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Mechanical and Physical Properties of Nano Carbon Tube with Carbon Fiber Reinforced with Polyester Resin

Abstract: *In this research, study some physical and mechanical properties of polymernano composites. The polymernano composites based on unsaturated polyester resin reinforced with carbon fibers (C.F). The samples are attended by hand lay – up method. The samples constituent were polyester resin as matrix with 3% volume fraction from carbon fiber and (0.5%, 1%, 1.5%, 2 %) volume fractions of carbon nanotube. The water absorption, hardness (shore D), flexural test, impact test and toughness fracture properties are studied. Results showed that water absorption increase with addition 3% volume fraction of carbon fiber and Carbon Nanotube, the sample (polyester+3%C.F+0.5% CNTs) has lower water absorption than other samples. The hardness (shore D), flexural test, impact testand toughness fracture for the sample (polyester+3%C.F+0.5% CNTs) has higher value for Nano- composites.*

Keywords: *Nano Composites, Carbon Nanotube, Carbon Fiber, physical properties, Mechanical properties.*

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1. Introduction

Carbon nanotubes (CNTs) were discovered in the soot of arch discharge by Sumio Iijima in 1991.Carbon nanotubes are allotropes of carbon and members of the fullerene structural family. Carbon nanotubes are categorized as single-walled nanotubes (SWCNTs) and multi-walled nanotubes (MWCNTs). Multi-walled nanotubes consist in a variable number of grapheme sheets rolled coaxially into a cylinder of nano metric diameter. Carbon nanotubes are promising additives for polymer nano composite due to their excellent special mechanical, electrical, and thermal properties. In addition, potential applications as nano fillers have not been fully ealized, despite extensive studies on CNT-filled polymer nano composites. Therefore, the fabrication of the polymer nano composites reinforced with various nano fillers is believed to a key technology on advanced composites for next generation [1]. Carbon nano tubes and nano composite can be used in different applications, such as propellers in ships and yacht, the submarine's body, turbines in different engines (water, gas and steam) and airplanes body.

Merad et al. studied the mechanical properties of nano composite that consists of epoxy resin reinforced with TiO_2 nanoparticles. These nanoparticles have (21nm) in diameter and volume fraction (0.5, 1, 5, 20 %). The result showed that the mechanical properties of nano composite such as hardness reduced at the volume fraction (0.5 and 1), while it increased at volume fraction (5 and 20). The tensile strength was higher than net epoxy and increased with increase addition of TiO_2 nanoparticles [2].

Kadhim et al. have study the mechanical properties of epoxy reinforced by nano Al_20_3 at different weight fraction (1, 2, 3, 4, 5, and 7) %wt. The results show that the increase weight fraction of nano Al_20_3 improvement the mechanical properties young modulus and flexure strength. Flexure strength of nano composite was improved 42% at 4-wt% comparing with neat epoxy sample. The young modulus enhanced maximum 187% at 7wt % [3].

Shivakumar Gouda et al. have study the effect of addition (0.2 wt %) of Graphene and multi-walled carbon nanotubes to the hybried composite consist of glass fiber (9, 13.5, 18 wt %), carbon fiber (12.5, 18.75, 25 wt%), epoxy resin (78.5, 76.75, 57 wt%). The mechanical properties results explain that the modulus of elasticity increased by 10-15 %, the flexural strength was increased by 35.4% without using 0.2% grapheme fillers and decreased by adding graphene. The impact strength increased by 48% without use of fillers and 37% with addition graphene and multi-walled carbon nanotubes, also the hybrid composite that made from graphene has hardness higher than that of

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MWCNT where the hardness of polymer composite increased 12.34% by adding 0.2% graphene, 8.5% by adding 0.2% MWCNT [4].
Selwyn Jebadurai et al. investigated the effect of addition (0.2, 0.5 %) weight fraction of multi-walled carbon nano tube to the polyester resin composite reinforced by two types of glass fiber. From the results can be seen that the polyester resin with (0.2%) weight fraction of multi-walled carbon nano tube exhibited higher mechanical properties (tensile strength and flexural strength) than polyester resin with (0.5%) weight fraction of multi-walled carbon nano tube, this is because of formation of agglomerated of nano carbon tube inside the polyester resin matrix [5].

