Wear and mechanical properties of epoxy/MgO-SiO_2 hybrid nanocomposites

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Abstract

Preparation of epoxy/MgO and epoxy/SiO_2 nanocomposites is studding. The nano composites were processed by different nano fillers concentrations (0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.07 and 0.1 wt%). Epoxy resin and nanocomposites containing different shape nano fillers of (MgO:SiO_2 composites), are shear mixing with ratio 1:1,with different nano hybrid fillers concentrations (0.025, 0.05, 0.1, 0.15, 0.2 and 0.25 wt%) to preparation of epoxy/(MgO-SiO_2) hybrid nanocomposites. Experimental tests results indicate that the composite materials have significantly higher modulus of elasticity than the matrix material but the hybrid nanocomposites have lower modulus of elasticity. The wear rate was decreased in nanocomposites and hybrid nanocomposites than the matrix material and fatigue resistance was increased in nanocomposites and hybrid nanocomposites than the matrix material.

Key words

Hybrid materials, epoxy/MgO-SiO_2, nano composites, elastic modulus.

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البلى والخصائص الميكانيكية لمتراكبات Epoxy/MgO-SiO_2 النانومترية الهجينة

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الخلاصة

تم دراسة تأثير إضافة كل من أوكسيد المغنيسيوم النانوي وثاني أوكسيد السيلكا النانوي على الخصائص الميكانيكية وبنسب وزنية مختلفة هي (0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.07 and 0.1 wt%). راتنج الأيبوكسي والمركب النانوي يحتويان أشكال مختلفة من الدقائق النانوية (متراكبات Mgo: SiO_2)، وتم إعتماد التركيب الهجيني بنسبة 1:1 وبنسب وزنية مختلفة (0.025,0.05,0.1,0.15,0.2 and 0.25%). نتائج الأختبارات التجريبية تشير الى ان المواد المركبة لديها أعلى بكثير من معامل المرونة للمادة الأساس، ولكن المتراكب الهجيني لها معامل مرونة أقل من معامل المرونة للمادة الأساس. وقد أنخفض معدل البلى في المركبات النانوية والمواد المتراكبة الهجينة عن معدل البلى للمادة الأساس ومقاومة الكلال تزداد في المواد المركبة والمواد المتراكبة الهجينة عن مقاومة الكلال للمادة الأساس.

Introduction

High-performance polymeric composites have been increasingly used for different engineering applications. These composites must provide unique mechanical, thermal, and electrical properties with low specific weight and high resistance to environmental degradation in order to ensure safety and economic efficiency[1]. They can produce property enhancement that is sometimes even higher than that of classical filled polymers at volume fractions in the range of 1–5% by Nanoparticle-filled polymers. A different inorganic materials, especially nanoceramic powders such as titanium dioxide (TiO_2),zirconium oxide (ZrO_2), aluminum oxide (Al_2O_3), and silicon dioxide (SiO_2)[2].Polymer matrix composites have excellent room –temperature properties with relatively low cost[3]. Particle concentration, type of the particles reinforcement, the size, shape of the particles and the interfacial adhesion between the matrix and the particles are the major parameters that influence the mechanical properties of the particulate composite [4]. Due to their good mechanical, thermal, and electrical properties epoxy resins are used widely in many engineering applications. Many types of epoxy resins have been developed, including bisphenol-aliphatic cyclic, novolac types, etc, to further strengthen the properties of epoxy resins, the use of an additional phase has been a common practice[5]. Inorganic particles such as, titanium dioxide, silica, alumina, fly ash, clay additives to epoxy resins modified have shown improved[6]. For inorganic/organic composites, the size of particles and the interfacial adhesion have great effect on the properties of the resin matrix. A polymer nanocomposite is defined as a composite material with a polymer matrix and filler particles that have at least one dimension less than 100 nm[7]. The aim of this work is to prepare a new type of inorganic-polymer materials of epoxy nanocomposites with new mechanical properties

Experimental

Materials and sample preparation

Epoxy resin is a FOSROC Co. product (nitofill EP L-V), Jordon. The density of epoxy resin is 1.04 gmcm^{-3}, with viscosity of resin about 12000 cp at 25°C, MgO and SiO_2 (50nm) nanoparticles were provided by Degussa company. Epoxy/MgO and epoxy/SiO_2 nanoparticles with filler concentration (0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.07 and 0.1 wt%) were prepared. Prepare mixture MgO:SiO_2 nanoparticles by ratio 1:1 of concentration of hybrid nanoparticle (0.025,0.05,0.1,0.15,0.2, and 0.25) wt% of resin were prepared respectively, the dispersion in the epoxy by using an ultrasonic stirrer, for mixing time 90 min at 50°C. A mixture of EP/ MgO:SiO_2 materials was degassed in vacuum at 70ºC for about 20 min. The resulting mixture was then cast into a mold at room temperature. All samples were cured at 70 ºC for 2h to satisfy a full curing.

