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Mechanical Properties Investigation of Glass/Fiber Reinforced Vinyl Ester/Clay Nanocomposites Fabricated by Vacuum Bag Molding

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Abstract: This research studies the mechanical properties of two-component and multi-component nanocomposites made by vacuum bag molding. In this study, vinyl ester as a thermoset resin is selected as matrix. Vinyl Ester Resin has been widely used in industries because of its good mechanical and physical properties. In recent years, the mechanical, physical and chemical properties of thermoset resins have been improved with the proper distribution of nanofillers in these resins. Accordingly, at first, the montmorillonite nanoclays are dispersed in the Vinyl Ester Resin with different weight percentages and the mechanical properties of the resulting nanocomposites areexamined. In the next step of this study, the resin containing nanofillers is added to the glass fibers using the vacuum bag method. Finally, the tensile and three-point bending tests are conducted on the standard specimens. Improvement of the mechanical properties of multi-component nanocomposites compared to the primary composite is one of the important findings of the research which can be used in industrial applications.

Key words: Vacuum bag method, glass/fiber composite, nanocomposite, mechanical properties, nanoclay

INTRODUCTION

Todays in many engineering applications, it is necessary to combine the properties of materials and there is no possibility of using a type of material that meets all desired properties. The composite is a multi-component material whose properties are greater than each of its components. So, the various components improve each other's efficiency. With the above definition, composites have been considered by humans since ancient times. Composites have prominent mechanical properties and have a good design flexibility and are relatively easy to fabricate. Composites are light weight, corrosion-resistant, impact-resistant and durable materials with excellent fatigue strength and can be converted into a product or piece in various ways (Brauer, 2004; Elahinia *et al*., 2015).

Most of the composite products are made by hand lay-up method which also known as open-mold method. Hand lay-up and resin spraying methods are the traditional methods of composite construction. Due to the high consumption of resin in these methods, the contamination caused by the resin evaporation is high and this causes pollution of the workshop environment and endangers the health of workers. Also, the high consumption of resin results in a high weight percentage of resin which in turn results in lower strength of the product. For this reason, closed mold methods were proposed and designed to end the problems and drawbacks of traditional methods (Brouwer *et al*., 2003). Several investigations have been conducted on silicate nanocomposites of silicate layers but studies on vinyl Ester Resin nanocomposites have been limited (Hammami and Gebart, 2000; Kunchur *et al*., 2015). Vinyl Ester Resin are of particular interest because of their close proximity to epoxies as well as the simple processability of polyester resins. The properties of Vinyl Ester Resin depend on vinyl end groups, viscosity, reactivity, molecular type and molecular weight of the resin complex (Rousseaux *et al*., 2010). Vinyl Ester Resin are useful due to its excellent chemical resistance, thermal stability, high impact resistance, good toughness, flexibility in design and easy use in composite components such as pipes, wires, wash towers and storage tanks in various oil and agricultural, marine, mining and food industries (Rodriguez *et al*., 2014).

Polymer nanocomposites are a series of materials in which nanoparticles with one-dimensional, spherical or polygonal structures are dispersed in the polymer bed. In comparison with pure polymers, polymeric nanocomposites have different physical and mechanical properties including modulus, strength, hardness, electrical conductivity, thermal resistance, moisture absorption and spray ability according to the type and amount of used nanoparticles (Jowdar *et al*., 2011;

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Soon *et al*., 2012; Kunchur *et al*., 2013). Yasmin *et al*. (2003) scattered nano-layers of clay in an epoxy matrix with shear mixing method. By adding 10 wt.% of nanoclay, an increase of 80% in the nano-epoxy elastic modulus was observed, although, the tensile strength of the material showed no considerable change. Chowdhury *et al*. (2006) studied the effect of nanoclay on the mechanical properties of carbonfiber/epoxy composite with woven fibers. They observed the most improvement in properties with 2 wt.% of nanoclay. Also, Ho *et al*. (2006) showed that with the dispersion of nanoclay in the epoxy matrix with different percentages, the highest ultimate tensile strength observes in the sample with 5 wt.% of nanoclay. However, the ductility of the material drops sharply and the sample suddenly breaks out after the ultimate stress. Siddiquia *et al*. (2007) investigated the properties of nanocomposites of carbon/epoxy-reinforced with nano-clay particles. They showed that with 3 wt.% of nanomaterial, the flexural modulus and toughness of statically-like fractures increases by 26 and 60%, respectively while the impact fracture toughness decreases significantly only by adding 1% nanoclay. Tahmassebpour and Otaghvari (2016) showed that with adding nanoclay up to 5 wt.% to glass/epoxy composite materials, the tensile strength, elastic modulus, strength and flexural modulus were improved. However by adding nano-clay >5%, the aforementioned properties were reduced. Pol *et al*. (2014) considered the effect of adding clay nanoparticles on the ballistic resistance of glass/epoxy composites. The results of their experiments exhibited that the highest energy absorption occurs in the composite material containing 3 wt.% of nanoclay and at the near-ballistic speed. Seyedhossein *et al*. (2016) studied the effect of adding nanoparticles of clayon the tensile and flexural strength of the epoxy resin. Their results showed that the tensile and flexural modulus as well as the flexural strength of the epoxy resin improve with the addition of the clay nanoparticles. Hosseini and Pol (2014) added clay nanoparticles to multilayered glass/epoxy composites made by vacuum-assisted resin transfer molding and showed that the highest increase in the tensile and flexural properties happens with 3 and 7 wt.% of nanoclays.

