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The Effect of Multi-Walled Carbon Nanotubes on the Mechanical Properties of Composite Material Carbon Fibers/Polyester Used in Ships Hulls

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Abstract

The study examined the effect of the multi-walled carbon Nanotubes(10-30) nm on the mechanical properties of composite materials of carbon fibers and polyester used in the hulls of the ships and speedboats. The study investigates the microstructure of the composite samples by using scanning electron microscope (SEM). The tensile specimens of the composite materials were prepared according to the standard (ASTM D3039) at a different weight fraction (16.67%, 30% and 44%) and different additions of nanotubes 0.16%, 0.2% and 0.24%. The experimental results showed that the maximum increase in tensile stress was 5.33 % when the weight fraction raised from 30% to 44% at the weight of multi-walled carbon nanotubes was 0.16 %, while the maximum increase in tensile stress was 5.48 % when the weight of multi-walled carbon nanotubes increased from 0.16 % to 0.2% at a weight fraction of the carbon fibers equal to 44%. It showed a maximum increase in the elongation by 43.2% when increasing the weight fraction from 16.67% to 30% at a weight ratio of 0.2% of multi-walled carbon nanotubes, while the maximum increase of 45% due to raising the weight of nanocarbon particles from 0.2% to 0.24% at a weight fraction of carbon fibers of 16.67%. The SEM images show the homogeneous distribution of multi-walled carbon nanotubes, which leads to improvement in the tensile stress and elongation, which represent the toughness of the composite materials.

Keywords: carbon Nanotubes,composite materials, carbon fibers, microstructure.

1. Introduction

There is widespread agreement regarding the usage of carbon fibers (CF) in a variety of industrial applications, including transportation, aviation, medical equipment, and military structures, as well as the impact of temperature variables on composite materials used in manufacturing [1–7]. While other studies investigated how nanoparticles in carbon fiber composites affected mechanical characteristics like resistance to fracture and high thermal and chemical stability, as well as how to achieve interfacial adhesion with carbon fibers by analyzing the microstructure using image analysis (SEM) [8–11].The researcher examined the impact of incorporating multi-walled nanotubes (MWCNTs) into elastomers at a concentration of 1% to 8% by weight while evaluating the change in electrical resistance that takes place during stretching and twisting as a physical and chemical indicator. Thermography was employed by the researchers to examine conductivity and thermal emission in various contexts. In the area of electrical heating and deformation control, they advise the development of flexible functional materials [12].By incorporating various types and weight fractions of carbon fiber and nanoparticles into composite materials, studies have been made to improve their mechanical properties (tensile stress, flexure stress, creep stress, and mechanical wear) for a variety of applications, including structures, boat hulls, artificial feet, and brake pads [13-23].The improvement of mechanical characteristics such as strength, toughness, and ductility simultaneously was addressed, and the researcher provided a description of how metallic nanoparticles effect experimental findings and theoretical ideas [24]. Researchers looked at how introducing carbon nanotubes (CNTs) affected the mechanical characteristics of polyester, and they found that the qualities of polymeric compounds had improved [25]. In order to increase the range of applications for polyester resins, the study looked into ways to improve their properties utilizing widely used, commercially accessible high-dispersion Nano-silica[26]. Due to their mechanical characteristics, such as hardness, elastic modulus, adhesion, and friction between nanoparticles or nanoparticles on surfaces, the researchers offered novel applications for nanomaterials, such as lubrication, coating, etc. [27].They used zirconia nanoparticles to analyze their effect on the mechanical properties with an addition of approximately (3%) by weight, which showed improvement of mechanical properties (tensile strength, tensile modulus, toughness, hardness, and critical strain energy release rate) in different proportions [28].The study provided a presentation on enhancing the mechanical

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properties of fiber-reinforced composite materials with nanoparticles for usage in diverse application fields[29]. The study examined the impact of the environment on the mechanical properties of a composite material (glass fiber/polyester) at salt concentrations of 99.9% and 0.008% potassium iodide and magnesium carbonate, respectively [30]. The results of the study, which looked at the mechanical properties of a composite material made of carbon fibers and polyester in a varied ratio with the inclusion of carbon nanotubes, showed an improvement in the mechanical properties of the composite material [31]. The study examined the mechanical, thermal, and electrical characteristics of a composite material reinforced with natural fibers (palm fibers), polyester, and fibers at various volume fractions, and came to the conclusion that the volume fraction at 30% had poor mechanical characteristics[32].The researchers showed how carbon nanotube behaviors may be studied experimentally to identify mechanical characteristics such as Young's modulus, shear modulus, bending behavior, and vibrational response [33–38]. The experiment results showed an improvement in tensile stress in various proportions, and the study examined the impact of silicon nano dioxide on the mechanical properties and crack growth in the microstructure of the composite material of carbon/polyester fibers at different weight fractions used in the manufacture of boat hulls [39]. The use of a few ratios of carbon fiber in the composite was found to lower the weight of the structure by about 30% without major changes in manufacturing processes, which reduces the weight to decrease fuel consumption even if the cost of carbon fiber is higher than that of glass fiber [40-42].In hybridization, elemental carbon can take the form of many incredible structures. Carbon can construct closed and open cages with a honeycomb atomic configuration in addition to the well-known graphite The C60 molecule was the first of these structures to be identified by Kroto et al. [43] Despite the study of numerous carbon cages, it was not until 1991 that Iijima [44] made the first observation of tubular carbon structures. The so-called multi-walled carbon nanotubes (MWNT) had up to several tens of graphitic shells, adjacent shell spacing of 0.34 nm, diameters of 1 nm, and a high length/diameter ratio. Multiwalled nanotubes (MWNT) are a collection of these nanotubes arranged in rings, much like the rings of a tree trunk as shown in Figure 1[45].

