OCTOBER 2017 M.Sc. in Mechanical Engineering AL-OGAIDI, BASHAR RIDA YOUNUS

UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
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EFFECTS OF NANOGRAPHENE PARTICLES ON HYBRID COMPOSITES

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IN
MECHANICAL ENGINEERING

BY
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Effects of Nanographene Particles on Hybrid Composites

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Supervisor

Assoc. Prof. Dr. Ahmet ERKLİĞ

by

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Bashar Rida Younus AL-OGAIDI

ABSTRACT

EFFECTS OF NANOGRAPHENE PARTICLES ON HYBRID COMPOSITES

AL-OGAIDI, Bashar Rida Younus

M.SC. Thesis in Mechanical Engineering

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Because of the great attention of researchers with composite materials, the studies deal with them are increasing day to day to satisfy the requirements of various industrial applications. A novel class of nano fillers newly discovered is graphene which had captured the attention of researchers recently due to unique features such as high absolute strength, tensile modulus, high aspect ratio, and high surface area. The present investigation was basically performed to highlight the influence of Graphene Nano-platelets (GNPs) on tensile strength, flexural strength, impact resistance and vibration properties of carbon-glass fiber/epoxy hybrid and non-hybrid composite laminates. GNPs were dispersed with different weight contents of 0.1, 0.25 and 0.5 %wt. within epoxy matrix. All tests with and without GNPs fillers were performed comparatively. From the experimental results, it can be said that the addition of GNPs into epoxy matrix has a considerable effect on the mechanical performance of the hybrid composite laminates. The improved strength refers to high bonding between GNPs, epoxy and fibers at the interphase.

Key word: Graphene Nano-platelets, impact resistance, tensile strength, flexural strength, vibration

ÖZET

NANOGRAFEN PARÇACIKLARIN HİBRİT KOMPOZİTLERDEKİ ETKİLERİ

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92 sayfa

Araştırmacıların kompozit malzemelere olan büyük ilgisi nedeniyle, çeşitli endüstriyel uygulamaların gereksinimlerini karşılamak için yapılan çalışmalar gün geçtikçe artmaktadır. Yeni keşfedilen yeni bir nano dolgu, yüksek mukavemet, gerilme modülü, yüksek en-boy oranı ve yüksek yüzey alanı gibi benzersiz özelliklerden dolayı son zamanlarda araştırmacıların dikkatini çeken grafendir. Bu çalışmada nano-grafen parçacıkları ile üretilen karbon-cam elyaf / epoksi melez ve melez olmayan kompozit plakaların gerilme ve eğilme mukavemetleri, darbe direnci ve titreşim özellikleri araştırılmıştır. Grafen nano parçacıkları, ağırlıkça% 0.1, 0.25 ve % 0.5 oranlarında epoksi reçine içerisine eklenmiştir. Grafen nano parçacıkları olan ve olmayan hibrit kompozitlerin deneyleri karşılaştırmalı olarak yapılmıştır. Deney sonuçlarına göre, epoksi matriks içine grafen nano parçacıkların eklenmesinin, hibrit kompozit plakaların mekanik performansı üzerinde önemli bir etkisi olduğu söylenebilir. Artan mukavemet değerleri, ara safhadaki grafen nano parçacıkların, epoksi ve lifler arasındaki yüksek bağlanmayı ifade eder.

Anahtar Kelimeler: Grafen nano parçacıklar**,** darbe direnci, gerilme mukavemeti, eğilme mukavemeti, titreşim

This thesis is dedicated to my beloved son (Youssef).

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LIST OF SYMBOLS/ABBREVIATION

A	Cross-Section of the Beam
ASTM	American Society for Testing and Materials
CF	Fiber Carbon
CFRP	Carbon Fiber-Reinforced Composites
CNC	Computer Numerical Control
CNT	Carbon Nano Tube
DAQ	Data Acquisition Card
DMA	Dynamic Mechanical Analysis
Ē	Storage Modulus of the Beam
È̀	Loss Modulus
EC	Electric Cutter
Ef	Flexural Modulus
EPC	Epoxy Reinforced Polymer composite
FG	Fiber Glass
FRF	Frequency Response Function
FRP	Fiber Reinforced Polymer
FREPC	Fiber Reinforced Polymer composite
FRPs	Fiber Reinforced Polymer Composites

GFRP	Glass Fiber Reinforced Polymeric composite
GNP	graphene nanoplatelet
GnPs	graphene Nano particles
GO	Graphene oxide
I	Moment of Inertia
L	Free Length of the Beam
MWCNT	Multi-Wall Carbon Nano Tubes
NHTSA	National Highway Traffic Safety Administration
PNCs	polymeric Nano-composites
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
UV	UltraViol
VARTM	Vacuum-Assisted Resin Transfer Molding
wt. %	Weight Percentage
σt	Tensile Strength
σf	Flexural Strength
ω_n	Natural Frequency
ξ	Damping Ratio
ρ	Density of the Beam.

CHAPTER 1

INTRODUCTION

1.1 Preview of Composite Materials

Materials are generally divided into three major groups which are namely metals, ceramics and plastics. Each of these three groups has different properties. Also, they have some weakness or superiority from each other’s. Due to gather superior properties of these groups in one material or to obtain a new feature from these groups, they combine at the macro level and these new structure is called as composite. There are several comments that define composite materials. Some of them are: A composite is an essential material that formed of two or more joint constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is known as the reinforcing phase and another one in which it is surrounded is known as the matrix. The reinforcing phase material may be in the form of particles, fibers, or flakes [1]. The fibers (or reinforcements) are the primary load bearing members.

1.2 Classification of Composites

Whatever the discussion and the analysis of how the composite properties are affected by their internal reinforcement of the geometries, a systematic classification of composite plays a major role. Fibrous and particulate are considered two sort of the composites. It can be subdivided into specific categories in addition to that each one has unique properties as it is clarified below in 1.1[2].

The strength, alignment and volume fraction from the sort of these materials, namely, the fibers is very essential by determining the composite of the last properties. It has the role of the binder, namely, the matrix to which holds the fibers in needed direction. What so called generally a polymer that stands for matrix and which described in a comical manner inert maintain the fibers towards the effects of opposed environment.

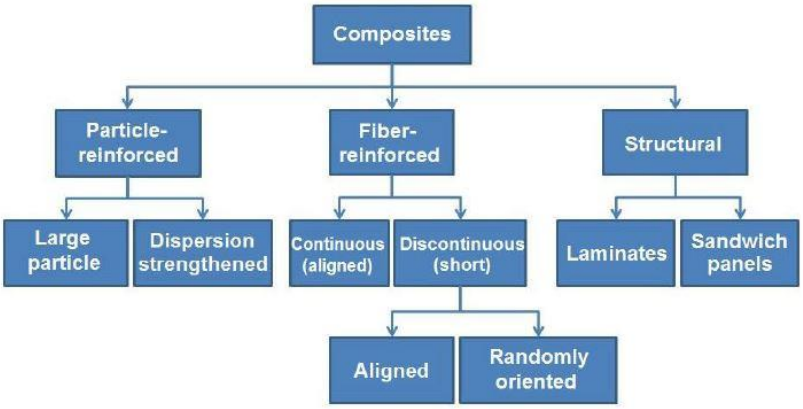

Figure 1.1 Composites Classification [2]

It is known that the matrix to the fibers is conveyed by the applied force. The essential trait of the composites inside the routine materials can be the high strength-to-weight ratio. The composites give different benefits like, fatigue resistance, corrosion resistance, electrical and thermal insulation that is additional to the structural advantage [3].

Material properties - A combination of the two characteristics of composites depend on

- Characteristics of phases
- Geometry of dissipated phase (particle size, distribution, orientation)
- Amount of phase

Some of fiber types:

- Natural fibers (cotton, hemp, jute, flax, ramie, sisal, bagasse, and banana, etc.)
- Synthetic fibers (Glass fibers, Carbon fiber, Aramid fiber ...etc.).

Polymer composites, the amazing materials are becoming substantial part of today's materials due to the specifications such as corrosion resistance, low weight, high fatigue strength, and faster assembly. They are used as materials in manufacturing of space vehicle, home building, aircraft structures, electronic packaging, medical equipment etc. The main difference between blends and composites is that the two major constituents in the composites remain recognizable while these may not be recognizable in blends. Over the years, toughening of fiber-reinforced polymer composites has been a highly active research area.

Polymer matrix can be divide to:

i. Thermoplastic (Acrylic, ABS, Nylons, polyethlenes, PVC)
ii. Thermoset (Epoxy, Phenolics, Polyimides)

Certainly, a very strong emphasis over the recent years has introduced for polymeric nano-composites which stands for (PNCs) in the place, the dispersed phase should be in nano-meter scale in addition to have various shape. By using nano-scale through micron-scale materials gives a good displaying of physical and chemical.

It simple to show why nanoparticles have exceptionally high surface areas. Here a strong cube of just one material of 1 cm on a side includes 6 square centimeters of surface area and it is the same amount in one side of half a stick of gum. In contrast, if the volume of only 1 cubic centimeter was put in other words, filled with cubes of 1 mm on a side, the results are 1,000 millimeter-sized cubes (10 x 10 x 10), under separate of them contains a surface area of 6 square millimeters, because of the whole surface area of 60 square centimeters, around one side of two-thirds of a 3” x 5” note card and they are the same. It has been noticed that If the 1 cubic centimeter is having the materials put inside with micrometer-sized cubes the results can be a trillion (10^{12}) of them and here each of them with a surface area of 6 square micrometers is the amounts of total surface area to 6 square meters. As the single cubic centimeter of volume can be put inside 1-nanometer-sized cubes—10^{21} of them, the results will be that each of them with an area of 6 square nanometers—their total surface area reaches to about 6,000 square meters as shown in Figure 1.2 [4].

It can be introduced into the polymeric matrix depending on the application that is to say many types of nano-particles. nano particles, nano-platelets, nano tubes, fullerenes and nano-wires are typical materials. Among the others carbon based nano-fillers are dominant as reinforcements because it shows better thermal and mechanical properties and having addition to that it has pointed in the field of polymer nanocomposites.

There are two major topics in improvement of PNCs, the selection of nano-filler which is suitable for polymeric matrix and the processing technique to disperse in the polymeric matrix. The dispersion state of nano-fillers has a huge impact on the characteristics of polymeric materials this is done in the polymeric matrix.

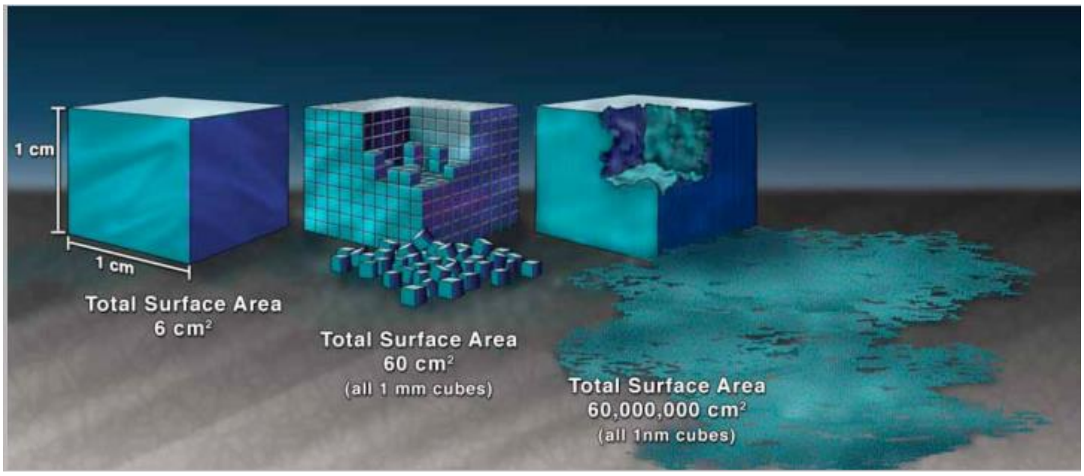

Figure 1.2 Explanation displaying the effect of the increased surface place supplied by nano-structured of these materials. [4]

Both of them, the matrices in addition to the Composite materials depending on the materials of epoxy resins which are frequently applied in the airspace, automotive and industries of marine [5]. It can be clear that structure of the epoxy matrices and the modification of molecular architecture are the mechanical property profile which is easy to be developed. When we add the amount of the crosslink density of material of epoxy, it can possibly to make it very well, namely, the strength and stiffness. Vice versa the way of highly cross-linked epoxy matrices undesirably could be very weak and as a result, it leads to spontaneous failure of these materials [5].

With high toughness by providing epoxy matrices in addition to maintain the thermo-mechanical materials is hard, and the area of heavy research is the result [5]. In epoxy polymers when we add nano-particles, it appears to develop highly the materials of the composite which has done above. Addition of nanoparticles can easily develop many properties of composite materials like flame resistance, strength, stiffness, electrical conductivity, and thermal [6]. Nanoparticles dispersed in a polymer matrix is the most of the problem which has been faced an agglomerate very easily and in addition to get a good dispersion of it [6-7]. Between polymer and nanoparticle, existence of poor interfacial adhesion cause problem has been reported [6]. The different structures of composite materials are used in the construction of aircraft Figure 1.3 [8].

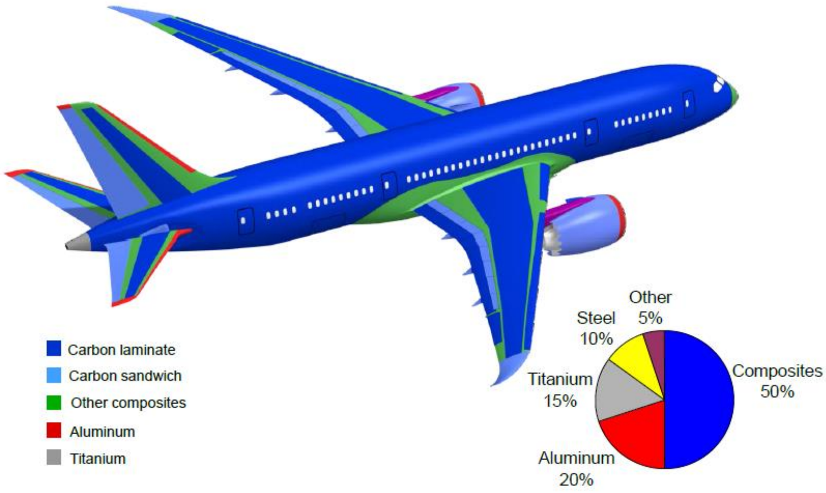

Figure 1.3 Use of composite materials in different bodies of an aircraft Boeing 787 [8]

Apart from the aerospace industry, advanced composites are also being used in high performance automobile components, as well as infrastructural applications. Modern high-performance cars are being fabricated with engine, transmission system and interiors assembled on a composite tub, as shown in Figure 1.4 [9]. This considerably reduces the weight of the car resulting in increased fuel efficiency and reducing emissions without compromising performance. Figure 1.5 [9] shows the application of composite tubes for reinforcing the structure of a bridge.

Figure 1.4 Carbon fiber composite tub used in high performance automobiles [9]

Figure 1.5 Composite tubing used in a bridge (infrastructural application) [9]

Many research have been done in the past about nanoparticles composite which contains alumina, clay, silica and carbon nanotubes refer to (CNTs) [6-7]. However, recently, considerable researches have directed towards graphene due to its many exceptional properties. Recently the studies have appeared and displayed promising results when it used graphene oxide as a precursor for graphene production. graphene oxide, in addition, has useful materials of its properties e.g. a high level of dispersion in polar solvents, with polymers a better compatibility when it is compared to CNT's

1.3 Hybrid Composite

The hybrid composite materials are composite materials that have more than one fiber (glass, boron, kevlar or carbon) or more matrixes (polyester, epoxy and ect.) in its production stage. Using hybrid composite can increase some of the properties of which cannot be achieved by using traditional composite materials. Also hybrid composites can be more cost-effective (by using less cost fibers with more durable and more expensive ones) from the traditional composites or conventional materials. There are four basic types of hybrid composites as showed in Figure 1.6.

- ❖ Interply hybrids, that consists of plies from two or more different unidirectional composites stacked according to a specific sequence.
- ❖ Intraply hybrids, consisting in two or more different fibers mixed in the same ply.
- ❖ Interply-intraply hybrids, in which interply and intraply hybrids are stacked according to a specific sequence.

❖ Super hybrids that are as and aspect of resin-matrix consist of plies which is stacked according to a specific sequence.

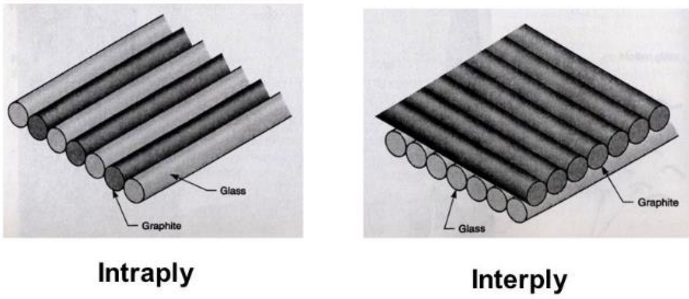

Figure 1.6 Type of hybrid composite.

1.4 Graphene

Graphene is called the mother of all graphitic forms Figure 1.5. In addition, it is considered the structure block for different of sp2 carbon allotropes. It can be wrapped up into bucky balls and rolled into [10-11]. The Figure shows a one graphene sheet + a Bucky ball + a carbon nanotube, and some graphite layers [10].

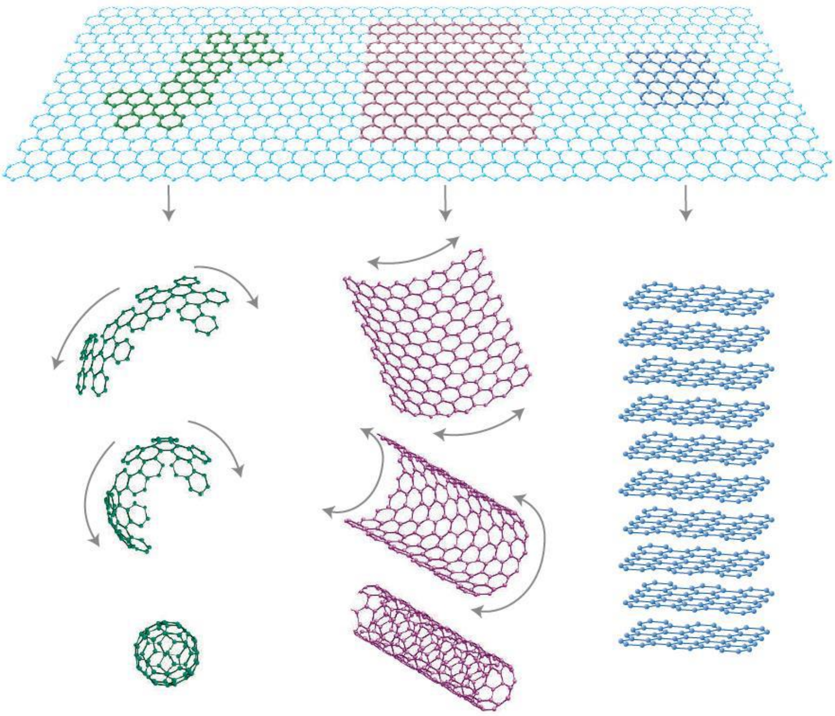

Figure 1.7 The mother of all graphitic forms is the Graphene [10].

The Figure clarifies one graphene sheet graphite layers, a carbon nanotube and a Bucky ball [10]. We come to clarify that graphene consists of just one-layer sheet of carbon which is arranged in a chicken wire what so called (hexagonal) lattice of sp2 carbon, the strongest material on earth [12]. It has a high surface-to-volume ratio and to different matrices, it is very advantageous for easy binding [13]. It is one layer, to have an intrinsic tensile strength higher than any other material which discovered [14]. Figure 1.8 [15] shows the structure of graphene.

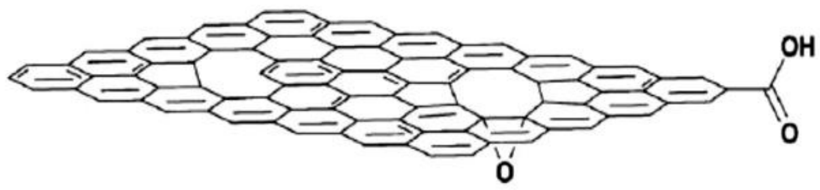

Figure 1.8 Structure of graphene. [15]

It can be prepared, namely, over various methods containing top-down methods like liquid phase exfoliation, or bottom-up methods like chemical vapor deposition (CVD) [16].

1.5 Application of Graphene Based Polymer Composites

For many applications for example engineering materials, graphene/polymer composites are both of them have been researched shielding, fire retardant materials, gas barrier, sensor, turbine blades, conductive composite, in automotive and so on [17-18]. It becomes very crucial components in the design of new windmill blades which is advanced polymer composites materials, these materials require light-weight, high-strength materials. Promising materials in the pursuit of developing structural components is graphene-based polymer composites which has a high strength-to-weight ratio. Dispersion of graphene in the matrix, the amount of filler loading and between them the interaction so that the components are very strong parameters by determining the prospect of graphene-based composites for real-world applications.

Yet remain very light Figure 1.9. This material will give the benefits to improve superior durability and dimensional stability and better flame behavior. [19]

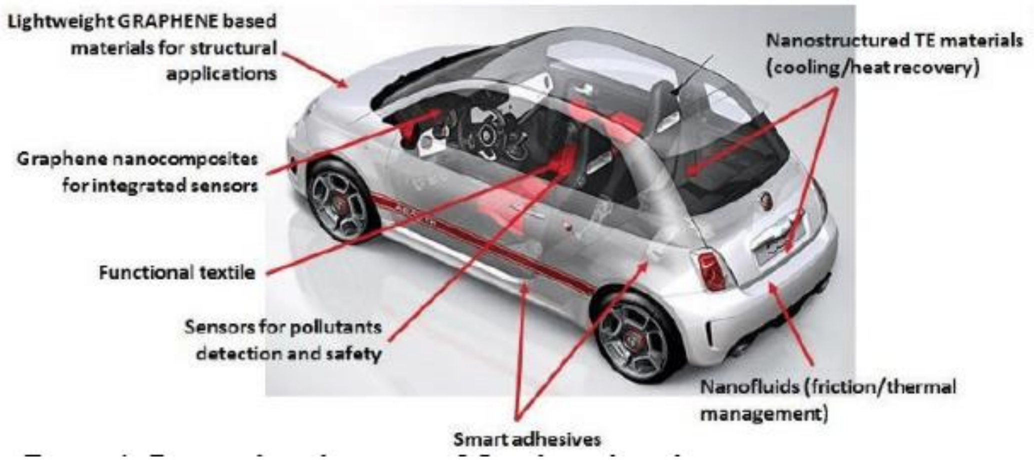

Figure 1.9 Potential applications of Graphene-based composite in automotive

1.6 Importance of the Study

Using nano-scale material over them micron-scale materials has trait for exhibiting good chemical and physical of properties due to their large surface area. Various nano-particles can be incorporated inside the polymeric matrix which is depending on that application which is aforementioned carbon based nano fillers spread as reinforcements as they display, electrical and thermal properties and the same time, can open the floodgates in the field of polymer nanocomposites. It has two major issues, namely, the development of PNCs; the first one is the choosing nano-filler the reason is compatible with the polymeric matrix on the other hand, the second one is the processing of the technique inside it, in the polymeric matrix is dispersed. In the polymeric matrix in the dispersion state of nano-fillers which has an enormous impact upon the materials of polymeric properties. Recent studies exhibit a real degree of dispersion which is attained by either to through sonication or to means of high shear mixing where the polymer is subjected to very high shear forces.

CNTs is specifically as additives to polymer matrices which explored widely. the properties of high aspect ratios in addition to stiffness and high specific strength have displayed the reason is improving strength and stiffness of resulting FREPC and EPC nanocomposites; their beneficial effects are happening by chance on the degree from its dispersion over "the composite polymer matrix "[8]. It can provide enhanced dispersion and improved interfacial interaction between the polymer matrix and functionalized nanotubes namely, Chemical fictionalization of CNTs.

The main advantages that drive the use of composites are weight reduction, corrosion resistance, wear resistance, part-count reduction, easy of handling, excellent damage tolerance and impact resistance great specific strength (high strength with less weight or more generally, it has high stiffness with less weight), enhanced fatigue life and low thermal expansion.

The significance of this thesis comes from increasing role of nanographene in advanced industry application due to its amazing properties. FREPCs offer higher specific strength and stiffness at a low density when it compared to steel. However, the brittle materials of FREPCs are strong and stiff fibers and in addition to owning their cross-linked polymer matrices. Both of them; the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) have given strict fuel economy manners for light duty vehicles. High performance, fiber reinforced epoxy polymer composites (FREPCs) in addition to light-weighting vehicles are going to play a very important role in carrying on to exceed NHTSA and EPA standards.

1.7 Scope of the Dissertation

In this thesis, several of epoxy based composite laminates having glass and carbon fiber are prepared with different arrangements and different graphene nano particles (GnPs) contents. Impact resistance and natural frequencies of manufactured composite plates are determined by Charpy impact test and vibration device. Also, tensile and three-point flexural bending tests are carried out using tensile testing machine

1.8 Research Objectives

The aim of the thesis is to investigate whether the addition of graphene nanoplatelets on mechanical behavior of nanocomposites based on an epoxy system. Such as (impact resistance, tensile, flexural strength, vibration and damping,) of hybrid glass-carbon/epoxy composite will be investigated.

