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Investigation on the Mechanical Behavior Impact of Plasma Treated Propylene in Carbon Fiber Composites

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Abstract

Improved mechanical characteristics for composites using a linear low-density propylene (PP) matrix and a carbon fibre (CF) filler were the focus of this study. The material was fabricated by a hand layup process in an oven. Oxygen plasma treatment of the PP matrix enhanced adherence. Before being filtered and dried for manufacture, CF and PP were first combined with standard stirring, ultrasonication, and mechanical stirring. The highest tensile strength was achieved in plasma-treated propylene (PPP) with 10 wt. percent CF, with overall property performance increasing by 13.46 percent comparison to non-PP with the same CF addition. Tensile strength was reduced from 19.4 MPa to 18.3 MPa when carbon fibers were added at 14 and 16 wt. percent. As a result of CF aggregation with plasma-treated and untreated PP, tensile strength (TS) was reduced.Better tensile qualities were seen in a factory setting with temperatures of 180°C for 20 minutes.After plasma treatment, the PP/8% CF blend had a flexural strength (FS) of 26.19 MPa, which was higher than that of untreated PP by a significant margin.

Keywords: propylene; carbon fiber; mechanical properties; plasma treatment.

1. Introduction

Thin films, adhesives, medical implants, electronics, batteries, and orthopedics are just some of the many uses for propylene, which is why it is one of the most useful polymers. For commercial use, rotomolding is the typical method of production. Fillers and reinforcements are added to the propylene (PP) matrices to increase their usefulness in a variety of contexts. The bond strength between fibres and the matrix is a major factor in how well composites perform mechanically. Increased compatibility between fibres and matrix is one of these benefits, and plasma treatment of propylene matrices is one way to achieve it. By applying a plasma to composites, the surface roughness and hardness can be increased.Better bonding is achieved via plasma treatment with oxygen when two polarity-opposed matrices, such as propylene and polyamide (PA), are sandwiched together. The 7.689 N/mm peel strength is more than twice as high as that of untreated samples. PP samples delaminated without intervention. The flexural strength of PP and PP treated with plasma was 35.40 MPa, which is higher than the flexural strength of an untreated mixture (31.80 MPa) [8]. Improved tensile, flexural, and impact properties were observed in PP that had been treated with plasma, and the material's inherent reinforcements were not compromised in the process.Adherence of composites is improved by the treated PP's functional groups reacting with the hydroxyl groups in the lignocellulosic coir fibres [9].. Tensile strength was greatest in 10% glass fibre (GF) reinforced plasma polypropylene (PP) composites. We found that plasma-treated PP with 20% GF had the highest tensile modulus [10].

Carbon fiber is a very desirable material for use in a wide variety of industries, including the automotive, sporting, and aviation sectors owing to its exceptional corrosive resistance, mechanical characteristics, and outstanding coefficient of thermal expansion. Composites made from polypropylene (PP) and high-density propylene (HDPP) have improved impact, tensile, and flexural characteristics by 60%, 18%, and 23%, respectively, when up to 20% carbon fibre was added [13]. When the fiber-to-resin ratio increases, the mechanical characteristics of the composites suffer because of a phenomenon called agglomeration. Using 80% by weight carbon fiber led to a maximalFS of 65.21 MPa and enhanced hardness equated to further epoxy resin mixtures. The TS and tensile modulus (TM) of HDPP were enhanced when carbon fibres were introduced at a concentration of up to 25 weight percent. The TS and TM of CF/high-density polypropylene (HDPP) composite were improved by spraying 2% weight percent carbon nanotubes (CNTs) over the materials. Recycled carbon fibers can be used in cars and other industrial uses much like fresh carbon fibers, but at a far lower price. But they don't have the mechanical properties of polymer matrices.

