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IMPROVEMENT OF MECHANICAL BEHAVIOUR OF WIND TURBINE BLADE USING NANOFLUID-GRAPHENE AND/OR GLASS FIBER IN EPOXY RESIN

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ABSTRACT

Extraordinary properties of composite materials have made them center of extensive researches. By blending nanofluids with conventional reinforced materials, composites with superior properties are produced than ordinary composites. In this experimentally based study, it is focused on the improvement of nanocomposites using graphene particles in epoxy resin. Additionally, it is aimed to improve nanocomposites by using glass fiber and graphene reinforced epoxy resin. For this purpose, 0.4 mg/mL and 0.8 mg/mL graphene oxide nanoparticles were added to the epoxy resin fluid and graphene oxide with same rates and glass fiber nanoparticles were added to the epoxy system. After the manufacturing process, longitudinal and transverse tensile, longitudinal and transverse compression and three-point bending tests were performed. By considering this twofold influence, the mechanical properties of graphene/epoxy resin were higher than epoxy resin. According to the obtained experimental data, it was found that the tensile and bending strengths of the graphene reinforced epoxy nanocomposites increased and the graphene improves the epoxy-based composite's mechanical properties.

Keywords: *Nanofluid, graphene, epoxy resin, wind turbine blade, mechanical property.*

INTRODUCTION

The resources such as fossil fuels which are non-sustainable and non-renewable are being run out worldwide because of ongoing consumptions. Therefore, technologies for renewable energy applications have been increased. About the desired plans in terms of energy requirements, The European Union claims that one in five of its renewable energy requirements is met [1]. Furthermore, more environmental concerns about the harmful consequences of global warming and carbon emissions have been creating new demand for renewable and sustainable sources of energy such as wind, solar, biomass, and geothermal energy in recent years [1-3]. In the last two decades, the wind energy industry has undergone considerably rapid growth with its energy cost reductions [4]. Like thinking of the European Union, Turkey should follow an equal policy with a population of 80 million to avoid a shortage of fossil fuels, which shortly will be a major problem. Turkey has commonly available renewable energy forms, including wind energy, bioenergy, solar energy, hydro energy, etc. Among them, energy harvesting from wind turbines in Turkey has been increasing day by day [4]. Turkey has begun to play an important role in worldwide on wind power production owing to its huge wind capacity. As seen in Figure 1, the energy harvesting from 3155 wind turbines reached 7615 MW wind power [4]. The high viability of wind energy generation projects in Turkey was also indicated in Figure 1. Technological changes made the efficiency of wind energy conversion systems to increase. For more efficiency at wind energy, aerodynamic researchers do many types of studies on how to improve the aerodynamic performance of a wind turbine blade [5-12].

Besides aerodynamic improvement studies, studies on blade design and its materials should be also carried out to increase blade strength and reduce damage on the blade. There are many wind damage opportunities turbine applications such as bird strikes, surface wear (Figure 2) [13]. Among these, mechanical breakdowns caused 55.9% of the damages. The decrease in mechanical failures will improve the life of wind turbines and allow more energy to be collected. So, the costs for maintenance or replacement will also be decreased.

Composites are commonly used in energy, aerospace, marine, and automotive structures because they simplify the design of highly lightweight, durable, and strength laminated structures depending on the application range [14, 15]. This material generally refers to the combination of a plurality of materials having different physical and chemical properties, resulting in the emergence of a new material having completely different properties. Each composite material usually has two types of material which are named as matrices and reinforcing materials. The

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reinforcement acts as a carrier, whereas the surrounding matrix phase serves to hold and support it together. Composite materials which have a very dynamic structure have an increase in utilization area at a wide range with the development of technology.

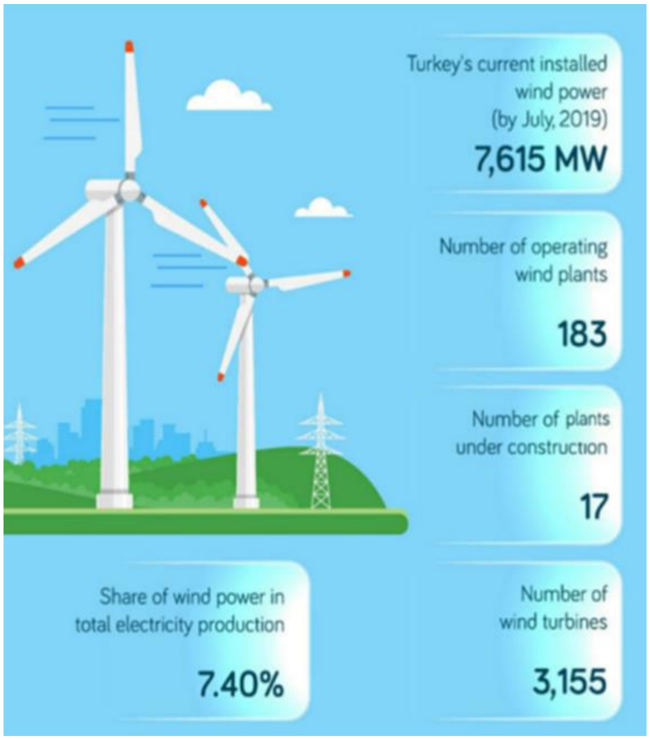

Figure 1. Wind energy capacity of Turkey [4]