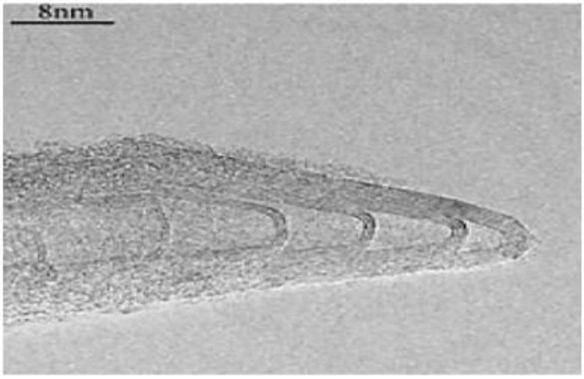


Figure 1. Tip of multi wall carbon nanotube

The current study aims to investigate the effect of adding multi-walled carbon nanoparticles at different weight fractions on improving the mechanical properties of the composite material consisting of polyester fibers and carbon fibers. The importance of the study lies in using the composite material consisting of carbon fibers /polyester is used increasingly in sailboats, super-yachts, and high-strength interior molds due to the advantages of ship stability, high performance, and less weight.

2. Methodology

Through experimental and laboratory testing based on the weight and volume fractions of the components contained in the composite material's composition, it is possible to determine the features of composite materials made up of two or three different materials. The mathematical equations based on experimental tests provide an accurate description of the properties of the composite material. The resin weight represents the difference between the composite material sample and the fiber weight. [46],[47]:

$$w_{m=}w_c - w_f \tag{1}$$

And for specimens consist of three composite material the equation will be:

$$w_m = w_c - w_f - w_{Nano} \tag{2}$$

The volume of the fibers (carbon fiber) in the composite:

$$V_f = \frac{W_f}{\rho_f} \tag{3}$$

The volume ratio of fiber (carbon fiber) to matrix (polyester resin) of the composite material which inserted in the specimens:

$$\frac{V_f}{V_m} = \left(\frac{W_f}{W_m}\right) * \left(\frac{\rho_f}{\rho_m}\right) \tag{4}$$

The density of composite material:

$$\rho_c = \rho_{f.}V_f + \rho_m.V_m + \rho_{Nano}.V_{Nano} \tag{5}$$

3. Materials and Methods

In-depth research has been done in recent years on the use of polymer composites in maritime systems, focusing on the potential advantages of replacing various parts including ship hulls, propeller blades, and wind, and tidal turbine blades, to name a few. The research resulted in papers on the most recent developments in this field, covering the use of advanced composites in ships and ship components, offshore oil and gas composites, marine renewable energy, and underwater mending [48].The study found that the cost of carbon fibers might be reduced by modifying the carbon fiber concentration to provide the best strength in speedboats used by the Navy and the Navy in relatively shallow waters [49] .The results of this work can be used to reinforce composite materials by incorporating carbon nanoparticles, leading to the development of speedboats with greater specifications.

3.1. Materials

The specimens were prepared by employing low cost polyester resin as a matrix whose specifications are shown in the Table 1 and reinforceing by mat carbon fibers (as a fiber) at a different weight fraction 16.7%, 30% and, 44% whose specifications are shown in the Table 2 ,as well as adding multi-walled carbon Nanotubes (10-30) nm as shown in Figure 2 at different ratio 0.16%, 0.2% and, 0.24% whose specifications are shown in the Table 3. The process of mixing the nanotube particles with polyester was carried out using theultrasonic processor (UP200Ht) to obtain a homogeneous distribution of nanotube particles within the polyester resin (the matrix) at room temperature. The dye was prepared to cast the samples that were later cut using CNC machines.

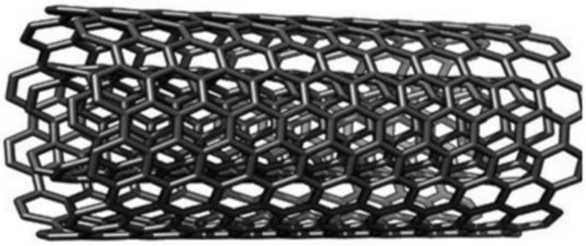


Figure 2. Multi-walled carbon Nanotubes

Table 1. Mechanical Properties of Polyester resin.[50]

Properties	Value
Specific density (at 20 C^o)	1.22
Tensile stress at break	65 N/mm^2
Elongation at break (50mm gauge length)	3.0 %
Modulus of elasticity	3600 N/mm^2
Density (p)	1268 kg/m^3
Rockwell Hardness	70

Table 2. The specifications of carbon fiber mat

Characteristic	Nominal
Mass per unit area (g/m^2)	200
Weave	Plain
Width (mm)	1000/2000
Thickness	0.16

Table 3. The properties of multi-walled carbon nanotubes

Items	Details
Purity	90% wt
Out diameter (OD)	10-30 nm
In diameter (ID)	5-10 nm
Length	10-30 nm
Specific Surface Area (SSA)	>200 m^2/g
Bulk density	0.06 g/cm^3
True density	˜ 2.1 g/cm^3
Cheap tube Inc., 3992 Rte 121 east STE3 Grafton , VT 05146 USA	

3.2. Methods

The weight fraction of the carbon fibers shown in Figure3 was determined at different weight ratios using a high-precision weight scale relative to the weight of the polyester resin in the die. The weight ratio of adding nanotubes to the weight of polyester was also determined by using weigth scale high accurcy. Polyester and nanotubes were mixing using (Ultrasonic Processor UP200Ht) as shown in Figure 4to achieve the highest homogeneity of the nanotubes distribution in polyester. The tensile specimens were prepared using the same weight fraction of carbon fibers or the percentage of addition of nanoparticles.The study used the method of casting a mixture by using the ultrasonic processor of polyester and carbon nanoparticles after carbon fibers were weight measured and cast in the mold, where they were left to harden and then cut into tensile samples according the standard of tensile specimen (ASTM D3039) as shown in Figure 5.The tensile tests were done by using the device type (Wp 300 Universal Material Tester).