1.9 Outline of the Study

This dissertation is subdivided into five different chapters:

Chapter 1 provides introduction of composite materials and definitions. Chapter 2 contains a literature survey of previous studies. This chapter summarizes how various nano materials effect on the mechanical properties of composites. Literature review has been grouped in six sections: first introduction, second general studies about particulate effect on composite material, third section studies on epoxy nano composite with various graphite compounds, forth section studies on epoxy nano composite with grapheme, fifth section studies on glass fiber nano composite with grapheme, sixth section studies on carbon fiber nano composite with graphene and seventh section conclusion on literature survey. Chapter 3 describes the materials which used throughout this thesis and experimental methods that utilized and mechanical tests which were applied. Chapter 4 contains standards to determine the mechanical properties and result with discussion are given in this chapter. Chapter 5 summarizes all key results of the hybrid graphene/polymer nanocomposite and suggests future research directions.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

The definition of advanced materials are the materials which provide high specified materials. The expansion of composite was a respond towards the requirements of modern technology. In contrast to these materials which are connected as a compliant matrix reinforced with stiff factors. This thought is lent from nature, plants' stalks and leaves, animal are anisotropic materials reinforced by fibers. Literature review has been arranged in 6 sections as: general literature survey on composites and nanocomposites reviewed in section 2.2. Some studies on epoxy nanocomposite with various graphite compounds are reviewed in section 2.3. Some studies on epoxy nanocomposite with grapheme are reviewed in section 2.4. Some studies on glass fiber nanocomposite with grapheme are reviewed in section 2.5. Some studies on carbon fiber nanocomposite with grapheme are reviewed in section 2.6. Finally, section 2.7 recorded conclusions on literature survey.

2.2 General Literature Review on Composites and Nanocomposites

Due to the high attention of researchers with composite material, the studies of composite material are increasing day to day to satisfy the requirements of various industrial applications. Some of studies about this type of materials are given in this section.

Anigol and Anil [20] examined the result of three filler materials on mechanical features of carbon/epoxy composites. The compositions weights were 40% epoxy, 50% carbon fiber and 10% granite powder or aerosil or coremat. Tensile, hardness and three-point bending test were performed. The results revealed that aerosil filled composites gave best values for tensile strength whereas coremat filled composites gave good results for bending and hardness.

Reddy et al. [21] studied the impact of composite laminates at various contents of nano clay and incident energy on the S2-glass/epoxy composite impact resistance. Various nano clay contents and various low velocity impact energy values were considered. The results showed that adding clay can improve the energy absorption of composites.

Sudheer et al. [22] studied the mechanical features of (PTW) reinforced epoxy based composites. Epoxy composites modified with PTW from 0 to 20 wt. % were produced and then tested. Results showed that inclusion of PTW led to an increasing in density, hardness and temperature of heat deflection. Also, tensile strength and flexural strength were improved with inclusion 10 wt. % PTW.

Daniel [23] studied the mechanical characteristics of four systems of polymer nanocomposite and two pure polymer reference systems. Nanoparticles of magnetite (Fe_3O_4) and alumina (Al_2O_3) were filled in polystyrene and poly methyl methacrylate matrices. The dynamic mechanical analysis, tensile and nano indentation tests were conducted. The results showed that these nanocomposite systems introduced worse properties than their neat polymer systems.

Uddin and Sun [24] investigated the improving of unidirectional glass/epoxy composite strength by enhancing matrix with particles of nano-silica. The results indicated that nano-silica particles addition can increase the longitudinal compressive strength, longitudinal and transverse tensile strengths.

Jumahat el al. [25] studied the influence of nano clay inclusion and compressive advantage of the Epikote 828 epoxy properties. Epoxy based nanocomposites with content of 1 to 5wt% nano-clay were prepared. Test results showed that the compressive advantage depend on amount of clay exfoliation in the epoxy. Also, decrease in compressive strength were recorded for 1 and 3 wt. % clay.

Hanemann and Szabo [26] gave a review about considerations of the inorganic nanoparticles features, the most important methods for ceramic nanoparticles and nanocomposites, modifying nanoparticles surface and composite formation and its problems. They introduced a summary about classical nanocomposite characteristics, like thermo- mechanical, dielectric, conductive, magnetic and optical characteristics.

Amir et al. [27] studied the flexural properties of the glass/epoxy nano-clay composites. The resin was prepared using a three roll mill machine to have exfoliated structure nanocomposites. Vacuum method was used to fabricate laminates specimens which were tried in three-point bending configuration with 1, 3 and 5wt% clay content. The results appeared that the maximum improvement of flexural strength and flexural modulus, respectively, were got at 5wt% nano-clay content.

Wildan & Ishak [28] investigated the influence of clay embedding on the mechanical characteristic of epoxy composite. nanocomposite was prepared using polymerization way. The flexural, tensile, impact strength, and fracture toughness were tested, also tribology and morphology behaviors were determined. Results indicated that the addition of clay up to 3wt% increased the tensile, flexural, impact strength, and the fracture toughness and more than 3wt. % of clay gave negative effect. 3 wt. % of clay Introduced best mechanical properties, water resistance and wear resistance

Naik et al. [29] examined the impact of carbon and glass fibers configurations on impact behavior and post impact compressive characteristics. They indicated that the hybrid composites were lower notch sensitive compared to neat glass or neat carbon composites. It was also shown that it is better to cover the glass fiber lamina with a carbon fiber lamina to get lower notch sensitivity.

Skandani et al. [30] fabricated epoxy filled zinc oxide (ZnO) nanorod Bi-layered carbon fiber hybrid composites and examined for vibration mitigations using dynamic mechanical analysis. The results showed that the growing of zinc oxide nanorods on the top of carbon fibers causes a slight decrease (~7%) on the storage modulus whereas increases the damping efficiency to 50%.

2.3 Some studies on epoxy nanocomposite with various graphite compounds

Chao and Demei [31] studied the enhancement of dielectric characteristics and toughness by modified epoxy with graphite nanosheets. They noted that the dielectric incorporate of epoxy/graphite nanosheet composites enhanced with 3.5 wt. % modified by graphite loading. Furthermore, they investigated about 35% enhancement in properties of toughness, tensile and storage modulus.

Rafiee et al. [32]. Investigated the chance of graphene oxide addition for fracture toughness enhancement and flexural strength. They utilized graphene oxide to modify epoxy in the bulk and 20 noted important enhancement in the stiffness, toughness, fatigue resistance and flexural strength at less graphene oxide content.
Zaman et al. [33] utilized two kinds of epoxies to study the effect of adding functionalized graphene. They used sonication and chemically modification to get exfoliated graphene for functionalization. They noted an obtained enhancement of 96% for fracture energy release rate at 4 wt% graphene content. Over that, glass transition temperature was significantly enhanced at 2.5 wt. %.

Safdari and Al-Haik [34] presented a modern model for evaluating the electrical conductivity of carbon nanotubes with a mixture and graphite nanoplatelets. In this stage it considers an electron tunneling like active mechanism for insulator–conductor transition. That model was reasonable in addition to relevant experimental data mainly depending on a mono-nanofiller. It was seen that the hybridized nanocomposites changed by mixing these conductive nanofillers attained and improved electrical conductivities at the degree of lesser volume fractions It was explained that the adding of slight quantities of a greater aspect ratio auxiliary phase to a lesser aspect ratio main phase increases the composite electrical conductivity by several magnitude orders, namely, the present simulations.

Li et al. [35]. Studied the impacts of (CNT) and (GNPs) on the epoxy nanocomposites electrical and mechanical characteristics. When the total reinforcement loading is fixed at 2 wt. %, the composite consists of 1% CNT and 1% GNP record the maximum electrical conductivity. It was also observed that the flexural properties do not change alot because the hybridization, the fracture toughness enhances by 21% compared to nanocomposite of 2 wt. % GNP, or 57% compared to pure epoxy.

Wan et al. [36] studied the influence of silane functionalized GO (silane-f-GO) as-produced GO and content and silane functionalization on the mechanical characteristics of epoxy composites comparatively. Such as silane functionalization loading epoxy ended-groups is found to excellently increase the compatibility between the silane-f-GO and the epoxy. Improved flexural and tensile strength as well as fracture toughness of the composites modified by silane-f-GO were also noticed in the tensile/flexural and CT tests compared compared to pure epoxy and GO/epoxy composites. Fracture mechanisms, like crack pinning, crack bridging of sheets and deflection as well as matrix plastic deformation affected by the debonding/delamination of sheets, were recognized.

Min & Yu [37] found the dielectric constants of the composites are improved with rises in graphite nanosheet weight percentage under 3.5 wt. %, and are often greater than 100 in the great frequency range with 3.5wt. % graphite. The storage modulus & tensile strength of the composites rise with addition nanosheet content. These epoxy/graphite nanosheet composites, which display both great toughness and dielectric constant, might have potential application in inserted capacitor equipment.

Debelak, and Lafdi, [38] Showed the polymers modified by 20wt.% exfoliated graphite has noted an important decrease in electrical resistivity from 1.58 to 0.5 X cm. Thermal conductivity for the polymers including 20wt% exfoliated graphite has also been significantly enhanced from 0.2 to 5 W/m K. The flexural modulus raised to high expansion of 3.8 GPa which is higher by 60% than 2.4 GPa which is the value for the neat polymer.

Abdullah and Ansari [39] studied the influences of Graphene oxide (GO) on composite. The results were indicated the addition of Graphene oxide (GO) excellently improved the mechanical properties and high aspect ratio. Adding 1.5 vol. % GO to the epoxy matrix improved the tensile strength, hardness and tensile modulus of the composite compared to the neat epoxy matrix. The significance of the homogeneity of the composite for the mechanical characteristics of composites was demonstrated by a rise in the tensile of modulus when plotted with vol. % of GO and as it is shown, the best value was at 6 vol. % of GO. And the Tensile strength was obtained at 1.5 vol. % GO. While the impact strength increased at 4.5vol. % of GO addition.

DeValve and Pitchumani [40] examined the damping influences of CNTs entrenched into the matrix of fiber-reinforced composite laminates. The outcomes display that the adding 2wt. % content of carbon nanotubes to the matrix of carbon fibre reinforced composite materials can rise the damping in a stationary composite beam more than 130%.

Bortz et al. [41] showed that graphene inclusion significantly increases the toughness of epoxy. That could give an enhancement of about 65% in fracture toughness. The enhancement in ductile properties of samples can be attributed to the same phenomena. It is also noticed that energy required to rupture samples was raised with increasing GnPs loading in the epoxy. This recorded that sample withstands efficiently the external loads when GnPs loading was at 0.1 wt. %.

Chandrasekaran et al. [42] utilized three nanofillers (MWCNT, Graphene Oxide & GNP) and dispersed in epoxy matrix. Exploiting single edge notch 3-point bending test, the fracture toughness was shown as a function of the filler content. The toughening influence of TRGO caused 40% rising in KIC for 0.5wt% of filler. Besides that, the toughness enrichments were 25% for graphite nano platelets /epoxy & 8% for multi-wall carbon nano tubes/epoxy. Studies on fracture surface that crack pinning or bi-furcation by TRGO and crack face separation initiated from TRGO contributed to improve the fracture toughness.

2.4 Some studies on epoxy nanocomposite with graphene

Kumar el al. [43] investigated that over 0.01 wt. %, GNCs formed micron-size aggregates in the matrix as shown by optical microscopy likely due their great aspect ratio & the density of aggregates enlarged with content and followed a power law curve. For 0.01 wt% composite, the mechanical feature, especially fracture toughness (KIC) and critical strain energy release rate (GIC) are noted to rise by ~51% and ~140%; but modulus strength and flexural incremented by 23% & 22%, respectively as compared to neat epoxy. The high enhancement in the mechanical feature at small GNCs weight percentage of 0.01 wt. % is indorsed by the superior distribution of these high aspect ratio functional fillers in the matrix as determined by spectral Raman mapping.

Shi et al. [44] theoretically performed calculations to determine the coefficient of thermal expansion (CTE) based on the effective medium approach using Green's function way. The impacts of micro structural features were ransacked, including volume fraction, aspect ratio, and the orientation of graphene fillers. They demonstrated strong anisotropy of CTE when all graphene sheets in the composite were aligned in the in-plane direction due to the significant contrast between the elastic moduli of the graphene and epoxy. The in-plane CTE in the graphene /epoxy composite can be effectively reduced with small additions of graphene. Orientation dispersion among the graphene fillers significantly decreases the anisotropy of CTE. Accounting for the influences of all microstructural features, simulation results closely align with current experimental results.

They presented a micromechanical finite factor approaching because of the guess of the elastic mechanical of characteristics of graphene reinforced composites namely, Spanos et al. [45]. Those include graphene monolayers which are given inside the matrix. The volume factors inside the reinforcement is modeled which are depended on its atomistic microstructure during the matrix is made without stopping. It can use the Spring-based finite elements for the simulation of the discrete geometric structure. Between graphene and matrix, the load transfer conditions are made by utilizing the elements which connecting both of the materials. The results from which are the finite factors simulations clarify good agreement by the helping of current numerical values that are establish in the open literature.

Zegeye et al. [46] discussed additives in an article. Four sets of syntactic foams contained 0, 0.1, 0.3, and 0.5 vol. % of GPs were fabricated and tested. Volume fraction of microballoons in all syntactic foam samples was kept constant at 30%. Results revealed that the compressive and tensile moduli of the syntactic foams were significantly increased as compared to samples that did not contain GPs. The addition of GPs also raised the tensile strength while the compressive strength was only slightly raised. Optimal property improvements were obtained for very low filling fraction of 0.3 vol. %. Specimens with higher volume fraction of GPs (0.5%) showed deterioration in mechanical properties when compared to other GP containing samples. TEM study indicated formation of voids enclosed by undispersed GPs in the samples which could explain the properties decline. High matrix porosity could also play an important role in this observation. Utilizing surface modified GPs could allow incorporation of higher volume fraction of GPs homogeneously, thus growing the mechanical properties of the syntactic foams.

Chandrasekaran et al. [47] utilized two different ways for mixing to separate graphite nano-platelet in epoxy by sonication combined with high speed shear mixing and a three-roll mill and. The effect of adding GNPs thermal conductivity and on the electrical, storage modulus of the nano-composite in addition to fracture toughness were looked for. It is prepared ,GPN, by three-roll mill technique which is introduced a supreme electrical of conductivity about 1.8 _ 10_03 S/m for 1.0 wt% which is in three orders of magnitude higher other than those done by sonication. Here it can be clear that the percentage of increasing thermal conductivity just was 14% for 2.0 wt.% filler loading and 11% for 1.0 wt.%. 16% rise in storage modulus for 0.5 wt.% are results of dynamic mechanical analysis showed, in spite of the Tg was not shown any increasing, it is normal. It achieved for dissimilar loading of the filler weight ratio namely, Single edge notch bending (SENB) fracture toughens (KIC) measurements. Most significant at 1.0 wt. % loading is the toughening effect of GNP was where about 43% increasing in KIC which was appeared. Two different dispersion techniques, among of them, It gives the optimum distribution namely, the three-roll mill process, where both of them the mechanical and electrical materials were very well.

Leopold et al. [48] studied the influence of unmodified and graphene nanoparticle modified matrix fibers size. Neat matrix fibers showed a clear size effect of increasing tensile strength with decreasing volume because of the statistical defect distribution. Nanoparticle modified matrix shows no important size effect. Nanoparticles act as crack initiators and consume fracture energy. The particles sizes are independent of specimen volume, so that the failure initiating as well as energy absorbing mechanisms are available, independently of the volume. Fractography analysis of SEM images showed different energy dissipation mechanisms such as micro-damage at the graphene particles. Graphene pull-out, layer separation, layer shearing, formation of micro voids as well as crack separation and crack bifurcation are observed that depend on the orientation of the graphite layers to the fracture plane. These mechanisms dissipate energy and so that a graphene nanoparticle modification result in an increased fracture toughness and thus increased strength of an epoxy matrix system if the volume is large enough. The maximum stress in specimen of small volume depends on graphene layer orientation, so that, the covalent bonds of the nanoparticles should be orientated in loading direction.

Shokrieh et al. [49] used molecular dynamics–micromechanics manner to determine its rigidity from graphene epoxy which is nano-composites. It was proposed that the materials graphene sheets are cut in a not regularly way inside the matrix. The stiffness of a multilayered graphene nanoplatelet, firstly, was assumed when it used in (MD) which stands for the molecular dynamics. These results which were got by the materials i.e. molecular dynamics were utilized by the Halpin-Tsai (HT) micromechanics models and the Mori–Tanaka (MT) the reason expecting rigidity of nanocomposite. Both of the models are named the MD–MT and MD–HT models. The results which has got refer that the MD–MT aspect is more equal to results of experiments at very low filler elements which is (<0.25 wt. %) compared to the MD–HT model. The MD–HT aspect is more real at high filler contents of (>0.25 wt.%) and the contents with several graphene of nanoplatelet in addition to these mechanical materials of graphene epoxy nanocomposites, i.e. 1wt.% were considered and the optimum amount of grapheme and 0.05, 0.1, 0.25, 0.5 were the results

Yang et al. [50]) in developing the thermal and mechanical materials conductivity of epoxy composites were looked for. There is an influence between multi walled carbon nanotubes (MWCNTs) and multi-graphene platelets (MGPs). By introducing one-dimensional MWCNTs, the Stacking of individual two-dimensional MGPs is efficiently reserved. It can bridge adjacent MGPs and inhibit their aggregation, namely, long and tortuous MWCNTs which is resulting in a high connected area I nthe middle of the structures of MGP/MWCNT and the polymer matrix. It showed that MWCNT/MGP hybrid nanofillers displayed better solubility and in the same than individual of multi walled carbon nanotubes and multi-graphene platelets carried on. 35.4% greater than that of neat epoxy was The tensile strength of GD400-MWCNT/MGP/epoxy composites, just comparing to a 0.9% increasing tensile strength for multi-graphene platelets /epoxy composites inside the compound of epoxy. It raised by 146.9% namely, Thermal conductivity raised by using 23.9% for MGP fillers and GD400-MWCNT/MGP hybrid fillers.

Daloia [51] found that the storage modulus and surface energy increased by 62.5% and 55% respectively with graphene embedding. The tribological performance of graphene composites exhibited that this nanofiller was so active in stabilizing the coefficient of friction and wear rate decreasing. Pure epoxy displayed a great wear rate & an unstable coefficient of friction. Besides that, 5wt. % of graphene showed the maximum stable coefficient of friction. The enhancement in wear resistance was observed, as, the 10wt. % composite caused in a wear decrease of nearly 98% when compared to neat epoxy. It may be noted that the producing of graphene modified epoxy based composites was relatively easy, quick, and inexpensive while the samples exhibited enhancement in many relevant properties.

Shokrieh et al [52] studied the influence of adding GPLs to the epoxy nanocomposites. They observed improve the flexural bending fatigue life and the behavior of neat epoxy matrix and GPL/epoxy nanocomposites under displacement-controlled flexural loading conditions at room temperature was compared. The flexural fatigue responses of GPL/epoxy nanocomposites at 0.1, 0.25 and 0.5 wt. % were taken into account. The experimental results show that 0.25 wt.% of graphene nanoplatelet on life of fatigue was more effective in comparison with 0.1 and 0.5 wt.% epoxy GPL nanocomposites and originate that the behavior of the graphene/epoxy nanocomposites are evidently recognized in comparing with pure epoxy.

Wan et al. [53] studied level of graphene/epoxy dispersion and interfacial quality in composites, also, mechanical in addition to thermal characteristics of the composites which had effects by the surfactant treatments where they were studied. The surface treatments of graphene sheets when it uses non-ionic surfactant, it will be efficient in terms of compatibility in addition to epoxy resin with graphenewett ability. Re-agglomerate during curing of resin is the purpose of the pristine graphene sheets. While strongly the re-agglomeration of grapheme will be prevented by the attachment of surfactant molecules the way is of wrapping the sheets in addition to series of materials which is polymer. Both the dispersion and interface between graphene and epoxy can be significantly enhanced was referred to by SEM and TEM and next surfactant treatments.

Gültekin et al.[54] studied the result about nanocomposite adhesive which has got when he added graphene at 3 various ratios to the adhesive upon the tensile failure load in 4 various manners , the failure loads of the joint that the temperature was seen by him, They had no effect on the adhesive namely , the mechanical mixing technique and acetone ·It was noted that the standard deviations in the failure loads of the joints which has been got by (Method I, Method II and Method III) are compatible with the literature when they used namely in the nanostructure-reinforced adhesive ; however, at a high value was the standard deviation, approximately 5 to 30 It was attained namely , the standard deviation in the nanostructure-reinforced joints by (Method IV) which is new and its use was lower, at 1 % in this stage . That gives a good result when it compares reinforced joints more accurately and the failure load of the non-reinforced in addition by making the connection more reproducible. It was used effects the growth rate of the failure load of the joint in the graphene ratio. The improved rate in the failure loads of the joints was investigated, the greatest graphene reinforcement ratio was determined, and the result is 1%.

Rafiee et al. [55] showed the low additive (0.1wt. %) of graphene to epoxy nanocomposites can enhance mechanical properties, where carbon of single-walled nanotubes, and multi-walled carbon nanotube addition both of them at a nano filler loading of 0.10.002% were compared. They were the Young's modulus namely, the mechanical properties measured, fracture energy and fracture toughness of its properties towards the spreading of fatigue crack. GNPs remarkable outperform carbon nanotube addition is the results. It was 31% the result of Young's modulus of graphene nanocompositeand it is better than the pristine epoxy when it compares to 3% enhancement for single-walled carbon nanotubes. It was supported, namely, tensile strength of neat epoxy by 40% in addition to GNPs when it compares to about 14% enhancement for multi-walled carbon nano-tubes. 53% enhancing was the mode I which displayed more than the materials of epoxy when it compares to 20% enhancement for multi-walled carbon nanotubes. Different trends were appeared.

Da et al. [56] investigated Influence added 2 methods were engaged to understand this phenomenon. The approach was direct exposure of the nanofilled epoxy system, with 0 wt. %, 1wt. % and 2wt. % graphene content, to UVA light. The samples were contact to UVA light for 200 hours, and then, nano-indentation tests were conducted after the aging process. The II method was to make single lap joints (SLJ) utilized the same graphene content and then exposure the SLJ to UVA light for two hundred hours. The graphene nanostructures formed inside the It is clear and according to tests that nanofilled adhesive prevent the aging procedure moreover, it seems to show a perfect distribution route namely, the force-displacement curves which got from nano-indentation, it laid down at the same path as the large majority of the curves. The effects also specified an average enhancement on bearing-load capacity of 24.76% & 28.36% for 1 wt. % & 2 wt. % the time the single lap joints were verified; the results are for 100 hours aging respectively. There is a reduction on load capacity on condition when the aging reached two hundred hours.

King et al. [57] found that the materials of GNP which had added to the materials of the epoxy had broght about the elastic modulus increase from 2.72 for better of epoxy to reach about 3.36 GPa for the 6wt. % of it. At ultimate tensile, the strain strength gets down to be 8.0 (pure epoxy) to 1.5% for the mode loading 6wt. % from GNP. The ultimate tensile strength declined from 77.6 (pure epoxy) to 35.5 MPa for the formulation loading 6wt. % GNP in epoxy. By nano indentation in modulus measurements which went after the trends which had enrolled in the literature because of polymers. They were better than that got from macroscopic testing. Nano indentation utilized a slight volume of material which depending on material that is matrix rich or GNP rich, between the indents performed the the results were a lot. Hardness values stayed nearly constant at 0.24–0.26 GPa this the reason of the pure epoxy of 1–6 wt % GNP in epoxy composites. By nano indentation which appeared in the steady-state creep range was noted for pure epoxy namely inside the creep test and after the reaching creep load

2.5 Some studies on glass fiber nanocomposite with graphene

Kamar et al. [58] studied effect of GNPs additive into glass fiber/epoxy matrix composite. The distribution of GnPs into the interplay regions of FREPCs formed with vacuum assisted resin transfer molding (VARTM) has been advanced. The GnPs content in the produced nanocomposites was improved to 0.25 wt% with enrichments of 25% in mode-I fracture toughness and 29% in flexural strength. Yet, at greater content of GnPs, the enhancement in strengths was rather slight and the flexural strength were like to pure samples. Equally, drastic discounts in fracture toughness were saw at great GnP loading. Proctographic analysis of the first mode verified specimens showed that channel regions, where the warp and fill cross over, had a rather rougher fracture surface morphology due to of GnPs additive. Impact test at low-velocity drop weight of the composites advanced in this work exposure raised energy absorption behavior by inter laminar blend of GnPs. This improvement was noted to growth with growing inter laminar loading of GnPs.

2.6 Some studies on carbon fiber nanocomposite with graphene

Hallad et al. [59] used two various size micro and nano of graphene with carbon fiber to fabricate beam composite. The addition of graphene and carbon fibres in the control beams varied from 0.1 to 0.4% percent by weight of polymer matrix.

Composite beams were tested under flexural strength, which was strengthened by 35%, in order to evaluate their mechanical property such as load-deflection criteria. These results were then compared with those obtained from plain polymer beams. Two distinct tests; SEM and energy dispersion X-ray spectroscopy; were conducted in this regard to examine the interfacial surface adhesion strength between matrix and fillers inside.

Ma et al. [60] used chemically modified high-structural integrity graphene platelets (GnPs) of 2–4 nm in thickness, covalently bonded graphene platelets with an epoxy matrix, and studied the morphology, functional & mechanical behavior of nanocomposites. This covalently bonded interface prevented graphene platelets stacking in resin. In comparison with unchanged composites display no decrease in electrical volume resistivity, the interface-modified composite at 0.489 vol% graphene platelets exposes an eight-order discount in the resistivity, a 47.7% more enhancing in modulus and 84.6% in fracture energy release rate. graphene platelets comparing with clay and multi-walled carbon nanotubes showed that our graphene platelets are further beneficial in terms of behavior and price.

