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M.Sc. in Mechanical Engineering

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**UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES**

**VIBRATION, DAMPING PROPERTY, TENSILE AND
FLEXURAL BEHAVIOR OF KEVLAR-
CARBON/EPOXY/NANOCLAY COMPOSITES**

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IN
MECHANICAL ENGINEERING**

**BY
MAJEED ABBAS ALWAN**

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Vibration, Damping Property, Tensile and Flexural Behavior of Kevlar-Carbon/Epoxy/Nano Clay Composites

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By

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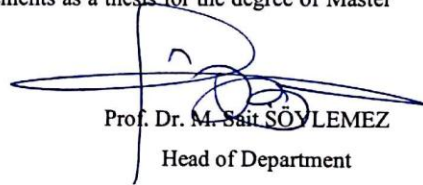
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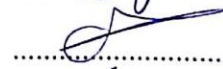
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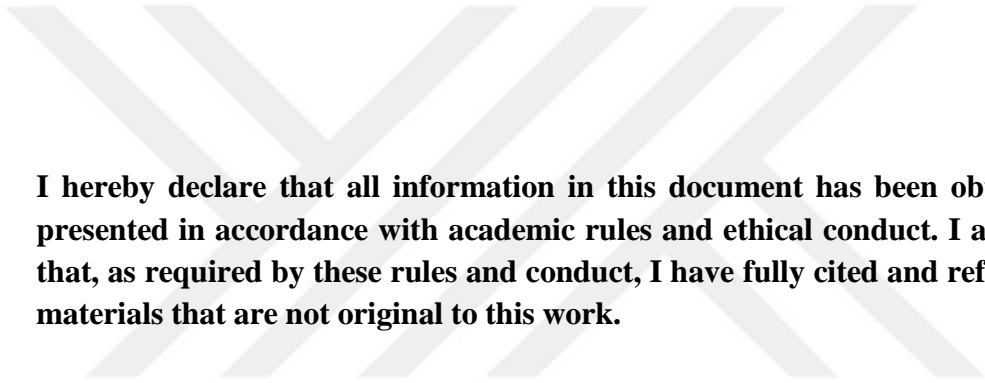


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Majeed Abbas ALWAN

ABSTRACT

VIBRATION, DAMPING PROPERTY, TENSILE AND FLEXURAL BEHAVIOR OF KEVLAR-CARBON/EPOXY/NANOCLAY COMPOSITES

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The present study investigated the effect of Nano clay additives on the tensile, flexural, vibration and damping properties of the intraply carbon/Kevlar fiber reinforced epoxy (CKFRE) composites. Six Nano-clay particle contents of 1, 2, 4, 6, 8 and 10 wt% were used to produce the composite laminates. The specimens were tested according to ASTM standards. The results indicated that the tensile and flexural strength improved by 13.1 % and 28.5% at Nano-clay contents of 1 wt% and 2 wt%, respectively, compared to unmodified CKFRE composite. Experimental modal analysis was used to determine a vibration properties of the produced composites.

Half power band-width method was applied to evaluate damping responses of first natural frequency mode of the composite samples. The inclusion of Nano-clay particles in the CKFRE laminate exhibited increase in natural frequency, damping ratio and storage modulus. Hence, the vibration modulus was increased from 8.72 GPa for unfilled CKRE to reach 14.80 GPa with Nano clay content of 4.0%, with maximum increment of 70%.

Keywords: Nano-clay , carbon/Kevlar fiber, epoxy, tensile, flexural, vibration.

ÖZET

KEVLAR-KARBON/EPOKSİ/NANOKİL KOMPOZİTLERİN TİTREŞİM, SÖNÜM ÖZELLİĞİ İLE ÇEKME VE EĞİLME DAVRANIŞI

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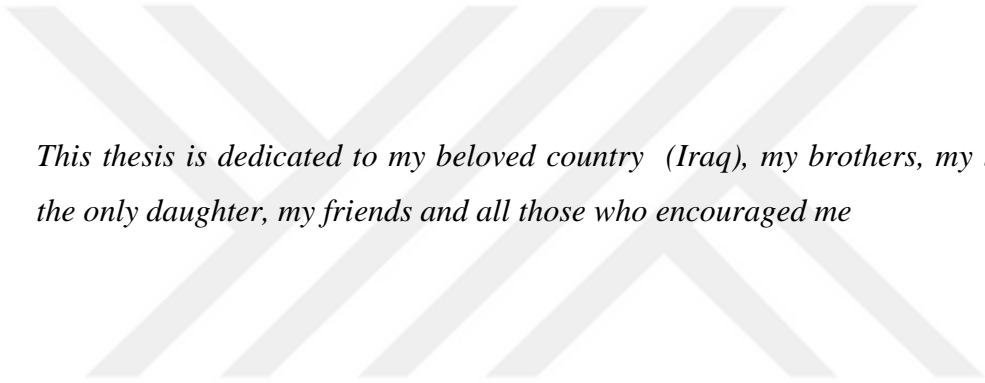
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Bu çalışmada nano kil katkısının iç içe örülmüş karbon/Kevlar elyaf takviyeli epoksi kompozitlerin (CKFRE) çekme, eğilme, titreşim ve sönümlenme özelliklerine olan etkileri araştırıldı. Ağırlıkça altı farklı nano-kil oran (%1, %2, %4, %6, %8 ve %10) içeriğine sahip hibrit kompozit plakalar üretildi. Numuneler, ASTM standartlarına göre test edildi. Sonuçlar, nano kil katkısız CKFRE kompozit plakaya kıyasla, çekme ve eğilme mukavemetinin, sırasıyla, ağırlıkça% 1 ve ağırlıkça% 2 nano-kil içeriklerinde % 13,1 ve %28,5 oranında iyileşme sağladığını gösterdi. Deneysel modal analiz ile üretilen kompozitlerin titreşim özellikleri belirlendi.

Sönümlenme tepkilerini değerlendirmek için yarım güç bant genişliği yöntemi (Half-Power Bandwidth Method) kullanıldı. Kompozit numunelerin doğal frekans modları CKFRE kompozit plaka içerisine nano-kil parçacıklarının dahil edilmesi, doğal frekans, sönüm oranı ve depolama modülünde artış sergiledi. Titreşim modülü ağırlıkça %4 nano kil katkısı ile %70 artış gösterdi. Katkısız CKRE kompozitin titreşim modülü 8,80 GPa'dan 14,80 GPa'ya yükseldi.

Anahtar Kelimeler: Nano-kil, karbon/Kevlar elyaf, epoksi, çekme, eğilme, titreşim.



*This thesis is dedicated to my beloved country (Iraq), my brothers, my lovely wife,
the only daughter, my friends and all those who encouraged me*

Majeed Abbas Alwan

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

A high specific stiffness, strength in addition to ease of production and low cost had been exhibited by fiber reinforced polymer (FRP) composite materials as compared to homogeneous metal alloy. Over the recent years, the wide interest generated these materials in various engineering fields, especially in automobile, pipeline, renewable energy, aerospace and water turbine applications [1]. For advanced composite, the widely-used matrix as thermosetting polymer is epoxy resin due to materials have its sensible stiffness, dimensional stability and chemical resistance properties [2]. In addition, a composite material is a material combination of 2 or more materials that are combined with macroscopic level. Composites have two constituents as (a) Matrix Material (b) Reinforcing Material [3].

Composite materials, principally represent a development of the science and technology of materials, since they blend the higher properties of many materials resulting it's one in every of the foremost vital technology which will modify them to understand the physical and mechanical properties of outstanding. The study of composites could be a sort of philosophy of materials, design aiming at reinforcing every of the composition of the materials itself and its structure, so resulting in a joining and interactive process. It's each a science and a technology, demanding a strict interaction between completely different study subjects, like mechanical processes and operations of all types, design, production. The speed of technological development leads to an in-progress demand for new and developed materials, and has been a higher force for the progress of composite materials. Till the first twentieth century, no essential progress was detected in composite materials. Attributable to the heavy value of developing composites, cheaper and additional resistant materials were utilized.

Recently, fiber reinforced chemical compound matrix composite materials, which may be rendered for a special space or use, began utilizing them progressively [4].

Polymer composite materials have made wide benefit in many engineering fields, especially in aerospace applications, as a result of these materials show high special power and hardness once it compared with homogeneous metal alloy [5].

Due to the easiness of production and least value, polymer composite materials show complete various enforcement, for example helicopter rotor blades, pipeline carrying sand thin liquid mixture in petroleum refining [6].

High-speed composites and, water turbine engine blades, and water turbines [7]. As materials are added to polymers are blended and have the flexibility to improve of mechanical characteristic. Nano clay is the most reasonable materials that have shown sensible expected consequence in polymers. Nano clay composed of montmorillonite mineral deposits that is famed by including platelet structure with an average dimension of (1 μm thick and 70 - 150) μm wide. Nano clays square measure renowned to lift characteristic of the many polymers like nylon 6, EVA, epoxy, improving the chemical, abrasion and dimensional stability in injection shaped products [8].

Epoxy matrix not possible utilized alone for superior structural applications due to its restricted mechanical properties. For this aim, a restricted range of researchers has investigated the Nanoparticles impacts on the mechanical properties of Nano-hybrid fiber reinforced composites that is one of the objectives of this study.

1.2 Definitions of Hybrid Composite

Latest developed technology and the aim for new applications of composites generate an enormous need of new material. So much of the well- established materials this metal, ceramics or plastics cannot displace all technological needs of the applications.

Discoverers and engineers have known early on that mixture of materials could display better characters and could be compared with their pure duplicate for instance, the set of composites that are manufactured by the integration of a basic structural material inside a second substance, the matrix.

Generally the incorporated systems are in the form of particles, whiskers, fibers lamellae, or a mesh. Resulting therefrom, it could be a material shown improved mechanical properties and a well-known clue is in particles filled fiber- strengthened polymer. In these days, there are regularly utilized for lightweight materials with developed mechanical characteristic, for instance, in the structure of composites of all kinds or sports tools. The constructional blocks in those materials that are combined into the matrix are mainly in particle into nature and display a size range from the lower micrometer to the millimeter range and because of that it is usually hidden to the eye because of the heterogeneous composition.

The term hybrid is of Greek-Latin origin. It is said that hybridization is known like a good method of incorporating of two reinforcements in unified polymeric matrix phase, or the integration of one strengthening in polymer blends so as to yield higher properties like compressive strength, high mechanical strength, thermal stability, stiffness and reduce water absorption properties that can't be realized in typical composite materials. Hybrid composite materials have comprehensive engineering application wherever strength to weight quantitative relation, ease of fabrication and low price requires. Some hybrids of current interest represent tries to minimize the cost of expensive composites containing reinforcements like carbon fiber by incorporating a proportion of cheaper, lower-quality fibers like glass without too seriously reducing the mechanical characteristic of the original composite. In high-technology fields the question of cost is also don't mention by comparison with the benefits of optimizing properties. In aerospace enforcement, in marine, automobile, railways, civil engineering, construction, sport production, etc. This can be attributed to high specific strength & specific hardness of the fiber reinforced composites. A very-known purpose of utilizing hybrids is to utilize the natural toughness of GRP or of Kevlar-fiber-reinforced plastics (KFRP) to offset a brittleness of CFRP typical. From the designer's point of view, the important aspect of utilizing hybrids is that provided there's an appropriate understanding of the underlying mechanisms of stiffening, strengthening and toughening, they permit even closer tailoring of composite properties to suit specific necessities than can be achieved with single-fiber kinds of composites [9].

Hybrid composites incorporate four major types:

- ❖ Interply hybrids, that are composed of plies from two or more various unidirectional composites stacked according to a specific sequence.
- ❖ Intraply hybrids, made of two or more various fibers jumbled in the same ply.
- ❖ Interply-intraply hybrids, in which interply and intraply hybrids are organized according to a given sequence.
- ❖ Super hybrids, which are resin-matrix composite plies arranged according to a certain order [10].

1.3 Particulate Composites

In this kind of composites, micro and Nano size particles can be scattered in the matrix. The particles don't have an effective resistance, good break, but reinforce the hardness of the composite to a limited scope. Particulate Composites have received a lot attention as reinforce materials for polymer as a consequence of its potentially high ratio and unique intercalation characteristics. The least quantity addition of Nano-clay for example into the polymer matrix exhibits sudden properties including reducing gas permeability, improved solvent resistance, being superior in mechanical characteristic and thermal stabilization, and reinforce flame retardant properties [11]. Particle fillers can be large scope utilized to enhance the characteristic of matrix materials, for instance to modify the thermal and electrical conductivities, improve pursuance at elevated temperatures, increase wear, decrease friction and abrasion resistance, improve the mechanical characteristic, increase stiffness and reduction shrinkage [12].

1.3.1 Nanoparticle on the Polymer

Nanoparticle incorporation could be a convenient method to reinforce the mechanical characteristic of polymer matrices. Within a number of previous years' plenteous research has distributed regarding the development of the mechanical properties of Nanoparticle stuffed polymers. For example, Nanoparticle as Nano clay. Add other Nanomaterial's as an example.

Nano clay is one of the best particle that is utilized and is considered one of the multiple functions of clay materials which are widely utilized in many areas. Nano clay has many improvements for a particular application. Polly Nano clay, is one of the well-studied groups of materials. Nano Clay is a material and widespread naturally happening in particles, minerals, of which plate-like montmorillonite it is most common in applications. Montmorillonite of (the content of 1 μm) thick aluminum layer of clay with metal cations and stacked in multi-layer stacks (10) microns in size multilayer stacks.

