OCTOBER 2016 M.Sc. THESIS in MECHANICAL ENGINEERING BAYAN JABBAR FAYZULLA

UNIVERSITY OF GAZIANTEP

GRADUATE SCHOOL OF

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DETERMINATION OF TENSILE AND NATURAL FREQUENCIES OF PARTICULATE FILLED FIBER REINFORCED POLYMER COMPOSITE MATERIALS

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Determination of Tensile and Natural Frequencies of Particulate Filled Fiber Reinforced Polymer Composite Materials

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Supervisor

Assoc. Prof. Dr. Ahmet ERKLIG

By

Bayan Jabbar FAYZULLA

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Bayan Jabbar FAYZULLA

ABSTRACT

DETERMINATION OF TENSILE AND NATURAL FREQUENCIES OF PARTICULATE FILLED FIBER REINFORCED POLYMER COMPOSITE MATERIALS

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M.Sc. in Mechanical Engineering
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This study aims to examine the influence of micro particles (borax, sewage sludge ash, silicon carbide and perlite) addition on tensile, damping and vibration response of S-glass/epoxy composite laminates. Tensile strength values have been determined according to ASTM standard. Natural frequency and damping response of particle filled composite laminates have been determined with different weight fractions between particles and epoxy resin with hardener. Micro-scale particles have been used as replacement material with epoxy resin and their particle contents except perlite were 0 (plain), 5, 10, 15 and 20 wt % while perlite particle contents were 1, 3, 5 and 10 wt %, respectively. Vibration properties of samples have been experimentally measured by using dynamic modal analysis procedures. For damping responses, half power band-width method has been employed with first mode of natural frequency. The results indicated that the replacement of borax, sewage sludge and silicon carbide as particles with epoxy resin by 10 wt % and 1 wt % of particle loading significantly increased the tensile while damping ratio showed the highest value with 5 wt % particle loading of all type fillers except sewage sludge ash that at 10 wt % recorded maximum damping ratio. Further increase in particle content caused a reduction in tensile strength and vibration values.

Keywords: Glass Fibers, Particle filled composites, Tensile Strength, Vibration

ÖZET

PARÇACIK KATKILI FİBER TAKVİYELİ POLİMER KOMPOZİT MALZEMELERİN DOĞAL FREKANS DEĞERLERİNİN TESPİTİ

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Tez Yöneticisi: Doç. Dr. Ahmet ERKLIG
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Bu çalışmanın amacı, S-cam/epoksi kompozit plakalar içerisine katılan mikro boyuttaki boraks, katı atık yakma külü, silikon karpit ve perlit parçacıkların malzemenin çekme, titreşim ve sönüm üzerine etkilerinin araştırılmasıdır. Çekme mukavemet değerleri ASTM standartlarına göre tespit edilmiştir. Epoksi matris içerisine ağırlıkça farklı oranlarda katılan parçacıkların kompozit plakalar üzerindeki doğal frekans ve sönüm değerlerine etkileri belirlenmiştir. Perlit haricindeki malzemelerin epoksi matris içerisindeki ağırlıkça oranları %5, 10, 15 ve 20 olacak şekilde kullanılmıştır. Perlit ise ağırlıkça %1, 3, 5 ve 10 oranlarında matris içerisine katılmıştır. Üretilen kompozit numunelerin titreşim özellikleri dinamik modal analiz prosedürü ile deneysel olarak ölçülmüştür. Sönüm değerleri ise Yarım-Güç Bant-Genişliği Metodu ve birinci doğal frekans değeri kullanılarak hesaplanmıştır. Yapılan deneysel ölçümlere göre ağırlıkça %10 oranında boraks, katı atık yakma külü ve silikon karpit parçacıkların ve ağırlıkça %1 oranındaki perlit parçacığının epoksi reçine içerisine katılması ile maksimum çekme mukavemeti elde edilmiştir. Ayrıca, ağırlıkça %5 oranında epoksi içerisine karıştırılan parçacıklardan maksimum sönüm oranı elde edilmiştir. Belirtilen oranların üzerine çıkıldığında çekme mukavemeti ve sönüm değerlerinde düşüşlere sebep olmaktadır.

Anahtar Kelimeler: Cam elyaf, Parça katkılılı kompozitler, Çekme mukavemeti, Titreşim

Dedicated to My Beloved Parents, Brothers and Sisters

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LIST OF SYMBOLS

Bx	Borax
SiC	Silicon Carbide
SSA	Sewage Sludge Ash
Pr	Perlite
GF	Glass Fiber
GE	Glass Fiber Reinforced Epoxy Composite
GE-Bx	Glass-Fiber-Reinforced Epoxy Composites with Borax
GE-SiC	Glass-Fiber-Reinforced Epoxy Composites with Silicon Carbide
GE-SSA	Glass-Fiber-Reinforced Epoxy Composites with Sewage Sludge Ash
GE-Pr	Glass-Fiber-Reinforced Epoxy Composites with Perlite
DMA	Dynamic Mechanical Analysis
ω_n	Natural Frequency
ξ	Damping Ratio
Ē	Storage Modulus of the Beam
Ȅ	Loss Modulus
FRF	Frequency Response Function
L	Free Length of the Beam
ρ	Density of the Beam.

I	Moment of Inertia
A	Cross-Section of the Beam
HDPE	High Density Polyethylene
PP	Polypropylene
CNTs	Carbon Nanotubes
DAQ	Data Acquisition Card
SEM	Scanning Electron Microscopy

CHAPTER 1

INTRODUCTION

1.1 General

Since the early years there has been a raise in the request of strong materials, and also stiff and lightweight to utilize in the aerospace industry, structure and transportation. Now a days the materials play a vital role in the manufacturing sections and automobiles. Because of all the components are made of metals. They are facing a lot of problems due to corrosion, vibrations, strength and lifetime, the repair and replacement of entire structure is very difficult [1].

A composite is any material made of more than one component. Composite materials are solid multiphase materials formed through the combination of materials with different structural, physical and chemical properties. This makes composites different from the other multi systems such as blends and alloys [2, 3].

These types of constitutive materials are there: matrix and reinforcement. Matrix carrying fibers together and form a strong bond together and transfer stresses between the reinforcing fibers/particles. Matrix phase is composed of resin and hardener, adding this resin hardener leads to treat and turn into hard so making it a solid material. Treatment of composite relies on hardener used (the curing temperature). Reinforcing maybe in the form of fibers, flakes or particulates. Taking into consideration fiber reinforcement, natural and synthetic fibers are one of the branch of the reinforcing phases of the composite materials. The goal is to pick feature of the excellent characteristics of both (reinforcement and matrix) without compromising on defect of either. Epoxy resin is high-performance thermosetting resins combining many superior properties, like high mechanical and adhesion properties, excellent dimensional and thermal stability, low cost and ease of processing [4, 5].

1.2 Classification of Composites

A systematic classification of composite is necessity in any discussion and analysis of how the composite properties are effected by their internal reinforcement of the geometries. Two classes of composites are fibrous and particulate. Each has unique properties, and can be subdivided into specific categories as shows in figure 1.1 [6].

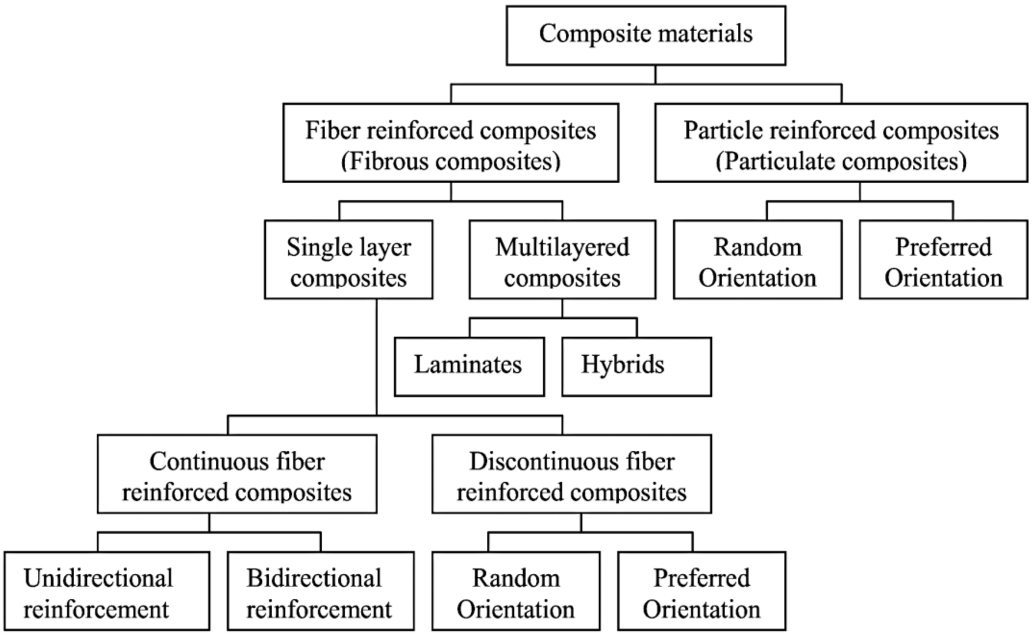


Figure 1.1 Composites Classification [7]

1.2.1 Fibrous composite

A fibrous reinforcement is recognized more of its length than the dimensions of cross-section. Fibers are extremely efficient in enhancement the resistance of fracture in the matrix for the reason that reinforcement own the long dimension. Dishearten the propagation of inception cracks normal to reinforcement that may otherwise lead to failure especially for brittle matrix. The single layer laminate possibly be made of several different layers with every layer possess the same orientation and characteristic and so the whole laminate perhaps considered a single layer laminate composites. The most utilized composite is multi-layered; that is, they consist of various layers of fibrous composites. Every layer its orientation is changed in accordance to design. Several layers are bonded with each other to create a multilayered composites. If the foundational contents in every layer are the same, this is called laminate. The multi-layer composite that composed of layers of different foundational are called hybrid laminates. Fiber reinforcement in composite of single layer probably be long or short. The long fibers composite is called continuous fiber reinforced composite and these have short fibers called discontinuous fiber-reinforced composite. The single layer composites may be continuous fiber alignment in one direction to create a unidirectional composite. Bidirectional reinforcement may be a single layer in orthogonal directions as in the woven fabric. In composite materials discontinuous fiber orientation cannot be controlled easily, and in most situation are assumed to be randomly oriented fibers [6].

1.2.2 Particulate Composites

Particulate reinforcements may be nano or micro filler. The shapes of the reinforcing particles may be spherical, cubic or any regular or irregular geometry. The particle, in contrast to fibers, does not have a privileged direction. Particles are generally used to improve basic properties of material such as stiffness, behavior under temperature, abrasion resistance, shrinkage decreased, etc. In various situation particles are used to reduce the materials cost without degrading the properties. Choose the particle matrix association depends on the features wanted. In the majority considering the particles reinforced composite orientation of the particles, for practical purposes, to be random. Table 1.1 is description of chemical families of fillers for plastics [6, 8].

Table 1.1 Chemical Families of Fillers for Plastics. [9]

Chemical family		**Examples**
Inorganics	Oxides	Glass (fibers, spheres, hollow spheres, and flakes), MgO, SiO2, Sb2O3, Al2O3, and ZnO
	Hydroxides	Al(OH)3 and Mg(OH)2
	Salts	CaCO3, BaSO4, CaSO4, phosphates, and hydrotalcite
	Silicates	Talc, mica, kaolin, wollastonite, montmorillonite, feldspar, and asbestos
	Metals	Boron and steel
Organics	Carbon, graphite	Carbon fibers, graphite fibers and flakes, carbon nanotubes, and carbon black
	Natural polymers	Cellulose fibers, wood flour and fibers, flax, cotton, sisal, and starch
	Synthetic polymers	Polyamide, polyester, aramid, and polyvinyl alcohol fibers

1.3 Fiber Material

Generally, fiber is the reinforcing phase of a composite material. The most popular fibers used in composites are glass, carbon, organic, and mineral fibers. Among them, glass fibers are the most widely used reinforcements for engineering composites [10, 11].

1.3.1 Glass Fiber

The glass fibres manufacturing are done by drawing molten glass into very fine threads then directly protecting them from contact with the atmosphere in order to keep the defect free structure that is created by the drawing operation [12].

Glass fiber is available in different forms like continuous, chopped and woven fabrics. The high strength, low cost, high chemical resistance, good insulation properties are the advantages of it while the disadvantages such as a low elastic modulus, bad adhesion of polymers, high specific gravity, sensitivity to erosion (decrease the tensile strength),weak fatigue strength. The viscosity of a glass decreases as the temperature increases. Based upon different applications, glass fibers are classified into E-glass, C glass and S glass fibers. E-glass is used as an insulator and mostly used in electrical industry, hence got the name ‘E’ before the word ‘glass’. E-glass also has good mechanical properties in addition to low cost and ease of usability. The letter ‘S’ in S-glass stands for structural applications or because of the higher content of silica. It keeps its strength at high temperatures in comparison with E glass and has higher fatigue strength. It is mainly used for aerospace applications S-glass got different chemical formulation and it has higher strength to weight ratio and higher elongation strain percentage but it is quite expensive. C-glass fibers are advantageous in resisting chemical corrosion; D of stained glass (insulator) used for applications that require low dielectric constants, such as radomes. A stained-glass (appearance) used to develop the surface appearance. Types of combination such as glass, E-CR (“E-CR" stands for electricity and corrosion resistant) glass AR (alkali resistance) also exist [13, 14, 15].

Here are some of the differences in property in Table 1.2. The difference in characteristics because of a combination of E-glass and S-glass fibers. The fundamental elements in two fiber kinds are in the Table 1.3 [13].

Table 1.2 Comparison of Properties of E-Glass and S-glass [13]

Property	**E-Glass**	**S-Glass**
Specific gravity	2.54	2.49
Young' smodulus (GPa)	72.40	85.50
Ultimate tensile strength (MPa))	3447	4585

Table 1.3 Chemical Composition of E-Glass and S-Glass Fibers [13]

	% Weight	
Material	E-glass	S-glass
Silicon oxide	54	64
Aluminum oxide	15	25
Calcium oxide	17	0.01
Magnesium oxide	4.5	10
Boron oxide	8	0.01
Others	1.5	0.8

1.4 Dynamic Behavior

Vibration is repeated, oscillatory or periodic response unwanted of a system. In general, it is classified into two classes namely the forced and free vibrations. Free vibrations happen when small displacement or deformation is given to a system and then released while forced vibration will happen if a system is applied by a cyclic force. Increased the request for safety and reliability on a structure or device result many research concerning to vibration. The dynamic responses of the structural or mechanical systems can be completely identified by obtaining the natural frequencies and mode shapes of the systems [16, 17].

Dynamic behavior of material is realized by three parameters: natural frequency, mode shapes and damping ratio. Damping is resistant to vibrations depended on the material properties. Natural frequency is defined as the frequency at which the system tends to oscillate in the absence of any driving force or damping. At a certain frequency dynamic response of the structure is high and thereafter it reduce, and again in some special high frequency, obtaining the same response, these keeps on continuing [18].

Every structures like bridges, aircraft wings and wind turbines has many natural frequencies. The structure will resonates, if the natural frequency is excited. The vibration amplitude increased significantly, so the stress of the structure will rise significantly, and then the life of the machine will reduces due to increasing of stress. It is therefore important to know the natural frequency in order to eliminate it for safety design of the system [19, 20].

Frequency Response Function (FRF) is structural response to an applied input force as a function of frequency which indicates natural characteristics of the excited structures. It performs as a transfer function from the time domain to the frequency domain. The dynamic response of the system may be obtained in terms of displacement, velocity or acceleration by introducing FRF curve [20].

Consider a linear system as given in Figure 1.2 FRF was obtained in terms of acceleration X (ω) by the application of input fore F (ω) and transfer function of H (ω). Relationship between input and output functions was expressed as [20].

$$X(\omega) = F(\omega)\, H(\omega)$$

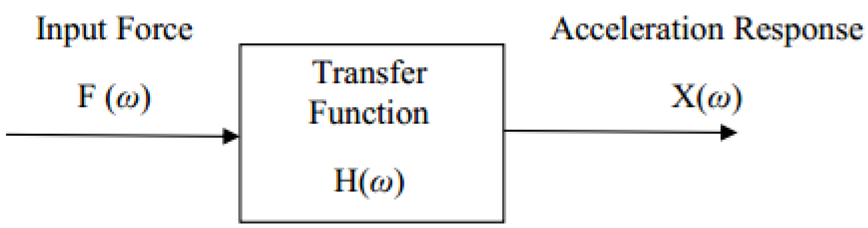


Figure 1.2 FRF of the Linear System [20]

A significant modal parameter is damping for the design of structures in which cyclic loading and vibration control are critical. Damping is also a significant factor for the fatigue life and impact resistance. All engineering material dissipates energy under cyclic load. Some, such as synthetic rubber, plastics, rubber, and dissipate more energy in each cycle of metal materials. Damping varies with different environmental effects. In addition, temperature is usually one of the most important factors for damping in polymers and polymeric materials .Polymer matrix composite materials is usually used in weight sensitive structures because of their high stiffness-to-weight ratios. They are especially important in aircraft, aerospace, and military applications [21].

If positioning reliability and dynamic stability are the requirements of the design in the polymer composites structures, their damping characteristics should be investigated under various temperature for probable using in various seasons. Damping properties of fiber reinforced composites show best vibration energy absorption within the material, as well as reduce the transport of noise and vibration to neighboring structures [21, 22].

To avoid the resonant behavior of the structures, the results of the analysis of the free-vibration for the laminated composite structures using in design are important. [23].

Vibration reduction can be achieved by increasing the ability of damping (loss of energy) and/or increasing the stiffness (storage modulus). The loss modulus is the product of these two quantities and thus can be considered a figure of merit for reduce vibration [24].

Damping of a structure can be achieve through active or passive methods. Passive methods make use of the natural capability of given materials. That way providing passive energy dissipation. Active methods are done by use of sensor and actuators. The vibration damping materials are at most 1.metals, 2.polymers and rubber because of their viscoelastic property [24].

1.5 Importance of the Study

Particle filled fiber reinforced polymer composites are finding increasing uses during the recent years in engineering applications including aerospace, biomedical, automobiles, marine, aviation, and defense industries. They have been reinforced with the different solid filler phase to improve strength, fatigue, specific stiffness, corrosion resistance, durability, flammability viscoelastic response, and damping capacity. In addition, being low cost and easily obtainable, it would hopefully supply a cost effective solution to composite industrialist.

In this thesis, the study involved the tensile strength and dynamic properties (e.g. natural frequency, damping ratio, storage modulus and loss modulus) of particles filled fiber reinforced polymer composite were determined by considering different kinds of micro particle with different weight fraction.

1.6 Methods and Outline of the Study

In this work particle filled fiber reinforced polymer composites were prepared with S- glass fiber using different particles and epoxy resin as matrix. Then from these composite laminates, specimens for tensile and vibration tests were prepared. Dimensions of the specimen were organized according to ASTM standards. The study has been divided into 5 chapters.

The general introduction and definitions on composite materials, classification of composites, glass fiber, dynamic behavior parameters (natural frequency, and damping factor) are defined in the first chapter. First chapter also includes importance of the study, research methods and outlines of the thesis.

Literature review is given in chapter 2. Literature review has been grouped in five sections: introduction, general studies about particulate effect on composite material properties, studies about particulate influenced on general mechanical properties of glass fiber reinforced composites, studies about particulate effect on dynamic properties of glass fiber reinforced composites and conclusion.

Chapter 3 presents information about production of particle filled fiber reinforced polymer composite plates by hand lay-up method under 0.3 MPa pressure with 80^{0}C temperature. Half power band-width method is introduced in order to determine damping and natural frequencies of particle filled fiber reinforced polymer composites.

Chapter 4 includes experimental results of tensile and vibration tests to see the effects of different particle with different particle content. Borax (Bx), sewage sludge ash (SSA) and silicon carbide (SiC) with ratios (5, 10, 15 and 20 wt%) and perlite (Pr) with ratios 1, 3, 5 and 10 wt% were used in this study.

General conclusion and future works are given in chapter 5.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Advanced materials are the search of materials which provide the prescribed properties. The development of composite materials was the response to the needs of high technology. Opposite materials are combined as a compliant matrix reinforced with stiff and strong elements .This idea was borrowed from nature, the leaves and stalks of plants, human and animal bones are anisotropic materials reinforced by fibers, i.e. composite materials. Literature review has been grouped in four sections as: general studies about particulate effect on composite material properties are reviewed in section 2.2, particulate effect on general mechanical properties of glass fiber reinforced composites are reviewed in section 2.3, particulate effect on dynamic properties of glass fiber reinforced composites are reviewed in section 2.4 and conclusion on literature survey.

2.2 General studies about particle effects on composite laminate properties:

Adding organic or inorganic solid filler to the matrix in composite production may be enhancing the mechanical and dynamic properties of composites. Studies about the composites are increasing. In this section, some studies about particle filled fiber reinforced polymer composite materials are given.

Lancaster [25] aimed to appear two important things: first the wide difference in the tribological characteristics of currently available polymer-based composites (carbon/epoxy), second the different effects of particles and reinforcing fibers on friction, wear and mechanical characteristics. The results observed that during sliding against metals, fillers played an essential role in friction and wear processes by modifying the topography of the counter face as a result of transfer, abrasion, or corrosion.

