SEPTEMBER 2017 M. Sc. in Mechanical Engineering WALEED KADHIM AL-AZZAWI

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

TENSILE AND FLEXURAL BEHAVIOR OF NANOSILICA FILLED EPOXY MATRIX BASED FIBER REINFORCED COMPOSITE LAMINATES

M. Sc. THESIS

IN

MECHANICAL ENGINEERING

BY
WALEED KADHIM AL-AZZAWI

SEPTEMBER 2017

Tensile and Flexural Behavior of Nanosilica Filled Epoxy Matrix Based Fiber Reinforced Composite Laminates

M. Sc. Thesis

in

Mechanical Engineering

University of Gaziantep

Supervisor

Assist. Prof. Dr. Ömer Yavuz BOZKURT

by

Waleed Kadhim AL-AZZAWI

September 2017

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

Name of the thesis: Tensile and Flexural Behavior of Nanocsilica Filled Epoxy Matrix Based Fiber Reinforced Composite Laminates

Name of the student: Waleed Kadhim AL-AZZAWI

Exam date: 08.09.2017

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Ahmet Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. M. Sait SÖYLEMEZ
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Ömer Yavuz BOZKURT
Supervisor

Examining Committee Members	Signature
Assoc. Prof. Dr. Ahmet ERKLİĞ	…………………
Assist. Prof. Dr. Erdoğan KANCA	…………………
Assist. Prof. Dr. Ömer Yavuz BOZKURT	…………………

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials that are not original to this work.

Waleed Kadhim AL-AZZAWI

ABSTRACT

TENSILE AND FLEXURAL BEHAVIOR OF NANOSILICA FILLED EPOXY MATRIX BASED FIBER REINFORCED COMPOSITE LAMINATES

AL-AZZAWI, Waleed Kadhim
M.Sc. in Mechanical Engineering
Supervisor: Assist. Prof. Dr. Ömer Yavuz BOZKURT
September 2017
78 pages

In the current study, the effect of nanosilica filler and different fiber orientation angles at 2wt% nanosilica content on both tensile and flexural characteristics for glass fiber reinforced polymeric composite laminates are detected. The glass fiber/nanosilica/epoxy nanocomposites are fabricated by hand layup process. Four weight fractions of nanosilica particles (1%, 1.5%, 2% and 3%) and different fiber orientation angles (0°, 15°, 30°, 45° and 60°) were utilized for the production of laminate composites. Subsequently, samples for the tensile test were produced according to ASTM D638–10 standards and samples for the flexural test were produced according to ASTM D-790. The acquired outcomes extracted from this study displayed the utmost improvement of the tensile strength, tensile modulus, flexural strength and flexural modulus and this obtained improvement was occurred at nanosilica contents of 2wt% and 1.5wt% with the values of 280.25 MPa, 17.8 GPa, 346.35 MPa and 18.77 GPa respectively, with increment ratios of 8%, 66%, 4% and 15% respectively as compared to unfilled GFRP composite laminates with nanosilica particles. It also revealed that silica filled composites exhibited better than unfilled epoxy composites. Moreover, the GFRP composites with fiber orientation angle of 0° at 2wt% nanosilica content were showed the highest values in tensile strength, tensile modulus, flexural strength and flexural modulus compared with the other fiber orientation angles and these values are 280.25 MPa, 17.8 GPa, 337.38 MPa and 16.74 GPa, respectively.

Keywords: Nanocomposite, Nanosilica, Glass fiber, Flexural strength, Tensile

ÖZET

NANOSILIKA KATKILI EPOKSİ MATRİS TABANLI ELYAF TAKVİYELİ KOMPOZİT LAMİNATLARIN ÇEKME VE EĞME DAVRANIŞLARI

AL-AZZAWI, Waleed Kadhim
Yüksek Lisans Tezi, Makine Mühendisliği Bölümü
Tez Yöneticisi: Yrd. Doç. Dr. Ömer Yavuz BOZKURT
Eylül 2017
78 sayfa

Bu çalışmada, nano silis katkısının ve farklı fiber yönelim açısının cam fiber takviyeli polimerik kompozit laminatların çekme ve eğme davranışları üzerine etkileri araştırılmıştır. Nano katkı içeren ve içermeyen kompozit laminatlar el yatırma yöntemi ile üretilmiştir. Dört farklı nano silis katkısı (%1, %1.5, %2 ve %3) içeren ve 0°, 15°, 30°, 45°, 60° gibi farklı fiber yönelimine sahip numuneler değerlendirilmiştir. Sonrasında, çekme test numuneleri ASTM D638-10 ve eğme test numuneleri ASTM D790 standartlarına göre hazırlanmıştır. Nano silis içermeyen numuneye göre en fazla iyileşme gösteren numuneler %2 ve %1.5 nano silis içeren numuneler olarak görülmüştür. Elde edilen sonuçlara göre çekme mukavemeti, çekme modülü, eğme mukavemeti ve eğme modülü sırasıyla 280.25 MPa, 17.8 GPa, 346.35 MPa ve 18.77 GPa olarak bulunmuş ve nano silis-içermeyen numuneye göre sırasıyla %8, %66, %4 ve %15 iyileşme elde edilmiştir. Faklı fiber yönelim açısı olarak 0° ve %2 nano silis içeriğine sahip cam fiber takviyeli kompozit laminat diğer yönelim açılarına göre en yüksek değerlere sahip olmuştur. Bu numunede çekme mukavemeti, çekme modülü, eğme mukavemeti ve eğme modülü sırasıyla 280.25 MPa, 17.8 GPa, 337.38 MPa ve 16.74 GPa değerlerindedir.

Anahtar Kelimeler: Nanokompozit, nano silis, Cam elyafı, Eğilme mukavemeti, Çekme

ACKNOWLEDGEMENT

First of all, great thanks to (**ALLAH)** his Majesty for enabling me to complete this work.

I would like to express my respect and regards to my supervisor, **Assist. Prof. Dr. Ömer Yavuz BOZKURT** for his guidance, advice, encouragement and suggestions during the preparation of this thesis.

I would like to express my deepest regards and respects to a Ph.D. student (**Mr. Özkan ÖZBEK)** for his encouragement and support throughout my thesis study.

A special thanks to my family. Words cannot express how grateful I am to my father Lecturer **Kadhim Salman AL-AZZAWI** that his words lead me to get certificates.

All my words cannot express about my thanks to my wife for her interest during this thesis **Dalya Abd AL-MUNAF**.

I extend my thanks to my sincere friend and brother **Dr. Hisham Al-ADHAMI** who has a good role to overcome so many difficulties and he led me to the right track in my academic career.

Special thanks to my son **Hussein** for his understanding, patience and great help.

Finally, I dedicate my efforts to my mother's spirit (God's mercy on her).

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS/ABREVIATIONS

FRP	Fiber Reinforced Polymer
FRPs	Fiber Reinforced Polymer Composites
CFRPs	Carbon Fiber-Reinforced Composites
GFRP	Glass Fiber Reinforced Polymeric composite
CFRP	Carbon Fiber Reinforced Polymeric Composite
CF	Fiber Carbon
FG	Fiber Glass
FK	Fiber Kevlar
PP	PolyPropylene
HDPE	High Density Poly Ethylene
CNT	Carbon Nano Tube
CNTs	Carbon Nano Tubes
KFRE	Kenaf Fiber Reinforced Epoxy
OMMT	Organo - Montmorillonite
PTW	Potassium Titanate Whisker
AIN	Aluminum Nitrides
MWNT	Multi Walled Carbon Nanotubes
LDPE	Low-Density Polyethylene
CKF	Carbon Fiber and Kevlar

SGF	Short Glass Fibers
SCF	Short Carbon Fibers
DC	Direct Current
BF	Basalt Fiber
FEM	Finite Element Method
σt	Tensile Strength
σf	Flexural Strength
Ef	Flexural Modulus
wt. %	Weight Percentage
EC	Electric Cutter
ASTM	American Society for Testing and Materials
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The composite material is a material formed basically from two or more materials which have different properties for producing new properties not provided in its constituent materials. General use of the composite material depends on both the mechanical and physical characteristics of these materials. Therefore, the study of these characteristics under the effect of the loads and forces in different circumstances is of big importance to determine the appropriateness of these characteristics to place the work of composite materials. There are many comments that define composite materials. Some of them are:

- Composite materials are solid systems resulting from mixing at least two materials. In the composite system, each material will represent as a separate phase. The first phase is called reinforcements or reinforcing materials, which particles or fibers or filaments or sheets. The first phase is surrounded by the second phase, which represents the matrix. These phases be utilized a polymeric material or ceramic or metal. (Grayson, 1983; Thomton et al., 1985)
- To define the composite as a structural material which composes from two or more common ingredients that are merged at a macroscopic grade and thus they are not dissolvable to each other. One ingredient is named the enhancing phase and the embedded one is known as the matrix. The enhancing grade material might take the style of particles, flakes, or fibers (Kaw et al., 2006)

The manufacturing technique of composite materials known in the simplest forms since for thousands of years, where the Babylonians utilized in the construction of their homes by mixing sawdust with clay to strengthen. Also, the Ancient Egyptians (1500 B.C.) used bamboo shoots to reinforce the mud walls. In the twentieth century, the first composites in modern concern were utilized (in the fabrication of aircraft and boats) when glass fibers strengthened with matrix (resin) in 1930s. This composite is mostly named as fiberglass. When boron, carbon and aramid fibers used at 1970s, the usage areas of composites increased dramatically. Consecutively, the 1980s detected a valuable improvement in the utilization of high-modulus fibers.

Nowadays, composite systems have extensively increased in the uses of engineering works due to those systems give the excellent properties; in addition to more applicable fabricating methods comparing the individual components. There are many various implementations of these composites such as: containers, boats, road vehicles, buried pipes, space devices and aeronautics, civil engineering usages, automotive compositions, biomedical products, sport equipments, and numerous other designed items to be high-mechanical properties and dimensional stability in various laminated and low-weight settings (Brigante, 2013).

Traditional composites mostly consist of fillers in shape long-fiber reinforcements. The reinforcements generally are in shape organic, inorganic, or metallic fibers. They have comparatively high modulus and high strength bonded to the polymer matrix. Fiber Reinforced Polymer (FRP) composites compose of a fibrous reinforcement connected along with a polymer matrix to develop the stiffness and strength of the composite laminate. The amalgamation of rigid inorganic nano-particles within FRP composites can improve the vibration and mechanical performances, in addition to growth the applications of the FRP composites like the production of medical and military equipment, as well as, manufacture some accessories of big boats and airplane.

For the purpose of developing polymeric properties, nanoparticles are added to polymer materials and FRP to obtain improved overall properties (i.e., electrical, mechanical, and thermal properties). These properties depend on nanoparticle loading, nanoparticle type and level of dispersion. The characterization, design, application and production of materials, equipments and systems by the domination of the size and shape of the nanoscale (E. Abad et al. 2005). Commonly used nanoparticles are nanosilica, nanoclay, nanotubes, etc. After adding them to composite material the system is called nanocompist. In mechanical properties, nanocomposites differ from traditional composite matters since the uncommonly high aspect proportion and its uncommonly large surface to volume ratio of the strengthing phase. The thermal, optical, electrical, electrochemical, mechanical and catalytic characteristics of the nanocomposite will vary significantly comparing to that of the component matters. Table (1.1) outlined the advantages and shortcomings of employing Nanocomosites.

Table 1.1 Advantages and disadvantages of using Nanocomposites

Advantages	**Disadvantages**
Mechanical characteristics (stiffness, tensile strength, toughness)	Viscosity increment (limits operation ability)
Dimensional stability	Sedimentation
Gas barrier	Dispersion difficulties
Chemical resistance	………………………
Thermal conductivity	………………………
Thermal expansion	………………………
Reinforcement	………………………
Synergistic flame retardant additives	………………………

1.2 Classification of Nanocomposites

Nanocomposites can be categorized depending on the matrix's basis into three types (Vikas, 2013):

1. Polymer matrix nanocomposites.

2. Metal matrix nanocomposites.

3. Ceramic matrix nanocomposites.

These types are illustrated in Figure (1.1).

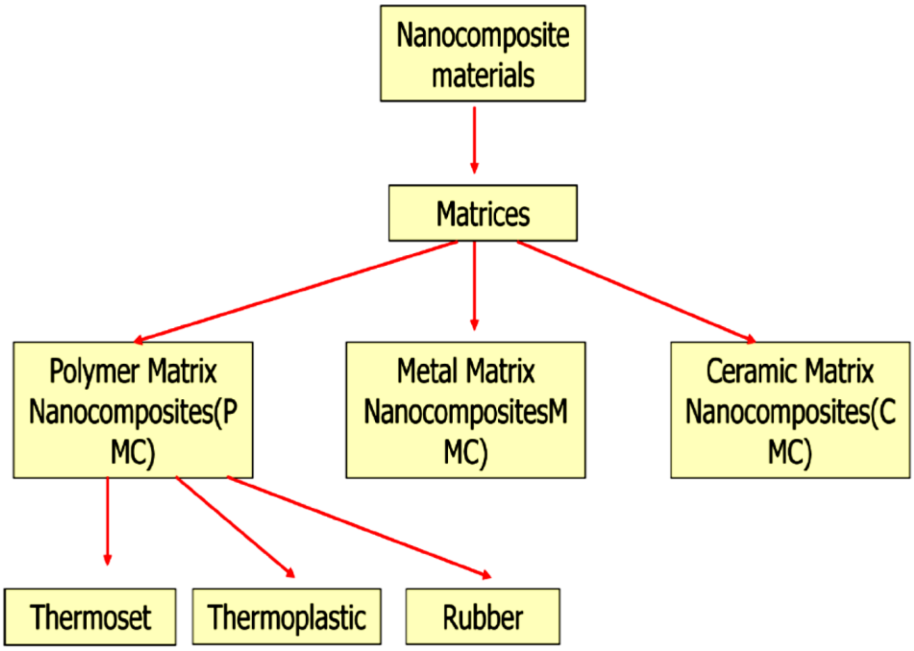


Figure 1.1 Categorization of Nanocomposites according to matrices

1.2.1 Polymer-matrix Nanocomposites

In the simplest situation, suitably if the nano particulates will be added to a polymer matrix it can improve its function and especially efficacious in achieving high accomplishment composites, since excellent filler distribution is occurred and the characteristics of nanoscale filler are principally better than the characteristics of the matrix. For instance, strengthen a polymer matrix by a lot stiffer nanoparticles of ceramics, silica, carbon nanotubes, or clays. Nanoscale dispersion of filler in the composite can produce novel behaviors and new physical characteristics which are truant for the unfilled matrices, as it improving the quality of the native matrix (like composite matters may be best characterized by the hybrids term or the real nanocomposites). Several patterns of this new characteristic are flame retardancy and accelerated biodegradability.

1.2.2 Metal-matrix Nanocomposites

Metal matrix nanocomposites might also be known as strengthened metal matrix composites. The aforementioned kind of composites will categorized as the non continuous and continuous strengthened materials. Carbon nanotube metal matrix composites as it represented one of the paramount nanocomposites is emerging new materials as they improved to take the vantage of the electrical conductivity and rise tensile strength of carbon nanotube materials. The investigation of CNT-MMC is possessing ideal performances in these areas and the improvement of synthetic ways are:

- Economically production.
- Providing a homogeneous dispersal of nanotubes within the metallic matrix.
- Leading to a good interfacial adhesion bonding the carbon nanotubes with the metallic matrix. Besides that boron nitride strengthened metal matrix composites, carbon nanotube metal matrix composites and carbon nitride metal matrix composites.

1.2.3 Ceramic-matrix Nanocomposites

The principle fraction of the ceramic-matrix composites's volume is occupied by a ceramic, i.e. it's chemical compound is composed from the group of nitrides, oxides, borides, silicides, etc. At most cases, a metal is the second component in ceramic-matrix nanocomposites. Ideally, the ceramic and the metallic are strictly scattered in each other with a view to grab the special nanoscopic characteristics. Nanocomposites of these fittings were proved by enhancing their magnetic, optical, and electrical characteristics, add to, corrosion resistance, tribological, and else protective characteristics.

1.3 Thermosets and Thermoplastics

Polymers can be categorized into two noticeable classes depending up on their warm preparing conduct as thermosets and thermoplastics (Table 1.2). Thermosets and thermoplastics can be important at the point when warmth is linked. With a thermoset, warm causes the material to decay and smolder with no softening, while with thermoplastic status the material will mollify and expel from the warmth brings about solidifying status. The particle in a thermoses style with three-dimensional frame of chains with cross-interfaces between chains likewise. The series and its bonds linking are rigid and it is not easy to destroy. In this manner, the chains unpractical to slide more than each other consequently so, thermosetting polymers are stiffer and more powerful than thermoplastics. Thermoplastics display the possibility of heating and then can be pressed into the required configurations. The steps thermosetting polymer can be modeled by the chemical step. Material is in the shape of the cross-connected chains are delivered. Thus, the outcome is a polymer molded as the frame by the shape. There are no further procedures other than perhaps some machining likely happens (Orozco, 1999).

Table 1.2 Variation between thermoplastics and thermosets

Thermoplastics	**Thermosets**
Mellow on warming and weight, and hence simple to repair	Break down on warming
High strains to disappointment	Low strains to disappointment
Inconclusive timeframe of realistic usability	Distinct timeframe of realistic usability
Can be reprocessed	Can't
Not shabby and simple to deal with	Cheap
Shortened cure cycles	Long cure cycles
Higher creation temperature and viscosities made it hard to prepare	Lower fabrication temperature
Great dis solvable resistance	Fair solvent resistance

1.3.1 Epoxy Resin

Epoxy resin frameworks possess accomplished approval as adhesives, potting compounds, matrices for continuous filament composites and molding compounds utilized in structural uses. Generally, the principal features of epoxy resin are:

- An inherently polar nature that grants superior adhesion to a spacious variety of fibers.
- Relatively low cure shrinkage that produces dimensional precision of manufactured structures easier to obtain.
- No volatile by- products of the treating reaction to reason void formation or undesired bubble.

- Crosslinked structure that grants good resistant to hostile environments, both non-aqueous and aqueous.

Epoxy resins have enormous versatility due to their formulation to meet a broad domain of certain performance and processing demands.

1.4 Glass Fiber

Glass fiber or fiberglass is a fabricated material from exceedingly superfine fibers of glass, and it considers as the largest reinforcement measured in sales. Glass fiber was feigned by Russell Games Slayter of Owens-Corning in 1938 as he illustrated to utilize it as isolation (Lowenstein, 1973). Ever since then, glass fiber has become vastly employed as composite reinforcement and insulation material. According to the composition and the application, glass fibers can be categorized in several kinds. The most ordinarily utilized glass fiber kind of composite applications is E-glass, because of its comparatively good electrical insulation and high mechanical properties. S-glass is also utilized in composite materials where high tensile strength is coveted, anyway, this material comes at a much higher price. R-glass is also employed in composite materials due to the high mechanical requirements such as high chemical resistant and fatigue life. Idealistic fiber diameter for glass fiber is ranged from 9 to17 µm and the specific gravity is approximately 2.5. The elastic modulus is in the order of 50-90 GPa and the tensile strength of glass fiber lies in order of 2000-4800 MPa, much superior to polymers (Biron, 1973).

1.5 Properties of Polymer–SilicaNanocomposites

Nanomaterial additives can supply several property features in comparison to both base polymers and their traditional filler counterparts. Properties that have been illustrated to undergo fundamental development composes of:

- Mechanical characteristics (e.g., modulus, strength, and dimensional firmness).
- Diminished permeability to water, gases, and hydrocarbons.
- Heat deformation temperature and thermal stability.

- Electrical conductivity.
- Chemical resistance.
- Optical clarity as compared to traditionally filled polymers.

Besides that these advantages it is important to distinguish that nanoparticulate/fibrous loading noticebly enhances property with very low loading grads, conventional nanoparticle additives requiring much higher loadings to attain identical performance.This, in turn, lead to essential weight reductions (of obvious importance for various aerospace and military applications) for identical performances, greater strength for identical constructional dimensions, and, for barrier applications, rose barrier performance for identical material thickness.

1.6 Fiber Reinforced Epoxy/Silica Nanocomposite

Fiber reinforced epoxy/silica nanocomposites are those in which epoxy adjusted with nanosilica is utilized with fibers. The dispersion of nano-silica in epoxy is accomplished by mechanical stirring, subsequently followed by ultrasonication. The fiber strengthened nanocomposites are then set by any of the traditional composites manufacturing technique (vacuum bagging, hand layup, vaccum assisted resin flux moulding, etc.). The resulting nanocomposite displays better mechanical properties and fire retardancy.

1.7 Mechanical Properties

Many researches have dealt with the effect of nanoparticles on the mechanical characteristic of polymer resins as well as ordinary composites. The most common mechanical performances measured are flexural and tensile strength.

1.7.1 Tensile strength

The tensile strength can be defined as the limit of a substance to resist tensile stress without happening failure in the substance. Tensile stress happens when a material is exposed to forces that make the substance extends. Opposite of tensile stress is compressive stress. Common epitome of tensile stress is pulling a rubber band; and if the stress is beyond its strength, then the rubber band will break.

1.7.2 Flexural strength

The flexural strength can be defined as the limit of a substance to whitstand flexural stress without failing. If a substance is exposed to flexural stress, it will undergo both compression and tension demeanor due to the bending moment. Anyway, flexural strength of any substance will have relied on either its compressive strength or tensile strength, whichever is minimal. Most common epitome of a flexural stress is by bending a sample in the shape of U. The outer surface of the sample will be exposed to compressive stress, whilst the bottom face will undergo tensile stress. If you bend it further, you may see the bottom face of the sample will begin to crack, which signalizes that it the stress subjected to it is beyond its flexural strength.

1.8 Research Objectives and Tasks

The main objective of the current work is to study the influence of nano-silica on tensile and flexural behavior of glass fiber enhanced composite laminates. Tasks of the research can be summarized as follows:

I. Fabrication of glass fiber enhanced composite laminates without addition nanosilica (pure).

II. Glass fiber enhanced composites laminates were prepared with various amounts of nanosilica content for the purpose of manufacturing.

III. Conduction of the tensile and flexural tests for all of the prepared laminates.

IV. Discussion about the influence of the nano-silica and different fiber orientation angles on the tensile and flexural behavior using the obtained results from the tests.

1.9 Layout of Thesis

This work is segmented into 5 chapters.

- Chapter 1 offers a generic introduction about the important phenomas and definitions about the composite materials; and definitions of nanocomposite materials. Additionally, the importances and outline of this study are displayed.

