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Effect of Multi-walled Carbon Nanotube on Mechanical Properties of Kenaf/Polypropylene Composites

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ABSTRACT

Kenaf fibre has a high potential to be used for composite reinforcement in hybrid composites. It has been varying combinations of physical and mechanical properties, such as low cost, low density, high strength and stiffness. Carbon nanotubes (CNTs) are encouraging additives for polymer composites due to their excellent special mechanical, electrical, and thermal properties. The compounded samples were organized into test specimens by injection moulding machine. The composites contained 1, 2, 3 and 4 wt% multi-walled carbon nanotubes (MWCNT). The purpose of this study is to investigate the mechanical properties of kenaf core fibre with a weight fraction of 30 wt% and varying weight fraction of MWCNT. The injection moulding technique is used to prepare the composite specimens for tensile, flexural and impact tests in accordance to the ASTM D638, ASTM D790 and ASTM D256 respectively. The optimum properties have been observed at MWCNT 3 wt% with the impact strength of, 8.512Kj/m^2, tensile strength, 23.447 MPa, Young's modulus, 1865.950 MPa, flexural strength, 36.728MPa and a flexural modulus, 1826.121 MPa.

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Introduction

The utilization of natural fibre as reinforcement in polymer composites is attracting much attention in replacing the synthetic fibre for engineering application. Natural fibres have been used due to their advantages such as low density, low cost, acceptable specific strength, biodegradability and renewability [1]-[3]. There are many types of natural fibres that have been used as reinforcement in the composites such as jute, bamboo, kenaf and others. The advantages using natural fibre as reinforcements in composites are low density and non-abrasiveness nature which resulting in low production cost and better specific properties.

Composite materials have been utilized in the aircraft industry, automotive, as well as tools for sport. The use of composites in various fields of superior properties owned by the composite that is lightweight, strong, stiff, and resistant to corrosion. The development of composite plastic started to develop since the discovery of composite material that literally is called reinforced plastic, but the use of composite plastic made from many causes new problems i.e. environmental pollution from waste created as well as depletion of resources will increasingly plastic which of course cannot be updated [4].

As the industry attempts to lessen the dependence on petroleum based fuels and products, thus there is an increasing need to investigate more environmentally friendly, sustainable materials to replace the existing glass fibre and carbon fibre reinforced materials. Therefore, attention has recently shifted to the fabrication and properties of natural fibre reinforced materials. Based on this, recently kenaf fibres have become more affordable to the automotive industry as an alternative reinforcement of glass fibre reinforced thermoplastics. Previous studies on mechanical properties of PP composites with kenaf and rice husk as natural fibers have been done. The researchers mentioned that the using of kenaf and rice husk as reinforcement in PP composites contributed to good mechanical properties and biodegradability properties [5].

There are many types of natural fibers that have been used as reinforcement in the composites such as jute, bamboo, kenaf and others. Kenaf (Hibiscus cannabinus L.) is an herbaceous plant originated from West Africa which has been cultivated since around 4000 B.C. Kenaf is commercially available and economically cheap among other natural fibre reinforcing materials. Furthermore, kenaf fibre offers the advantages of being biodegradable, of low density, non-abrasive during processing and environmentally safe [5].

Carbon nanotubes (CNTs) were found in the soot of arch discharged by Sumio Iijima in 1991 [6]. Carbon nanotubes are classified as single-walled nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) [7].

MWCNTs consist of a variable number of graphene sheets rolled coaxially into a cylinder of nanometric diameter [8]. The typical diameter of MWCNTs are between 10–20 nm; their typical length is above 20 μm. Several production methods have been developed aiming at the manufacture of carbon nanotubes in large scale, such as laser vapourisation [9], electric arc discharge [10] and catalytic chemical vapour deposition of hydrocarbons over metal catalysts (CCVD technique) [11]. The first two methods are high-temperature processes and can produce high-quality nanotubes. Nevertheless, the yields are weak and therefore not adaptable for large-scale production. In contrast, the CCVD technique is a suitable method to produce MWCNTs because it is able to produce nanotubes at relatively low temperatures on a large scale at a reasonably low cost [12]. Polymer composites filled with CNTs have been widely used in many areas [13]. CNTs are encouraging additives for polymer composites due to their excellent mechanical, electrical, and thermal properties. The tensile strength of carbon nanotubes is 75-times greater than of steel filaments of the same size, and 15-times greater than of carbon fibres. In other word, the density of carbon nanotubes is one-sixth of steel. Their densities may be as low as 1.3 g/cm3. Plastics enhanced with carbon nanotubes might be the new family of light and strong composites [14].