MATERIALS AND METHODS

The fibers used in this research aremade by the Mety x Corporation of Turkey. These fibers are 3-directional and are visible in Fig. 1. Also, the X and Y directions are depicted to be denoted in the tensile and flexural tests.

Fig. 1: The directions of X and Y in 3-directional glass fibers

Montmorillonite nano-sheets of clay used in this research are from sigma aldrich company in Germany and branded as MMT-K10. The thickness of a sheet of nanoclay is 1 nm and the nano-sheet dimensions are about 100 nm. The maximum distance between 2 sheets is 30 Angstroms or 3 nm. Vinyl Ester Resin is used as the composite matrix.

In this research, 5 plates made of clay nanocomposites with different percentages of 0, 1, 3, 5 and 7 are fabricated. After determining the best nanocomposite in terms of improved properties based on the results of the tensile test, the three-component composite is made of vinyl ester/glass fiber/nano-clay.

The vacuum bag molding method is one of the methods for producing composites. The parts produced by this method are of better quality than those produced by hand lay-up method. This improvement is due to the reduction of trapped air in the pieces produced by vacuum bag molding method. In the vacuum bag method, the vacuum is applied on the pieces until fullcuring. In this method, the volume fraction of fiber is more than the hand lay-up method. In this part of the research, 4 composites/nanocomposites of Vinyl Ester/fiber glass/nanoclay with weight percentages of 0, 0.25, 1 and 3 are fabricated using the vacuum bag method. Figure 2 shows the composite made by vacuum bag method. In the beginning, the mold is coated with a layer of separator material and the edges of part are sealed by the sealant tape. Then, 7 layers of glass fiber with 25×25 cm are cut and placed in front of each other. The outlet is connected to the vacuum pump and the sealant tape is used to fix the outlet of the mold. Afterwards, 15 g of nanoclayis added to 500 g of Vinyl Ester Resin while they are mixed with a

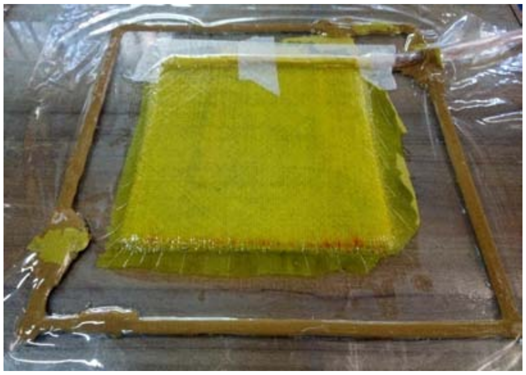

Fig. 2: Composite made by vacuum bag method

mechanical stirrer for 30 min. Then, the resin and nanoparticles are placed in the ultrasonic apparatus surrounding with water-ice bath. The distribution process is stopped every minute for 30 sec to prevent overheating of the resin. After the dispersion process, the resin containing the clay nanoparticles are mixed with the hardener. Consequently, using the brush, the layers of fibersare impregnated with the resin andthe additional resins as well as the trapped air between the layers of fibers and resinare removed by using rollers. At this stage, the bag is placed on the part and after ensuring that there is no air leak, the vacuum pump is used. After 24 h, the part is separated from the mold surface and is placed inside the oven for post curing. Eventually, the samples are trimmed from the fabricated part in order to perform the tests.

RESULTS AND DISCUSSION

In this study, the ASTM D 3039 standard is used for the composite tensile test. The specimens have dimensions of 120×15 mm according to the standard instruction for 3-directional composite specimens (Fig. 3).