Ma et al. [61] investigated covalently modified graphene platelets (GnPs) of 3 nm thickness by the reaction between the GnPs' epoxide groups & the end-amine groups of a commercial long-chain surfactant (Mw = 2000), compounded the modified GnPs (m-GnPs) with a model polymer epoxy, and also examined the structure and features of both m-GnPs and their epoxy composites. A low Raman ID/IG ratio of 0.13 was found for m-GnPs corresponding to high structural integrity. A percolation threshold of electrical conductivity was noted at 0.32 vol. % m-GnPs, and the 0.98 vol. % m-GnPs enhanced the modulus of elasticity, glass transition temperature and fracture energy release rate of epoxy by 14%, 13% and 387%, respectively.

Hsieh et al. [62] observed when the concentration of GNPs was 0.25 wt. %, the ILSS provided the superior reinforcing effect compared with neat composite laminate under three environmental aging conditions. The experimental results also showed that the ILSS of CFRP composite laminate with 0.25wt% GNPs-added was aging in an environment with high temperature and humidity conditions (85_C/85% RH) provided the significant improvement compared with other two environmental conditions. A noticeable improvement was noted in the crack initiation and also propagation energy of the GNPs/ CFRP composite laminates, especially in 25_C/65% RH and 25_C/85% RH. Depending on the mentioned literature and experimental obtained results, the crack growth suppression behavior in composite laminate was initially caused by the crack deflection of GNPs.

Wang et al. [63] investigated influence additive graphene nanoplatelet and multi walled carbon nanotube hybrids reinforced epoxy/carbon fiber composites were utilized to reinforce epoxy composite and epoxy/carbon fiber composite plates in order to increase their mechanical features. These features of CNTs/GNPs hybrids on a same concentration of 1wt. % with mixing diverse content reinforced epoxy nanocomposite. The mechanical properties for example flexure features and ultimate tensile strength, of epoxy/carbon fiber composite plates loading dissimilar features of GNPs/ CNTs hybrids (0.5, 1.0, 1.5wt %) were increased over that of pure plates. Therefore, important enhancement in the mechanical features was achieved for these epoxies nanocomposites & carbon fiber-reinforced epoxy nanocomposite plates.

Ávila et al. [64] showed influence addition nanographene to carbon/epoxy composites into bending strength in addition to on bending stiffness. The modulus of elasticity in bending achieved 76.87 GPa at 0.5 wt. % nanographene, while the modulus of elasticity was 27.94 GPa when without grapheme addition. A moderate growth on stiffness, 38.44 GPa and 58.71 GPa, was noted for the 1.0 wt. % and 1.5 wt. % samples. Slight rise can be ascribed to graphene clusters formation, because the epoxy distribution saturation limit.

The bending strength was greatly affected by the formation of graphene pileups into the epoxy matrix and its distribution around the carbon fibers. The growth on bending strength got a peak of 1355.94 MPa for the 0.5 wt. % specimens. Increasing dispersed nanographene into epoxy matrix, improved the average bending strength from 623.01 MPa (without nonagraphene) to 1259.91MPa (for a 0.5 wt. % nanographene), and 1143.72 MPa and 1187.53 MPa, 1.0 wt. % & 1.5 wt. %, respectively. This huge rise on bending strength can be credited to changes on failure mechanism, moving from intra-laminar failure to a mix failure mode where inter and intra-laminar failure is combined in a zigzag pattern. A probable description for such behavior is the formation of strong bonds at fiber/matrix surroundings because nanostructures formation.

Du et al [65] used a simple thermal reduction method in air at 700 ^{o}C and used to prepare graphene/epoxy (G/E) composites. They indicated the 1.0 wt. % of graphene into epoxy significantly improve the matrix fracture energy by ~150% and reduce the thermal expansion coefficient by ~30%. When these partially cured G/E composites were used as interleaves in carbon fiber/epoxy (CF/E) composites and co-cured, a remarkable 140% increase in mode I inter laminar fracture energy was achieved.

Kostagiannakopoulou et al. [66] utilized GO and GNP fillers for the development of multi-scale composite laminates. Towards this direction, the integration of nano-fillers into the epoxy matrix was occurred using 3roll-mill technique while the development of nano modified carbon fiber/epoxy laminates fabricated using an in-house prepreging way. The inter laminar fracture toughness for mode I loading type and the fractographic analysis of these composites were performed in order to evaluate the toughening effect of GO and GNPs in the fracture characteristics of final composites. The initial fracture toughness of doped composites showed no significant difference with respect to the composites with pure matrix. The total fracture toughness of the examined composites presented similar trend with the values of the propagation fracture toughness highest increase in fracture toughness (51%) was achieved by the incorporation of 0.5 wt. % GNPs in final composite. The results demonstrated that the presence of graphene particles enhanced the fracture properties of composite laminates and this is due to the more toughening mechanisms that are introduced by the incorporation of GO and GNPs in the epoxy matrix and interface of matrix and fiber.

2.7 Conclusion of literature survey

The following conclusions can be obtained from the previous literature review:

Nanomaterials were utilized to enhance the characteristics of the coating due to they have great surface area to volume ratio which provides rising to unique features in nanomaterials. As the aspect ratio of nanomaterials is so great, the additive of slight loading of nanomaterials is enough to get some favorite features. So, the characteristics can be exponentially enhanced with minor rise in weight.

All those studies are interested with the determination and the analyses of composite structures behaviors to enhance the mechanical characteristics of these composites.

- The nanoscale interaction between polymer molecules & nanoparticle is a main factor in decisive the macroscale strength of the composite
- Benefits of adding nano-particles to composite matrix could be achieved with low contents of nano-particles.
- The physical and mechanical nanocomposites properties depend on the dispersion of filler agent into the matrix.
- The particle size, filler loading, and the interfacial adhesion between particle & matrix impact the mechanical characteristics of a composite.
- Nanoparticles can provide superior interfacial interaction area with a polymer matrix related to micron-sized particles. This influence is resulted from the higher specific nanoparticles surface area.
- The reinforcing result of the nano-filler is dependent on the interfacial compatibility. The great rise in interfacial area reasons the features of the composite to be led by the features of the interface or the interphase.
- Distribution of the Nano-filler is a critical stage when creating polymer nanocomposites. The excellence of the distribution disturbs the whole matrix of the nanocomposite & the final characteristics of the nanocomposite. A homogenous & well distributed system is so a main effort when making a nanocomposite
- The dispersion techniques were examined: conventional mechanical mixing, three-roll mill and sonication.
- The additive of nanoparticles doesn't continuously impact the bulk composite material positively; at times the nanoparticles can lead to discount of the composites properties slightly than an enrichment. As result of agglomeration.
- Scattering and Interfacial adhesion of the nanofiller material is significant for fabricating homogenous nanocomposites. nanoparticle incompatibility & high surface area with polymer matrix could produce to problems with the dispersal of nanoparticles.
- Interfacial adhesion between polymer and particles explains how easy the particles are discrete in the polymer. A decent scattering occurs when the interfacial adhesion between the particles and the surrounding polymer is great, when there are only separate particles in the mixture.

Utilizing nanographene is significantly increased in the last of decades. Graphene was the addition that was utilized to increase the features of the coating. It was selected as the nano material because of its unique mechanical feature. Tensile strength of graphene was notified to be between 0.5 and 1.0 TPa. It was hypothesized that with these high mechanical properties, graphene would be an ideal binding material to prevent or minimize the blistering of the coating.

- ❖ The GNP volume fraction in the hybrid composite can have a strong impact the composite transverse tensile & shear features.
- ❖ The GNP distribution excellence has a high result on the transverse tensile and shear features of the composite.
- ❖ The GNP volume fraction and distribution have a minimal effect on the hybrid composite axial features where the carbon fiber is the primary reinforcement agent.
- ❖ Some of studies illustrates the superior enhancements produced by graphene compared to carbon nanotubes, especially at low nano-filler content. In addition, the unit cost of graphene is a fraction of the cost of SWCNTs.

The above literature exploration shows that the research involving the mechanical performance of epoxy reinforced with graphene and glass or carbon fiber nanocomposite. Nobody has studied the effect of used glass/carbon epoxy together modified nanographene. The toughening mechanisms and strengthening of graphene in EPCs have been reported. However, the existing literature does not describe the incorporation of pristine GnPs in the hybrid composites. As such, this work will investigate the mechanical effects of GnPs on glass/carbon epoxy hybrid composite

CHAPTER 3

EXPERIMENTAL STUDIES

3.1 Introduction

The technique and materials utilized in the Manufacturing section of this work are described in the following parts. In this work four different (0, 0.1, 0.25 & 0.5) wt.% of nanographene have been added to four laminates of eight plies in each group. There are four groups that have different fiber reinforcement's configuration. Each group has been prepared with adding glass or carbon fibers.

3.2 Manufacturing Techniques of Composite Materials

Composite materials can be formed by dissimilar manufacturing methods and manufacturing depends on experience, cost, desired quality and geometry. These methods can roughly divide into two categories as closed and open molding. Types of manufacturing techniques of composite materials are:

1. Spraying method.
2. Vacuum bagging molding method.
3. Filament winding method.
4. Resin transfer molding (RTM) method.
5. Structural resin injection molding method (SRIM).
6. Autoclave curing.
7. Pultrusion method.
8. Hand lay-up method.

3.2.1 Hand Lay-Up Method

In this work, hand lay-up method is used. It is generally used for boats, tanks and building panels. In the production, the woven fibers are usually selected as a reinforcement agent. But to gain additional strength and modulus of elasticity also glass, carbon or other fibers can be added in to manufactured structure [67].

This process has low tooling costs and preferred thickness can be reached. Experienced operators can be produce complex geometries. Unwanted gaps, slow process and lack of adaptation to mass production can be said as disadvantages. Marine applications and turbine blades like boat hulls and kite boards can be formed with this method [68].

3.3 Materials

In experimental studies, hybrid composite plates were fabricated with eight layers. Woven Carbon and woven S-Glass fibers were used as reinforcements, epoxy resin (MGS L160) and hardener as catalyst (M65 H260 S) were used in production of non-hybrid and hybrid composite plates.

3.3.1 Glass Fiber

Fiber glass refers to a collection of products made from individual glass fibers into a collective kind of shapes. Glass fibers can be classified into two main groups related to their geometry: continuous fibers utilized in yarns and textiles, and the discontinuous (short) fibers used as blankets, batts, or boards for filtration and insulation. Fiber glass can be shaped into yarn more such as cotton or wool, and woven into fabric which is sometimes utilized for drapery. Fiber glass textiles are usually used as a strengthener material for mold and laminated plastics. Fiber glass wool, a thick, superfine material is made from discontinuous fibers, is used for absorbed sound and thermal insulation. Plain weave S-glass fabric (03G200.080) with an areal density of (200 g/m^2) was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey. A general properties of glass fiber are given in Table 3.1. Figure 3.1a shows glass fiber.

3.3.2 Carbon Fiber

Carbon fiber, alternatively graphite fiber, carbon graphite or CF, composed mostly of carbon atoms and is a material consisting of thin fibers about 5-10 μm in diameter. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The fabric or yarn is combined with a plastic resin and molded or wound into shape to form several composite materials called carbon fiber reinforced plastics. As carbon fiber has low density compared to steel, therefore, it’s the best choice for applications required a low weight. The features of carbon fiber for example low thermal expansion, high tensile strength and low weight make it very common in motorsports, military, civil engineering, and aerospace, along with other competition sports. Carbon fabric was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey. A general properties of carbon fiber was given in Table 3.1.In Figure 3.1 b shows carbon fiber.

Table 3.1 General features of fibers

Fiber Type	Density (g/cm3)	Weight (g/m2	Young’s Modulus (GPa)	Tensile Strength (MPa)
Carbon	1.75-1.96	200	200-700	2500-3000
S-glass	2.48-2.60	200	72-82	3000-5000

a **b**

Figure 3.1 Bi woven glass, carbon

3.3.3 Epoxy and hardener

Epoxy resins are a very attractive class of polymer for the following properties: high temperature resistance, low creep, high stiffness and strength, thermal stability, good adhesion, chemical resistance. But, cured epoxy resins are generally brittle with a low toughness when subject to impact and quasi-static loading, requiring tougher resin systems to be advanced without losing the inherent features of current resins. Epoxy resins are generally in a viscous state, however harden with treatment, adding of hardener, and through curing. Predetermined ratios of hardener and resin are utilized for the mixing, and different curing temperatures are required for the mix to cure and give the best polymer characteristics. Different hardeners can be mixed with the epoxy resin for condensation curing of the composite and multiple combinations of resin and hardener are available. The hardener usually reacts with the polymer making a cross-linking network. Epoxy and hardener Figure 3.2 was supplied by

DOST Chemical Industrial Raw Materials Industry, Turkey. A physical characteristic of the epoxy resin and hardener were listed in Tables 3.2 & Tables 3.3 respectively.

Table 3.2 Physical characteristic of the epoxy resin

Properties		Laminating resin L 160
Density	**[g/cm³]**	**1.13-1.17**
Viscosity	**[mPas]**	**700-900**
Epoxy equivalent	**[gr/equivalent**	**166-182**
Epoxy value	**[eq/100gr]**	**0.55-0.60**
Refractory index		**1.5480-1.5530**

Table 3.3 Properties of hardener.

Properties		Hardener 260 S specification
Density	**[gr/ cm³]**	**0.93-0.97**
Viscosity	**[mPas]**	**80-100**
Amine Value	**[mgr KOH/gr**	**450-500**
Refractory index		**1.4980-1.4985**

Figure 3.2 Epoxy resin, hardener and nanographene

3.3.4 Graphene

Graphene is a material which has the maximum surface area per unit mass and it is even higher to carbon nanotubes and fullerenes [69]. Graphene is moreover one of the stiffest famous materials with a Young's modulus of about 1TPa. Since graphene does not have interlayer interaction as in graphite. Graphene nanofiller was supplied from Grafnano Teknolojik Malzemeler Co. Ltd. It appears as a black and grey powder, and has purity of 99.5%, bulk density of 0.05 g/cm^3, 5 µm diameter of graphene, thickness of 5 - 8 nm, and specific surface area of 150 m^2/g, as well as Raman spectra ID/IG Ratio of 0.08 and XRD 2-theta of 26 peak.

3.4 Preparation and Fabrication of Composite Laminates

In this research 16 laminates were produced of different nanographene ratios and various configuration glass and carbon fiber composite reinforced with various nanographene particles according to these steps:

1. Woven glass fiber and carbon were cut by using EC fiber cutter with 270x330 mm dimension as shown in Figure 3.3.
2. Weight of epoxy 147 gr + 53 gr hardener depending on the epoxy/hardener ratio of 100:36 was formulated.
3. Laminates with nanographene were prepared by a several of nanographene with weight ratio 0.0 wt%, 0.1 wt%, 0.25 wt% and 0.5wt% respectively.
4. Mechanical stirrer was used to mix epoxy and nanographene particles 900 rpm a constant speed for 15 minutes as illustrated Figure 3.4
5. The hardener agent was added to the mixture and stirred up for 5 minutes.
6. Laying the ply of fiber and distributing resin on woven by a roller as Figure 3.4
7. Mold was cleaned and polished with anti-adhesive agent (QZ 511) as Figure 3.4
8. Laminated fabrics were placed on flat mold and subjected to 0.3 MPa pressure for 1 hour curing time with 80º C under press Figure 3.5.
9. After three-hour laminate removed from mold and waited two weeks before cutting for curing time by CNC machine into samples for deferent testes as Figure 3.6 .

Figure 3.3 Cutting carbon and S-glass fibers

Composite plates were concocted by hand lay-up process at room temperature (25°C), proper care was taken during the preparation of laminates to prevent the voids. The first ply of woven fiber cloth was put, and resin was spread uniformly over the cloth by means of brush, the same procedure was repeated for the second ply. After second ply, to increase impregnation and wetting a teethed steel roller is used to roll.

Figure 3.4 Mixing, Laying of nanographene/epoxy resin, Molding

Figure 3.5 composite production unit. (1) Combination of heat, pressure (2) Hydraulic unit.

3.4.1 Production of Hybrid Composites

In the production of hybrid composite plates, the same production stages have been used in above and symmetric hybrid laminates were generated. There were 8 plates generated with the following configuration described below:

1. C2G4C2: was generated with four various weight ratio of nanographene: 0.0%, 0.1%, 0.25%, and 0.5%
2. G2C4G2: was generated with four various weight ratio of nanographene: 0.0%, 0.1%, 0.25%, and 0.5%

Figure 3.6 cutting laminates by CNC machine

3.5 Types of Tests Being Applied to Composite Materials

Composite materials should be examined by several mechanical tests in order to assess their performance in different environments and operation conditions. The experimental results of these tests indicate the maximum loading which can be carried by these composites and hence avoid sudden failure and permanent damages. Each mechanical test must be conducted according to standard such as ASTM to measure the strength and other properties of the composite materials. To find mechanical behavior of produced composites, impact, tensile strength, flexural strength and modules, damping and vibration characteristics of hybrid composites were examined. Five samples were tested for each test.

3.5.1 Impact Test

Besides the advantage of composite materials there are some usage restrictions exist. The most important of these limitations is reaction against regional impact which they are exposed from external body under operating conditions. In this study, Charpy impact test were used to examine impact behavior of produced composite.

3.5.1.1 Charpy Impact Test

Initially, the pendulum apparatus (Köger 3/70 with ISO 179/92 standard) was positioned and balanced on the table. Then, the pendulum hammer was released freely from the upper position. Two composite samples ($55\,mm \times 10\,mm$) were tested in two different orientation; edgewise position with notch on the opposite side of the striking area and flatwise position without notch. Later, information obtained on the energy absorption mechanisms of the two composite samples was noted down. However, during impact test, absorbed energy is read by help of a scale that showed on test device as Figure 3.7 and Figure 3.8

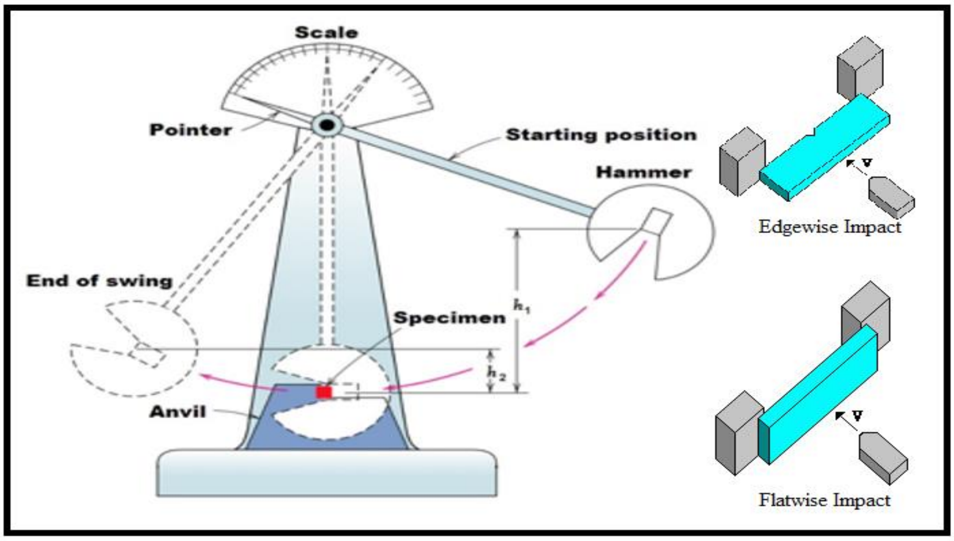

Figure 3.7 Schematic Illustration of Charpy Impact Test.

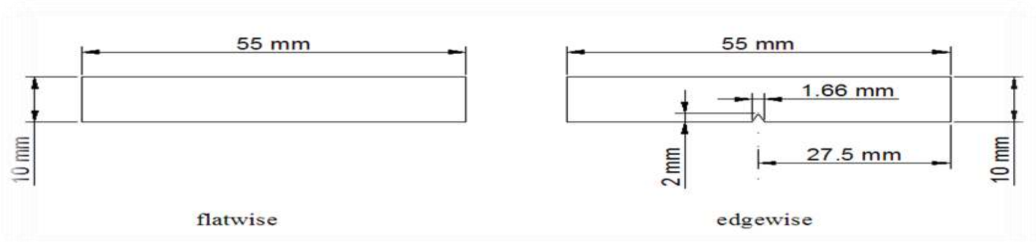

Figure 3.8 Dimension of flatwise and edgewise specimens.

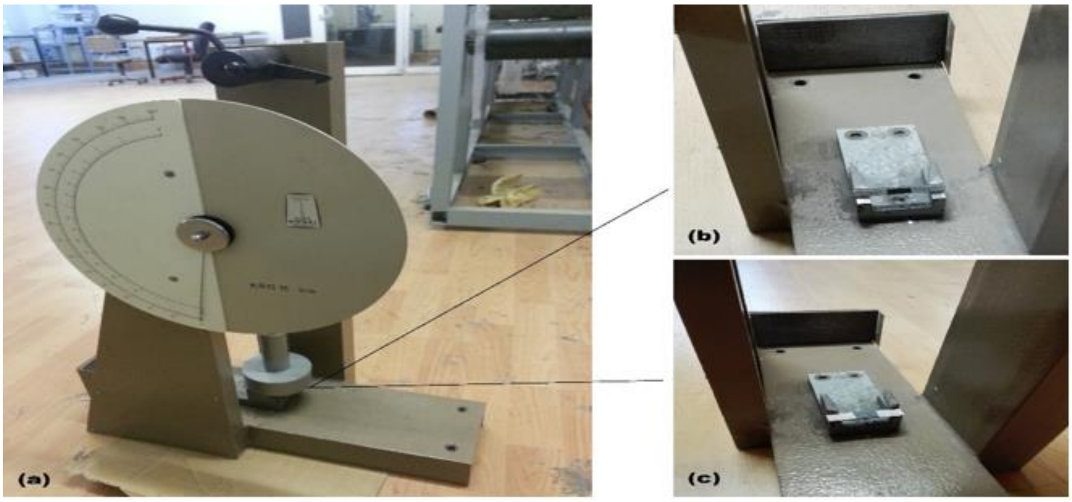

Figure 3.9 Köger 3/70 charpy impact test machine; a) The calibrated dial, b) Un-notched specimen for flatwise test, c) Notched specimen for edgewise test

Figure 3.10 Flatwise and edgewise specimens.

Flatwise and edgewise specimens were subjected to impact loads while they were put in positions shown in Figure 3.9. For each laminate structure and test configuration (edgewise and flatwise), five specimens were tested.

3.5.2 Tensile Test

The purpose of the tensile test is determining the elastic and plastic behavior of materials under constant load. Accordance to test standard, circular or rectangular pieces are being connected the tensile test device and axial forces are applied.

Tensile test device is composed of two jaws which can move basically up and down relative to each other. The test piece is connected to these jaws which give force and movement. By one of the jaws move with a constant speed, varying amounts of tensile force is applied to the test piece and elongation corresponding to this force is recorded. In this work, tensile properties of specimens of laminates were determined according to the ASTM D638–10 [70] in Figure 3.11. The tests were conducted using universal testing machine (300 kN capacity Shimadzu Corporation, made in Japan) as shown in Figures 3.12**.** The cross-head speed was 2 mm/min. Figure 3.13 showed samples of test.

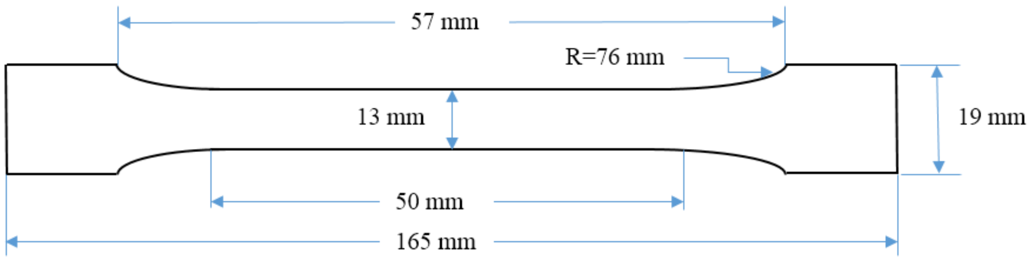

Figure 3.11 The Dimensions of Tensile Test Specimens

Figure 3.12 Test set-up Shimadzu AG-X series testing machine, specimen under test.

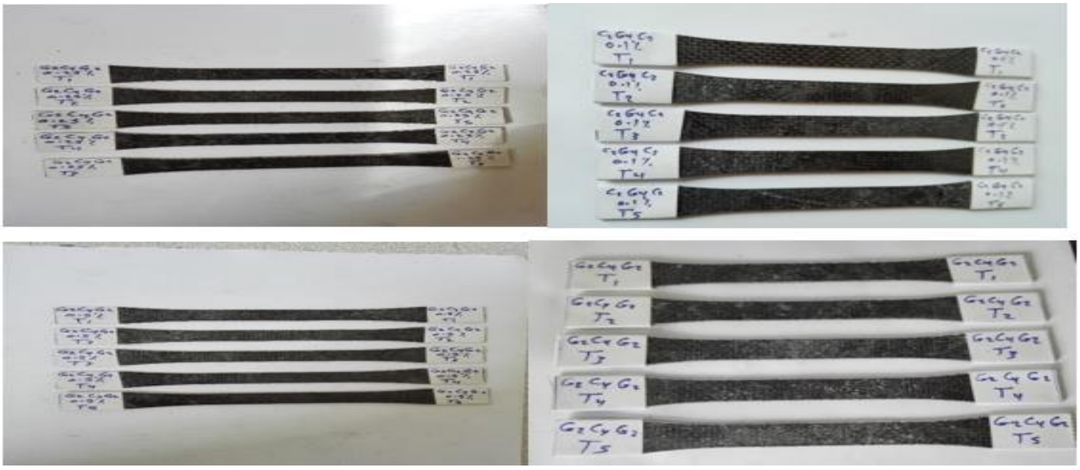

Figure 3.13 Tensile samples of group G2C4G2 with nanographene

3.5.3 Three Point Bending Test

Three-point bending test can be defined as the deformation occurring in the sample when force is applied in the middle of a test sample which is a circular or rectangular cross-section that placed freely on the two supports. If the sample is broken, applied load measured during the fracture. Bending test specimens can be circular section or rectangular section. There is no problem about connection of samples to bending test device. According to the total number of supports which contact with specimen and load applications bending test is divided into different groups, such as three-point bending test or four-point bending test. The main purpose of the bending test is to determine the ability to endure the cold state cracking of the material. Tensile and compressive stresses occur at the cross section of sample is subjected to bending.