Skandani et al.[26] prepared Bi-layered carbon fiber- ZnO nanorod hybrid composites with resin (epoxy) and examined for vibration mitigations utilizing dynamic mechanical analysis. The results displayed that the growth of zinc oxide nanorods on top of carbon fiber increases the damping efficiency about 50% while cause a slight decrease (~7%) on the storage modulus.

Wetzel et al. [27] looked into the effect of the micro- and nano-dimensional (SiC, 5 µm and 10 µm; TiO_2, 300 nm) ceramic particles as reinforcing fillers in an epoxy matrix into mechanical and tribological characteristics of the composites. According to results the micro-composites containing SiC exhibit a significantly lowered impact strengths, even below that of the neat matrix. The 5 µm sized SiC particles seem to strongly increase the brittleness of the composite material, probably due to the inhomogeneous particle shape and the impact strengths of the TiO nano composites on the contrary are remarkably improved, especially at a low filler content of 7.5vol. % TiO.

Bhagyashekar and Rao [28] discussed the effect of adding a filler on the mechanical properties of epoxy consists system composed metallic and non-metallic fillers; brittle (SiC), ductile (Cu and Al), and soft (Gr). The results demonstrate that the tensile and flexural strength of the particulate composites degraded with filler content, whereas the modulus (tensile and flexural) increased with the filler content for the a group of filler contents considered (10–40 wt%). Increased compressive strength of all composites up to a maximum load of filler 30 wt% and then fell beyond this value

Spiliotis et al. [29] used either pet coke (PC) or sewage sludge (SSA) as admixtures up to about 6% content into clayey materials for ceramic production. The outcomes show that the use of PC and SSA in ceramic industrialization operations might lead to changes in processing parameters, to energy savings and to materials with improved thermal insulation properties.

McGrath et al. [30] investigated the fracture toughness of alumina (α-Al2O3)-filled epoxy resins as a function of average sized filler, distribution of the size, shape of the particle, loading, and epoxy crosslink density. The resin crosslink density and filler content was the most important variables, cause changes into relative fracture toughness and shear storage modulus properties.

Rusu et al. [31] investigated thermal and mechanical characteristics of zinc powder filled high density polyethylene (HDPE) composites. Zinc powder contents varied between 0 and 20% by volume. The results demonstrated that the incorporation of zinc powder on HDPE induced by low mechanical characteristics, compared with those of the unfilled polymers. There were two exclusions, breaking tensile strength, which appeared a maximum value at 4% vol of powder metal and Young's modulus, with a maximum value correspondent to 14% of powder metal. Both the hardness and the density of the HDPE/zinc composites were increases with increasing fillers content in the mixture. While the density increasing is directly in proportion to the content of filler (zinc powder). The incorporation of zinc powder in HDPE increased the thermal conductivity and thermal diffusivity but declined the specific heat.

Gülsoy and Taşdemir [32] studied mechanical and physical properties of polypropylene (PP) reinforced with iron particles polymer composites. It was found that by increase the volume % of iron (Fe) in PP, reduced the yield and tensile strength, % elongation, and notched Izod impact strength of PP. While, adding of Fe increased the modulus of elasticity, hardness (Shore D), vicat softening point and heat deflection temperature (HDT) values of the PP.

Gungor [33] investigated experimentally mechanical properties of HDPE containing 5, 10 and 15 vol. % Fe powders. The preparation of composite samples were done by a twin screw extruder and injection molding. For each sample microstructure of fracture surface, the modulus of elasticity, yield and tensile strength, % elongation, hardness (Shore D), and Izod impact strength (notched) were determined. It was found that Fe particles had significant effect on the mechanical properties of HDPE compared with the unfilled HDPE. Iron filled polymer composites showed lower yield and tensile strength, % elongation, and Izod impact strength, while the hardness and modulus of elasticity of the composite sample were higher than those of HDPE. Addition of 5 vol. % Fe reduced Izod impact strength and % elongation of HDPE about 40% and 90% respectively and increase the modulus of elasticity of HDPE by 31%.

Jajam and Tippur [34] tested the role of nano- vs. micro-filler particle- scale size of silica filled epoxy on static and dynamic fracture behaviors under quasi-static and stress-wave loading conditions. Mode-I crack initiation and crack growth behaves were examined using 2D digital image correlation method and high-speed photography in symmetrically the influence of samples. The quasi-static fracture tests appeared fracture toughness enhancement in case of nano-composites relative to micro-particle filled ones. On the other hand, the dynamic crack-initiation toughness is constantly higher for micro-particle filled composites compared to the nano-filler counterparts.

Ozsoy et al. [35] examined the influence of micro- and nano-filler content on the mechanical properties of epoxy composites. The micro-fillers using were Al_2O_3, TiO_2 and fly ash; the nano-fillers were Al_2O_3, TiO_2 and clay. The test samples were prepared using an open type mold die. The following tests: tensile, hardness and three-point bending were carried out. The results were demonstrated that the tensile strength, flexural strength and elongation at the break values of composite materials decreased whereas the tensile and flexural modulus increased with the increasing micro- and nano-filler contents.

Fu et al. [36] examined the influences of particle size, particle/matrix adhesion and particle content on stiffness, strength and toughness for composites of a scale of particulate composites having both of micro- and nano-fillers with small aspect ratios of unity and thereabout were examined in detail. It was found that composites strength and toughness were highly influenced by all those three factors.

Ratan et al. [37] analysed free vibration of polypropylene-nanoclay composite beam with crack. Analysis is carried out using Finite element package ANSYS-14.5. The nano clay in composite is varied from 0 to 15 percentage and crack depth to width ratios are chosen as 0, 0.25, 0.5, and 0.8. It was noted that natural frequencies of the composites increased with the increase of nanoclay percentage.

Hoysala et al. [5] reviewed the effect of silicon dioxide (SiO_2) as filler on the dynamic behavior of the jute fiber reinforced epoxy composite materials. The dynamic behavior of the material refers to the natural frequency, damping and mode shapes of the material. SiO_2 increased the flexural and tensile modulus, vibration properties of the jute fiber reinforeced composites.

Nagesh and Manjunath [38] studied on evaluation of mechanical properties of borax and graphite based Al-6061 composites. The addition level of reinforcement is being varied from 3-9 wt% in step of 3wt%. Graphite and Boron reinforcements are used for enhancing the structural rigidity and weight reduction. Mechanical characteristics like tensile strength, compression strength and modulus of elasticity were decreased and percentage of elongation increased in addition of particles become less stiff and the resistance afforded by the material against the tensile load decreased.

Shubhan and Tiwari [39] examined the damping properties of fly ash filled fiber reinforced epoxy resin was by varying the fly ash concentration from 0 to 30% by weight. It was found that the damping value improved with adding of fly ash more than 15 wt% which any further addition decreased damping value. Also, the storage modulus and loss modulus was increased with an increasing in fly ash concentration.

Borbón et al. [40] studied on damping response of composite beams with addition of 5 wt% carbon nanotubes (CNTs). Simple and sandwich beams were manufactured with aluminum, epoxy resin and different types of CNTs. Damping ratio was obtained by means of logarithmic decrement and half-power bandwidth method It was found that CNTs in the epoxy resin improved the damping ratio of the composite materials.

Wang et al. [41] studied on the damping properties, thermal stability, tensile and impact strength of a short carbon fiber and micro hollow glass bead filled with polyurethane/epoxy resin graft interpenetrating polymer network composite materials. Results revealed that good damping properties, good thermal stability and relatively good strength showed by the composite materials that contained 3% hollow glass bead and 5% carbon fibers, which may be used in damping construction materials.

Rajoria and Jalili [42] examined the stiffness and damping characteristic s of carbon nanotube-epoxy composite materials for use in structural applications of vibration. Both of single-walled and multi-walled nanotube-epoxy composite materials were prepared with several ratios of nanotubes. Free and forced vibration tests were carried out on those samples (in the form of cantilevered beams) to extract natural frequency and damping ratio from the gained responses. It was noted that the damping ratio more dominant enhancement than the stiffness utilizing carbon nanotube reinforcement

DeValve and Pitchumani [43] experimentally investigated the damping influences of carbon nanotubes entrenched into the matrix of fiber-reinforced composite materials. The outcomes display that the adding of two weight percent of CNTs to the matrix of carbon fiber reinforced composite materials can increase the damping in a stationary composite beam by more than 130%.

Imoisili et al. [44] investigated the effects of coconut shell ash (CSA) concentration on the tensile properties of epoxy composite. Composites with amount ratios of CSA ranging 5, 10, 15, 20, and 25 wt. % were fabricated, test results shows that at 15% filler content maximum tensile strength was achieved compared to other filler concentration. Also percentage elongation and load at break decreased with increasing in fillers concentration.

Takashima et al. [45] investigated the influences of perlite addition on the fracture property of poly vinyl alcohol (PVA) fiber reinforced cementitious composites by extrusion molding. Direct tension tests of the PVA fiber composite materials offered that the adding of perlite is effective to improve particularly the composite strain capacity.

Chen et al. [46] examined mechanical properties of polypropylene composite materials filled with magnesium hydroxide (MH). The results showed that the tensile strength and the elongation at break decrease with increasing MH content. Reduction observed in tensile properties at most because of poor compatibility between the filler particles and the matrix in PP/MH composite materials.

Sahraeian et al. [47] prepared nano composites based on low-density polyethylene LDPE and nano perlite (having 2, 4, 6 and 9 weight ratios) particles. The dynamic mechanical analysis (DMA) tests were done to determine dynamic properties of samples. The results assured the basing of interactions between treated nano-perlite and LDPE matrix. The storage modulus was increased with increasing frequency and perlite loading. This was related to the elastic nature of nano-perlite.

Sreedhar et al. [48] prepared starch-poly vinyl alcohol (PVA) blends with borax (2, 2.5, or 3 wt %). Increased tensile strength and elongation at break decreased with increasing concentration of borax. Mechanical properties of the starch–PVA blends improved after treatment with borax and were higher than those of the pure blends.

The tensile strength of the blends increased at the expense of elongation as the concentration of borax in the blends increased.

2.3 Particulate effect on mechanical properties of GF reinforced composites

Patnaik [49] investigated the effects of fly ash, alumina and SiC particles on the mechanical properties of glass–polyester composites. Comparative analysis showed that the tensile strength of the composites decreased significantly with the incorporation of those fillers,. The flexural properties, interlaminar shear strength, density and hardness are also influenced with the content and type of filler particles. It was concluded that it was important to find that such waste fly ash industrial filler made the best characteristics compared to those of alumina and SiC.

Mridha et al. [50] researched the effect of useing OPWF (less than 250 µm size of particles) as filler in the woven glass fiber reinforced epoxy composite materials on impact strength. The fabrication for hybrid composites were done using a hand lay-up method and cured at room temperature under a compressive load of 196N (20 kg). The impact test was conducted on samples at various temperatures. It was observed that the thermal expansion of epoxy matrix was 10 times higher than the glass fiber. The thermal conductivity variation was generated compressive stresses in the composite samples. This stress was assumed to create more interlocking between matrix and fiber interface, and thus it requested additional energy to break.

Srivastava and Hogg [51] determined the mechanisms of toughening in interlayered quasi-isotropic glass–fibre reinforced polyester resin composite materials. Particles of aluminium tri-hydrate $Al(OH)_{3,}$ and polyethylene, were mixed with the polyester resin prior to laminating with woven E-glass-fibre cloth. The results indicate that the interlaminar toughness (GIc and GIIc), absorbed energy and residual compressive strength values of the glass–fibre reinforced polyester resin composite materials increasesed with increasing of particle ratio. Polyethylene particles increase the toughness of the matrix material, which results in composites with higher values of mode-I, mode-II and impact than the composites with aluminium tri-hydrate particles.

Sayer [52] focused on the influences of the various ceramic particles, such as silicon carbide (SiC) which has two particle sizes, aluminum oxide (Al2O3) and boron carbide (B4C), on elastic properties and critical buckling loads of E-glass/epoxy composite plates.

Detomi et al [53] studied on the effect of micro-ceramic filler particles on the flexural behavior of glass fiber composite materials. A series of experiments have been done in order to identify the influence of the weight fraction, location and type of particles over the modulus, flexural strength and bulk density of glass fiber composites. According to experimental results, the use of 10 wt% of silica micro-particles in the upper side of the sample as the best micromechanical configuration to obtain the highest mechanical performance in the composites.

Callıoğlu et al [54] looked over the impact behavior for the 0% (unfilled), 10% and 20% of (SiC) ceramic filled woven G/polyester-matrix composite material plates subjected to increasing impact energies. It was complete that addition the particles to resin, till a specific ratio, increases the puncture (tear) thresholds of the woven glass/polyester. The puncture (tear) of 10% filled composite was more about 37% than that of the 20% filled composite and 6% higher than ones of the 0% (neat) of composite samples.

Suresha and Chandramohan [55] presented the friction and wear properties of E-glass–epoxy (GE) and graphite filler of three different levels in GE composites using a pin-on-disc set-up in various loads and sliding velocities. From this investigation, it turned out to be 7.5% by weight graphite filled GE composite system offered least coefficient of friction and highest wear resistance comparison to the GE composite system.

Asi [56] investigated the mechanical properties of glass-fiber reinforced epoxy composite filled with various content ratios of Al_2O_3 particles. The results appeared that while ultimate tensile strength and shear strength of the composites decreased with increasing Al_2O_3 particles content, flexural strength increased with the Al_2O_3 particles content of up to 10% beyond which it decreased.

Manjunatha [57] investigated the tensile fatigue behavior of a silica nano-particle modified glass fiber reinforced epoxy composite. An anhydride-cured thermosetting epoxy polymer was modified by merging 10 wt. % of well-dispersed 20 nm diameter silica nanoparticles. It was shown that the fatigue life of the GFRP composite with 10 wt% silica nano-particle modified epoxy matrix is about three to four times higher than that of the GFRP with the neat epoxy matrix.

Cao and Cameron [58, 59] submitted a new method of manufacturing glass fiber reinforced epoxy composites. To achieve this aim, samples were prepared by four various ways: Method A, using ‘neat’ GE as the reinforcement (i.e., with no modification or additional treatment to the as-received fiber); Method B, modifying with silica particles the surface of the GE before applying in the composite system; Method C, prestressing the neat GE during the curing procedure of the composite; and Method D, prestressing the silica modified GF during the curing procedure of the composite. The results indicate that the flexural modulus, and shear modulus of the composite specimens process by this new method (Method D) are greater than the sum of the results produced by (Methods B and C) when they were compared to the composite specimens prepared by the basic manufacturing condition (Method A) and the impact property of the composites prepared by this novel Method D was greater by up to 100% comparison with method A and lesser but, significant, amounts by other two methods.

Patnaik et al. [60] displayed a comparative study of the influence of fly ash, alumina Al_2O_3 and silicon carbide SiC on the erosion properties of E-glass polyester composite materials. This study demonstrated that addition of hard particulate fillers like fly ash, Al_2O_3 and SiC make efficient of the erosion resistance of glass-polyester composites significantly.

Nayak et al. [61] studied effect of different ceramic powders ($Al_2O_3/SiO_2/TiO_2$) in epoxy resin on mechanical effectiveness of glass fiber hybrid composite materials. It was notice that the mechanical properties like, flexural strength and flexural modulus were more in case of SiO_2 modified epoxy composite compare to other fillers. Alumina modified epoxy composite material samples increased the hardness and impact energy compare to other modifiers.

Reddy et al. [62] studied the influence of fly ash filler content ratios on both of flexural strength and tensile strength at 10 wt were used. The fly ash content were 0, 2, 4, 6, 8 and 10 grams. The results showed that with the increase in fly ash up to 6 grams the tensile strength increased, thereafter it decreased, while the maximum tensile modulus of elasticity and flexural strength were at 8 grams and 4 grams respectively.

Agarwal [63] investigated the influence of adding of silicon carbide (SiC) filler on physical properties using different weight percentages, thermal characteristics, and mechanical characteristic of chopped glass fiber GF-reinforced epoxy composites. The resuls reported that with the increase in SiC filler content up to 10 to 15 wt. %, mechanical properties such as hardness, tensile strength, interlaminar shear strength, flexural strength, and impact strength were increased whereas addition of SiC content beyond 15 wt. % caused the decrease on mechanical properties.

Devendra et al. [64] studied the ultimate tensile strength of E-glass fiber reinforced epoxy composites filled with varying content ratios of aluminum oxide (Al_2O_3), magnesium hydroxide ($Mg(OH)_2$) and silicon carbide (SiC). The outcomes of experimental process shown that composites filled by 10 volume % $Mg(OH)_2$ offer maximum ultimate tensile strength (375.36 MPa) but lower than the 0% (unfilled) composite (450.24 MPa). Also composites filled by Al_2O_3 exhibited better ultimate strength (292.8 MPa) at 10 vol. % when compared with SiC filled composites (285 MPa) at 10 vol. %.

Kumar et al. [65] proposed a method for mixing coal ash powder (size 52-75 μm) in the resin. The fabrication of ash reinforced polymer composite materials were done by using hand lay-up method in different weight ratios of coal ash in polymer with 0%, 4%, 8%, 12%, 16% and 20%. It was showed that coal ash powder reinforced polymer composite at 20% having better tensile strength in comparison with other ash percentages.

Bhandakkar et al. [66] prepared the epoxy glass fiber laminate composite materials contained precipitator fly ash using hand layup technique. Additions particulate reinforcement precipitator fly ash (25 - 45 μm) to the epoxy matrix by mechanical mixer up to 10% by weight. The results showed that the effects of additions precipitator fly ash reinforcement on the mechanical properties and interlinear fracture toughness of epoxy glass fiber laminate composite is improvement by the addition of fly ash reinforcement 10% (By weight) by 49.43%. Tensile strength of the fly ash/glass fiber reinforced-epoxy composite specimens were lower than that of glass fiber-epoxy GE composites.

2.4 Particulate effect on dynamic properties of GF reinforced Composites

Sankar et al. [67] studied mechanical and damping properties of epoxy-filled glass fiber composites with inclusions of natural rubber particle. Fabricated samples with the addition of natural rubber particles of different sizes. SEM micrographs of the surface of fracture during tensile testing of glass fiber reinforced epoxy resin composite samples with rubber particles show the distribution of rubber particles in the well-observed in matrix. It was notce that the tensile and flexural modulus decreased with increasing rubber particle size. The influence of particle size on resonant frequency was not great and damping was decreased with increasing resonant frequency in all the test conditions also effected by the rubber particle size impurities impurities.

Datta and Włoch [68] investigated the effect of various submicron-scaled fillers particle (zinc oxide ZnO and silicon dioxide with 2 and 4 wt.%) ratios for both of particle types on mechanical and thermo-mechanical characteristics of epoxy matrix composites reinforced with glass fibres. It was discovered that addition of 2 wt.% of SiO2 showed a maximum improvement of 23.3% in flexural strength and 23.9% in storage modulus in comparison with the control samples. The composites with 4 wt.% ZnO exhibited the greatest (31.8%) improvement in flexural modulus. Dynamic mechanical analysis demonstrated the increase of storage modulus and loss modulus.

Pol et al. [69] presented the influence of nanoclay particles on dynamic response of E-glass/epoxy hybrid composites. The results shown that with increasing the ratio of nano-clay (1 to 5%) the natural frequency and damping ratio of the beams were increased, but at 7% nano-clay ratio, both of the natural frequency and damping ratios began to decreasing.

Sankar et al. [70] studied the improvement of the material damping of glass fiber epoxy composite materials with particle rubber addition. It was experimentally studied the effect of particle size on the damping and stiffness parameters at different frequencies and temperatures. Considerable enhancement in damping at lower particle sizes without significant reduction in stiffness was noticed. The damping property in both bending and shear modes was more with 0.254 mm rubber particle inclusions among the all particle sizes.

Kumar et al. [71] studied improvement with inclusion carbon (600 mesh) fillers with different weight fractions for glass-epoxy composite materials and to characterize the mechanical and damping properties. Evaluation of the damping properties were done by using free and forced vibration test with different amplitudes. The result indicated that the damping properties improved with increasing in weight ratio of carbon reinforcement content. It was also concluded that glass fiber/ epoxy matrix with 5% carbon particles had best damping characteristics.

Cerbu et al. [72] proposed a method of utilizing of the recycled rubber as filler to manufacture a hybrid composite material. The particulate influence on dynamic and mechanical properties of woven glass fiber reinforced composites based on epoxy resin GE were analyzed. Glass fiber/epoxy matrix reinforced with recycled rubber particle filler appeared good mechanical characteristics in the both flexural test and tensile test.

Chandradass et al. [73] presented the experimentally the study about free vibration and damping properties of hybrid nano-composite laminates by using short fiber chopped strand mat reinforcing with organically modified clay content ratio (0, 1, 3 and 5 wt.%) based on the vinyl ester matrix by hand lay-up method. Also theoretical study was carried out to research the vibration and damping characteristics of hybrid nano-composites. Dynamic results showed significantly enhancements occurred for the the internal damping of hybrid composites due to second phase nano-scale dispersion in the matrix and E-glass fiber.

2.5 Conclusion on Literature survey

The following conclusions can be derived from the literature survey:

1. In literature there are many studies on the effects of particle on composite materials. Also, the addition of filler effects is still a question due the varied results. The specific objectives are to elaborate on these results by utilizing different configurations of filler and different ratio with glass fiber.

