Effect of water absorption on some mechanical and physical properties of epoxy/polyurethane blend reinforced with nano silica powder

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Abstract

The aim of this work is to evaluate some mechanical and physical properties (i.e. the impact strength, hardness, flexural strength, thermal conductivity and diffusion coefficient) of (epoxy/polyurethane) blend reinforced with nano silica powder (2% wt.). Hand lay-up technique was used to manufacture the composite and a magnetic stirrer for blending the components. Results showed that water had affected the bending flexural strength and hardness, while impact strength increased and thermal conductivity decreased. In addition to the above mentioned tests, the diffusion coefficient was calculated using Fick's 2nd law.

Key words

Hand lay-up, nano SiO_2, diffusion coefficient, flexural strength, Fick's 2nd law.

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تأثير امتصاصية الماء على بعض الخصائص الميكانيكية والفيزيائية على خليط الأيبوكسي / بولي يوريثان المدعم بدقائق السيليكا النانوية

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الخلاصة

يهدف البحث الى دراسة بعض الخصائص الفيزيائية والميكانيكية (الصدمة، الصلادة، متانة الانحناء، معامل التوصيل الحراري) وكذلك معامل الأنتشار للماء في مادة متراكبة اساسها خليط من الأيبوكسي والبولي يوريثان مدعمة بدقائق السيليكا النانوية وبكسر وزني 2%. استخدمت تقنية القولبة اليدوية لتصنيع النماذج مع استخدام الهزاز المغناطيسي لخلط المكونات. اوضحت النتائج ان متانة الصدمة تزداد بعد الغمر بالماء بينما تقل متانة الانحناء والصلادة والتوصيل الحراري. تم حساب معامل الأنتشار للنماذج استنادا الى قانون فك الثاني في الأنتشارية.

Introduction

Polymer blends are the most common polymers used nowadays as a matrix, due to their modified properties when alloying two or more types of polymers that are compatible [1]. Blending provides a fast and inexpensive way to develop and produce a new polymer with desired properties when miscibility and homogenization are the main topics needed [2]. Polymer-polymer adhesion plays a significant role in determining the ductility related properties of miscible, or partially miscible blends. A new material, including nano fillers with polymer matrix to reach optimum values of mechanical and physical properties such as nano silica, alumina, magnesium, etc. [3].

Charpy test is commonly used to determine the energy of fracture of the specimens, so impact strength can be calculated using Eq. (1) [4]:

$$I.S. = \frac{U}{A} \quad (1)$$

where *I.S.* is the impact strength (kJ/m^2), *U* is the energy absorbed (kJ) and A is the cross sectional area (m^2). Bending test is also used to evaluate many factors (Young's modulus, flexural strength, shear stress). The 3-Point bending test is used preferably to find the flexural strength according to Eq. (2) [4]:

$$F.S. = \frac{3FL}{2bd^2} \quad (2)$$

where F is the load applied (N), L is the distance between supports (m), b is the width of the specimen (m) and d is the thickness of the specimen. Polymers and polymer blends and their composites were more affected by aggressive liquids including water, so diffusion coefficient can be calculated after a certain time using Fick's 2nd law:

$$D = \pi \left(\frac{Kb}{4M_\infty} \right)^2 \quad (3)$$

where K is slope of the curve (weight gain % versus square root of the time), b is the thickness of specimen, M_∞ is the maximum weight gain of the specimen before degradation and D: is the diffusion coefficient. Weight gain % can be calculated from Eq. (4):

$$\text{Weight Change\%} = \frac{Wt - W\,o}{Wo} \times 100\% \quad (4)$$

where w_o: weight of the sample before immersion in liquid, w*t*: weight of the specimen after immersion in liquid. Polymers and blends are bad conductors, so thermal conductivity can be attributed to vibrational motion of molecular chains, and could be affected by crystal structure, so the type of filler, the interface region and the environment could affect thermal conductivity [5]. Dheyaa had studied the effect of aggressive liquids (H_2O, H_2SO_4, KOH) on the impact behavior of epoxy/glass composites and noticed that H_2SO_4 acid had a higher effect on the specimens [6]. In 2016, Hanaa studied the influence of water on the mechanical properties of (polyester/polyurethane) blend filled with nanosilica and noticed that impact strength increased while thermal conductivity, hardness and flexural strength decreased [7].

Experimental procedure

1. Materials

In this study, epoxy resin (Nitofill, EpLv with Nitofill EpLv hardener from Fosroc™ company) was used, the mixing ratio was 3:1 and gelling time 60 minutes at 35 °C, mixed viscosity (1.0) poise and specific gravity (1.04). Polyurethane rubber is used, it is a liquid with moderate viscosity and capable to be converted to solid by adding a hardener, with a density (1.13 g/cm^3), produced in Jordan. Silica nano powder (40 nm) diameter was provided by Degussa™, was used as a filler with a weight fraction of 2%.

