Polymer-Plastics Technology and Engineering, 44: 619–632, 2005

ISSN: 0360-2559 print/1525-6111 online
DOI: 10.1081/PTE-200057787

Mechanical and Electrical Properties of Coconut Coir Fiber-Reinforced Polypropylene Composites

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Abstract: Natural Fibers have an outstanding potential as reinforcement in thermoplastics. The objectives of this experiment are to evaluate the suitability of producing Fiber composites using coconut coir fibers. This study deals with the preparation of coconut coir composites by using compression technique in which good interfacial adhesion is generated by a combination of fiber modification and matrix methods. Initially the coconut fibers were treated in order to improve resin fiber interfacial bonding. The treatment agents used included alkali, stearic acid, acetone, and potassium permanganate. The various reactions between the modified fiber and polypropylene chains were used improve the interfacial adhesion between the fiber and polymer using the new bond. Generally, composites that contain treated fiber have a higher tensile modulus and greater flexural modulus than do untreated fiber composites. Typical mechanical tests on strength, flexability, hardness, and dielectric were performed and the results are reported.

Keywords: Short-fiber composites, polymers, fracture, stress transfer, scanning electron microscopy (SEM)

1. INTRODUCTION

The need for lighter materials has led to the increase use of polymer composites. Lightweight and high performance polymeric materials, in many applications, have already replaced steel as major structural materials. However, there are more compelling reasons why the new materials

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are gaining dominance. The continuing development and increasing sophistication of technology, and the desire for a higher standard of living by people in the so-called developing countries are now drawing on world resources at an alarming rate.

Short fiber reinforced–composites are finding ever increasing applications in engineering and in consumer goods. They can offer a unique combination of properties, and they are more economical than are competing materials. Fiber reinforcement improves stiffness and the strength and, for many polymers, it improves toughness, although the toughness may be decreased in polymers that are already tough in unreinforced form[1]. The dimensional stability is improved and, in the case of rubbery composites, better green strength is obtained. Benefits such as creep resistance and better aging and weathering properties may be crucial in some applications. Conductive fibers may be added to change the electrical properties[2].

Yamani et al.[3] studied the effect of varying resin contents in the oil palm fruit bunch where the fruit is already removed of palm oil composites particles and on some strength and physical properties of composites. Generally, the strength properties increased with an increase in resin content.

Sapuan et al.[4] carried out investigations on the mechanical properties of coconut fiber composites. The resin system used was epoxy. Initially, the coconut fibers were treated in order to improve resin-fiber interfacial bonding. The treatment agents used included alkali, acetylenes, peroxide, stearic acid, and potassium permanganate. The mechanical testing carried out included flexural and tensile tests. It was concluded that the use of fiber treatment agents produced higher load-bearing capacity compared to the use of fibers untreated.

2. MATERIALS AND METHODS

The aim of this experiment was to investigate the mechanical and electrical properties of coir composites. In this work, the study about the use of natural fiber (coconut bunch) and polypropylene was done. The coir fibers were chopped into a suitable size before the mixing process began. The Brabender Haakee machine was used to mix the natural fiber and the polypropylene. In this process the temperature and the speed of the rotating machine is controlled. Four types of fiber were used (a different chemical treatment was used on each fiber). After the mixing process was completed, the compression machine was used to press the sample into a rectangle shape of the required thickness.

Measurement of the tensile and flexural properties was carried out after the sample was cut into a dumbbell shape. The dielectric properties

were measured using a frequency response analyzer (FRA) and Chelsea dielectric interface (CDI).

2.1. Materials

Filler used for reinforced composites materials was obtained from the fruit of the coconut tree. Coconut coir is the seed-hair fiber obtained from the outer shell (endocarp), or husk, of the coconut, the fruit of *Cocos nucifera*, and a tropical plant of the Arecaceae (Palmae) family. The coarse, stiff, reddish brown fiber is made up of smaller threads, composed of lignin, a woody plant substance, and cellulose. In this experiment, the coir fibers were chopped and sieved into two different sizes—0.315 mm and 0.500 mm.

The polypropylene (PP) used in the study was the products of the Titan Polymer, Malaysia Sdn. Bhd. The types of PP selected was PP with a melt flow index of 24. All PP were in pellet form. In the plastics industry, PP is normally used for manufacturing appliances, house wares, toys, and containers.