2. Some of these studies are related with particle effect on mechanical properties of glass fiber reinforced composite materials.

3. There are a little work on particulate effect on dynamic properties of glass fiber reinforced composite materials.

4. There are many researcher used SiC as a filler in general, and also in composites reinforced with glass fiber, but using it with glass for study the influence dynamic properties is very few . Studies on (Pr) and (SSA) are limited whereas; studies on (Bx) are rarely made. In this study, particulate filled fiber reinforced epoxy composite materials with different types and content ratios of fillers have been produced. The specific objectives are:

- To produce particulate filled fiber reinforced polymer matrix composites using different S-glass fiber with addition of Borax, Sewage Sludge Ash, Silicon carbide using 5%, 10%, 15%, 20 wt% and Perlite using 1%, 3%, 5%, 10 wt%.

- To find the effects of composites and its ratio on tensile strength and dynamic properties (e.g. natural frequency, damping ratio, storage modulus, and loss modulus) of particulate filled fiber reinforced polymer matrix composite materials experimentally.

CHAPTER 3

EXPERIMENTAL STUDIES

3.1 Introduction

This chapter describes the materials and techniques to prepare the composite materials under this study. The experimental details was presented in three stages: fabrication process; mechanical test and vibration analysis.

3.2 Fabrication process

3.2.1 Materials

In this study woven plain S-glass fiber plies with areal density of 200 g/m2 [74] was used as reinforcement as shown in Figure 3.1(a). An epoxy resin (MOMENTIVE-MGS L285) as shown in Figure 3.1(b) with hardener (MOMENTIVE-MGS H285) as shown in Figure 3.1(c) at a stoichiometric ratio of 100:40 was used as a resin shown in figure 3.1. All materials were provided from Dost Kimya Company in Istanbul. The anhydrous borax (Etibor-68) supplied by Etibor A.Ş., Bandırma, Turkey, Perlite supplied from Inper Perlit, Gaziantep, Turkey, SSA supplied from Gaziantep Büyükşehir Belediyesi, Turkey, SiC supplied from Esan Company, İstanbul, Turkey. The micro-fillers of borax (Bx), sewage sludge ash (SSA) and silicon carbide (SiC) with ratios (5, 10, 15 and 20 wt %) and perlite ratios 1, 3, 5 and 10 wt% were used in this study as shown in Figure 3.1 (d).

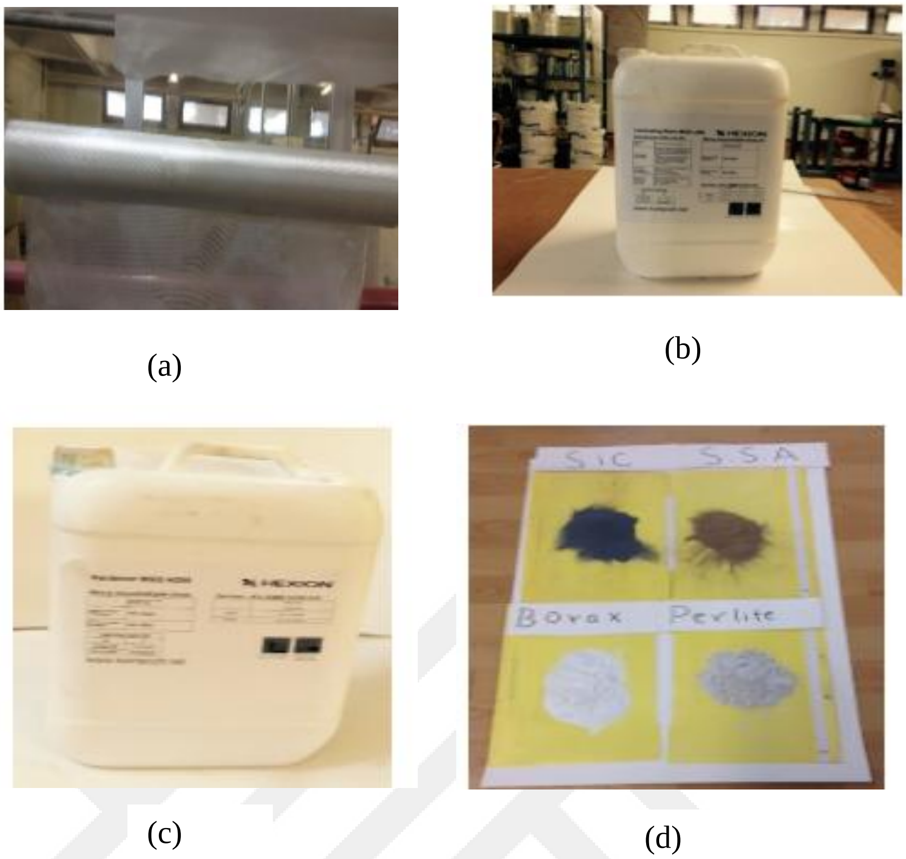


Figure 3.1 Fabrication Materials a) Plain Woven S-Glass Fiber, b) Epoxy Resin, c) Hardener, d) Four Type of Micro Fillers

The physical properties and chemical compositions of these particulate fillers are given in Table 3.1 and Table 3.2 respectively. The density in Table 3.1 was measured experimentally.

Table 3.1 The Physical Properties of Particulate Used Fillers

Properties	**Bx(kg/m^3)**	**Pr(kg/m^3)**	**SiC(kg/m^3)**	**SSA(kg/m^3)**
Density	590	160	1490	720
Color	White	White,gray and shades	Black	Brown

Table 3.2 The chemical compositions of fillers

Filler	Chemical formula/Composition wt.%
Bx	99% Sodium tetraborate decahydrate, $Na_2B_4O_7$ / (B_2O_3) , (Na_2O)
Pr	SiO_2 (73), AlO_3 (15), Na_2O_3 (3.5), K_2O (3), Fe_2O_3 (0.3), MgO (0.15), TiO_2 (0.09), SO_3 (0.1).
SSA	SiO_2 (16.45), Al_2O_3 (5.93), Fe_2O_3 (10.71), CaO (2.24), MgO (2.49), SO_3 (17.07), TiO_2 (1.82), P_2O_5 (6.33), ZnO (3.53), K_2O (1.24), Na_2O (1.20)
SiC	SiC (100).

3.2.2 Sample Preparation

Crusher machine (see Figure 3.2(a)) was used to crush the filler to obtain micro size. Then sieving machine was used to sieve the filler in order to get particle size less than 35 µm as shown in Figure 3.2 (b).

(a) (b)

Figure 3.2 (a) Crusher machine, (b) Sieving machine

Before the production of plates, electrical cutter was used to cut the glass fiber (GF) in dimensions of (350 x 200 mm). Particle and epoxy resin were mixed with a mixer at constant speed (800 rev/min) for 10–15 min into a bowl before addition of hardener at a ratio of 0.285 by mass of epoxy. The production process was carried out using a hand lay-up method (hand lay-up method is used to fabricate simplest and less volume of composites and very cost effective also requires very less labor [75]. Mixture has been added to fibers layer by layer. Mild steel cylinder was used in each layer of the composite to remove air trap and maintaining of uniform thickness of epoxy as shown in the in the Figure 3.3(a).

This process is repeated till all the 16 layers were placed. After that the fibers mixture system was transferred to the production unit device which is shown in in the Figure 3.3 (b).

(a) (b)

Figure 3.3 Composite Production a) Resin Application b) Production

This device is supported composite production unit consist of. (1) Combination of heat, pressure, (2) Hydraulic unit as shown in Figure 3.4. Laminated fabrics of 16 plied woven glass fiber of (220 × 320) mm size were first laid on the flat mold and subjected to 0.3 MPa pressure for 1 h curing time at 80 °C. Then, composite laminates were cooled to room temperature under pressure. A typical curing cycle is given in the Figure 3.5.

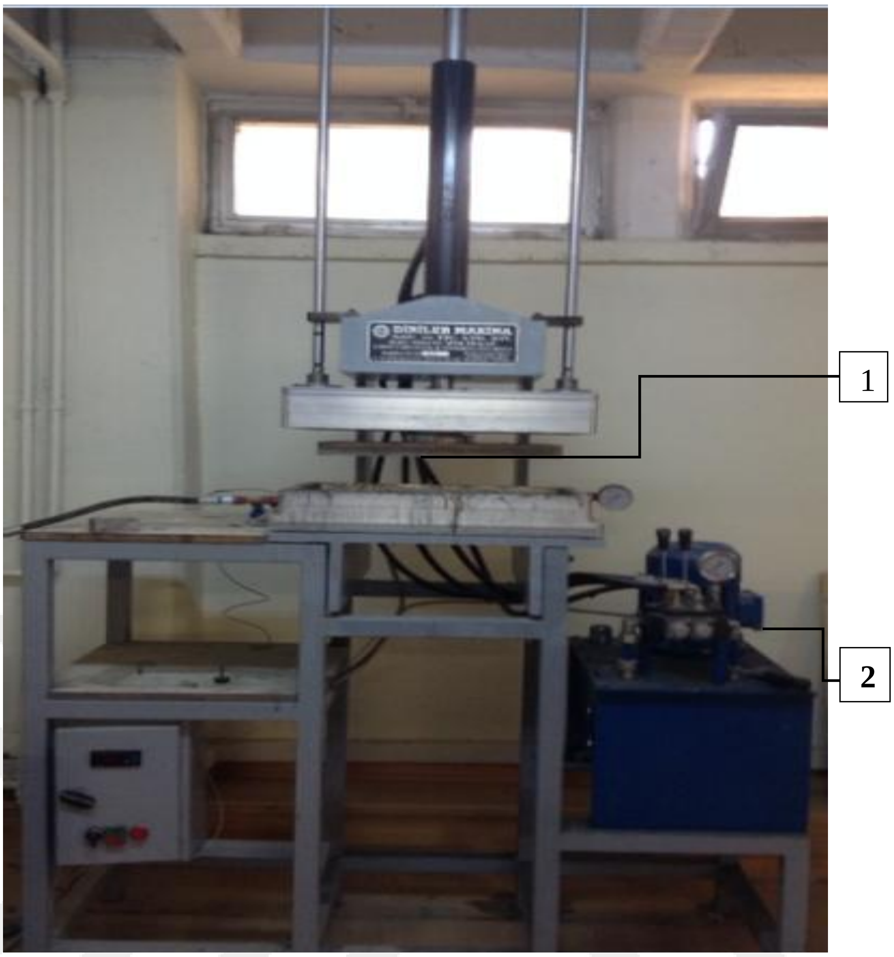


Figure 3.4 Composite Production Unit. (1) Combination of Heat, Pressure (2) Hydraulic Unit

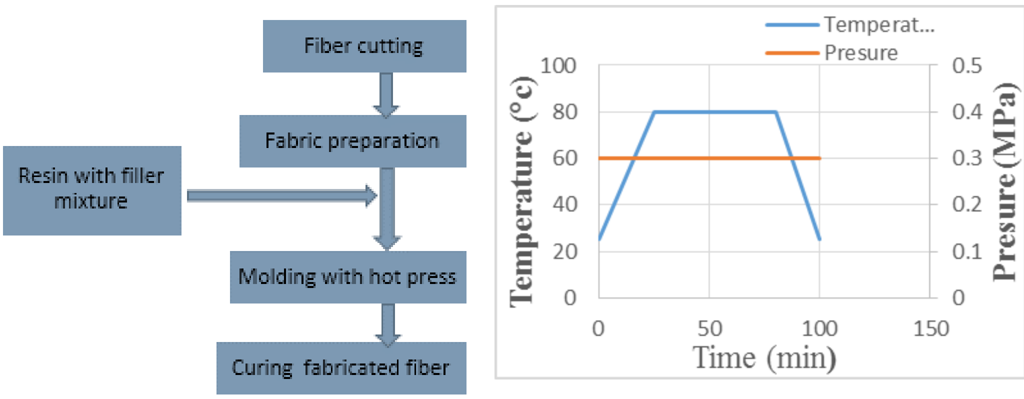


Figure 3.5 Cure Cycle

Each laminate was cut to (3) tensile test specimens and (3) vibration test specimens using CNC machine is given in Figure 3.6. The specimen's edges of the produced composite were finished with emery papers. Fabricated laminates is shown in Figure 3.7 a) before cutting b) after cutting.

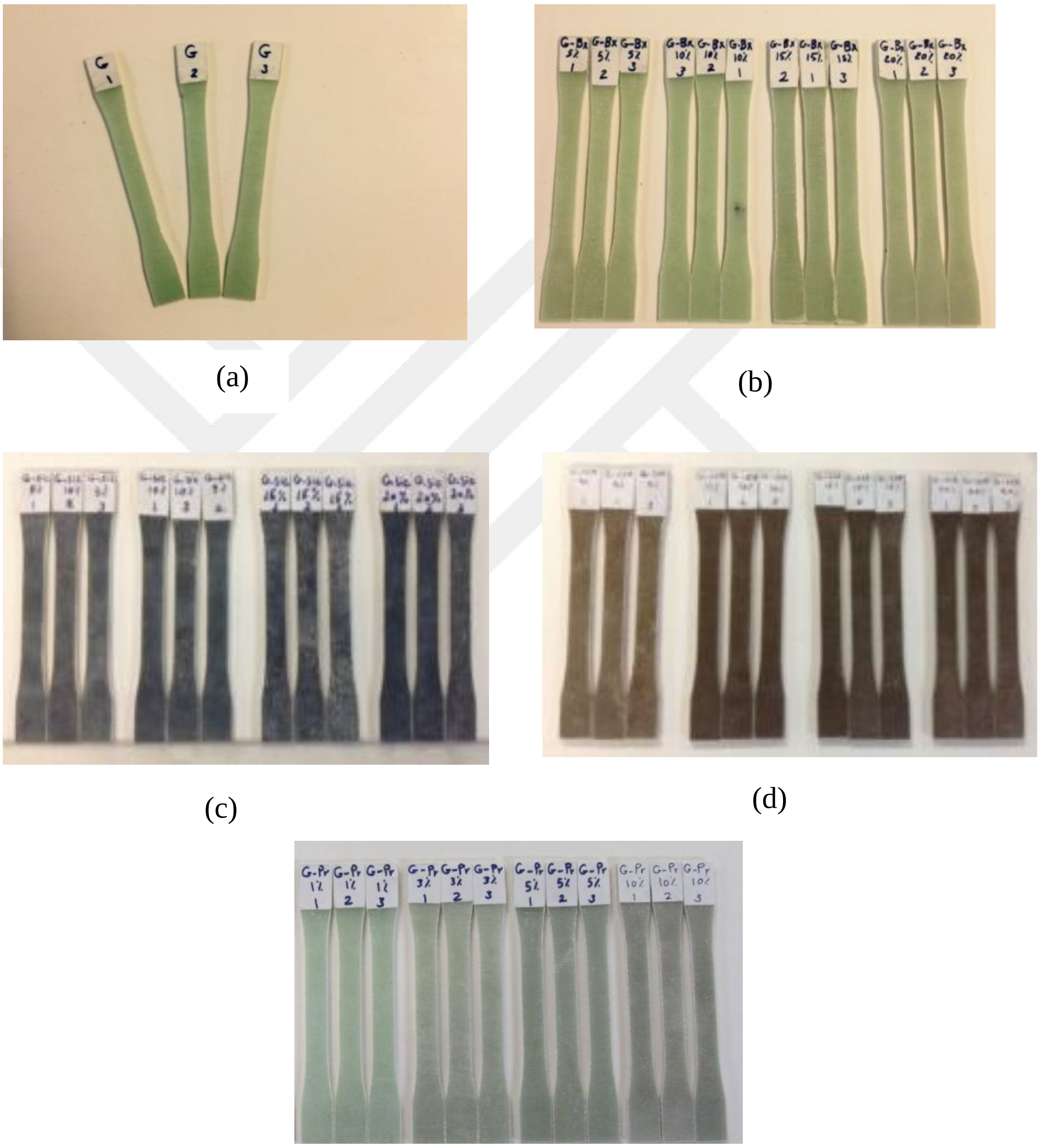
Figure 3.6 CNC Machine

(a) (b)

Figure 3.7 Fabricated Laminates a) Before Cutting b) After Cutting

3.3 Tensile Testing

Tensile properties of specimens are determined according to the ASTM D638–10 [76] standard test method. The generally used samples for tensile test are the dog-bone kind, generally performed on the straight side and flat type with end tabs. The produced tensile test specimens are shown in Figure 3.8. The thickness (T) of the specimens is between 2.96 and 4.05 mm.



(a) (b)

(c) (d)

(e)

Figure 3.8 Produced Tensile Test Specimens a) GE, b) GE-Bx, c) GE-SiC, d) GE-SSA, e) GE-Pr Composites

Type 1 configuration of ASTM 638-10 standard have been used considering specimen dimensions as length of narrow section 57 mm, width of narrow part section 13 mm, overall width 19 mm, gage length 50 mm, distance between grips 115 mm, overall length 165 mm, and radius of fillet 76 mm shown in Figure 3.9.

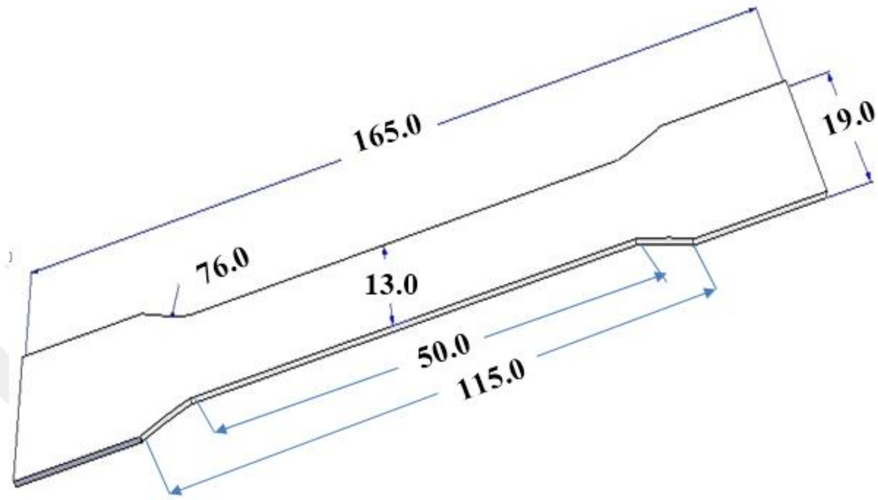


Figure 3.9 The Dimensions of Tensile Test Specimens

Mechanical properties of samples were obtained using Shimadzu AG-X series testing machine (Figure 3.10). Specimens were loaded in tension direction with the 2 mm/min speed up to failure. Then tensile strength were determined using the stress and strain data's obtained from the testing machine. The test was done for all (51) specimens.

Figure 3.10 Test set-up Shimadzu AG-X Series Testing Machine (Tensile Test)

3.4 Vibration Test

Vibration test specimens were prepared from the composite laminates using an experimental device as shown in Figure 3.11 and prepared specimens are given in Figure 3.12. Then dynamic characteristics of (51) specimens were determined. Manufactured test specimens were fixed in the frame having fixed-free boundary condition. The accelerometer was fixed on the surface of the test specimens near the fixed edge (Figure 3.13). Specimens were excited with a constant points. Both impact hammer and accelerometer were connected as an analog input to DAQ by connection cables. The dimensions of all the specimens were 185 mm × 12.7 mm as shown in Figure 3.13 and thickness of the specimens was between 2.96 and 4.05 mm.

LABVIEW software was run in order to plot FRF on monitor, then impact hammer was struck three times on the specimen for better excitation. FRF and time signal graph were plotted on a computer by using LABVIEW software and natural frequencies were plotted on the screen from FRF curves by the application of modal impact hammer.

