Damage Analysis of Carbon/ Glass Fiber Hybrid Composite Pipes

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To Cite This Chapter:
Doğan, A. F., Kayrıcı, M., & Günay, İ. Ç. (2025). Damage analysis of carbon/glass fiber hybrid composite pipes. In F. Z. Saltan, H. Arıkan, & Y. Uzun (Eds.), *Current studies in basic sciences, engineering and technology 2025* (pp. 108–138). ISRES Publishing.

Introduction

Composite materials have an important place in the industry in order to meet the innovations and increasing needs. In the studies carried out for the defense, space technologies, aircraft, automotive sector, which are important for the future vision of our country, materials with better properties have been sought. Designers have turned to composite materials in their search for materials with these properties.

A composite material is a new material formed by combining two or more materials with different chemical components and macro-level size ranges. Composite materials are superior to conventional materials due to their mechanical and chemical properties such as specific strength, specific gravity and corrosion.

The first use of composite materials in history dates back to the pre-bellum period, when the Egyptians used a mixture of mud and straw to create strong and durable buildings. Later, in 1200 A.D., the Mongols invented the bow and continued their work in the field of composites. While vegetable and animal resins were used until the early 1900s, synthetic materials such as vinyl, polystyrene, phenolic and polyester have shown better performance than those obtained from nature since the early 20th century. In the chronology of these studies, Owens Corning introduced the first glass fiber fiberglass in 1935 and stated that it was a light and strong material. Another one of the areas in question was the first composite commercial boat hull in 1946, adding a new one to its areas of use. Around 1975, as the composites industry developed, better resins and reinforcing materials were produced. DuPont developed an aramid fiber known as Kevlar, which became the product of choice for body armor due to its high tensile strength, high density and light weight. These developments paved the way for carbon fiber materials and replaced parts made of steel. Today, in addition to being used in sectors such as defense, space technologies and automotive, studies for the blades of wind turbines continue.

Made a comparison between two types of loading under biaxial loading of composite pipe specimens produced by filament winding method with different winding angles. They recorded the highest values according to the test values in the closed-end system from the loading conditions in the specimens wound with ±55 (Martins vd., 2013).

Mentioned that fiber reinforced composite materials are increasingly being used as an alternative to conventional materials due to their high specific strength, specific stiffness and special properties. At the same time, damping studies including macromechanical, micromechanical and viscoelastic (relaxation and creep) approaches were mentioned in the study and it was emphasized that they are suitable for high performance structural applications. They emphasized the impact damping advantages of polymer matrix composite materials (Chandra vd., 1999).

Investigated the damage behavior of FRP pipes manufactured by ±55° filament winding method under internal pressure. In the study, cracks were formed at different angles with respect to the axis of the pipe and in such a way that the wall thickness of the pipe was twice the crack depth. The bursting strength of the specimens was determined and the effect of the surface crack parameter was investigated. In the experimental study, it was concluded that the bursting pressure increased with increasing crack angle (Arikan, 2010).

Investigated the behavior of glass fiber/epoxy composite pipes under biaxial load. Tangential stress value of 290 MPa and axial stress value up to 165 MPa were obtained in composite pipes wound with a winding angle of 45°. As a result of the study, it was concluded that the stress ratio affects the linear elastic modulus (Ellyin vd., 1997).

Subjected glass fiber reinforced tubes produced by filament winding method to biaxial fatigue tests. The fatigue behavior of the material was investigated for tangential and axial loading conditions in the experiments. The fatigue event was performed according to ASTM D2992 standard and it was emphasized that larger (1-10 cm) matrix cracks were observed in areas with higher matrix density on the sample (Ellyin & Martens, 2001).

Investigated the damage behavior of glass fiber and epoxy composite pipes with 55° filament winding angle at internal pressure. In the study, it was stated that the cracks were perpendicular to the tensile direction in non-fiber areas and micro cracks occurred in fiber areas by separation of the fiber-matrix interface (Bai vd., 1997).

Fatigue and damage behaviors of glass reinforced plastic pipes made of E-Glass and epoxy materials under variable pressure were investigated. Samples with different winding angles were prepared in four layers and it was stated that both internal pressure values and fatigue life increased as winding angles increased (Gemi, 2004).

Investigated the fatigue behavior of glass reinforced composite pipes under internal pressure by damaging them with certain impact energy for winding angle ±55°. In the experiment performed in accordance with ASTM D 2992-06 standard, the damage energy of the glass reinforced composite pipe increased and the fatigue life decreased with the increase of the impact energy. It was emphasized that the damage was in the form of bursting in the pipes damaged with no impact and 5J impact energy, and in the form of leakage and pressure leakage in the samples damaged with 10J impact energy (Şahin, 2011).

E-glass/epoxy composite materials were subjected to heavy mass impact at low speed to investigate both in-plane dimensional and thickness effects. Impact tests were performed with a vertical drop weight tester using 150x100mm (±50mm) dimensions to investigate the dimensional effects and two nominal thicknesses of 1.4 and 2.8mm to investigate the thickness effect. As a result, it was concluded that the most important properties of composite materials subjected to impact loading are peak force and contact time, and the stiffness of the composite material is related to the width and thickness of the material (Aslan vd., 2002).

Investigated the effect of surface cracking by creating cracks at different angles in pipes made of glass reinforced material. They used low weights to create these cracks. Based on the ASTM D 1599-99 standard, they concluded that changing the angle of the surface crack has an effect on the burst pressure (Uyaner & Güvensoy, 2011).

Conducted fatigue tests on hybrid composite pipes and the first damage that occurs at low stress values is the separation of the fiber/matrix interface, which occurs in the direction of the fiber winding angle. These damages in the form of whitening grew in the fiber direction and formed matrix cracking in the following cycles (Gemi, 2016).

Reported that cylinders made of single-walled carbon nanotubes (SWCNT) are easier to bend and rotate and can be returned to their original shape after shape change, and that the tensile stiffness is higher than multi-walled carbon nanotubes (Yu vd., 2000).

Examined the effect of frequency lifetime on damage in their study and stated that the lifetime increases with increasing frequency, but this increases up to a certain point, that is, it has no effect on the lifetime after a certain frequency effect (Perreux & Joseph, 1997).

Investigated the damage behavior of GRP pipes obtained by filament winding method under internal pressure. They reported that the leakage damage in these pipes starts with the moisture formed on the pipe surface (Richard & Perreux, 2000).

Investigated the stress-strain deformation mechanism of carbon nanotubes (CNTs) and reported that CNTs have extraordinary flexibility properties and also have larger stresses without any sign of brittleness (Yakobson vd., 1996).

Reported that uniform distribution of carbon nanotubes in polymer matrices plays an important role in improving the properties of polymeric nanocomposites (PNC) (Soni vd., 2020).

Reported that the ideal winding angle for burst analysis, matrix cracking and fracture mechanisms is ±55° (Manoj Prabhakar vd., 2019).

Studied the dimensional analysis on impact damage and dynamic response of cylindrical structures made of glass/epoxy material and used specimens of different sizes and dimensions with ±55° winding angle. They reported that these manufacturing parameters significantly affect the physical properties of the specimen and the occurrence of damage (Tarfaoui vd., 2007).

Investigated the effect of bursting strength for the specimen of filament wound hybrid composite pipes under impact. Functionally graded hybrid composites, glass-glass/glass-carbon/ glass-carbon/ carbon-carbon-glass/ carbon-carbon were combined in different variations. Pipes were pre-stressed with internal pressures of 4, 16 and 32 bar. The effect of pre-stressing at different energy levels on the damage structures was studied. Pipes pre-stressed at 32 bar had the highest impact strength (Gemi, Kara, vd., 2016).

Reported that he studied Carbon/Glass/Glass (CGG), Glass/Carbon/Glass (GCG) and Glass/Glass/Carbon (GGC) as stacking array configurations. In this study, it was concluded that no leakage damage was observed in the pipes with GCG arrangement, while the pipes with CGG arrangement had higher impact resistance (Gemi, 2018).

Also examined the effects of winding angles of filament wound composite materials and produced and examined composites with 45°, 55°, 60°, 75° and 88° winding angles symmetrically and asymmetrically. As a result of the tests, they observed that the best properties were realized with 55° winding angle (Önder vd., 2009).

