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EFFECT OF ADING NANOCARBON BLACK ON THE MECHANICAL PROPERTIES OF EPOXY

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ABSTRACT: - The study covers the effect of nanocarbon black particles (N220) on some important mechanical properties of epoxy reinforced with it [carbon black nanoparticles]. The nanocomposites were prepared with (1 to 10 wt. %) of carbon black nanoparticles using ultrasonic wave bath machine dispersion method. The results had shown that the tensile strength , tensile modulus of elasticity, flexural strength and impact strength are improved by (24.02%,7.93%,17.3% and 6%) respectively at 2wt % .The compressive strength and hardness are improved by (44.4%, 12%) at 4wt%.

Keywords: Nanocarbon black, mechanical properties, epoxy

1- INTRODUCTION

High performance polymer composite materials are used increasingly for engineering applications under hard working conditions. The materials must provide unique mechanical and tribological properties combined with a low specific weight and a high resistance to degradation in order to ensure safety and economic efficiency [(1)].

Epoxy resin systems are increasingly used as matrices in composite materials for a wide range of automotive and aerospace applications, and for shipbuilding or electronic devices. They serve as casting resins, adhesives, and as high performance coatings for tribological applications, such as slide bearings and calender roller covers. 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) [(2)].

A new approach aiming to overcome this basic problem is related to the nanotechnology and uses fillers in the nanometer scale. One aspect of nanotechnology is the possibility to design materials on a nanometer scale [(3)]. The new approach demonstrates the potential to change characteristics of thermosetting and thermoplastic polymers fundamentally, aiming to improve their general performance (4, 5).

Carbon black is essentially elemental carbon in the form of extremely fine particles having a partially amorphous molecular structure. It is classified as aggregated traditional particle with nanoscopic dimension (1-100 nm) and high electrical conductivity but low aspect ratio. Carbon black is among the nanoscale particles produced in commercial (tons) 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 (6-8).

Carbon materials, such as graphite, carbon black (CB) and carbon nanotubes (CNTs), are widely used as fillers in conductive polymer composites due to low density and high conductivity, Recently carbon conductive filler in polymer matrices have emerged as another promising because of high aspect ratio, low cost, easy production and low resistance (9,10) .

There are many researches that have been made to improve the epoxy by adding nanofillers which enhancing the mechanical, triybological and physical properties: Dehghani et. al. (11) improved the electrical conductivity of epoxy resin by adding carbon black (4-33 wt. %). Abdul Khalil et.al. [12] enhanced the flexural, impact properties and thermal stability of epoxy filled by three types of carbon black, but he did not study the other important mechanical properties. Kim (13), Etika (14) and Wei (15) were improved the electrical conductivity of epoxy using carbon black as a hybrid nanofiller. The main objective of this work is to improve the mechanical properties of epoxy by adding the reinforcing nanocarbon black (N220) at different loading levels and to optimize the effect of loading level of carbon black (N220) as well as economic efficiency by using low cost nanoparticles.

2-Experimental Work

Epoxy resin of a trade mark (Euxit 50 KI) is a liquid of low viscosity resin as compare with other thermosets and its converted to solid state by adding hardener (Euxit 50 KII) at ratio of (1:3), which were Supplied by Egyption Swiss chemical industries company .The properties of epoxy resin used in this work shown in table (1) according to the properties of Product Company.

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

The molds of specimens used in tensile test were fabricated from wood while molds of other tests were fabricated from carbon steel. 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 the figure (1), except for hardness test, where one sample was fabricated and five readings were taken from different places of the sample to get high accuracy in the results. The procedure of specimens fabrication can be described as follow:

a. Drying of nanocarbon black in an electric oven at a temperature of 200°C for 12 hrs.
b. The weight of carbon black was calculated according to the required weight fraction (1, 2, 4, 6, 8 and 10) wt. % of epoxy resin.
c. Nanocarbon black manually mixed with epoxy resin for about 15 minute at room temperature continuously and slowly to avoid bubbling during mixing until a homogeneous state of the mixture.
d. Intermingling the mixture by ultrasonic wave bath machine {Ultrasonic wave bath machine (Power Sonic 410) model (LUC) (220 V,50Hz and 400W)} for 45 minutes to avoid heat generated during mixing which is affect on the properties of epoxy resin and to disperse the nanoparticles homogeneously.
e. Adding of hardener to the mixture with gentle mixing, and then mixture was 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 (90) °C for two hrs, this step is important to accomplish complete polymerization, best coherency, and to relieve residual stresses.