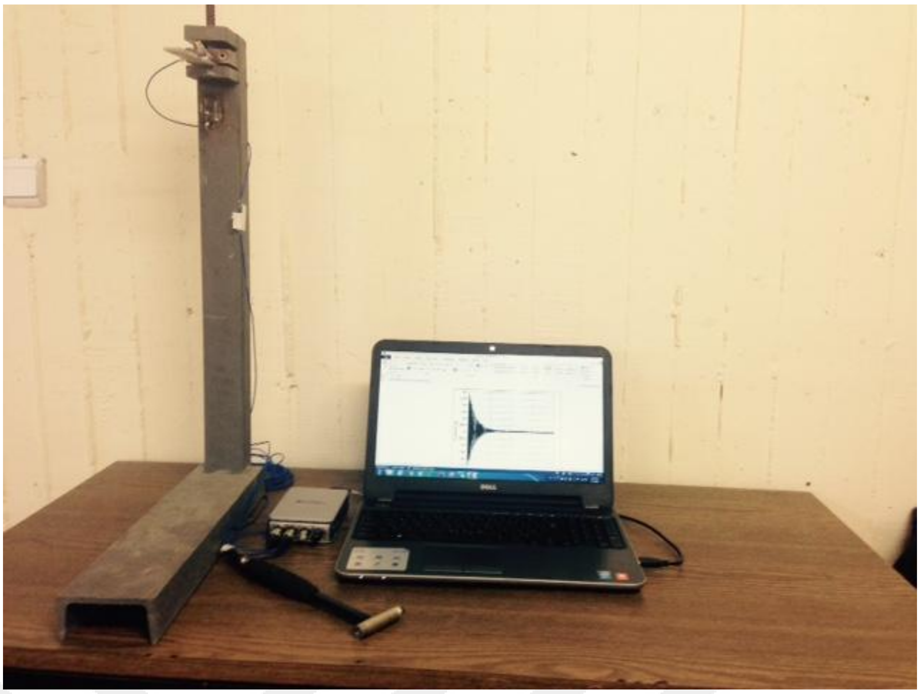
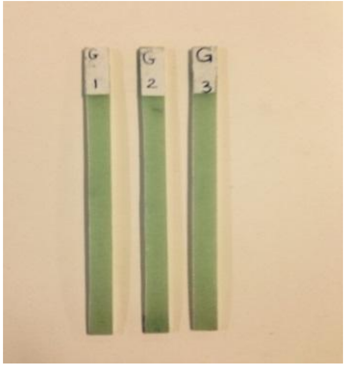
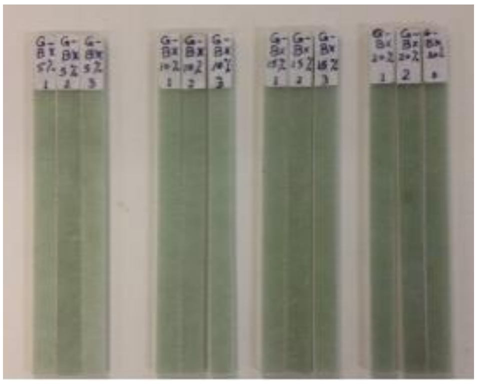


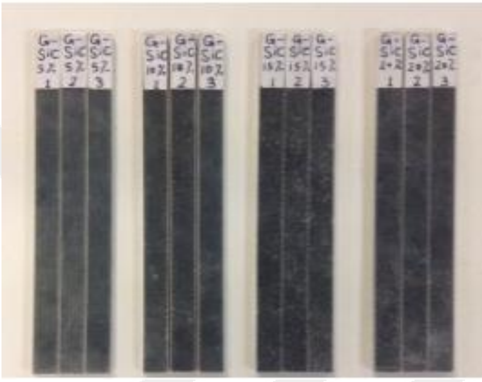
Figure 3.11 Vibration Experimental Device



(a)



(b)



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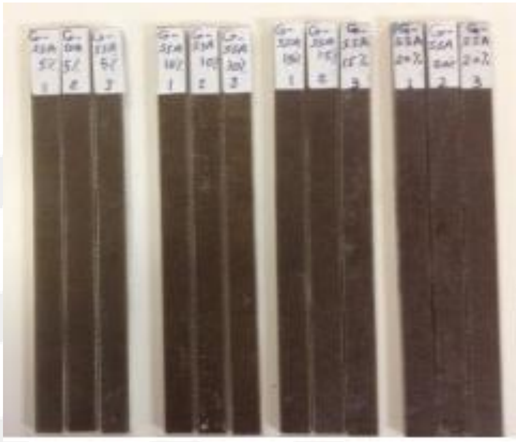

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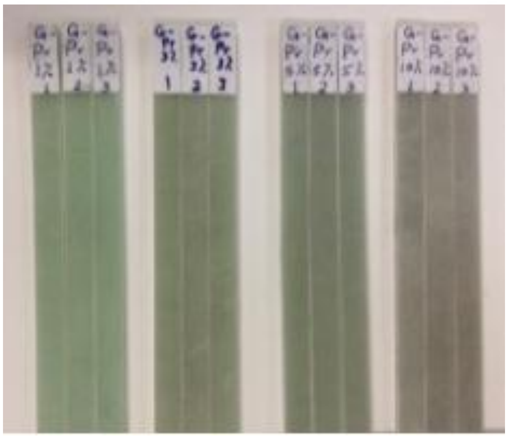


(e)

Figure 3.12 Vibration Test Specimens a) GE, b) GE-Bx, c) GE-SiC, d) GE-SSA, e) GE-Pr Composites

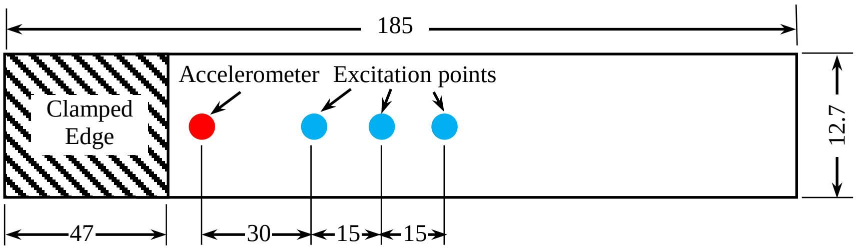


Figure 3.13 Vibration Test Specimen (All dimension are in mm)

The main dynamic properties of composites were determined (e.g. natural frequency (ω_n), damping ratio ξ, storage modulus Ē and loss modulus Ȅ). Time-dependent acceleration responses of the samples were measured by the application of an impact hammer. Accordingly, natural frequency responses were determined by the application of fast fourier transforms. Frequency responses were extracted within the constant frequency range from 0 Hz to 500Hz.

3.4.1 Damping Ratio

Half-power bandwidth method was used for determining the damping ratio. Maximum amplitude of first mode frequency was determined from the frequency response curve, then ω_1 and ω_2 frequencies corresponding to Z_1 and Z_2 points were found by dividing maximum amplitude value of first mode to the value of $\sqrt{2}$ as shown in Figure 3.14 [77].

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_n} \qquad (1)$$

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

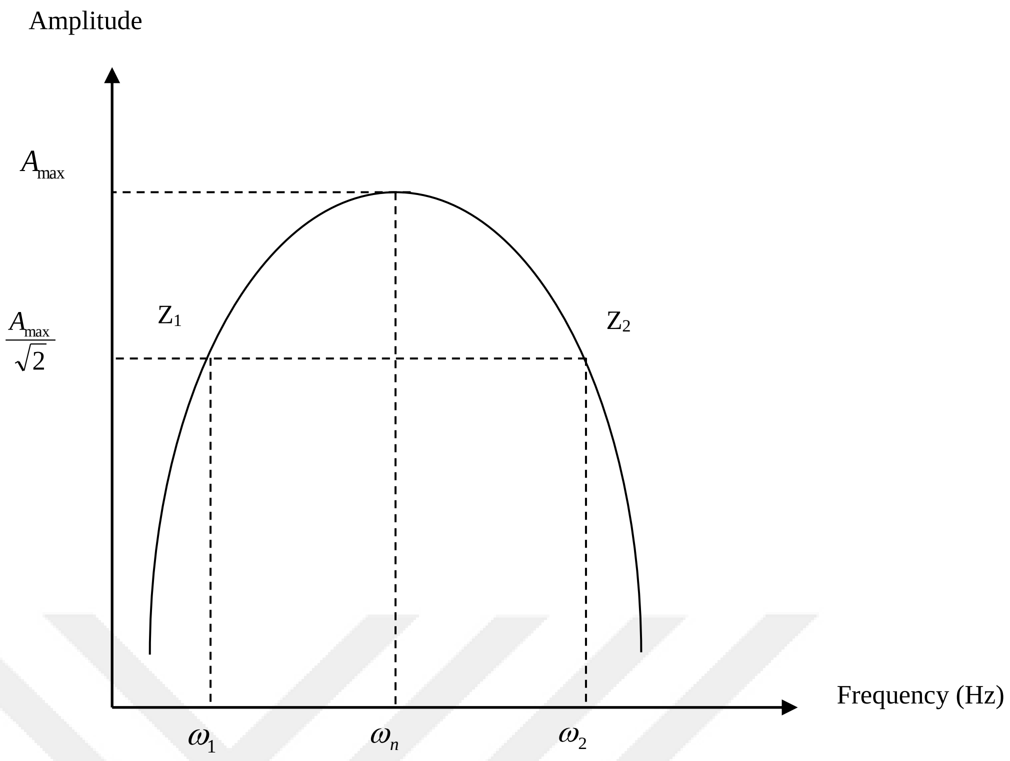


Figure 3.14 Half-Power Bandwidth Method [77]

3.4.2 Storage Modulus (E′)

In addition of damping ratio, material storage modulus can be obtained from Euler–Bernoulli beam theory as Eq. (2) [78].

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

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

3.4.3 Loss Modulus (Ē)

Loss modulus of the beam can be found using storage modulus. The relationship between loss and storage modulus is given in Eq. (3) [78].

$$E''(\omega) = 2E'(\omega)\xi(\omega) \quad (3)$$

3.5 The experimental Device

3.5.1 Accelerometer PCB 352C03

General purpose, PCB 352C03 ceramic shear ICP® accelerometer device was used for sensing vibration frequencies of the test the specimens once the excitation was begun by the application of impact hammer on the test specimens as shown in the Figure 3.15.

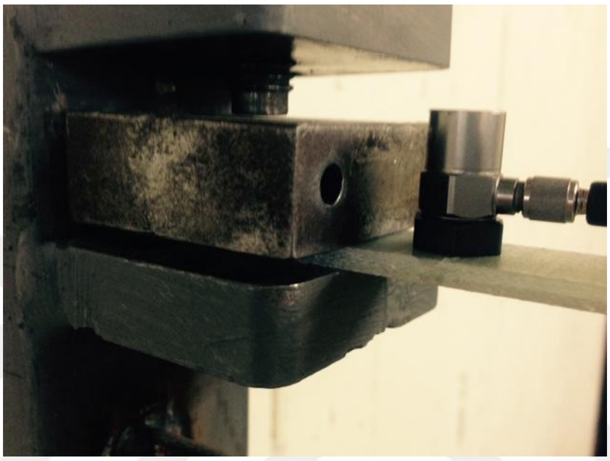


Figure 3.15 PCB 352C03 Ceramic Shear Accelerometer

3

3.5.2 Modal Impact Hammer PCB 086C03

PCB 086C03 general purpose modal impact hammer was used in order to provide stimulus input force signal to the plate for the excitation as seen in Figure 3.16. Variable impact hammer tips were used in order to better amplitude and band-width of excitation.

Figure 3.16 PCB 086C03 Modal Impact Hammer

3.5.3 Data Acquisition Card DAQ

The main function of the DAQ is to receive time varying data kept from accelerometer and impact hammer and convert it to the frequency based signals. National Instrument product NI 9234 data acquisition device was used for modal analysis testing as shown in Figure 3.17.

Figure 3.17 Data Acquisition Card (DAQ) Specific Functions of NI 9234 DAQ

CHAPTER 4

TENSILE TEST RESULTS

4.1 Density Results

Density of the samples was measured and listed in Table 4.1. The density of unfilled specimens is about 1722 (Kg/m^3). This is in agreement with previous studies [19, 24]. The results demonstrated that the addition of any type of filler at all particle ratio induces a decrease of the density, in comparison with those of the unfilled specimens. Same behavior is reported by some researchers [49, 50]. The results demonstrate that the density decreases not exactly linear with increasing filler addition in all type composites. Density of a composite depends on the relative proportion of matrix and reinforcing materials and this is one of the most important factors determining the properties of the composites. The void content is the cause for the difference between the values whereas here the voids content is negligible. The voids significantly affect some of the mechanical properties. The knowledge of void content is desirable for estimation of the quality of the composites. It is understandable that a good composite should have fewer voids. However, presence of void is unavoidable in composite making particularly through hand-lay-up route [6, 49].

Table 4.1 Density value of particulate filled fiber reinforced Polymer composites

Composites	**Particle ratio (wt. %)**	**Density (Kg/m^3)**	**Thickness (mm)**
GE	Unfilled	1721.994	2.99
GE-Bx	5	1664.697	3.30
	10	1667.127	3.37
	15	1617.876	3.60
	20	1628.540	3.76
GE-SiC	5	1663.078	3.35
	10	1645.628	3.49
	15	1546.814	3.98
	20	1691.460	3.72
GE-SSA	5	1592.083	3.74
	10	1632.435	3.60
	15	1632.122	3.70
	20	1661.900	3.90
GE-Pr	1	1632.231	3.47
	3	1616.639	3.56
	5	1619.730	3.60
	10	1616.435	3.66

4.2 Tensile Strength Results

The results obtained from the experimental work of the tensile testing for different particle modified fiber reinforced Polymer matrix composite materials are given in the Table 4.2. Figures 4.1-4.4 represent tensile stress strain curves of GE-Bx, GE-SiC, GE-SSA, and GE-Pr composites. The results showed that the tensile strengths of composites significantly influenced by the type and content of filler.

It was demonstrated from the experimental results that the tensile strength for glass/epoxy composite was about 389.05 MPa. This is in agreement with previous studies [79, 80].

Table 4.2 Tensile properties for GE-Bx, GE-SiC, GE-SSA, GE-Pr

Composite	Particle ratio (wt. %)	Max.tensile stress (MPa)	Max. tensile strain
GE	unfilled	389.05	0.0229
GE-Bx	5	418.18	0.0264
	10	430.07	0.0272
	15	401.34	0.0280
	20	394.35	0.0263
GE-SiC	5	373.47	0.0211
	10	394.86	0.0218
	15	354.36	0.0239
	20	343.78	0.0223
GE-SSA	5	391.11	0.0245
	10	422.10	0.0271
	15	386.58	0.0259
	20	370.35	0.0218
GE-Pr	1	443.07	0.0261
	3	432.19	0.0240
	5	413.14	0.0231
	10	379.01	0.0213

It is found that the presence of Bx enhances tensile strength for all ratios used (as seen Figure 4.1). Tensile strength were increased from (0 to 10 wt.%) of Bx content, whereas further increasing in Bx content caused to the decreasing the value of tensile strength. This was because of the filler particles act as a barrier in transferring stresses from one point to another, and an increase beyond 10 wt.% in Bx content caused to increasing of transfer of stresses from one point to another. Also bonding surface area increases as the fiber/filler content increases, and hence bonding strength was decreased. Due to insufficient amount of bonding between three different constituents (fiber, filler epoxy), the loads may not effectively be transferred from one end to another and hence there is reduction in tensile strength of the composite specimens. Same behavior is reported by some researchers [62, 63, 64, 81] The maximum improvement occurred at 10 wt. % of Bx particle, that tensile strength reached to 430.07 MPa, which results in increase of tensile strength by 10.5% according to unfilled composite.

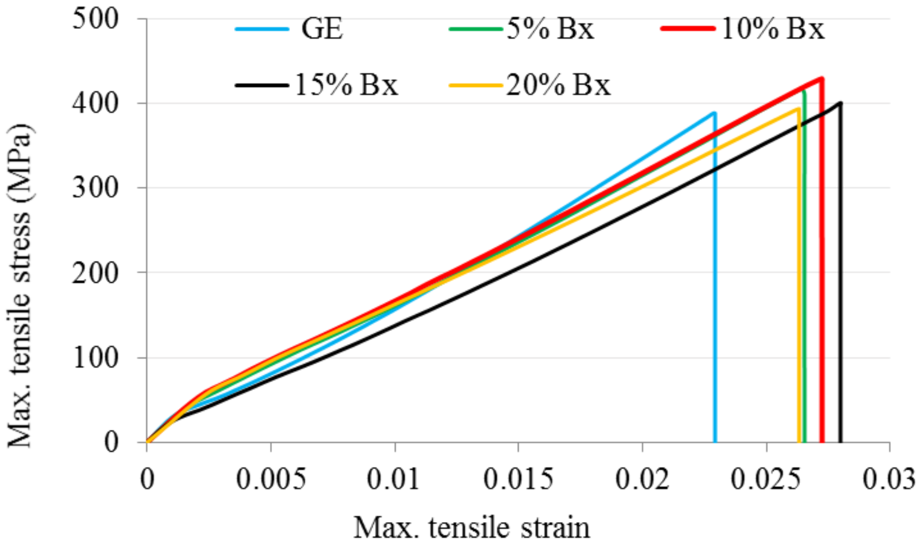


Figure 4.1 Tensile Stress–Strain Curves for GE-Bx

The inclusion of Pr showed maximum tensile strength at 1wt.%, and reached to 443.07 MPa, which increased by 13.8% (from Figure 4.2). There can be two reasons for the increasing trend in the strength of these hybrid Composites compared to the unfilled GE. One possibility was that the chemical reaction at the interface between the filler particles and the matrix may be too strong to transfer the tensile stress; the other was that the porous shape of particles and due to the size reduction (<35 μm) resulted in less stress concentration in the polymer matrix [82] but it is seen the tensile strength stated trend to decreases with increase in filler content.

There was negatively effect in tensile strength of composites with addition of SSA and SiC particles except 10 wt% addition (shown in Figure 4.3-4.4). Tensile strength increased by 1% and 8.4 % from GE to GE-SiC and GE-SSA respectively. Mechanical properties of the filler reinforced composites are mainly influenced by the interfacial adhesion between the fillers and the matrix polymer. The decrease in the tensile strength of SiC and SSA filled composites may be due to the improper bonding resulting in poor interface adhesion between the filler and resin. The corner points of irregular shapes of SiC may produce stress concentration in the composites [83]. It found reduction in tensile strengths for all ratios for GE-SSA with exception 10wt% for GE-SSA composites a positive particulate effect exists at 10 wt. % when tensile strength reached to 422.10 MPa and increased by 8.4 %.

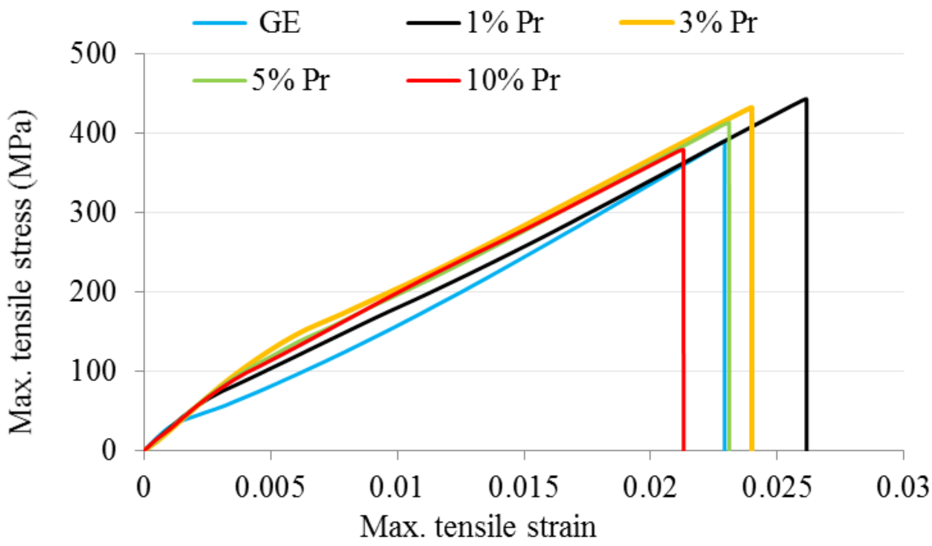


Figure 4.2 Tensile stress–strain curves for GE-Pr

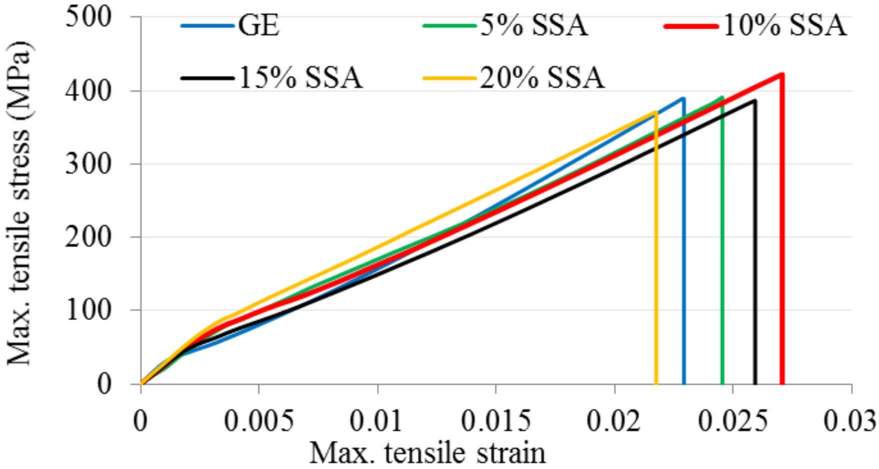


Figure 4.3 Tensile Stress–Strain Curves for GE-SSA

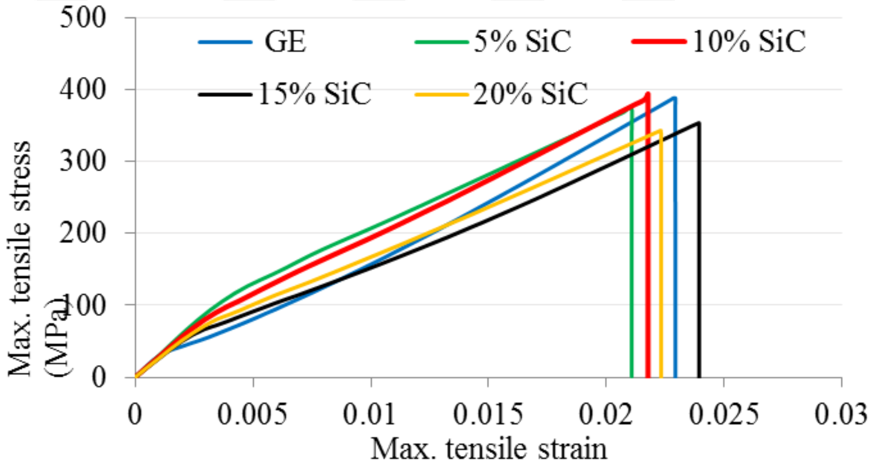


Figure 4.4 Tensile stress–strain curves for GE-SiC

Comparison of maximum tensile strength values of particle ratios is shown in Figure 4.5. The lowest tensile strength was showed at 20 wt% among all ratio for fillers type where the values were as follows for Bx, SSA, SiC 394.35 MPa, 370.35 MPa, and 343.78 MPa respectively whereas at 10 wt% of Pr . The decrease in the tensile properties at high wt% of filler may be due to the improper bonding resulting in poor interface adhesion between the filler and the epoxy resin matrix [56]. High filler content leads to difficulty in stirring process and hence uniform distribution of filler in the laminate cannot be ensured.

