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Transverse Direction Loading Effect on the Elasticity and Strength of Micro and Nano Silica Oxide Composites

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Abstract

Using three-point bending experiments, the effect of the particle size of SiO_2 on the flexural properties of epoxy composites was investigated. Young modulus and flexural strength were studied for different weight percentage of filler (2,4,6,8 and 10) wt%.The size of SiO_2 particles varied from micro (100um) to nano (12nm) . Flexural strength and Young modul were found to increase with the filler content, but when the particle size decreased to the nanoscale, the Young module increased. Flexural strength was higher for microcomposites than nanocomposites.

Key word : **nano silica oxide composites**,mechanical properties,three point bending test ,fracture

تاثير الاجهاد المستعرض على مرونه ومتانه المتراكبات المسلحة بجزيئات السليكا المايكروية والنانوية

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الخلاصة

باستخدام طريقة فحص الانحناء الثلاثي الارتكاز , تم دراسة تاثير الحجم الحبيبي لثنائي اوكسيد السيليكون على خواص الانحناء لمتراكبات الايبوكسي .

تم دراسة معامل يونك اجهاد الانحناء لنسب وزنية مختلفة من المواد الداعمة (2,4,6,8و10)% .حجم حبيبات ثنائي اوكسيد الاوكسيد تتراوح مابين الحجم المايكروي(100مايكرو متر) والحجم النانوي (12 نانو متر).

وجد ان كل من اجهاد الانحناء ومعامل يونك قد زاد مع زيادة محتوى التدعيم , ولكن عند نقصان الحجم الحبيبي الى المستوى النانوي لوحظ ان معامل يونك يزداد ,ولوحظ ايضا ان قيم اجهاد الانحناء اكثر زيادة للمتراكبات ذات المحتوى المايكروي من المحتوى النانوي

1-Introduction

In recent years, the concept of forming hybrids using polymers and inorganic materials has received a significant amount of attention. Many of these studies have used surface-treated silicates or organoclays to produce layered-silicate nano-composites, e.g. [1]. A nano-composite is defined as a composite where one of its components has a dimension in the nanometre scale. Many claims for the potential of these organic/inorganic hybrids have been made, but for some important combinations of materials, little experimental data has been produced. The addition of inorganic filler to a polymer matrix can greatly increase its

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stiffness[1] which initiates cracks and makes them bigger than the size of the failure,causing critical cracks. Therefore, it is a good to reinforce polymers with nano-particles in order to enhance fracture toughness without losing the mechanical strength of the polymers, since well-dispersed nano-particles are far smaller than the critical crack size to initiate failure. Therefore, nano-particles have an opportunity to toughen and reinforce polymers at the same time [2].

Enhancing toughness by the addition of particles was investigated by many researchers[3-4] . Kinloch have addressed the effect of particle size on flexural properties [5]. Different nanomaterials with different properties have been developed in recent years. Due to their much larger reactive surface area per unit volume compared to large particles [6-7].

2- Experimental Part

2-1 The preparation of materials and specimens

The details of the composite processing and the experimental procedures are described in this part. In this work, the raw materials used are: E-glass fiber (random and woven roving glass fiber), Micro SiO_2 filler with particle size of (100μm) and fumed nano SiO_2 particle filler with particle size of (12 nm) (manufactured by Nanoshell lc, USA), Epoxy resin and hardener as a matrix (Nitofill, EPLV with Nitofill EPLV hardener from Fosroc Company)

2-2 Specimens cutting

The hand lay-up method was used to prepare the samples as sheets with (20×20×0.4) cm size. The sheets were cut according to ASTM (D790-84a) for the preparation of specimens for the bending test,(Figure 1). Specification of the specimens are described in Table 1.

Table 1-Dimensions for flexural test

Nominal specimen depth (mm)	*Specimen width (mm)*	*Specimen length (mm)*	*Support Span (mm)*
4	**10**	**80**	**64**