Carbon fibres' tensile characteristics were marginally improved after treatment with oxygen plasma at 80 W. Shear strength at the interface increased to 72 MPa after being treated with 20 W of plasma [19]. Epoxy-based matrix polymers with shape memory enhanced mechanical capabilities when combined with continuous and short carbon fibres. Carbon strengthened materials likeCF, single- and multi-wall CNT, and carbon black (CB) have found usage in electrical conductivity applications with a wide range of thermo- and thermo-setting polymers. Composites produced from propylene showed a decrease in mechanical properties when carbon black and carbon nanotube fillers were added. Plasma treatment of a composite comprising polycarbonate, carbon fiber, and CNT improved the composite's dynamical mechanical characteristics. Surface roughness was enhanced and mechanical interlocking between CF and PEEK was achieved using radiofrequency plasma treatment with air, argon, or a mixture of the two gases. The interfacial strength of the PEEK composites improved as a result. Surface-energy-rich materials including glass/PP, pure polypropylene, and HDPP composites have their interfaceconnection improved with the use of oxygen plasma.

According to the research, plasma therapy is a viable method for enhancing matrix-fiber phase interaction. Recycled carbon fibre has similar mechanical capabilities to normal carbon fibre without the high price tag. It is also better for the environment. In order to make recycled carbon fibres commercially viable, more research is needed in this area. The flexural strength, flexural modulus, tensile strength, tensile modulus, and morphological properties of plasma-treated propylene and carbon fibres have not been investigated in any published work. In this research, FTIR and XPS measurements were used to determine how plasma therapy affected PP. The optimum settings for oven processing were determined by applying various fabrication circumstances. As a last step of verification, plasma treatment was applied to carbon fibres.

2. Materials and Methods

2.1. Materials

The matrix material was supplied from Dow Corporate and consisted of a hexane-based linear low-density propylene (PP) polymer powder designated as DowlexTM 2629.10UE. The density is 0.9370 g/cm3 (ASTM D792) Index of Melt Flow Density:3.80 Density in Larger Quantities = 0.352 g/cm3. To make chemical barrels and other bulk and freezer containers [3]. Propylene and carbon fibres were treated with plasma but not pretreated. Surface treatment with plasma was given to propylene powder (PPP) using an industrial-use apparatus (LA 400) (a. s. Turnov, Czech Republic). Two microwaves, with a combined 2 kW of power, were used to apply the plasma. Treatment with oxygen plasma was performed for 30 seconds at a gas flow rate of 100 sccm. As was the case previously [3,] we applied the plasma treatment approach.

The PP matrix was filled with recycled carbon fibres that were made from PAN fibres that were 99 percent pure and ranged in size from 80 to 350 µm. MSV STUDENKA sro of Bilovec, Czech Republic, was the supplier of the recycled carbon fibres. The fibres measured 8 mm in length, 7 µm in diameter, 1.8 g/cm3 in density, and 250-550 g/L in bulk volume. These fibers are useful in a wide variety of contexts because of their many desirable features, including as higher strength and elasticity, minimal density, heat, abrasion, corrosion, electricity, and electrical conduction. Industrial equipment (LA 400) used a 100 sccm oxygen flow to cure the carbon fibres.

2.2. Fabrication

Using the hand layup method, composites made of carbon fibre and linear low-density propylene (PP) were created. Carbon fibre (CF) was added to the polypropylene (PP) matrix at 4, 6, 8, 10, 14, and 16 weight percent for reinforcement. Before anything else, carbon fibres were mixed with isopropyl alcohol (IPA). Ultrasonication (at 50 °C, 40 kHz for 60 minutes) was used to combine the PP matrix, IPA, and carbon fibre, and then mechanical stirring was used to distribute the mixture (for 10 min). After removing the isopropyl alcohol by filtering the mixture through filter paper, it was dried in a hot oven with ambient air. To lessen the amount of leftover mixture, the dried powders were sifted before being pressed into 100 x 25 x 3 mm^3 silicon molds. The samples were rolled using a roller, then dried in an oven at 180°C for 20 minutes before being chilled to room temperature. Both the PP and CF plasma treatments followed the same protocols. The optimal conditions for fabrication were determined by testing temperatures between 180 and 200°C and times ranging from 20-60 minutes. Plasma-treated polypropylene improved matrix/fiber adhesion.

