OCTOBER 2017 M.Sc. in Mechanical Engineering BAHJAT HARDAN SULAIMAN

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

VIBRATION DAMPING PROPERTY, TENSILE AND FLEXURAL BEHAVIOUR OF KEVLAR-CARBON/EPOXY/NANOGRAPHENE COMPOSITE

M. Sc. THESIS

IN

MECHANICAL ENGINEERING

BY

BAHJAT HARDAN SULAIMAN

October 2017

Vibration Damping Property, Tensile and Flexural Behavior of Kevlar-Carbon/Epoxy/Nanographene Composite

M.Sc. Thesis

in

Mechanical Engineering

University of Gaziantep

Supervisor

Assoc. Prof. Dr. Ahmet ERKLİĞ

by

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October 2017

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
MECHANICAL ENGINEERING DEPARTMENT

Name of the thesis: Vibration Damping Property, Tensile and Flexural Behavior of Kevlar-Carbon/Epoxy/Nanographene Composite

Name of the student: Bahjat Hardan SULAIMAN

Exam date: 28/10/2017

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Bahjat Hardan Sulaiman

ABSTRACT

VIBRATION DAMPING PROPERTIY, TENSILE AND FLEXURAL BEHAVIOUR OF KEVLAR-CARBON/EPOXY/NANOGRAPHENE COMPOSITE

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M. Sc. in Mechanical Engineering

Supervisor: Assoc. Prof. Dr. Ahmet ERKLİĞ

October 2017

92 pages

In this study, the impact, tensile, vibration and flexural properties of Kevlar, carbon and hybrid Kevlar/carbon filled epoxy with nanographene matrix based composite laminates were investigated. Multi configurations were fabricated as (C_8, $C_2K_4C_2$, $K_2C_4K_2$, and K8) were investigated by Charpy impact, vibration, tensile and flexural test. The composite laminates were fabricated by hand lay-up process. The Charpy impact test of fabricated composite laminates was conducted following ISO 179/92 standard by Köger 3/70 Charpy impact test machine. The vibration test were conducted by ASTM E756. The tensile and flexural tests were conducted by following ASTM D638-10 for uniaxial tensile and ASTM D790-10 for three-point bending. The results of vibration showed the best ratio of nanographene was 0.1 % wt. for all configurations. Also the results of tensile stress showed the ratio of nanographene that 0.1 % wt. give best value for all configurations. But flexural strength and flexural modulus results of K_8 and C_8 show the best ratio of nanographene were 0.5 % wt. As well as the results of impact energy showed the best ratio of nanographene was 0.25 % wt. for all configurations.

Key Words: Charpy Impact, Tensile, Flexural, Vibration, Kevlar fiber, Carbon fiber and nanographen.

ÖZET

KEVLAR-KARBON / EPOKSİ / NANOGRAFEN KOMPOZİTLERİN TİTREŞİM SÖNÜM ÖZELLİKLERİ, ÇEKME VE EĞİLME DAVRANIŞI

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Tez Danışmanı: Doç. Dr. Ahmet ERKLİĞ
Ekim 2017
92 sayfa

Bu çalışmada, Kevlar, karbon ve hibrit Kevlar / karbon fiber ve epoksi ile nanografen matris esaslı kompozit laminatların darbe, gerilme, titreşim ve bükülme özellikleri araştırılmıştır. (C8, C2K4C2, K2C4K2 ve K8) gibi çoklu konfigürasyonların darbe etkisi, titreşim, gerilim ve eğilme testleri ile araştırılmıştır. Kompozit laminatlar el yatırma metoduyla farklı nanografen oranlarına göre imal edilmiştir. Üretilen kompozit laminatların Charpy darbe testi, Köger 3/70 Charpy darbe test makinesi ile ISO 179/92 standardı uyarınca gerçekleştirildi. Titreşim testi ASTM E756 standarına göre gerçekleştirildi. Çekme ve eğilme testleri, tek eksenli çekme için ASTM D638-10 ve üç nokta eğme için ASTM D790-10 standartlarına göre gerçekleştirildi. Tüm konfigürasyonlar için titreşim sonuçları nanographen'in en iyi oranının ağırlıkça% 0.1 olduğunu göstermiştir. Aynı zamanda gerilme sonuçları, ağırlıkça% 0.1 nanographen oranını göstermiştir. Ancak, K8 ve C8'in eğilme mukavemeti ve eğilme modülü sonuçları, nanographen'in en iyi oranının ağırlıkça% 0.5 olduğunu göstermektedir. Darbe enerjisinin sonuçlarının yanı sıra nanographen'in en iyi oranı ağırlıkça% 0.25 elde edilmiştir.

Anahtar Kelimeler: Charpy Darbe, Çekme, Eğilme, Titreşim, Kevlar fiber, Karbon fiber, nanographen

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the ALLAH for his guidance and rewards toward me and my family, then, I'd like to express my deepest respect and most sincere gratitude to my supervisor, Assoc. Prof. Dr. Ahmet ERKLIG, for his guidance and encouragement at all stages of this mutual work. I will always be grateful for the valuable advice and insight supervision and encouragement to me during this research.

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LIST OF SYMBOLS/ABBREVIATION

FRP	Fiber Reinforced Polymer
FRPs	Fiber Reinforced Polymer Composites
CFRP	Carbon Fiber-Reinforced Composites
GFRP	Glass Fiber Reinforced Polymeric composite
CFRP	Carbon Fiber Reinforced Polymeric Composite
CF	Fiber Carbon
FG	Fiber Glass
CNT	Carbon Nano Tube
GNP	Graphene nano pellets
UV	UltraViolet
LCP	Liquid Crystalline Polymer
VARTM	Vacuum-Assisted Resin Transfer Molding
CNC	Computer Numerical Control
σt	Tensile Strength
σf	Flexural Strength
Ef	Flexural Modulus
wt. %	Weight Percentage
EC	Electric Cutter
ASTM	American Society for Testing and Materials

MWCNT	Multi-Wall Carbon Nano Tubes
PNCs	polymeric Nano-composites
EPC	Epoxy Reinforced Polymer composite
GnPs	Graphene nano particles
GO	Graphene oxide
DMA	Dynamic Mechanical Analysis
ω_n	Natural Frequency
ξ	Damping Ratio
Ē	Storage Modulus of the Beam
È	Loss Modulus
FRF	Frequency Response Function
L	Free Length of the Beam
ρ	Density of the Beam.
I	Moment of Inertia
A	Cross-Section of the Beam
DAQ	Data Acquisition Card
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
KF	Kevlar fiber

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Fiber reinforced polymer composite materials have attracted significant interest in the past few decades due to their outstanding performance-to-weight ratio in relation to conventional engineering materials [1].

Composite materials at those that are created by the combination of two or more materials to obtained properties those were superior to that of its constituents. In generally composite material was composed of reinforcement embedded in a matrix. When designed properly the new combined material displays better strength than would each individual material. In recent years most of the manufacturing plants such as automotive, aerospace industries were using glass fiber reinforced composites as they display a high modulus and strength compared to other metallic materials. The main benefit of these composite materials is their excellent surface finish, low density, high strength to weight ratio and fatigue damage tolerance. Hence, fiber reinforced composites are emerging as the substitution for other commercially available metals in preparing most of the components in aerospace and automotive industries where weight of the component is the critical factor.[2].

Over the last two decades, more researchers have reported that the addition of small quantities of nanoparticles, such as nanometal oxides, carbon nanotubes, nanosilica, graphene and nanoclays, lead to remarkable enhancement in mechanical, morphological, thermal, electrical and optical characteristics of polymer composite materials without compromising on, density, toughness and manufacturing process [3,4-7].

In a few years ago, there has been maximizing interesting in applying hybrid composite materials for constructional applications due to their enhanced and better characteristics than their individual mineral constituent [8]. Hybrid composite fiber is manufactured by combining two or many antithetical reinforcement materials in a shared matrix. By doing so, a new material is manufactured with new and additional characteristics [9]. This is named hybridization, which can guide to benefits of cost and improvement of mechanical and physical properties, thus creating new type of material. The mechanical properties of hybrid composite almost depended on the reinforcing fiber placement [10].

Graphene has attracted large attention in many recent years owing to its exceptional thermal, mechanical, electrical and optical characteristics [11–13]. It is two-dimensional allotrope of carbon, created by single carbon atoms layers, bonded by sp2 orbitals into hexagonal two-dimensional crystal lattice. One of the most hopeful applications of this material was in polymer nanocomposites, polymer matrix composites which combine nano scale filler materials. To date, many search in the field of graphene-based polymer nanocomposites has concentrated on properties modification used graphene [14–17]. This confirmation can be slightly attributed to the fundamental characteristics of the graphene, which caused in remarkable properties improvement at low graphene concentrations [12]. The supreme characteristics of graphene liken to polymers are also reflected in polymer nanocomposites/graphene, which display supreme thermal, mechanical, electrical, gas barrier and flame retardant characteristics as compared with to the pure polymer [18, 19, 20]. It was likewise noticed that the enhancement in electrical properties and mechanical properties of graphene based polymer nanocomposites are much greater as compared to that of other carbon filler-based polymer nanocomposites or nanoclay [21, 22].

1.2 Nano-particle:

"Nano" denotes nanometer (10^{-9} m). A nanoparticle is a microscopic molecule with at the minimum one dimension little than 100 nm. Nanomolecule research is currently a region of intense scientific research, due to a broad kind of potential enforcement in optical, biomedical, and electronic scope. Nanomolecules are of large scientific benefit as they are influentially an embankment between size materials and atomic or molecular structures. [23]. A size material should have fixed physical props regardless of its magnitude, but at the nano-scale this is frequently not the case. Then nanotechnology has advanced into a multidisciplinary scope of technology and practical science. The capability to work on a level of about 1–100 nm was nanotechnology in order to create, understand, characterize and use material structures, devices and systems with new characteristics derived from their nanostructures (Roco, 2003). Because of their magnitude, nanomolecules have proportionately larger surface big and consequently more surface atoms than their microscale counterpart. Figure 1.1 shows some nano-particles. [24]

Figure 1.1 Nano-particles [25]

1.3 Graphene

Graphene is known the strongest material has many amazing property that can be beneficial in more applications. It has the ability to importantly enhance various characteristic of the composites at so minimum loadings. Derivatives of graphene and graphene have been studied on extensively in relation to energy storage, polymer composites, flame- retardant and biology properties to name a few. With the expansion techniques of advanced processing, graphene is getting more interest as important material in future technology.

Derivatives of graphene and graphene have been rated as an effective filler in enhancing composite's mechanical characteristic; however, there are a little researches that report enhancements in parameters of mechanical like as elongation, elastic modulus, tensile strength, and toughness. It is showed that the filler additive may be useful for the enhancements of a certain characteristics but may reason the decline of other characteristics. As a result, careful optimization of fillers (GO, GNPs), interfacial strength, and dispersion is paramount to fabricate multifunctional composites that high-performance [26].

1.4 Polymer nanocomposites:

Polymer nanocomposites are polymer matrix composites in which the fillers are little than 100 nm in at the minimum one dimension. That composites have displayed inordinately attractive characteristics. A defining trait of polymer nanocomposites is that the little magnitude of the fillers cause a dramatic increment in the interfacial region as likened to conventional composites. This interfacial region produces an important interfacial volume fraction of polymer with characteristics various from the size polymer even at down loadings. The structure and characteristics of this interfacial area are not yet famous quantitatively, presenting adefy both for predicting and controlling the characteristics of polymer nanocomposites. This definition supplied a concise overview of polymer nanocomposites with focusing on the effect of the interfacial area. [27]

1.5 Nanotechnology:

The capability to restructure and control the subject at the molecular and atomic scales in the domain of about 1–100 nm, and exploiting the phenomena and distinct characteristics at that level as likened to those linked with molecules or single atoms or bulk manner. The purpose is to make materials, apparatus, and systems with principally modern characteristics and engineering functions their tiny structure. This is the final frontier to economically vary materials characteristics, and the majority effective length scale for fabricating and molecular medicine. The similar principles and equipment is applicable to various regions of relevance and more assist establishing a unifying platform for engineering, technology and science at the nano scale. The transmission from molecules or single atoms manner to collective manner of molecular and atomic assemblies is encountered in nature, and nanotechnology exploits this natural sill. And Figure 1.2 shows the diverse enforcement of nanotechnology. [28]

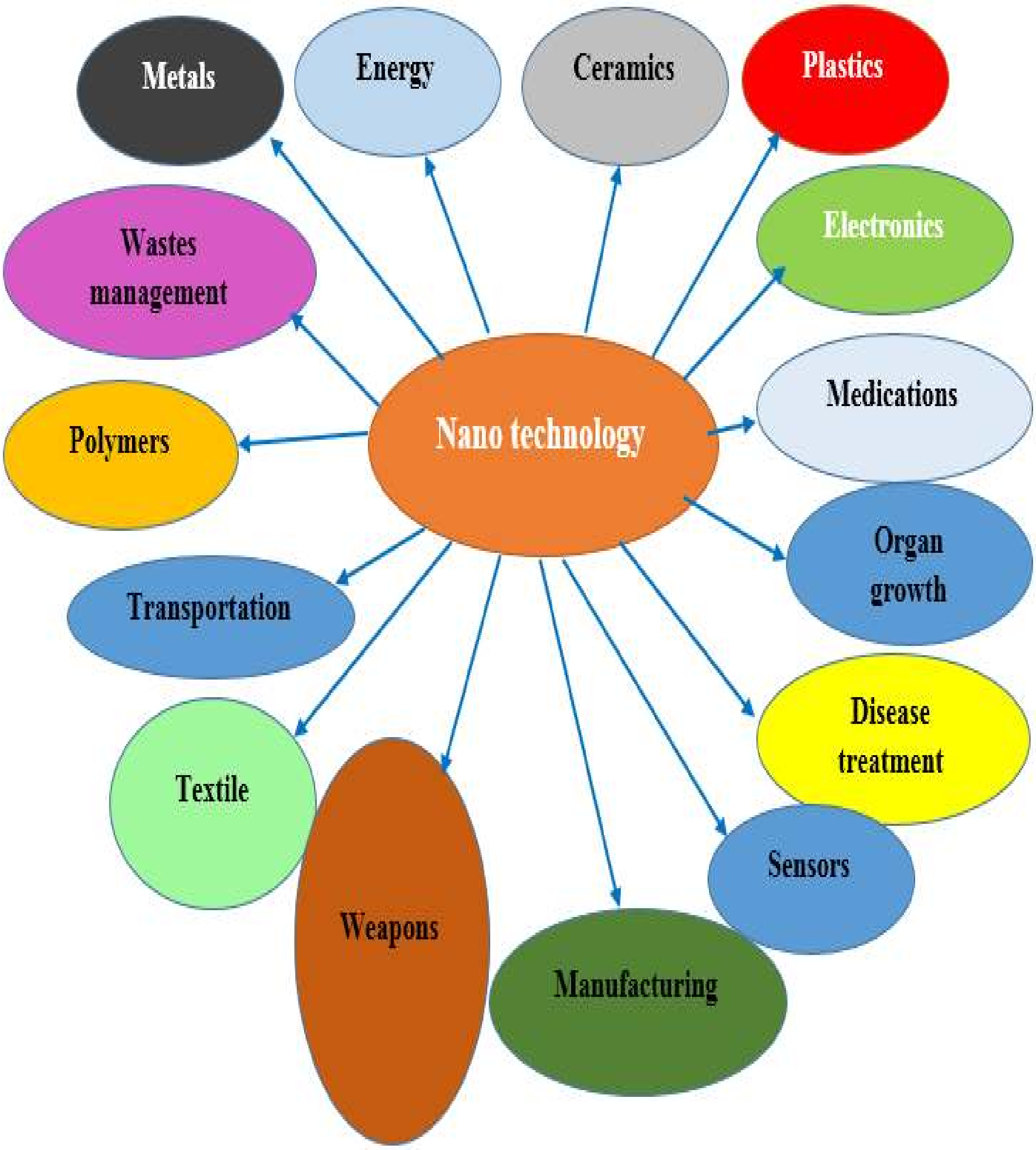


Figure 1.2 Diverse enforcement of nanotechnology [3]

1.6 **Fiber**

It is a natural or synthetic substance that is importantly longer than it is wide. Fibers are frequently used in the manufacture of other materials. The most powerful engineering materials frequently merged fibers, for example, silicon carbide fiber, glass fiber, carbon fiber... etc. ultra-high-molecular-weight polyethylene. There are two types of fiber ((Natural fibers (hemp, cotton, flax, jute, ramie, sisal, banana, and bagasse ...etc.) and (synthetic fibers (Polymer fibers, Mineral fibers, Fiberglass, Silicon carbide fiber, Carbon fiber, etc.)) [3]. as shown in Figure 1.3.

Figure 1.3 fibers

1.7 Kevlar (aramid)

Kevlar® is DuPont's name for aramid fibers. This type of fibers have a high resistance to impact damage, they are strong, light weight and tough, offering the best properties in damage tolerance of all fibers available. But these fibers present some disadvantages like susceptibility to degradation by UV radiation and large absorption of moisture by the fiber which means weight increases of the order of 7-8%. Two types of Kevlar fibers can be distinguished in aviation industry: (i) Kevlar® 49, which has a high stiffness and (ii) Kevlar® 29, which has a low stiffness. Most common application of Kevlar are military ballistic and body armor applications. [29]

1. 8 Carbon fibers

Fibers of carbon (CF) showed on the market in 1960 and are manufactured of organic fibers (rayon, acrylics etc.) or from tar distillation or petroleum remaining. Carbon fibre are the strongest and stiffest reinforcing fibers for polymer composites, that high used after fiber of glass. Made from neat carbon in form of graphite, they have little density and the coefficient of longitudinal was negative for thermal expansion. Carbon fibers are more expensive and can give galvanic abrasion in contact with metals. They are usually used together with epoxy, where high stiffness and strength are required, i.e. automotive, race cars, space applications and sport equipment [30

1.9 Matrix

The purpose of the matrix in a composite material is to transfer and redistribute loads towards and between reinforced fibers. It also maintains the fibers with the correctly orientation, protects the fibers of the environment and provides resistance to interlaminar shear, compressive strength and transverse resistance. Matrix is also the responsible of determining the processability and the maximum service temperature of the composite material. It is possible to distinguish between polymerics, metallics and ceramics matrix. The most widely used and interesting are the first ones. Polymeric matrix could divide between thermosetting and thermoplastic. Thermosetting are presented without polymerization, doing it during the manufacturing process of the final piece while thermoplastics are presented in solid state polymerized already. [29].

1.10 hybrid composites

Hybrid composites are materials produce by merging more or two different kind of fibers in a common matrix. By hybridization it is likely to achieve a balance between performance characteristics and cost of composite, which would not be acquired by a single variety of reinforcement. Hence by heedful choice of processing and reinforcements techniques, it is likely to engineer the hybrid material to improve suit the different practical requisites with economic gains. [31,32] as shown below:

Hybrid composites include more than one fiber or one matrix system in a laminate. The principal four types of hybrid laminates follow.

• Interply hybrid laminates include plies produced of more or two different composite systems. Examples include car bumpers created of glass/epoxy layers to supply torsional rigidity and epoxy/graphite to give stiffness. The combinations as well lower the cost of the bumper.

• Intraply hybrid composites include of more or two several fibers used in the same ply. Examples include golf clubs that use aramid and graphite fibers. Aramid fibers provide tensile strength and toughness . The graphite fibers provide the torsional rigidity.

• An interply–intraply hybrid include of plies that have more or two different fibers in the same ply and clear composite systems in more than one ply.

•Resin hybrid laminates combine more or two resins instead of incorporating more or two fibers in a laminate. Generally, one resin is rigid and the other one is flexible. Tests have proven that these resin hybrid laminates can increment work and shear of fracture characteristics by more than 50% over those of all-rigid or all-flexible resins. [33, 34] . Fig.1.4 shown some hybrid fiber.

Figure 1.4 Hybrid fiber

1.11 Advantages and Disadvantages of Composites

Composite materials bring a significant advantage by collecting the original characteristics of the contained material. Today, composite materials are produced in order to ensure adaptation with outstanding features include the difficult working conditions. Superior features expected from a material generally is as below;

- High strength,
- High rigidity,
- High fatigue resistance,
- Excellent wear resistance,
- High temperature capability,
- High corrosion resistance,
- High thermal conductivity,
- Formability,
- Low density,
- They reduced the number of complex parts because of the part produced as a single.

Thus, the reduction in production time is shortened.

All of features mentioned above in a composite material can be obtained if it is regarded to suitable matrix/reinforcement element pairs, manufacturing techniques, the strength features of the components and other factors. The choice of suitable matrix/reinforcing elements is important on the mechanical and physical properties of the system. For a composite material the interface bond between matrix and reinforcement elements should be strong in order to transmit the load from matrix to reinforcing element. This depends on the harmony of pair. Besides, apart from the production technique selection, the homogeneous distribution of the reinforcing elements in the matrix/resin depends on the choice of matrix alloy and reinforcing element [35, 36]. Besides the above-mentioned excellent properties, some disadvantages are also available for composite materials. These are as follows;

• Production difficulties,

• It is expensive,

• There is no recycling for composite material,

• Operating problems,

• High operating costs,

• It is difficult to achieve the required surface roughness,

• The air particles in the polymer based composite materials adversely affects the fatigue properties of material [36, 37, 38].

1.12 The Objectives of Research and Tasks

In this study, the main aim is to investigate the effects of nanographene on tensile, flexural, vibration damping and Charpy impact behavior of Kevlar-carbon fiber reinforced hybrid fiber composite laminates. The research tasks can be summarized as follows;

Fabrication of Kevlar fiber reinforced composite laminates filled nanographene.

Production of Kevlar-carbon hybrid fiber reinforced composite laminates filled nanographene using different stacking sequence.

Production of carbon fiber reinforced composite laminates filled nanographene.

Conduction of the tensile, flexural, vibration damping and Charpy impact tests for all of the prepared laminates.

Discussion about the effects of nanographene on the mechanical properties of composite using the obtained results from the tests.

1.13 Layout of Thesis

The study has been divided into five chapters.

A general introduction, research objectives and tasks of the study are given in Chapter 1.

A comprehensive literature review is presented in Chapter 2. Literature review has been classified in four parts; introduction, , and literature survey conclusion.

In Chapter 3, information about the materials (fibers, epoxy) and fabrication method used in this study are provided.

The results and discussions of tensile, flexural and Charpy impact experiments are presented in Chapter 4.

General conclusions about the results are given in Chapter 5.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

In the literature review, some examination is observed about effects of dissimilar fillers on mechanical, thermal and some other properties of composite material. Present study is about effect of particles on the mechanical properties of composite material hence similar studies in literature are investigated prior to any work..

Literature review has been arranged in five sections as:

2.2 general Literature Review on fiber reinforced Composites

2.3 Some studies on epoxy nanocomposite with various graphite compounds

2.4 Some studies on epoxy nanocomposite with graphene

2.5 Some studies on virous fiber nanocomposite with graphene and conclosion

2.2 General Literature Review on fiber reinforced Composites

The vibration and damping properties of basalt/epoxy and aramid/epoxy composites have been examined by Bulut et al. [39]. They utilized the two fibers to produce basalt-aramid/epoxy hybrid composite laminates with improved damping properties. The presence of aramid fibers in composite laminates enhances vibration characteristics like the damping characteristics of laminates, but reduces the tensile strength values

The result of the research that was performed by Aktaş and Karakuzu [40] indicated that the tensile modulus & tensile strength of glass/epoxy composites reduction after 60 & 80 °C respectively. The shear modulus of unidirectional glass/epoxy composite laminates is fairly affected with rising temperature.

The influence of temperature on the mechanical characteristics of SiC fiber reinforced glass-matrix composite system was examined by Prewo and Brennan [41] It was found that good material characteristics can be achieved, and excellent fracture toughness and flexural strength were observed over the temperature from 22 to 700°C.

Zhong et al. [42] examined the damage & impact performance properties of hydrothermally controled epoxy/carbon fiber composite plates. It was indicated that the interface between matrix and fiber, was reduced when exposed to subsequent aging and water immersion.

A comparison between the characteristics of different fiber types was carried out by Lopresto [43]. It was shown that the young modulus of epoxy composite laminates base basalt fiber were 35-42 % higher than E-glass fiber reinforced laminates. Also, basalt fiber composite laminates have better compressive flexural and strength behavior. On the other hand, E-glass fiber reinforced laminates have higher tensile strength than basalt fiber reinforced ones.

In basalt fiber type, a work was executed by Bozkurt et al. [44] to show the effect of fiber orientation on damping & vibration characteristics of epoxy/ basalt fiber composite plates. The results indicate that the fiber angle orientation affects the natural frequency of the laminate. The increase in angle of fiber orientation from 0˚ to 45˚ resulted in a decrease in natural frequency.

The flexural behavior of hybrid composites reinforced with S-2 glass & T700S carbon fibers was investigated by Dong et al. [45] in an intra-ply arrangement. A growth in flexural strength was shown with respect to span-to-depth ratio. The maximum flexural strength was indicated for the [G/C_7] hybrid arrangement. The utilization of hybridization can enhance the flexural strength.

The effect of surface treatment on flexural strength & interfacial adhesion strength was investigated by Wan et al. [46]. The result of this work showed that after 2 step surface treatment, the fiber hybridization showed significant enhancements. Moreover, the 2 step surface treated aramid/carbon hybrid fiber reinforced composite led a positive hybrid influence on flexural strength.

One of the utmost significant issues which influence the mechanical characteristics of the laminates is the stacking sequences of the laminates. Salman et al. [47] explored the influence of stacking sequence on tensile characteristics of glass/carbon hybrid fiber reinforced composite materials. Tensile characteristics of carbon & glass hybrid fiber reinforced composites with a varied number of layers and stacking sequences were investigated in the work. It was showed that the best mechanical characteristics were achieved with three layers of carbon and two layers of glass.

Rathnakar et al. [48] experimentally studied the stiffness and flexural strength of glass/graphite fiber reinforced composites. The chief concern of this research is to determine the flexural parameters of glass/graphite fiber reinforced epoxy composites under static flexural loading.

Flexural and impact characteristics of hybrid composites based on basalt & Kevlar fiber were examined by Sarasini et al. [49]. The outcome of this research indicated that absorbed damage tolerance & impact energy capability with respect to the all-aramid plates can be enhanced by using hybrid plates with intercalated arrangement (alternating sequence of aramid and basalt fabrics). It was also shown that the best flexural conduct can be present by using basalt and hybrid plates with sandwich-like arrangement (7 basalt fabric layers at the center of the plate as core & three aramid fiber plies for each side of the composite as skins).