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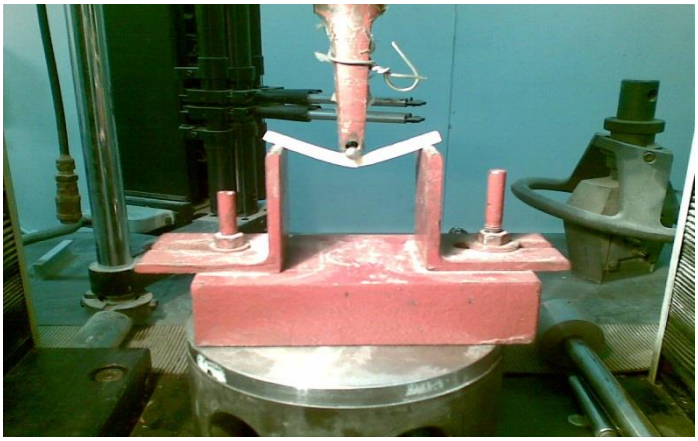

Figure 1-Bending test apparatus

The bending strength of a material is expressed as the stress on the outermost fibers of a bent test specimen at the moment of failure. In a traditional test, the flexural strength (expressed in MPa) can be calculated according to Equation (1):

$$\text{Flexural Strength} = 3PL / 2bd^2 \quad \text{--------- (1)}$$

Where: P is the applied central load (N), L is the sample test span (in m), B is the specimen's width (in m), and d is the specimen thickness(in m).

In each of the specifications, flexural modulus is defined in the same manner as in Equation (2) for a three-point bending test:

$$E_f = L^3 m/4bd^3 \quad \text{---------- (2)}$$

Where: the flexural module is E_f , L is the support distance, m is the load/deflection curve slope, with the width and thickness of the beam being b and d, respectively.

2-3 Preparation of Micro-composites

SiO_2 microparticles of particle size (100μm) of different percentage of weight of (2, 4, 6, 8 and 10) were added to a mixture of epoxy resin with hardener. To prepare the micro-composites, a thin layer of resin was spread on a glass plate with a brush. Sheets of glass fiber were stuck on a glass plate ,then immersed in the mixture. A rolling brush was used to get rid of entrapped air bubbles in the specimen.This was repeated until 8-plies were spread on the glass plate.The specimens were then left in room temperature for 24 hour for curing and were casted in an oven for 1 hour in 50 ^oC. Finally,the specimens were cut according to ASTM D790-84a for flexural test.

2-4 Preparation of Nano-composites

Samples were prepared by mixing epoxy resin with (2%,4%,6%,8% and 10%) wt%.of nanoparticles , then blended with a magnetic stirrer for 60 min at 60 ^oC. to gate. The mixture was left to cool then hardener was added to the mixture. A Sheet of glass fiber was stuck on a glass plate ,then immersed in the mixture using a brush.A rolling brush was used to get rid of entrapped air bubbles in the specimen.This was repeated until 8-plies were reached for flexural test in the longitudinal direction, while for flexural test in the transverse direction 16-plies are needed. The specimens were left in room temperature for 24 hour for curing, after this they were casted in an oven at 50 ^{o} C for 1 hour.

All the prepared samples were left at room temperature for 72 hours.

As seen before pulling out of the molds, left in the vacuum chamber

for 7 days before cutting and checking to ensure faster healing

3-Results and Discussion

From Table (1), it can be noted that modulus of elasticity increased with the addition of microparticles to the epoxy composites.It increased with increasing the wt% of SiO_2 nanoparticles. These particles act as toughing agents. they fill the space in the rich resin region making the matrix stiffer.It was observed that the composite with 8% wt SiO2 nanoparticles have higher modulus of elasticity; this means that better homogeneity was found at this wt %. It was also noted that flexural strength increased with increasing the filler content. The addition of microparticles changes the matrix from brittle to ductile. Also when the particle size increased the debonding was increased and this lowered the failure stress. This can be explained because of particle size, which leads to the increase of the constraint between epoxy chains i.e. increase of chains immobility [8]. The addition of SiO_2 nanoparticles, which are polar particles[7], results in the filling of the free spaces between chains and attracting resin molecules, this leads to a decrease in space distance (i.e. reduce of free space distance between epoxy chains) and hence the formation of epoxy chains, during curing processes, creating more complicated network chains[9].

Table 1- Elasticity Modulus and Flexural Power of Microcomposites

Materials	Modulus of elasticity (GPa)	Flexural strength (MPa)
0	17.2	615
2%	12.8	558
4%	15.1	552
6%	13.8	459
8%	17.7	729
10%	23.1	744

No brittle to ductile transformation was observed while moving down to the nanoscale. Flexural strength was lower for nanocomposites than for microcomposites, because in nanocomposites there is a strong interaction between the nanoparticles and the polymer chain.