Objectives of the research:
1. Prepare nano composites of polyester resin reinforced with carbon fiber and carbon nanotube.
2. Study some physical and mechanical properties (water absorption, XRD, AFM, hardness shore D, impact test and flexural strength).

2. Raw Material Used in Work

The materials used in the preparation of samples consist of carbon fibers (Carbon UD Stockinette) from Tenax Company, polyester resin as the matrix from the Saudi Arabia Company with a density of (1.11 gm/cm^3). Multi-walled carbon nanotube (Intelligent Materials Pvt. Ltd, NANOSHEL LLC).
The dimensions required of moulds for preparing the specimens were made from glass (120×120×5) mm. The mean grain size of carbon nanotube (CNTs) was (48), as shown in Figure 1. The properties of material used in preparation of nano composites material as shown in Table 1.

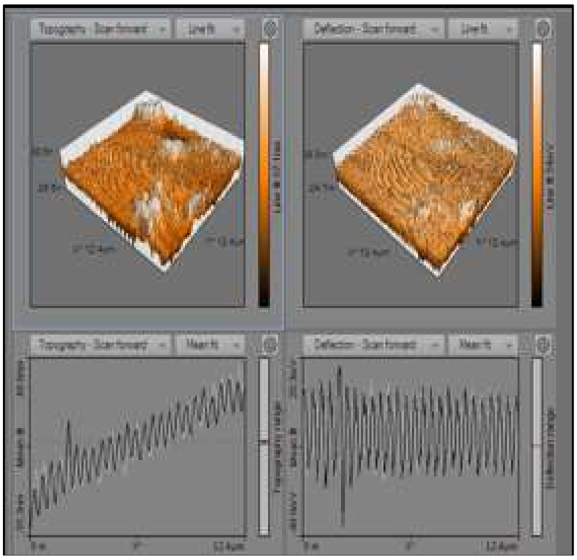

Figure 1: Atomic forcing microscope of nanocarbon tubes (CNTs)

Table 1: Properties of material

Polyester [6]	**Carbon–fiber [7]**	**Carbon nano tube [8]**
Density (1.11gm/cm^3)	Density (1.81gm/cm^3)	Density (1.7 gm/cm^3)
Tensile strength (65 N/mm^2)	Tensile strength (5600 MPa)	Tensile strength (150 Gpa)
Flexural strength (110 N/mm^2)	Tensile Modulus (290 Gpa)	Particle size (48 nm)
Viscosity (1.0 poise)	Elongation (1.9 %)	Young modulus (1200 Gpa)

Figure 2 of X-Ray Diffraction pattern confirmed that (CNT) powder. High intensities of Sharpe peaks could be obtained indicating a high Crystalline in the synthesized powder. All peaks could be indexed to a hexagonal structure.

3. Preparation of Nano Composites Materials

Nano composites samples were prepared from polyester reinforced with 3% volume fraction of carbon fiber, and carbon nanotube with volume fraction of (0.5 %, 1%, 1.5%, and 2%). The method used in the preparation of the samples in study is the (Hand lay-Up Molding). The nano composites are prepared by cutting carbon fibers of dimensions (120 × 120) mm according to the dimensions of the mould. The used volume fractions are (3%) from carbon fiber , then weighing the reinforcing carbon nanotube to specify a volume fraction of (0.5%, 1%, 1.5%, and 2%), Weighing the polyester depending on the volume fraction of reinforcement materials (fiber and powder), with taking into consideration the weight of hardener. The polyester was mixing with the hardener slowly and continuously by using a glass rod in order to avoid bubbles and then the powder was adding gradually into the mixture and stirring it to obtain homogeneity for a period of (10-15) minutes. While Pouring the mixture into the mould, carbon fiber putting the mat into the mould and continuing of mixture pouring until it covers the entire mat then Pressing the mixture with an appropriate load. Finally leaving the samples in the mould for a period of (24) hour at room temperature.
Samples are then extracted from the mould and then heat treated in an oven at (60Ċ) for a period of (60) minutes. This process is very important for obtaining the best cross-linking between polymeric chains, and to remove the stresses generated from the preparation process and complete the full hardening of the samples [9].

