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By

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On the subject

Modeling and Analysis of a Chassis Frame by Using Carbon Fiber and E-Glass Epoxy as Composite Materials: A Comparative Study

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Dedication

First of all we thank Allah almighty for granting us the will to make this project possible.

We would like to dedicate this project to our families, who have been our constant source of support, and inspiration throughout our academic journey. Your unwavering Encouragement and belief in our abilities have been Invaluable, and we are grateful for the sacrifices you have made to help us pursue our dreams.

We would also like to express our gratitude to our professors in general and in particular our esteemed professor Mr. Rachid Tiberkak, whose guidance and expertise have challenged us to grow and develop as students. Your dedication to teaching and commitment to excellence have been a source of motivation and inspiration, and we are honored to have had the Opportunity to learn from you.

Finally, we would like to acknowledge our classmates and friends, whose support have made this journey all the more fulfilling.

Your encouragement, Collaboration, and friendship have helped us to overcome obstacles and celebrate achievements, and we are grateful for the memories we have shared with you., thank you for being a part of our academic journey and for helping us to achieve our goals. This project is a testament to our efforts and your support and we are proud to share it with you.

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Nomenclature of the 3nd chapter

C : the damping matrix.

$\omega 0$:p proper pulsation of the system.

λ : damping coefficient.

ξ : damping factor.

W: is the pulsation of the excitation force.

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Abstract:

The first chapter was devoted to the presentation of a literature review on composite materials and hybrid composite materials, presenting the different aspects characterizing these materials. In the second chapter, we are first interested in a brief reminder of the finite element method, and then we end this chapter with a basic understanding of the dynamics of structures, in the Third chapter we will briefly discuss the Modal analysis method ,lastly in the fourth chapter we are going to discuss the results of the study that has been done using a computer assisted design application

ملخص :

تم تخصيص الفصل الأول لعرض مراجعة الأدبيات حول المواد المركبة والمواد المركبة الهجينة ، مع عرض الجوانب المختلفة التي تميز هذه المواد. في الفصل الثاني ، نهتم أولا بتذكير موجز بطريقة العناصر المحدودة ، ثم ننهي هذا الفصل بفهم أساسي لديناميكيات الهياكل ، في الفصل الثالث سنناقش بإيجاز طريقة التحليل المشروط ، وأخيرا في الفصل الرابع سنناقش نتائج الدراسة التي تم إجراؤها باستخدام تطبيق التصميم بمساعدة الكمبيوتر

Résumé

Le premier chapitre a été consacré à la présentation d'une revue de littérature sur les matériaux composites et les matériaux composites hybrides, présentant les différents aspects caractérisant ces matériaux. Dans le deuxième chapitre, nous nous intéressons d'abord à un bref rappel de la méthode des éléments finis, puis nous terminons ce chapitre par une compréhension de base de la dynamique des structures, dans le troisième chapitre, nous discuterons brièvement de la méthode d'analyse modale, enfin dans le quatrième chapitre, nous allons discuter des résultats de l'étude qui a été réalisée à l'aide d'une application de conception assistée par ordinateur

General Introduction

Composite materials present a very interesting alternative to replace so-called traditional materials. These materials are manufactured at the request of users, with attractive mechanical properties, and at the same time they are very light to be exploited in the field of aeronautics. The increasing use of composite materials in the various fields of application requires designers to ensure that they present a material that is highly hard, lightweight and competitively priced. This trade-off requires finding a better fiber and matrix to make a composite that meets its requirements.

The reinforcement (fibers, particles, etc.) and the matrix (polymers) are the basic constituents of a composite material, but in some cases, and in order to reduce the cost of manufacturing and improve the mechanical properties, designers use several types of reinforcements in the same polymer to obtain a new hybrid composite material. Hybrid composite materials occupy an important place in the various industrial sectors and in particular in high-tech fields (aeronautics) and in high-use sectors (automotive, housing, packaging,...). This great emergence is mainly due to the better performance of its materials (strength and lightness), and their very low manufacturing costs compared with other so-called traditional materials (performance/cost/lightness compromise).

The first chapter was devoted to the presentation of a literature review on composite materials and hybrid composite materials, presenting the different aspects characterizing these materials. In the second chapter, we are first interested in a brief reminder of the finite element method, and then we end this chapter with a basic understanding of the dynamics of structures, in the Third chapter we will briefly discuss the Modal analysis method ,lastly in the fourth chapter we are going to discuss the results of the study that has been done using a computer assisted design application

Chapter I: Literature Review on Composite Materials

1. Definition

A composite material is made up of the assembly of two or more materials of different natures. That complements each other and results in a heterogeneous material whose overall performance is superior to that of the components taken separately. The main advantage of the use of composite materials is its excellent characteristics. **[1]**

2. Classification of Composite Materials

Most of the time, these materials are made up of a matrix and a reinforcement (e.g. natural composites.**[2]** The classic classification of composites can be applied according to the nature of the matrix, in ascending order of operating temperature.**[3]** Reinforcements that are embedded in a matrix with much lower mechanical strength**[4]**

2.1 Matrix-based classification

The matrix of the composite material is a polymer resin. Polymer resins exist in large numbers and each has a particular area of use.

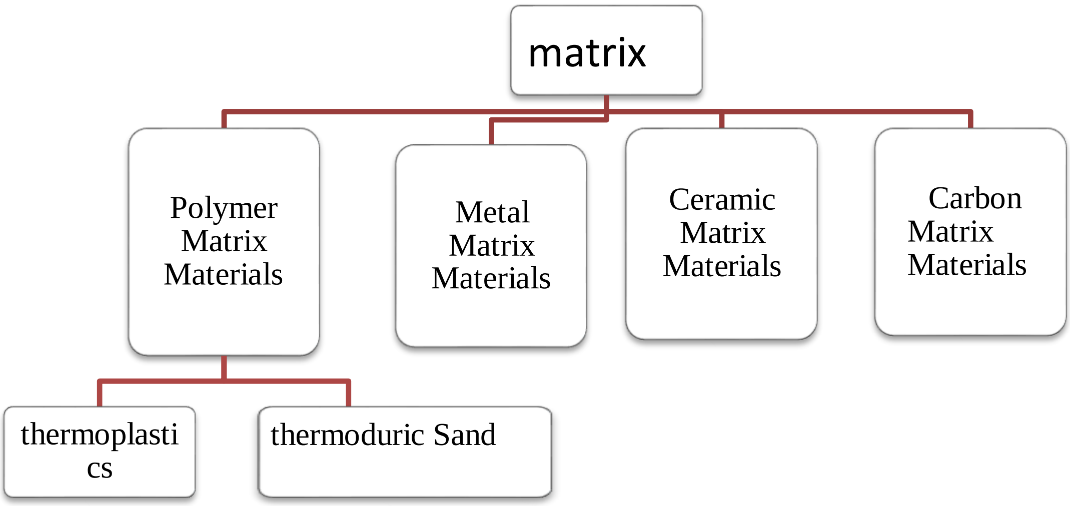


Figure 1. 1 : Matrix-based classification of composite**[5]**

2.1.1 Metal Matrix Composites (MMC)

In this case the matrix is metallic; the most commonly used metals are: aluminum, magnesium and titanium, for high temperatures it is cobalt (sometimes alloyed with nickel). The metal matrix gives the composite material new properties. **[6]**

2.1.2 Ceramic Matrix Composites (CMC)

Ceramic matrix composites or CMCs are composite materials that are part of engineering ceramics. They are characterized by a set of ceramic fibers incorporated into a ceramic matrix.

2.1.3 Polymer Matrix Composites (PMC)

These composites are the most widespread. Depending on the nature of the matrices and reinforcements, these are high-diffusion composites or high- and very high-performance composites. Matrices can be thermoplastics polymers or thermosets (unsaturated polyesters and epoxy resins). **[7]**

2.2 Classification of composites based on reinforcement

Depending on the reinforcement shape, composites are classified into two broad classes: particle composites and fiber composites

2.2.1 Fiber Composites

A reinforcing fiber is a material in the form of a thin filament with good breaking strength and a high modulus of elasticity**.[6]** A composite material is a fiber composite if the reinforcement is in the form of a fiber.**[8]** Fibers are used to ensure mechanical strength and solidify the system. But the response of the system depends on the direction of the efforts.**[6]**

2.2.2 Particulate Composites

A composite material is a particulate composite when the reinforcement is in the form of a particle. A particle, as opposed to fibers, does not have a privileged dimension. Particles are typically used to improve certain properties of materials or matrices, such as stiffness, temperature resistance, abrasion resistance, decreased shrinkage, etc. In many cases, particles are used as fillers to reduce the cost of the material, without diminishing its characteristics**.[8]**

3. Different types of basic constituents

3.1 Reinforcement

The reinforcements can be of mineral origin (glass, boron, ceramic, etc.) or organic (carbon or aramid). The most commonly used fibers are glass fibers, carbon fibers are preferred**.[9,10]**

3.1.1 Fiberglass

They are generally made from the melting and extrusion of silica combined with various oxides (alumina…….ect). There are different types of fiber:

- E-glass: the most common, it has good dielectric properties.
- Glass D: it is intended for construction or electronic applications, due to its superior dielectric properties compared to other glass fibers.
- C: It is highly chemically resistant and is mainly used for anti-corrosion applications.
- R or S glass: it is intended for high-performance applications due to its higher tensile strength and modulus of elasticity than other glass fibers.

Glass fibers are brittle and susceptible to abrasion. For this reason, they are coated with a resin or sizing which has the function of protecting the fibers but also promotes the adhesion of the matrix.

The mechanical characteristics of the glass fibers described above are summarized in Table 1.

Table 1.1: Mechanical Characteristics of Glass Fibers **[9,10]**

Characteristics	**Type E**	**Type D**	**Type C**	**Type R**	**Type S**
Resistance Traction (MPa)	3500	2450	2800	4650	4650
Module Traction (GPa)	73.5	52.5	70	86.5	86.5
Elongation at the Out of stock (%)	4.5	4.5	4.0	5.3	5.3

3.1.2 Carbon Fibers

Carbon fibers have the structure of graphite. They come from acrylic fiber and pitch. Currently, there are two processes for preparing carbon fiber: one of the channels is used to obtain HM (High Modulus) and THM (Very High Modulus) fibers, the other gives HR (High Strength) and HT (High Toughness) fibers.

A graphitization step, carried out after the oxidation and carbonization steps, in the preparation process of HM and THM fibers differentiates the two pathways.
Graphitization is used to obtain HM and THM fibers**.[9,10,11]**

3.1.3 Boron Fiber

They are obtained by the chemical deposition of boron chloride (BCI) and hydrogen (H2) on a tungsten wire with a diameter of 13µm, heated to a temperature between 1100 and 1300°C by the joule effect.

3.2 Matrix

In many cases, the matrix of the composite material is a polymer resin. Polymer resins exist in large numbers and each has a particular area of use. In applications where structural resistance to very high temperatures is required, metal, ceramic or carbon matrix composite materials are used. In the case of carbon materials, temperatures of 2200°C can be reached. The classification of commonly encountered types of matrices is given **[11,12]**

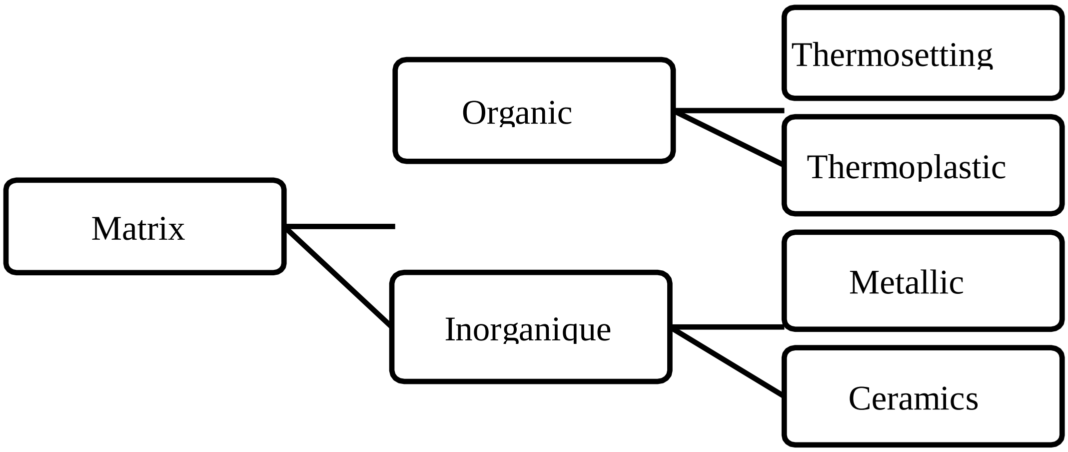


Figure.1.2 Types of Matrices

3.2.1 Thermosetting

Thermoset resins have high mechanical properties. These resins can only be shaped once. They are in solution as a non-cross-linked polymer suspended in solvents. Polyester resins

Unsaturated condensation resins (phenolics, aminoplasts, furanics) and epoxy resins are thermosetting resins. Examples of classically encountered thermoset resins are 914, 5208, 70, LY556. , the best performing materials have high mechanical characteristics and low density. [12,13]

3.2.2 Thermoplastic

Thermoplastic resins have weak mechanical properties. These resins are weak and require processing at very high temperatures. Polychloride polyethylene, polypropylene, polystyrene, polycarbonate polyamides are some examples of these thermoplastic resins. The thermoplastic resins classically encountered are PEEK, K3B. As with thermosetting resins, the best performing materials have high mechanical characteristics and low density. **[12,13]**

4. Characteristics of composite materials

The properties of composite materials depend on many factors and are different for different types of composite materials

- The properties, nature and quality of the constituent materials.
- The geometry and distribution of the reinforcement
- Their interactions and the nature of the matrix-reinforcement interface The main characteristics of parts made of composite materials are:
- Mass Gain
- Good fatigue life (increased service life)
- Absence of corrosion
- The absence of plasticity (their elastic limit corresponds to the breaking limit)
- Ageing due to humidity and sensitivity to certain chemicals
- Resistant to impacts and shocks
- Very strong anisotropy.