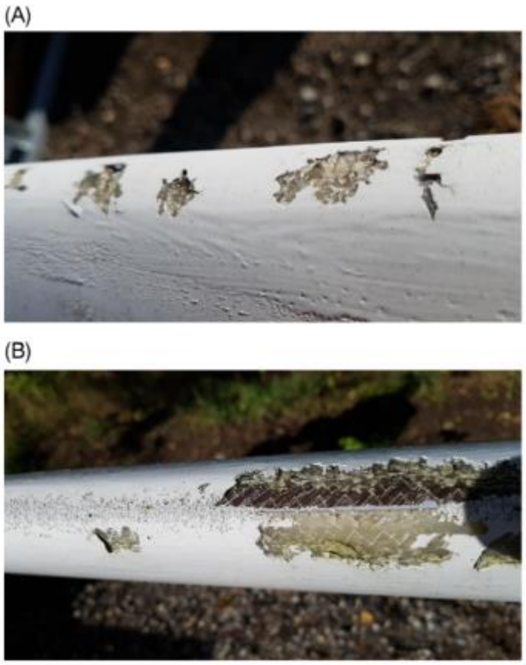

Figure 2. Leading-edge of a wind turbine blade with erosion A) initiation case, B) developed stage [10]

In terms of wind energy, with the rapid development of technology, the sub-standards of the turbines produced by all companies in the sector have increased. Design, material, and production style of blades have gained importance as an important element. Nowadays, significant investments are made in engineering applications since it is accepted that wind turbine blades have a significant effect on turbine efficiency. Technology and continuous developments/changes are also experienced. The greatest expectations from wind turbine blades are as follows: (*i*) long-term durability, (*ii*) aerodynamically contributing to the turbine's energy efficiency, (*iii*) integrity and consistency of surface against any outside influences. All studies and experiments were conducted to provide these characteristics. It has been seen that the production of wind turbines blades with composite technology is the most appropriate method and it is supported by the development of the materials used day by day [16].

In previous studies, there are not many studies in the literature, especially on graphene-glass fiber. However, there are studies on graphene. Xie et al. [17] investigated the effects of composites on the mechanical properties and fracture morphologies by adding Graphene to epoxy nanocomposites. The results show that the stress and modulus of graphene/epoxy composites first increase and then decrease with increasing graphene addition, and when the content of the graphene load reaches 0.1%, the tensile strength reaches the highest value of 60.9 MPa. Subaşı vet al. [18] have investigated changes in the mechanical and thermal properties of nanocomposites resulting from the incorporation of nanomaterials such as graphene, graphite oxide, and graphite into the polyester matrix, a polymer matrix composite. As a result of the literature research, it has been observed that the mechanical and thermal properties of polyester matrix composites using nanomaterials such as graphene, graphite oxide, and graphite have significantly improved between 0.05 and 3% by weight.

In this study, the aim is to improve the properties of the composite material using graphene particles and glass fiber in epoxy resin. The results of longitudinal and transverse tensile, longitudinal and transverse compression and three point bending tests are presented to show mechanical properties of the epoxy resins.

MATERIALS AND METHODS

Epoxy Resin

Thermoset resins in polymer structure are generally used in the production of wind turbine blades as a composite structure. Epoxy resins are especially preferred for their volumetric tensile strength and dimensional stability values compared to other thermoset resins. Epoxy resins are primarily used in the production of high-performance composite products as superior mechanical properties, resistance to corrosive liquids and environments, superior electrical properties, high-temperature resistance, or a combination of these values. Epoxy resins are mixed with a hardener in appropriate proportions before they are combined with reinforcing materials to form any composite element. These curing chemicals, called as hardeners, are substances such as polyamine, polyamide, polysulfide, and acid [19]. The mechanical properties of some thermoset polymers are shown in Table 1.