.The influence of combination of carbon fiber and Kevlar fiber in a common epoxy matrix on fracture toughness of composites has been studied by Yadav et al. [50]. They were shown that the fracture toughness improved twice in all laminates. The improvement in fracture toughness was considerable in interleaved plate than Kevlar one due to huge absorbed energy capabilities of interleaf.

Zulfli and Shyang [51] studied the morphological and flexural characteristics of epoxy/GF/silane treated organo- montmorillonite (OMMT) composites. It was shown that the flexural modulus enhanced significantly as the loading of silane-treated OMMT increased. In addition, the flexural modulus of E/GF/Si-15/OMMT was enhanced by13% and reached 4.98GPa.

Preparation and characterization of a specific type of composite of plies silicate with epoxy/glass fiber hybrid nano composites via vacuum assisted resin transfer molding

(VARTM) was investigated by Lin et al. [52]. They were indicated that the thermal & mechanical characteristics of this type of composite can be enhanced by adding a slight quantity of organic clay to the epoxy/ glass fiber composites.

Zaman et al. [53] studied compares the manufacture, morphology, thermal & mechanical characteristics of epoxy nano composites tuned by clay plies & graphene platelets. It was observed that a chemical modification, ply expansion & distribution of filler within the epoxy matrix resulted in an enhanced interface between the filler material & epoxy matrix. This was assured by Fourier transform infrared spectroscopy & TEM. The improvement interface command to enhance mechanical characteristics (i.e fracture toughness, glass transition temperatures & stiffness modulus) compared with pure epoxy. At 4 wt% graphene platelets, the critical strain energy release rate G1c of pure epoxy enhanced by 240 % from 179.1 to 608.6 J/m2 & Tg improved from 93.7 to 106.4 C. In contrast to m-clay, which at 4 wt%, only enhanced the G1c by 45 % & Tg by 7.1 %. The greater level of enhancement offered by graphene platelets is ascribed to the strong interaction of graphene sheets with epoxy due to the covalent bonds between the carbon atoms of graphene sheets are much stronger than silicon-based clay.

2.3-Some Studies on Epoxy Nanocomposite with Various Graphite Compounds

Svendsen [54] studied dissimilar epoxy based composites were utilize with GO as reinforcement found potential for improved stiffness & strength of epoxy based nanocomposites when addition GO as reinforcement the results of the composites were not as favorable as results from earlier study, even though a variety of systems were verified. The GO particles were probably not distributed homogenously enough due to re-flocculation during fabrication.

Chao and Demei. [55] Studied on the toughness enhancement & dielectric features of epoxy modified by graphite nano-sheets. They noted that the dielectric constant of epoxy/graphite nano-sheet composites enhanced with 3.5 wt% graphite modified loading. They also investigated a 35% enlargement in toughness, tensile & storage modulus features.

Rafiee et al. [56] discovered the probability of GO as nano-fillers for fracture toughness enhancement and other characteristics. They utilized thermally exfoliated GO to vary epoxy resins in the bulk & 20 showed important enlargement in the stiffness , toughness, fatigue resistance, & flexural strength at least content of the nano-filler.

Zaman et al. [57] investigated like work on 2 kinds of epoxies with functionalized graphene. They exfoliated graphene utilizing chemically & sonication modified to acquire functionalization. They noted a 96% enhancement of fracture energy produce rate at 4 wt% graphene percentage. Similarly, an enlargement in glass transition temperature was showed at 2.5 wt%.

Safdari and Al-Haik [58] presented a latest model for evaluating the electrical conductivity of nanocomposites with a mixture of graphite nanoplatelets & carbon nanotubes. The model was confirmed with pertinent practical data according to mono-nanofiller. It was detected that the hybridized nanocomposites filled with a mixture of these conductive nanofillers attain, synergistically, improved electrical conductivities at minimize volume fractions. The present simulations detected that, usually, the adding of minimal quantities of a higher portion ratio auxiliary phase to a minimize portion ratio prime phase increases the electrical conductivity of the nanocomposite by several amount instructions

Li et al. [59] examined the influences of hybrid (GNPs) & (CNT) on the electrical & mechanical characteristic of epoxy nano-composites. As soon as the total reinforcement contents is stable at 2 wt. %, the nanocomposite consist of 1% graphite nanoplatelets and 1% carbon nanotubes achieves the highest electrical conductivity. While the flexural characteristics unchanged much by effect the hybridization, the fracture toughness enhances by 21% compared to the nanocomposite with57% compared to neat epoxy, or 2 wt. % graphite nanoplatelets alone.

Wan et al. [60] studied the impact of as produced silane functionalized (silane-f-GO) & Go content & silane functionalization on the mechanical features of epoxy composites comparatively. Such (silane-f-GO) loading epoxy ended-groups is discovered to efficiently increase the compatibility between the (silane-f-GO) and the epoxy matrix. Improved flexural & tensile strength as well as fracture toughness of the composites by filling the (silane-f-GO) were also detected in the flexural & tensile and CT trials compared with the pure epoxy and GO/epoxy composites. Relative fracture mechanisms, such as crack pinning, deflection & crack bridging of sheets as well as matrix plastic deformation induced by the debonding & delamination of sheets, were recognized.

Min & Yu. [61] investigated The dielectric constants of the composites are increased with rises in (GNPs) graphite nano-sheet loading least than 3.5 wt%, & are still upper than 100 in the great frequency range with 3.5 wt% GNPs filler loading. The storage modulus and tensile strength of the composites augment with growing GNPs concentration. These epoxy/ (GNPs) composites, which display both constant toughness and high dielectric, could have potential application in embedded capacitor technology.

Debelak and Lafdi. [62] They showed the polymers modified by 20% wt. exfoliated graphite has showen an important decrease in electrical resistivity from 1.58 to 0.5 X cm. The thermal conductivity for the polymers loading 20% wt exfoliated graphite has also been radically enriched, improving from 0.2 to 5 W/m K. The flexural modulus attained an extreme growth of 3.8 GPa which is a 60% above the value for the neat polymer (2.4 GPa).

Abdullah and Ansari [63] studied the influences of Graphene oxide (GO) on composite. The results were indicated the addition of Graphene oxide (GO) improvement excellent mechanical properties and high aspect ratio. Adding 1.5 vol.% GO to the epoxy matrix increased the tensile strength, tensile modulus & hardness of the composite compared to the neat epoxy matrix. The significance of the homogeneity of the composite for the mechanical features of composites was demonstrated by a growth in the tensile modulus when plotted with the vol. % of GO & 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.

Bortz et al.[64] showed that graphene inclusion significantly increases the toughness of epoxy, resulting in a 65% enhancement in fracture toughness. The augmentation in ductile features of samples can be credited to the same phenomena. It is also clear that energy required to rupture samples was increased as increasing GnPs loading in the epoxy. This suggests that sample withstands efficiently the external loads when GnPs loading was at wt %.

Hussain et al. [65] investigated the impact of chemical attachment of the GO nano-sheets to the surfaces of aramid fibres on the adhesion & strength features of the fibres for application in polymer composites. Aramid fiber GO multiscale reinforcement fibers arranged by chemically attaching GO nano-sheets on amine primed surfaces of the fibers under two reaction conditions. The observed enhancement in breaking strength of modified fibers may be credited to the coverage of defect sites, superior load scattering and strength contribution of the GO nano-sheets (and the strong bonding between the fiber & graphene oxide as previously and best adhesion with epoxy matrix has been showed with sample treated in alkaline reaction conditions

2.4 Some Studies on Epoxy Nanocomposite with Graphene

Daloia [66] investigated the storage modulus and surface energy increased by 62.5% and 55% respectively with graphene loading. The tribological behavior of graphene composites indicated that this nano-filler was very active in steadying the reducing wear rate and coefficient of friction as well. Pure epoxy exhibited a great wear rate and an unstable coefficient of friction. Oppositely, 5wt% of graphene showed the maximum stable coefficient of friction. The enhancement on wear resistance was significant, quick, easy & inexpensive while the samples exhibited improvements in many relevant properties.

Shokrieh et al. [67] examined effect of adding the GPLs to the epoxy nanocomposites. They observed improve the flexural bending fatigue life and the performance of pristine epoxy resin & 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 fatigue life was more effective in comparison with 0.1 and 0.5 wt. % epoxy GPL nanocomposites & observed that the behavior of the graphene/epoxy nanocomposites are clearly higher in comparison with the pristine epoxy.

Wan et al. [68] studied interfacial quality and the distribution level in the graphene/epoxy composites, and the thermal and mechanical features of the composites influenced by the surfactant treatments are explored. It is verified that the surface treatments of graphene sheets using nonionic surfactant is effective to improve compatibility and wettability of graphene with epoxy resin. The pristine graphene sheets tend to re-agglomerate during curing of resin, whereas the attachment of surfactant molecules effectively inhibits the re-agglomeration of graphene by wrapping the sheets with polymer chains. Transmission electron microscopy & Scanning electron microscopy images indicate that both the interface & dispersion between the graphene and epoxy matrix can be meaningfully enriched after surfactant treatments. Additionally, the thermal stability of the graphene/epoxy composites is a little better in comparison with that of the pristine epoxy.

Gültekin et al. [69] used four different methods for mixing nanographene into epoxy matrix. A three percentage of graphene was added. The result of a nanocomposite showed adhesive obtained by addition graphene to the adhesive with– on the tensile failure load. Rising the graphene-reinforcement content decreases the failure load of the joint standard deviation in a single-lap joint geometry.

Rafiee et al. [70] showed the small additive (0.1%wt) of Graphene to epoxy nanocomposites, better mechanical features. Where (SWCNT) single-walled carbon nanotubes, & (MWCNT) multi-walled carbon nanotube addition were compared at a nano-filler content of 0.10.002%. The mechanical features measured were the ultimate tensile strength, tensile modulus, fracture energy, fatigue resistance & fracture toughness. The effects show that graphene platelets meaningfully outdo carbon nanotube addition. The tensile modulus of the graphene nanocomposite was 31% better than the neat epoxy as compared to3% growth for (SWCNT). The tensile strength of the neat epoxy was higher by40% with graphene platelets compared to14% enhancement for multi-walled carbon nanotubes. The mode I fracture toughness of the nanocomposite with graphene platelets showed 53% rise over the epoxy compared to 20% enhancement for (MWCNT). The fatigue resistance effects too displayed meaningfully dissimilar trends.

Da et al.[71] investigated Influence added 2 methods were employed to understand this phenomenon. The first one was direct exposure of the nano modified by this ratio of grapheme (0 wt. %, 1 wt. % & 2 wt. %), to UVA light. The samples were exposition to UVA light for 200 hours. After the aging process, nano-indentation exams were carry out. The second method was to make single lap joints by similar percentage of graphene & they display the single lap joints to UVA light for two hundred hours. The graphene molded inside the epoxy nano modified adhesive appears to block the aging process, as none of the specimens presented a decrease on stiffness.. After SLJ were examined, the results also showed an average rise on bearing-load capacity of 24.76% & 28.36% for 1 wt. % and 2 wt. %, respectively for 100 hours aging. When the aging reached 200 hours, there is a reduction on load capacity when compared against the one hundred hours results. While, the average load capacity was 12.48% & 18.04% upper than the not aged nano modified epoxy SLJ.

King et al. [72] studied addition GNP to epoxy affected on elasticity modulus to growth from 2.72 for the pure epoxy to 3.36 GPa for the 6 wt % GNP/epoxy composite. While the ultimate tensile strength reduced from 77.6 to 35.5 MPa at 6 wt % GNP in epoxy. The strain at ultimate tensile strength reductions from 8.0 to 1.5% at 6 wt % GNP in epoxy. It should be renowned that due to nano indentation uses a very small quantity, depending on whether this volume of material is GNP rich or matrix rich, the effects vary between the indents performed. The creep test by nano indentation displayed that the steady-state creep range was noted for pristine epoxy and all GNP/epoxy composites soon after the creep load was got. At 2 & 5 mN loadings, the creep compliance of the pristine epoxy was a little greater than that of the GNP/epoxy composites. At loadings of 10–45 mN, the creep compliance was like for pristine epoxy & GNP/epoxy composites.

Ma et al. [73] used chemically modified (GnPs) of 2–4 nm in thickness, covalently bonded graphene platelets with an epoxy matrix, & inspected the morphology, functional & mechanical properties of these composites. This covalently bonded interface prevented graphene platelets stacking in the matrix. In comparison with unmodified composites displaying no decrease in electrical volume resistivity, the interface-modified composite at 0.489 vol% graphene platelets shows 8 order discount in the resistivity, a 47.7% more development in modulus and 84.6% in fracture energy release rate. Comparison of graphene platelets with clay & multi-walled carbon nanotubes displays that our graphene platelets are more beneficial in terms of price & behavior.

Ma et al. [74] studied modified 3 nm thick graphene platelets (GnPs) by the reaction between the graphene platelets' epoxide groups & the end-amine groups of a commercial long chain surfactant (M_w = 2000), compounded the modified graphene platelets' with a model polymer epoxy, & inspected the structure & properties of both graphene platelets & their epoxy composites. A small Raman I_D/I_G ratio of 0.13 was observed for graphene platelets corresponding to high structural integrity. A percolation threshold of electrical conductivity was showed at 0.32 vol% graphene platelets, & the 0.98 vol% graphene platelets enhanced the fracture energy release rate, glass transition temperature and tensile modulus of epoxy by 14%, 387% and 13%, respectively.

2.5 Some Studies on Various Fiber Nanocomposite with Graphene

Hsieh et al. [75] 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 practices effects also displayed 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 observed 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. Based on the aforementioned literature and experimental results, the crack growth suppression behavior in composite laminate was primarily caused by the crack deflection of GNPs.

Kamar et al. [76] explored the possibility of graphene nano platelets (GnPs) to increase the interlaminar mechanical features of glass reinforced multilayer composites. A new technique was advanced for the inclusion of graphene nano platelets into the interlaminar regions of plain-weave, glass fiber-reinforced/epoxy polymer composites processed with vacuum assisted resin transfer molding. Only 0.25 wt% graphene nano platelets achieved a 29% enhancement in flexural strength. Similar percentage 0.25 wt% of (GnPs), mode-I fracture toughness testing exposed a 25% enhancement. Furthermore, low-velocity drop weight impact testing exhibited enhanced energy absorption capability with aggregate percentage of graphene nano platelets. Ultrasonic C-scans and dye penetration inspection of the impact- & back-sides of the specimens qualitatively support these effects. Lastly, the impact damage area was quantified from the C-scan data. These results displayed that the impact-side damage area reduced with aggregate percentage of graphene nano platelets whereas the back-side damage area improved.

Bulut [77] Studied the effect of graphene nano-pellets (GnPs) addition on mechanical features (flexural, impact resistance & tensile) of basalt/epoxy composite plates. Variation of mechanical properties was described by changed GnPs loading by weight ratios (0.1, 0.2 and 0.3 wt %) between epoxy and filler, controlling with full basalt/epoxy laminates (unfilled). Failure characteristics of the prepared samples were also presented and compared along with GnPs filler loadings. Results indicated from this study that incorporation of GnPs fillers at 0.1 wt % meaningfully developed the mechanical ar of basalt/epoxy composites because great bonding strength at the interphase between GnPs epoxy- fiber interactions.

Wang et al.[78] investigated influence additive nano platelet (GNPs) & multi walled carbon nanotube hybrids reinforced epoxy/carbon fiber composites were utilized to reinforce epoxy composite and epoxy/carbon fiber composite plates to increase their mechanical properties. These features of CNTs/GNPs hybrids obtain at percentage (1wt %) with mixing dissimilar percentage reinforced epoxy nanocomposite. such as flexure strength & ultimate tensile strength properties, of epoxy/carbon fiber nanocomposite plates modified by CNTs/GNPs hybrids (0.5, 1.0, 1.5wt %) were better over that of pure plates. So, remarkable enhancement in the mechanical characteristics was achieved for these epoxy resin composites and carbon fiber-reinforced epoxy composite plates.

Ávila et al. [79] 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 & 58.71 GPa, was noted for the 1.0 wt. % & 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), & 1143.72 MPa & 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 & intra-laminar failure are 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.[80] Inspected the effects of adding nanographene to epoxy matrix with carbon fiber .After GnPs content of 0.1 wt %, a decreasing trend was followed for energy required to rupture & tensile strength. It was claimed from previous studies that a decreasing trend was observed after the critical graphene sheet loading rate of 2.0 and 0.5 wt % in terms of fracture toughness, & this was ascribed to the agglomeration of graphene sheets at high contents by weight.

Leopold et al. [81] noted the size influence of unmodified and graphene nanoparticle modified matrix fibres is experimentally studied. An important size effect that display increasing tensile strength with decreasing volume due to a statistical defect distribution in neat matrix fibres is identified, which is according to Weibull's theory The nanoparticle modified matrix shows almost no size effect. Nanoparticles act as crack initiators.

Kostagiannakopoulou et al. [82] studied the improvement of a novel types of carbon fiber reinforced polymers (CFRPs) with a nanomodified matrix based on graphene nano-species. The best objective is the raise of the interlaminar fracture toughness of carbon fiber composites improved with graphene nanospecies under mode 1 loading. A domestic advanced methodology for the dispersal of the nanofillers & the manufacturing of nano-doped prepregs is analytically defined.

Feng et al. [83] investigated the nonlinear bending conduct of a new type of multi-ply polymer nanocomposite beams reinforced with graphene platelets (GPLs) that are non-uniformly dispersed along the thickness direction. A complete parametric work is then showed, with a particular focus on the impacts of size, scattering pattern, geometry & weight fraction of graphene platelets together with the total number of plies on the linear and nonlinear bending performances of the beams. Numerical results establish the meaningfully enhanced bending behavior through the adding of a very slight amount of graphene platelets into polymer matrix as reinforcements.

Conclusion of Literature Review

The resulting conclusions can be taken from the earlier literature survey

- In writing, there are many investigations about the characteristics of fiber reinforced and on nano composites characteristics. Every one of those investigations are intrigued with the assurance and the examinations of composite structures conduct expect to improve mechanical characteristics of these composites.
- Studies have shown that the uses of nanotechnology give us more improvement on the great mechanical properties(tensile strength ,young's modulus,fracture toughness,etc).
- The effect of stacking sequence on mechanical properties of composite is significantly present.
- In case of using Kevlar carbon reinforced epoxy composite, the fracture toughness will significantly increase.
- The effect of GO on composite is that it enhances the mechanical properties and increases the aspect ratio, and the volume increase of GO increases the tensile strength, hardness and young modulus compared to neat composite.
- Some of studies showed that the increasing in weight fraction of graphene leads to improve the mechanical properties like tensile, flexural strength and impact resistance while another studies showed that the increasing of GNPs more than 0.1 wt. % leads to decrease some of properties like tensile strength and rupture energy due to graphene sheets agglomeration.
- Some researches proved that 0.1 wt. % GNPs is the perfect percentage because the more increasing leads to agglomeration of GNPs and that could weaken the bond between fibers and epoxy. As for the effect of GNPs on failure mechanism, it changes it from intra laminar to mix failure mode.
- Studies have also shown that nano graphene has a significant effect on mechanical properties relative to other nanoparticles.

  According to this review nobody used kevlar with graphene and kevlar/carbon with graphene base epoxy therefore this study is very important.

CHAPTER 3

EXPERIMENTAL STUDIES

PRODUCTION OF COMPOSITE LAMINATES AND DETERMINATION OF MECHANICAL PROPERTIES

3.1 Introduction

This chapter concerned with a brief presentation about the fabrication of composite laminates, preparation of specimens and experimental procedure of flexural, tensile, vibrations and impact tests. Some common information about the constituents of the prepared composites like carbon fiber, Kevlar fiber, epoxy resin system, nanographene particle are revealed and the fabrication technique with hand layup technique, was described.

3.2 Materials

3.2.1 Nanographene

Graphene nanofiller was supplied from Grafnano. Teknolojik Malzemeler Co.Ltd. It appears as a grey and black powder, and has purity about 99.5%, bulk density 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^o peak was used during this study [84]. As shown in Figure 3.1.

Figure 3.1 Nanographene

3.2.2 Kevlar

Aramid fibers are man-made organic fibers based on aromatic polyamide chains. DuPont developed aramid fibers. They are closely related to nylon. Aramids have low solubility due to aromatic groups they cannot be drawn so are spun from liquid crystalline solution. They have pale yellow color with high strength and low density hence gives very high specific strength [85].Twill aramid fabric with an areal density of 170 g/m^2 was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey. Figure 3.2 shows Kevlar fabric that used in this study.

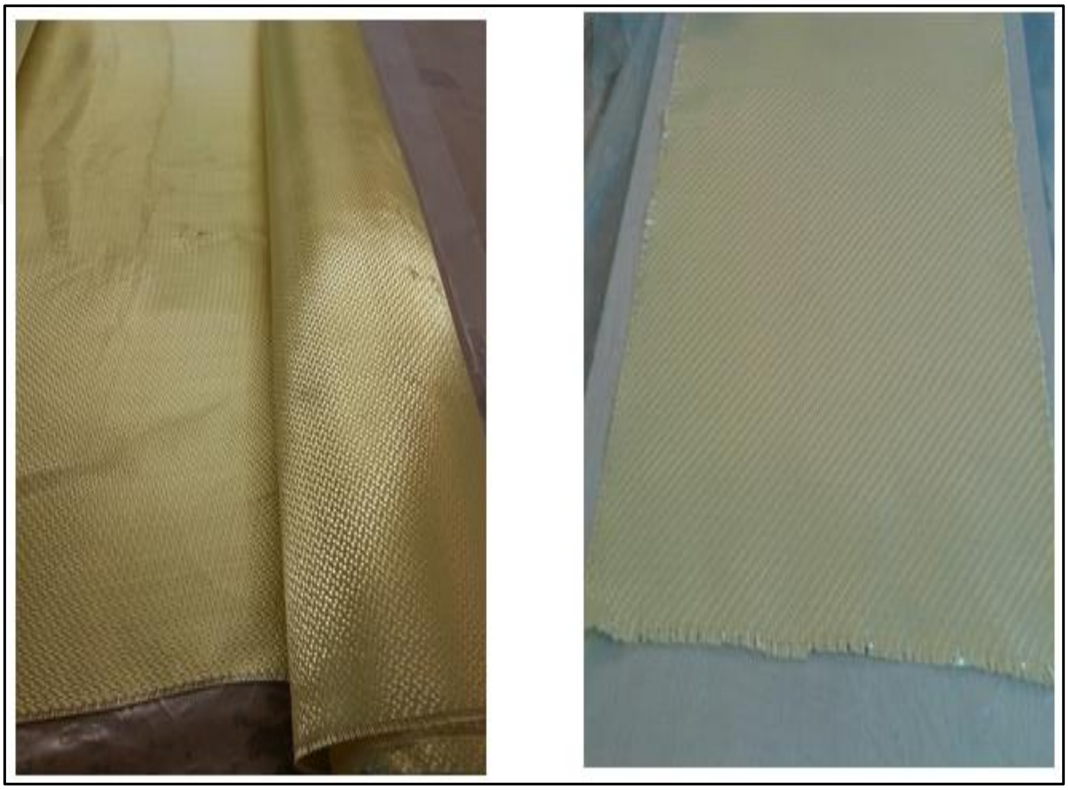


Figure 3.2 Kevlar fiber.

3.2.3 Carbon Fiber

Carbon fiber are the strongest and stiffest reinforcing fibers for polymer composites, the most utilized after glass fibers. Produced of neat carbon in form of graphite, they have negative coefficient of longitudinal thermal expansion and low density [30]. Plain weave carbon fabric with an areal density of (200 g/m^2) was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey that is used in this thesis. Figure 3.3 shows carbon fiber.

Figure 3.3 Carbon fiber.

3.2.4 Epoxy resin

Epoxies are being used in order to bind the strengthening fiber and locking them in a position so that they can sustain their position to do their job. Fibers are placed in specific directions in the fiber reinforced structures to focus the reinforcement according to need and the epoxy helps in retaining the position of fibers where they are needed. The aim of the epoxy matrix is to surround the fiber and transfer the loads to the fibers even though it is a strong material itself. It helps in protecting the fibers from damage and offers impact resistance [86]. Figure 3.4 show epoxy resin and hardener. The physical properties of epoxy and hardener were given in the Table 3.1and 3.2 measured at 25°C. The epoxy was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey

Figure 3.4 Epoxy Resin and Hardener

Table 3.1 Physical characteristic of the epoxy resin [87]

Properties	Epoxy (EPIKOTE MGS LR160) specification
Density [g/cm³]	1.13 – 1.17
Viscosity [mPas]	700 – 900
Refractory index	1.548 – 1.553

Table 3.2 Physical characteristic of the hardener [87]

Properties	Hardener (EPIKOTE MGS LH160) specification
Density [g/cm³]	0.96 – 1.00
Viscosity [mPas]	10 – 50
Refractory index	1.517 – 1.520

3.2.5 Composites

A composite material is make by merging two or much material to give an unparalleled combination of characteristics. The definitive characteristics of composite materials are best than constituent material properties. In this study, several composite materials were produced with different ratios of nanographene addition.

3.3 Hybrid Fiber Reinforced Composite

The hybrid fiber reinforced composites were prepared by combination of Kevlar fiber and carbon fiber with different stacking sequences. Four configurations were produced as K_8, C_8, $C_2K_4C_2$, $K_2C_4K_2$ with 0 wt.%, 0.1 wt.%, 0.25wt.% and 0.5 wt.% of nanographen particles.