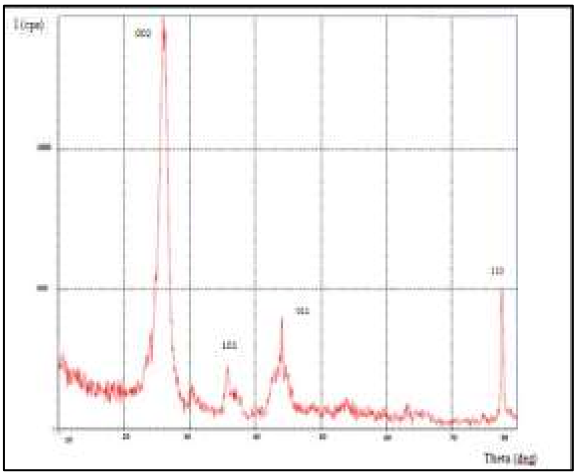

Figure 2: X- Ray Diffraction of the CNTs powder

4. Mechanical Test

I. Hardness test measurement

This test is performed by using hardness (Shore D) and according to ASTM D-2240 standard. Prepared Specimens have been cut into a diameter of 40mm and a thickness of 5mm. Figure 3(A) appears standard specimens for this test [10]. Figure 3(B) show the prepared specimens. Figure 4 shows hardness device used in this research. For each specimen five hardness measurements were taken and the average hardness is calculated.

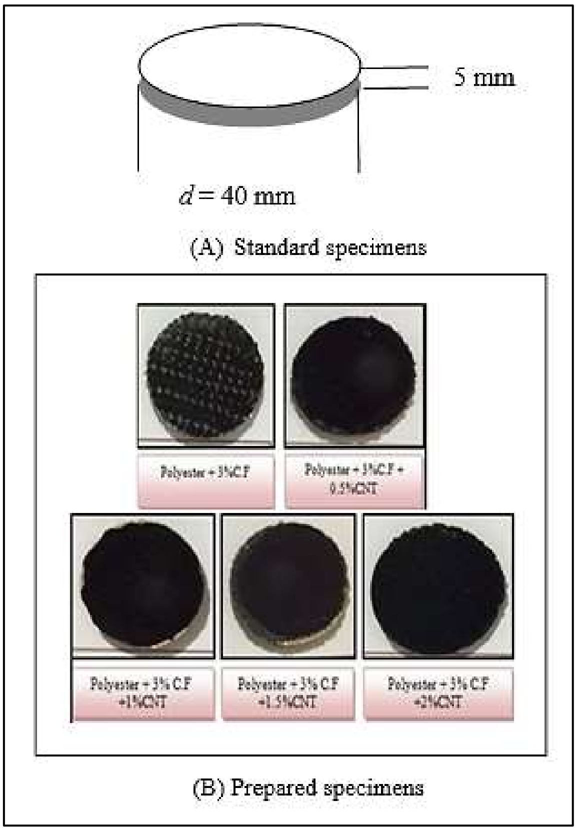

Figure 3: (A) Hardness (Shore D) standard specimens [10], (B) Prepared specimens

Figure 4: Hardness device

II. Flexural strength test

This test is according to ASTM D790 at room temperature. Specimens have been cut into the dimensions 100*13*4.8 mm. Figure 5(A) shows standard specimens for this test [11], (B) Prepared specimens. Figure 6 shows flexural strength device used in this research. The flexural strength is calculated according to the equations [12].

$$F.S = \frac{3PL}{2bd^2} \quad (1)$$

Where

F.S: flexural strength (MPa).

P: force at fracture (N).

L: length of the sample between Predicate (mm).

b: thikness (mm).

d: width(mm).