- A comprehensive literature review and the dissussion about the influence of nano particles on mechanical characteristics of composite materials are given in Chapter 2.
- In chapter 3, information about the materials (fibers, nanosilica, epoxy) and fabrication method used in this work are provided.
- Chapter 4 provides the tensile and flexural characteristics of neat GFRP, nanosilica modified GFRP composites, different fiber orientation angles and the debate about the outcomes of the experimental works.
- The important conclusions are displayed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 provides background on the basic matters to be represented in the current study and also to emphasize the importance of the current thesis. This study searches the influence of nanoparticles (nanosilica) on the mechanical characteristics of the composite materials, hence similar investigations in the literature are studied prior to any work. A brief literature related to the trend of behavior of composite materials under static and dynamic loads is presented in this chapter. This chapter imposes reviews of available research reports:

- The effect of some factors on the characteristics of composite laminates.
- Studies on investigating effect of different fillers on mechanical characteristics of composite material.
- NanoSilica effect on general mechanical characteristics of fiber reinforced composite plates.
- The effect of hybridization on the general mechanical characteristics of fiber reinforced composite.
- Tensile and flexural strength of fiber reinforced composites.
- Conclusions of the literature review.

2.2 The Effect of Some Factors on the Characteristics of Composite Laminates

There are several factors that effect on the characteristics of laminated composites which cannot be confined to such research, but some of them mentioned through presenting in the following paragraph:

By numerical analysis conducted by Sun et al. (2001) to identify the delamination influences on the compressive failure response of composites. The Von Karman's formulations were inserted in this analysis to find the buckling, post buckling, contact influences of delaminated region, progress of delaminated region, fiber and matrix cracking. Progress of delaminated zone was considered through using a fracture theory which controls energy dissipated during fracture along delaminated zone. They concluded that the delamination growth was extremely affected the from boundary kinds, and stiffness deterioration have considerable effects on buckling strength.

Zou and Lam (2002) observed the effect of some factors on buckling of composites such as layer numbers, thickness of laminate, ratio of Young's modulus in plane and lateral direction and fiber orientations (cross-ply and angle-ply) using Finite Element Method (FEM). The results in this study were adopted on using high-order shear deformation theory. The scolars determined these factors have a huge affect the composites.

Through addition granite powder in composite systems, the most important mechanical properties were presented by Krishna et al. (2005). Different weight granite powder percentages were added (30, 35, 40, 45, 50, 55 and 60 wt%) to the epoxy resin. The elasticity and strength were at a greatest for the half rock powder-strengthened epoxy composite, while they diminished at 60wt% were founded. The concoction resistance test proves that the composite materials are impervious to acidic corrosive, sodium hydroxide, concentrated hydrochloric corrosive, carbon tetrachloride, benzene, and n-hexane at half support of stone powder.

Based on the experimental and numerical analyses conducted by Ahn et al. (2005) to specify the failure study of composite substances of unidirectional woven fiber which utilized in the airplane control rod. Specimens having many unlike geometries (formed changing the width to hole diameter and the edge distance to the hole diameter ratios, considering hole size constant) were used in the test. Failure patterns and loads were specified by examining under the pin loading and the effects of different geometries were obtained. An excellent agreement was achieved between the numerical and experimental studies. It was found that these different geometries have a huge affect the composite characteristics.

Aktas and Karakuzu (2009) determined the effects of increasing temperature on mechanical characteristics (compressive, tensile, shear) of glass/epoxy composite plates. The increment temperature of this experimental study was from 20°C to 100°C by step variation 20°C at constant pressure of 250 KPa. The most observation of this work was that reduction of the overall mechanical characteristics caused by increasing of temperature.

Yousif et al. (2012) investigated the flexural features of uni-directional long natural fiber (Plant Fiber) which was Kenaf Fiber Reinforced Epoxy (KFRE) composites. The kenaf fibers were set up into two kinds as a treated and the untreated (with NaOH ratio 6%). The findings showed that strengthening of epoxy with treated kenaf fibers enhanced the flexural strength of the composite by approximately 36%, whilst the untreated kenaf fibers presented 20% amelioration only.

The mechanical characteristics of potassium strengthened epoxy based Polymer Matrix Composites (PMCs) were researched by (Sudheer et al. 2012). By utilizing the casting method was considered to find epoxy composites loaded with potassium titanate whisker (PTW) in different material of 0 to 20 wt% with step variation 5%. It was found that the thickness, hardness and warmth redirection temperature of epoxy with increasing of Potassium content. Additionally, they detected that the epoxy stacked with 10 wt% of Potassium indicated awesome change in flexural strength and flexibility. It was noticed that Potassium substance is not useful in upgrading the influence nature of epoxy. Moreover, composites under the maximum percentage (20 wt% of Potassium) showed the minimum effect strength.

Under different weight percentages 10, 20, 30 and 40 wt% of walnut particles were used to reinforce the epoxy matrix, which carried out by Nitin and Singh (2013) to observe the mechanical properties of their systems. The increment of wt% of walnut particle from 10 wt% to 20 wt% worked to successfully increased misfortune in extreme elasticity and pick up in rate of lengthening, in contrast with increasing in 20-40% wt. Furthermore, the increment in modulus of versatility was practically reliable.

2.3 Studies on Investigating Effect of Different Fillers on Mechanical Characteristics of Composite Material.

The utilized fillers in polymers are significant for many reasons such as to improve mechanical properties, thermal conductivity, control density, thermal expansion, flame retardance, electrical properties, and to improve processing. Each filler type has different properties depending on shape, particle size and surface chemistry (Rothon, 2002). The most commonly utilized fillers for thermoset resins are alumina hydrat, kaolin, and calcium carbonate. Other commonly used filler include carbon black, silica, clay, mica, glass whiskers, glass micro-spheres, fly ash, silicon carbide, sewage sludge ash, etc.

Based on the experimental work conducted by (Ruse et al. 2001) to study the effects of zinc powders on high density polyethylene (HDPE) composites relating to thermal and mechanical features. In this work, the volume fractions were utilized zinc powders as a range from 0 to 20 %. The scolars concluded that the addition of zinc powder decreased from overall mechanical properties, but the density and hardness of HDPE/zinc composites increased with compared to unfilled HDPE composite. Besides that they discovered that the thermal stability of HDPE/zinc composites is superior to unfilled composite.

Mahrlz and Riledel (2003) examined two kinds of nanofiller on the angle ply GFRP laminates. The nanofiller used in this study was Barium Sulfate ($BaSO_4$) and Silicon Dioxide (SiO_2). The results of this study showed that the mechanical characteristics such as tensile strength and tensile modulus increased about 25%, 64%, respectively.

The effect of dispersion of clay nanoparticles through the composite materials were studied by (Daniel et al. 2003). The researcher used a three roll mills with a condensation of the weight percent ranging from 1 to 10. The most important results of this research was that the elastic modulus has been adjusted to 80 % with 10 weight percent addition of clay nanoparticles in the epoxy. Additionally, they interpreted the improvement of the tensile strength of nanocomposites over pure epoxy is due to the clustering of nanoparticles and to the occasional incident of nano to micro size voids in the microstructure.

By including different volume fractions of fly ash to epoxy composites systems conducted by Gu et al. (2007) to investigate the damping properties of prepared composites. The volume fractions of fly ash used in this work were 30, 40, 50 and 70 vol%, respectively. It was found that the peak value of damping of the composite was achieved when the fly ash addition approached to 30 vol %. However, the findings in this study showed that under various volume fractions of fly ash gave higher damping ratio than unfilled epoxy composite. Moreover, they found that the inclusion of fly ash significantly strengthening the damping capacity of epoxy resin.

The influences of addition the powder of alumina to epoxy on mechanical performance were investigated by (McGrath et al. 2008). The results of the mentioned study proved that the changes in particle size, shape and size distribution were affected by a slim amount on the final characteristics. Moreover, the most critical changes on the mechanical characteristics were density of the resin crosslink and filler loading as a compared to other variables.

Amit and Muhammad (2008) explained that nano TiO2 fillers were impact on the mechanical attributes of TiO2-epoxy nanocomposite. They disclosed that the nano filler infusion works to improve the mechanical, viscoelastic and thermal features of the epoxy resin. A modification that took place on storage modulus, flexural modulus, tensile modulus, and short beam shear strength of neat epoxy resin was indicated by their study.

Kochetov et al. (2009) searched the efficiency of composite by producing nanocomposites filled with three kinds from ceramic substance represented by silicon dioxide (SiO_2), aluminum oxides (Al_2O_3), and aluminum nitrides (AIN) under various rates of particle size. The researchers detected that the maximum direct current (DC) inactivity strength for 0.5 weight percent for two portions system. It was also indicated that the DC electrical breakdown strength was rising to 10 weight percent as compared to 2 and 5 weight percent and again reduced with 15 weight percent Nano-fillers.

Davis et al. (2010) studied the improvements in mechanical characteristics of a carbon fiber epoxy composite using nanotube science and technology. It was shown that one cause of the onset of buckling is due to the curvature or waviness of the component fabric.

Aktas and Altan (2010) investigated the influence of nanoclay amount on the characteristics of glass fiber reinforced, waterborne epoxy laminates. In this research, fourteen prepared ply nanocomposite laminates which contained 0, 0.1, 0.2, 0.5, 1 and 2 wt% closite Na+nanoclay were manufactered by employing a hot press. The flexural and shear strength of the sheets, in addition to the flexural stiffness of the manufactured nanocomposites were presented. Additionally, thermogravimetric analysis has been implemented to study the behavior of the laminates according to thermal stability. The dispersion state was assessed by using X-ray diffraction, while adhesion of the fiber–matrix was investigated using scanning electron microscopy on fracture surfaces. The mechanical characteristics peaked at a 0.5 wt% of nanoclay loading. At this nanoclay loading percentage, the development in interlaminar shear strength, flexural strength and flexural stiffness were 5, 8 and 12% respectively.

Iovu et al. (2011) prepared a special based nanocomposites epoxy to reinforce with multi walled carbon nanotubes (MWNT). Iovu et al. (2011) detected that the structure of amine multiple walled carbon nanotubes B100 display compatibility with the epoxy matrix and the nanocomposites obtained were based on diglycidyl ether of bisphenol A (DGEBA) and modified MWNT.

Setsuda et al. (2012) studied the influences of injection molding of fly ash in composites. The findings indicated that the material of fly ash debris is profoundly huge and contributive to the shrinkage proportion and bowing strength. The shrinkage proportion, bending strength and flexural modulus of low-density polyethylene (LDPE) composites containing crude fly ash powder were found to progress. The shrinkage proportion and flexural modulus of PP composites containing ground fly slag were additionally found to move forward.

Chitsazzadeh et al. (2014) investigated the effect of the addition of multiple walled carbon nano-tubes on the mechanical characteristics of divided strand mat/polyester composites. They detected through adding a weight percent of only 0.05 carbon nano-tube could be improved the flexural strength for the hybrid composite by 45%, whilst the strength of tensile still without varied significantly.

Through the numerical and experimental studies, Sayer (2014) studied the effect of the addition various types of ceramic particles on the elastic characteristics and load carrying capabilities of E-glass/epoxy composite plates. Based on the weight of composite, the particle weight fractions were studied is 0%, 5%, 10% and 15%, respectively. Two particle sizes, aluminum oxide (Al_2O_3) and boron carbide (B_4C) are characterized in the study. The outcomes demonstrated that the load carrying capability of composites is effected by distinctive molecule sizes, molecule weight divisions and diverse ceramic particles (fillers). Consequently, the load carrying capabilities of compounds filled with 10 wt% ceramic particles were gave a higher as a compared with other particle sizes. Furthermore, the inclusion of 10 wt% boron carbide (B_4C) molecules to compounds increase the critical buckling load value of composite approached to 42 %.

2.4 Nanosilica Effect on General Mechanical Characteristics of Fiber Reinforced Composite Plates

Nanosilica is one of the most important kind of nanoparticles uses to improve the mechanical characteristics of the polymer. Furthermore, among the numerous polymer composites, nanosilica/polymer (nanocomposites) is the most commonly mentioned in the literature and employed in a variety of implementations, such as automotive, electronics and the space applications due to its good mechanical characteristics (Moisala, 2006).

Moloney et al. (1987) have studied 40% volume fraction silica-filled epoxy with particle size in the range of 60–300 µm. The researcher finds out that the particle size did not influence the fracture toughness and flexural modulus.

Zheng et al. (2003) studied a nanosilica in epoxy resin and characterized the effect of nanocomposite with impact and tensile testing. Mechanical methods and ultrasonic were used to disperse the nanoparticles in epoxy resin. They were studied the effects of nanometer-sized SiO2 particles on free volume of nanocomposites were using positron annihilation lifetime spectroscopy.

Zheng and Ning (2005) adopted the silica nanocomposites in conjunction with the glass fiber to form hybrid glass/silica/epoxy nanocomposites. The scholars disclosed that the bending characteristics in addition to the tensile characteristics of the fiber composites were strengthened by the inclusion of silica nanoparticles. The strengthening could be contributed to the promoted bonding forces between the glass fiber and matrix adjusted by the silica nanoparticles.

Jasiuk et al. (2005) studied the trend of the enhanced polyurethane matrix with nano sized and micron sized silica implications. Jasiuk and friends found that the density of composite can be reinforced with inclusions of micron sized as compared to the density of inclusions of nano-sized.

Rosso et al. (2006) investigated fracture and tensile characteristics of silica nanocomposites. The authors indicated that the addition of ratio of 5% silica nanoparticles from the total volume of composite material could be developed the stiffness and facture energy at the range from 20% to 140%.

Rongguo et al. (2008) searched the impact of nano silica filler on mechanical characteristics of epoxy. The researchers discovered that the moduli of elasticity of the nano-SiO_2/epoxy composite are larger comparing to those of neat epoxy resins. Additionally, it was found that the extension of the composites reduces with rising nanosilica mass portion.

Uddun et al. (2008) analyzed the strength of unidirectional glass/epoxy composite with silica nanoparticle-enhanced matrix. They found that the silica nanoparticles could be dramatically increased the longitudinal compressive strength and moderately increased the transverse and longitudinal tensile strength.

Mahrholz and Stagle (2009) studied the influence of the additional quantities of silica nano particle on the behavior of Glass Fiber Reinforced Polymer (GFRP). At their research, they explained about amount of silicon content utilized in polymer for better property. They illustrated that the increase of the amount of silicon content reach to 25% wt of the epoxy resin worked to increase strength, stiffness and toughness of composite and also the shrinkage and thermal expansion of the resin will be reduced. They detected that one may fill with silica reach to 25% wt. Relying on the silica amount stiffness, strength and toughness of composite will rise and also the shrinkage and thermal expansion of resin will decrease. Additionally, in this research the refinement in tensile behaviors of GFRP whilst by filling with Silicon Dioxide nano particle.

Manjunatha et al. (2009) studied the tensile fatigue trends of a silica nanoparticle-filed glass fiber epoxy composite. The epoxy resin was a standard diglycidyl of Bisphenol A with an epoxide. The GFRP composite plates were fabricated by resin infusion under flexible tooling method. An anhydride-cured thermosetting epoxy polymer was adjusted by commingling 10 wt. % of well- sprinkled silica nanoparticles. The fatigue life of 10 wt. % silica nanoparticle-adjusted bulk epoxy was about 3 to 4 times higher than that of the total net epoxy. The weariness life of the GFRP combined by 10 wt.% silica nanoparticle adjusted matrix of epoxy was nearly 3 to 4 times greater than GFRP with the total net epoxy matrix. It is important to mention that the restrained matrix cracking and reduced crack growth rate as a result of the particle debonding and plastic void growth mechanisms appeared to contribute for the detected improvement of the fatigue life in the GFRP with the nanoparticle-modified matrix.

Manjunatha (2010) examined the tensile and fatigue behavior of nanosilica particles modified GFRP composite. The researchers found that the tensile strength increased by about 5% to19%, while the modulus increased by about 7% and 17% in the GFRP composite and bulk epoxy.

Tsai et al. (2010) investigated the mechanical characteristics of silica strengthened composites. The outcomes of this study proved that the extent of the silica nanoparticles were more appreciable in the brittle matrix system rather than in the ductile matrix systems. Additionally, they found that the in-plane shear strength was dramatically increased with increasing the quantity of nanosilica in the matrix.

The effect of nano-silica with 5–25 wt% particle content on the tensile stress-strain findings of epoxy A 40 wt% nano-silica/epoxy was accomplished by Jumahata et al. (2012). This study showed that the incorporation of a well-disperse nanosilica increased the tensile modulus and strength of about 38% and 24%, respectively.

The tensile behavior of GFRP system under the addition nano at different strain rates, was studied by Sujesh et al. (2012). In this research, the epoxy – nanosilica substances is employed as matrix for Glass Fiber Reinforced Plastics which is fabricated by Vacuum bagging method. Its improvement in tensile strength, tensile modulus are illustrated. Furthermore, the increase of nanosilica filled bi-directional fiber enhanced polymer under the action of uniaxial loads is specified at various strain averages such as 5, 50, 500 mm/min. The experimental works were implemented by Universal Testing Machine. The outcomes of this study showed that the slight decreasing in ultimate tensile strength and tensile modulus of the material by increasing the strain rates.

Marjetka and Conradi (2013) concluded that the filled of a polymer matrix by nano-silica particles provides significant increase in the modulus and strength of the matrix to the overall compound characteristics.

Zamanian et al. (2013) noticed that the mechanical characteristics of an epoxy have been modify drastically by the inclusion of silica nanoparticles with various sizes. The best amelioration being approached with the smaller nanoparticles.

The effect of silica and graphite fillers with different particulate fractions on the mechanical characteristics of epoxy composite laminates were analysed by Sriram A et al. (2015). In this study, the content of fillers was diverse from 5, 10, 15, 20, and 25% of total weight matrix of epoxy in the composite laminate. The results from this study indicated that the mechanical features of the combined materials mainly depending on the dispersion condition of the filler particles and aggregate structure. However, the characteristics of composites developed in impact strength, tensile strength, flexural strength, and hardness with an increase of silica filler material content. But, these characteristics except hardness were illustrated decreasing trend by increasing the content of graphite filling substances. The hardness of the composite laminate is rises with increasing in the content of graphite filler material. The 15% silica filled epoxy composite laminate has illustrated superior to other materials.

2.5 The Effect of Hybridization on the General Mechanical Characteristics of Fiber Reinforced Composite

The influences of stacking sequence and hybridization level on impact strength of hybrid composites studied by Marom et al. (1986). The Hybrid composites were manufactured by using Kevlar and carbon fibers, and epoxy resin. When one carbon layer was put between two Kevlar layers, the positive hybrid impact happened.

Peijs and De Koki (1993) investigated both of the elastic and exhaustion conduct of unidirectional carbon-elite polyethylene/epoxy crossover composites imposing the impact of hybrid outline and surface treatment of the superior polyethylene (HP-PE) filaments. The findings displayed that the ductile conduct of carbon-HP-PE hybrids in both exhaustion and monotonic testing can be translated. Receiving the traditional 'consistent strain' demonstrate for hybrid composites. The hybrid effects under tractable stacking conditions were in sensible concurrence with calculations representing measurable stretch and impacts fixations as dictated by limited component investigations

Gustin et al. (2005) studied the impact, compression after impact, and tensile stiffness characteristics of carbon fiber and Kevlar (CKF) sandwich composites. The CKF hybrid composite plates were set by considering impact part. Carbon fiber was kept in the bottom side of part because of its high flexural stiffness. The focus of this research was to determine the possibility of improvement on impact properties with respect to replacement of carbon fiber on impacted-side face sheet layers with Kevlar or hybrid. The impact experiences were carried out on different specimens kinds to get data about absorbing energy and peak impact force.

Yadav et al (2006) explored improvement on the fracture toughness of carbon fiber epoxy composite with Kevlar enhanced interleave, this work was showed how fracture toughness is influenced by interleave having Kevlar fiber enhancement in the fracture plane. Outcomes obtained explained that fracture toughness strengthening amounted to about two times in all the laminates.

Belingardi et al. (2006) investigated the bending fatigue demeanor of glass–carbon intraply hybrid biaxial fiber strengthening epoxy matrix composite. The bending fatigue behavior hybrid laminae was also compared with that of biaxial carbon laminae and biaxial glass laminae.

Sarasini et al. (2013) explained the impacts of basalt fiber hybridization on low velocity impact behavior of carbon/epoxy layers. The hybrid specimens with two distinctive stacking successions were generated. The outcomes showed that hybrid overlays with intercalated structures have beast effect energy absorption ability and reinforced damage tolerance as for the all-carbon covers, whilst mixture covers with sandwich-like configuration present the best flexural conduct.

Fernandes et al. (2013) manufactured composite systems from HDPE filled with fitting coconut short, and powder fibers. The extension of coconut fiber to cork–HDPE composites extended the adaptable inflexibility and modulus by 47% and 27%, respectively stood out of cork–HDPE composites.

Boopalan et al. (2013) examined the influence of adding banana fiber to jute-epoxy composites and reported an improvement on mechanical characteristics with minimum moisture absorption.

Ramesh et al. (2013) produced hybrid composites made of sisal–jute–glass fibers and their tensile, flexural and impact strengths were measured. It was found that the usage of sisal–jute fiber with GFRP can be ameliorate the mechanical characteristics.

Fonseca et al. (2014) investigated the mechanical properties of polyethylene-(pine/agave) fibers based hybrid composites made with two characteristic fibers: agave and pine. The outcomes showed that expansion of agave fibers enhances the elastic moduli and flexural strength, while pine fibers diminishes water take-up.

2.6 Tensile and Flexural Strength of Fiber Reinforced Composites

Kalnin (1972) investigated the hybridization effect on flexural behavior of composite laminate composing of graphite and glass reinforcement. In this study, the results showed that the flexural strength reduces swiftly by the replacement of glass fiber with graphite fiber.

Park and Jang (1999) tested the effect location of polyethylene (PE) fibers in carbon-PE/vinyl ester hybrid composites on the mechanical properties. They utilized PE fibers due to its high specific strength and stiffness, and high elongation at break. They disclosed that the mechanical performances of hybrid composite robustly depended on the reinforcing fiber location, such that, when carbon fiber was laid at the outermost layer, the hybrid composite illustrated the highest flexural strength.

Li et al. (1999) investigated the flexural and compressive behavior of ultra-high-modulus carbon fiber hybrid and polyethylene fiber composites. In this work, the experimental findings exhibited that the connecting of a direct measure of carbon fiber into an UHMPE-fiber-strengthened composite incredibly improves the compressive strength, flexural strength and flexural modulus whilst the increase of a small quantity of UHMPE fiber into a carbon reinforced composite basically enhances the flexibility with solely a small reduction in the compressive strength.

Fu et al. (2000) searched the tensile properties of polypropylene reinforced with adding short carbon fibers (SCF) and short glass fibers (SGF) composites. It was found that the tensile failure strain of the composites reduced with the increment of fiber volume fraction and the flexural, tensile strength and flexural modulus of the SCF is higher than SGF.