Table 1. Mechanical properties of thermoset polymers [14]

Properties	Polyester	Epoxy	Silicon
Stress (MPa)	42~71	~ 85	21~49
Bending (MPa)	60~120	~130	~ 69
Strain failure (%)	5	5	1
Density (kg/cm^3)	1.10~1.46	1.11~1.23	1.70~1.90

Epoxies have high electrical, heat resistance, chemical resistance, and mechanical properties. In addition to hardness, flexibility, and impact resistance, high bond strength and protection against corrosion are the prominent features of epoxies [20].

The density of the epoxy is between 1.12-1.40 g/cm3. It shows a tensile strength of 280 MPa when it is used alone due to its mechanical properties. The electrical insulation resistance is very high and the dispersion factor is very low [20].

Glass fiber

As reinforcements, fabrics obtained by weaving yarns consisting of versatile glass or carbon fibers are generally used. Figure 3 contains an enlarged view of glass and carbon fibers. The most obvious differences between glass materials and carbon materials can be explained as follows: (*i*) the lightness and high strength of carbon fibers, (*ii*) the cheaper and widespread use of glass fabrics, (*iii*) the higher electrical conductivity of carbon, (*iv*) easier traceability of glass fabrics in infusion and hand lay-up applications.

The use of fabrics woven from glass or carbon threads has carried considerable advantages in terms of processing. In addition to this, with the technological advancement of weaving machines, the transition from the weaving of yarns on one axis to multi-axis weaving was made. In particular, this has extended the movement areas of the blade designers and enabled the use of different fabrics according to the calculation of the load distributions coming to the blade [19].

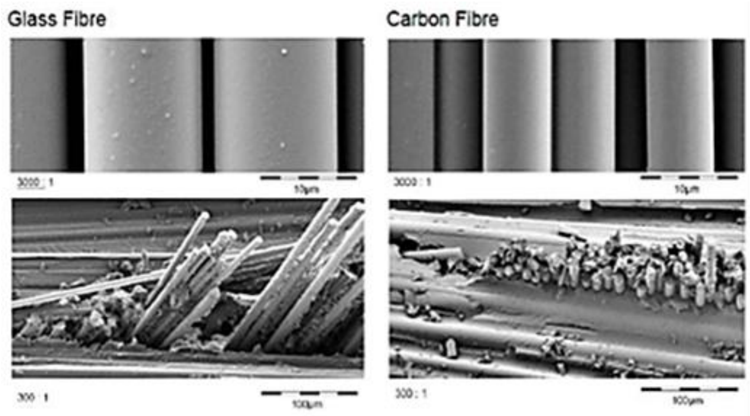

Figure 3. Enlarged view of glass and carbon fibers in free and composite structure [19]

Graphene

Nowadays, the development of nanoparticle reinforced composites is the most widely used field in material science and engineering applications. The extraordinary properties of nanoparticles have made them the center of extensive research. In order to increase the mechanical and thermal properties of polymers, some fillers have traditionally been used for years. These fillers are powder, glass fiber, carbon black, silicates, and calcium carbonates. In recent years, nanoparticles smaller than 100nm have been preferred as fillers because nanoparticles can improve the physicomechanical properties of composites to a much greater extent. Since graphene is a nano-sized material (2-20nm), they improve material properties much better than other fillers. Graphene is quite different from carbon nanotube and fullerene and has extraordinary properties as shown in Figure 4 [21]

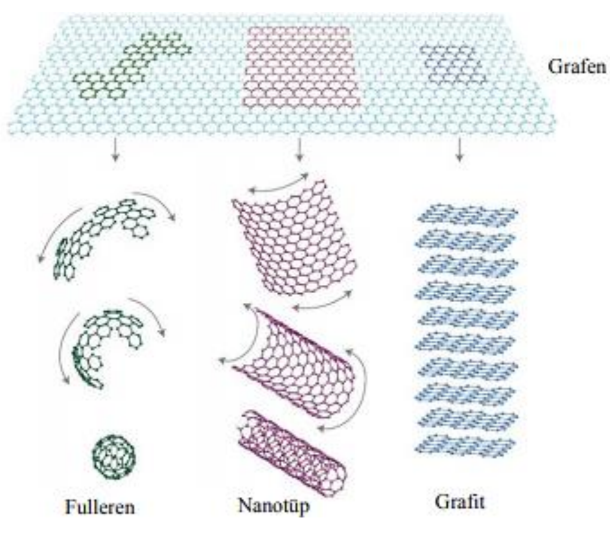

Figure 4. Carbon-based materials [21]

The ideal graphene structure is a monolayer. However, structures with several layers are equally important. Ideally, the estimated surface area of monolayer graphene is 2600 m2/g, thickness 1-2 nm, thermal conductivity 4840-5300 W / (m K), actual density 2.25 g/cm3, modulus of elasticity 1 TPa. [22].

