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The effect carbon nanotube on three-point bending behavior of fiber reinforced composite

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The aim of this research article is to show the effect of Carbon Nanotube (CNT) additive on the performance of composite plate materials with fiber reinforced polymer matrix produced by vacuum infusion method under bending test. In this study, multiple layered composite plates have produced by glass, carbon, and aramid fiber reinforcements with 0.5% CNT addition by mass. In addition, a hybrid composite plate containing glass, carbon and aramid (Kevlar) fiber has produced with CNT addition by using the same production parameters. Three point bending test has performed on the composite plates under 1 mm/min bending with ASTM D7264 standard. As a result, CNT addition has increased the flexural performance but has decreased the elongation of glass and carbon fiber reinforced systems. In aramid reinforced system, both flexural strength and elongation has increased. However, in the hybrid fiber reinforced system, different fiber types have damaged at different elongation distances within the structure under different loads, and gradually more than one failure have observed. When the CNT has added to the hybrid system, the elongation increased but the flexural strength has decreased.

Key words: Carbon nanotube, Composite, Three-point bending behavior, Flexural strength

1 Introduction

At the beginning of the 20th century, especially with the introduction of polymer resins into the composite industry, the modern composite concept has begun to emerge. With the advent of synthetic resins, the first steps have taken in this modernization of composites. The widespread use of high-performance resins, including epoxy resins, especially in the 1930s, and the application of these types of resins to textile products in the 1940s, has been a turning point for fiber-reinforced polymer matrix composites in the future[1,2].

Composite material is a type of material has obtained by combining two or more different materials in a specific order at a macro scale. The performance of the composite material has obtained by adding the materials that make up it to the composite structure in certain proportions. The main purpose of composite material production is to support materials that are not sufficient and not suitable for service conditions with other materials and to make them suitable for service conditions[3,4].

Polymer matrix composites, which is sub-branch of composites according to the type of matrix, have been composites containing fibers and other reinforcing materials, which also have been used as a polymer matrix and reinforcement material. Also, polymer matrices often have been reinforced with fibers. Physical and chemical control between the polymer matrix and the fiber reinforcement could have achieved by coating the fiber reinforcements with suitable materials. Production methods of polymer matrix composites have been easier than composite types containing other matrix materials. Its tensile strength, stiffness and fracture toughness have been higher. It has been resistant to abrasion and puncture. The low thermal resistance and high thermal expansion of the polymer matrix composites have been among the important disadvantages. However, high fiber reinforced polymer matrix composites have preferred materials in a wide variety of branches due to their lightness, corrosion resistance, fatigue resistance and easy assembly. Fiber-reinforced polymer matrix composites have been preferred in consumer composites such as boats and bathtubs, industrial composite products such as underground storage tanks and pressure tubes, and many advanced composites used in aviation [2,3,5].

Fiber reinforcement alone in fiber reinforced polymer matrix composites has become insufficient

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for advanced composite material applications. For this reason, researchers have developed some new applications to increase the performance of composite materials. For this purpose, the concept of hybrid composite material has emerged, in which the material performance is increased by adding other reinforcement materials to the structure in addition to the main reinforcement material. Hybrid composites could have been defined as joining the second reinforcement material to the composite structure because both reinforcement materials work together and the main reinforcement material alone cannot increase the performance of the matrix material sufficiently[6,7].

Different reinforcement materials also assist the polymer matrix reinforced with fibers such as glass, carbon and aramid (Kevlar). The use of powder particle materials in polymer matrices has been also one of the preferred material types for this reinforcement selection. It has been also preferred to use carbon-based powder particle materials as ceramic reinforcement. Two-dimensional graphene and three-dimensional carbon nanotube (CNT) materials with carbon allotrope for carbon-based reinforcement have been widely used as second reinforcement materials for hybrid composite materials containing fiber reinforcement[8].

