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M.Sc. in Mechanical Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

THE EFFECT OF HYBRIDIZATION ON THE MECHANICAL PERFORMANCE OF CARBON/ARAMID EPOXY FABRIC COMPOSITE

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Humam Mezher FLAYYIH

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Humam Mezher FLAYYIH

ABSTRACT

THE EFFECT OF HYBRIDIZATION ON THE MECHANICAL PERFORMANCE OF CARBON/ARAMID EPOXY FABRIC COMPOSITE

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The effects of hybridization with glass layers on the mechanical and vibration properties of carbon/aramid hybrid composites were investigated. In order to determine the effect of the hybridization on the mechanical properties of carbon/aramid, pure carbon/aramid epoxy and pure glass/epoxy composite laminates were compared with hybrid composites. The results showed that the replacing of S-glass fibers with carbon/aramid fibers in the composite laminate could give enhancements in the flexural properties while the hybridization showed negative effect on tensile characteristics. Moreover, the results of flexural test were found that when putting S-glass fibers on the compressive side of composite laminates were realized important enhancements for flexural properties in contrast with the putting carbon-aramid fibers on tensile side. Utilizing the half power band-width technique, the damping characteristics were deduced from the vibration response envelope curve. Loss modulus, storage modulus and damping ratio of the structures were also calculated. It was observed that the result of hybrid configuration could provide improvements in the vibration characteristics.

Keywords: Hybrid composites, flexural modulus, tensile strength, vibration.

ÖZET

HİBRİDİZASYONUN İÇ İÇE DOKUNMUŞ KARBON/ARAMİD-EPOKSİ KOMPOZİTLERİN MEKANİK PERFORMANSINA ETKİLERİ

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Karbon/aramid kompozitlerinin cam elyafla hibridizasyonun mekanik ve titreşim özellikleri üzerine olan etkileri araştırılmıştır. Hibridizasyonun karbon / aramid mekanik özellikleri üzerindeki etkisini belirlemek için saf karbon / aramid epoksi ve saf cam epoksi kompozitler hibrit kompozitlerle karşılaştırılmıştır. Sonuçlar, kompozit plaka içerisinde S-cam elyaflarının hibrit karbon / aramid elyaflarla değiştirilmesinin eğilme özelliklerinde iyileştirmeler ve yüzde değerinin gerilme özellikleri üzerinde olumsuz bir etki sağlayabileceğini ortaya koymuştur. Ayrıca, eğilme testi sonuçları, kompozit plakaların bası tarafına S-cam elyafı yerleştirildiğinde, çekme tarafında karbon-aramid elyafların yerleştirilmesinin aksine eğilme özelliklerinde önemli iyileştirmeler görülmüştür. Yarım güç band genişliği tekniğini kullanarak sönümlenme özellikleri, titreşim tepki zarf eğrisinden türetildi, yapıların kayıp modülü, depolama modülü ve sönüm oranı da hesaplandı. Hibrit konfigürasyon sonucunun titreşim özelliklerinde iyileştirmeler sağlayabileceği gözlemlenmiştir.

Anahtar Kelimeler: Hibrit kompozitler, eğilme modülü, gerilme mukavemeti, titreşim.

This thesis is dedicated to my beloved mother, father, brother and sisters for their endless love, support and encouragement.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Composite materials have been used for various applications for hundreds of years. There is no specific date shows the first use of composite materials. The oldest known history retreats to the Egyptians, who is credited with info plywood, utilize a straw in the mud to bolster the blocks. Similarly, the old Inca and Mayan civilizations utilized put fibers to support, blocks and earthenware [1].

Composite materials can be defined as a system made out of at least two phases, whose properties and features higher than the original components. The two phases are a strengthening and a binder. The most important features of composite materials are their high stiffness and strength, with low density, when contrast with bulk materials, taking into weight diminishment in the completed part. The reinforcing part works to give stiffness and strength. Generally, the support is harder, more grounded, and stiffer than the matrix. The support is normally a fiber or a particulate.

Most fiber widely used are carbon, glass and aramid. Carbon fibers are brittle and has high specific strength, corrosion resistant, good fatigue resistance and good tensile strength. It can be described a glass fiber as a one of the most important composites that have a good temperature resistance, lightweight, heat-insulation, flexibility and good stability. While aramid has high strength, good fabric integrity at elevated temperatures, resistance to absorption and abrasion damage, no melting point [2].

The other part is the matrix, it is often a polymer and it can also be ceramic, or metal. The matrix has great significance to maintaining the fibers in the proper orientation and transfers the load between the fibers [3].

A material is mostly stronger and stiffer in fiber form than in bulk form. The quantity of microscopic flaws that go about as fracture initiation sites in bulk materials are diminished when the material is drawn into a thinner section. In fiber frame the material will ordinarily contain very few microscopic flaws from which cracks may initiate to produce catastrophic failure. Therefore, the strength of the fiber is greater than that of the bulk material. [1, 2]

The individual fibers are difficult to control and form into useable components without a binder material to separate them, they can get to be knotted, twisted, and hard to separate. The binder material must be continuous and surround each fiber so that they are kept distinctly separate from contiguous fibers and the entire material system is less demanding to handle and work with.

The physical and mechanical properties of composites are reliant on the properties, geometry, and concentration of the constituents. Increasing the volume content of reinforcements can increase the strength and stiffness of a composite to a point. If the volume content of reinforcements is too high there will not be enough matrix to keep them discrete, and they can get to be tangled. Similarly, the geometry of individual reinforcements and their arrangement within the matrix can affect the performance of a composite. [4]

There are a lot of factors that must be introduced in the design of composite materials. The type of reinforcement and matrix, the geometric arrangement and volume fraction of each constituent, the expected mechanical loads, the operating environment for the composite, etc., must be taken into account.

1.2 Definitions of Hybrid Composite

Recent decades have witnessed a significant increase in the use of hybrid material because of its properties that exceed those individual material constituent [5]. Hybrid composite material is produced by using at least two distinctive support materials in a same binder. And this is the production of new material with better characteristics. [6].

Motivation behind hybridization is to make such that raise a resistance across the interlinear toughness that can't be acquired with just customary composite material [7]. Hybrid composites offer the most ideal method for improving the ultimate strain and impact characteristics with reducing the total cost of production. [8].

There are three main types of hybridization:

- Intraply hybrids, comprising at least two distinctive fibers blended in the same ply.
- Interply-intraply hybrids, in which interply and intraply hybrids are placed as indicated by specific arrangement.
- Super hybrids that are resin-matrix composite plies are placed as indicated by specific arrangement.

1.3 Definitions of Tensile, Flexural Strength and Damping, Vibration Characteristics

Tensile strength is the measurement of a material withstand up to specimen failure. It is measured in units of force per cross-sectional area. It is considered one of the most important concepts of structural and mechanical engineering. Basically, the tensile strength have a three kinds:

- Yield strength - Material ability of the resistance to deform without a change in the original dimensions
- Ultimate strength - The highest point can material reach them before failure.
- Breaking strength - The stress coordinate on the stress-strain curve at the point of rupture.

Materials generally have two candidates toward failure:

- Ductile failure - Material first pass yield phase, then fail when the limit of "neck" point
- Brittle failure - the failure happens suddenly to many pieces without "neck" stage.

Meanwhile, the flexural strength as the resistance of material to the forces of bending before the failure. When the material to be under the influence of a flexural forces to be exposed to tensile on the one side and compressive on the other side. Flexural strength of a material will count on either its compressive strength or tensile strength, whichever is lesser. Most basic cases of a flexural anxiety are by twisting an example into a U shape. The upper surface of the example will be subjected to compressive anxiety while base surface will experience pliable anxiety. On the off chance that it is twisted further, the base surface of the example will begin to break, which shows that it the anxiety connected to it is past its flexural quality. Free damped vibration can be defined as the single degree-of-freedom spring-mass system portrayed above, once set into movement, would keep on moving here and there until the end of time. Free damped vibration in principle, the single degree-of-freedom spring-mass system, once set into movement, would keep on moving here and there for eternity.

1.4 Importance of the Study

Several authors advocated composites and hybrid composites as an important factor in in designs because of the light weight with good characteristics and the capacity to solve the industrial problems. This is especially valid for applications that needs strength under hard conditions such as aerospace, automobile, and infrastructure industry. The high mechanical, physical and chemical properties are accomplished using composites and hybrid composites. Composite material has a lot of advantages that make it to the fore, such as a weight reduction, corrosion resistance, wear resistance, part-count reduction, easy of handling, excellent damage tolerance and impact resistance greater specific strength (high strength with less weight or more generally, it has high stiffness with less weight), enhanced fatigue life and low thermal expansion. 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.

1.5 Methods and Outline of the Study

In this work, interply hybrid composites were prepared with carbon/aramid fiber and glass fiber as reinforcements and epoxy resin as matrix. Then from these hybrid composite laminates, specimens for tensile, flexural and vibration tests should be prepared with dimensions as per ASTM standards.

The study has been divided into 5 chapters.

General introduction and definitions of composite materials and hybrid composites, tensile and flexural strengths are given in the first chapter. First chapter also includes the importance of the study and outline of the study.

The second chapter is divided into six sections; Introduction, studies on composite laminates and some factors effect on their characterization, studies of the intreply hybrid effect of the general mechanical properties, studies of the intraply hybrid effect of the general mechanical properties, studies on vibration properties of composite material and conclusion on literature review.

In chapter 3, Information about designed, production unit and production methods of composite are given. Also mechanical properties, standards and test methods to resolve these mechanical characteristics are given in this chapter.

Tensile, flexural and vibration experiments and the results which were conducted to see the effects of different hybrid configurations of these properties are given in chapter 4 for different fiber stacking configurations. General conclusions and future works are given in chapter 5.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

A brief literature review related to composite, hybrid composite materials, tensile, flexural and vibration characteristics of composite materials is presented in this chapter. The literature review is given in this chapter, it's divided into six sections; Introduction, studies on composite laminates and some factors effect on their characterization, studies of the intreply hybrid effect of the general mechanical properties, studies of the intraply hybrid effect of the general mechanical properties, studies on vibration properties of composite material and conclusion on literature review.

2.2 Studies on Composite Laminates and Some Factors Effect on Their Characteristics

There are many factors affect the properties of laminate composites which cannot be confined to such research, but some of them can be mentioned:

Oktan et al. [9] explored the impacts of woven fiber and the proportion of edge separation to the gap distance across (E/D) on the bearing strength of woven laminated composites. Glass/epoxy composites were created by compressing at 120C. The glass/epoxy woven composites were put over the pins. The exploratory outcomes demonstrate that a definitive load limit of woven-glass-fiber, reinforced epoxy laminates with pin contact. However, expanding the E/D proportion beyond 2 and expanding the W/D proportion beyond 3 insignificantly affects a definitive load ability of the association.

Yousif et al. [10] studied the flexural characteristic of long kenaf fiber reinforced epoxy (KFRE) composites. The kenaf fibers were created in two sorts as additive and non-additive (with 6% NaOH). The outcomes demonstrated that fortification of epoxy with additive kenaf fibers expanded the flexural by around 36%, while non-additive fibers presented 20% increment.

Suresha et al. [11] studied the three-body abrasive wear conduct of carbon and glass fiber fortified epoxy composites. The used surface components have been analyzed utilizing scanning electron microscope (SEM). SEM micrographs of wearied composite samples uncovered the higher rate of crush glass fiber contrasted with carbon fiber furthermore superior interfacial attachment amidst the epoxy and carbon fiber. Glass fibers in epoxy framework crushed into little pieces and expelled effectively, though the carbon fiber and epoxy matrix indicated less wear out. This outcome uncovered superior interfacial grip amidst carbon strands and epoxy when contrasted with the bond amidst glass filaments and epoxy.

Esmael et al. [12] studied the examination of e-glass /epoxy & e-glass /polyester composites for auto body panel. The compressive, shear and flexural properties of e-glass/epoxy composite have an increasing trend when the strain rate is increasing; whereas the tensile strength diminishes as the strain rate increments. On the status of e-glass/polyester composite, the tensile strength and compressive strength expansion as the strain rate expansion and the in-plane shear and flexural strength show a diminishing trend as the strain rate increments. SEM observation indicates the main problem of E-glass reinforced with epoxy and polyester is that fiber pull-out and delamination.

Deogonda and Chalwa [13] studied the mechanical property of new polymer composites comprising of glass fiber support, epoxy matrix and filler material such as TiO_2 and ZnS. The outcomes demonstrate that higher the filler material volume rate more than the strength for TiO_2 and ZnS filled glass epoxy composites, ZnS filled composite demonstrate extra keeping up qualities than TiO_2.

Reddy et al. [14] investigated the ballistic execution of an E-glass/phenolic composite as an element of plate thickness and projectile impact velocity utilizing mellow steel core projectile. The outcomes demonstrated that there is a nonlinear relation between the energy absorption and plate thickness. It is additionally attended that disfigurement of the projectile is more reliant on the objective thickness than the strike speed.

2.3 Studies on Intreply Hybrid Effect of the General Mechanical Properties

Zhang et al. [15] studied the mechanical practices of flax and glass fiber strengthened hybrid composites. The tensile characteristics of the hybrid composites were redesigned with the expanding of glass fiber content. The stacking arrangement was appeared to clearly impact the tensile strength and tensile failure strain, but not the tensile modulus. Each of interlaminar shear strength and fracture toughness of the hybrid composites were much higher than those of glass fiber reinforced composites on account of the superior hybrid achievement of the hybrid interface.