Preparation of mold and samples

As a composite material production technique, many methods are used by researchers like vacuum infusion, filament winding, etc. In this study, the lay-up method with a mold as a composite material production technique was preferred, because this technique is being used for both small and medium-sized composites at a very low cost [23].

In order to determine mechanical properties of the composite materials produced, it is necessary to calculate the values obtained at the end of the mechanical tests. Samples were produced based on the composite standard of each mechanical test, which enabled a better and easier comparison of similar studies.

Epoxy resin and hardener products were used for the first pure sample. Epoxy material and hardener were the most suitable material for the selected production method. Before adjusting the thickness of the material to be molding, trial molding was made, and the epoxy-hardener mixture ratios were adjusted. The epoxy-hardener ratio was adjusted as 10: 4 and a totally of 9.45 g and poured into the molds. After molding, it was stripped with the help of a teflon plate and left to dry. It took 12 hours for the epoxy-hardener to cure fully. The product photo was shown in Figure 5.

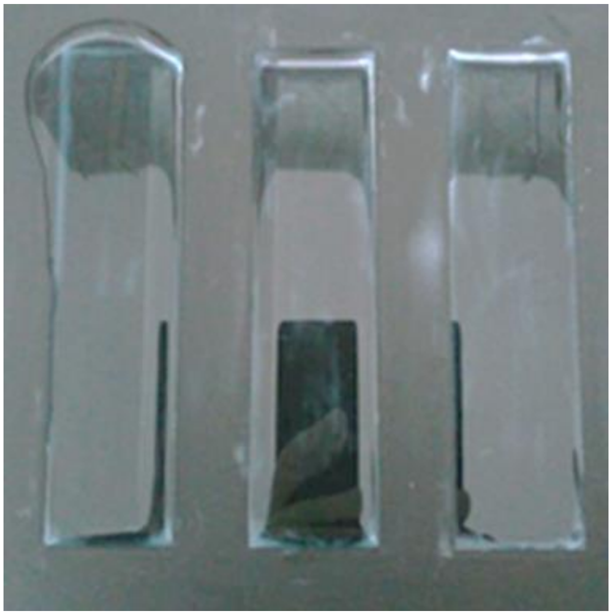

Figure 5. The epoxy-hardener pure sample

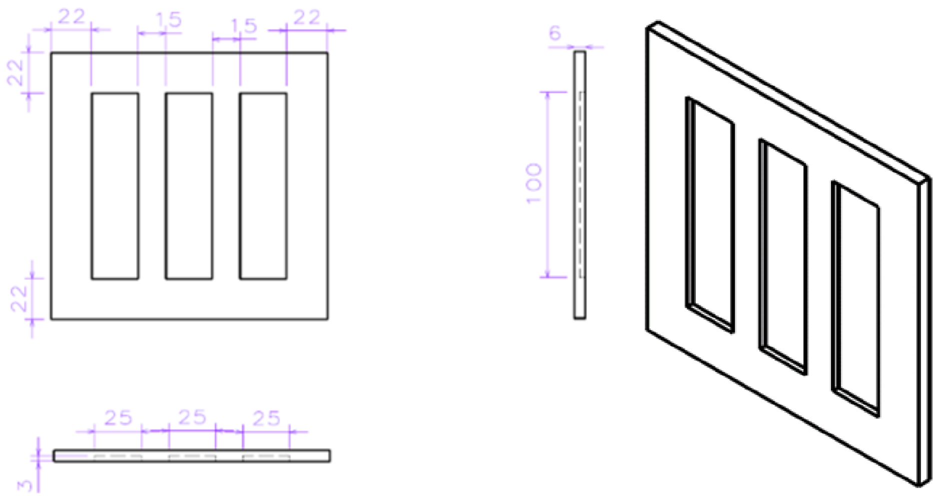

Figure 6. Sketch of the mold for the desired specimen (length units were mm)

As a result of the literature studies, it was observed that there was a significant improvement in mechanical and thermal properties in polyester matrix composites by using nanomaterials such as graphene, graphene oxide, and graphite in the range of 0.05% to 3% by weight. In addition, due to the convenience of the cost of graphene, it was envisaged to add 0.4 mg/mL and 0.8 mg/mL graphene epoxy nanocomposites in the composite structure. In the preparation of the samples, graphene nanoparticles were added to the epoxy and poured into the mold. The materials were then removed from the mold and made ready for the necessary tests. The molded materials were shown in Figure 6.