2.2. Methodology

In compression molding the PP and fiber are placed in a two-piece male/female mold. The mold is closed, and heat and pressure are applied so that in most cases the material plasticizes and flows to fill the mold. Some compression molding processes do not require flow, as in advanced composite prepreg molding. In conventional compression molding one of the mold halves (usually the female) is loaded with a molding charge sufficient to produce an accurate replica of the mold form. The charge usually covers 30%–70% of the female mold cavity surface. As soon as the male/upper cavity surface comes into contact with the charge, it is heated very rapidly by conducting from all surfaces of the hot mold and the material begins to flow, taking only a few seconds to fills the enclosed cavity completely.

Shortly after flows ends, heat from the mold cures the resin matrix, producing a solid part in one to three minutes. The temperature and pressure requirements may vary considerably depending upon the thermal and rheological properties of the polymer. For most compression molding materials operating conditions are within the ranges 135–170°C and 7–20 MNm^{-2} pressure, respectively. A slight excess of material is usually placed in the mold to ensure it is completely filled[5]. The excess polymer is squeezed out between the mating surfaces of the mold in a thin, easily removed film, known as flash. The compression molding process is fairly slow, labor intensive, and, therefore, quite expensive method of producing parts.

2.3. Chemical Treatment

2.3.1. Alkali Treatment

The chopped fibers were put in a stainless vessel containing a 10% solution of NaOH and stirred well. This was kept for 1 hour with subsequent stirring, after which the fillers were washed thoroughly with water to remove the excess of NaOH on the filler. Final washings were carried out with distilled water and the fibers were dried in air.

2.3.2. Permanganate Treatment

The alkali-treated fibers were soaked in 20 grams $KmnO_4$ solution (in 2 liter acetone) for 2 minutes. These fibers were then decanted and dried in air.

2.3.3. Stearic Acid Treatment

Stearic acids have been mixed with the ethyl alcohol (1%). The solution is dropped on the alkali-treated fibers. After that the fibers are dried in the oven around 24 hours at 60°C[6].

2.4. Mechanical Properties

After the specimen was cut into a suitable size for different types of testing, the mechanical tests began. At least five specimens were tested for each composite blend with polypropylene. Tensile tests were conducted following ASTM D638, the flexural test using ASTM D790, and dielectric constant conduct using the frequency response analyzer (FRA) and Chelsea dielectric interface (CDI). A PHILIP XL 30 environmental scanning electron microscope was used to observe the tensile fracture surface of the samples.

3. RESULTS AND DISCUSSION

3.1. Tensile Strength Properties

Figures 1 and 2 show that when the loading of fiber increases, the properties of tensile strength decrease. The same result also occurs for the fiber size of 0.5 mm. The properties of tensile strength drop 3% when the fiber content is 5%. When the filler loading is increased to 25% the values of tensile strength is decreased 32%. The same conditions also happened for the 0.5 mm size fiber. For the 0.5 mm size fiber, when the loading of fiber is increased to 25% the tensile properties are decreased 27%. It can be

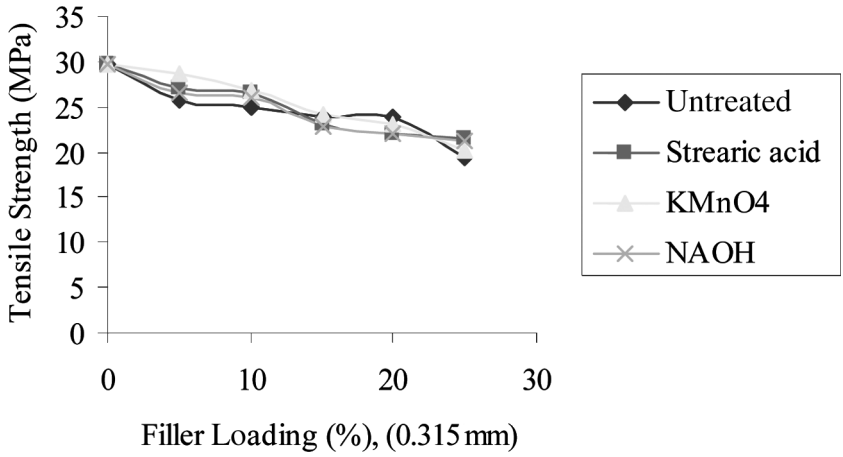

Figure 1. Comparative tensile strength for different treatments for 0.315 mm fiber length.

concluded that, the size of the fiber is influenced by the tensile properties of the composites.