2. Composite preparation

For the Preparation of the composite material, the filler was dried in an oven at 70°C for 3 hours, Epoxy resin was blended with polyurethane to form a binary blend with ratios (90:10, 80:20, 70:30, 60:40) and the best ratio was chosen according to the results obtained from the impact test carried out on specimens made from the mixing ratios mentioned above. The filler (nano silica powder), was added to the blend and mixed using a magnetic stirrer for 1.5 hrs., Afterwards, the composite was poured into the open mould at room temperature, a metal mould with

dimensions (20×20×2) cm was used for casting the blend and it's composite. and left to solidify for 24 hrs., then the material was cured at 60 °C for 3 hrs. to achieve a full cross-linking. All specimens were cut according to the international standards; ISO 179 [8] standard specification was used to carry out impact test, the standard specification ASTM D790 [9] was used to carry out flexural strength test, and Lee's disc was used to calculate thermal conductivity. Shore D hardness tester type (TH 210) was used to for hardness test. Finally, a digital balance (4 digits) was used to calculate the weight change after immersion in water, for 8 weeks.

Results and discussion

1. Impact strength

Impact strength can be defined as the behaviour of material when subjected to quick stress, and it can be calculated according to Eq. (1). Fig.1 shows the value of the impact strength of all blends, the optimum mixing ratio (OMR) was used as a matrix, it shows that the 3rd sample with (70:30) % weight ratio of (epoxy/ PU) has the maximum impact test. Table 1 shows the OMR for blends according to the impact test. Fig. 1 shows the values of impact strength for different blend ratios.

Table 1: Impact strength for (Ep/PU) blends.

Ep/PU	**90:10**	**80:20**	**70:30**	**60:40**
Impact strength kJ/m^2	**6.3**	**11.4**	**14.0**	**10.5**

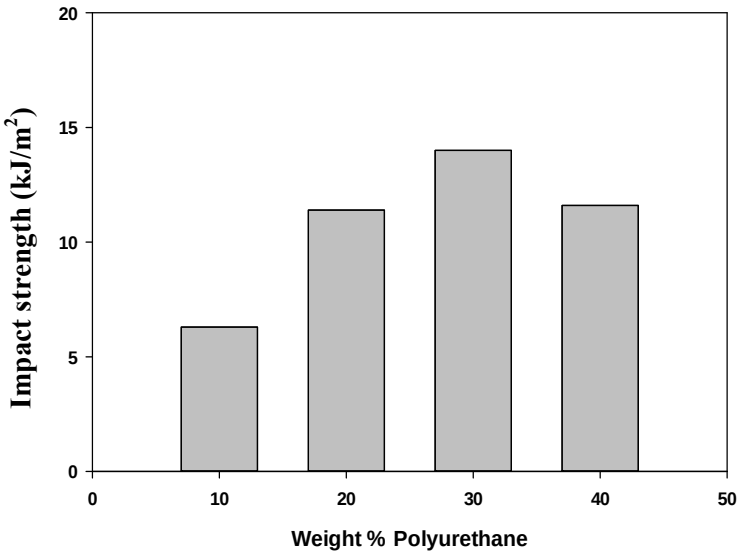

Fig. 1: Impact strength of (EP/PU) blends.

Then nano silica was added to this OMR blend, with a weight fraction (2%), and the impact strength has increased by (6.4%), and Fig. 2 shows that the presence of nano silica enhanced the impact strength to (14.8) Kg/m², compared to wet blend as the nanosilica forms abstacles in the path of fractures, making it more difficult for them to grow, thus the impact strength was increased [10, 11].

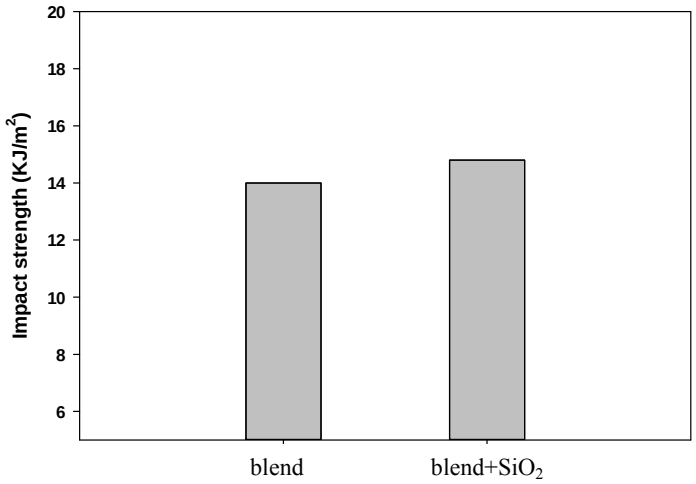

Fig. 2: Impact strength of OMR blend and composite (EP/PU + nano silica).