The use of carbon allotropes such as carbon nanotubes and graphene to improve the performance of fiber-reinforced polymer matrix composites have been studied by researchers in many ways. In the study conducted by Fernandez *et al.*, it has shown that the shear mechanical behavior of multi-walled carbon nanotubes (MWCNT) glass fiber reinforced polymer composite has been investigated and carbon nanotubes added to the resin did not reduce the in-plane shear effect of the composite[9]. In the study of adding carbon nanotubes to the structure for the control of structural health conducted by Sanchez-Romate *et al*., carbon nanotube in the composite structure has been used as sensors for the control of material damage[10]. Davis *et al*. has investigated the mechanical properties of functionalized carbon nanotubes in carbon fiber reinforced polymer matrix composites and has observed that carbon nanotube has increased the performance of the carbon fiber reinforced composite structure's stiffness, tensile strength and resistance to fatigue damage[11]. In the study of Sanchez and his colleagues have carried out, it has been observed that flexural performance in the composite structure has increased when the carbon nanotubes added to the resin of carbon fiber reinforced composite[12] . Kwon *et al.* also have increased the affinity between carbon fiber and epoxy matrix by oxidizing the graphite in the graphene and carbon nanotube hybrid material and harmonizing it with the carbon nanotube. Thus, higher short beam strength and higher electrical conductivity has been obtained in graphene/carbon nanotube hybrid material coated carbon fiber reinforced composites compared to uncoated composites[13]. Boroujeni and Al-Haik also has achieved to increase the performance of the composites by growing uniform and patterned multi-walled carbon nanotube (MWCNT) on the carbon fiber fabric, and these carbon fiber fabrics have been made into composite materials with epoxy resin and have increased fatigue life performance[14]. Badakhsh *et al.* have showed that the addition of carbon nanotube to the epoxy resin and curing mixture has increased the flexural strength performance in carbon fiber reinforced polymer matrix composites[15].

CNT contribution to fiber reinforced polymer matrix composite structure has been investigated by various studies for flexural strength. In the study conducted by Rathore *et al.*, it has been observed that there has been a 20% increase from approximately 300 MPa to 360 MPa under flexural load in the composite structure with a contribution of 0.5% CNT by mass[16]. In the study conducted by Kim *et al.* by adding 0.3% CNT by mass to the carbon fiber reinforced composite structure, it has been determined that CNT contribution in flexural strength has provided 17% performance increase from approximately 630 MPa to 740 MPa[17]. In the study conducted by Sharma *et al.,* it has been observed that there has been an increase from 160 MPa to 215 MPa under bending load with the addition of different CNT ratios by mass to the aramid fiber reinforced structure[18].

In this study, the effect of Carbon Nanotube (CNT) additive on bending performance on composite layered composites with fiber reinforced polymer matrix produced by vacuum infusion method has been investigated. Layered composite plates with fiber-reinforced polymer matrix have been produced using glass, carbon, and aramid fabrics with similar areal density (g/m^2) and similar fabric weave systems. In addition to glass, carbon, and aramid fiber reinforced composite plates, it has been thought that different bending performance can be observed in different fiber reinforced composite materials, so a hybrid fiber structure reinforced composite plate containing glass, carbon and aramid fibers has produced. CNT has added to composite by 0.5% of total mass. For CNT addition to composite structure, an isopropyl alcohol-CNT colloid mixture has prepared. The mixture has applied to fabric layers by spraying with a pressure paint spray gun. As a result of these applications, a total of eight composite plates have produced with the same production parameters. Samples have prepared in accordance with ASTM D7264 standard for three point bending test. Finally, three-point bending tests have applied to the samples.

2 Materials and Methods

In this study, three different fiber fabric types were used, namely glass, carbon and aramid. Supplied fabrics were produced with vacuum infusion method using Hexion LR285 and LH285 epoxy and hardener Fiber fabrics, resins and hardening materials were obtained from Dost Chemical (Table 1, and 2). 2/2 weave for all reinforcement fabrics were preferred, and the areal density (g/m^2) of the fabrics were preferred similar. For fiber/resin ratio were used 50:50 by weight for all composite plates (Table 3). At last, Multiple Walled CNT (MWCNT) was used as CNT additive, which added to composite structures, obtained from Ege Nanotek (Table 4).