Sarasini et al. [16] investigated the effects of basalt fiber hybridization on low velocity impact conduct of carbon/epoxy overlays. Interply hybrid examples with two distinctive stacking arrangements (sandwich-like and intercalated) are tested. Results demonstrated that hybrid overlays with intercalated structure (exchanging grouping of basalt and carbon textures) have better impact energy absorption capability and upgraded damage tolerance with concern the all-carbon laminates.

Li et al. [17] studied the flexural and compressive properties of ultra-high-models polyethene fiber and carbon fiber with epoxy resin as a matrix. The result exhibited that the consolidation of direct amount of carbon fiber into UHMPR-fiber-reinforced composite incredibly upgrades the compressive strength, flexural strength and flexural modulus while the expansion of little of UHMPE fiber into carbon-fiber-fortified composite to amazingly upgrade the pliability with only a little decline in the compressive strength. .

Mehmood et al.[18] investigated the hybridization effect of the glass and carbon fiber on mechanical characteristics of epoxy based composites. The results have clearly shown the depending upon the ratio of the two fibers present. The mechanical properties extended as relative the extent of carbon diminished. The carbon fiber and glass fiber present in the epoxy showed multiple failure modes especially at lower carbon properties.

Zhang et al. [19] researched how the glass/carbon hybrid composites affected by changing the stacking arrangement of on the strength for lightweight load bearing structures. Hybrid composite overlays were made utilizing a fluctuating proportion of glass woven texture and carbon woven texture in an epoxy matrix. Static tests, including three types, compression, flexural and tension tests were done with composite coupons containing different proportions of carbon fibers to glass fibers. The outcomes demonstrate that half and half composite covers with half carbon fiber support give the best flexural characteristics when the carbon layers are on the outside, while the rotating carbon/glass lay-up gives the most noteworthy compressive quality. The elasticity is coldhearted to the stacking grouping. Investigative arrangements are additionally created and are appearing to give great relationship the test information, which permit the improvement of stacking grouping of half and half composites to accomplish the most extreme quality.

Valença et al. [20] studied the mechanical conduct of epoxy composite strengthened with Kevlar plain texture and glass/Kevlar hybrid texture. The consequences of the mechanical characteristics of composites were procured by impact, tensile and flexural tests. Composites with Kevlar/glass hybrid structure of the support fabric demonstrated the better outcomes as for mechanical strength, as well as flexural and impact energy.

Jagannatha and Harish [21] investigated the flexural resistance and flexural modulus of each glass and carbon fiber reinforced epoxy hybrid composites. The hardness, flexural strength and flexural modulus were enhanced as a fiber support contents increased in the epoxy matrix material. The carbon fibers have more flexural resistance and flexural modulus than that of the glass and carbon fibers reinforced hybrid composites.

Guermazi et al. [22] investigated the manufacture and characterization of glass/epoxy, carbon epoxy and hybrid laminated composites utilized as a part of the fortifications and the repair of flying structures. The main results come about demonstrating that after water inundation, all composites showed significant moisture absorption particularly for glass/epoxy composite. Thermogravimetric analysis showed that the hybrid composite exhibited the best thermal stability behavior while the glass/epoxy composite the bad behavior. The mechanical characteristics of the carbon/epoxy composites, in the bulk material, were higher than those of glass/epoxy; the hybrid structure introduced intermediate mechanical characteristics.

Jagannatha and Harish [23] researched on the mechanical characteristics of carbon and glass fiber strengthened epoxy hybrid composite. The hybrid composites were produced by changing their enforcements from 15%, 30%, 45% and 60% of glass fiber and carbon fiber in 40% epoxy grid under vacuum pack handle. The miniaturized scale hardness of carbon fiber strengthened composites higher than other composites. The consideration of carbon fiber mat reinforced polymeric composite significantly improved the ultimate tensile strength, yield and peak load reinforced of the composite. The flexibility of carbon fiber reinforced composite is higher than alternate composites.

Prashanth et al. [24] studied flexural strength of glass and carbon fiber reinforced epoxy matrix hybrid composite. Glass fiber reinforced composite essentially has a flexural strength more than carbon fiber fortified composite; this is because of the brittleness of carbon fibers regardless of their high values ultimate tensile strength. The outcome demonstrated that the flexural strength of hybrid composite is highly enhanced when contrasted with glass fiber reinforced composite/carbon fiber strengthened composite.

Naik et al. [25] examined the impact conduct and post impact compressive property of glass-carbon/epoxy hybrid composites with the substitute stacking arrangement. Plain wave E-glass and twill T-300 carbon have been utilized as fortifying material. The outcome demonstrated that hybrid composites are less snick delicate diverged from just carbon or just glass composites. Further carbon-outside/glass-inside grouped hybrid configuration gives bring down snick affectability contrasted with other hybrid arrangements.

Bozkurt [26] investigated the mechanical characteristics aramid/basalt hybrid composite laminates and the effect of intreply hybridization on the mechanical characteristics. The comparison was made between the pure aramid and basalt with aramid/basalt hybrid by changing the stacking arrangement for hybrid composite.

The outcomes demonstrated that the placement of basalt fibers for partial substitution of aramid fibers in the composite laminate could give enhancements in the tensile and same thing for bending characteristics. Moreover, the results of flexural tests showed a significant effect by which fiber and which one in tensile side. The result shows improvement for flexural properties when putting basalt on compressive side.

Park and Jang [27] investigated the bending characteristics of aramid-UHMPE hybrid composites affected by changing the stacking arrangement fibers layers. The flexural strength greatly affected by the fiber types at the compressive side and the scattering degree of fibers. The result shows a positive effect when aramid fiber was at the compressive side and scattering degree of fibers was small. The flexural modulus shows affected by the stiffness of compressive side, but rarely the scattering degree of fibers. For symmetrical laminate case, the result shows enhancement when the aramid fiber position was neighbors at the surface layer of the plat. The stacking arrangement also shows effect in the result.

Bozkurt et al. [28] investigated the charpy impact of basalt/aramid fiber affected by the hybridization. The impact energy of hybrid composite shows increasing when the ratio of aramid layers increases, but the deformation of aramid layer increase in the same time. The increase of basalt ratio shows a reduction in the degree of deformation.

Yahaya et al. [29] studied the mechanical execution of woven kenaf-kevlar hybrid composites. The mechanical characteristic of hybrid composites was seen to be impacted diversely by the Kevlar/kenaf weight proportions. General execution of Kevlar/epoxy is best contrasted with the kenaf/epoxy, which was normal on account of the poor mechanical characteristics of kenaf contrasted with Kevlar. Taking all things together, it was demonstrated that the hybridization influences in intermediate mechanical characteristics of composites diverged from the higher Kevlar/epoxy characteristics and minimal properties of kenaf/epoxy composite.

Pincheira et al. [30] investigated the mechanical conduct of hybrid carbon/aramid reinforced epoxy composite affected by aramid fiber. The results recommend that the enhancements because of the addition of aramid fibers are considerable in the case of energy absorption and fracture properties. The test proved revealed that despite a reduction of the overall stiffness and strength of the material, aramid fibers positively affected the impact and fracture resistance of the composite. This is ascribed to a more ductile response of aramid fiber compared to the carbon reinforcement.

Bandaru et al. [31] studied mechanical behavior of thermoplastic composites reinforced with Kevlar/basalt yarns. The mechanical properties of the laminates were determined using static tensile and in-plane compression tests. Experimental tests showed that the Kevlar/basalt hybrid composites have better tensile and in-plane compressive behavior as compared with Kevlar and basalt composites. Elastic modulus, strength and failure strain in both tension and in-plane compression increased with hybridizing Kevlar composites.

Wang et al. [32] studied the mechanical characteristics each of aramid and glass fibers fortified. Glass fiber reinforced composites showed a low level of nonlinearity and higher strength in flexure, compression, and short beam shear compared Kevlar composites. In addition, it was watched that at comparable fiber volume fractions, the structure of the fortification had a grounded affected the toughness than fiber sort.

Salman et al. [33] experimental compared Kevlar/glass hybrid fibers and carbon/glass hybrid fiber. A comparison, between the test outcomes was evaluated to demonstrate the appropriateness of the hybrid composite material in laminated plate manufacture. The outcomes demonstrated that for a similar number of layers of the hybrid composite laminates which strengthened with carbon/glass fiber give the most elevated amount of the compression stress value by up to 40% contrast with composites fortified with Kevlar/glass fiber.

Shaaria et al. [34] studied the impact of Kevlar/glass fiber hybrid composite laminates. Four different sorts of composite laminates with various ratios of Kevlar to glass fiber (0:100, 20:80, 50:50 and 100:0) were made. The effect of Kevlar/glass fiber content on the impact damage conduct was studied at 43J nominal impact energy. Expansion of Kevlar fiber of glass fiber has enhanced the load conveying ability, energy absorbed and damage degree of the specimen. These results proved that Kevlar showed better resistance towards impact loading.

Abdullah et al. [35] studied the bending property for epoxy/Kevlar-Glass fiber and hybrid composite. The Kevlar fiber and glass fiber strengthened hybrid composites have beneficial effects as material reinforcement, on the grounds that enhance bending resistance. On –reinforced pure Epoxy has lower flexural resistance than (glass / Kevlar) fibers and hybrid composites. Bending test outcome demonstrates that the sample which reinforced (Kevlar - regular glass- Kevlar) characterized the high bending (8mm).The less bending reinforced sample was (regular glass-Kevlar-regular glass) (4.5mm)

Almeida et al. [36] studied the mechanical characteristics of curaua/glass fiber affected by hybridization. The tensile strength and elastic modulus expanded upon glass fiber consolidation and for higher volume fraction. This conduct is generally because of the greater strength and stiffness of the glass fiber in connection to curaua and the superior adhesion of the former with the polyester resin. In general, hybridization was adequately done and the mechanical properties showed middle lead between the immaculate glass and unadulterated curaua composites, here and there near the immaculate glass fiber composites. Among the contemplated composites, the 30 vol.% a general substance with 30% of curaua and 70% glass fiber demonstrate a perfect general execution..

Muhammad et al. [37] investigated the effect of hybridization on the compressive characteristics of woven carbon, glass and kevlar hybrid composites. The presence of Kevlar fiber enhanced the characteristics of glass fiber composites. Glass/Kevlar Hybrid composites have better properties such as stiffness, ductility and strength that cannot be carried out by single fiber reinforced, composites alone. Setting carbon layers on the outside and Kevlar layers on the inside gave higher compressive strength compared to putting glass layers in the outside and Kevlar layers on the inside. The presence of carbon and glass fibers at the outside layers results in improvement of compressive properties of Kevlar composites. In addition, the presence of Kevlar fiber in the inner layers resulted in a better failure mode of the hybrid composites when compared to their pure systems.

Shaaria et al. [38] investigated the hybridization effect on bending characteristics of epoxy woven Kevlar/glass and carbon/glass composites. Hybrid laminates based on carbon/glass fiber and Kevlar/glass were then produced utilizing a hand lay-up method and tested. The result proved that the kevlar fiber more suit with glass, when the flexural modulus decrease with carbon/glass but increase with glass Kevlar/glass and the same thing happened with flexural strength.

Subagia et al. [39] investigated the effect of arrangements laminate changing on the bending characteristics of hybrid composites fortified with carbon and basalt fibers. The present outcomes demonstrated that the flexural strength and modulus of hybrid composite shows an actively reliant on the arrangements laminate changing of fiber reinforcement. All the arrangements demonstrated a positive result. And the other important thing was when putting carbon fiber on the compressive side showed higher flexural characteristics than basalt fabric.

Dorigato and Pegoretti [40] studied the flexural and impact conduct of carbon/basalt and carbon/E-glass fibers hybrid laminates. The flexural modulus of the composites relied on upon their installation allow to a rule of mixture, while a significant agreeing effect was recognized for the ultimate bending characteristics. The charpy impact test proves a strength increment as basalt and glass fiber content expanded. Hybridization with basalt fibers advanced an expansion of the adsorbed impact energy because of an improvement of the fracture propagation component.

Karahan et al. [41] studied the effects of carbon fiber addition to carbon-aramid hybrid and the weaving structure effect on the mechanical characteristics of carbon-aramid hybrid. In view of a similar fiber volume fraction, Young’s modulus diminishes by 34% in the warp orientation and 39% in the fill orientation because of the expanded yarn crimp. The tensile strength diminished by 27% in the warp orientation and by 24% in the fill orientation upon the expanded yarn crimp

2.4 Studies on Intraply Hybrid Effect of the General Mechanical Properties

Dehkordi [42] examined impact damage conduct and leftover compression strength of intraply basalt/nylon hybrid composites affected by hybridization. Five distinct sorts of woven fabric with various substances of nylon (0%, 25%, 33.3%, 50% and 100%) were utilized as reinforcement. The outcomes show that at low impact energy, hybridization and variation in basalt/nylon fiber content cannot enhance the impact execution of composite laminates. With expanding impact energy, the impact execution shows a big affected by nylon and basalt increasing ratio.

Vaughan and McCarthy [43] studied the micromechanical properties with effect of intraply characteristics on transverse shear deformation of a carbon fiber/epoxy composite. The micromechanical model created indicates comparable conduct to in situ experimental observations and could accordingly demonstrate valuable in deciding ideal constituent characteristics allowing for expanded interlaminar shear strength of fiber reinforced composite laminates.

Belingardi [44] studied the bending fatigue conduct of intraply biaxial glass–carbon laminate in addition biaxial glass laminate and biaxial carbon laminate. The results showed the possibility of using glass–carbon hybrid composites a basis for the structural design of components because of it has a good fatigue conduct and the leftover mechanical characteristics of the tested.