Fig. 3 shows the change in values of impact strength for OMR nano silicate composite before and after immersion in water; the impact strength has increased in a little increment and this increase can be attributed to the plasticization effect [12].

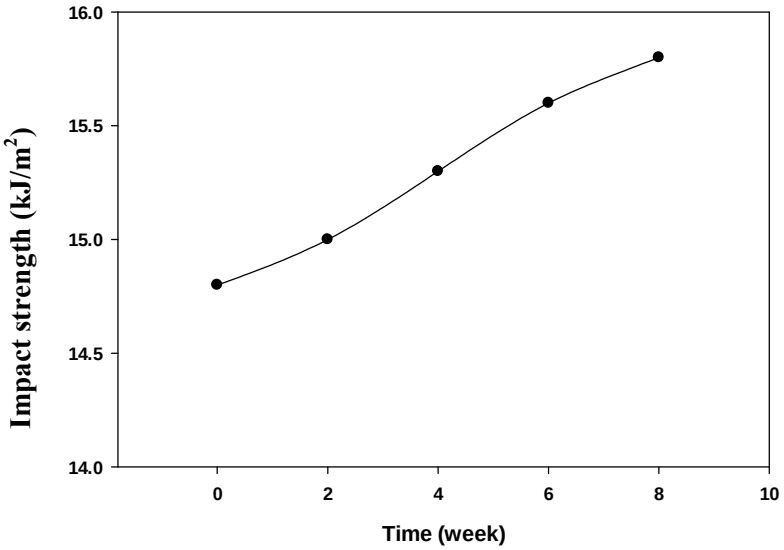

Fig. 3: Impact strength of optimum (EP/PU(70:30) + nano silica) before and after immersion in water.

2. Shore D hardness

The Shore D hardness was studied for all specimens and the results show that water absorption caused a decrease in values of shore D hardness up to 10%, compared with the sample before immersion in water. The hardness was affected by water penetrating into the polymer chain and caused a little degradation leading to the failure of the sample. The diffusion of water causes swelling, which increases free volume to the chain mobility, and the latter facilitates transition transport process [13, 14]. Fig. 4 shows values of shore D hardness of (EP/PU + nano silica) composite before and after immersion in water.

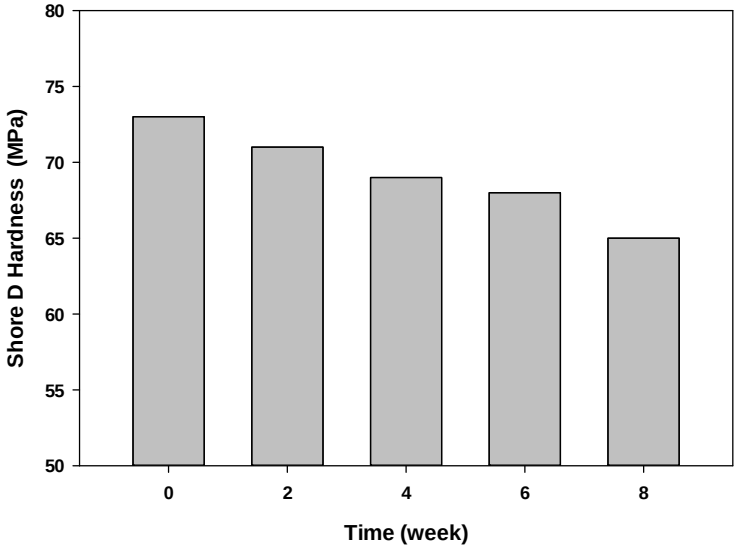

Fig. 4: Shore D hardness of (EP/PU (70:30) + nano silica) before and after immersion in water for 8 weeks.

3. Three-Point Bending Test

Three-point bending test was used to evaluate the flexural strength for samples as shown in Fig. 5, and the test results showed that increasing the time of immersion in water caused a decrease in the values of flexural strength as the diffusion of water caused a micro cavitation and formation of voids, so the distance between the polymer chains is increased, leading to destruction of the interphase region [15].