These nanospheres can be debonded with others, leading to fracture under high-stress concentration and eventually leading to the process of toughening of energy dissipation.
By raising the content of the nanoparticle filler, it can be seen that as the interparticle distance decreased , a 3-dimensional spatial network in the matrix can be built around the interspace material around the nanoparticles, leading to an increase in flexural modulus[10] .

Table 2-Elasticity Modulus and Flexural Power of Nanocomposites

Materials	Modulus of elasticity (GPa)	Flexural strength (MPa)
0	17.2	615
2%	5.78	232
4%	27.4	498
6%	25.6	455
8%	15.6	518
10%	21.7	544

Fractography of Woven Roving Composites

Many phenomena were observed when specimen were tested in bending methods .Two modes were performed in the bending test. The upper area was under compression mode and the lower area under tension mode. Long fibers will split from lower area and some of laminates split in transverse direction at edges of specimen with buckling . Fiber debonding and pull –out occured as a result of delamination cracks which were generated above and below the layers , as shown in Figure 2.

Figure 2-Fractography of Woven roving Composites

The mechanical behavior of nanocomposites is critically dependent on their structural composition. Phase contrast atomic force microscopy (AFM) was used to study the surfaces of a layered polymer nanocomposite. AFM provides mechanical information on the surfaces of nanocomposites.

The AFM images show high roughness of the nanocomposite surfaces of 1%wt SiO_2 nanoparticles ,as shown in Figure 3, while a great nanoparticle dispersion was noticed with the surfaces of 7%wt nanoparticles, as seen in Figure 4.

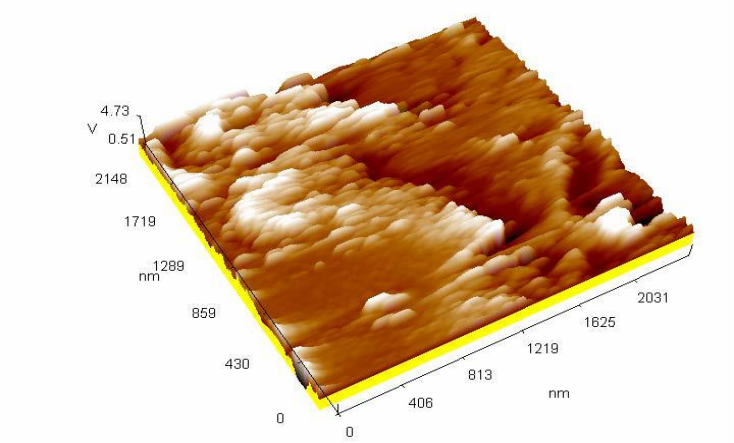

Figure 3-AFM image of nanocomposite surface with 1% wt SiO_2 nanopaeticles.

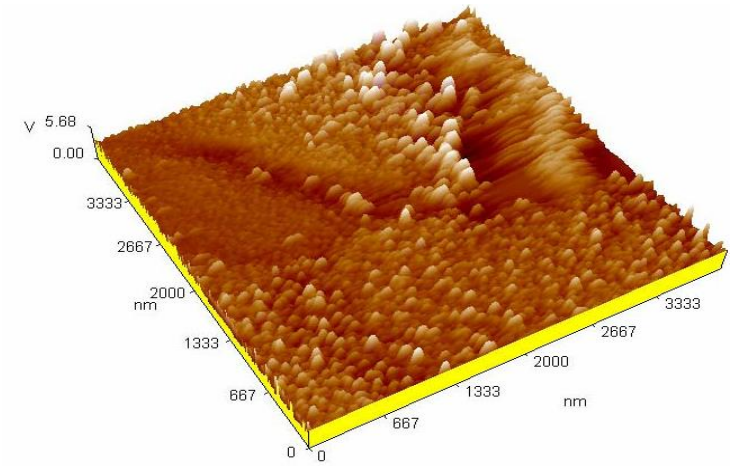

Figure 4-AFM image of nanocomposite surface with 7% wt SiO_2 nanopaeticles.

Conclusions

The addition of the micro and nanoscale silica particles showed a clear effect on the mechanical properties, especially on both he Young module and flexural strength. The results showed that the %wt and the particle size of the added nanopaerticles have a clear effect on Young module and flexural strength .

Flexural strength and Young module were found to increase with the filler content, but when the particle size decreased to the nanoscale, the Young module was noted to increase. Flexural strength was higher for micro composites than nanocomposites.

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