The Pros and Cons of Composite Materials

Composites are preferred over other materials because they offer advantages related to:

- Low ageing due to the action of moisture, heat, corrosion
- Insensitivity to chemicals
- Compare to metals, they have a high strength.
- They have a low density.
- The rigidity of the material is improved at high temperatures, they also maintain weight.
- Possibility of taking several forms (complex parts).
- Good fire resistance (beware of toxic releases).
- Toughness is also improved.
- Production is lower.
- Manufacturing is also cheaper.

- Fatigue and creep resistance is better.
- Measured electrical conductivity is possible. **[9,10]**

However, there are some drawbacks to their spread:

- Compare with forged metals, composites are more brittle and are easily damaged.
- Costs of raw materials and manufacturing processes.
- Cast metals also tend to be brittle during transport, the material requires cooling.
- Special equipment is needed and hot curing is also required for the curing process, it takes time for cold or hot processing.
- After the completion of the last rivet, the process is complete.
- The management of the waste generated and the increasingly strict regulations.
- The rivets are removed without causing damage.
- Before starting the repair, the composite must be cleaned**. [9,11,13]**

5. Natural Fiber

Natural fibers are generally classified according to their origins: animal, vegetable, and mineral. Plant-based fibers are mainly made up of cellulose and have superior mechanical properties than those of animal origin. The latter, such as wool and silk, are widely used in the textile industry. Plant-based fibers can be classified into subfamilies according to where they were extracted from; seeds, fruits, bark, leaves, wood, stems or cane. **[14]**

Table. 1.2. Classification and Examples of Natural Fibers**.[14,15]**

Origin	Provenance	Examples
Vegetable	Seeds, Fruits, Bark, Leaves, Wood, Stems Canes and reeds	Cotton, kapok, milkweed Coconut Flax, hemp, jute, ramie, kenaf. Sisal, henequen, abaca, Ananas
Animal	Wool/Hair Silkworms	Wool, Hair, Cashmere Tussah Silk, Silk mulberry
Mineral		Asbestos, Wollastonite

Natural fibers have managed to gain increasing interest as a reinforcement in composites. This is due to their **:[14]**

- Mechanical properties, particularly low densities and low production costs.
- The plant's fiber yields are quite high.
- The price of labor is relatively cheap in the countries where source plants are grown, which can in some cases be harvested several times a year.
- The cost of obtaining natural fibers is three times lower than glass fibers, four times lower than aramid fibers, and five times lower than the cost of carbon fibers.

6. Bio composite Materials

Bio composites are composite materials made from natural fibers/bio-fibers and petroleum-derived non-biodegradable polymers (PP, PE) or biodegradable polymers (PLA, PHA).

The latter category, i.e. bio composites derived from fibers derived from plants (natural/bio-fibers) and crops/plastics derived from biodiversity (bio-polymers/bioplastics) are likely to be more environmentally friendly and these composites are called green composites. **[13-17]**

Bio composites are composite materials comprising one or more phases derived from a biological origin. In terms of reinforcement, this could include plant fibers such as cotton, flax, hemp and the like, or recycled wood fibers or waste paper, or even by-products of food crops. **[12:14-19]**

7. Hybrid Materials

7.1 Definition

A hybrid material is a material that includes 2 components (one organic and the other inorganic) mixed at the molecular level (diameter of an atom 0.2 nm). The system is homogeneous.**[12-17]**

These hybrids are the subject of much research because they allow the development of new applications by combining the properties of both components (organic and inorganic). These hybrids are used in various fields such as optics (nonlinear optics, integrated optics and ophthalmic optics), cosmetics and sun protection, the manufacture of light-emitting diodes (used in thin display or lighting devices), the biomedical field (chemical biosensors, MRI probe, drug delivery). **[13-16]**

7.2 Classification of Hybrid Materials

The structure of hybrid materials can be divided into two classes depending on the type of interaction or bonding between the components:

a. Class I:

The organic component (single molecule (orga or organic), oligomer, low molecular weight polymer) and the inorganic component exchange weak interactions such as van der Waals, hydrogen or ionic bonding.

b. Class II:

The 2 components are fully or partially linked by strong covalent or iono-covalent chemical bonds (strong orbital overlap)

In fact, the transition is continuous between weak and strong interactions, so not really two separate classes. **[12-20]**

c. Class I Interests : [12-20]

- Ease of material synthesis
- No need for hetero functional metal-organic precursors
- Ease of removal of the organic phase if necessary
- Easy creation of functional architectures by self-assembly (spontaneous).

d. Class II Interests :[12-20]

- Possibility from synthesis from materials new at leave functionalized alkoxides.
- Minimization of phase separations
- Better definition of the organic-inorganic interface, which allows, for example, an easier adjustment of the hydrophilic-hydrophobic balance.

e. An advantage of Class II over Class I :[12:17-21]

The grafting of organic functions to the inorganic network avoids a disadvantage of class I hybrid compounds, which is the eventual departure of organic components during the use of the material.

7.3 Characterization of hybrid materials

The characterization of hybrid materials is a key point for the success of their preparation. Indeed, in addition to controlling the growth of the polymer crown on the surface of the particles, it is essential to monitor the evolution of colloidal stability, in the case of suspended particles, to determine the nature of the bond involved between the chains and the support as well as the grafting density. To achieve this information, the literature mentions a large number of techniques. The most commonly used are**: [20,21-30]**

- Transmission electron microscopy , or TEM.
- Atomic force microscopy , or AFM.
- Thermo gravimetric analysis , or TGA.

- Differential Scanning Calorimetry, or DSC.
- Fourier transforms infrared spectroscopy or FTIR.
- X-ray photon spectrometry, or XPS.
- X-ray diffraction or XRD.
- Light scattering, dynamic (DLS) and static (SLS).

8. Hybrid bio-composite

A hybrid bio-composite material is a combination of "hybrid" and "bio-composite". This material is simply a hybridization of bio composite materials. The meaning of "hybrid" in hybrid bio composite materials is hybridization in the macroscopic structure at the metallographic scale. **[30-34]**

Chapter II : Fundamentals on Finite Elements Method

1. Reminders about the finite element method

1.1 Introduction

In this chapter, we are first interested in a brief reminder of the finite element method, and then we end this chapter with a basic understanding of the dynamics of structures

1.2 Definition[35]

Calculation occupies an important place in the industry, thanks to it the engineer can test several configurations to optimize the behavior of a model, and this avoids multiplying prototypes and real test tests. And it allows us to reduce the cost and manufacturing time.

The finite element method is a discretization method and one of the most effective and general tools for structural analysis in many sectors of industry.

The principle of the finite element method is to subdivide the continuous structure into sub domains of extremely simple forms called (finite elements), which leads to defining an approximation of the solution for each of the building blocks of the structure.

There are several kinds of finite element formulations in structural mechanics: displacement, stress.

In the finite element method, there are three aspects:

- The discretization of the structure into elements.
- The choice of an approximation for each element.
- The choice of physical coordinates [nodal displacements] for each element.

In dynamics, the most widely used method is the one based on a spatial discretization by finite elements of the displacement type, which allow the study of the behavior of the structure in knowledge of the displacements at the nodes. The calculation steps can be highlighted as follows:

- The spatial discretization of the domain into finite elements.

1.2.1 Finite element discretization

We subdivide the structure or continuous medium to be studied into finite elements of simple geometry form, so as to approximate its geometry as best as possible.

2. 2D Triangular Elements

2.1 Two Dimensional FEA

Frequently, engineers need to compute the stresses and deformation in relatively thin plates or sheets of material and finite element analysis is ideal for this type of computations. We will look at the development of development of finite element schemebased on triangular elements in this chapter. We will follow basically the same path we used in developing the FEA techniques for trusses.

In both cases, we developed an equation for potential energy and used that equation to develop a stiffness matrix. In the development of the truss equations, westarted with Hook's law and developed the equation for potential energy.

$$F = k\Delta x \tag{2.1}$$

$$u = k\int_0^Q x dx = \frac{1}{2}kQ^2 \tag{2.2}$$

From here we developed linear algebraic equations describing the displacement ofthe nodes (end points) on the truss elements to define a stiffness matrix

$$k = \frac{AE}{L}\begin{bmatrix} c^2 & cs & -c^2 & -cs \\ cs & s^2 & -cs & -s^2 \\ -c^2 & -cs & c^2 & cs \\ -cs & -s^2 & cs & s^2 \end{bmatrix} \tag{2.2.1}$$

We used this elementary stiffness matrix to create a global stiffness matrix and solve for the nodal displacements using 3.38.

$$KQ=F \tag{2.3}$$

We are going to use a very similar development to create FEA equations for a twodimensional flat plate.

2.2 Potential Energy

The potential energy of a truss element (beam) is computed by integrating the force over the displacement of the element as shown in equation 2.2. We will use the same idea but express it in a slightly different manner since we are not working with a one dimensional object such as a beam.

If we apply forces to a thin plate, the plate will deform and in the process store potential energy much the same way a spring will when an external force is applied. If welook at a small element of material in a plate that has been deformed, we can use the stress, σ to represent the force in the material and the strain , to represent the displacement of the material. The product of these can be integrated over the volume to compute the potential energy due to external forces applied to the object. This is shownin the equation 2.4.

Compute the potential energy due to external forces applied to the object. This is shownin the equation 2.4.

$$U = \frac{1}{2}\int_V \varepsilon^T \sigma dV \qquad (2.4)$$

In 2.4 we are integrating over the entire volume. Since we are studying a flatplate of constant thickness, we can rewrite the equation as

$$U = \frac{1}{2}\int_A \varepsilon^T \sigma t dA \qquad (2.5)$$

where: ε : is the strain in a differential element of the plate

σ : is the stress in a differential element of the plate

t : is the thickness of the plate (we assume it is a constant)

A : is the area of the plate

In this equation, we are expressing the volume as the area of the plate times the thickness of the plate. We will use this equation for potential energy to develop the stiffness matrix for triangular elements in a thin plate. Our goal in this development is to replace both the stress and strain terms with linear equations for nodal displacement.

Equation 4.2 involves both the stress and strain which we do not know. In the following development, we will eliminate both of these terms replacing them with the stiffness matrix and material properties.

2.3 FEA Elements

We can take a thin plate and divide it into triangles as shown in Figure 2.1 below.

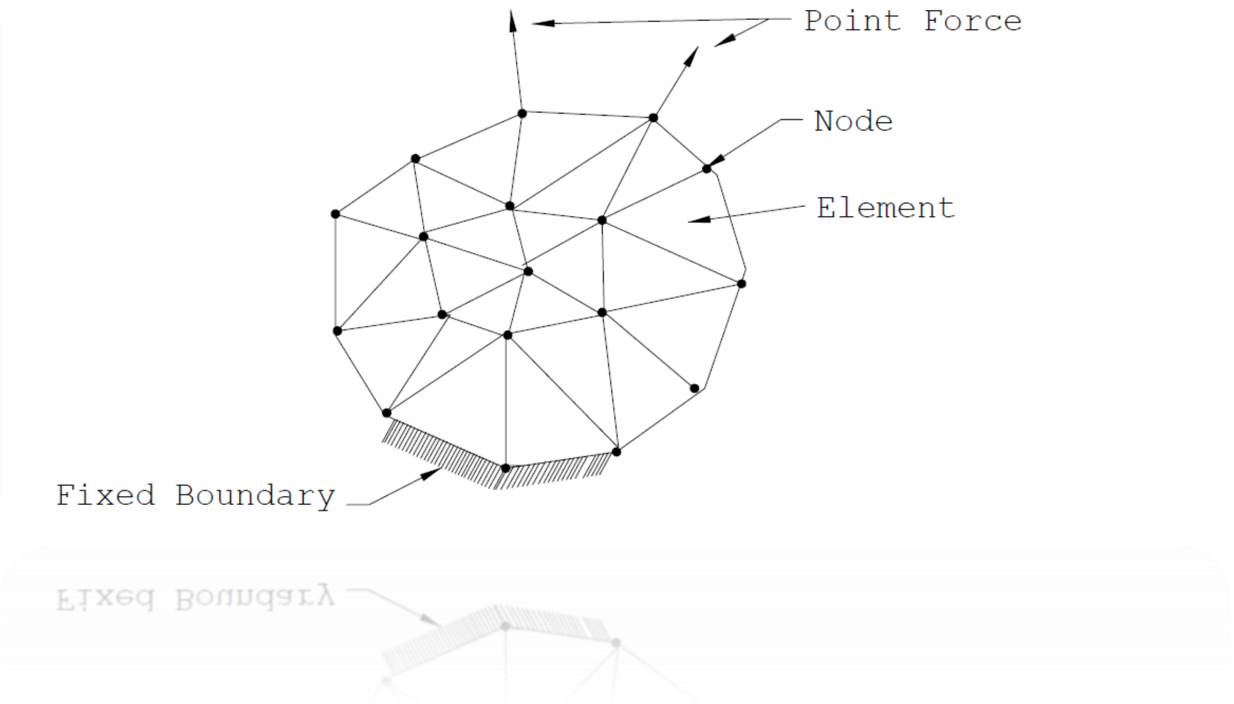


Figure 2.1: Triangular elements used to approximate a flat plate.

The triangles share vertices with other triangles. The vertices are nodes and triangles are elements. We will use the elements and nodes to approximate the shape of the object and to compute the displacement of points inside the boundary of the object.

The object is fixed along part of the boundary and does not move. External forces are applied at points.

These external forces may arise from simple point forces, tractions or forces applied along a length of the boundary, or body forces such as gravity.

Regardless of the source, all forces are applied at the nodes only. Tractions, and body forces may be distributed across several nodes but they are still applied at the nodes.

2.4 2D Triangular Elements

In the two dimensional truss problem, we computed the displacements of the nodes and we will do the same here. We will have displacements in the X and Y directions and we will number them as shown in Figure 2.2.

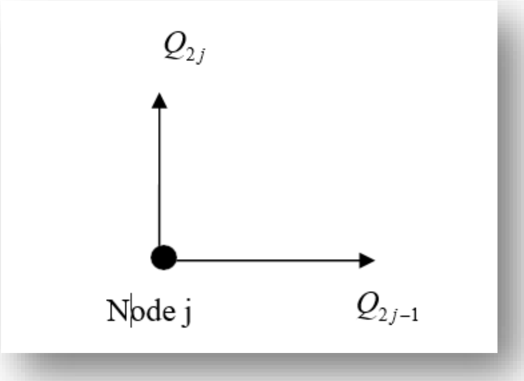


Figure 2.2 Diagram showing the numbering of nodal displacements.