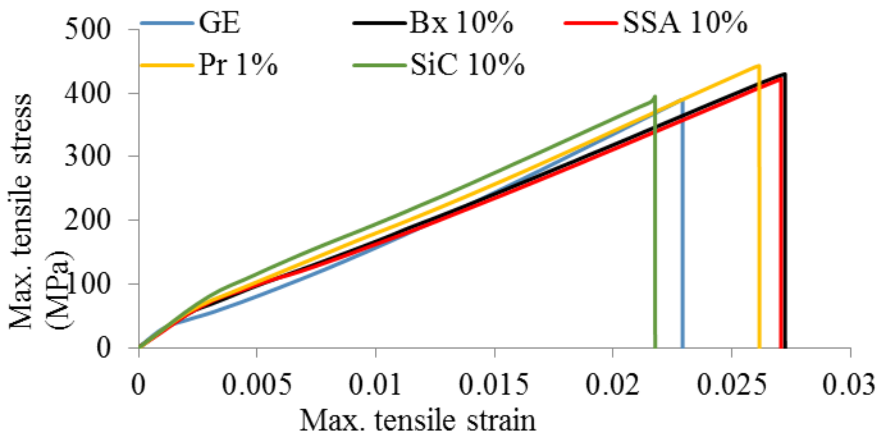


Figure 4.5 Comparison of Maximum Tensile Strength for GE-Bx, GE-SiC, GE-SSA and GE-Pr

For failure strain, generally, an increasing trend was observed for all fillers and all ratios. However resulting minimum value was recorded at particle content (20 wt.% of Bx, SSA and 10 wt.% of Pr) with the exception of GE-Sic, which had the lowest value at SiC content of 5 wt.%, it is also larger than specimens without particles. That's indicating a ductile property due to adding fillers. The increase of elongation at break values of the composite with filler content could be explained to the elastic properties of the composite depend on the polymer matrix, which show ductile behaviors in the presence of the fillers. This is due to the fact that these fillers restrict mobility of the polymer chain.

4.2 Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) micrographs of the fractured surface for the tensile specimens are shown in Figures 4.6. The fractured surface of the tensile specimen (Figure 4.6 a) were flat without any necking, which indicated that specimens were failed in a brittle way. Besides, there was no noticeable permanent decreasing in samples' cross sectional area. Therefore, all composites specimens show a brittle behavior when they were tested. In addition, SEM image for unfilled composite (Figure 4.6 b) showed the pulled from matrix and broken fibers. The fractured surface of the composite specimens (Figure4.6 c to f) were taken at maximum strength i.e. (c) GE-10 wt% Bx, (d) GE-10 wt% SiC, (e) GE-10 wt% SSA, (f) GE-1 wt% Pr composites. These images observed the glass fibers are exposed from matrix, however the fibers are adhered to the matrix (Figure d, e) fibers are pulled out from the fracture surface and this improve the damage features and prove that micro-cracking occurs within the plies in the matrix around the particles [84]. These micro-cracks interact with the adjacent particles, growing through and around them. Furthermore, the particles act to bridge the micro-cracks, which form during fracture within the plies. These particle bridging may absorb significant energy dissipated prior to main failure in the subsequent particles deformation by plastic deformation, leading to increased fracture strength of particulate -filled polymer composites [84, 85].

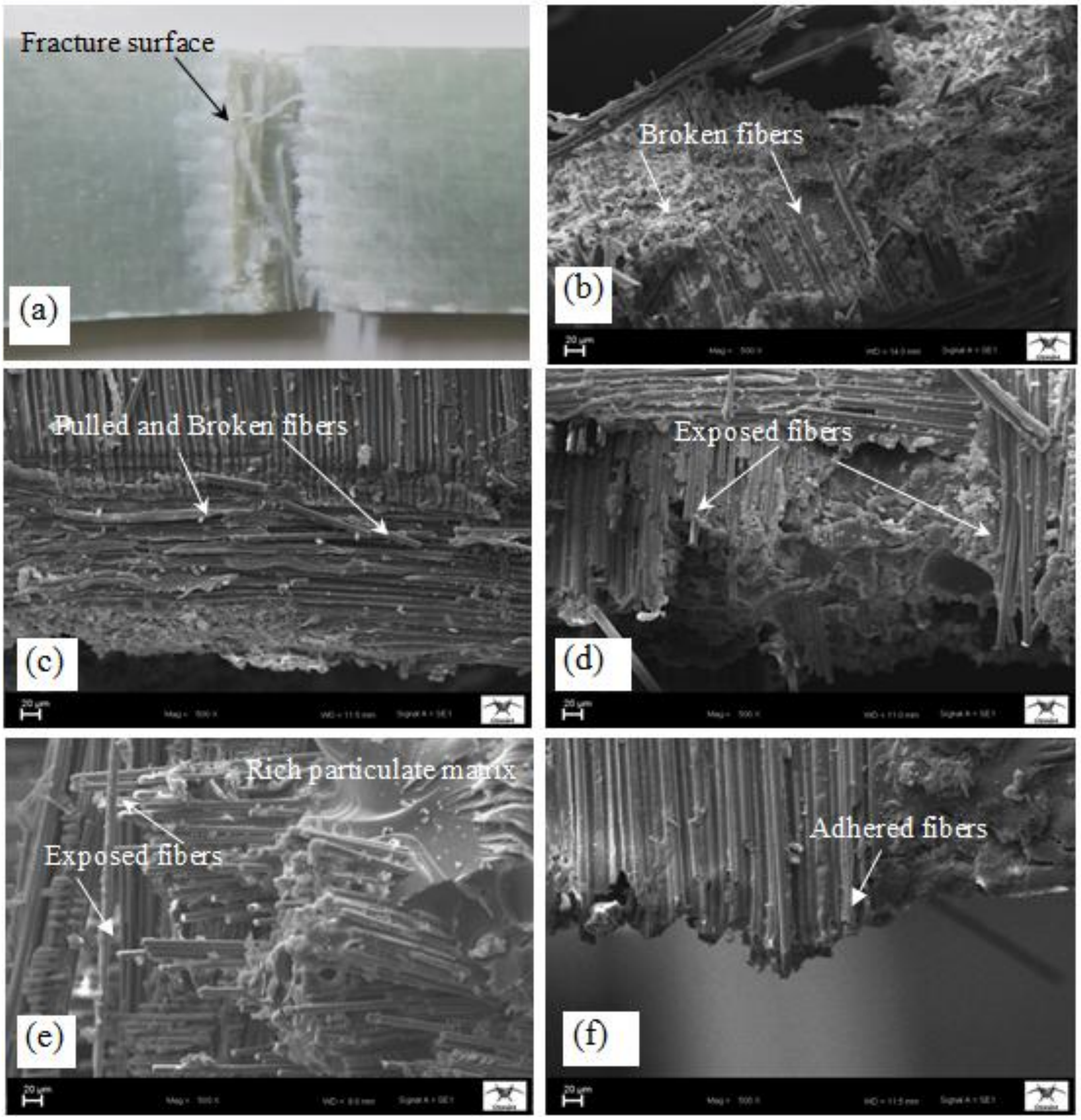


Figure 4.6 SEM photos of fracture surface for the tensile specimens have maximum strength (a) specimen's fracture surface, (b) GE (c) GE-Bx, (d) GE-SiC, (e) GE-SSA, (f) GE-Pr.

CHAPTER 5

VIBRATION TEST RESULTS

5.1 Introduction

Dynamic behavior of composites is very important when they are used in primary applications. However the research on effect of filler materials on Dynamic behavior is still at its beginning. Vibrations are undesirable for structures. Vibration reduction can be attained by increasing the damping capacity (loss of energy) and/or increasing the stiffness (storage modulus) owing to the need for structural stability [71].

5.2 Natural Frequency and Damping Ratio

The variation of first mode natural frequency and damping ratios of composites laminates for all particle ratios is given in Table 5.1 and frequency responses were illustrated in Figure 5.1. As shown in the Table 5.1 natural frequency recorded for glass/epoxy specimens is 87.04 (Hz). This values was increased with increase the filler content of all types of filler at all particle ratio, this is in agreement with previous studies [35, 69, 71, 87]. Also the results show that natural frequency increase in strength of composites indicates the trend of increase in the natural frequency [86]. Also, particles are positively affecting the damping ratios of composites.

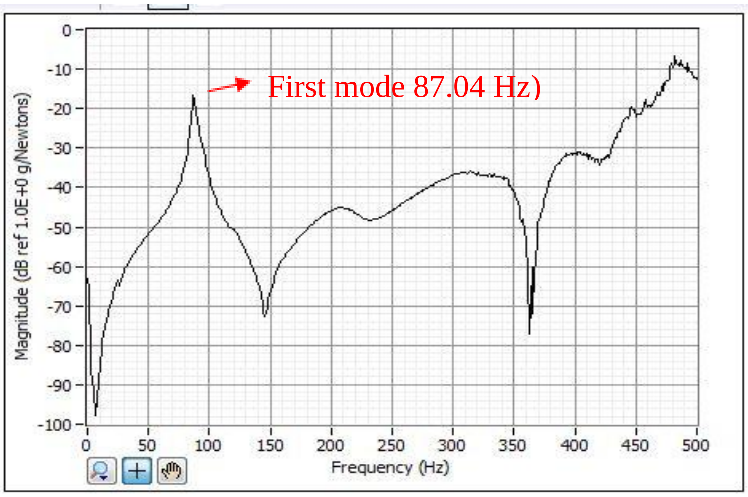


Figure 5.1 a Frequency Response of GE Composite

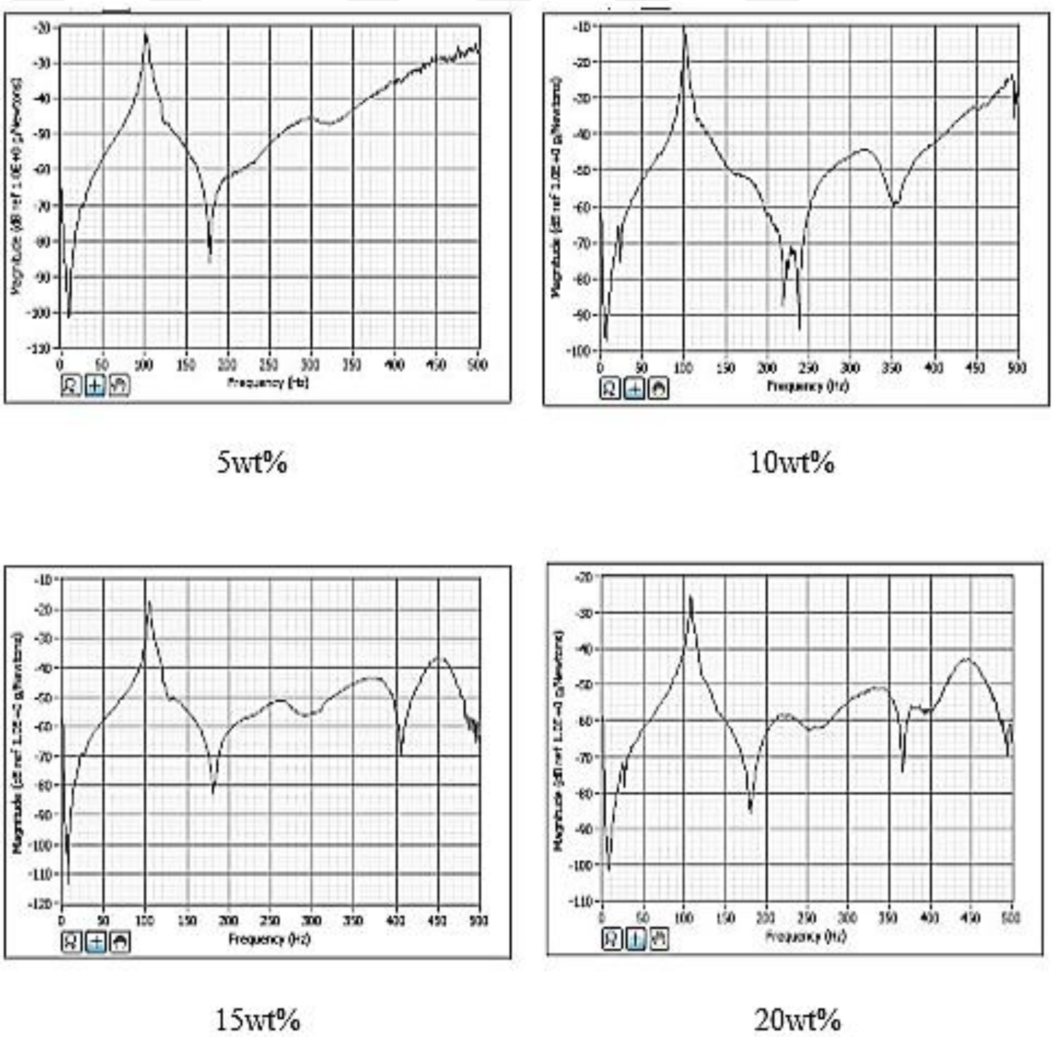
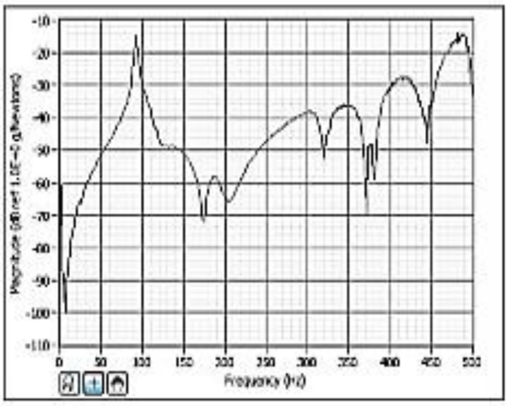
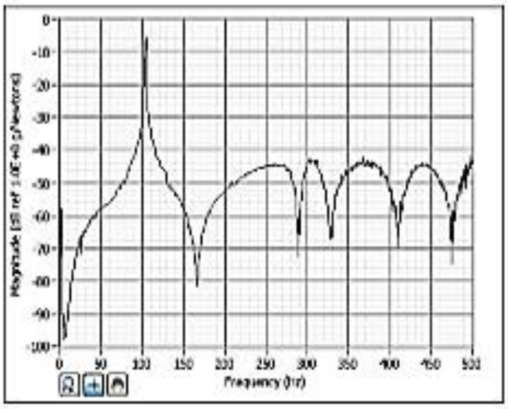


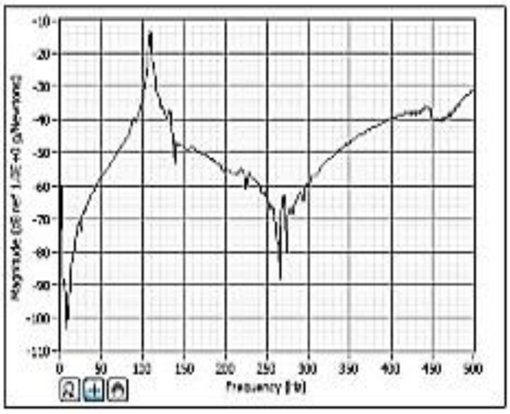
Figure 5.1 b Frequency Response of GE-Bx Composite



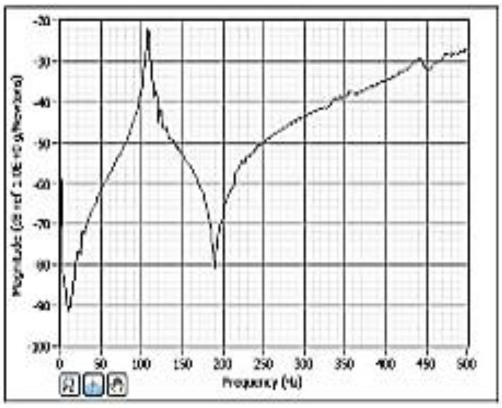
5wt%



10wt%

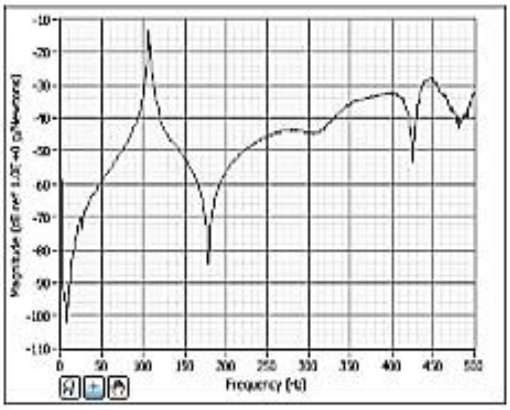


15wt%

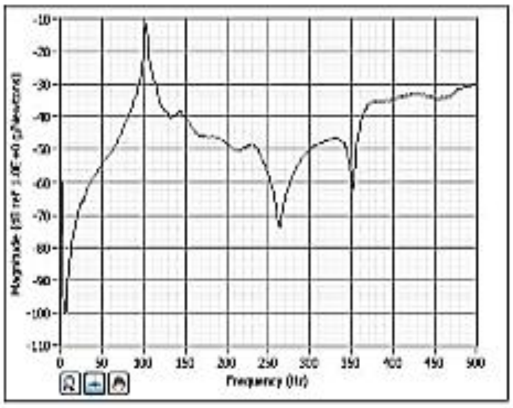


20wt%

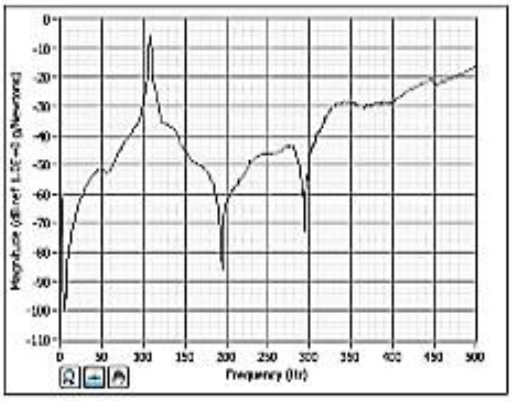
Figure 5.1 c Frequency Response of GE-SiC Composite



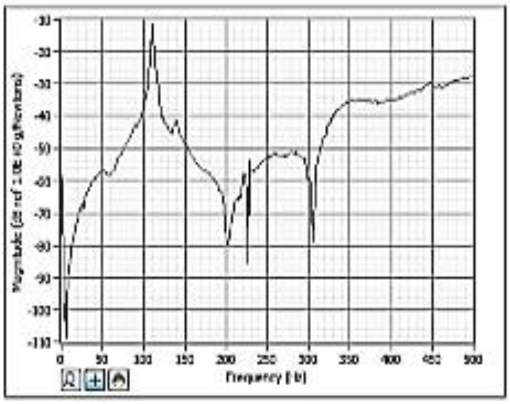
5wt%



10wt%



15wt%



20wt%

Figure 5.1 d Frequency Response of GE-SSA Composite

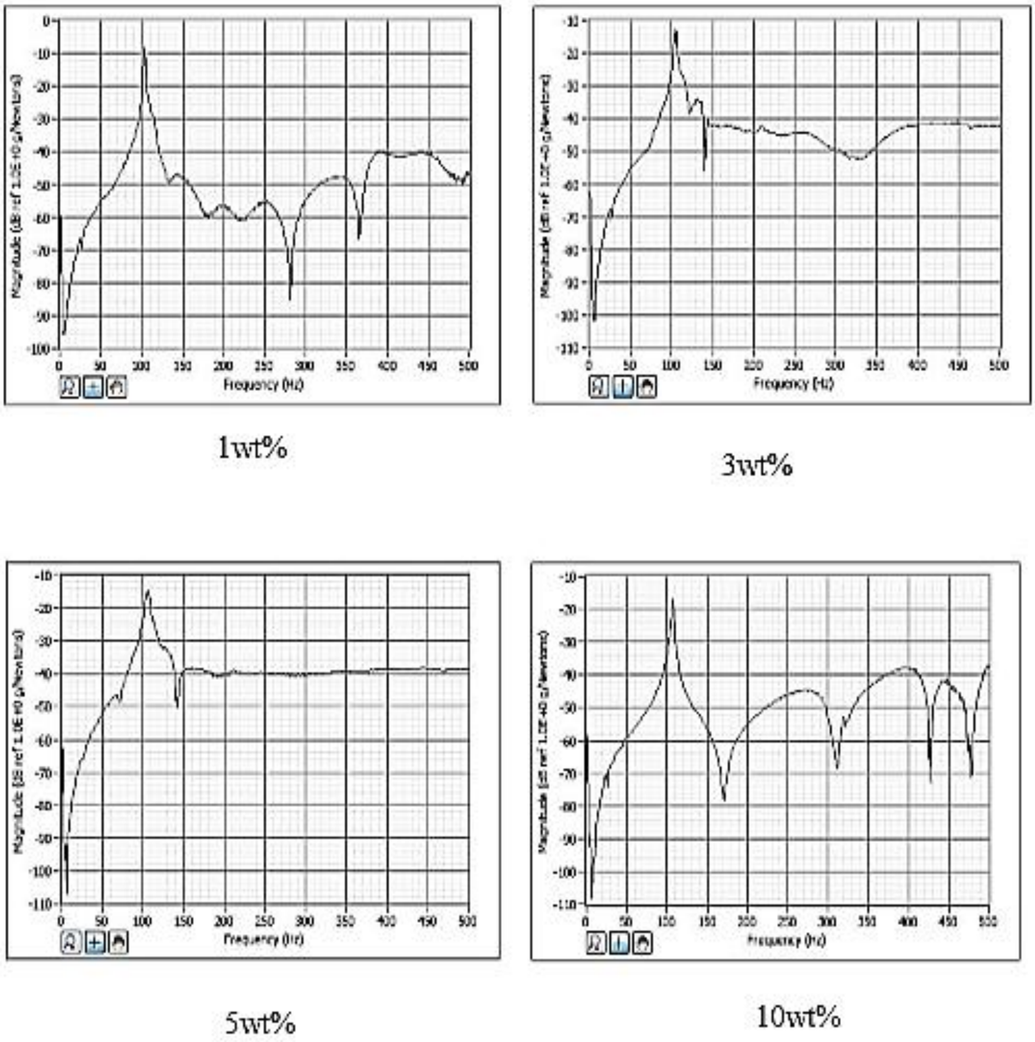


Figure 5.1 e Frequency Response of GE-Pr Composite

Figure 5.1 Frequency Response of a) GE, b) GE-Bx, c) GE-SiC , d) GE-SSA and e) GE-Pr Composites.