Dong and Davies [45] worked on the flexural and tensile moduli of S-2 glass and T700S carbon fiber fortified hybrid epoxy composites in intra-ply arrangements. The results demonstrate that flexural modulus shows appositive affective by the span-to-depth ratio increment, it expanded from 16 to 32 and becomes stable as the span-to-depth ratio advance increments. Since the modulus of carbon fibers is much upper than that of glass fibers, both bending and tensile moduli diminish with expanding hybrid volume. From the pure carbon/epoxy laminate, when a carbon/epoxy lamina close to the near the furthest surface of the overlay is supplanted by glass/epoxy lamina, the flexural modulus reduces rapidly.

Dong and Davies [46] studied on the flexural characteristics of E glass and TR50S carbon fiber strengthened hybrid composites. Specimens were made with changing degrees of the glass fiber ratio of the surface of a carbon laminate. Demonstrated that positive hybrid effects exist for the flexural strengths of most of the hybrid arrangements. The hybrid effect shows that the decrement of hybrid ratio, which might be credited to the relative position of the GFRP layer(s) regarding the neutral plane.

Pegoretti et al. [47] explored the mechanical characteristics of Intraply and interply hybrid composites in light of E-glass and poly (vinyl alcohol) woven fabrics. In this study the results were obtained through two tests impact and tensile test. For tensile test the better results achieved from symmetric interply hybrids with E-glass layers. While the Impact test shows that hybrid intraply composites reached higher ductility index value. When E-glass and PVA fibers intimately mixed with a similar layer.

Park and Jang [48] studied on the flexural, shear strength and impact characteristics of aramid/polyethylene intraply fabric composites affected by hybridization. The mechanical performance of these composites has been considered as a component of aramid fiber substance and loading direction. Two different stacking sequences ($[0/0]_4$ and $[0/90]_4$) were selected for this study, and composites of four different aramid fiber contents (100, 75, 50, and 0% by volume) have been studied. For the flexural strength and modulus the result shows expand with the aramid fiber ratio expand. Intraply hybrid composites exhibited lower impact resistance than aramid fiber composites because the level of maximum load had a major effect on the impact absorption energy.

Dong and Davies [49] studied the flexural characteristics of glass and carbon fiber fortified epoxy hybrid composites. The samples were made by changing of glass fibers adding ratio to the surface of a carbon plate .The addition of glass fiber to the carbon fiber shows the positive effect also when putting GFRP on the compressive surface highest the bending strength was increased.

Dong and Davies [50] examined the bending strength of hybrid epoxy composites fortified by the S-2 glass and T700S carbon fibers in an intra-ply configuration, different stacking arrangement of carbon fiber (C) and glass fiber (G) laminas were studied as shown in the Figure 2.1 .The bending strength was acquired from the flexural test at various span-to-depth ratios as described in the Figure 2.2 .It was demonstrated that the bending strength increments with span to-depth ratio and converges when the span-to-depth ratio is more than 32. Also, it was demonstrated that hybridization, can be utilized to enhance the flexural quality.

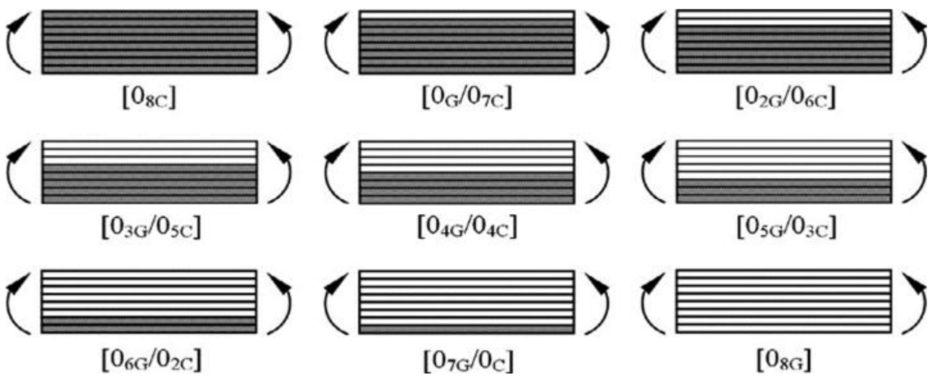


Figure 2.1 Stacking arrangement of carbon fiber (C) and glass fiber (G) laminas [50].

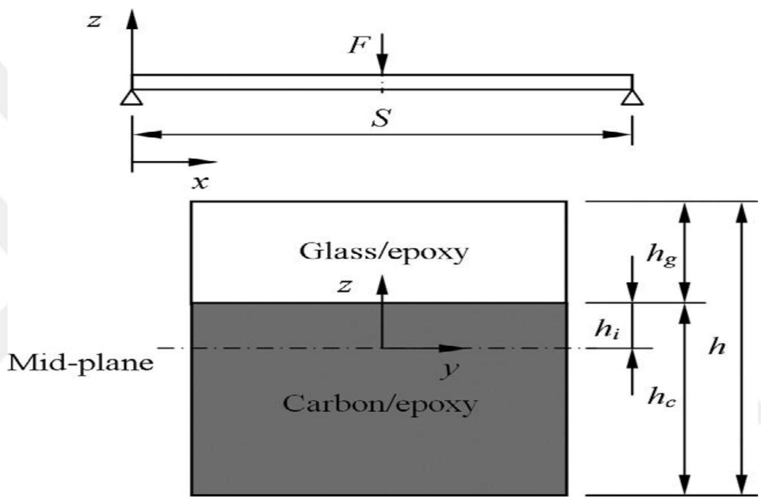


Figure 2.2 A hybrid composite specimen in the three point bending [50].

Swolft et al. [51] studied the tensile behavior of intralayer hybrid composites of carbon fiber and self-strengthened polypropylene. The intralayer hybrids of SRPP and CFPP can consolidate the high stiffness and high strength of carbon fiber composites, without losing the ductility of the SRPP. The plain weave pattern had a marginally higher strength in the second part of the tensile diagram, as it was less affected by the carbon fiber failure because of the higher number of cross-overs. Interleaved films, which expanded the interlayer bonding, tended to localize the strain after the carbon fiber failure. While the interleaved films may be essential for thermoform ability, they decrease the ultimate failure strain of the composite because of a too high interlayer bonding.

2.5 Studies on Vibration Properties of Composite Material.

Bulut et al. [52] investigated damping and vibration characteristics of basalt-aramid/epoxy hybrid composite laminate. The hybrid configuration showed that the expansion of a number of aramid fiber layers instead of basalt fibers improves the damping capacity of the overall lamina while diminishing the vibration frequency values.

Khan et al. [53] researched vibration damping characteristics of nanocomposites and carbon fiber strengthened polymer. For free vibration, the result showed the damping ratio of hybrid composite increase with the addition of CNTs, consistent with the previous hypothesis of sliding at the CNTs-matrix.

Kumar et al. [54] studied damping properties of hybrid polymer used glass-epoxy with the addition of carbon filler with different weight fraction the result showed that the hybrid composite is comparatively more than efficient than the glass reinforced.

Adams and Maheri [55] studied the damping characteristics of advanced polymer-matrix composites. The theoretical result for the most part correlates. The fundamental mechanisms governing the model damping in laminated beam and plate were highlighted, and these were appeared to take after precisely the variety the parameters as fiber introduction, staking arrangement and the nature of the disfigurement.

Adali and Verijenko [56] investigated the ideal stacking sequence design of symmetric hybrid laminate undergoing free vibration. The effect hybridization is explored for various parameters of plies. The least cost design of the laminate by utilizing a base number of the expensive. The outcomes were acquired for graphite-epoxy/glass hybrid laminates Comparison of discrete and continues designs demonstrates that the discrete plan gives prevalent outcomes for most perspective proportions if the similar ply angle is used for all in the continues the case.

Lavanya et al. [57] examined the effect of the glass fiber orientation on the damping ratio calculated from numerical analysis for different orientation. Damping ratio is influenced by fiber orientation and where maximum at orientation of 60^o in all the selected orientations. The orientation at other layers is more influencing compared to the inner layers. By placing alternative layers of fiber and viscoelastic material, damping ratio of the hybrid material is in between the fiber and rubber.

Baştürk et al. [58] studied the nonlinear dynamic response of a hybrid laminated woven composite plate, composed of basalt fabric, Kevlar/epoxy and E-glass/epoxy under the blast load including damping effect has been researched. The outcome found that the deflection amplitude and the vibration frequencies increment while expanding the peak pressure value.

2.6 Conclusion of Literature Review

The most important points that have been deduced from the conclusions:

- Hybrid composites took a wide interest in recent decades in research and industrial circles because of its great importance in improving the mechanical properties.
- The researches about composite materials that were more than the researches on hybridization and researches about intraply hybrid composite less than intreply hybrid composite.
- There are several of researches that performed tensile, flexural tests, while researches on vibrators were few.
- This study expects to expound on these outcomes by using distinctive arrangements of twill woven carbon/aramid fiber, plain Glass fiber layers and researches the effect of hybrid composite laminates and the stacking arrangements on the tensile, flexural and vibration conduct experimentally.

In this study, two sorts of fibers twill woven carbon/aramid fiber (CAFRP), plain glass/epoxy (GFRP) used. Interply intraply hybrid composite plates having two kinds of layers (carbon/aramid with Glass,) with 8 layers and hybrid composite plates having two different sorts of fiber (carbon/aramid with glass) laminates as reinforcement and epoxy resin as the matrix have been created.

CHAPTER 3

EXPERIMENTAL STUDIES

PRODUCTION OF COMPOSITE PLATES AND DETERMINATION OF MECHANICAL PROPERTIES

3.1 Introduction

This chapter demonstrates the production of composite plates and determination of mechanical properties of these laminates.

3.2 Materials

In the production of composite plates, twill 2/2 woven carbon/aramid (190 g/sqm) and (0.24 mm) thickness, plain E-Glass fibers (200 g/sqm) and (0.19 mm) thickness were used. MGS L285 epoxy resin and MGS H285 hardener have been used at a ratio of (100:40) in the production of composite plates.

3.3 Production of Hybrid Composite Laminates

Fibers were cut to the required dimensions (for the present work 220mm x 300mm) by using an EC fiber cutter as shown in Figure 3.1. The laminates were produced in a clean environment to avoid the defects that adversely affect the results and all the laminates produced at room temperature (25 ^{o}C). Laminates were fabricated by hand lay-up process, where the first layer of fiber saturated with resin and then the second layer placed above it, the process was repeated for the eight layers. It is important to put a sufficient amount of resin to ensure that the resin reaches into all areas equally. After the completion of this process, the layers were placed to the production unit as shown in Figure 3.2. Laminates were produced by production unit, as shown in Figure 3.3.

(a) (b)

Figure 3.1 Cutting fibers by EC, a) Carbone/Aramid b) E-glass

(a) (b)

Figure 3.2 a) Resin application b) Production unit

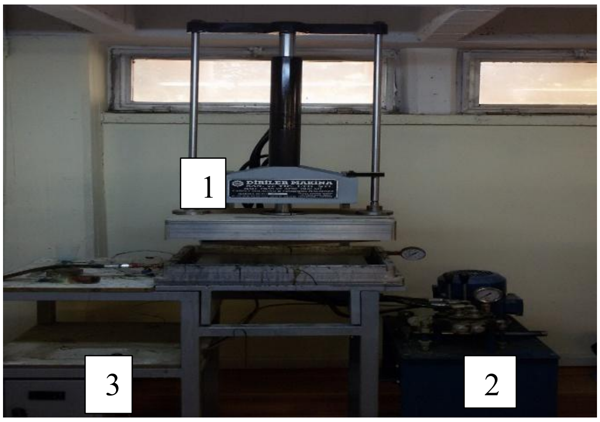
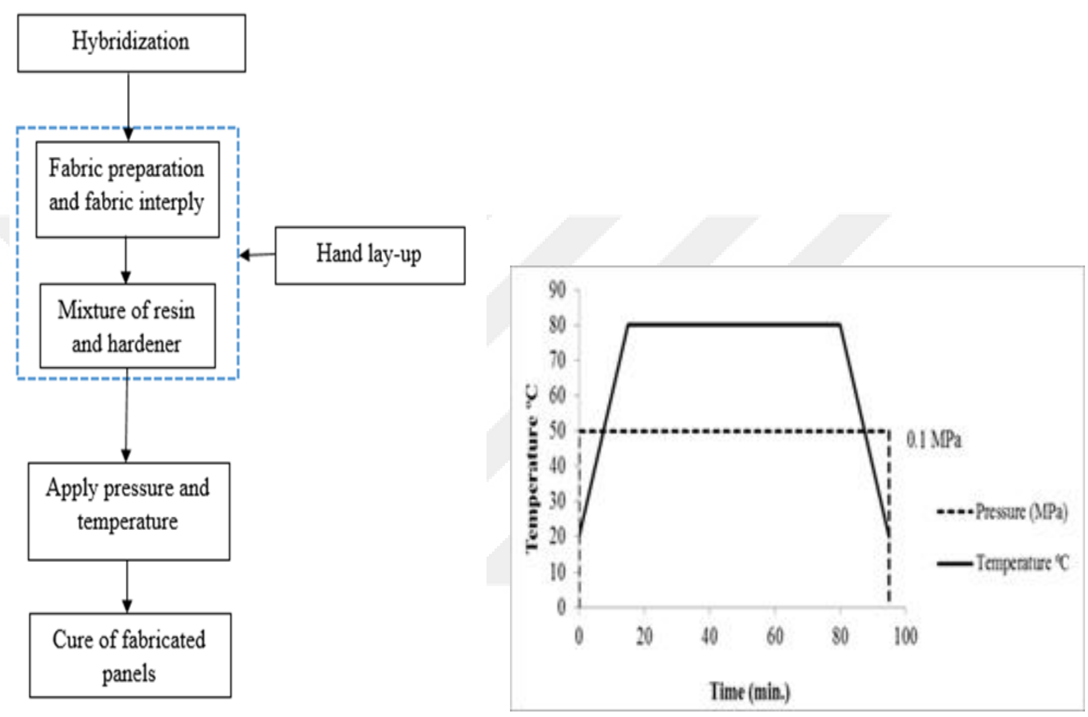


Figure 3.3 Production unit. (1) Combination of heat and pressure, (2) Hydraulic unit, (3) Control unit.