For a single triangle we have

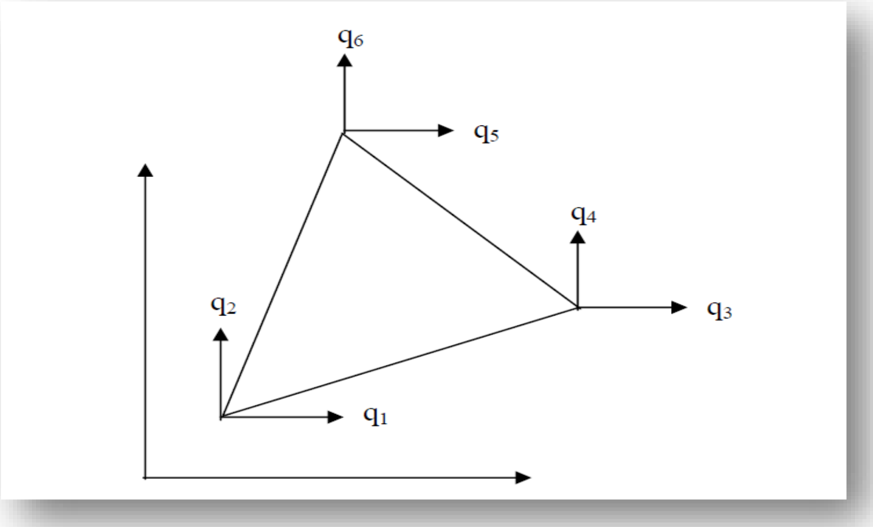


Figure 2.3 Diagram of a triangle showing the numbering of the displacements of its nodes.

We can write the local displacement vectors for each triangle as

$$q = \{q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5 \quad q_6\}^T \tag{2.6}$$

For the whole object the global vectors can be written as

$$Q = \{Q_1 \quad Q_2 \quad Q_3 \ldots . Q_n\}^T \tag{2.7}$$

Which includes all of the q_n terms.

2.5. Shape Functions

We are going to compute the displacement of the nodes at the triangle vertices butwe also need to compute the displacement for points inside the triangle. We will use shape functions to interpolate the nodal displacements to compute the displacements of arbitrary points inside the triangles.

We will start by moving only one point on the triangle and holding the other two fixed. We can draw both the deformed and non-deformed triangles on top of one anotheras shown in Figure 2.4.

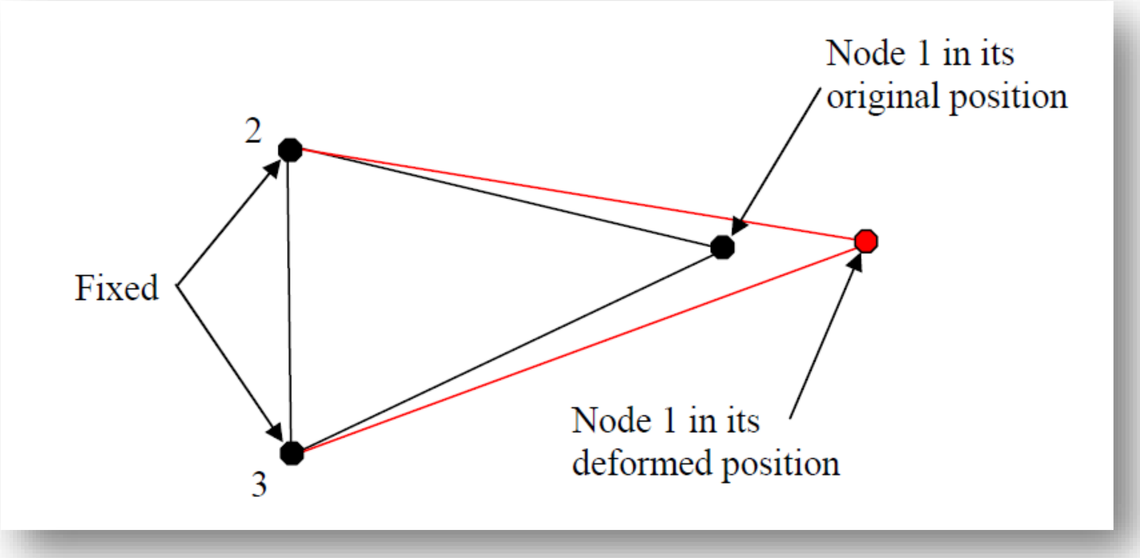


Figure 2.4 Triangle in both non-deformed and deformed states.

Chapter III : Fundamentals about Modal Analysis

1. Introduction

In the past two decades, modal analysis has become a major technology in the quest for determining, improving and optimizing dynamic characteristics of engineering structures. Not only has it been recognized in mechanical and aeronautical engineering, but modal analysis has also discovered profound applications for civil and building structures, biomechanical problems, space structures, acoustical instruments, transportation and nuclear plants.**[37]** To appreciate its significance in the modern engineering arena and its potential for future science and technology, it is appropriate to capture some of the background facts which will help to underline this unique technology. Contemporary design of complex mechanical, aeronautical or civil structures requires them to become increasingly lighter, more flexible and yet strong. For instance, resources have been devoted by car manufacturers to achieve microscopic reductions of product body weight. Aerospace structures such as satellite antennas do deserve eight reduction of every possible gram in order to minimize their inertial property during operation in space. These stringent demands on contemporary structures often made them more susceptible to unwanted vibrations.**[38,39]** Another relevant fact in modern life is the increasing demands of safety and reliability upon contemporary structures either defined by government regulations or accrued by consumers. These demands have created new challenges to the scientific understanding of engineering structures. Where the vibration of a structure is of concern, the challenge lies on better understanding its dynamic properties using analytical, numerical or experimental means, or a combination of them. As the significance of dynamic behavior of engineering structures is better appreciated, it becomes important to design them with proper consideration of dynamics. Finite element analysis as a computer modeling approach has provided engineers with a versatile design tool, especially when dynamic properties need to be perused. This numerical analysis requires rigorous theoretical guidance to ascertain meaningful outcomes in relation to structural dynamics. An important part of dynamic finite element analysis is modal analysis.**[40-43]**

Computer modeling alone cannot determine completely the dynamic behavior of structures, because certain structural properties such as damping and nonlinearity do not conform with traditional modeling treatment. There are also boundary condition uncertainties which modeling needs additional help to work. Substantial advances in experimental techniques have complemented modeling with the experimental determination of structural properties. A milestone of this endeavor is the advent of digital Fourier transform analyzers. The experimental techniques are nurtured by the theory of modal analysis and in turn provide new impetus to it.**[44]**

1. What is modal analysis

Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior.**[45]** The formulated mathematical model is referred to as the modal model of the system and the information for the characteristics are known as its modal data. The dynamics of a structure are physically decomposed by frequency and position. This is clearly evidenced by the analytical solution of partial differential equations of continuous systems such as beams and strings. Modal analysis is based upon the fact that the vibration response of a linear time-invariant dynamic system can be expressed as the linear combination of a set of simple harmonic motions called the natural modes of vibration. This concept is akin to the use of a Fourier combination of sine and cosine waves to represent a complicated waveform. The natural modes of vibration are inherent to a dynamic system and are determined completely by its physical properties (mass, stiffness, damping) and their spatial distributions. Each mode is described in terms of its modal parameters: natural frequency, the modal damping factor and characteristic displacement pattern, namely mode shape. The mode shape may be real or complex. Each corresponds to a natural frequency.**[46]** The degree of participation of each natural mode in the overall vibration is determined both by properties of the excitation source(s) and by the mode shapes of the system. Modal analysis embraces both theoretical and experimental techniques. The theoretical modal analysis anchors on a physical model of a dynamic system comprising its mass, stiffness and damping properties. These properties may be given in forms of partial differential equations. An example is the wave equation of a uniform vibratory string established from its mass distribution and elasticity properties. The solution of the equation provides the natural frequencies and mode shapes of the string and its forced vibration responses. However, a more realistic physical model will usually comprise the mass, stiffness and damping properties in terms of their spatial distributions, namely the mass, stiffness and damping matrices. These matrices are incorporated into a set of normal differential equations of motion. The superposition principle of a linear dynamic system enables us to transform these equations into a typical eigen value problem. Its solution provides the modal data of the system. Modern finite element analysis empowers the discretization of almost any linear dynamic structure and hence has greatly enhanced the capacity and scope of theoretical modal analysis. On the other hand, the rapid development over the last two decades of data acquisition and processing capabilities has given rise to major advances in the experimental realm of the analysis, which has become known as modal testing.**[47]**

3.Application of Modal Analysis

Both theoretical and experimental modal analysis ultimately arrive at the modal model of a dynamic system. Compared with the FRF (frequency response functions) or the vibration response, the modal model explicitly portrays the dynamic characteristics of a system. Therefore, applications of modal analysis are closely related to utilizing the derived modal model in design, problem solving and analysis. Before embarking on the discussion of applications, it is important to refresh the two different paths from which a modal model is derived. Theoretical modal analysis relies on the description of physical properties of a system to derive the modal model. Such a description usually contains the mass, stiffness and damping matrices of the system. Thus, it is a path from spatial data to modal model. Experimental modal analysis obtains the modal model from measured FRF data or measured free vibration response data. Thus, it is a path from response data to modal model. Once the modal model is derived, a number of applications can be instigated. Some applications of modal analysis involve direct use of modal data from measurement while others use these data for further analysis.**[47]**

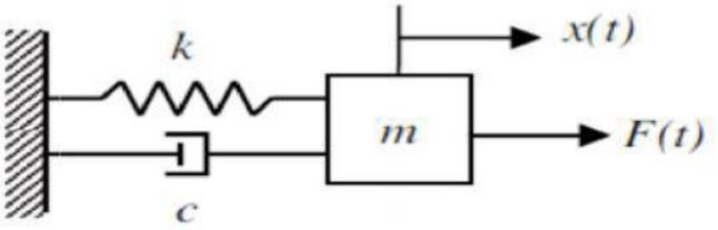
4. Mathematical formulation of modal analysis

I.4. Reminders on the dynamics of structures:

I.4.1. Introduction

In this part, we are interested in the basic notions of vibrations, starting with by the study of linear systems at a degree of freedom, we then broaden the field to the study of systems with N degree of freedom.

I.4.2. Study of one-degree-of-freedom systems :



The one-degree-of-freedom system is the most basic vibration model, but it is the basis for understanding systems with several degrees of freedom. The modelling of such a system is done by characterizing its constituent elements which are: a mass m (rigid body), a spring k (elastic element), and a shock absorber c (dissipative element).

The equation of motion of a system with a degree of freedom in the general case is given by:

$$M\ddot{x} + C\dot{x} + K\,x = F(t) \qquad (3.1)$$

1.4.2.1. Undamped free system :

The free regime describes the behavior of a system after an initial release, without Applying subsequent energy by an external force. In this case which is conservative The equation of motion is:

$$M\ddot{x}(t) + K\,x(t) = 0 \qquad (3.2)$$

His solution will be in the form of:

$$x(t) = A\ cos(w_0 t) + B\ sin\ (w_0 t) \tag{3.3}$$

With $\omega_0 = \sqrt{\frac{k}{m}}$: the system's own pulsation.

1.4.2.2. Cushioned free system :

The equation of motion of this system is:

$$M\ddot{x}(\ t) + C\dot{x}(t) + Kx(t) = 0. \tag{3.3}$$

Solving this equation is like solving a differential equation with constant coefficients. Dividing the terms of this equation by m, it Become:

$$\ddot{x} + 2\lambda\ \dot{x} + w^2{}_o = 0 \tag{3.4}$$

With$\lambda = \frac{c}{2m}$ is the damping factor. The damping factor is also defined by : $\xi = \frac{\lambda}{\dot{w}_0}$ The solution is form :

$$x(t) = Ae^{rt} \tag{3.5}$$

Its characteristic equation,

$$r^2 + 2\ \lambda\ r + w_0^2 = 0 \tag{3.6}$$

Depends on the value of the value of ξ, which can take three values ξ< 1, ξ = 1 ou ξ > 1.

a) Under-amortized (sub-critical) case: ξ < 1

The roots of the characteristic equation are complex

$r_{1,2} = -\xi \pm jw_0 \sqrt{(1 - \xi^2)}$And the displacement is no longer periodic, By replacing r1 and r2by their values in equation (I.2.6), we obtain :

$$x(t) = e - \xi w_0 t\ [A\ cos\ (w_0 \sqrt{1 - \xi^2\ t}\,) + B\ sin\ (w_0 \sqrt{1 - \xi^2\ t}\,)] \tag{3.7}$$

A and B are to be determined by the initial conditions of displacement and velocity.

b) Case on – damped (on – critical) : ξ >1

In this case the roots of the characteristic equation are real : $r_{1.2} = -\xi \pm w_0 \sqrt{\xi^2 - 1}$:

The solution of the differential equation of motion is :

$$x(t) = A\ e^{r1t} + B\ e^{r2t}. \tag{3.8}$$

c) Critical case ξ = 1 :

The equation will have a double root : $r_1 = r_2 = -\xi\ w = -w_0$, and the solution of the equation is:

$$x(t) = (A_1 + A_2 t\ )\ e^{-w_0 t} \tag{3.9}$$

Forced Motion (Harmonic Force) :

In this case, the second side of the differential equation is not zero. The Solution is the sum of the solution of the free motion and a particular solution of equation. Quite often we are only interested in steady-state motion. That is to say, we will take into account that the particular solution.

Let us take a sinusoidal force applied to the mass m:

$$F(t) = f_0 \, sin \, (wt). \tag{3.10}$$

w : is the pulsation of the excitation force.

Hence the solution is in the form of : $x(t) = x_H(t) + x_P(t)$.

And as we mentioned above, we will take into account that the particular solution (xp(t)), which is in the form:

$$x_P(t) = A \, sin \, (w \, t + Q) \tag{3.11}$$

With Q: phase shift of the response with respect to the excitation.