Table 5.1 Natural Frequency and Damping Ratio for GE-Bx, GE-SiC, GE-SSA, GE-Pr Composites

Composite	Particle ratio (wt.%)	First mode of natural frequency (Hz)	Damping ratio
GE	Unfilled	87.04	0.276
GE-Bx	5	102.40	0.355
	10	102.78	0.299
	15	104.45	0.216
	20	107.52	0.271
GE-SiC	5	92.16	0.300
	10	104.45	0.103
	15	108.54	0.245
	20	107.52	0.290
GE-SSA	5	106.5	0.202
	10	102.40	0.405
	15	107.52	0.262
	20	110.59	0.167
GE-Pr	1	103.42	0.183
	3	104.45	0.309
	5	105.47	0.330
	10	107.52	0.200

The Figure 5.2 represents natural frequency response of (GE-Bx, GE-SiC, and GE-SSA) composite specimens and Figure 5.3 represent natural frequency response of GE-Pr composite. When particle is added to the composite, natural frequency is sharply increased and getting stable form. The highest natural frequencies were recorded as 107.52 Hz, 108.55 Hz, 110.592 and 107.52 Hz at particle content 20 wt.% for GE-Bx, GE-SiC, GE-SSA filler types (but at 10 wt.% for GE-Pr) with increment of 23.5%, 24.7%, 27.0% and 23.5%, respectively.

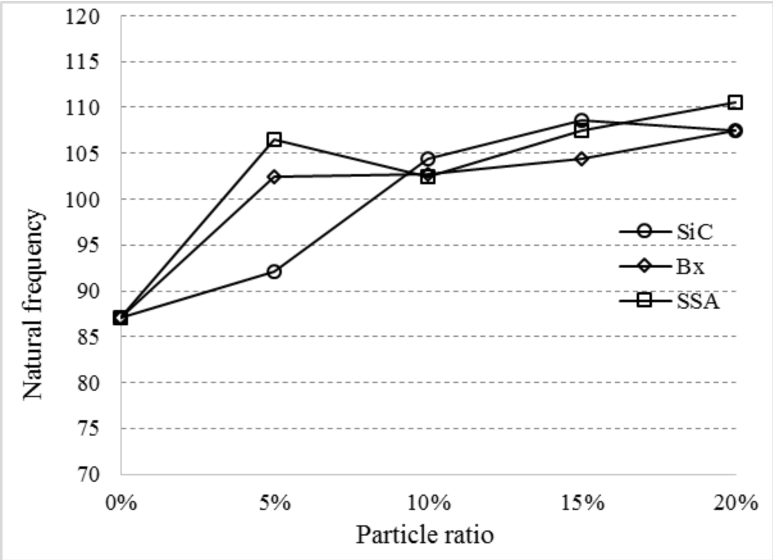


Figure 5.2 Natural frequency response graph for GE-Bx, GE-SiC, GE-SSA composite

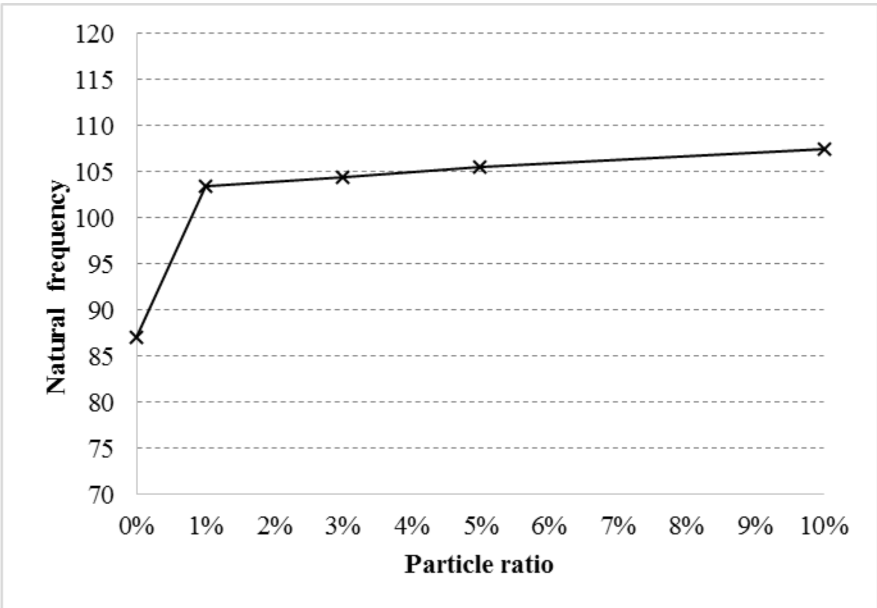


Figure 5.3 Natural Frequency Response Graph for GE-Pr composite

Figure 5.4 shows comparison of the highest natural frequencies for composites. As a result of, the addition of particle is nearly same affecting the first mode natural frequency of S-glass/epoxy composite. So, particle type didn't effecting the first mode natural frequency of the composites.

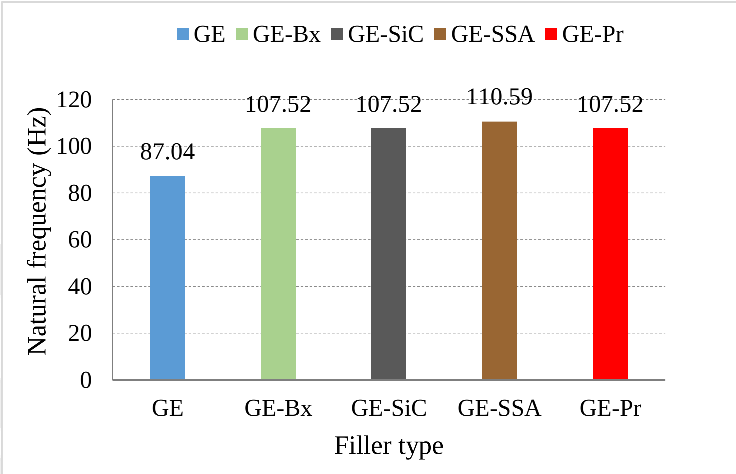


Figure 5.4 Comparison of Maximum Natural Frequencies at high filler content

5.3 Damping Ratio

Damping ratio of composite samples were determined using half-power bandwidth method (Eq. 3.1). The damping ratios of composite laminates for all particle ratios is given in Table 5.1 and illustrated in Figure 5.5 (a, b, c, d) for GE-Bx, GE-SiC, GE-SSA and GE-Pr respectively. The damping ratio was obtained from glass/epoxy is nearly equal to 0.27647. Damping ratio of the particulate filled fiber reinforced Polymer matrix composite is dependent to the interfacial interactions of polymer/filler system [77]. There were both increasing and decreasing reports of damping for particulate filled fiber specimens. Same behavior was reported by [69, 71]. With addition of 10 wt.% of SSA, damping was increased by 46.5%. For other filler types the maximum damping ratio was observed at particle content of 5 wt.% as 0.355 (28.6%), 0.3(8.69%), 0.33(19.5%) for GE-Bx , GE-SiC , GE-Pr fillers type respectively. The Figure 5.6 shows comparison of damping ratios for particle contents (5 wt.% of GE-Bx, GE-SiC, GE-Pr and 10 wt.% GE-SSA). The highest damping ratio was obtained from 10 wt% addition of SSA to the composite. This can be explained by the content of the SSA which has different metallic parts.

Time decaying graph of material were plotted on a computer by using LABVIEW software as shown in figures 5.7-5.11 for G, GE-Bx , GE-SiC ,GE-SSA and GE-Pr respectively.

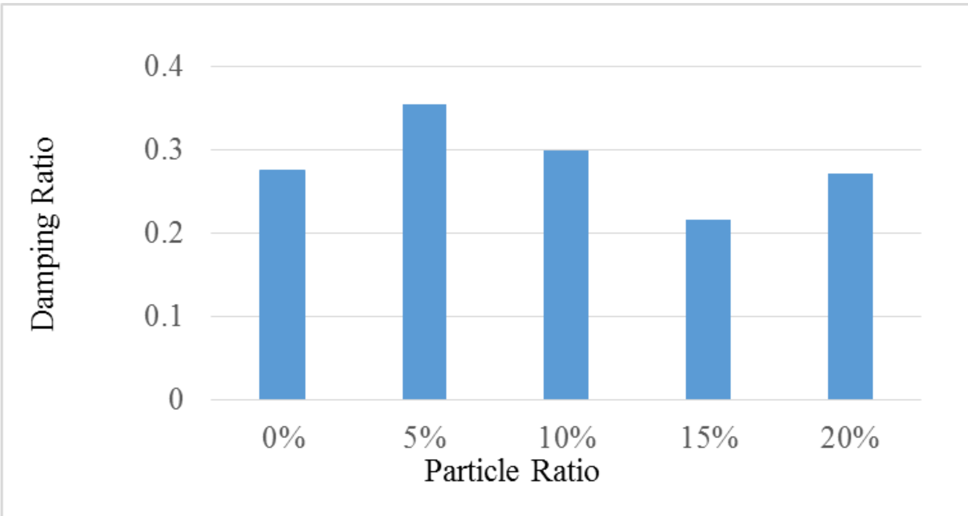
Damping properties were determined from the time decaying curves using the logarithmic decrement method [22].

Overlay there are:

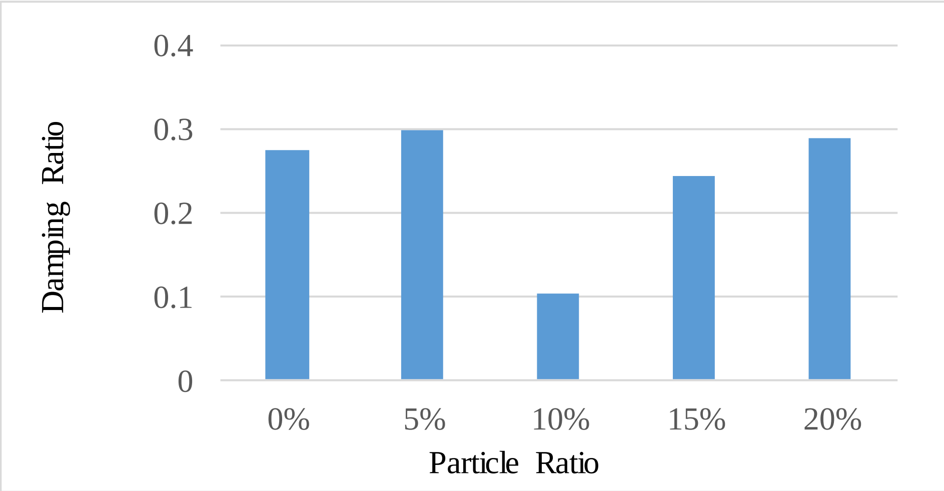
- Critically damped response $\xi = 1$ it is the case that provides the fastest return to the equilibrium position without oscillation

- Over damped response $\xi > 1$ here he larger damping leads to quicker energy dissipation and does not allow the system to vibrate.

- Under damped response $0 < \xi < 1$ it can be seen that the amplitude of the vibration decays over time. This case like our work



(a)



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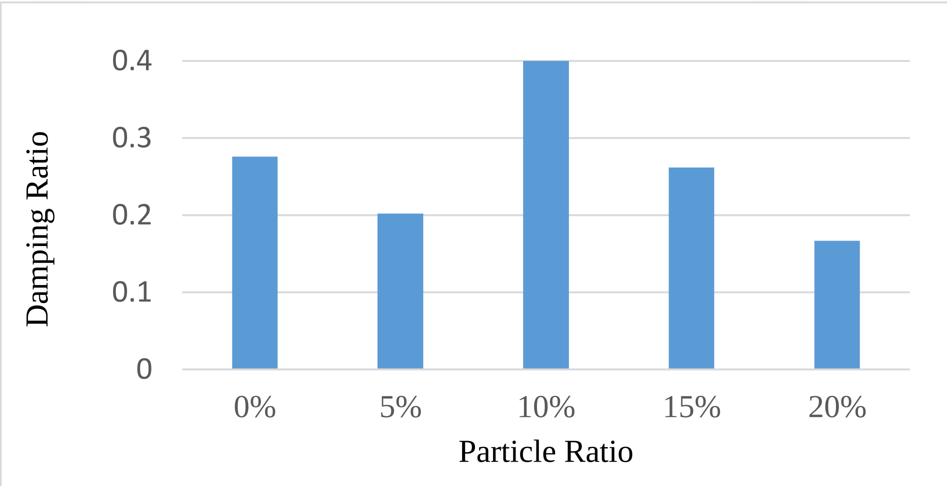
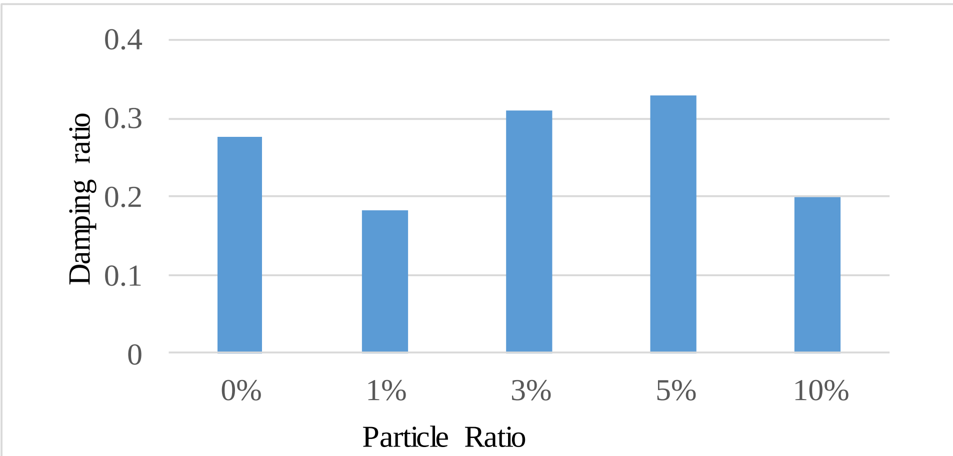


(c)



(d)

Figure 5.5 Damping Ratio of a) GE-Bx, b) GE-SiC, c) GE-SSA and d) GE-Pr Composites

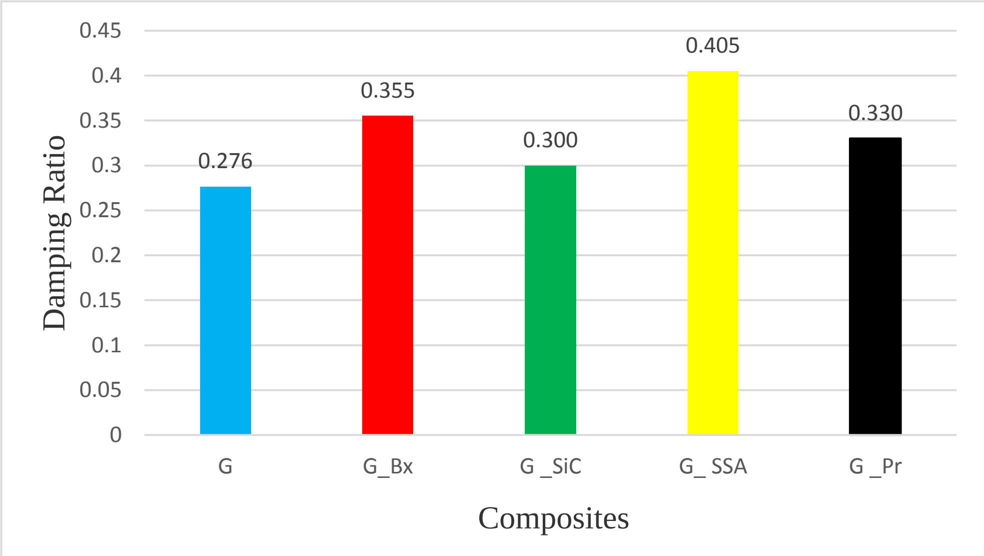


Figure 5.6 Comparison Damping Ratio at (5 wt.% GE-Bx, GE-SiC, GE-Pr and 10 wt.% GE-SSA) Composites

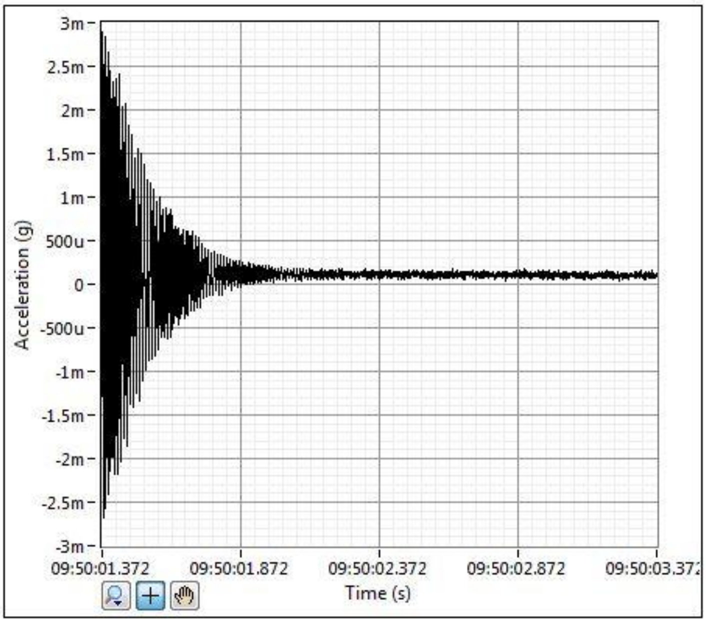
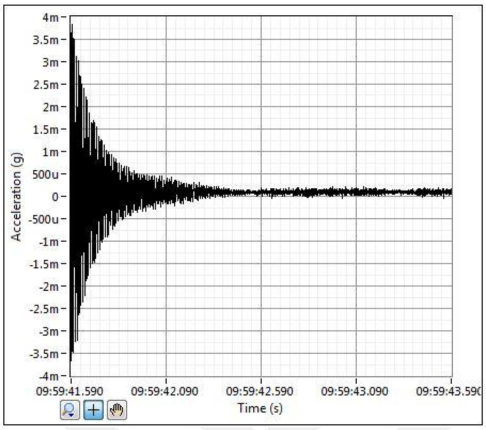
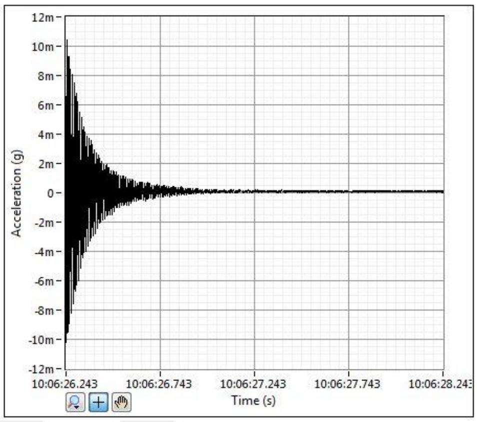


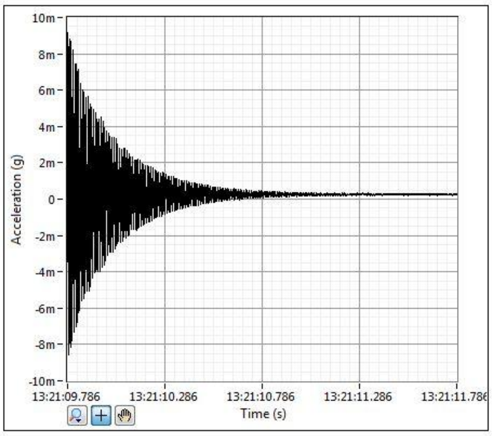
Figure 5.7 Time Decaying Graph for GE Composites