Das S. (2001) explored the cost of automotive polymer composites. It was found that the utilization of CFRP in cars could reduce the vehicle's weight by forty to sixty percent. Anyway, the high cost of carbon fiber only limits its application to luxury aerospace vehicles and cars. Therefore, there is a need to decrease the cost of CFRP without sacrificing a lot in its mechanical properties.

Thwe et al. (2002) comparatively searched the tensile and flexural behavior of short bamboo fiber reinforced polypropylene composites (BFRP) and short bamboo-glass fiber reinforced polypropylene hybrid composites (BGRP). The composite specimens were fabricated by using a compression molding method. When the ratio of the mass of glass fiber approached to 20% of the total mass of composites both of the flexural and tensile modulus of BGRP were increased by 10 and % 12.5, respectively; and the flexural and tensile strength increased by 25 and 7%, respectively, compared to those of BFRP. Thus, it was shown that the durability of BFRP can be improved the hybridization with small amount of glass fibers.

Wan et al. (2006) estimated the mechanical performances both of unidirectional and three-dimensional braided carbon/Kevlar hybrid fibers. They found that the hybrid composites exhibited important enhancements in flexural strength and interfacial adhesion strength (IAS) after two-step surface handling, proposing this way was efficient.

Wan et al. (2007) studied unidirectional, short and laminated layers composites extensively. 3-D braided Kevlar fibers and carbon were hybridized to reinforce a bismaleimide (BMI) resin. The impact of Kevlar to carbon ratio on such mechanical performances as load displacement demoner, modulus and flexural strength, shear strength, and impact properties were studied. The influence of surface treatment of hybrid fabrics on the flexural performances was also detected. Experimental outcomes demonstrated that the modulus and flexural strength of the 3-D braided carbon/Kevlar/BMI composites rose with relative carbon fiber loading up to a Kevlar to carbon ratio 2:3 and then decreased. Positive hybrid influences were determined for both modulus and flexural strength. The outcomes demonstrated that hybridization with certain amount of ductile Kevlar fiber drastically increased the impact energy absorption characteristics, shear strength and damage tolerance of the all-carbon composite, which is of importance for the 3-D layered composites to be employed in bone fixations.

Sudarisman (2008) studied the hybridization influences on the flexural performances of unidirectional glass fiber-reinforced polymer composites. It was detected that the replacement thirty-three percentage of E-glass fiber by S-2 glass fiber generated the increment in flexural strength of twenty-three percentage, without any important impacts of the hybridization on the flexural modulus.

Davies (2008) examined the flexural characteristics of unidirectional carbon fiber-reinforced polymer matrix composites. The composite plates were wetted by using a concentration of epoxy (45-65 wt%) within an acetone solution. It was found that the maximum flexural strength was 1292 MPa for 50 wt% of epoxy resin content.

Pavia et al. (2009) studied compressive, tensile, flexural, and shear tests of carbon fiber reinforced composites (CFRC) based on two epoxy resin systems (F584 ^{TM} and 8552^{TM}) and two carbon fiber fabric reinforcements that were Plain Weave (PW) and

Eight Harness Satin (8HS). It was observed that the F584-epoxy matrix laminates give higher mechanical properties in the tensile and compressive tests than 8552 composites.

Rongxian and Hui (2010) determined the effect of reinforcement the Kevlar fibers (KFs) on the wood-flour/high-density polyethylene composites (WF/HDPE) to develop the mechanical performances of the resulting composite systems. Addition of a small amount from two to three percentage of KF caused a development in the flexural, tensile, and impact performances of WF/HDPE. It can accordingly be disclosed that the grafted KF can be utilized as a reinforcement to develop the toughness and strength of WF/HDPE composites.

Davis et al. (2010) proved the improvements in tensile strength and stiffness and durability of carbon fiber enhanced epoxy composite laminates, with the inclusion of 0.2, 0.3 or 0.5 weight percent (wt%) fluorine functionalized ‘‘XD” carbon nanotubes (f-XD-CNTs). The carbon nanotubes were incorporated at the fiber fabric-matrix interfaces. It has been shown that one of the reasons for the beginning of bukling is due to the curvature or waviness of the Component Textile.

Valente et al. (2011) studied hybrid thermoplastic composites from wood flour and recycled glass fibers. The hybrid composites composing of virgin glass fibers were fabricated and examined in order to estimate the effect of recycled glass fibers. Mechanical characteristics of the composites imposing strength and flexural modulus, hardness as a function of temperature were investigated. The hardness and flexural modulus were found to increase as a function of increasing glass and wood flour fiber content, while the flexural strength reduced as a function of increasing wood flour content, in spite of a positive effect of the addition of glass fibers was found. The recycled glass fibers displayed a comparable demeanor to that of the vestal ones.

Dong et al. (2012) studied the strength of flexure of hybrid epoxy composites strengthened by T700S carbon and S-2 glass fibers in an intra-ply figure, several stacking configuration of carbon fiber and glass fiber laminas were considered. The strength of flexure was acquired from the application of the three-point bending test. It was seen that increase of percentage of S-2 glass fibers decreased flexural modulus. Positive hybrid effects occurred when carbon fibers take placed with glass fibers.

Zhang et al. (2012) investigated the strength of hybrid composite laminates utilizing varying ratio of carbon woven fabric and glass woven fabric in an epoxy matrix. It has been shown that substitution the carbon layers to the exterior led to obtained the better flexural characteristics.

Ho and Lau (2012) introduced a new hybrid composite by using short silk fibers into the woven glass fiber reinforced polymer composites to improve Young's modulus and impact resistance characteristics. The results of experimental studies showed that the addition of short silk fiber with 0.4 % wt. had better tensile and impact strengths.

Do Rigato and Poretti (2012) investigated the behavior of epoxy laminates carbon (CF), basalt (BF) and E-glass (GF) -balanced woven fabrics under fatigue conditions. Results showed that superior performances of BF laminates with respect to the corresponding GF composites.

Rathnakar et al. (2013) experimentally studied the strength and stiffness of glass-graphite/epoxy fiber reinforced composites under flexural loading. It was observed that the fundamental discoveries of this examination were the direct effect of thickness on flexural strength. They also found there is an important development in strength and stiffness of graphite laminates compared with glass for same thicknesses under test.

Zhang et al. (2013) studied the mechanical behaviors of unidirectional flax and glass fiber reinforced hybrid composites. The tensile properties of the hybrid composites were improved with the increasing of glass fiber. Based on the hybrid effect of tensile failure strain, a modified model for the evaluation of the tensile strength wasgiven. The influence of stacking sequence on the tensile strength and tensile failure strain was presented. The fracture toughness of the hybrid composites was even higher than those of glass fiber reinforced composites due to the excellent hybrid performance of the hybrid interface.

Petrucci et al. (2013) studied the tensile, flexural and interlaminar shear strength of hybrid laminates. The hybrid laminates were prepared using basalt, glass, hemp and flax fibers with different stacking configurations. The mechanical performance of all the hybrid laminates appears superior to pure hemp and flax fiber reinforced laminates and inferior to basalt fiber laminates.

Almeida et al. (2013) investigated the effect of hybridization on mechanical properties of glass and curaua fiber reinforced composite. The neat glass, neat curaua and glass/curaua hybrid fiber reinforced composite laminates with different volume fractions were produced using hot press. It was shown that mechanical performance of vegetable/synthetic fiber can be increased with addition of glass fibers.

Brocks et al. (2013) studied the flexural properties of hybrid composites reinforced by S-2 glass and T700S carbon fibers. The controlling failure style is compressive failure and flexural modulus decreases with increasing percentage of S-2 glass fibers.

Diharjo et al. (2013) determined the flexural characteristics of bisphenol-A reinforced woven roving carbon/glass fibers hybrid composites. The composites were fabricated utilizing a hand lay-up technique. The parameters in this research were the replacement of glass fibers with carbon fibers on both lower and upper sides symmetrically. The finding demonstrated that the modulus and bending strength increased with increment of carbon fibers. The highest flexural strength is happened when reinforcement fiber of the samples compose of 90% carbon fibers.

Dong et al. (2013) studied the flexural performances of and hybrid glass carbon fiber reinforced epoxy composites. Three combinations of the carbon and glass fibers, i.e., S-2&TR30S S-2 and T700S, and E and TR30S, were selected to make hybrid composite samples. It was noted that the dominant failure style was compressive failure. The experimental results of this study proved that when the increase percentage of glass fibers the flexural modulus decreases. Additionally, by substituting carbon fibers with glass fibers, the positive hybrid achieved on the compressive surface of specimens.

Ary-Subgiant and Kim (2013) examined the flexural characteristics of the carbon-basalt/epoxy hybrid composites based on the stacking sequence and the number of basalt layer. The experimental results proved that the location of carbon and basalt fiber on laminate directly affecting on the flexural characteristics of hybrid composites. Carbon fiber in tension side had the highest flexural strength in based on hybrid structures.

The effect of fiber kinds and their combinations on the characteristics of unsaturated polyester composite were studied experimentally by Isa et al. (2013). The specimens were fabricated utilizing hand lay-up way followed by compression and tested based on ASTM standards. The outcomes proved that the Kevlar reinforced composite (KFRP) had the highest tensile strength and with the least value of the hand woven nylon fiber reinforced composite (LNFRP). Moreover, the addition of fibers enhanced the thermal stability of the hybrid composites. It also observed that the positive effects of hybridization for density and water absorptivity.

Babukiran and Harish (2014) investigated the influence of resin system & thickness on characteristics of flexure of carbon, graphite and glass fiber strengthened laminates. The epoxy and polyester resins were used as resin system. It was found, the flexural strength is dependent basically on the type of resin utilized and thickness of laminated polymer composites.

Subgiant et al. (2014) researched the influence of different stacking sequences of basalt and carbon fabrics on the flexural performances of hybrid composite laminates. By using the vacuum bagging method, the hybrid composites were fabricated. Their findings demonstrated that all the stacking distributions were responsible to produce a positive hybridization effect. The exchange hybrid composite with carbon fiber at the compressive side showed a higher flexural strength and modulus than when basalt fiber was put on the compressive side.

Valença et al. (2015) studied experimentally the mechanical performances of epoxy matrix (DGEBA) reinforced with the Kevlar/glass hybrid fabric and Kevlar fiber plain fabric plate. The outcomes of this study exhibited that the composites with Kevlar/glass hybrid configuration in the reinforcing fabric give better certain mechanical strength.

2.7 Conclusions of Literature Review

According to the survey of literature review, the main conclusions can be drawn as follows:

- There are many studies dealt with polymer matrix composites.
- The investigation of the tensile and flexural properties of composite materials have been implemented by a lot of researchers.
- It is seen from the literature another procedure to enhance the mechanical properties of fiber reinforced polymer composites is the addition of low weight content of nanoparticles like nanosilica into the matrix of composites.
- The existence nanosilica through composite systems was responsible to improve the overall mechanical properties of these systems.
- Relatively rare studies carried out on the nanosilica of composites under the tensile and flexural tests as compared with the other nanoparticles.
- In this work, tensile and flexural properties of glass epoxy and different fiber orientation angles composite were examined with the incorporation of nano-silica particles.

CHAPTER 3

EXPERIMENTAL STUDIES PRODUCTION OF COMPOSITE PLATES AND DETERMINATION OF MECHANICAL PROPERTIES

3.1 Introduction

The current chapter illustrates the manufacturing of composite plates and determination of the mechanical characteristics of these laminates. Productions steps, standards for tensile and flexural tests are explained. Also, all the method of operation and installation of the devices that utilized in the current experimental work are explained in details in this chapter.

3.2 Materials

3.2.1 Epoxy and Hardener

The stoichiometric ratio of epoxy (Momentive MGS L285) to hardener (Momentive MGS H285) and this ratio100:40 was used in the production of composite plates as shown in Figure 3.1. Epoxy and hardener utilized in this work were supplied from DOST Chemical Industrial Raw Materials Industry, Turkey.

Figure 3.1 Epoxy resin and hardener

Epoxy resins are compound or semi-polymeric substances, and as such seldom exist as pure materials, since the variable chain length results from the polymerization reaction utilized to manufacture them. Properties of the used epoxy resin are given in the Table 3.1.

Table 3.1 Characteristics of typical epoxy

Properties	Resin (MGS L285) specification
Density (g/cm³)	1.18 – 1.23
Viscosity (mPas)	600 - 900
Epoxy equivalent (gr/equivalent)	155 - 170
Epoxy value (eq /100gr)	0.59 – 0.65
Refractory index	1.525 - 1.530

The hardener was added to the epoxy to convert it from fluid to solid state by a stoichiometric proportion of 100:40. The hardener utilized in this work is blue liquid and the properties are given in the Table 3.2.

Table 3.2 Hardener characteristics

Properties	Hardener (H285) specification
Density (gr/ cm³)	0,94 - 0,97
Viscosity (mPas)	50 - 100
Amine Value (mgr KOH/gr)	480 - 550
Refractory index	1.5020 – 1.5500

3.2.2 Glass fiber

E-glass is the most prevalent form of enhancing fiber utilized in the polymer matrix compounds. The advantages of this type of fibers are good electrical insulation, good stiffness and tensile and compressive strength, non-flammable, relatively low density, good chemical resistance, relatively insensitive to moisture, lower cost than other composite materials and electrical characteristics. Woven E-glass fabric as appeared in Figure 3.2 having areal density of 202 g/m^2, thickness of 0.15 mm was supplied from Dost Kimya Co., İstanbul, Turkey.

Figure 3.2 Woven E-glass fiber utilized in this study

3.2.3 Nanosilica

Nanosilica is an inorganic chemical substance generally known as silica, added to the polymer material to modify the mechanical characteristics. Nanosilica was supplied from Grafen Chemical Industries, Turkey with a high purity 99.5%, average particle size is 15 nm, specific surface area is 300 m^2/gr and bulk density is 0.05 gr/cm^3. Nanosilica particles and SEM picture of nano-silica particles are shown in Figure 3.3

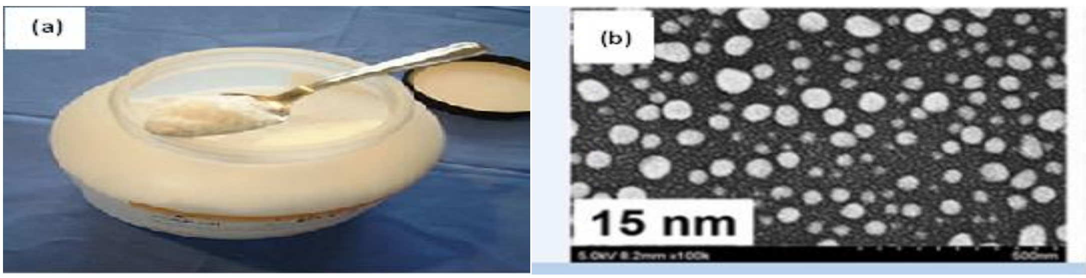


Figure 3.3 (a) Nanosilica particles (b) SEM picture of NS particles

3.3 Fabrication of Composite Laminates

In order to manufacture composite specimens, glass fibers were cut to the dimensions of 330 mm × 270 mm by using an electric cutter for fiber (EC) as appeared in Figure 3.4. Woven glass fiber with an areal density of 202 g/cm² and thickness of 0.15 mm was utilized as a reinforcement material in the composite laminate. Also, (Momentive-MGS L285) epoxy resin with (Momentive-MGS H285) hardener in a stoichiometric ratio of 100:40 were utilized in the common matrix. The laminating resin (MGS L285) has specification as: parts by weight / 100:40 ±2, parts by volume / 100: 50±2. All materials provided from DOST Chemical Industrial Raw Materials Industry, Turkey.

3.4 Nanosilica Modified Compsite Fabrication

The modifying of glass fiber reinforced composite was conducted by using four weight fractions of nanosilica as 1, 1.5, 2 and 3%. Nanosilica was obtained from Grafen Chemical Industries, Turkey with a high purity 99.5%, specific surface area is 300 m^2/gr, average particle size is 15 nm and bulk density is 0.05 gr/cm^3.

Epoxy, nanosilica and hardener were calculated the weight ratios for them by utilizing an electronic balance. After that, the epoxy, nano silica and hardener are initialized prior to the mixing operation (Figure 3.5a). The mixture of nanosilica and epoxy resin was performed by a mixer rounding at a fixed speed of 800 rev/min for 35 min in a plastic container (Figure 3.5b). After that, the hardener was added to the mixture (mix epoxy and nanosilica) at a ratio of 0.285 by mass of epoxy and mixed well again to get a homogeneous mixture. Afterwards the mixture was poured upon the layer by layer for ten layers and distributed regularly (Figure 3.5c) by hand layup process at room temperature. After that the wetted composite laminate was transferred to the production unit appeared in the (Figure 3.5d).

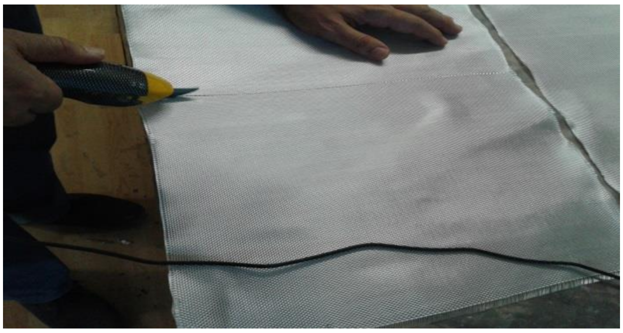


Figure 3.4 Cutting fibers by EC, Glass fiber

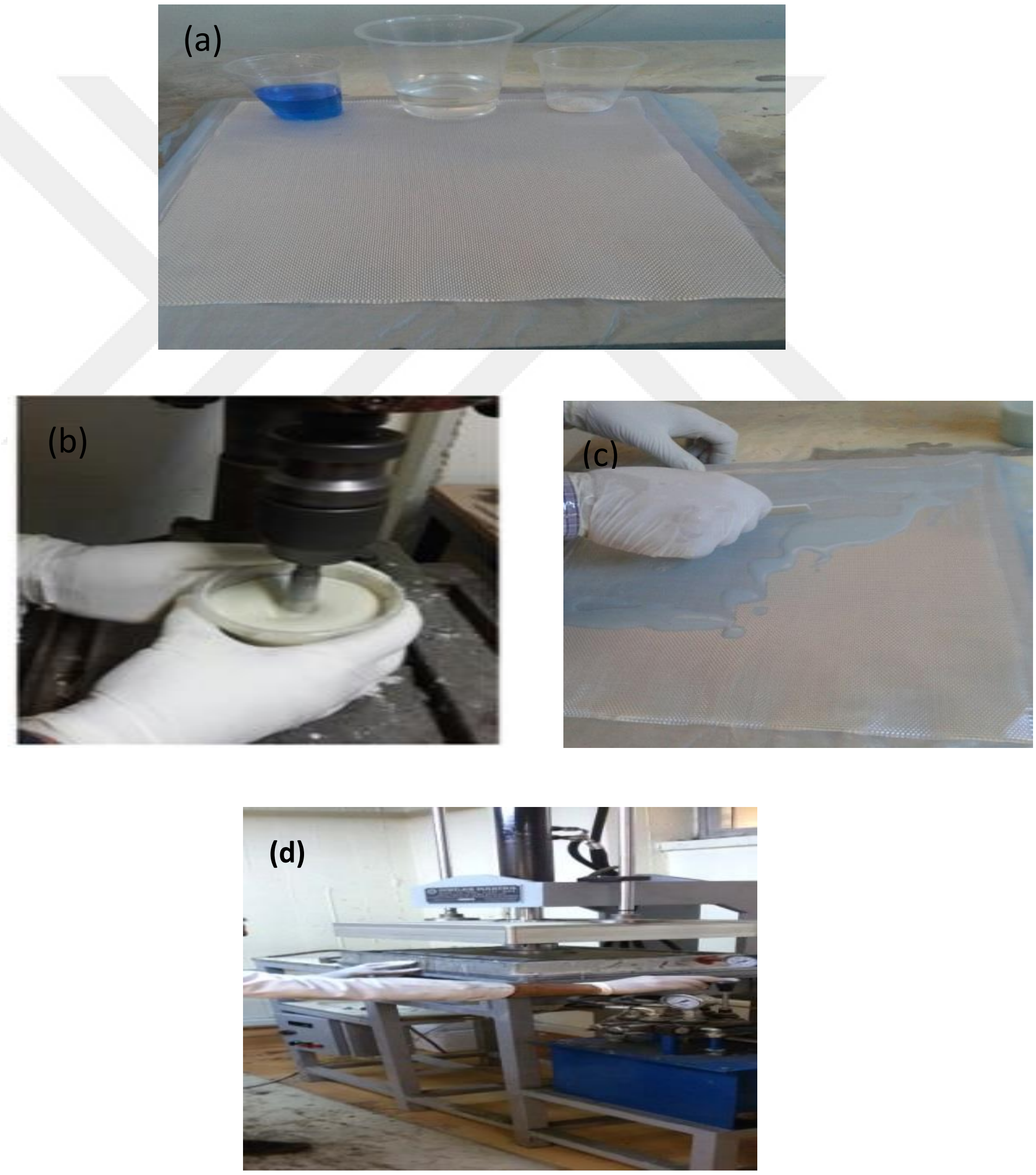
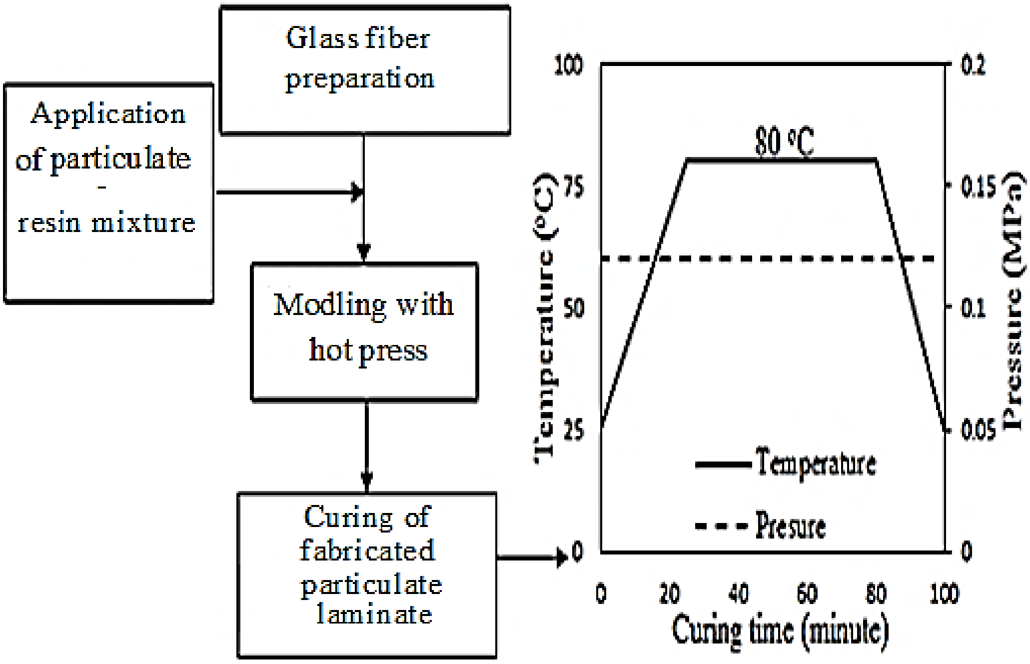


Figure 3.5 Composite production (a) Preparation stage (b) mixing (c) hand layup method (d) production unit

The wetted composite laminate was cured in the production unit for 1 hour at a 80°C temperature and 0.16 MPa pressure constant. At that point, the composite laminate was cooled to room temperature under pressure for three hours. Finally, the cured laminate lifted from the mold. This operation was repeated for all of the nanocomposite laminates. A flow chart utilized in the manufacture of nanocomposites and curing operation is described by Figure 3.6.