The tensile properties (tensile strength, modulus of elasticity and elongation percentage at break) of the PNCs were tested according to ASTM D638M- 87b for samples at 20ºC with a constant strain rate of about (1 mm/min), with the use of dumbbell shaped samples as shown in figure (1).The tests being carried out using the microcomputer controlled electronic universal mechanical test machine model (TINIUS OISEN H50KT).

Flexural 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).

Izod impact test machine (XJU-22) used for testing PNCs materials according to (ISO-180) at room temperature.

Hardness test is performed using Shore hardness (D) (No.DW53505) and according to (ASTM D2240) at room temperature.

3. Results and Discussion

3.1 Tensile Properties

3.1.1 Ultimate Tensile Strength

The ultimate tensile strength of nanocarbon black reinforced epoxy with different weight fraction is shown in figure (2).This figure show that the ultimate tensile strength increase with increase of carbon black in a nonlinear relationship up to 2wt% of epoxy nanocomposite then decrease with increase carbon black.

The ultimate tensile strength is (24.02%) higher than neat epoxy, this may be attributed to a small amount of nanocarbon black particles filled epoxy disperse homogenously in epoxy which is lead to a strong interface between particles surface and epoxy ,thus the tensile 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 epoxy so that lead to weak interface between particle and epoxy matrix, thereby decreasing the tensile 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 tensile 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.

3.1.2 Elongation Percentages at Break

Figure (3) shows the relationship between elongation percentages calculated at break point and the weight fraction of carbon black (N220) which was added to epoxy. The elongation percentage at break does not decrease strongly up to a filler content of 2 wt.% and then decreasing sharply with increase weight fraction of carbon black .the results had revealed that the maximum amount of elongation percentage at break (5.32% at 1wt%) compared with the elongation percentage at break of neat epoxy (5.4%). This is may be attributed to that the nanoparticles rather induce deformation process than constraining the matrix deformation, that the nanoparticles do not raise the brittleness of polymer matrix, and instead it preserves its ductility. These results are consistent with those of other studied [16, 17].

3.1.3 Tensile Modulus

Figure (4) shows the relationship between the modulus of elasticity and weight fraction of carbon black (N220) filled epoxy resin matrix at different loading level. This figure shows that the tensile modulus of elasticity reaches maximum value at 3wt% and then decrease but remain high neat epoxy at 4wt% , after that continuous decrease with increase weight fraction of carbon black due to agglomeration in epoxy so that lead to weak interface between particle and epoxy matrix and reduce modulus of elasticity.

The improvement in tensile modulus is 7.93%, which may be attributed to adhesion between the particles and polymer matrix at low weight fraction range and better dispersion especially for the used the ultrasonic wave bath machine mixed composite. This is supported by the consistency with other studied (18, 19) which showed the ultrasonic wave machine more efficient method as compared with the high shearing method.

3.2 Compressive Strength

This test involve an axial compressive load being applied to a standard compression specimen of a square cross section with a constant speed rate of about (0.5 mm/min). Figure (5) shows the effect of carbon black (N220) at different loading level on the compressive stress of epoxy resin matrix. The results had revealed that the maximum value of compression strength (116.044MPa at 4wt %) compared with the compression strength of neat epoxy (80.367MPa). 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 (4wt %). Its indicates that the lower degree of nanoparticles-polymer interaction occurred at higher filler contents. This result is in a good agreement with Lin study (20).