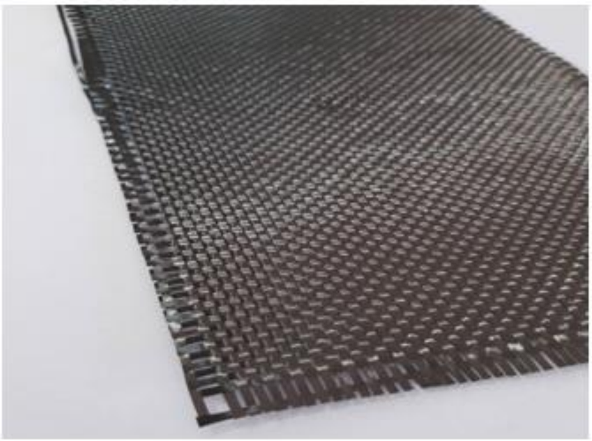


Figure 3. Mat of the carbon fibers(CF)

Figure 4. The ultrasonic processor UP200Ht device

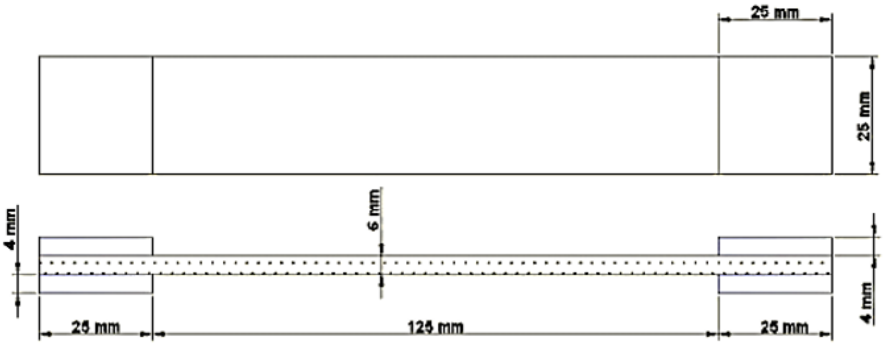


Figure 5. The standard of tensile specimen (ASTM D3039)

4. Results and Discussion

Carbon nanotube-infused resin helps to dramatically increase the toughness of existing robust carbon-fiber composites without sacrificing rigidity, frequently even boosting stiffness. The addition of carbon nanotubes to the resin also improves the material's resistance to surface abrasion, slowing down the rate at which surfaces deteriorate, and it helps direct energy into the fibers, which are more resilient than the resin.

The current study agreed with many studies in the field of improving the mechanical properties as well as the electrical and thermal properties by using carbon nanotubes in carbon fiber composites to obtain compounds with improved properties [51].

4.1. The effect of weight fraction of carbon fibers

According to Figure 6. The experimental results, increasing the weight of carbon fibers from 16.67% to 30% causes an increase in tensile stress of 14.9%, while increasing by 36.4% due to increasing the weight of carbon fibers from 30% to 44% at a weight of multi-walled carbon nanotubes of 0.16%. When the weight fraction of carbon fibers is increased from 16.67% to 30%, the elongation of composite samples increases by 16.15%, whereas it increases by 6.06% when the weight fraction is increased from 30% to 44%. The composite material's increased elongation indicates that its toughness has improved, which means that it is better able to absorb stress energy before failure, and improves its characteristics.

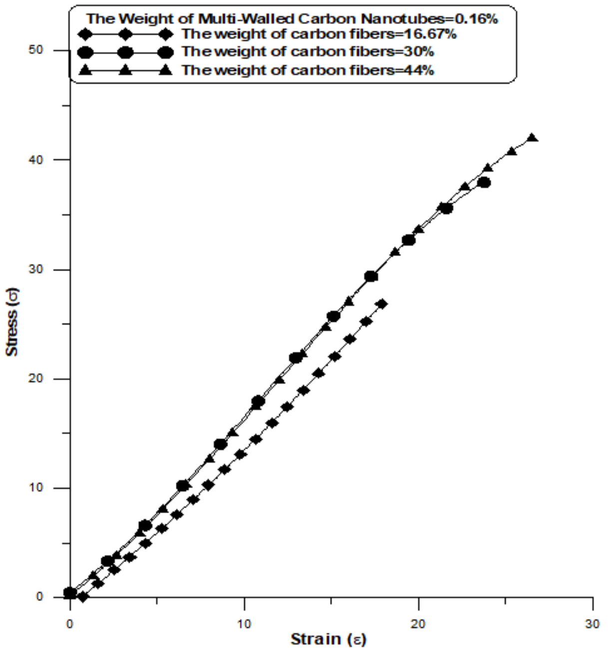


Figure 6. The relationship of stress-strain of different weight fraction at multi-walled carbon nanotubes weight 0.16 %

According to the results shown in Figure 7, a weight ratio of 0.2% of multi-walled carbon nanotubes causes the tensile stress to rise by 3.48% when the weight fraction of carbon fibers is increased from 16.67% to 30%. In comparison, it increases by 1.58% due to the rise in the weight fraction of carbon fibers from 30% to 44%.Increasing the weight fraction of carbon fibers from 16.67% to 30% led to rising the elongation by ratio 43.2%, while it rose by 10% caused by increasing the weight fraction from 30% to 44%. The elongation increase is an indicator of the improvement of the toughness of the composite material as a result of the bonding of carbon fibers with polyester resin during tensile stress.

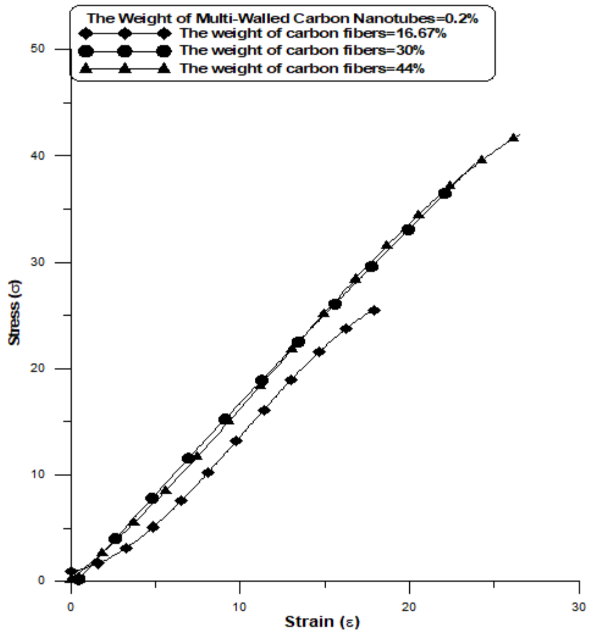


Figure 7. The relationship of stress-strain of different weight fraction at multi-walled carbon nanotubes weight 0.2 %

The testing results for multi-wall nanocarbon at 0.24% are shown in Figure 8, where the tensile stress increased by 1% when the weight fraction rose from 16.67% to 30% and by 5.33% when it increased from 30% to 44%. According to the findings, the elongation increased by 32.5% when the weight fraction got up from 30% to 44% as opposed to 27.7% when the weight fraction increased from 16.67% to 30%. The toughness represents the material's ability to absorb the energy generated by tensile stress and represents the area under the stress-strain curve [52] which showed an increase in the area under the stress-strain curve.