It has been around this topic, investigation and analysis of the impact of Nano clay for his or her promotion of Kevlar / carbon hybrid and also the statement of his behavior in epoxy matrices were saturated epoxy resin to the present article by direct combining has been getting ready test samples consistent with prevailing standards. The investigation reveals that, found throughout the investigation within the results that the inclusion or add Nano clay in epoxy composite gave spectacular results compared with neat epoxy. Once adding the amount of this material reinforced lots of the mechanical properties.

1.4 Definitions of Tensile and Flexural Strength

Tensile testing is simply called tension testing could be a main materials science. The test results are utilized for the chosen of the materials required for engineering applications like, quality, and guess the reactions of materials under the influence of different kinds of forces. Characteristic, that area unit measured directly by a tensile test are final tensile strength, most elongation and decrease in area. From these measure young's modulus, Poisson's ratio, strength, and strain-stiffness characteristics can be determined. Uniaxial tensile testing is that the more typically utilized for getting the mechanical characteristic of isotropic materials. For anisotropic materials, like composite materials and woven, biaxial tensile testing is needed [13].

Flexural strength, additionally called modulus of rupture, or bend strength, or transverse rupture strength may be a material property, defined because the stress in a very material only before it yields in a flexure test.

The flexural force represents the best stress witnessed within the material at its moment of failure. It's measured in terms of stress, and it has the symbol σ [14].

1.5 Importance of the Study

Carbon fibers are widely known reinforcement substance for their superior characteristics such as the ideal mechanical capacity and modulus of elasticity, low density, and good flame resistance. It makes carbon fiber irreplaceable in wide fields of engineering technology like for automobile, sport equipment, ships, construction, and aircraft. However, carbon fiber composites are rather liable to stress concentration due to the brittleness of carbon fiber. In addition, carbon fiber involves costly production. One way to improve the weakness of carbon- fiber reinforced plastic (CFRP) composite is via replacing some layers of the carbon fiber by ductile fibers such as Kevlar fiber or together (Kevlar-carbon) hybrid as in this study. More durable and less flexural affected materials can be obtained with the use of hybrid composite material. Material distribution in layers, required number of layers to avoid flexural can be determined. In this way, the benefits of hybrid laminated composites can be determined specially for automotive and aircraft industry.

Technological interest in producing lighter and higher quality materials is due to the possible reduction of the costs and thus, consequently, attracts new customers. The composite quality is based on the phases involved and also in the process. Fiber construction in different weft and warp permits a variety of mechanical properties and can be generated for a given part design. Anyway, composite Kevlar/carbon prone as a replacement to stress concentration due to the brittleness of the carbon also carbon involves high production costs. One way to enhance the weakness of Kevlar/carbon (KCFRP) is by adding the Nano clay and can be affected by the flexural of the material and can determine the distribution of the required number of layered materials to avoid flexural layers. In this way, the benefits of hybrid laminated composite identify specifically for the automotive industry and the aircraft industry.

1.6 Outline of the Study

The aim of this thesis is to study the effect of different particle contents of Nano-clay on the tensile, flexural and vibration properties of carbon-Kevlar hybrid composites. Twill 2/2 woven carbon-Kevlar fiber was utilized as reinforced fiber for epoxy matrix CKFRE. Six weight fractions (1% wt, 2% wt, 4% wt, 6% wt , 8% wt and 10% wt) were used for production of laminate composites. Test samples were produced according to ASTM standards.

The study was divided into five main chapters. Chapter 1 contains the introduction of this research work that contains introductory data on the breath of the total study. Chapter 2 contains a literature survey of this study.

As such, it contains the subsequent sections: studies about particle filled composites, effect of hybridization on mechanical characteristic of fiber reinforces composites, effects of hybridization with Kevlar fibers on mechanical and vibration properties, effects of addition of Nano clay on hybrid composites, and importance of this study. Chapter three is methodology section. This chapter gives information about the production of composite plates and determination of their mechanical properties. Chapter four is the discussion of experimental results. This study's fifth chapter is made up of the conclusions reached by this study.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

The impact of fillers on the mechanical properties such as flexural strength, tensile strength and vibration damping of hybrid composite materials are examined via reviewing related studies in this chapter.

Literature survey has been grouped into five areas: describes the Particle-filled Composites 2.2, general mechanical properties of fiber-strengthened composite plates are checked on in section 2.3. Tensile, flexural strength and vibration damping of hybrid composite reinforced by Kevlar fibers explained in section 2.4, studies on the effect of flexural, tensile strength, and damping by adding Nano clay particles in section 2.5. The conclusion of the literature review is assessed in section 2.6.

2.2 Particle-filled Composites

Yasmin et al. [17] observed a great increase in tensile modulus with Nano-clay inclusion of 1-10 weight% within epoxy resin.

Mahesh et al. [18] investigated the effect of the addition of Nano-clay to basalt/epoxy composites on solid particle erosive wear behavior having different impingement angles and velocities. They observed the addition of Nano clay in basalt /epoxy composite increases the corrosion resistance of the composite with the rise in Nano clay content.

Jena et al. [19] investigated the mechanical properties such as tensile strength, flexural modulus, Young's modulus, flexural quality, interlinear shear quality, and micro hardness of glass/epoxy/Nano clay hybrid composites. Nano clay was utilized as an additive in epoxy resin with 0-6wt% ratios. Empirical studies showed that

mechanical properties of hybrid composites increased with the increase of the Nano clay ratio up to 5wt%.

Subramaniyan and Sun [20] reported that interlaminar fracture toughness in mode I and mode II of glass/epoxy Nano-clay hybrid composite was decreased with increase of Nano-clay ratio. This can be a decrease due to the arrangement of nano clay along the fiber pivot.

Haqie et al. [21] studied the impact of nano clay particles on mechanical and thermal characteristic of fiber strengthened polymer matrix composite materials. Basic links between polymer morphology, strength, modulus, hardness, and thermic stabilization of thermosetting Nano-composites were studied as an operate of layered silicate content. S2-glass/Epoxy-clay Nano-composites were factory-made through a reasonable vacuum supported resin infusion technique (VARIM). Have the consequences appeared important enhancements in mechanical and thermic characteristic of typical fiber strengthened composites with low loading of organic salt Nano-particles. By dispersing 100 and twenty fifth by weight Nano-silicates, S2-glass/epoxy-clay Nano-composites attributed to almost forty-four, twenty-four and twenty third improvement in interlaminar shear strength, flexural and fracture hardness as compared to plain S2-glass/Epoxy composites. Similarly, the Nano-composites exhibit a lot of or less 26 celcius higher decomposition temperatures than that of typical composites. This improved property of fiber strengthened polymer Nano-composites are achieved for the foremost part as a result of increased interface surface areas, improved bond advantage and intercalated exfoliated morphology of the Nano clay/epoxy composites.

Patnaeik et al. [22] modified glass/fiber reinforced polyester composites by utilize flyash, Al_2O_3 , and SiC particles as filler materials. The results of these 3 particles on the mechanical characteristic of the glass-polyester composites are studied and investigated. It has influenced the mechanical characteristics of composite add those fillers. This study disclosed that industrial waste fly ash having 10 wt% showed better filler characteristics compared to other used fillers.

Shishavan et al. [23] explored the impact of the Nano clay addition and process parameters on the tensile strength and toughness of Nano-composite parts using the (Taguchi) mode of design of experiences. Nano clay content (in 3 levels: zero, 2 and 4 wt%), melting temperature (in 3 levels: 190, 200 and 210°C), and holding the pressure (in 3 levels: 80, 105 and 135 MPa) and holding pressure time in three levels (1, 2.5 and 4 hours) are considered because the variable parameters, while the most noteworthy hardness belongs to Nano-composites with 4 wt% Nano clay. Acquired results additionally indicated that injection temperature has the most necessary effect on tensile strength and stiffness of ABS-clay Nano-composites.

Shuvoa and Shorowordi [24] developed the nano-clay strengthened polyester nanocomposites with a semi-commercial method. 2 kind of nano-clays as hierarchical and non-graded nano-clay were utilized as reinforcements. Every of the Nano clay was additional 1% wt. at some point of polyester separately and also the impact of the addition of nano-clay on the polyester were investigated by mechanical characterization. Instron Universal Testing Machine were used to measured tensile and flexural strength. Toughness of the advanced Nano-composites was measured by a Shore Stiffness Tester. The fracture surfaces were investigated by Scanning microscope (SEM). It's found that the modulus and strength of graded Nano-clay reinforced Nano-composite is most than that of the unreinforced polyester and non-graded Nano-clay reinforced Nano-composite. The flexural strength it found to be higher within the hierarchical nano-clay composites as compared to the unreinforced polyester and non-graded Nano-clay strengthened Nano-composite. The toughness of unreinforced polyester and the Nano-composites were almost same.

Gustin et al. [25] investigated impact, compression after effect, and tensile hardness characteristic of carbon/Kevlar fiber and sandwich composites. Bottom surface of composite plates remained as carbon fiber to get the high flexural stiffness. Impact side face sheet layers were made of carbon, Kevlar or hybrid.

Pandya et al. [26] investigated the mechanical characterization of the glass/carbon/epoxy hybrid composites. Experimental studies showed that usage of glass layers within the exterior and carbon layers within the internal has the highest tensile strength and tensile modulus than the usage of carbon layers within the exterior of the hybrid composite.

Shaari et al. [27] investigated the effect behavior of glass- Kevlar/fiber hybrid composites laminates by the falling weight test (ASTM D7136). Composite laminates were fabricated utilizing a vacuum bagging technique with an epoxy matrix strengthened with twill woven Kevlar fiber and plain woven glass fiber. Four-completely various kinds of composite laminates with various ratios of Kevlar to glass fiber (0:100, 20:80, 50:50 and 100:0) were manufactured. The results of Kevlar-glass fiber content ratio at 43 J nominal energy level indicated that hybridization of Kevlar fiber to glass fiber improved the load carrying capability, energy absorbed and break force of composite laminates and a small reduction in deflection. These results were additional supported through the damage analysis, deepness of penetration and X-ray analysis tests.

Valençaa et al. [28] investigated the hybrid composite plates with epoxy matrix. Hybrid composites were strengthened with plain Kevlar-fiber fabric and Kevlar-glass hybrid fabric, utilize to an innovative design. Consequence of the mechanical properties of composites was obtained by tensile, bending and impact tests. These tests were completed inside the parallel direction or fill directions of the deformation and in a 90° direction. FTIR was utilized so as to verify the minimum curing time of the resin to perform the mechanical tests, and scanning research was utilized to watch reinforcement and matrix fractures. Composites with Kevlar-glass hybrid structure inside the reinforcing cloth showed the higher results with respect to mechanical strength, bending and impact energy.

Sudarisman et al. [29] investigated the flexural characteristic of E/glass and TR50S carbon fiber strengthened hybrid composites. Samples were created by the hand lay-up method in an intraply arrangement with a varied grade of glass fibers extra to the surface of a carbon laminate. These samples were then tested between the order of bends 3 points according to the ASTM D790-07 at (3) three span-to-depth ratios: 16, 32, & 64. Flexural strength, modulus and failure strain were calculated according to ASTM standard. Failure modes of specimens were inspected under SEM. It's shown that although the span to-depth quantitative relation shows an effect on the stress-strain relation, it's no results of the failure mode. The majority of specimens failing by either in-plane or out-of-plane local buckling followed by kinking and splitting at the compressive GFRP facet and matrix cracking combined with fiber breakage at

the CFRP tensile force. It's been appearing that positive hybrid impact exists for the flexural strengths of more of the hybrid configurations.

Amir et al. [30] studied the flexural of the glass/epoxy Nano-clay composites. The Nano-clay epoxy resin was prepared with the use of three-roll mill machine to get homogeneous distribution of Nano-clay into resin. Glass/epoxy Nano-clay composites were fabricated using 1 wt%, 3 wt% and 5 wt% Nano-clay content. The results appear that the flexural strength has increased with the addition of Nano-clay in the glass/epoxy composite.

Khan et al. [31] studied impact of Nano-clay addition to the cyclic fatigue habit and residual properties of carbon fiber-strengthened composites (CFRPs) after fatigue. The tension cyclic fatigue examination space device conducted at varying weight levels to determine the S-N curve. The recurring strength and modulus area unit measured at all completely various stages of exhaustion cycles. The scanning electron (SEM) and scanning service acoustic microscopy (SAM) can be used to characterize the root fatigue harm mechanisms and progressive hurt growth. The integration of Nano-clay into CFRP composites not just increases the mechanical characteristic of the composite in static loading, but and additionally the fatigue life for a given cyclic load level and additionally the residual mechanical characteristic once a given period of cyclic fatigue. Related fatigue damage area is considerably reduced applicable to Nano-clay. Nano-clay acts to suppress and hold off delamination harm growth and ultimate failure by increasing the fiber-matrix interfacial relationship and through the development of Nano-clay.