After the desired mold was prepared, the container part of the mold was cleaned in conjunction with a wax to avoid sticking problems to the container surface. Then, the initial layer of the mold was made with epoxy (10 gr) and hardener (4 gr). Epoxy-graphene of 0.4 mg/mL with glass fiber was mixed with hardener at a ratio of 7: 1.55 to yield 9 samples and epoxy-graphene of 0.4 mg/mL with glass fiber was mixed with hardener at a ratio of 7: 2 to yield 9 samples. Whole mixtures were allowed to react and warm-up for 15 minutes. Then, the specimen was taken with using of mold separator as seen in Figure 7(a) and Figure 7(b), respectively.

a) b)

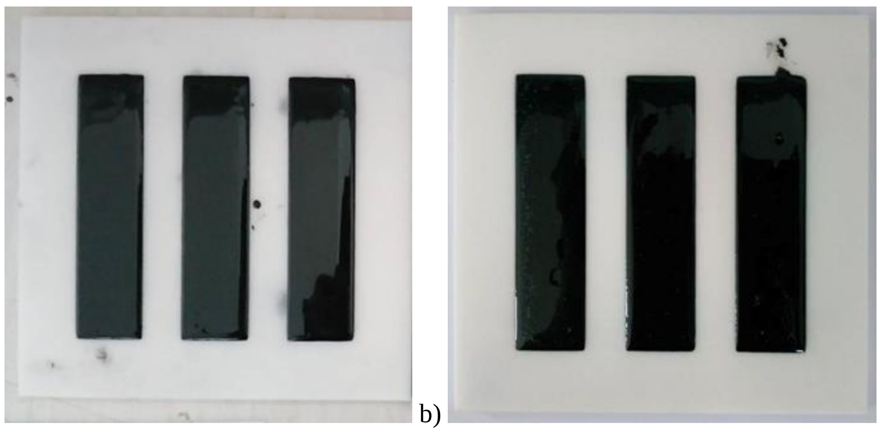

Figure 7. Graphene epoxy nanocomposite prepared with glass fiber in the amount of 0.4 mg/mL, b) graphene epoxy nanocomposite prepared with glass fiber in the amount of 0.8 mg/mL

TESTS

Properties of manufactured materials through different tests were necessary. This kind of requirements might include compression, tension, and bending tests [24]. Tensile testing was the most popular test method in most of the researchers [25]. Apart from tensile testing, hardness tests and microstructural tests could be performed for a prepared specimen. In this study, tensile and three-point bending tests were conducted for a fabricated specimen as seen in Figure 8, respectively.

a) b)

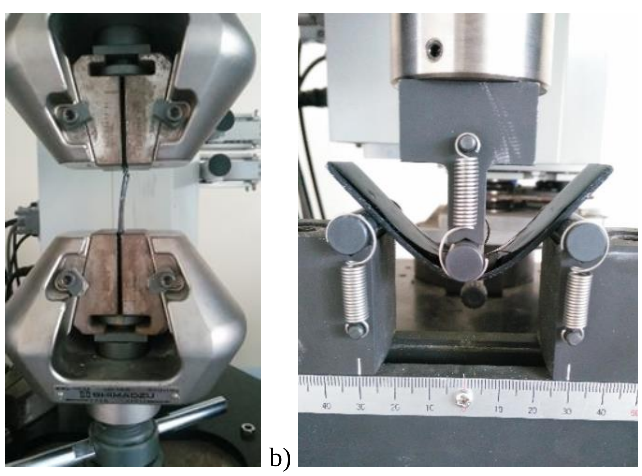

Figure 8. Tests for the prepared specimens in a) Tensile testing, b) Three-point bending testing

RESULTS AND DISCUSSION

Tensile Results

Three specimens were produced from each sample and tested separately to obtain a more accurate result. After the test procedure, graphs were obtained by using the Trapezium-X software program.

As a result of the studies on graphene reinforced nanocomposites, it was determined that the mechanical properties of the composite were increased with the addition of 0.4 mg/mL and 0.8 mg/mL graphene epoxy nanocomposite. In Figure 9 and Figure 10, the force-elongation graphs are given as a result of the tensile tests. The tensile strengths were calculated by dividing the force values obtained from the test. While the tensile strength of the epoxy-hardener was 18.8662 MPa in pure form, it was observed that the maximum tensile strength of the composite increased up to 21.52 MPa and 21.43 MPa adding the graphene of 0.4 mg/mL and 0.8 mg/mL, respectively. All properties can be seen in Table 2.