The strength of a composite may increase or decrease with the introduction of natural lignocellulose fibers to the polymer matrix. Normally, fibers such as these are able to improve the strength, as lignocellulose fibers can support stresses transferred from the polymer. However, some of the fibers obtained are not consistent or are irregularly shaped, which influences the strength of the composites. The strength was decreasing due to the inability of the fiber to support stresses transferred from the

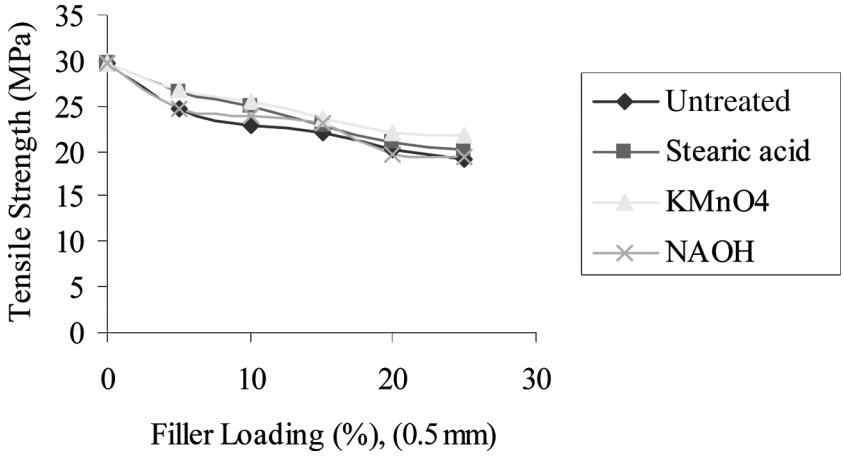

Figure 2. Comparative tensile strength for different treatments for 0.500 mm fiber length.

polymer matrix[7]. In this study, poor reinforcement of the fiber in the PP matrix is the main cause of the lower tensile strength value. This could also be due to the lack of filler adhesion. When the percentage of the matrix lessens, the fibers do not have any place to reinforce, making it easy for them to slip off and facture if stress is applied.

3.2. Tensile Modulus Properties

While fiber loading has adverse effect on tensile strength, at the same time, it has direct proportional effect on tensile modulus. Increase of fiber filler loading will increase the tensile modulus of a composite. From Figures 3 and 4, the tensile modulus for PP is 322.422 MPa with the increase of fiber content and the values of the tensile modulus is increasing rapidly. When the fiber-filler loading is 25%, the tensile modulus property is 15% higher then is the unfilled PP. In this case, the fiber with the bigger size is contributes effect on the tensile modulus.

On the contrary, the addition of fiber has a positive effect on the tensile modulus, which measures the stiffness of the composites. As indicated in Figure 4, the tensile modulus of NaOH-treated fibers peaked at 25% fiber loading in all types of fiber-filler size. On average, it was approximately 16% higher in tensile modulus compared to unfilled PP.

3.3. Flexural Strength Properties

Filler loading exhibited the same effect on the flexural strength for all the chemical treatment composites. When the fiber loading increases, it