In the study, for production of composite materials, square 1 m^2 of fabric was used for each composite production and these 1 m^2 fabrics were divided into nine equal pieces with a side of 0.33 meters. Then isopropyl alcohol colloid mixture with CNT was applied to nine fiber fabrics with a paint spray gun (Fig. 1). After the alcohol evaporated, the nine square fabric pieces were stacked on top of each other as nine layers. Layer layouts of the fabrics preferred as $[(0_{glass})_9]$ for glass fiber, $[(0_{carbon})_9]$ for carbon fiber, $[(0_{aramid})_9]$ for aramid fiber and $[(0_{glass}/0_{carbon}/0_{kevlar})_3]$ for hybrid structure. Finally, composite plates were produced by using the vacuum infusion method (Fig. 2).

2.1 Specimens and bending test

Square shaped composite plates were produced by the vacuum infusion method and with a side of approximately 0.33 meters, and they were turned into standard samples with a water jet cutter machine (Fig. 3). Composite plates are produced in dimensions in accordance with the ASTM D7264 standard (Fig. 4). Composite plates from which standard samples are obtained; there are total of eight CNT reinforced and CNT unreinforced carbon fiber, glass fiber, Kevlar fiber and hybrid fiber reinforced polymer matrix composite plates. Six samples were obtained from each composite plate and five of these samples were used as the main test sample. Another sample was used as a trial to observe the performance of the material under the bending test.

3 Results and Discussion

3.1 Experimental results

Three-point bending tests were applied on a total of eight composite plates with the same production parameters, including glass, carbon, aramid (Kevlar) and hybrid fiber structure reinforced, with and without CNT (Fig. 5).

In the study, flexural performance analysis of the CNT addition to composite were conducted to 300 g/m^2 glass fiber, 245 g/m^2 carbon fiber, 300 g/m^2 aramid fiber, and 281 g/m^2 hybrid fiber systems (Table 5). For flexural strength (MPa), 15% increase in aramid, 2.9% decrease from 383 MPa to 372 MPa in hybrid fiber, 3% from 657 MPa to 635 MPa in carbon fiber, and a decrease of 5.5% from 464 MPa to 439 MPa in glass fiber were found at flexural strength parameter (Fig. 6, Table 5).

For maximum flexural force (N), the increase was seen 21.1% in aramid, 15.2% in carbon and 13.3% in glass fiber reinforced systems. Unlike the sole fabric systems, the CNT additive caused 2.9% decrease in the hybrid fiber reinforced composite system (Fig. 7, Table 6).

For average elongation (mm) at maximum flexural force, increase was obtained as 17.3% in the aramid fiber reinforced structure. Unlike aramid fiber reinforced system, glass, carbon fiber and hybrid fiber reinforcements were showed decrease in elongation when the CNT added to the composite structure.

Table 2 — Properties of glass, carbon, and aramid (kevlar) twill woven fabric

Reinforcing Fabric Material	Weave Type	Weight (g/m^2)
Glass	twill 2/2	300
Carbon	twill 2/2	245
Aramid	twill 2/2	300

Table 1 — Properties of epoxy resin and hardener (HEXION LR285 – LH285)

Material	Brand	Density (g/cm³)	Viscosity (mPa·s)	Refractory Index
Epoxy	Hexion LR285	1,18-1,23	600-900	1525-1530
Curing Agent	Hexion LH285	0,94-0,97	50-100	1500-1506

Table 3 — Matrix and fiber properties in glass, carbon, and aramid fabric reinforced composites. The masses of reinforcement and matrix materials were kept the same in composite production with and without CNT additive

Reinforcing Fiber	Fiber Mass (g)	Epoxy Mass (g)	Fiber/Epoxy Ratio (wt%)	CNT Mass (g)	Composite/CNT Ratio (wt%)
Glass	300	300	50:50	3,00	0,5
Carbon	245	245	50:50	2,45	0,5
Aramid	300	300	50:50	3,00	0,5
Hybrid	281	281	50:50	2,81	0,5

Table 4 — Properties of carbon nanotube (MWCNT)

Material	Inner Diameter (nm)	Outer Diameter (nm)	Length (µm)	Purity (%)
MWCNT	2-6	<8	10-35	>96

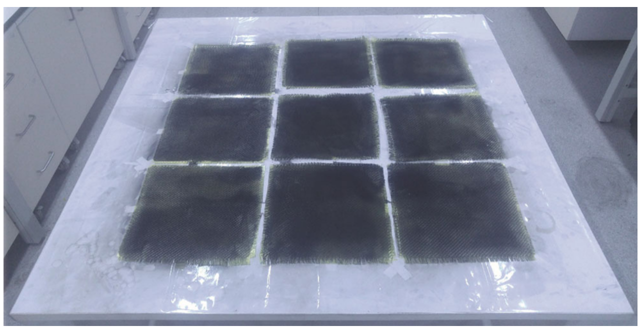

Fig.1 — Kevlar fiber fabrics coated with CNT with a spray gun.