1.4.3 Study of systems with n degrees of freedom :

In this part, we will present the method of solving undamped systems with n degrees of freedom, the system of differential equations of motion can be put in the following matrix form:

$$[K]\{x\} + [C]\{\dot{x}\} + [M]\{\ddot{x}\} = \{0\} \tag{3.12}$$

In the case of an undamped free system, equation (3.12) becomes:

$$[K]\{x\} + [M]\{\ddot{x}\} = \{0\} \tag{3.13}$$

The solution of equation (3.13) is in the form:

$$x\{t\} = \{X\} \, e^{jwt} \tag{3.14}$$

Replacing the expression (3.14) and its second derivative in the equation of motion, we will have:

$$[K - w^2 M] \{X\} e^{jwt} = 0 \tag{3.15}$$

By simplifying by e^{jwt} the solution (3.15) becomes:

$$[K - w^2 M] \{X\} = 0 \tag{3.16}$$

Equation (I.2.19) is an eigenvalue problem. The characteristic equation is in the form:

$$det \, [(K) - w^2 (M)] = 0 \tag{3.17}$$

Chapter IV: Applications and Results

1. Modeling and Analysis of a Chassis Frame

1.1 Introduction

Frame of a vehicle is act like a skeleton it holds all the important component of a automobile like engine, steering systems, suspension, drive line, differential and all the essential components which constitute together to form a chassis. Chassis Frame must be stiff enough to withstand all the forces and loads acting on it statically and dynamically and forces like shock, twist and vibration. Composite material like carbon fiber and E-glass Epoxy fiber recently gained a wide acceptance in the automobile industry due to their light weight and high strength as compare to conventional automobile frame which is manufactured from steel and its alloy. Increasing demand of highly efficient and less weight automobile's have made the researcher to do brain storming to search new materials and composite materials gained wide attention to be introduced in auto vehicle due to their less dense and high strength and stiff in nature.**[49]**

1.2 Types of chassis frame

Cruciform frame:

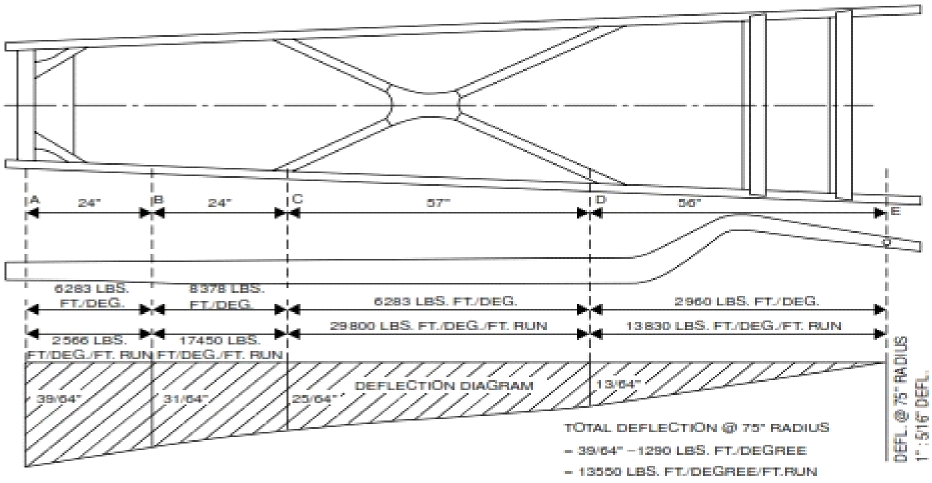


Figure 4.1 Cruciform braced chassis frame (Booth 1938 Council of I.Mech.E.)

It is a frame to carry torsion loads where no element of the frame is subject to a torsion moment and is made of two straight beams and a center X shaped cross member. It will only have bending loads applied to the beams. This type of frame has good torsional stiffness provided the joint at the center is satisfactorily designed.

Space frame:

Figure 4.2 Space frame structure

In this type, the suspension, engine, and body panels are attached to a three-dimensional skeletal frame of tubes and the body panels have little or no structural function. To maximize rigidity and minimize weight, the design makes maximum use of triangles and all the forces in each strut are either tensile or compressive, never bending, so they can be kept as thin as possible.

Ladder frame:

It is clear from its name that the ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by lateral and cross braces. This design offers good beam resistance because of its continuous rails from front to rear, but poor resistance to torsion or warping.

DETAILS OF CHASSIS FRAME

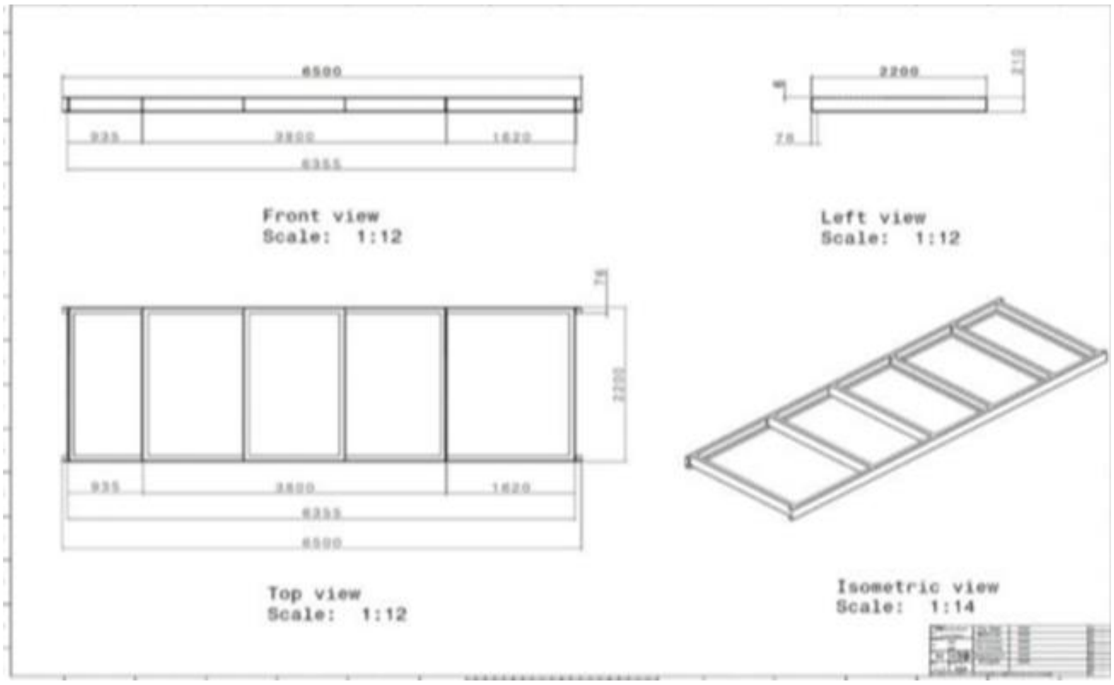


Figure 4.3 : 2D Model- EICHER 11.10

Side bar cross section= 210mm×76mm×6mm

Number of side bar= 2

Number of cross bar= 6

Channel = C- channel

Rear overhang= 1620mm

Front overhang= 935mm

Wheel base= 3800mm

Capacity of truck =8 ton

Weight of body and engine= 2 ton

Load Acting on Chassis Frame =8000 Kg = 78480N

Engine and Body Weight = 2000Kg = 19620N

Over loaded Truck Capacity = 1.25%×78480=98100N

Total Load on Chassis Frame = 19620+98100=117720N

Load Acting on single frame = Total load/2= 58860N

1.3 Material Properties

Table4.1 MATERIAL PROPERTIES

.No	Properties	Units	Steel- 52	Carbon Fiber	E-Glass Epoxy Fiber
1	Density	Kg/m^3	7850	1750	1800
2	Young's Modulus	GPA	200	230	40.3
				15	6.21
				15	3.07
3	Poisson Ratio	-	0.3	0.28	0.2
				0.28	0.2
				0.28	0.2
4	Ultimate tensile strength	Mpa	520	500	827

1.4 CAD Design of Chassis Frame (Computer assisted Drawing)

Solid Works 2022 is used to model the chassis frame of Eicher11.10 of the chassis frame as shown in Figure 4.2 below.

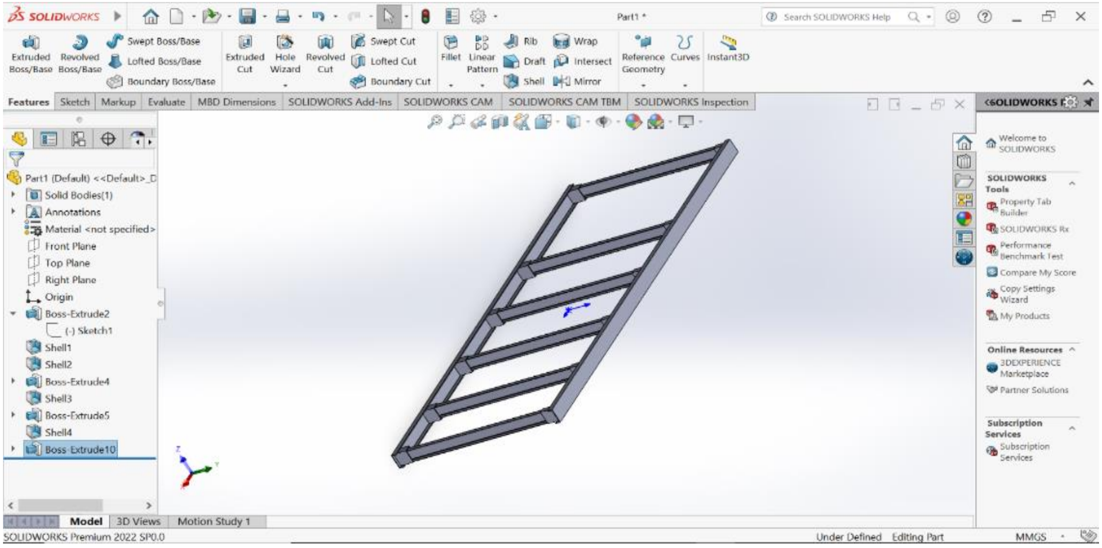


Figure 4.4 Chassis Frame Model 11.10

1.4 Meshing of the Chassis Frame

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems FEM subdivides a large problem into smaller, simpler, parts, called finite elements .Meshing of chassis frame is done in Solid Works Simulation. The size of elements is kept as minimum as possible to get the accurate results and at some points the finer meshing is also done to get better results. Figure 4.3 clearly shown.

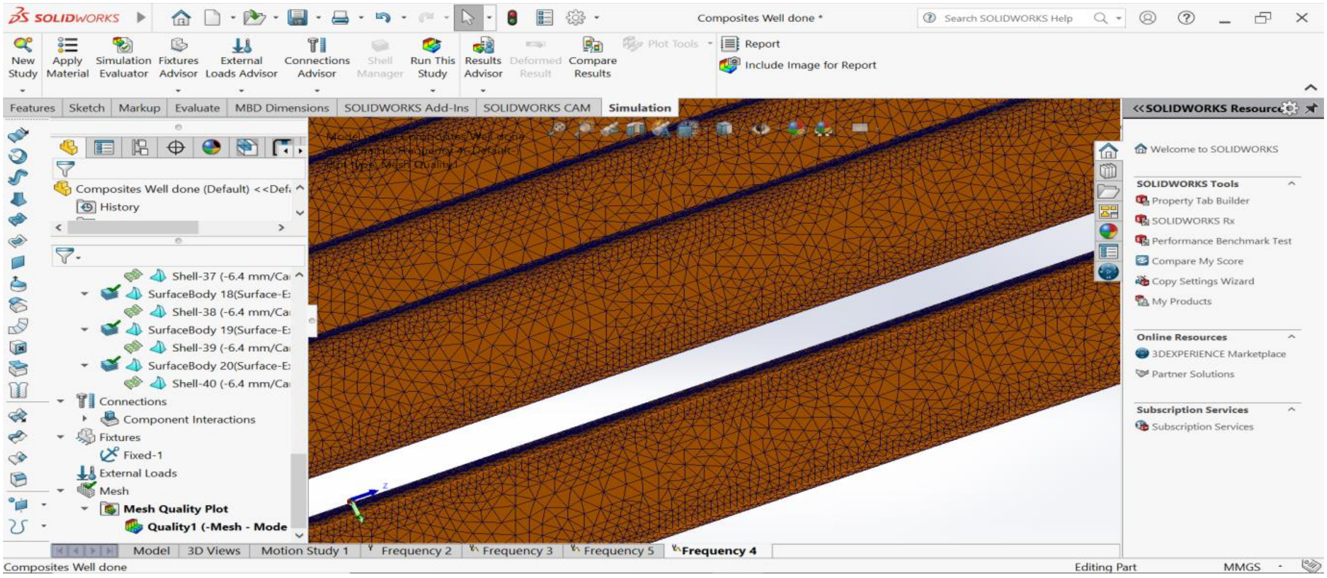
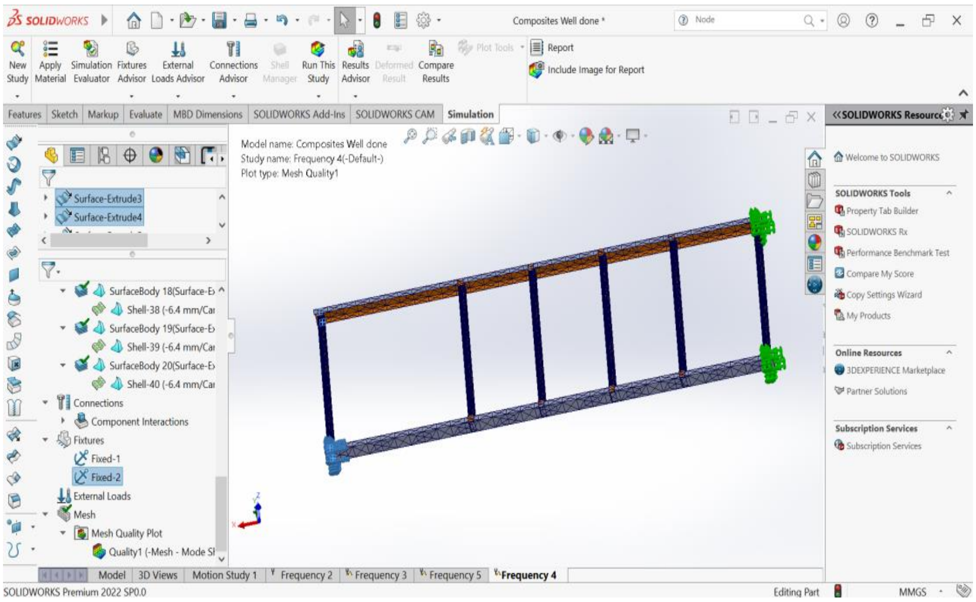


Figure 4.5 Chassis Frame Meshing

the meshing of the chassis frame which is been done in SolidWorks 2022 Simulation

1.6 Boundary conditions for Modal Analyzing

While doing software based analysis there is need to apply boundary conditions. In Modal analysis the front and rear are fixed in order to have an axial load on the chassis, there is no need to apply loading conditions while doing modal analysis, natural frequencies of chassis frame outcome in modal analysis. Boundary conditions for modal analysis is shown in Figure 4.4



Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Mesh Quality1

Figure 4.6 Boundary conditions for Modal Analysis

1.7 Modal Analysis of chassis Frame Eicher 11.10

Modal analysis is used to judge the behavior of a body under vibrational conditions and corresponding natural frequency is determine Dynamic analysis can predict these variables with respect to time/frequency. To determine natural frequency of the component its basic design property. Natural frequency information is also helpful for avoiding resonance, reducing noise.