3.3 Flexural Strength

Figure (6) shows the relationship between the bending strength (Flexural strength) and the weight fraction of the nanocarbon black powder which was added to epoxy resins, respectively. The results had revealed that the maximum amount of flexural strength (80.7 MPa at 2wt. %); compared to the bending strength of the neat epoxy (68.8 MPa). The same reasons of increase and decrease of ultimate tensile strength explain the effects of nanocarbon black on the flexural strength. This result is in a good agreement with Abdul Khalil's study (12) which improved the flexural strength by 8.05% at 5 wt. %, but in this work the improvement of bending strength is higher as well as less weight fraction because of used nanocarbon black as compared with his study which used micro carbon black.

3.4 Impact Strength

Figure (7) shows the relationship between the impact strength and the weight fraction of the nanocarbon black which was added to epoxy resin. The results had revealed that the maximum amount of impact strength (7.867 KJ/m^2 at 2wt %); compared to the impact strength of the neat (7.422 kJ/m^2).

The toughening modification mechanism of nanoparticles can be explained either nanoparticles produce a stress concentration effect initiate the surrounding resin to produce micro gaps which absorb some deformation work and prevent development of fissures in the resin matrix, or to the specific surface area of nanoparticles is large and this lead to a large contact area between the filler and the matrix .when material is impact, they can produce more micro gaps and absorb more impact work. But if the amount of the nanocarbon black is excessive (2wt%)the particles are so close to each other that the micro gaps easily develop to macro gaps, and the properties decrease. This result is in a good agreement with other study (21).

3.5 Hardness Test

Figure (8) shows the relationship between hardness and weight fraction of the nanocarbon black N220 particles. The results had revealed the shore D's hardness increases sharply when the carbon black content is at (4 wt. %) and then decreases slightly but remain higher than the neat epoxy. The maximum amount of hardness (85.1); compared to the hardness of the neat epoxy (76). 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 epoxy. This result is in a good agreement with other studies (22, 23).

4-Conclusions

The study covers the effect of adding nanocarbon black particles (N220) on mechanical properties of epoxy. It can be concluded that even small contents (1–4 wt. %) of nanocarbon black (N220) in the epoxy can increase the mechanical properties of the nanocarbon black /epoxy composite. When the amount of nanocarbon black is 2 wt. %, the tensile strength, tensile modulus, flexural strength and impact strength were improved by (24.02%, 7.93%, 17.3% and 6%) respectively, but decreasing elongation at brake and it does not raise the brittleness of epoxy matrix and preserve it ductility. When the amount of nanocarbon black is 4wt%, the compression strength and hardness are improves by (44.4%, 12%).

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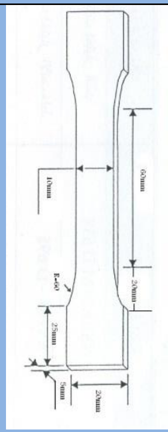
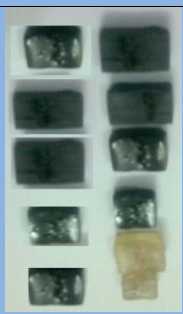
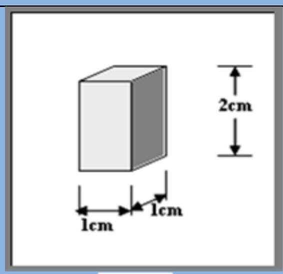
Table (1): Properties of epoxy used in this work according to the properties of Product Company which depended on the ASTM.

Density (gm / cm^3)	Viscosity (Poise) at 35 °c	Compression strength (MPa)	Fracture Toughness ($MPa\text{-}m^{0.5}$)	Tensile strength(MP)	Flexural strength (MPa)	Percent Elongation at break (% EL)	Modulus of elasticity (MPa)
1.05	1	70	0.6	27	63	<6	2800

Table (2): Properties of nanocarbon black (N220) used in this work according to the properties of Product Company which depended on the ASTM.