Reported that the blending of different types of reinforcing fibers such as glass, carbon, aramid and natural fibers with fillers such as calcium, carbonate, silica nanoparticles, clay, etc. improves structural properties in order to produce products with good properties compared to conventional materials (Santosh Savnur et al., 2020).

Studies have been conducted to investigate which mechanical properties CNTs, the most important reinforcing element used for reinforcement in the resin, the main phase of the composite material, impart to the resin. İnvestigated the improvement of mechanical and electrical properties of MWCNT-epoxy resin composites compared to composite structures made with pure epoxy matrix and reported that Young's Modulus and yield strength of polymer composites can be increased by 1 and 4%, respectively, with the addition of 1-4% MWCNTs to pure resin (Allaoui vd., 2002).

Reported that the interlaminar shear strength, fracture toughness and load transfer capability can be increased by adding nanoscale fillers such as carbon nanotubes through CNT/matrix (Üstün vd., 2016).

Reported that the hybrid composite strength depends on the properties of the fiber content of both fibers, the length of different fibers, fiber/matrix bonding and fiber sequence arrangement (Supian vd., 2018).

Preferred glass and carbon fiber composite materials for leaf spring production and conducted research on bending response. They reported that the bending response of leaf springs made of hybrid composite material was superior. Harmeet Singh and GurinderSingh Brar (2018) reported that the composite material leaf spring has high strength, low weight and low density in their study to compare conventional steel spring, metal matrix composite material spring and carbon epoxy based leaf spring (Rajesh & Bhaskar, 2014).

Reported in his study that for filament wound composite tubes , winding angle and number of layers are the parameters affecting impact toughness, and as the number of layers increases, the bending stiffness of composite tubesincreases during impact (Demirci, 2020).

Reported in their study that filament wound composite materials have replaced metal materials used in the production of pressure vessels and that composite tubes containing carbon fiber are one of the most effective solutions for high pressure vessels (Huang vd., 2020).

Reported in their study that as the tangential prestress level increases, the fatigue damage size increases and fiber breakage and bursting occurs after a certain loading (Gemi vd., 2017).

Reported that the resin system reinforced with multi-scale nanoparticles is suitable for industrial applications requiring high strength and thermal resistance (Taşyürek, 2021).

Reported in their study that crack growth rates and stress intensity change show a linear relationship and that the crack growth will increase as the stress intensity factor increases (Avci vd., 2007).

In summary, there are many studies in the literature examining the effects of fatigue, fracture toughness, machinability, impact strength and nano-additives on the matrix and composite structure of polymer matrix composite pipes. However, the differences between fabric winding technique and filament winding technique, prepreg material and normal fabric material, other production techniques and autoclave production techniques have not been sufficiently emphasized. In our study, material production was carried out using autoclave production technique using fabric winding technique, using both prepreg material and hybrid fiber CNT reinforced material combination. The aim of these materials is to determine the differences between normal fabric and prepreg material with balanced fiber/matrix combination and to compare autoclave production with other production techniques in different hybrid combinations at the same CNT reinforcement ratio.

Material

Properties of glass fiber prepreg material

Glass fiber prepreg material was supplied from SPM Composite company as SPM EGU 110 model fabric twill woven 110 g/m2 and stored in deep freezer by paying attention to cold chain transfer. Technical specifications of glass fiber prepreg materials are given in Table 1 and the supplied material is given in Figure 1.

Table 1

Glass Fıber Materıal Propertıes

Material	g/m^2	Woven	Weft(10cm)	Warp(10cm)	Weft	Warp	Width
Glass fiber	110	Twill	144	160	EC9 34	EC9 34	100

Figure 1

Glass Fiber Material

Carbon fiber material properties

In our study, Twill-430 gr/m2 carbon fiber prepreg material was supplied from SPM Composite company by paying attention to cold chain transfer. Technical specifications of carbon fiber materials are given in Table 2 and the material supplied is given in Figure

Table 2

Glass Fıber Materıal Propertıes

Material	g/m^2	Woven	Weft(10cm)	Warp(10cm)	Weft	Warp	Width
Carbon fiber	430	Twill	29	25	12K	12K	100/127

Figure 2

Carbon Fiber Material

Nanotechnology and MWCNT

With the addition of carbon nanotubes, a balanced electrical conductivity and homogeneous nano-distribution in the material has resulted in an extra strength increase. MWCNT was supplied from Nanotek-Ankara and technical specifications are given in Table 3.

Table 3

CNT Technical Specifications

Purity	Outer diameter	İnner diameter	Length	Surface area
%95 CNT	10-20 nm	5-10 nm	10-30 µm	>200 m^2/g

Autoclave Resin

Prepreg resin VTP DA100 model material was supplied from SPM Composite Company. Since we could not produce nano doped prepreg material, considering the decrease in the resin / matrix concentration of the prepreg material, nano doping was provided by using the same prepreg resin in order to add nano doping to the prepreg material. The supplied prepreg resin material is given in Figure 3

Figure 3

Resin

Cylindrical mold

The pipe used as a mold was obtained from seamless steel with an outer diameter of 72 mm and a length of 1300 mm by grinding the surface with a 0.1% taper. Our mold has a surface roughness value of N7 and the surface quality and taper are made to ensure easy mechanical removal of the composite material from the mold.

Figure 4

Cylindrical mold

Methods

One of the most frequently used methods in pipe manufacturing is filament winding.

However, this technique also has disadvantages such as the same fibers overlapping each other. It is also prone to production errors. The fabric winding method is preferred because the fibers are geometrically more regular in the form of fabric and production errors are at a minimum level. The point to be considered here is the degree of tension of the fabric during winding.

In our study, firstly, polyvinyl alcohol (PVA) mold release agent was applied on our hollow mold and covered with thin film nylon. For better penetration of the material into the mold, the mold was homogeneously heated to 50 °Cwith the help of a heater. Before the fabric winding process, a cover was produced for the mold so that it could be perfectly connected to the mold heads. Since one of the issues to be considered for the winding to be made in the turning process is the tension of the fabric, the prepreg material was wound on a pipe and the stretching process was performed. For the sequence parameters determined for the study in question, the process was completed by first applying resin to our pipe mold in the CGC sequence and wrapping four turns of carbon fiber, then two turns of glass fiber, and then four turns of carbon fiber again. The same process was performed for the GCG array.

Low Velocity Impact Test

Impact tests were carried out with a vertical weight testing machine. The testing machine is suitable for tests requiring low to medium impact energies. The mass of the impactor was 5.6 kg and the diameter of the impact nose was 12.7 mm. During the impact tests, an anti-kickback device was used to prevent multiple impacts on the target. The tests were performed at three different impact energy levels (5, 10 and 15 J).

The specimens with and without carbon nanotubes were impacted at least 3 times each at 5J-10J-15J energy values with a device with a cylindrical nose geometry. Since the selected material was both carbon fiber and carbon nanotube, no color separation was observed in the damage zone and it was not possible to observe it with penetrant liquid. The specimens impacted at 5 cm intervals were cut from the impact damage zone with a band saw and the damage zones were examined with a digital microscope. The results of the examination are given in the relevant section. The low-speed impact testing machine we used in our study is given in Figure 5.