2.3. Method of testing

ISO 527 tensile testing was done using a UTM set at a 6 cm gauge length and a speediness of 6 mm/min. The results of all mechanical tests were averaged among ten different samples. A three-point bending test was conducted at a speediness of 2 mm/min using the same ASTM D 790 standard equipment to assess flexural properties. After subjecting the material to tensile testing, the distribution and adhesion of carbon fibres within the PE matrix were examined using scanning electron microscopy [JSM-7600F (JEOL, JP)].

The chromium layer was sputtered off so that the electron beams could penetrate the material without causing any charge. The working voltage ranged from 1 to 5 kV, and the working distance was measured from 5.4 to 10 mm.

3. Results

3.1. Tensile Testing

Figure 1. TS of Carbon Fiber/PP composites.

As anoutcome of plasma treatment, the tensile strength of carbon fibre (CF)/polypropylene (PP) composites was significantly improved (Fig 1). The first combination of plasma treatment without carbon fibre yielded less spectacular tensile results (2.94 percent). Two types of PP, plasma-treated (PPP) and untreated (PP), are shown in Figure 1. Plasma-treated PP (denoted as 4P) and untreated PP (denoted as 4N) both have a CF of 4%. Like 6P and 6N, 8P and 8N, 10P and 10N refer to CF concentrations of 6, 8, and 10 weight percent in plasma- and non-plasma-treated polypropylene. Similar rules apply to the other permutations (14P, 14N, 16P, and 16N)treated with oxygen plasma has been demonstrated to have improved wettability, leading to better matrix adhesion with fillers.

The fundamental mechanism of the oxygen plasma therapy was etching, which also stimulated the surface. This indicates that polymer powder wettability can be improved without introducing oxygen groups. The creation of polar groups was made possible by the plasma and was made possible by the brief duration of the plasma treatment. Additional abrasion was created on the PP composites through prolonged exposure, making their surfaces rougher. Improved adherence and application were achieved through oxygen plasma treatment of the polymers.The highest tensile strength was attained at 22.6 MPa with 10 wt. percent CF, while improvements in characteristics reached as high as 13.46 percent in comparison to non-plasma PP with the similar quantity of Carbon fiber. The tensile strength properties dropped from 19.4 MPa to 18.3 MPa when carbon fibres were added at 14 and 16 wt. percent. Agglomeration of CF with plasma-treated and untreated PP led to decreased tensile strength. No additional increase in tensile strength of the PP composites was seen after including plasma-treated CF with plasma PP (Figure 2). With the addition of 6, 8, and 10 wt. percent CF, the tensile strength dropped to 21.6 MPa, 21.7 MPa, and 21.9 MPa, respectively, after plasma treatment of CF.

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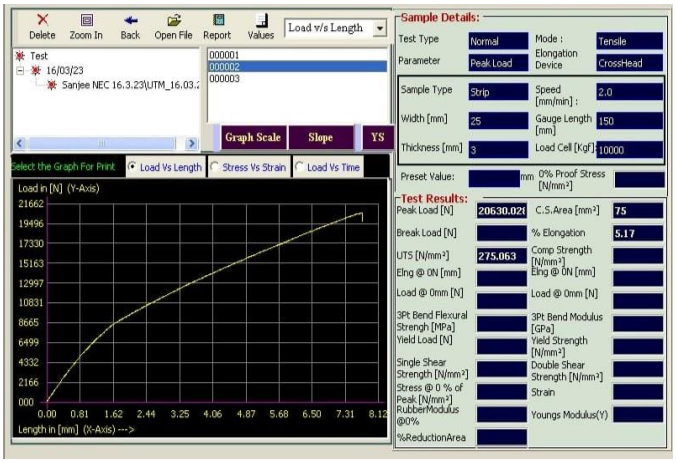
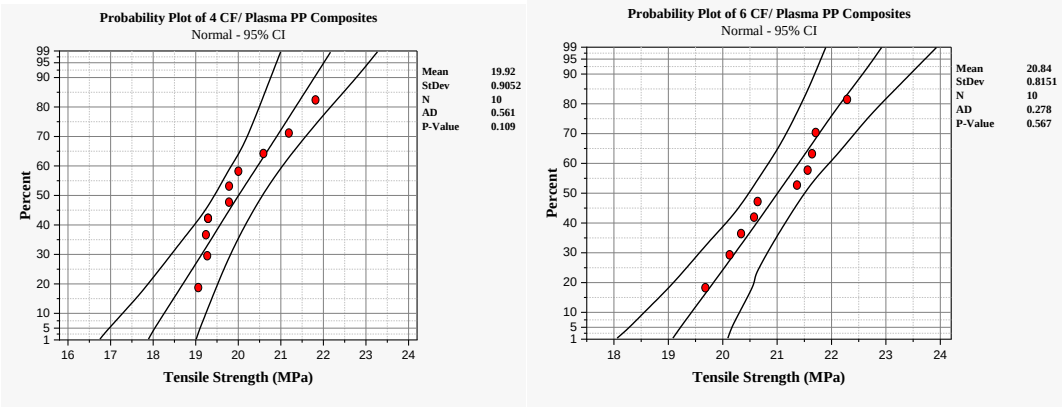