3.3.1 Production of Hybrid Composite Laminates

Production of hybrid composite laminates, fibers were cut with a desired dimension 300 mm × 250 mm that enough to prepare specimens for test using EC cutter Figure

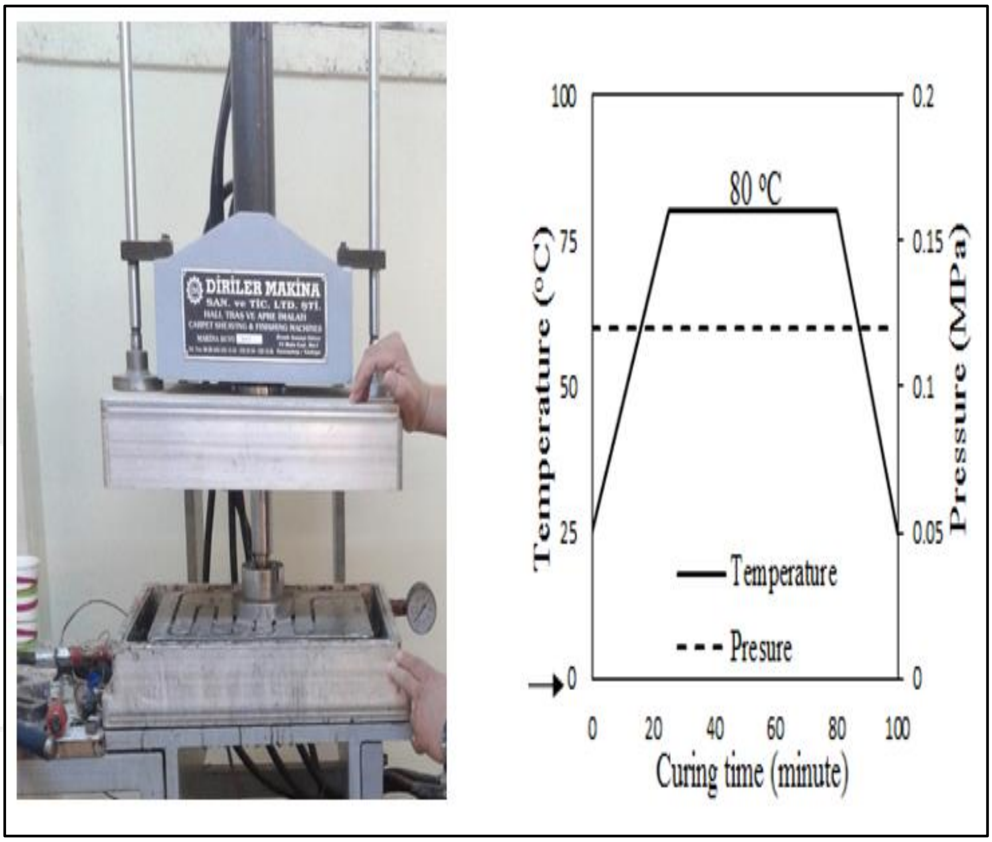
3.5. The ratio of epoxy (EPIKOTE MGS LR160) to hardener (EPIKOTE MGS LH160) was 100:25±2 by weight and prepared with suitable and enough amount.

Figure 3.5. Electric cuter

In the beginning mixed epoxy with nanographene particles, the time of mixing nanographen particles with epoxy approximately 20 minutes and the nanoparticles were added step by step to prevent agglomeration in particles and then hardener added and mixed for approximately 2 minutes to get a homogenous matrix. Mixer shown in Figure 3.6.

Figure 3.6. Mixer

After that the mixture was poured on the layer by layer for all layers, then laminated fabrics was put it on the hot press Figure 3.7 a and subjected to 0.4 MPa pressure for 1h curing time with 80°C temperature Figure 3.7 b. This method for fabricated laminate called hand lay-up.



(a) (b)

Figure 3.7 (a) Production unit, (b) Curing procedure

The composite laminates were cooled to room temperature under constant pressure for three hours. Finally, the composite laminate was removed from the hot press to get a fine finished composite laminates and hybrid composite configuration as shown in Figure 3.8. And Figure 3.9 show the hybrid configuration that produce for this study.

Figure 3.8 Composite and hybrid composite configuration

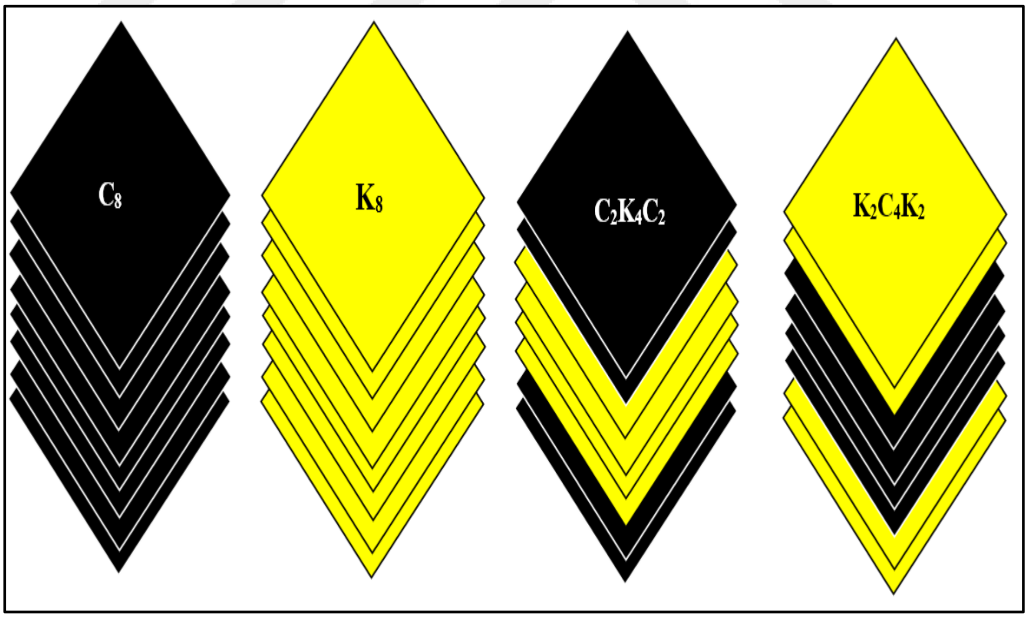


Figure 3.9 Hybrid configuration

The produced composite laminates in a size of 300 mm × 250 mm was cut to the required size of specimens using CNC machine as shown in Figure 3.10 according to the ASTM standards. ASTM D 638 [88] used for tensile test. ASTM D 790 [89] used for flexural test and ISO 179/92 for impact test. Each vibration test specimen dimension is 200 mm × 12.7 mm and clamped with free beam length of 153 mm. 4 laminates of $K_2C_4K_2$, 4 laminates of $C_2K_4C_2$, 4 laminates of C_8 and 4 laminates of K_8 with 0 wt.%, 0.1 wt.%, 0.25 wt.% and 0.5 wt.% were prepared to show hybridization effects.

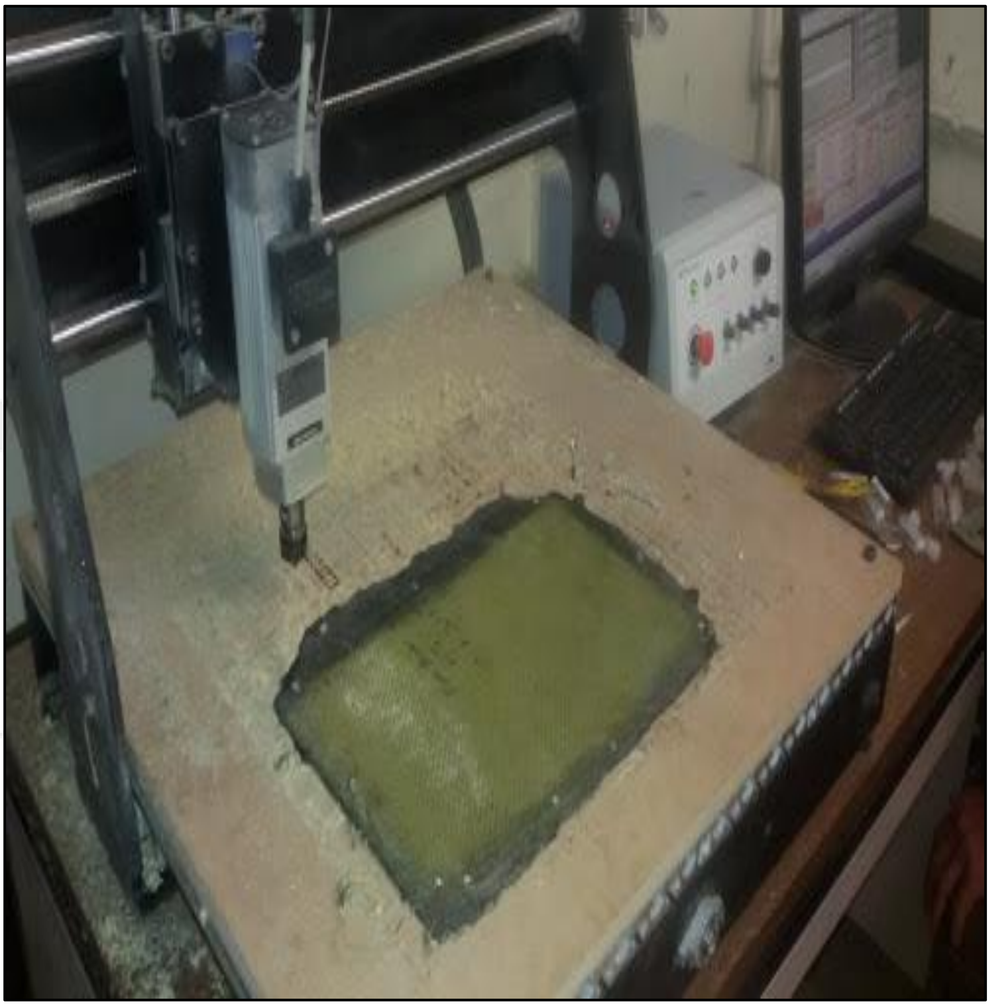
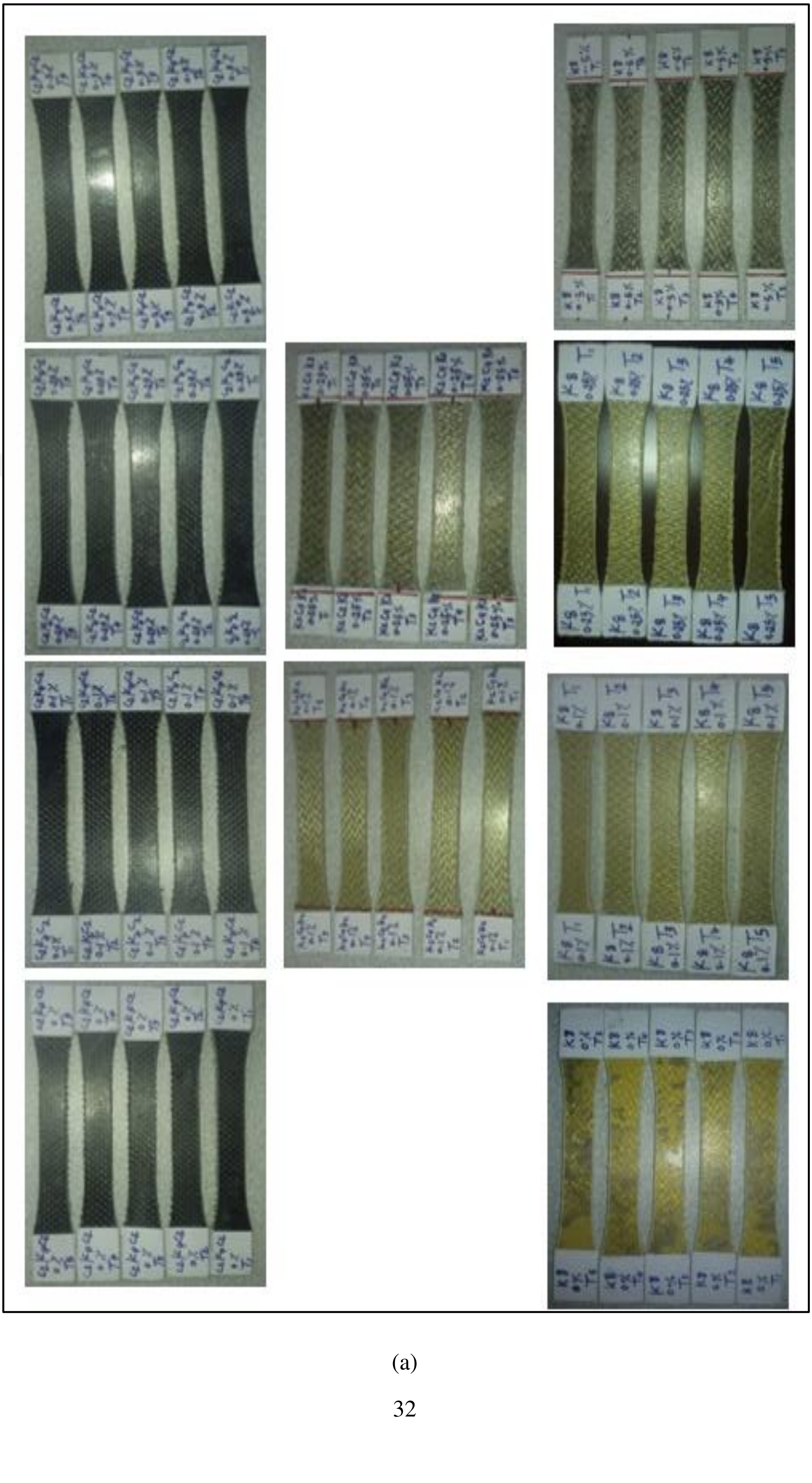


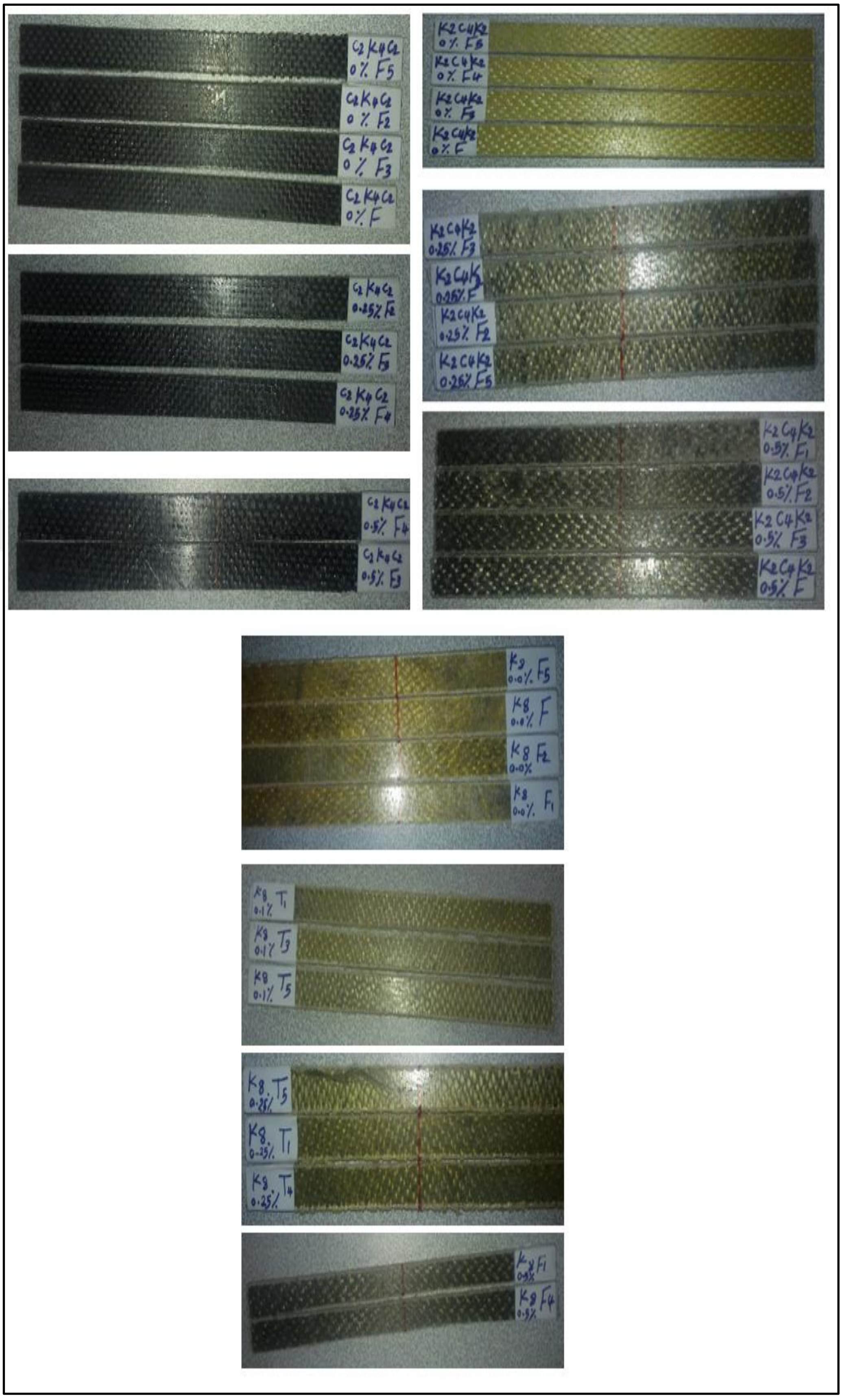
Figure 3.10 Cutting the specimen using CNC

3.3.2 Preparation of Test Specimens

After the production method completed the test specimens were cut from the sheet to the desired size as per ASTM standards (D638-00) for tensile test, (D-790) -00) for flexural test, ASTM E756 [90] for vibration and ISO 179/92 for impact test using CNC machines. Specimens for tensile test, flexural test, impact test and vibration test have been prepared for testing hybrid composites was shown in Figure 3.11.



(a)


C2K4C2 0% F5
C2K4C2 0% F2
C2K4C2 0% F3
C2K4C2 0% F
C2K4C2 0.25% F2
C2K4C2 0.25% F3
C2K4C2 0.25% F4
C2K4C2 0.5% F4
C2K4C2 0.5% F3
K2C4K2 0% F5
K2C4K2 0% F4
K2C4K2 0% F3
K2C4K2 0% F
K2C4K2 0.25% F3
K2C4K2 0.25% F
K2C4K2 0.25% F2
K2C4K2 0.25% F5
K2C4K2 0.5% F1
K2C4K2 0.5% F2
K2C4K2 0.5% F3
K2C4K2 0.5% F
K8 0.0% F5
K8 0.0% F
K8 0.0% F2
K8 0.0% F1
K8 0.1% T1
K8 0.1% T3
K8 0.1% T5
K8 0.25% T5
K8 0.25% T1
K8 0.25% T4
K8 0.5% F1
K8 0.5% F4

(b)

(c)

Figure 3.11 Specimens of (a) tensile test (b) flexural and vibration test (c) impact test

3.4 Determination of Mechanical Properties

The tensile and flexural strength characteristics of the composite samples were measured at room temperature utilizing the AG-X series-Shimadzu testing machine (Kyoto, Japan) Figure 3.12. Appropriate samples were prepared with a size of 165 mm × 13 mm for a gauge length of 50 mm for test of tensile and 200 mm × 12.7 mm with span to thickness ratio of 32:1 for test of flexural. The thickness of tensile, flexural and impact specimens was changed depended on variation of nanographene content. The crosshead speed was 3 mm/min for test of flexural and 2 mm/min for test of tensile. And for impact test the Köger 3/70 Charpy impact test machine, as shown in Figure 3.20 was used in the tests with 55 mm ×10 mm dimension of test specimen. For vibration test used National Instrument product NI 9234 with LABVIEW software with a general aim PCB 352C03 ceramic shear ICP ® accelerometer and a PCB 086C03 general purpose modal effect hammer were utilized for outcome signal acquisition, information acquisition and stimulus force signal, respectively. Five samples were examined at least for each compound, and the average value was calculated.

Figure 3.12 Test set-up Shimadzu AG-X series testing machine

3.4.1 Determination of tensile properties

Testing of tensile, also known as testing of tension, is a fundamental materials science test in which a specimen is subjected to a controlled tension until failure. The outcome results from the exam are commonly utilized to select a material for an application, for quality control, and to predict how a material will respond under other kinds of forces. Characteristics that are directly determined via a tensile test are ultimate tensile strength, reduction in area and maximum elongation. From these measurements the following characteristics can also be measured: Poisson's ratio, Young's modulus, strain-hardening and yield strength characteristics. Uniaxial testing of tensile is the most commonly utilized for obtaining the mechanical qualities of isotropic materials. For anisotropic materials, like as textiles and composite materials, biaxial tensile examining is required. Figure 3.13 show tensile test.

Figure 3.13 Tensile test

3.4.1.1 Tensile specimen

Tensile characteristics of samples were determined according to the ASTM standards (D638-00) standard test method, a suitable specimens cutting to make test with L= 165 mm, w =13 mm. Figure 3.14 show the tensile test specimen with dimensions.

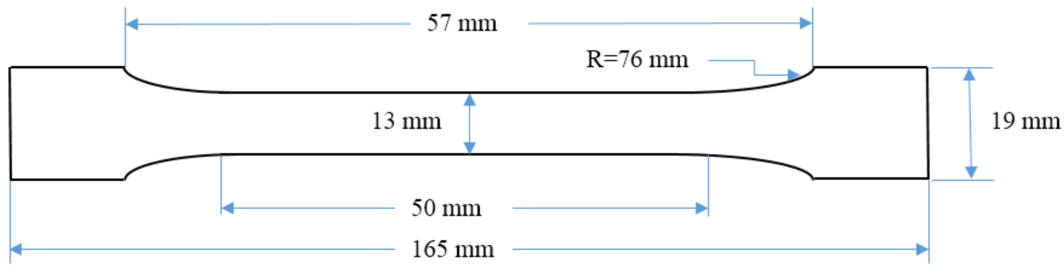


Figure 3.14 The dimensions of the tensile samples according to ASTM 638-00

Through this method, the recording section elongation measured against the applied force. Engineering strain is calculated using the equation:

$$\varepsilon = \frac{\Delta L}{Lo} = \frac{L-Lo}{Lo} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where ΔL is the amount of change in length, (Lo) is the length of the initial measurement, and (L) it is the ultimate length.

The force measurement is utilized to calculate the engineering stress, σ, utilize the next equation:

$$\sigma = \frac{Fn}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where Fn is the tensile force and A is a cross-section nominal sample.

Mechanical characteristics of sample were acquired utilize Shimadzu AG-X series testing machine. To calculate tension characteristics, sample was loaded in tension direction with the 2 mm/min velocity up to failure. Then tensile strength (σ_t) was determined to utilize the stress and strain data's obtained from the testing machine.

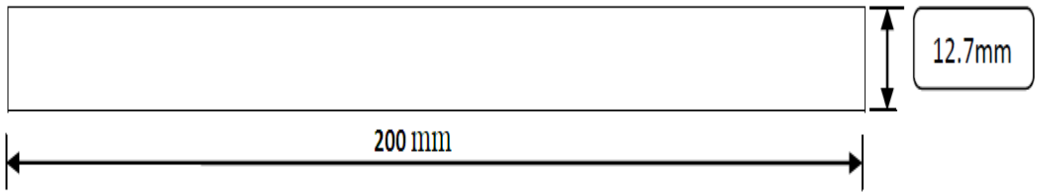
3.4.2 Determination of flexural properties

Flexural strength, as well known as modulus of rupture, fracture strength or bend strength, is a material properties, defined as the stress in a material only before it yields in test of flexure. The transverse test of bending is most frequently employed, in which a samples having either a rectangular or circular cross-section is bent until yielding or fracture using a three point flexural test method. The flexural strength symbolizes the highest stress experienced within the material at its moment of failure. It is measured in terms of stress. Figure 3.15 show flexural test.

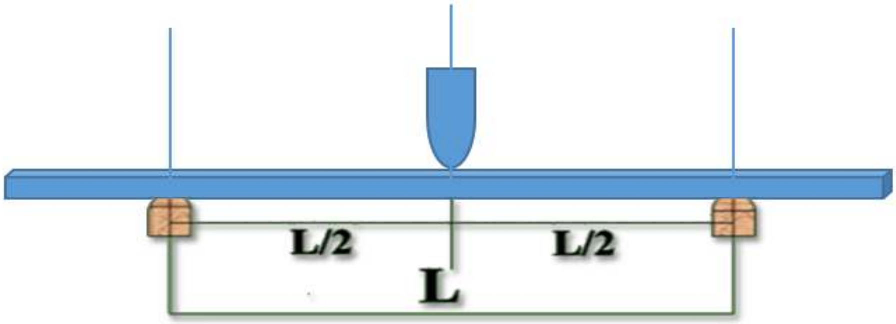
Figure 3.15 Flexural test

3.4.2.1 Flexural specimen

Flexural characteristics of samples were determined according to the ASTM D790-00 standard test method as shown in Figure 3.16 a, a suitable specimens of rectangular cross section with L= 200 mm, w =12.7 mm rests on two supports and was loaded midway between the supports. as shown in Figure 3.16 b.



(a)



(b)

Figure 3.16 (a) Flexural specimens according to ASTM D 790 – 00 (b) loaded specimens

Flexural strength, flexural modulus & strain were determined from the test machine data's through the over the use of the formulas [3-1008].

$$\sigma_F = \frac{3P_{max}L}{2bh^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{h}{L}\right)\left(\frac{D}{L}\right)\right] \quad \ldots\ldots\ldots\ldots \quad (3.3)$$

$$E_F = \frac{mL^3}{4bh^3} \quad \ldots\ldots\ldots\ldots \quad (3.4)$$

$$\varepsilon_F = \frac{6Dh}{L^2} \quad \ldots\ldots\ldots\ldots \quad (3.5)$$

Where L, b and h square measure the span, width and depth of the sample respectively, m is that the slope of the tangent to the initial line a part of the load deflection curve, D is that the maximum deflection before failure and P is that the load at a given point on the load-deflection curve.

3.4.3 Impact Test

The most important of those limitations is a reaction against regional impact which they are exposed to the foreign material under operating situation. To know the impact react of composite materials, several researches were accomplished. Test apparatuses used to measure the response to the impact load of a composite are Izod and Charpy pendulum impact test, drop weight test and gas gun test.

3.4.3.1 Charpy Impact Test

Charpy impact test was conducted according ISO 179/92 standard. A Köger 3/70 Charpy impact test machine, as shown in Figure 3.17 was used in the tests. Before starting test, the device was calibrated and scaled by putting the device on a smooth and flat surface to obtain more reliable results during testing. Edgewise specimens and flatwise specimens are illustrated in Figure 3.18.

