Mechanical and physical properties of carbon nano tubes with kevlar fiber reinforced with polyester resin

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Abstract

In this research study Hardness (shore D), Water absorption, Flexural, Impact Test, and Fracture Toughness of polymer nano composites. The polymer nano composites based on unsaturated polyester resin reinforced with Kevlar fibers (K.F). The samples are attended by hand lay – up method according to (Rule mixture) for various volume fractions of unsaturated polyester resin, fiber and carbon nanotube. The polyester resin was matrix strengthened with 3% volume fraction from Kevlar 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 were studied. Results showed that the water absorption increase with volume fraction increase of fiber with Carbon Nanotube, the sample (polyester+3%K.F+0.5% CNTs) has lower water absorption than other samples. The hardness (shore D), flexural test, impact test and toughness fracture for the sample (polyester+3%C.F+0.5% CNTs) has higher value for Nano- composites.

Key words

Nano composites, Carbon nanotube, Kevlar fiber, Hardness (shore D), Water absorption, Flexural Strength, Impact Test, Toughness Fracture.

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الخواص الميكانيكية و الفيزيائية لانابيب الكاربون النانوية مع الياف الكفلر المقواة مع راتنج البولي استر

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الخلاصة

تم في هذا البحث دراسة الصلادة (شور D)، امتصاصية الماء، مقاومة الكسر، اختبار الصدمة و متانة الكسر لمتراكبات نانوية ذات اساس راتنج البولي استر غير المشبع مقواة بألياف الكفلر. العينات جهزت بطريقة الصب اليدوي وفقا لقاعدة الخلط لكسور حجمية مختلفة من راتنج البولي استر غير المشبع والالياف وانابيب الكاربون النانوية. راتنج البولي استر كان ارضية مقواة مع 3% كسر حجمي من الياف الكفلر و (0.5، 1، 1.5، 2) % كسر حجمي لانابيب الكاربون النانوية. تم دراسة خواص امتصاصية الماء، صلادة (شورD)، اختبار الصدمة ومقاومة الكسر. اظهرت النتائج بان امتصاصيه الماء تزداد مع زيادة الكسر الحجمي للالياف مع انابيب الكاربون النانوية، العينه (بولي استر + 3% الياف كفلر + 0.5 % انابيب اكاربون النانوية) تمتلك اقل امتصاصية ماء من العينات الاخرى. الصلادة (شورD)، فحص الكسر، فحص الصدمة ومتانة الكسر للعينه (بولي استر + 3% الياف كفلر + 0.5 % انابيب الكاربون انانوية) تمتلك اعلى قيمه للمتراكبات النانوية.

Introduction

Polymer nano composites, which is a new class of polymeric materials based on the reinforcement of polymers using nano fillers, have attracted a great deal of interest in fields ranging from basic science to the industrial applications because it is possible to remarkably improve the physical properties of composite materials at lower filler loading [1, 2]. These attempts include studies of the polymer nano composites with the introduction of nano reinforcing fillers such as carbon nanotube CNT, carbon nano fibers, inorganic nanoparticles, and polymer nanoparticles into the polymer matrix [1- 4]. In particular, excellent mechanical strength, thermal conductivity, and electrical properties of CNT have created a high level of activity in materials research and development for potential applications such as fuel cell, hydrogen storage, field emission display, chemical or biological sensor, and advanced polymer nano composites [5, 6]. This feature has motivated a number of attempts to fabricate CNT/polymer nano composites in the development of high-performance composite materials. In this regard, much research and development have been performed to date for achieving the practical realization of excellent properties of CNT for advanced polymer nano composites in a broad range of industrial applications. However, because of their high cost and limited availability, only a few practical applications in industrial field such as electronic and electric appliances have been realized to date [7].

There are many studies about composite materials.

The effect of addition (0.2, 0.5%wt) of multi-walled carbon nano tube to the polyester resin composite reinforced by glass fiber. The results show that the polyester resin containing higher than 0.5% wt MWCNTs was not able to impregnate completely the last layer of glass fiber mat due to increase in viscosity while the composite containing lower than 0.5% wt MWCNTs exhibited good mechanical properties. also can be found that the composite with 0.2 % wt was apparent better mechanical properties than composite with 0.5% wt MWCNTs [8].