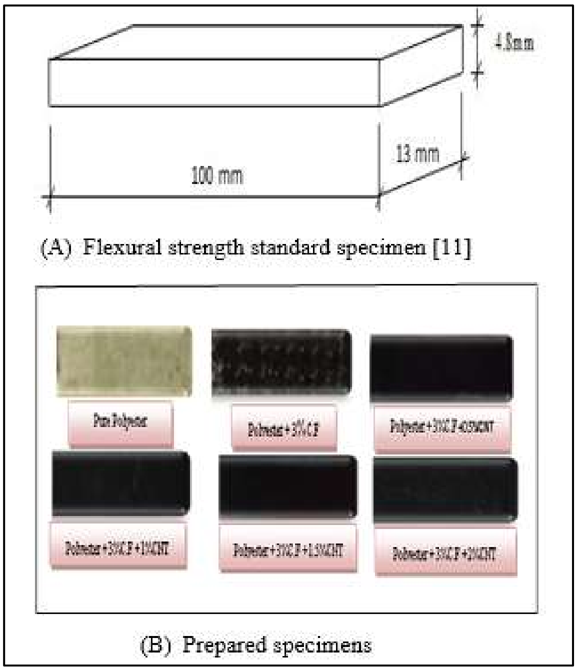

Figure 5: (A) Flexural strength standard specimen [11], (B) Prepared specimens

Figure 6: Flexural Strength device

III. Impact test

The impact tests of specimens were prepared according to (ISO-180 standard) [13]. Impact resistance is calculated for samples from the following relationship [14]. Samples have been cut into the dimensions (80*10*4) mm as shown in Figure 7-A, Figure 7-B show the prepared specimens. Figure 8 shows affect strength device used study.

$$G_c = Uc / A \qquad (2)$$

Where

G_c=Impact strength of material (KJ/m^2).

U_c=Impact energy (J).

A= cross- sectional area of specimen (m^2)

Fracture toughness can be expressed as.

$$Kc = \sqrt{Gc\ E} \qquad (3)$$

Where:

K_c= Fracture toughness of material ($MPa.m^{1/2}$).

E= elastic modulus of material (MPa).

5. Physical Tests

I. Water absorption

The water absorption test is performed according to ASTM D 570 standard at room temperature [15]. Specimens have been cut into a diameter of 40mmand a thickness of 5mm. The mechanism of water absorption is explained to be the direct uptake and flow of water by capillary and transport along the reinforcement-matrix interface [16]. Water absorption percentage is calculated using (Archimedes base) according the following formula [17]. Figure 9 shows standard specimens for this test.

$$M\ (\%) = \frac{mt - m_0}{m_0} \times 100 \qquad (4)$$

Where

M (%): water absorption percentage m_o: mass of specimen before immersion (g).

m_t: mass of specimen after immersion for seven days (g).