The intention of doing the modal analysis is to determine the natural frequency of chassis frame at which maximum deformation incur into the chassis frame so that this maximum deformation natural frequency is used as input in harmonic analysis and corresponding stress is taken as out of all the materials that has been used in this analysis.

1.7.1 Frequency study of Steel

Steel is widely used in the auto industry for its a high-strength material, particularly in tension, and can be used for structural loads. It is also highly durable and may last for almost a 100 years

Using steel as base for our comparative study in order to see if composite materials are better suited for making a chassis.

Table 4.2 Natural Frequency Results Steel-52

Modes	Frequency(Rad/s)	Frequency(Hertz)	Deformation
1	63.927	10.174	8.06783
2	152.41	24.257	9.82802
3	152.64	24.294	6.77121
4	190.43	30.308	9.1552
5	271.86	43.269	9.65283

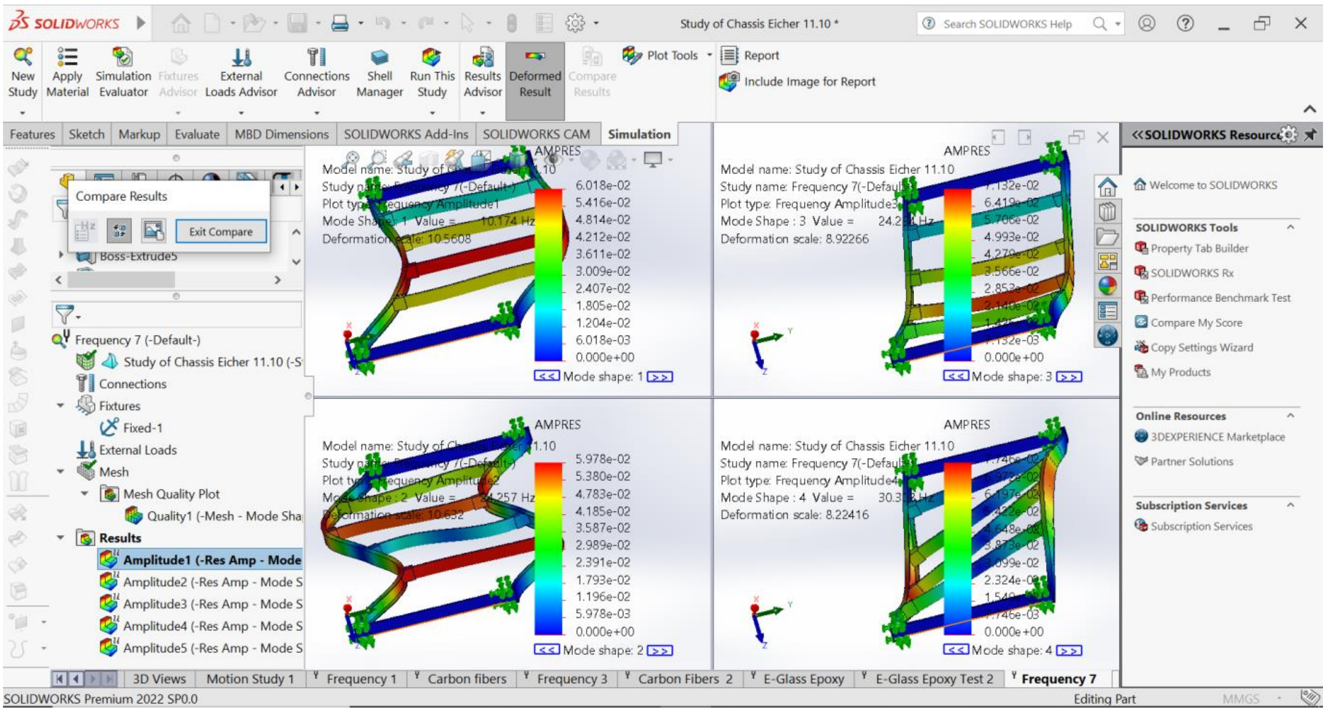


Figure 4.7 Deformed Shapes and modes Steel-52

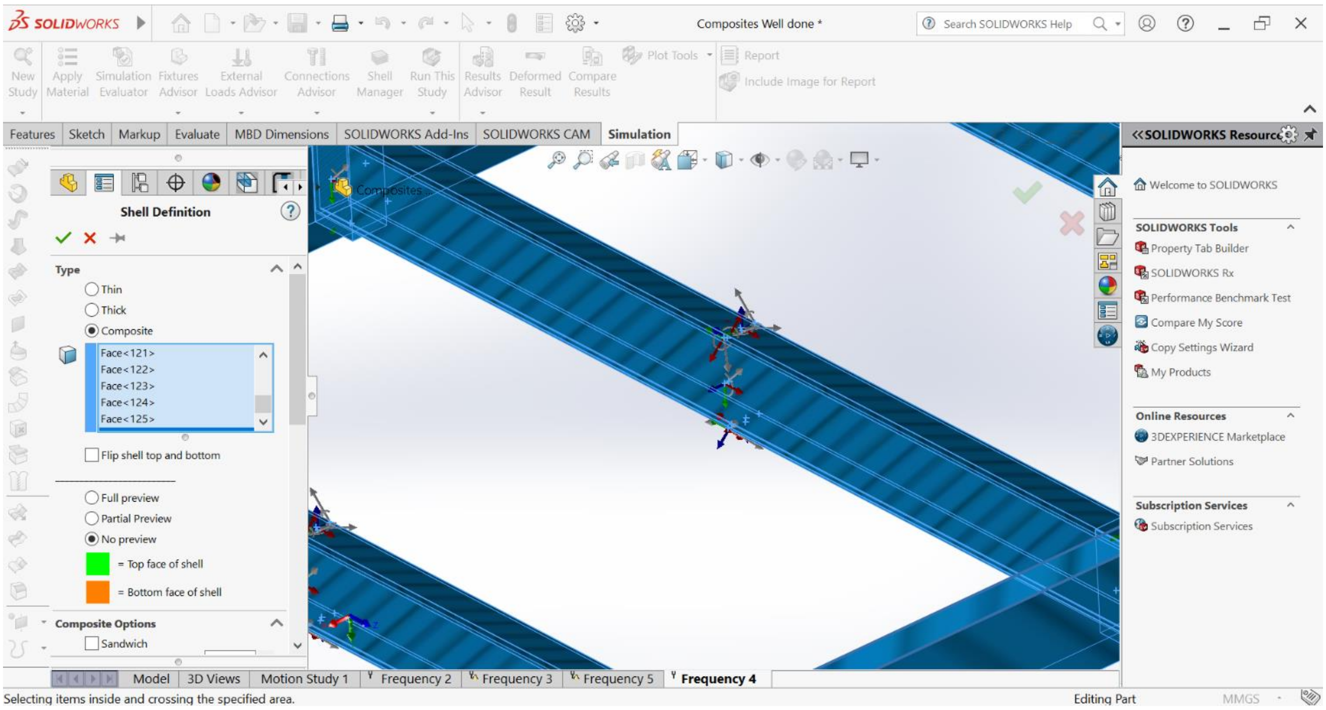
1.8 Parametric Study

1.8.1 Effects of the material

Using the Same Geometric properties with two different materials from table 4.1

The Thickness Used is tp=0.25 mm

Ply Orientation $(0/90/+45/-45)_{2s}$



Shell Definition

Type

○ Thin
○ Thick
● Composite

Face<121>
Face<122>
Face<123>
Face<124>
Face<125>

☐ Flip shell top and bottom

○ Full preview
○ Partial Preview
● No preview

🟩 = Top face of shell
🟧 = Bottom face of shell

Composite Options

☐ Sandwich

Selecting items inside and crossing the specified area.

Editing Part MMGS

Figure 4.8 Composite layers orientation

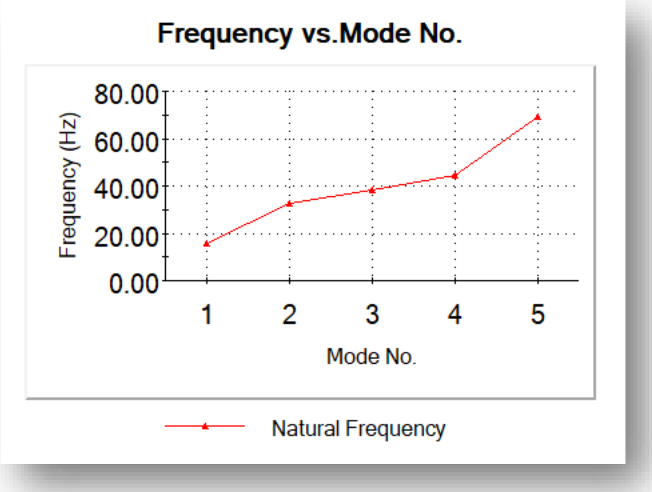
We had this results using Solid Works simulation.

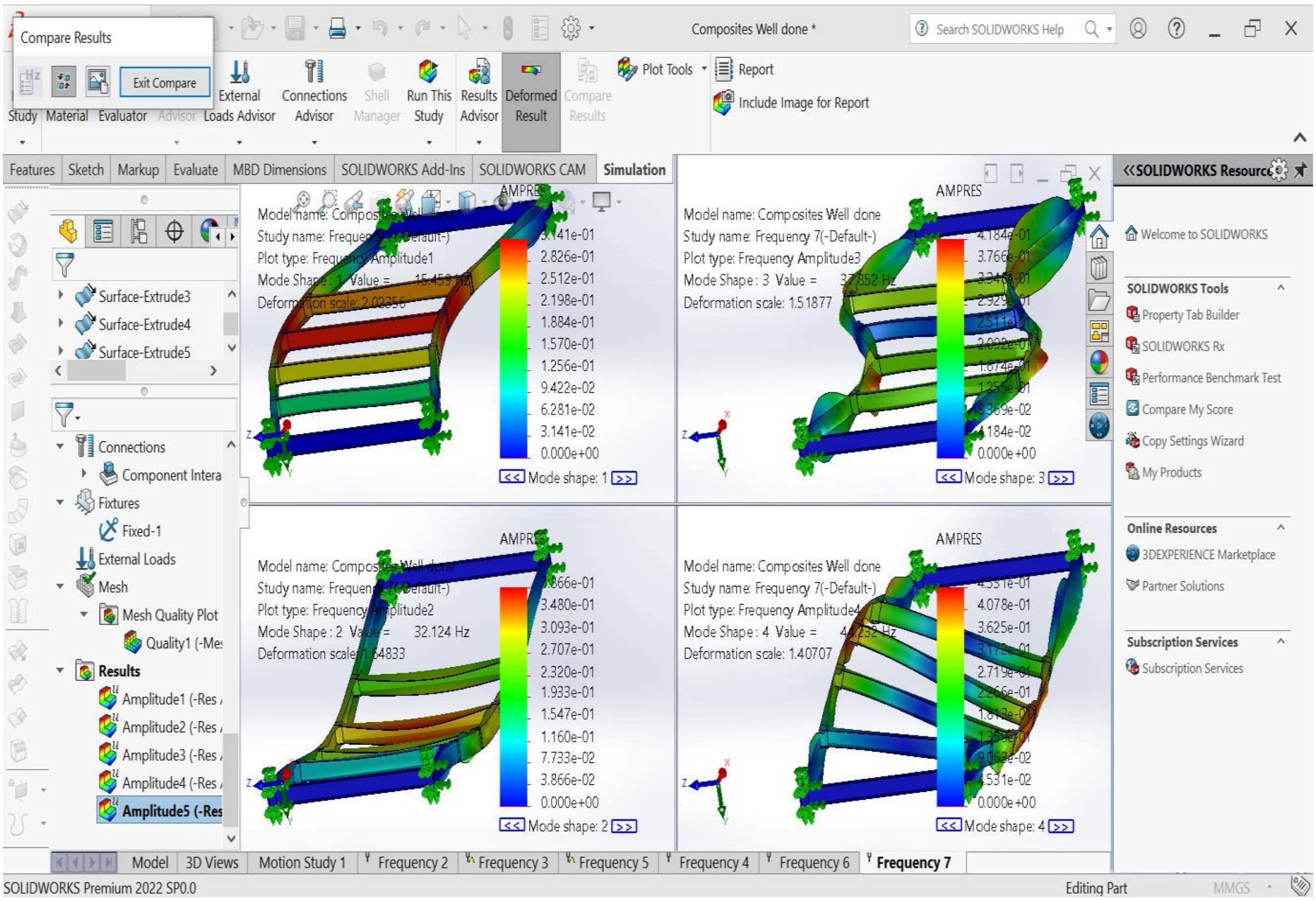
Table 4.3 Frequency and Deformation Results

Carbon Fibers			**E-Glass Epoxy**		
Mode	**Frequency(Hertz)**	**Deformation**	**Mode**	**Frequency(Hertz)**	**Deformation**
1	15.459	2.0234	1	7.0804	6.6071
2	32.124	1.6483	2	14.508	5.9001
3	37.852	1.5187	3	17.581	5.5274
4	44.232	1.4070	4	19.984	4.6371
5	49.536	0.3246	5	31.666	6.1721