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	0.5-.65	121 ± 4	6 - 9	355 ±20	1.5	24-26	106-116

<table>
<tr><th>Type of test</th><th>specimens before test</th><th>specimens after test</th><th>Specimen dimensions (mm)</th></tr>
<tr><td>Tensile test ASTM D 638</td><td></td><td></td><td></td></tr>
<tr><td>Compression Test ASTM D695-85</td><td></td><td></td><td>
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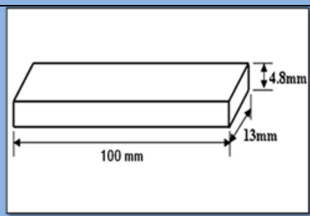
<tr><td>Bending test ASTM D790</td><td></td><td></td><td>
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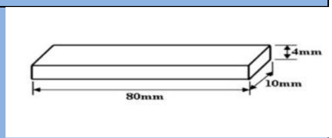
<tr><td>Impact test ISO-180</td><td></td><td></td><td>
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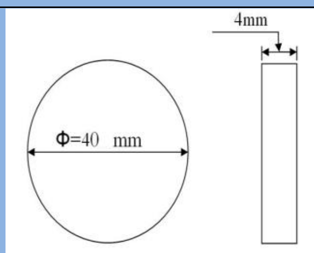
<tr><td>Hardness Test ASTM D2240</td><td></td><td>This test is not destactivespecimens</td><td>
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Figure (1): specimens prepared in this work according to stader specification.

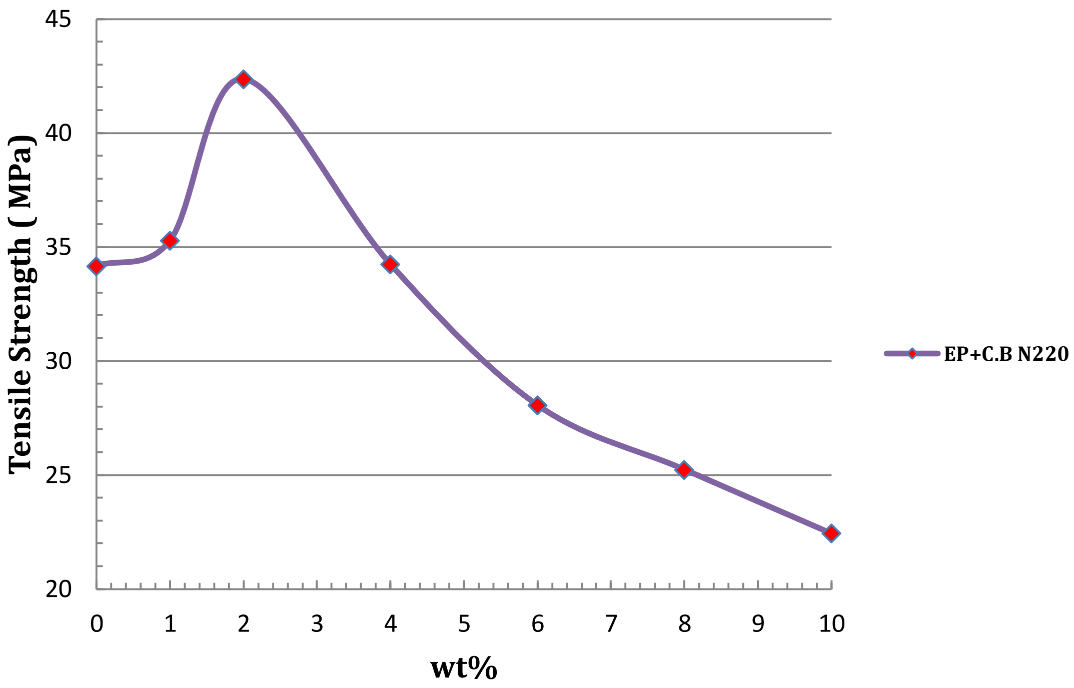

Figure (2): Effect of nanocarbon black (N220) on tensile strength of epoxy.