Figure 3.17 Charpy impact test (flatwise and edgewise impact loadings)

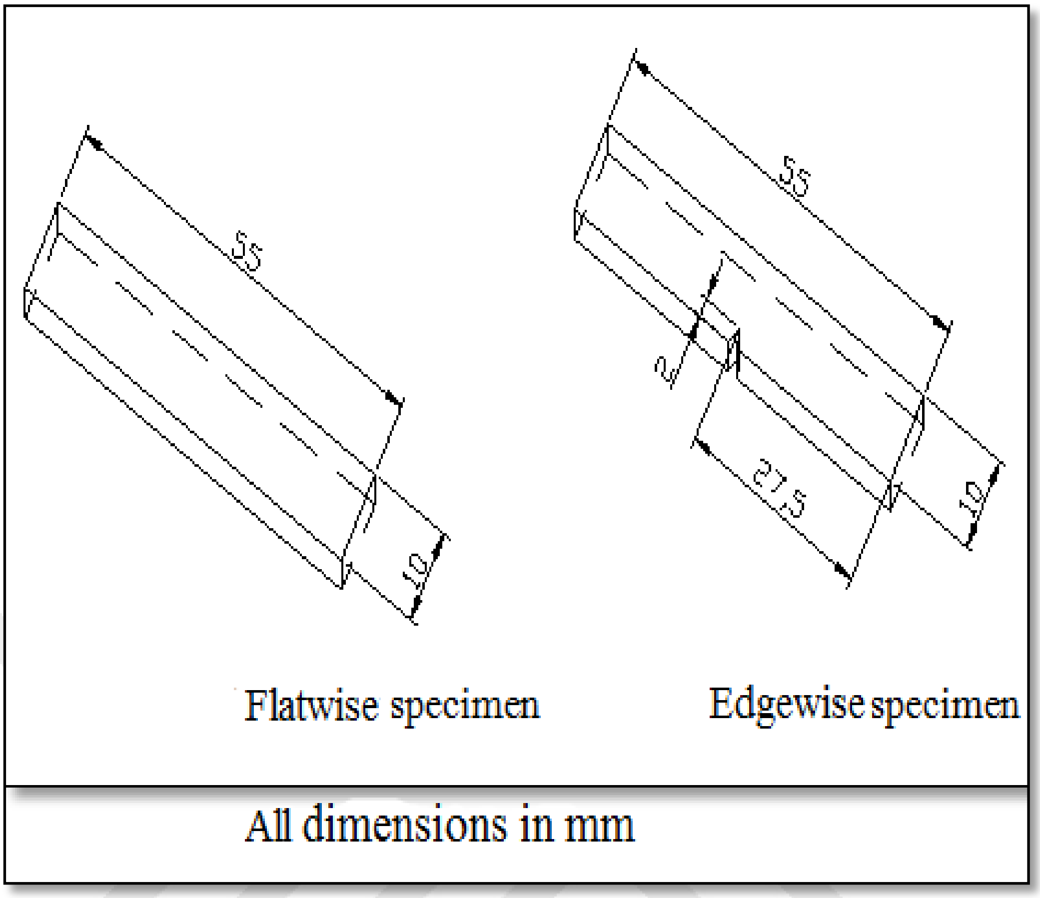


Figure 3.18 Flatwise and edgewise specimens.

The absorbed impact energy and impact toughness of specimens were determined according to the following equations:

$$E = E_a - E_b \quad (1)$$

$$a_{cu} = \frac{E}{b \times h} \quad (2)$$

where, E, E_a, E_b, in Equation (1) represent the absorbed impact energy, potential energy of the weighted pendulum before and after impact respectively, and a_{cu} , h and b in Equation (2) represent impact toughness, thickness of test specimen and width of the test specimen, respectively. Figure 3.19 shows all the parameters.

Average values and standard deviations for the absorbed impact energy and impact toughness were used to assess the effect of nanographene particles.

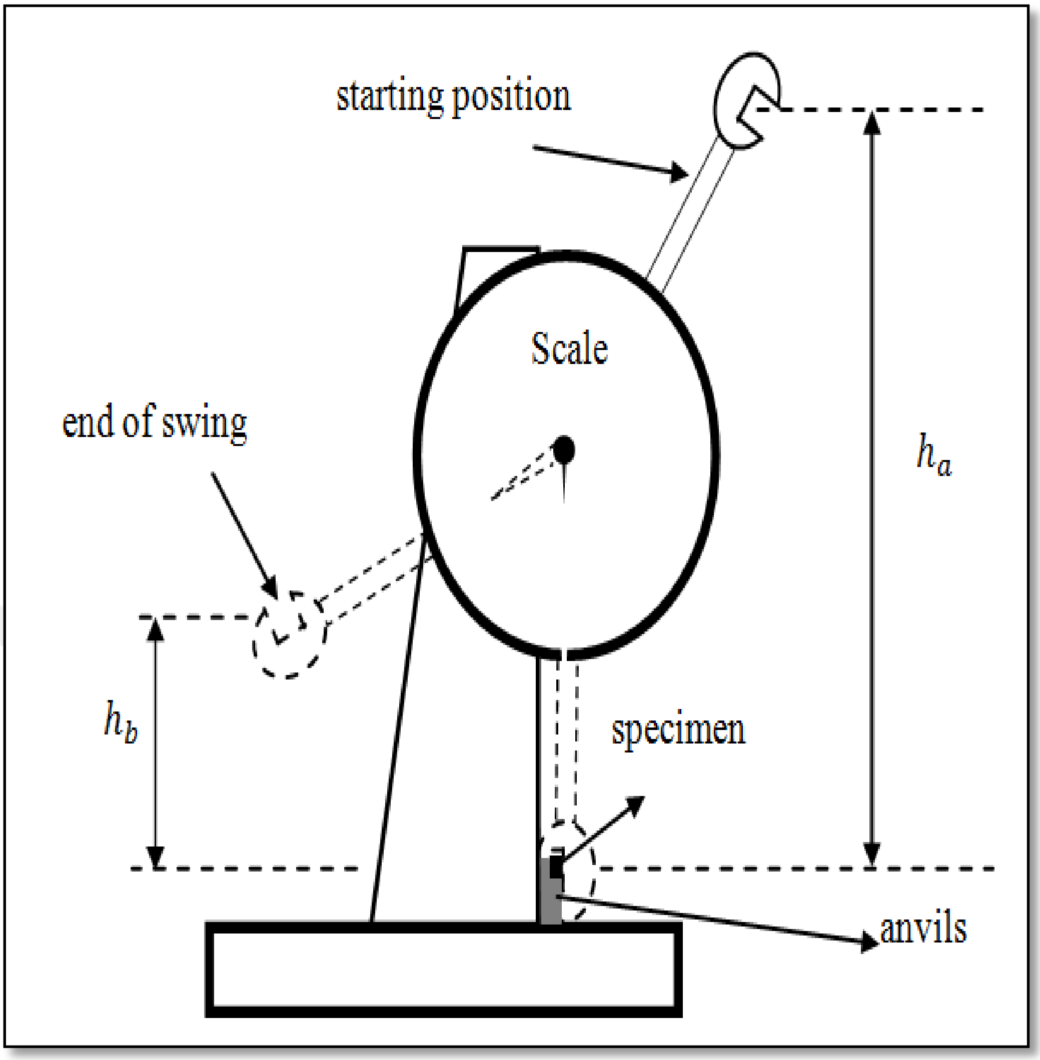


Figure 3.19 Pendulum before and after impact.

3.4.4 Vibration test

Vibration and damping characteristics of nanographene inclusion by hybrid composite laminates were measured by test set-up according to ASTM E756. Figure 3.20 shown vibration test set-up. In the testing, National Instrument product NI 9234 with LABVIEW software with a general aim PCB 352C03 ceramic shear ICP ® accelerometer and a PCB 086C03 general purpose modal effect hammer were using for result signal acquisition, information acquisition and stimulus force signal, respectively. Half power bandwidth method was applied to evaluate responses of damping of first natural frequency modes of the composite samples.

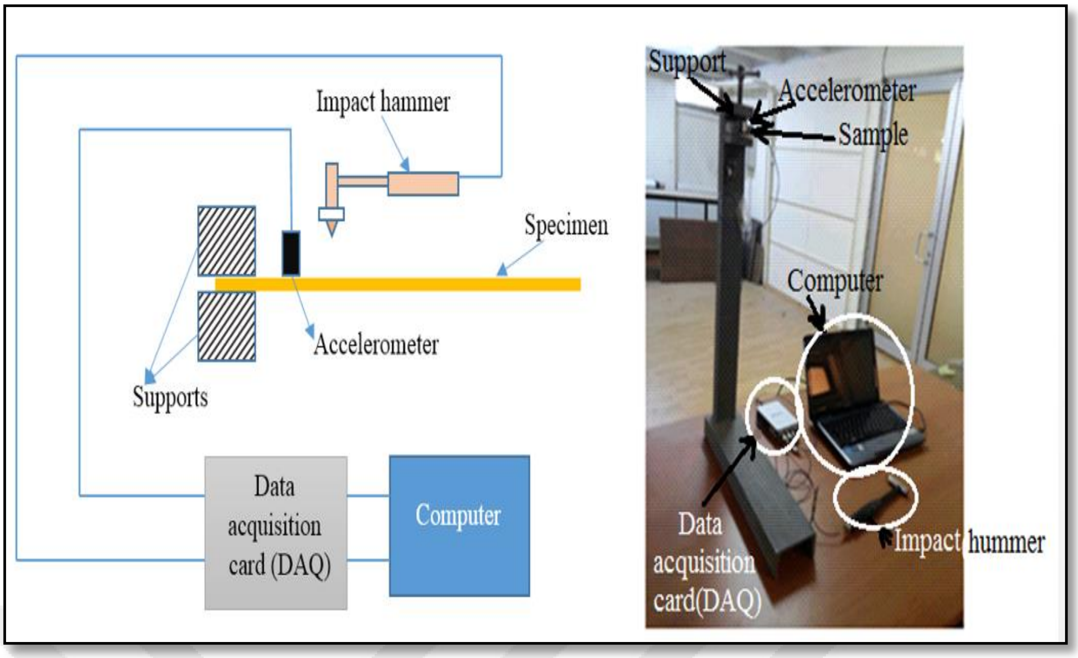


Figure 3.20 Vibration test set-up

The damping ratio was resulted in accordance with the half-bandwidth method Figure 3.21 [90]. Damping ratio (ξ) can be calculated by using the logarithmic decrement according to formula 3.6.

$$\xi = \frac{\omega_2 - \omega_1}{2.\omega_n} \qquad \text{(3.6)}$$

Where ω_n was the natural frequency of first mode and $\omega_2 - \omega_1$ is the bandwidth. The storage modulus E" and loss modulus E' is given in formula 3.7 and 3.8.

$$\omega_1 = \frac{1.875^2}{2.\pi.L^2}\sqrt{\frac{E'.I}{\rho.A}}$$

(3.7)

Similarly, loss modulus of the beam can be get it by using the storage modulus. Relationship between storage modulus and loss modulus is shown as follows

E" (ω)=2E'(ω)ξ(ω)…………………….……………………………….. (3.8)

Where ω_1 was the natural frequency of the first mode, L is the free length of the specimen, I is the moment of inertia for the given cross-section of the specimen, ρ is the density of the specimen and A is the cross-section of the specimen.

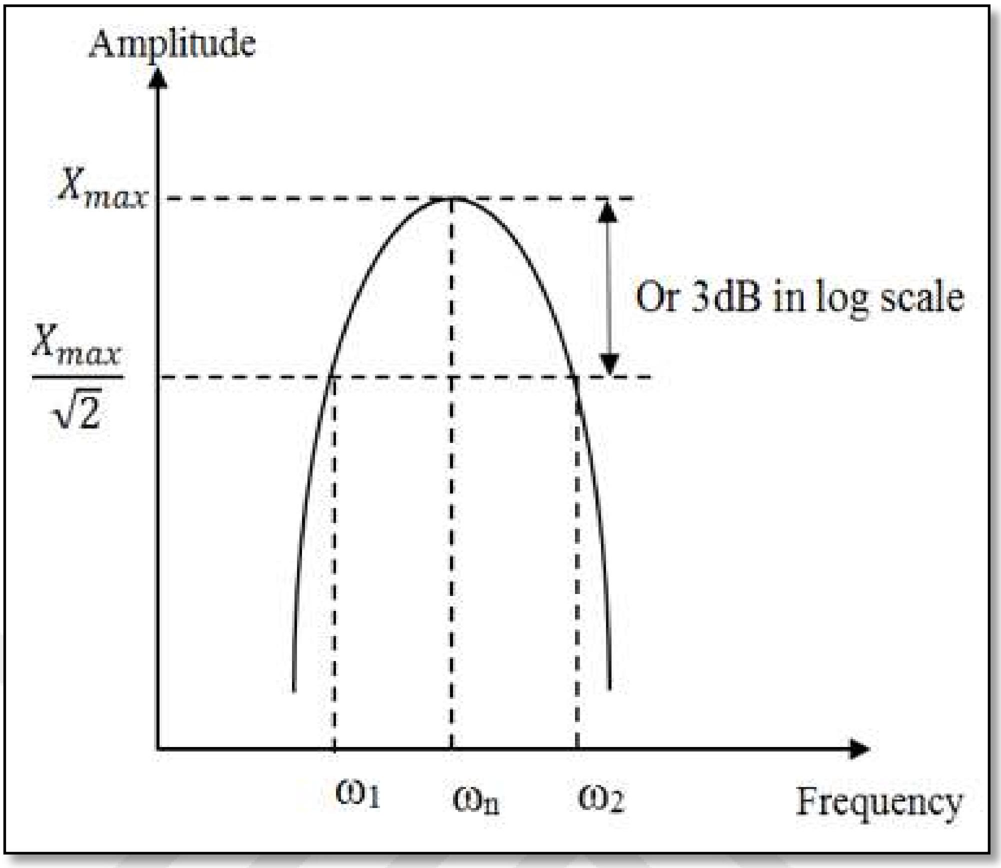


Figure 3.21 Half-power bandwidth method

3.4.4.1 Vibration specimen

Vibration characteristics of specimens were determined according to the ASTM D756- 00 standard test method, a suitable specimens of rectangular cross section with L= 200 mm, w =12.7 mm. Figure 3.22 show the vibration test specimen with dimensions.

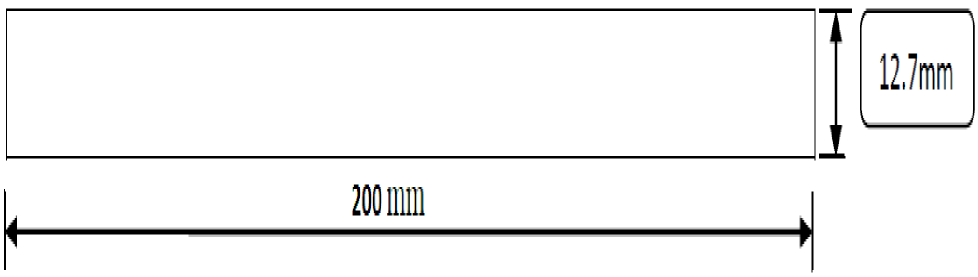


Figure 3.22 Vibration specimens according to ASTM D 756

CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 Introduction

Mechanical tests have a significant role in the detection of appropriate materials in mechanical use to perform high efficiency at work. Many tests have been made upon the Kevlar/carbon/epoxy and hybrid composite with Nanographene addition. Test results are explained in terms of figures and tables.

4.2 Vibration Test Results

Dynamic performance of composites is very significant when they are utilized in primary applications. Though the study on result of filler materials on Dynamic performance is still at its beginning. Vibrations are unwanted for structures. Vibration decrease can be gotten by mounting the damping capacity (loss of energy) & mounting the stiffness (storage modulus) owing to the want for structural stability [91].

4.2.1. Vibration Damping of Carbon

Vibration test results are listed in table 4.1 for the carbon fibre reinforced epoxy composite filled with nanographene

Table 4.1 Vibration results of the carbon fibre 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

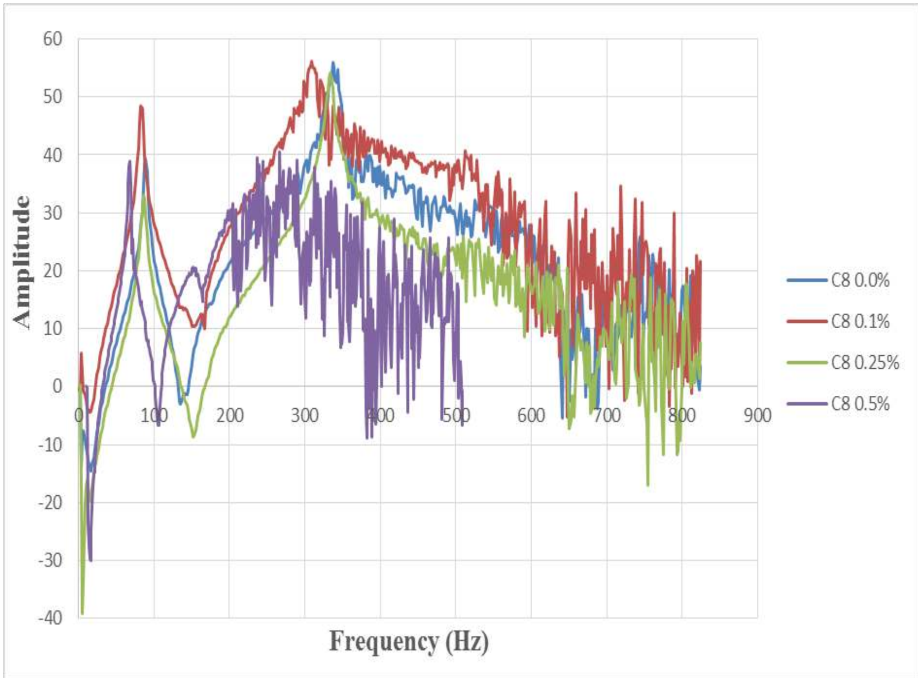


Figure 4.1 Amplitude – Frequency diagram of the carbon fibre reinforced epoxy composite filled with nanographene

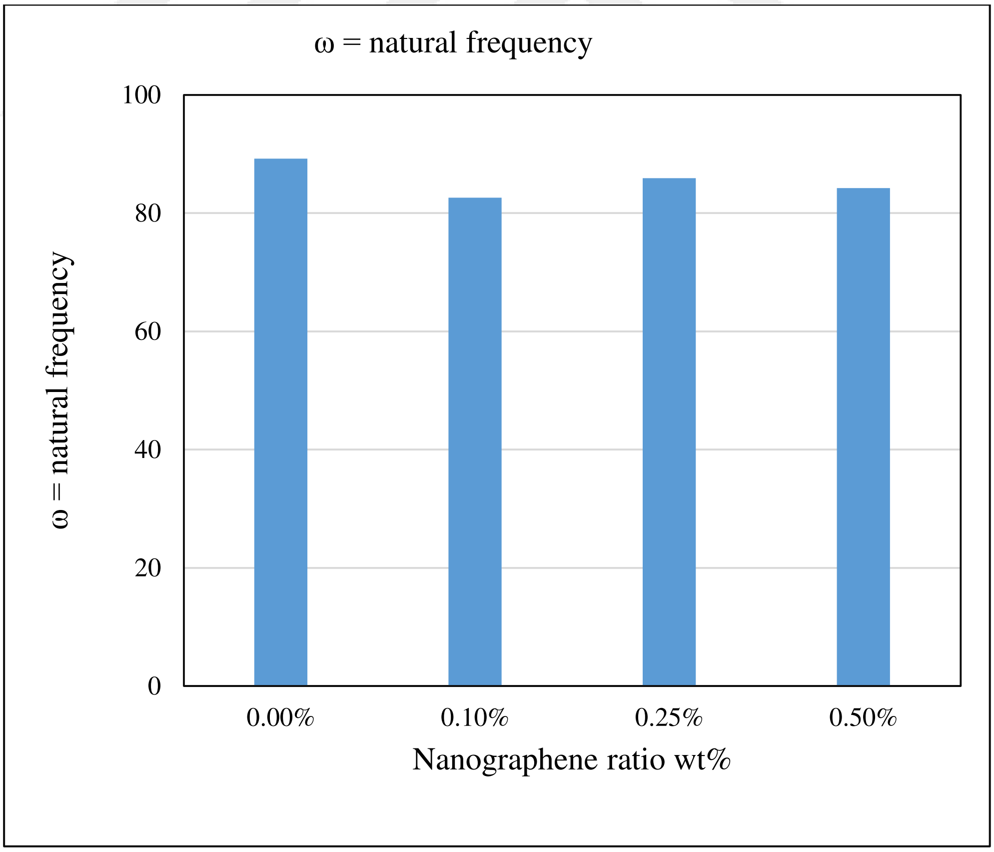


Figure 4.2 Natural frequency for Carbon/epoxy Nanographene composites

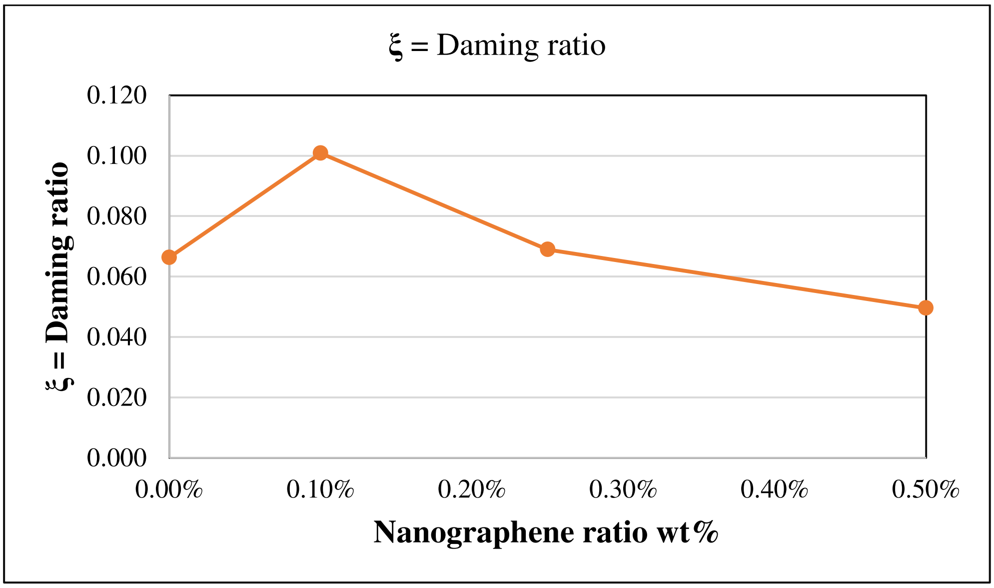


Figure 4.3 Damping ratio for Carbon/epoxy with nanographene composite

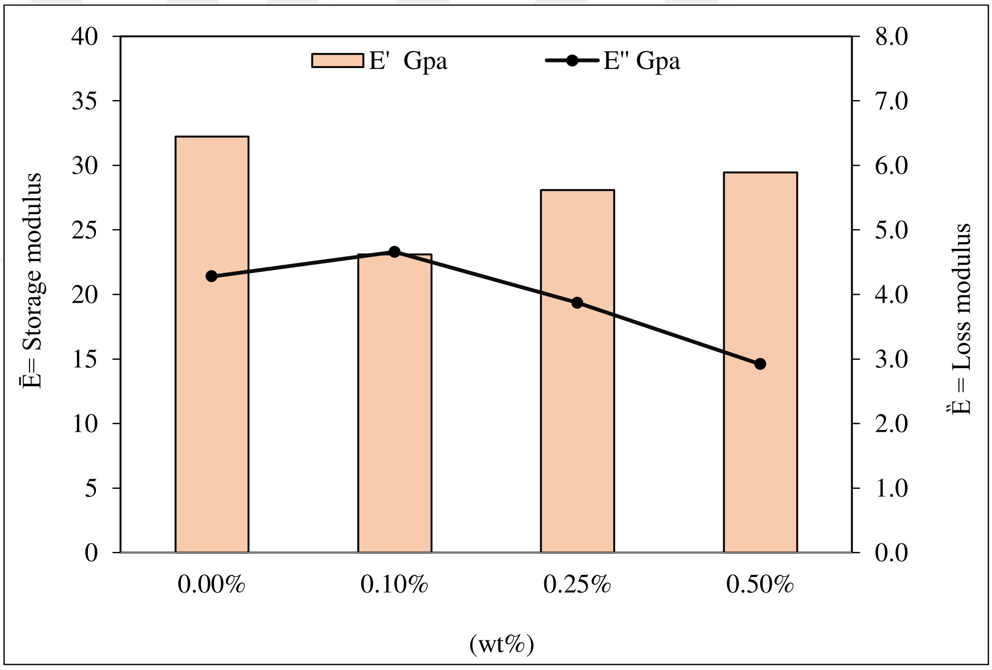


Figure 4.4 Storage and loss modulus for Carbon/epoxy with nanographene composites

Above figures from 4.1, 4.2, 4.3 & 4.4 the damped ratio of the carbon /epoxy became farthest after the incorporation of graphene into the matrix because of the improvement of damping ratio. Like to the damping behavior of graphene reinforced nanocomposite, the graphene –epoxy/carbon composites indicated an amplitude dependent vibration features, which shows that the graphene modified matrix material was responsible for the enlargement in damping features

4.2.2 Vibration Damping Of Kevlar

Vibration Test Results are listed in table 4.2 for the Kevlar fibre reinforced epoxy composite filled with nanographene

Table 4.2 Vibration results of the Kevlar fiber reinforced epoxy composite filled with nanographene

wt %	ω Hz	E' Gpa	ξ	E'' Gpa
0.00%	77.625	16.38	0.052	1.70
0.10%	71.019	13.82	0.084	2.31
0.25%	75.974	16.71	0.043	1.43
0.50%	80.929	18.08	0.057	2.07

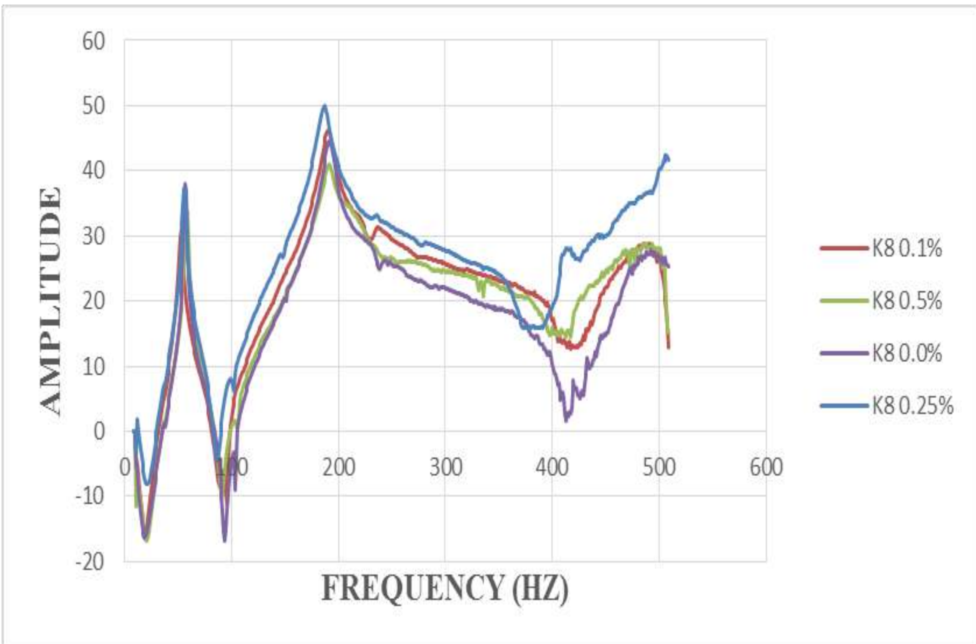


Figure 4.5 Amplitude – Frequency diagram of the kevlar fibre reinforced epoxy composite filled with nanographene