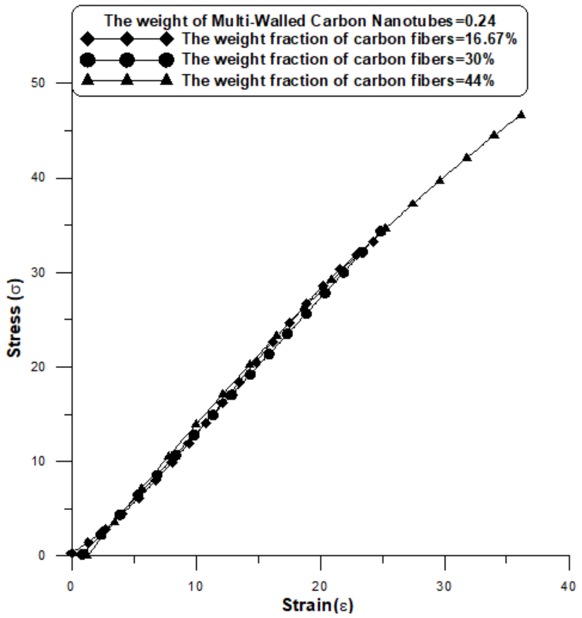


Figure 8. The relationship of stress-strain of different weight fraction at multi-walled carbon nanotubes weight 0.24 %

4.2. The effect of weight of multi-walled carbon nanotubes

Increasing the weight of nanocarbon particles from 0.16% to 0.20% at the weight fraction of carbon fibers at 16.67% results in a 2.31% increase in stress, as shown in Figure 9. Thus, whereas elongation increases by 45% when the weight of nanocarbon particles increases from 0.2% to 0.24% at a weight fraction of carbon fibers equal to 16.67%, it increases by 12.01% when the weight of nanocarbon particles increases from 0.1% to 0.2%.

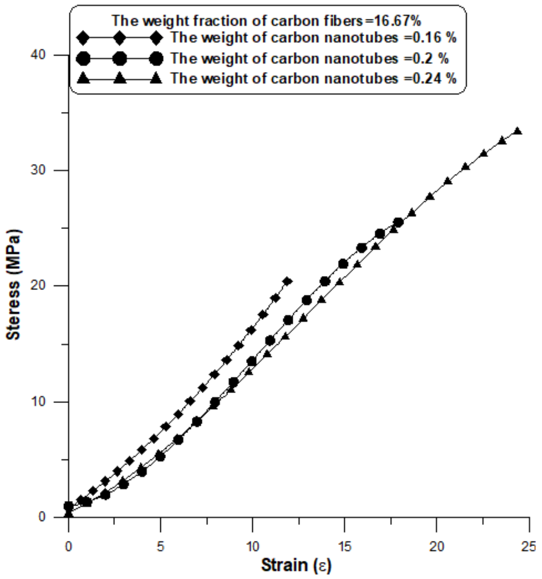


Figure 9. The relationship of stress-strain of different weight fraction of carbon fibers at multi-walled carbon nanotubes weight 0.16 %

The weight fraction of carbon fibers at 30% in Figure10 shows the effect of increasing the weight ratio of nanocarbon particles from 0.16% to 0.2% increased tensile stress by 1.17% While increasing the weight of carbon nanoparticles from 0.2% to 0.24% raised the tensile stress by 2.85%. The elongation increased by 40.4% due to increasing the weight of the nanocarbon particles from 0.16% to 0.2%. In comparison, it increased by 2.85% due to raised the nanocarbon particle weight from 2.0% to 0.24%.

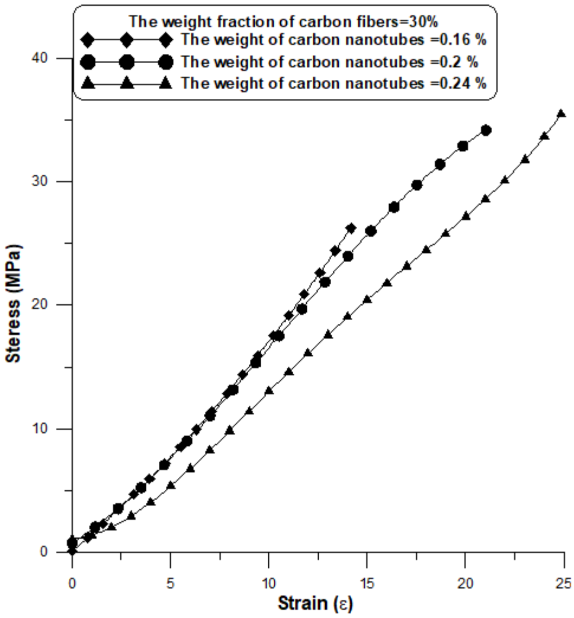


Figure 10. The relationship of stress-strain of different weight fraction of carbon fibers at multi-walled carbon nanotubes weight 0.2 %

At weight fraction of the carbon fibers is 44% in Figure 11, displaying that the effect of increasing the nanocarbon particles from 0.16% to 0.2% raised the tensile stress by 5.48 %, while the tensile stress increased by 2.67% as a result of the increase in the weight of the nanocarbon particles from 0.2% to 0.24%. The experimental results at the weight fraction of carbon fibers 44% increasing the stress by a ratio of 42.8% due to an increase in the carbon particles' weight from 0.16% to 0.20%, while it was increased by 26.6% due to rise the nanocarbon particles weight from 0.2% to 0.24%. The improvement in the elongation of the composite material is an indicator of improving the toughness of the composite material and its ability to absorb the energy applied to it before failure occurs.