The mechanical properties of multi-walled carbon nanotube reinforced epoxy resin at different fraction (0.2, 1)%wt. From the results can be seen that the viscosity of the epoxy resin increase with the increase of weight fraction of CNTs and this lead to increase dispersion of CNTs in the matrix [9].

Objectives of the research

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

Experimental work

The materials used in the preparation of samples consist of Kevlar fibers (fabric 49), polyester resin as the matrix from the Faralop Company with a density of (1.11 gm / cm^3). Multi-walled carbon nanotube from (Intelligent Materials Pvt. Ltd, NANOSHEL LLC) [10]. The dimensions required of moulds for preparing the specimens were made from glass (120×120×5) mm. The mean grain size of carbon nanotube was (48) nm, as shown in Fig.1.

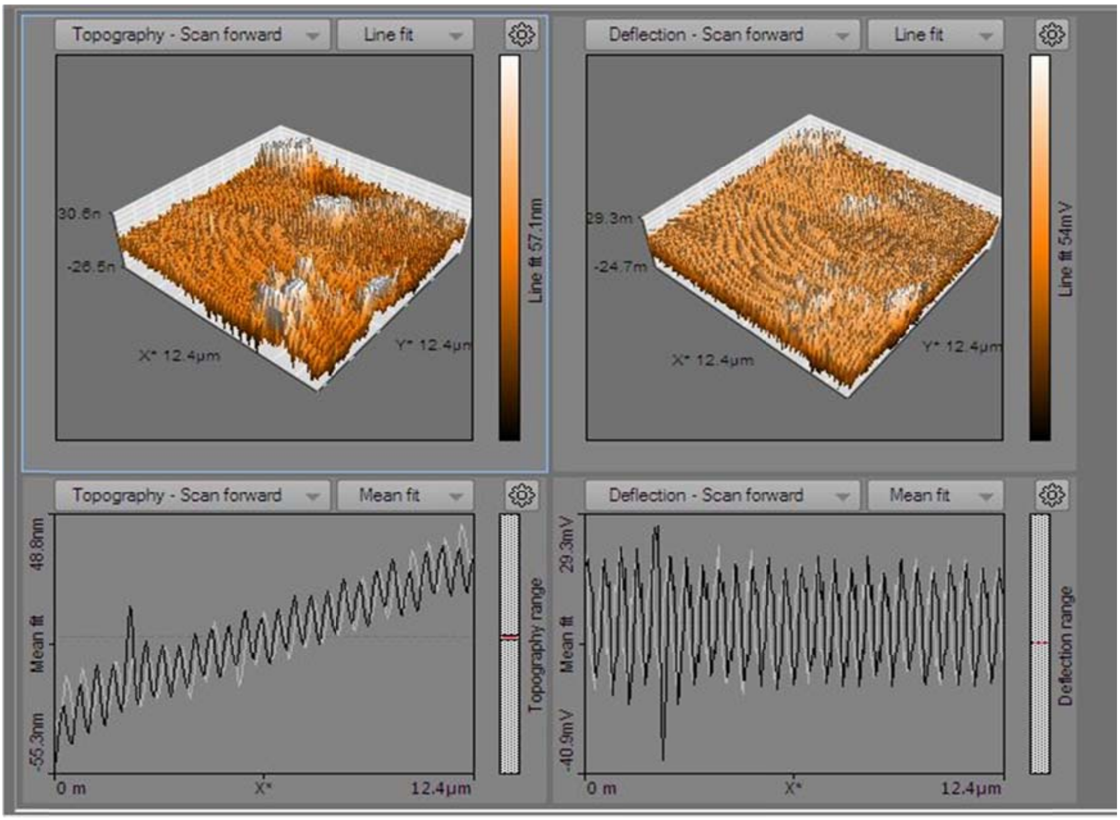

Fig.1: Atomic forcing microscope of nano carbon tubes (CNTs).

Raw material

The properties of material used in preparetion of nano composites material as shown in Table1.

Table1: Properties of material

Materials	**Properties**			
polyester	Density (1.11) gm/cm^3	Tensile strength (65) N/mm^2	Flexural strength (110) N/mm^2	Viscosity (1.0) poise
Kevlar –fiber (49)	Density 1.44 gm/cm^3	Tensile strength 3750 MPa	young Modulus 139 GPa	Poisson's Ratio 0.36
Carbon Nano Tube	Density (1.7) gm/cm^3	Tensile strength (150) GPa	Particle size (48) nm	Young modulus (1200) GPa

Fig. 2 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 [11].