Table 2. Summary table of all results

	Tensile Testing Results		Three-Point Bending Testing Results	
	Max. Strength (MPa)	**Max. Force (N)**	**Max. Strength (MPa)**	**Max. Force (N)**
Epoxy-Hardener	18.8662	2122	32.9772	93.8018
Epoxy-Glass Fiber	26.6679	3000	46.9135	133.443
Graphene Epoxy-0.4 mg/mL	21.5245	2421	63.3616	180.229
Graphene Epoxy-0.8 mg/mL	21.4334	2411	50.8446	144.625
Graphene of Epoxy Glass-0.4 mg/mL	37.4162	4209	86.0179	244.673
Graphene of Epoxy Glass-0.8 mg/mL	23.7911	2676	81.9358	233.062

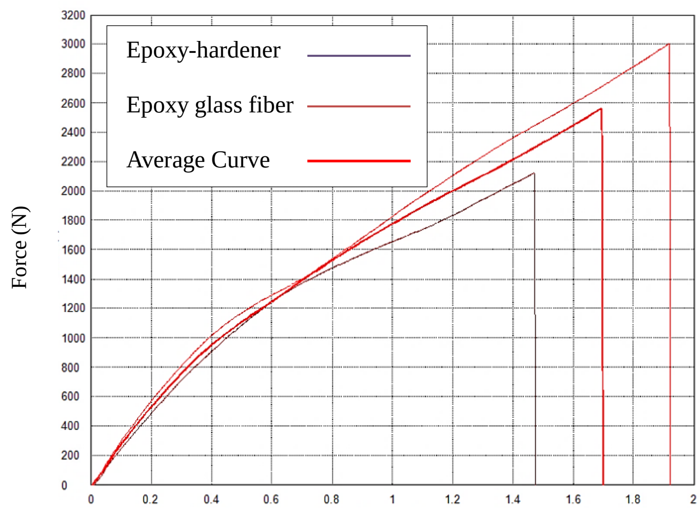

Figure 9. Tensile force-elongation graph of a pure epoxy specimen

The maximum tensile strength of the epoxy with glass fiber increased from 26.6629 MPa to 37.4162 MPa with 0.4 mg/mL graphene, while the maximum tensile strength of the epoxy with glass fiber decreased from 26.6629 MPa to 23.7911 MPa with 0.8 mg/mL graphene (Figure 11). The strength decreased as the amount of graphite increased. This is an expected event. Because the literature also supports this [17]. It can be said that the material was not in a rigid structure up to these forces, but it turned into a rigid structure at values above this maximum force. Besides, it was observed that the deformation of the material did not increase compared to the maximum force. After the maximum pressure applied in the tensile and bending tests of the samples, it was observed that the sample was deformed by breaking.

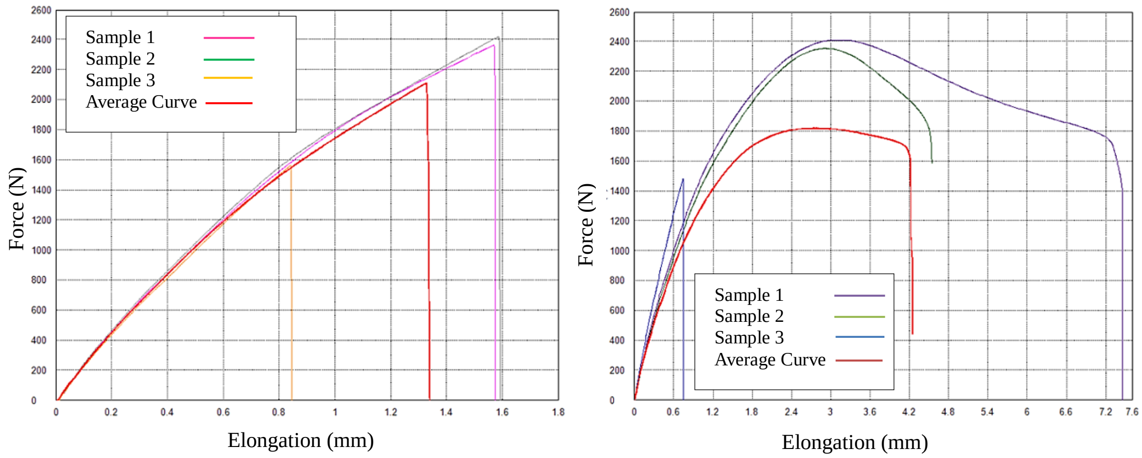

Figure 10. Tensile force-elongation graph of graphene epoxy nanocomposite a) 0.4 mg/mL b) 0.8 mg/mL

