the addition of hemp fiber to the matrix was found to decrease the impact strength making it more brittle. Therefore, the impact resistance of fiber/matrix composite is highly influenced by the interfacial bond strength. The thermal stability of all hemp fiber/PP composites is better than that of the fibers or the matrix as individual entities. This is attributed to the improved hemp fiber/matrix adhesion resulting from the treatment of the composites with the MAPP compatibilizer. At present, South African hemp fibers need a new technology for production of better quality yarns from short or long fibers using cotton technology.

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