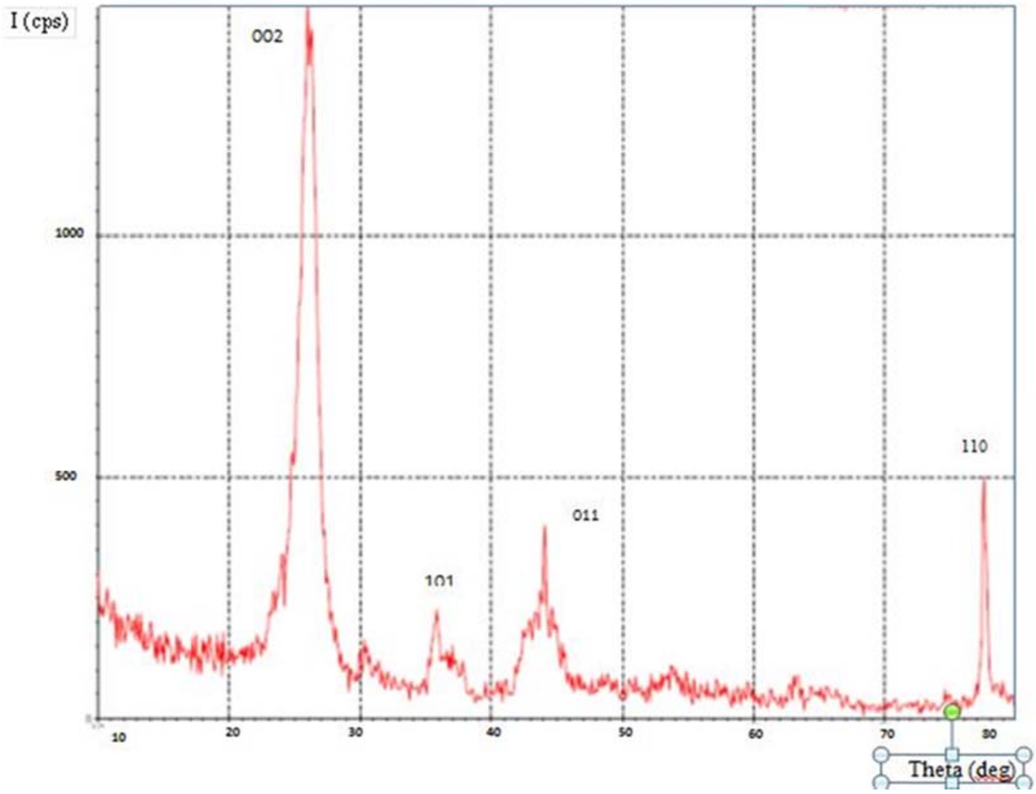

Fig. 2: The X- ray diffraction of the CNTs powder.

Preparation of composites

Nano composites samples were prepared from polyester reinforced with 3% volume fraction of Kevlar 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 this research is the (Hand lay-Up Molding). The nano composites are prepared by cutting Kevlar fibers of dimensions (120 × 120) mm according to the dimensions of the mould. The used volume fractions are (3%). 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, kevlar 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 the purpose of 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 [12].

Mechanical test

1. Hardness test measurement

This test is performed by using hardness (Shore D) and according to ASTM D-2240 standard [13]. Prepared Specimens have been cut into a diameter of 40mm and a thickness of

5mm. For each specimen five hardness measurements were taken and the average hardness is calculated.

2. 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 [14]. The flexural strength is calculated according to the equations [15].

$$F.S = \frac{3PL}{2bd^2} \qquad (1)[15]$$

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).

3. Impact test

The impact tests of specimens were prepared according to (ISO-180 standard) [16]. Impact resistance is calculated for samples from the following relationship [17]. Samples have been cut into the dimensions (80*10*4) mm.

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

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

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

E= elastic modulus of material (MPa).

Physical tests

1. Water absorption

The water absorption test is performed according to ASTM D 570 standard at room temperature [18]. Specimens have been cut into a diameter of 40mm and 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 [19]. Water absorption percentage is calculated using (Archimedes base) according the following formula [20].

$$M\,(\%) = \frac{(mt - m_o)}{m_o} \times 100 \qquad (3)$$

where

M (%): water absorption percentage

m_o: mass of specimen before immersion (g).