Tsai and Wu [32] investigated the organo-clay impact on the mechanical behaviors of glass/epoxy Nano-composites. The most concern of this study is the tensile, flexural, also as interlaminar fracture stiffness. To make sure that the organo-clay effect, there are 3 of various loadings, 2.5, 5 and 7.5 wt % of organo-clay were scattered in the epoxy resin utilizing a mechanical mixer followed by sonication. The corresponding glass-epoxy Nano-composites were prepared by putting the organo-clay epoxy mixture into the dry glass fiber through a vacuum hand lay-up operation. Tensile tests made very clear that the longitudinal tensile strength decreases much as organo-clay loading increases; in the opposite, the transverse tensile strength increases with the rise of the organo-clay. SEM observations of the transverse failure

specimens refer to the supported mechanism is so due to the improved interfacial bonding between the fibers and the surrounding matrix modified by organically. The increasing tendency was also found in the transverse flexural strength of the Nano-composites. Nevertheless, mode I fracture tests indicated that with the increase of the organo-clay, the corresponding fracture toughness of the Nano-composites decreases appreciably.

Naik et al. [33] studied impact and post effect compacting features of glass-carbon/epoxy hybrid composites with alternate stacking sequences. Plain weave E-glass and carbon twill weave T-300 utilized as reinforcing materials. The comparison of hybrid composites, laminates containing just-carbon and just-glass strengthening also were studied. Laboratory results had done with instrumented drop weight impact examination tools. It was known by this way that hybrid composite is so lower notch sensitive compared with just-carbon, or just-glass composites. Adding to this, carbon-outside/glass-inside clustered hybrid arrangement gave a less notch sensitivity compared by other hybrid configurations.

Hitchen and Kemp [34] investigated the impact of ply sequence on the mechanical characteristic and the minimum speed impact behavior of carbon/epoxy composites. The results showed that energy absorbed throughout delamination initiation increased by placing 45° fibers within the surface plies and by placing ultra-high-performance fibers within the 0° plies.

Kar et al. [35] examined the fatigue of hybrid composites containing glass and carbon fiber one-way rods. The rods were composed of a nucleus enveloped by a carbon fiber and glass fiber shell. This feature nominal the damage characteristics. The limit of the stiffness evaluated as a function of cycles, and also the results showed fatigue failures at totally various levels.

Marom et al. [36] studied the impact of stacking series and degree of hybridization on the effect energy of Kevlar-carbon/epoxy hybrid composites. A positive hybrid result was noticed for a detached hybrid throughout that one layer of carbon fibers was sandwiched between 2 layers of Kevlar. Hybrids with a bigger degree of hybridization were appear a negative hybrid impact, regardless of whether the outer layers were carbon or Kevlar. The impact of energy on the 2 styles of full-hybrid

composite plates were determined through perforation of samples. The failing energy of the broken samples had totally different effects as determined by examining the curve load deflection and photos of the broken samples taken from on either facet. The cross-sections of the samples were additionally broken and visually examined to evaluate and estimate the quantity of injury, like broken fibers within the layers and additionally the expansion of the lines between the adjacent layers.

Park and Jang [37] investigated the effect of hybridization of aramid polyethylene composite on the mechanical performance. The flexural characteristic, interlaminar shear strength (ILSS), and impact characteristic of those composites have been studied as a function of aramid fiber content. There are 2 not an equivalent stacking sequences $[0/0]_4$ and $[0/90]_4$, these were selected for this study, adding to that composites of the four totally different aramid fiber contents (50, 75, 100, and 1/3 by volume) was studied. Additionally, scanning electron microscopy (SEM) utilized to test the fracture surfaces of the intraply hybrid composites. The flexural strength and modulus became raised additional with the volume fraction of aramid fibre, and negative deviations from this rule of mixture were very clear by all intraply laminates.

2.3 Tensile, Flexural Strength and Vibration, Damping of Hybrid Composite Reinforced by Kevlar Fibers

Woo and Kim [38] investigated the high strain rate failure properties of the carbon-Kevlar hybrid composite if that subjected to compressive loading. They found that the failure method of the carbon-Kevlar hybrid plain-woven composite showed an initial matrix fracture and so brittle carbon fiber breakage. Thereafter, multiple failure mechanisms emerged, like fiber-matrix debonding, fiber pullout, excessive deformation and breakage within the Kevlar fiber tips together with splitting and fibrillation.

Isa et al .[39] studied thermal properties of unsaturated polyester composites and the impact of fiber varieties (Kevlar, glass and nylon) and their combinations on the tensile. The hybrid and monolithic composite specimen were created by using hand lay-up methodology followed by compression.

The consequence was observed that the Kevlar strengthened composite contain the best tensile strength between the monolithic composites and hand woven nylon fiber reinforced composite with the littlest quantity worth. The mixture of fibers (hybridization), Kevlar and glass fibers composite and Kevlar-glass/nylon fibers composite led to in strength and specific tensile strength improvement over the homogeneous glass fiber composite. The mixture of fibers additionally improved the thermal stabilization of the hybrid composites. Positive impact of hybridizing were additionally determined from density and water absorptivity.

Wan et al. [40] evaluated mechanical properties of surface treated three-dimensional braided carbon-Kevlar hybrid fibers. Hybrid impact of the composites with varied fiber-matrix interfacial bonding was estimated. It absolutely was found that the hybrid composites appear significant improve in flexural strength and interfacial adhesion strength after two-step surface treatment, suggesting this method was efficient. However, the 2-step surface treated Kevlar/carbon hybrid fibers strengthened composite appear a positive hybrid impact on flexural, indicating the presence of hybrid result's related with the nature of fiber matrix interface.

Valença et al. [41] used plain Kevlar fiber cloth and Kevlar/glass hybrid fabric to produce composite panel using hand lay-up methodology. Tensile, bending and impact tests were carried out to see mechanical properties of composites. Experimental results appear that Kevlar-glass hybrid composite has higher specific mechanical properties compared with Kevlar composite.

2.4 Tensile, Flexural Strength and Vibration Damping of Hybrid Composite Reinforced by adding Nano clay

Shaifi et al. [42] investigated the effect Nano-clay on the fracture resistance and mechanical properties of epoxy-based Nano composites and also the corresponding continuous carbon fiber epoxy matrix composites. The incorporation of Nano-clay into epoxy and CFRP reinforce the impact and quasi-static fracture resistance, still because the flexural strength and modulus of the composites. Microscopic examination depending on the double-notch bending test determines pertinent toughening mechanisms accountable for the improved toughness of clay Nano-composites, namely micro-cracking, crack pinning, crack tip bifurcation and

deflection, and micro voids along the clay galleries. Multi-layer delaminations were between the key toughening mechanisms limited for the Nano-clay -CFRP hybrid composites.

Chowdary and Kumar [43] investigated the effect of Nano-clay content on the mechanical and morphological behavior of the S-glass fiber and polyester resin. Nano-clay content was 1, 3, 5, and 7wt% in polyester resin with 40% of fiber content. The results suggested that the inclusion of Nano-clay has a considerable impact on the mechanical behavior of composite materials, highest improvement was obtained with 3 wt% addition of Nano clay.

Suresha and Manpinder [44] produced hybrid composite with the utilize of carbon fiber and organo-modified montmorillonite nanolayers with epoxy matrix carbon fabrics and organic-modified montmorillonite Nan-layers (1.5, 3, and 5%wt) were utilized to produce hybrid carbon/epoxy composites using hand lay-up technique followed by autoclave action, aiming to evaluate their static mechanical . Higher organo-modified montmorillonite content in carbon/epoxy yielded a small reduction within the weight and lower voids in carbon/epoxy composite. Transmission electron micrographs appear that the organo-modification improved the dissipation and interfacial bonding of organo-modified montmorillonite with an epoxy at Content of 1.5 and 5%wt .

Islam et al.[45] modified and changed the fiber carbon strengthened epoxy composites with 2% wt. The worries montmorillonite Nano clay and 3% wt. Common multiple wall fullerene. 3 points flexural test, dynamic mechanical analysis and low speed effect test were carried out and results compared with unmodified carbon/epoxy composite. Experimental studies were appearing that Nanoparticle reinforcement enhanced the mechanical properties of carbon-epoxy composites.

Chandradas et al. [46] examined that the vibration behavior in glass fabric/vinyl ester composites with inclusion of Nano-clay particle contents of zero, 1, 3 and 5 wt%. The consequences presented that the addition of organically modified Nano-clay particles within glass fabric/vinyl ester laminate increased the natural frequency due to the increasing of the modulus. Furthermore, the damping ratio improvement of composite laminates was obtained up to Nano-clay content of 3 wt%.

Avila et al.[47] investigated the influence of nano-clay addition on glass fiber-epoxy laminated composites behavior by low-velocity impact tests. The nano-clay contents in an epoxy resin was 1, 2, 5, and 10 weight percent. As the amount of nanoclay dispersed was increased, there was an increase in stiffness. The results showed that as the stiffness reached its peak value, the fracture toughness and damping were reduced. Specimens with 5% nanoclay content showed the best performance with respect to damping. The low-velocity impact results were showed an increase on energy absorption close to 48% for low energies, 20 J, 15% increase for medium–high energies, 60 J, and 4% for high energy, 80 J. As the amount of intercalated nanoclay content varied from 0% to 10%, the optimum condition for low-velocity impact seemed to be around 5%.

Ferareira et al. [48] studied the properties of the fatigue strength of a Kevlar/epoxy laminate composite moreover, because the advantages obtained using a Nano-clay filled epoxy matrix. Twelve ply laminates, all in a similar direction, of woven bidirectional Kevlar- 292, were preparation by hand lay-up, utilizing SR 1500 epoxy. The composite plates were made by a vacuum molding method. The addition of Nano clays reduced static strength and support the stiffness in every tension and bend loading.

Kabir [49] proved the addition of Nanotechnology improves the property of damping and fatigue behavior of composite materials enhanced fiber. Nano clay was distributed in epoxy by a solvent-free high-velocity mix methodology used a high speed homogenizer. This modified resin was utilized to industry S-glass/epoxy composite laminates by hand lay-up and autoclave curing. The dynamic properties of the specimens were tested utilizing a dynamic mechanical analyzer. At the most of 16.8% improvement among the flexural storage modulus was accomplish for add up to a 2wt% Nano-clay. The most improvement among the loss modulus was twenty two for a similar quantity of clay loading. Log decrement test was used to get damping effect of nanoclay and most increase was obtained as 57% compared with unfilled S-glass/epoxy composite.

Velmurugian et al. [50] inquired that montmorillonite clay gives higher properties to the composite and this montmorillonite clay is that the organically modified kind of clay. Montmorillonite clay filled composites appear competitive mechanical and damping properties of fiber strengthened composites. Damping properties of glass fiber reinforced and Nano clay, stuffed hybrid composites has got to be studied to enhance the properties, as a result of within the aerospace industries vibration damping is taken into account together of the important material property. throughout this work epoxy, glass fiber and montmorillonite clay are utilized to prepare the hybrid composite laminates by hand lay-up methodology. The laminates were ready using three layers of glass woven roving mates of 610 gsm and montmorillonite clay have varied from 0.33, 1%, 3% and 5%. The impact test was performed utilize the drop mass setup and additionally the sharp nose projectiles are utilized for the test .The damping factor is calculated by the logarithmic decrement methodology and the results also appear considerable difference due to the Nano-clay addition.

Chowdhury et al. [51] produced plain weave carbon/epoxy Nano composites using Nano-clay addition utilized hand-layup method followed by vacuum bagging. Control specimens of knitted carbon fiber-Epoxy were feigned for comparison purposes. Results of flexural tests indicated significant enhancements in flexural strength and modulus for Nano-clay strengthened composites as compared to the control specimens, DMA studies additionally showed improvement in thermo mechanical properties mostly in storage modulus although no appreciable modification was noticed in glass transition temperature.

2.5 Conclusion of Literature Review

All the researchers aimed to enhance the behavior of polymers by reinforcing with different types of reinforcement materials. The literature was focused on polymer-polymer composites, modifying of thermoset polymers, particulate reinforcing and the mechanical tests that related to our work. They concluded that the behavior of the composite may depend on many things such as filler content, the conditions of the test, particle size, etc.

based on the above researches, the tensile, flexural, impact and vibration properties of various Nanoparticles modified composite laminates have been investigated. To the best of found knowledge, researchers in literature did not inspect the effect of Nano-clay content on flexural, vibration and damping properties of hybrid woven carbon/Kevlar fabric/epoxy composite. In this work, tensile, flexural, vibration and damping properties of CKFRE composite were examined with the incorporation of Nano-clay particles.



CHAPTER 3

EXPERIMENTAL STUDIES

PRODUCTION OF COMPOSITE PLATES AND DETERMINATION OF MECHANICAL PROPERTIES

3.1 Introduction

This chapter deals with the preparation and determination of mechanical properties of composite plates. Production steps, standards for tensile, flexural and vibrations tests are explained.

3.2 Materials:

In the production of composite plates, twill interplay Kevlar/carbon woven fiber (190 g/m²) (Dostkimya Company, Tuzla, Istanbul, Turkey) was used during this study. Montmorillonite (NM-MMT) Nano clay was bought from Grafen Chemical Industries in Turkey.

3.2.1 Kevlar- carbon

Kevlar/carbon fabric (weight: 190 g/m², weave: 2/2 twill, width: 1000 - 1200 mm, thickness: 0.23 mm) was used due to its high tensile strength-to-weight ratio. Kevlar fabric is five times powerful than steel [52]. On the basis of equal weight. It's additionally used to create drum heads and different composite products which will hold up to repetitive high impacts over the course of their period, as a result of its high abrasion resistance and tensile strength of the aramid fiber combines with high the compressive however comparatively high cost.

