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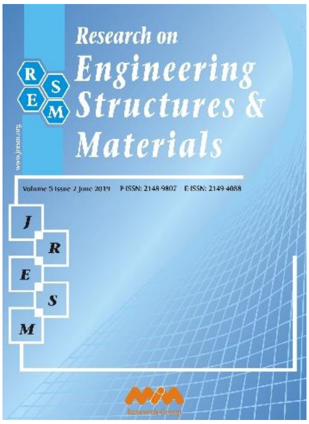

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Research Article

Influence of seawater on mechanical properties of SiO_2-epoxy polymer nanocomposites

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Abstract

In this study, dispersion of nano SiO2 in epoxy composite aged in seawater and its effect on mechanical properties were studied. The SiO2-epoxy polymer nanocomposite materials were kept in seawater for a total of six months to be tested every two months. Tensile and bending tests were applied to composite materials as a mechanical test. According to the mechanical test results, there was less decrease in strength in SiO2-epoxy polymer nanocomposite material compared to unmodified material. In usage of seawater, the mechanical properties were observed to be the best in 3 % added SiO2-epoxy nanocomposite material.

1. Introduction

Epoxy resins are thermoset materials widely used (used widely) in structural and composite materials due to their properties such as high strength, low shrinkage, effective electrical insulation, excellent adhesion, chemical and solvent resistance, low toxicity and low cost. Moreover, it has high hardness, heat and wear resistance (1-3). Also, epoxy resins are generally used as coatings, casting materials, binders and adhesives application (4). The use of nanoparticles is a common method used to improve the strength of epoxy resins. Nanoparticles can enhance interfacial area between fillers and polymer (5). Thus, an increment in performance on the properties of epoxy resin is observed (5, 6). In the literature, boron nitride, CNT (7), nano clay (8), silica (9), graphene (10), nano-Al_2O_3, nano-SiO_2, nano-$CaCO_3$ (11-16) nanoparticles are commonly used to improve composite material properties. For instance, Zhai et al. improved adhesion properties with 2 wt % of nano-Al_2O_3 in epoxy matrix (11). Bauer et al observed that the epoxy's glass transition temperature and viscoelastic properties changed with the addition of nano-sized silica, alumina and titania (12). Zhang et al. introduced different rates of Nano SiO_2 to the epoxy polymer. They increased the toughness of the Epoxy/ SiO_2 composite as a result of impact test (13). Suraj and Raman investigated the effect of nano and micro sized aluminum

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particles in epoxy polymer on fracture toughness. They found that enhancement on(of) fracture toughness and highest values for increase in fracture toughness of epoxy is found for addition of 20 -100 nm aluminum particles (14). Park and Jana achieved to increase the tensile and impact strength of composite materials with nano clay reinforcement (17). It is known that polymeric resins can be influenced by water in marine applications. The interface of filler-polymer or fiber-polymer may weaken when the resin absorbs water (18). Wei et al. examined the effect of seawater on the tensile and bending strength of fiber reinforced composite materials. They observed that these strengths decreased with the effect of seawater (19). Li and Weitsman concentrated on seawater induced damage in composite sandwich structures, gaining weight, expansion strain, and on possible deterioration in the properties of the materials (20). Davies et al. studied on four different thermoset resins and their glass fiber reinforced composite under three immersion conditions (21). In other studies conducted in the literature, it is stated that moisture and salt water absorption directly affects the mechanical, physical and chemical properties of composite materials (20-23).

In this research, the influence of seawater aging on the mechanical performance of epoxy nanocomposites filled with different proportions from 1 wt % to 5 wt % of nano-SiO_2 have been studied for marine application. The nanocomposites were submerged in seawater for up to six months at room temperature for the first time in the literature. The specimens were mechanically examined every two months. Tensile and bending tests were evaluated as mechanical properties according to the related standard methods. The experimental results illustrate that the SiO_2 nanoparticles left a positive influence on the mechanical performance of the nanocomposites in the sea water conditioning.

2. Material and Methods

2.1. Material

The diglycidylether of bisphenol-A (DGEBA) epoxy resin (L160 code) and suitable curing agent (H160 code) supplied by Momentive Hexion Inc. as the commercially available. The SiO_2 nanoparticles, have a specific surface area of 650 m^2/g, was purchased from MKnano Canada Company and average primary particle diameter of 15 nm. It can be seen powder SiO_2 in Fig 1.