Figure 2. Comparison of tensile strength of plasma and non-plasma composites

Fig 3 is a normal probability plot values of TS measurements for 4, 6, 10, and 16 weight percent carbon fiber with plasma PP, all of which are within the allowable range. In terms of tensile strength, the combination of CF and PP with 10 weight percent CF and plasma treatment yielded the best results, with a value of 21.8 MPa. Several iterations of composite combinations were tried, each with a unique set of fabrication parameters (Figure 4). The first round of tests was run at 180 degrees Celsius for 20 minutes (or "T 180 20"). A similar range of temperatures and times was used for the T180 40, T180 60, T200 20, T200 40, and T200 60 fabrication circumstances. There was a decline in characteristics across the board for all fabrication circumstances except T180 20.



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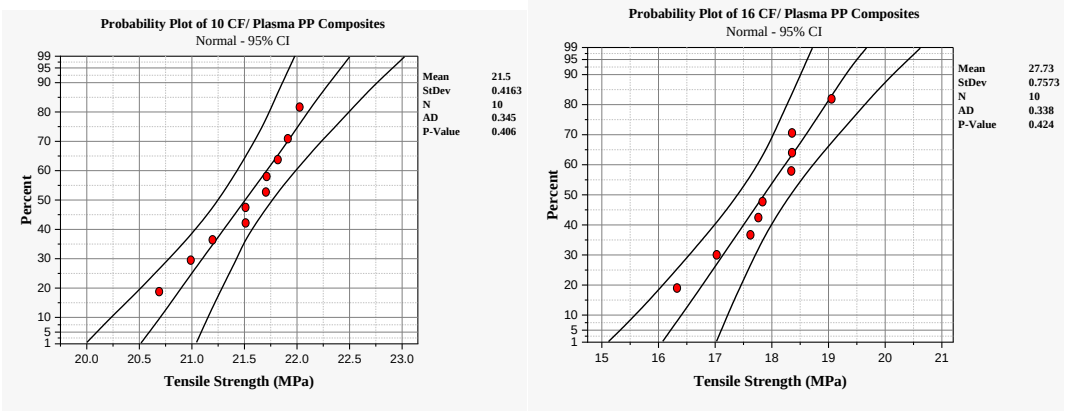

Figure 3. Normal probability plot for TS: (a) 4% Carbon Fiber/plasma PP, (b) 6% Carbon Fiber /plasma PP, (c) 10% Carbon Fiber /plasma PP and (d) 16% Carbon Fiber /plasma PP combinations.