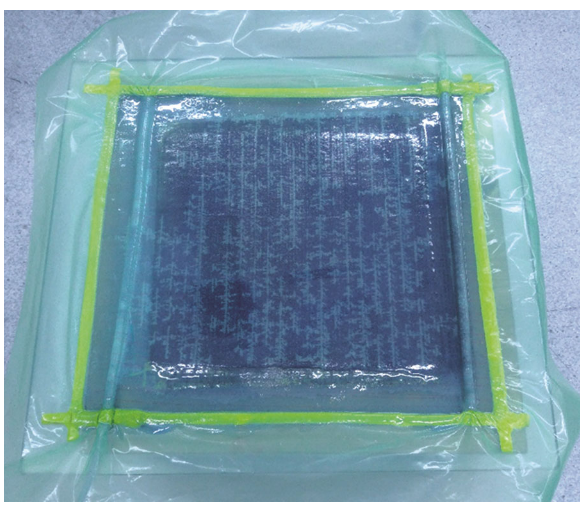

Fig. 2 — Composite plate that started to cure by applying the Vacuum Infusion production method.

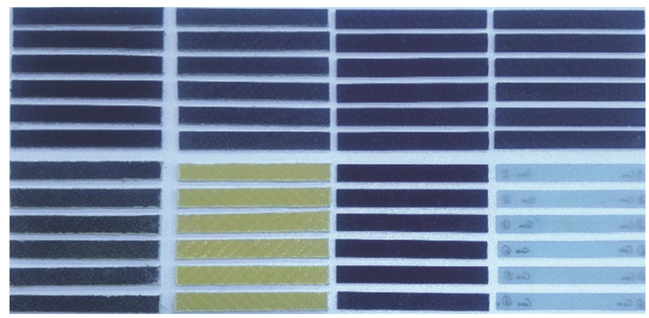

Fig. 3 — Tensile test samples produced in accordance with ASTM D7264 obtained from eight different composite plates.

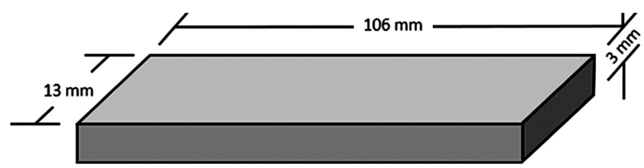

Fig. 4 — Dimensions of samples produced in accordance with the ASTM D7264 standard.

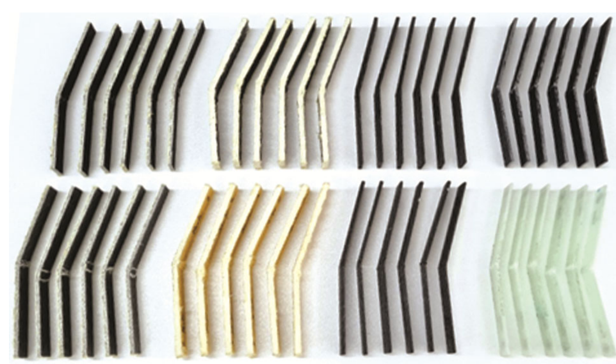

Fig. 5 — Three point bending test samples of layered composites after testing.

These decreases were 4% in carbon, 6.7% in glass, 15.1% in hybrid composite systems (Fig. 8, Table 7).