(a) (b)

Figure 3.6 (a) Process flow outline used as a part of the manufacture of nanocomposites, and (b) The curing procedure

Produced laminates (Figure 3.7) are prepared for the next process that cut the laminates by using Computer Numerical Control (CNC) machine.

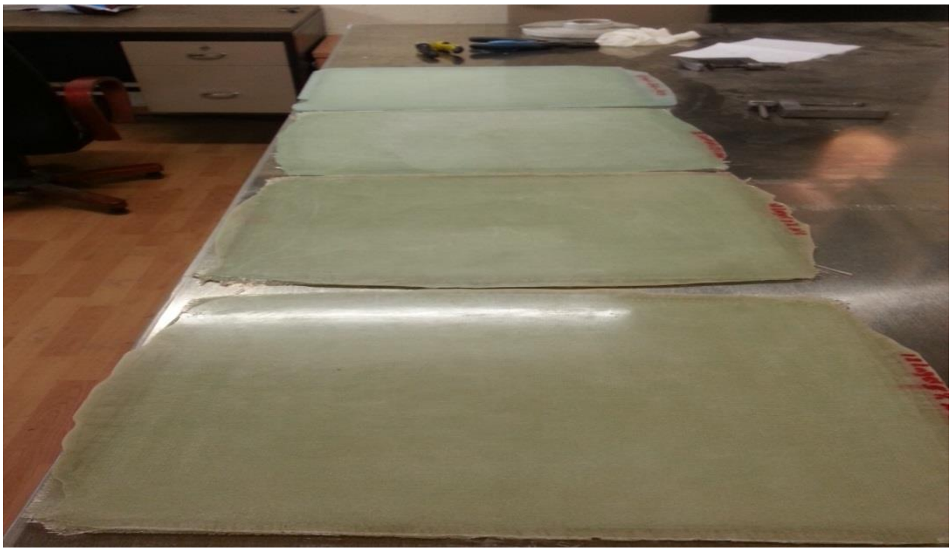


Figure 3.7 Examples of producing nanocompsite laminate

3.5 Computer Numerical Control (CNC) machine

Computer Numerical Control (CNC) machine is automated cutting device that makes industrial components without direct human assistance. They utilize coded instructions that are sent to a computer, which enables factories to manufacture parts quickly and accurately. The CNC machine automatically cuts materials, utilizing a cutting spindle, which can move to various different depths and positions as directed by the computer instructions. In this study CNC used to cut the laminates (Figure 3.8) under the American Society for Testing and Materials (ASTM) standards for tensile and flexural tests samples.

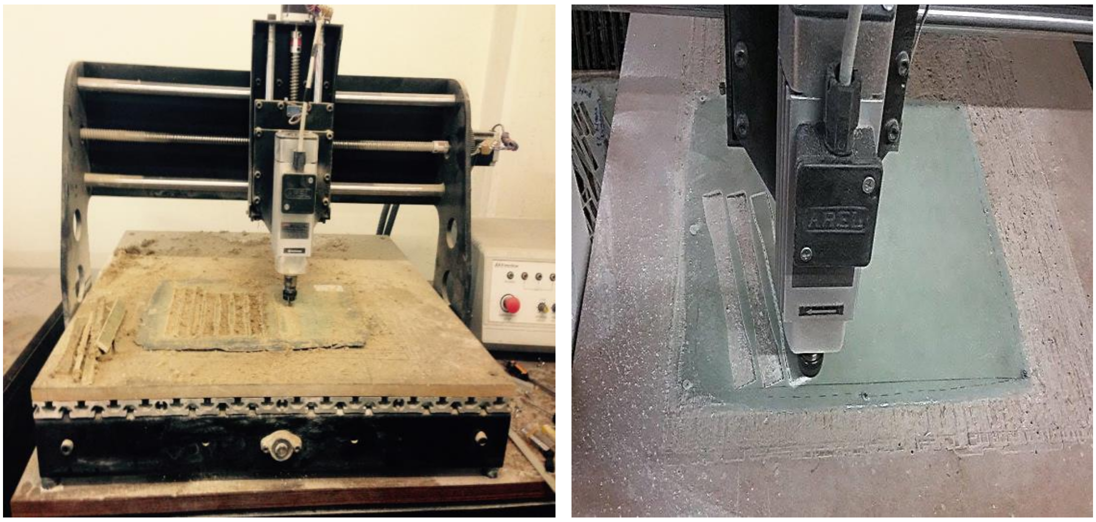
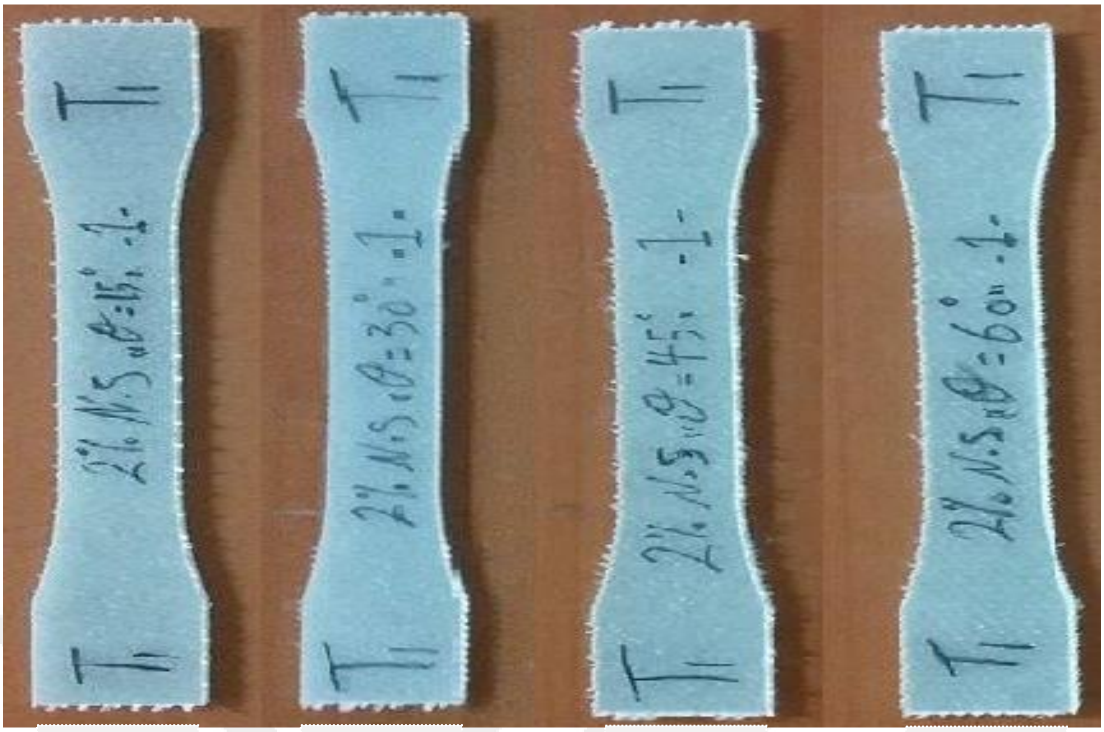


Figure 3.8 CNC Machine

3.6 Tensile Testing

Tensile test samples were cut as per ASTM D638-10 (ASTM D 638-10, 2010) standard. The utilized samples for tensile test are usually taking the style of dog-bone and generally carried out on flat and straight surface. The number of the created tensile samples are 45, as demonstrated in Figures 3.9 and 3.10.

Figure 3.9 GFRE-NS composite samples for tensile test



θ = 15° θ = 30° θ = 45° θ = 60°

Figure 3.10 Specimens at 2wt% nanosilica content with different fiber orientation angles for tensile test

The tensile characteristics of the plate specimens were estimated as per to the ASTM D638–10 standard test method. Forms of the ASTM D638-10 samples have been utilized with dimensions of 13 mm as a width of the narrow section, 57 mm as a length of the narrow section, 19 mm as overall width, 165 mm as overall length (LO), 50 mm as a gage length (G), 115 mm as the distance between grips (L) and 76 mm as radius of fillet (R) as appeared in Figure 3.11.

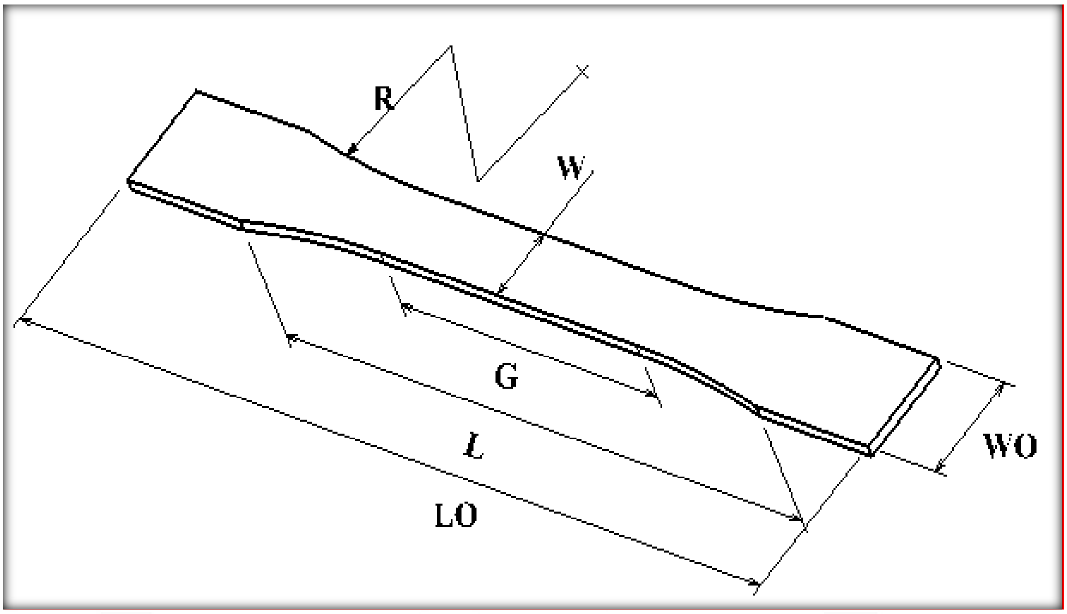


Figure 3.11 Dimensions of the tensile sample as per to ASTM D638-10

Tensile tests were performed by 300 KN load capacity Shimadzu AG-X tensile testing machine (made in Japan) appeared in Figure 3.12. Tensile load was applied with a 2 mm/min crosshead speed as per the standard.

Figure 3.12 Tensile test set-up Shimadzu AG-X arrangement testing machine

3.7 Flexural Test

Flexural test samples were cut as per ASTM D790 (ASTM D 790-10, 2010) standard. The produced flexural samples have appeared in Figures 3.13, 3.14.

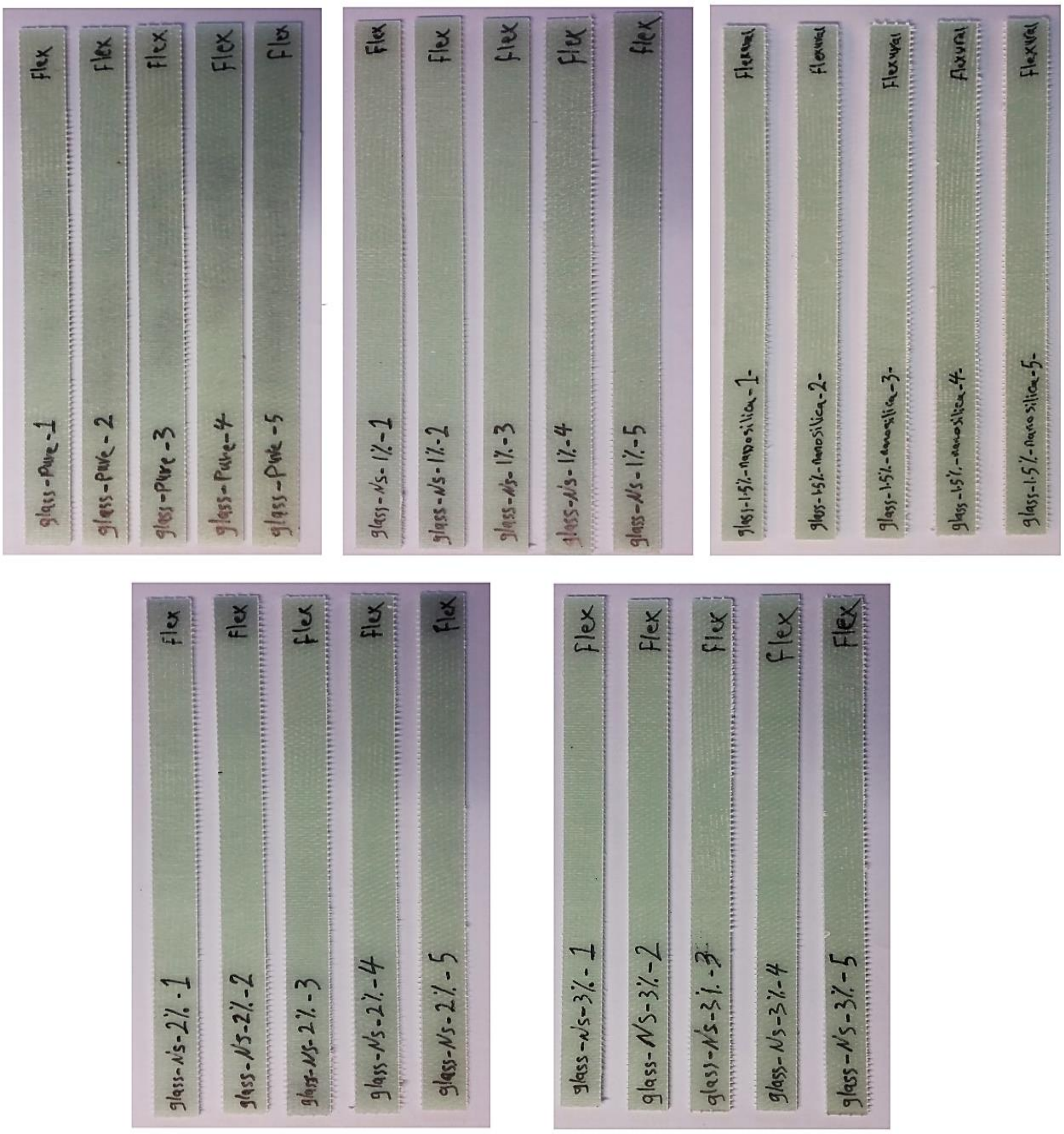


Figure 3.13 GFRE-NS composite specimens for flexural test

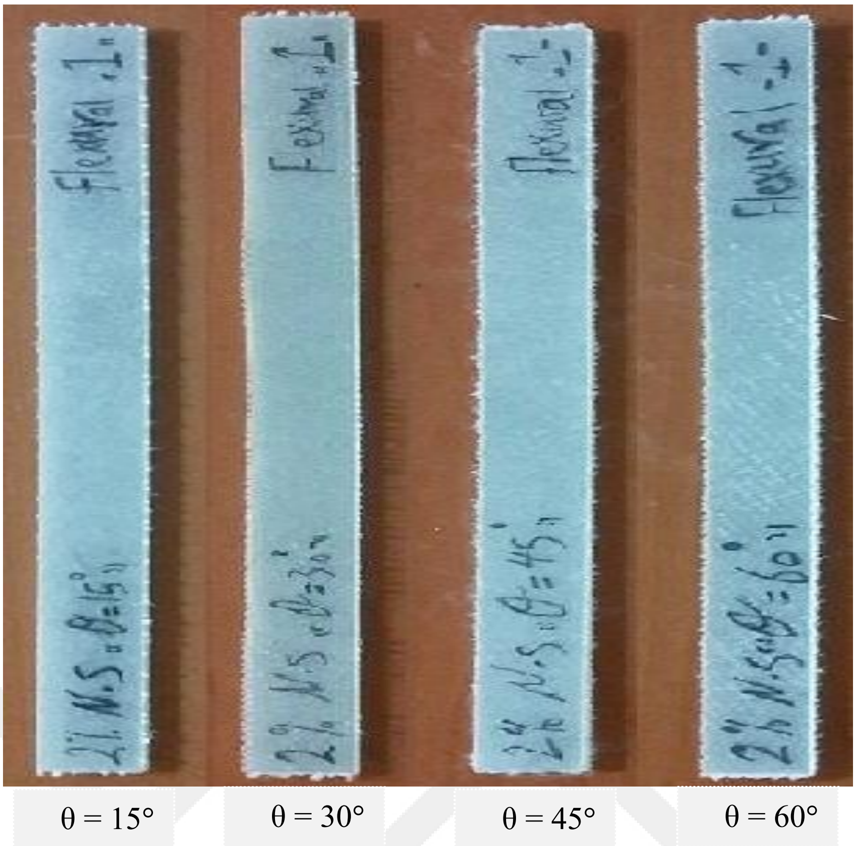


Figure 3.14 Specimens at 2wt% nanosilica content with different fiber orientation angles for flexural test

Flexural characteristics of the tested samples were gained by employing Shimadzu AG-X tensile testing device as appeared in Figure 3.15. Flexural specimen length is 200 mm and width is 12.7 mm laid on two cylindrical rods as appeared in Figure 3.16. The sample was loaded in the perpendicular direction with the 3 mm/min speed up to failure. Span-to-thickness ratio was selected as 32:1. Load-displacement curves were got for each tested sample and at least five samples were tested for each content ratios of nanosilica in the laminate. The flexural characteristics of the samples, flexural modulus, flexural strength and strain were determined from the test machine data's through the over the use of the equations (ASTM American Society for Testing and Materials. 2000).

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

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

$$\varepsilon_F = \frac{6Dh}{L^2} \quad (3.3)$$

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 greatest deflection before failure and P is that the load at a given point on the load-deflection curve.

Figure 3.15 The flexural test device (Shimadzu AG-X testing)

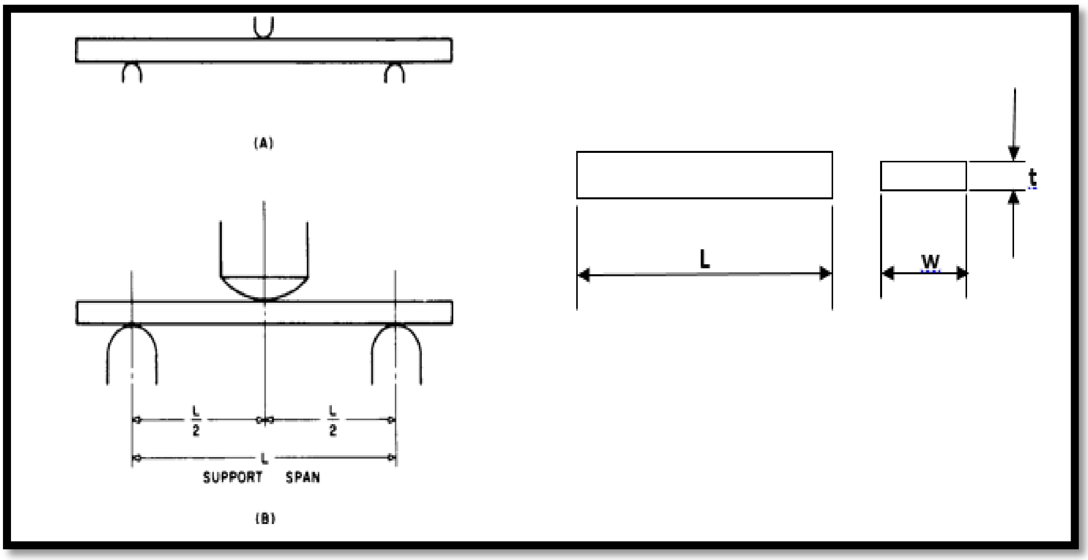


Figure 3.16 Flexural specimen dimensions as per to ASTM D 790

CHAPTER 4
EXPERIMENT RESULTS AND DISCUSSION

4.1 Introduction

In the current chapter, the results obtained from the experimental work on the tensile and flexural tests for examined GFRP were disscussed. The influence of adding different proportions of nanosilica (1wt%, 1.5wt%, 2wt%, 3wt%), and different fiber orientation angles (0°, 15°, 30°, 45°, 60°) at 2wt% nanosilica content were studied. Tensile test and three-point bending test were conducted to five prepared specimens for each different group. Furthermore, the effects of adding different nanosilica contents and the different fiber orientation angles on the mechanical properties of the composites were also discussed.

4.2 Tensile Properties

Tensile test results are illustrated in Table 4.1 and the tensile loading performance can be shown as a stress - strain graph (Figure 4.1). It is shown from Figure 4.1 that the tensile stress and strain have been increased with the superfat of nanosilica content and this is identical with (Aidah et al. 2012) and (Pibo et al. 2015). The stress-strain graphs for the GFRP composite laminates with various nanosilica contents showed failure at higher strain as compared to the GFRP composite laminate without nanosilica content (pure). The maximum tensile strain of 0.1mm/mm was found for 2wt% nanosilica composite laminate, thereby a 25% increase in tensile strain was attained in comparision with the pure GFRP composite. Add to that, it has been observed that the tensile strain was increased with the addition of nanosilica particles because of the chemical compatibility of the nanosilica with composite system. The percentages of increase in tensile strength of nanosilica composite laminates compared to that one of pure GFRP composite laminate are 4%, 4.5%, 8%, and 1% for 1wt%, 1.5wt%, 2wt%, and 3wt%, respectively. The maximum tensile strength of 280.25 MPa is achieved for 2wt% nanosilica content.

