Mechanical and Tribological Behavior of Unsaturated Polyester Nan carbon Black Composite

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Abstract

Experimental work had been done to demonstrate the effect of nanocarbon black particles (N220) contents on the mechanical and tribological behavior of unsaturated polyester nanocomposite prepared via ultrasonic wave dispersion method. The results showed that the mechanical and tribological behavior was enhanced when the nanocarbon black particles content was increased up to 2%wt. and then decreased after that. The improvements in compressive strength and flexural strength are (16.13% at 2%wt. and 25.2% at 1%wt.), respectively, While The improvements in the hardness and wear resistance are (14.65% and 25.76%) at 2%wt. , respectively.

Keyword: *compressive strength, flexural strength, hardness resistance, wear resistance, nanocarbon black, unsaturated polyester.*

السلوك الميكانيكي والترايبولجي لمتراكب البولي استر الغير مشبع المدعم بحبيبات الكاربون الأسود النانوية

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الخلاصة

تم أجراء دراسة تجريبية لبيان تاثير كمية حبيبات الكاربون الاسود النانوي (N220) في السلوك الميكانيكي و الترايبولوجي لراتنج البوليستر المدعم بها بطريقة التشتت بالموجات فوق الصوتية .بينت النتائج العملية ان السلوك الميكانيكي والترابيولجي للمتراكب النانوي يتحسن عند زيادة النسبة المئوية إلى حد 2 % من الكاربون الأسود النانوي وبعد ذلك ينخفض، حيث ان نسبة التحسن لمقاومة الانضغاط ومقاومة الانحناء هي (16.13 % عند النسبة المئوية

2 % و25,2 % عند النسبة المئوية 1 %) على التوالي، بينما مقاومة الصلادة والبلى تحسنت بنسبة (14,65 % و25,76 %) عند النسبة المئوية (2 %) على التوالي .

الكلمات الدالة : مقاومة الانضغاط ، مقومة الانحناء ، مقاومة الصلادة ، مقاومة البلى ،الكاربون الأسود النانوي والبوليستر الغير مشبع .

Nomenclature

m1	Mass before test (g)
m2	Mass after test (g)
Δm	Mass loss (g)
n	the number of disk rotating (cycle/min)
r	radius from the center of the sample to the disk center (cm)
t	Sliding Time (s).

Introduction

In recent years, the successful use of nanoscale particles in Polymer nanocomposite (PNC) enabled new combinations of mechanical, electrical, magnetic, optical, chemical and surface properties and their applications in many industries such as automotive, electronics, packaging, aerospace, information, pharmaceuticals, biomedical, energy, sports goods and personal care. [1].

PNCs are a new class of composites commonly defined as the combination of a polymer matrix and additives that have at least one dimension in the nanometer range. The additives can be one-dimensional (examples include nanotubes and fibres), two-dimensional (which include layered minerals like graphite plates or clay), or three- dimensional (including spherical particles),these additives are improve mechanical properties like elastic stiffness and strength and other superior properties of PNCs include barrier resistance, flame retardancy, compression strength, cratch/wear resistance as well as optical, magnetic and electrical properties , with only a small amount of the nano additives. This is caused by the large surface area to volume ratio of nano additives when compared to the micro- and macro-additives [2-4]. The properties of PNCs, related to local chemistry, degree of thermoset cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix [5].

Unsaturated polyester (UP) resin of the most polymeric materials using in the present time in a wide range of automotive and aerospace applications, and for shipbuilding or electronic devices because of the low cost, characterization of high performance and operating at a fast rates. However, because the polymer matrix must withstand high mechanical and tribological loads, it is usually reinforced with nanofillers. These nanofillers can be chosen as sheets (e.g. exfoliated clay stacks) , nanofibres (e.g. carbon nanotubes) or spherical particle (e.g. carbon black) [1,3].

Carbon black (CB) among the nanoscale particles produced in commercial (tonne) quantities. Depending on the method of production, average primary particle diameters in several commercially produced carbon blacks range from10-500 nm, while average primary aggregate diameters range from 100-800 nm Carbon black was one of the long established nanotechnology applications and nanomaterial used to modify the mechanical, electrical and other physical properties of polymers.[5-7].

The main objective of this work is to modify the mechanical and tribological properties of unsaturated polyester by adding the reinforcing nanocarbon black (N220) at different loading levels and to optimize the effect of loading level of carbon black (N220).