When three-point bending test data were examined (Table 6), the highest performance for average maximum flexural force (N) was seen in carbon fiber, then in hybrid fiber and Kevlar fiber, and the lowest in glass fiber. When CNT was added, there was an increase in maximum flexural force performance in glass, carbon and Kevlar fiber reinforced structures. Performance increase was observed for an average of 21.1% in the strength of the Kevlar fiber reinforced structure, an average of 15.2% in the strength of the carbon fiber reinforced structure and an average of 13.3% in the strength of the glass fiber reinforced

Table 5 — Flexural strength (MPa) data for three point bending tests performed on samples in the study

Composite Type	CNT (wt%)	Number of Samples	Minimum Strength (MPa)	Maximum Strength (MPa)	Average Strength (MPa)	Standard Deviation
Glass	0	5	447,57	486,75	464,63	16,53
Glass	5	5	430,40	448,15	439,24	8,03
Carbon	0	5	563,07	712,67	657,53	56,25
Carbon	5	5	614,84	651,87	635,40	16,09
Aramid	0	5	205,11	231,33	214,09	11,38
Aramid	5	5	232,30	254,74	246,68	9,25
Hybrid	0	5	352,04	426,02	383,58	30,09
Hybrid	5	5	348,51	389,90	372,60	17,50

Table 6 — Maximum flexural force (N) data for three point bending tests performed on samples in the study

Composite Type	CNT (wt%)	Number of Samples	Minimum Force (N)	Maximum Force (N)	Average Force (N)	Standard Deviation
Glass	0	5	193,95	210,92	201,34	7,16
Glass	5	5	223,63	232,85	228,22	4,17
Carbon	0	5	356,11	452,15	416,94	36,16
Carbon	5	5	464,21	492,19	479,75	12,14
Aramid	0	5	281,61	317,61	293,94	15,61
Aramid	5	5	335,28	367,67	356,02	13,34
Hybrid	0	5	288,41	349,02	314,25	24,65
Hybrid	5	5	285,52	319,43	305,26	14,33

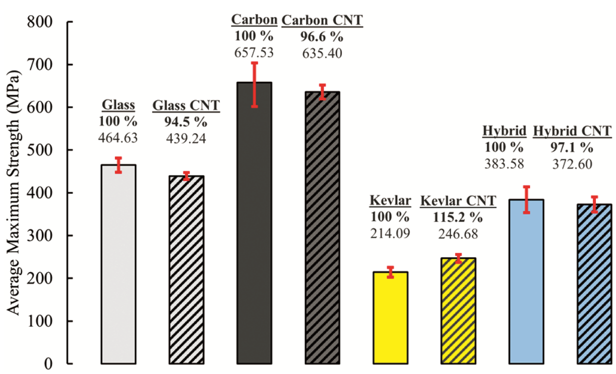

Fig. 6 — Average maximum flexural strength (MPa) data of the layered composites.

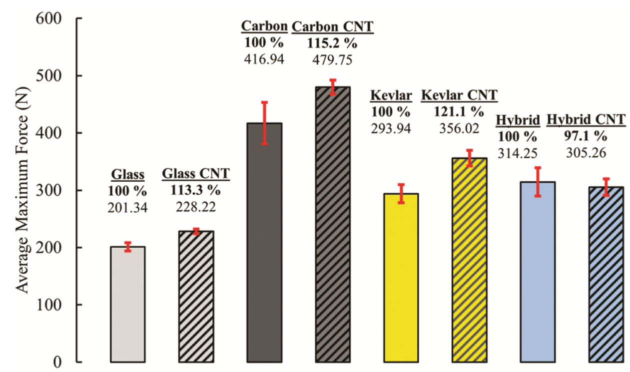

Fig. 7 — Average maximum force (N) data of the layered composites.

structure. Unlike Kevlar, carbon and glass fiber reinforcements, the CNT additive caused a decrease in the flexural strength performance of the hybrid fiber reinforced polymer matrix composite. This reduction was up to 2.9% for hybrid fibers. In kevlar fiber reinforced and hybrid structure fiber reinforced polymer matrix composite materials without CNT additive, kevlar fiber reinforcement showed lower strength performance than hybrid structure fiber reinforcements. However, CNT additive to both structures did not cause an increase in the flexural force performance in the hybrid structure fiber reinforced composite structure as in the kevlar fiber reinforced structure. While the hybrid structure with no CNT added kevlar fiber reinforced structure performs lower than the flexural force of the fiber reinforced composite structure, CNT reinforcement has carried the kevlar fiber reinforced structure to a higher bending strength performance than the hybrid structure fiber composite structure (Fig. 7).