Wearing test

Disc diameter of 40mm was used in all the tests. However, each test was run on a fresh track, a normal load of 7 Newton and a sliding velocity of 0.98 m/s. A transducer attached to the dry wear tests of the epoxy composites were carried out on a pin-on-disc machine, as illustrated in Fig.1. A fixed track specimen holder recorded the tangential force. The volumetric wear was measured by the weight loss of a specimen using an analytical balance of resolution 0.01mg.The wearing characteristic was assessed by the weight loss, *W*, which was calculated by the following equation:

$W = W_1 - W_2$

where W_1 and W_2 are respectively the weight of a sample before and after its test.

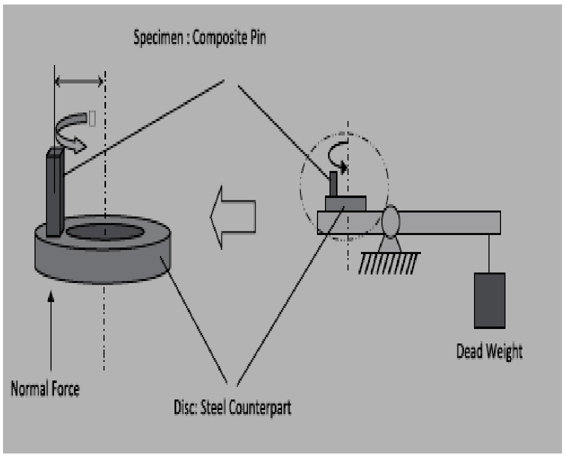

Fig. 1: The pin-on-disc wear test.

Bending test

Three point bending test has been used to investigated the mechanism of crack propagation. Instron 1122 was used and the cross head speed were fixed (1mm/min). Load -deflection curves were obtained for different samples. The support span (distance between the supports) was depending on the specimen at the middle of support span for rectangular sample under a load in a three –point setup:

$F.S=3PL/2bd^2$

$E_B= ML^3/ 4 bd^3$

F.S: Flexural strength (N/mm^2), E_B:-Flexural modulus (Mpa).

P: The applied load at the highest point of (load- deflection) curve (N).

L: The span length (cm),

b: The width of test specimens (cm).

d: The thickness of test specimens (cm), M:- The line of curve load –deflection.

Fatigue test

Fatigue tests were performed according to (ASTM-D3479) specimens using an HI-TECH LIMITED Model No.:HSM 19,SER.No.E280 computer controlled loading frame. The applied load was sinusoidal with a frequency of 2 Hz, with 2 mm deflection a maximal load of (P_{max}) 9 N and a stress factor of (R) 0.2. Specimens were tested from the composite and reinforced hybrid composite on room temperature. All fatigue specimens were tested using the same machine. The machine cycles the specimens to failure and the number of cycles-to-failure was recorded by computer data acquisition system.

Results and discussion

The flexural stress-strain could be used to study the changes induced by addition of nano filler. In this study, we have analyzed the changes in terms of flexural stress-strain curves with addition of nano MgO and nano SiO_2 into the epoxy resin. The effects of nano MgO and nano SiO_2 content on flexural strength Fig.2, MgO nano content is decreased from epoxy but SiO_2 nano content is increased from epoxy at 0.03% and 0.04% and at 0.05% in case of nano hybrid content because a rapid increase in bending strength takes place, this is consistent with reference [8].