Experimental Work:

Materials :

Unsaturated polyester is type of thermosetting polymer; it's used as matrix materials in this work.

Unsaturated polyester of a trade mark (TOPAZ-1110TP) is a viscous liquid resin and convert to solid stat by added a curing catalyst, methyl ethyl ketone peroxide (MEKP) at a concentration of 2%wt. of the matrix, Catalyst accelerator (cobalt) is added to matrix resin at percentage 0.5g for 100 gm of resin. All these material supplied by (ICR) Saudi Arabia Company. This resin (UP) system was chosen for its relative low viscosity, low shrinkage and for general applications purpose .**Table (1)** showed the important properties of unsaturated polyester according to the properties of Product Company.

The nanocarbon black (N220) used in this work was obtained from Korea Carbon Black Company. The properties of carbon black shown in **Table (2)** according to the properties of Product Company.

Table (1):The properties of unsaturated polyester (according to the properties of Product Company).

Density gm / cm3	Thermal conductivity w/m.°C	Specific Heat J/ kg. k	Coefficient of thermal expansion $10^{-6}(°c)^{-1}$	Fracture Toughness MPa-$m^{0.5}$	Tensile strength MPa	Percent Elongation (EL%)	Modulus of elasticity GPa
1.2	0.17	710-920	100-180	0.6	41.4-89.7	<2.6	2.06-4.41

Table (2): The properties of nanocarbon black (N220) (according to the properties of Product Company).

Property	Ash content, %, max.	Iodine adsorption , (g/kg)	PH	Pour density kg/m^3	Sulfur content, %, max	Mean Particle diameter (nm)	Surface Area m^2/g
Value	106-116	24-26	1.5	355 ± 20	6 - 9	20-25	117±5

Preparation of Polymer Nanocomposite Specimens:

The mould of specimens used in this work was fabricated from carbon steel alloy. The internal base and internal walls of the mould were coated with thin layer of release agent to avoid sticking between cast material and the mould wall.

Five samples were prepared for each test as shown in **Figure (1),** except for hardness test, where one sample was prepared and five readings were taken from different places of the sample to get high accuracy in the results. The procedure of specimens preparation can be described as follow:

A. Drying the nanocarbon black in an electric oven at a temperature of (200°C) for (12) hrs .

B. The weight of carbon black is calculated according to the required weight fraction (1, 2,4,6,8 and 10) % wt. of unsaturated polyester.

C. Nanocarbon black manually mixed with unsaturated polyester resin for about 15 minute at room temperature continuously and slowly to avoid bubbling during mixing until a homogeneous sate of the mixture.

D. Intermingling the mixture by ultrasonic wave bath machine (Power Sonic 410 model (LUC)) for (45) minute to avoid heat generated during mixing which is affected on the properties of unsaturated polyester resin and to disperse the nanoparticles homogeneously.

E. Adding of hardener to the mixture with gentle mixing, and then the mixture is poured from one corner into the mould (to avoid bubble formation which causes cast damage) and the uniform pouring is continued until the mould is filled to the required level. The mixture was left in the mould for (24) hours at room temperature to solidify.

F. The cast is placed inside a drying micro wave oven (post curing) at (60°C) for one hour, this step is important to accomplish complete polymerization, best coherency, and to relieve residual stresses.

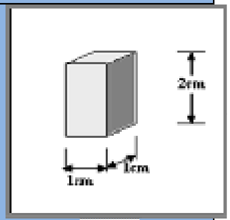
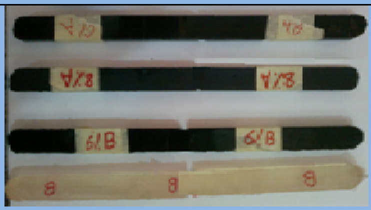
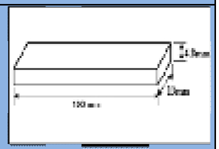
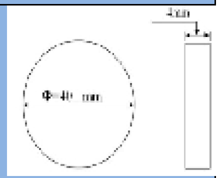
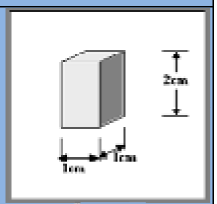
Type of test	specimens before test	specimens after test	Specimen dimensions (mm)
Compression Test ASTM D695-85			
Bending test ASTM D790			
Hardness Test ASTM D2240		The test is not destruct the specimens	
Wear abrassion test ASTM (D 5963)		 Specimens during the test	