Table 4.1 Tensile Properties for GFRE-NS composites

Laminate	Elongation at break (mm/mm)	Max. Tensile Strength (MPa)	Average elongation at break	Average Tensile Strength (MPa)
PURE-1	0.0878	265.23	0.08404±0.00456	259.88±6.45
PURE-2	0.0809	264.50		
PURE-3	0.0811	257.16		
PURE-4	0.0901	249.82		
PURE-5	0.0803	262.653		
1%- 1	0.0944	281.08	0.09158±0.00195	270.47±12.32
1%- 2	0.0914	273.27		
1%- 3	0.0889	269.42		
1%- 4	0.0918	249.98		
1%- 5	0.0914	278.59		
1.5%- 1	0.0850	275.45	0.09332±0.01156	272.002±3.974
1.5%- 2	0.0855	266.07		
1.5%- 3	0.0846	275.12		
1.5%- 4	0.1089	273.44		
1.5%- 5	0.1026	269.93		
2%- 1	0.1024	269.42	0.10054±0.00841	280.25±8.75
2%- 2	0.0926	277.04		
2%- 3	0.0924	277.05		
2%- 4	0.1027	285.69		
2%- 5	0.1126	292.04		
3%- 1	0.0912	271.06	0.08864±0.00298	267.43±4.61
3%- 2	0.0886	264.85		
3%- 3	0.0920	272.99		
3%- 4	0.0852	261.63		
3%- 5	0.0862	266.59		

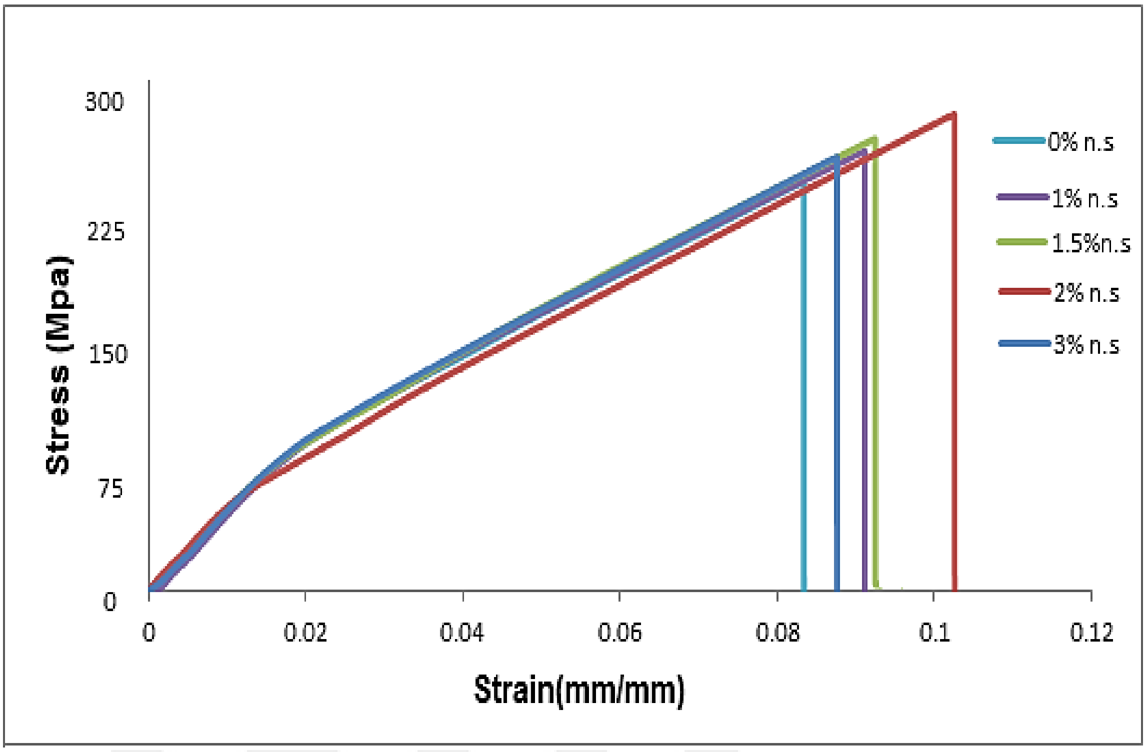


Figure 4.1 Tensile stress-strain curves of the GFRP-NS composites

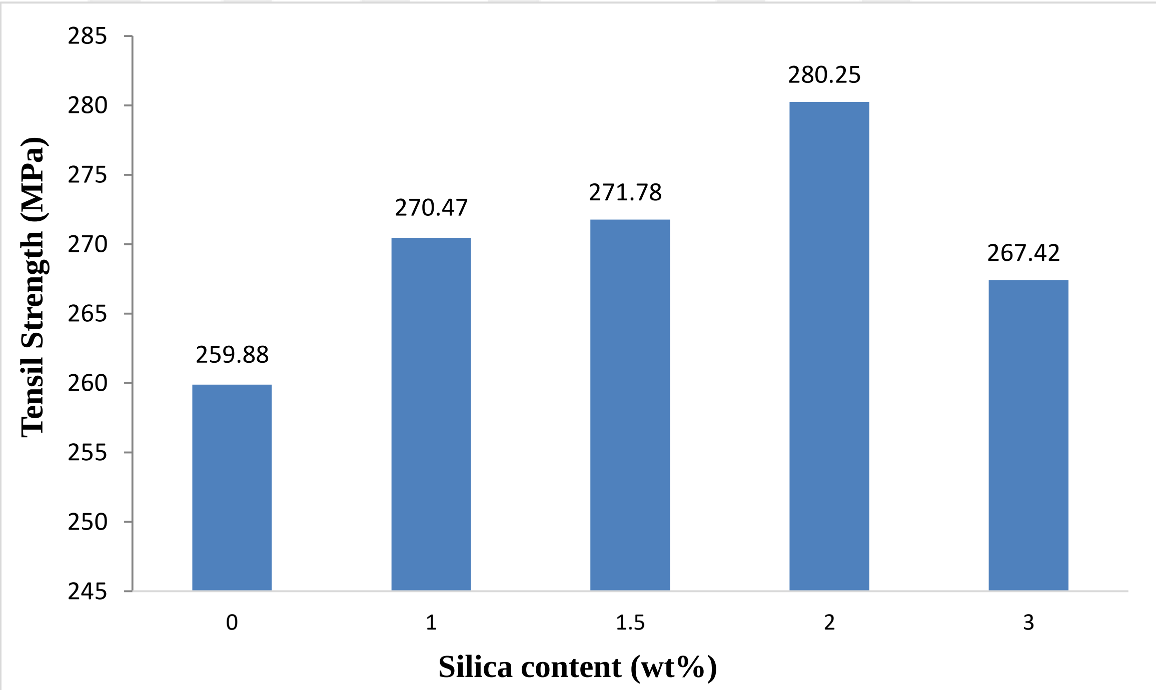


Figure 4.2 Variation of tensile strength according to nanosilica content

From the values of tensile strength, as that being explained in Figure 4.2, the tensile strength of glass/epoxy composite unfilled nanosilica (pure) was gradually increased by adding nanosilica particles. The tensile strength reached the maximum improvement which is 8% with particles content of 2wt%. In other words, the least value for tensile strength is 259.88 MPa at the glass/epoxy composite (pure), whilst the glass/epoxy composite of 2wt% nanosilica content produced the highest tensile strength of 280.25 MPa. Adding fibers and nanosilica to epoxy will improve its resistance to tensile hugely as confirmed in this study, since the larger part of the force would be resisted by the fibers and consequently will lead to enhance composite tensile strength. The samples of glass fiber which reinforced with epoxy-nanosilica composites showed a brittle style. Both the filled and unfilled GFRP samples showed failure at higher stresses. The increasing in tensile strength value due to the increase in nanosilica content might be explained as a good interfacial bonding between epoxy and nanosilica particles.

Tensile modulus of nanosilica filled glass/epoxy composite was plotted against nanosilica contents as appeared in Figure 4.3. Nanosilica modified composites showed higher tensile modulus compared to the composites without nanosilica content. The addition of 1wt%, 1.5wt% and 2wt% of nanosilica into glass fiber reinforced epoxy composites resulted in increasing the tensile modulus from 10.72 GPa to 11.14 GPa, 14.17 GPa and 17.89 GPa, respectively. The utilization of nanosilica was so effective in tensile modulus enhancement. While the addition of 3wt% of nanosilica showed a decrease in tensile modulus from 10.72 GPa to 9.63 GPa. The reduction in tensile modulus with addition of nanosilca of 3wt% can be observed as a result of agglomeration or poor dispersion. The agglomeration or bad dispersion results in poor bonding between epoxy and silica particles.

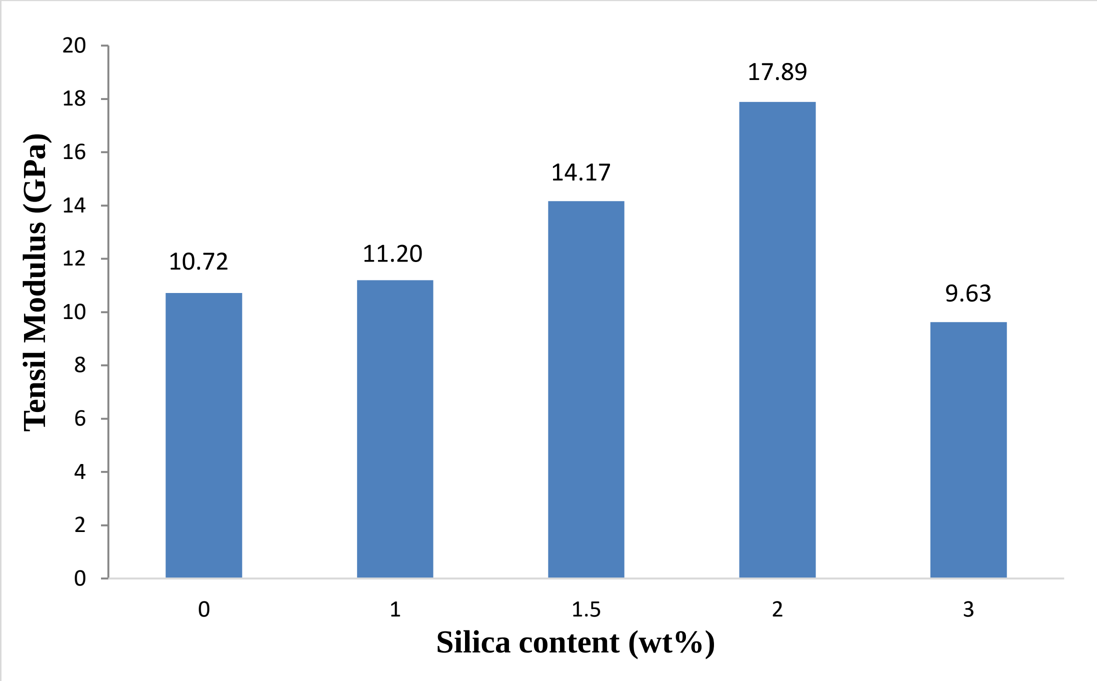


Figure 4.3 Variation of tensile modulus according to nanosilica content

In Figure 4.4, the failure of samples is clearly shown after applying the tensile test.

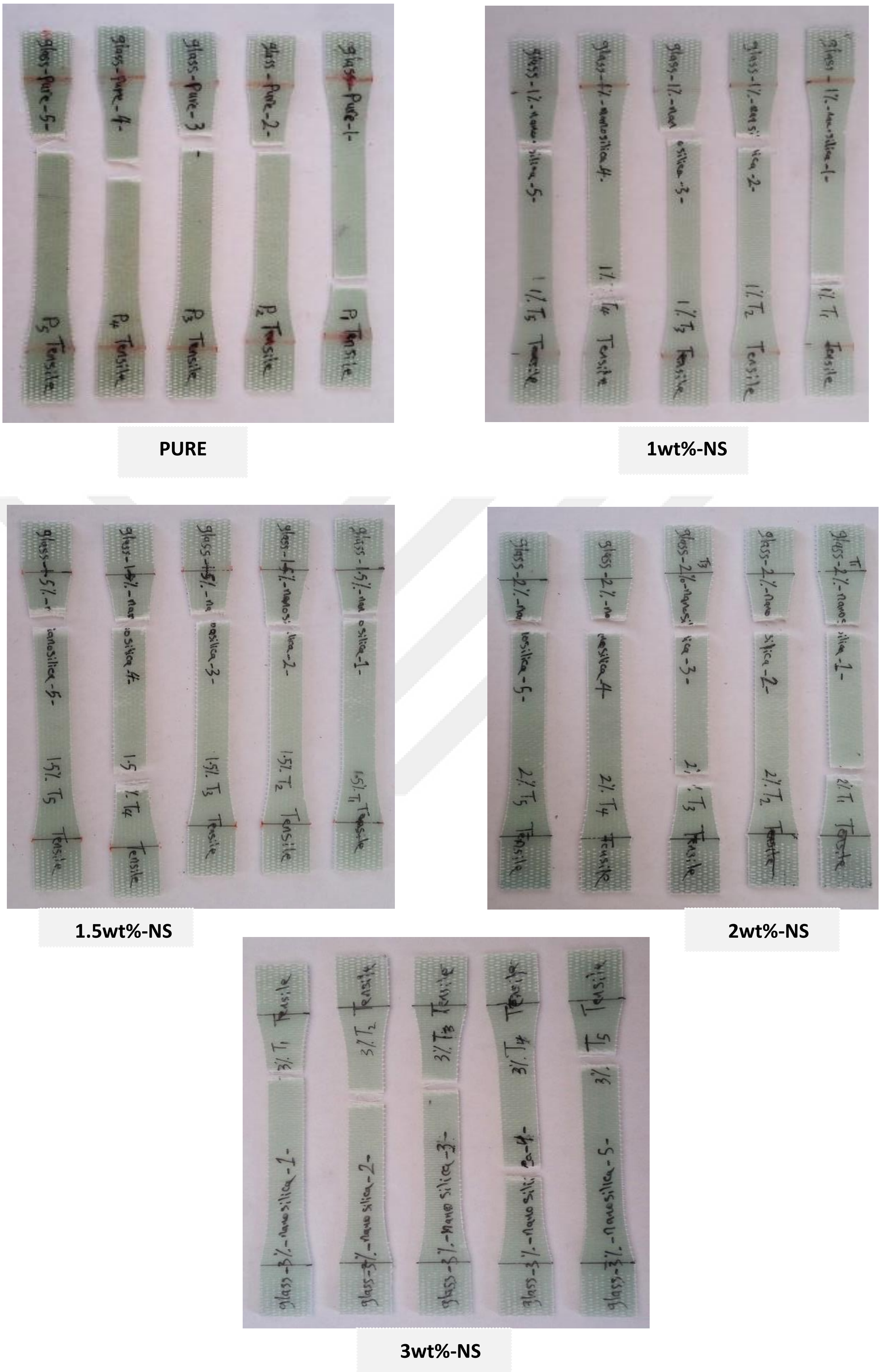


Figure 4.4 Failure of specimens with different composite laminates after tensile test

4.3 Flexural Results

The flexural results which received from the experimental work on the flexural testing (three-point bending test) for neat GFRP composite laminate and others filled GFRP composite laminates with nanosilica particles are tabulated in the Table 4.2. The table shows flexural strength and flexural modulus values of the GFRP-NS composites with their averages. The load-displacement curves for the three-point bending tests of GFRP composite laminate and GFRP-NS composite laminates for various additions of nanosilica are shown in Figure 4.5. The initial load height parts of all curves are similar, but the yield displacements, failure manners, and maximum loads are different. The curve of 1.5wt% content of nanosilica showed the highest maximum load and the lowest elongation. Whilst, the load-displacement graph which clarified the lowest maximum load and the highest yield displacement was exhibited by the 3wt% content of nanosilica. These conclusions suggest that failure happened in a ductile manner. The results showed that the failure strain was reduced by the addition of nanodilica particles. This behavior may be explained dut to the mobility and deformity of the polymer matrix which was restricted by the inclusion of nanosilica particles, thus reducing the failure strain during the flexural test. At contents of 1wt% and 3wt%, a decrease in the bending load which is responsible of failure in the specimen was noticed. The best values for bending load were observed for nanosilica contents of 1.5wt% and 2wt%. The bending load reached the maximum value at 1.5wt% nanosilica content. From the flexural tests, a linear response of the load-displacement curves of the studied composites has been noticed. The flexural strength decreased suddenly then the fracture occurred.

Table 4.2 Flexural characteristics for filled nanosilica and unfilled (pure) GFRE

Laminate	Flexural Strength (MPa)	Average flexural strength (MPa)	Flexural Modulus (GPa)	Average Flexural Modulus (GPa)
PURE-1	325.57	334.38±11.01	16.15	16.38±0.61
PURE-2	334.22		15.48	
PURE-3	327.55		16.60	
PURE-4	331.43		16.15	
PURE-5	353.15		17.15	
1%- 1	319.44	324.20±23.20	15.94	16.49±1.07
1%- 2	347.29		17.66	
1%- 3	346.12		17.46	
1%- 4	316.47		16.30	
1%- 5	291.69		15.09	
1.5%- 1	366.03	346.35±16.97	18.51	18.77±0.41
1.5%- 2	339.27		19.10	
1.5%- 3	325.30		18.93	
1.5%- 4	361.43		19.12	
1.5%- 5	339.72		18.17	
2%- 1	320.52	337.38±15.46	16.25	16.74±0.61
2%- 2	340.26		16.83	
2%- 3	346.75		16.21	
2%- 4	356.48		17.72	
2%- 5	322.87		16.68	
3%- 1	314.76	309.68±10.45	15.71	15.64±0.54
3%- 2	317.37		14.88	
3%- 3	292.05		15.60	
3%- 4	308.27		15.82	
3%- 5	315.93		16.40	

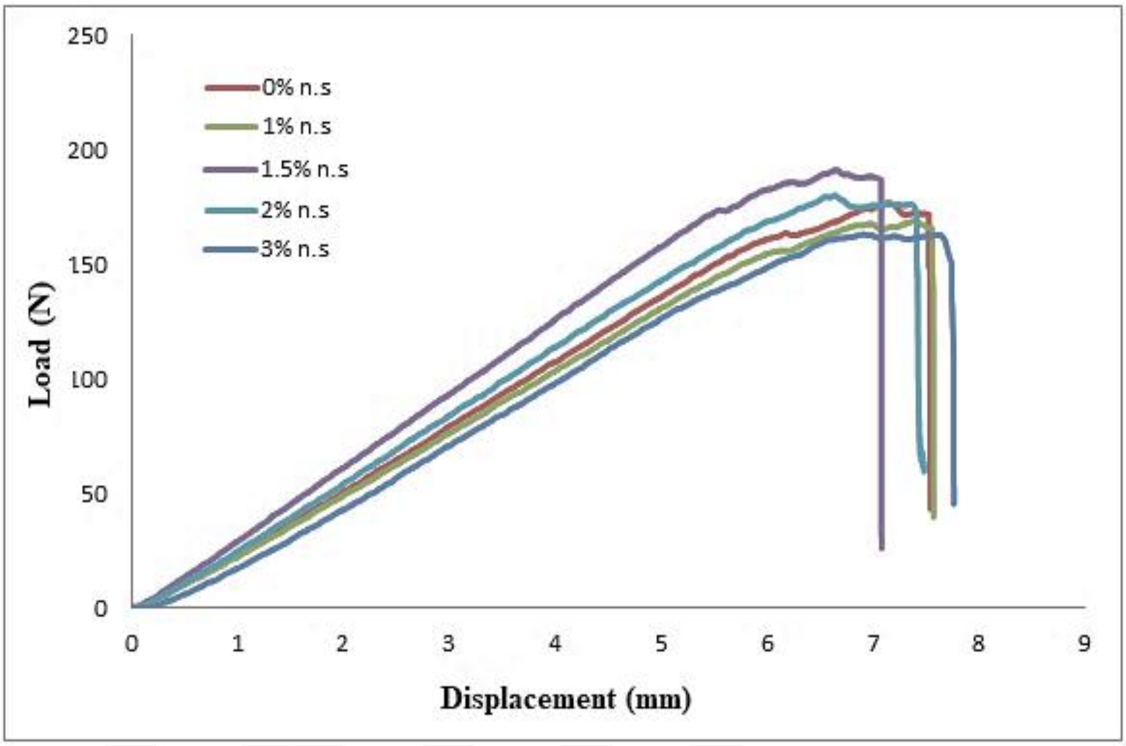


Figure 4.5 Flexural load-displacement curves for the GFRP-NS composites

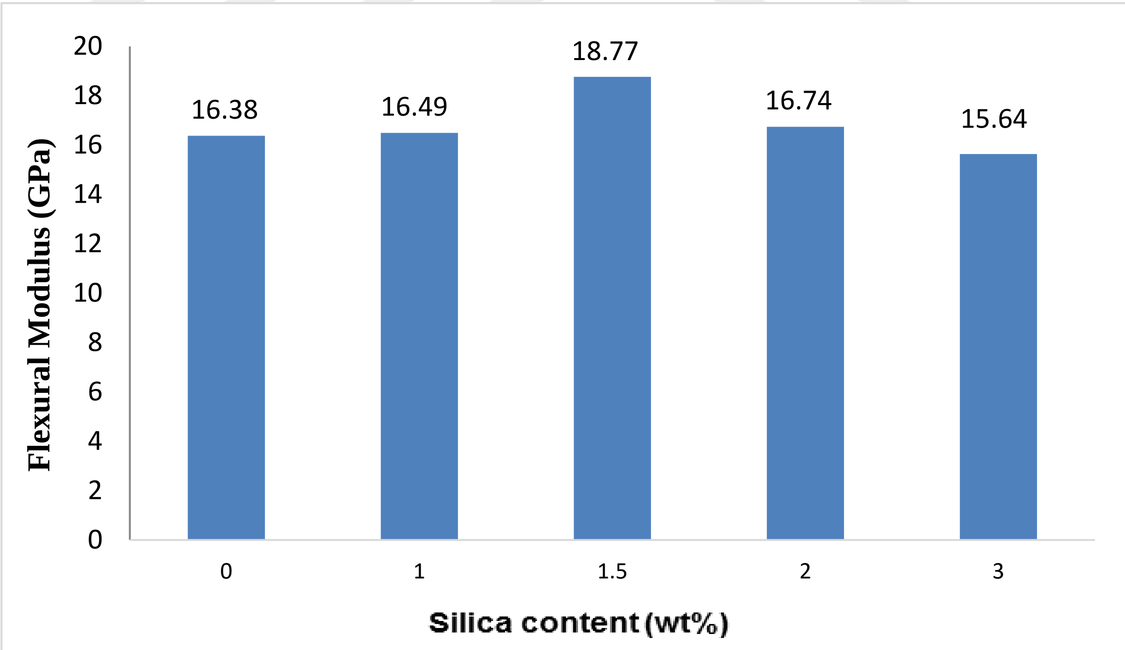


Figure 4.6 Variation of flexural modulus according to nanosilica content

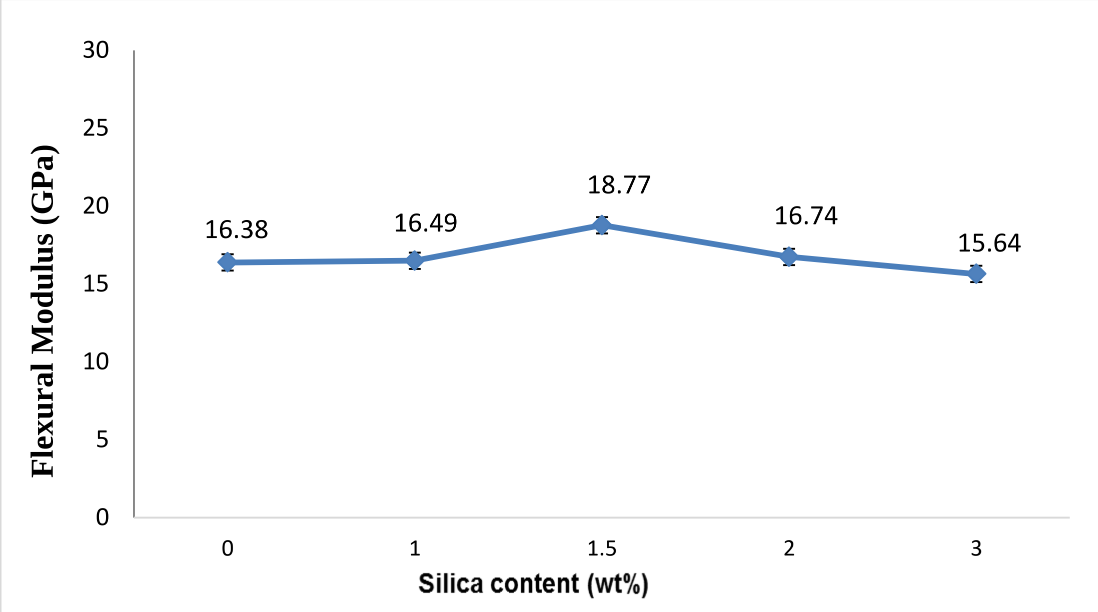


Figure 4.7 Relationship between average flexural modulus and wt% of GFRP-NS

Flexural modulus of nanosilica filled GFRP and unfilled composite laminates GFRP were plotted in Figure 4.6. As seen in the figure, the flexural modulus of all nanocomposite laminates, except for the 3wt% content nano silica, showed an increase in the values of the flexural modulus compared to GFRP (pure). The obtained improvement in the flexural modulus specimens were 0.7%, 15% and 2% for 1, 1.5 and 2wt.% nanosilica filled glass fiber reinforced epoxy composites, respectively. The results indicated that by the addition of nanosilica into glass fiber reinforced epoxy an improvement of the flexural modulus at 1wt%, 1.5wt% and 2wt% contents of nanosilica has been occurred. The 1.5wt% nanosilica content showed the highest flexural modulus by 15% improvement. At higher content of nanosilica in the 3wt% contant, it derogated the flexural modulus. Figure 4.7 shows clearly the behavior of the flexural modulus before and after the addition of the nano silica to the glass fiber reinforced epoxy.