Figure 5

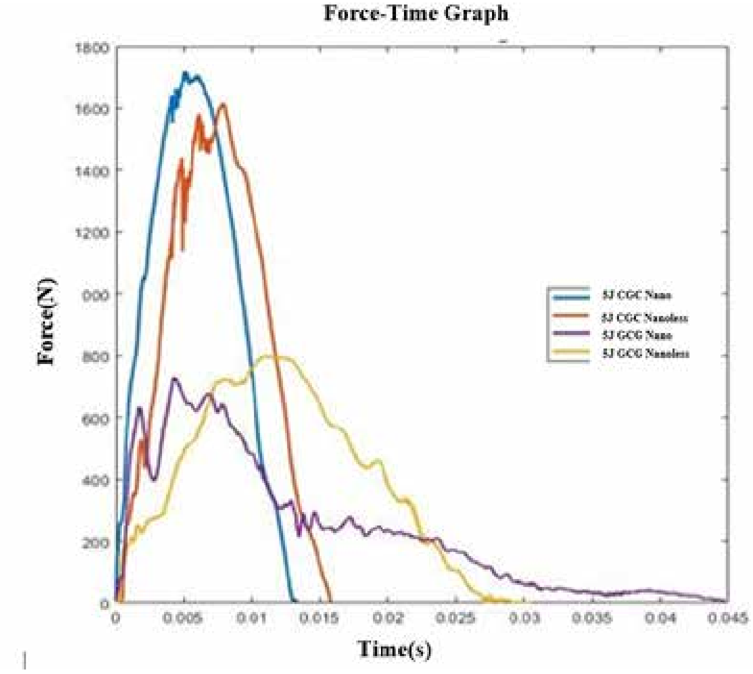
Low Speed Impact Device Test

Force- time graphs

Figure 6, Figure 7 and Figure 8 show the time-dependent variation of the contact force for different impact speeds. As can be seen, the contact force starts to increase at the first point of contact. This trend continues until Hertzian damage is encountered. Hertzian damage can be associated with matrix fracture damage encountered in the contact zone. However, the tubes may not lose their structural integrity and resist the applied deformation. Thus, an additional increase in contact strength is observed.

Figure 6

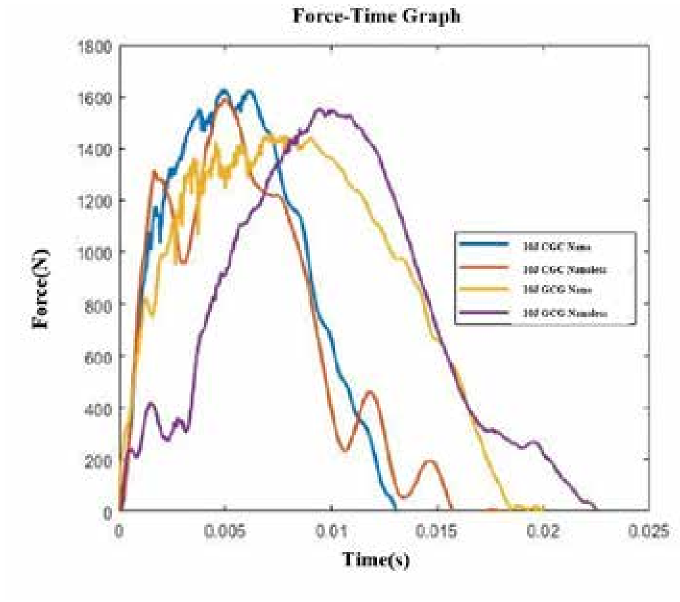
Test graphs with 5J



The difference between the material with and without nanos in the CGC array at 5J is 150-200 N. Earlier matrix cracking damage propagation was observed in the material without nanos. In the GCG array, the damage propagation at the same forces occurred in a longer period in the nanosized material, which leads to the conclusion that the nano reinforcement prevents the damage from spreading. Because the force contact time was realized in a longer period in the nanosized material. It is expected that the contact force is different between the CGC array and the GCG array. Because the CGC array is a stronger structure containing 8 times carbon.

Figure 7

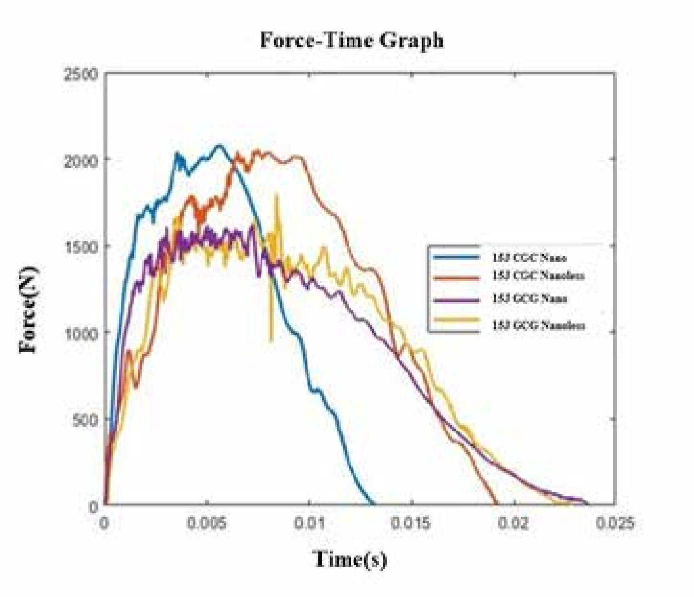
Test graphs with 10J



When the energy effect is increased, it is seen that the CGC array has a more stable structure in which the nanosilver materials have a larger force contact time compared to the materials with nanosilver and start to be damaged earlier.

Figure 8

Test graphs with 15J



In this graph, it can be said that the CGC array has a more resistant and brittle structure, while the GCG array has a more elastic structure. In contrast to the sudden matrix and fiber fractures in the CGC array, the GCG array shows deformation in a wider area spreading at a slower rate.

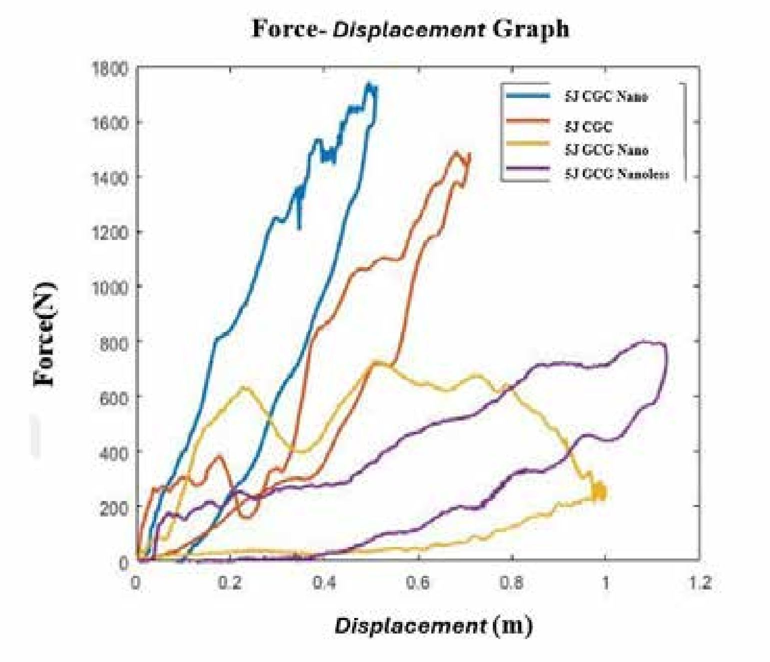
In general, when the force is increased, it can be concluded that the structures with nanotubes are damaged in shorter time periods at higher forces, while in the GCG array, this time period is more, so the damage area is wider and the fractures are more at smaller sizes. 1% nanotube additive reduces the damage of the materials and increases the force strength, but it is thought that the impact strength will increase at a more predictable level by increasing the nanotube additive up to 3% in accordance with the literature.

Force-displacement graphs

Figure 9, Figure 10 and Figure 11 show the change in contact force versus vertical displacement of the pipes. The slope of the contact force-displacement curve represents the bending strength. As the contact force starts to bend the pipe, a lower bending strength is observed. When the maximum contact force is reached, the displacement is also at its maximum value. Then the rebound phenomenon starts. It provides the remaining bending strength by pushing the impact tip back.