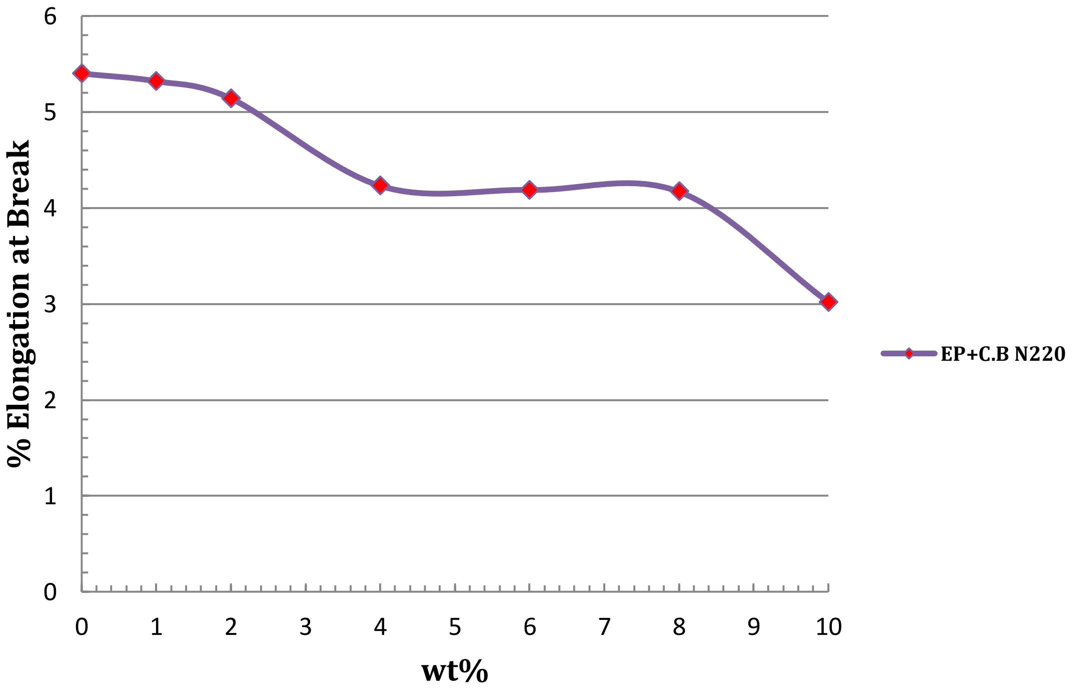

Figure (3): Effect of nanocarbon black (N220) on elongation % at break of epoxy.