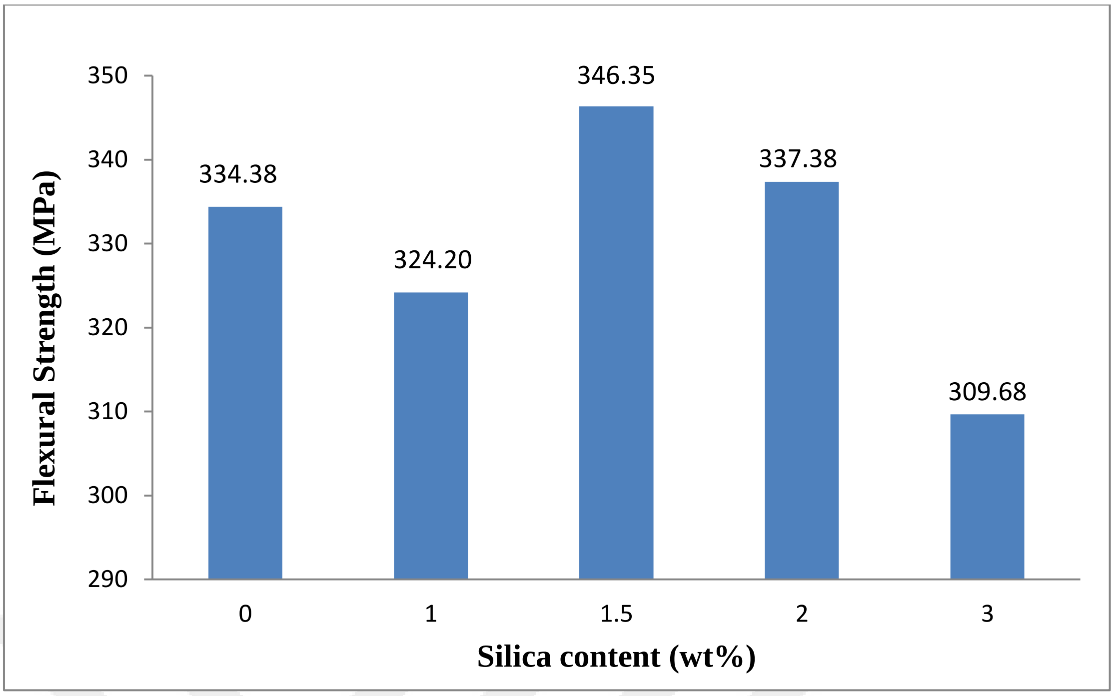


Figure 4.8 Diversity of flexural strength according to the ratio of nanosilica

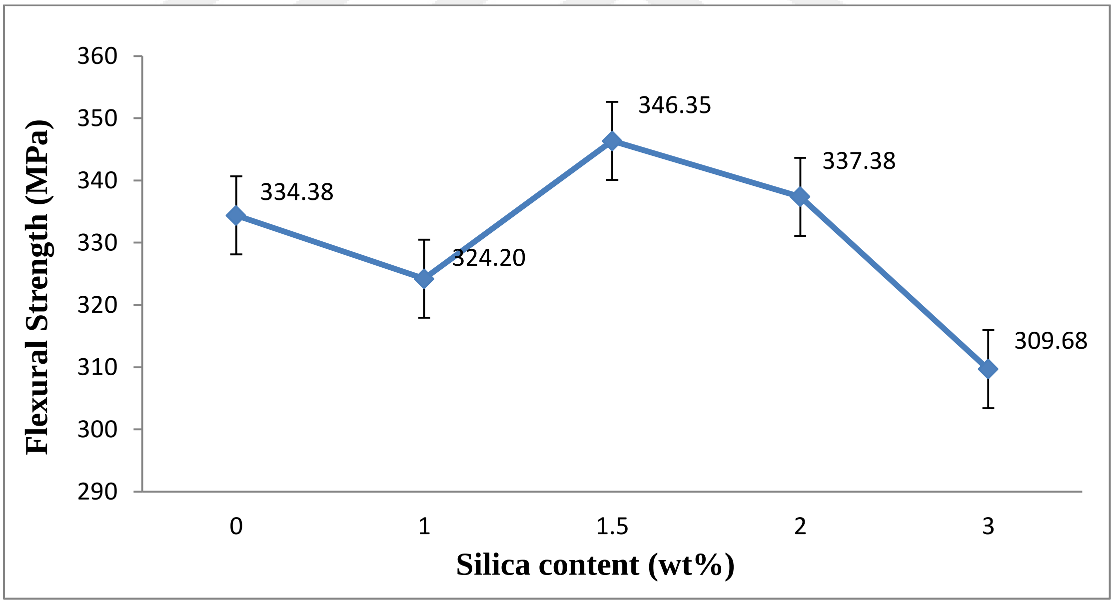
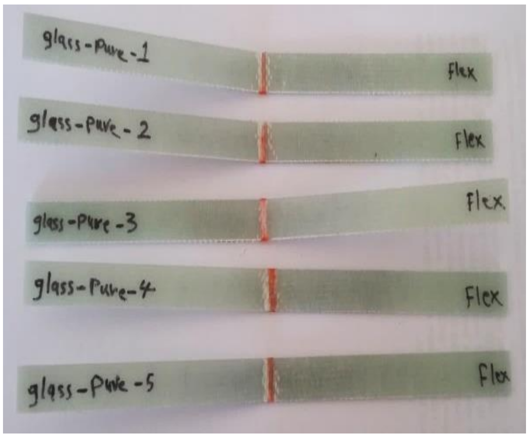


Figure 4.9 Relationship between average flexural strength and wt% of GFRP-NS

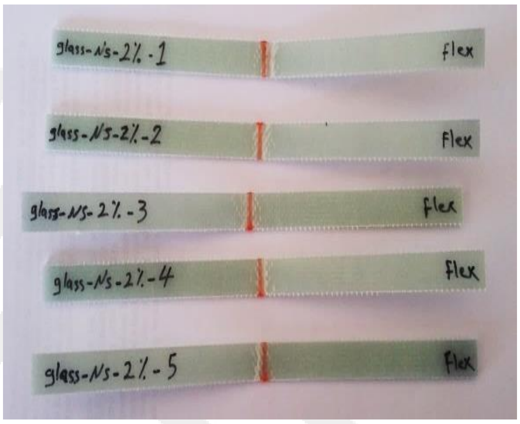
The variation of flexural strength values against nanosilica contents were presented in Figure 4.8. The flexural strength of the pure laminate decreased from 343.38 MPa to 324.20 Mpa at 1% nanosilica content. With the increment of nanosilica content up to 1.5 wt% the flexural strength increased by 4 %. The results showed that the addition of nanosilica into glass fiber reinforced epoxy has been improved the flexural strength by 4% and 1% at 1.5wt% and 2wt% contents of nanosilica respectively. After the 2wt% nanosilica content, the flexural strength followed the trend of decreasing to reach 309.63 MPa at a content of 3wt%. Add to that, the highest improvements of flexural modulus and flexural strength were obtained at 1.5 wt% content of nanosilica. This may be interpreted that the chemical compatibility and adhesion strength between nanosilica particles and epoxy/glass fiber were optimum at this content. Reduction in the flexural strength and the flexural modulus with the addition of nanosilica may be occurred due to the agglomeration of nanosilica particles, the weak interaction between nanosilica and epoxy matrix and the formation of stress concentration sites and thus crack initiation led to the weaknesses in the composite strength. The mutual failures under flexural loading contain tensile failure, compressive failure, shear and/or delamination, wherein failure by compression is the most common one. The fail of a nanosilica composite is dependent on the maximum bending moment of the materials involved in the composition of the nanocomposite. It was observed that all the specimens failed at the specimen center by bending load, this can be seen clearly in Figure 4.10.



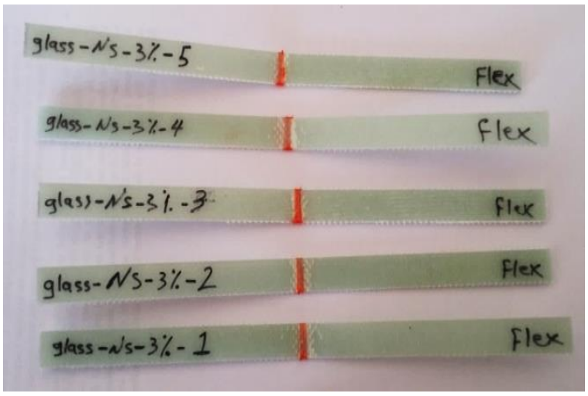
PURE

1wt%-Ns

1.5wt%-Ns



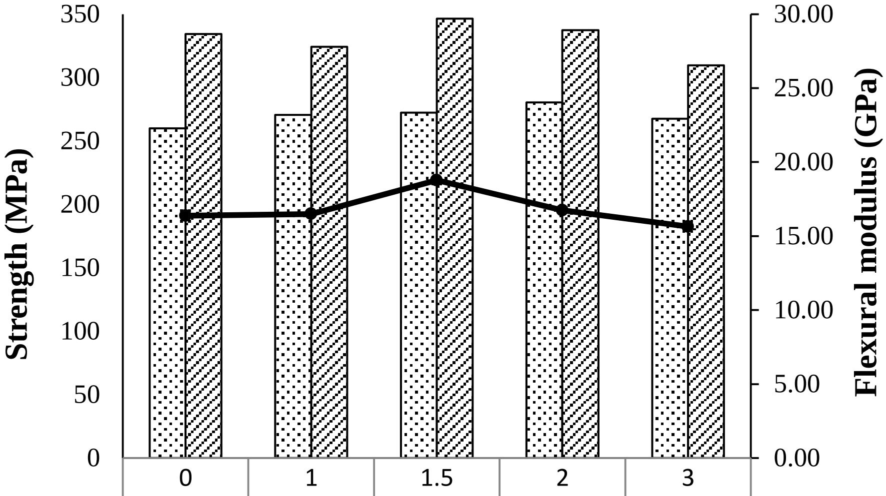
2wt%-Ns



3wt%-Ns

Figure 4.10 Failure of specimens after flexural test

Figure 4.11 shows the relationship between tensile strength, flexural strength and flexural modulus for GFRP-Ns. The improvement in tensile and flexural characteristics is due to the chemical compatibility of nanosilica particles with epoxy resins and E-glass fibers in a composite laminate system. Moreover, the tensile and flexural properties were degraded when the increment of nanosilica particles content exceeded 2wt. This may be ascribed to the particle aggregation phenomena which formed weaknesses in composite laminate and thus decreasing the flexural strength.



	0	1	1.5	2	3
Tensile strength	259.8796	270.47	272.21	280.2502	267.4262
Flexural strength	334.38	324.20	346.35	337.38	309.68
Flexural modulus	16.38	16.49	18.77	16.74	15.64

Figure 4.11 Tensile strength, flexural strength and flexural modulus versus nanosilica particle content of Glass/epoxy nanosilica composites

4.4 Tensile Test Results of Glass/Epoxy with 2%Nano-silica Content and Different Fiber Orientation Angles

Tensile tests were performed on the glass fiber reinforced composite with 2wt% nanosilica content to observe the effect of different fiber orientation angles on the tensile behavior of nanocomposite. Table 4.3 and Figures (4.12, 4.13) illustrated the average tensile strength, tensile modulus and average tensile load of the 2wt% nanosilica content at different fiber orientation angles.

Table 4.3 Average tensile load and average tensile strength values of 2wt% nanosilica content at different fiber orientation angles

2wt% Nanosilica content with different fiber orientation angles	Average tensile load (N)	Average tensile strength (MPa)
0°	7287	280.25
15°/-75°	6370	245
30°/-60°	3933	151.25
45°/-45°	3263	125.49
60°/-30°	4213	162

The average of the values for each composite configuration were presented in the table mentioned above. From this table, it was noticed that the highest value of tensile load which recorded for 2wt% nanosilica content was 7287 N with fiber orientation 0° angle. While, the least tensile load value which obtained from 2wt% nanosilica content was 3262 N with 45° angle orientation. The variations of tensile strength and tensile modulus values against 2wt% nanosilica content with different fiber orientation angles were presented in Figures 4.12 and 4.13.

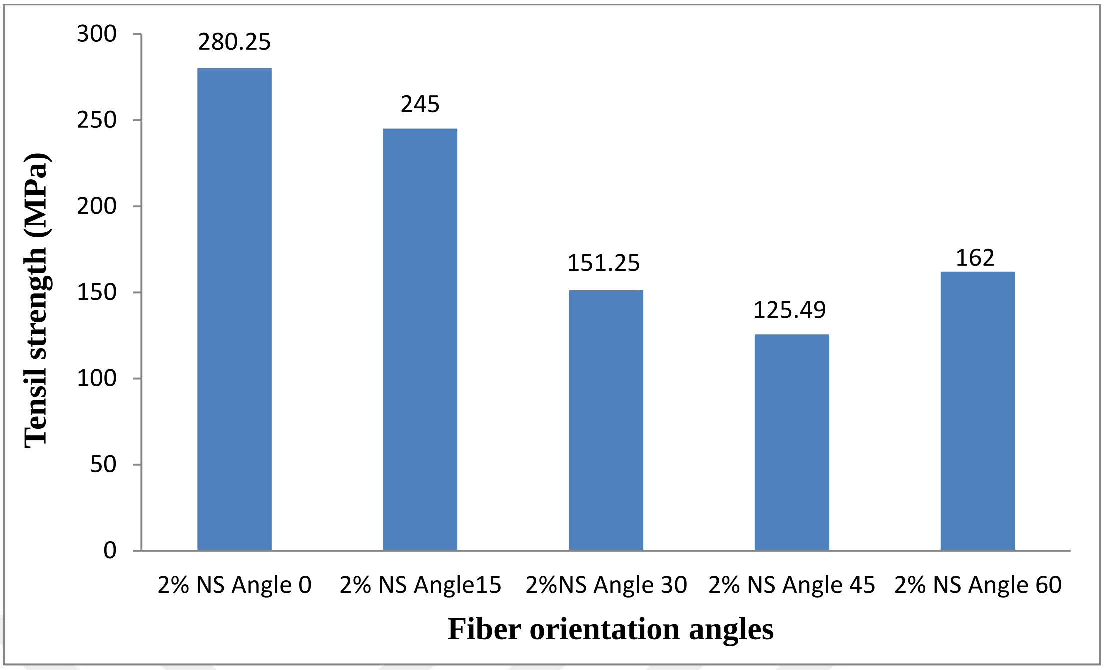


Figure 4.12 Variation of tensile strength of 2wt% nanosilica content according to the orientation of glass fiber angles

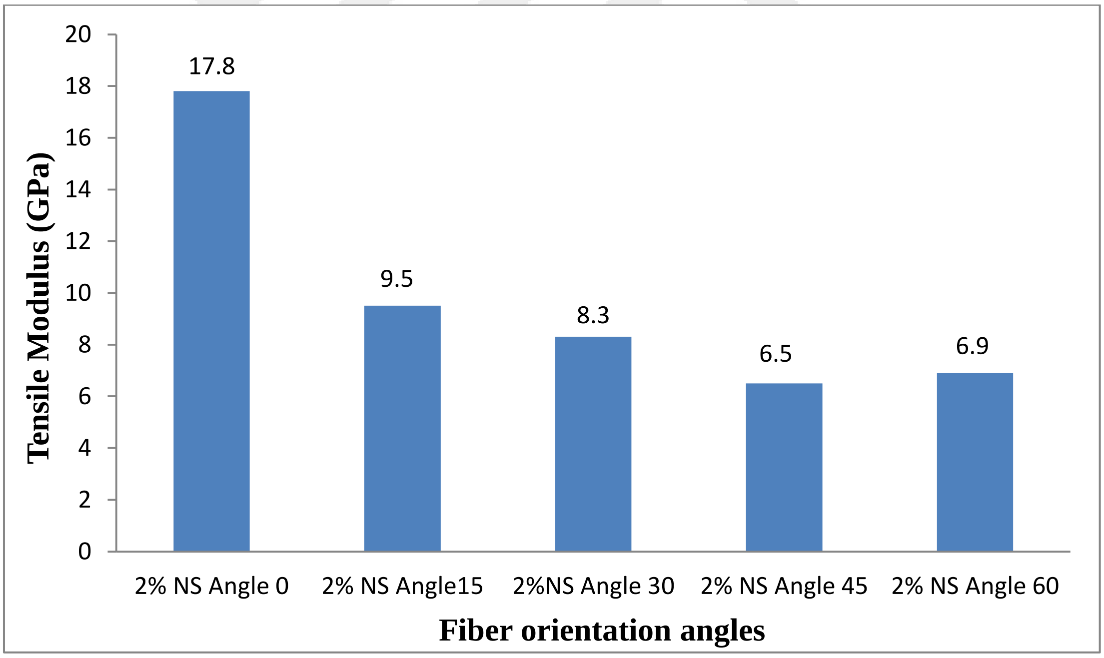


Figure 4.13 Variation of tensile modulus of 2wt% nanosilica content according to the orientation of glass fiber angles.

Comparison of the values of tensile strength and tensile modulus for the 2wt% nanosilica content at the fiber orientation angle 0° with the values of the same nanosilica content (2wt%) but with different fiber orientation angles (15°, 30°, 45°, 60°) was implemented. It was observed that at 2wt% nanosilica content with fiber orientation angle 0°, both the tensile strength and tensile modulus have reached to their maximum values which are 280.25 MPa and 17.8 GPa, respectively. Whereas the 2wt% of nanosilica content with fiber orientation angle 45° showed the lowest values of tensile strength and tensile modulus with 125.49 MPa and 6.5 GPa, respectively. Through tensile strength and tensile modulus values, it appears clearly the ability of nanocomposite material to withstand the stresses, but this ability starts to decrease with increasing the fiber orientation angle.

The enhancement of tensile strength at 2wt% of nanosilica content with fiber orientation angle 0° yielded the highest tensile strength and tensile modulus values. The increase in the tensile strength and tensile modulus values at 2wt% of nanosilica content with fiber orientation angle 0° might be attributed to the good interfacial bonding between the nanosilica and epoxy. (Bagherpour, 2012) stated that the concept of mixtures is to improve the tensile strength. Besides that, composite material has better ability to carry out loads in the direction of reinforcement fibers. Also, for angle 0°, the applied tensile load is distributed equally on all the fibers and transmitted along the fibers axes.

At the other angles (15°, 30°, 45°, 60°), the tensile strength and tensile modulus start to decrease gradually until they reached to their lowest values at angle 45°. This may return to the ability of composite material as it starts to decrease with increasing fiber orientation angle. At these angles the fiber axes are non-parallel to load axis in addition to the increment of stress concentration, as a consequence earlier failure of laminates will occur.