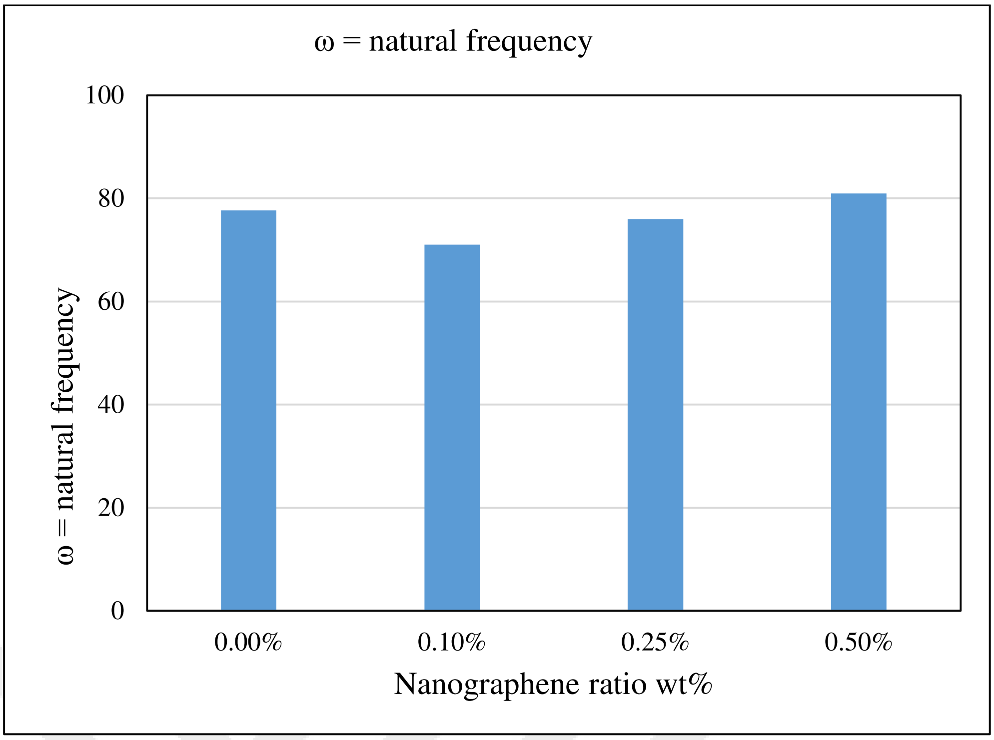


Figure 4.6 Natural frequency for Kevlar /epoxy Nanographene composites

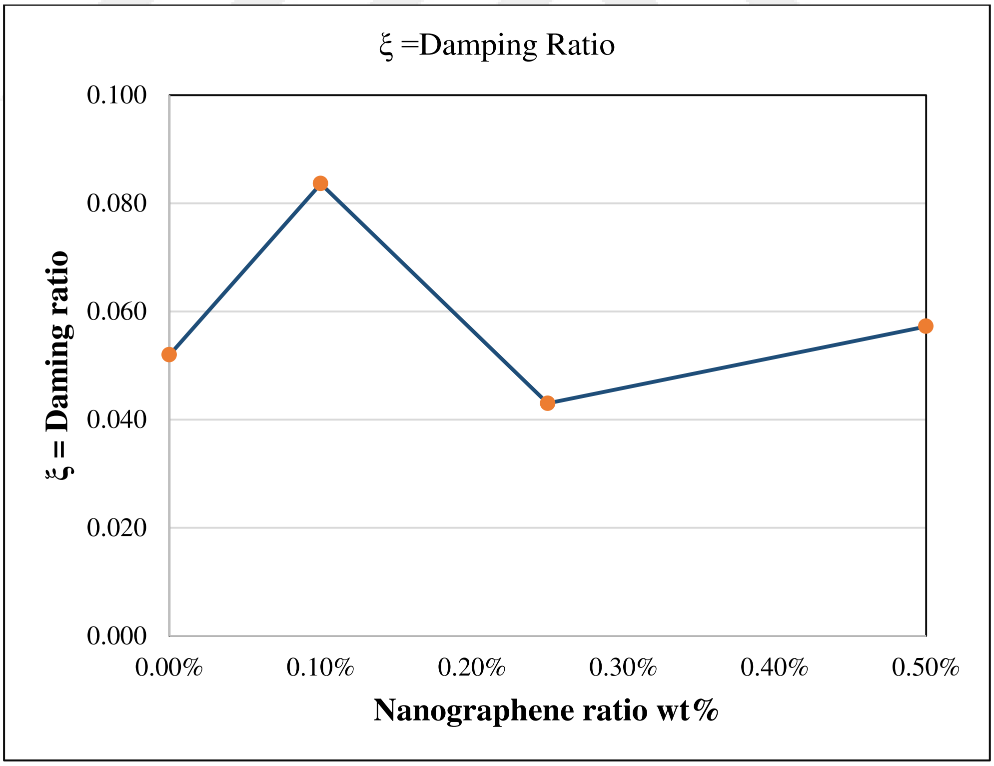


Figure 4.7 Damping ratio for Kevlar/epoxy nanographene composite

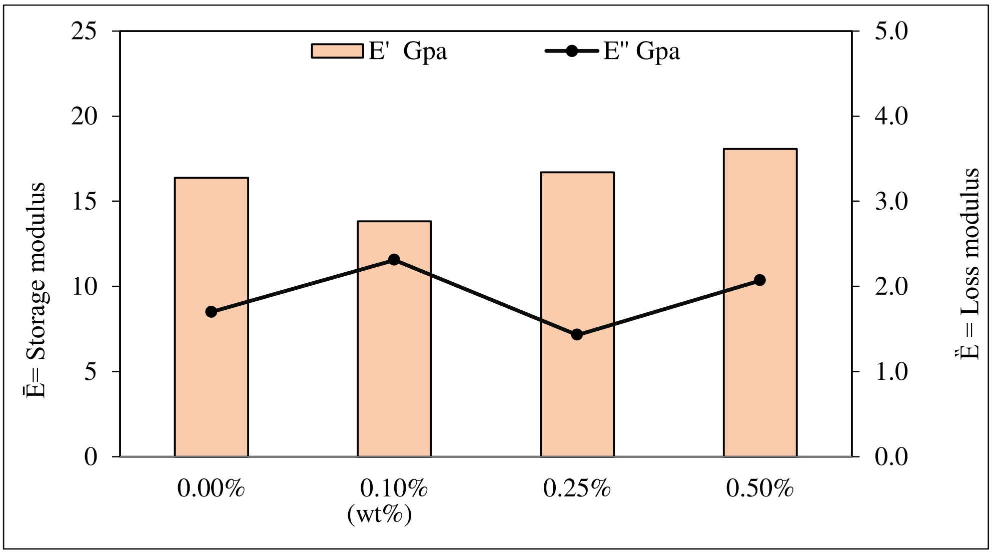


Figure 4.8 Storage and loss modulus for Kevlar /epoxy with Nanographene composites

Above figures 4.5, 4.6, 4.7 & 4.8 the damped ratio of the Kevlar /epoxy became farthest after the incorporation of graphene into the matrix because of the improvement of damping ratio. Like to the damping performance of graphene reinforced nanocomposite, the graphene epoxy/Kevlar composites indicated an amplitude dependent vibration features, which shows that the graphene modified matrix material was responsible for the enlargement in damping features.

4.2.3 Vibration Damping Of C2K4C2

Vibration test results are listed in Table 4.3 for the C2K4C2 fiber reinforced epoxy composite filled with nanographene

Table 4.3 Vibration results of the C2K4C2 fibre reinforced epoxy composite filled with nanographene

wt %	ω Hz	E' Gpa	ξ	E'' Gpa
0.00%	87.535	28.53	0.049	2.77
0.10%	92.49	29.95	0.089	5.30
0.25%	80.929	22.56	0.053	2.38
0.50%	94.191	27.91	0.046	2.55

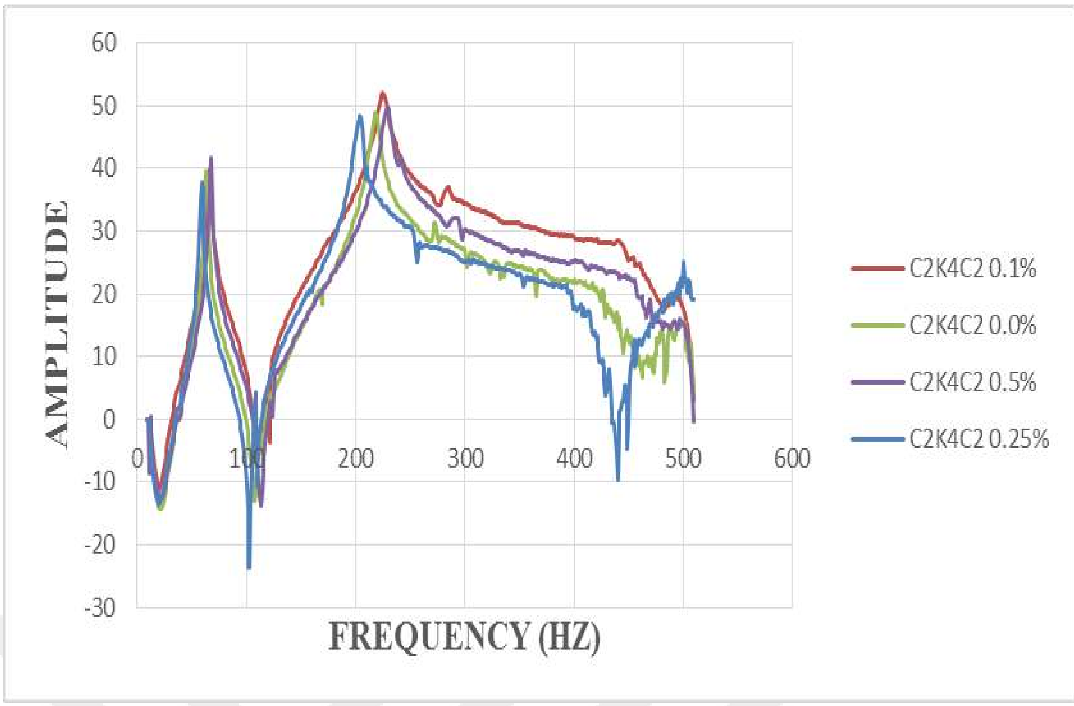


Figure 4.9 Amplitude – Frequency diagram of the C2K4C2 fibre reinforced epoxy composite filled with nanographene

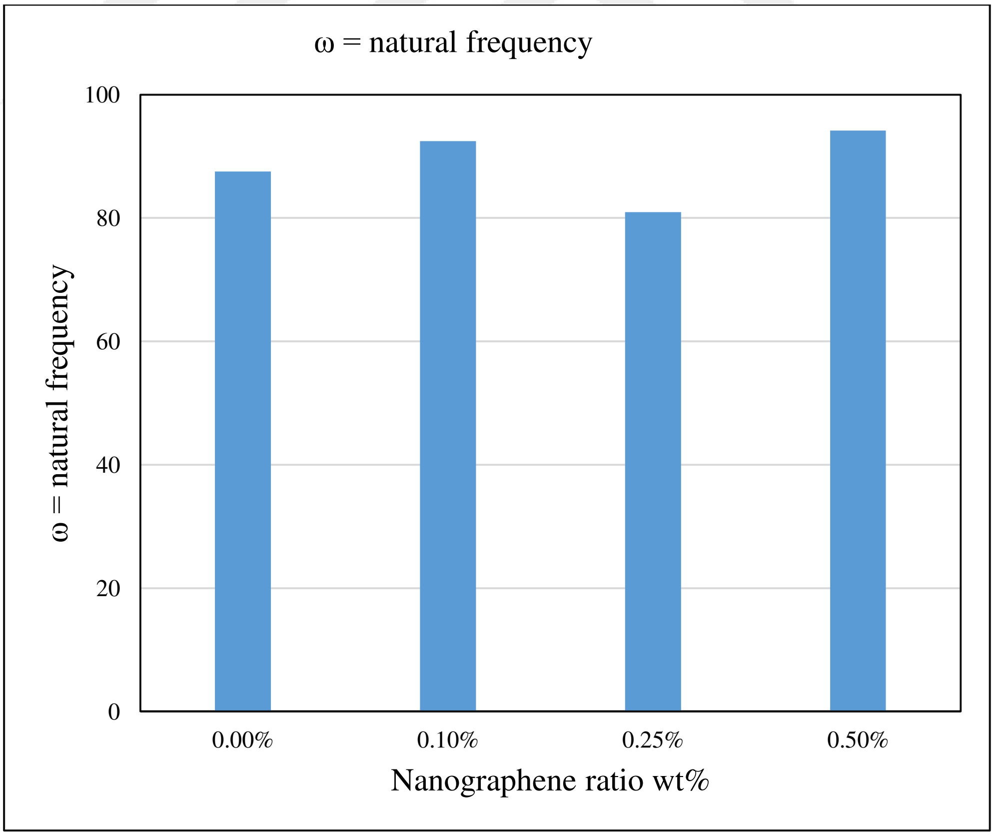


Figure 4.30 Natural frequency for C2K4C2/epoxy nanographene composite

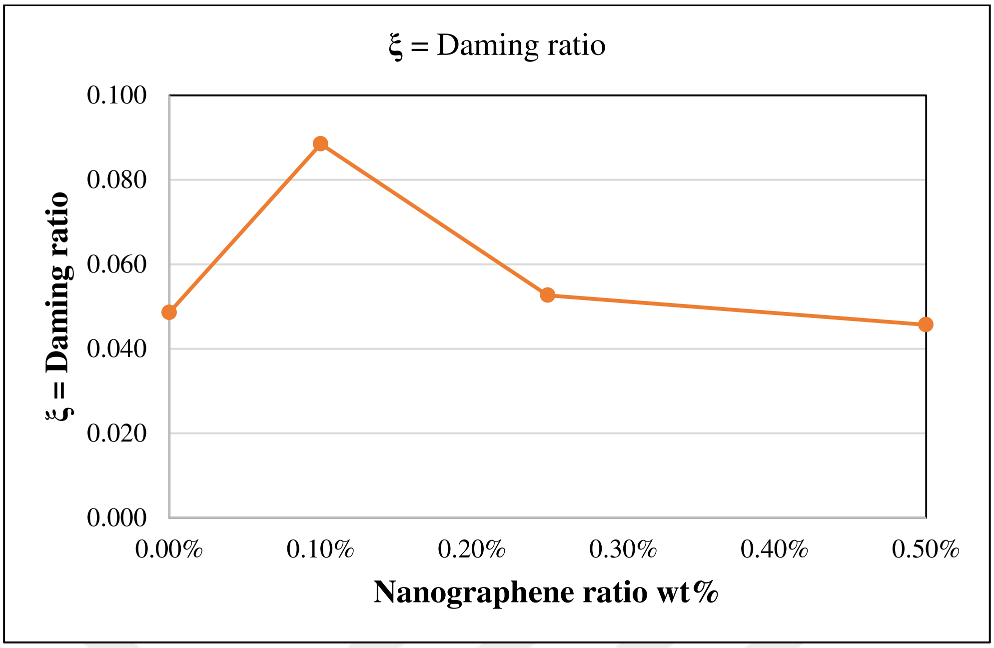


Figure 4.11 Damping ratio for C2K4C2//epoxy nanographene composite

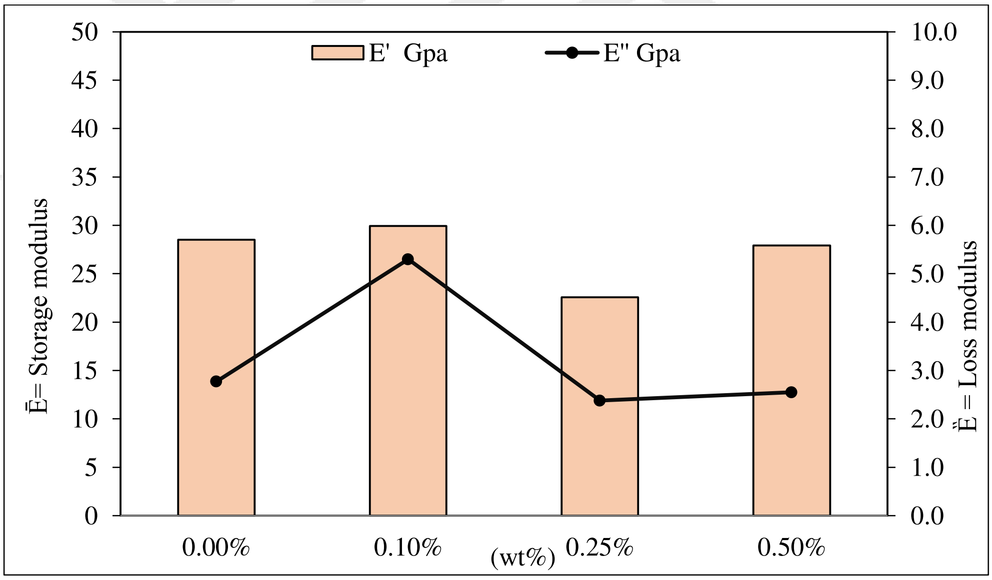


Figure 4.14 Storage and loss modulus for C2K4C2 /epoxy with Nanographene composites

Above figures 4.9, 4.10, 4.11 & 4.12 the damped ratio of the C2K4C2 /epoxy became farthest after the incorporation of graphene into the matrix because of the improvement of damping ratio. Like to the damping behavior of graphene reinforced nanocomposite, the graphene –epoxy/ C2K4C2 composites showed an amplitude dependent vibration features, which indicates that the graphene modified matrix material was responsible for the development in damping features.

4.2.4 VIBRATION OF K2C4K2

Vibration test results are listed in Table 4.4 for the K2C4K2 fiber reinforced epoxy composite filled with nanographene

Table 4.4 Vibration results of hybrid composite (K2C4K2) epoxy composite filled with nanographene

wt %	ω Hz	E' Gpa	ξ	E'' Gpa
0.00%	69.3677	18.04	0.060	2.17
0.10%	66.06452	15.16	0.081	2.46
0.25%	69.3677	15.66	0.048	1.50
0.50%	67.716	13.07	0.070	1.84

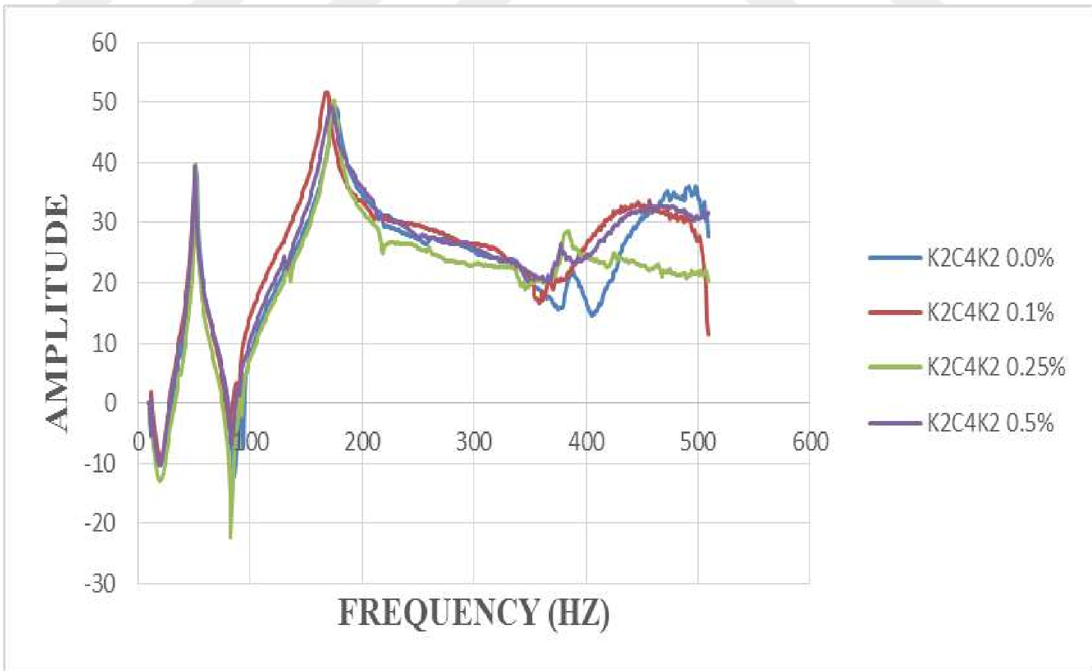


Figure 4.13 Amplitude – Frequency diagram of the K2C4K2 fibre reinforced epoxy composite filled with nanographene

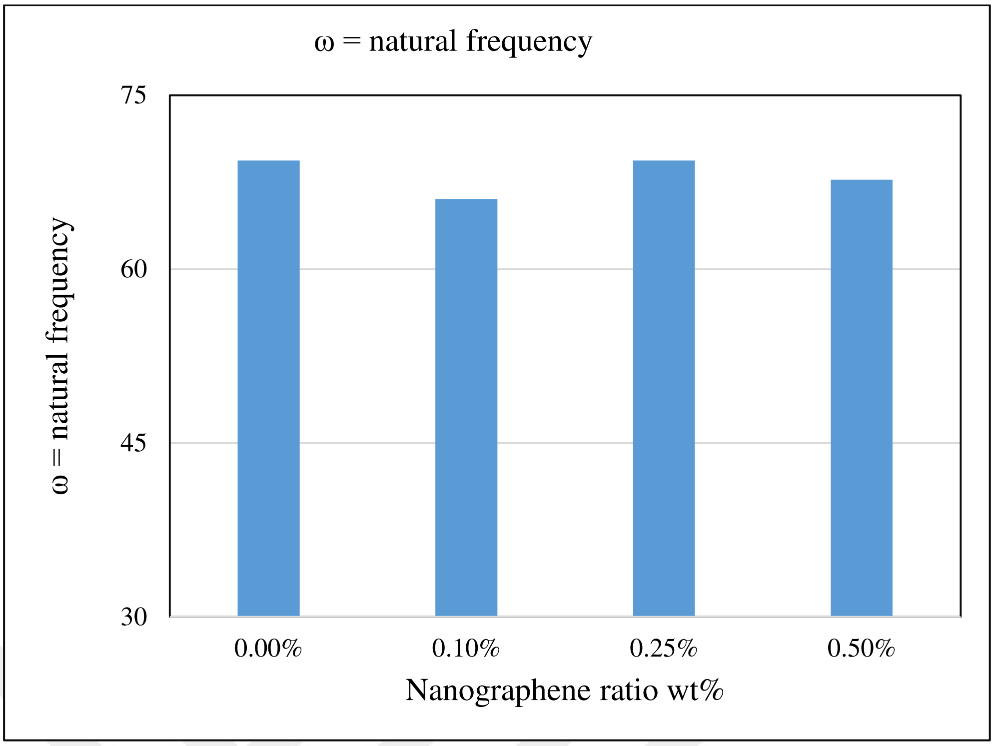


Figure 4.14 Natural frequency for K2C4K2/epoxy nanographene composites

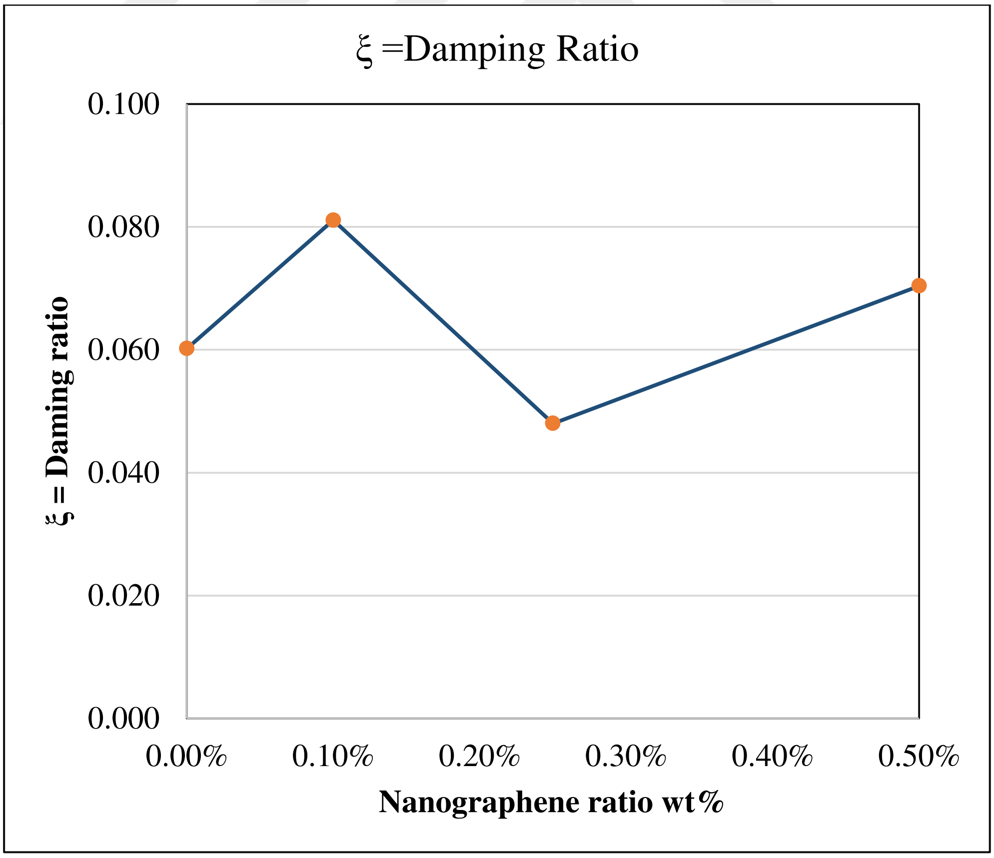


Figure 4.15 Damping ratio for K2C4K2/epoxy Nanographene composite

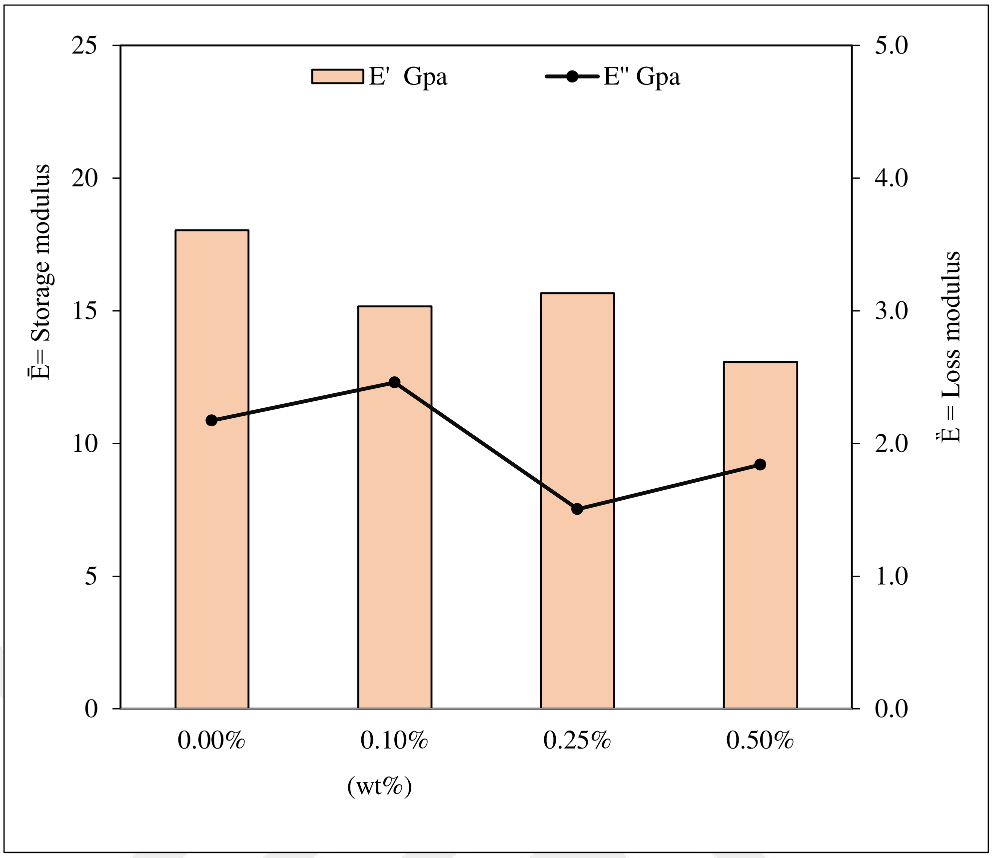


Figure 4.16 Storage and loss modulus for K2C4K2/epoxy with Nanographene composites.