3.5.3.1 Determination of Flexural Properties

Three-point bending test can be defined as the deformation occurring in the sample when force is applied in the middle of a test sample which is rectangular cross-section that placed freely on the two supports. The flexural strength depicts the higher stress endured within the material at its moment of rupture. It is measured in terms of stress. The main purpose of the bending test is to determine the ability to endure the cold state cracking of the material. The specimens were prepared using span-to-depth ratio as 32:1 [71, 72].

Flexural characteristics of samples were concluded according to ASTM D790-00[73] standard test procedure. An appropriate sample of rectangular cross section (L=200mm, w=12.7 mm and t=thickness of the plat) rests on two supports and was loaded by means of a loading nose middle between the supports shown in Figure 3.14

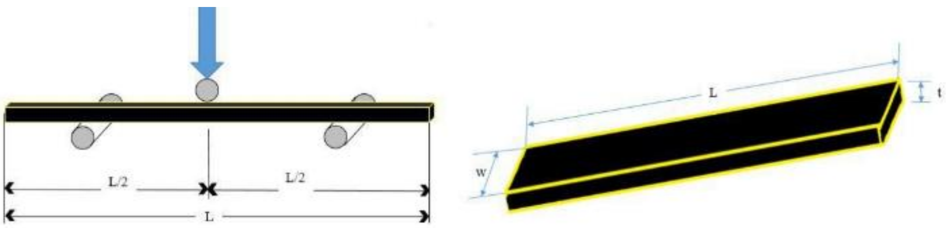

Figure 3.14 A basic illustration of bending test types

The flexural strength and modulus of the samples were evaluated using equations below.

$$\sigma_f = \frac{3PL}{2bd^2} \quad \mathbf{(1)}$$

$$E_f = \frac{L^3 m}{4bd^3} \quad \mathbf{(2)}$$

Where**:**

σ_f = flexural strength, MPa,

E_f = modulus of elasticity in bending, MPa,

P = load at a given point on the load-deflection curve, N,

L = support span, mm,

b = width of beam tested, mm,

$\boldsymbol{d}$ = depth of beam tested, mm,

m = slope of the tangent to initial straight-line portion of load-deflection curve

The tests were conducted using universal testing machine (300 KN capacity Shimadzu Corporation, made in Japan) as shown in Figures 3.15**.** The cross head speed was 3 mm/min. Figure 3.16 showed samples of test.

Figure 3.15 (a) Flexural test method, (b) Specimen under test.

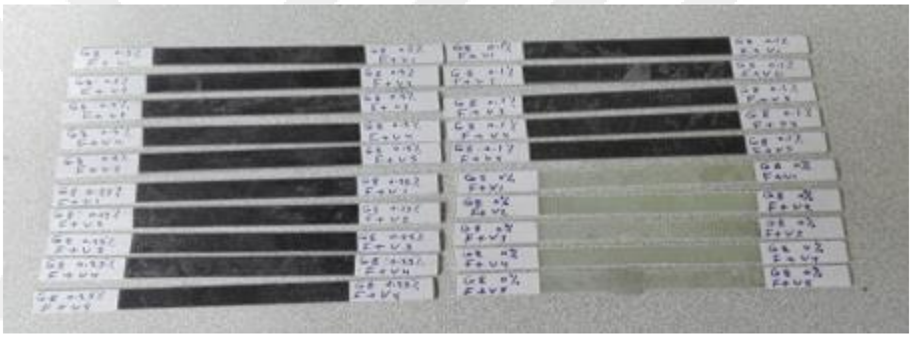

Figure 3.16 Flexural samples of group GFRP with nanographene

3.5.4 Vibration Test

Vibration testing is an effective tool for nondestructively measuring the influence of any damage on the mechanical features of composite materials according to ASTM E756 [74]. Half-power bandwidth method [75] was used to get natural frequencies of the hybrid composite samples as shown in Figure 3.16. The size of the vibration test is 200 × 12.7 mm and samples were fixed by supports. Produced samples exposed to excitation for by impact hammer to obtainable dynamic characteristic.

Using half-power bandwidth method as Figure 3.17 can be determined damping ratios of hybrid composites. This method is based on a time domain method which shows exponential decay characteristic of the free response of the structure in order to get the knowledge of damping ratio. The damping ratio in composite materials is essential to avoid failure in the mechanical parts that are exposed to the vibration and it necessary to calculate the damping time because it helps us to extend the life of these mechanical parts.

3.5.4.1 Damping Ratio

Half-power bandwidth method was used for determining Damping Ratio as Eq. (3). Maximum amplitude of first mode frequency was determined from the frequency response curve, then ω_1 and ω_2 frequencies corresponding to Z_1 and Z_2 points were found by dividing maximum amplitude value of first mode to the value of $\sqrt{2}$ as shown in Figure 3.17 [75].

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_n} \quad (3)$$

Where ξ is (damping ratio), ω_n is the (natural frequency of first mode) and $\omega_2 - \omega_1$ is the (bandwidth).

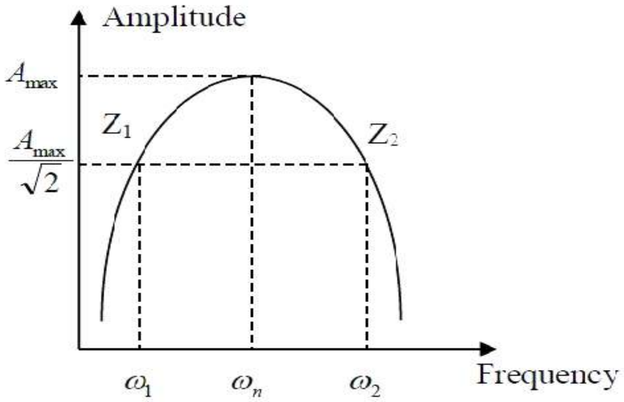

Figure 3.17 Half-power bandwidth method

3.5.4.2 Storage Modulus (E′)

Storage modulus can be gotten from Euler–Bernoulli beam theory as Eq. (4).

$$\omega_1 = \frac{1.875^2}{2\pi L^2}\sqrt{\frac{E^{'} I}{\rho A}} \quad (4)$$

Where ω_n= natural frequency of the first mode, L = free length of the beam, ρ = density of the beam, *I* = moment of inertia for the given cross-section of beam and A = cross-section of the beam.

3.5.4.3 Loss Modulus (E″)

Loss modulus of the beam can be obtained using storage modulus. The relationship between loss and storage modulus is given in Eq. (5)

$$E''(\omega) = 2E'(\omega)\xi(\omega) \quad (5)$$

3.5.4.4 Test Set-up

The experimental method for specimen's analysis used to calculate damping ratios and natural frequencies of composite. Accelerometer for output signal acquisition, impact hammer for stimulus force signal, data acquisition card device and the specimen analysis explain in Figure 3.18. Dynamic characteristics of composite laminates were measured using an experimental set-up. In figure 3.19 showed the experiments, a general-purpose ceramic shear ICP ® accelerometer (PCB 352C03), general purpose modal impact hammer (PCB 086C03) and a National Instrument product NI 9234 with LABVIEW software was run in order to plot FRF on monitor, then impact hammer was struck three times on the specimen for better excitation. FRF and time signal graph were plotted on a computer by using LABVIEW software and natural frequencies were plotted on the screen from FRF curves by the application of modal impact hammer.

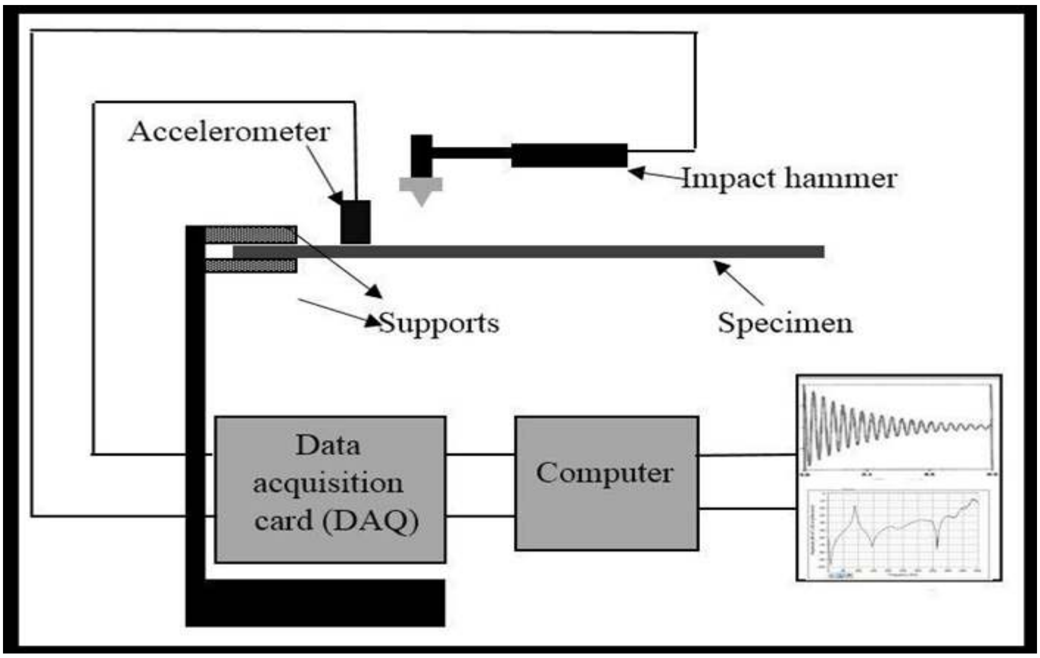

Figure 3.18 A Basic Illustration of Vibration damping testing

Figure 3.19 Experimental set-up of vibration damping test

CHAPTER 4

EXPERIMENT RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the various experiments and analyses performed during the thesis. When polymers are used in different engineering applications it is crucial to have knowledge about the mechanical properties. It is necessary to know the stiffness of the polymer, the material strength, and the rheological properties of the polymer [76]. How much the polymer deflects under a given load and what level of stress the polymer can support before it breaks or deforms, is decisive when selecting a polymer? Furthermore, the hardness, ability to withstand cyclic loading (fatigue), resistance to loading in the presence of an organic solvent, and the toughness of the material are other important mechanical properties [76]. The results are discussed under each experiment performed, and a summary of the total results and experiments are discussed in a summarizing discussion. All the different composites were tested for mechanical properties by Charpy impact, tensile test, three-point flexural bending test and vibration damping test to compare their mechanical properties, and to investigate the effect of the addition of nanographene particles when added to the GFRP, CFRP and hybrid based nanographene modified epoxy composites. Mechanical tests were performed for five different specimens and results are interpreted taking the average of five samples.

4.2 Impact test

The Charpy impact test was performed to measure the absorbed impact energy for 8 layers glass/epoxy, carbon/epoxy and hybrid nanographene composite.

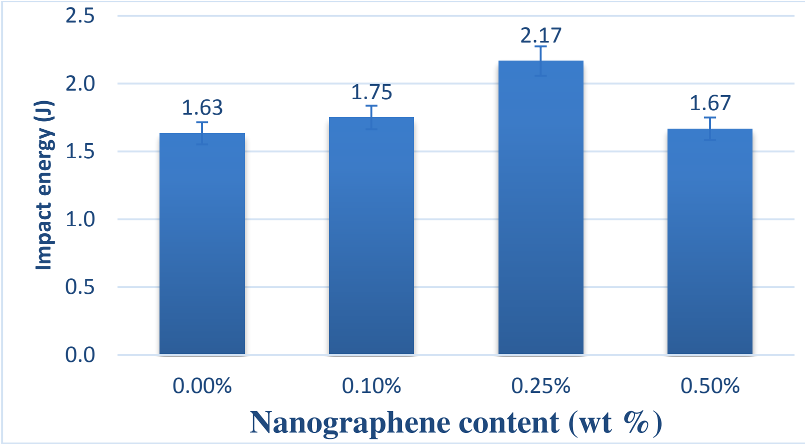

Figure 4.1 Impact energy of [G8] flatwise samples with respect to GNP content

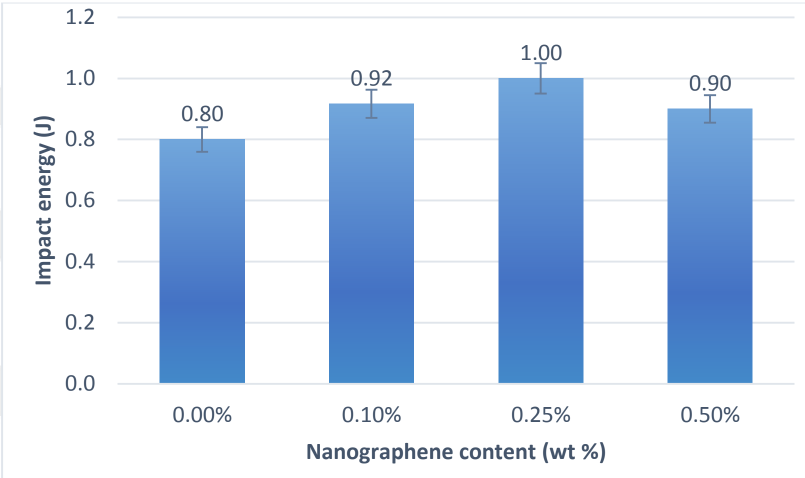

Figure 4.2 Impact energy of [C8] flatwise samples with respect to GNPs content

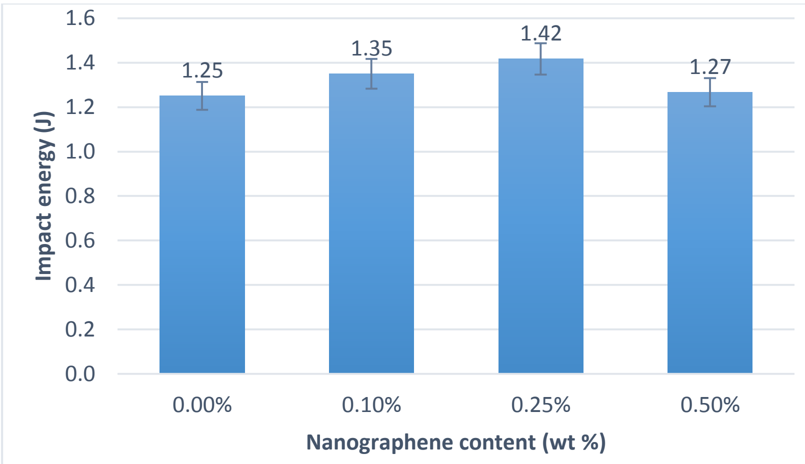

Figure 4.3 Impact energy of [C2G4C2] flatwise samples with respect to GNPs content

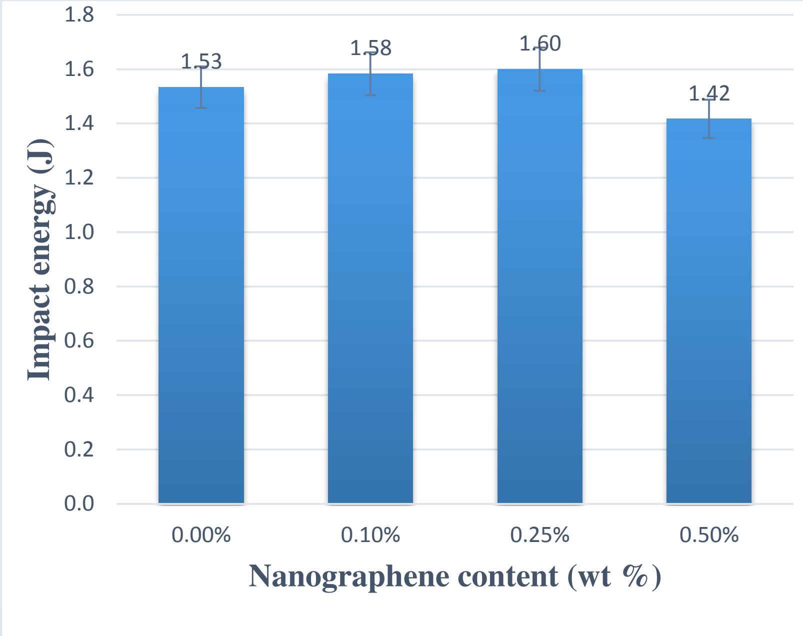

Figure 4.4 Impact energy of [G2C4G2] flatwise samples with respect to GNPs content

Impact resistance of the designed composites was determined by absorbed energy at the fracture point of samples using Charpy impact test. The glass/epoxy and carbon/epoxy composite samples were tested to show their performance and compare them with the hybridization states. The glass/epoxy laminate as Figure 4.1 showed an energy absorption as 103.75% greater than that of the carbon/epoxy laminate as Figure 4.2 (1.63 with respect to 0.80 J) for the case of flatwise impact and 35.33% as Figure 4.5 higher than that of the carbon/epoxy laminate as Figure 4.6 (1.8 with respect to 1.33 J) for the case of edgewise impact. It may be attributed to the brittle structure of carbon fabrics or less hardness of woven glass fabrics as compared with carbon fabrics. Both analyses (flatwise and edgewise) of the hybrid composites showed absorbed energy values between those of the glass/epoxy and carbon/epoxy laminates. [C2G4C2] hybrid laminate as Figure 4.3 showed lower impact energy than that of [G2C4G2] hybrid laminate as Figure 4.7 by 22.4% and 2.3% for flatwise and edgewise, respectively.

Thus, the presence of glass fiber in a common matrix significantly enhanced the impact resistance of carbon fiber composite. On the other hand, the addition of different amounts of GNPs into the epoxy matrix had positively affected the impact resistance of considered composite laminates. Figures 4.1to 4.4 show the absorbed impact energy values of flatwise test samples and Figures 4.5 to 4.8 show the absorbed impact energy values of edgewise test samples all subjected to 15 J impact energy at room temperature. It is obvious that impact energy a bit increased with the addition of GNPs by 0.1 wt. %, then this increase was continued with more addition of GNPs to 0.25% which resulted in highest improving of absorbed energy. After that the addition of GNPs by 0.5% led to decrease the absorbed energy of the composite samples. Absorbed energy at GNPs loading of 0.5 wt. % showed higher values compared with control samples of neat matrices except for those of the [G2C4G2] configuration which had values less than those of control samples (Fig.4.4 and 4.8). The increase in impact energy was attributed to the perfect adhesion between the fabrics and matrices via GNPs, providing more energy absorption capability and improved properties compared with control samples. Hence, better load transfer between glass-carbon fibers and matrices was achieved due the presence of GNPs within epoxy making the composites withstand higher impact loadings Varga et al. [77].

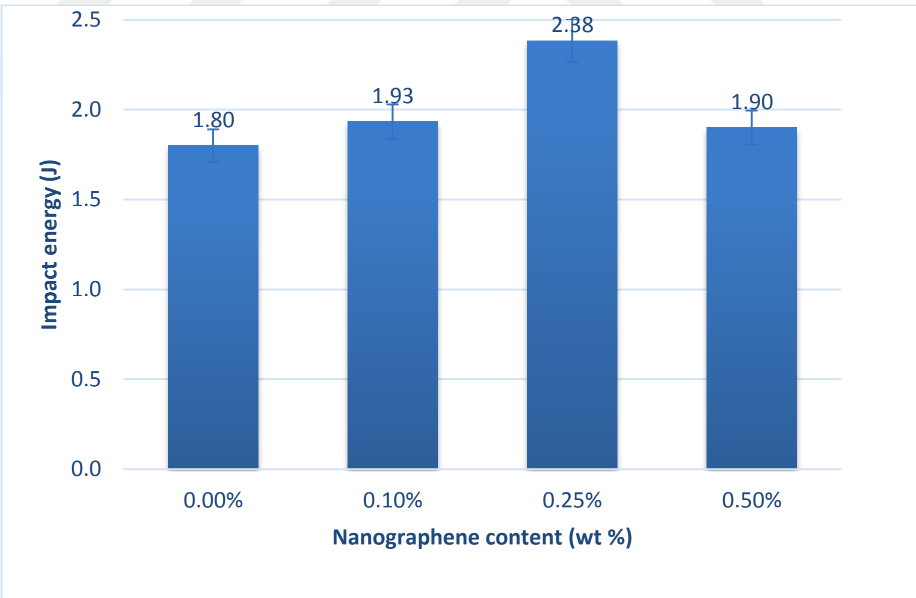

Figure 4.5 Impact energy of [G8] edgewise samples with respect to GNPs content

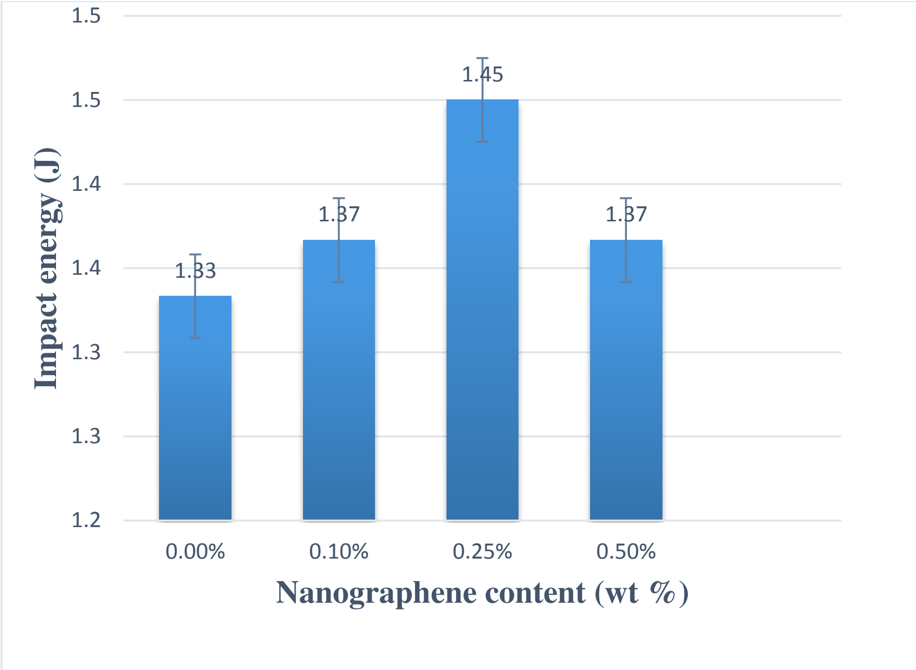

Figure 4.6 Impact energy of [C8] edgewise samples with respect to GNPs content

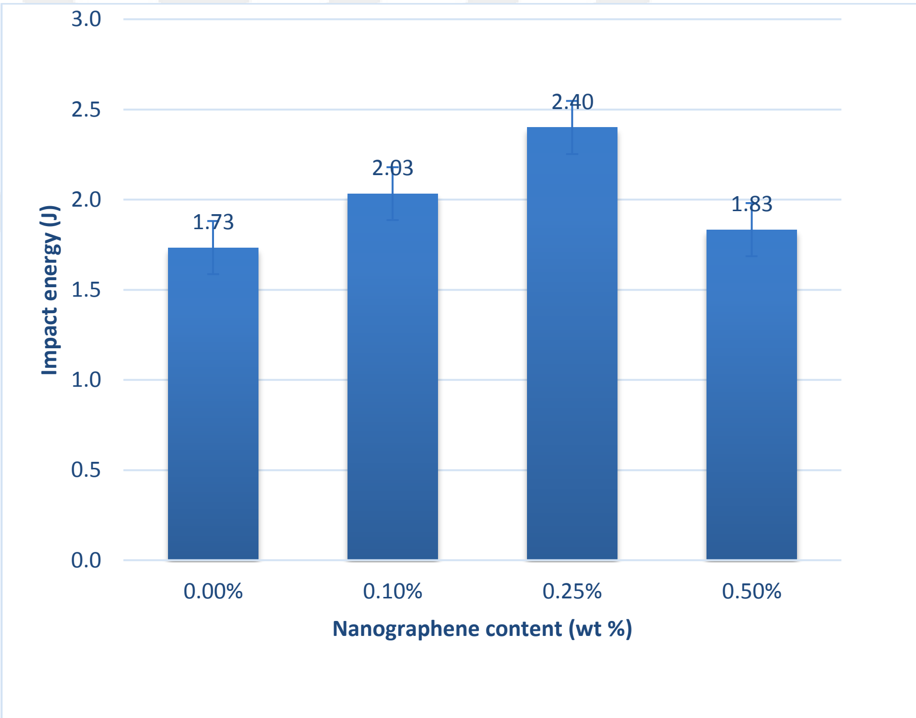

Figure 4.7 Impact energy of [C2G4C2] edgewise samples with respect to GNPs content

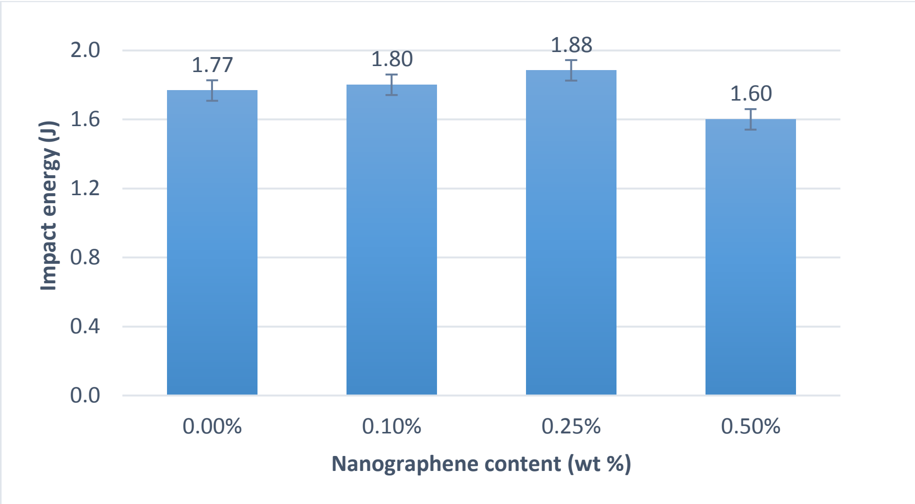

Figure 4.8 Impact energy of [G2C4G2] edgewise samples with respect to GNPs content