3.2.2 Epoxy resin

Epoxy resin is a low molecular weight pre-polymers or higher molecular weight polymers that usually contain a minimum of two epoxide combination. The epoxide group is in addendum typically noted as a glycidyl or oxidant cluster. A wide range of epoxy resins is formed industrially. The raw materials for epoxy production are these days for the most half oil derived, although some plant derived source area unit presently changing into commercially obtainable (e.g. Plant derived glycerol utilized to produce epichlorohydrin).

Epoxy resins are compound or semi-polymeric materials, and as such seldom exist as pure substances, since the variable chain length results from the polymerization reaction utilized to manufacture them. High purity grades is also created certainly applications, e.g. using a distillation purification operation. One downside of high purity liquid grades is their tendency to create crystalline solids thanks to their extremely regular structure that require melting to enable processing.

The application of epoxy-based materials are intensive and contain coatings, adhesives and composite materials like those utilizing carbon fiber and fiberglass strengthening (although polyester, vinyl ester, and totally various thermosetting resins are utilized for glass-reinforced plastic). The chemistry of epoxies and in addition the range of commercially attainable variations allows cure polymers to be created with an awfully broad range of properties. In general, epoxies are well-known for their wonderful cohesion, chemical and heat resistance, good-to-excellent mechanical properties and excellent electrical insulating properties. A lot properties of epoxies are also modified (for example silver-filled epoxy with sensible electrical conduction area unit out there, although epoxies are typical electrically insulating). Variations offering high thermal insulation, or thermal conduction combined with high electric resistance for electronics applications, is available [53]

3.2.3 Nano clay

The nanoparticles distributed within the epoxy resin to require advantage of the direct methodology of blending. According to ASTM standards complete the assembly the samples and check them. The study reveals that, because of the combination of Nano additives of epoxy composite to some extent provide hopeful

results in comparison with the neat epoxy. It has been utilized during an analysis Nanoparticle that carry the subsequent specifications: Montmorillonite Nano-clay was obtained from Grafen Chemical Industries, Turkey with a lateral width of 0.5-2 μm , thickness of 1-10 nm and bulk density of 200-500 kg/m^3 [54]. SEM image of NC particles is shown in Figure 3.1. Eight layers of carbon/Kevlar were prepared to show hybridization effects. The laminates prepared for this study by adding Nano-clay particles in epoxy with six different particle contents as 1, 2, 4, 6, 8 and 10 wt % .

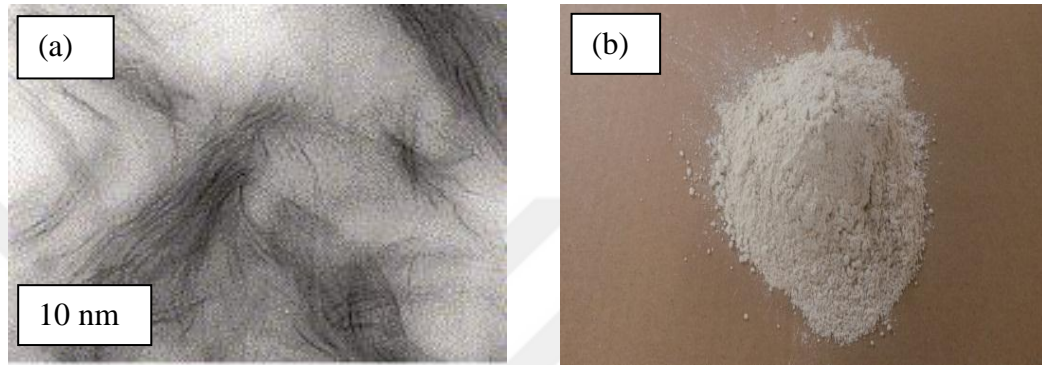


Figure 3.1. (a) SEM image of NC particles, (b) NC particles

3.3 Production of Hybrid Composite Laminates

Production of hybrid composite laminates: fibers were cut with a desired dimension (300 mm x 280 mm) using EC cutter the figure (3.2). The stoichiometric ratio of epoxy (Momentive MGS L285) to hardener (Momentive MGS H285). The laminating resin (MGS L285) has specification as: parts by weight / 100:40 \pm 2, parts by volume / 100: 50 \pm 2. It has the following applications, (motor planes, shipbuilding, sports equipment, model airplanes, molds and tools), and is outfitted at temperatures between 10 $^{\circ}\text{C}$ and 50 $^{\circ}\text{C}$ all usual processing methods. Carbon/Kevlar twill 2/2 woven with areal density of 190 g/m^2 and thickness 0.24 mm were utilized as reinforcement in the lamina. All materials provided from DOST Chemical Industrial Raw Materials Industry, Turkey. Nano-clay was obtained from Grafen Chemical Industries, Turkey with a lateral width of 0.5-2 μm , thickness of 1-10 nm and bulk density of 200-500 kg/m^3 . Eight layers of carbon/Kevlar were prepared to show hybridization effects.

Epoxy was mixed with Nano-clay particles for 35 minutes, then hardener was added and mixed to obtain homogeneity (Figure 3.3), afterwards the mixture was poured

upon the layer by layer for all layers, then laminated fabrics was laid on the flat mold (Figure 3.4 a) and subjected to (120 KPa) pressure for 1 h curing time with 80°C temperature (Figure 3.4 b).

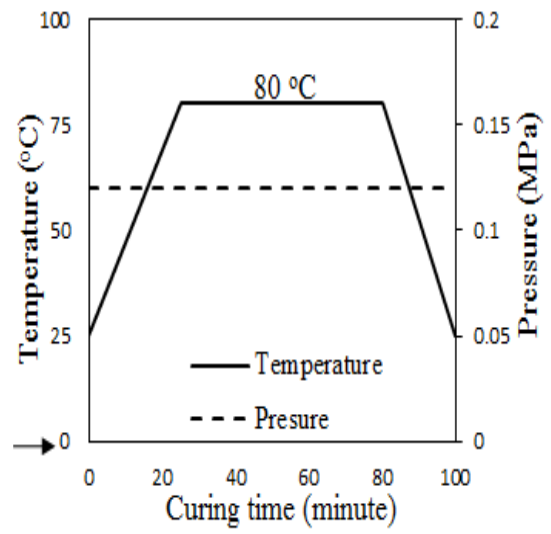
The composite laminates were cooled to room temperature under constant pressure for three hours. Finally, the composite laminate was removed from the mold to get a fine finished composite plate (Figure 3.5). The produced composite laminates in a size of 220 mm × 200 mm was cut to the required size of specimens using CNC machine (Figure 3.6) according to the ASTM standards. ASTM D 638 [55] used for tensile test and ASTM D 790 [56] used for flexural test. Each vibration test specimen dimension is 200 mm × 12.7 mm and clamped with free beam length of 153 mm.



Figure 3.2. Cutting fibers by EC, (Kevlar / Carbon)



Figure 3.3 Mixing and application of Nano-clay and epoxy resin



(a)

(b)

Figure 3.4 (a) Production unit, (b) Curing procedure



Figure 3.5 Examples of produced composite and hybrid composite plates



Figure 3.6 Cutting the specimen using CNC

3.3 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 and (D-790) -00) for flexural test, using CNC machines. Specimens (3 for tensile test and 3 for flexural) have been prepared for testing hybrid composites. Example of produced tensile and flexural test samples is given in Figure 3.7.

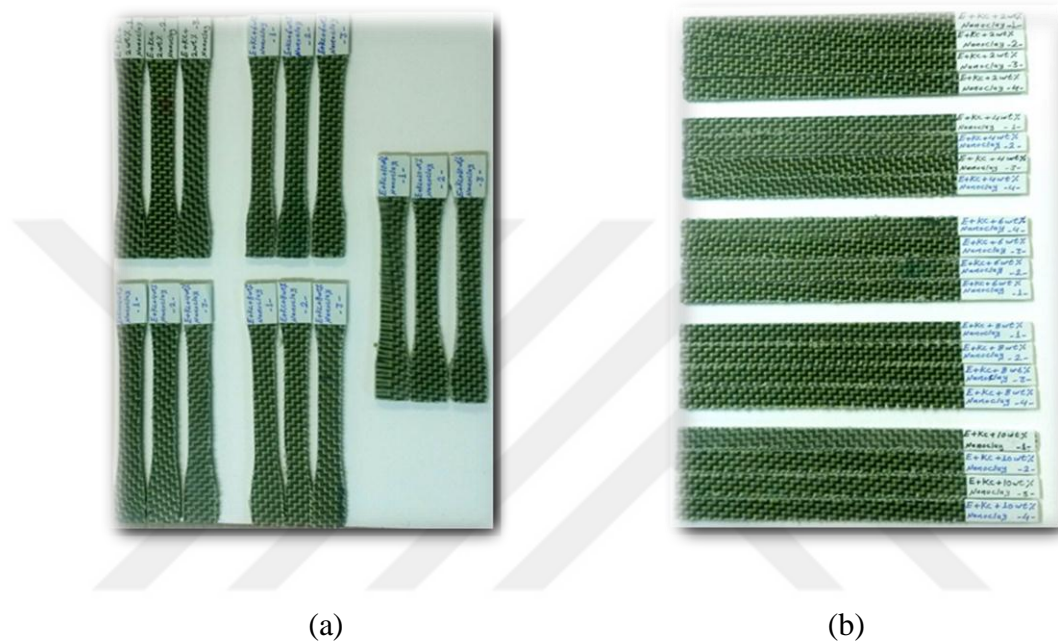


Figure 3.7 Examples of (a) tensile test (b) flexural test specimens

3.4 Determination of Mechanical Properties

The tensile and flexural strength properties of the composite samples were determined at room temperature utilizing the AG-X series-Shimadzu testing machine (Kyoto, Japan) (Figure 3.8). Appropriate samples were prepared with a size of 165 mm × 13 mm for a gauge length of 50 mm for tensile test and 200 mm × 12.7 mm with span to thickness ratio of 32:1 for flexural test. The thickness of tensile and flexural specimens was in the range of 2.5 ± 0.1 mm due to variation of Nano-clay content. The crosshead speed was 2 mm/min for tensile test and 3 mm/min for flexural test. Three samples were examined at least for each compound, and the average value was calculated.



Figure 3.8 Test set-up Shimadzu AG-X series testing machine

3.4.1 Determination of tensile properties

Tensile test, referred as the stress test, could be a test of basic materials during which they 'resubmitting a sample to a controlled tension till failure. The consequence of the test are normally utilized to select a fabric for an application, and to foretell how a material can react beneath other kind of force properties that are measured directly by the tensile test is that the final tensile strength, and most elongation in the length. From this measurement, it can even be the subsequent properties: Young's modulus, Poisson's ratio, yield strength, and stiffness properties of the type. Tensile properties of samples of laminate were limited according to the ASTM D638-10 standard test process. Type 1 configuration of ASTM 638-10 standard have been utilized considering sample dimensions as the width of narrow section (W) 13 mm, length of narrow section (L) 57 mm, overall width (Wo) 19 mm, total length (Lo) 165 mm, gage length (G) 50 mm, a space between grips (L) 115 mm and radius of the fillet (R) 76 mm (Figure 3.9).

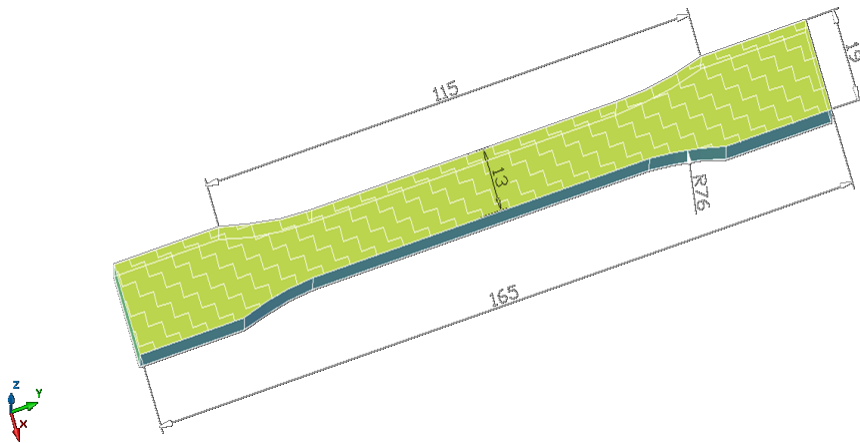


Figure 3.9 Dimensions of the tensile specimens according to ASTM 638-10

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

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \dots\dots\dots (3.1)$$

Where ΔL is the amount of change in length, (L_0) 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:

$$\sigma = \frac{F_n}{A} \dots\dots\dots (3.2)$$

Where F_n is the tensile force and A is a cross-section nominal sample. Machine do these accounts also increases strength, thus that information points can be graphed in the stress-strain curve [57].

Mechanical properties of sample were acquired utilize Shimadzu AG-X series testing machine. To determine tension properties, 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 properties of the sample were specified according to the ASTM D790- 00 standard test method, a suitable sample of rectangular cross section ($L= 200\text{mm}$, $w =12. 7\text{mm}$ and $t =$ thickness of the laminate) rests on two supports and was loaded by

means of a loading nose midway between the supports (Figure 3.10 a, b). A support span-to-depth ratio of (1:32) was utilized (These test processes utilize 3-point bending system applied to a simply supported beam). Loading of specimens appears in Figure 3.11. To determine the flexural properties, the sample was loaded in the perpendicular direction with the 3 mm/min speed up to failure.