From figures above 4.13, 4.14, 4.15 & 4.16The damped ratio of the K2C4K2 /epoxy became farthest after the incorporation of graphene into the matrix because of the improvement of damping ratio. Like to the damping behavior of graphene reinforced nanocomposite, the graphene epoxy/K2C4K2 composites showed an amplitude dependent vibration features, which indicates that the graphene modified matrix material was responsible for the enhancement in damping features.

4.3 Tensile Results

4.3.1 Tensile Results of Carbon

Tensile test results are listed in Table 4.5 for the carbon fibre reinforced epoxy composite filled with nanographene.

Table 4.5 Tensile characteristic of carbon fiber with various Nanographene ratio

wt%	spesim	m.F	m.Stro	max.T	ave. T	max.t.stri	ave.t.stin
	1	14699.1	5.55	551.56		0.0483	
0%	3	15545.2	5.29	569.42	**547.8274**	0.0460	**0.0450**
	3	14974	4.90	548.50		0.0426	
	4	15860.8	4.98	580.98		0.0433	
	1	16372.6	5.19	599.73		0.0451	
0.1%	2	16619.5	5.45	608.77	**569.3405**	0.0474	**0.0442**
	3	16032.6	4.87	573.62		0.0423	
	4	14890.2	4.89	**545.43**		0.0425	
	5	15348.5	5.02	**575.93**		0.0437	
	1	18093	5.17	**632.62**		0.0450	
0.25%	2	16770	4.83	**586.36**	**550.7316**	0.0439	**0.0436**
	3	17864	5.33	**624.62**		0.0463	
	4	16770.3	4.83	**600.01**		0.0420	
	5	15823.4	4.92	**579.61**		0.0428	
	1	15135	4.90	**517.44**		0.0426	
0.50%	2	15496	4.96	**529.78**	**526.0639**	0.0431	**0.0454**
	3	15325	5.48	**512.54**		0.0477	
		15065.7	5.39	**526.77**		0.0469	
		16060	5.40	**561.54**		0.0469	

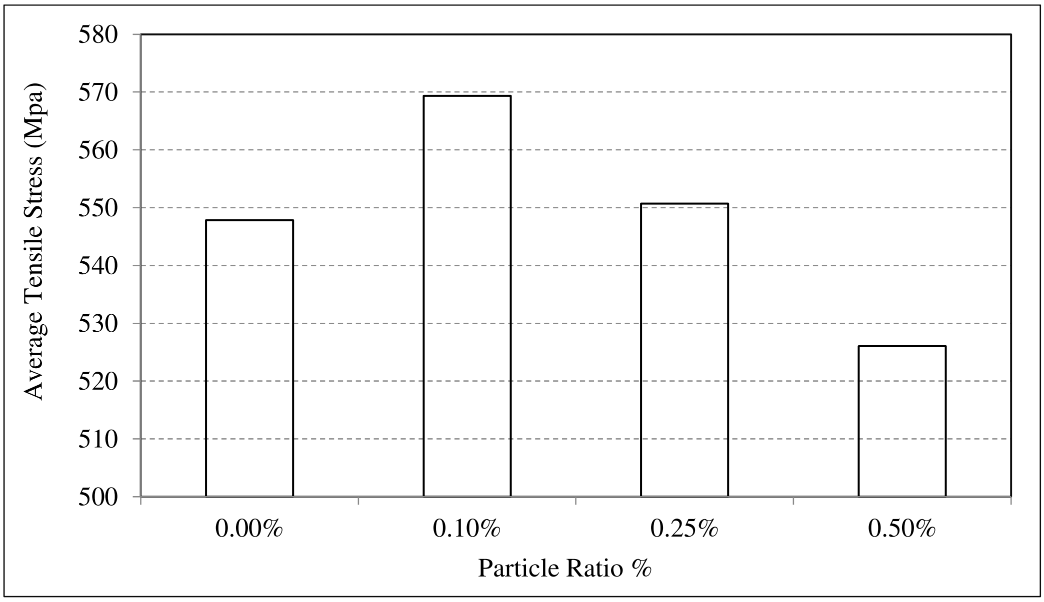


Figure 4.17 Tensile stress- Particle ratio (wt. %) diagram of the carbon fibre reinforced epoxy composite filled with nanographene particle

Figure 4.17 and data in Table 4.5, the tensile strength of unfilled carbon fiber epoxy composite is increased rapidly with adding graphene that the maximum reinforcement is **3.93 %**% at particle content of 0.1 wt%, after this ratio the tensile was reduced.

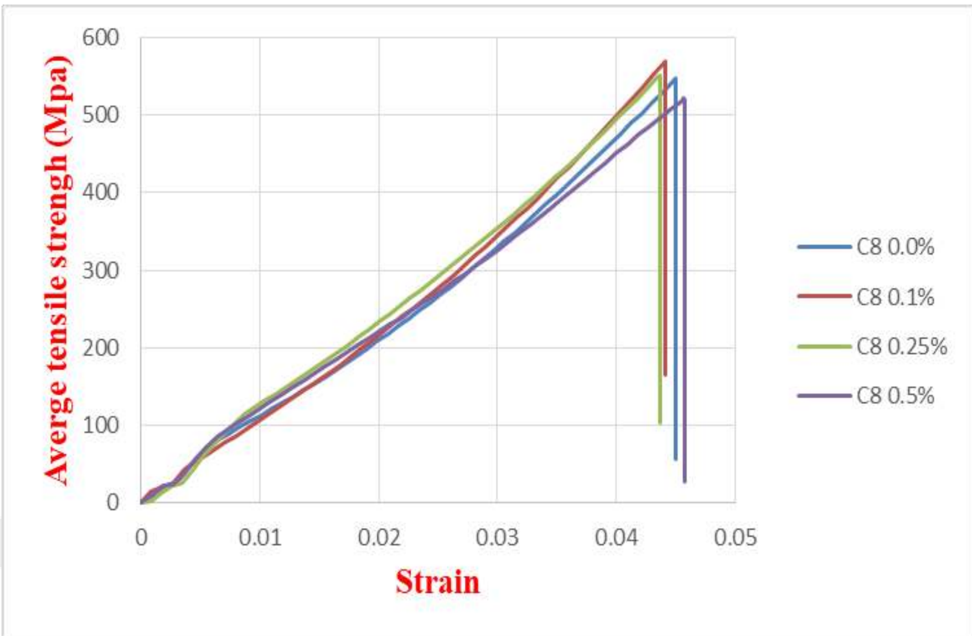


Figure 4.18 Tensile stress-strain curves of the carbon fibre reinforced epoxy composite filled with nanographene particle.

Figure 4.18 designed the relation between stress and strain for carbon fiber epoxy composite modified by nanoographene the maximum stress value occurred at 0.1 wt% of graphene while , the maximum of strain occurred at 0.5 wt% .

The graphene agglomeration depends on size, shape, synthesis methods and surface chemistry. The use of graphene to improve the characteristics of the system to which it is going to reinforce is fairly dependent on its dispersion state [92].

Figure 4. 19 samples of carbon fiber epoxy graphene composite after failure

All samples as showed in figure 4.19 of 0.1% graphene carbon fiber epoxy composite after failure were broken to three pieces. And the section of break showed brittle fiber breakage and matrix cracks at the same time for this ratio.

4.3.2 Tensile results of Kevlar

Tensile test results are listed in table 4.6 for the kevlar fibre reinforced epoxy composite filled with nanographene

Table 4.6 Tensile characteristic of Kevlar with various nanographene ratio

wt%	spesim	m.F	m.Stro	max.T	ave. T	max.t.stri	ave.t.stin
	1	12721.2	5.02	407.73		0.0437	
0%	3	10945.9	4.54	350.83	**372.00**	0.0394	**0.0437**
	3	11000.6	4.66	352.58		0.0405	
	4	11777.3	5.93	377.48		0.0516	
	5	11586.6	4.99	371.37		0.0434	
	1	15176.9	6.22	486.44		0.0540	
0.1%	2	14321.8	7.19	459.03	**461.96**	0.0625	**0.0640**
	3	14181.8	7.10	454.54		0.0617	
	4	14172.1	7.36	**454.23**		0.0640	
	5	14213.7	8.94	**455.57**		0.0777	
	1	12820.4	7.35	**410.91**		0.0639	
0.25%	2	12699.6	6.73	**407.04**	**404.52**	0.0612	**0.0589**
	3	12289.2	6.38	**393.88**		0.0555	
	4	12804.9	7.17	**410.41**		0.0623	
	5	12490.9	5.94	**400.35**		0.0516	
	1	14099.8	5.84	**451.92**		0.0507	
0.50%	2	13876.8	7.04	**444.77**	**401.37**	0.0612	**0.0510**
	3	14061.6	5.98	**450.69**		0.0477	
		12652.9	5.70	**405.54**		0.0477	
		11586.4	5.69	**371.36**		0.0477	

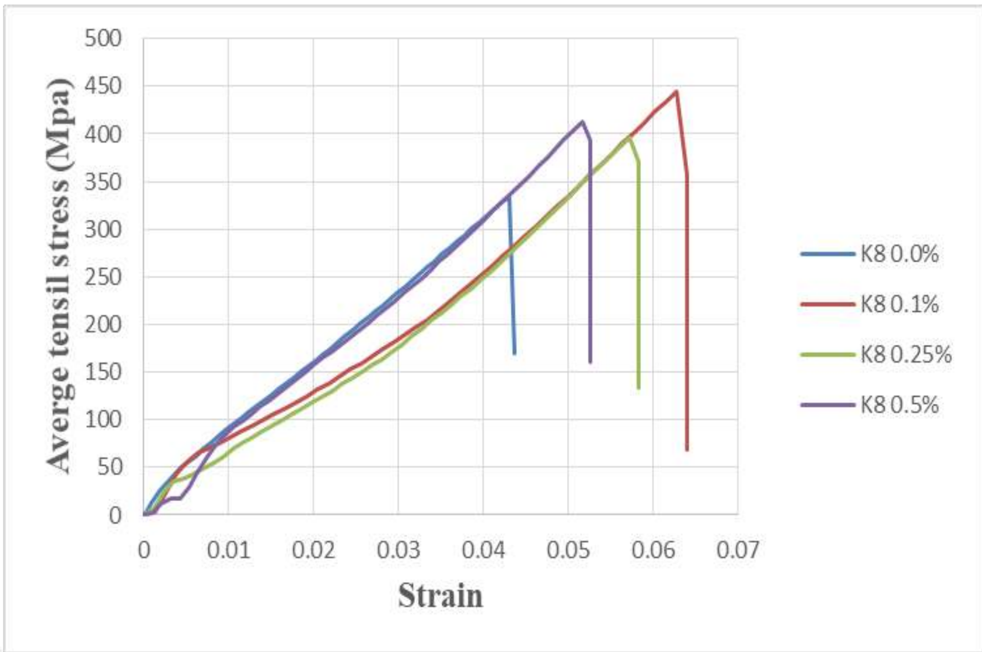


Figure 4.20 Tensile stress-strain curves of the Kevlar fibre reinforced epoxy composite filled with nanographene particle.

From figuer 4.20 have highest value stress and strain at 0.1% graphene 461.96 Mpa , 0.064 for stress and strain respectively.The lawer value of strain at K8 without graphene.

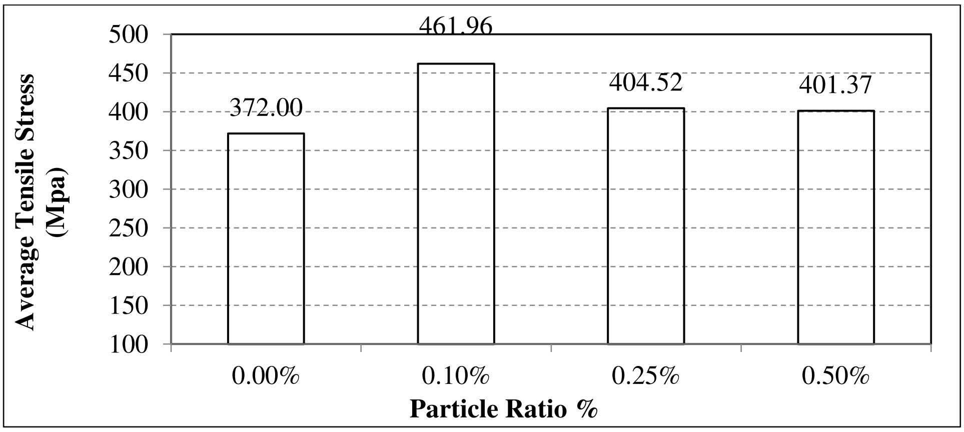


Figure 4.21 Tensile stress- Particle content (wt. %) diagram of the Kevlar fibre reinforced epoxy composite filled with nanographene particle

Compared to tensile strength of neat (without nanographene content) [K8] composite laminate, the increase in tensile strength were 24% at 0.1% nano-graphene filled . the enhancement of tensile strength at lower nanographene contents was more significant and at 0.1 wt.% nanographene content yielded the highest tensile strength. At higher content, the introduction of nanographene was not so effective in enhancement of tensile strength. Probably, it can be attributed to the agglomeration of nanographene particles which resulted with poor adhesion.

4.3.3 Tensile results of C2K4C2

Tensile test results are listed in Table 4.7 for the C2K4C2 hybrid reinforced epoxy composite filled with nanographene

Table 4.7 Tensile characteristic of C2K4C2 with various nanographene ratio

wt%	spesim	m.F	m.Stro	max.T	ave. T	max.t.stri	ave.t.stin
	1	11603	3.39	405.70		0.0294	
0%	3	12936.6	3.80		**429.41**	0.0330	**0.0318**
	3	12436	3.74	434.83		0.0325	
	4	13505.6	3.80			0.0330	
	5	12804.1	3.55	447.70		0.0309	
	1	12593.9	3.96	461.32		0.0344	
0.1%	2	12996.5	4.39	476.06	**458.29**	0.0381	**0.0334**
	3	12092.6	3.75	442.95		0.0326	
	4	12163	3.42	445.53		0.0297	
	5	12710.3	3.69	465.58		0.0321	
	1	11958.8	3.45	**418.14**		0.0300	
0.25%	2	9706.64	2.85	**339.39**	**408.30**	0.0248	**0.0289**
	3	12387.4	3.54	**433.13**		0.0308	
	4	12958.9	3.64	**453.11**		0.0316	
	5	11375.7	3.16	**397.75**		0.0274	
	1	10568.8	3.17	**338.74**		0.0275	
0.50%	2	12238.9	4.34	**409.33**	**399.42**	0.0377	**0.0416**
	3	12442.6	3.49	**416.14**		0.0477	
		12477.5	3.45	**417.31**		0.0477	
		12426	3.40	**415.59**		0.0477	

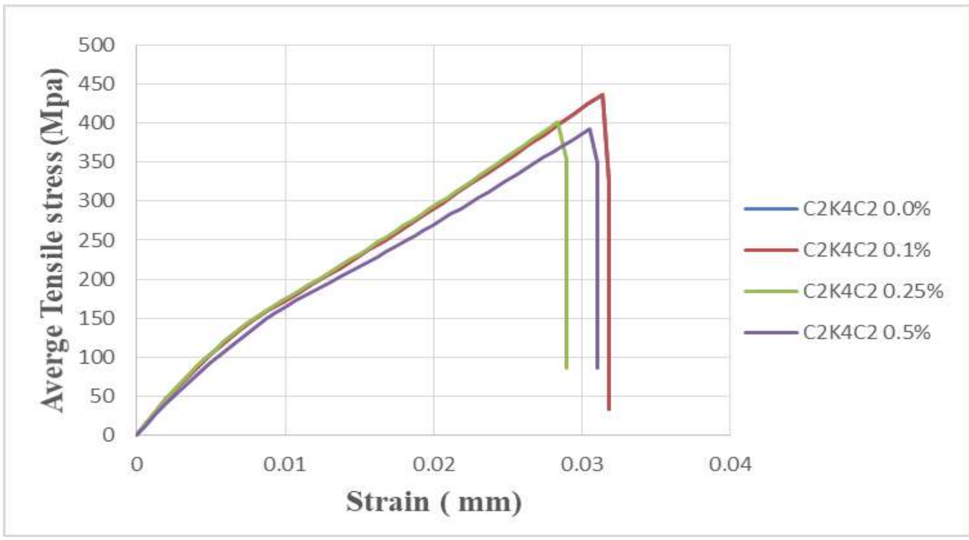


Figure 4.22 Tensile stress-strain curves of the C2K4C2 fiber - reinforced epoxy composite filled with nanographene particle.

From Figure 4.22 showed a rapid tensile strength rise, obtaining the smallest strain and the highest stress among. At 0.1% graphene the best ratio to improve tensile strength.

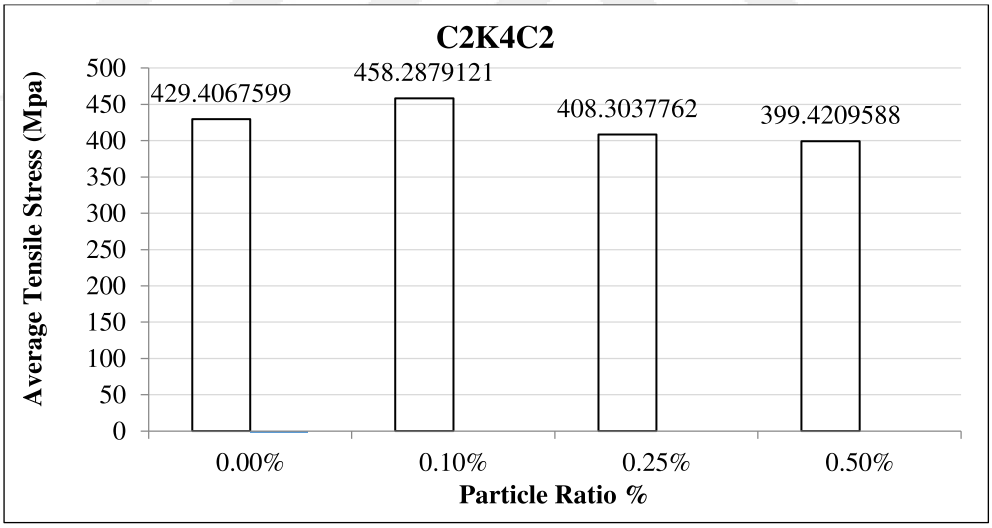


Figure 4.23 Tensile stress- Particle content (wt. %) diagram of the C2K4C2 hybrid epoxy composite filled with nanographene particle

Compared to tensile strength of neat (without nanographene content) [C2K4C2] hybrid composite laminate, the increase in tensile strength were 6.7% at 0.1% nano-graphene filled. The enhancement of tensile strength at lower nanographene contents was more significant and at 0.1 wt. % nanographene content yielded the highest tensile strength. At higher content, the introduction of nanographene was not so effective in enhancement of tensile strength. Probably, it can be attributed to the agglomeration of nanographene particles which resulted with poor adhesion.

4.3.4 Tensile results of K2C4K2

Tensile test results are listed in Table 4.8 for the K2C4K2 hybrid epoxy composite filled with nanographene

Table 4.8 Tensile characteristic of K2C4K2 with various nanographene ratio

wt%	spesim	m.F	m.Stro	max.T	ave. T	max.t.stri	ave.t.stin
	1	12216.5	4.70	427.15		0.0409	
0%	3	12825.4	4.33		**419.07**	0.0377	**0.0372**
	3	11175.6	3.79	390.76		0.0330	
	4	12563.9	3.64	439.30			
	5	12854.8	3.46				
	1	8629.42	2.80	301.73		0.0243	
0.1%	2	8930.4	5.45	581.10	**437.80**	0.0474	**0.0335**
	3	10193.1	3.31			0.0288	
	4	11364.8	3.55	**397.37**			
	5	12590.5	4.57	**440.23**			
	1	12568.1	3.60	**439.44**		0.0313	
0.25%	2	12848.7	3.66	**449.26**	**425.84**	0.0318	**0.0311**
	3	12398.1	3.49	**433.50**		0.0303	
	4	12382.2	3.40	**432.94**			
	5	12082.1	3.24				
	1	12557.6	3.48	**402.49**		0.0302	
0.50%	2	13698.4	3.61	**439.05**	**422.46**	0.0314	**0.0364**
	3	13467.5	3.75	**431.65**		0.0477	
		13896.6	3.84				
		12999.9	4.01	**416.66**			

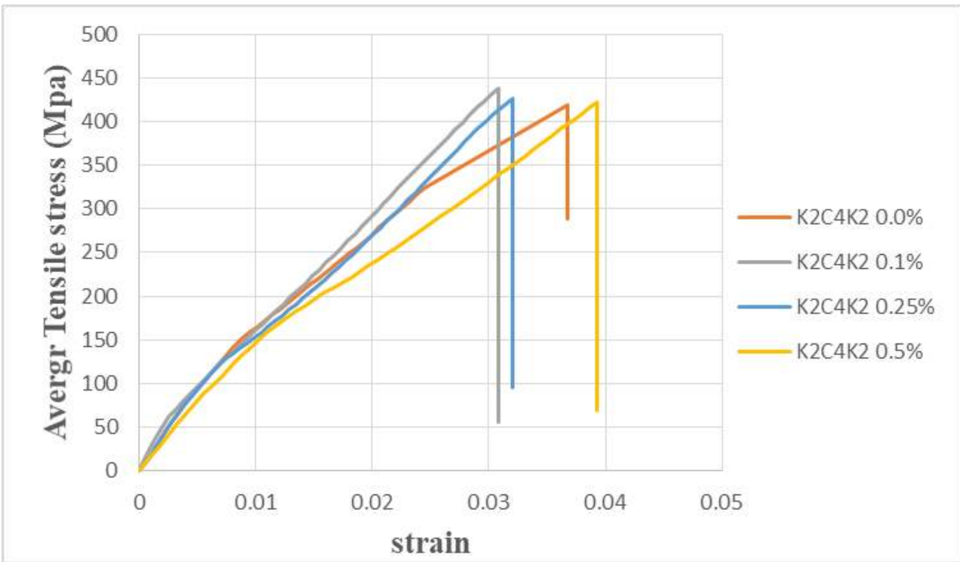


Figure 4.24 Tensile stress-strain curves of the K2C4K2 hybrid epoxy composite filled with nanographene particle.

From Figure 4.24 & Table 4.8 showed the enhancement of tensile strength at lower nanographene contents was more significant and at 0.1 wt.% nanographene content yielded the highest tensile strength. At higher content, the introduction of nanographene was not so effective in enhancement of tensile strength. Probably, it can be attributed to the agglomeration of nanographene particles which resulted with poor adhesion.