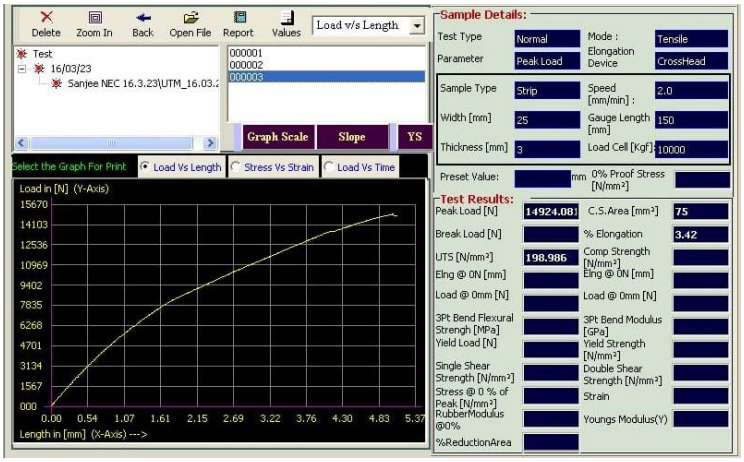

Figure 4. TS of 10 weight% CF/plasma PP under Various Fabrication Circumstances

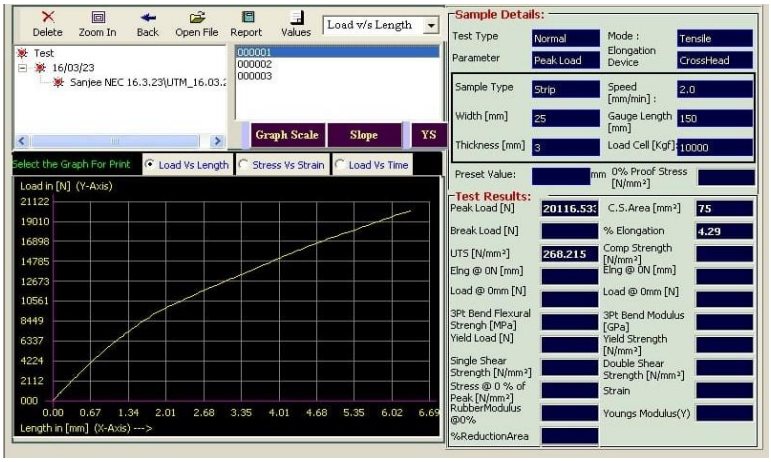

Figure 5. Comparison of Tensile modulus of CF/PP composites

Figure 5 displays the dramatic increase in tensile modulus characteristics of the Carbon Fiber/PP composite after plasma treatment of the propylene and carbon fibre

insertion. Tensile modulus values of 488, 551.1, 626.2, and 679.8 MPa were attained by incorporating carbon fibres into plasma-treated PP at 4, 6, 8, and 10 wt. percent, respectively. Incorporating the same amount of carbon fibre into non-plasma-treated PP resulted in improved characteristics. At 10 weight percent Carbon Fiber with plasma PP, both the TS and TM improved.TM characteristics were shown to decrease with increasing CF content between 14 and 16 wt.

3.2. Flexural Testing

Figure 6. Comparison of Flexural strength of Carbon Fiber/PP composites

Fig 6 demonstrates that similar to the tensile characteristics, the FS of CF/PP composite rises with PPP and CF insertion.FS was somewhat increased from the starting combination's 18.53-19.2 MPa after plasma treatment to PP.The flexural characteristics of a composite made from plasma propylene powder and 4 weight percent carbon fibres were improved from 19.47 MPa to 20.45 MPa. With plasma-treated PP incorporating carbon fibres at 6, 8, and 10 wt. percent, similar improvements in flexural characteristics were reported. The combination of plasma-treated polypropylene and eight percent carbon fibre reached a maximum flexural strength of 26.19 MPa.

Flexural characteristics at 25.54 MPa were nearly identical in PP treated with 10 wt. percent CF/plasma. Flexural strength for 14 and 16 wt. % CF with plasma-treated PP was lowered to 25.98 and 24.2 MPa. Polar groups including hydroxyl, carbonyl, and carboxyl were found to be present when oxygen was treated with plasma. Functional groups can be added to or interlocked with the surface of polymers by inducing the production of polymer chains containing free radicals, as observed in the presence of these polar groups. This would have improved the composites' adhesion, which in turn would have helped activate the polymer surface. The flexural characteristics of the polymer composites were diminished due to the agglomeration of carbon fibres. Incorporating plasma-treated PP into 14 and 16 wt. % CF improved the characteristics compared to adding the same amount of carbon fibre to untreated PP. The results of adding 6, 8, and 10% CF to plasma-treated PP-based composites showed no significant increase in FS(Figure 7). The flexural propertiesof plasma-treated 6, 8, and 10 wt. percent CF/plasma PP were reduced from 24.5 to 23.8 MPa, 27.29 to 26.3 MPa, and 26.64 to 26.08 MPa, respectively, when equated to the similarcarbon Fiber combination without plasma/PPP. When the filler and matrix stopped interacting so strongly, the combination's FS dropped. Flexural strength in 4, 6, 10, and 16 wt. percent carbon fiber with plasma PP