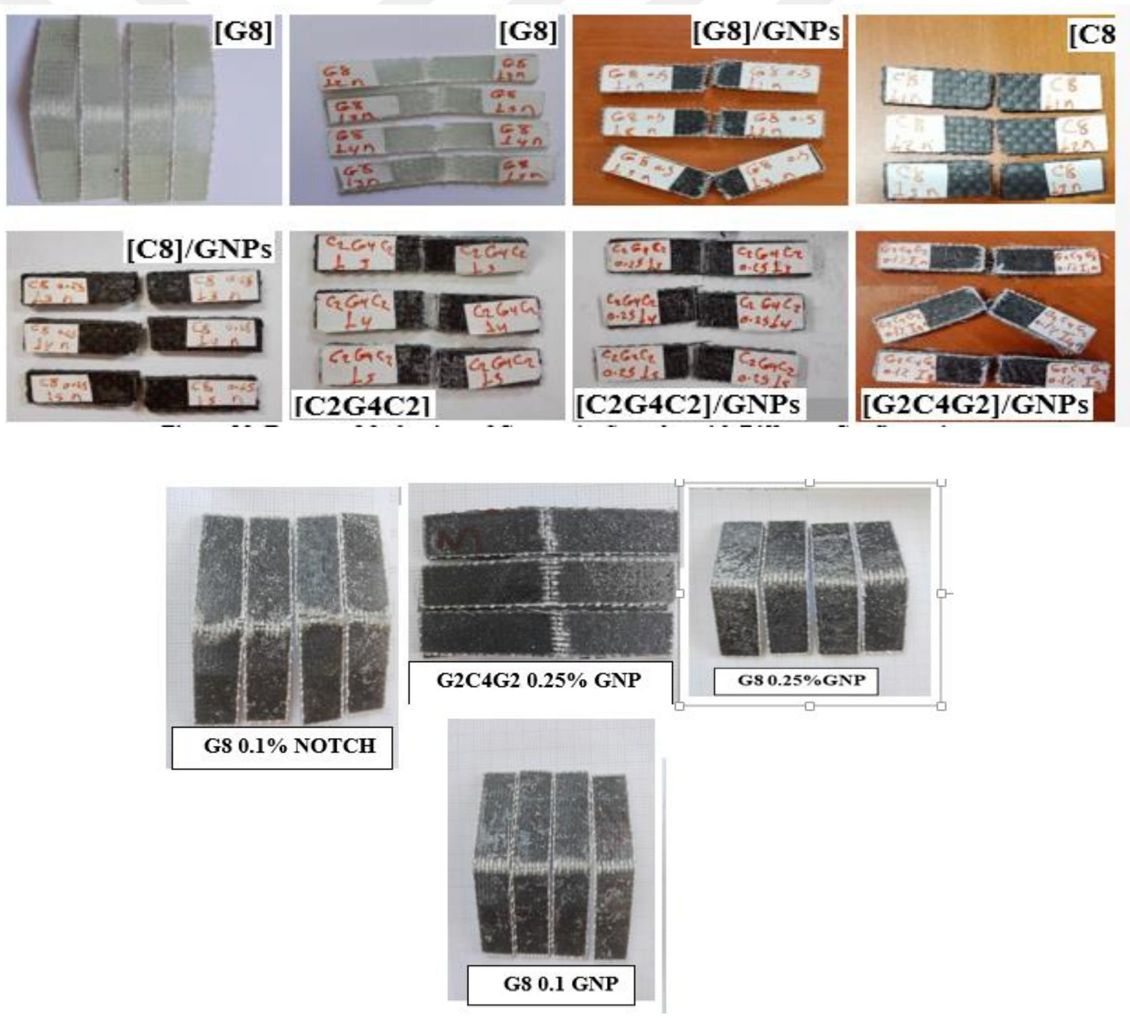

Figure 4.9 Fracture mechanism of composite samples with different configurations

Localized fracture with full fiber breakages and separation at the impacted area was the major damage mechanism for all samples Figure 4.9 except those composed of glass fiber with pure epoxy matrix [G8]. This is an evidence that the impact stress generated at the impact surface was not spread through wide region and the impact energy was absorbed by small area where no delamination was observed along fiber direction of composite laminates. The brittleness of glass-carbon fibers can be the reason for preventing impact stress to spread through big area. For [G8] composites without GNPs fillers, they were found to be fractured with localized damages with a bit fiber delamination were no separation was observed Figure 4.9. This failure mechanism may be attributed to low brittleness of glass fibers compared to carbon fibers.

4.3 Tensile Characteristic

This section discusses the results obtained for tensile characteristics of GFRP, CFRP and hybrid composites for various nanographene contents. Tension test was performed to measure the tensile strength and fracture strain of both base and GNPs /epoxy hybrid nanocomposites. The glass/epoxy and carbon/epoxy composite samples were tested to show their performance and compare them with the hybridization states. The dog bone shaped samples following ASTM standard D638 were prepared for uniaxial tensile tests at a crosshead speed of 2 mm/min. at room temperature. The edges of the specimens were polished using fine polishing paper to remove any visible surface roughness. To ensure reproducibility of results, five samples were tested. Bottom end of the specimen was first gripped with tensile fixture and make sure that it is at the center of the grip and perfectly perpendicular on the gripper vertical and parallel to the load direction. The gage length 115 mm was measured and identified to measure axial strain.

4.3.1 GFRP with various nanographene particles contents

Table 4.1 depicts the tensile characteristic of GFRP and various nanographene particles contents. The tensile strength was calculated by dividing fracture load by cross sectional area. Fracture strain is the strain at which specimen fractured.

Table 4.1 Tensile characteristic of GFRP with various nanographene contents

Specimen	Particle ratio (Wt. %)	Force (N)	Stroke	Max. Stress (MPa)	Average Tensile Stress (MPa)	Strain	Average Tensile Strain %
G8	0.0%	8541 8377 7833.96 8744.48 7292.27	5.83 4.08 5.83 5.88 4.33	423.87 415.73 388.78 420.41 350.59	399.88	0.0507 0.0355 0.0507 0.0511 0.0377	4.51
	0.1%	9136.3 8728.93 8808.99 8837.56	5.15 4.82 4.97 4.83	439.25 419.66 423.51 424.88	426.82	0.0448 0.0419 0.0432 0.0420	4.3
	0.25%	7613.33 6802.6 7258.37 6878.66 6595.33	4.62 3.94 4.43 4.20 3.96	366.03 327.05 348.96 320.68 317.08	335.96	0.0402 0.0359 0.0385 0.0365 0.0344	3.71
	0.5%	7968.66 8782.34 8938.12 8150.1	4.89 4.69 4.51 3.98	383.11 404.44 368.78 406.75	390.77	0.0425 0.0477 0.0477 0.0257	4.09

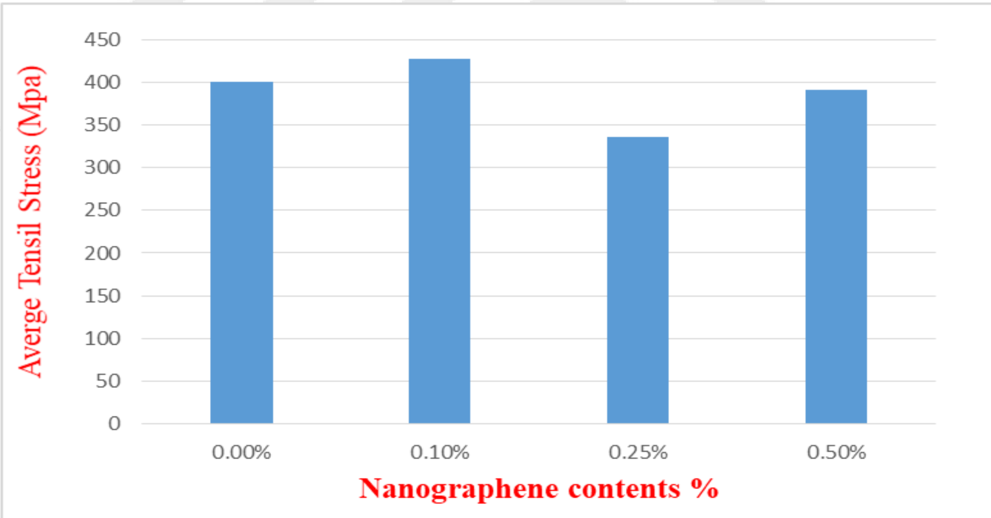

Figure 4.10 Tensile stress- particle content (wt. %) diagram of the glass fibre reinforced epoxy composite filled with nanographene particle

As shown in Figure 4.10 and Figure 4.11 and corresponding data in Table 4.1, the tensile strength of unfilled GFRP composite is increased with nanographene particles addition that the maximum strengthening is 6.74% at particle content of 0.1 wt%, after this content the tensile was reduced.

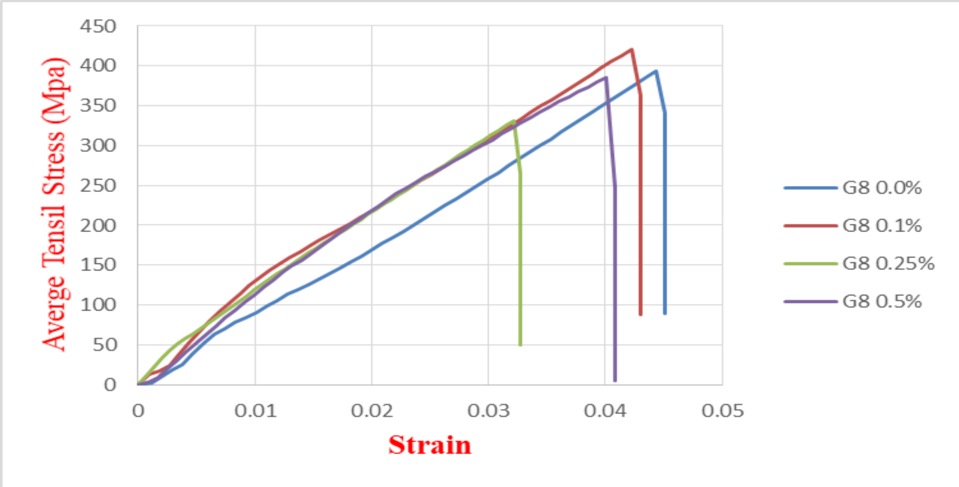

Figure 4.11 Tensile stress-strain curves of the glass fibre reinforced epoxy composite filled with nanographene particle.

From figure 4.11 it is observed that the maximum tensile strength was 426.82 MPa with specimens of 0.1 wt. % nanographene addition. This is could be attributed to good adhesion and interfacing between epoxy, fiber and graphene. Also, the elongation at fracture reached maximum amplitude in specimens of nanographene, but the minimum tensile strength and strain occurred with laminate samples of 0.25% graphene and it is possible to attribute that to graphene particles might be agglomerated and stress concentrations might be occurred and then failure occurred.

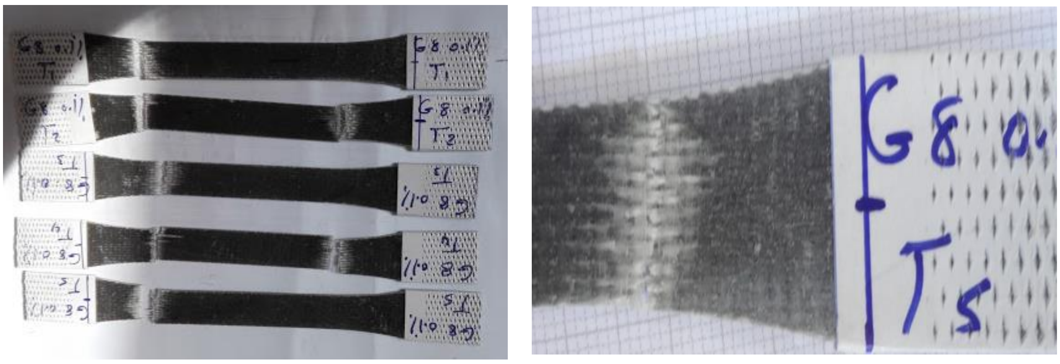

Figure 4.12 Failure for tensile specimens after testing of 0.1% /nanographene contents

From Figure 4.12 was noted all the specimens were broken without any nicking and the fracture surfaces were flat. That means the specimens fractured in a brittle style during a tensile test.

Different weight fractions of nanographene were used as fillers in epoxy matrix and tested. 0.1 wt. % of filler was observed to be the optimum filler amount for obtaining an excellent combination of dispersion and improved properties. At higher filler content, deterioration in the dispersion quality was observed. Hence for comparing the mechanical properties of pristine and nanographene –epoxy composites, 0.1 wt.% of nano-filler content was chosen Due to very high surface-to-volume ratio and attractive Van der Waals forces causing agglomeration of graphene, a uniform dispersion of graphene in polymer matrix becomes quite difficult beyond certain weight fraction. In most of the reported literature, the mechanical properties increased up to 0.1 wt% of graphene and decreased afterwards which can be attributed to agglomeration of graphene and generation of cracks around the graphene agglomerates [78] [79].

4.3.2 CFRP with various nanographene particles contents

Table 4.2 depicts the tensile characteristic of CFRP and various nanographene particles contents. The tensile strength was calculated by dividing fracture load by cross sectional area. Fracture strain is the strain at which specimen fractured.

Table 4.2 Tensile characteristic of CFRP with various nanographene contents

Specimen	Particle ratio (Wt. %)	Force(N)	stroke	Max. Stress (MPa)	Average Tensile Stress (MPa)	Strain	Average Tensile Strain %
C8	0.0%	14699.1 15545.2 14974 15860.8	5.55 5.29 4.90 4.98	551.56 569.42 548.50 580.98	547.82	0.0483 0.0460 0.0426 0.0433	4.5
	0.1%	16372.6 16619.5 16032.6 14890.2 15348.5	5.19 5.45 4.87 4.89 5.02	599.73 608.77 573.62 545.43 575.93	569.34	0.0451 0.0474 0.0423 0.0425 0.0437	4.42
	0.25%	18093 16770 17864 16770.3 15823.4	5.17 4.83 5.33 4.83 4.92	632.62 586.36 624.62 600.01 579.61	550.73	0.0450 0.0439 0.0463 0.0420 0.0428	4.40
	0.5%	15135 15496 15325 15065.7 16060	4.90 4.96 5.48 5.39 5.40	517.44 529.78 512.54 526.77 561.54	521.12	0.0426 0.0431 0.0477 0.0477 0.0477	4.57

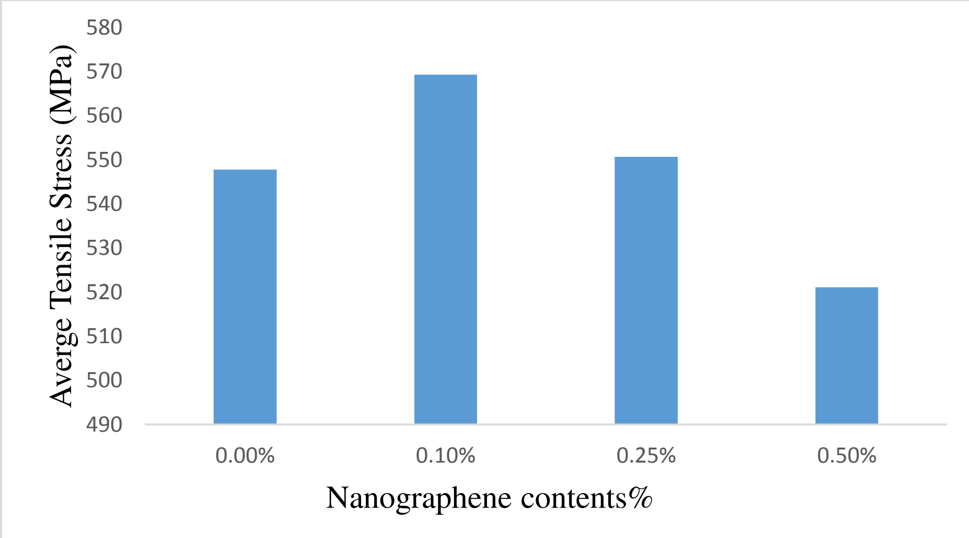

Figure 4.13 Tensile stress- particle content (wt. %) diagram of the carbon fibre reinforced epoxy composite filled with nanographene particle

As shown in Figure 4.13 and data in Table 4.2, the tensile strength of unfilled CFRP composite is increased with nanographene particles addition that the maximum strengthening is 3.93 **%** at particle content of 0.1 wt. %, after this content the tensile was reduced.

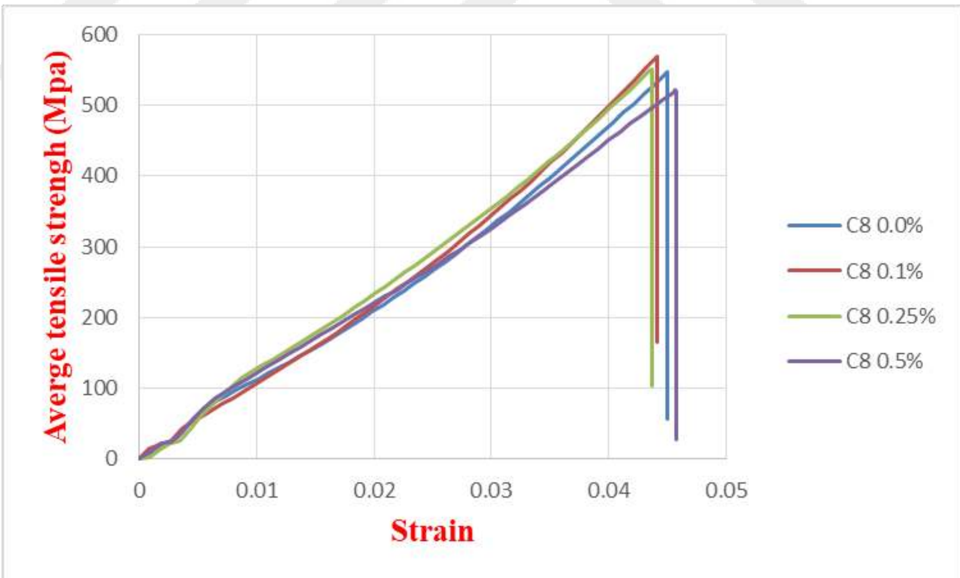

Figure 4.14 Tensile stress-strain curves of the carbon fibre reinforced epoxy composite filled with nanographene particle.

From Figure 4.14 it is observed that the maximum tensile strength was with specimens of 0.1% nanographene addition with value of (569.34) MPa.

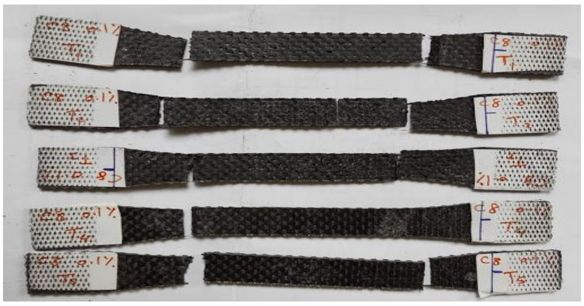

Figure 4.15 Tensile samples after failure of CFRP hybrid composite

The corresponding tensile fracture surfaces for graphene CFRP hybrid composite specimens are shown in Figure 4.15 smooth surfaces of homogenous matrix material. The fiber surfaces were very clean without any trace of attached resin particles. All samples were broken from two place at same time

4.3.3 G2C4G2 with various nanographene particles contents

Table 4.3 depicts the tensile characteristic of G2C4G2 and various nanographene particles contents. The tensile strength was calculated by dividing fracture load by cross sectional area. Fracture strain is the strain at which specimen fractured.

Table 4.3 Tensile characteristic of G2C4G2 with various nanographene contents

Specimen	Particle ratio (Wt. %)	Force(N)	stroke	Max. Stress (MPa)	Average Tensile Stress (MPa)	Strain	Average Tensile Strain %
G2C4G2	0.0%	9772.54	4.53	417.63	398.82	0.0394	3.26
		8461.86	3.08	361.62		0.0267	
		9324.46	3.71	377.51		0.0322	
		10396.6	3.71	444.30		0.0323	
		9953.55	3.74	413.87		0.0325	
	0.1%	11696.9	4.17	473.56	430.37	0.0363	3.47
		8944.8	3.48	382.26		0.0302	
		9214.78	3.71	373.07		0.0323	
		10307.1	4.15	440.47		0.0361	
		11301.7	4.47	482.98		0.0389	
	0.25%	11822.1	4.63	505.22	424.39	0.0402	3.65
		11907.6	4.34	508.87		0.0359	
		11642.9	4.00	471.37		0.0385	
		10773.7	3.86	487.50		0.0365	
		11225.9	4.15	479.74		0.0344	
	0.5%	11500	4.83	453.65	402.65	0.0420	4.53
		11872.3	4.78	424.77		0.0416	
		10963.1	4.42	383.33		0.0477	
		10235.3	4.54	403.76		0.0477	
		11872.4	5.31	468.34		0.0477	

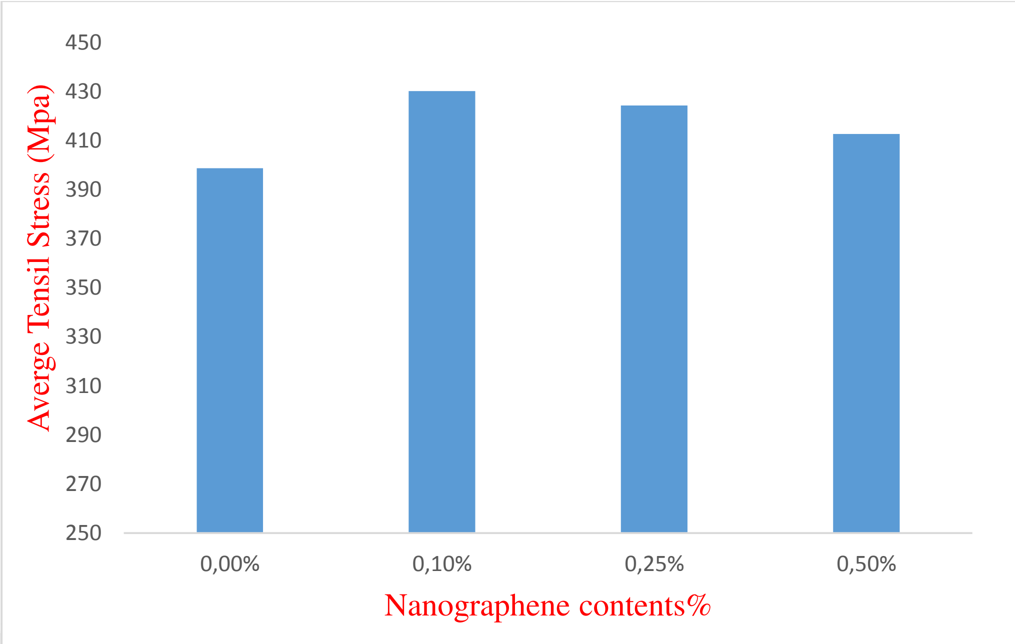

Figure 4.16 Tensile stress- particle content (wt. %) diagram of G2C4G2 hybrid composite filled with nanographene particle

As shown in Figure 4.16 and data in Table 4.3, the tensile strength of unfilled G2C4G2 composite was increased by addition nanographene particles that the maximum strengthening is 7.91 % at particle content of 0.1 wt%, after this content the tensile was reduced.

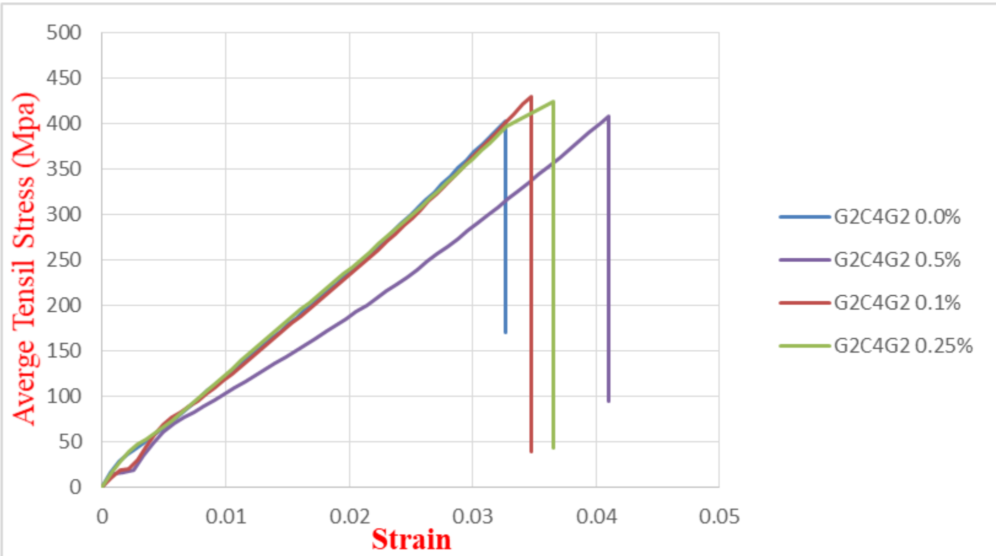

Figure 4.17 Tensile stress-strain curves of G2C4G2 hybrid composite filled with nanographene

From Figure 4.17 was indicated the G2C4G4 plate content 0.1 wt. % nanographene have a higher tensile stress 430.37 MPa compared with author plates. Hence G2C4G2 without graphene have minimum tensile stress and strain.