$m_{t:}$ mass of specimen after immersion for seven days (g).

Results and discussion

1. Hardness shore (D)

The results of hardness test type (Shore (D)) of unsaturated polyester resin reinforced by 3% volume fraction of Kevlar fiber and various volume fractions of carbon nanotubes are shown in Table 2. Where the hardness value has been carried out on pure polyester before and after Kevlar fiber and nano fillers were added and the average of five readings in each case was taken to obtain higher accuracy results. From Fig. 3 it is clear that there is apparent effect of the addition of 3% Kevlar 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 addition of the fiber leads to an increase in the elasticity and a decrease in the matrix surface resistance to the indentation, thus specimen (polyester+3% K.F) have higher hardness than specimen (pure polyester). And can be seen from figure a pronounced effect of the addition of 3% Kevlar 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 (83.5) 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 2: Hardness shore (D) of nano composites

Types of composite	**Hardness Shore (D)**
polyester	77
polyester+3% Kevlar fiber	78
(Nano Composites)	
polyester+3%K.F+0.5%CNTs	83.5
polyester+3%K.F+1%CNTs	82
polyester+3%K.F+1.5%CNTs	81.5
polyester+3%K.F+2%CNTs	80.4

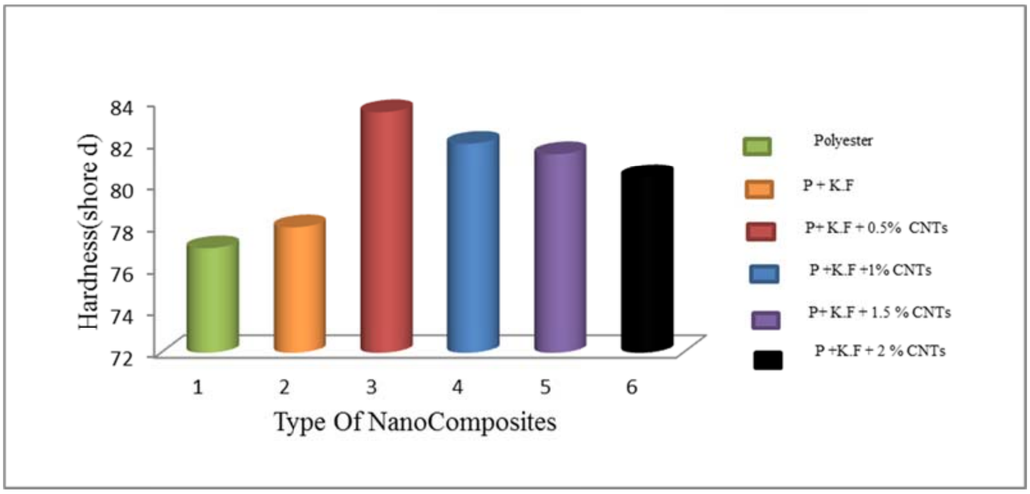

Fig.3: Hardness shore (D) of nano composite.

2. Flexural strength

The results of flexural strength for the prepared (pure polyester, polyester +3% Kevlar fiber and nano carbon tube) nano composites are shown in Table 3. From Fig.4 can be see the specimen (polyester +3% Kevlar fiber) have higher flexural strength than specimen (pure polyester) due the addition of 3% volume fraction of Kevlar 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 that has contributed to the drop in the flexural properties of composite [8]. Flexural strength of pure reference polyester was (150 MPa) then an increasing had observed with increasing in volume fraction till it reached to its maximum value of (239MPa) by the addition of (3% Kevlar fiber) and volume fraction of (0.5%CNTs).

Table 3: Flexural strength of nano composites.

Types of composite	flexural strength(MPa)
polyester	150
polyester +3% Kevlar fiber	203
(Nano Composites)	
polyester+3%K.F+0.5%CNTs	239
polyester +3%K.F+1% CNTs	232
polyester+3%K.F+1.5%CNTs	221
polyester +3%K.F+2% CNTs	213