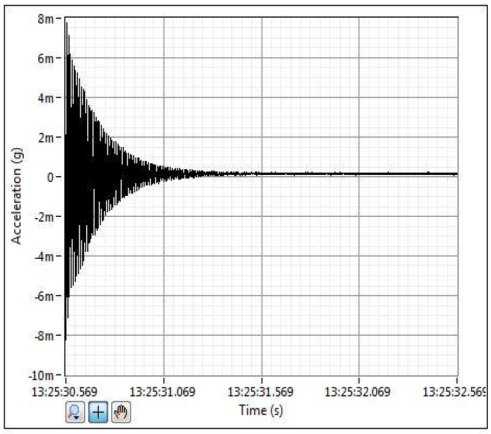
5wt%



10wt%

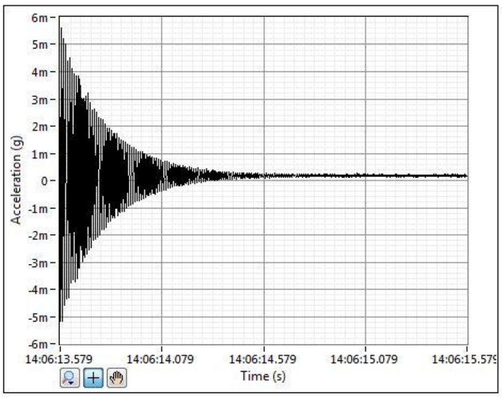


15wt%

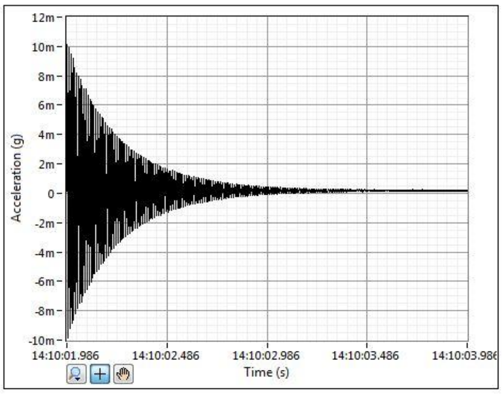


20wt%

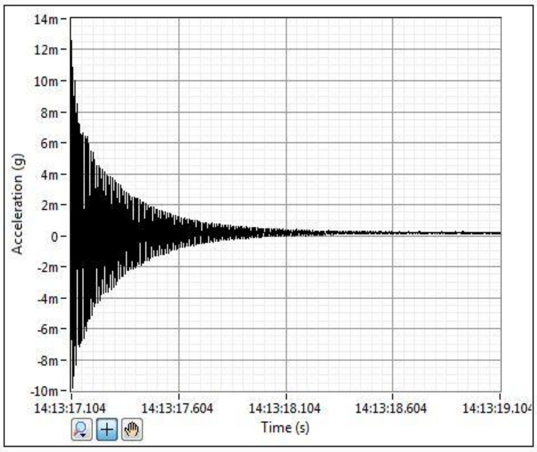
Figure 5.8 Time Decaying Graph for GE-Bx Composite



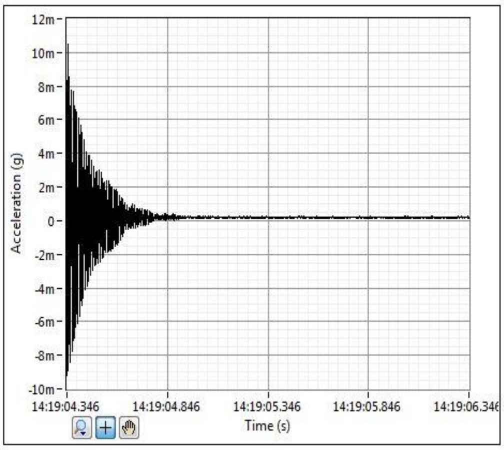
5wt%



10 wt%

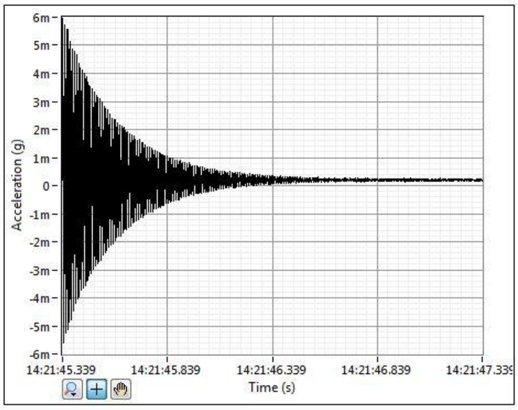


15wt%

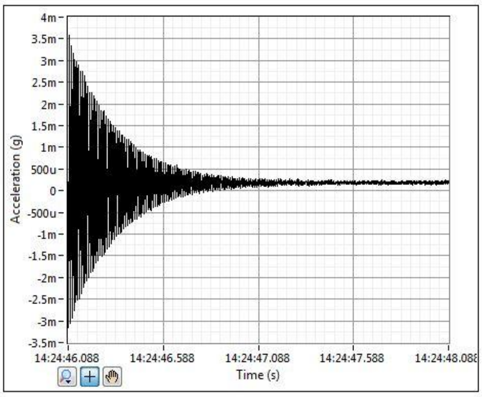


20 wt%

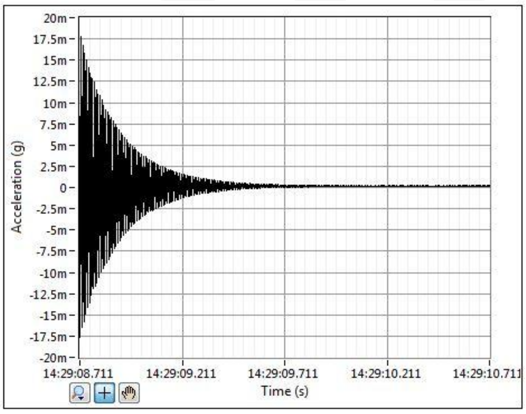
Figure 5.9 Time Decaying Graph for GE-SiC Composite



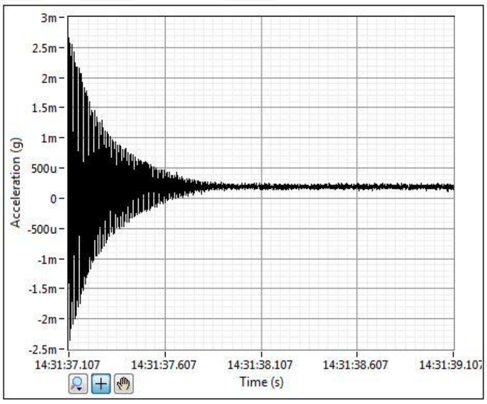
5wt%



10wt%

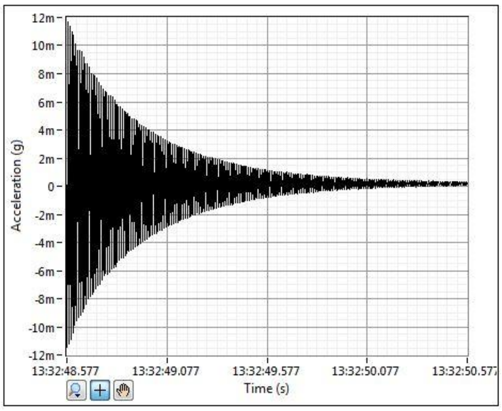


15wt%

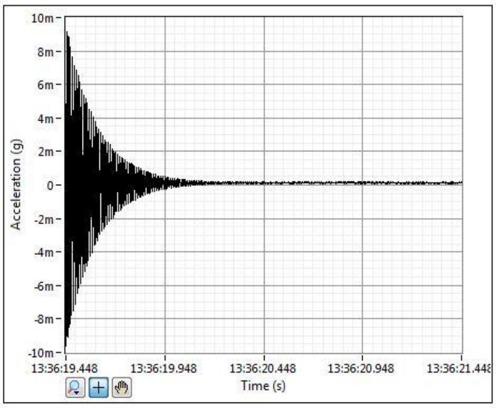


20wt%

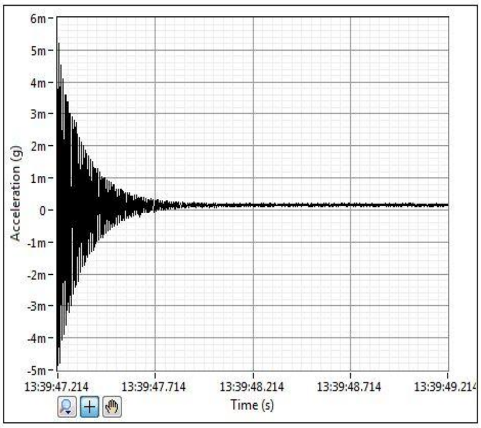
Figure 5.10 Time Decaying Graph for GE-SSA Composite



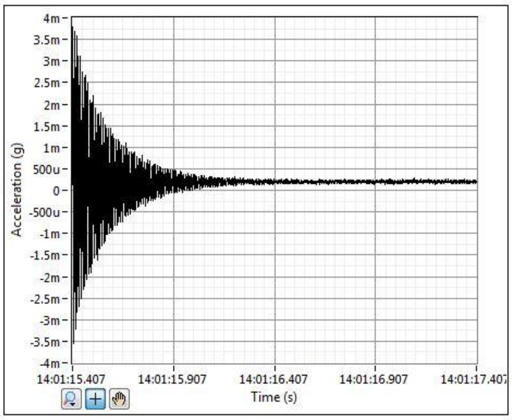
5wt%



10wt%



15wt%



20wt%

Figure 5.11 Time Decaying Graph for GE-Pr Composite

5.4 Storage Modulus

Storage modulus, (elastic response) is a measure of the energy stored during a cycle, which is an inherent property of the material [70, 88].

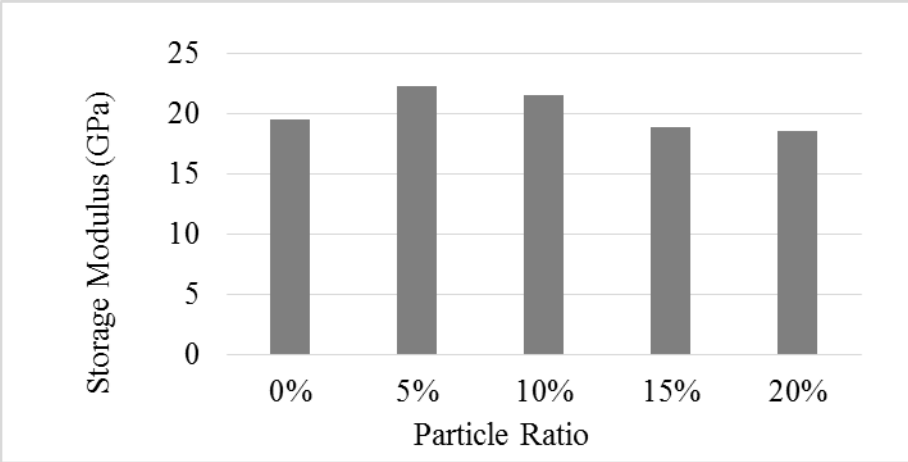
We need to calculate storage modulus because high storage modulus lead to enhance the ability to absorb energy before failure. Storage modulus is indicators of energy absorbing of material [89].

In order to figure out the damping properties of particle filled composite laminates, loss and storage modulus of all composite laminates were identified using dynamic modal analysis (via. Eq.3.2) as given in Table 5.2. As shown in the table there are both increasing and decreasing results. The storage modulus reported the improvement with addition higher than the reference samples about 14.1 % at 5 wt.%, 5.2 % at 10 wt.%, 1.48 % and 3.2 at 1 wt.% for Bx, SiC and Pr respectively.

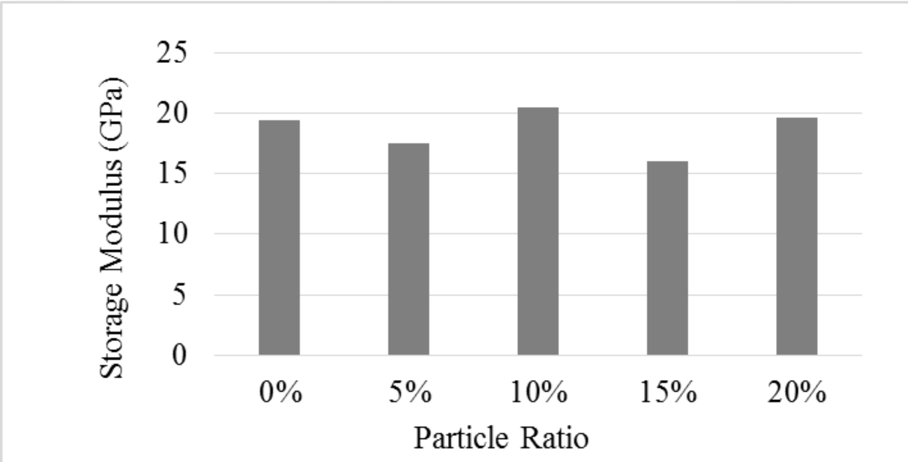
It can be attributed to the good dispersion and interaction between the micro fillers and the polymer matrix [68] while negative effect occur with SSA for for all particle ratios. The storage modulus of baseline sample (glass fibre composites with no particle inclusions) was nearly equal to 19.47 GPa as shown in Table 5.2 This is in agreement with previous study [78]. The storage modulus of composites laminates for all particle ratios is given in Table 5.2 and were illustrated in figure 5.12 (a, b, c, d) for GE-Bx , GE-SiC ,GE-SSA and GE-Pr respectively.

Table 5.2 Storage Modulus and Loss Modulus for GE-Bx, GE-SiC, GE-SSA, GE-Pr Composites

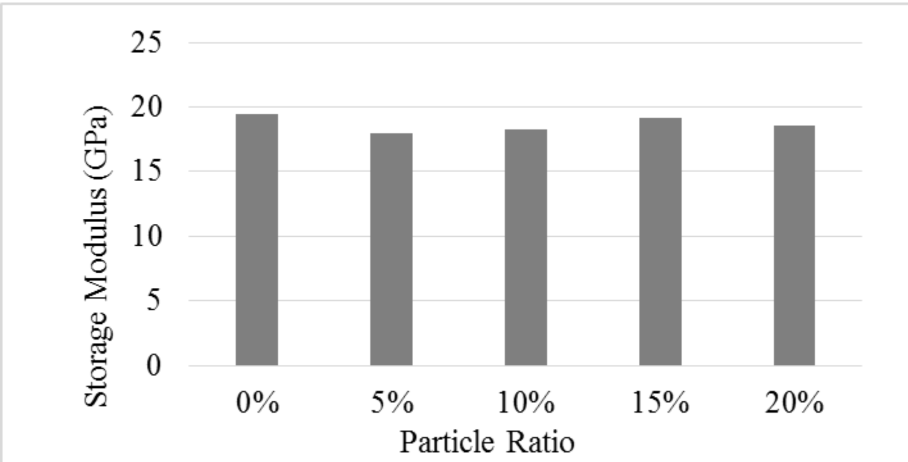
Composites	**Particle ratio (wt.%)**	**Storage modulus (GPa)**	**Loss modulus (GPa)**
GE	unfilled	19.47	10.77
GE-Bx	5	22.22	15.77
	10	21.55	12.89
	15	18.88	8.14
	20	18.51	10.05
GE-SiC	5	17.55	10.53
	10	20.49	4.21
	15	16.04	7.86
	20	19.64	11.41
GE-SSA	5	17.94	7.24
	10	18.31	14.83
	15	19.16	10.04
	20	18.52	6.17
GE-Pr	1	20.10	7.36
	3	19.18	11.84
	5	19.33	12.76
	10	19.39	7.75


25
20
15
10
5
0
Storage Modulus (GPa)
0%
5%
10%
15%
20%
Particle Ratio

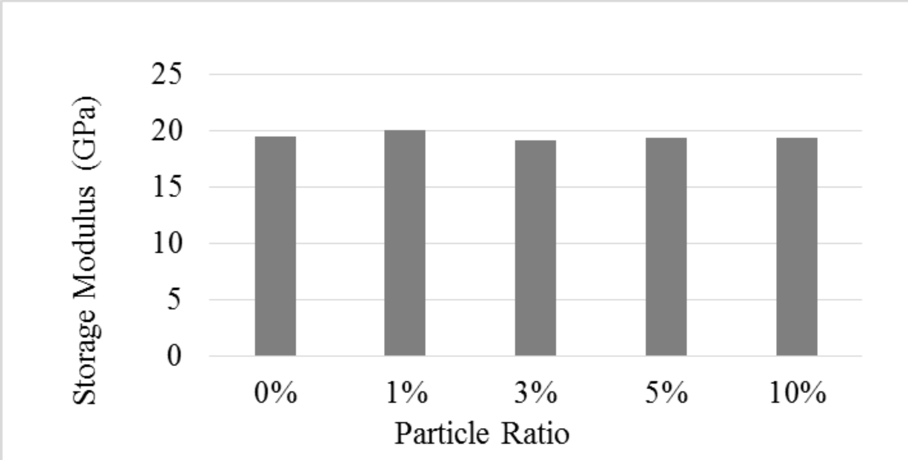
(a)


25
20
15
10
5
0
Storage Modulus (GPa)
0%
5%
10%
15%
20%
Particle Ratio

(b)


25
20
15
10
5
0
Storage Modulus (GPa)
0%
5%
10%
15%
20%
Particle Ratio

(c)



(d)

Figure 5.12 Storage Modulus of (a) GE-Bx, (b) GE-SiC, (c) GE-SSA, and (d) GE-Pr Composites

Figure 5.13 represents maximum values of storage modulus of (GE-Bx at 5wt%, GE-SiC at10wt%, GE-SSA at 15wt%, and GE-P at 1wt %) fillers type. According to this figure, all particle ratios have nearly same effect. The highest value was obtained from 5 wt% addition of Bx to the composite plate. It can be attributed to the good dispersion and interaction between the borax filler and the polymer matrix [68].

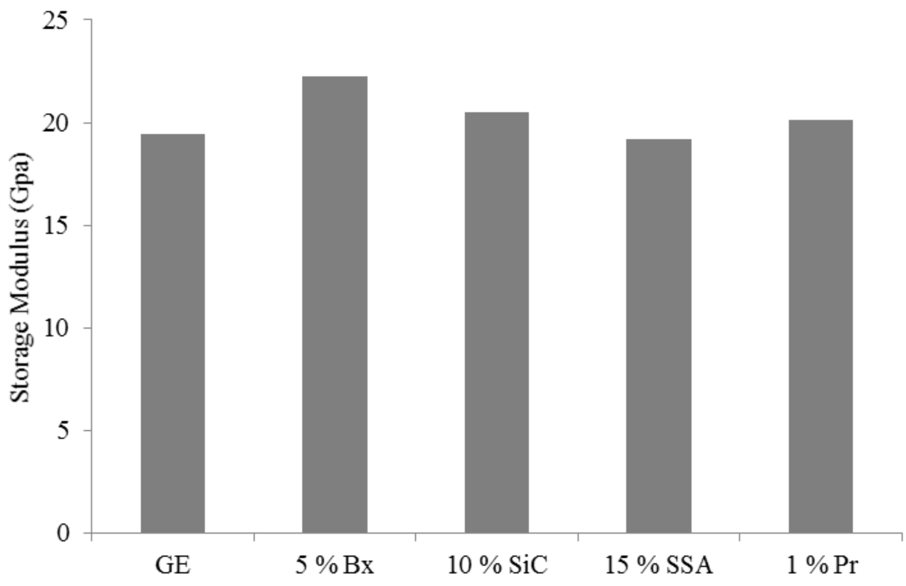


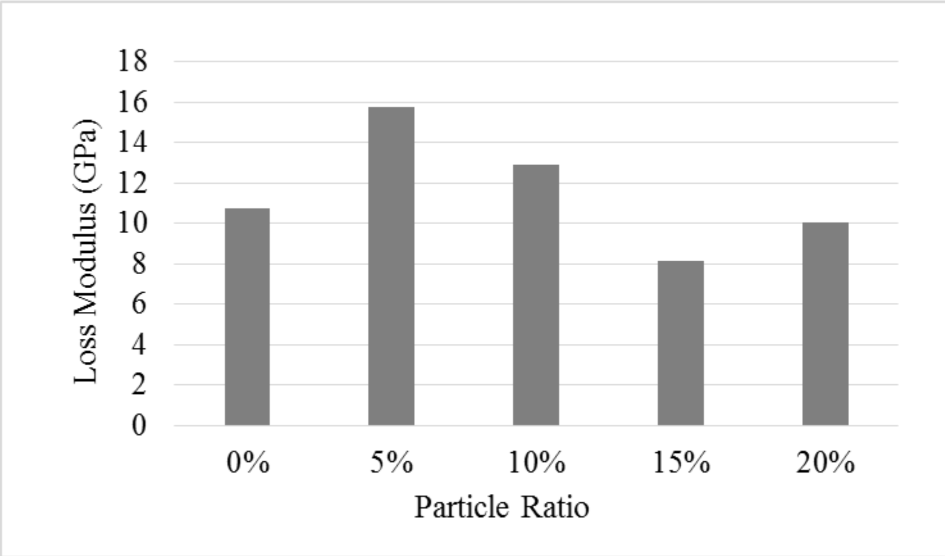
Figure 5.13 Comparison of maximum values of Storage modulus

5.5 Loss Modulus

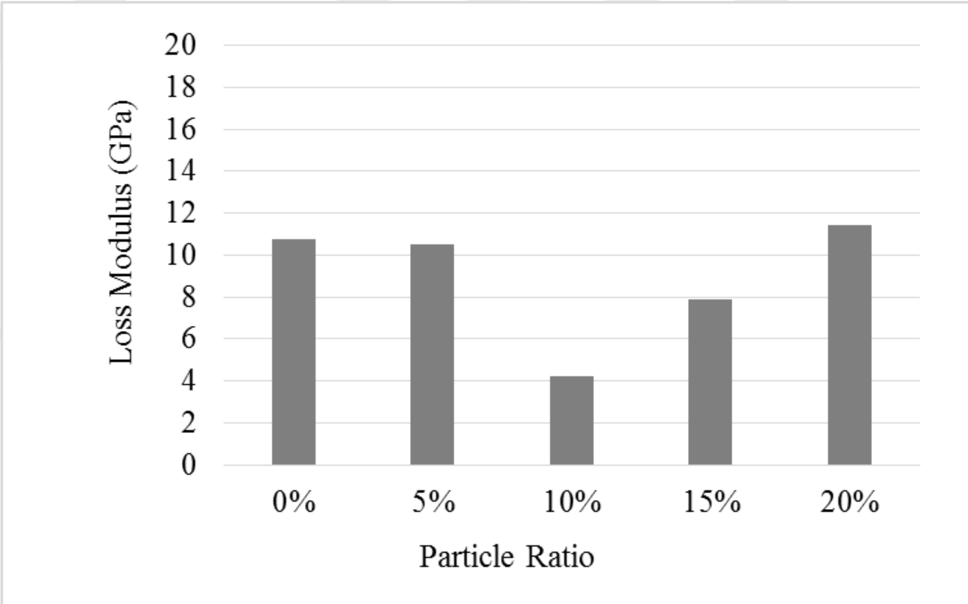
Loss modulus (viscous response) is a measure of the energy lost [88]. Loss modulus is indicators of energy dissipating capacity of a material. The aim of measure loss modulus is due to the high loss modulus enhance the ability to dissipate the energy before failure [89].