Materials and Methods

The composition of the material used in this experiment are listed in Table 1. In this study, the Kenaf core in size of 20 mesh was used as shown in Figure 1. The kenaf fibre was obtained from the National Kenaf and Tobacco Board (Lembaga Kenaf dan Tembakau Negara) which is the diameter of kenaf between 17.7 – 21.9 μm, length is 2-6 mm, density of kenaf is 1.4 g/cm3, tensile strength is 930 MPa, and flexural strength is 98000 MPa [15]. This fibre was used as reinforcement of the composite. MWCNT was obtained from Nanocyl SA (Belgium) with the average diameter of the tubes 9.5 nm, the length of 1.5 μm, 90% purity, surface area of MWCNT was 250-300 m^2/g and volume resistivity of 10-4 Ω.cm.

For the experiment, feedstock was composed of PP, kenaf and different MWCNT percentages (Table 1). The materials were mixed using the sigma blade mixer at optimum processing condition. Processing temperature, time and rotating speed were 190°C, 30 min and 45 rpm, respectively. Once mixing completed, blends were crushed using a crusher machine to get in pellet form as seen in Figure 1. All composites were injection moulded into notched Izod for impact test, tensile test and flexural test specimens by using a Battenfeld injection moulding machine type BA250CDC. All specimens were moulded on stabilized processing condition. Composites constitution was presented in Table 1. All samples were tested by the notched Izod impact test universal tensile strength and three-point bending flexural strength test according to ASTM D256, ASTM D 638, ASTM D790 respectively.

Table 1: Composition of materials used in the experiment

Kenaf (wt%)	PP (wt%)	MWCNT (wt%)
0	100	0
30	70	0
30	69	1
30	68	2
30	67	3
30	66	4

Figure 1: Digital image of the hybrid composite in pellet form

Results and Discussion

Mechanical characterisation

Impact Test Results

Generally, the impact strength of MWCNT/ Kenaf/ PP hybrid composite was increased by adding the weight percentage of MWCNT as shown in Figure 2.

In Figure 2, the impact strength of PP as a raw material was 7.617 kJ/m^2, the addition of kenaf 30 wt% on PP decreased the impact strength of Kenaf/PP composite became 1.493 kJ/m^2 or this impact strength dropped 80.4% compared to Pure PP. Especially for the addition of kenaf 30 wt% as a first reinforcement and MWCNT 1wt% as a second reinforcement, the impact strength became 8.148 kJ/m^2 or increased 7% compared to pure PP. The next addition of MWCNT 2 wt% to the Kenaf/PP composite became 8.296 kJ/m^2 or this impact strength increased 8.9% from Pure PP. The addition of MWCNT

3 wt% to the Kenaf/PP composite became 8.512 kJ/m^2 or this impact strength increased 11.75% compare to Pure PP. The impact strength with addition of MWCNT 4 wt% on Kenaf/PP composite was 8.443 kJ/m^2 or increased 10.8% compare to Pure PP. Most of the results shows that by addition of MWCNT to the Kenaf/PP composite will enhance the impact test. This is due to the change of morphology during the impact. It can be noted that the processing parameters have more influence on the impact strength of MWCNT/Kenaf/PP composites [18].

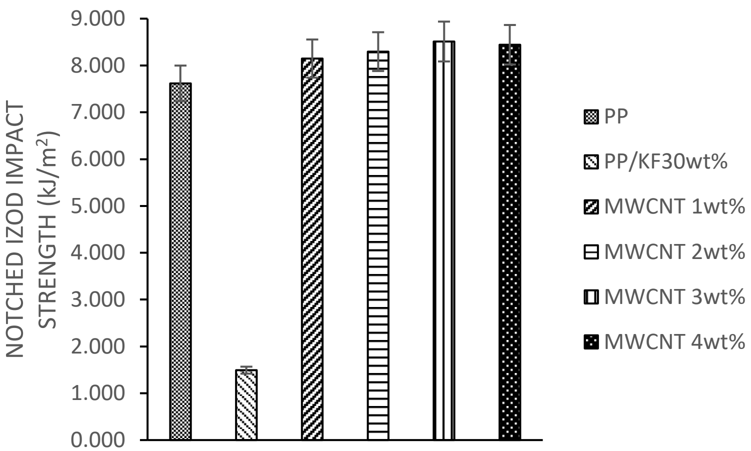

Figure 2: Impact strength of Kenaf/PP composite at different MWCNT loading.