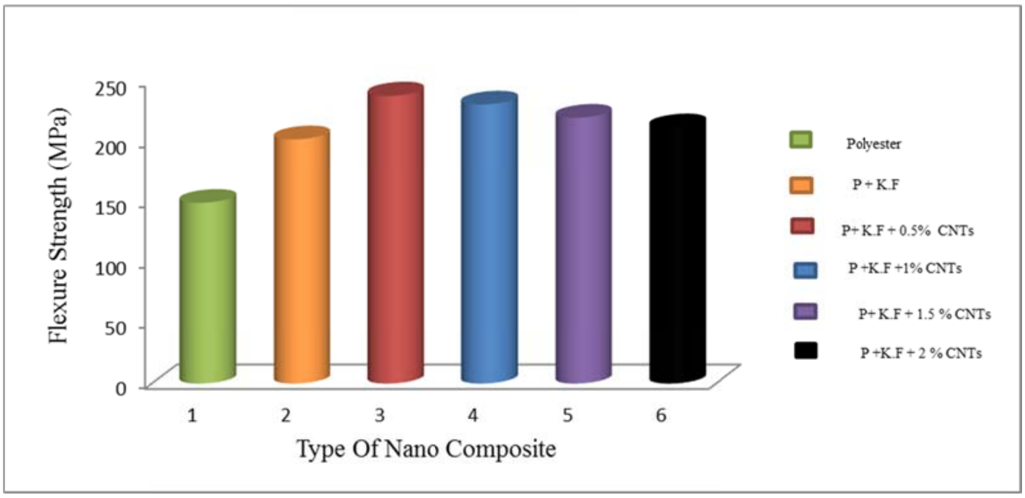

Fig.4: Flexural strength of nano composites.

3. Impact energy

Tables 4, 5 and Figs. 5, 6 shows the values of impact strength (G_c) and fracture toughness (K_c) for the prepared (pure polyester, polyester +3% Kevlar 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 till it reached to its maximum value of (2368 J/m^2) by the addition of (3% Kevlar 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 CNTs can cause the mechanical properties of the nano composites to decrease [21].

Table 4: Impact strength of the prepared composites.

Types of composite	Impact strength (J/m^2)
polyester	1000
polyester +3% Kevlar fiber	2000
(Nano Composites)	
polyester+3%K.F+0.5%CNTs	2368
polyester +3%K.F+1% CNTs	2300
polyester+3%K.F+1.5%CNTs	2270
polyester +3%K.F+2% CNTs	2200

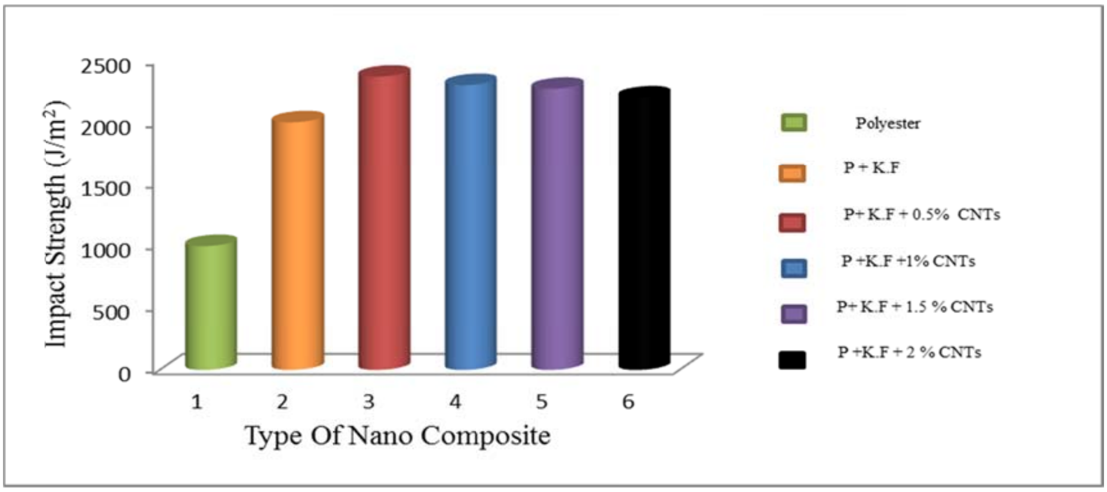

Fig.5: Impact strength of nano composites.

Table 5: Fracture toughness of the prepared composites.