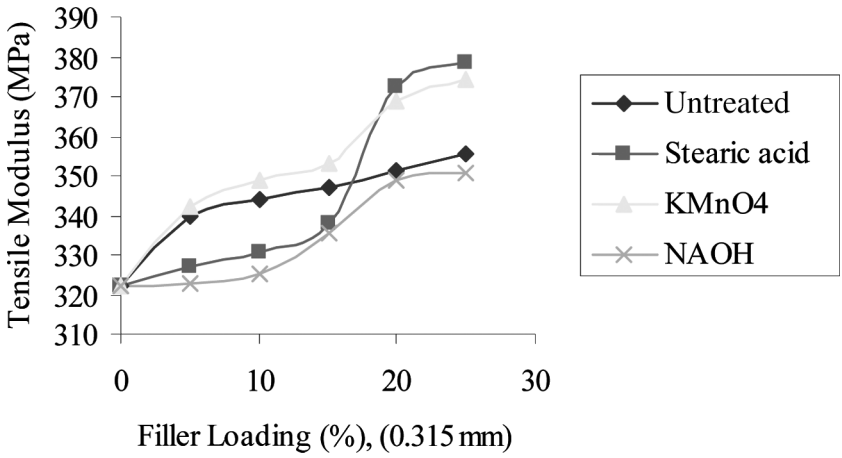

Figure 3. Comparative tensile modulus for different treatments for 0.315 mm fiber length.

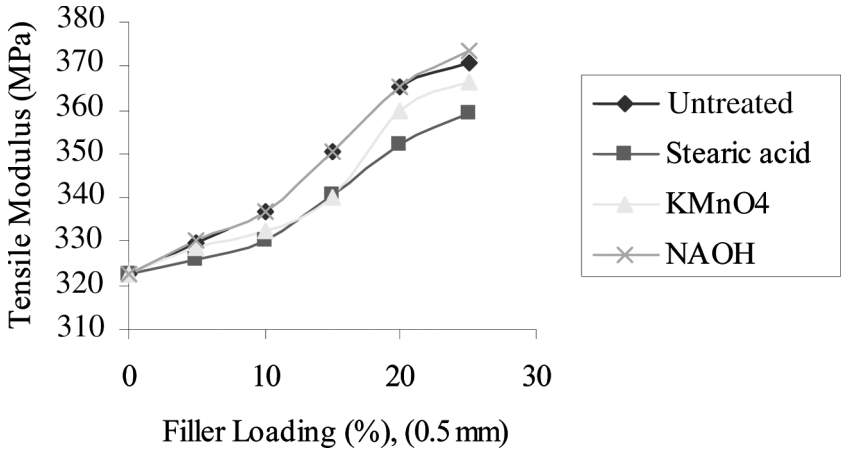

Figure 4. Comparative tensile modulus for different treatments for 0.500 mm fiber length.

decreases the property of the flexural strength in the same manner as tensile strength. In Figures 5 and 6, it is clearly shown that the property of flexural strength decreases rapidly. On average, at 5% fiber loading the flexural strength decreases 8.5%, for 10%, 15%, and 25% fiber loading, the flexural strengths were 10%, 11%, and 13% lower than unfilled PP.

Being higher in aspect ratio might be the reason why fibers with greater length resulted in higher flexural strength. The aspect ratio of

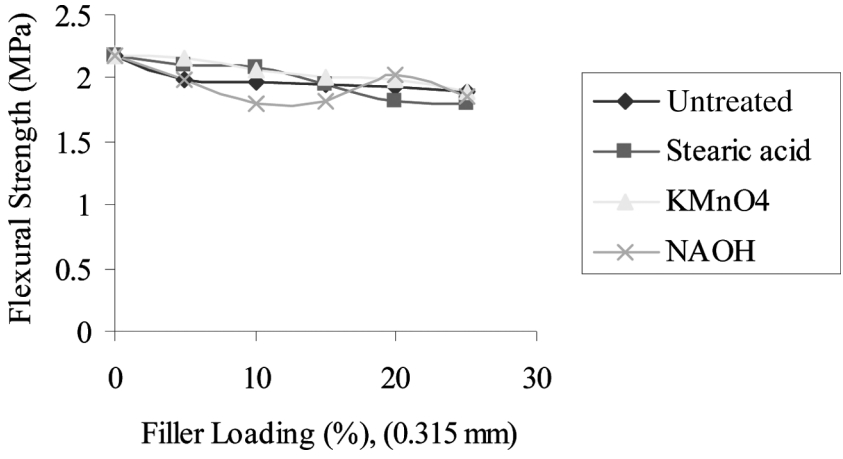

Figure 5. Comparative flexural strength for different treatments for 0.315 mm fiber length.