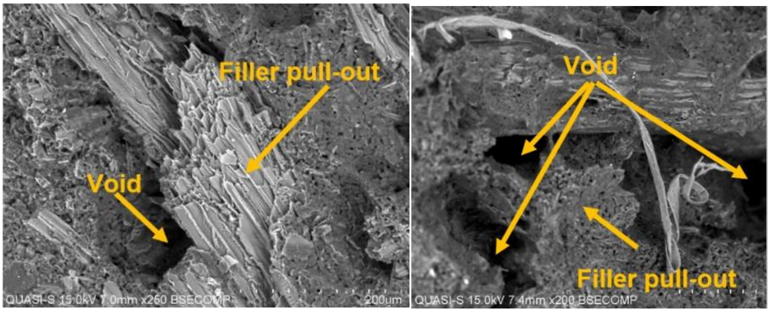

Figure 3: SEM image of impact strength of MWCNT 3 wt% /KENAF 30wt% /PP

Tensile Test Results

The experimental results of tensile strength are shown in Figure 4. The tensile strength of PP was 18.627 MPa, the addition of kenaf 30 wt% on PP decreased the tensile strength of Kenaf/PP composites became 15.908 MPa or dropped 14.6% compared to Pure PP. The addition of MWCNT 1 wt% to the Kenaf/PP composite became 18.239 MPa or dropped 2.1% compared to pure PP. The tensile test with addition of MWCNT 2 wt% on Kenaf/PP composite was 20.663 MPa or increased 12.9% compare to Pure PP. In the addition of MWCNT 3 wt% on Kenaf/PP composite was 23.447 MPa or this tensile test enhanced 25.9% compare to pure PP. Finally, the addition of MWCNT 4 wt% on Kenaf/PP composite became 20.517 MPa or decreased 12.5% compare to Kenaf/PP composite with MWCNT 3 wt% contents. It also can be observed that the composite of MWCNT 3 wt% content showed the highest tensile strength for composites which represents as optimal MWCNT content. Other results [16, 17] shown similar trend. The better tensile strength at lower filler content could be attributed for a better dispersion of MWCNT in the PP resin matrix, better wet ability, absence of void or porosity and good interfacial bond. The lower tensile strength at MWCNT 4 wt% could be attributed to inefficient stress transfer between the particle-matrix interface due to poor interface adhesion. This is expected because strength depends on effective stress transfer between filler and matrix, and toughness/brittleness is controlled by adhesion.

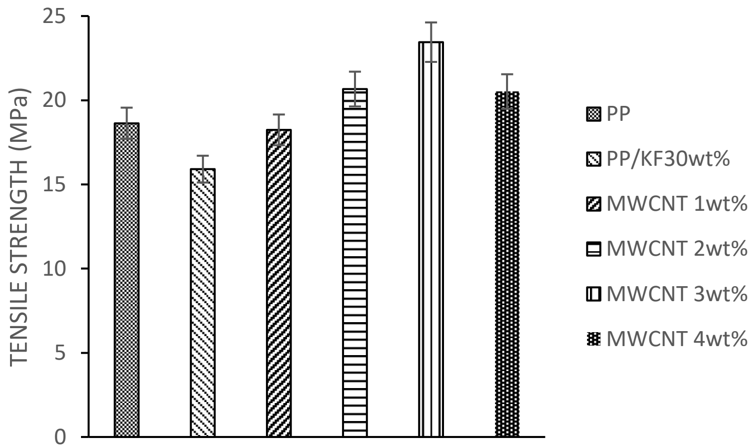

Figure 4: Tensile strength of Kenaf/PP composite at different MWCNT loading.