Figure 9

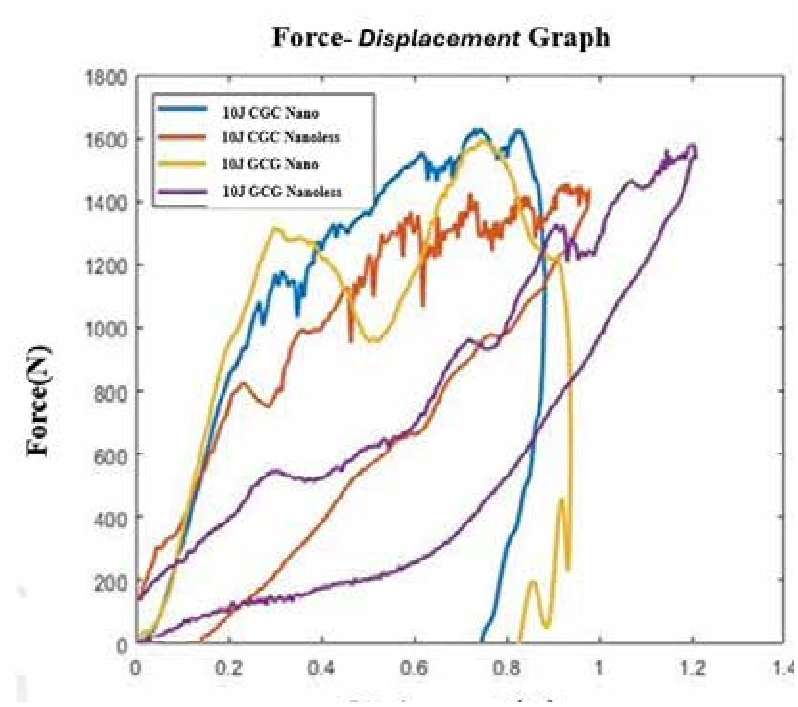
Test graphs with 5J



The material with CGC nanoparticles was destroyed at higher forces with a smaller displacement ratio and a stiffer rebound. In the non-nano material of the same array, lower force, earlier deformation, larger displacement and more moderate rebound occurred. In the GCG array, larger displacement and much lower rebound forces occurred due to a more flexible impact glass fiber. The non-nanosized version of this array has a larger displacement and therefore a larger deformation zone. This may be due to the more rigid structure of the carbon fiber layer under the glass fiber layer.

Figure 10

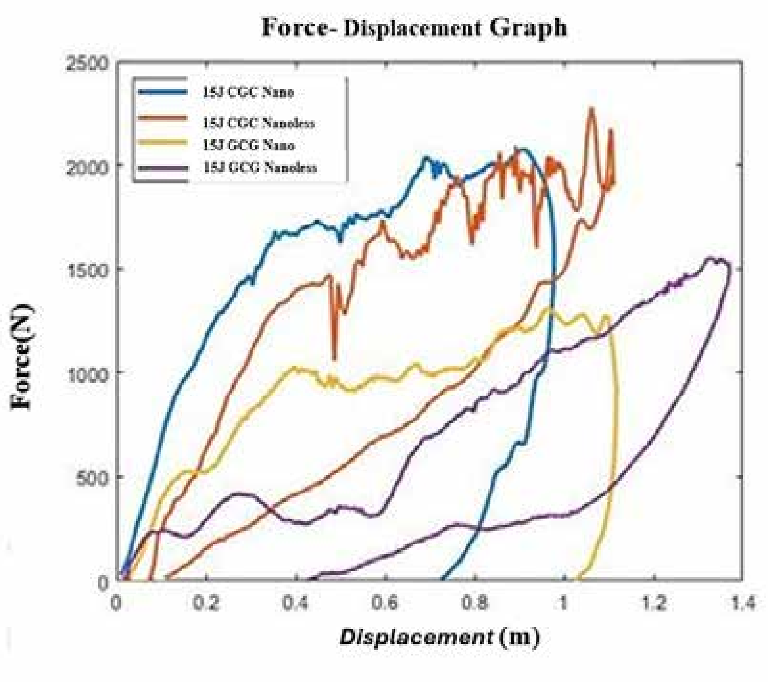
Test graphs with 10J



In the material with CGC nanoparticles, smaller-scale damage mechanisms occurred at high forces and the material reached a larger displacement period. Although the damage started later in the non-nanosized version of the same array, fiber fracture occurred, probably due to the effect of being non-nanosized, and after the material reached almost the forces of the nanosized version, the rebound effect was not fully visible due to the effect of fiber fracture and the material deformed. In the GCG array, the material started to be destroyed at lower forces. The material flexed significantly with the effect of glass fiber. In this array, the effect of the nanotube enabled the material to be damaged at higher forces with a smaller diameter.

Figure 11

Test graphs with 15J



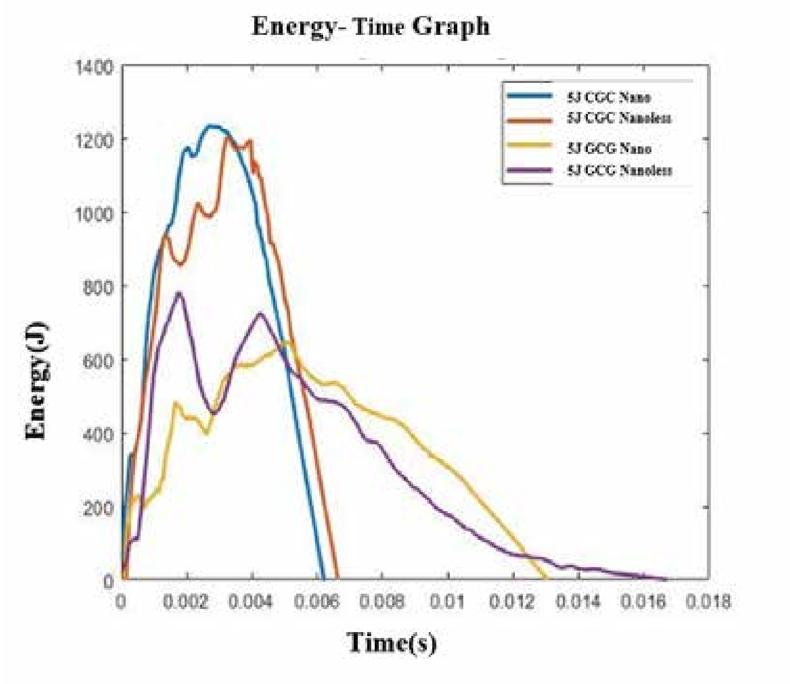
At this energy level, the material with nanos in the CGC array suffered small-scale and large-area deformation damages, while the material without nanos suffered stiffer and sudden damages, but reached higher strength. In the GCG array, relatively lower forces, larger deformation area and displacement rates were achieved.

Energy-time graphs

Figure 12, Figure 13 and Figure 14 show the change in energy with respect to time during contact for different impact velocities. As can be seen, the majority of the impact energy was spent on deformation and a small amount of energy was used for rebound. It can also be seen that the contact time becomes larger as the impact velocity increases in this specimen.

Figure 12

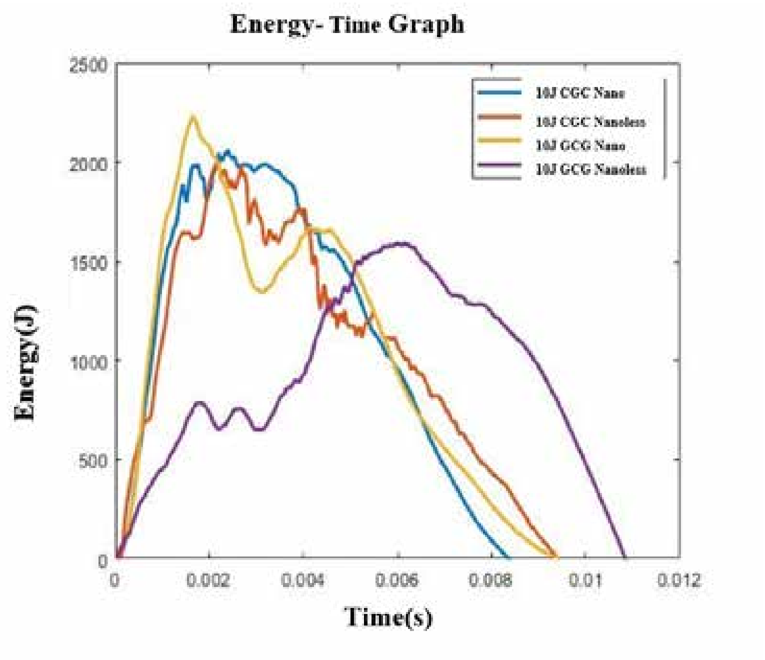
Test graphs with 5J



In the CGC array, most of the energy in the samples with and without nanos was discharged in a very short time. The amount of rebound energy was also spent in a very short time. Here, the nano difference is evident even if it is very small. In the GCG array, on the other hand, since it has a weaker flexible structure in terms of strength, the energy levels were discharged in longer periods of time and the material was destroyed more severely. This is because the glass fiber has a weak structure.