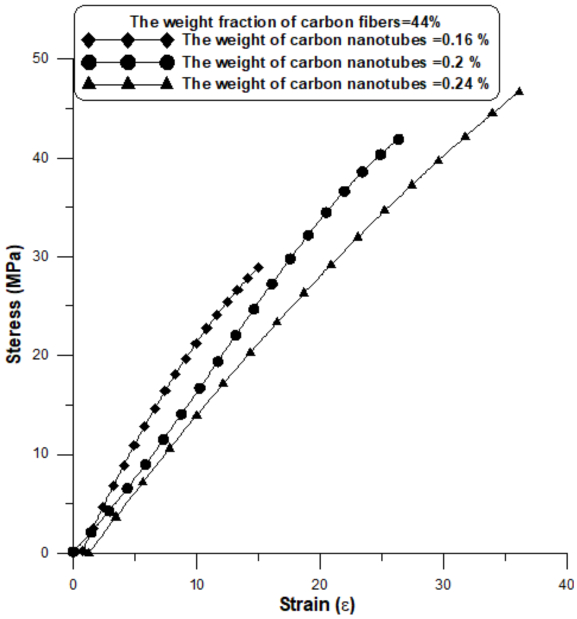


Figure 11. The relationship of stress-strain of different weight fraction of carbon fibers at multi-walled carbon nanotubes weight 0.24 %

4.3. SEM pictures of fracture surface of composite tensile specimens

Figure 12 displays the magnification (MAG) of composite microstructure at carbon fibers 16.67% and 0.16% of multi-walled carbon nanotubes by 500 k and 1.0 kx, where the nanoparticles diffusion appears in white color in the structure of the composite sample as shown in Figure (12-a). Figure (12-b) shows the image of scanning electron microscope (SEM) when magnifications at 1kx that the nanoparticles follow and gather on the paths of carbon fibers mat, and thus they enhance the cohesion of carbon fibers of the fiber material in the composition of the composite material with polyester (i.e.matrix).The improvement of cohesion contributes to the advance of the mechanical properties of the composite material.

In Figure 13, the SEM images magnification at 500x and 1kx shows a composite sample in which the weight fraction is 30% carbon fibers, and the weight of nanoparticles is 0.16%. The pictures show the distribution of nanoparticles in the composition sample in white color. So that displays pitting on the surface of the composition sample marked with circles due to increasing the percentage of fiber at the expense of reducing the weight ratio of polyester, which leads to faster solidification of polyester.

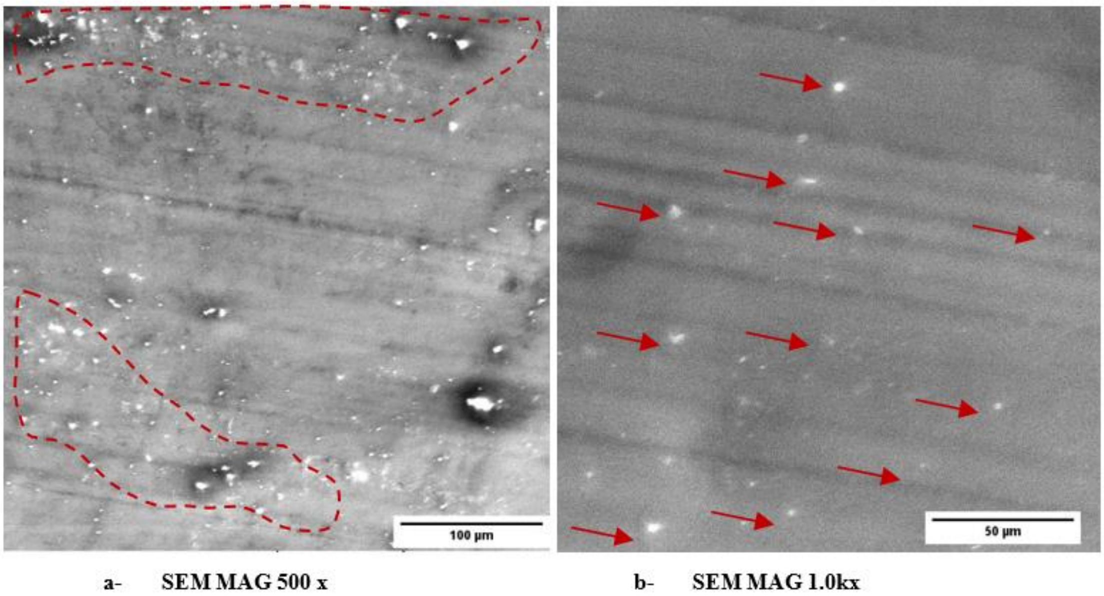


Figure 12. The SEM images of composite specimens at a weight fraction of carbon fibers 16.67% and 0.16 % of multi-walled carbon nanotubes

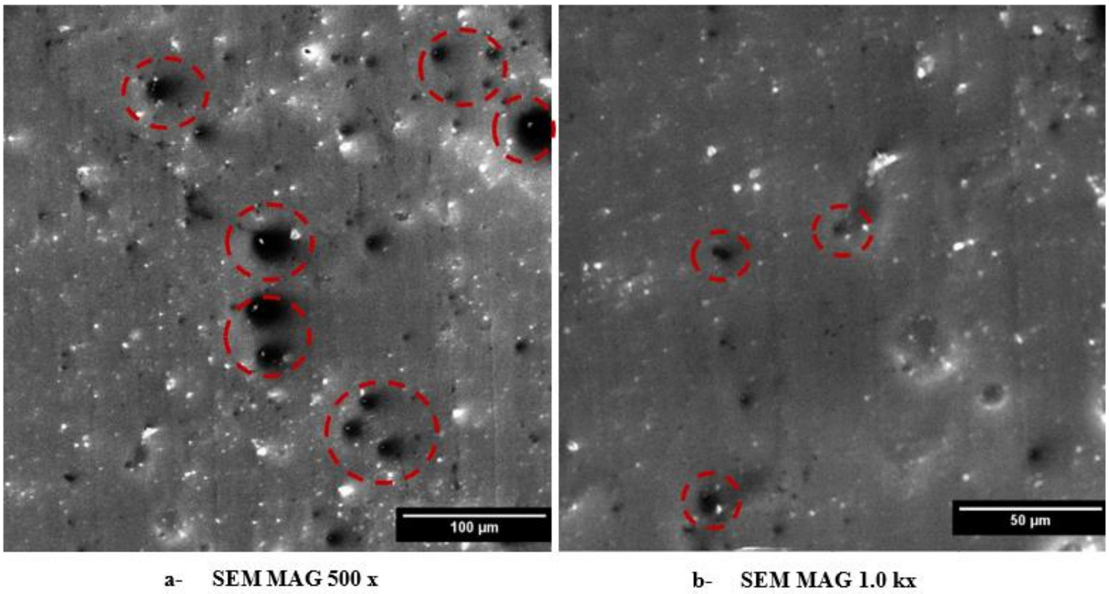


Figure 13. The SEM images of composite specimens at a weight fraction of carbon fibers 30% and 0.16 % of multi-walled carbon nanotubes