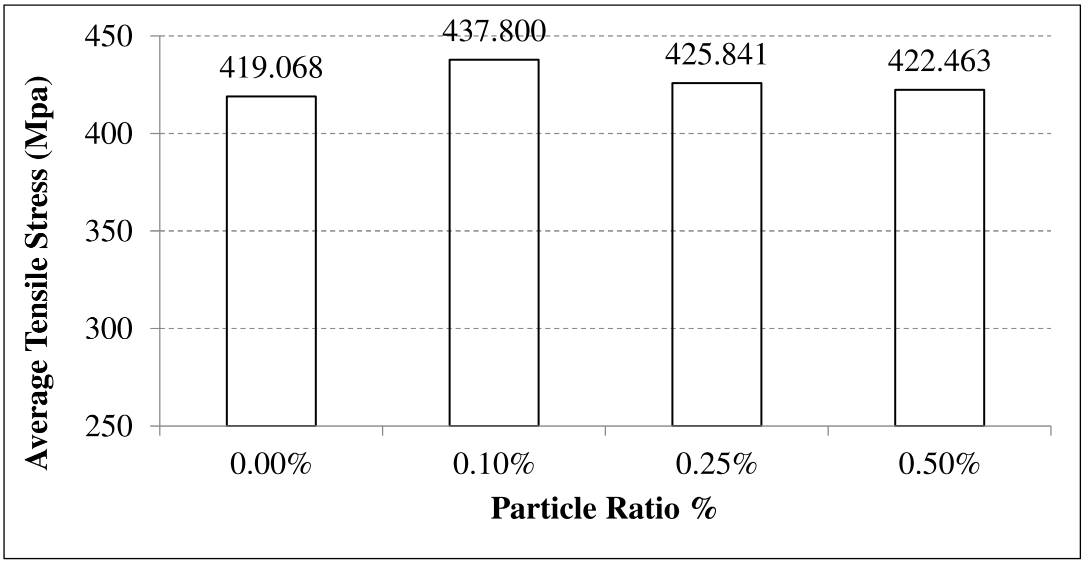


Figure 4.25 Tensile stress- Particle content (wt. %) diagram of the K2C4K2 hybrid epoxy composite filled with nanographene particle

Compared to tensile strength of neat (without nanographene content) [K2C4K2] hybrid composite laminate, the increase in tensile strength were 4.7% at 0.1% nanographene filled. The enhancement of tensile strength at lower nanographene contents was more significant and at 0.1 wt. % nanographene content yielded the highest tensile strength. At higher content, the introduction of nanographene was not so effective in enhancement of tensile strength. Probably, it can be attributed to the agglomeration of nanographene particles which resulted with poor adhesion

4.4 Flexural result

4.4.1 Flexural result of carbon

Flexural test results are listed in Table 4.9 for the carbon fibre epoxy composite filled with nanographene

Table 4.9 Flexural characteristic of carbon fiber with 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%	250.816 247.383 280.38 265.265 247.049	5.451 5.065 5.226 5.062 5.510	484.98 434.88 492.89 466.31 434.29	462.67	50.74 48.38 46.44 41.47 43.98	46.20
	0.1%	336.933 300.46 346.09 292.92 328.45	5.027 4.286 4.825 4.570 4.812	565.68 528.18 608.39 551.43	563.42	36.12 40.31 43.00 41.05 39.13	39.92
	0.25 %	337.219 363.159 330.353 294.352 325.68	5.000 5.434 5.434 5.062 5.099	592.80 669.17 580.73 517.45 546.79	581.39	46.07 45.14 45.15 42.06 39.51	43.59
	0.5%	360.60 311.52 357.58 375.46 385.57	5.277 5.281 6.251 6.000 5.564	605.42 574.01 600.35 630.37 647.34	611.50	46.31 46.15 37.63 42.14 48.16	44.08

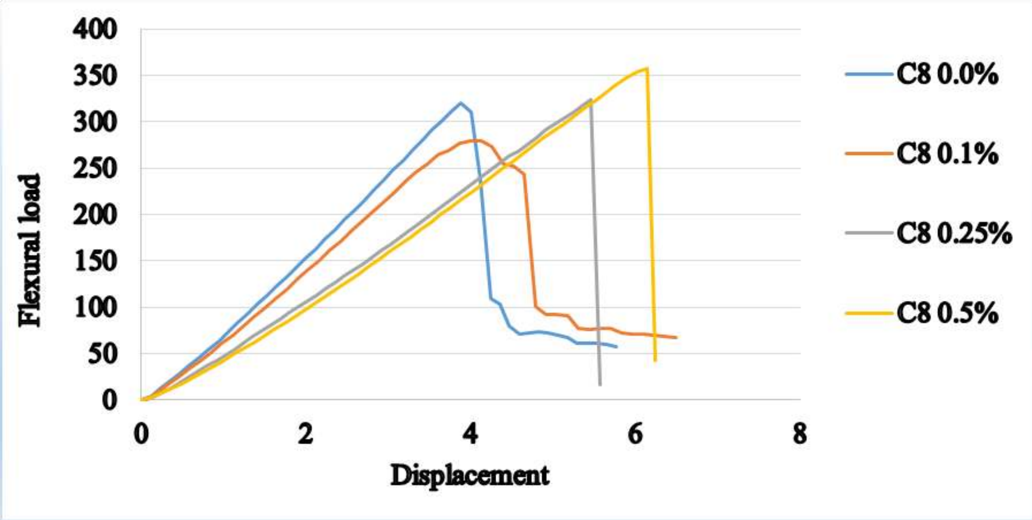


Figure 4.26 Flexural load- Displacement curves of the carbon fiber reinforced epoxy composite filled with nanographene.

The data is plotted in the figure 4.26 and table 4.9 it can be observed significant effect of addition nanographene at 0.5wt% with maximum flexural load and displacement

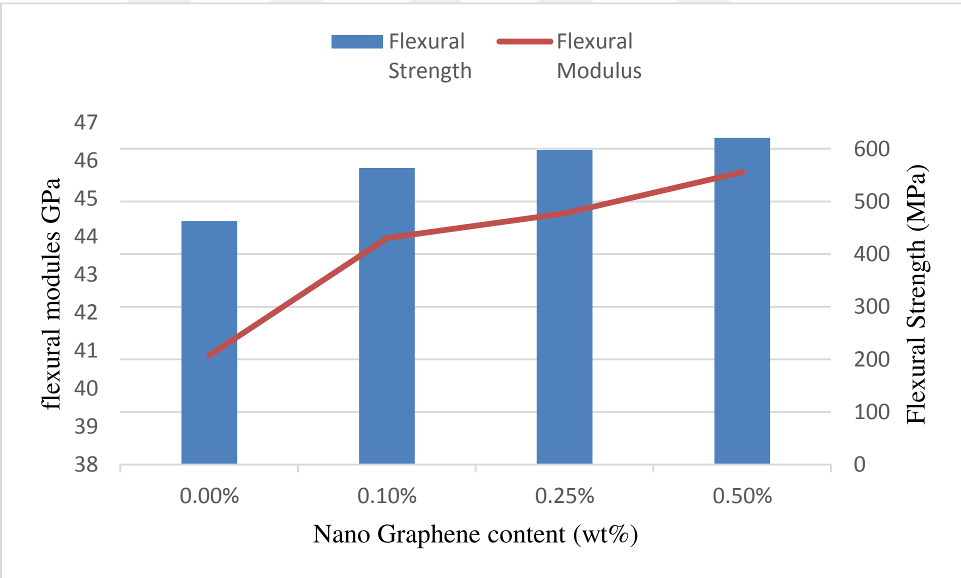


Figure 4.27 Flexural strength and modulus of the carbon fiber reinforced epoxy composite filled with nanographene

Figure 4.27 as a result, the maximum enhancement of flexural strength was obtained at 0.5 wt% content of nanographen of 34.2 %. In addition the flexural modules improvement 11.78%. This indicated that the chemical compatibility and adhesion strength between nanographene particles and epoxy/carbon fiber was optimum at this content. Similar too like regions have been observed by Ávila et al [79] who they used epoxy composite with carbon fiber modified by graphene

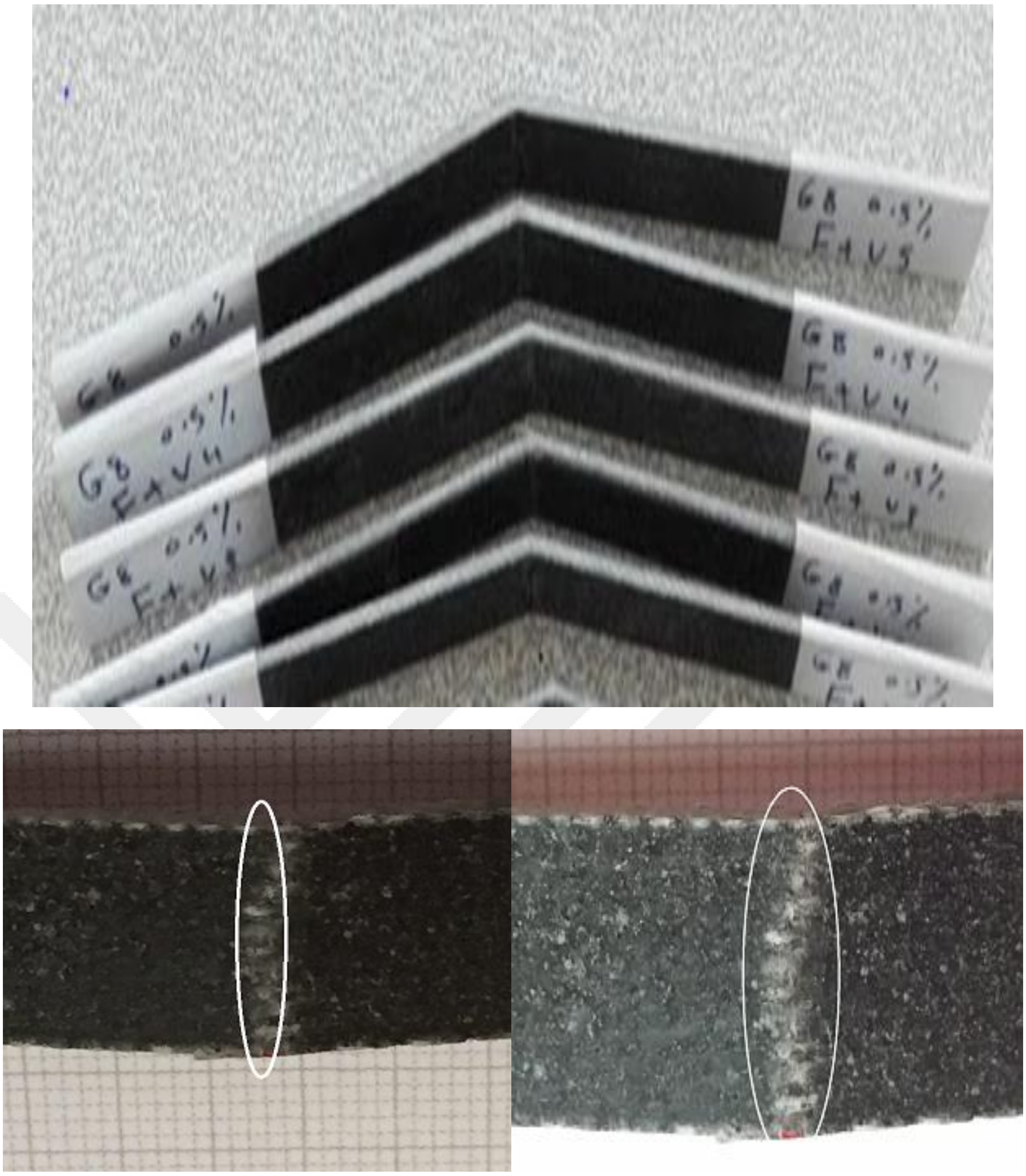


Figure 4.28 Flexural samples carbon fibre 0.5% graphene after failure

Figure 4.28 Flexural samples carbon fiber 0.5% graphene after failure showed the failure occurred without pullout of fiber.

4.4.2 Flexural result of Kevlar

Flexural test results are listed in Table 4.10 for the Kevlar fiber epoxy composite filled with nanographene

Table 4.10 Flexural characteristic of Kevlar fiber with nanographene particles

Specimen	Particle ratio (Wt. %)	Force(N)	stroke	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
K8	0.0%	153.8277 178.0033 161.1233 221.3478 176.0483	17.2646 18.87207 16.27156 18.66808 19.34907	242.25 280.32 253.74 277.24	263.39	20.88 20.87 21.94 21.27	21.24
	0.1%	165.7486 195.551 149.393 199.843 181.246	22.22258 14.3616 18.15057 14.36107 17.26259	261.02 307.95 235.26 285.43	272.42	17.37 29.16 19.68 20.20	21.60
	0.25%	145.102 201.6068 180.292 141.192 149.536	18.33609 16.11257 19.55409 19.09709 18.6071	326.59 292.06 242.24	286.96	18.67 29.38 32.07 18.02 16.46	22.92
	0.5%	228.167 200.558 183.106 174.475	13.56607 11.98957 14.90758 15.85808	359.32 375.87 343.17 326.99	351.34	44.59 50.78 37.98 36.43	42.45

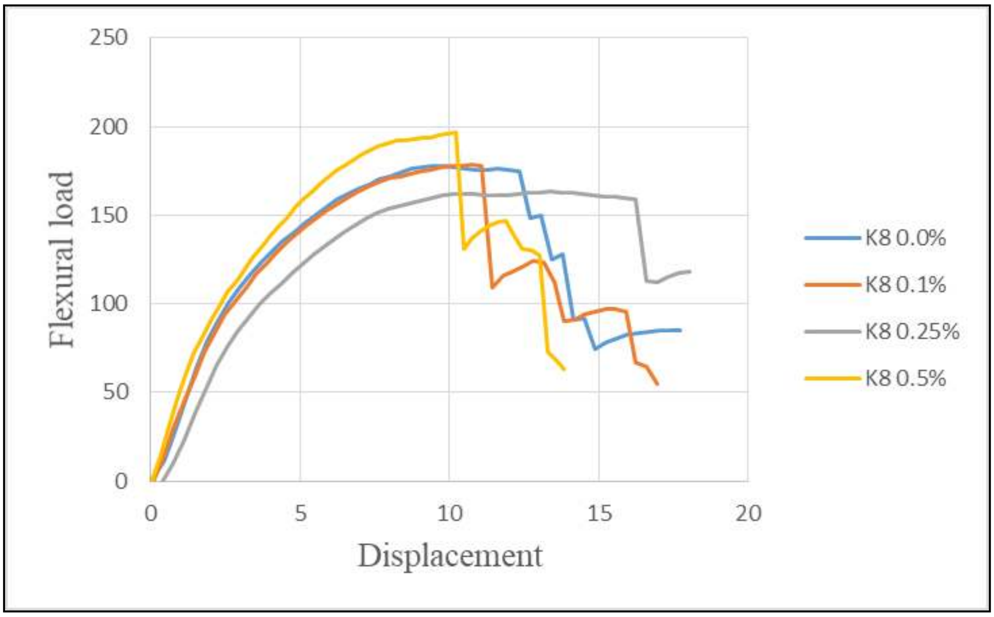


Figure 4.29 Flexural load- Displacement curves of the Kevlar fiber reinforced epoxy composite filled with nanographene.

The data in Table 4.10 is plotted the Figure 4.29 it can be observed significant effect of addition nanographene at 0.5wt% with maximum flexural load and displacement

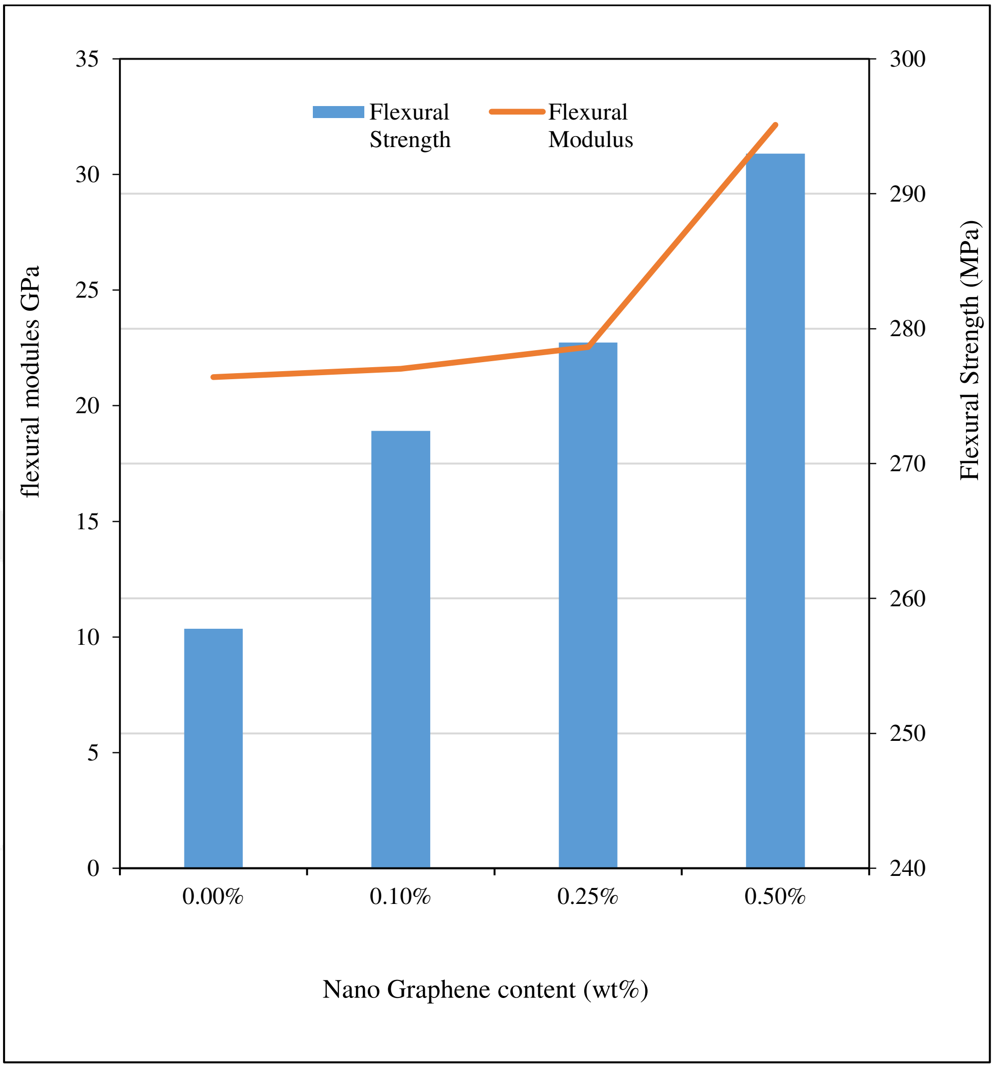


Figure 4.30 Flexural strength and modulus of the Kevlar fiber reinforced epoxy composite filled with nanographene

Figure 4.30 as a result, the maximum enhancement of flexural strength was obtained at 0.5 wt% content of nanographen of 13.7 %. In addition the flexural modules improvement 51.34%. This indicated that the chemical compatibility and adhesion strength between nanographene particles and epoxy/ Kevlar fiber was optimum at this content. Similar too like regions have been observed by Ávila et al [79].

4.4.3 Flexural result of C2K4C2

Flexural test results are listed in Table 4.11 for the C2K4C2 hybrid composite filled with nanographene

Table 4.11 Flexural characteristic of C2K4C2 fiber with nanographene particles

	Particle ratio (Wt. %)	Force(N)	stroke	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
C2K4C2	0.0%	338.244 301.361 334.597 310.612 240.755	7.820073 8.526573 13.46859 11.36207 10.65859	445.89 517.73 413.61	459.07	38.28 34.38 32.57 31.12	34.09
	0.1%	300.551 253.868 224.114 319.29 204.182	10.89309 8.714073 7.707573 9.004094 6.619594	516.34 436.14 548.53	500.33	17.74 39.24 36.70 48.81	35.62
	0.25%	204.182 248.718 221.109 237.417 238.705	6.588094 8.266084 6.246604 9.460073 6.248083	335.53 408.71 363.34 390.14 392.26	378.00	34.59 34.73 35.40 37.55 38.78	36.21
	0.5%	266.314 257.301 191.641 177.05	7.009073 10.18258 7.628573 7.328583	428.32 413.82 308.22 284.75	358.78	38.85 30.58 39.08 41.43	48.37

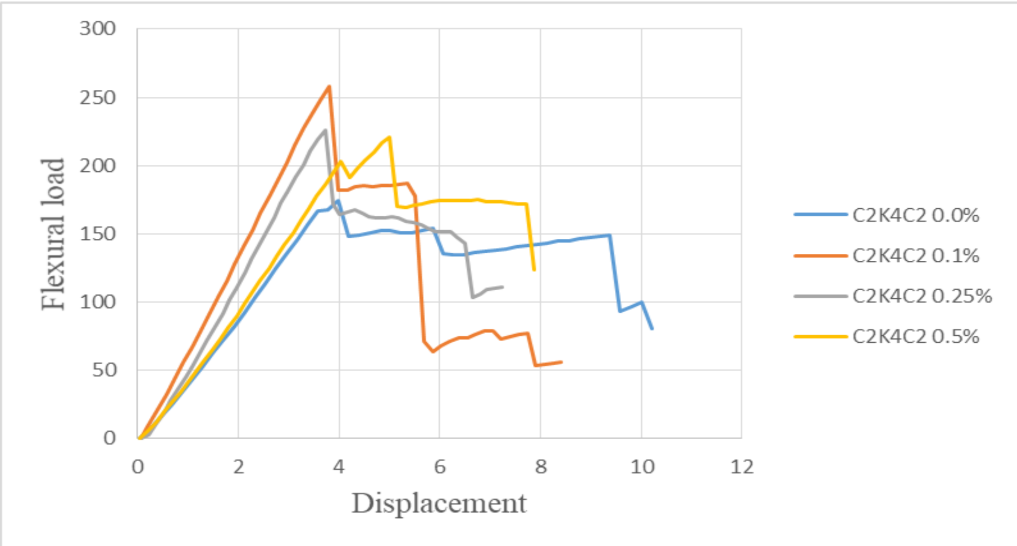


Figure 4.31 Flexural load- Displacement curves of the C2K4C2 hybrid epoxy composite filled with nanographene

The data is plotted in the Figure 4.31 it can be observed significant effect of addition nanographene at 0.1 wt% with maximum flexural load and displacement

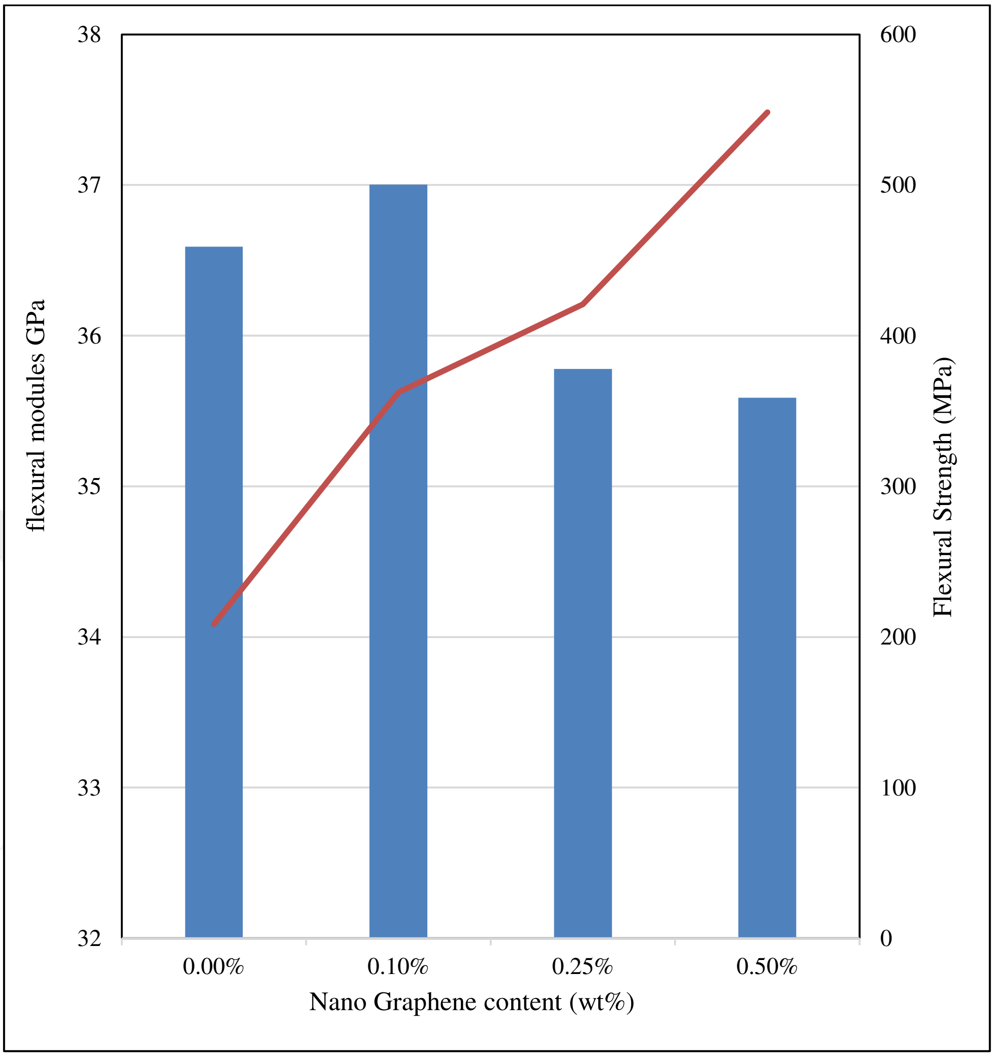


Figure 4.32 Flexural strength and modulus of the C2K4C2 hybrid epoxy composite filled with nanographene

Figure 4.32 as a result, the maximum enhancement of flexural strength was obtained at 0.1 wt% content of nanographen of 9%. In contrary the flexural modules improvement at 0.5% graphene 9.97%. This indicated that the chemical compatibility and adhesion strength between nanographene particles and epoxy/ C2K4C2 fiber was optimum at this content.