Production of single laminates took about four hours, at first wet layers put in the production unit for 45 minutes under 0.1 MPa pressure at temperature 80 °C, then leave it to cool for three hours until reaches room temperature and then production process have been finished. A stream graph utilized as a part of the manufacture of hybrid composites and curing procedure is given in Figure 3.4.



(a) (b)

Figure 3.4 (a) A stream graph utilized as a part of the manufacture of hybrid composites (b) The curing procedure.

To check the effect of stacking configurations, different fabric layers of carbon/aramid and glass fibers were used for a total of 11 composite laminates, and varied their stacking configurations according to the arrangements. The designs of composite laminates were assigned by the utilization of first letter of reinforcement material according to a number of layers. It was using the “H” letter for asymmetric and "S" letter for symmetric hybrid configurations. The Table 3.1 shows the arrangement of layers and the volume fraction for each fiber. The produced plates are shown in Figure 3.5.

Table 3.1 Configurations of CAFRP, GFRP and hybrid composite laminates

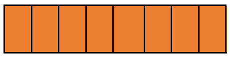
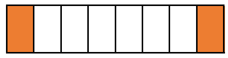
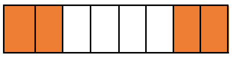
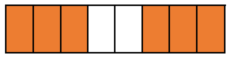
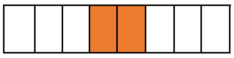
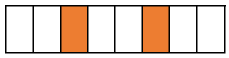
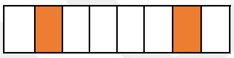
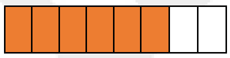
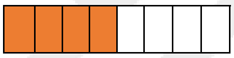
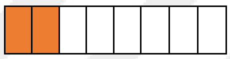
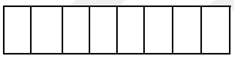
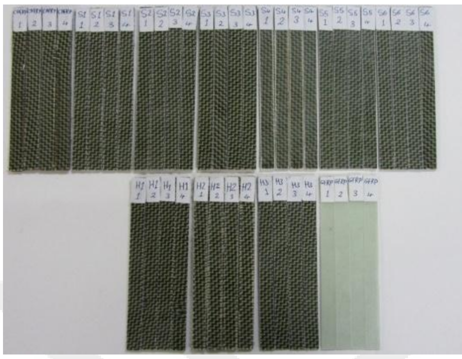
Naming	Laminate stacking configurations	Thickness (mm)	Density (kg/m^3)	Laminate Codes	Weight fractions (%)	
					W_{fca}	W_{fg}
CA_8		2.23±0.02	1.33±0.02	CFRP	54.76±0.59	0.0
CA_2G_6		1.89±0.02	1.37±0.07	S_1	15.74±0.16	44.99±0.46
CA_4G_4		2.26±0.01	1.18±0.03	S_2	30.45±0.45	29±0.4
CA_6G_2		2.26±0.01	1.21±0.01	S_3	45.32±1.06	14.39±0.33
CA_2G_6		1.83±0.03	1.56±0.03	S_4	14.75±0.28	42.15±0.82
CA_2G_6		2.01±0.1	1.42±0.12	S_5	14.1±0.55	40.19±1.47
CA_2G_6		1.92±0.02	1.51±0.15	S_6	14.03±0.37	40.09±1.05
CA_6G_2		2.35±0.25	1.27±0.11	H_1	42.43±0.53	13.55±0.11
CA4G_4		2.2±0.01	1.33±0.06	H_2	28.47±0.92	27.12±0.88
CA_2G_6		1.7±0.12	1.69±0.14	H_3	14.66±0.33	41.9±0.94
G_8		1.73±0.02	1.47±0.04	GFRP	0.0	61.53±0.47

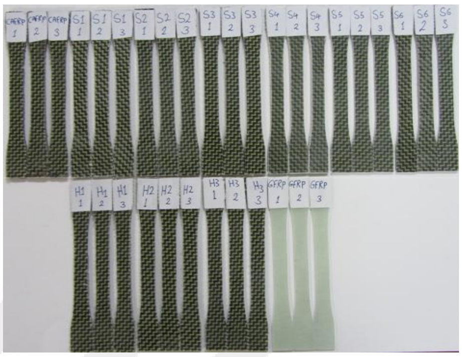
Figure 3.5 Samples of the produced hybrid composite plates.

3.4 Preparation of Mechanical Test Specimens

All samples used in the tests were produced in accordance with ASTM standards (D638-10) [59] for tensile test and (D790) [59] for flexural test in terms of dimensions and size. The samples have been cut by using CNC machine. Samples of producing tensile and flexural test samples were shown in Figure 3.6.



(a)



(b)

Figure 3.6 a) Tensile test specimens b) Flexural test specimens

3.5 Determination of Tensile Properties

Tensile properties of specimens of plates were determined according to the ASTM D638–10 standard test method. Suitable dimensions for this standard are given in the Figure 3.7. Type 1 configuration of ASTM 638-10 standard have been used considering specimen dimensions as width of narrow section (W) 13 mm, length of narrow section (L) 57 mm, overall width (WO) 19 mm, overall length (LO) 165 mm, gage length (G) 50 mm, distance between grips (L) 115 mm and radius of fillet (R) 76 mm.

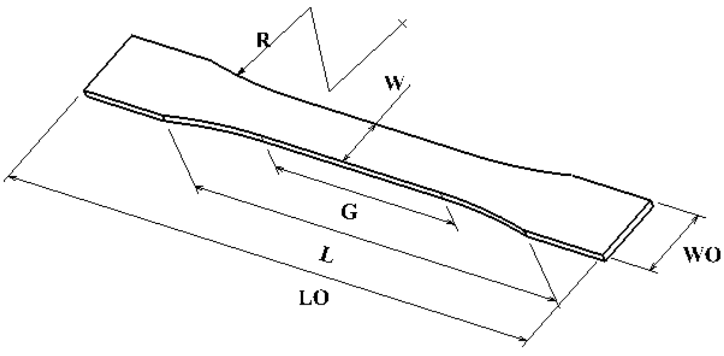


Figure 3.7 The measurements of the tensile examples as indicated by ASTM 638-10

Tensile characteristics of the specimen were obtained using Shimadzu AG-X series testing machine Figures 3.8. To decide tension characteristics, examples were loaded in the tension direction with the 2 mm/min cross-head speed up to failure. Then tensile strength (σt), were resolved utilizing the stress and strain information's acquired from the testing machine.

Figure 3. 8 Test set-up Shimadzu AG-X series testing machine (tensile test)

3.6 Determination of Bending Characteristics

Bending characteristics of samples were obtained by using ASTM D790- 00 standard test method. Appropriate samples of rectangular cross section (L= 200mm, w =12.7mm and t = thickness of the laminate) lays on two backings and was stacked by method for a stacking nose halfway between the backings Figure 3.9. A support span-to-depth ratio of 32:1 was utilized (These test strategies use a three-point loading system applied to a simply supported beam). To resolved flexural characteristics, samples were loaded with the 3 mm/min cross-head speed up to failure.

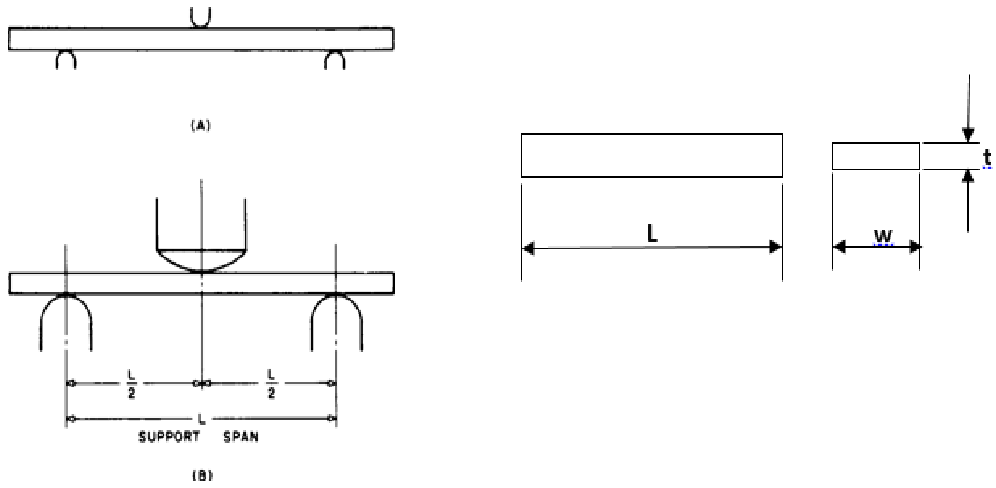


Figure 3.9 The measurements of the flexural examples as indicated by ASTM D 790 – 00

The flexural data of the specimen were obtained using Shimadzu AG-X series testing machine Figures 3.10. The flexural characteristics (flexural stress, σ_F, flexural modulus, E_F and flexural strain ε_F) of the samples were determined from the test machine data's by using the following equations. [60]

Figure 3.10 Test set-up Shimadzu AG-X series testing machine (flexural test)

$$\sigma_F = \frac{3P_{max}\,L}{2bh^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\,\left(\frac{h}{L}\right)\,\left(\frac{D}{L}\right)\right] \tag{3.1}$$

$$E_F = \frac{m\,L^3}{4bh^3} \tag{3.2}$$

$$\varepsilon_F = \frac{6Dh}{L^2} \tag{3.3}$$

Where L, b and h are the span, width and depth of the example, m is the incline of the tangent to the initial straight-line portion of the load-deflection curve, D is the greatest deflection before disappointment and P is the load at a given point on the load-deflection curve.

Since the stacking nose more extensive than the test specimen's width, the inside load is consistently circulated along the width of the examples, and the heap is unidirectional

3.7 Determination of Vibration and Damping Properties

Dynamic properties of composite laminates were measured using test set-up as indicated by ASTM E756 [61] as appeared in Figure 3.11. Vibration test examples with measurements of 200 mm × 12.7 mm were set up from the composite laminates, and specimens were clasped by backings. Produced hybrid and non-hybrid composite examples were excited by an impact hammer to accomplish dynamic properties. Time-dependent acceleration responses of the samples were measured by the application of an impact hammer. As needs be, natural frequency responses were controlled by the using of quick Fourier transforms. Frequency responses were taken within the constant frequency range from 0 Hz to 500 Hz. As shown in Figure 3.11c, time and frequency responses of hybrid composites were measured by the application of the impact hammer to the aramid fiber side of the overall lamina. During the experiments, three times vibration tests for three different specimens were recorded in each time.

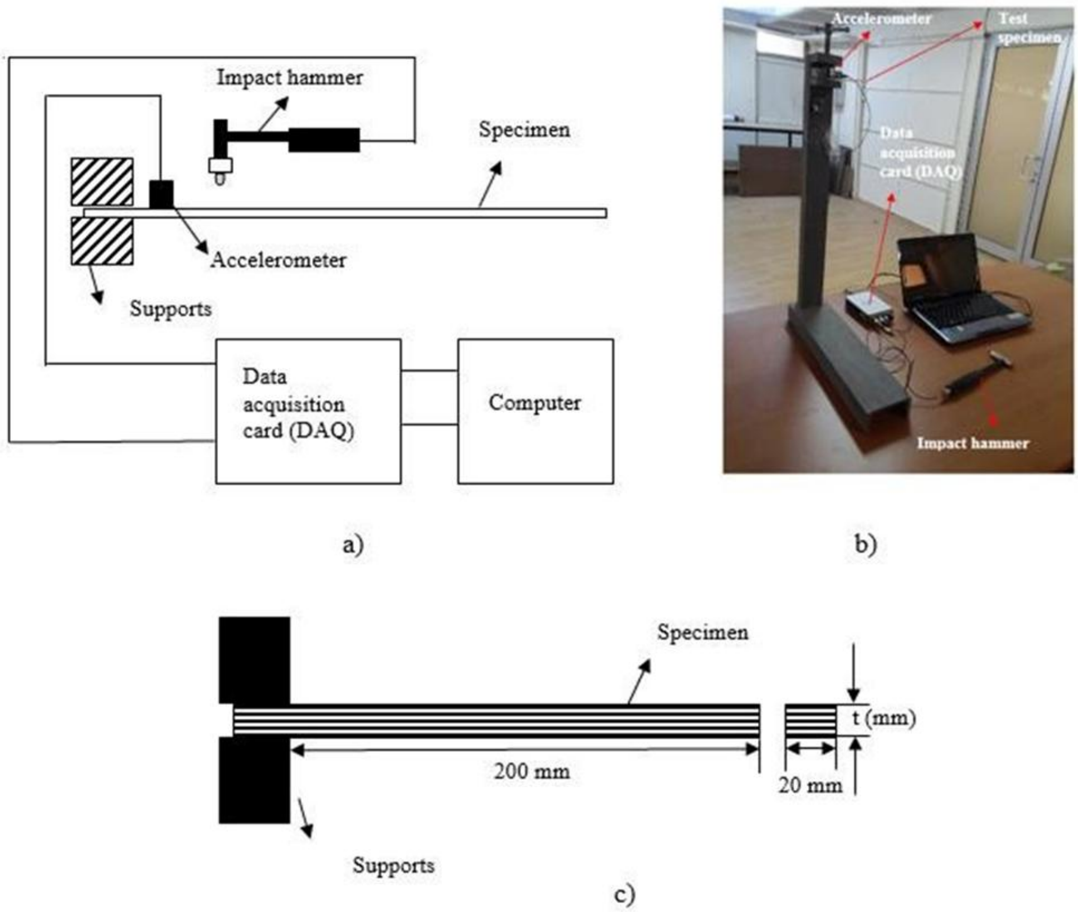


Figure 3.11 Vibration test set-up. (a) Sketch of vibration test mechanism, (b) Overall view of vibration test set-up, (c) Test specimens with dimensions of the frame.