The SEM images in Figure 14 display the magnification ratio of 500x and 1.0 kx for a sample in which the weight fraction of carbon fibers is 44% and the weight ratio of nanoparticles is 0.16%. The images show the distribution of nanoparticles on the surface of the composite sample with the appearance of small fibers of carbon fibers near the surface due to the increased fiber ratio in the composition of the composite material.

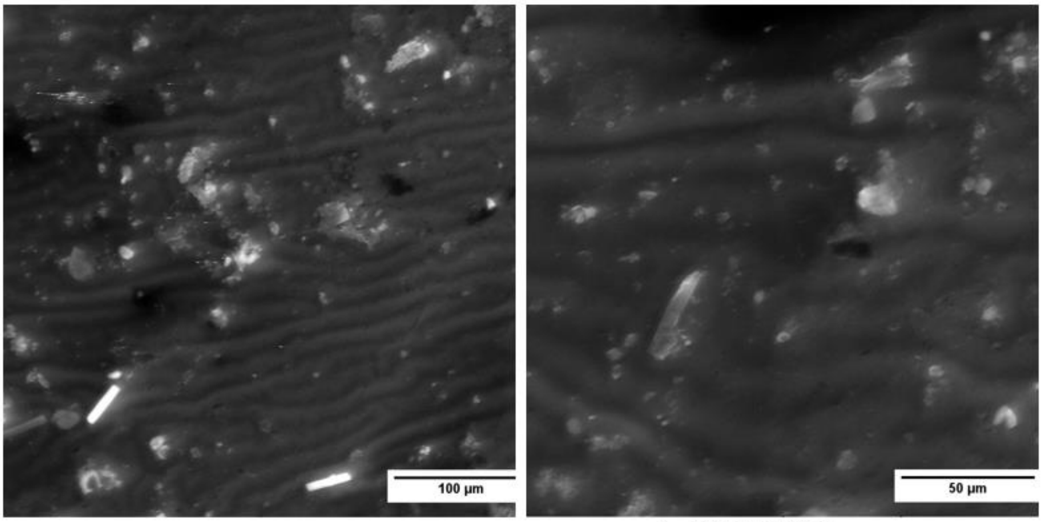
The SEM images at 500 x and 1 kx in Figure 15 showed multi-walled carbon nanotubes distributed uniformly in the composition of the composite material with a small percentage of particles flocculation on the surface of the sample indicated in pictures 13-a and b. The homogeneous diffusion of the carbon nanoparticles gives the microstructure of the composite material greater strength. It indicates that the time used for the mixing period of the carbon nanoparticles with polyester was appropriate to achieve homogeneity in the composition of the material.

Figure 16 also shows microstructure images using SEM images of composite samples at a weight fraction of carbon fibers of 30% and 0.2% of multi-walled carbon nanotubes. Carbon nanoparticles spread within the composite samples regularly, with occurring of some particles flocculation indicated in the images by a small percentage at the surface. While in Figure 17 the SEM images of composite samples at a weight fraction of carbon fibers 44% and 0.2% of multi-walled carbon nanotubes show an increasing ratio of particles flocculation of carbon nanoparticles near the surface of the sample, and this is due to an increase in the weight fraction of carbon fibers, which leads to a decrease in the weight fraction of polyester in the composition of the samples. The rising weight fraction of the carbon fibers contributes to pushing the polyester and carbon nanoparticles mixed with it to approach the surface of the samples.

Figure 18 shows the SEM images at 504 x and 1.0 kx magnifications of the surface of the composite samples have a weight fraction of carbon fibers of 16.67% and 0.24% of multi-walled carbon nanotubes. The images show the homogeneity of the microstructure of the composition samples at a weight fraction of 16.67% of carbon fiber and display complete immersion of the carbon fibers in the polyester, with a decrease in the percentage of particles flocculation of the nanoparticles, displays in the images.

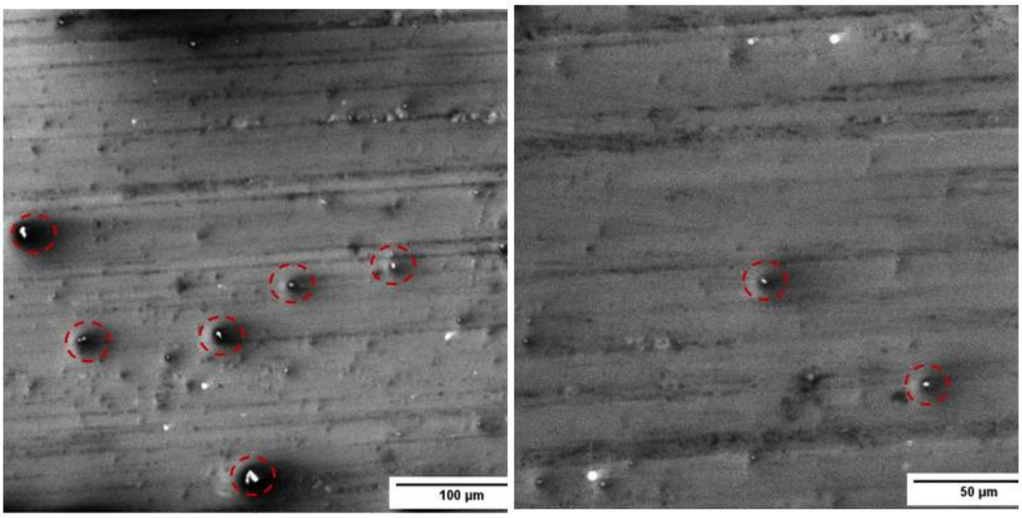
The SEM images at 498 x and 1.0 kx magnifications show in Figure 19 of composite specimens at a weight fraction of carbon fibers of 30% and 0.24% of multi-walled carbon nanotubes. The images show the distribution of carbon nanoparticles in white color in the microstructure of the composite samples. The distribution of the composite samples appears homogeneous and uniform in the microstructure.