Fig. (1). Specimens prepared in this work according to standerd specification

Mechanical and Tribological Tests

In order to characterize the effect of nanocarbon black filler on the mechanical and tribological behavior of unsaturated polyester nanocomposites, the following tests were performed:

1- Compression test: Universal Mechanical test machine, TINIUS OISEN H50KT was used for the compression, this test was performed according to ASTM (D695-85) at room temperature with a speed rate of about (0.5 mm/min) .

2- Flexural test: This test is performed according to (ASTM D790) at room temperature using microcomputer controlled electronic universal mechanical test machine with a speed rate of about (5 mm/min).

3- Hardness test: This test was performed using Shore hardness (D) (No.DW53505) and according to (ASTM D2240).

4- Wear abrasive test: The pin-on-disk abrasive wear machine was used according to ASTM-D 5963. The applied load and the sliding time were (5 N) and (5 min), respectively, as well as the radius from the center of sample to disk center was (12.5 cm) for each one of samples and the speed of the disk was 900 (r.p.m). The weight loss of the sample was determined by noting the difference between the initial and final weight readings of the sample. Five samples were run for each combination of the test parameters employed to ensure the taken data while the results reported are the average of the five readings. The wear rate (WR) is evaluated on the basis of the following equation [8-10]:

$$\mathbf{WR = \Delta m / 2\pi rnt} \qquad \mathbf{(1)}$$

Results and Discussion

Figure (2) shows that the compression strength of PNC had revealed the maximum value of (125.534 MPa) at (2%wt.) ; compared with the compression strength of neat unsaturated polyester (108.09MPa). This may be attributed to the reinforcing capability and well adhered filler of nanoparticles, furthermore, the compression strength of nanocomposite declines gradually when the filler beyond (2% wt.). Its indicates that that the lower degree of nanoparticles-polymer interaction occurred at higher filler contents due to the agglomerated of nanocarbon black when filler content increased.

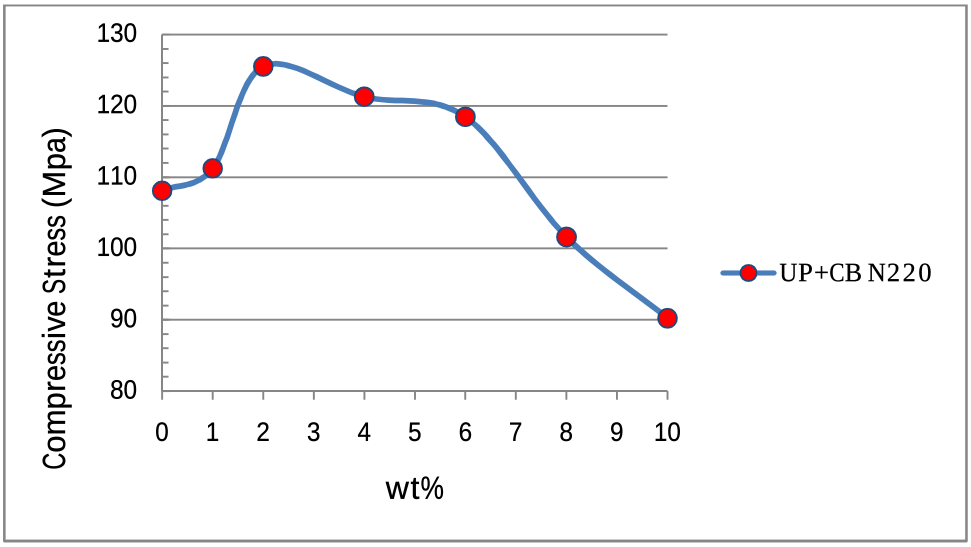


Fig. (4). Effect of nanocarbon black (N220) on compressive strength of unsaturated polyester