In order to measure damping responses, half power band-width method was used for the first natural frequency mode of the specimen as shown in Figure 3.12.

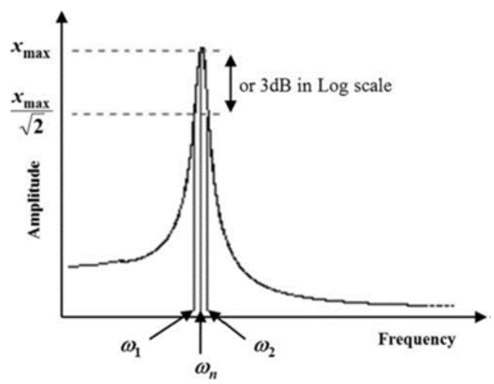


Figure 3.12 Half power band-width method.

Damping ratio of composite samples are calculated using Equation 3.4.

$$\xi = \frac{\omega_2 - \omega_1}{2.\omega_n} \tag{3.4}$$

Where ω_1, ω_2 are the bandwidth, ω_n is the natural frequency of the first mode, and ξ is the damping ratio. The storage modulus (E') of samples was obtained using Equation (3.5).

$$\omega_1 = \frac{1.875^2}{2.\pi.L^2}\sqrt{\frac{E'.I}{\rho.A}} \tag{3.5}$$

Where ρ is the density of the beam, A is the cross-section of the beam, I is the moment of inertia of the given cross-section of the beam, E' is the storage modulus, L is the free length of the beam and ω_1 is the natural frequency of the first mode. Similarly, loss modulus (E'') of the beam can be found using the following relationship amongst loss and storage modulus.

$$E'' = E'(\omega) \cdot (\delta) = 2 \cdot E'(\omega) \cdot \xi(\omega) \tag{3.6}$$

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Introduction

This chapter discuss the experimental results that were conducted to investigate the effect of glass fiber addition and changing its stacking arrangement on the mechanical characteristics of the carbon-aramid epoxy composite.

4.2 Tensile Characteristics

The tensile testing result of various configurations of laminated composites are given in the Tables 4.1-4.2. Table 4.1 represents the elongation at break and maximum tensile strength of the symmetric arrangements of the laminates. Table 4.2 shows tensile result of hybridization of asymmetric arrangement of the laminate. Tensile stress to strain curves of symmetric laminates are given in Figure 4.1.

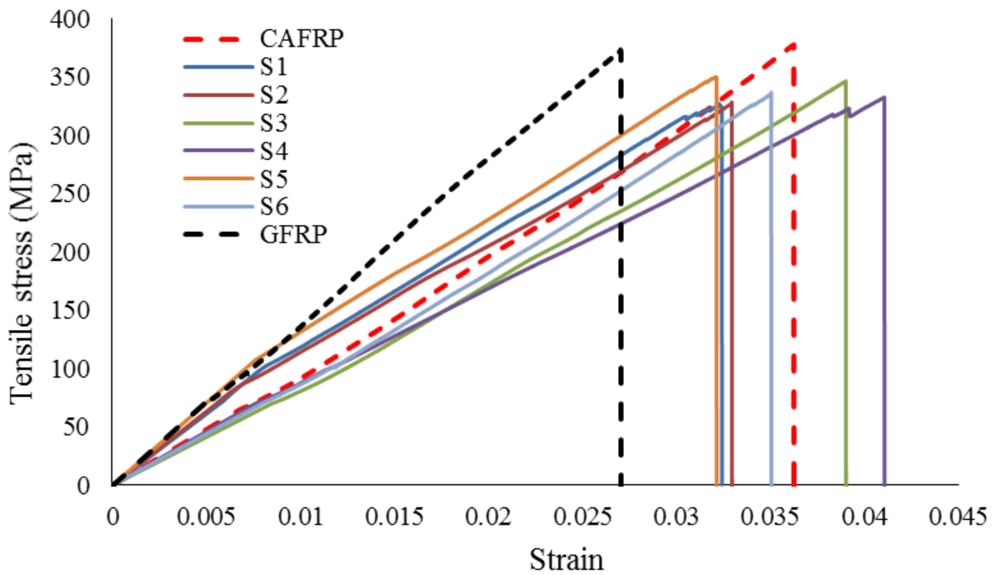


Figure 4.1 Stress–strain variation of symmetric hybrid CAFRP and GFRP composites laminates.

Table 4.1 Tensile characteristics of symmetric hybrid, CAFRP, and GFRP composite laminates.

Laminate	Elongation at break	Max. Tensile strength(MPa)	Average tensile strength(MPa)
CAFRP- 1	0.0314	376.62	
CAFRP- 2	0.0363	361.63	378.68
CAFRP- 3	0.0409	397.793	
S_1- 1	0.034	328.20	
S_1- 2	0.034	350.55	327.10
S_1- 3	0.027	302.497	
S_2- 1	0.031	358.320	
S_2- 2	0.032	289.717	328.44
S_2- 3	0.0361	337.299	
S_3- 1	0.0373	351.93	
S_3- 2	0.0401	353.31	349.72
S_3- 3	0.0395	343.93	
S_4- 1	0.0332	320.17	
S_4- 2	0.0366	339.28	335.18
S_4- 3	0.0294	346.11	
S_5- 1	0.0306	368.12	
S_5- 2	0.0328	338.49	347.70
S_5- 3	0.0330	336.62	
S_6- 1	0.0342	331.07	
S_6- 2	0.0283	314.89	336.63
S_6- 3	0.0425	363.94	
GFRP- 1	0.236	373.39	
GFRP- 2	0.256	350.79	373.52
GFRP- 3	0.032	396.39	

From the experimental study for symmetric laminates, it was observed that CAFRP composite has the maximum tensile strength of 378.68 MPa, where S1 composite has the lowest value at 327.1 MPa and GFRP composite has a tensile strength about

373.52 MPa. Also, it is shown from the results above that the hybridization has negative effect on the tensile strengths of composites. The stress strain graph for the tensile test of symmetric hybrid composite laminate are shown in Figure 4.1 and the tensile strain and tensile strength of CAFRP, GFRP and all symmetric hybrid composite laminate presented in Table 4.1. The pure carbon/aramid fiber shows a good tensile strength and tensile strain when compared with pure glass, the glass fiber showed lowest tensile strain because that it decrease the tensile strain for hybrid laminates and could not to increase the tensile strength for any type of hybrid. Also from the Figure 4.1 the GFRP shows a small elastic region with a high stress value that mean it's a lot of stress without more deformation. The maximum negative effect occurs at (S2) laminate, where the tensile strength decreased by a ratio of 13% from full carbon/aramid epoxy and decreased by a ratio of 12% from full glass.

Table 4.2 Tensile characteristics of asymmetric hybrid, CAFRP, and GFRP composite laminates.

Laminate	Elongation at break	Max. tensile strength(MPa)	Average tensile strength(MPa)
CAFRP- 1	0.0314	376.62	
CAFRP- 2	0.0363	361.63	378.68
CAFRP- 3	0.0409	397.793	
H_1 – 1	0.0353	319.949	
H_1 – 2	0.041	372.917	337.10
H_1 – 3	0.0333	318.416	
H_2 – 1	0.0396	315.11	
H_2 – 2	0.0336	357.20	333.68
H_2 – 3	0.0384	328.74	
H_3 – 1	0.0312	314.91	
H_3 – 2	0.0302	292.57	307.26
H_3 – 3	0.0235	314.31	
GFRP-1	0.236	373.39	
GFRP-2	0.256	350.79	373.52
GFRP-3	0.032	396.392	

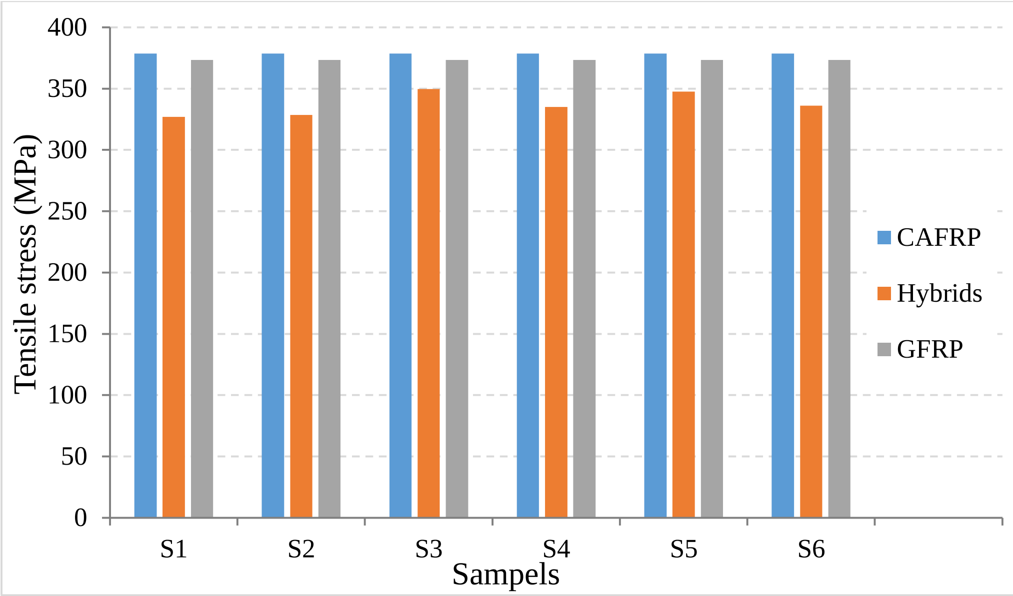


Figure 4.2 Comparisons between average stress of tensile stress of CAFRP, GFRP and symmetric hybrid composites.

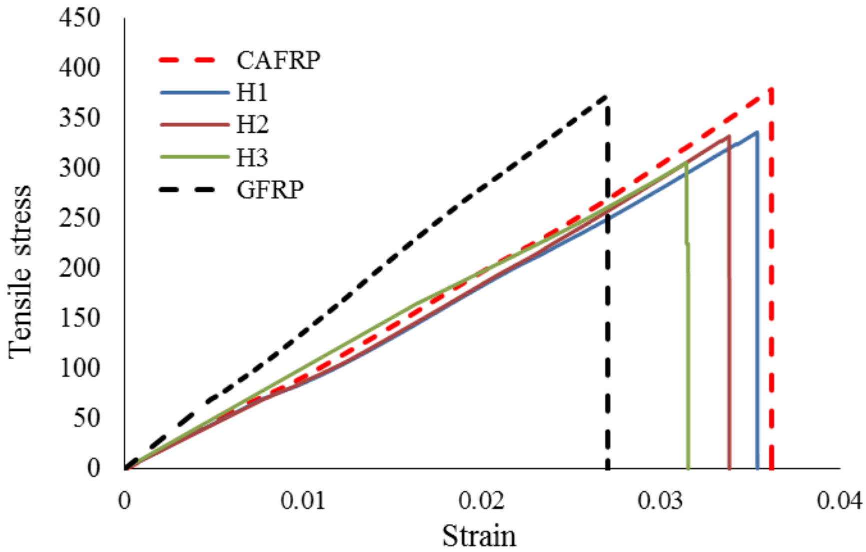


Figure 4.3 Stress–strain variation of CAFRP, GFRP and asymmetric hybrid composites laminates.

The results of tensile test for non-hybrid and asymmetric hybrid composite laminate were presented in Figure 4.3 as stress-strain graphs in order to determine the tensile loading performance. The Figure 4.3 shows a negative hybrid effect exists when the two topmost lamina of a full carbon/aramid epoxy laminate replaced by a glass epoxy lamina, as more tensile strength decreases gradually up to H1 (two layers glass with 6 layers Carbon-Aramid).

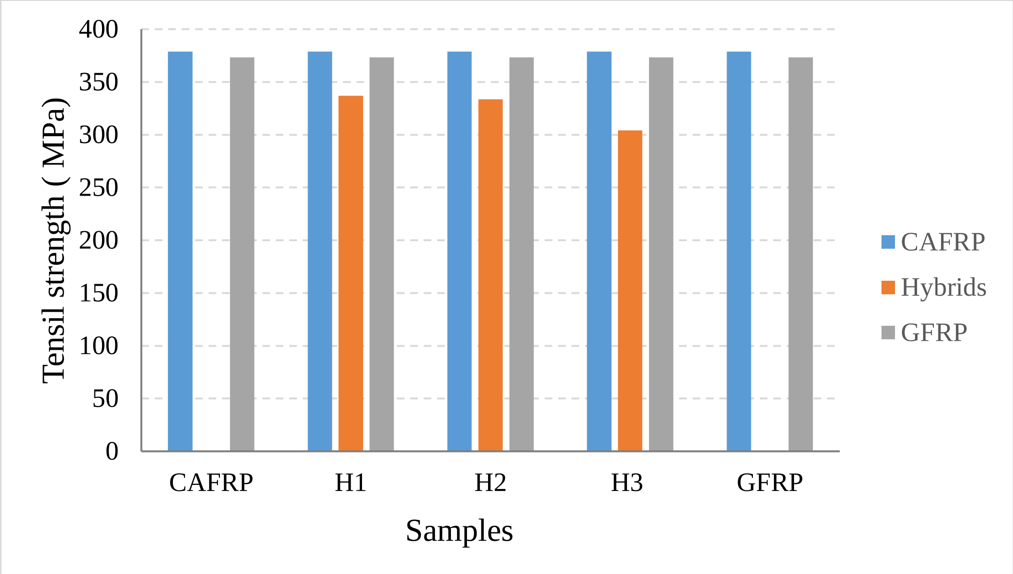


Figure 4.4 Comparisons between average stress of tensile stress of CAFRP, GFRP and asymmetric hybrid composites

The tensile strain and average of tensile strength of CAFRP, GFRP and all asymmetric hybrid composite laminate presented in Table 4.2.The maximum negative effect occurs at (H3) laminate, where the tensile strength decreased by a ratio of 18% from full carbon/aramid-epoxy and decreased by a ratio of 17% from full Glass.