Figure 20 shows the SEM images of composite specimens at a weight fraction of carbon fibers of 44% and 0.24% of multi-walled carbon nanotubes. The images show the homogeneity of the microstructure of the composite samples, with the appearance of a few ratios of particle flocculation of nanoparticles at the surface of the composite samples, as shown in the images.



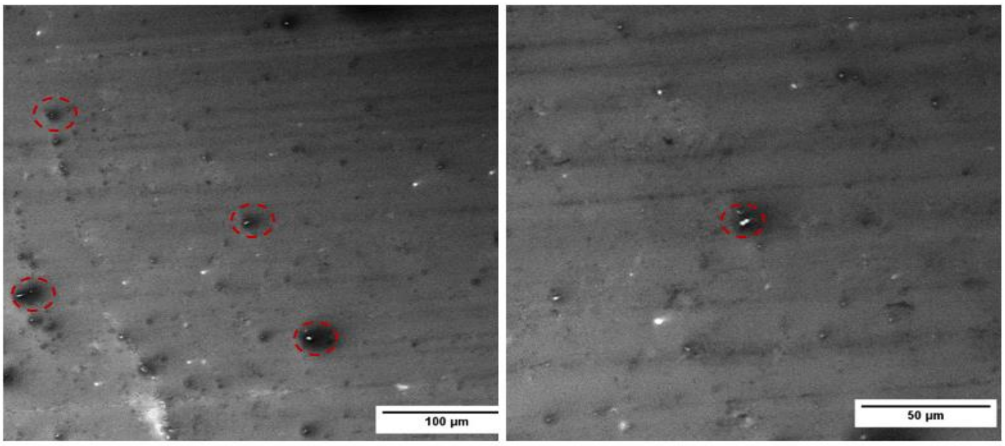
a- SEM MAG 500 x **b- SEM MAG 1.0 kx**

Figure 14. The SEM images of composite specimens at a weight fraction of carbon fibers 44% and 0.16 % of multi-walled carbon nanotubes



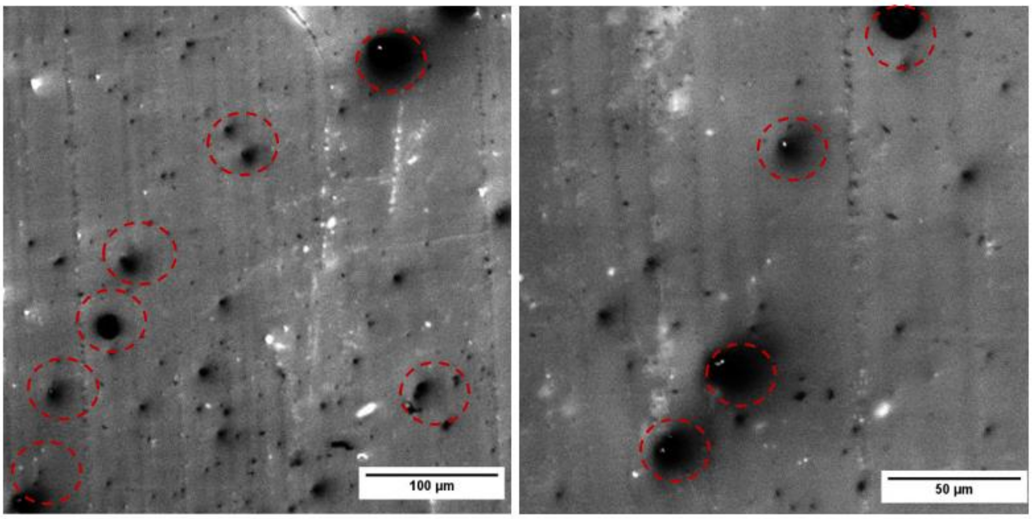
a- SEM MAG 500 x **b- SEM MAG 1.0 kx**

Figure 15. The SEM images of composite specimens at a weight fraction of carbon fibers 16.67% and 0.2 % of multi-walled carbon nanotubes



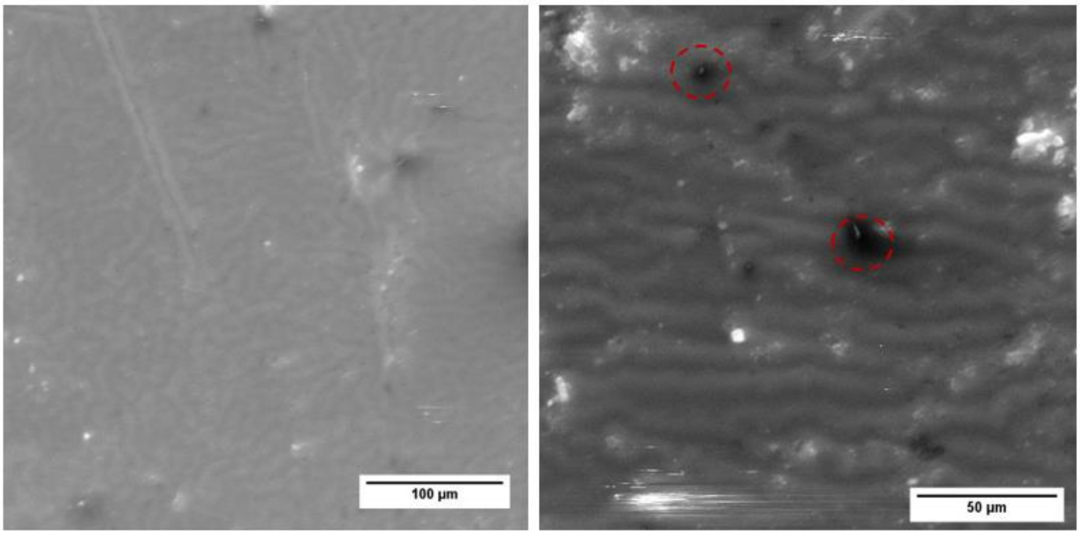
a- SEM MAG 500 x **b- SEM MAG 1.0 kx**

Figure 16. The SEM images of composite specimens at a weight fraction of carbon fibers 30% and 0.2 % of multi-walled carbon nanotubes