When the three-point bending test data were examined (Table 7), the highest performance was observed for the glass fiber for elongation (mm) under the average maximum flexural force, followed by the hybrid structured fiber and carbon fiber, and the lowest for the Kevlar fiber. When CNT was added, there was a 17.3% increase in elongation performance under the maximum flexural force in the Kevlar fiber reinforced structure. Unlike Kevlar fiber, in glass, carbon fiber and hybrid fiber reinforcements, CNT additive caused a decrease in elongation performance under load. This decrease is 4% in carbon fiber reinforced structure, 6.7% in glass fiber reinforced structure and 15.1% in hybrid structure reinforced composite structure (Fig. 8).

When the three-point bending test data (Table 8) were examined, the highest performance for the elongation (mm) under the average maximum flexural force was observed in the hybrid fiber-reinforced composite structure, followed by the glass fiber and Kevlar fiber, and the lowest in the carbon fiber reinforced composite structures. When CNT was added, there was an increase of 2.9% in the average breaking elongation performance under flexural load in the hybrid fiber reinforced composite structure. Contrary to the hybrid fiber reinforced composite structure, CNT additive in glass, carbon and kevlar fiber reinforcements caused a decrease in the elongation performance under bending load. This decrease is 3.7% in kevlar fiber reinforced structure, 7.4% in glass fiber reinforced structure glass and 11.6% in carbon fiber reinforced composite structure respectively (Fig. 9, Table 8). In glass and carbon fibers, CNT has increased in performance at the applied maximum force but decreased in elongation. Applied flexural force and

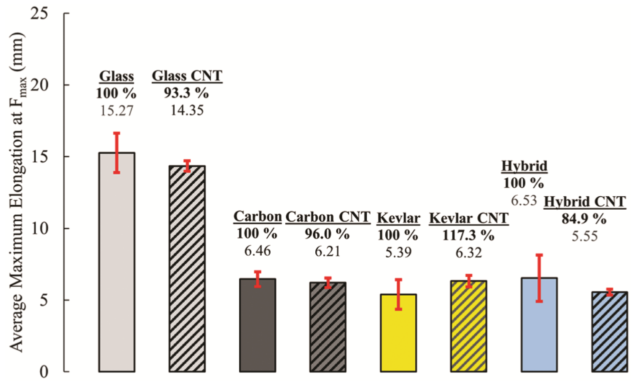

Fig. 8 — Average maximum elongation at maximum flexural force (mm) data of the layered composites.

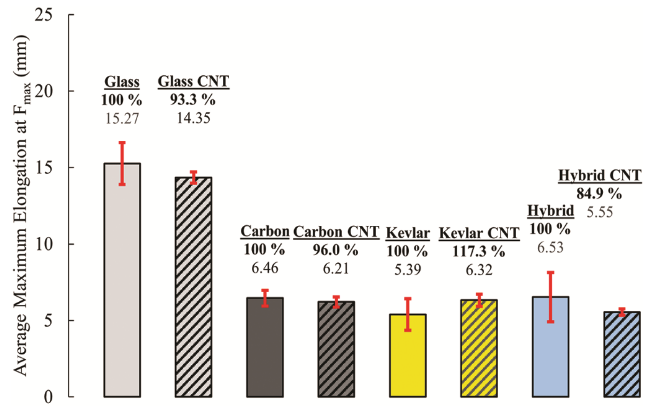

Fig. 9 — Average maximum elongation at critical failure (mm) data of the layered composites.

Table 7 — The bending elongation (mm) data under maximum flexural force load for three-point bending tests performed on samples in the study

Composite Type	CNT (wt%)	Number of Samples	Minimum Elongation (mm)	Maximum Elongation (mm)	Average Elongation (mm)	Standard Deviation
Glass	0	5	14,40	17,55	15,27	1,37
Glass	5	5	13,90	14,86	14,35	0,36
Carbon	0	5	5,73	7,1	6,46	0,51
Carbon	5	5	5,97	6,74	6,21	0,32
Aramid	0	5	4,24	6,94	5,39	1,02
Aramid	5	5	5,71	6,75	6,32	0,39
Hybrid	0	5	5,56	9,38	6,53	1,60
Hybrid	5	5	5,37	5,86	5,55	0,20

Table 8 — The critical damage elongation (mm) data after applying the maximum flexural force of the samples for the three-point bending tests performed on the samples in the study