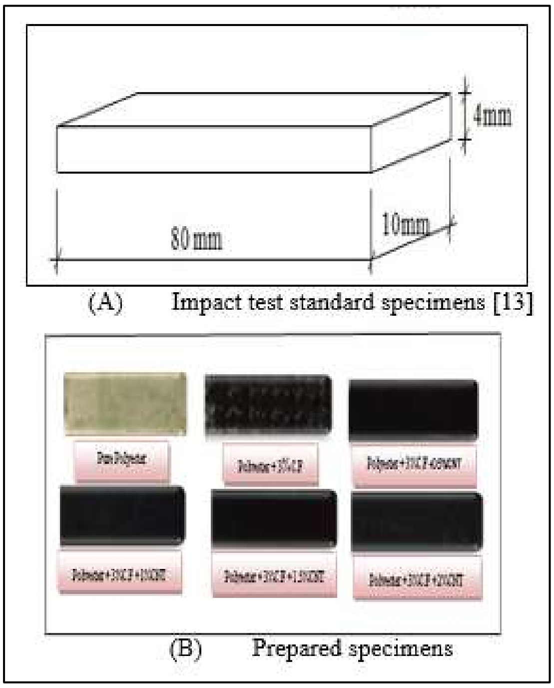

Figure 7: (A) Impact test standard specimens [13], (B) Prepared specimens

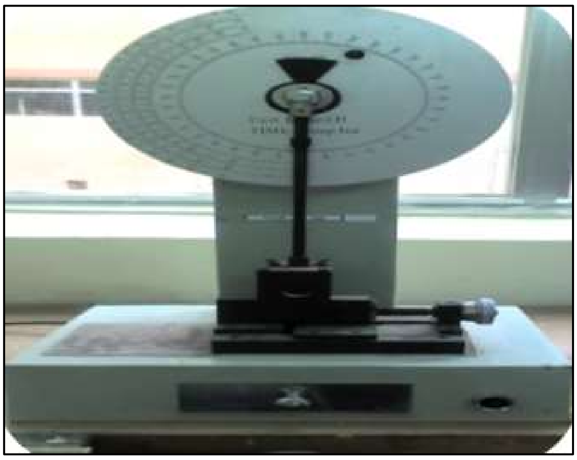

Figure 8: Impact test Device

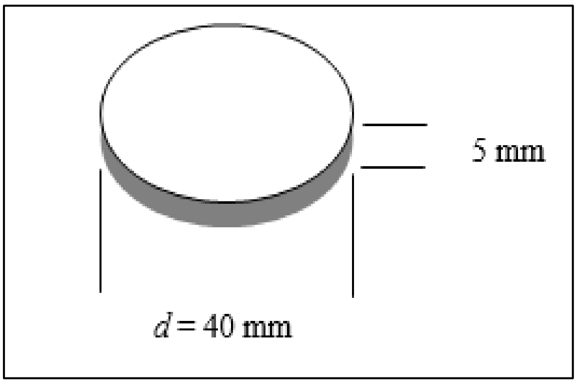

Figure 9: Standard specimens [15]

6. Results and Discussion

I. Hardness shore (D)

The results of hardness test type (Shore (D)) of unsaturated polyester resin reinforced by 3% volume fraction of carbon fiber and various volume fractions of carbon nanotubes are shown in Table 3. Where the hardness value has been carried out on pure polyester before and after carbon fiber and nano fillers were added and the average of five readings in each case was taken to obtain higher accuracy results. From Figure 10 it is clear that there is apparent effect of the addition of 3% carbon fiber volume fraction on the hardness of the material. Increase in fiber content leads to an increase in the hardness, this may be due to the fact that the hardness is generally considered to be a property of the surface therefore this behavior of hardness is expected. The value of hardness improves with the addition of volume fraction of carbon fiber because of their chemical consensus between fiber and polyester resin [18]. The addition of the 3% carbon fiber leads to an increase in the elasticity and a decrease in the matrix surface resistance to the indentation, thus specimen (polyester+3%C.F) have higher hardness than specimen (pure polyester). In addition, can be seen from figure a pronounced effect of the addition of 3% carbon fiber with 0.5%, 1%, 1.5% and 2% volume fraction from (nano carbon tube) on the hardness of the material. It can be seen that the hardness decreases with increasing volume fraction of carbon nano tube. Result had revealed that the hardness of pure polyester alone was (77 shore D) compared to maximum value (85.2) at volume fraction of (0.5% CNTs) with particle size is (48nm). The reason of the increase in hardness is that CNTs contains an elements harder than the pure polyester that lead to an increase in hardness than pure polyester but the hardness decrease with increased volume fraction of carbon nanotube because the CNTs increase elasticity.