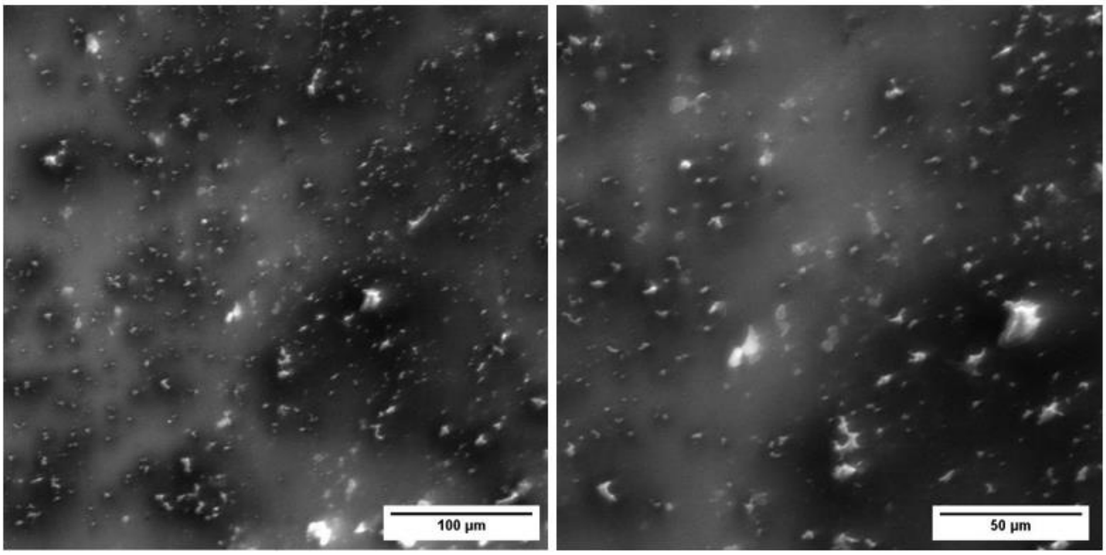
a- SEM MAG 500 x **b- SEM MAG 1.0kx**

Figure 17. The SEM images of composite specimens at a weight fraction of carbon fibers 44% and 0.2 % of multi-walled carbon nanotubes



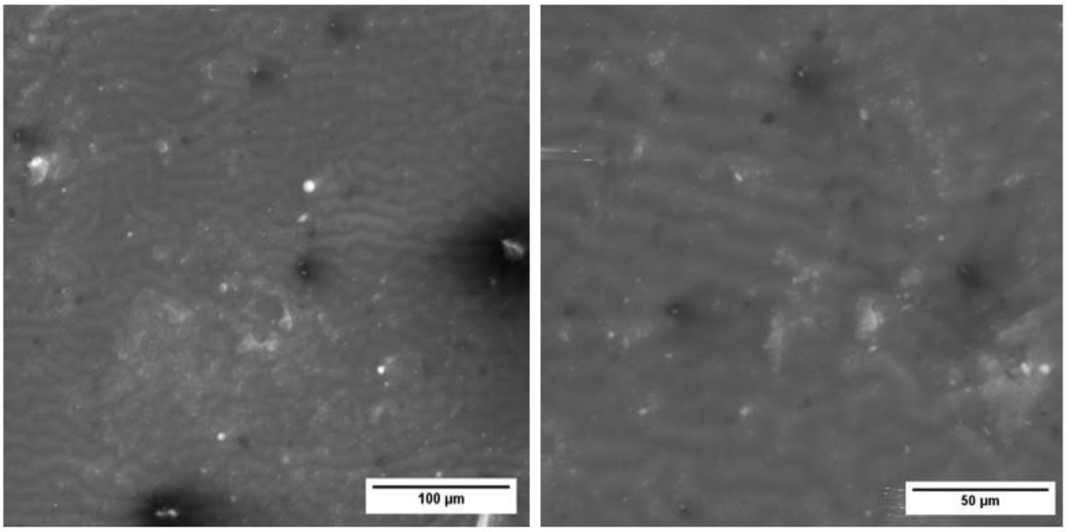
a- SEM MAG 504 x **b- SEM MAG 1.0kx**

Figure 18. The SEM images of composite specimens at a weight fraction of carbon fibers 16.67% and 0.24 % of multi-walled carbon nanotubes



a- SEM MAG 498 x **b- SEM MAG 1.0kx**

Figure 19. The SEM images of composite specimens at a weight fraction of carbon fibers 30% and 0.24 % of multi-walled carbon nanotubes



a- SEM MAG 497 x **b- SEM MAG 1.0 k x**

Figure 20. The SEM images of composite specimens at a weight fraction of carbon fibers44% and 0.24 % of multi-walled carbon nanotubes

5. Conclusions

The study showed an improvement in the mechanical properties of composite materials consisting of carbon fibers and low-cost polyester at different weight fractions used in manufacturing the ship hulls at different weight ratios of multi-walled carbon nanotubes. The experimental results showed that the highest increase in tensile stress was 5.33%, caused by increasing the weight fraction of carbon fibers from 30% to 44% at the weight of multi-walled carbon nanotubes equal to 0.16%. While, the maximum increase in tensile stress was 5.48% due to raising the weight of multi-walled carbon nanotubes from 0.16 % to 0.2% at a weight fraction of the carbon fibers equal to 44%. In addition to that, the experimental result shows a maximum increase in the elongation by 43.2% due to increasing the weight fraction of carbon fiber from 16.67% to 30% at a weight ratio of multi-walled carbon nanotubes equal to 0.2%, while the maximum increase of 45% caused by raising the weight of nanocarbon particles from 0.2% to 0.24% at a weight fraction of carbon fibers equal to 16.67%. The SEM images show the homogeneous distribution of multi-walled carbon nanotubes, which leads to improvement in the tensile stress and elongation, which represent the toughness of the composite materials. Finally, the significance of the study is to improve the mechanical specifications of various marine structures and boat hulls by using a low-cost matrix (i.e., polyester) with carbon fibers and multi-walled carbon nanotubes as reinforcing materials.

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