Composite Type	CNT (wt%)	Number of Samples	Minimum Elongation (mm)	Maximum Elongation (mm)	Average Elongation (mm)	Standard Deviation
Glass	0	5	15,49	17,87	16,86	1,03
Glass	5	5	14,53	15,61	15,07	0,36
Carbon	0	5	7,13	7,52	7,31	0,15
Carbon	5	5	6,10	6,77	6,46	0,30
Aramid	0	5	11,57	15,59	14,03	1,68
Aramid	5	5	11,63	16,19	13,49	1,96
Hybrid	0	5	16,10	17,68	16,73	0,71
Hybrid	5	5	15,92	18,97	17,22	1,13

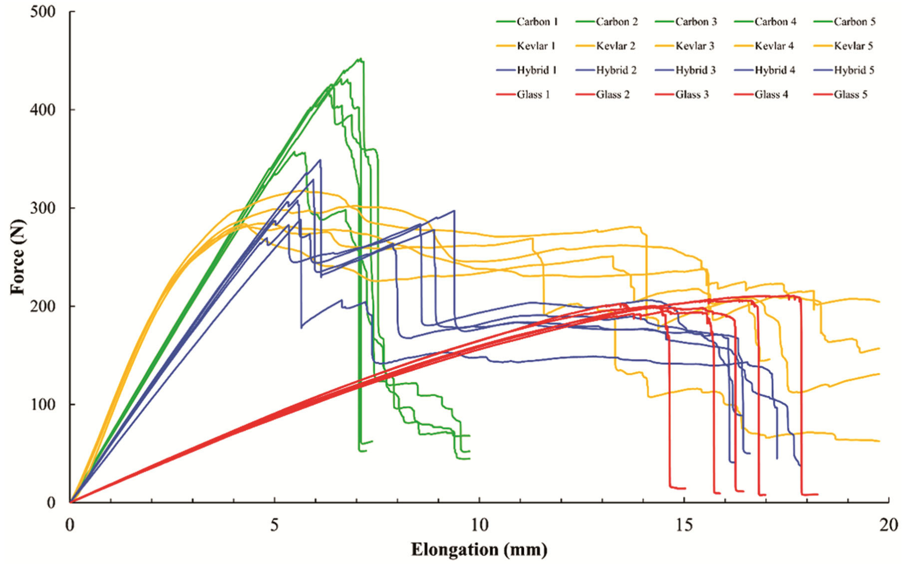

Fig. 10 — Three-point bending test results of layered composites.

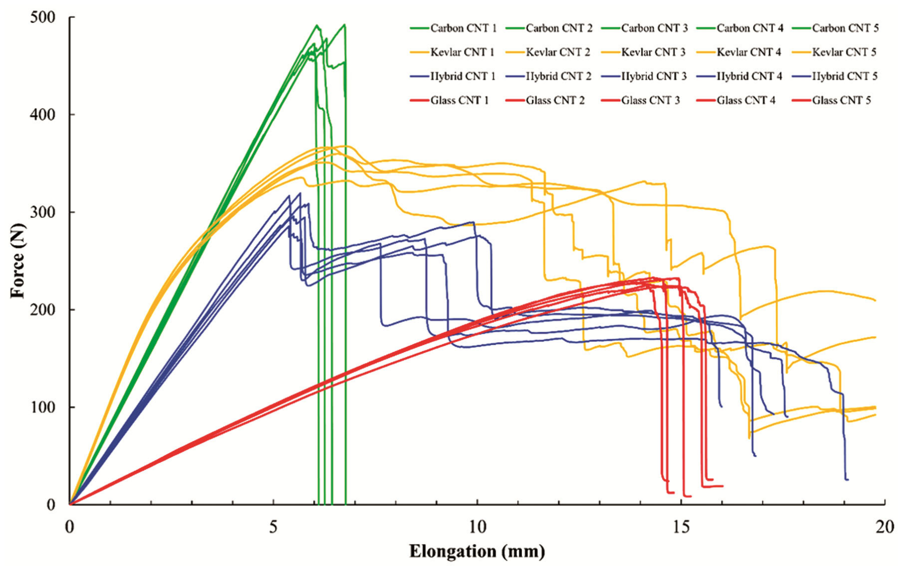

Fig. 11 — Three-point bending test results of layered composites with CNT additive.

flexural elongation performance have observed in different characteristics due to effects of CNT and types of fibers (Fig. 10, Fig. 11).