Based on the results, it indicates that the strength of Kenaf/PP composite is increased with the addition of MWCNT 3 wt%. The MWCNT 4 wt% sample exhibited slightly decreased flexural strength because of insufficient PP content.

The conclusion can be generalized that the MWCNT loading significantly affects the mechanical properties of the composites. It means that the MWCNT has proven its function by increasing the tensile strength of the Kenaf/PP composites compared to pure PP and Kenaf/PP composite alone. The result shows that tensile strength increased as filler content increased from 1% to 3% but dropped at 4% filler content. The dropped tensile strength at 4% filler content could be attributed to inefficient stress transfer between the particle-matrix interface due to poor interface adhesion.

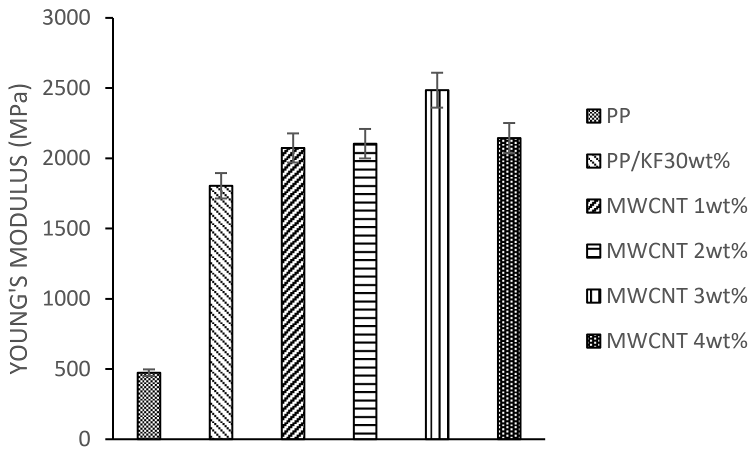

Figure 5: Young's modulus of MWCNT/Kenaf/PP hybrid composites

Figure 5 shows that the MWCNT/Kenaf/PP composites had the highest Young's modulus value (i.e., 1865.95 MPa). The MWCNT/Kenaf/PP composites had the highest stiffness value at MWCNT 3 wt% loading. This increase in modulus may have been due to the stiffness factor, where the MWCNT fillers were bonded to the PP; thus, the mobility of the molecule was arrested. For this reason, the flexibility was reduced, and the stiffness was increased.

Flexural Strength Results

Flexural properties such as flexural strength and modulus are determined by ASTM Test method D790. In this composite test specimen of rectangular cross section is loaded in three-point bending model. The flexural test was conducted to study the behaviour and ability of material under bending load. The load was applied to the specimen until it was totally broken. The flexural test was conducted for different percentage of MWCNT weight as shown in Figure 6.

In Figure 7, the flexural strength of pure PP was 25.258 MPa. the addition of kenaf 30 wt% on PP composite became 29.420 MPa or increased 16.5% compare to pure PP. The addition of MWCNT 1 wt% to the Kenaf/PP composite became 28.017 MPa or increased 10.9 % compare to Pure PP. The flexural strength with addition of MWCNT 2 wt% on Kenaf/PP composite was 30.937 MPa or increased 22.5% compare to pure PP. In the addition of MWCNT 3 wt% on Kenaf/PP composite was 36.728 MPa or this tensile test enhanced 63% compare to pure PP.

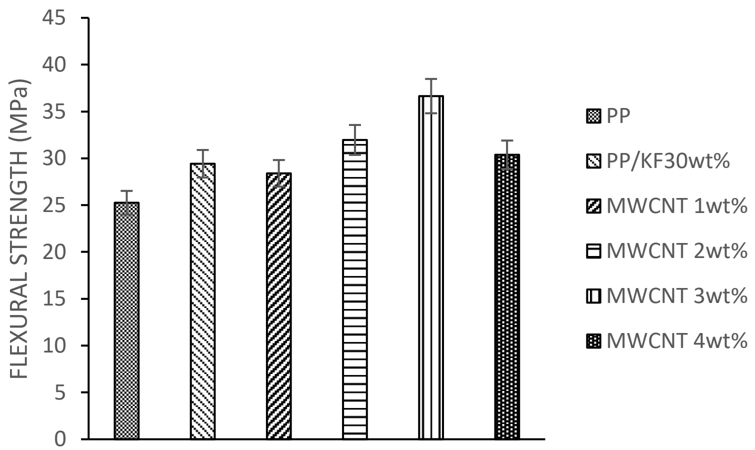

Figure 6: Flexural strength of MWCNT/Kenaf/PP hybrid composites

Like tensile strength, the flexural strength increases gradually as the filler content increases but decreases at 4 wt% filler content. The reduction in flexural strength as the filler content increases could be attributed to control the mobility of matrix by filler particles.