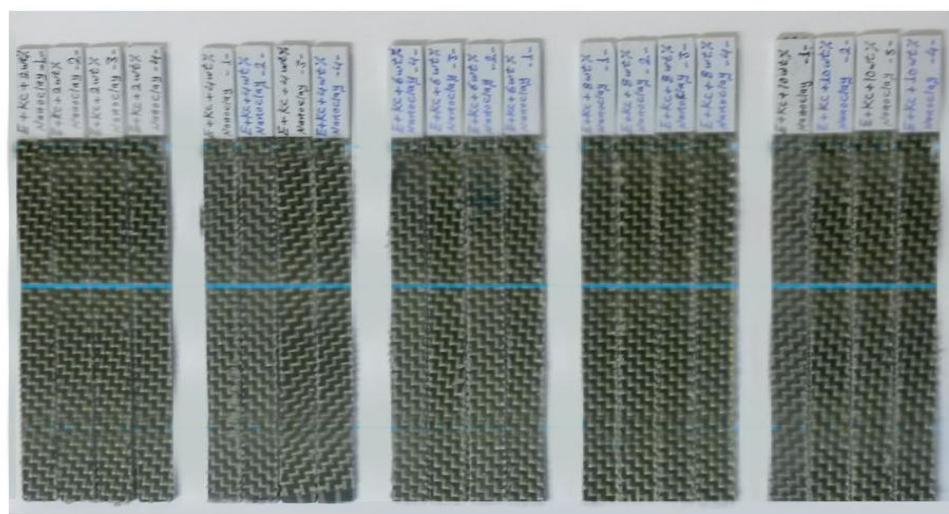
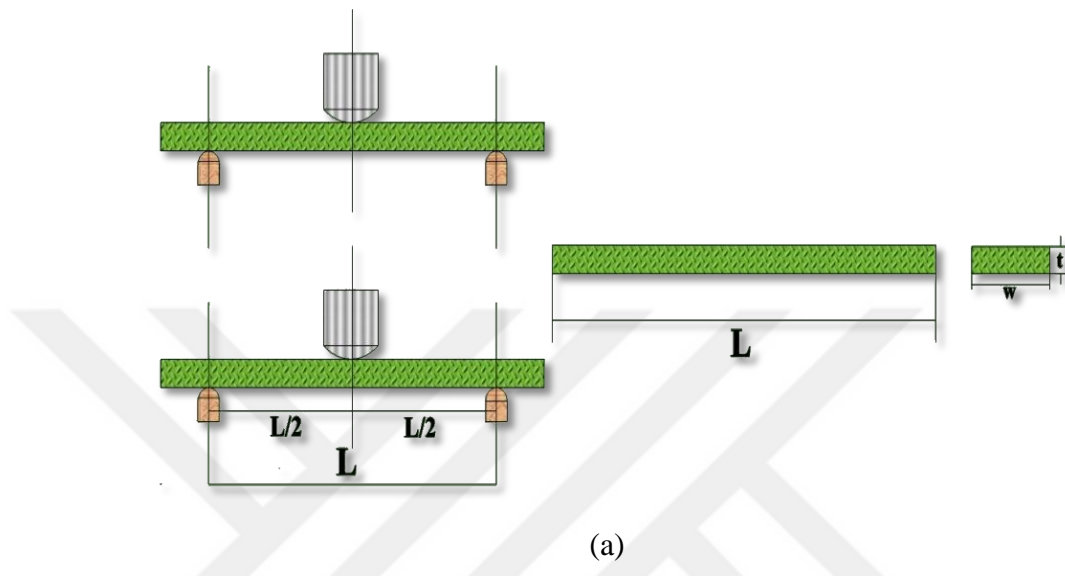


Figure 3.10 (a) Dimensions of the flexural specimens according to ASTM D 790 (b) Flexural specimens

Flexural strength, flexural modulus & strain were determined from the test machine data's through the over the use of the equations [58].

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

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

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

Where L, b and h square measure the span, width and depth of the sample, 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.



Figure 3.10 Flexural testing

3.4.3 Vibration test

Vibration and damping properties of Nano-clay modified CKFRE composite laminates were obtained utilizing test set-up according to ASTM E756. (Figure 3.12a). 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 utilized for output signal acquisition, information acquisition and stimulus force signal, respectively. Half power bandwidth method was applied to evaluate damping responses of first natural frequency modes of the composite samples.

The damping ratio was evaluated in accordance with the half-bandwidth method (Fig. 3.12 b) [59]. Damping ratio (ξ) can be obtained using the logarithmic decrement according to equation (3.6).

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_n} \dots\dots\dots (3.6)$$

Where ω_n Is the natural frequency of first mode and $\omega_2 - \omega_1$ Is the bandwidth. The loss modulus (E') and storage modulus (E'') is given in equations (3.7) and (3.8).

$$\omega_1 = \frac{1.875^2}{2\pi L^2} \sqrt{\frac{E' I}{\rho A}} \dots\dots\dots (3.7)$$

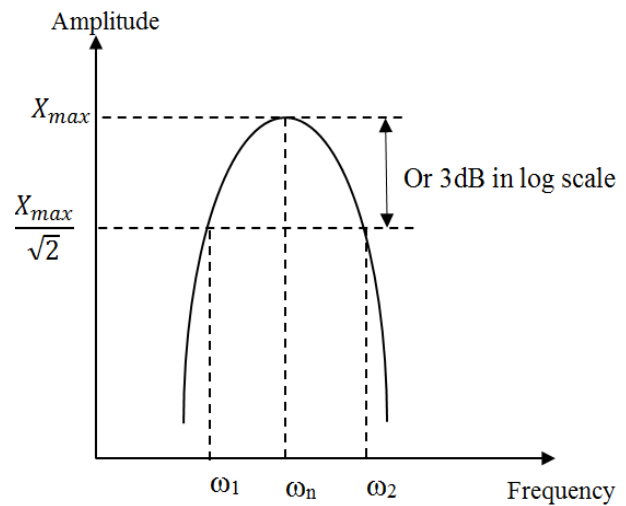
Similarly, loss modulus of the beam can be obtained using the storage modulus. Relationship between storage modulus and loss modulus is given as follows:

$$E''(\omega) = 2E'(\omega)\xi(\omega) \dots\dots\dots (3.8)$$

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



(a)



(b)

Figure 3.11 (a) Vibration test set-up, (b) Half-power bandwidth method

3.4.4 Measurement of dynamic moduli

The modulus of elasticity (also called as the coefficient of elasticity, Young's modulus or the tensile modulus) could also be a number that measures an object or substance's resistance to being distorted elastically (i.e., non-permanently) once a force is applied to that. It could also be defined as a result of the slope of its stress–strain curve within the elastic deformation region [60].

The dynamic modulus of elasticity was resolved by vibration damping measurements. The main principle upon which to measure and record free vibrations of a prismatic cantilever beam, clicking on them with an acceptable hammer as appear in Figure 3.13. The amplitude decay as a function of time and so the vibration modes were obtained using test set-up according to ASTM E756.

The test parameters, the analysis of a spread of 500 Hz; acquisition time of 500 milliseconds. Rectangular observation window and additionally the resolution frequency of 5HZ. It had been measured decay capability (amplitude) to require advantage of (0.6 g) acceleration. Beam dimensions appear in Table 3.1. Following the testing procedure, it had been obtained 2 styles of curves: vibration damping function of frequency response free personal. Measure the length and width and thickness of the specimen on the beam. Thickness, and calculate the typical values derived provide and additionally the level of 10 measurements. The maximum and minimum limits of the standard derivation of the pattern dimensions were thought of within the calculations. Vibration test offers a free vibration a damping decay and frequency response function (FRF), at only one occasion as a consequence of. Contemplate the linear system with one degree of freedom, and in response FRF is that the decomposition of the natural frequencies of the structure or sample, that he corresponds to an exemplary edition symmetry of the vibration modes. The amount of peak frequencies of vibration (vibration modes) and in addition the type of response FRF might also be a direct consequence of the toughness of the fabric [61].

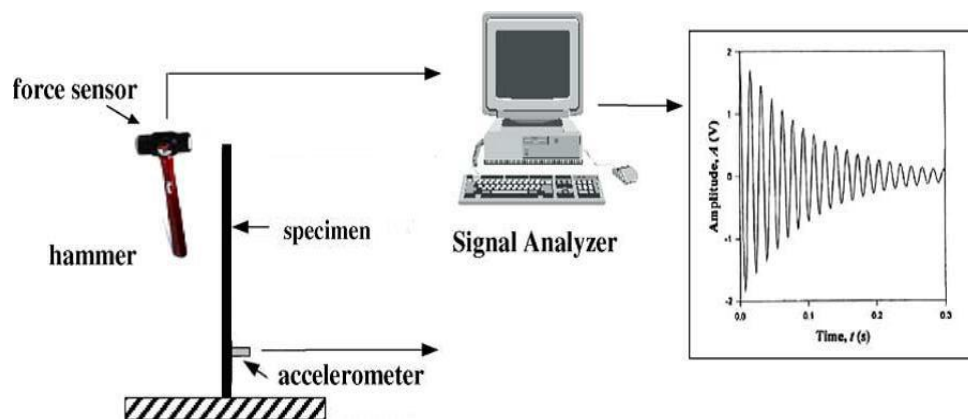


Figure 3.12 Vibration damping testing

Table 3.1 Dimensions and weight of specimens utilized in damping test

Wt %	t(mm)	m _c (g)	ρ(kg/m ³)	A (m ²)	L (mm)	I (m ⁴)
0%	2.4	8.4	1377.953	3.048E-05	153	1.46304E-11
1%	2.4	8.6	1410.761	3.048E-05	153	1.46304E-11
2%	2.4	8.9	1459.974	3.048E-05	153	1.46304E-11
4%	2.6	9.4	1423.380	3.302E-05	153	1.86013E-11
6%	2.6	9.6	1453.664	3.302E-05	153	1.86013E-11
8%	2.9	9.7	1316.861	3.683E-05	153	2.08312E-11
10%	3.1	10	1270.003	3.937E-05	153	3.15288E-11

CHAPTER 4

EXPERIMENT 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 with Nano- clay addition. Test results are explained in terms of figures and tables

4.2 Tensile properties

The results acquired from the test take away at the tensile testing of varied Nano-clay content of laminated composites were shown in the Tables 4.1.

Table 4.1 Tensile results for Kevlar/carbon/epoxy hybrid composites

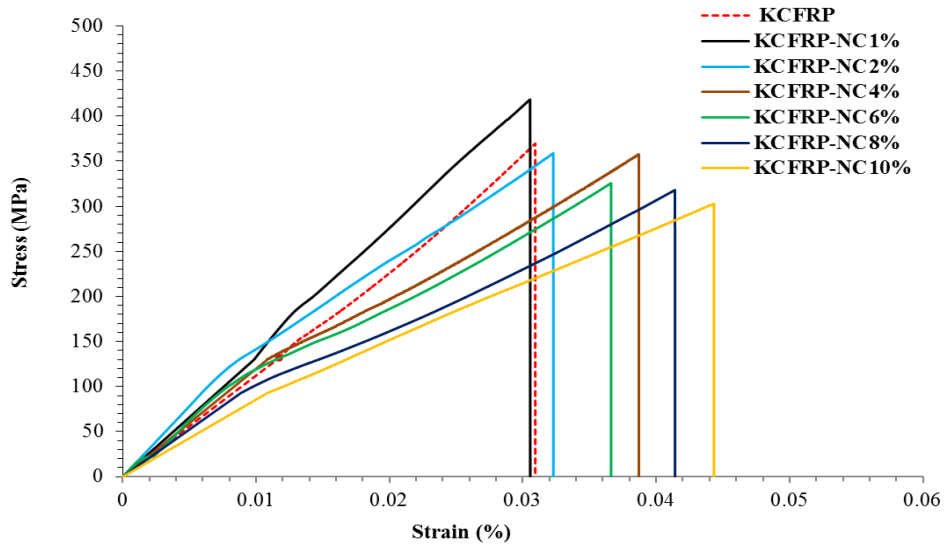
Laminate	Max. Tensile Strain	Max. Tensile Stress(MPa)	Average Tensile Stress(MPa)
Pure-1	0.0196	335.964	371.45
Pure-2	0.0276	402.240	
Pure-3	0.0376	376.150	
1%- 1	0.0341	426.601	421.06
1%- 2	0.0265	418.484	
1%- 3	0.0329	418.116	
2%- 1	0.0261	360.006	366.47
2%- 2	0.0302	387.435	
2%- 3	0.0308	351.977	
4%- 1	0.0391	358.428	358.59
4%- 2	0.0343	367.017	
4%- 3	0.0273	350.352	
6%- 1	0.0334	334.096	326.18
6%- 2	0.0353	321.993	
6%- 3	0.0276	322.475	
8%- 1	0.0359	314.923	319.48
8%- 2	0.0344	325.989	
8%- 3	0.0404	317.543	
10%-1	0.0541	308.439	302.93
10%-2	0.0312	288.367	
10%-3	0.0404	311.985	

From the experimental study, it was observed that Kevlar/carbon/epoxy composite (pure) has a tensile strength of 371 MPa, where Kevlar-carbon/epoxy - 1wt % Nano clay composite has the maximum tensile strength of 421 MPa. It is shown from the results in Table 4.1 that the hybridization strongly effects the tensile strength of composites. This is identical with previous literature studies [19, 28 and 40]. Those of the research, experimental studies showed that mechanical properties of hybrid composites increased with increase of Nano-clay ratio up to 5wt%, like a flexural quality, flexural modulus, tensile strength, Young's modulus, according to their reports.