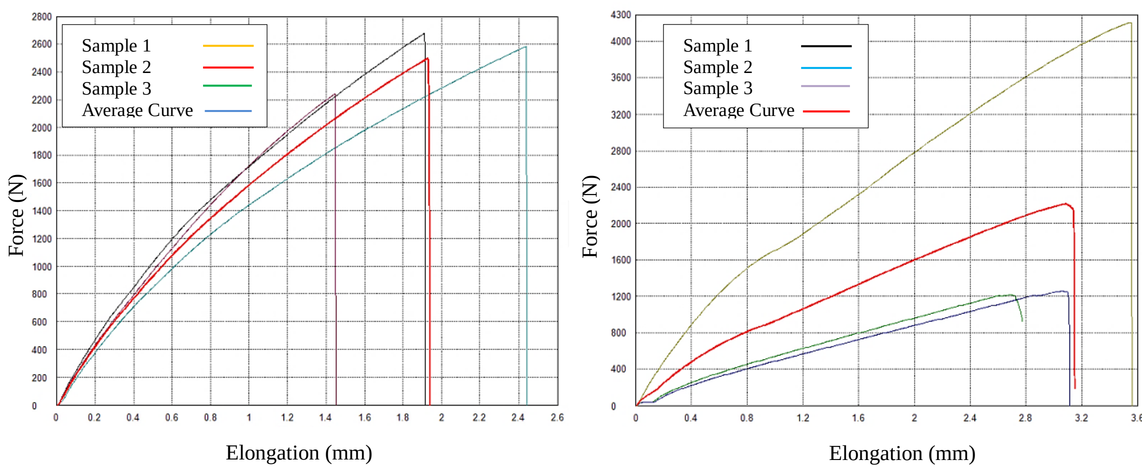

Figure 11. Tensile force-elongation graphene of epoxy glass a) 0.4 mg/mL b) 0.8 mg/mL

Three-point bending testing results

Figure 12 and Figure 13 showed the force-elongation graphs as a result of the bending test of the samples. It was observed that graphene epoxy nanocomposite which had a density of 0.8 mg/mL was more ductile material than both from 0.4 mg/mL graphene epoxy nanocomposite and pure epoxy in the bending strength tests. The bending strength of pure epoxy was found to be 32.9772 MPa. The maximum bending strength of graphene epoxy nanocomposite with a density of 0.8 mg/mL was 50.8446 MPa, while the maximum bending strength of the 0.4 mg/mL graphene epoxy nanocomposite was 63.3616 MPa.

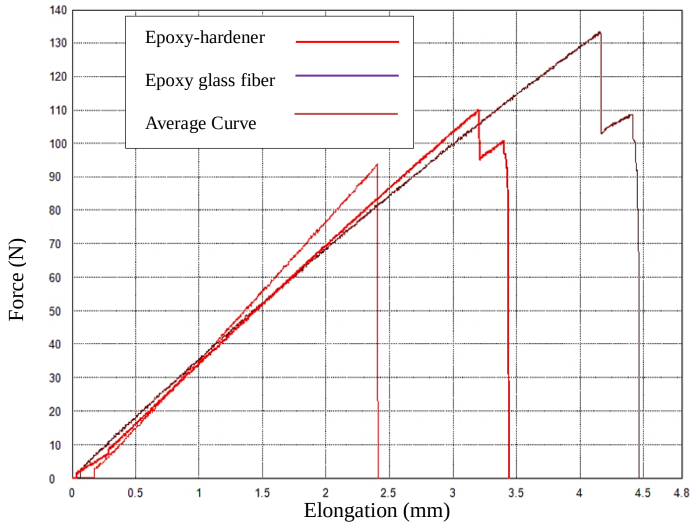

Figure 12. Bending force-elongation graph of the epoxy-hardener

In three-point bending test results as illustrated in Figure 14, the maximum flexural strength of the epoxy glass fiber composition was 46.9135 MPa and increased to 86.0179 MPa with 0.4 mg/mL graphene additive. It also increased to 81.9358 MPa when 0.8 mg/mL graphene utilized. According to obtained data, graphene epoxy nanocomposites with a density of 0.4 mg/mL glass fiber added increased the average flexural strength by approximately 45%. Graphene epoxy nanocomposites with a density of 0.8 mg/mL and glass fiber increased the average flexural strength by approximately 43%. Graphene epoxy nanocomposite with a glass fiber with a density of 0.4 mg/mL was found to be more ductile than both glass fiber with 0.8 mg/mL graphene epoxy nanocomposite and epoxy-glass fiber. After the maximum pressure applied in the tensile and bending tests of the samples, it was observed that the sample was deformed by breaking.