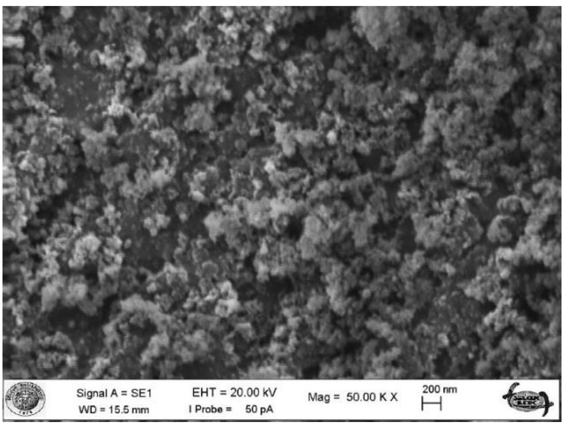


Fig. 1. SEM image of powder SiO_2

2.2. Production of Composites

Nanocomposite materials were manufactured at rates of 1 % to 5 % nano- SiO_2. These ratio values are taken in accordance with the literature (13). Epoxy and powdered nano-SiO_2 were mixed with the ultrasonicator for 30 minutes in the ice bath. After dispersing process curing agent was added in to epoxy and the mixture was degassed at 25 °C and 0.6 bar at approximately 20 min. Steel molds are covered with mold release in Fig 2(a). The epoxy mixture was cast into steel molds. Curing was performed firstly at 80 °C for approximately 1 h, then at 120 °C at approximately 2 h. After that it was slowly cooled to room temperature in the oven. Subsequently, the specimens were removed from the steel molds in Fig 2(b). All samples conventionally polished with SiC sandpapers with grit numbers of 800 to minimize effect stress concentration caused by sharp edges. The produced composite materials were transported to seawater environment and kept in seawater for 6 months.

(a) (b)

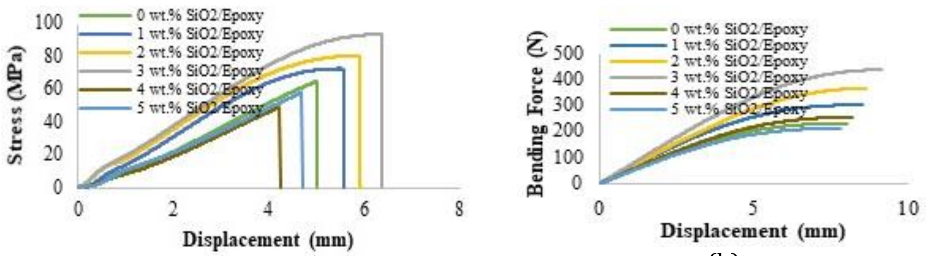
Fig. 2 a) Steel mold b) Test specimens

2.3. Test procedure

Bending and tensile tests were performed as a mechanical test in the study. The ASTM D7264/ D7264M-07 standards were used for the bending test and the ASTM D4762 - 11a standards for the tensile test, respectively. The specimens were tested every two months. Shimadzu test machine which has 1 kN load cell was used for mechanical test. Tensile tests were carried out with 2 mm·min^{-1} tensile speed and bending tests were performed under 1 mm·min^{-1}.

3. Results and Discussions

In a previous study, we conducted that stress-displacement curves of different proportions of nano SiO_2 containing epoxy composites are shown for dry conditions in Fig. 3. It can be seen highest enhancement of the tensile strength and bending force is achieved with the 3 wt. nano % SiO_2 adding in Fig. 3 (a) and (b), respectively. Furthermore, mechanical properties of 1 wt. % and 2 wt. % epoxy/SiO_2 added nanocomposite are also increased. However, these figures shows that the tensile and bending properties are getting worse at 4 and 5 wt. % nano SiO_2 addition. We know that tensile properties decrease occurs due to the agglomerations of nano SiO_2 (24). Then, the composite specimens, aged under sea water condition, were tested every two months. Fig. 4 illustrated that curves of tensile and bending tests for SiO_2/Epoxy nanocomposite in seawater condition. It is clear that the all of composite specimens are negatively affected by sea water when the tensile strength and bending force are examined. In addition, it is seen that nano reinforced composites are less effected than 0 wt. % epoxy/SiO_2. According to all curves, reinforcement of 3 wt. % SiO_2/Epoxy has better mechanical performance than the other proportions. In the end of 6th month, we did not get any results for bending test, due to excessive displacement in the nanocomposites.