In contrary, the KCFRP-NC 1% showed a rapid load rise, obtaining the smallest strain and the highest stress among all tested samples. Suggesting that KCFRP has good stiffness mainly due to high strength property of Kevlar-Carbon. Therefore addition of 1%w of NC to the Kevlar-Carbon/epoxy layers, tensile-strength was seen to increase by 13.1%. Addition of NC increased strain at rupture. That means the inclusion of NC in the CKFRE laminate can increase the ductility of the specimens. Hence, the elongation at break increased by 74.0% at NC of 10 wt%. Similarly, Balakrishnan et al. [62] indicated that the elongation at break was increased by adding 5.5 wt% of NC in an epoxy matrix. Furthermore, the curve behavior was affected by stiffness differences between carbon and Kevlar fibers in the hybrid intraply carbon/Kevlar Fiber layers, which Kevlar elongation is more than carbon elongation.

All the specimens were broken without any nicking and the fracture in intra-layered samples, (Figure 4.2), that means the specimens fail in a brittle fashion during a tensile test. Besides, there was no more effective, reducing in the cross-sectional territory of the specimens. Therefore, the samples of CKRE-NS composites show a brittle style. In addition, whether it was filled or unfilled with (NS) particles, the tensile samples were failed at higher stress. From the experimental study, it was observed that (CKFRE) composite has the maximum tensile strength of 421. MPa, where Kevlar-carbon/epoxy composite has a minimum tensile strength about 371 MPa.

**Fig
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Ten
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for Kevlar/carbon/epoxy hybrid composite

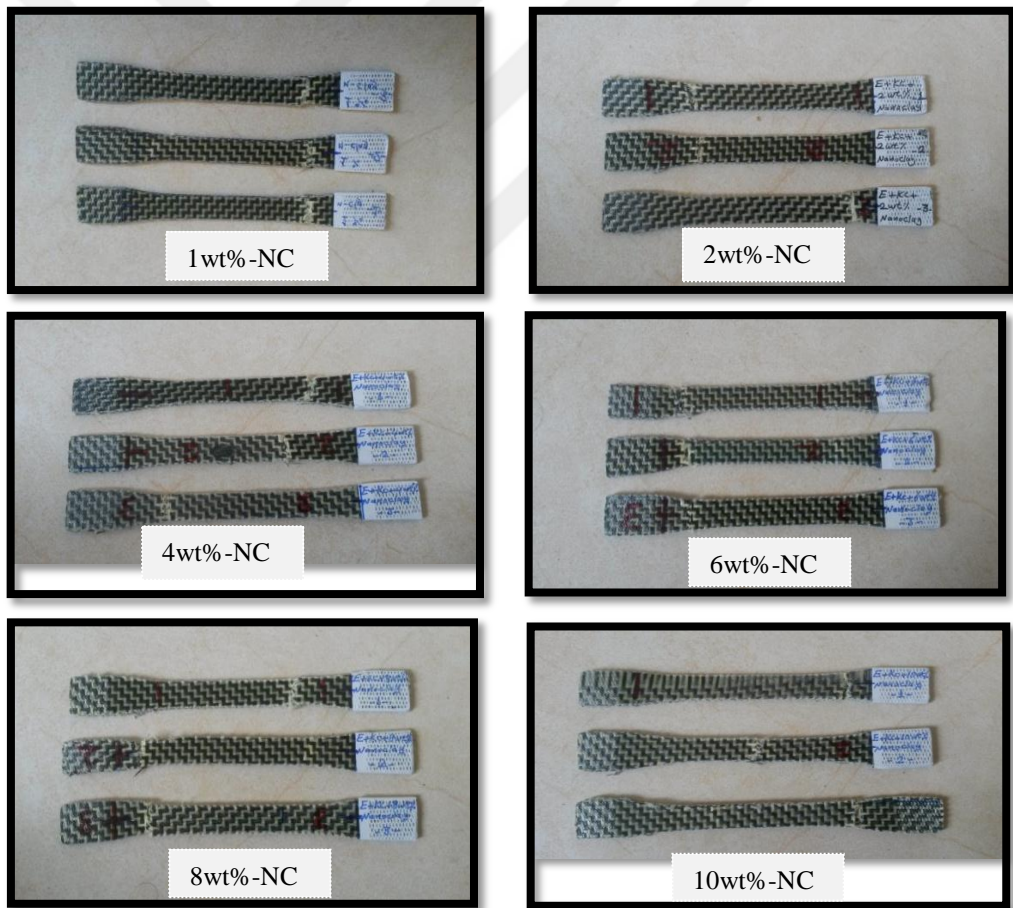


Figure 4.2 Failure specimens of different the tensile test laminates after tensile test

4.3 Flexural Results

The average results that acquired from the experimental work on the flexural testing fibers and the Nano clay of laminated composites are listed within the Table 4.2. Flexural specimens were loaded with cross head velocity of 5 mm/min up to failure. Load deflection curves for each ratio of Nano-clay hybrid composites is shown in Figure 4.3. Flexural stress-strain values were calculated according to equations given in Chapter 3 and its variation is given in Figure 4.4.

A linear response of the load-displacement curves of the studied composites has shown from the flexural tests, then the fracture was occurred showing unstable conducting and the flexural strength gradually would be so reduced. This behavior may be attributed to the stiffness differences effect of intraply carbon/Kevlar fiber could delay the specimen failure. The results indicated that the failure strain was reduced with the addition of Nano-clay particles, this behavior may be the attributed to the mobility and deformity of the polymer matrix was restricted by the inclusion of Nano-clay particles, thus reducing the failure strain during the flexural test. As shown in Table 4.2, flexural strength was improved by the addition of Nano-clay particles to the CKFRE. Hence, the composite flexural strength was increased from 431 MPa for unfilled CKFRE to reach 554 MPa with Nano-clay content of 2.0 wt%, afterword flexural strength follow the trend of decreasing to reach 269 MPa at the content of 10 wt%.

As a result, the highest improvement of flexural strength was obtained at 2.0 wt% content of Nano-clay with maximum increment of 28.5 %. This indicated that the chemical compatibility and adhesion strength between NC particles and epoxy/carbon-Kevlar fiber was optimum at this content.

The flexural modulus of CKFRE-NC composites were significantly affected by addition of NC (Figure 4.5), that the maximum modulus increased by 12.1% at NC content of 2 wt%. To sum up, the strong cohesion between NC particles and epoxy matrix was due to the presence of octadecylamine in the NC and so improved the tensile strength and flexural of the composites.

The strength was degraded at a high amount of particle content due to NC agglomerates and forming stress concentration sites and thus crack initiation led to

weaknesses in the composite strength [63]. This consequence is in agreement with previous studies, Chowdhury et al. [43] maximum improvements in flexural-strength and modulus were found for 2wt% Nano-clay strengthened composites.

Table 4.2 Average flexural stress for CKFRE-NC and interplay hybrid composites

Laminate	Thickness (mm)	Max. Strain	Max. Flexural Stress (MPa)	Average Flexural Stress (MPa)	E_f modulus (GPa)
PURE-1	2.4	0.0221	443.11		20.82
PURE-2	2.4	0.0223	454.42	430.99	21.76
PURE-3	2.4	0.0211	395.46		19.88
1%- 1	2.4	0.0325	419.16		21.80
1%- 2	2.4	0.0428	474.91	446.36	20.40
1%- 3	2.4	0.0471	445.00		21.40
2%- 1	2.4	0.0592	592.58		24.55
2%- 2	2.4	0.0500	511.99	554.09	22.31
2%- 3	2.4	0.0518	557.72		24.21
4%- 1	2.6	0.0173	333.24		20.33
4%- 2	2.6	0.0198	416.50	412.65	22.20
4%- 3	2.6	0.0188	488.20		21.60
6%- 1	2.6	0.0365	353.76		19.61
6%- 2	2.6	0.0355	356.83	364.95	20.21
6%- 3	2.6	0.0416	384.26		21.01
8%- 1	2.7	0.0383	308.26		18.25
8%- 2	2.7	0.0364	320.53	315.42	19.01
8%- 3	2.7	0.0390	317.46		18.71
10%-1	3.1	0.0471	248.85		18.32
10%-2	3.1	0.0415	291.06	269.65	20.72
10%-3	3.1	0.0393	269.05		19.10

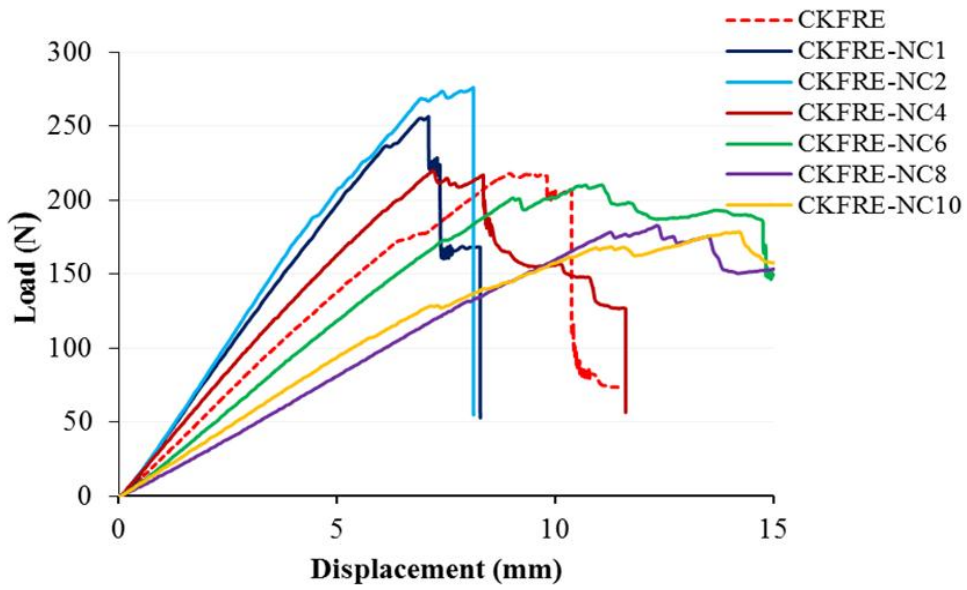


Figure 4.3 Flexural load-deflection curves for KCFRP and Kevlar/carbon/epoxy Nano clay hybrid composite

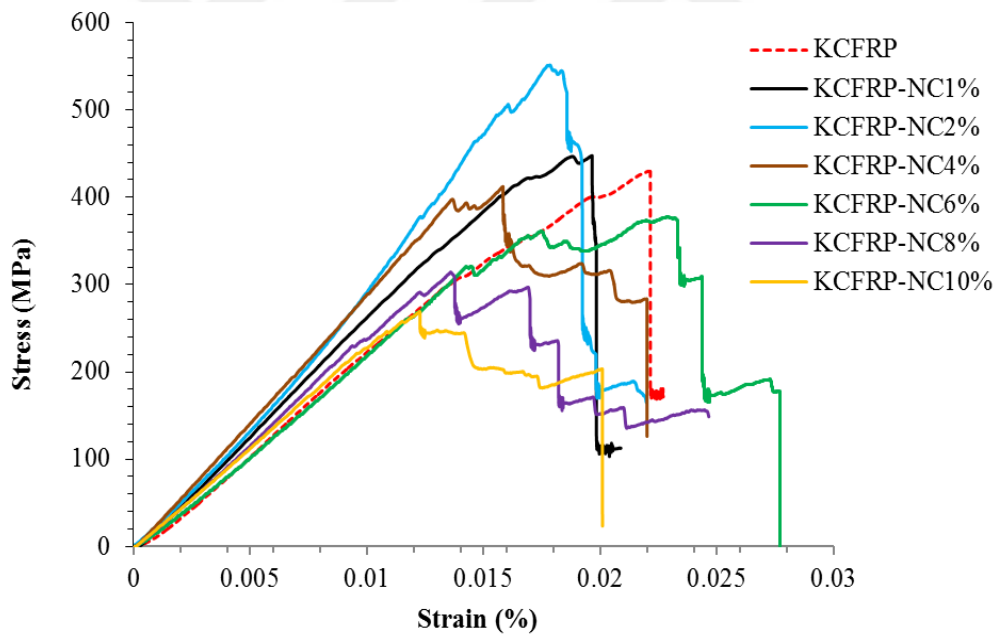


Figure 4.4 Flexural stress-strain curves for KCFRP and Kevlar/carbon/epoxy Nano clay hybrid composite

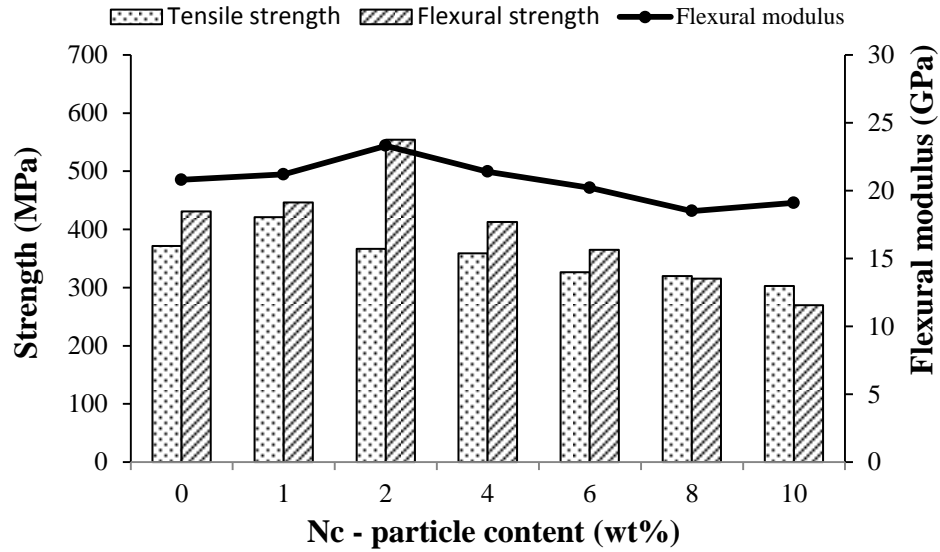


Figure 4.5 Tensile strength, flexural strength and flexural modulus versus Nano-clay particle content of Kevlar/carbon/epoxy Nano clay composites.