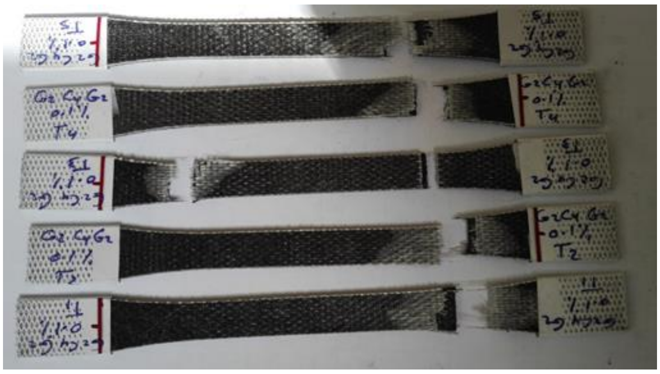

Figure 4.18 Tensile samples after failure of G2C4G2 hybrid composite filled with nanographene

4.3.4 C2G4C2 with various nanographene particles contents

Table 4.4 depicts the tensile characteristic of C2G4C2 and various nanographene particles contents. The tensile strength was calculated by dividing fracture load by cross sectional area. Fracture strain is the strain at which specimen fractured.

Table 4.4 Tensile characteristic of C2G4C2 with various nanographene contents

	Particle ratio (Wt. %)	Force(N)	stroke	Max. Stress (MPa)	Average Tensile Stress (MPa)	Strain	Average Tensile Strain %
C2G4C2	0.0%	11111 11624.4 11567.4 9491.25	4.25 4.20 4.41 3.70	502.76 496.77 523.41 429.47	468.38	0.0370 0.0365 0.0383 0.0322	3.6
	0.1%	11625 11000 11818 11849.2 12218.2	4.36 4.00 5.06 4.56 4.60	510.99 512.82 550.96 552.41 552.86	536.01	0.0379 0.0347 0.0440 0.0397 0.0400	3.93
	0.25%	11810.2 11470.9 11592.8 10846 11947.3	4.80 4.83 5.12 4.16 4.90	465.89 441.19 424.64 397.29 471.29	440.06	0.0417 0.0439 0.0446 0.0362 0.0426	4.18
	0.5%	12268.6 11989.5 11467.4 11783.8 11321.2	5.04 4.54 4.55 5.36 4.47	449.40 419.21 400.96 412.02 395.85	415.49	0.0438 0.0394 0.0396 0.0466 0.0389	4.17

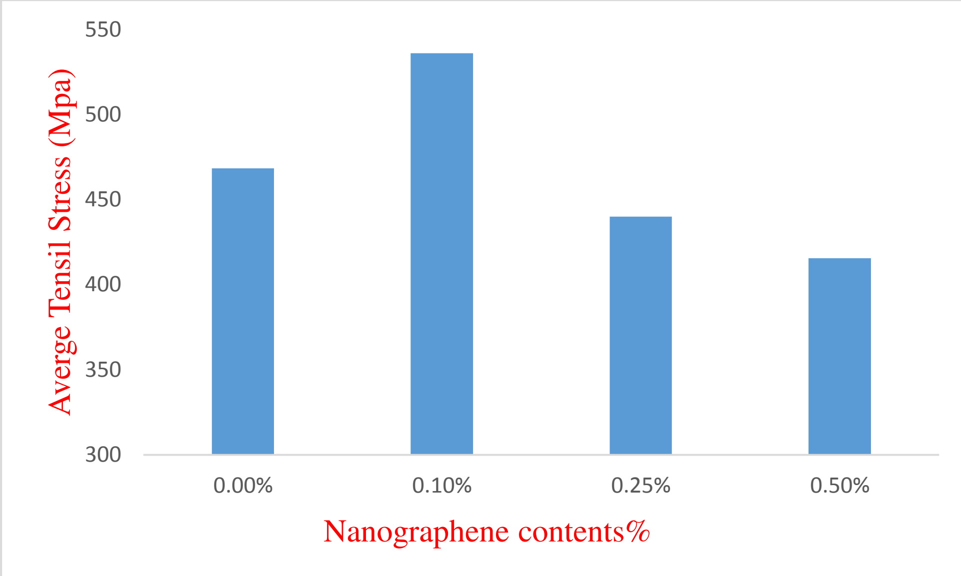

Figure 4.19 Tensile stress- particle content (wt. %) diagram of C2G4C2 hybrid composite filled with nanographene particle.

As shown in Figure 4.19 and data in Table 4.4, the tensile strength of unfilled C2G4C2 composite was increased by addition nanographene particles that the maximum strengthening is 14.4 % at content of 0.1 wt%, after this content the tensile was reduced.

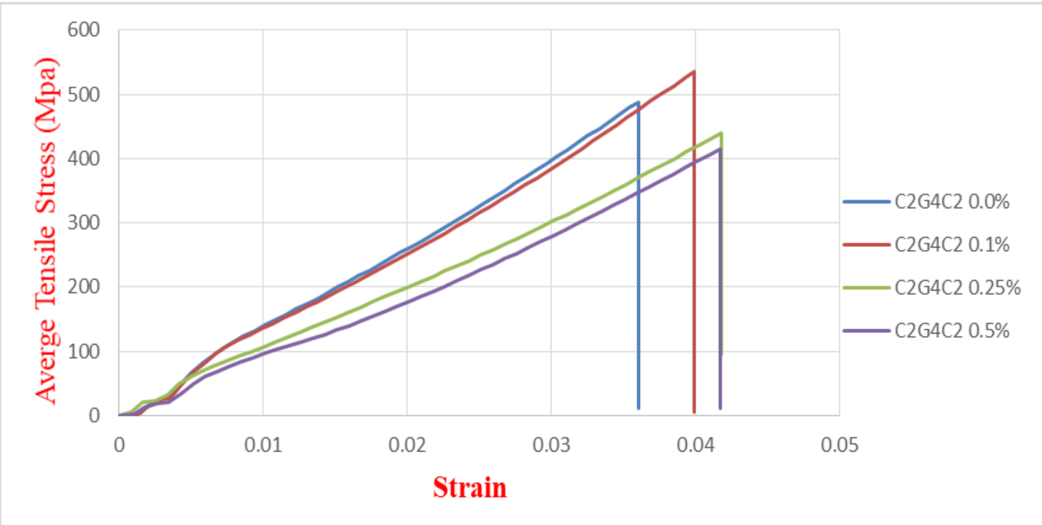

Figure 4.20 Tensile stress-strain curves of C2G4C2 hybrid composite filled with nanographene particle.

From Figure 4. 20 it was indicated the C2G4C2 laminate content 0.1% nanographene have a higher tensile stress 536.01 Mpa compared with author laminates. Hence C2G4C2 without graphene have minimum tensile stress and strain.

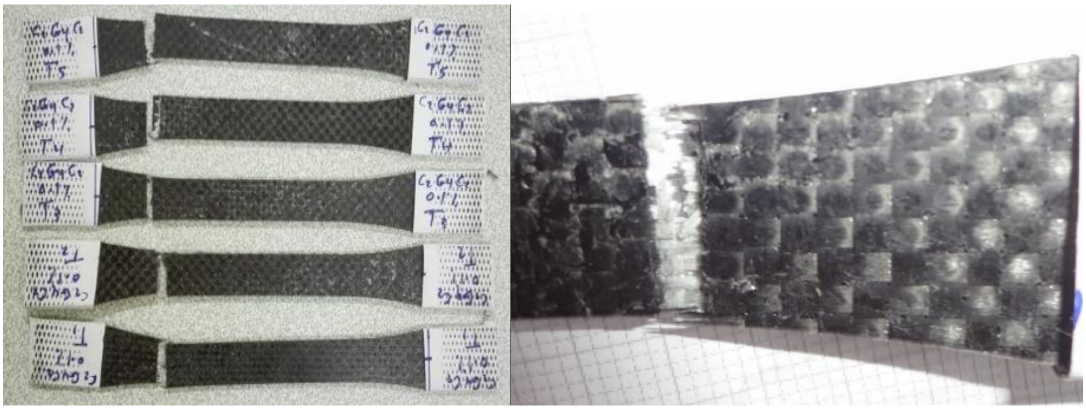

Figure 4.21 tensile specimens after testing,

In light of result to know the benefit of hybridization technique, it is showed C2G4C2 laminate a higher improvement in tensile strength compare with G2C4G2 and pure G8, C8 about 14.4%

4.4 Flexural Results

This section presents experimental works on the flexural tests of GFRP, CFRP and hybrid composites for various addition of nanographene contents. The flexural properties of the samples were measured by three-point bending tests on Shimadzu AG-X machine (Kyoto, Japan). Flexural modulus and strength values were calculated according to equations in ASTM standard (D-790-00). During a three-point flexural bending test, a specimen is placed on two supports and a load is applied at the center of the specimen. Crosshead speed of the test machine was set to 3 mm/min and span to depth ratio was 32:1. The specimen is under tensile stress at the convex surface (the lower surface) and under compressive stress at the concave surface (the upper surface) during the test. The materials flexural strength is the load at yield. The flexural modulus gives a value of the stiffness of a material under bending. The higher the flexural modulus, the stiffer the material is. Five specimens were tested for each set of conditions. The flexural modulus and flexural strength calculated from equation in chapter three. The average value was used in the analysis.

4.4.1 Flexural Results of GFRP and Various Addition of Nanographene Contents

Flexural characteristic of GFRP- nanographene particles and calculated values are given in Table 4.5.

Table 4.5 Flexural characteristic of GFRP- nanographene particles

Specimen	Particle ratio (Wt. %)	Force (N)	Displacement (mm)	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
G8	0.0%	236.61 235.27 210.19 238.37 201.23	7.315583 6.53859 6.24209 6.60959 6.18757	558.91 592.19 529.06 599.99 475.33	551.10	22.17 27.84 25.71 25.97 27.67	25.87
	0.1%	314.38 303.41 270.08 266.60 296.97	6.58607 6.626094 6.28059 6.17907 6.55209	698.30 716.72 637.99 629.76 701.51	676.86	26.17 27.69 27.94 27.82 27.45	27.41
	0.25%	312.85 309.09 277.71 310.47 264.55	6.27058 5.96508 6.20408 6.74356 6.29425	694.91 686.54 656.01 689.62 665.89	678.59	27.90 29.19 28.61 25.62 29.53	28.17
	0.5%	292.59 327.21 263.02 281.00 317.53	6.49008 6.13557 6.3606 5.76009 6.6671	708.70 702.05 637.09 640.01 723.20	682.21	30.32 29.02 28.01 31.03 28.37	29.35

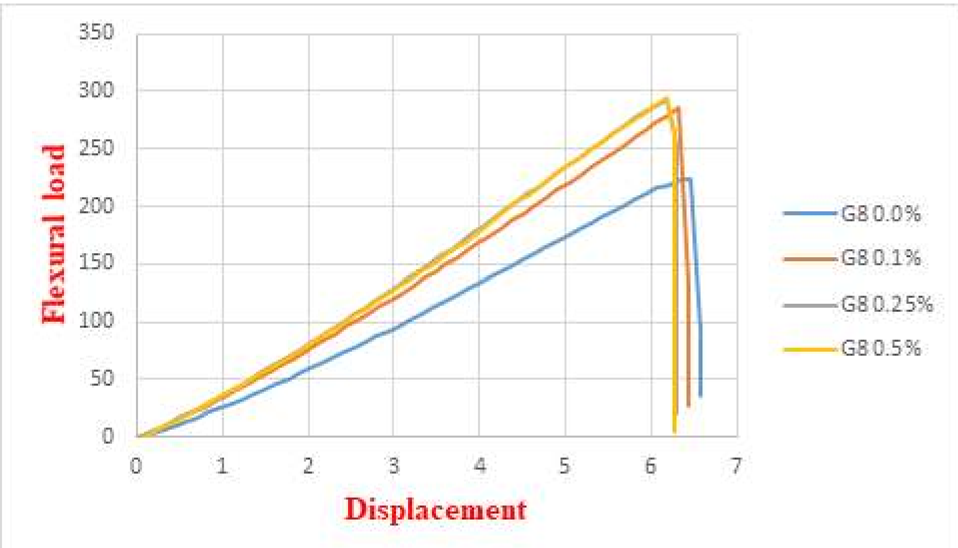

Figure 4.22 Flexural load- displacement curves of the glass fiber reinforced epoxy composite filled with nanographene

Figure 4.22 shows the typical load-displacement response of the GFRP epoxy composite filled with nanographene. It shows the maximum value of flexural load is

296.16 N at 0.5% graphene and the displacement appears same value (6.5 mm). This is relationships seems a linear response of the load-displacement figure.

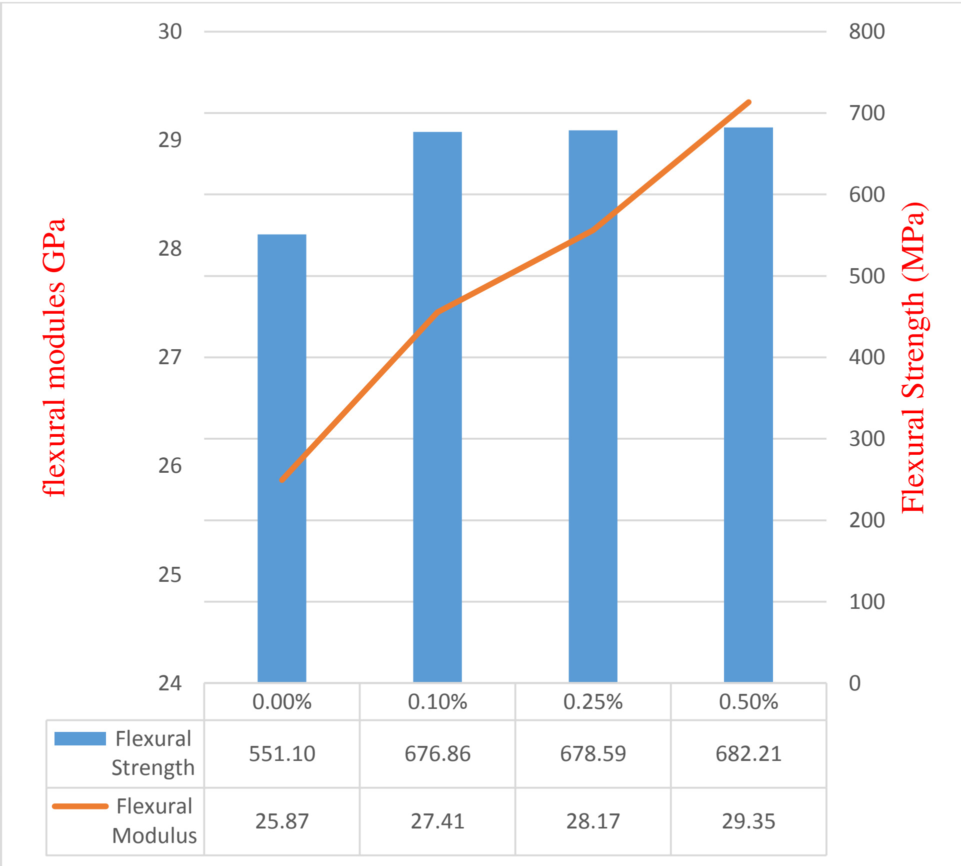

Figure 4.23 Flexural modules and flexural strength – particle content (wt. %) diagram of the GFRP reinforced epoxy composite filled with nanographene

The graph of the flexural strength and flexural modules Figure 4.23 represents the highest stress value and gives the strength of the material. As a result, the highest improvement of flexural strength was obtained at 0.5 wt. % content of nanographene with maximum increment of 23.8 %. This indicated that the chemical compatibility and adhesion strength between nanographene particles and epoxy/glass fiber for flexural properties of composite was optimum at this content. Similar too like regions have been observed by Ávila et al [64], who used carbon fiber epoxy composite modified nanographene

Figure 4.24 Flexural samples after failure

4.4.2 Flexural Results of CFRP and Various Addition of Nanographene Contents

Flexural characteristic of CFRP nanographene particles and calculated values are given in Table 4.6.

Table 4.6 Flexural characteristic of CFRP- nanographene particles

Specimen	Particle ratio (Wt. %)	Force(N)	stroke	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
C8	0.0%	250.816	5.451	484.98	462.67	50.74	46.20
		247.383	5.065	434.88		48.38	
		280.38	5.226	492.89		46.44	
		265.265	5.062	466.31		41.47	
		247.049	5.510	434.29		43.98	
	0.1%	336.933	5.027	565.68	563.42	36.12	39.92
		300.46	4.286	528.18		40.31	
		346.09	4.825	608.39		43.00	
		292.92	4.570			41.05	
		328.45	4.812	551.43		39.13	
	0.25%	337.219	5.000	592.80	581.39	46.07	43.59
		363.159	5.434	669.17		45.14	
		330.353	5.434	580.73		45.15	
		294.352	5.062	517.45		42.06	
		325.68	5.099	546.79		39.51	
	0.5%	360.60	5.277	605.42	611.50	46.31	44.08
		311.52	5.281	574.01		46.15	
		357.58	6.251	600.35		37.63	
		375.46	6.000	630.37		42.14	
		385.57	5.564	647.34		48.16	

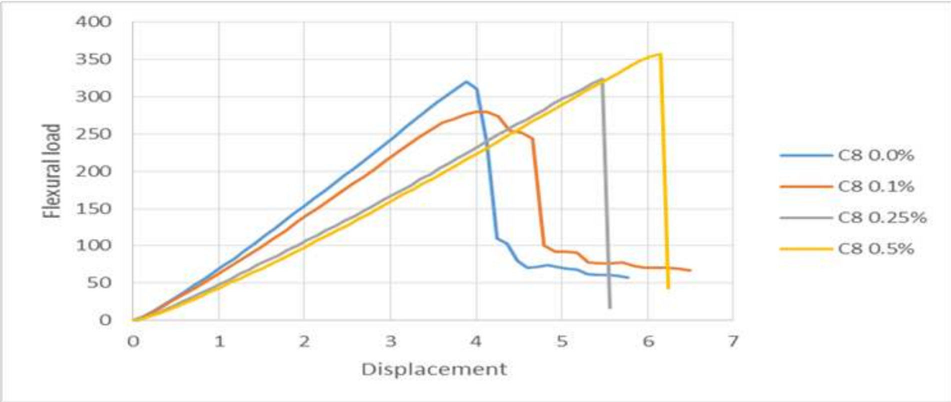

Figure 4.25 Flexural load- displacement curves of the carbon fiber reinforced epoxy composite filled with nanographene

Flexural load vs deflection displacement curves has shown in Figure 4.25 from the flexural tests, the fracture was occurred showing unstable conducting and the flexural strength gradually increased. This behavior may be attributed to the stiffness differences effect of epoxy/glass fiber could delay the specimen failure. The results designated that the failure displacement was reduced with the addition of nanographene particles, this behavior may be the attributed to the mobility and deformity of the polymer matrix was restricted by the inclusion of nanographene particles. As shown in Table 4.6, flexural strength was improved by the addition of nanographene particles to the CFRE. Hence, the composite flexural strength was increased from 258.17 N for unfilled CFRE to reach 358.15 N with Nanographene content of 0.5 wt%, it is similar behavior observed by Ávila et al [64].

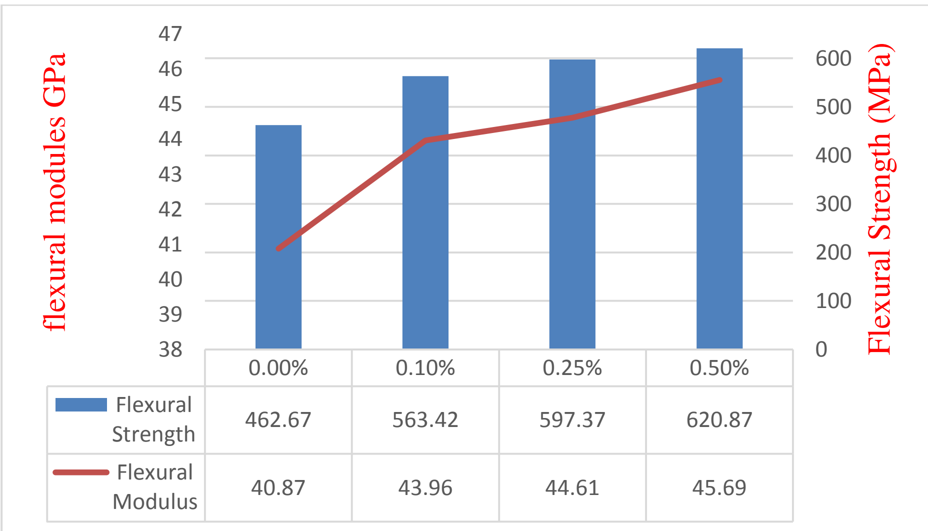

Figure 4.26 Flexural modules and flexural strength – particle content (wt. %) diagram of the CFRP reinforced epoxy composite filled with nanographene.

Figure 4.26 and Table 4.6, the flexural strength and modulus of the nanocomposites were increased by 34.2 % and 11.78%, respectively, with 0.5wt % graphene content. The Flexure strength showed gradual increase with the increase of nanoparticles ratio in the samples with maximum value equal to 620.87 at nanoparticle ratio equal to 0.5%. At the same time, the flexural modulus showed also an increase in value as long as the nanoparticles in the samples are increased with optimal value equal to 45.69 at 0.5% of nanoparitcles ratio. The obtained results were exactly compatible with the results (in term of nanoparticle content ratio) obtained by Ávila et al [64], who has used modified carbon fiber by nonographane.

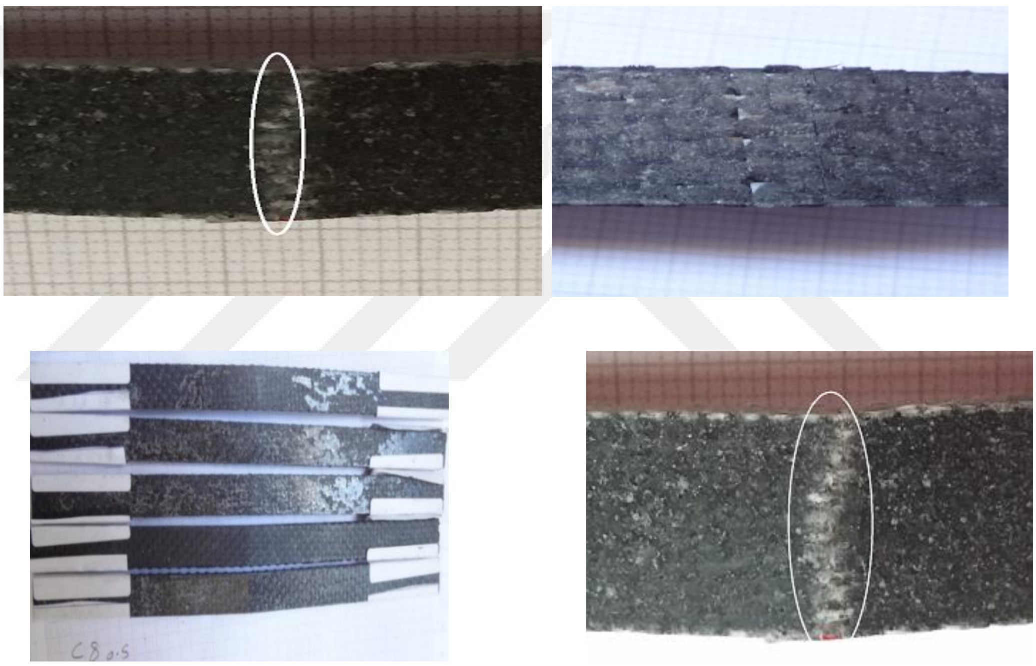

Figure 4.27 Flexural samples CFRP 0.5% grapheme content after failure.

The corresponding flexural sample fracture surfaces for CFRP hybrid composite specimens modified by graphene are shown in figure 4.27 showed smooth surfaces of homogenous matrix material. The fiber surfaces were very clean without any trace of attached resin particles

4.4.3 Flexural Results of G2C4G2 and Various Addition of Nanographene Contents

Flexural characteristic of G2C4G2 nanographene particles and calculated values are given in Table 4.7.