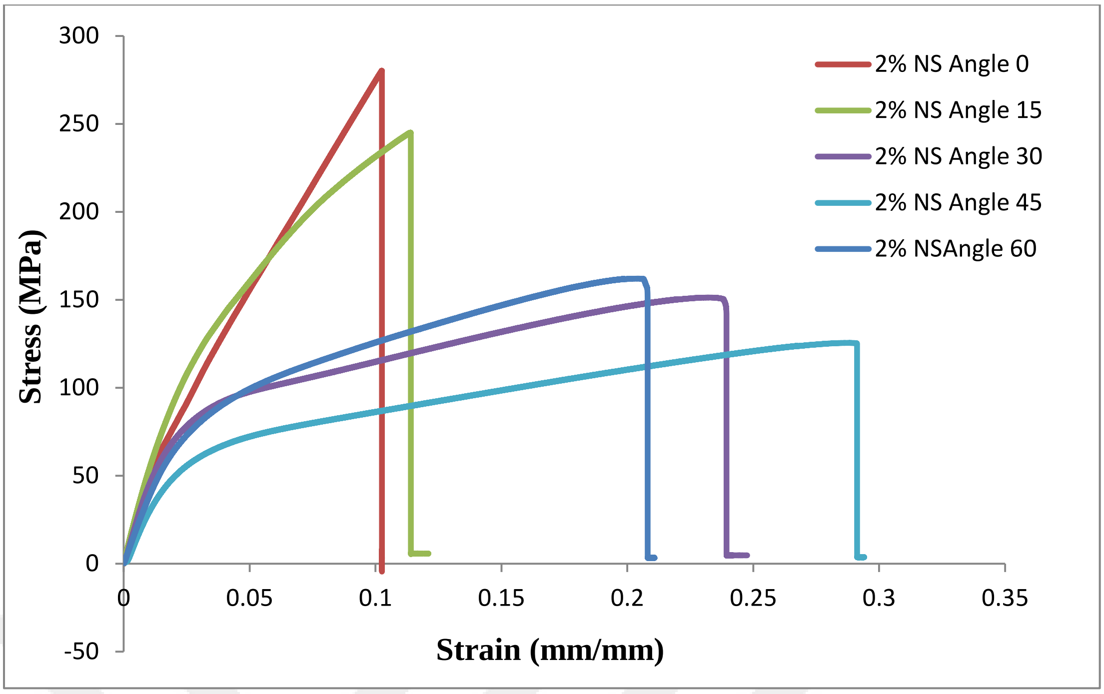
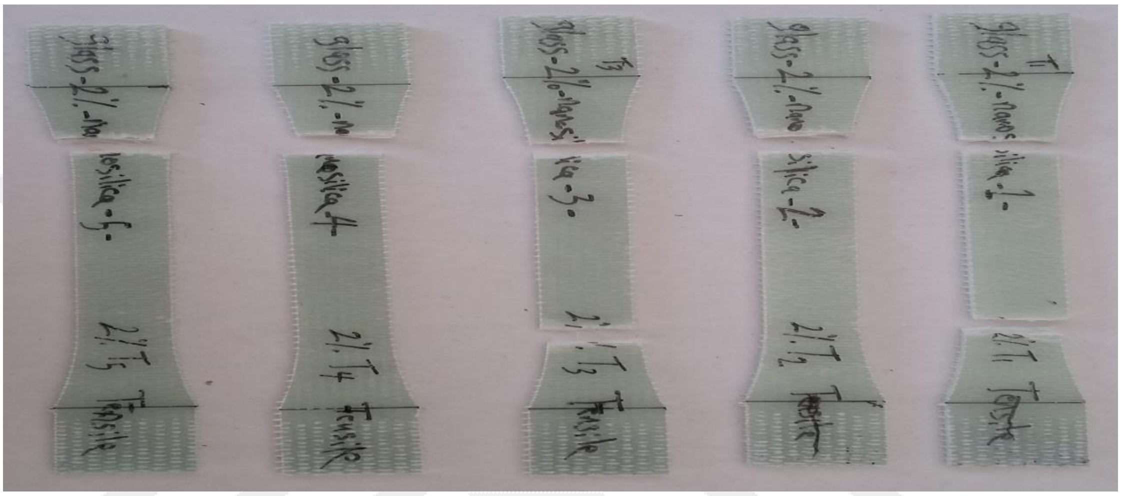


Figure 4.14 Tensile stress–strain curves for 2wt% nanosilica content at different fiber orientation angles

From Figure 4.14, the 2wt% nanosilica content with fiber orientation angle 0° showed a rapid load rise, obtaining the smallest tensile strain 0.1 mm/mm and the highest stress 280.25 MPa among all of the tested samples. Suggesting that GFRP for the 2wt% nanosilica content with angle 0° has a good stiffness due to the high strength property of glass fiber. Therefore, the addition of 2wt% of nanosilica content to the glass /epoxy layers will increase the tensile strength. The added nanosilica increased the strain at rupture. That means the inclusion of 2wt% nanosilica content with the orientation of angle 0° in the GFRP laminate can increase the ductility of the specimens.

At the lowest value of the tensile strength of 125.49 MPa for the fiber orientation angle 45°, the highest tensile strain value was obtained which is 0.29 mm/mm. By comparing the highest tensile strength value at angle 0° with the lowest tensile strength value at angle 45°, it was found that the tensile strain of laminate with angle 45° is larger than the laminate with angle 0°, this is owing to the off axis loading and the pull out of fiber before fracture (Kaleemulla et al., 2010). Furthermore, it was shown from the stress-strain graph that the tensile test at the angle 0° showed a linear behavior up to fracture. While for the other angles the tensile test shows a nonlinear behavior up to fracture.

It is significant that different fracture modes were observed from the test results like brittle fracture of the matrix. The result refers to that the gradual breaking of the fibers is significantly dependent on the fiber orientation angle. For angle 0°, the failure was irregular and the crack propagates in different directions due to the higher strength of the fibers in longitudinal direction as it is proved by (Rajesh et al., 2010). While the failure for the other angles (15°, 30°, 45°, 60°) occured by shear and splitting of the matrix parallel to the direction of reinforcement. Figure 4.15 shows the modes of failure for samples with the different fiber orientation angles.



$\theta = 0°$

$\theta = 15°$ $\theta = 30°$ $\theta = 45°$ $\theta = 60°$

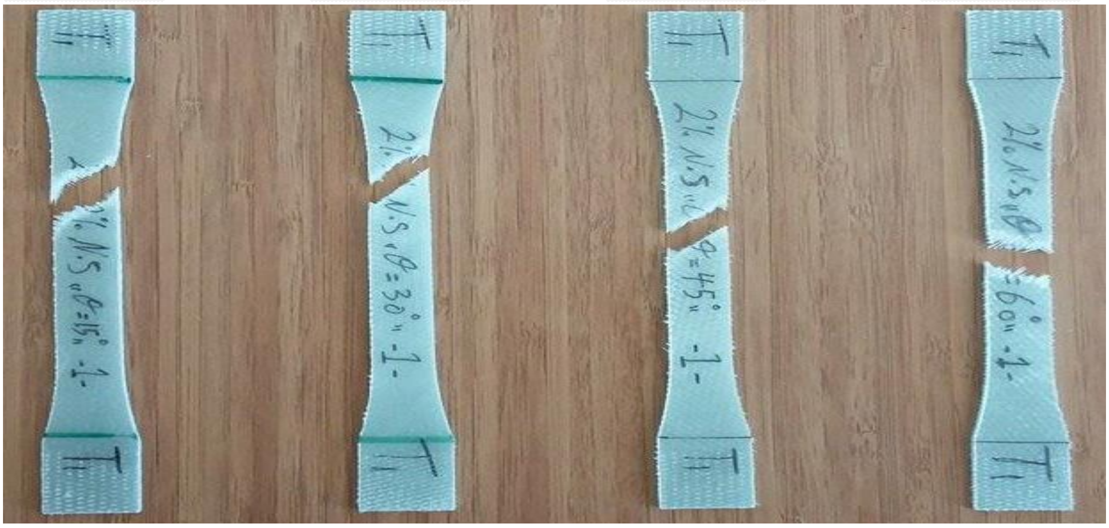


Figure 4.15 Failure specimens at 2wt% nanosilica content with different fiber orientation angles after tensile test

4.5 Flexural Test Results of Glass/Epoxy with 2%Nanosilica Content and Different Fiber Orientation Angles

The laminate samples for the 2wt% nanosilica content with fiber orientation angle 0° have the highest flexural strength and flexural modulus of 337.38 MPa and 16.74 GPa, respectively. While the laminate samples of 2wt% nanosilica content with fiber orientation angle 45° showed the least value for the flexural strength and flexural modulus of 174.16 MPa and 8.08 GPa, respectively. This change may be attributed to the presence of long fibers which participating in taking up the bending loads at angle 0° in comparison to fibers with angle 45°. Furthermore, the results showed that the laminates of 2wt% nanosilica content with fiber orientation angles (15°, 30°, 45°, 60°) suffered a decrease in the flexural strength and flexural modulus compared to the laminates of 2wt% nanosilica content with fiber orientation angle 0°.

The bending test gave the best results at fiber orientation angle 0°, and this may be due to viability of composite materials to withstand applied stresses since the reinforcement fiber is working to rise most of these loads, and this ability decreases with increasing fibers orientation angle. The results of flexural test for 2wt% nanosilica content with different fiber orientation angles (0°, 15°, 30°, 45°, 60°) were presented in Table 4.4. The variation of flexural strength and flexural modulus for 2wt% nanosilica content with various fiber orientation angles were illustrated in Figures 4.15 and 4.16.

Table 4.4 Average flexural loads and strength values of 2wt% nanosilica content at different fiber orientation angles

2% Nanosilica content with different fiber orientation angles	Average flexural load (N)	Average flexural strength (MPa)
0°	178.53	337.38
15°/-75°	173.76	328.36
30°/-60°	139.97	256.80
45°/-45°	94.92	174.16
60°/-30°	117.29	221.64

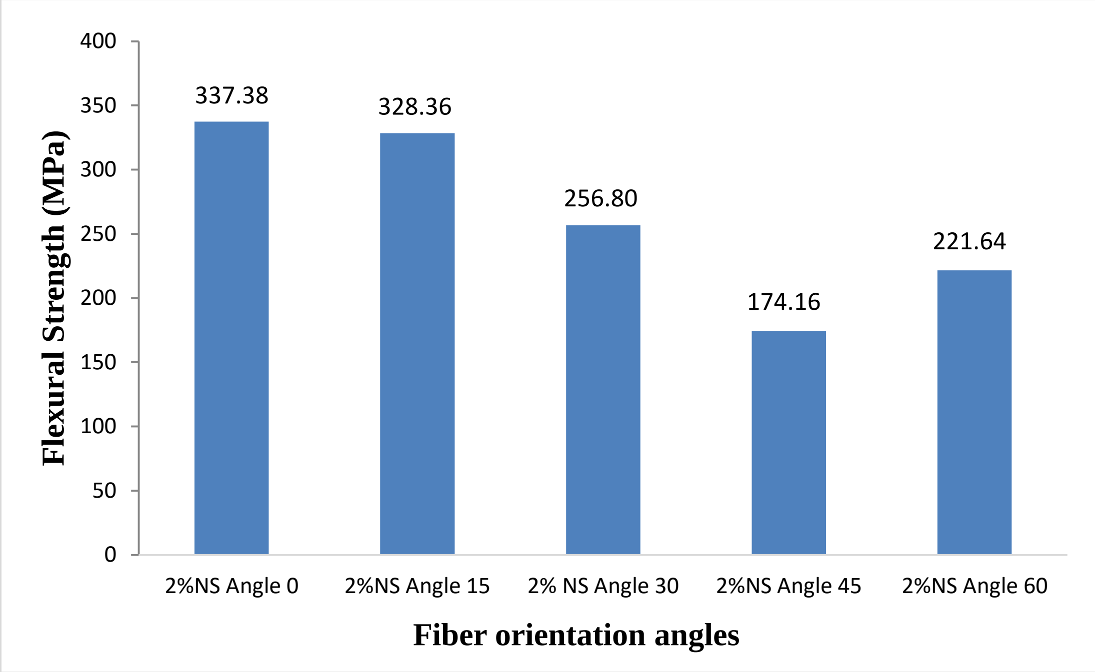


Figure 4.16 Variation of flexural strength of 2wt% nanosilica content according to the orientation of glass fiber angles

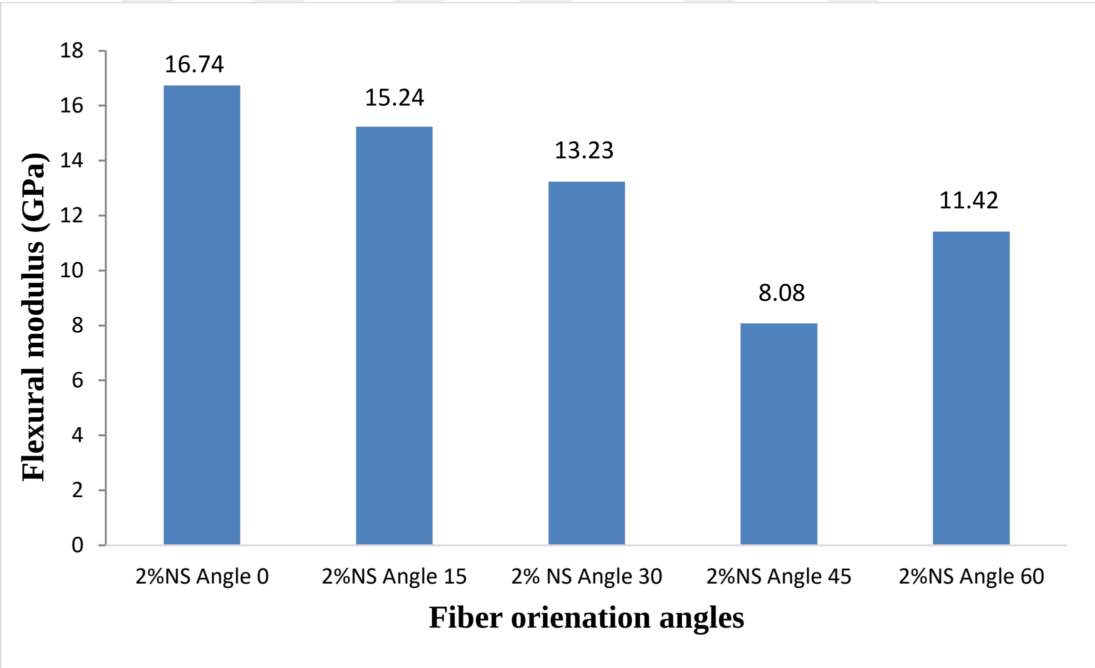


Figure 4.17 Variation of flexural modulus of 2wt% nanosilica content according to the orientation of glass fiber angles

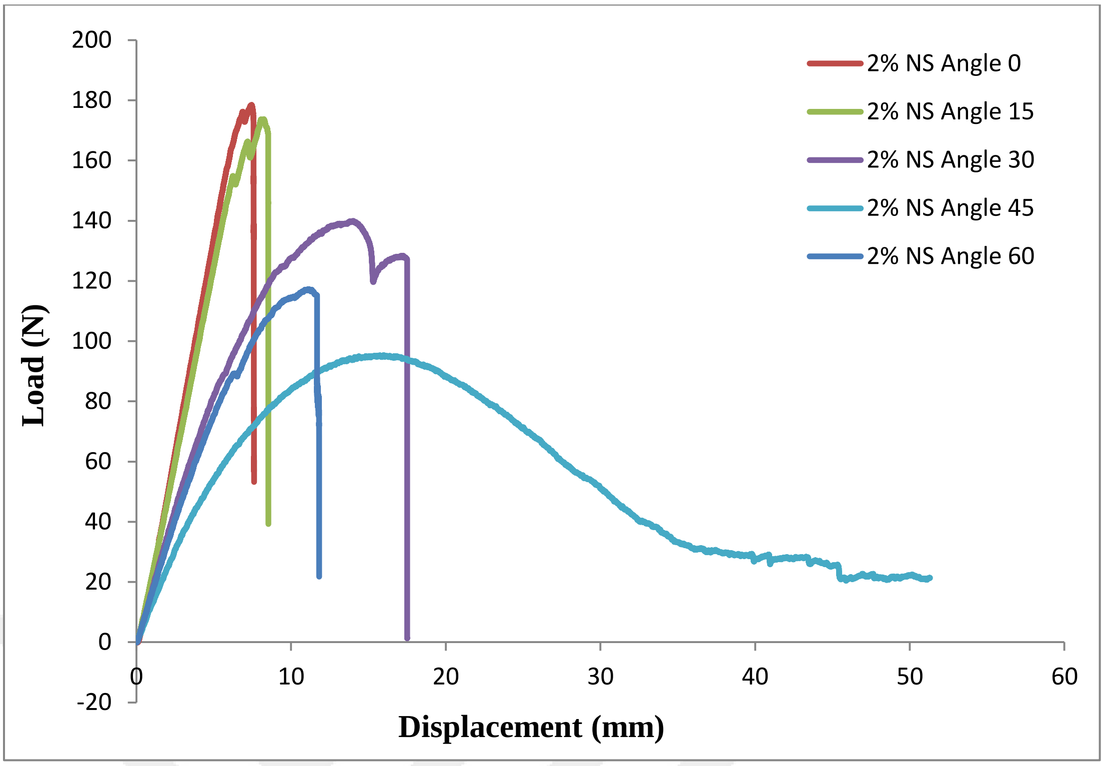


Figure 4.18 Flexural load–displacement curves for 2wt% nanosilica content at different fiber orientation angles

The load-displacement curves for the three-point bending tests of 2wt% nanosilica content with different fiber orientation angles (0°, 15°, 30°, 45°, 60°) composite laminate is shown in Figure 4.18. The curve concerned with 2wt% nanosilica content and fiber orientation angle 0° showed the highest maximum load of 178.53 N and the lowest elongation. As well, the load-displacement graph clarified the lowest maximum load of 94.92 N and the highest yield displacement for 2wt% nanosilica content with fiber orientation angle 45°. The reason of that is due to the failure happened in a ductile manner and the short fibers were in the direction of angle 45°. A linear response of the load-displacement curves of the studied composites has shown from the flexural tests at 2wt% nanosilica content with fiber orientation angle 0° and 15°. While for the other angles (30°, 45°, 60°) the flexural test shows a nonlinear behavior up to fracture. The outcomes presented that the loads decrease with increasing the fiber orientation angle in contrast to the displacement as it increased with increasing the fiber orientation angle.

It was noticed that the different fracture styles of the samples were depending on the fiber orientation angles and this can be seen clearly in Figure 4.19.

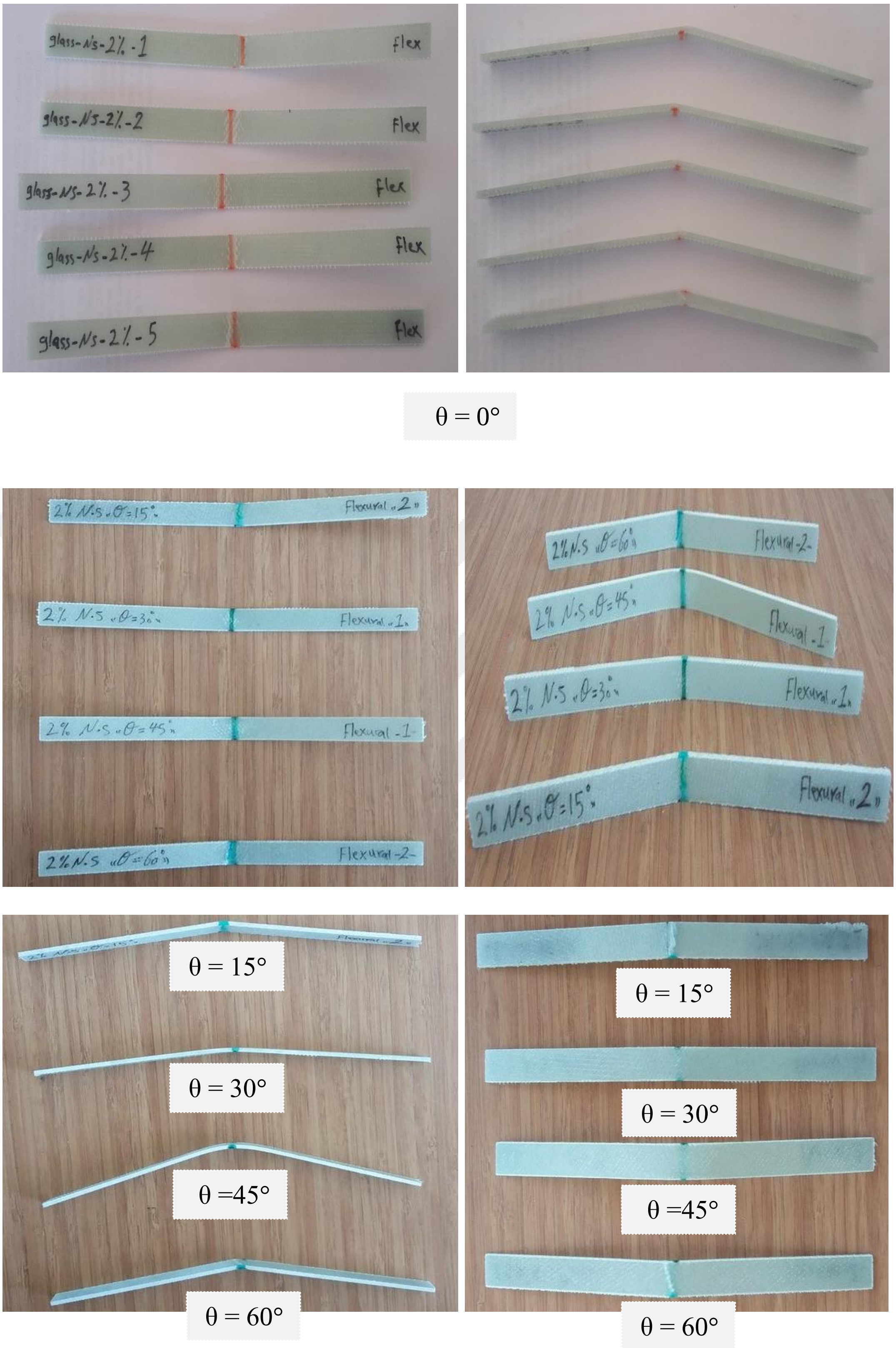


Figure 4.19 Failure of specimens at 2wt% nanosilica content with different fiber orientation angles after the flexural test

CHAPTER 5

CONCLUSIONS

The experimental investigation of the influence of nanosilica and different fiber orientation angles on the tensile and flexural characteristics of epoxy based glass fiber reinforced composites was discussed in this study. The composites were prepared by adding different percentages of nanosilica (1wt%, 1.5wt%, 2wt% and 3wt%) from the weight of the matrix and different fiber orientation angles (0°, 15°, 30°, 45°, 60°) at 2wt% nanosilica content by employing the hand layup process. Nanocomposites (with ten layers of glass fabrics) were examined for their tensile and flexural properties. In the light of the experimental results, the following results can be drawn:

- In the tensile test, the addition of nanosilica provided an improvement in the tensile strength regardless of nanosilica content. The improvement in the tensile strength was increased to the maximum by 8% at 2wt% of nanosilica content and showed diminishing improvement for further addition of nanosilica.

- The highest values of tensile strength and tensile modulus are 280.25 MPa and 17.8 GPa, respectively. These values were obtained for the GFRP composite with angle 0°orientation at 2wt% nanosilica content.