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all fall within the acceptable range of fluctuation, as indicated in Fig 8's normal probability plot. The PP matrix's enhanced mechanical characteristics were the result. Increased adhesive in the fiber phase with reduced void after plasma treatment in PP is seen in images as well, improving the polymer composites' tensile and flexural capabilities.

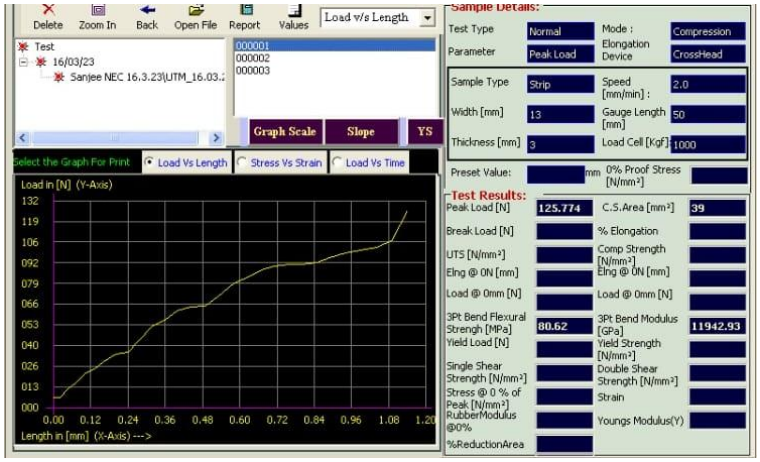

Figure 7. FS of Carbon Fibers/plasma PP composites

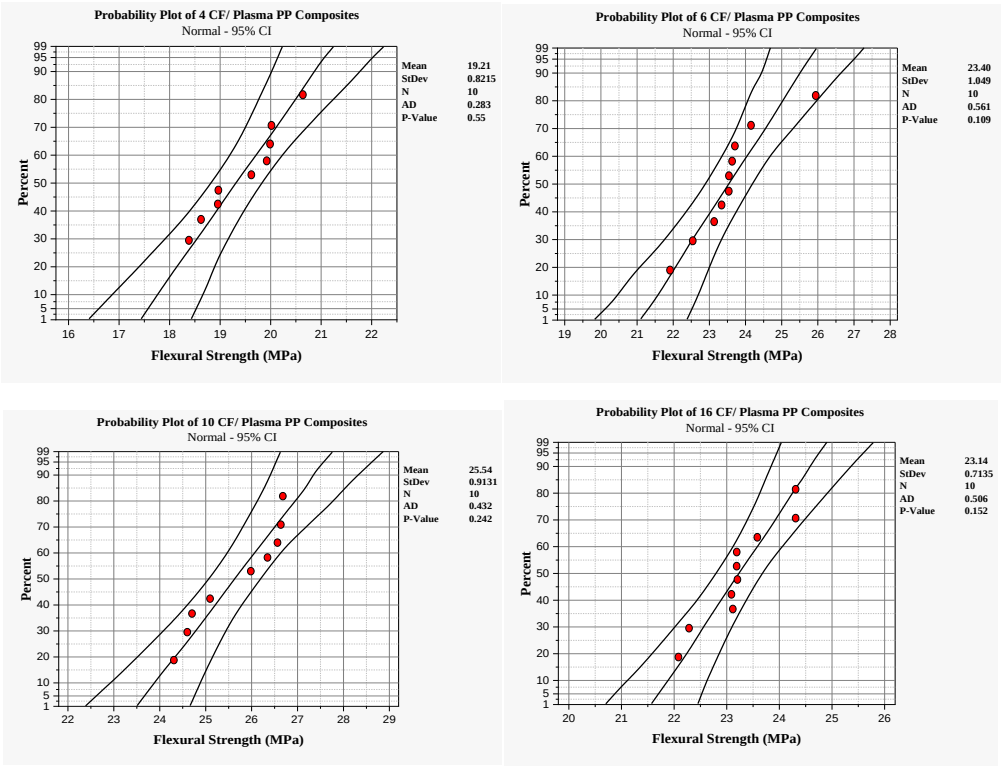

Figure 8. Normal probability plot for FS: (a) 4% Carbon Fiber/plasma PP, (b) 6%CarbFiber /plasma PP, (c) 10% Carbon Fiber /plasma PP and (d) 16% Carbon Fiber /plasma PP combinations.

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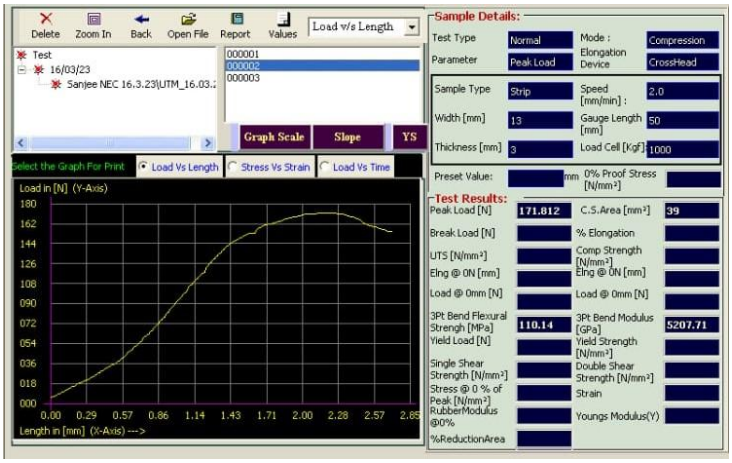

Figure 9. Flexural modulus of CF/PP composites

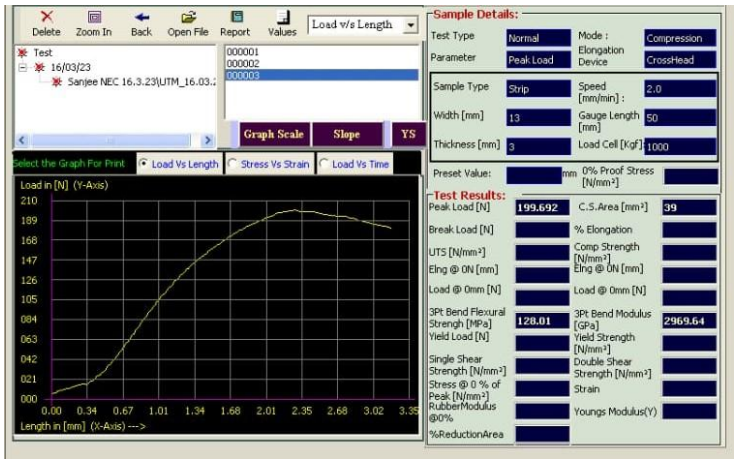

Figure 10. FTIR spectrum analysis of untreated and plasma-treated polypropylene (PP) samples

Fig.9 shows that the CF-based composites' flexural modulus tends to improve after plasma treatment of the PP. With the same amount of carbon fibre added to either the pure PP matrix or plasma-treated PP, it is evident that the qualities associated with the flexural modulus of the latter improved. Mechanical characteristics were also significantly improved in PP composites thanks to the CF filler. Eight weight percent CF/plasma PP showed the highest flexural modulus characteristics, at 816.1 MPa. Neither the treated nor the untreated PP samples underwent any modifications to their functional groups, as shown by the FTIR study (Figure 10). The extending vibration of Carbon-Hydrogen asymmetric and Carbon-Hydrogen symmetric groups account for the peaks at 2965cm1 and 2847 cm-1 for both PP samples. C-H groupdeformation vibration also contributed to the peak at 1508 cm-1 [6]. From the XPS analysis clearly demonstrates that the concentration of O-C=O groups in the PP that was treated with plasma for 30 seconds is significantly lower than predicted. In the yellow line represents an Oxygen-Carbon=Oxygen bond, the orange line a Carbon-Carbon bond, and the maroon and pink lines, respectively, C=O and C-O bonds. The percentage of C-O groups was 2.2%, while the percentage of C=O groups was just 0.6%. We recently reported [27] that functional

groups in plasma-treated PE were equivalent to those in untreated PP. During plasma treatment of PP, a single O2 atom bonds chemically with the polymer surface, resulting in -OH groups and functional groups with richer O2 [3].