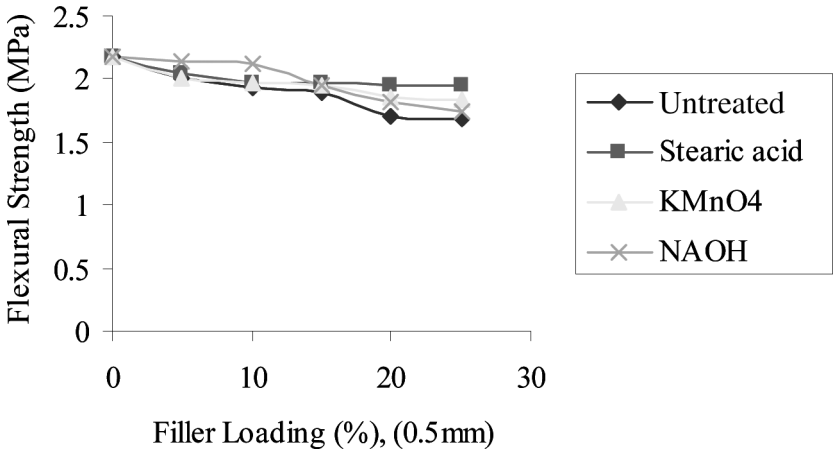

Figure 6. Comparative flexural strength for different treatments for 0.500 mm fiber length.

the fiber has been found to be one of the factors affecting the mechanical strength of the composites. Alger and Dyson[8] have shown that the flexural strength of the PP can be greatly enhanced by using glass fibers of higher aspect ratio. This is due to fewer fiber ends, which results in better stress transfer.

3.4. Flexural Modulus Properties

The significant property advantages of fiber loading on the flexural modulus are clearly illustrated in Figures 7 and 8. The flexural modulus increased with the amount of fiber loading. On average, the flexural strength for PP filled with 5% is 1028 MPa compared with unfilled PP at 1020.08 MPa (fiber size 0.500 mm). The same condition also is true for PP reinforced with 0.315 mm fiber. For the composites with the fiber loading until the 25% fiber shown, the higher the flexural modulus is in all cases. The results indicated no negative influence of fiber loading on the flexural modulus.

Figures 7 and 8 illustrate the comparison of flexural modulus concerning the effect of fiber size. As indicated in the bar graph, flexural modulus of composites retained at sizes 0.315 mm and 0.500 mm were statically comparable to each other. Both sizes resulted in higher flexural modulus compared to unfilled PP. The result shows similarity with the observation by Zaini et al.[9], which indicated that greater aspect ratio of the oil palm wood flour enhances the composites stiffness. Modulus of the composites is well influenced by the stiffness of the fiber.

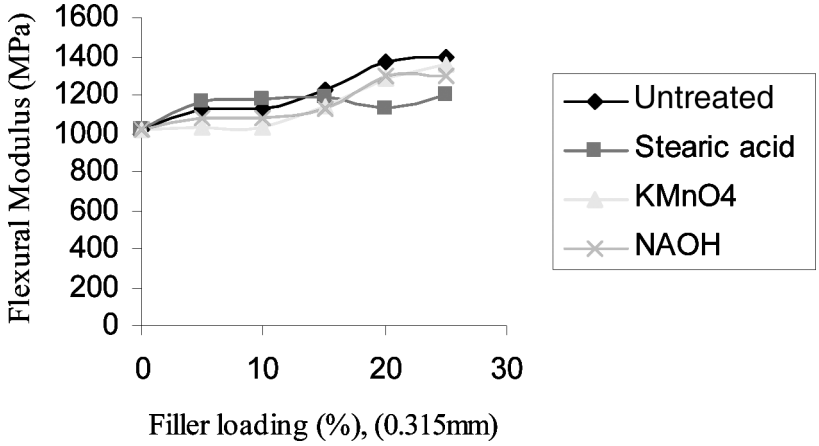

Figure 7. Comparative flexural modulus for different treatments for 0.315 mm fiber length.

3.5. Rockwell Hardness Properties

The effect of fiber loading on Rockwell hardness is illustrated in Figures 9 and 10. Generally, fibers that increase the moduli of composites increase the hardness of the thermoplastic. This is because hardness is a function of the relative fiber volume and modulus[10]. In practice, the average molecular weights of polymers are classified by melt-flow index (MFI). Higher MFI is normally characterized by lower molecular weight.