- Fiber orientation with angle 45° showed the least values of tensile strength and tensile modulus and they are 125.49 MPa and 6.5 GPa, respectively.

- Fiber orientation with angle 0° has the best tensile strength and tensile modulus compared with other fiber orientation angles. This was because the

- GFRP composites with angle 0°orientation have better ability to carry out loads in the direction of reinforcement fibers. Also, for angle 0°, the applied tensile load is distributed equally on all the fibers and transmitted along the fiber axis.
- In the three-point bending test, the flexural strength from GFRP starts to decrease by adding 1wt% nanosilica filler up to 1.5wt%. At 1.5wt% flexural strength reached it's maximum value which is 346.35 MPa. The improvement in flexural strength was reached by 4% and 1% at 1.5wt% and 2wt% contents of nanosilica respectively. After that, when increasing the content of nanosilica to 3 wt% the flexural strength come back in the decline again.

- It was found an improvement in flexural modulus of 0.7%, 15% and 2% for nanosilica contents of 1wt%, 1.5wt % and 2wt%, respectively.

- The highest improvement of flexural strength and flexural modulus was obtained at 1.5 wt% content of nanosilica.

- The GFRP composites with fiber orientation angle of 0° at 2wt% nanosilica content were showed the highest flexural strength and flexural modulus and they are 337.38 MPa and 16.74 GPa, respectively.

- Fiber orientation with angle 45° showed the least value of flexural strength and flexural modulus and they are 174.16 MPa and 8.08 GPa, respectively.

The results showed that the mechanical properties of glass fiber reinforced composites could be improved by the addition of varying amounts of nanosilica. One can use nanosilica filler to compensate for the weakness of the mechanical characteristics of GFRP offered by the polymer. It also revealed that composites filled with nonosilica exhibited better performance than unfilled epoxy composites.

REFERENCES

Ahn, H. S., Kweon, J. H., and Choi, J. H. (2005). Failure of unidirectional-woven composite laminated pin-loaded joints. *Journal of Reinforced Plastics and composites*, **24** , 735-752.

Aidah, J., Costas, S., Shahrud, A., and Abdullah, Sa. (2012). Tensile properties of Nanosilica / epoxy nanocomposites. *Procedia Engineering*, **41**, 1634 – 1640.

Almeida, J. H. S., Amico, S. C., Botelho, E. C., and Amado, F. D. R. (2013). Hybridization effect on the mechanical properties of curaua/glass fiber composites. *Composites Part B: Engineering*, **55**, 492-497.

Andritsch, T., Kochetov, R., Gebrekiros, Y. T., Lafont, U., Morshuis, P. H. F., and J. J. Smit. (2009). Synthesis and dielectric properties of epoxy based Nano composites. *Proceedings of The Annual Report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP '09)*, (pp. 523–526).

ASTM D790-10. (2010). *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.*

ASTM. (2000). *Standard test method for flexural properties of unreinforced and reinforced plastics and electrical insulating materials D 790 – 00.* Philadelphia, PA.

ASTM D 638-10 . (2010). *Standard Test Method for Tensile Properties of Plastics.*

Bagherpour, S. (2012). *Fiber Reinforced Polyester Composites.* Najafabad.

Bahadur S., and Zheng Y. (1990). Mechanical and Tribological Behaviour of Polyester Reinforced with Short Glass Fibers. *Wear*, **137**, 251-266.

Belingardi, G., Cavatorta, M.P., and Frasca, C. (2006). Bending fatigue behavior of glass–carbon/epoxy hybrid composites . *Composites Science and Technology*, **66**, 222–232.

Biron, M. (1973). *Thermosets and Composites-Technical Information for Plastics Users.* New York: Elsevier.

Boopalan, M., Niranjanaa, M., and Umapathy, M. J. (2013). Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. *Composites Part B: Engineering*, **51**, 54-57.

Brocks, T., Cioffi, M. O. H., and Voorwald, H. J. C. (2013). Effect of fiber surface on flexural strength in carbon fabric reinforced epoxy composites. *Applied Surface Science*, **274**, 210-216.

Cnradi, M. (2013). Nano silica reinforced polymer composites. *Materials and technology*, **47**, 285–293.

Damian, C. M, Pandele, A. M, Andronescu, C., Ghebau, A., Garea, S. A, and Iovu, H. (2011). Epoxy-based Nano composites s rein- forced with new amino functionalized multi-walled carbonnanotubes. *Fullerenes Nanotubes and Carbon Nanostructures*, **19**, 197–20.

Das, S. (2001). *The cost of automotive polymer composites: a review and assessment of DOE's lightweight materials composites research* . Oak Ridge. TN: Oak Ridge National Laboratory.

Davies, I. J. (2008). The effects of processing parameters on the flexural properties of unidirectional carbon fiber-reinforced polymer (CFRP) composites. *Mater Science Engineering*, **498**, 65–8.

Davis, D. C., Wilkerson, J. W., Zhu, J., and Eyewash, D. O. (2010). Improvements in mechanical properties of a carbon fiber epoxy composite using nanotube science and technology. *Composite Structures*, **92**, 2653-2662.

Diharjo, K., Priyanto, K., Purwanto, A., Shorty, N. S., Jihad, B. H., Nasiri, S. J. A., and Widia to, D. (2013). Study of flexural strength on hybrid composite of glass/carbon-bisphenol for developing car body of electrical vehicle. *In Rural Information Communication Technology and Electric-Vehicle Technology (rICT Ice-T)* (pp. 1-4). Joint International Conference, IEEE.

Do Riga Ato, A., and Poretti, A. (2012). Fatigue resistance of basalt fibersreinforced laminates. *Journal of Composite Materials,* **46**, 1773-1785.

Dong, C., and Davies, I. J. (2013). Flexural properties of glass and carbon fiber reinforced epoxy hybrid composites. Proceedings of the Institution of Mechanical Engineers, Part L. *Journal of Materials Design and Applications,* **227**, 308-317.

Dong, C., and Davies, I.J. (2012). Optimal design for the flexural behavior of glass and carbon fiber reinforced polymer hybrid composites. *Materials and Design*, **37**, 450-457.

Dong, C., Ranaweera-Jayawardena, H. A., and Davies, I. J. (2012). Flexural properties of hybrid composites reinforced by S-2 glass and T700S carbon fibers. *Composites Part B Engineering ,* **43**, 573-581.

Dorigato, A., and Pegoretti, A. (2012). Fatigue resistance of basalt fibers-reinforced laminates. *Journal of Composite Materials,* **46**, 1773-1785.

Fernandes, E. M., Mano, J. F., and Reis, R. L. (2013). Hybrid cork–polymer composites containing sisal fiber: morphology, effect of the fiber treatment on the mechanical properties and tensile failure prediction. *Composite Structures*, **105**, 153-162.

Ferreira, J.A.M., Costa, J.D.M., and Reis, P.N.B . (1999). *Static and fatigue behaviour of glass fiber reinforced polypropylene composites.* Elsevier Theoretical and Applied Fracture Mechanics.

Grayson, M. (1983). *Encyclopedia Materials and Components.* New York: John Wiley and Sons.

Gu, J., Wu, G., and Zhang, Q. (2007). Preparation and damping properties of fly ash filled epoxy composites. *Materials Science and Engineering Elsevier*, 452–453.

Guru Raja, M. N., and Hari Rao, A. N. (2013). Hybrid effects on tensile properties of carbon/glass angle ply composites. *Advances in Material,* **2**, 36-41.

Gustin, J., Joneson, A., Mahinfalah, M., and Stone, J. (2005). Low velocity impact of combination Kevlar/carbon fiber sandwich composites. *Composite Structures*, **69**, 396-406.

Ho, M. P., and Lau, K. T . (2012). Design of an impact resistant glass fiber/epoxy composites using short silk fibers. *Materials and Design*, **35**, 664-669.

Hosur, M. V., Abdullah, M., and Jelani, S. (2005). Studies on the low-velocity impact response of woven hybrid composites. *Composite Structures*, **67**, 253-262.

Hwang, S.F., and Mao, C.P. (2001). Failure of delaminated interplay hybrid composite plates under compression. *Composites Science and Technology,* **61**, 1513-1527.

Isa, M. T., Ahmeda, A.S., Aderemia, B.O., Taibb, R.M., and Mohammed-Daboa I.A. (2013). Effect of fiber type and combinations on the mechanical, physical and thermal stability properties of polyester hybrid composites. *Composites Part B: Engineering*, **52**, 217-223.

Jordan, J., Jacob, K. I., Tannenbaum, R., Sharaf, M. A., and Jasiuk,I. (2005). Experimental trends in polymer Nano composites s—a review. *Materials Science and Engineering A*, **393**, 1–11.

Jumahata, A., Soutis, C., Abdullah, S., and Kasolang, S. (2012). Tensile Properties of Nanosilica / Epoxy Nanocomposites. *Procedia Engineering,* **41**, 1634-1640.

Kaleemulla, K. M., and Siddeswarappa, B. (2010). Influence of Fiber Orientation on the In-plane Mechanical Properties of Laminated Hybrid Polymer Composites. *Journal of Reinforced Plastics and Composites*, **29**, 1900-1914.

Kalnin, I. L. (1972). Evaluation of unidirectional glass--graphite fiber / epoxy resin composites. *Celanese Research Co.* Summit, NJ.

Katas, M., and Karakuzu, R. (2009). Determination of mechanical properties of glass-epoxy composites in high temperatures. *Polymer Composites*, **30**, 1437-1441.

Kaw, A. K. (2006). *Mechanics of Composite Materials*. London: Taylor & Francis, Inc.

Kitano, T., Hag Hani, E., Tanegashima, T., and Asha, P. (2000). Mechanical properties of glass fiber / organic fiber mixed–mat reinforced thermoplastic composite. *Polymer Composites*, **21**, 493-505.

Krishna, H.V.R., Priya, S.P., and Rai, S.K. (2005). Tensile, impact, and chemical resistance properties of granite powder–epoxy composites. *Journal of Reinforced Plastics and composites*, **24**, 541-455.

Krishna, H.V.R., Priya, S.P.,and Rai, S.K. (2005). Tensile, impact, and chemical resistance properties of granite powder–epoxy composites. *Journal of Reinforced Plastics and composites*, **24**, 541-455.

Li, Y. X. (1999). Compressive and flexural behavior of ultra-high-modulus polyethylene fiber and carbon fiber hybrid composites. *Composites Science and Technology*, **59**, 13-18.

Lowenstein, K. L. (1973). *The Manufacturing Technology of Continuous Glass Fibers*. New York: Elsevier.

Mahrholz, T., Stängle, J., and Sinapius, M. (2009). Quantitation of reinforcement effect of nanosilica particles in epoxy resin used in liquid composite moulding processes. *Composites: Part A* , **40**, 235–243.

Manjunatha, C.M., Taylor, A.C. , Kinloch, A.J. , and Sprenger, S. (2010). The tensile fatigue behavior of a silica nanoparticle-modified glass fiber reinforced epoxy composite. *Composites Science and Technology*, **70**, 193-199.

Marom, G., Drukker, E., Weinberg, A., and Banbaji, J . (1986). Impact behavior of carbon / Kevlar hybrid composites. *Composites*, **17**, 150-153.

May, C. E. (1987). *Epoxy resins: chemistry and technology*. CRC press.

McGrath L. M., Richard S. P. , Saskia H. K. , John L. S. , Daniel A. F. , and Joseph L. L. (2008). Investigation of the thermal, mechanical, and fracture properties of alumina epoxy composites. *Polymer,* **49**, 999-1014.

Moisala, A., Kinloch, Q. Li. I. A., and Windle, A. H. (2006). Thermal and electrical conductivity of single- and multi-walled carbon nanotubeepoxy composites. *Composites Science and Technology,* **66**, 1285–1288.

Moloney AC, Kausch HH, Kaiser T, and Beer HR. (1987). Review-parameters determining the strength and toughness of particulate filled epoxide resins. *Journal of Mater Sci.,* **22**, 381–393.

Naik, N.K., Ramasimha, R., Arya., Prabhu, S. V., and ShamaRao, N. (2001). Impact response and damage tolerance characteristics of glass–carbon/epoxy hybrid composite plates. *Composites Part B: Engineering,* **32**, 565-574.

Nitin, S., and Singh, V.K. (2013). Mechanical behavior of walnut reinforced composite. *Journal of Material. Environ. Science,* **4**, 233-238.

Önal, G. (2006). Mechanical buckling behavior of hybrid laminated composite plates with inclined crack. *Journal of Reinforced Plastics and Composites,* **25**, 1535-1544.

Orozco, R. (1999). *Effects of Toughened Matrix Resins on Composite Materials for Wind Turbine Blends.* M.Sc. Thesis, Montana State University: Bozeman, Montana.

Osmani. (2009). Mechanical Properties of Glass-Fiber Reinforced Epoxy Composites Filled with SiO2 Particles. *Journal of Reinforced Plastics and Composites,* **28**, 2861-2867.

Ou, R., Zhao, H., Sui, S., Song, Y., and Wang, Q. (2010). Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-densitypolyethylene composites. *Composites Part A: Applied Science and Manufacturing,* **41**, 1272-1278.

Park, R., and Jang, J. (1999). Performance improvement of carbon fiber/polyethylene fiber hybrid composites. *Journal of Materials Science,* **34**, 2903-2910.

Patnaik, A., Satapathy, A., Mahapatra, S. S., and Dash R. R. (2009). A comparative study on different ceramic fillers affecting mechanical properties of glass– polyester composites. *Journal of Reinforced Plastics and Composites*, **28**, 1305-1318.

Pavia, J. M. F. D., Santos, A. D. N. D., and Rezende, M. C. (2009). Mechanical and morphological characterizations of carbon fiber fabric reinforced epoxy composites used in aeronautical field. *Materials Research*, **12**, 367-374.

Peijs, A.A.J.M., and De Koki, J.M.M. (1993). Hybrid composites based on polyethylene and carbon fibers, Part 6: tensile and fatigue behavior . *Composites*, **24**, 19-32.

Pérez-Fonseca, A.A., Robledo-Ortiz, J.R., Ramirez-Arreola, D.E., OrtegaGudiño, P., Rodrigue, D., and González-Núñez, R. (2014). Effect of hybridization on the physical and mechanical properties of high density polyethylene– (pine/agave) composites. *Materials & Design*, **64**, 35-43.

Petruchio, R., Santali, C., Puglia, D., Sarasin, F., Torre, L., and Kenny, J. M. (2013). Mechanical characterization of hybrid composite laminates based on basalt fibers in combination with flax, hemp and glass fibers manufactured by vacuum infusion. *Materials and Design*, **49**, 728-735.

Pibo, M., Maoming, J., Yanyan, L., and Wenxin, Z. (2015). The Impact Compression Behaviors of Silica Nanoparticles—Epoxy Composites. *Journal of Textile Science and Technology*, **1**, 1-11.

Rajesh, M. N., and Jerald, J. (2010). Experimental Investigation of Woven E-Glass Epoxy Composite Laminates Subjected to LowVelocity Impact at Different Energy Levels. *Journal of Minerals & Materials Characterization & Engineering*, **9**, 643-652.

Ramesh, K N., Alina, D., and Ray, B.C . (2014). Effect of epoxy modifiers on mechanical performance of Epoxy/Glass fiber hybrid composites. *Elsevier, Procedia Materials Science*, **6**, 1359 – 1364.

Ramesh, M., Palanikumar, K., and Reddy, K.H. (2013). Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites. *Composites Part B: Engineering*, **48**, 1-9.

Rathnakar, G., and Shivanan H. K. (2013). Experimental Evaluation of Strength and Stiffness of Fiber Reinforced Composites under Flexural Loading. *International Journal of Engineering and Innovative Technology*, **2**, 219-222.

Rosso, P., Ye, L., Friedrich, K. and Sprenger, S. (2006). A Toughened Epoxy Resin by Silica Nanoparticle Reinforcement. *Journal of Applied Polymer Science,* **100**, 1849-1855.

Rothon, R. N. (2002). *Particulate Fillers for Polymers.* New York: Elsevier.

Ruse, M., Sofian, N., and Ruse, D. (2001). Mechanical and thermal properties of zinc powder filled high density polyethylene composites. *Polymer Testing*, **20**, 409– 417.

Sarasini, F., Tirillò, J., Valente, M., Valente, T., Cioffi, S., Iannace, S., and Sorrentino, L. (2013). Effect of basalt fiber hybridization on the impact behavior under low impact velocity of glass/basalt woven fabric/epoxy resin composites. *Composites Part A: Applied Science and Manufacturing*, **47**, 109-123.

Sayer, M. (2014). Elastic properties and buckling load evaluation of ceramic particles filled glass/epoxy composites. *Elsevier Ltd. Composites: Part B,* **59** , 1220.

Setsuda, R., Fukumoto, I., and Kanda, Y. (2012). Effects of fly ash in composites fabricated by injection molding. *Published online in Wiley Online Library Society of Plastics Engineers Polymer Composites*.

Sevkat, E., Liaw, B., Delale, F., and Raju, B. B. (2010). Effect of repeated impacts on the response of plain-woven hybrid composites. *Composites Part B: Engineering,* **41**, 403-413.

Shokrieh, M.M., Saeedi, A., and Chitsazzadeh, M. (2014). Evaluating the effects of multi-walled carbon nanotubes on the mechanical properties of chopped strand mat/polyester composites. *Materials and Design*, **56**, 274–279.

Subagia, I. A., and Kim, Y. (2013). A study on flexural properties of carbonbasalt/epoxy hybrid composites. *Journal of Mechanical Science and Technology,* **27**, 987-992.

Subagia, I. A., Kim, Y., Tijing, L. D., Kim, C. S., and Shon, H. K. (2014). Effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers. *Composites Part B: Engineering,* **58**, 251-258.

Sudarisman, D. I. (2008). The effects of processing parameters on the flexural properties of unidirectional carbon fiber-reinforced polymer (CFRP) composites. *Mater Sc.i Eng.: A, 498*, 65–8.

Sudheer, M., Subbaya, K.M., Jawali, D., and Bhat, T. (2012). Mechanical properties of potassium titan ate whisker reinforced epoxy resin composites. *Journal of Minerals & Materials Characterization & Engineering,* **11**, 193-210.

Sun, X., Tong, L., and Chen, H. (2001). Progressive failure analysis of laminated plates with delamination. *Journal of Reinforced Plastics and Composites,* **20**, 1370-1389.

Thomton, P. A. and Colengelo, V. J. (1985). *Fundamentals of Engineering Materials.* Prentic- Hall, Inc.

Thorsten, M. J. M., Dirk, R., Ulrich, R., and Lars, H. (2003). New high performance fibre reinforced material with nano composites. *Materials for Aerospace Applications, Paris Nov.* , 24-26.

Thwe, M.M., and Liao, K. (2002). Effects of environmental aging on the mechanical properties of bamboo–glass fiber reinforced polymer matrix hybrid composites. *Composites Part A: Applied Science and Manufacturing,* **33**, 4352.

Tsai, J.L., Hsiao, H. and Cheng, Y.L. (2010). Investigating Mechanical Behaviors of Silica Nanoparticle Reinforced Composites. *Journal of Composite Materials,* **44**, 505-524.

Uddin, M.F. and Sun, C. (2008). Strength of Unidirectional Glass/Epoxy Composite with Silica Nanoparticle-Enhanced Matrix. *Composites Science and Technology,* **68**, 1637-1643.

Valença, S. L., Griza, S., de Oliveira, V. G., Sussuchi, E. M., and de Cunha, F. G. C . (2015). Evaluation of the mechanical behavior of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric. *Composites Part B: Engineering,* **70**, 1-8.

Valente, M., Sarasini, F., Marra, F., Tirillò, J., and Pulci, G. (2011). Hybrid recycled glass fiber/wood flour thermoplastic composites: Manufacturing and mechanical characterization. *Composites Part A: Applied Science and Manufacturing,* **42**, 649-657.

Vikas, D. (2013). *Glass Fiber Reinforced Nanocomposites – Effects of Fiber Orientation and Nanoclay Content.* M.Sc. Thesis, Thapar University: Patiala, India.

Wan, Y. Z., Lian, J. J., Huang, Y., Wang, Y. L., and Chen, G. C. (2006). Two-step surface treatment of 3D braided carbon/Kevlar hybrid fabric and influence on mechanical performance of its composites. *Materials Science and Engineering: A*, **429**, 304-311.

Wan, Y. Z., Wang, Y. L., He, F., Huang, Y., and Jiang, H. J. (2007). Mechanical performance of hybrid bismaleimide composites reinforced with threedimensional braided carbon and Kevlar fabrics. *Composites Part A: Applied Science and Manufacturing,* **38**, 495-504.

Yadav, S. N., Kumar, V., and Varma, S. K. (2006). Fracture toughness behavior of carbon fiber epoxy composite with Kevlar reinforced interleave. *Materials Science and Engineering: B,* **132**, 108-112.

Yasmin, A., Abot, J. L., and Daniel, I. M. (2003). Processing of clay/ [4] epoxy Nano composites s by shear mixing. *Scripta Materialia,* **49**, 81–86.

Yousif, B. F., Shalwan, A., Chin, C. W., and Ming, K. C. (2012). Flexural properties of treated and untreated kenaf / epoxy composites. *Materials & Design,* **40**, 378-385.

Zamanian, M., Mortezaei, M., Salehnia, B., and Jam, JE. (2013). Fracture toughness of epoxy polymer modified with nanosilica particles: particle size effect. *Eng Fract Mech,* **97**, 193–206.

Zhang, J., Chaisombat, K., He, S., and Wang, C. H. (2012). Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures. *Materials and Design,* **36**, 75-80.

Zhang, Y., Li, Y., Ma, H., and Yu, T. (2013). Tensile and interfacial properties of unidirectional flax/glass fiber reinforced hybrid composites. *Composites Science and Technology*, **88**, 172-177.

Zhao, R., and Wenbo, L. (2008). Fracture surface analysis on nano-SiO2 / epoxy composite. *Materials Science and Engineering A*, 483–484,313–315.

Zheng, Y. and Ning, R. (2005). Study of SiO2 Nanoparticles on the Improved Performance of Epoxy and Fiber Composites. *Journal of Reinforced Plastics and Composites*, **24**, 223-233.

Zheng, Y., Zheng, Y., and Ning, R . (2003). Effects of nanoparticles SiO2 on the performance of nanocomposites. *Journal of Materials Letters,* **57**, 2940-2944.

Zheng, Y., Zheng, Y., and Ning, R. (2003). *Journal of Materials Letters*, **57**, 2940-2944.

Zou, G.P., and Lam, S.S.E. (2002). Buckling analysis of composite laminates under end shortening by higher-order shear deformable finite strips. *International Journal for Numerical Methods in Engineering,* **55**, 1239-1254.