Table 3: Hardness shore (D) of nano composites

Types of composite	Hardness shore (D)
polyester	77
polyester+3% carbon fiber	80.2
(Nano composites)	
polyester+3%C.F+0.5%CNTs	85.2
polyester+3%C.F+1%CNTs	84
polyester+3%C.F+1.5%CNTs	83
polyester+3%C.F+2%CNTs	82.5

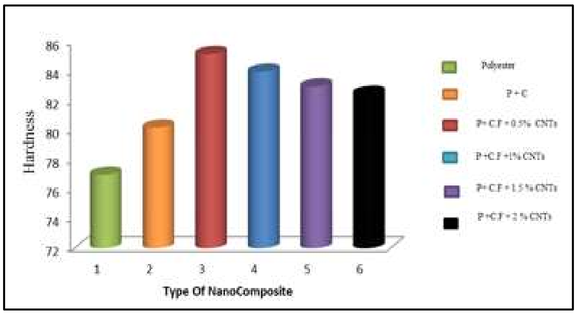

Figure 10: Hardness shore (D) of Nano composite

II. Flexural strength

The results offlexural strengthfor the prepared (pure polyester, polyester +3% carbon fiber andnano carbon tube)nanocomposites are shown in Table 4. From Figure 11 can be see the specimen (polyester +3%carbon fiber) have higher flexural strength than specimen (pure polyester) due the addition of 3% volume fraction of carbon fiber, it can be seen that the flexural strength decreases with increasing volume fraction of carbon nanotube. The increasing volume fraction of (2% CNTs) cause to increasing in viscosity and agglomeration of CNTs Wight has contributed to the drop in the flexural properties of composite [19]. Flexural strength of pure reference polyester was (150 MPa) then an increasing had observed with increasing in volume fraction until it reached to its maximum value of (220MPa) by the addition of (3% carbon fiber) and volume fraction of (0.5%CNTs).

Table 4: Flexural strength of nano composites

Types of composite	flexural strength (MPa)
polyester	150
polyester +3% carbon fiber	190
(Nano composites)	
polyester+3%C.F+0.5%CNTs	220
polyester +3%C.F+1% CNTs	212
polyester+3%C.F+1.5%CNTs	205
polyester +3%C.F+2% CNTs	197

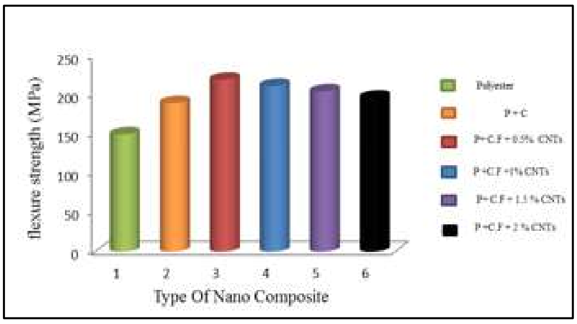

Figure 11: Flexural strength of nano composites

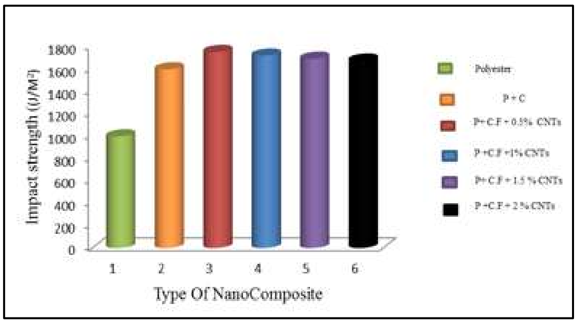

Figure 12: Impact strength of nano composites

III. Impact energy

Tables 5 and 6, Figures 12 and 13 shows the values of impact strength (G_c) and fracture toughness (K_c) for the prepared (pure polyester, polyester +3% carbon fiber and nano carbon tube) nano composites. The results of (G_c) &(K_c) for pure polyester are lower than that of Nano composites. The reinforcements affect positively in bearing impact load and increasing the impact energy required to fracture the specimen. Impact strength of pure reference polyester was (1000 J/m^2) then an increasing had observed with increasing in volume fraction until it reached to its maximum value of (1753 J/m^2) by the addition of (3% carbon fiber) and volume fraction of (0.5%CNTs). From the results can be seen the increase volume fraction of CNTs decrease the value of impact strength and fracture toughness, the decrease in the values at 2% CNTs may be attributed to the increased brittleness and crystallinity in the nano composites, which restricts the movement of polymer chains. This causes micro cracks when impact occurs, causing easy crack propagation. Therefore, the higher agglomeration CNTscan cause the mechanical properties of the nano composites to decrease [20].