The standard used in this research for the flexural bending of specimens is ISO 178. According to this standard, the length is 80 mm and the width is 10 mm. This standard does not consider any difference between thetypes of the material. Therefore, the composite and polymer parts are tested with equal dimensions. In Fig. 4, a specimen for the flexural bending test is depicted.

In the next part, the results of the standard experiments including tensile and flexural bending tests are reported. To ensure the validity and reliability of the observed results, each sample is tested 3 times and the results are presented as an average of those values. The maximum standard deviation is accepted to be 5%. Otherwise, the test is performed again and the new results are reported.

Fig. 3: Aspecimen for composite tensile test with dimensions of 120×15 mm

Fig. 4: A composite specimen forflexural bending test

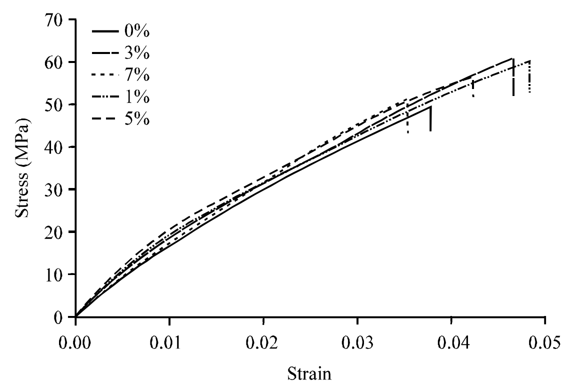

Fig. 5: Stress-strain of 5 various weight percent of clay nanocomposite

As mentioned before 4 different weight percentages of clay/nanocomposites are considered for the tensile test. The results of the test are compared with those of Vinyl Ester Resin and presented in the form of stress-strain diagram. Figure 5 shows the stress-strain graph of nanocomposites containing 0, 1, 3, 5 and 7 wt.% of nanoclay.

By studying the stress-strain curve of clay/nanocomposite, it is found that the optimum weight percentage of clay to make the nanocomposite with the highest ultimate strength is with 3 wt.% of nanoclay. The ultimate strength level of this nanocomposite is 61.8 MPa which exhibits an increase of 23.8% compared to the Vinyl Ester Resin. Beyond the nanocomposite containing 3 wt.% of nanoclay, increasing the weight percentage of nanoparticles leads to decreasing of the tensile strength. This reductionis due to the agglomeration of nanoparticles. The highest fracture strain is observed in the nanocomposites with 1 wt.% of nanoclay. The

Fig. 6: Clay/nanocomposite during the tensile test

observed increase in the tensile strength of nanocomposite against the pure polymer is due to the mechanism of transferring some parts of the applied force to the nano-phase. The transfer of force from the resin as polymer matrix to the nanoparticles requires that the nanoparticles have a proper chemical bond with the polymer and also the nanoparticles in the resin bed are well distributed. Figure 6 shows the clay/nanocomposite specimen during the tensile test.

At the next stage, three-component nanocomposites containing vinyl ester/fiber glass/nano-clay are fabricated using the same procedure as explained before. After that, the tensile test is performed and the obtained results areshownin the strain-strain diagram as depicted in Fig. 7. To compare and evaluate the effect of clay nanoparticles on the glass/fiber composite, the diagram of two-component composite made by vacuum bag method is also drawn. Initially, the tensile test is done in the X direction.

According to the stress-strain diagram, adding 0.25 wt.% of nanoclay to the glass/fiber composite, the ultimate strength is increased by amount of 4.6 MPa compared to the glass/fiber composite. However, by adding 1 wt.% of nanoclay we observed 17.1 MPa increase in comparison with the two-component

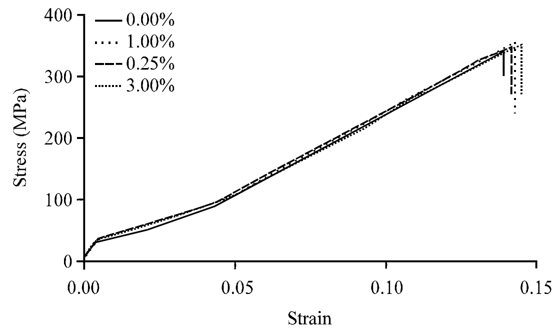

Fig. 7: Stress-strain diagram of three-component nanocomposite in the X direction