However, tensile strain of hybrid laminates exhibited the average value between CAFRP, GFRP up to the fracture point and the glass did not have a significant effect on tensile characteristics of carbon/aramid fibers.

4.3 Flexural Results

The average results that achieved from the experimental work on the flexural testing of various fibers of laminated composites were explained in the Tables 4.3 - 4.4, which represent a maximum flexural strain, maximum flexural stress and modulus of the various stacking arrangements.

Table 4.3 shows flexural strength values of hybridization of carbon-aramid fibers with E-glass fibers and also flexural stress to strain curves are given in Figure 4.3.

Table 4.3 Average flexural properties for CAFRP, GFRP and interply symmetric hybrid composites with different stacking configurations.

Laminate	Strain at break	Flexural strength (MPa)	Average flexural strength (MPa)	Flexural modulus (GPa)
CAFRP- 1	0.05	488		16.3
CAFRP- 2	0.048	481.4	484.9	18.2
CAFRP- 3	0.054	485.8		14.6
S_1- 1	0.037	507.4		24.8
S_1- 2	0.036	511.5	507.1	22.5
S_1- 3	0.036	502.6		22.3
S_2- 1	0.022	527.7		20.8
S_2- 2	0.020	522	524.5	20
S_2- 3	0.026	523.8		21.1
S_3- 1	0.025	570.1		20.6
S_3- 2	0.020	573.1	562.5	25.3
S_3- 3	0.020	544.54		23.3
S_4- 1	0.028	671.9		21.9
S_4- 2	0.029	673.9	675.0	21.9
S_4- 3	0.029	679.2		25.9
S_5- 1	0.028	693.1		24.65
S_5- 2	0.028	683.1	688.7	22.3
S_5- 3	0.025	690.8		22.7
S_6- 1	0.031	654.1		25.3
S_6- 2	0.032	656.2	653.16	21
S_6- 3	0.031	649.1		25
GFRP- 1	0.024	788.6		25.2
GFRP- 2	0.022	788.6	787.7	26.2
GFRP- 3	0.024	785.8		23.1

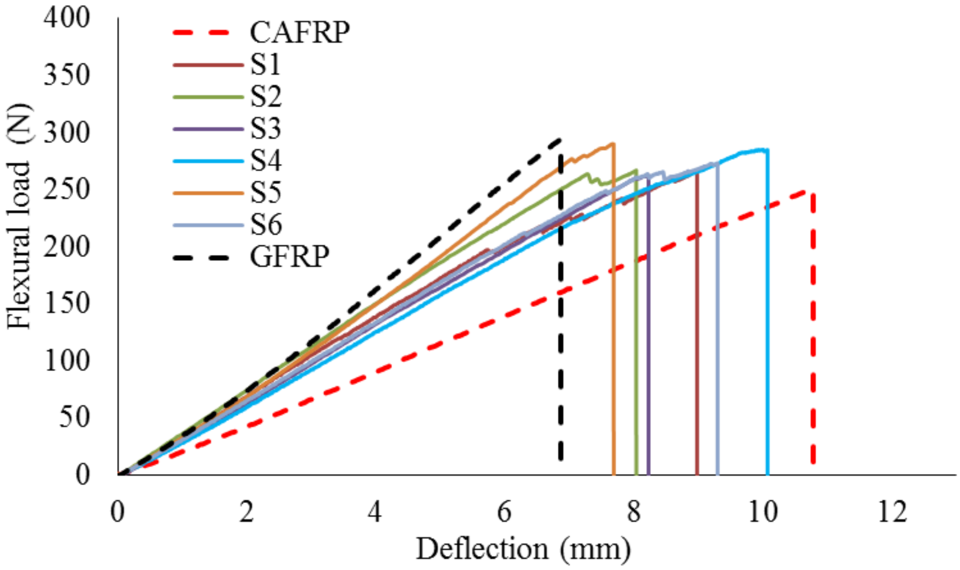


Figure 4.5 Load-deflection curves of CAFRP, GFRP and the symmetric hybrid composite laminates.

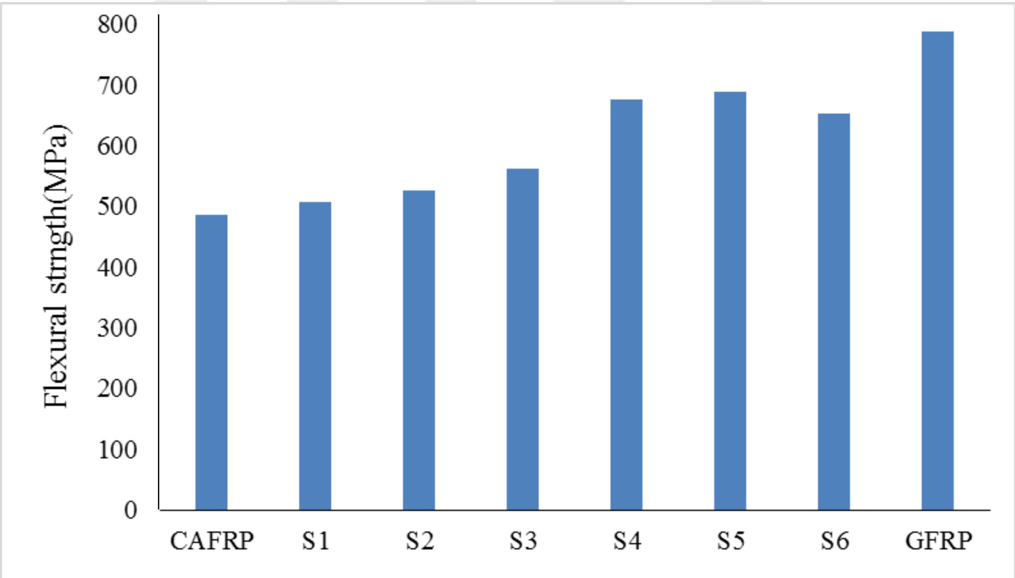


Figure 4.6 The flexural strength of symmetric hybrid.

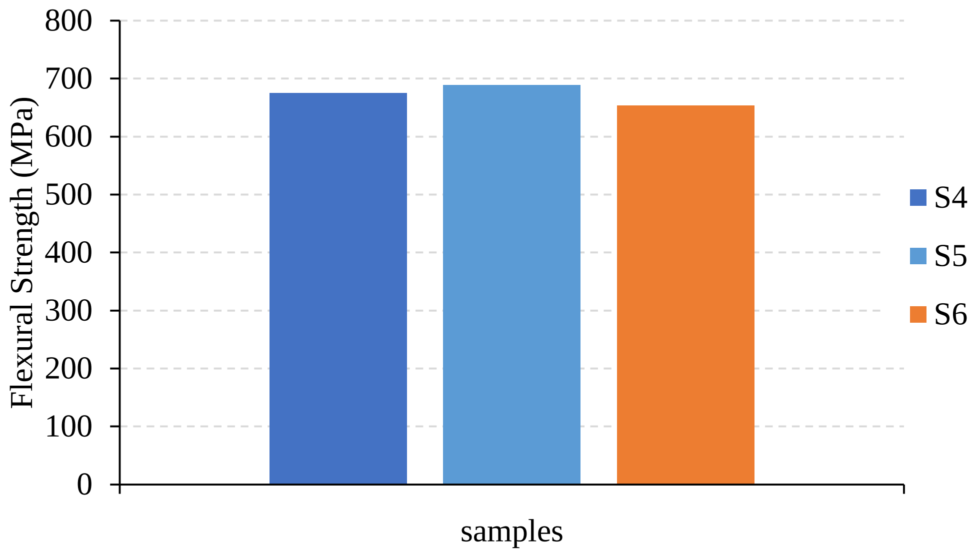


Figure 4.7 The effect of stacking configurations on flexural strength value.

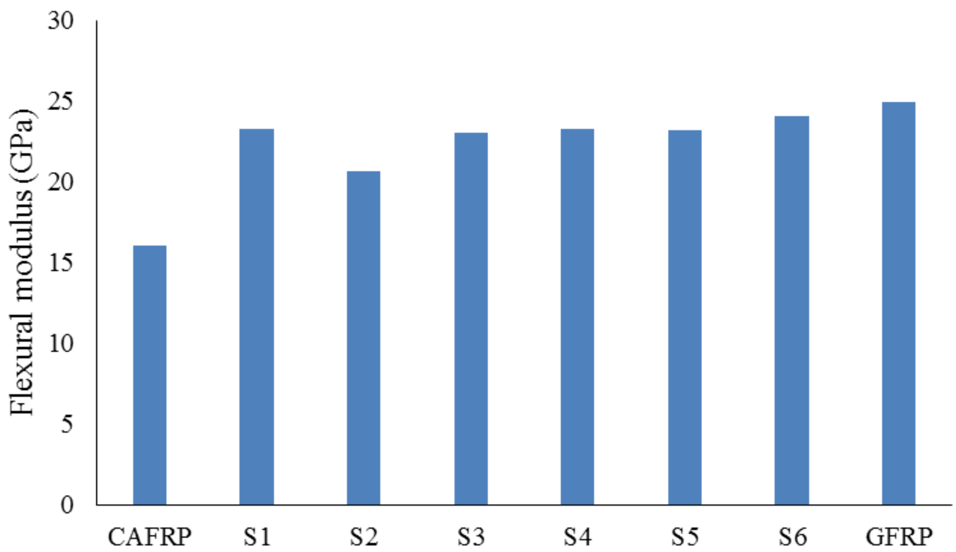


Figure 4.8 The flexural modulus of symmetric hybrid composite laminates.

Table 4.4 shows flexural strength values of hybridization of carbon/aramid fibers with E-glass fibers and also flexural load to deflection curves is given in Figure 4.9.

The experimental investigation for three-point bending shows the suitability of glass to improve the flexural properties of the carbon-aramid, this can be seen clearly through the Tables 4.3-4.4, where the glass showed a higher flexural strength and it has been able to increase the flexural strength for hybrids laminate compared with CAFRP, the H3 (G_6CA_2) appeared the highest increasing rate was about 42%.

Table 4.4 Average flexural Properties for CAFRP, GFRP and interply asymmetric hybrid composites with different stacking configurations.

Laminate	Strain at break	Flexural strength (MPa)	Average flexural strength (MPa)	Flexural modulus (GPa)
CAFRP-1	0.050	488		16.3
CAFRP-2	0.048	481.4	485.06	18.2
CAFRP-3	0.054	485.8		14.6
H_1- 1	0.024	515.5		19.7
H_1- 2	0.022	516.4	517.3	19.9
H_1- 3	0.021	520		20.9
H_2- 1	0.023	608.6		21.4
H_2- 2	0.033	605.5	608.3	24.1
H_2- 3	0.027	610.6		22.9
H_3- 1	0.031	688.2		25
H_3- 2	0.039	697	690.2	20.6
H_3- 3	0.033	685.2		24.8
GFRP- 1	0.024	788.6		25.2
GFRP- 2	0.022	788.6	787.7	26.2
GFRP- 3	0.024	785.8		23.1

The load-deflection curves from the flexural tests of non-hybrid and symmetric hybrid composite laminate shown in Figure 4.6. The CAFRP present lowest value of the load and the highest elongation compare when GFRP shows highest load with lowest elongation and all other laminates stay between GAFRP and CAFRP. The result explains the brittle behavior of glass and its effect on the hybrid laminate and the ductile properties of carbon-aramid fibers. The improvement ratio of flexural strength when replaced the GAFRP with CAFRP as was followed for S1, S2, S3, S4, S5 and S6 symmetric hybrid composite laminates are measured as 4.5%, 8.3%, 15.9%, 39.1%, 42%, and 34.6%, respectively.

The effect of glass layers configuration between carbon/aramid layers present clearly in Figure 4.7 when using three types of symmetric hybrids have the same number of glass fiber layers with different argument S4 ($G_3CA_2G_3$), S5 ($G_2CAG_2CAG_2$) and S6 ($GCAG_4CAG$) shows increasing in flexural strength value with differentiated rates compare with CAFRP the maximum increasing was for S5 with 42%.

Flexural modulus of symmetric hybrid composite laminate are presented in Figure 4.8.GFRP show the highest value of flexural modulus and its succeed in raising the flexural modulus for all hybrid types with different ratio. The highest improvement when replacing CAFRP with GFRP was for S6 with 49.9%.

Asymmetric flexural test value are shown in Table 4.4 .The three hybrid types show increases in the flexural strength compare with CAFRP. The increasing in the flexural properties was consistent with increasing of GFRP. The highest value was for H3 composite laminate (G_2CA_6) with 42.3%, increasing ratio, while each of H2 (G_4CA_4) and H1 (G_2CA_6) composite laminate was having 25.3% and 6.6 %, respectively. The second reason of this increasing it was putting CAFRP in the tension side at testing because of the high tensile properties of CAFRP compare with GFRP.