Table 5: Impact strength of the prepared composites

Types of composite	Impact strength (J/M^2)
polyester	1000
polyester +3% carbon fiber	1600
(Nano composites)	
polyester+3%C.F+0.5%CNTs	1753
polyester +3%C.F+1% CNTs	1720
polyester+3%C.F+1.5%CNTs	1692
polyester +3%C.F+2% CNTs	1675

Table 6: Fracture toughness of the prepared composites

Types of composite	Fracture toughness ($MPa.m^{1/2}$)
polyester	8.95
polyester +3% carbon fiber	20.851
(Nano composites)	
polyester+3%C.F+0.5%CNTs	25.534
polyester+3%C.F+1% CNTs	24.865
polyester+3%C.F+1.5%CNTs	23.423
polyester +3%C.F+2% CNTs	21.753

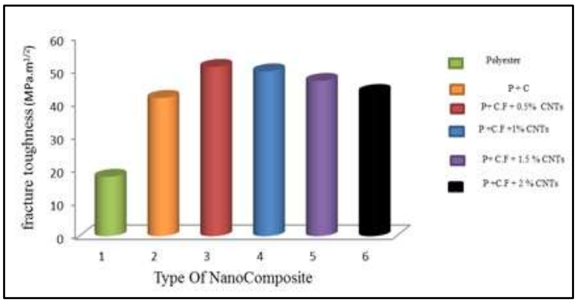

Figure 13: Fracture Toughness of Nano Composites

IV. Water absorption

In Table 7 and Figure 14 shows the water absorption of all prepared nano composites can be seen the specimen (polyester+3%C.F) have higher water absorption than specimen (pure polyester). The higher water absorption percentage of nano composite has been found to specimen (polyester +3%C.F+2%CNTs) while the specimen (polyester + 3%C.F+o.5% CNTs) have lower than specimen of other specimens. The increasing water absorption percentage with increasing volume fraction of fiber depends on the rule of mixture theory where fiber has a higher water absorption percentage than specimen pure polyester [20]. The water absorption attacked the fiber-matrix interface, causing de-bonding of the fiber and the matrix. The failures of the composite materials were due to voids [22].

Table 7: Water absorption of the prepared composites

Types of composite	Water absorption%
polyester	0.014
polyester+3% Carbon fiber	0.019
(Nano composites)	
polyester+3%C.F+0.5%CNTs	0.022
polyester+3%C.F+1% CNTs	0.026
polyester+3%C.F+1.5%CNTs	0.027
polyester +3%C.F+2% CNTs	0.029

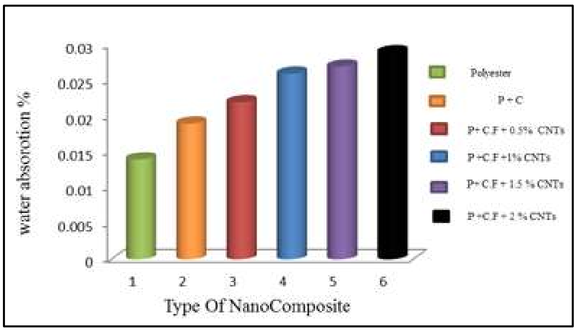

Figure 14: Water absorption of nano composites

7. Conclusions

1. (polyester+3%Carbon fiber) composites and nano composites has higher physical and mechanical properties than Pure unsaturated polyester.
2. The values of water absorption of specimen (pure polyester) lower than specimen (polyester+3% carbon fibers). Nano composite with 3% carbon fiber and 2% nano carbon tube have the higher water absorption when compared with specimen (pure polyester) and specimen (polyester +3% carbon fibers) composites. Nano composite with (polyester +3% carbon fibers +2%CNTs) has the maximum water absorption of (0.029%).
3. Result shows that the best flexural strength value was (220MPa), hardness (85.2 shore D), impact strength (1753), fracture toughness (25.534) at volume fraction of (3%carbon fiber) with (0.5% CNTs).

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