Figure 13

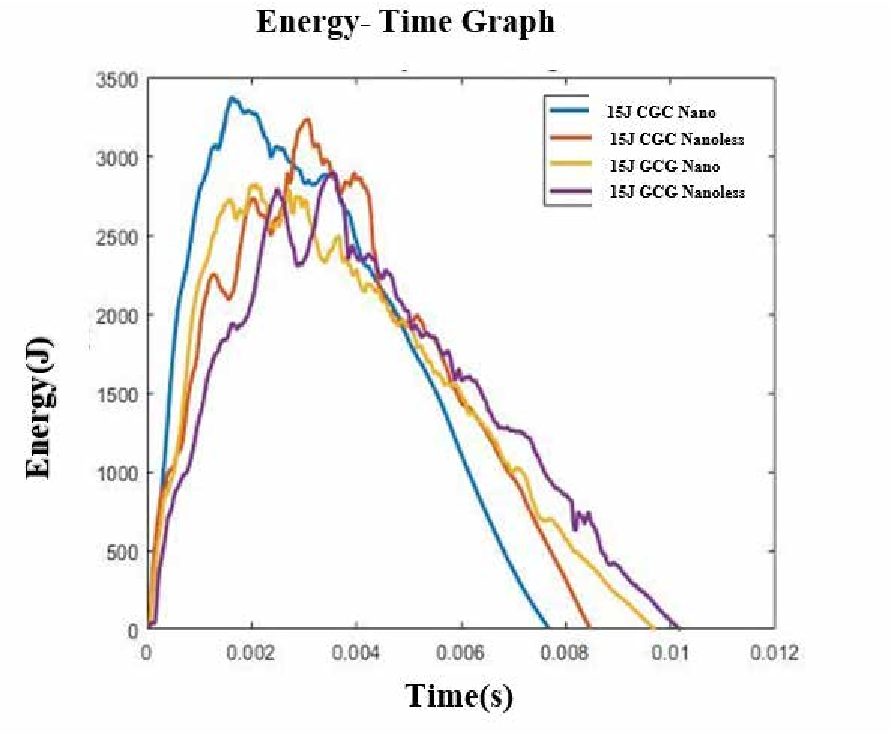
Test graphs with 10J



At this energy level, there is a relative parallelism in the CGC sequence. Energy is discharged in almost the same periods. It is seen that the nanomaterial deforms in a shorter time and consumes energy. In the GCG array, on the other hand, there is a sudden energy discharge due to high energy levels and high degree of fiber breakage in short periods. The reason for this should be further investigated. In the non-nano form of the same array, there is energy discharge with matrix breakage at lower energy levels and then energy increase with fiber strength. Due to its flexible structure, energy discharge occurred in a wider time period.

Figure 14

Test graphs with 15J



There is a correlation at this energy level for both arrays. All specimens were deformed with small matrix fractures, but again the materials with nanos were more severely damaged in shorter time periods. In the GCG array, especially the non-nano material was deformed with larger fiber fractures over larger periods of time.

Since the CGC array has a more stable and rigid structure in terms of strength, it absorbed more energy and spent this energy through matrix and fiber fractures. In the GCG array, there is a deformation with larger time periods and lower amplitude.

Effect of impact energy on the damage behavior of the specimen

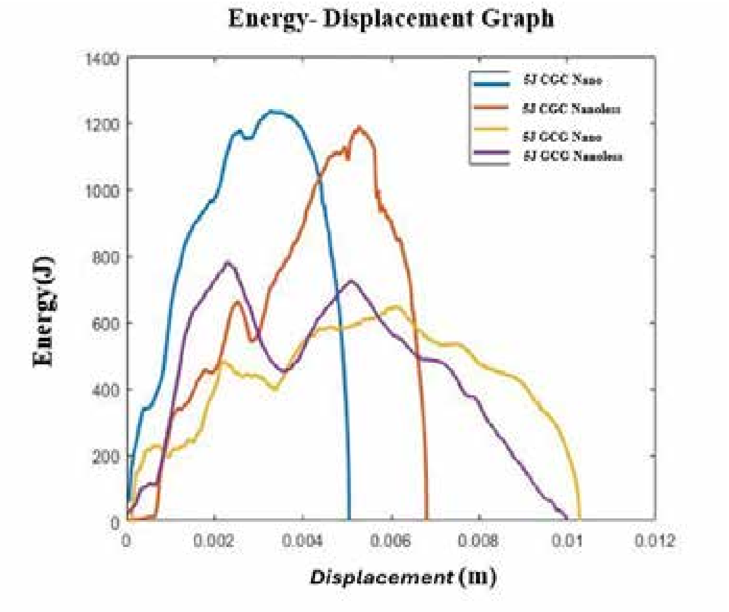
In the impact behavior of composite pipes, the ability of the impact tip to discharge the kinetic energy gained by the material starts from the moment the tip first touches the material. Since matrix cracking, fiber breakage and fabric winding technique are applied in composite materials, delamination damage is expected since each fabric layer will act as a laminate. However, the energy of the impact tip creates a deflection, i.e. collapse, at the material contact point. If the tip does not cause penetration in the material, the impact tip rebounds due to the impact resistance of the material, that is, the impact tip is pushed back by the material. In this case, the impact mechanism cannot discharge all of its energy to the material. All this mechanism creates a number of graphs and values that allow us to comment on both the impact resistance of the material and the damage caused by the impact tip on the material. These are force/time, force/displacement, energy/time and energy/displacement graphs and values.

Energy-displacement graphs

Figure 15, Figure 16 and Figure 17 show the energy-displacement plots and the deformation and rebound energy change/displacement change of GCG and CGC arrays are analyzed.

Figure 15

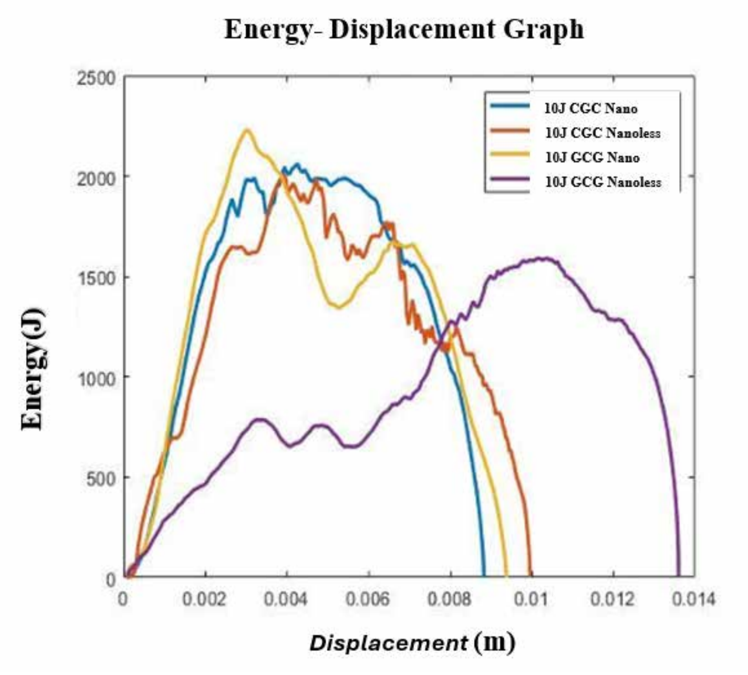
Test graphs with 5J



At this energy level, a higher amount of energy in the CGC array can be considered as a measure of the strength of the material as it creates lower displacement amounts. The fact that the nanoporous material in this array has a more stable structure shows the effect of nanotube doping. Despite the high level of energy expenditure, very small displacements were realized. The material without nanos has a larger displacement level with severe deformation damage. In the GCG array, since both samples have a more flexible structure, the structure with nanotubes consumed more stable energy and the structure without nanotubes was observed to deform with serious fiber fractures in a longer period.