The load-deflection curves for the three-point bending tests of non-hybrid and asymmetric hybrid composite laminates are shown in Figure 4.10. GAFRP composite laminate demonstrates the most noteworthy greatest load and the low elongation when CAFRP show the low load with highest elongation because the ductile properties of carbon-aramid, and all asymmetric hybrid shows increasing in load commensurate with the increasing of glass ratio as the Figure 4.10. Asymmetric spacemen have been putting the CAFRP in the tensile side because of the high tensile properties of CAFRP.

Flexural modulus of asymmetric hybrid composite laminate presented in Figure 4.12. The H3 asymmetric hybrid laminate composite displays the best positive change in flexural modulus value of 34 GPa, which was approximately about 46% higher than CAFRP when H2 was having 42.9% increasing ratio and H1 was having 26.4% increasing ratio from the CAFRP.

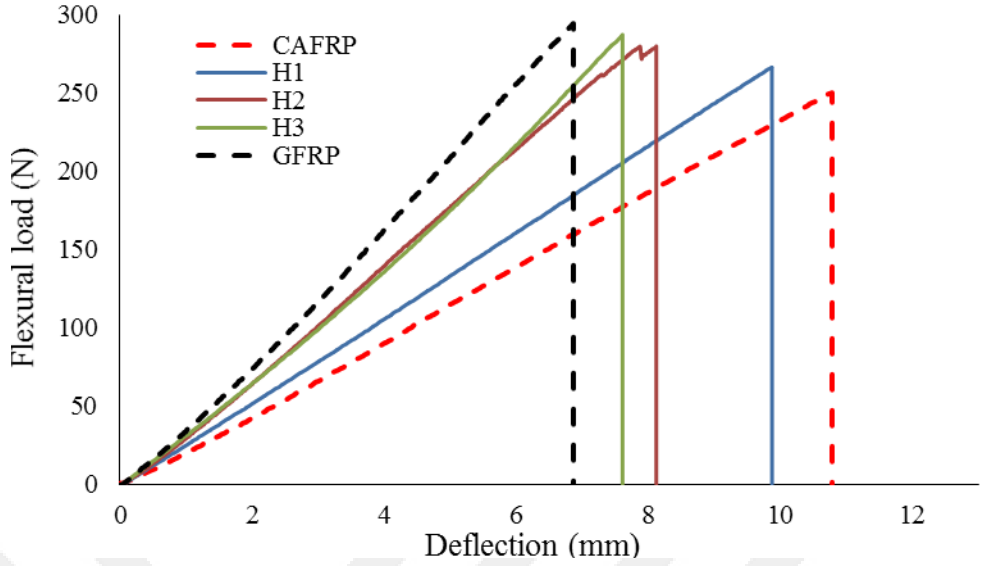


Figure 4.9 Load-defection curves of CAFRP, GFRP and the asymmetric hybrid composite laminates.

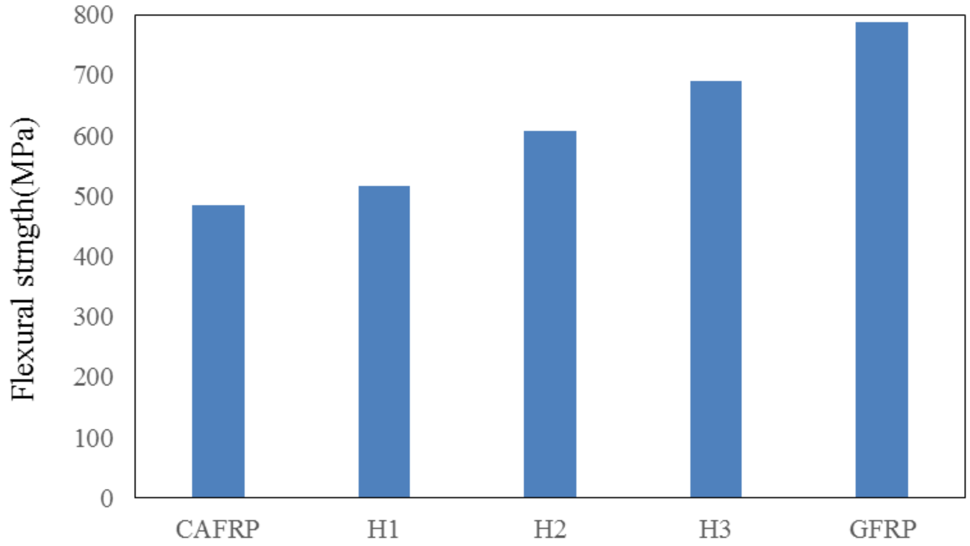


Figure 4.10 The flexural strength of asymmetric hybrid composite laminates.

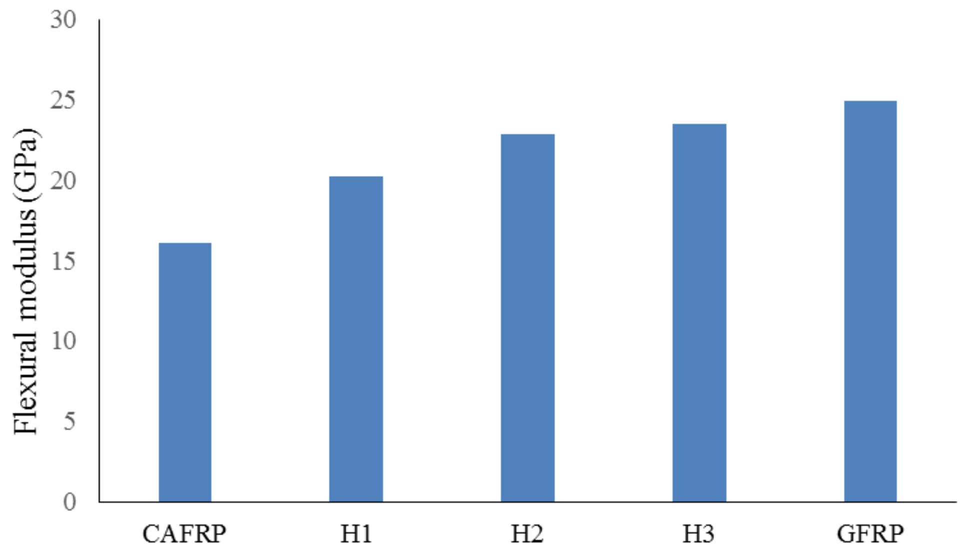


Figure 4.11 The flexural modulus of asymmetric hybrid composite laminates

4.4 Vibration Results

The results achieved from the experimental work on the vibration testing of various configuration of laminated composites are presented in the Tables 4.5,

Table 4.5 Vibration Properties for CAFRP, GFRP and interply hybrid composites with different stacking configurations.

Code	First mode (Hz)	Damping ratio	Storage modulus (GPa)	Loss modulus (GPa)
CAFRP	68.6	0.11848	32.49	7.69
S1	58.8	0.03002	29.49	5.46
S2	78.8	0.06125	31.59	4.04
S3	73.7	0.07236	31.25	4.47
S4	40.6	0.16741	26.06	8.69
S5	53.8	0.15991	24.94	7.94
S6	50.5	0.12433	25.46	6.30
H1	70.65	0.09215	31.84	5.86
H2	54.27	0.14535	26.88	7.81
H3	36.8	0.15231	24.08	7.33
GFRP	35.8	0.11292	18.65	4.21

The results imply that the increase in stiffness causes a trend of increase in the natural frequency [62]. However, an increase in stiffness may not lead to increase in the damping ratio, since the damping properties of the structures strictly depend on viscoelastic properties, which means the better absorption of vibration energy and good storage modulus [63]. From the vibration test results, the frequency response curves were plotted as shown in Figure 4.12 and 4.13. It is observed that the first mode natural frequency is clearly dominant for all samples.

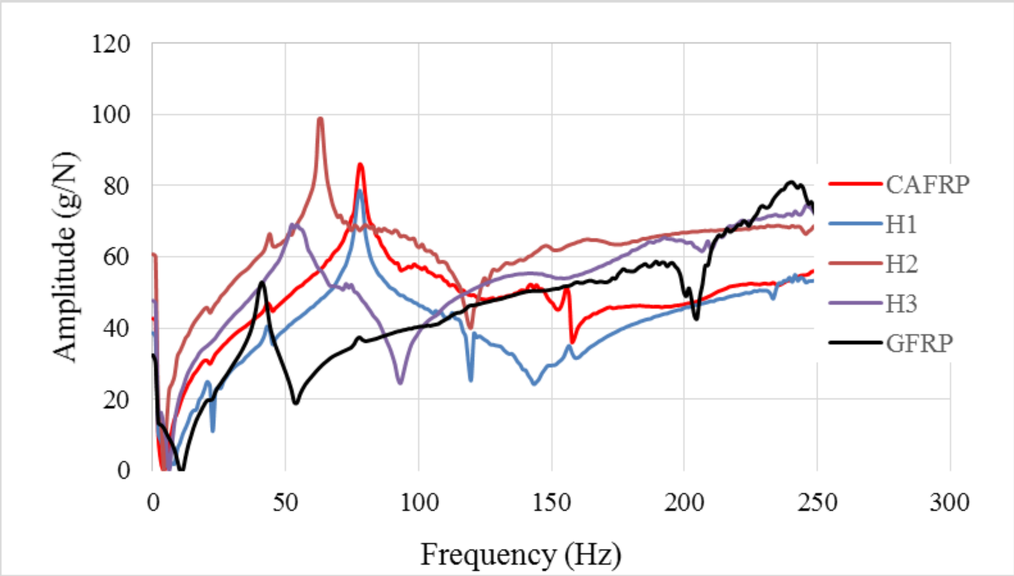


Figure 4.12 Frequency responses figure for CAFRP and GFRP interply asymmetric hybrid.

As can be seen, GFRP has a lower amplitude value and H2 (G_4CA_4) showed a highest amplitude value. The first mode is dominant for hybrid and non-hybrid laminates in all cases. Due to this reason, the first mode of natural frequency was used to study damping analysis of all composite samples. Results also showed that vibration properties of composite laminates were highly sensitive to properties of constituent materials. CAFRP shows the highest damping ratio and the increasing in the addition of GFRP reduce the damping ratio of hybrids because of the low damping ratio of GFRP. Hybrid composite H3 (CA2G8) displayed better vibration characteristics compared to other hybrid composites. Figure 4.16 shows the Relationship between loss modulus and storage modulus of CAFRP and GFRP asymmetric hybrid composites, CAFRP have been higher storage and loss modulus when GFRP have been lowest storage and loss modulus and all asymmetric hybrids between them.

As can be seen in Figure 4.13 for symmetric hybrid composite S4 (CA2G8) exhibited better vibration properties with increasing ratio with the damping ratio was about 41% compared with CAFRP.

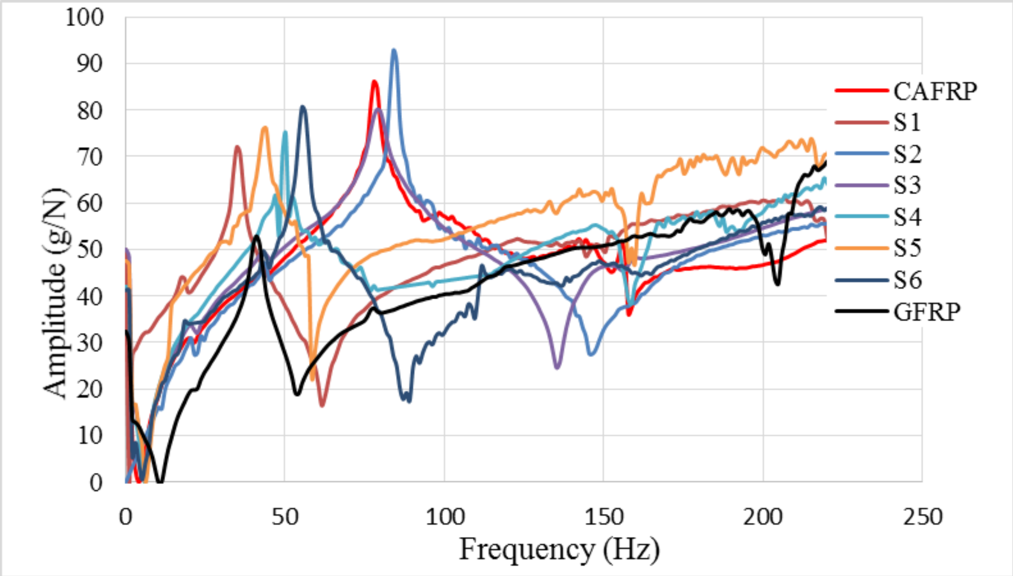
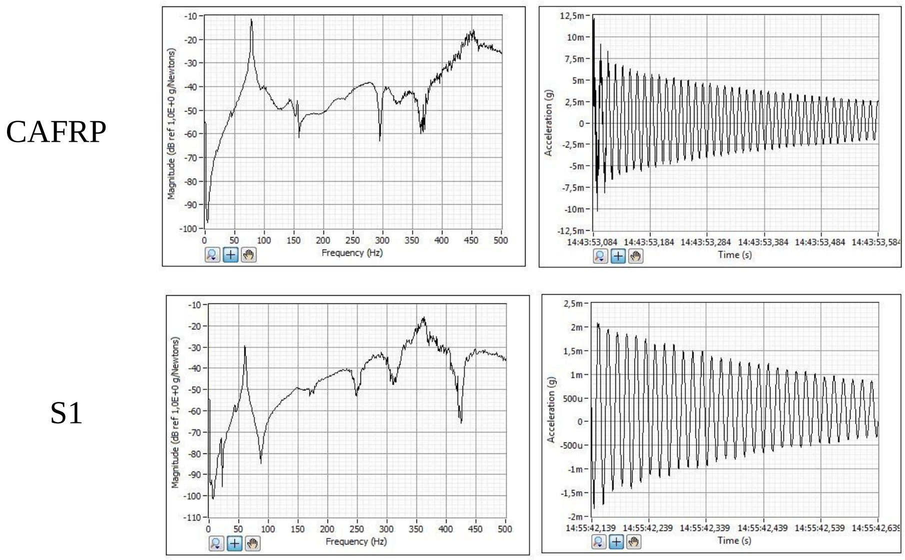


Figure 4.13 Frequency responses for CAFRP and GFRP interply symmetric hybrid.