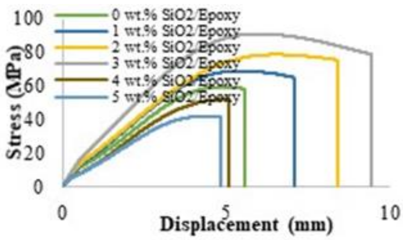


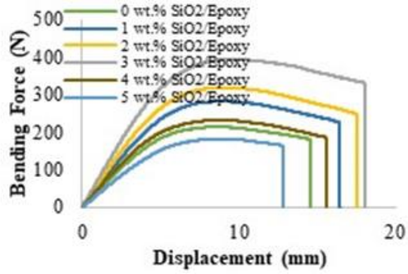
(a) (b)

Fig 3. (a) Tensile curve (b) Bending curve in dry condition (24)

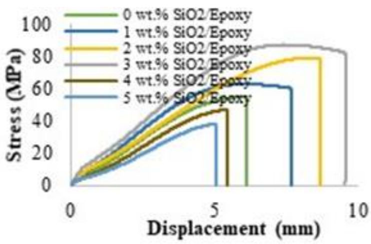
Tensile Test Curves | Bending Test Curves

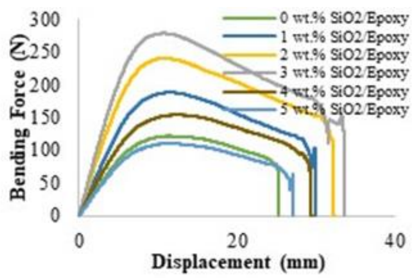
End of 2nd month





End of 4th month





End of 6th month

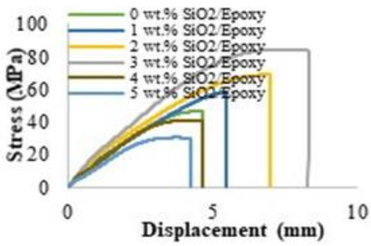


Fig 4. Tensile and Bending Curves in sea water condition for SiO_2/Epoxy nanocomposite

The nano-SiO_2 particles incorporated into the epoxy polymer have caused absorbing or deflection of the cracking in the matrix. The cracks in the epoxy have compelled to break and debonding the nano-SiO_2 particles. Since the composite needs more energy to achieve this event, the tensile strength and bending force values of the nanocomposite specimens are higher than neat composites. Fig. 5 gives an information about toughening mechanisms of nanocomposite materials such as crack deflection and particle debonding. The reduction of tensile strength and bending force in high proportions of nano-SiO_2 such as 4 and 5 wt. % is caused by the agglomeration of the particles. Fig. 6 demonstrates agglomeration of the SiO_2 nanoparticles in epoxy nanocomposites.

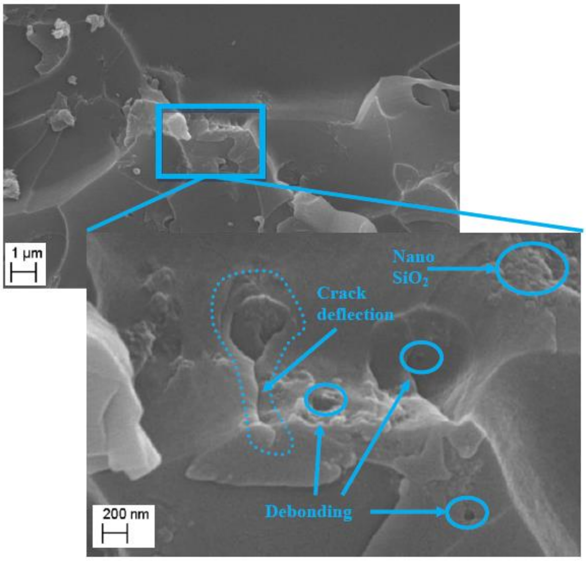


Fig 5. 3 wt. % SiO2/Epoxy Nanocomposite (24)