Figure 16

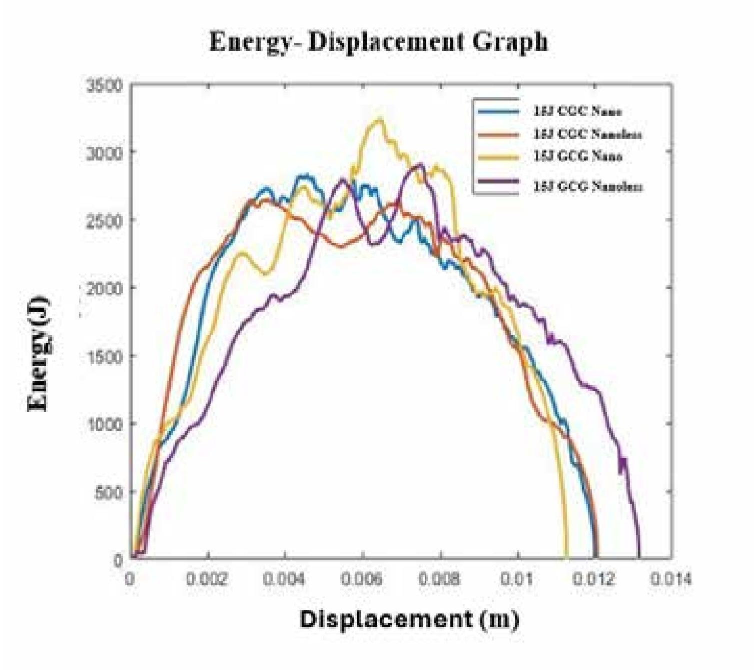
Test graphs with 10J



At this energy level, there is an equilibrium that does not resemble the nanotube difference of the CGC array. Sudden fractures, albeit very small, indicate a sample without nanotubes. In the GCG array, the material with nanotubes has a serious strength that we do not know the reason, but it absorbed energy at lower displacement rates due to very serious fiber fracture. The sample without nanotubes showed a more flexible structure and showed large displacement at low energy levels due to low stiffness.

Figure 17

Test graphs with 15J



At this energy level, in the CGC array, the nanomaterial absorbed energy stably at a large displacement ratio. The nanosized version of this array absorbed energy over a wide displacement range through matrix fractures at a relatively high level. In the GCG array, again, the material with nanosize absorbed energy stably and the nanosize version was more flexible and absorbed energy over a wide displacement range.

As the energy levels increase, it is seen in the graphs that the carbon nanotube difference in both sequences affects the material values very little. Nevertheless, nanomaterials exhibit more stable energy absorption and displacement ratios at all energy levels. Since the GCG array has a more flexible structure in terms of strength, it absorbed lower energy levels at larger displacement ratios. The carbon layers in the center of this array increased the energy absorption capability of the material.

Investigation of Damage Types

Nanolayered CGC array

Microscope examination images of the post-impact section of the nanolayer CGC array are given in Figure 18, Figure 19 and Figure 20.

As the energy levels increase in the nanomaterial, the number and orientation of fiber fractures in the damage zone increases. Delaminations are more balanced but tend to occur between the arrays. As the energy levels increase, the delamination lengths increase and the number of small delaminations increases in different regions.

Figure 18

Test graphs with 5J

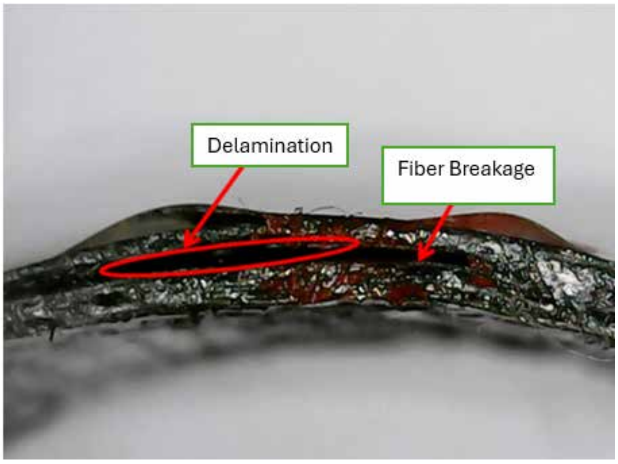


Figure 19
Test graphs with 10J

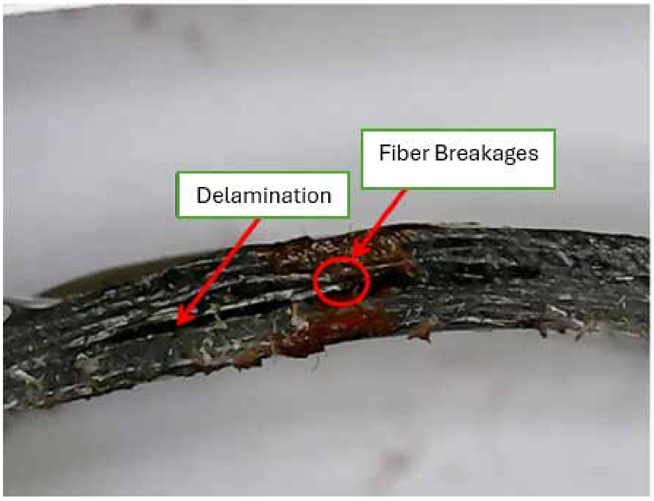
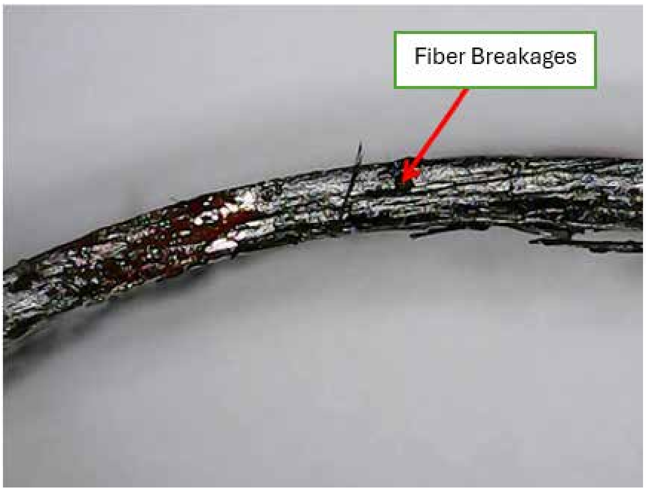


Figure 20
Test graphs with 15J



Nanoless CGC array

Microscope examination images of the post-impact section of the nanosized CGC array are given in Figure 21, Figure 22 and Figure 23.