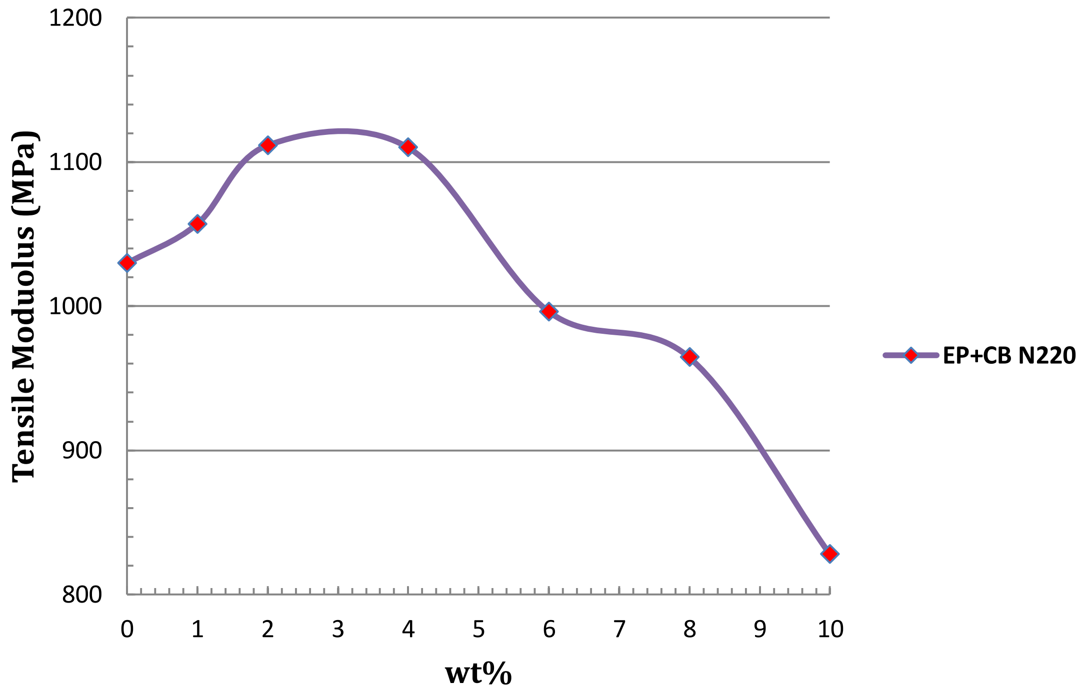

Figure (4): Effect of nanocarbon black (N220) on tensile modulus of epoxy.

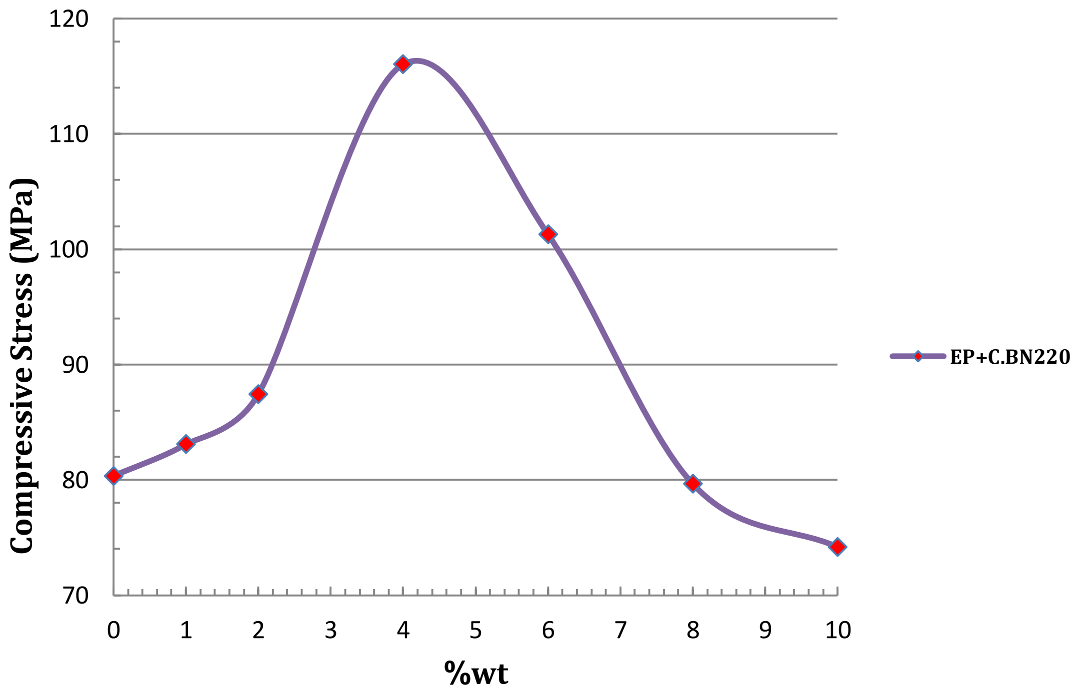

Figure (5): Effect of nanocarbon black (N220) on compressive stress of epoxy.