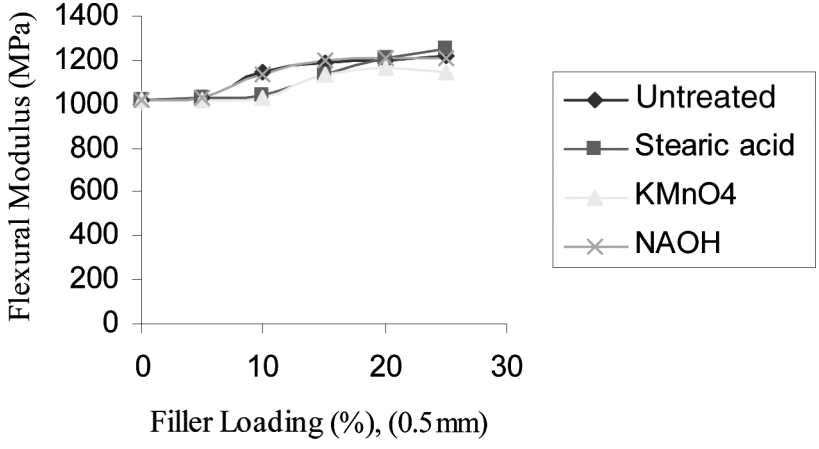

Figure 8. Comparative flexural modulus for different treatments for 0.500 mm fiber length.

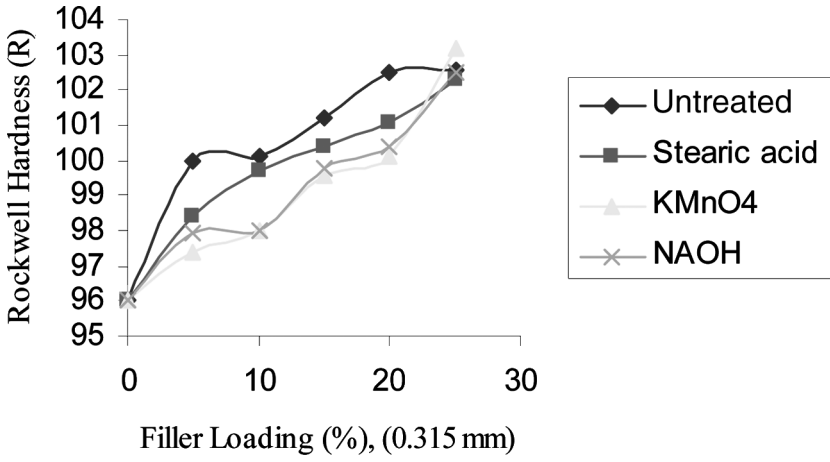

Figure 9. Comparative Rockwell hardness for different treatments for 0.315 mm fiber length.

This is because the higher molecular weight, the greater the entanglement of polymer chains, therefore, their relative mobility is reduced[11].

3.6. Dielectric Constant Properties

The property of the dielectric constant is shown in Figures 11 and 12. In this study, the dielectric property of the composites is almost the same for

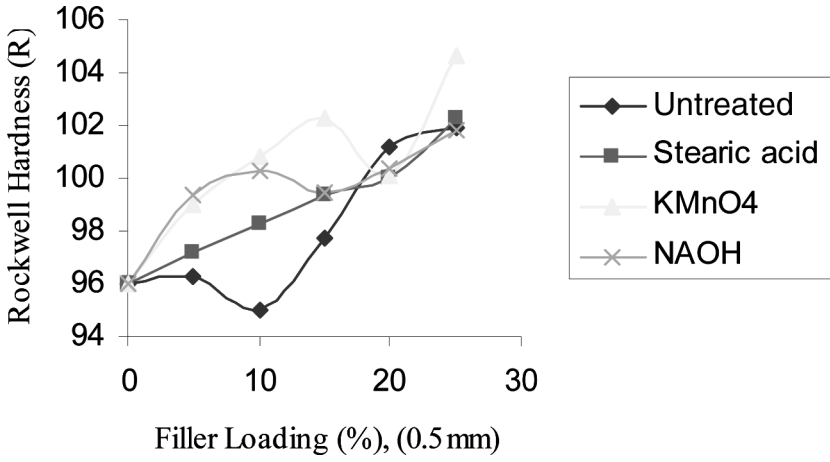

Figure 10. Comparative Rockwell hardness for different treatments for 0.500 mm fiber length.