Figure 21

Test graphs with 5J

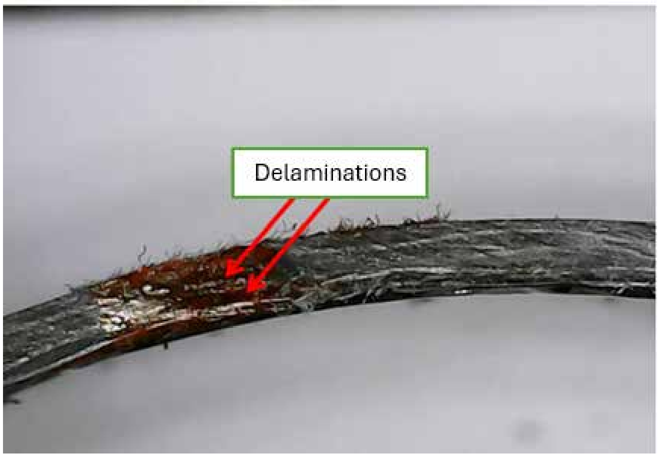


Figure 22

Test graphs with 10J

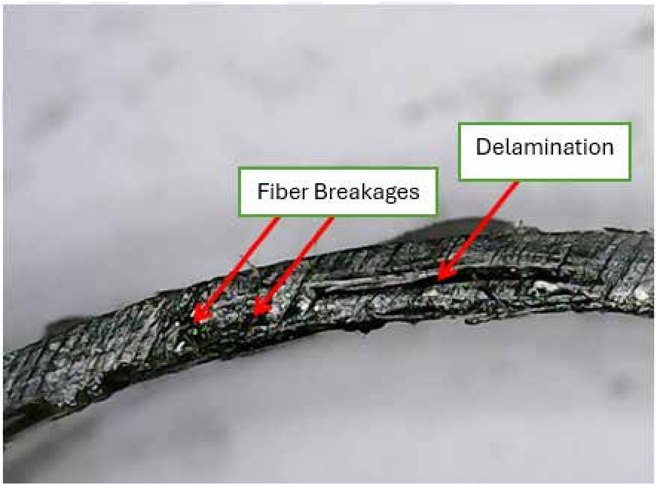
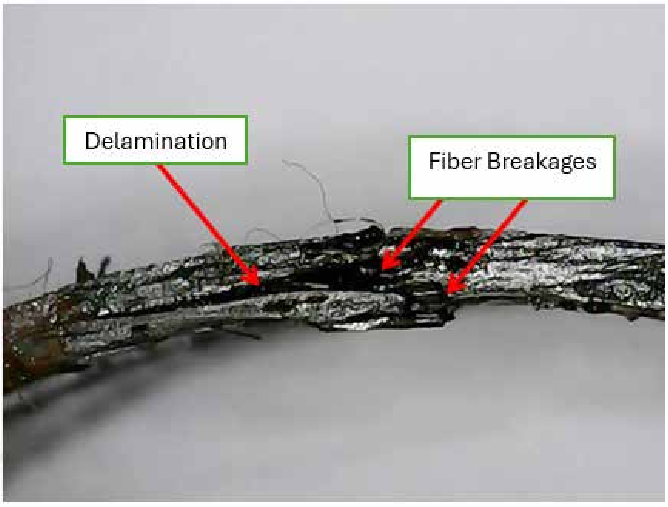


Figure 23

Test graphs with 15J



Fiber fracture and delaminations increased again as the energy level increased in the nanosilver material. At the energy level with 15J, delamination occurred.

When a comparison is made at the same energy levels of nanofibrous and non-nanofibrous materials, more balanced and stable fiber fractures and shorter delamination lengths are observed in the nanofibrous material. In the non-nano material, longer delaminations, stiffer fiber fractures and delamination are observed.

Nanolayered GCG array

Microscope examination images of the post-impact section of the nanolayer GCG array are given in Figure 24, Figure 25 and Figure 26.

Figure 24

Test graphs with 5J

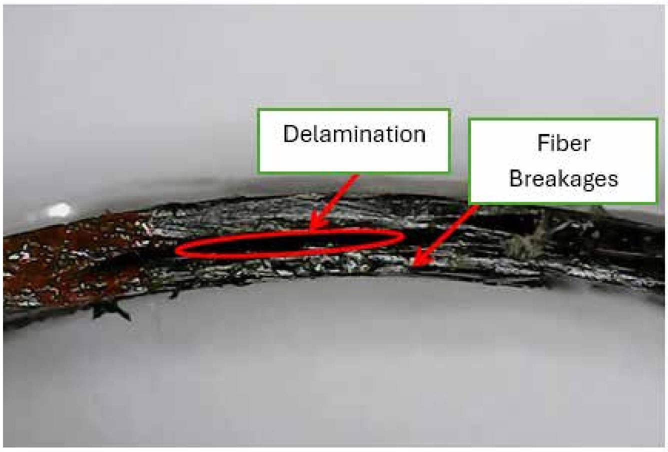


Figure 25

Test graphs with 10J

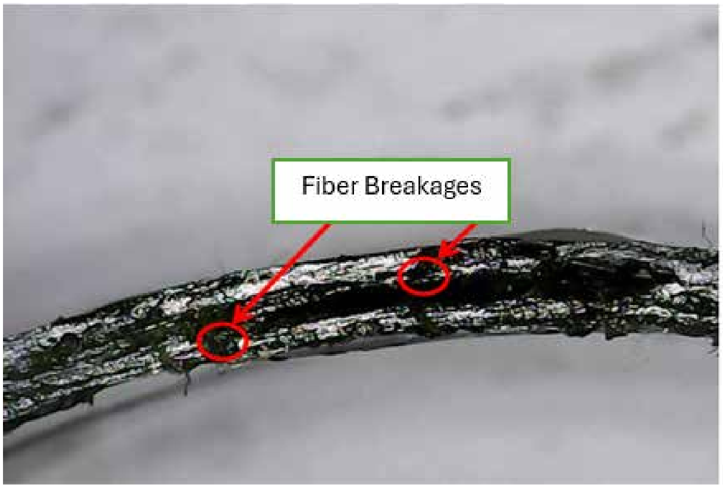
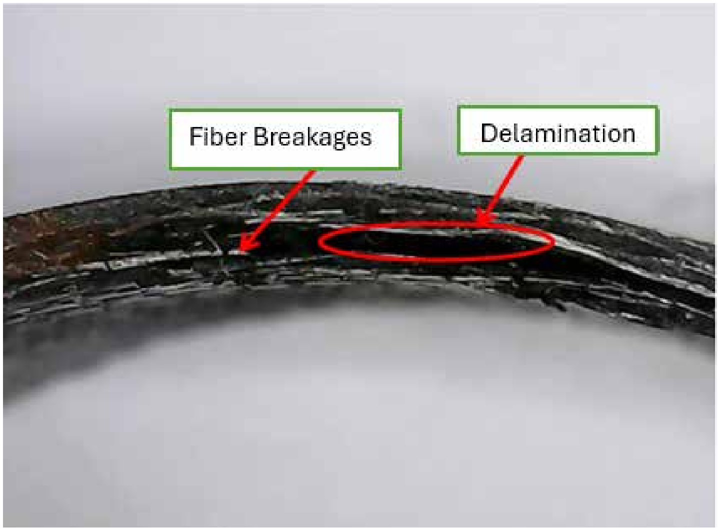


Figure 26

Test graphs with 15J



Since the GCG array contains 8 layers of glass fibers inside and outside and 2 layers of carbon fibers in the middle, it is a less strong structure compared to the CGC array. Therefore, the number of fiber fractures and delaminations continues to increase at increasing energy levels. Damage types are more stable in the material damage zone. Damages in the form of matrix cracks were observed on the impact tip contact surface.

Nanoless GCG array

Microscope examination images of the post-impact section of the nanosized GCG array are given in Figure 27, Figure 28 and Figure 29.