Figure (3) shows that the flexural strength of PNC had revealed the maximum value (88.06 MPa) at (1% wt.); compared to the flexural strength of the neat unsaturated polyester (70.34 MPa). This may be attributed to a small amount of nanocarbon black particles dispersed homogenously in unsaturated polyester which leads to a strong interface between particles surface and unsaturated polyester due to its (nanocarbon black particle) own high surface area, thus the flexural strength is improved. As the carbon black concentration increase continuously, a small size of nanocarbon black cause agglomeration of the carbon black take place which difficult to disperse in unsaturated polyester which leads to weak interface between particle and polymer matrix, thereby decreasing the flexural strength. On other hand, the defect size is play important role in the strength which depends on the size of filling particles approximately and the finer nanocarbon black particle (24 nm) is smaller defect size that leads to an improvement of the flexural strength of the material but the small size of nanocarbon black particles cause agglomeration of its when weight fraction is increased that lead to bigger defect size and strength of nanocomposite decrease

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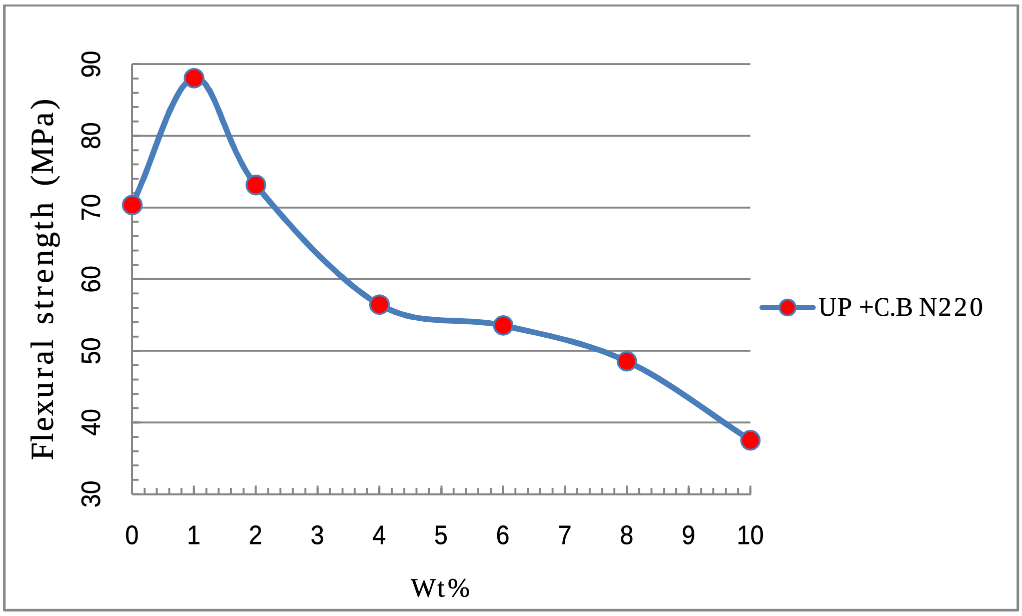

Fig. (3). Effect of nanocarbon black (N220) on flexural strength of unsaturated polyester

Figure (4) shows the shore D's hardness of PNC increases sharply when the nanocarbon black content is (2%wt.) and then decreases slightly but remain higher than the neat unsaturated polyester. The maximum amount of hardness (92.4); compared to the hardness of the neat epoxy (80.6). It may be attributed to the conglomeration of carbon black in the nanocomposite matrixes. Thus, it is inferred that adding appropriate amount of carbon black as reinforcing agent will improve the load-carrying capacity and mechanical properties of unsaturated polyester.