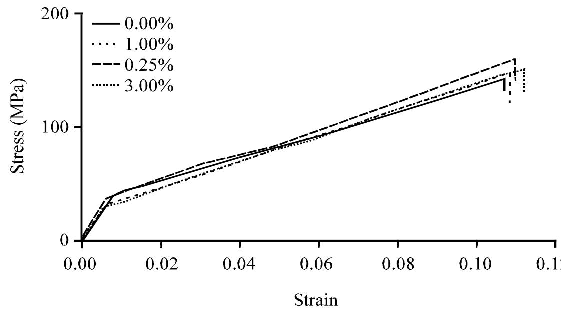

Fig. 8: Stress-strain diagram of three-component nanocomposite in the Y direction

composite. The ultimate tensile strength of the 3 component composite containing 1 wt.% of nanoclay is 419.5 MPa which is 4.4 MPa higher than nanocomposites with 0.25 wt.%. Accordingly, the tensile test is repeated in the Y direction as can be seen in Fig. 8.

According to the diagram in the Y direction, the highest stress is related to the three-component nanocomposite containing 1 wt.% of nanoclay. The ultimate tensile strength of this composite is 157 MPa. It is seen that the tensile strength of the nanocomposite with 3% of nanoclay is 6 MPa lower than the former one. The reason for the reduction of the strength is due to the poor bonding of nanoparticles and formation of agglomeration in the higher weight percentages. It is interesting that just by adding 1 wt.% of nanoclay yields to an increase of 10% for this mechanical property compared to the two-component composite in the Y direction.

At the final stage, the flexural test is performed by standard three-point bending test. The higher support is moved downward at a constant predetermined speed. In Fig. 9, the nanocomposite under the flexural bending test is demonstrated.

Fig. 9: Nanocomposite under the flexural bending test

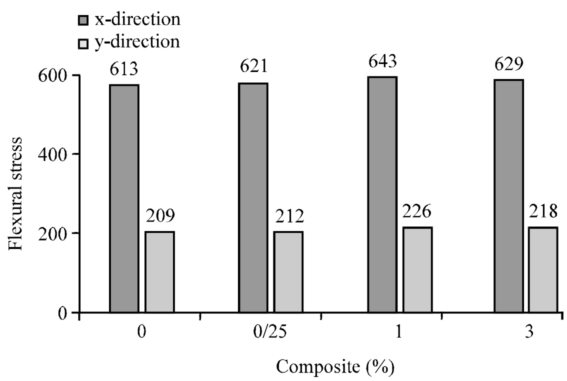

Fig. 10: Flexural strength of three-component nanocomposite in the directions of X and Y

After trimming the standard specimens from the 3 component nanocomposite, the flexural test is performed in two directions of X and Y. Meanwhile, the highest flexural strengths of nanocomposite samples in MPa are compared with each other considering different weight percentages of nanoclays. The results of this test are show in Fig. 10.

It can be concluded that by adding nanoclay fillers as a two-dimensional nanoparticle to a glass/fiber composite, the amount of flexural strength is increased. The optimum amount of clay nanoparticles to enhance the flexural strength is seen again with 1 wt.%. In this case, the flexural strength in the X direction increases to 643 MPa. Also, we observe an amount of 17 MPa increase in theflexural strength in the Y direction compared to the 2 component composite. On the other hand by adding 3 wt.% of nanoclay to the two-component composite, the flexural strength decreases to 629 MPa inthe X direction. Additionally, the flexural strength reduces by 8 MPa in the Y direction compared to the nanocomposite containing 1 wt.% of nanoclay.

CONCLUSION

In this study, clay nanocomposite was initially made with a vinyl ester and different weight percentages using the vacuum bag molding. Then, the tensile test was carried out on the nanocomposites. The results showed the optimum weight percentage of nanoparticles for improving tensile properties. Employing the same fabrication process, three-component nanocomposites containing vinyl ester/fiber glass/nanoclay are made with different weight percentages of clay nanofillers. Different standard texts including tensile and three-point bending experiments are performed on the prepared standard specimens. Eventually, the improved mechanical properties for each sample and test were reported. In clay nanocomposites, the ultimate strength was observed in the nanocomposite containing 3 wt.% of nanoclay which exhibitedstrength of 61.8 MPa. For the case of three-component nanocomposites, the highest ultimate strengths were seen with the 1 wt.% of nanoclays in both the X and Y directions. The amount of stress obtained at the fracture point in the X direction was 419.5 MPa while this value was equal to 157 MPa in the Y direction. Meanwhile, the highest improvement in the flexural strength of the 3 component clay/nanocomposites was determined in weight percentage of 1% for the both directions.

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