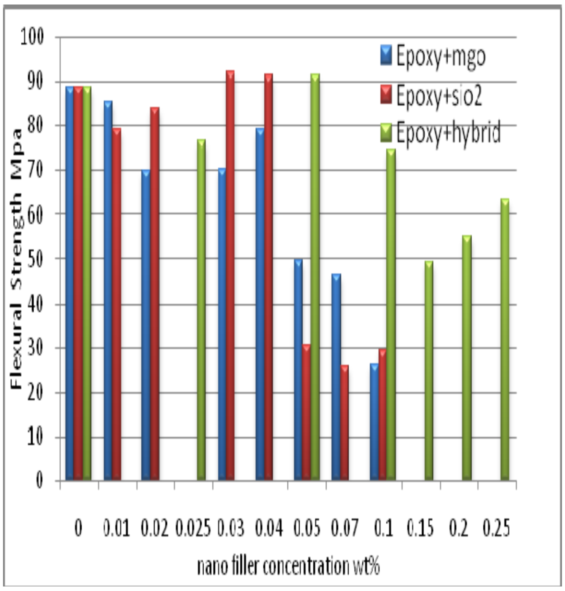

Fig. 2: The behavior of flexural strength with nano filler concentration.

Fig.3 show result of flexural modulus, the flexural modulus of the MgO and SiO_2 nano composites were clearly improved compared to that pure epoxy at 0.02% and 0.03% concentration. These results indicate that the rigid nano filler particles in epoxy networks directly enhance the stiffness of composites, allowing a uniform stress distribution in the polymer, and leading to increased flexural strength and moduli. As the rigidity of nano filler particles is greater than that of epoxy resin, it can be expected that nano filler particles will assist in improving the mechanical properties of the composites. Small sand particle with larger surface area achieve better wetting and adhesion which leads to better reinforcing ability and stiffer composite system[9]. The flexural strength of the hybrid $MgO:SiO_2$ nanocomposites were clearly decrease compared to that of MgO, SiO_2 epoxy nanocomposites and pure epoxy.

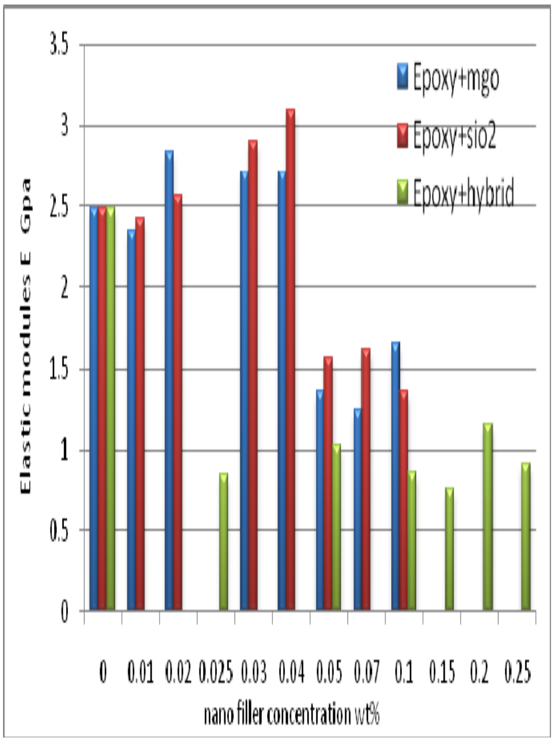

Fig. 3: The behavior of elastic modulus with nano filler concentration.

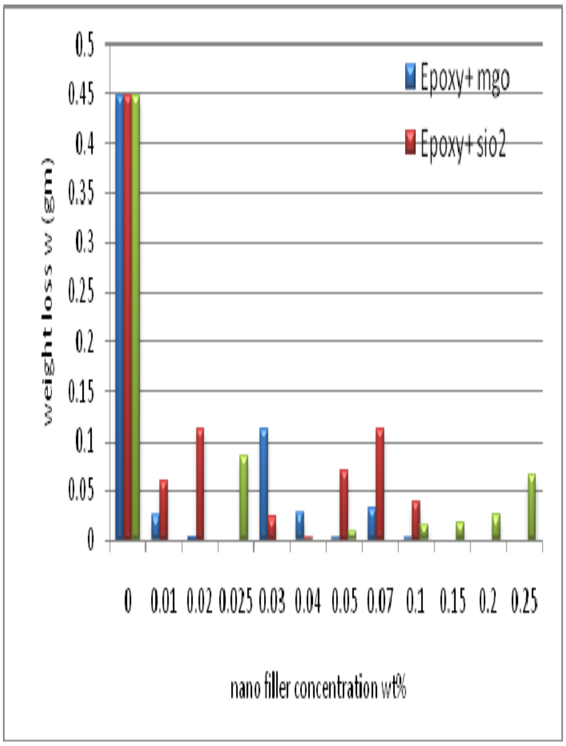

Fig. 4: The behavior of weight loss with nano filler concentration.