4 Conclusion

At the end of the study, 5 samples of 4 different fiber fabric reinforced polymer matrix composite plates, each with or without CNT, have tested with the three-point bending test, and it has been aimed to determine how the mechanical properties of layered fabric fiber reinforcements would have affected by the CNT contribution under the flexural force of the composite structure.

In the study, the structural failure has occurred under bending force in carbon fiber and glass fiber reinforced composite structures, and this failure has seen as sudden break. In the aramid fiber reinforced composite structure, after showing maximum performance at approximately 5 mm elongation, sudden breakage hasn't occurred as in the glass and carbon fiber reinforced composite structure. The flexural elongation has been observed up to 20 mm, but no rupture hasn't occurred in the sample. In hybrid fiber structure reinforced composite, more than one critical damage behavior has observed in the material at different elongation (mm) values, due to the different bending characteristics of glass, carbon, and aramid fibers in the structure. In the hybrid structure, it couldn't have determined which fiber type has damaged first. However, it has been found that different fiber types have damaged under bending load.

CNT additive has increased the flexural strength (MPa) performance of the aramid fiber reinforced polymer composite material structure, and this increase has been 15.2%. In contrast to the performance increase caused by the CNT additive in the aramid reinforced structure, a decrease in the strength performance has been observed for other fiber reinforced structures. This decrease in performance has been 2.9% for hybrid structural fibers, 3.4% for carbon fiber and 5.5% for glass fiber. When the maximum bending strength (N) data has been examined, CNT additive has increased the performance of aramid, carbon and glass fiber reinforced composites. This increase has been 21.1% for aramid fiber, 15.2% for carbon fiber and 13.3% for glass fiber. In the hybrid fiber reinforced composite, the CNT contribution has caused a decrease in performance under the bending force, resulting in a decrease of 2.9% in performance. When the elongation (mm) data under the maximum flexural force has been examined, the CNT additive has provided a performance increase in the aramid fiber reinforced composite structure and this increase has been 17.3%. Unlike aramid fiber reinforcement, in carbon fiber, glass fiber and hybrid fiber reinforced composites, CNT additive has caused a decrease in elongation performance under maximum bending force. The decrease in elongation performance under maximum force has been 4% for carbon fiber, 6.7% for glass fiber and 15.1% for hybrid fiber reinforced composite. When the fracture elongations (mm) of the samples under flexural force have been examined, a small increase in elongation performance has observed in the hybrid fiber reinforced composite and this increase has been about 2.9%. Contrary to the hybrid structure, the elongation performance at break has decreased in aramid, glass and carbon fiber reinforced composite structures, and this decrease has been 3.7% for aramid fiber, 7.4% for glass fiber and 11.6% for carbon fiber, respectively.

CNT addition to fiber fabric reinforced laminated composite plate structures has affected the mechanical properties. The CNT contribution of 0.5% by mass to the structure has showed that the performance increase for some bending test parameters under flexural load and performance decrease for some parameters in composite structures reinforced with glass and carbon fiber reinforced composites. CNT has increased both the maximum applied flexural force and flexural elongation performance in the aramid fiber reinforced composite structure. In glass and carbon fibers, CNT has increased in performance at the applied maximum force but decreased in elongation .

In the hybrid composite, CNT addition has caused the hybrid composite to exhibit different mechanical behavior. There have been three critical damage zones in the hybrid composite. One has been at the maximum force application (~ 5 mm elongation), the next has been at the point where the second force application after the first critical damage peaks (~ 10 mm elongation) and finally, it has been at the final critical damage point of the specimens (~ 17 mm elongation). Unlike glass, carbon and aramid fiber reinforced composite, CNT addition has caused a performance decrease in the first and second peak of the flexural strength values in the hybrid composite. However, unlike glass and carbon fiber reinforced composites, no significant change has been observed in the elongation values with these two flexural force peaks. In the force-elongation curve that progresses linearly from the second critical damage zone (~ 10 mm elongation) to the final critical damage point (~ 17 mm elongation), the force values have been observed to be higher in the CNT-added structure.

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