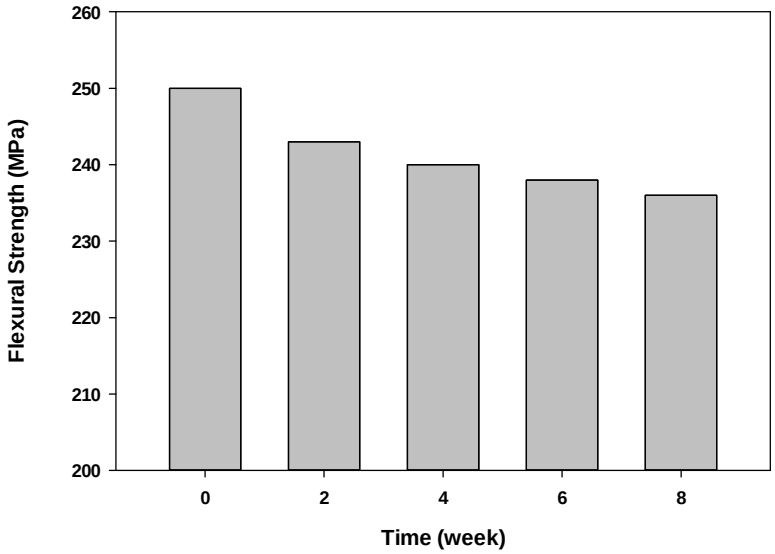

Fig. 5: Flexural strength values for (EP/PU(70:30) + nano silica) before and after immersion in water for 8 weeks.

4. Weight change after immersion in water

Fig. 6 shows the relation between weight gain % for the samples immersed in water for 8 weeks, and it's found that the weight of the specimens increased as the water molecules passes through the polymer and the interphase region between the blend and the reinforcement filler; causing to destroy in the interphase region, then the weight will be

decreased after that due to the degradation, diffusion coefficient (D) was calculated using Eq. (3), and its value is (2×10^{-12} m²/sec).

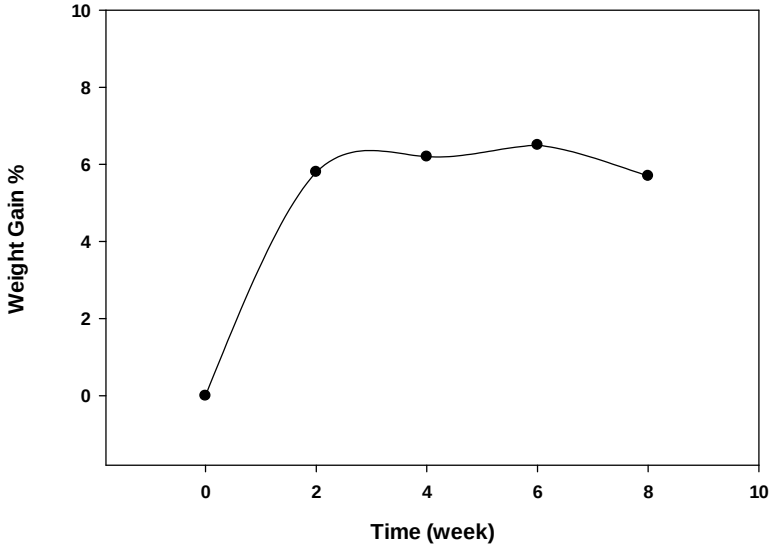

Fig. 6: Weight gain for (EP/PU(70:30)+ nano silica) before and after immersion in water for 8 weeks.

5. Thermal conductivity

Table 2 gives the values of thermal conductivity for the specimens used in this study. It can be noticed that there was a decrease in the values of thermal conductivity (K) after immersion in water for 8 weeks, as the water causes holes inside the material and affects the interphase region between the blend and the nano filler (SiO_2), so the decreasing values of thermal conductivity is due to the increase in the free volume as the water causes to increase the number of holes between the polymer chains so the thermal conductivity decreases [16, 17].

Table 2: Thermal conductivity (K) values W/m.°C before and after immersion in water.

(Ep/PU) + nano silica 2%	Before immersion	2 weeks in water	4 weeks	6 weeks	8 weeks
	0.62	0.58	0.53	0.52	0.5

Table 3 shows the results of all properties before and after reinforcing with nanosilica.

Table 3: Mechanical properties & thermal conductivity of blend and it's nanocomposites (as it is).

Property	Blend	Blend+nanosilica
Impact strength (kJ/m$^{2)}$	14	14.9
Hardness (MPa)	61.5	72.5
Flexural strength (Mpa)	188	250
Thermal conductivity (W/m.°C)	0.68	0.62

Conclusions

Optimum mixing ratio (OMR) of (Epoxy/Polyurethane) blend was (70:30) % weight. All the mechanical properties were increased after addition of nano silica, Water affected

the Impact strength (it was increased), while hardness, bending and thermal conductivity decreases with increasing the time of immersion in water.

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