Fig. 4 shows the wear rate of the investigation specimens. The wear rates are plotted as a function of nano filler weight concentration with constant applied pressure about 7 N. The wear results show that the reinforced specimens have better wear resistance than the pure epoxy. It is clear from figure that nano MgO and nano SiO_2 and the hybrid MgO: SiO_2 nanocomposites enhanced the wear resistance of pure epoxy.

The wear rate decrease from 0.45gm for epoxy to 0.01gm for nano MgO, to 0.03gm nano for SiO_2 and to 0.2gm for the hybrid MgO: SiO_2 nanocomposites at applied pressure equal to 7 N. This is probably due to the fact that epoxy can easily remove at sliding surfaces (contact area) but in the composite case the ceramic nano particles act as a rough surface relative to the counter face against which they slide[10].

Fig. 5 shows the rate of wearing, it can be observed that in two concentration recorded high number of cycles (using the same frequency value), the first at 0.03 concentration of nano SiO_2 and the second at 0.25 hybrid/epoxy nanocomposites was showed an increase in the fatigue life values, a high number of cycles, (higher than 1400,000 cycles) these values are higher when compared with those found in low cycles of pure epoxy, According to the results presented in Fig.5, it is observed that when fatigue tests are performed at high and low number of cycles, the repaired specimens can be affected by void rich regions created during repair. These voids are responsible for delamination but, due to the low loads, the composite did not present catastrophic fracture but can most likely be affected by debonding. The debonding occurred randomly in the specimen before the rupture, but parallel to the fatigue loading direction. When this kind of debonding propagation occurs, fatigue damage can be concentrated in one particular region of the specimen. As a consequence, that region will become weaker and critical[11]. Fig.6 shows Atomic Force Microscopy (AFM) observation uniformity and three-dimensional surface profile of 0.03 MgO nanospheres in the nanocomposite. Fig.7 shows Atomic Force Microscopy (AFM) observation uniformity and three-dimensional surface profile of 0.03 SiO_2 nanospheres in the nanocomposite.

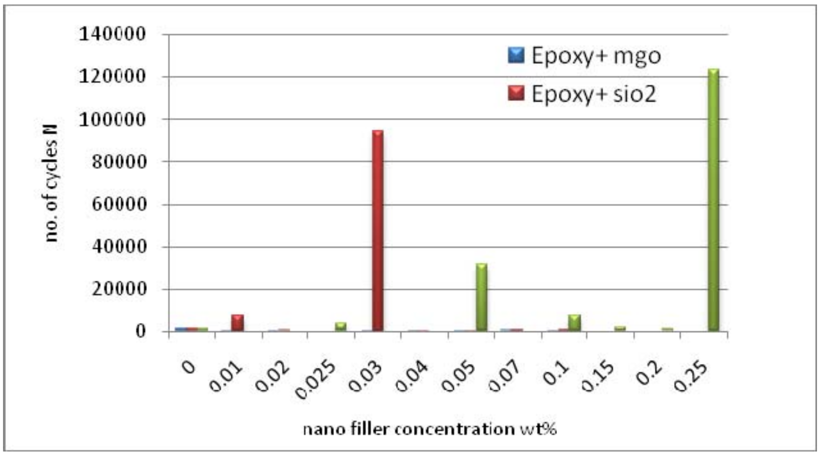

Fig. 5: The behavior of no. of cycles with nano filler concentration.