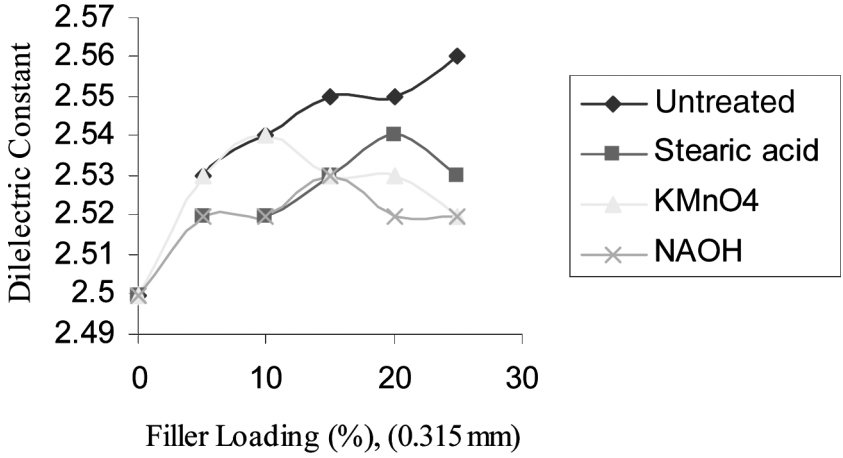

Figure 11. Comparative dielectric constant for different treatments for 0.315 mm fiber length.

all the chemical treatments. On average, the dielectric value of the pure PP is 2.5. When fiber is add to the pure PP, the values of the dielectric constant is increased. When the loading fiber increases to 25%, the property of the dielectric constand is increased until its maximum value is 2.56. In this study, it is clearly specific that the dielectric property is influence by chemical treatment on the fiber. From the graph, it is clearly illustrated that when fiber loading is increased, the values of dielectric properties also increased rapidly[12].

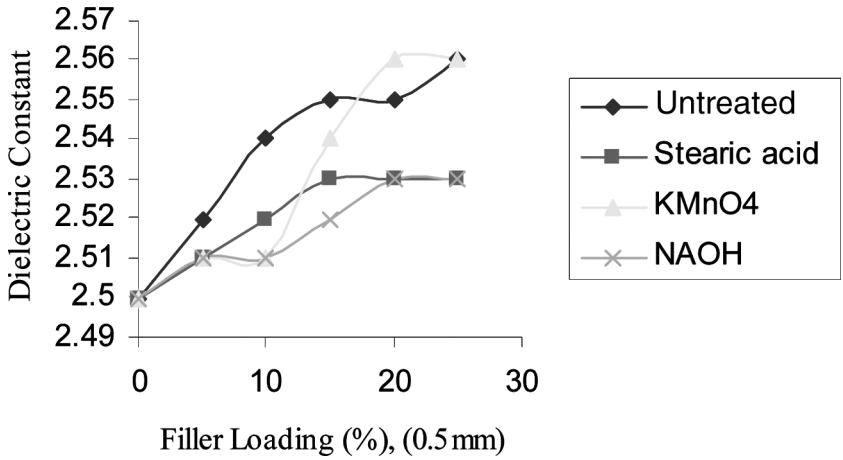

Figure 12. Comparative dielectric constant for different treatments for 0.500 mm fiber length.

3.7. Effect of Mixing Time Properties

The mix characteristics of PP/fiber composites were studied using the Haake Rheographs, which are plots of torque vs. mix time. These mixes were carried out at a temperature of 180°C and a rotor speed of 50 rpm. It is clear from Figure 13 that the mixing torque initially increases rapidly when PP granules are charged into the mixer chamber. As the mixing time increases, the PP undergoes melting, that results in a decrease of torque, which levels off at longer times. The molten PP was mixed with fiber, which results in an increase of torque because of the increased viscosity of the system. The torque attains constant value at longer times when addition of fiber into the molten PP is complete. These mixes were carried out at a temperature of 180°C and at a rotor speed of 50 rpm. When the mixing time is lower, tensile strength and Young's modulus are low because of the ineffective mixing and poor dispersion of the fiber in the PP matrix. As the mixing time increases, melting of the polypropylene matrix becomes extensive, which enhances the dispersion of the fiber in the matrix. Also with an increase in time, fiber breakage also will be predominant, which also will influence the overall performance of the materials. However, as the mixing time increases, the tensile strength increases and attains maximum value at 10 minutes, which levels off at higher mixing time. The modulus exhibits maximum value in 10 minutes and decreases as mixing is continued.