Frequency analys graph

Every structure has has a tendecy to vibrate at certain frequencies, called naturale frequencies





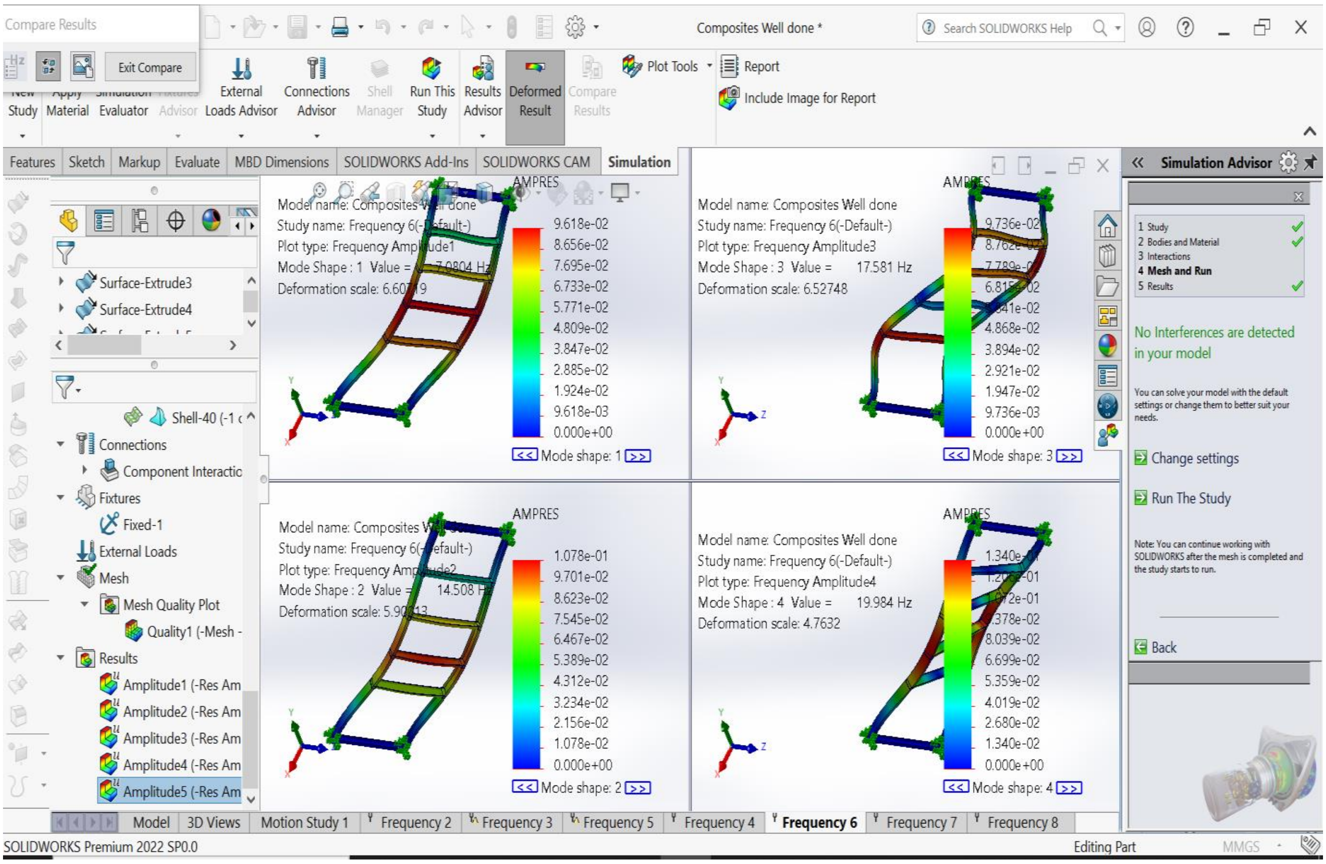
Model name: Composites Well done
Study name: Frequency 7(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 15.459 Hz
Deformation scale: 2.02356

Model name: Composites Well done
Study name: Frequency 7(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 37.852 Hz
Deformation scale: 1.51877

Model name: Composites Well done
Study name: Frequency 7(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 32.124 Hz
Deformation scale: 1.64833

Model name: Composites Well done
Study name: Frequency 7(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 44.232 Hz
Deformation scale: 1.40707

Figure 4.9 Carbon Fibers Chassis Deformed Shapes and modes



Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 7.0804 Hz
Deformation scale: 6.60719

Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 17.581 Hz
Deformation scale: 6.52748

Model name: Composites W
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 14.508 Hz
Deformation scale: 5.90[illegible]13

Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 19.984 Hz
Deformation scale: 4.7632

No Interferences are detected in your model

You can solve your model with the default settings or change them to better suit your needs.

Note: You can continue working with SOLIDWORKS after the mesh is completed and the study starts to run.

Figure 4.10 E-Glass Epoxy Chassis Deformed Shapes and modes

As we clearly can see from Table 4.3 the frequency values of carbon fibers are higher that of E-Glass Epoxy because of the Difference between the material properties of the said materials one such property is Young’s modulus and also the density .

We can also notice from Figure 4.7 and 4.8 that the chassis has been deformed by effects of Flexion and Twisting . Therefore we can conclude that E-Glass Epoxy has a lower stiffness than Carbon fibers because it has a smaller natural frequency.

1.8.2 Stacking Sequence effects

In this study we are going to observe the effects of applying different ply orientation settings to our two materials using the same thickness value . tp=0.25 mm . And with same material properties

Plies orientations used:

a-$(0/90/+45/-45)_{2s}$

b-$(0/90/0)_{10}$

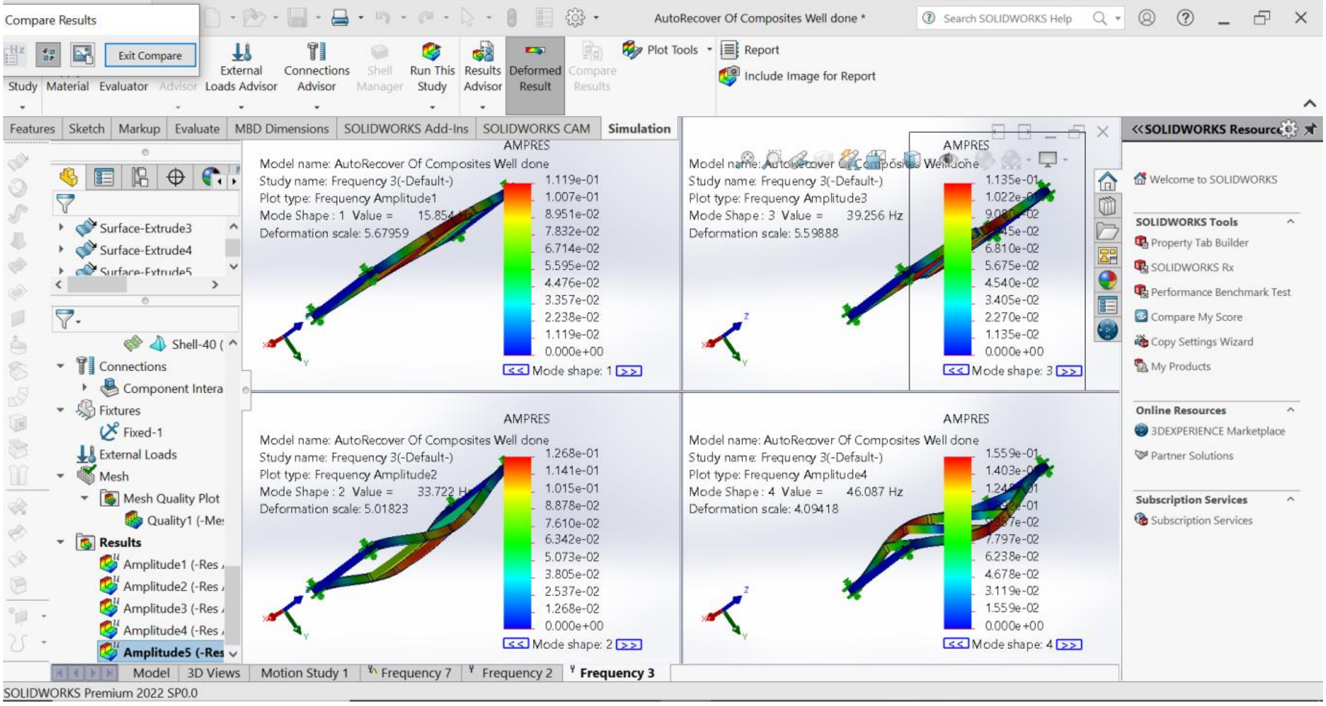
c-$(0/90/0)_{15}$

a- Using the first Orientation settings we get the previous results while retaining the same Material properties and thickness as mentioned in table 4.3 and figures 4.6 – 4.7 above .

b- Using the second Orientation settings we found the following results

Table 4.4 Frequency and Deformation Results

Carbon Fiber			E-Glass Epoxy		
Mode	Frequency(Hertz)	Deformation	Mode	Frequency(Hertz)	Deformation
1	15.854	5.6795	1	7.1907	5.5795
2	33.722	5.0188	2	15.109	5.1007
3	39.256	5.5988	3	17.81	5.6629
4	46.087	4.0941	4	20.686	4.1337
5	69.718	5.2508	5	31.667	5.3336



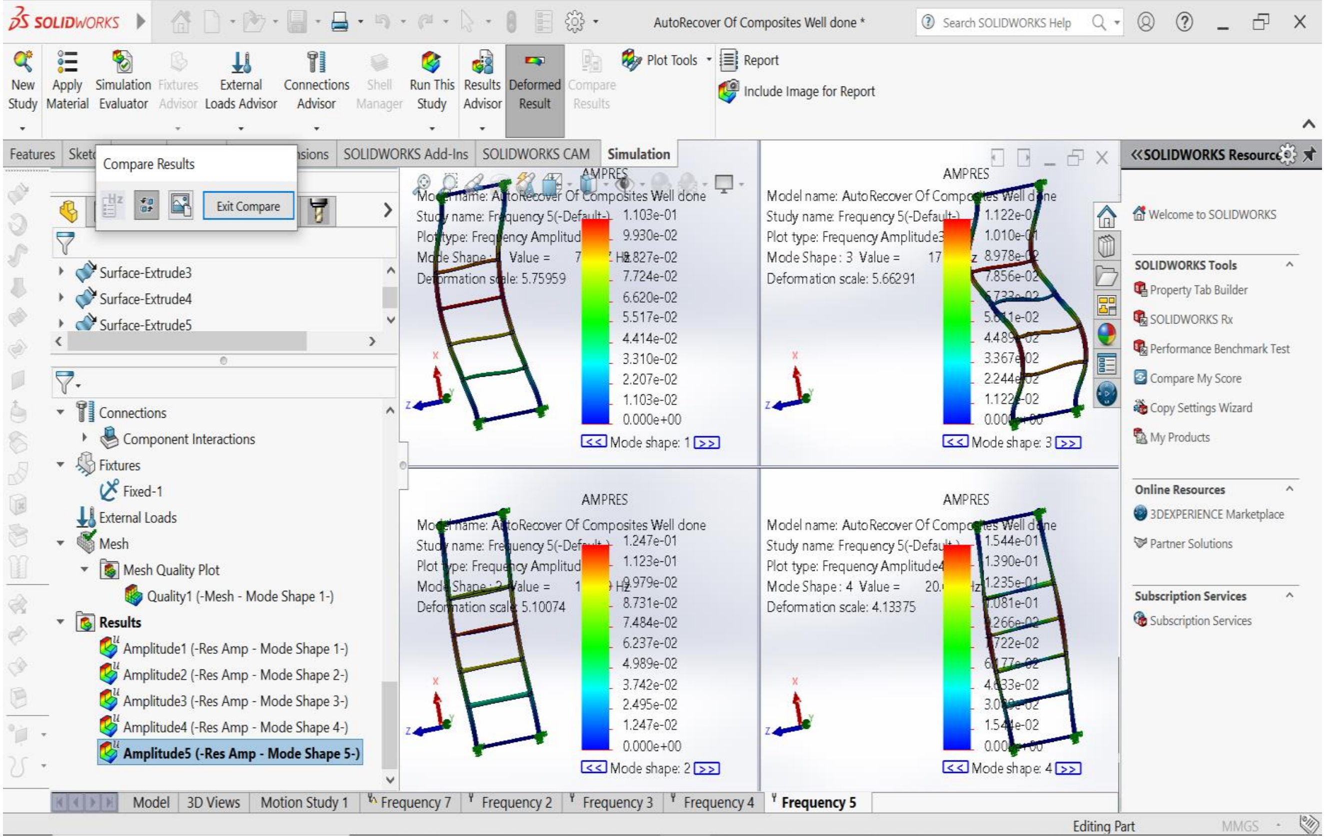
Model name: AutoRecover Of Composites Well done
Study name: Frequency 3(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 15.854 Hz
Deformation scale: 5.67959

Model name: AutoRecover Of Composites Well done
Study name: Frequency 3(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 39.256 Hz
Deformation scale: 5.59888

Model name: AutoRecover Of Composites Well done
Study name: Frequency 3(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 33.722 Hz
Deformation scale: 5.01823

Model name: AutoRecover Of Composites Well done
Study name: Frequency 3(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 46.087 Hz
Deformation scale: 4.09418

Figure 4.11 Carbon Fibers Chassis Deformed shapes and modes



Model name: AutoRecover Of Composites Well done
Study name: Frequency 5(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 17
Deformation scale: 5.66291

Model name: AutoRecover Of Composites Well done
Study name: Frequency 5(-Defau
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 20.
Deformation scale: 4.13375