Figure 4.14-4.15 shows time-dependent acceleration variations of the symmetric and asymmetric samples. CAFRP shows a high viscoelastic properties when GFRP shows low viscoelastic properties. The increasing of viscoelastic properties enhance the damping capacity of hybrid [52].



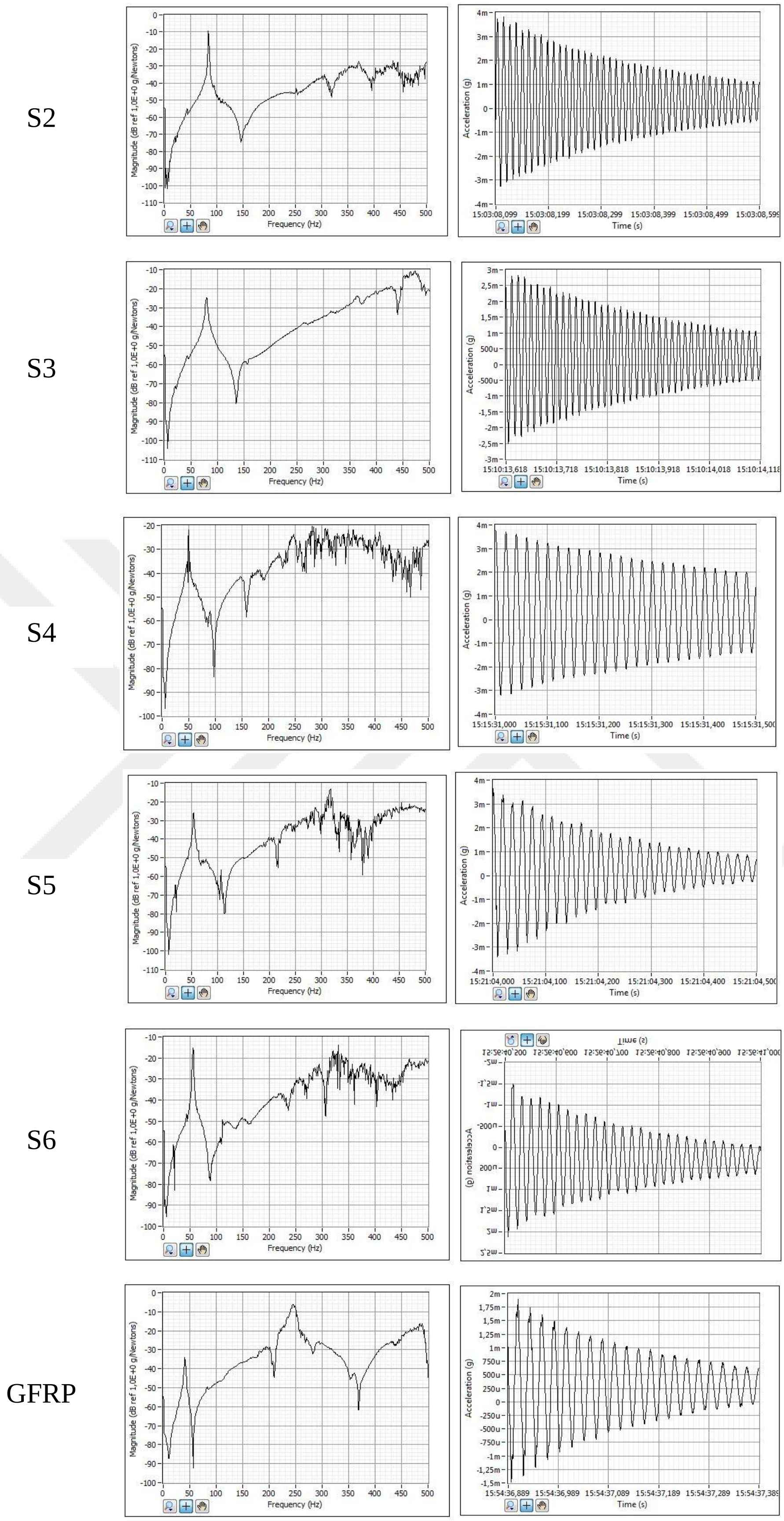


Figure 4.14 Relationship between time and frequency of vibration damping for symmetric hybrid composite.

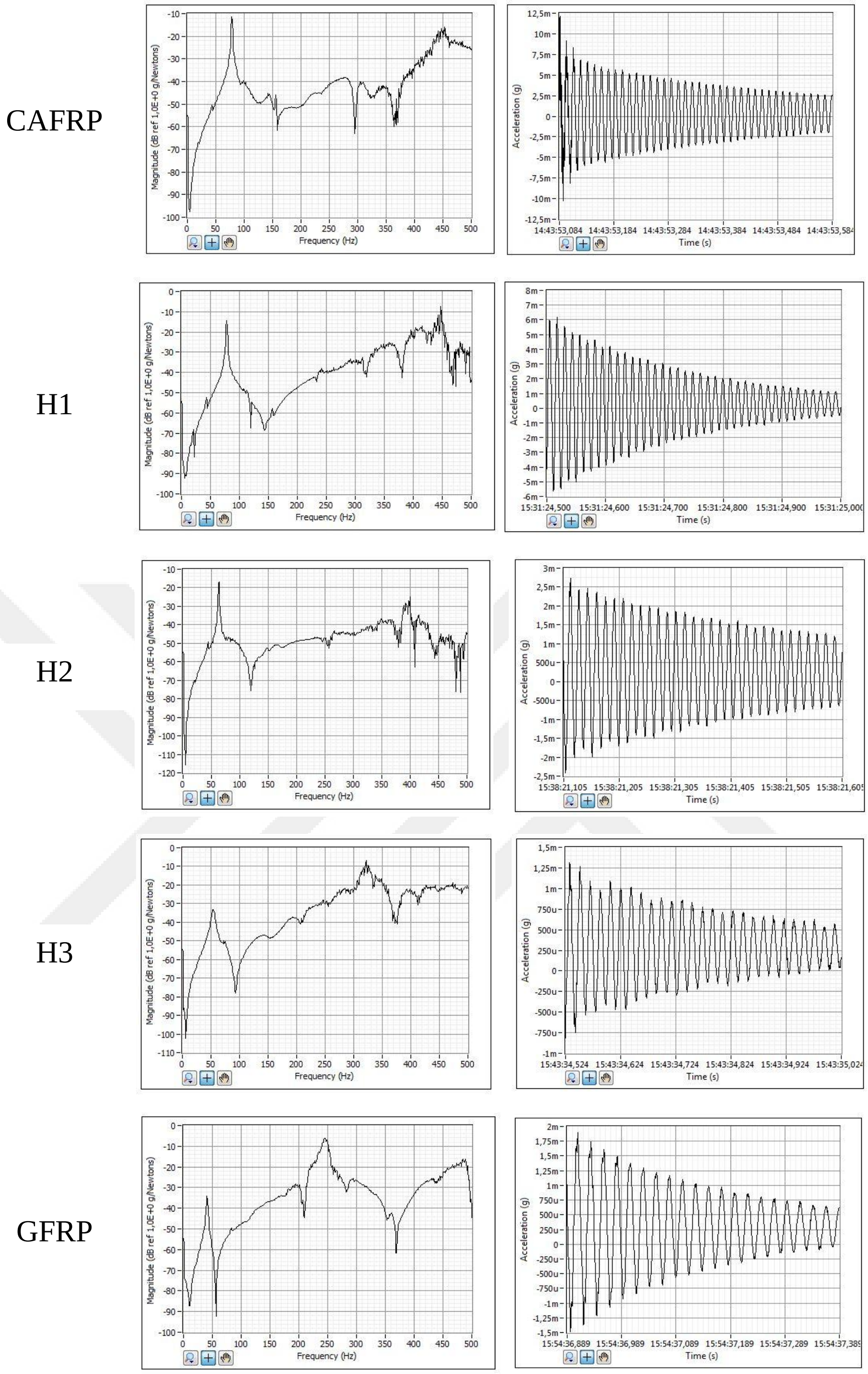


Figure 4.15 Relationship between time and frequency of vibration damping for asymmetric hybrid composite.

The relationship between loss modulus and storage modulus of CAFRP, GFRP and all hybrid configuration present in the Figure 4.16. CAFRP has the highest storage modulus and GFRP has the lowest storage modulus. All hybrid configuration are between GFRP and CAFRP. When hybrid composite were considered, S4 has highest loss modulus, but less than CAFRP with 13% reduction.

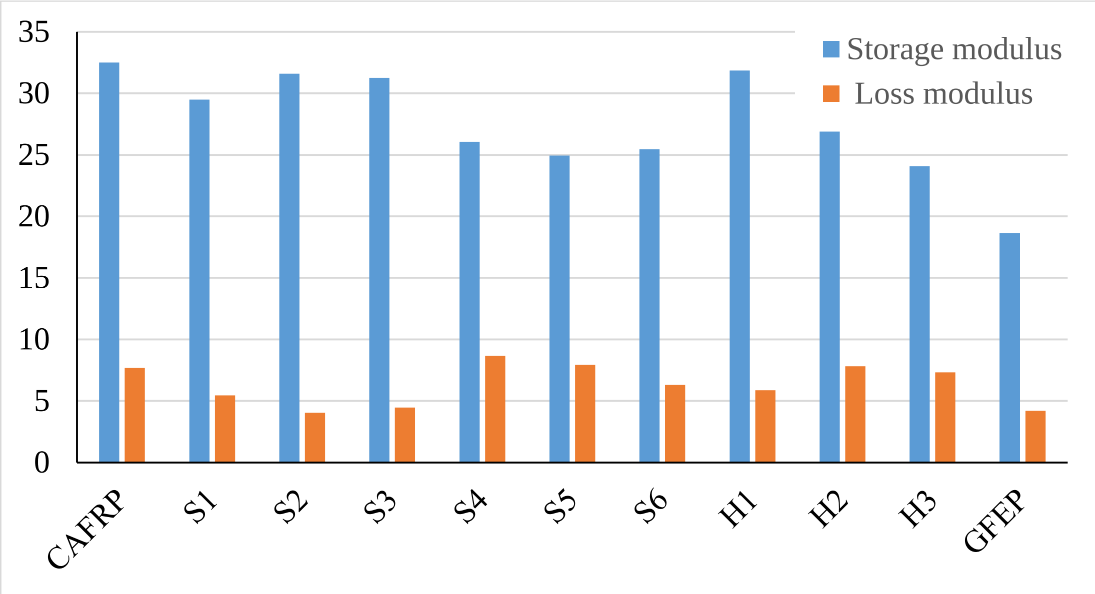


Figure 4.16 The relationship between loss modulus and storage modulus of CAFRP, GFRP and all hybrid configuration.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

This study explored the possibility of incorporating glass fibers with carbon/aramid fiber reinforced composite and search the effect of stacking configurations on the tensile, flexural and vibration characteristics of the hybrid composite. Hand lay-up process was utilized to fabricate the interply hybrid composites. Interply hybrid composites containing 8 layers of carbon/aramid and glass fabrics with different stacking configurations were tested to determine the tensile, flexural and vibration properties. The results showed that the dominant failure mode in flexural specimens was compressive failure.

Main results can be summarized as:

- The flexural and vibration characteristics of the hybrid composites were significantly affected by the stacking configurations.
- The hybrid showed negative effect in tensile strength for all stacking configurations.
- The maximum negative effect occurred at S2 laminate, where the tensile strength decreased by a ratio of 13% from full carbon/aramid epoxy and decreased by a ratio of 12% from full glass.
- The maximum negative effect occurred at H3 laminate, where the tensile strength decreed by a ratio of 18% from full carbon/aramid-epoxy and decreased by a ratio of 17% from full Glass.
- The hybrid showed positive effect in flexural strength and vibration for all stacking configurations.
- The improvement ratio of flexural strength of symmetric hybrids when replaced the GAFRP with CAFRP was followed as S1, S2, S3, S4, S5 and S6 symmetric hybrid composite laminates. Flexural strength values of symmetric

hybrid laminates were higher than CAFRP composite with a ratio of 4.5%, 8.3%, 15.9%, 39.1%, 42%, and 34.6% respectively.

- The highest value of flexural strength was for H3 composite laminate (G2CA6) with 42.3% increasing ratio, while each of H2 (G4CA4) and H1 (G2CA6) composite laminate was having higher flexural strength with ratio of 25.3% and 6.6 % compared with CAFRP respectively.
- S4 showed the highest damping ratio and the increasing the addition of GFRP laminate were reduced the damping ratio of hybrid composites because of the low damping property of GFRP.
- S2, S3 and H1 have the highest storage modulus compared with hybrid composite due to the ratio of CAFRP laminate. They were higher than CAFRP composite with ratio of ~68%.

5.2 Future Works

This study can be extended in the following aspects:

- Tensile, flexural and vibration characteristics of hybrid plates with different stacking angles can be determined.
- Hybrid plates can be produced containing different particulate additives to increase the mechanical properties of hybrid composites.

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