4. Water absorption Testing

Fig.7.11 Water Absorption Test Machine

Water-absorption test a test to determine the moisture content of soil as a percentage of its dry weight (British Standard 1377, 1967). The sample is weighed, dried in an oven, and then reweighed under standard conditions. Water absorption gives an idea of strength of aggregate. Aggregates having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness tests. Water absorption is defined as the amount of water absorbed by a material and is calculated as the ratio of the weight of water absorbed to the weight of the dry material. The amount of water is determined by subtracting the dry weight from the initial weight, and the moisture content is then calculated as the amount of water divided by the dry weight or total weight, depending on the reporting method. Even this simple loss-on-drying method is mined with potential variability traps.

- Sample preparation: Cut the composite material into specimens of a standardized size and shape. The specimens should be representative of the material and its intended application.
- Initial weighing: Weigh each dry specimen using a precise balance and record their initial weights (Wi).
- Immersion: Submerge the specimens in a container filled with the liquid environment of interest, such as water or a specific solution. Ensure that the specimens are fully immersed and free from air bubbles.
- Time intervals: Define specific time intervals for measurements based on the test duration requirements. Common intervals include 24 hours, 48 hours, 7 days, and so on.
- Removal and drying: After each time interval, carefully remove the specimens from the liquid environment, and gently blot or wipe them to remove any excess surface moisture.

- Weighing after absorption: Weigh the wet specimens (Wf) immediately after removing excess moisture.

Conclusions

- Mechanical qualities, such as tensile and flexural strength, were enhanced when plasma-treated PP and CF were incorporated into CF/propylene (PP) composites.
- A greater TS of 22.6 MPa and an increase in characteristics up to 13.46 percent were achieved with 10 wt. percent CF related to non-plasma PP with the similar carbon fiber addings.
- With the accumulation of CF at 14 and 16 wt. percent, the TS dropped from 19.4 MPa to 18.3 MPa. Carbon fiber aggregation with both plasma-treated and untreated polypropylene led to a decrease in tensile strength.
- When equated to other fabrication conditions, the tensile properties were best under an oven temperature of 180°C for 20 minutes.
- Analyzing tensile test results with a scanning electron microscope (SEM) demonstrated enhanced adhesion of carbon fiber filler with plasma polypropylene (PP), with less surface deformations.
- Tensile modulus values of 488 MPa, 551.1 MPa, 626.2 MPa, and 679.8 MPa were attained by incorporating carbon fibres into plasma-treated PP at 4, 6, 8, and 10 wt. percent, respectively. These numbers were better than those seen for similar quantities of carbon fibre added to PP that hadn't been plasma treated.
- Tensile modulus, including tensile strength, improved at 10 wight percent carbon fiber with plasma PP.
- The flexural characteristics of a composite made from plasma propylene powder and 4 weight percent carbon fibres were improved from 19.47 MPa to 20.45 MPa. Flexural characteristics were similarly improved in plasma-treated PP containing carbon fibres at 6, 8, and 10 wt. percent.

- The combination of plasma-treated polypropylene and eight percent carbon fibre reached a highestFS of 26.19 MPa. The FS of 25.54 MPa was nearly equal after adding 10 wt. % CF/plasma-treated PP.
- After combining CF with plasma PP, the flexural strength of 14 and 16 weight percent decreased to 25.98 MPa and 24.2 MPa.
- The greatest flexural modulus value of 816.1 MPa was achieved with a CF/plasma PP composition containing 8 wt. percent CF.
- Tensile and flexural characteristics of propylene composites were not improved by oxygen-carbon fiber plasma treatment.
- These mixtures have limited car industry use. The electrical conductivity properties can be examined in further studies

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