Table 4.7 Flexural characteristic of G2C4G2- nanographene particles

Specimen	Particle ratio (Wt. %)	Force(N)	stroke	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
G2C4G2	0.0%	360.394 330.78 373.51 362.02 292.73	8.042 7.331 7.848 8.249 7.138	756.73 694.56 784.27 760.14 581.88	715.51	26.34 27.79 28.57 26.23 24.08	26.60
	0.1%	392.77 365.30 371.65 309.82 373.75	8.135 8.141 8.209 8.404 7.596	740.19 767.04 780.36 583.87 784.77	731.24	24.15 27.41 26.78 22.18 29.80	26.06
	0.25%	298.79 312.57 311.66 312.95 277.71	7.721 7.467 7.229 7.819 7.493	680.15 711.52 632.82 635.43 632.17	658.42	26.31 27.95 23.75 22.07 25.71	25.16
	0.5%	311.28 357.25 388.62 361.06 348.43	8.907 8.396 9.297 8.971 8.836	623.92 589.03 640.77 624.01 663.89	628.32	24.59 21.52 20.69 22.43 24.73	22.79

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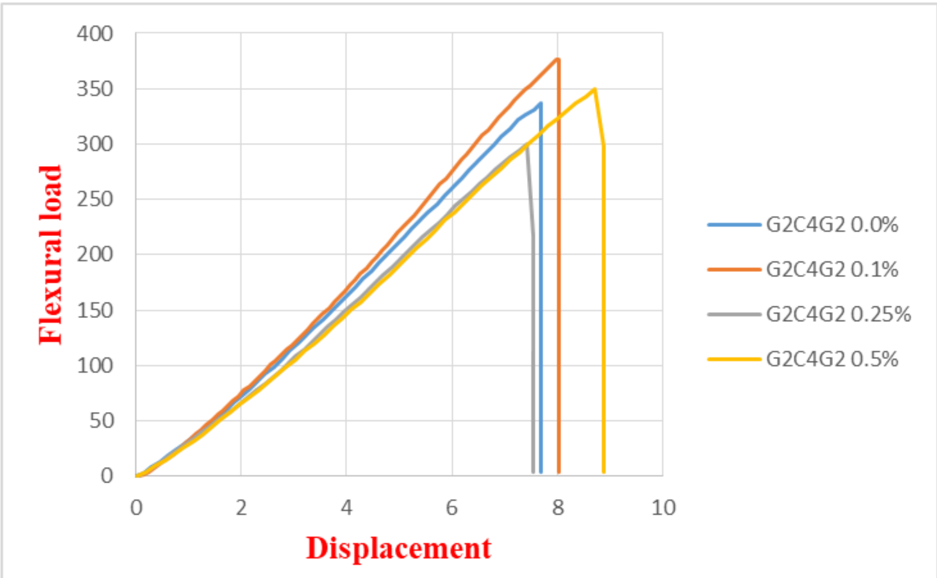


Figure 4.28 Flexural load- displacement curves of the G2C4G2reinforced epoxy composite filled with nanographene

Figure 4.28 between flexural load vs displacement curves of the G2C4G2 fiber reinforced epoxy composite filled with nanographene shows the maximum value of flexural load (362.66) N at 0.1% graphene and the maximum displacement occurs at 0.5% graphene content about (9) mm. This is relationships seems A linear response of the load-displacement

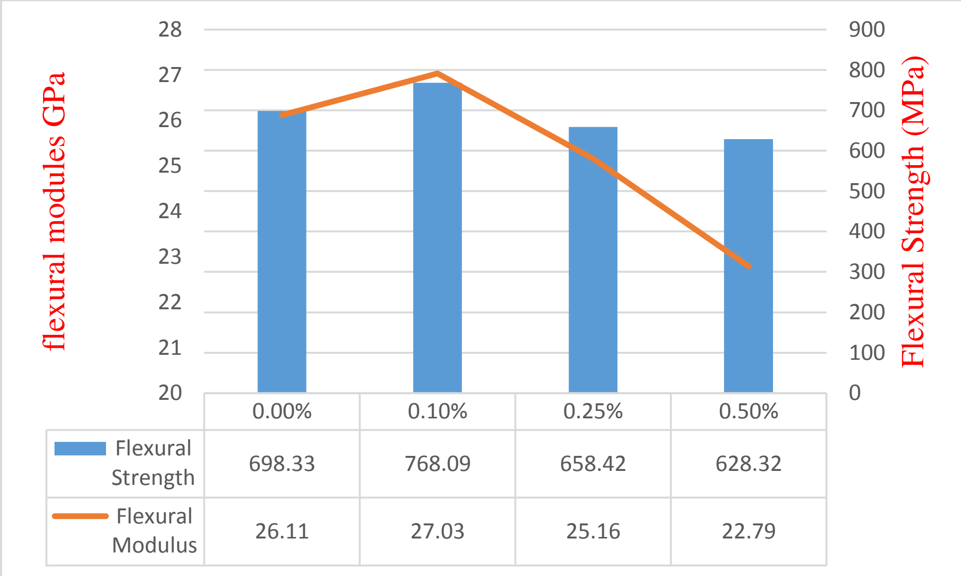


Figure 4.29 Flexural modules and flexural strength – particle content (wt. %) diagram of the G2C4G2 reinforced epoxy hybrid composite filled with nanographene

Figure 4.29 as a result, the highest improvement of flexural strength was obtained at 0.1 wt% content of nanographene with maximum increment of 10 %.

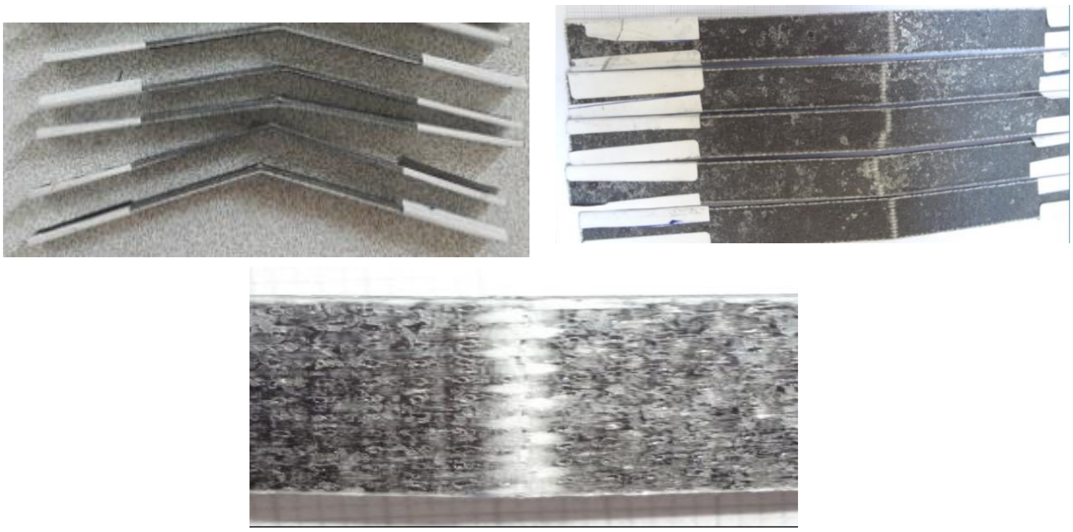


Figure 4.30 Flexural samples after failure

During a three- point flexural bending test, a specimen is placed on two supports and a load is applied at the center of the specimen. The specimen is under tensile stress at the convex surface (the lower surface) and under compressive stress at the concave surface (the upper surface) during the test. The materials flexural strength is the load at yield. The flexural modulus gives a value of the stiffness of a material under bending. The higher the flexural modulus, the stiffer the material is. As figure 4.31

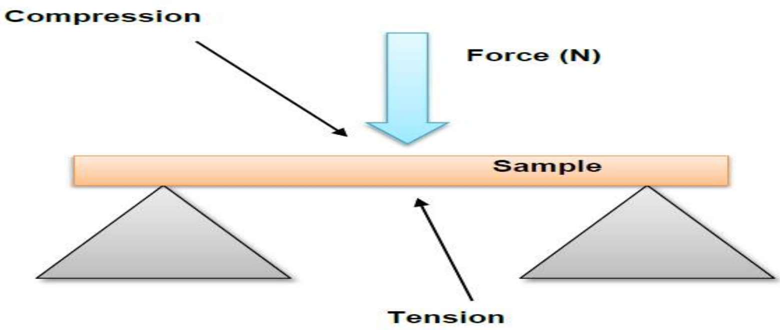


Figure 4.31 Illustration of a three –point flexural bending test.

4.4.4 Flexural Results of C2G4C2 and Various Addition of Nanographene Contents

Flexural characteristic of C2G4C2 nanographene particles and calculated values are given in Table 4.8.

Table 4.8 Flexural characteristic of C2G4C2 - nanographene particles

Specimen	Particle ratio (Wt. %)	Force (N)	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
C2G4C2	0.0%	296.402 380.14 301.55 274.37 357.82	658.98 753.84 670.43 610.00 750.71	688.79	54.29 42.32 51.33 50.15 52.30	50.08
	0.1%	315.66 303.60 299.36 313.81 296.97	693.54 708.08 698.18 731.88 652.48	696.83	51.85 52.00 51.83 52.29 52.73	52.14
	0.25%	233.03 258.92 306.03 283.81 288.30	462.30 488.31 523.50 485.49 493.16	490.55	35.43 31.20 29.16 29.91 30.13	31.16
	0.5%	208.62 211.48 195.36 256.40 213.91	389.77 360.01 332.57 436.47 364.15	376.59	32.12 29.79 28.55 28.34 29.54	29.67

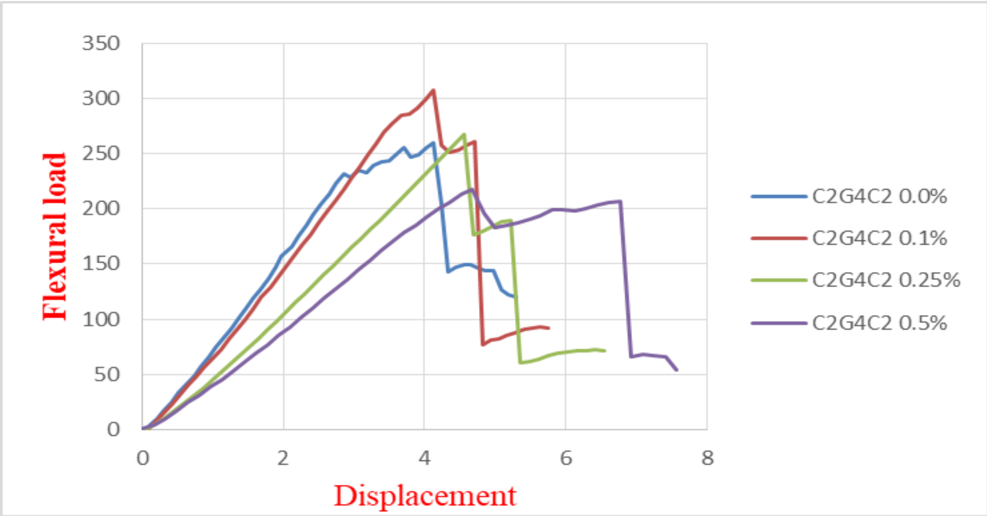


Figure 4.32 Flexural load- displacement curves of the C2G4C2 reinforced epoxy composite filled with nanographene

Figure 4.32 between flexural load vs displacement curves of the C2G4C2 fiber reinforced epoxy composite filled with nanographene shows the maximum value of flexural load (305.88) N at 0.1% graphene and the maximum displacement occurs at 0.5% graphene content about (7.5) mm. This is relationships seems A linear response of the load-displacement.

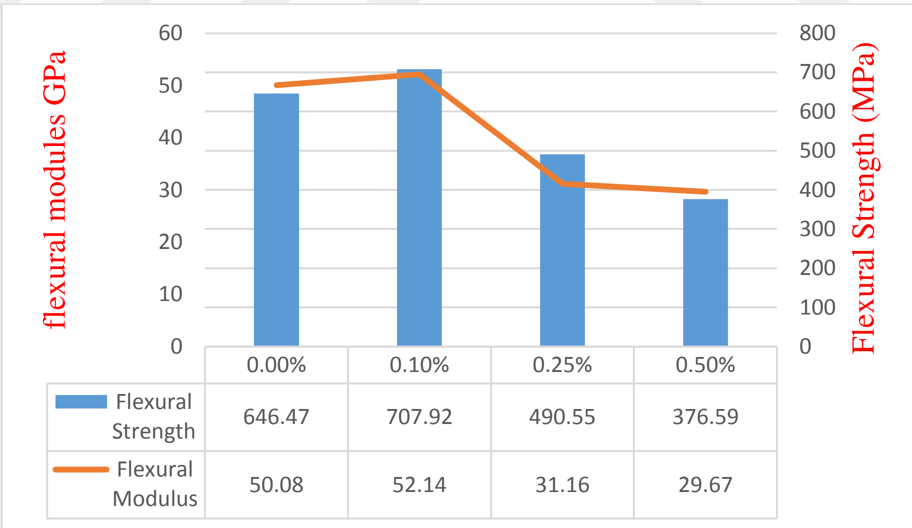


Figure 4.33 Flexural modules and flexural strength – particle content (wt. %) diagram of the C2G4C2 hybrid composite filled with nanographene.

Figure 4.33 as a result, the highest improvement of flexural strength was obtained at 0.1 wt% content of nanographene with maximum increment of 9.5 %.

Figure 4.34 flexural samples after failure

4.5 Vibration Test Results

The composites are having very good static and dynamic mechanical properties and they are light weight in nature. Good strengths, stiffness and high damping are the desirable properties of structural applications. These properties are found to be good in these composites and can be used in aerospace applications like airplane wings, fuselage, control surfaces, high lift devices, landing gear struts or any other struts and beams. They are also used in general applications like marine industry, automobile industry, civil industry etc. Aircraft structures are subjected to aerodynamic flutter during their service, due to air load. The resonant amplitude of vibration is considerably influenced by damping associated with each mode of the structure. It is mandatory to find the natural frequency and the modal damping. Materials with high damping or absorbing properties are crucially important to extend the life of structures. Many research works have been carried out in the dynamic characteristics of composite materials [80], [81]. Static properties, dynamic properties, storage modulus and damping are the important characteristics which gives vital role in the design of composite materials. Storage modulus is related to the stiffness of composites and damping is associated with the energy dissipation of composites [82], [83] proved that through toughening of polymer matrix the damping effect can be improved. Vibration, mechanical and thermal properties of structural composites can be improved by adding some nanoparticles with natural fibers. Chandra et al [] suggested that viscoelastic nature of matrix is one of the reasons for contribution of damping in composites.

4.5.1 Vibration test results of GFRC with nanographene

Table 4.9 depicts the obtained results of the Vibration test of GFRP with various nanographene contents.

Table 4.9 Vibration results of the GFRP reinforced epoxy composite filled with nanographene

wt %	Natural frequency ω Hz	Storage modulus E' Gpa	Damping Ratio ξ	Loss modulus E'' Gpa
0.00 %	37.987	11.17	0.115	2.58
0.10 %	46.245	18.49	0.125	4.63
0.25 %	46.245	20.57	0.047	1.95
0.50 %	47.897	20.33	0.092	3.73

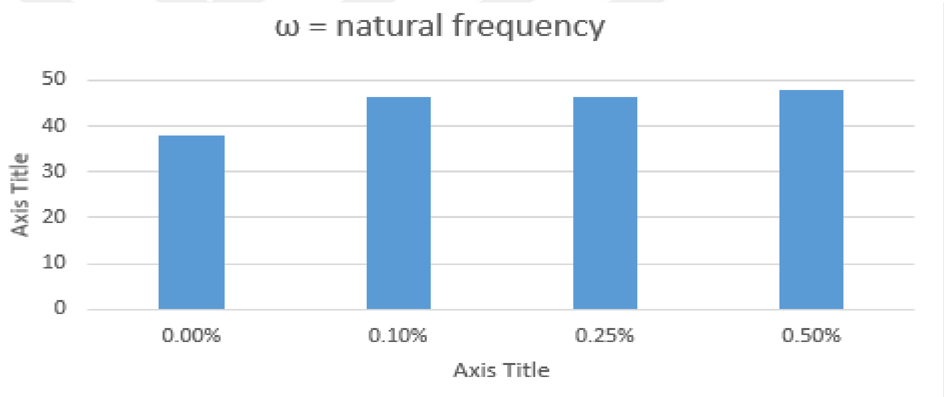


Figure 4.35 Comparison of maximum natural frequencies at high filler content

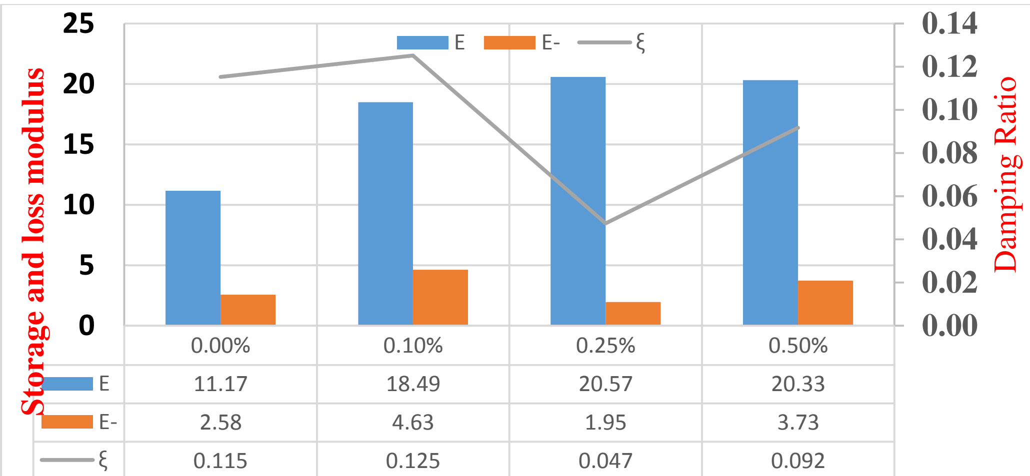


Figure 4.36 Comparison Dynamic Characteristics of GFRP with graphene epoxy composite

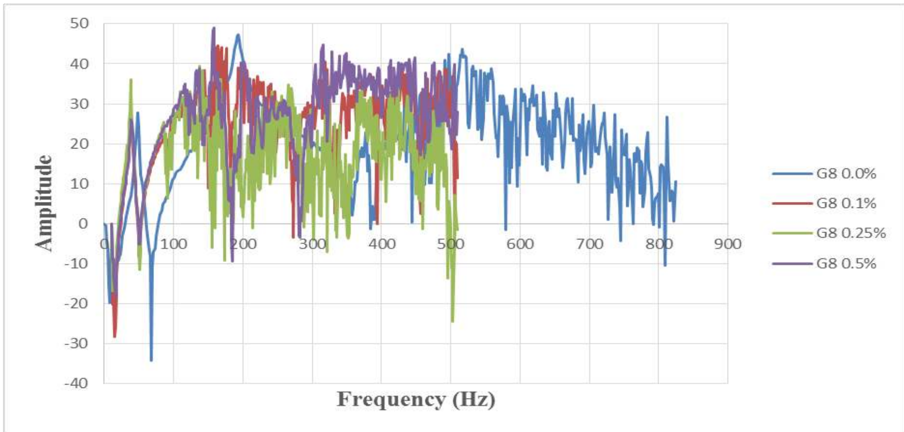


Figure 4.37 Amplitude – Frequency diagram of the glass fibre reinforced epoxy composite filled with nanographene

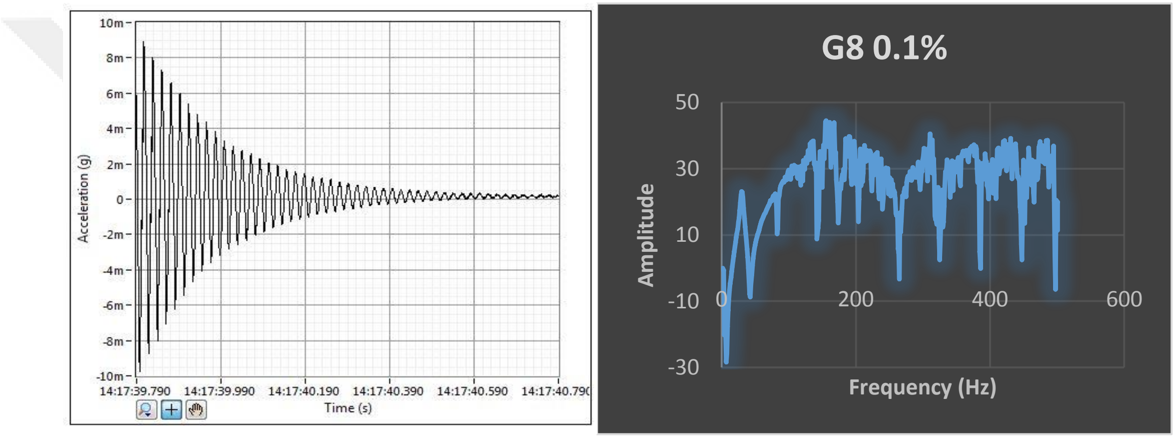


Figure 4.38 Frequency response and time decaying graph of GFRP nanographene epoxy modified

From Figure 4.37 and Figure 4.38 the damped natural frequency of GFRP became higher after the incorporation of graphene into the matrix due to the enhancement of damping ratio. Similar to the damping behavior of graphene reinforced nanocomposite, the graphene GFRP hybrid composites showed an amplitude dependent vibration characteristic, which indicates that the graphene modified matrix material was responsible for the improvement in damping characteristics.

4.5.2 Vibration test results of CFRC with nanographene

Table 4.10 depicts the obtained results of the Vibration test of CFRC with various nanographene contents.

Table 4.10 Vibration results of the carbon fiber reinforced epoxy composite filled with nanographene

wt %	Natural frequency ω Hz	Storage modulus E' Gpa	Damping Ratio ξ	Loss modulus E″ Gpa
0.00%	89.187	32.15	0.066	4.27
0.10%	82.581	22.95	0.101	4.63
0.25%	85.884	28.10	0.069	3.88
0.50%	84.232	29.46	0.069	2.92

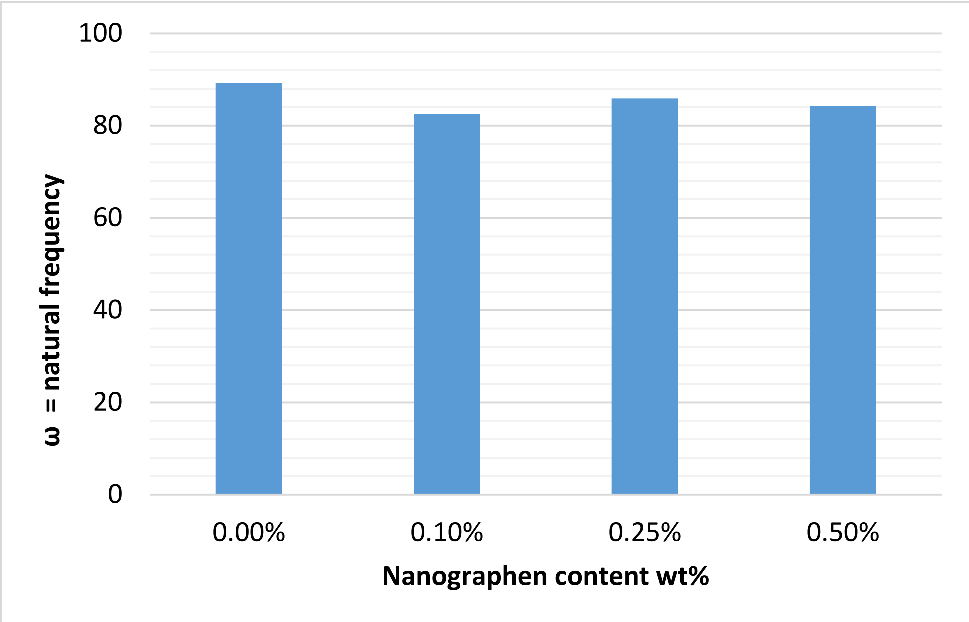


Figure 4.39 Damped natural frequency of nanocomposites and CFRP composites different nanographene contents

4.6 Dynamic Characteristics

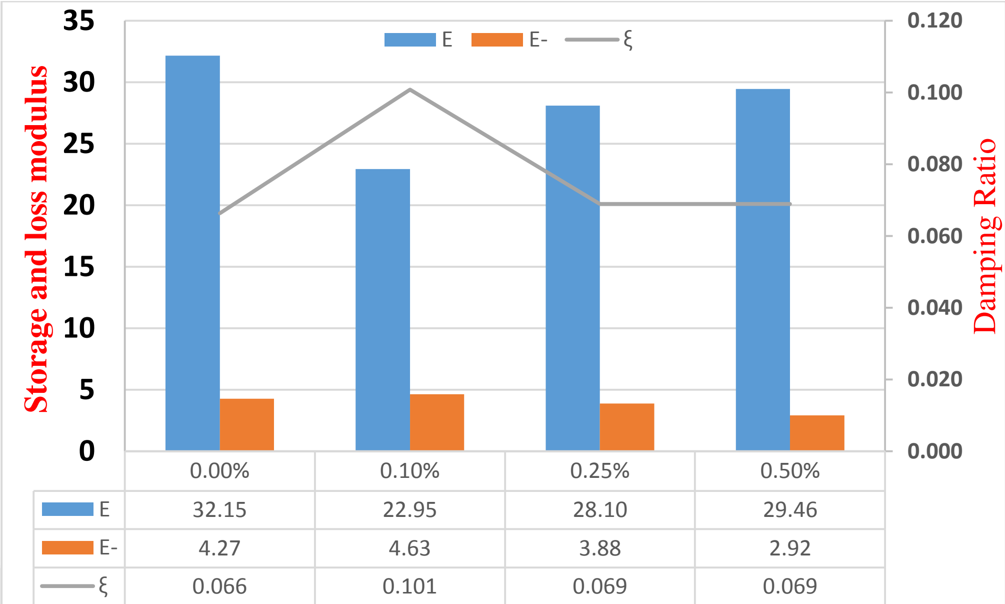


Figure 4.40 Comparison dynamic characteristics of CFRP with graphene epoxy composite.

In summary, the 1st mode is dominated by the inherent damping characteristics of materials, such as viscoelasticity, whereas the 2nd mode is dominated by the structural response. Further studies are required to draw any conclusion regarding the relative importance of the damping arising from the 1st and 2nd modes of vibration as shown in figure 4.41[84].

The enhanced damping capacity was achieved without sacrificing the elastic (storage) modulus.