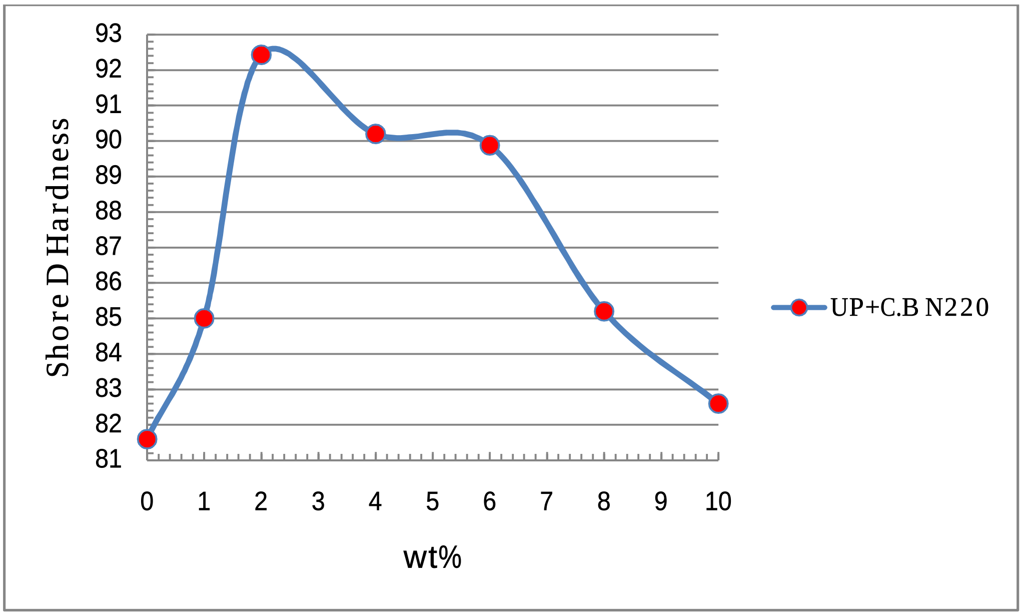

Fig. (4). Effect of nanocarbon black (N220) on hardness of unsaturated polyester

Figure (5) shows that the wear rate decrease in a non-linear as the weight fraction of nanocarbon black increase, and reaches its maximum amount (2.357 $\times 10^{-8}$) at (2 %wt.) compared to wear rate of the neat matrix which is equal to (3.175$\times 10^{-8}$), after these percentage of weight fraction the wear rate increase but remain lower than neat matrixes. It means the nanocarbon black particles are very effective in improving the tribological performance of polymers. The improvement in abrasion wear my be attributed to the improved dispersion of the nanoparticles. On other hand, surface hardness is generally taken as one of the most important factors that govern the wear resistance of materials, the result of hardness testshow higher shore hardness (92.43 at 2%) at same weight fraction of nanocarbon black.

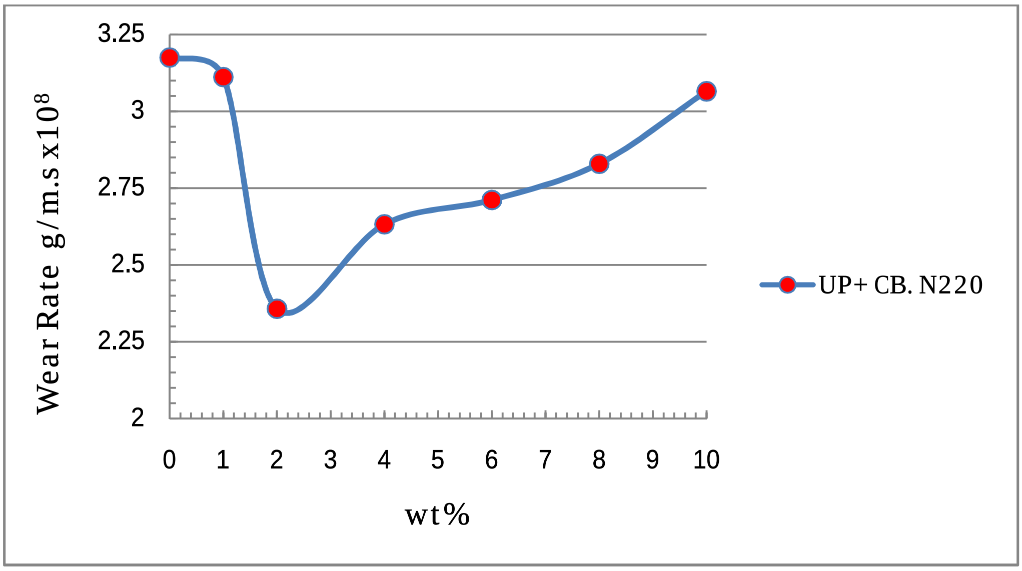

Fig. (5). Effect of nanocarbon black (N220) on wear rate of unsaturated polyester

Conclusions

The following conclusions can be drawn:

1- The mechanical and tribological behavior were improved when the nanocarbon black filler content was increased up to 2%wt and then decreased after that.
2- The compressive and flexural strength are increased by (16.13% at 2%wt and 25.2% at 1%wt), respectively.
3- The shore hardness and wear resistance are increased by (13.27% and 25.76% at 2%wt), respectively.

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