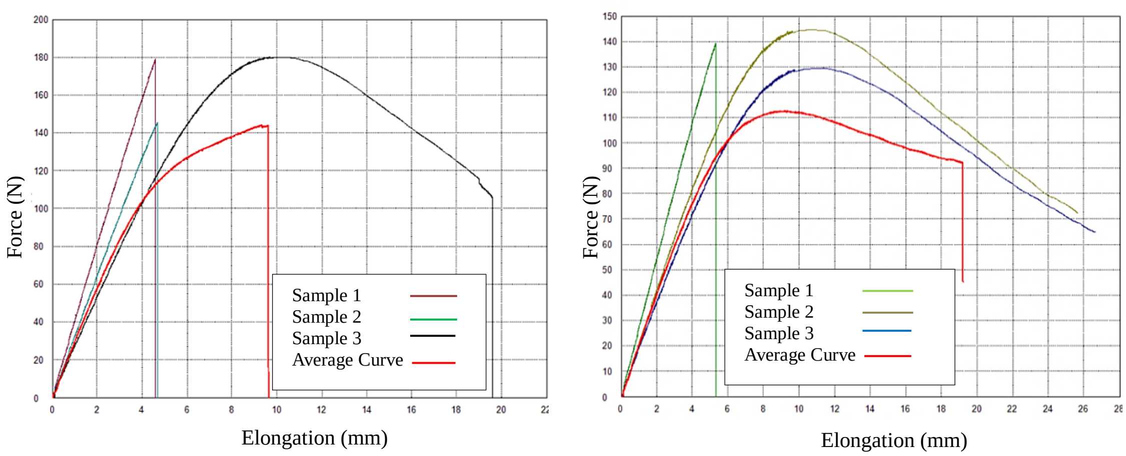

Figure 13. Bending force-elongation graph of the graphene epoxy nanocomposite a) 0.4 mg/mL b) 0.8 mg/mL

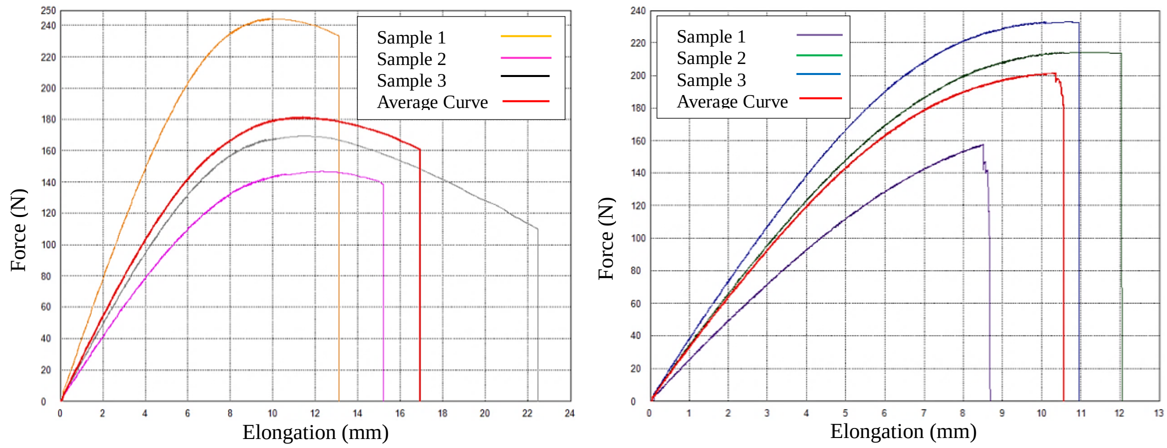

Figure 14. Bending force-elongation graph of the graphene epoxy with glass fiber a) 0.4 mg/mL b) 0.8 mg/mL

CONCLUSION

This study aims to investigate the mechanical improvement of nanocomposites using graphene particles in epoxy resin and utilizing glass fiber and graphene reinforced epoxy resin. In this context, this current study revealed the following conclusions:

- The tensile strengths were calculated by dividing the force values obtained from the tests into the sample areas. While the tensile strength of the epoxy-hardener was 18.8662 MPa in pure form, it was observed that the maximum tensile strength of the composite increased up to 21.52 MPa and 21.43 MPa adding the graphene of 0.4 mg/mL and 0.8 mg/mL, respectively.
- It was found that the average bending strength of graphene epoxy reinforced nanocomposites with 0.4 mg/mL increased by approximately 48%, while the strength of the nanocomposite with 0.8 mg/mL raised by approximately 33%.
- Experimental results of nanocomposites with the glass fiber revealed that the average bending strength of the 0.8 mg/mL graphene epoxy nanocomposites with the glass fiber increased by 43%, whilst the average bending strength of the 0.4 mg/mL graphene epoxy with the glass fiber increased by 45%.
- In this study, a small-scale mold and small-scale graphene epoxy nanocomposite sample were used and tested. Similar strength enhancement results will be obtained in strength tests if graphene oxide is used in composite structures in real-life applications.

Consequently, it was determined that graphene improved the mechanical properties of epoxy-based composites. It was a new generation composite that could meet the demands and might arise in industrial areas in the future, having more durable wind turbine blade samples.

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