Deformation scale: 5.75959

Deformation scale: 5.10074

Figure 4.12 E-Glass Epoxy Chassis Deformed shapes and modes

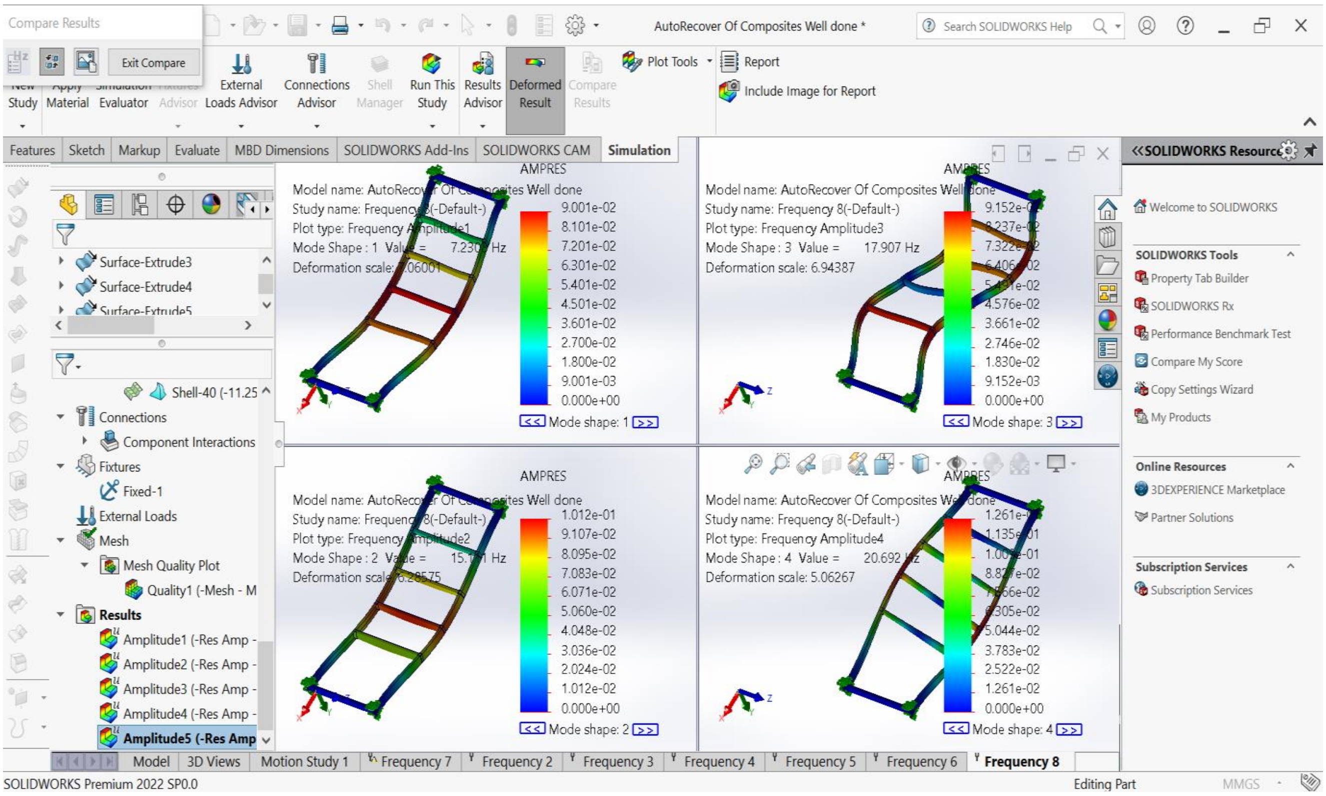
In case of the carbon fibers, as we observe the chassis deformed shapes in modes 1,2,3 its clear that the chassis is flexed with the flesh getting bigger with each mode . As for mode 4 the chassis is under the effect of a mixture of flexion and twisting as shown in Figure 4.9

In case of the E-Glass Epoxy, we can see in modes 1.2. That the chassis is bending. We call this phenomena by flexion, while in mode 3 the chassis is under the effect of a double flexion as its shown in figure 4.10 .

c- Using the third orientation settings we find the following results :

Table 4.5 Frequency and deformation Results

Carbon Fibers			**E-Glass Epoxy**		
Mode	**Frequency(Hertz)**	**Deformation**	**Mode**	**Frequency(Hertz)**	**Deformation**
1	15.973	6.9629	1	7.2308	7.06001
2	33.728	6.1785	2	15.111	6.28575
3	39.533	6.8651	3	17.907	6.9438
4	46.086	5.0140	4	20.692	5.0667
5	70.138	6.4278	5	31.1818	6.52828



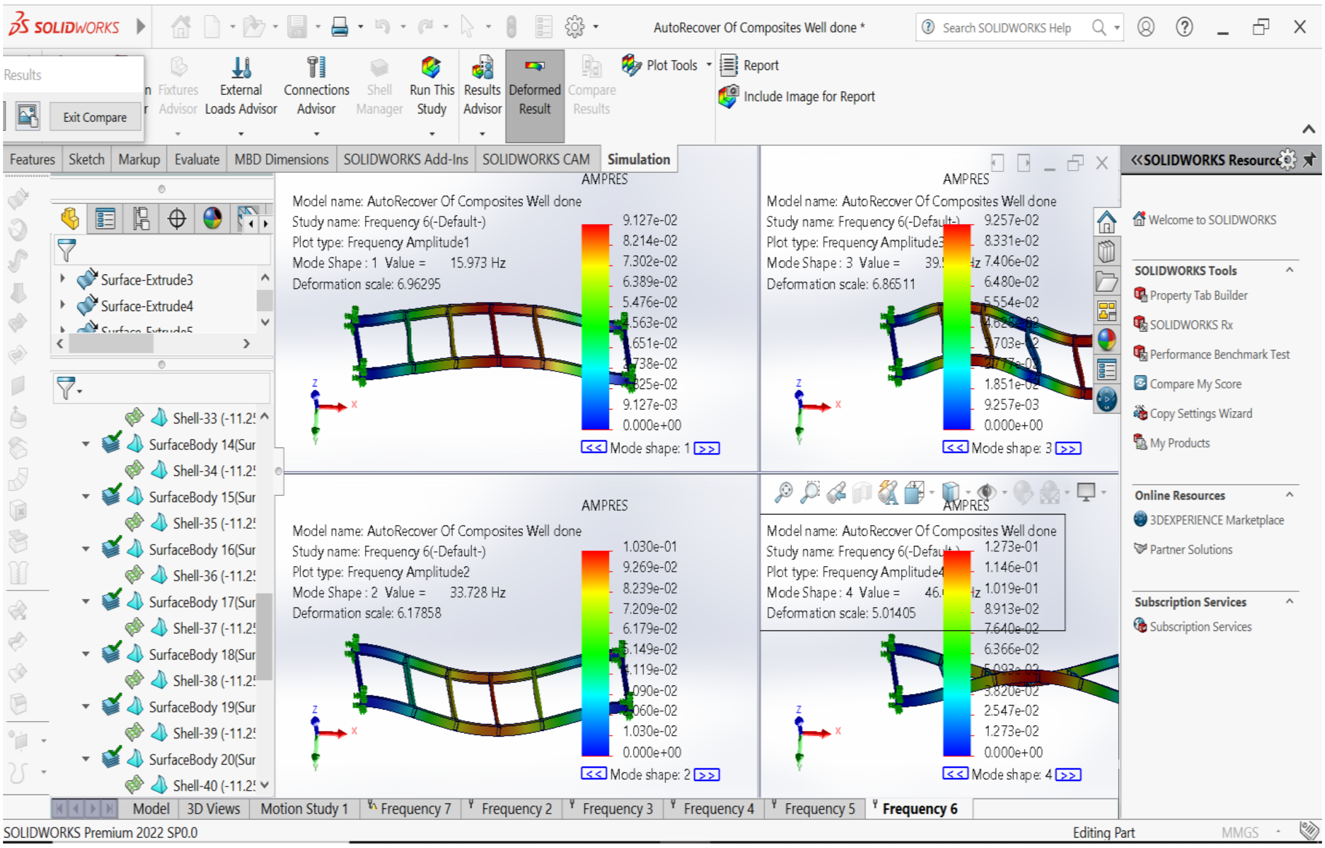
Model name: AutoRecover Of Composites Well done
Study name: Frequency 8(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 7.230 Hz
Deformation scale: 6.06001

Model name: AutoRecover Of Composites Well done
Study name: Frequency 8(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 17.907 Hz
Deformation scale: 6.94387

Model name: AutoRecover Of Composites Well done
Study name: Frequency 8(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 15.711 Hz
Deformation scale: 6.28575

Model name: AutoRecover Of Composites Well done
Study name: Frequency 8(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 20.692 Hz
Deformation scale: 5.06267

Figure 4.13 E-Glass Epoxy Chassis Deformed shapes and modes



Model name: AutoRecover Of Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 15.973 Hz
Deformation scale: 6.96295

Model name: AutoRecover Of Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 39.5 Hz
Deformation scale: 6.86511

Model name: AutoRecover Of Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 33.728 Hz
Deformation scale: 6.17858

Model name: AutoRecover Of Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 46. Hz
Deformation scale: 5.01405

Figure 4.14 Carbon Fibers Chassis Deformed shapes and modes

From both the figures 4.11 and 4.12 we notice that the chassis is flexing and twisting more than the previous study possibly due to the increase of the thickness of the chassis since we added more layers to the stacking sequence .

Analyzing the data from Tables 4.4 , 4.5 , the values of Frequency of Carbon Fibers is almost identical .Same thing can be said about E-Glass Epoxy however there is a significant increase in the deformation value for both of our Materials so we can say that changing the orientation of the composites layers decreases the resistence of the said material .

1.8.4 Effects of the layer thickness

After analyzing the effects of the material properties and the ply orientation now we are going to study the effects of the layer thickness and how it is going to impact the frequency and the deformation of the carbon fibers and E-Glass Epoxy using two different thickness values

Stacking Sequence : $(0/90/+45/-45)_{2s}$

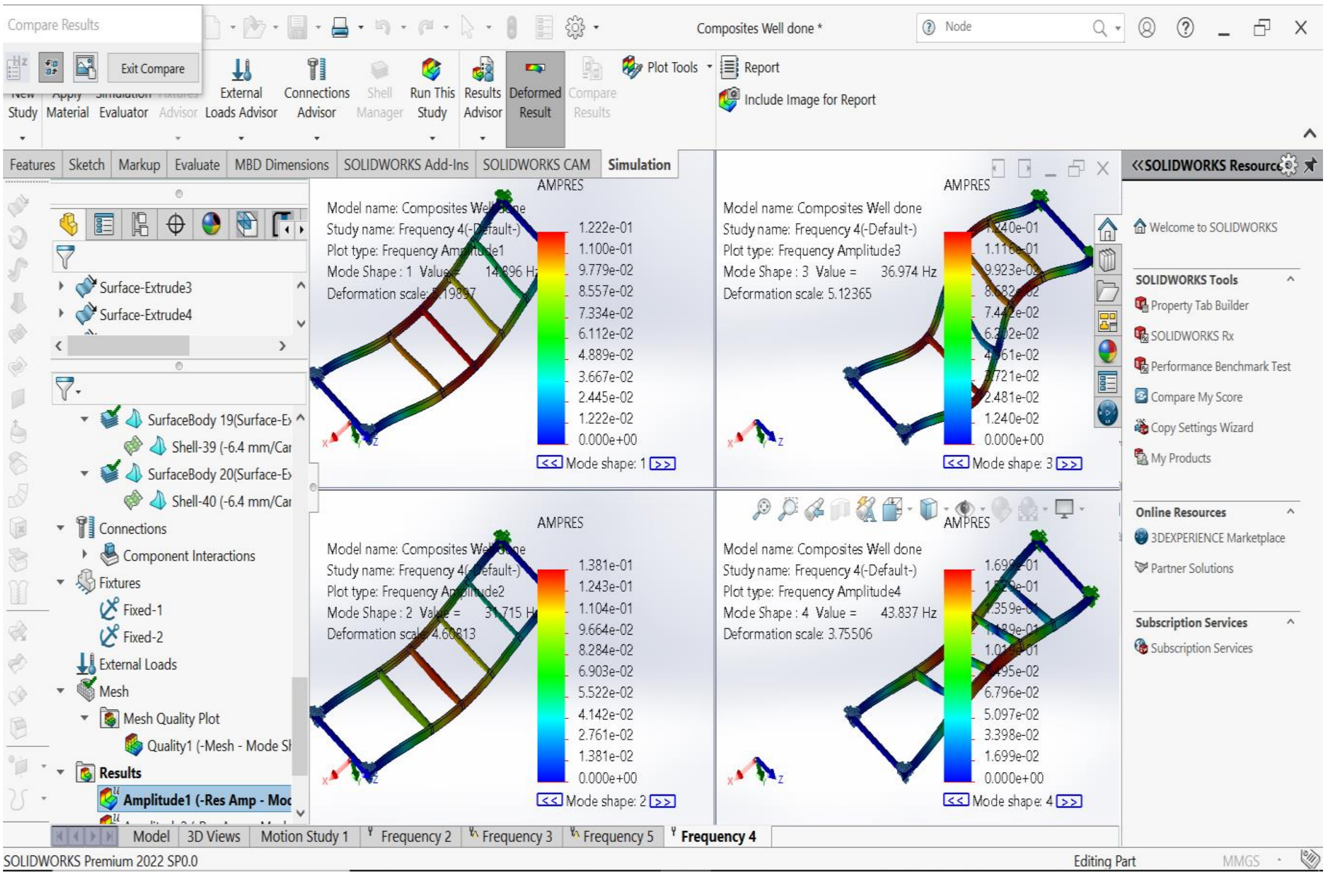
a- Tp=0.4 mm

b- Tp=0.6 mm

a-Using the first Value we find this results tp=0.4mm

Table 4.6 Frequency and Deformation Results

Carbon Fibers			E-Glass Epoxy		
Mode	Frequency(Hertz)	Deformation	Mode	Frequency(Hertz)	Deformation
1	14.896	5.1987	1	6.8937	5.2787
2	31.715	4.6081	2	14.62	4.6788
3	36.974	5.1236	3	17.108	5.2012
4	43.837	3.7550	4	20.191	3.8009
5	66.747	4.8768	5	30.835	4.9441



AMPRES

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 14.896 Hz
Deformation scale: 5.19897

AMPRES

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 36.974 Hz
Deformation scale: 5.12365