Figure 27

Test graphs with 5J

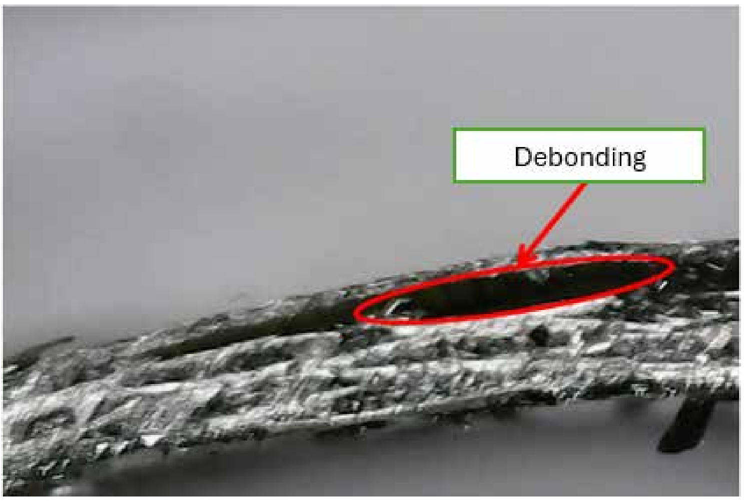


Figure 28

Test graphs with 10J

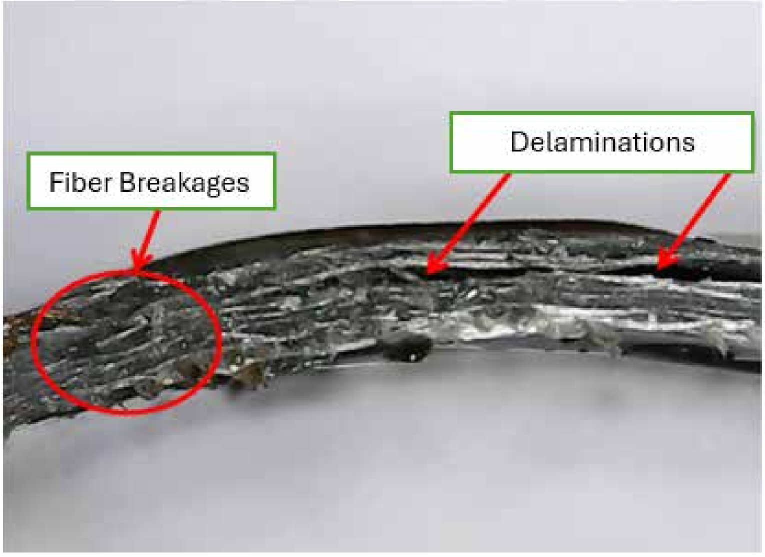
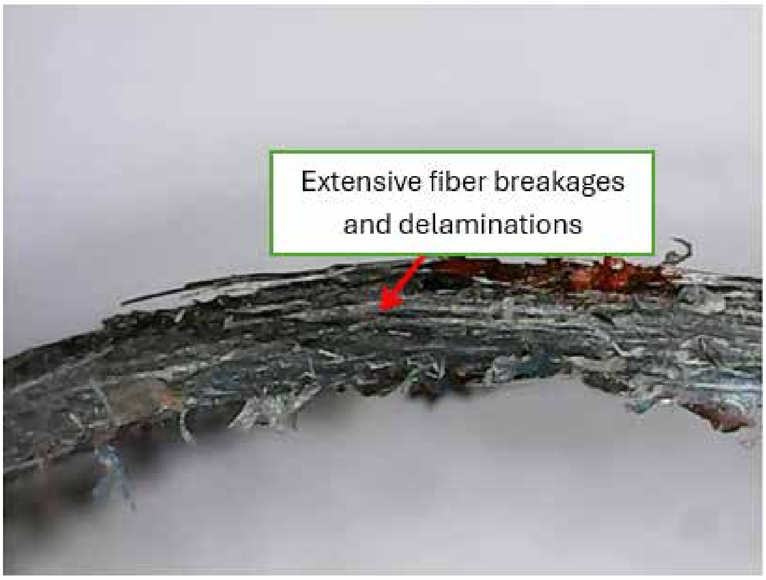


Figure 29

Test graphs with 15J



In this array, an increasing number of delaminations and fiber fractures were observed at increasing energy levels. At the 5J energy level, delamination between glass fiber and carbon fiber was observed. It is thought to be probably caused by a manufacturing defect.

When the damages were compared at equal energy levels with and without nanos in the GCG array, it was observed that the material with nanos was more stable, with shorter delaminations and fewer fiber fractures, while the material without nanos showed longer and more fiber fractures.

Results

Compared to the filament winding technique, the fabric winding method exhibits a structure similar to the layered composite production. This method has a function of reducing shear stresses compared to the filament winding technique. Since the preferred CGC array contains 8 layers of carbon, it is a more stable and rigid structure than the GCG array containing 8 layers of glass fiber. In this study, the effects of 1% carbon nanotube reinforcement on the impact strength of the hybrid structure at the layer level are as follows;

- CGC arrays have higher impact strengths than GCG arrays at the nanoporous and non-nanoporous level.

- Compared to GCG arrays, CGC arrays have higher energy absorption and rebound energy at lower time and displacement ranges with and without nanos than GCG arrays.

- In general, when the force is increased, it is concluded that the nanostructures are damaged in shorter time periods at higher forces in accordance with the literature, while in the GCG array, this time period is wider, so the damage area is wider and the fractures are more numerous in smaller sizes. 1% nanotube additive reduces the damage of the materials and increases the force strength, but it is thought that the impact strength will increase at a more predictable level by increasing the nanotube additive up to 3% in accordance with the literature.

- The material with CGC nanoparticles was destroyed at higher forces at a smaller displacement rate and rebounded harder. In the non-nano material of the same array, lower force, earlier deformation, larger displacement and more moderate rebound occurred. In the GCG array, larger displacement and much lower rebound forces occurred due to a more flexible impact glass fiber. The non-nanosized version of this array produced a larger displacement and therefore a larger deformation zone. This may be due to the more rigid structure of the carbon fiber layer under the glass fiber layer.

- In the material with CGC nanoparticles, smaller damage occurred at high forces and the material reached a larger displacement period. Although the damage started later in the non-nanosized version of the same array, fiber fracture occurred, probably due to the effect of being non-nanosized, and after the material reached almost the forces of the nanosized version, the rebound effect was not fully visible due to the effect of fiber fracture and the material deformed. In the GCG array, the material started to be destroyed at lower forces. The material flexed significantly due to the effect of glass fiber. In this array, the effect of the nanotube caused the material to suffer smaller damage at higher forces.

- Since the CGC array has a more stable and rigid structure in terms of strength, it absorbed more energy and spent this energy through matrix and fiber fractures. In the GCG array, on the other hand, there is a deformation with larger time periods and lower amplitude.

- As the energy levels increase, it is seen in the energy/displacement graphs that the carbon nanotube difference in both sequences affects the material values very little. Nevertheless, nanomaterials exhibit more stable energy absorption and displacement rates at all energy levels. Since the GCG array has a more flexible structure in terms of strength, it absorbed lower energy levels at larger displacement ratios. The carbon layers in the center of this array increased the energy absorption ability of the material.

- As a result, the homogeneous distribution of CNTs in the matrix, due to the large number of interfaces, increased the strength of the composite more in the CGC array than in the GCG array. In low reinforced specimens such as GCG array, 1% CNT reinforcement resulted in higher impact strength.

- The damage mechanism of unreinforced CNT pipes is fiber separation, first matrix fracture and then delamination and fiber breakage. MWCNT reinforcement led to crack tip opening instead of delamination, which reduces the strength of the interlayer.

- Optical monitoring of composite pipe cross-sections reveals visual and quantitative reduction of delaminated regions by the addition of nanoscale reinforcements to the epoxy matrix.

- Hybrid pipes with CGC stacking have higher impact resistance, while pipes with GCG stacking have larger damage area.

- It is concluded that the resistance to impact force increases when a carbon fiber layer is placed in the interlayer of the GCG pipe.

- The smallest displacement amount of the damage formation in the hybrid pipes during impact was obtained in the sample with CGC nanos, while the largest displacement amount was obtained in the sample without GCG nanos.

- The maximum contact force and contact time increase with increasing impact energy. The addition of CNT to the composite tube affected the displacement and the amount of energy absorption of the specimens during impact. For the same energy level, the maximum displacement value and minimum energy absorption were obtained from 1.0 wt% CNT doped tubes. CNT doping had a positive effect on the impact behavior of GRP tubes. This is because the addition of CNT improved the interfacial bonding between the matrix and the reinforcing elements. Morphology characterization studies of the composites showed that CNTs were well dispersed in the polymer matrix at the nanoscale. Thus, it provides mechanical interlocking between the fiber and the matrix. Therefore, the laminar fracture strength was increased and low-speed impact resistance was improved.

When the microscope images are examined;

- As the energy levels increase in the CGC nanofiber material, the number of fiber fractures and their orientations increase in the damage zone. Delaminations are more balanced but tend to occur between layers. As the energy levels increase, delamination lengths and numbers increase.

- In the CGC nanosilver material, fiber fracture and delaminations increased again as the energy level increased. At the energy level with 15J, delamination occurred.

- When a comparison is made at the same energy levels of CGC nanoporous and non-nanoporous materials, more balanced and stable fiber fractures and shorter delamination lengths are observed in the nanoporous material. In the nanosilver material, longer delaminations, stiffer fiber fractures and delamination are observed.

- Since the GCG array contains 8 layers of glass fibers inside and outside and 2 layers of carbon fibers in the middle, it is a less strong structure than the CGC array. Therefore, the number of fiber fractures and delaminations continues to increase at increasing energy levels in GCG nanomaterial. Damage types are more stable in the material damage zone. Damages in the form of matrix cracks were observed on the impact tip contact surface.

- In the GCG material without nanos, an increasing number of delaminations and fiber fractures were observed at increasing energy levels. At 5J energy level, delamination between glass fiber and carbon fiber was observed. It is thought to be probably caused by a manufacturing defect.

- When the damages were compared at equal energy levels in the GCG nanofiber and non-nanofiber materials, it was observed that the nanofiber material was more stable, with shorter delaminations and fewer fiber fractures, while the non-nanofiber material had longer and more fiber fractures.

- Further studies are planned to compare the production of composite material with circular cross-section by fabric winding technique with the production of carbon fiber material by filament winding technique.

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