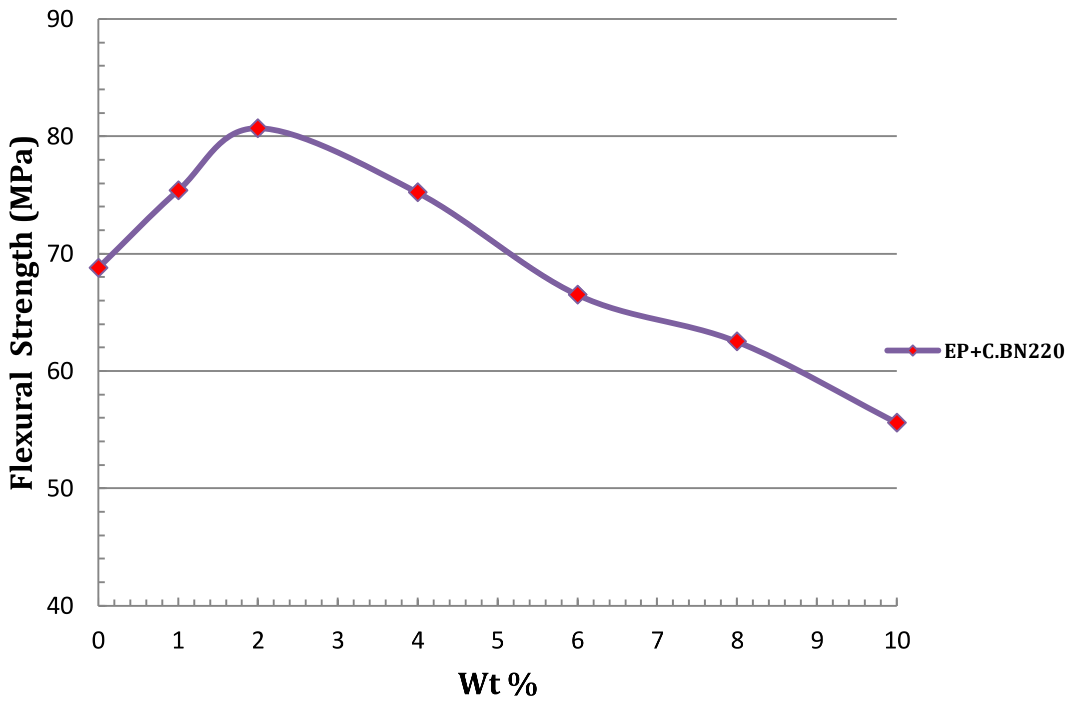

Figure (6): Effect of nanocarbon black (N220) on flexural strength of epoxy.