Table 4.3 displays the tensile and flexural properties of CKFRE and CKFRE-NC composites for various NC contents. The flexural of unmodified CKFRE composite was increased after insert of NC particles (Figure 4.4) and the maximum improvement was 28.5% at particle content of 2 wt%. Moreover, the elongation at break was also increased with the addition of NC particles that means the inclusion of NC in the CKFRE laminate can increase the ductility of the specimens.

4.4 Fracture Properties of the Hybrid Laminates

The mutual failures under flexural loading contain compressive failure, tensile failure, shear and/or delamination, wherein failure by compression is the most common. The fail of a hybrid composite is dependent on the maximum bending moment that the individual constituent material could carry. To provide the damage mechanism of the present specimen after flexural test, some images were taken on the breaking surfaces of the hybrid composites as given in Figure 4.6.

Table 4.2 Tensile and flexural properties of Carbon/Kevlar reinforced epoxy composite modified by Nano-clay particles.

Composite Type	NC Content (wt%)	Elongation at break (%)	Tensile Strength (MPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)
CKFRE	0	3.04 (± 0.09)	372 (± 07)	431 (± 10)	20.8 (± 0.41)
CKFRE-NC ₁	1	3.10 (± 0.72)	421 (± 03)	444 (± 14)	21.2 (± 0.56)
CKFRE-NC ₂	2	3.22 (± 0.75)	366 (± 08)	554 (± 12)	23.3 (± 0.12)
CKFRE-NC ₄	4	3.69 (± 0.50)	358 (± 11)	412 (± 12)	21.4 (± 0.62)
CKFRE-NC ₆	6	3.58 (± 0.12)	326 (± 09)	364 (± 06)	20.2 (± 0.46)
CKFRE-NC ₈	8	4.15 (± 0.43)	319 (± 08)	315 (± 17)	18.5 (± 0.75)
CKFRE-NC ₁₀	10	4.44 (± 0.58)	302 (± 06)	270 (± 15)	19.1 (± 0.59)

Crack of flexural test



(1% w) Nano clay



CKFRE



(2%w) Nano clay



(4%w) Nano clay



(6%w) Nano clay



(8%w) Nano clay

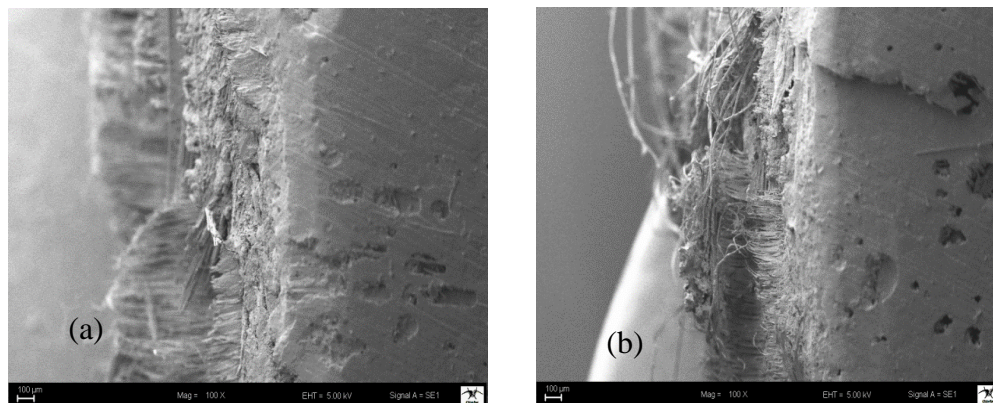


(10%w) Nano clay

Figure 4.6 Failure surfaces of hybrid laminates after flexural test

The fractured surface of the tensile specimens was also observed using SEM micrographs for NC particle content of 1, 4, 8 and 10 wt%, as presented in Figure 4.7. SEM images indicate the bonding among Nano-clay, epoxy and carbon/Kevlar fibers. The samples of 1 wt% NC exhibited strong adhesion of the NC/epoxy and the carbon/Kevlar fibers (Figure 4.7(a)).

As obvious in Figure 4.7 (b), (c) and (d) for the specimens of 4, 6 & 10 wt% NC, respectively, the interface bonding is weak between the NC/epoxy and carbon/Kevlar fibers. In addition, these images show the fiber pull-out increased due to weakness of the CKFRE-NC composite systems. Hence, when the viscosity of the resin increased at high NC particle contents, the wetting out of the composite layers was reduced [65].



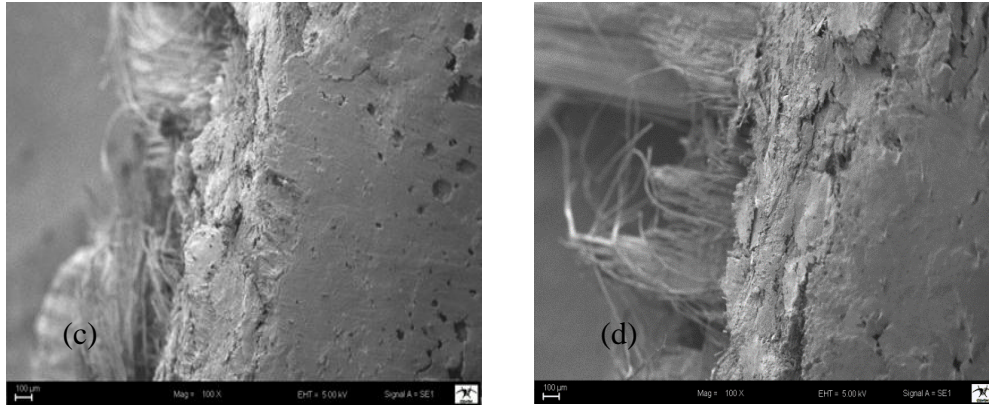


Figure 4.7 SEM images of (a) 1 wt% NC, (b) 4 wt% NC, (c) 6 wt% NC, (d) 10 wt% NC-dispersed CKFRE samples

4.5 Vibration Properties

The results obtained from the vibration test of CKFRE-NC composite specimens are illustrated in the Tables 4.4. The frequency response curves are shown in Figure 4.8. The loss modulus and storage modulus results are depicted in Figure 4.9. It was noted that for all Nano-clay particle contents the first mode natural frequency of the composite was dominant. The maximum amplitude and natural frequency were increased with increase of Nano-clay inclusion within CKFRE composite.

Therefore, the highest increment of maximum amplitude and natural frequency were 22.7 % of Nano-clay particle content of 10wt%. The specimens of 1wt% Nano-clay content exhibited the maximum storage modulus with increment of 24.5 %, while specimens with Nano-clay content of 4 wt% had the highest loss modulus with increment of 70.0 % compared to CKFRE composite. In accordance with equation 4 (given in chapter 3) that stiffness and natural frequency have a direct proportional correlation, it is found that stiffness of the CKFRE composite specimen increase with the increasing of Nano-clay content. That, in general, the damping ratio decreases with increasing of natural frequency [66].

Table 4.4 Vibration properties of Kevlar\carbon \Epoxy composites

Composite Type	NC Contet (wt%)	Natural Frequency, ω_n (Hz)	Damping ratio, ξ	Storage Modulus, \bar{E} (GPa)	Loss modulus, \ddot{E} (GPa)
CKFRE	0	77.62	0.200	3.027E+10	1.211E+10
CKFRE-NC ₁	1	84.23	0.220	3.650E+10	1.606E+10
CKFRE-NC ₂	2	82.58	0.230	3.631E+10	1.670E+10
CKFRE-NC ₄	4	84.99	0.370	3.195E+10	2.364E+10
CKFRE-NC ₆	6	82.58	0.350	3.080E+10	2.156E+10
CKFRE-NC ₈	8	90.83	0.240	2.713E+10	1.302E+10
CKFRE-NC ₁₀	10	95.23	0.220	2.517E+10	1.108E+10

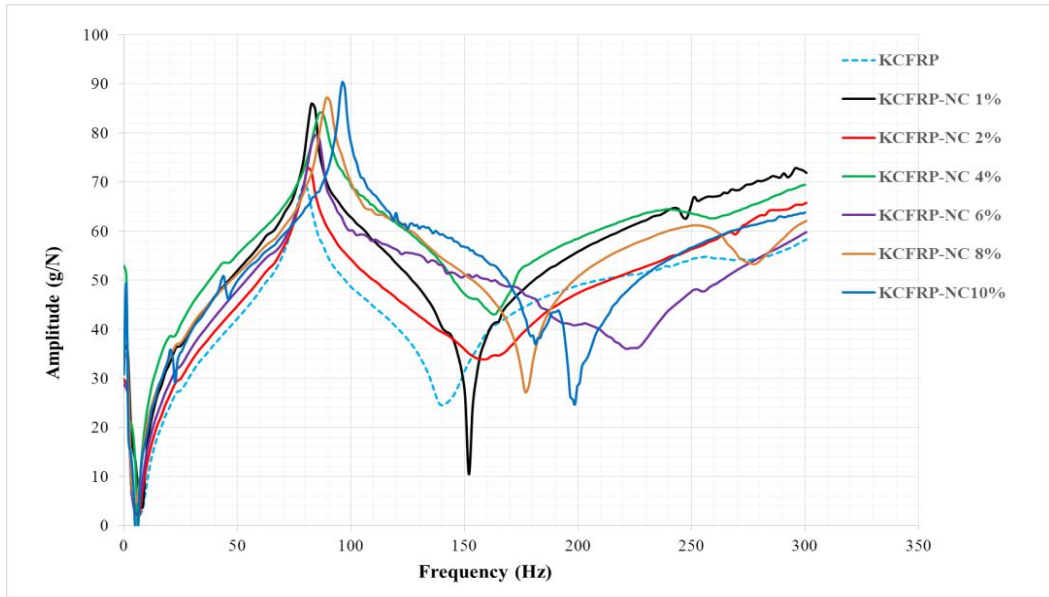


Figure 4.8 Vibration test curves for Kevlar/carbon Nano clay composites

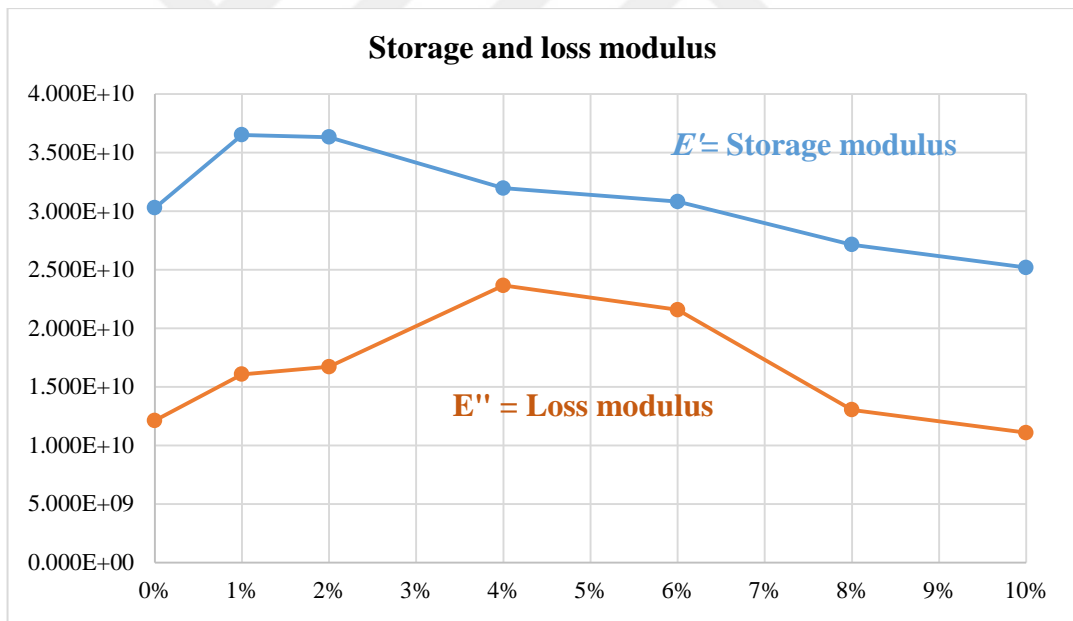
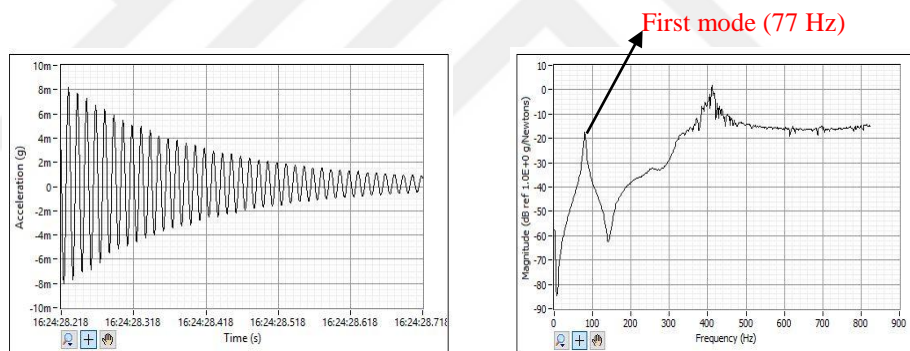