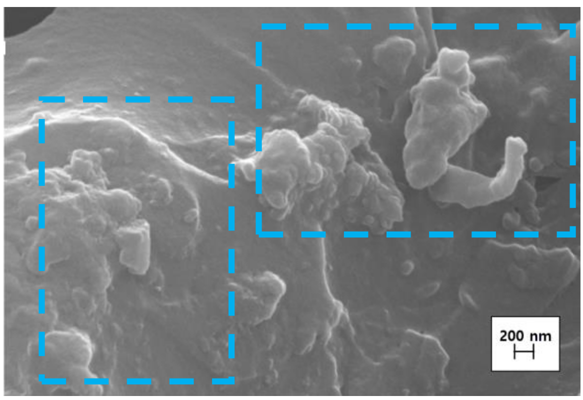


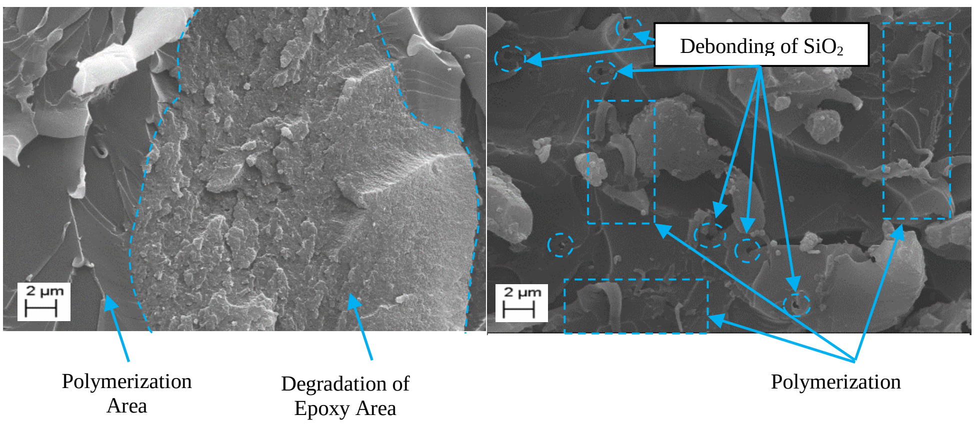
Fig 6. 5 wt. % SiO2/Epoxy Nanocomposite (24)

Compared to 0 wt. % SiO_2/Epoxy composite, the mechanical properties of 3 wt. % SiO_2/Epoxy nanocomposite are presented in Table 1. Although SiO_2 nanoparticles are enhanced the performance of tensile strength and load bending capacity in dry condition, the particles cannot be prevented decrement of these mechanical performances after aging due to the detrimental effect of the absorbed seawater. Nevertheless, SiO_2 nanoparticles are succeeded in delaying the damage mechanisms when the numerical results in Table 1 are considered.

Table 1. Results of mechanical test for 0 wt.% and 3 wt.% SiO_2/Epoxy nanocomposite.

Mechanical Properties	**Condition**				**Nanocomposites**
	Dry	**Sea water** 2nd	**Sea water** 4th	**Sea water** 6th	
Tensile Strength (MPa)	65.2	59.4	54.9	46.7	0 wt.% SiO_2/Epoxy
	93.9	90.8	87.4	84.4	3 wt.% SiO_2/Epoxy
Bending Force (N)	233	213.5	121.2	-	0 wt.% SiO_2/Epoxy
	438.5	393.7	277.9	-	3 wt.% SiO_2/Epoxy

The mechanical properties of the composite specimens under the seawater effect are reduced in Fig. 3 and Fig. 4. In addition to the reduced load carrying capacities under the influence of seawater, the displacements under stress are increased in both of composites. In composite specimens immersed in seawater, the absorbed water interacts chemically with the epoxy polymer by way of Van der Waals and hydrogen bonds. This chain mobility causes polymerization and reducing mechanical strength for tensile and bending in the composite material (25). The minimum reducing mechanical strength is obtained for nanocomposite specimens. The fracture surfaces of tested specimens were observed by Scanning Electron Microscope (SEM) for 0 wt. % epoxy/SiO_2 composite and 3 wt. % epoxy/ SiO_2 nanocomposite in Fig. 7. Polymerization and degradation areas of 0 wt. % epoxy/ SiO_2 composite in seawater condition are shown in Fig. 7(a). Besides, strengthening mechanism of the 3 wt. % epoxy/ SiO_2 nanocomposite are seen in Fig. 7(b). Larger polymerization areas in composite material are seen compared to the nanocomposite material. Nano- SiO_2 particle debonding in fracture surface is ensured that nanocomposite is swallowed more energy and is increased its strength.



(a) (b)

Fig. 7 SEM images of fracture surface (a) 0 wt. % epoxy/SiO_2 composite (b) 3 wt. % epoxy/SiO_2 nanocomposite

3. Conclusion

Consequently, the studies on the mechanical properties show that the reinforcement of SiO_2 nanoparticles in the epoxy matrix polymer has significant positive or negative influences on nanocomposites for both of dry and seawater conditions. From the results of this study, the following conclusions can be drawn:

- High proportions of SiO_2 nanoparticles (e.g. 4-5 wt. %) have shown weak performance in load capacity due to agglomeration of particles.
- The other proportions of SiO_2 nanoparticles in epoxy matrix polymer are demonstrated superior properties in both of condition.
- According to result of mechanical test, sea water absorption is weaken both tensile strength and bending force. But, SiO_2 added nanocomposites are less affected after aging than the others.
- At the end of the sixth month of bending test results, a displacement exceeding the device capacity has occurred.
- The reducing mechanical strength is fewest for 3 wt. % epoxy/SiO_2 in seawater condition.

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