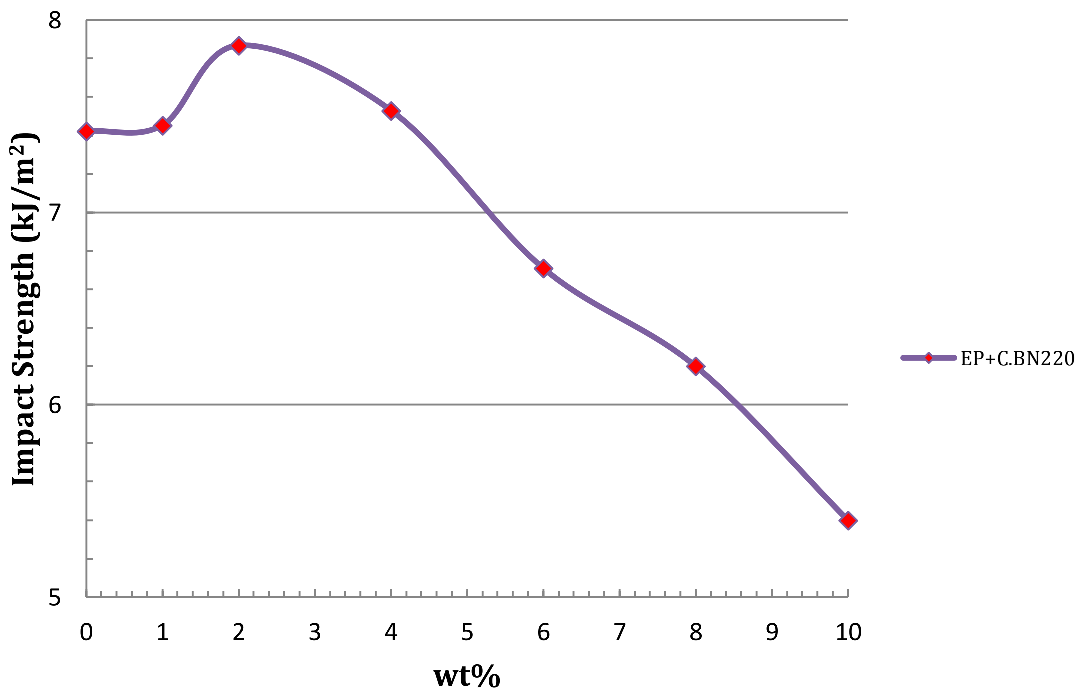

Figure (7): Effect of nanocarbon black (N220) on impact strength of epoxy**.**

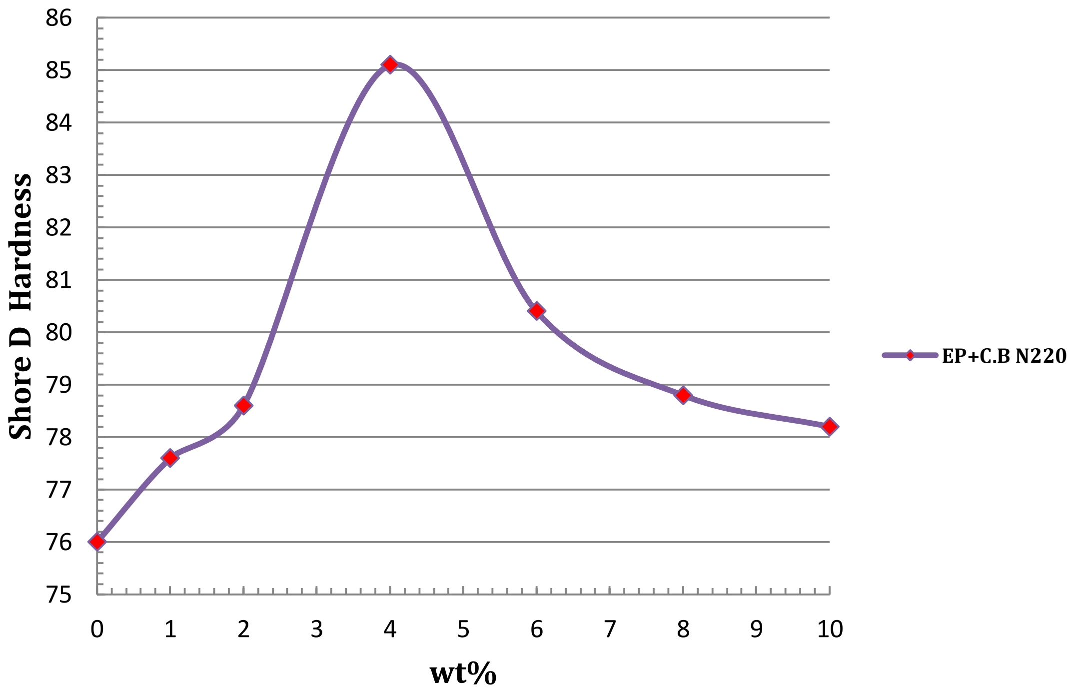

Figure (8): Effect of nanocarbon black (N220) on hardness properties of epoxy.

تأثير اضافة الكاربون الاسود النانوني على الصفات الميكانيكة للايبوكسي

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الخلاصه

يتضمن البحث بيان تاثير حبيبات الكاربون الاسود النانوية (N220) على بعض الخواص الميكانيكية المهمة لراتنج الايبوكسي المدعم بها. تم تحضيرالمتراكبات النانوية بنسب وزنية مختلفة (1-10 %) من الكاربون الاسود النانوي باستخدام طريقة التشتت بالموجات فوق الصوتية. وبينت النتائج ان مقاومة الشد ومعامل المرونه ومقاومة الكسر ومقاومة الصدمة قد تحسنت بنسبة (24.02% و7.93% و17.3% و6%) على التوالي عند نسبه وزنيه (2%)، اما مقاومة الانضغاط والصلادة فقد تحسنت بنسبة (44.4% و21%) عند نسبه وزنيه (4%).

الكلمات الداله: الكاربون الاسود النانوي، الخواص الميكانيكيه، راتنج الايبوكسي.