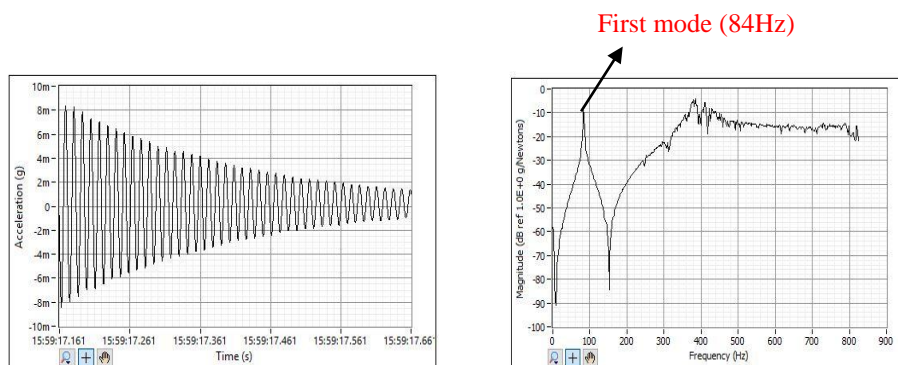
Figure 4.9 Storage and loss modulus for Kevlar/carbon Nano clay composites

The effects of Nano-clay content at the time-dependent acceleration variations are demonstrated in Figure 4.10. In order to figure out the damping properties of the CKFRE-NC composite specimens, the time decaying curves were recorded within

one second. It was observed that the incorporation of Nano-clay particles were improved damping ratio for all Nano-clay contents and reached maximum at 4 weight% with increment of 70.0 % compared to unmodified CKFRE composite specimens. That can be related to the large variation of stiffness between additives and matrix. It has been found in previous studies considerable resemblance between them and this study, Kabir. [49] Ultimate 16.8% improvement within the flexural storage modulus was accomplished for adding up to a pair of wt.% Nano clay in the simplex laminate, Ludwigson et al. [66] indicated that the effective damping ratio results could be affected by the matrix dislocations during manufacturing of laminate. That, in general, the damping ratio decreases with increasing of natural frequency. Iqbal et al. [67] investigated the effect of Nano-clay on the impact harm resistance of carbon fiber- epoxy composites using the low-speed impact and compression. They showed as optimum clay content is 3 wt% for the highest impact resistance.

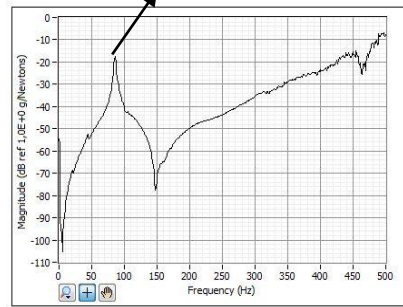
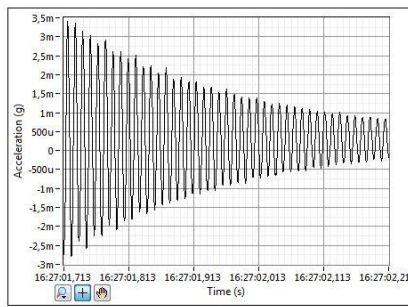


Vibration test frequency for CKFRE



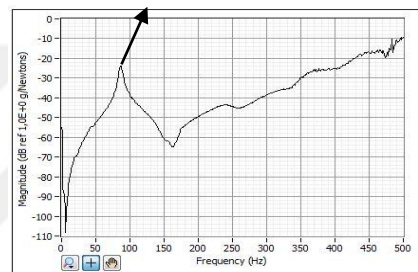
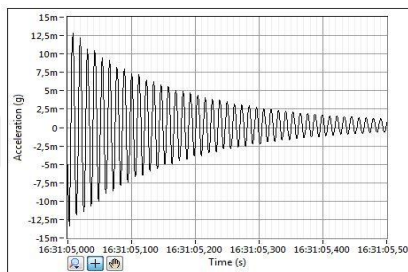
Vibration test frequency for 1%W Nano clay

First mode (82Hz)



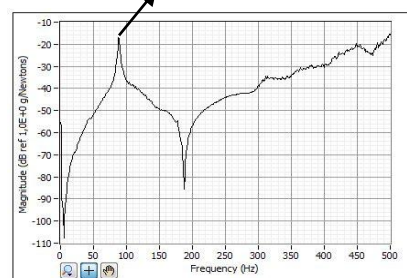
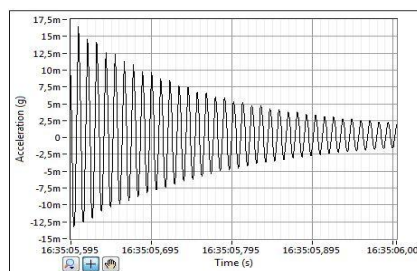
Vibration test frequency for 2%W Nano clay

First mode (85Hz)

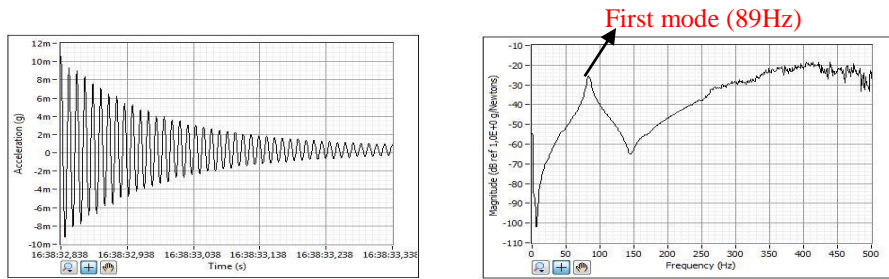


Vibration test frequency for 4%W no clay

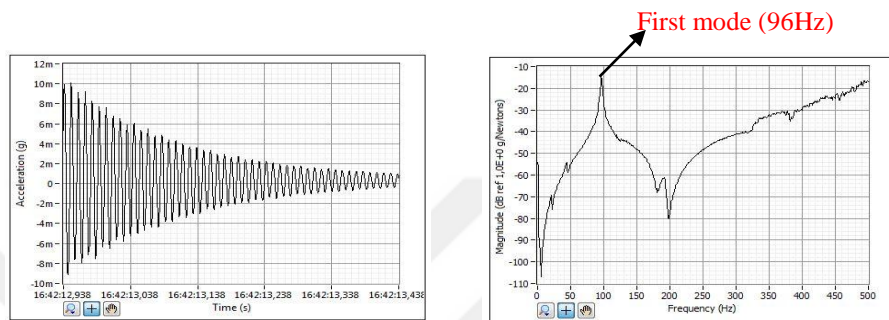
First mode (84Hz)



Vibration test frequency for 6%W Nano clay



Vibration test frequency for 8%W Nano clay



Vibration test frequency for 10%W Nano clay

Figure 4.10 Time dependent acceleration responses of CKFRE-NC composite Specimens

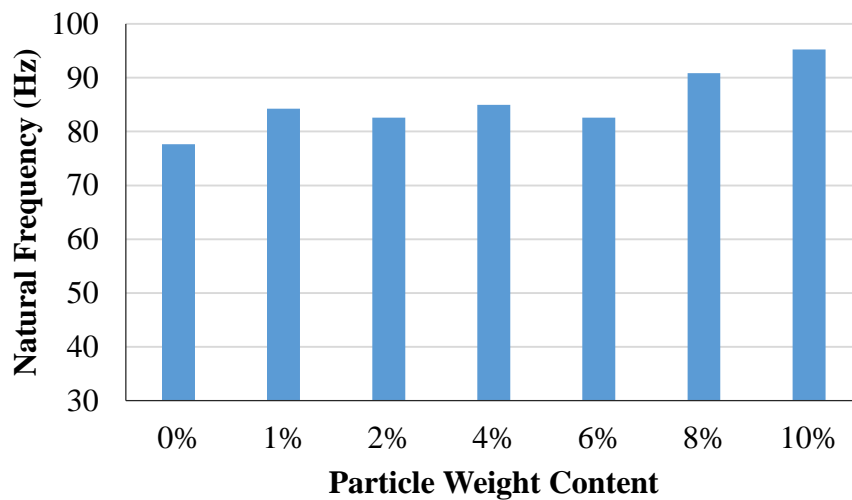


Figure 4.11 Natural frequency for Kevlar/carbon Nano clay composites

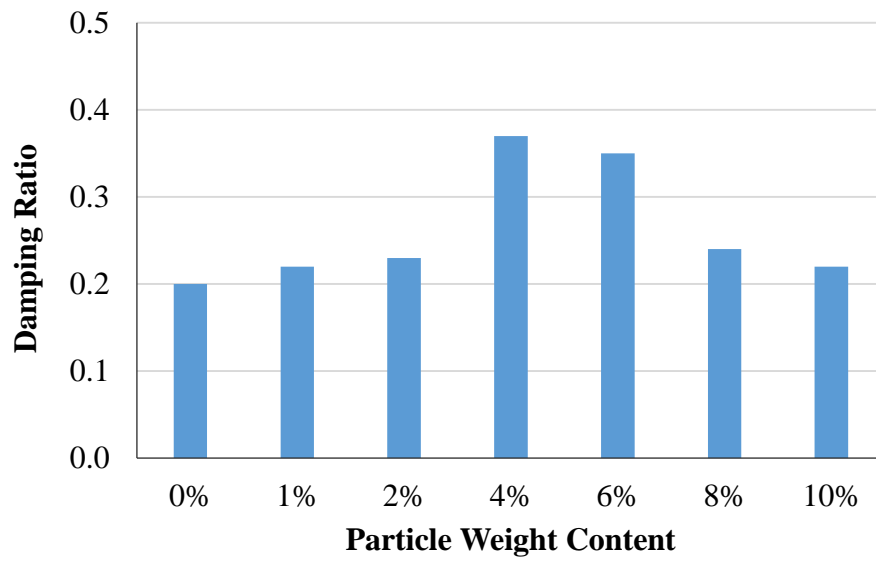


Figure 4.12 Damping ratio for Kevlar/Carbon Nano clay composite

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

This study figure out the sake of consolidate Kevlar-Carbon fiber with Nano clay particle and in addition, inspected the influence it on the tensile and flexural properties of the hybrid composite. Intraply hybrid composites have eight layers of Kevlar-Carbon fabrics were examined for their tensile and flexural properties. Experimental results can be seen the dominant fail technique was compressive failure-mode. The effect of Nano-clay contents of 1, 2, 4, 6, 8 and 10% wt on tensile, flexural and vibration properties of the intraply carbon-Kevlar fiber reinforced epoxy composites were inspected.

Main results may be summarized as:

Higher tensile, flexural strengths, modulus and vibration damping were obtained with (1wt% Nano clay), (2 wt% Nano clay), (4 wt% Nano clay) showing the better tensile, flexural strength and vibration from among unfilled composite respectively.

For Kevlar-Carbon/epoxy the flexural strength and vibration follows the trend: KCFRP- 1wt% Nano clay – 2wt% Nano-clay – 4 wt% Nano-clay – 6 wt %Nano-clay – 8wt% Nano-clay -10 wt% Nano-clay .

The highest improvement of the tensile & flexural strength was obtained at Nano-clay content of 1.0 and 2.0% wt with maximum increment of 13.1% and 28.5%, respectively.

So that figuring out the damping properties of the CKFRE-NC composite samples, the time decaying curves were recorded within one second. It had been observed that the incorporation of Nano-clay particles were improved damping ratio for all Nano-clay contents and reached maximum at 4 weight% with increment of 72.0 % compared to unmodified CKFRE. Hence, the composite vibration damping was increased from 20.0% for unfilled CKRE to reach 37% with Nano clay content of 4.0 weight%, and vibration modulus has been improved by the addition of Nano clay particles to the CKRE. Hence, the vibration modulus was increased from (12.11GPa) for unfilled CKRE to reach (23.64 GPa) with Nano clay content of 4.0 weight%, with maximum increment of 95%.

The vibration and damping properties were improved by the addition of Nano-clay particles in the CKFRE composite. The first mode frequency and natural frequency were considerably increased up to Nano-clay content of 10% wt. In addition, the storage modulus, loss modulus and damping ratio reached to highest values at Nano-clay content of 1, 2 and 4% wt , respectively, more than 4% , with maximum increment of 20% , 95% and 72% respectively, then followed the trend of decreasing.

5.2 Future Works

Although carbon- Kevlar fibers are utilized in this study, the methodology is convenient for other fiber varieties provided that they need various strains-to-failure. Future work has multiple aims and is perfect study is required to achieve the best design on the requirement of optimum and durability. In future, the study will be extended to new polymer composites having totally various fabrics/matrix combinations and thus it'll be investigated within the experimental results.

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