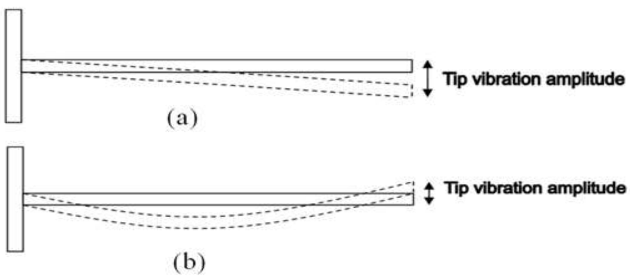


Figure 4.41 Modal vibration in (a) the 1st vibration mode; and (b) the 2nd vibration mode

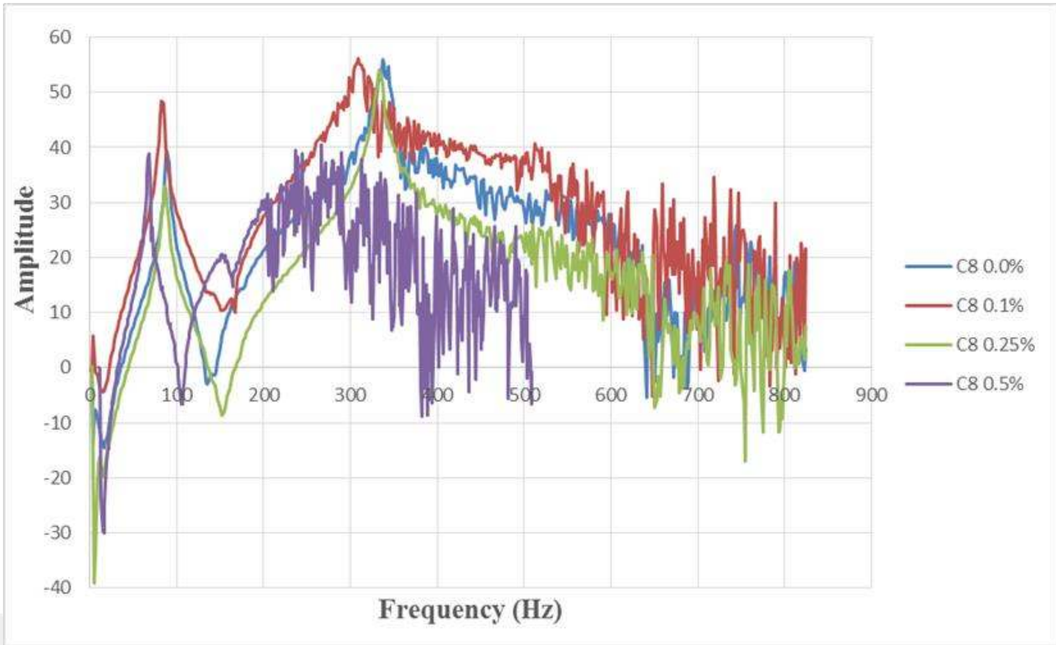


Figure 4.42 Amplitude – frequency diagram of the carbon fibre reinforced epoxy composite filled with nanographene

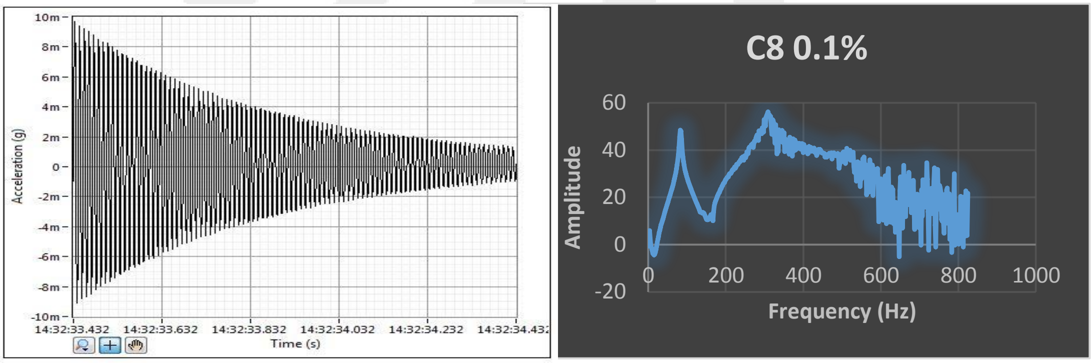


Figure 4.43 Frequency response and time decaying graph of CFRP nanographene epoxy modified

From Figure 4.42 and Figure 4.43 the damped natural frequency of CFRP became lower after the incorporation of graphene into the matrix due to the enhancement of damping ratio. Similar to the damping behavior of graphene reinforced nanocomposite, the graphene CFRP hybrid composites showed an amplitude dependent vibration characteristic, which indicates that the graphene modified matrix material was responsible for the improvement in damping characteristics.

4.6.1 Vibration Test Results of Hybrid Composite G2C4G2 with Nanographene

Table 4.11 depicts the obtained results of the Vibration test of G2C4G2 with various nanographene contents.

Table 4.11 Vibration results of hybrid composite (G2C4G2) epoxy composite filled with nanographene

wt %	Natural frequency ω Hz	Storage modulus E' Gpa	Damping Ratio ξ	Loss modulus E'' Gpa
0.00%	62.761	20.95	0.107	4.48
0.10%	57.806	20.85	0.145	6.07
0.25%	56.155	19.57	0.107	4.18
0.50%	59.458	17.63	0.083	2.91

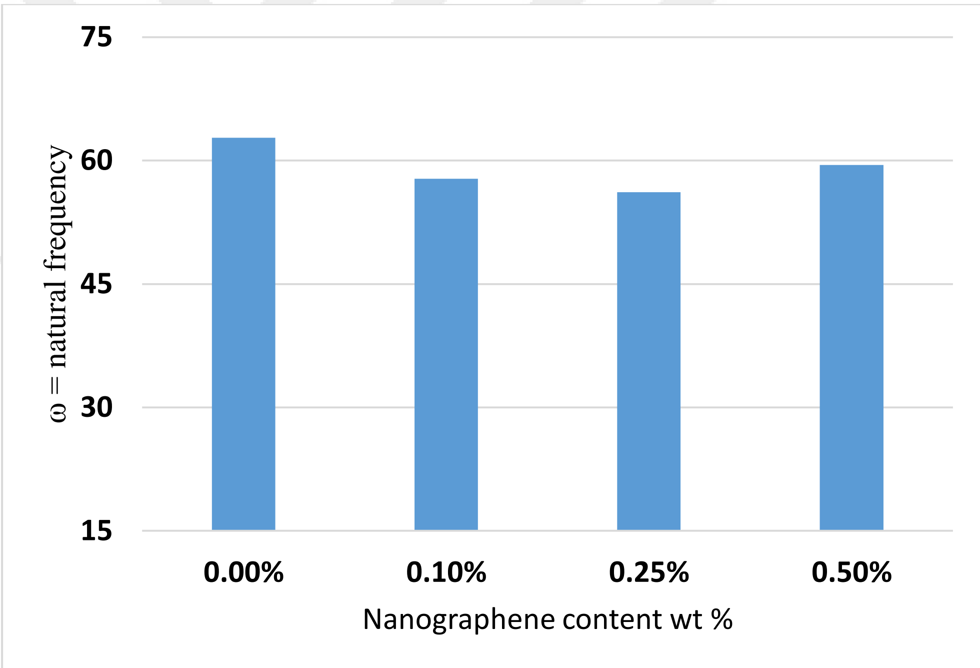
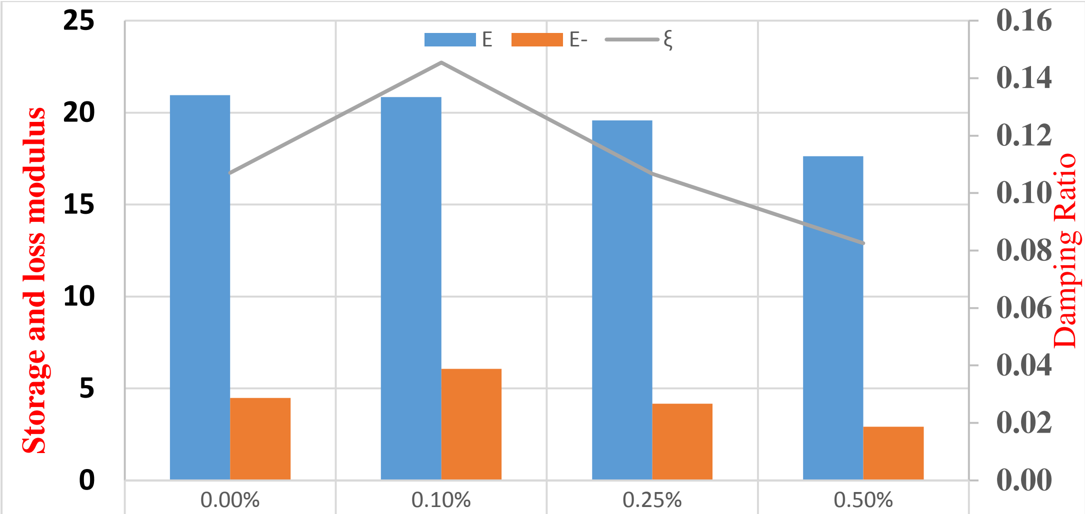


Figure 4.44 Damped natural frequency of G2C4G2 and nanocomposites



	0.00%	0.10%	0.25%	0.50%
E	20.95	20.85	19.57	17.63
E-	4.48	6.07	4.18	2.91
ξ	0.107	0.145	0.107	0.083

Figure 4.45 Comparison dynamic characteristics of G2C4G2 with graphene epoxy hybrid composite.

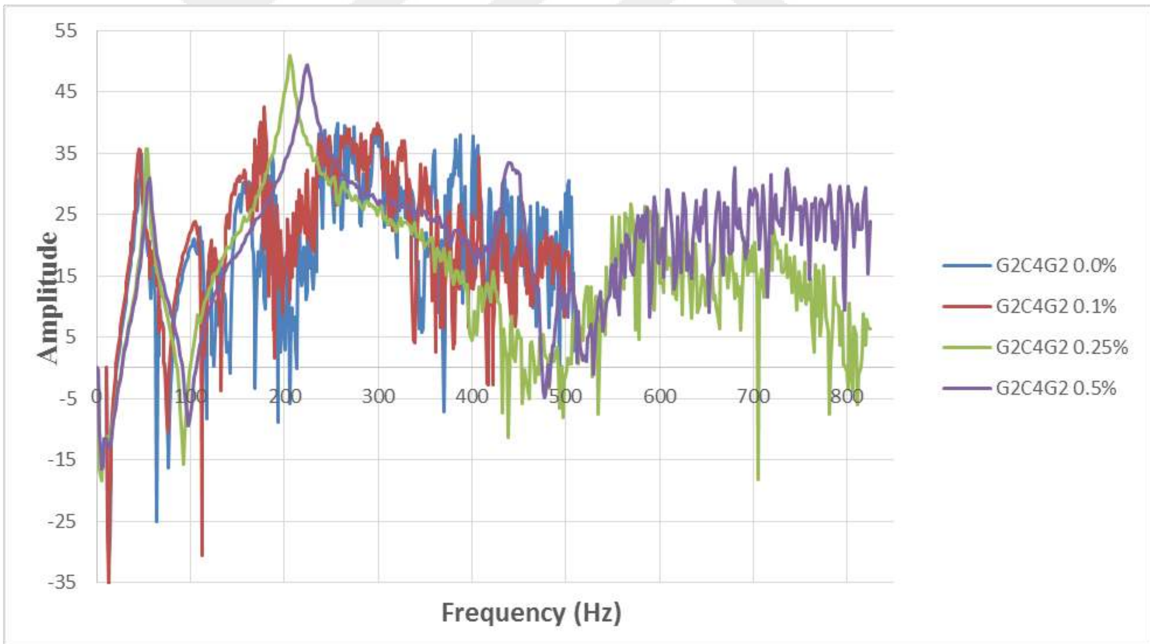


Figure 4.46 Amplitude – frequency diagram of the G2C4G2 fibre reinforced epoxy composite filled with nanographen

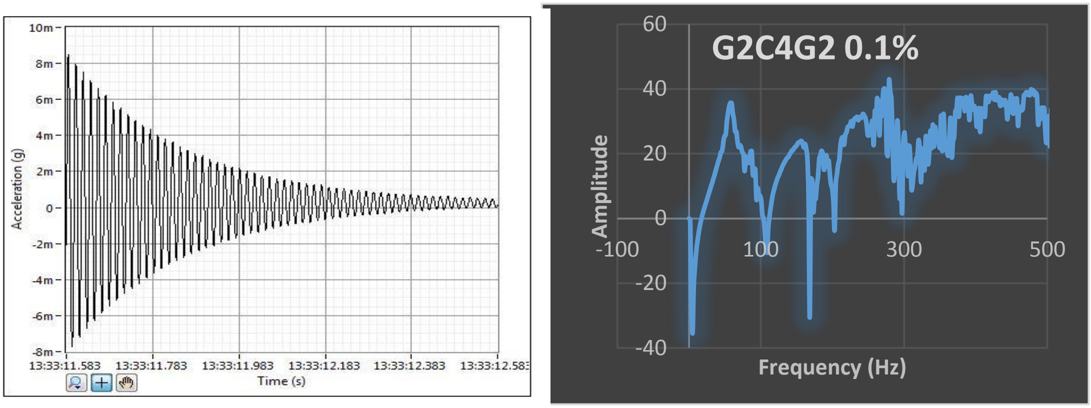


Figure 4.47 Frequency response and time decaying graph of G2C4G2 nanographene epoxy modified

From Figure 4.44 and Figure 4.45 shows incorporation nanographene into matrixes improvement damping ratio, storage and loss modulus at 0.1% graphene, which indicates that the graphene modified matrix material was responsible for the improvement in damping Characteristics.

4.6.2 Vibration Test Results of Hybrid Composite (C2G4C2) with Nanographene

Table 4.12 Vibration results of hybrid composite (C2G4C2) epoxy composite filled with nanographene

wt %	Natural frequency ω Hz	Storage modulus E' Gpa	Damping Ratio ξ	Loss modulus E″ Gpa
0.00%	97.443	64.84	0.042	5.39
0.10%	75.974	38.23	0.089	6.19
0.25%	80.929	32.85	0.059	3.90
0.50%	82.58	24.25	0.032	1.57

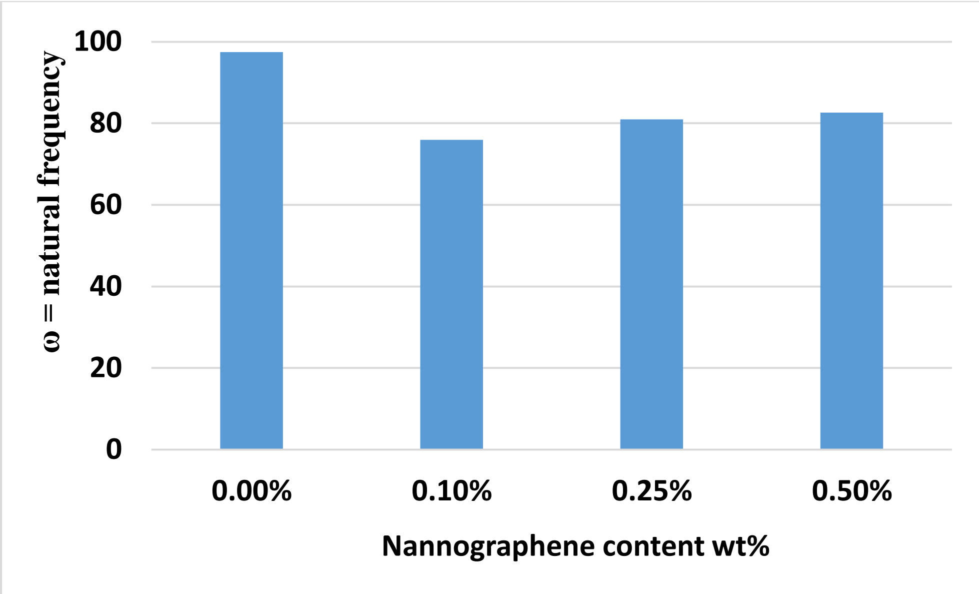


Figure 4.48 Damped natural frequency of C2G4C2 with nanocomposites

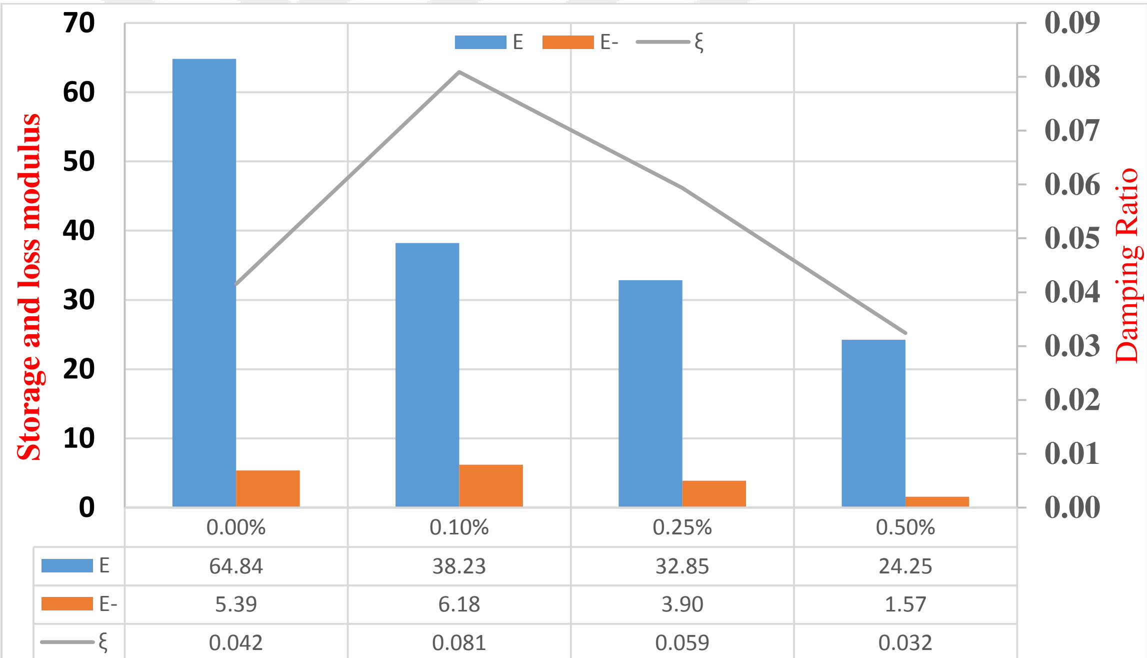


Figure 4.49 Comparison dynamic characteristics of C2G4C2 with nanographene epoxy hybrid composite.

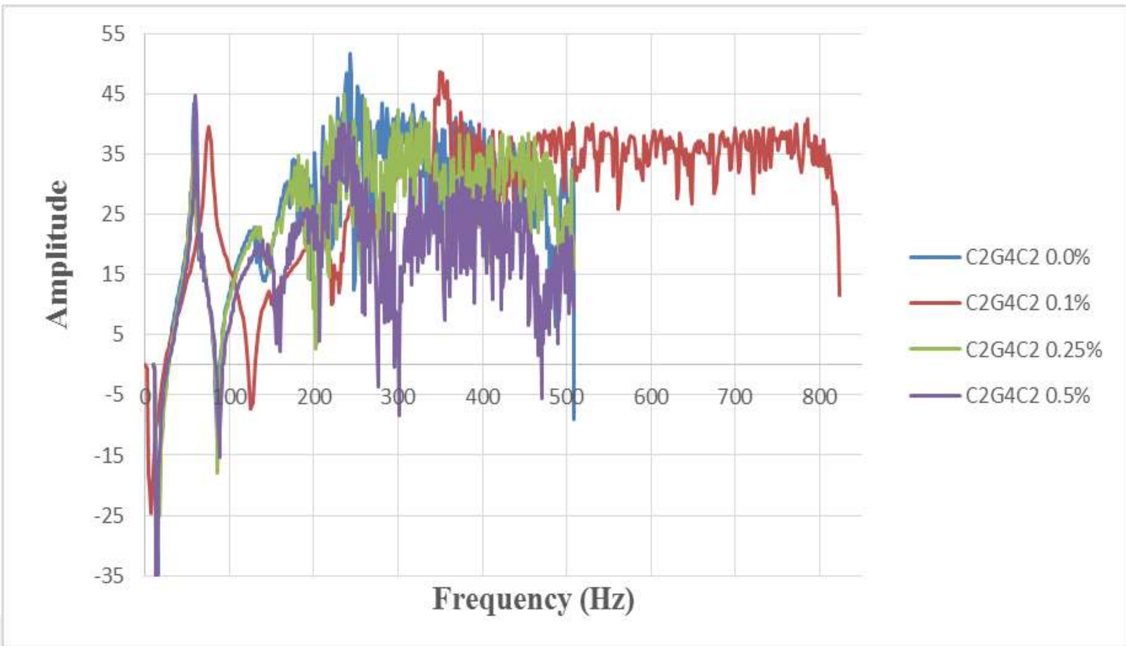


Figure 4.50 Amplitude – frequency diagram of the C2G4C2 fibre reinforced epoxy composite filled with nanographene

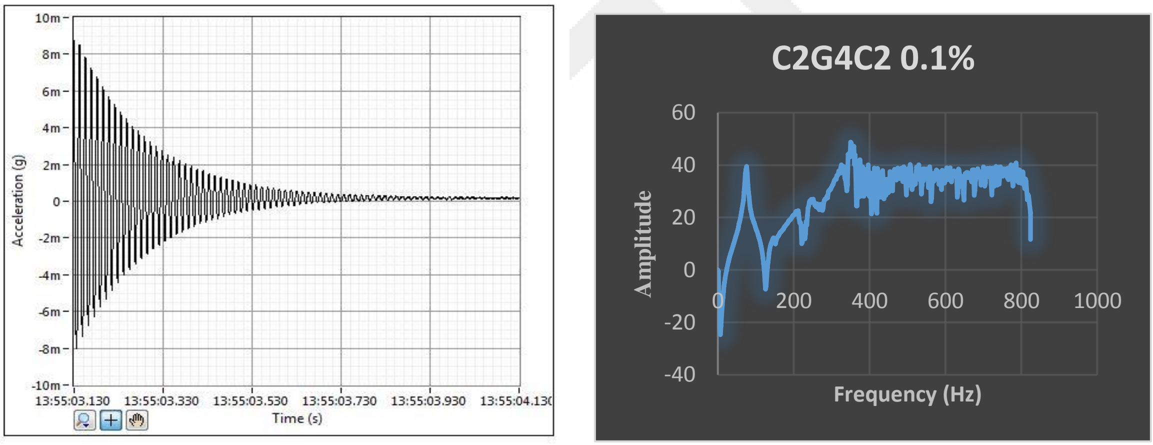


Figure 4.51 Frequency response and time decaying graph of C2G4C2 nanographene epoxy modified

From figures above shows incorporation nanographene into matrixes improvement damping ratio, storage and loss modulus at 0.1% graphene, which indicates that the graphene modified matrix material was responsible for the improvement in damping characteristics.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

In this thesis addresses effects of nanographene particles on hybrid composites, an investigation of nanographene addition on mechanical properties of glass and carbon fiber reinforced hybrid composite epoxy matrix based at different weight percentage contents of graphene nanoplatelet (GNP). Nanocomposites were prepared by hand lay–up technique and hot pressing.

5.1 Conclusions

Fore major findings drawn from this thesis are highlighted in the following

- ❖ From Charpy impact test, the experimental results showed that adding small amount of GNPs into the epoxy resin increased the impact resistance of glass-carbon/epoxy composites. It was observed that impact energy of composite samples increased with the increase of GNPs amount up to 0.25 wt. %, then, a reduction trend of absorbed energy has occurred with more addition of GNPs as 0.5 wt. %. The maximum improving in impact energy was resulted when GNPs added by 0.25 wt. % for both cases of flatwise and edgewise impact test. Furthermore, The GFRP laminate showed an energy absorption as 103.75% greater than that of the CFRP laminate (1.63 with respect to 0.80 J) for the case of flatwise impact and 35.33% higher than that of the carbon/epoxy laminate (1.8 with respect to 1.33 J) for the case of edgewise impact. While, C2G4C2 hybrid laminate showed lower impact energy than that of G2C4G2 hybrid laminate by 22.4% and 2.3% for flatwise and edgewise, respectively
- ❖ From tensile test, the highly effect of reinforcement provided by graphene in polymer matrix, at loading fractions as small as 0.1 wt. % is a very significant result. At hybrid nanocompsite C2G4C2 the maximum strengthening is 14.4 %while at hybrid nanocompsite G2C4G2 the maximum strengthening is 7.91 % . .Whereas GFRP and CFRP the maximum strengthening is 6.74%, 3.93% respectively.

- ❖ From the flexural test results show an improvement of flexural strength was obtained at 0.5 wt% content of nanographene with maximum increment of 23.8%, 34.2 % apiece of GFRP and CFRP respectively. While at hybrid nanocomposite G2C4G2 and C2G4C2 10 %, 9.5 % respectively at 0.1 wt. % percentage.
- ❖ From the vibration damping properties of nanocomposites was obtained at 0.1% the best damping ratio for each group which test. Yet, the greatest result of vibration damping ratio for GFRP and CFRP were 8.5% and 53% respectively. While, G2C4G2 & C2G4C2 laminates were 35.9% & 82.09% respectively. Add to that loss modulus increased rapidly at 0.1% graphene percentage after that reduced.

According to this result could be indicated that the addition nanographene to hybrid composite epoxy based of glass and carbon fiber reinforced improved mechanical properties as a result of the good interfacial bonding at interaction of the GNPs with epoxy matrix and fiber.

5.2 Recommendations for Future Work

Having completed this thesis, it should be noted that there are still ample opportunities for further research in this exciting field of study. Due to the great effects of preparation methods on composite properties, it is necessary to control one processing parameter during preparation process.

Researchers are making rapid progress in exploring the unique properties of graphene, and finding effective ways to produce graphene as well as its potential applications. Future work may be focused on two directions: one is aimed at producing high-quality graphene with fewer defects, and the other aimed at developing new fabrication techniques for composites with better alignment of graphene within the matrix. This could be obtained by utilizing the next steps:

- ❖ Mechanical mixing with high speed, three roll mill and sonication dispersion techniques in presence heat and without in order to investigate getting a uniform dispersing nanographene in matrix
- ❖ Utilizing vacuum assisting process to prepare composite materials.
- ❖ Apply hand lay-up method and vacuum assisting process at the same time.
- ❖ Make a comparison between these methods to choose the best one.

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