The effect of particulate filled fiber reinforced on the Loss Modulus values depends on Storage Modulus and damping ratio (via Eq. 3.3). It was clearly shown in Table 5.2 the variation of filler content do not give any definite correlation with Loss Modulus. There were both increasing and decreasing reports of Loss modulus for particulate filled fiber specimens. Same behavior was reported by [68]. The non-filled specimen loss modulus was 10.77GPa. The maximum value 15.77 GPa was observed at 5 wt%of Bx when increased by 46.4 %, while for other filler types the increase recorded at 20 wt% for SiC by 5.94%, SSA was rising at a rate close to 38.6% at 10 wt%. Finally Pr influenced the increase nearly to 18.5% at 5 wt%. The loss modulus of composites laminates for all particle ratios is given in Table 5.2 and were illustrated in figure 5.14 (a, b, c, d) for GE-Bx , GE-SiC ,GE-SSA and GE-Pr respectively.

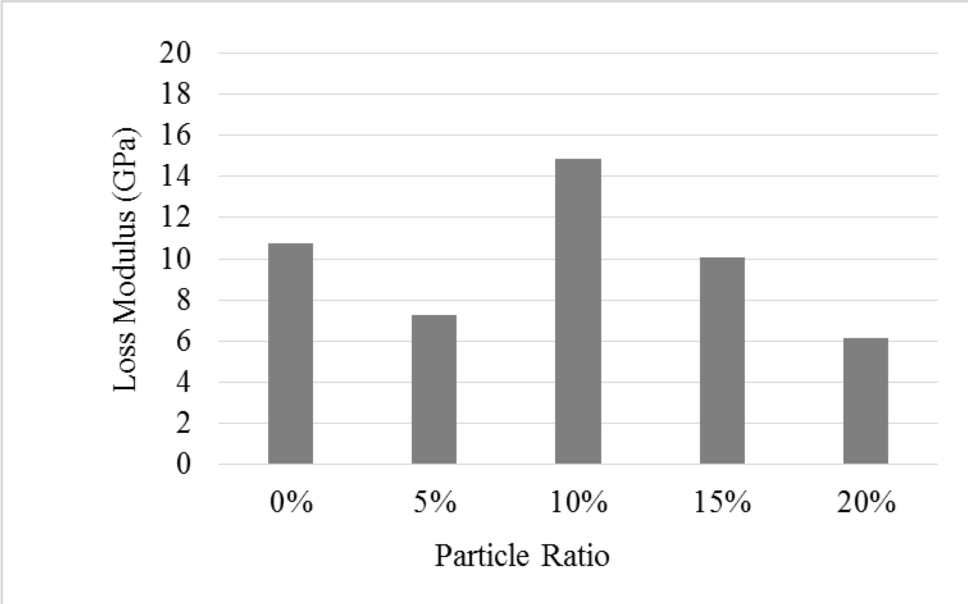
The decline caused by adding filler were as follows 8.14 GPa (22.4%) at 15 wt%, 4.21 GPa (60.9%) at 10 wt%, 6.17GPa (42.7%) at 20 wt% and 7.36 GPa (31.6%) at 1 wt% for GE-Bx , GE-SiC ,GE-SSA and GE-Pr respectively.


18
16
14
12
10
8
6
4
2
0
Loss Modulus (GPa)
0%
5%
10%
15%
20%
Particle Ratio

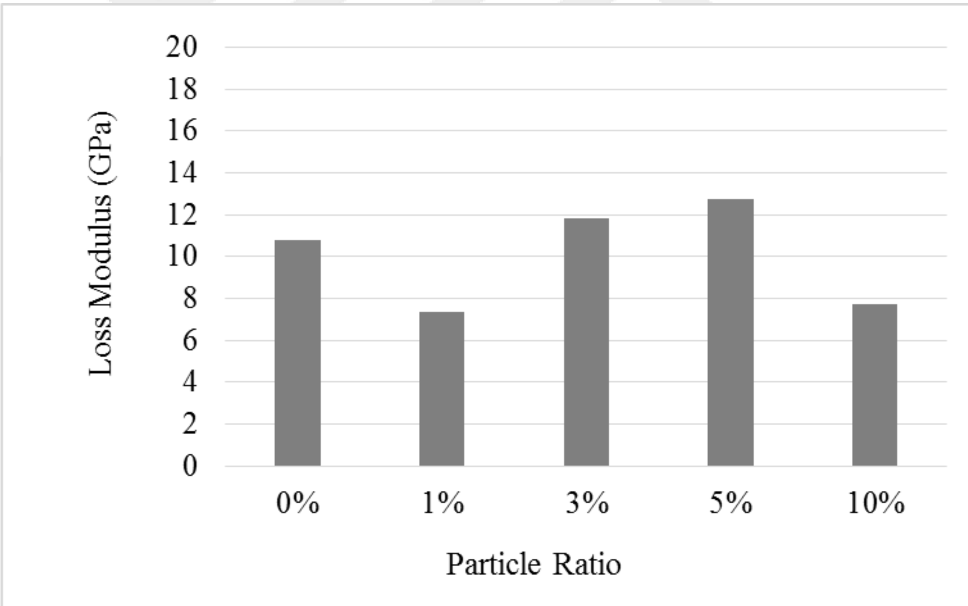
(a)


20
18
16
14
12
10
8
6
4
2
0
Loss Modulus (GPa)
0%
5%
10%
15%
20%
Particle Ratio

(b)



(c)



(d)

Figure 5.14 Loss Modulus for (a) GE-Bx, (b) GE-SiC, (c) GE-SSA, and (d) GE-Pr Composites

The Figure 5.15 shows maximum values of loss modulus for (GE-Bx at 5wt%, GE-SiC at 20wt%, GE-SSA at 10wt%, and GE-Pr at 5wt %) composites.

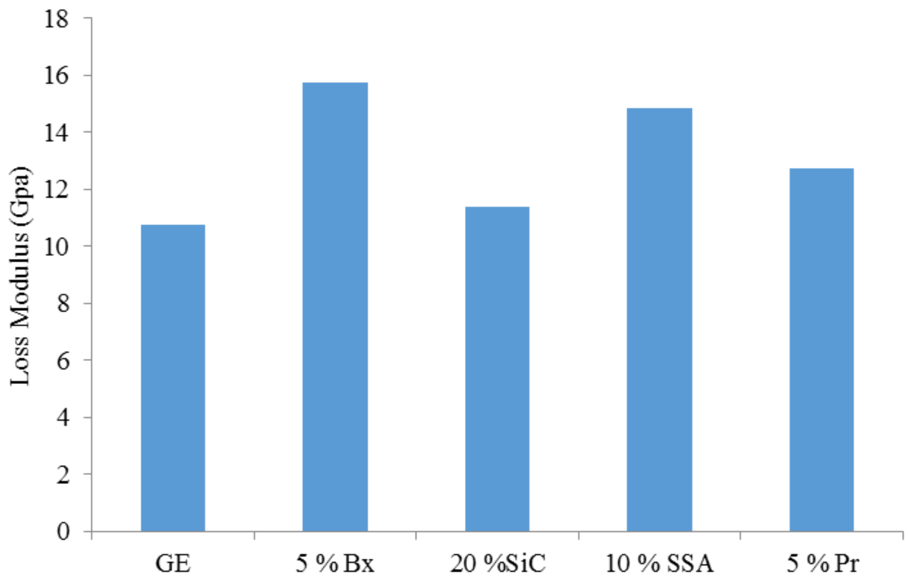


Figure 5.15 Comparison of Maximum Values of Loss Modulus of Particle Filled Composites

5.6 Dynamic Characteristics

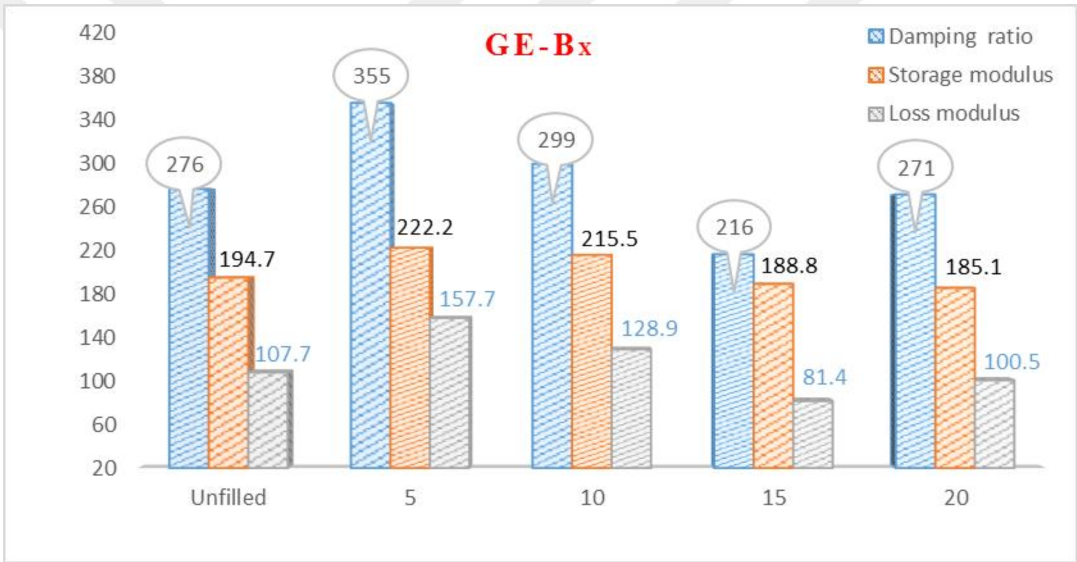
Vibration reduction can be attained by increasing the damping capacity (loss of energy) and/or increasing the dynamic stiffness (storage modulus) which is an inherent property of the material ξ and E' are complimentary to each other, and an optimal decision to strike a break-even is crucial. The loss modulus is the product of these two quantities and thus can be considered a figure of merit for the vibration reduction. DMA is a tool to characterize these properties.

Figure 5.16 a represents comparison dynamic characteristics of GE-Bx composite. As it appears in the figure at 5wt% and 10wt.% both damping ratio and storage modulus were increased and that led to the increased loss modulus, while at the remain ratios exactly the opposite occurred.

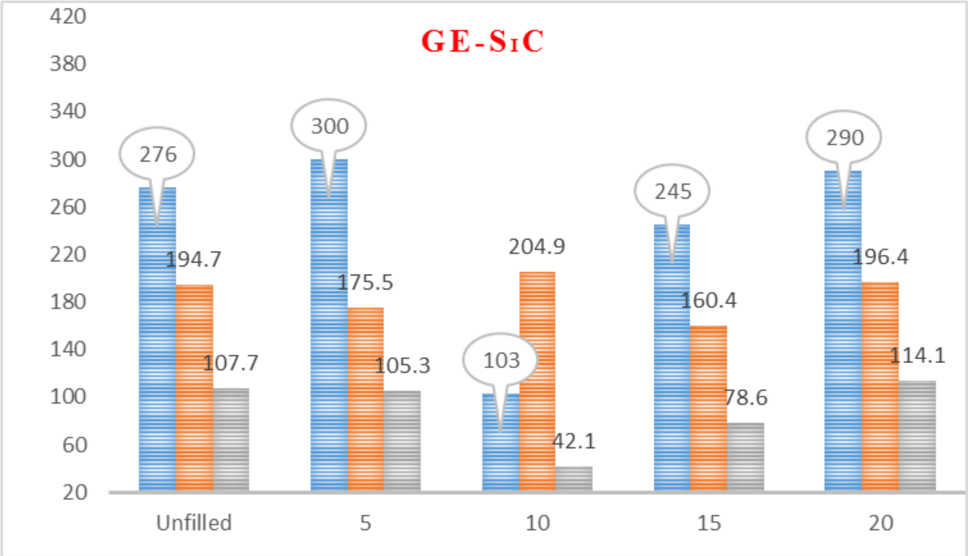
Figure 5.16 b represents comparison dynamic characteristics of GE-SiC composite. As it appears in the figure only at 20wt% positive effect was achieved as a result of the increase both damping ratio and storage modulus. Despite damping ratio was increased at 5wt%, a slight decreased occur in loss modulus due to the high decline in the storage modulus. Whereas a sharp decline earned at remain ratios as a result of decrease in both damping ratio and storage modulus.

Figure 5.16 c represents comparison dynamic characteristics of GE-SSA composite. As it appears in the figure only at 10wt% positive effect was achieved as a result of the height increase in damping ratio. Whereas a sharp decline earned in loss modulus at 5wt% and 20wt% particle ratios but a slight decreased occur at 15wt% as a result of decrease in both damping ratio and storage modulus.

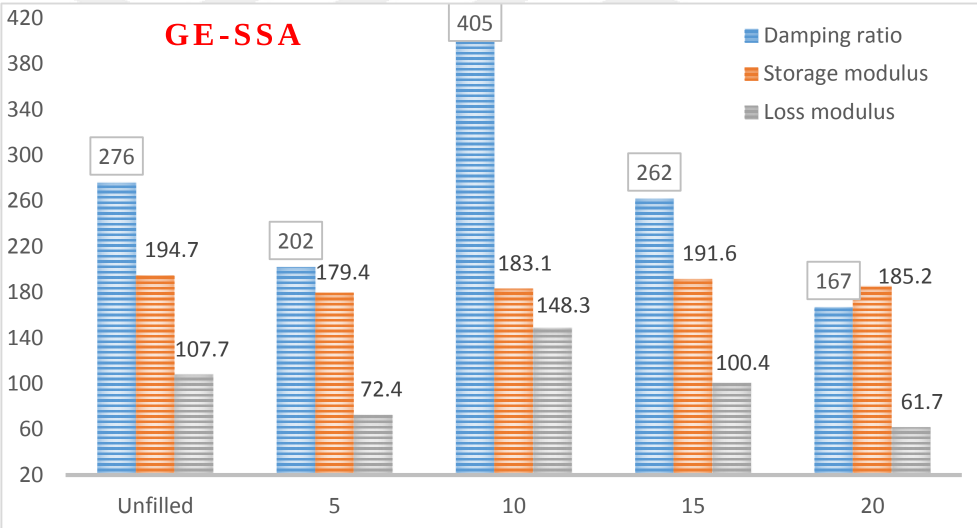
Figure 5.16 d represents comparison dynamic characteristics of GE-Pr composite. As it appears in the figure slight increase occur at 3, 5wt%. Whereas a sharp decline earned at remain ratios as a result of decrease in both damping ratio and storage modulus.



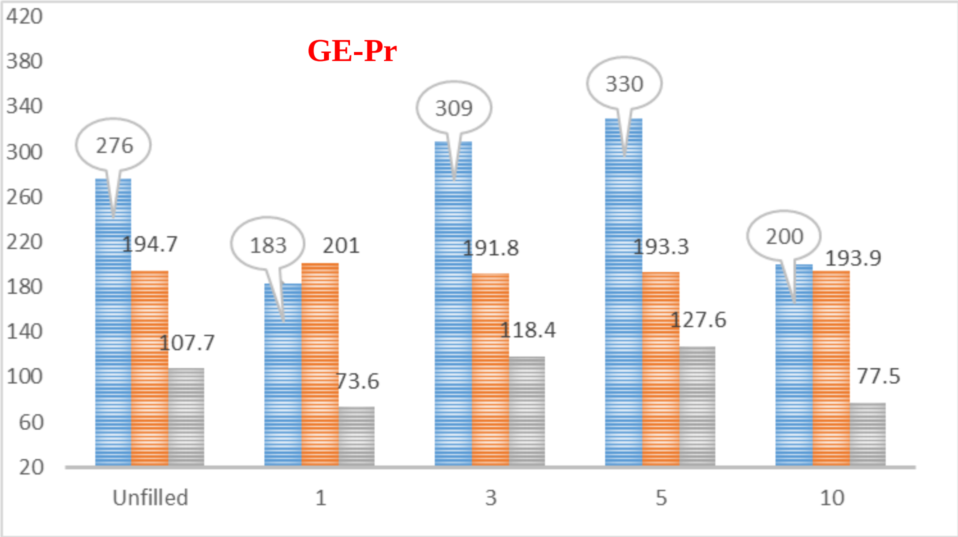
(a)


GE-SıC
420
380
340
300
260
220
180
140
100
60
20
276
194.7
107.7
300
175.5
105.3
103
204.9
42.1
245
160.4
78.6
290
196.4
114.1
Unfilled
5
10
15
20

(b)


GE-SSA
420
380
340
300
260
220
180
140
100
60
20
276
194.7
107.7
202
179.4
72.4
405
183.1
148.3
262
191.6
100.4
167
185.2
61.7
Unfilled
5
10
15
20
Damping ratio
Storage modulus
Loss modulus

(c)



(d)

Figure 5.16 Comparison Dynamic Characteristics of (a) GE-Bx, (b) GE-SiC, (c) GE-SSA, and (d) GE-Pr Composites (Damping Ratio x10^{-3}, Storage Modulus x10^{-1}, Loss Modulus x10^{-1})

CHAPTER 6

CONCLUSIONS AND FUTURE WORKS

6.1 Conclusion

In this study particles filled glass fiber reinforced epoxy composites were prepared with S- glass fiber using four different micro particle types and epoxy resin used as matrix. In the experimental part hand lay-up method under 0.3 MPa pressure with 80 °C temperature was used. Effects of particle types and particle ratios on the tensile strength and dynamic properties (e.g. natural frequency, damping ratio, storage modulus and loss modulus) have been investigated. The following main conclusions can be drawn based on this study:

- The results show that the tensile strengths of composites greatly influenced by the type and content of fillers.
- The maximum tensile stress of particulate filled composite recorded at 10 wt% of GE-Bx , GE-SiC , GE-SSA and 1 wt% of GE-Pr composites.
- The lowest stress was showed at 20 wt% among all ratio for where the values were as follows for Bx, SSA, SiC respectively whereas at 10 wt% of Pr.
- For strain, the increasing is recorded for all fillers and all ratios. The minimum value was found at highest content value(20 wt% for Bx, SSA and 10 wt% of Pr) with the exception of Sic, which had the lowest value at 5 wt%.
- The minimum natural frequency was observed for unfilled glass/epoxy composites. Natural frequencies increase with increase the filler content of all types of filler at all particle ratio.
- There were both increasing and decreasing reports of damping for particulate filled fiber specimens. The maximum value 0.405 was observed at 10 wt% of SSA when increased by 46.5 %, while for other composites the maximum

- damping ratio was seen at 5 wt% particle content as 0.355 (28.6%), 0.3(8.69%), 0.33(19.5%) for GE-Bx, GE-SiC, GE-Pr respectively.

- The storage and loss modulus of the micro-particles filled s-glass/epoxy composite have the highest value at 5 wt% borax addition, after that values are decreasing.

6.2 Future work

This study can be extended in the following field:

1. Composite materials that are different than S-glass fibers can be used to produce laminate containing different particulate additives.

2. Determined impact, buckling, fatigue and other mechanical properties.

3. Examine different percentage of these fillers.

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