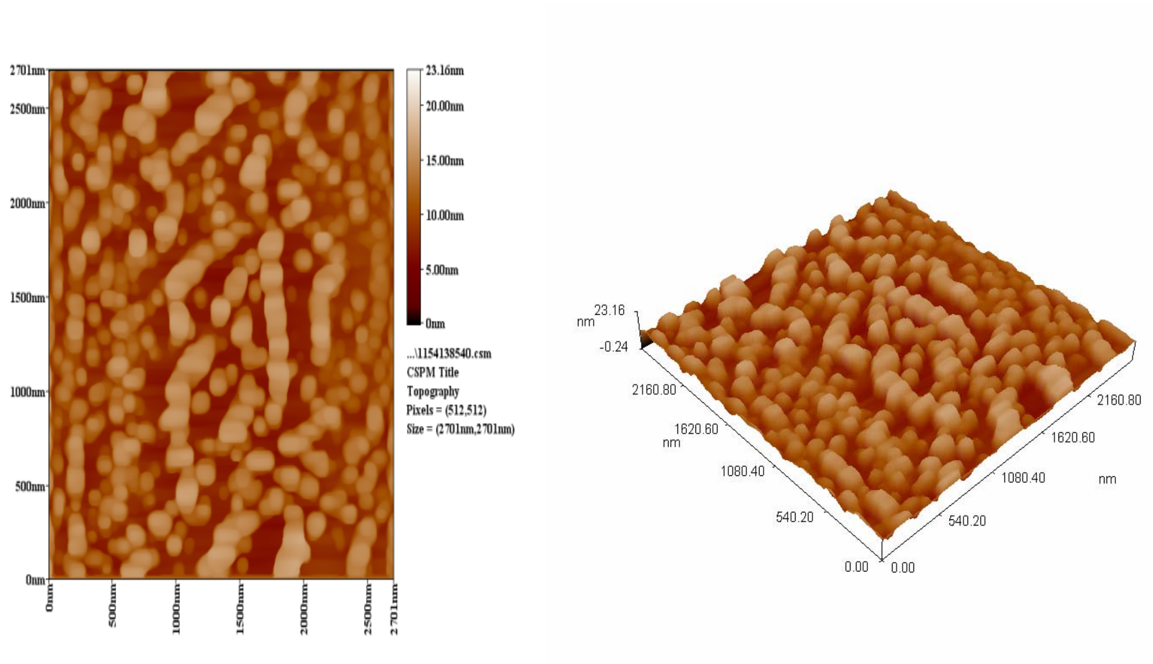

Fig. 6: AFM micrograph showed uniformity and a three-dimensional surface profile of 0.03 MgO nanospheres in the epoxy nanocomposite.

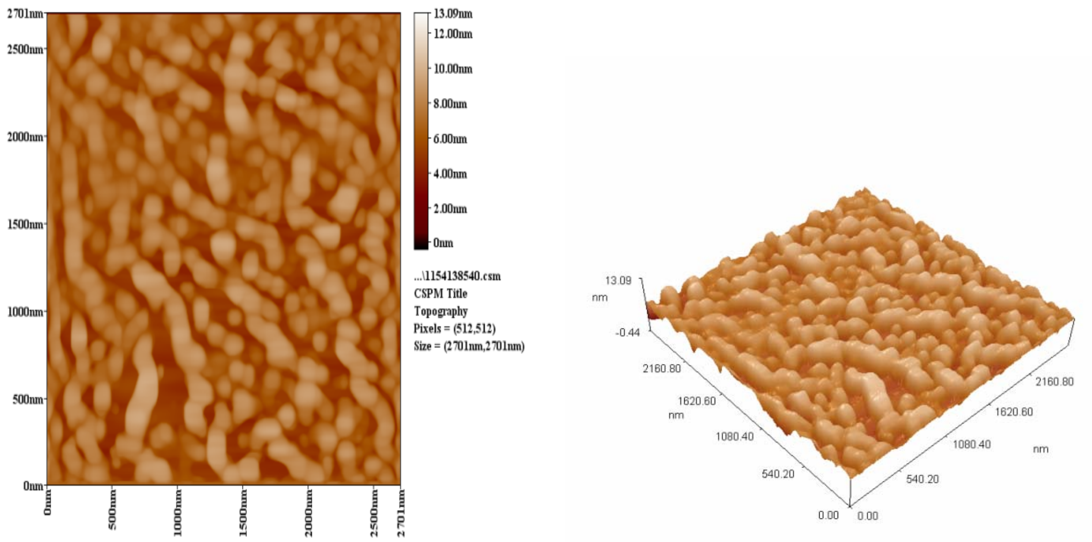

Fig. 7: AFM micrograph shows uniformity and a three-dimensional surface profile of 0.03 SiO_2 nanospheres in the epoxy nanocomposite.

Conclusions

1-The effects on flexural strength of MgO nano content is decreased from epoxy (about 4 Mp) but SiO_2 nano content is increased from epoxy at 0.03% (about 4 Mp) and 0.04% and at 0.05% in case of hybrid nano content.

2- Reinforced specimens have better wear resistance than the pure epoxy (about 20 times). It is clear from nano MgO and nano SiO_2 and the hybrid MgO: SiO_2 nano composites enhanced the wear resistance of pure epoxy.

3- Fatigue at high number of fatigue cycles at 0.03 concentration SiO_2 (9 times), and 22 times at 0.25 concentration hybrid MgO: SiO_2.

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