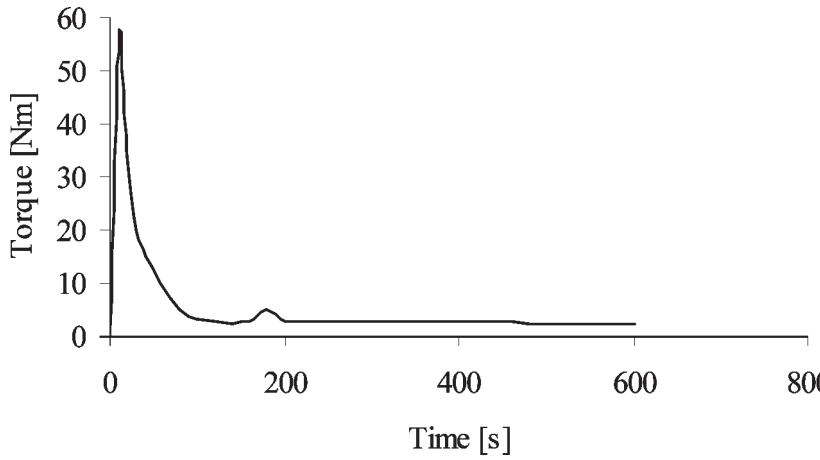

Figure 13. Plastographs for coir fiber/PP composites at 10% loading fibers are added after 3 minutes (rotor speed is 50 rpm, mixing time 10 min, and temperature 180°C).

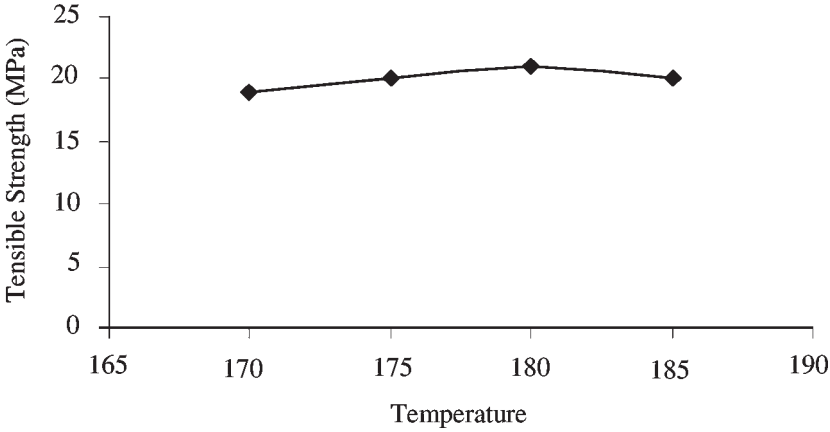

Figure 14. Variation of tensile strength with temperature of melt-mixed composites (fiber content 10%).

3.8. Effect of Mixing Temperature

Figure 14 shows the effect of mixing temperature on the tensile properties of coconut fiber reinforced–polypropylene composites at a rotor speed of 50 rpm and a mixing time of 10 minutes. It can be seen that tensile strength of the composites increases with the rise in temperature and then decreases, showing maximum improvement at 180°C. In fact, in short fiber composites, the fiber aspect ratio, the quality of dispersion, and the interface between fiber and polymer directly control the performance of the composites. At low temperature the viscosity as well as the shear stress generated in the mixture is very high, and this causes the breakdown of the fibers during mixing.

4. CONCLUSIONS

The results presented in this work indicate that it is possible to enhance the properties of fiber-reinforced composites through fiber surface modification. Composites based on the modified fiber surface have, in general, superior mechanical properties to composites containing unmodified fibers. This is primarily a result of improved adhesion and enhanced polar interactions at the fiber/matrix interfaces.

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