Types of Composite	fracture Toughness (MPa.m$^{1/2}$)
polyester	8.95
polyester +3% Kevlar fiber	30.725
(Nano Composites)	
polyester+3%K.F+0.5%CNTs	44.438
polyester+3%K.F+1% CNTs	35.331
polyester+3%K.F+1.5%CNTs	33.207
polyester +3%K.F+2% CNTs	32.180

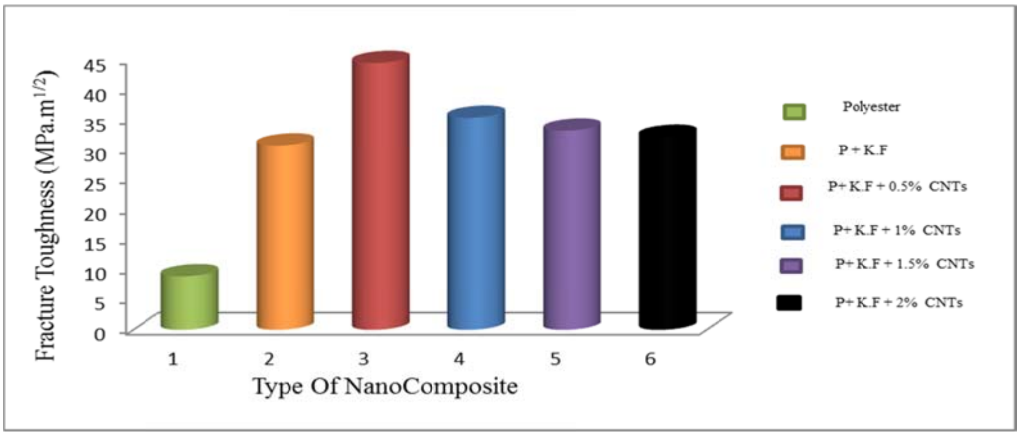

Fig.6: Fracture toughness of nano composites.

4. Water absorption

In Table 6 and Fig.7 show the water absorption of all prepared nano composites can be seen the specimen (polyester +3%K.F) have higher water absorption than specimen (pure polyester). The higher water absorption percentage of nano composite has been found to specimen (polyester +3%K.F +2%CNTs) while the specimen (polyester +3%K.F +0.5% 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 [22]. 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[23].

Table 6: Water absorption of the prepared composites.

Types of composite	water absorption%
polyester	0.014
polyester+3% Kevlar fiber	0.033
(Nano Composites)	
polyester+3%K.F+0.5%CNTs	0.038
polyester+3%K.F+1% CNTs	0.040
polyester+3%K.F+1.5%CNTs	0.042
polyester +3%K.F+2% CNTs	0.043

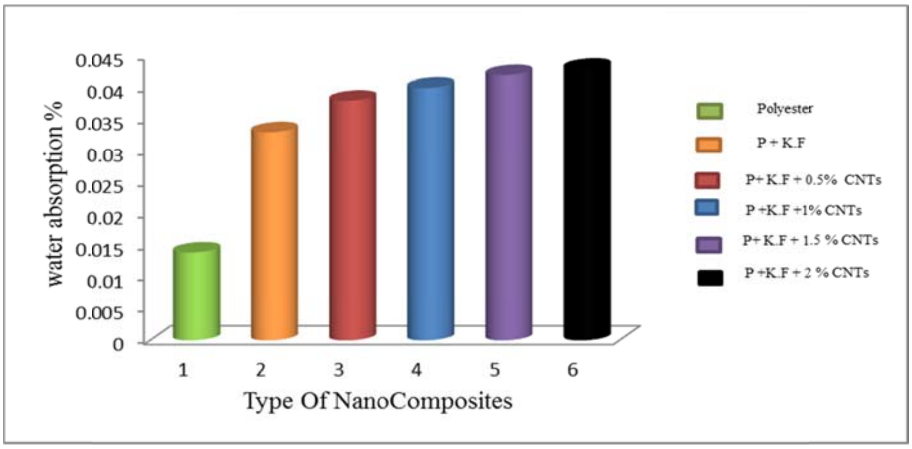

Fig.7: Water absorption of nano composites.

Conclusions

The specimen (polyester+3%Kevlar fiber) and nano composites have higher physical and mechanical properties than pure unsaturated polyester. The values of water absorption of all specimens increase positively with increased volume fraction of filler content and the specimen (polyester +3% Kevlar fibers +2%CNTs) has the maximum water absorption. The result shown that the flexural strength, hardness, impact strength and fracture toughness increase positively with (0.5% CNTs) while decrease at volume fraction (1%, 1.5% and 2% CNTs) than (0.5% CNTs).

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