Generally, the more filler loading, the greater flexural modulus increament. It shows that the flexural modulus (Figure 7) increased on the addition of MWCNT. It can be observed at 1, 2 and 3 wt % and slowly decreased at 4 wt% of MWCNT concentration.

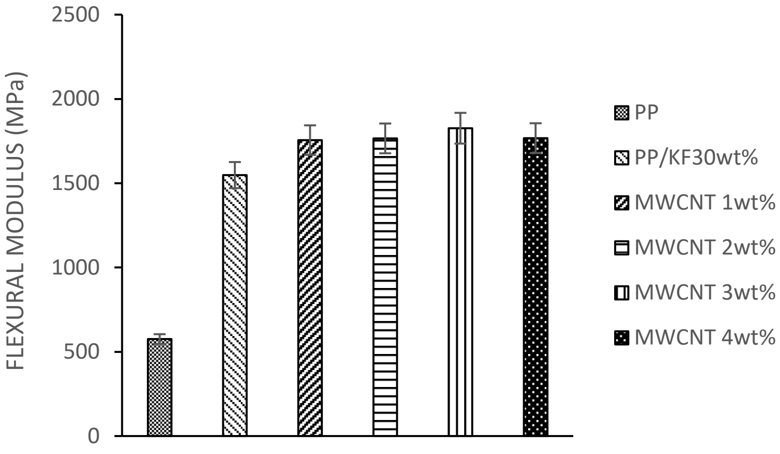

Figure 7: Flexural modulus of MWCNT/Kenaf/PP hybrid composites

Morphology Characterization

Morphological and structural changes of the fractured surface were observed under SEM. The fracture surface of MWCNT 3 wt% /Kenaf 30 wt% /PP and MWCNT 4 wt% /Kenaf 30 wt% /PP composites were illustrated in Figure 9. The combination of kenaf particle breakage and the particle embedded indicated that the adhesion of Kenaf/PP was adequate (Figure 8a).

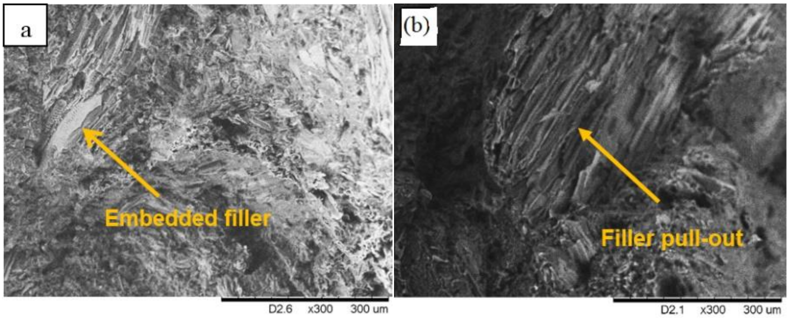

Figure 8 SEM micrograph for tensile fracture structure. (a) MWCNT 3 wt% / Kenaf 30 wt% / PP composites and (b) MWCNT 4 wt% / Kenaf 30 wt% / PP composites

Conclusion

Multi-walled carbon nanotube/ Kenaf/ Polypropylene composites were produced via injection moulding machine. The composites contained MWCNT 1, 2, 3 and 4 wt% have shown different results. The Izod impact strength, tensile strength, flexural strength and flexural modulus of the composites have been examined. It can be summarized, that the properties of the composites produced with MWCNT 3 wt% content are most suitable and better properties. The suitable mechanical value can be achieved with MWCNT 3 wt% content. According to the measurement results, it can be concluded, that the injection moulding machine is more appropriate for producing of the MWCNT/ Kenaf/ Polypropylene Composites.

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