4.4.4 Flexural result of k2C4K2

Flexural test results are listed in Table 4.12 for the k2C4K2 hybrid composite filled with nanographene

Table 4.12 Flexural characteristic of k2C4K2 fiber with nanographene particles

Specimen	Particle ratio (Wt. %)	Force(N)	Flexural Strength (MPa)	Average Flexural Strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
k2C4K2	0.0%	228.31 227.928 201.082 216.532 224.924	392.23 391.57 345.45 371.99 386.41	377.53	25.06 22.36 23.51 22.82 22.96	23.34
	0.1%	272.274 260.88 268.65 251.25 288.15	467.76 448.18 461.53 431.63 495.04	460.83	17.35 19.06 20.62 18.88 18.80	18.94
	0.25%	270.99 270.61 260.83 236.89 255.25	445.31 444.68 428.61 389.28 419.45	425.47	19.19 20.27 21.18 23.52 19.27	20.68
	0.5%	248.81 266.84 265.50 227.36 227.64	400.17 429.16 427.01 365.66 366.12	397.62	18.82 18.32 19.26 20.80 19.80	19.40

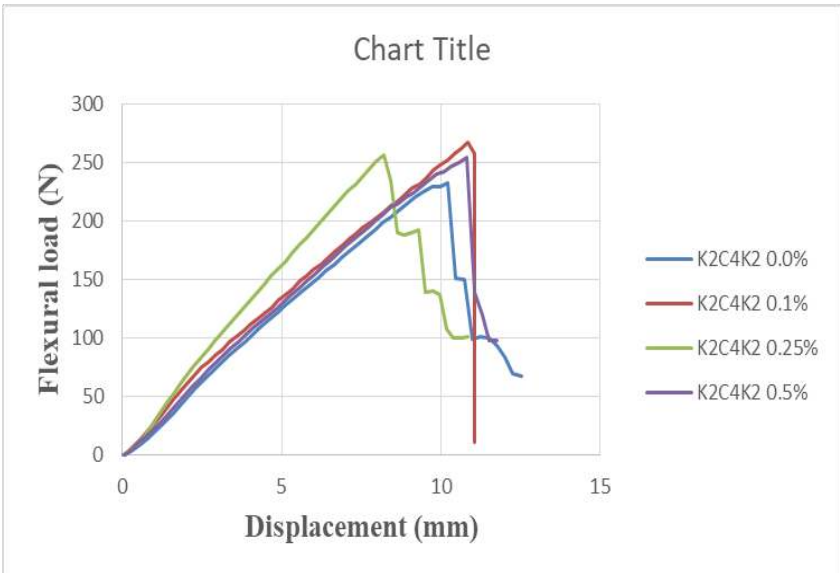


Figure 4.33 Flexural load- Displacement curves of the K2C4K2 hybrid epoxy composite filled with nanographene

The data is plotted in the Figure 4.33 and it can be observed significant effect of addition nanographene at 0.1 wt% with maximum flexural load and displacement. This indicated that the chemical compatibility and adhesion strength between nanographene particles and epoxy/ C2K4C2 fiber was optimum at this content.

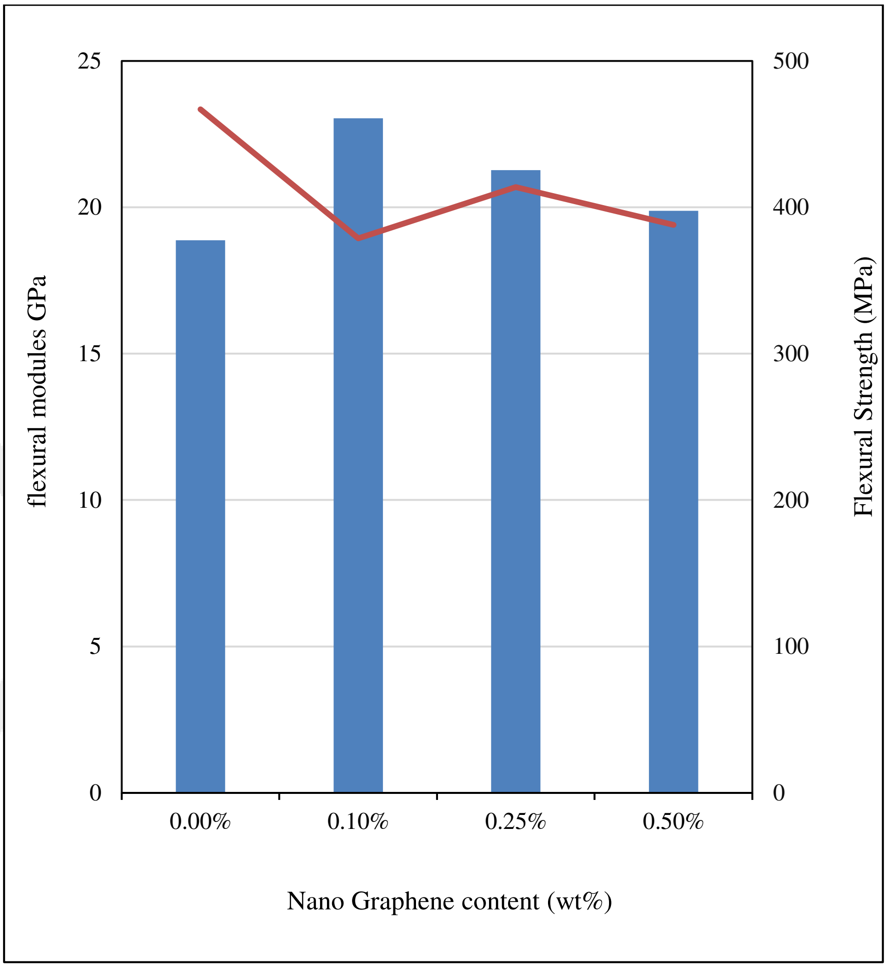


Figure 4.34 Flexural strength and modulus of the K2C4K2 hybrid epoxy composite filled with nanographene

Figure 4.35 as a result, the maximum enhancement of flexural strength was obtained at 0.1 wt% content of nanographen of 22.1%. In contrary the flexural modules improvement at 0.0% without graphene

4.5 Impact Result

Absorbed energy by hybrid and non-hybrid composite systems was evaluated at fracture point of samples through Charpy impact test. The carbon/epoxy and Kevlar/epoxy non-hybrid composite laminates were tested and compared with the hybrid ones to show the benefit of hybridization technique.

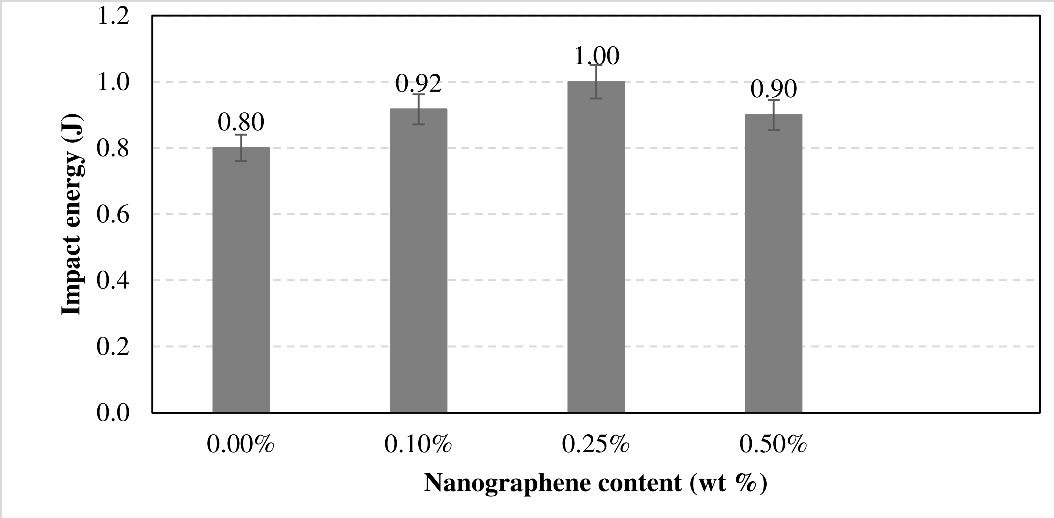


Figure 4.35 Impact Energy of [C8] Flatwise Samples with Respect to GNPs ratio

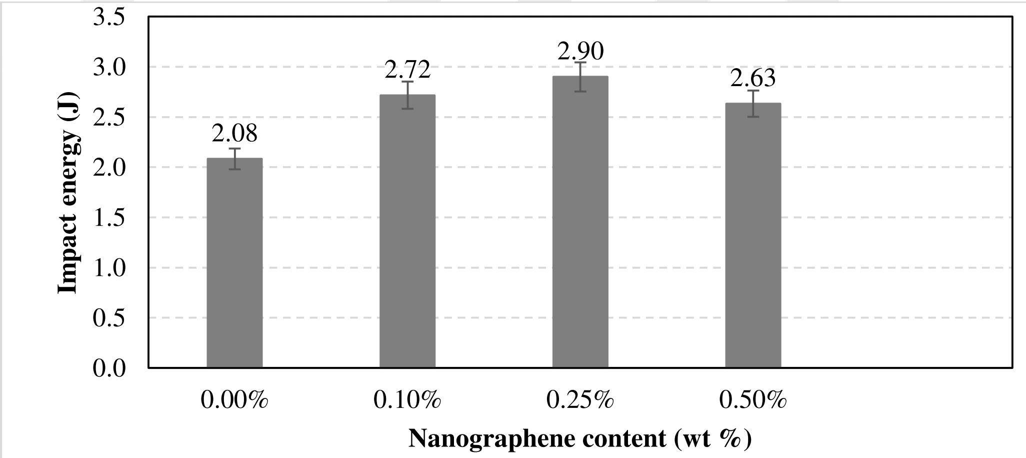


Figure 4.36 Impact Energy of [C2K4C2] Flatwise Samples with Respect to GNPs Content

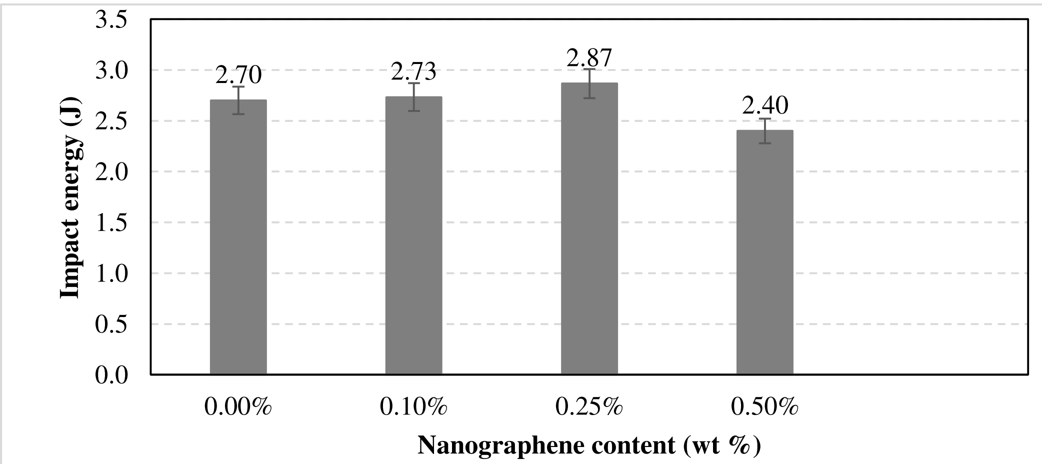


Figure 4.37 Impact Energy of [K2C4K2] Flatwise Samples with Respect to GNPs Content

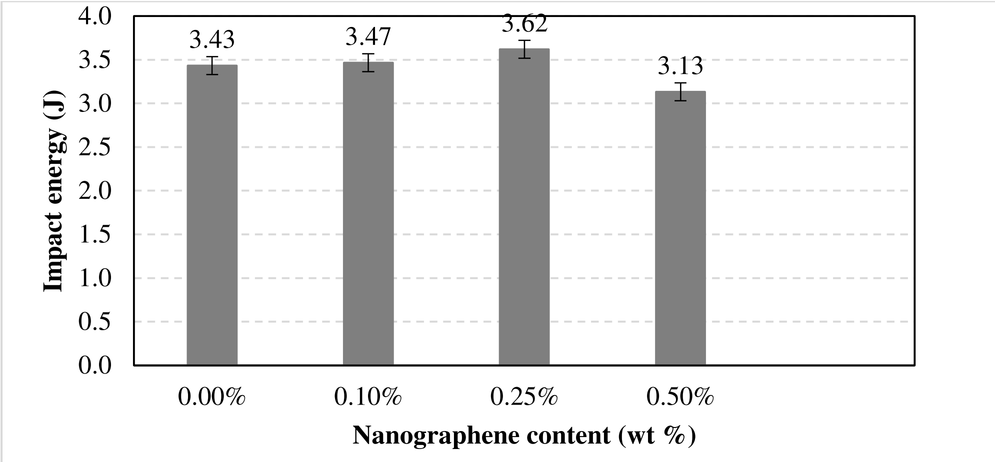


Figure 4.38 Impact Energy of [K8] Flatwise Samples with Respect to GNPs Content

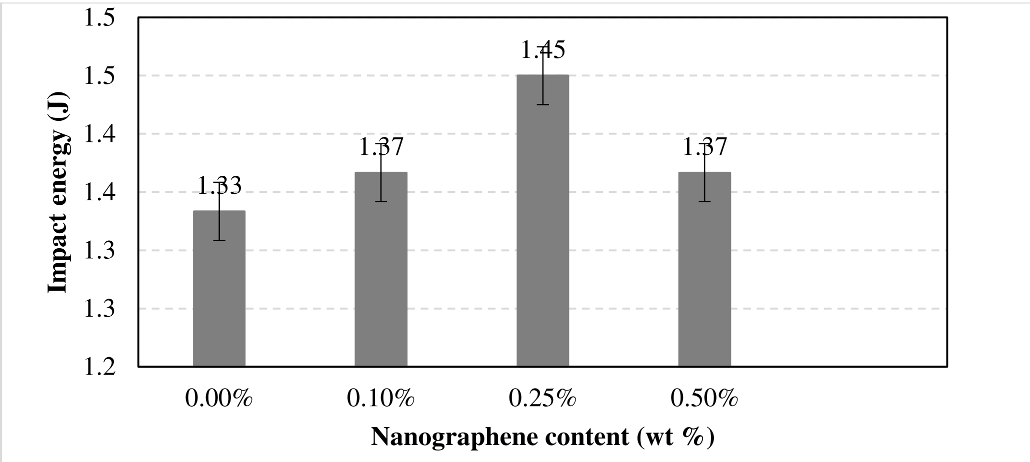


Figure 4.39 Impact Energy of [C8] Edgewise Samples with Respect to GNPs Content

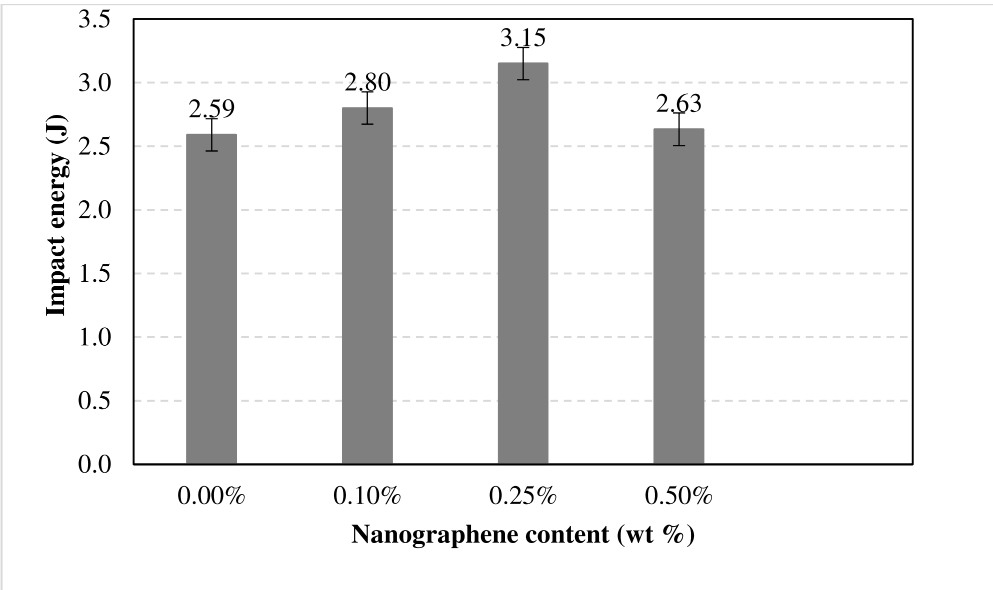


Figure 4.40 Impact Energy of [C2K4C2] Edgewise Samples with Respect to GNPs Content

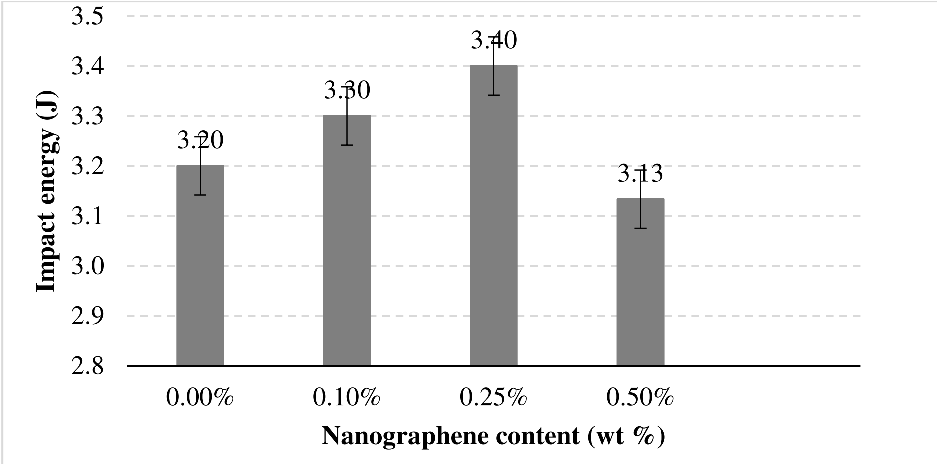


Figure 4.41 Impact Energy of [K2C4K2] Edgewise Samples with Respect to GNPs Content

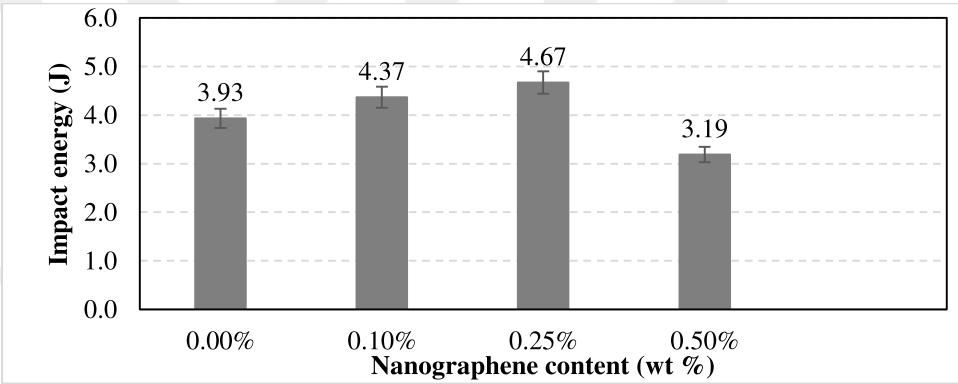
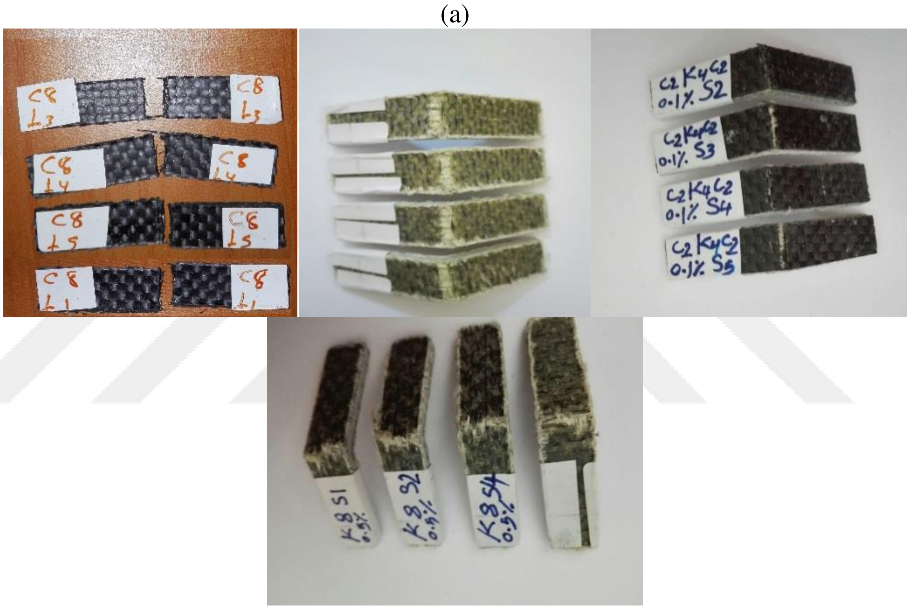


Figure 4.42 Impact Energy of [K8] Edgewise Samples with Respect to GNPs Content

The Kevlar/epoxy composite produced an absorbed energy 328.75% higher than that of the carbon/epoxy composite (3.43 with respect to 0.80 J) in case of flatwise test and 195.48% greater than that of the carbon/epoxy composite (3.93 with respect to 1.33 J) in case of edgewise test. The high flexibility and strength of Kevlar fibers could be the reasons behind the high impact strength of Kevlar composites compared to carbon composites which showed small resistance to impact load due to the brittle structure. The experimental analysis of the hybrid composites under flatwise and edgewise impact loads revealed that those hybrid systems absorbed energy more than the carbon/epoxy laminates and less than the Kevlar/epoxy laminates. [K2C4K2] hybrid laminate has shown impact energy higher than that of [C2K4C2] hybrid laminate by 29.8% and 23.55% for flatwise and edgewise cases, respectively. Thus, the benefit of hybridization was quite clear and replacing some carbon fiber layers by Kevlar fiber has presented better properties based impact strength of carbon/ epoxy composites. Beside hybridization technique, use of fillers was adopted in the present study to obtain additional improve in impact resistance of the hybrid and non-hybrid composite systems. Different weight ratios of GNPs were added into epoxy resin matrix in order to show their effects on the impact resistance of laminates. The absorbed impact energy values of composite samples under flatwise impact test are shown in Figures 4.32 to 4.35 and Figures 4.36 to 4.39 illustrate the absorbed impact energy values of the composite samples under edgewise impact test. All tests were performed at room temperature with a constant impact load of 15 J. It was found that absorbed energy values gradually increased with the addition of GNPs up to 0.25 wt. % and the highest improving of impact energy was determined at 0.25 wt. %. After that more addition of GNPs to 0.5wt. % had reduced the absorbed energy values of the composite test samples and most probable reason for this is particle agglomeration. Homogenous dispersion is difficult because the large surface area of the particulates induces attractive forces between them, which lead to excessive agglomeration Zaldivar et al., [93]. At 0.5 wt. % of GNPs, absorbed energy have showed values higher than those of control samples of neat matrices for the case of composite systems of [C8] and [C2K4C2] (Figures 4.35, 4.36, 4.39 and 4.40) and lower than those of the control samples for the case of composites of [K8] and [K2C4K2] (Figures 4.37, 4.38, 4.41 and 4.42). The improved impact strength can be interpreted by the high adhesion between the fibers and matrices with the presence of GNPs, providing high capacity of energy absorption and improved characteristics in comparison with samples of neat matrices. Thus, the stress transfer across glass-carbon-epoxy system has become more efficient with the inclusion of GNPs and results in higher resistance to impact loads Varga et al [94]. Localized delamination with full fiber breakages and separation at the impacted area was the major damage mechanism of all samples reinforced by GNPs. 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 at 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.

(a)



(b)

Figure 4.43 Failure Mode of Kevlar-Carbon Composites; a) Notched Specimens, b) Un-notched Specimens.

Figure 4.43 shows the failure modes of composite samples considered in this study. For edgewise impact test, regardless of graphene content, all composite samples containing Kevlar fibers were failed due to severe crack starts at notch point and grows up to impacted edge which resulted in separation along crack path except small part still connected in fiber pull-out mode. While for the composite samples of carbon fiber only, the separation took place completely without any fiber pull-out. For flatwise impact test, regardless of graphene content also, the composites of pure carbon fiber failed as the same way that the notched samples failed. Whereas, the composites containing Kevlar and Kevlar-carbon fibers failed in local damage with moderate fiber pull-out at the back side (un-impacted surface) if Kevlar fiber was considered or with moderate fiber breakage at the back side if carbon fiber was considered.

CHAPTER 5

CONCLUSION

5.1 Introduction

In this study, the tensile, vibration, flexural and low velocity impact behavior of Kevlar/carbon composite laminate consisting of an epoxy matrix with nanographene were investigated. The tensile and flexural test are determined by using a 300 kN Shimadzu AG-X series universal testing machine. The impact behavior of each specimen were determined by performing Charpy impact test. The vibration test was determined by vibration test set-up device. The Kevlar/carbon hybrid fiber reinforced composites laminates were fabricated using hand layup technique. The hybrid composite laminates were prepared with different stacking configurations. The following conclusions can be highlighted from the study.

5.2 Conclusion

- The best result of vibration damping ratio for (C_8, K8, $C_2K_4C_2$, and $K_2C_4K_2$) are (0.101, 084, 0.089 and 0.081) with enhancement (53 %, 61.54 %, 81.63 % and 35 %) compared with pure laminate for each configuration respectively that occurred with 0.1% wt. nanographene.
- The best result of tensile stress for (C_8, K8, $C_2K_4C_2$, and $K_2C_4K_2$) are (569.34, 461.96, 458.29 and 437.80) MPa with enhancement (4 %, 24.18 %, 6.72 % and 4.45 %) compared with pure laminate for each configuration respectively that occurred with 0.1% wt. nanographene.
- The best result of flexural strength for (C_8 and K8,) are (620.87 and 293) MPa with enhancement (34.19 % and 13.68 %) compared with pure laminate for each configuration respectively that occurred with 0.5 % wt. nanographene.
- The best result of flexural modulus for (C_8 and K8,) are (45.69 and 32.15) GPa with enhancement (11.79 % and 51.36 %) compared with pure laminate for each configuration respectively that occurred with 0.5 % wt. nanographene.

- The best result of flexural strength for ($C_2K_4C_2$ and $K_2C_4K_2$) are (500.33 and 460.83) MPa with enhancement (9 % and 22.06 %) compared with pure laminate for each configuration respectively that occurred with 0.1 % wt. nanographene.
- The best result of impact energy of flatwise samples for (C_8, K8, $C_2K_4C_2$, and $K_2C_4K_2$) are (1, 3.62, 2.9, and 2.87) J with enhancement (25 %, 5.54 %, 39.42 % and 6.29 %) compared with pure laminate for each configuration respectively that occurred with 0.25 % wt. nanographene.
- The best result of impact energy of edgewise samples for (C_8, K8, $C_2K_4C_2$, and $K_2C_4K_2$) are (1.45, 4.67, 3.15, and 3.40) J with enhancement (9.02 %, 18.83 %, 21.62 % and 6.25 %) compared with pure laminate for each configuration respectively that occurred with 0.25 % wt. nanographene.

5.3 Recommendation

- Other kind of processes can be applied to mix up nanoparticles with resin in order to investigate how these new processes can affect the mixture in term of optimal scattering.
- Used two methods together hand lay-up and vacuum.

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