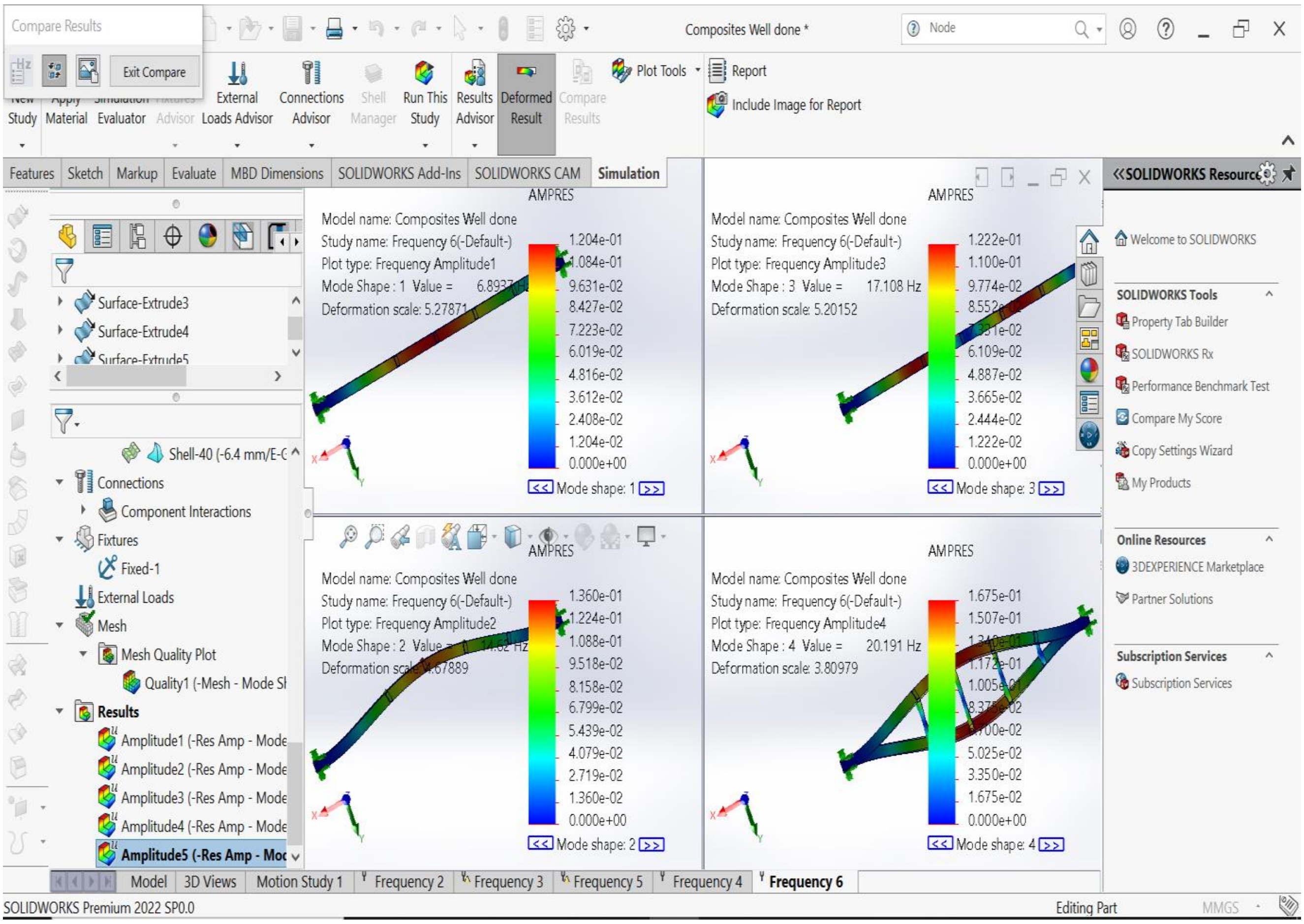
AMPRES

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 31.715 Hz
Deformation scale: 4.60813

AMPRES

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 43.837 Hz
Deformation scale: 3.75506

Figure 4.15 Carbon Fibers Chassis Deformed Shapes and modes



AMPRES

Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 6.893
Deformation scale: 5.27871

AMPRES

Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 17.108 Hz
Deformation scale: 5.20152

AMPRES

Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 14.62 Hz
Deformation scale: 4.67889

AMPRES

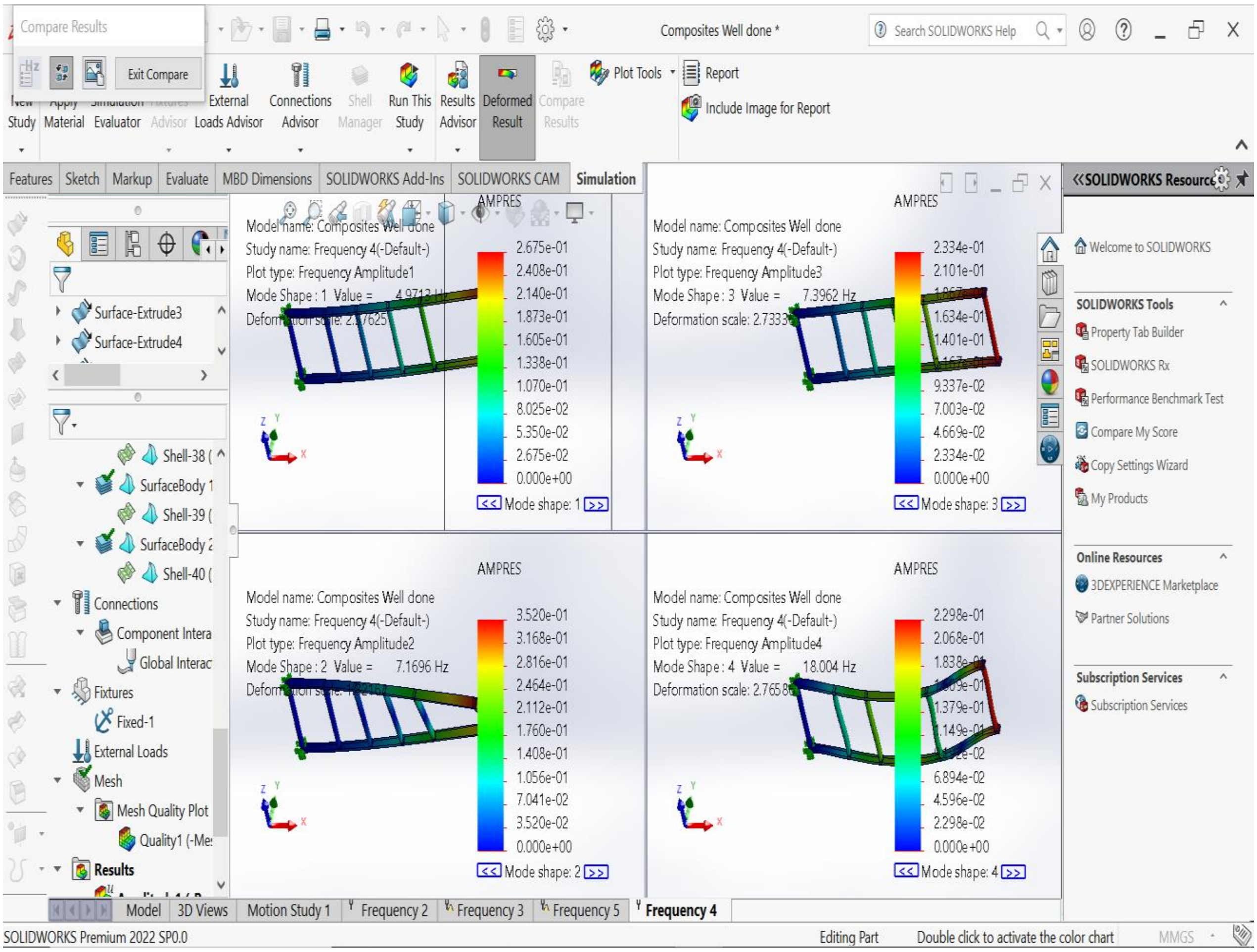
Model name: Composites Well done
Study name: Frequency 6(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 20.191 Hz
Deformation scale: 3.80979

Figure 4.16 E-Glass Epoxy Chassis Deformed shapes and modes

b-Using the second value we find this results tp=0.6mm

Table 4.7 Frequency and Deformation Results

Carbon Fibers			E-Glass Epoxy		
Mode	Frequency(Hertz)	Deformation	Mode	Frequency(Hertz)	Deformation
1	14.911	6.3718	1	6.456	6.4915
2	31.711	5.6884	2	14.421	5.7937
3	37.013	6.2836	3	16.672	6.4032
4	43.839	4.8988	4	19.908	4.6767
5	66.807	5.6970	5	30.092	6.0569



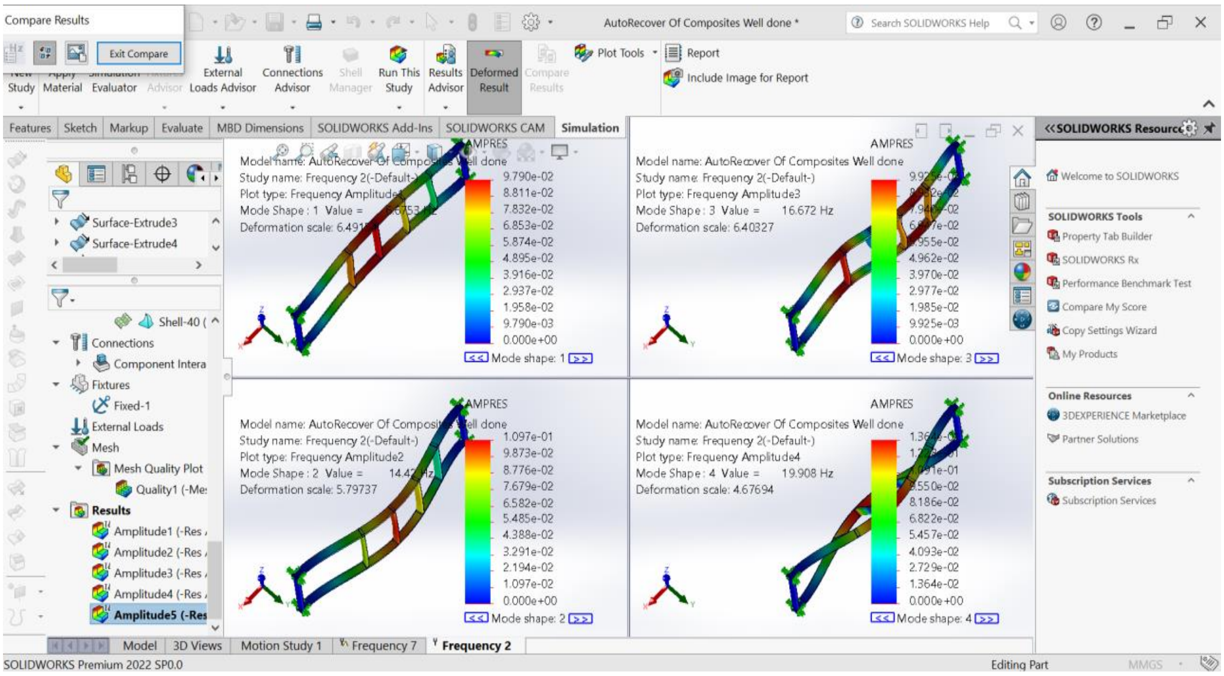
Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 4.9713 H
Deformation scale: [illegible]

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 7.3962 Hz
Deformation scale: 2.7333

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 7.1696 Hz
Deformation scale: [illegible]

Model name: Composites Well done
Study name: Frequency 4(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 18.004 Hz
Deformation scale: 2.7658

Figure 4.17 Carbon Fibers Chassis Deformed Shapes and modes



Model name: AutoRecover Of Composites Well done
Study name: Frequency 2(-Default-)
Plot type: Frequency Amplitude1
Mode Shape : 1 Value = 6.6753 Hz
Deformation scale: 6.491

Model name: AutoRecover Of Composites Well done
Study name: Frequency 2(-Default-)
Plot type: Frequency Amplitude3
Mode Shape : 3 Value = 16.672 Hz
Deformation scale: 6.40327

Model name: AutoRecover Of Composites Well done
Study name: Frequency 2(-Default-)
Plot type: Frequency Amplitude2
Mode Shape : 2 Value = 14.42 Hz
Deformation scale: 5.79737

Model name: AutoRecover Of Composites Well done
Study name: Frequency 2(-Default-)
Plot type: Frequency Amplitude4
Mode Shape : 4 Value = 19.908 Hz
Deformation scale: 4.67694

Figure 4.18 E-Glass Epoxy Chassis Deformed shapes and modes

Looking at the values form table 4.6 and 4.7 , we can notice that there is almost no increase in natural frequency and deformation since the change in thickness is insignificant, but carbon fibers still have higher natural frequency than E-Glass Epoxy most likely due to the E-Glass epoxy's low stiffness.

From Figures 4.15 , 4.16, 4.17 ,4.18 its clear that carbon fibers shows a higher stiffness than E-glass epoxy as it is not bending as much as E-glass epoxy does .

Conclusion

After analyzing all the previous data and performing the needed simulations its evident that carbon fiber has managed to surpass both steel-52 and E-glass Epoxy in terms of stiffness and vibration resistance due to fact that it can withstand higher natural frequencies than both of the said materials , though either material is substantially stronger than steel, industrial carbon fiber is more than 20 percent stronger than the best E-Glass Epoxy. Carbon fiber boasts a strength to weight ratio roughly twice that of E-Glass Epoxy.

Compared to metals like steel, both carbon fiber and E-glass epoxy materials are remarkably light in weight given their inherent strength. In environments and applications in which minimal weight is imperative (aerospace or car racing, for example) both materials are in high demand and used quite frequently. Typically, however, carbon fiber weighs about 15% less than E-Glass Epoxy composites.

But in terms of costs generally, E-Glass Epoxy components are viewed as more cost-effective as compared to their carbon fiber counterparts. This is due in large part to the fact that fiberglass is used in a wider range of applications and manufacturing costs are significantly lower. Carbon fiber manufacturing is a much more involved process and there are fewer established manufacturers in the industry.

Both E-Glass Epoxy and carbon fiber boast excellent strength to weight ratios and are the superior and preferred material for a range of practical and industrial applications. However to say that they can or should be used more often would be inaccurate.

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