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Carbon Fiber Material Analysis for Bicycle Frame using Finite Element Analysis

Mohammed Abuzar Shaikh[1,*], Siuli Das[2], Diptee Patil[3], Prashant Jadhav[4]

Abstract

This Research is based on Carbon fiber composite material for Bicycle frame analysis using Finite Element Analysis (FEA). Carbon fiber composite materials have become increasingly popular in the production of high-performance bike frames, primarily due to their superior strength, lightweight nature, and advanced mechanical properties. The primary objective of this research is to assess the structural reliability of bike frames using finite element analysis (FEA). This approach enables an in-depth evaluation of stress distribution and deformation across critical sections of the frame under various loading conditions. By employing FEA, the study aims to understand how different design configurations influence overall performance, specifically focusing on optimizing strength and stiffness while reducing weight. One of the key aspects of this research is to design frames that not only exhibit enhanced strength but also maintain durability over prolonged usage. The analysis provides valuable insights into how the material behaves under real-world stress scenarios, ensuring that the bike frame can withstand extensive use without compromising structural integrity. This research can contribute significantly to the development of more efficient, high-performance bike frames, offering cyclists better durability and improved ride quality.

Keywords: Carbon fiber material, bicycle frame, finite element analysis (FEA), ansys, tensile strength.

INTRODUCTION

The Choice of materials for construction bicycle frames has involved over the years with a focus on achieving optimal strength, durability and customization possibilities [1]. the bike is construct using advanced carbon fiber materials. Carbon fiber knowing for its excellent high tensile strength lightweight and strong Structures [2–9]. This construction not only enhances the bike performance by reducing overall load and ensure strength and resistance to wear and tear which provided that a longer duration for bike [10, 11]. Carbon Fiber is higher tensile strength, shear strength, flexural strength and corrosion resistance material [12, 13]. it can be resisting higher loads and stresses without deformation or failure.

The Aluminum and steel have been used for numerous decades [14] but Carbon Fiber material popularity rise as a Production techniques and material advancements enhanced. Carbon fiber allows for complex designs, aerodynamic shapes and customizable ride quality. It makes the top choice for cyclists seeking the latest in technology and performance. Carbon fiber has become a reputed in industry for those who prioritize lightweight approachable bike frames. Carbon fiber is a lightweight and strong material [13] that

*__Author for Correspondence__
Mohammed Abuzar Shaikh
E-mail: abuzzul_dsneng98@yahoo.com

[1-4]Student, Department of Instrumentation Engineering, Ramrao Adik Institute of Technology, D.Y. Ptil Deemed to be University, Nerul, Navi Mumbai, Maharashtra, India

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allows for precise control over frame design and stiffness [15].

Analyzing carbon Fiber materials by using Finite Element Analysis (ANSYS) Software is advance software to evaluate the behavior of the material under various loading conditions. ANSYS software is an influential simulation software that is commonly used in engineering field for analysis and design purpose [2, 3]. ANSYS perform analysis measures to evaluate the mechanical behavior of material [16]. This includes factors such as stress and deformation, it help to design performance and safety. ANSYS is capable for fatigue analysis which is important for materials that may be subjected to repeated stresses. This type of analysis helps to find out the material's performance over the time and under repeated stress [14]. ANSYS can simulate failure scenarios to predict possible points of failure in carbon fiber material structures. This includes rupture and other failure modes allow to design for safety and reliability.

MATERIAL ANALYSIS

Figure 1 The Von Mises stress is also known as von Mises yield criterion or von Mises Stress, It's a used for evaluate stress of material under various loading condition. The Von Mises Stress σ_{vm} equation is given by [1].

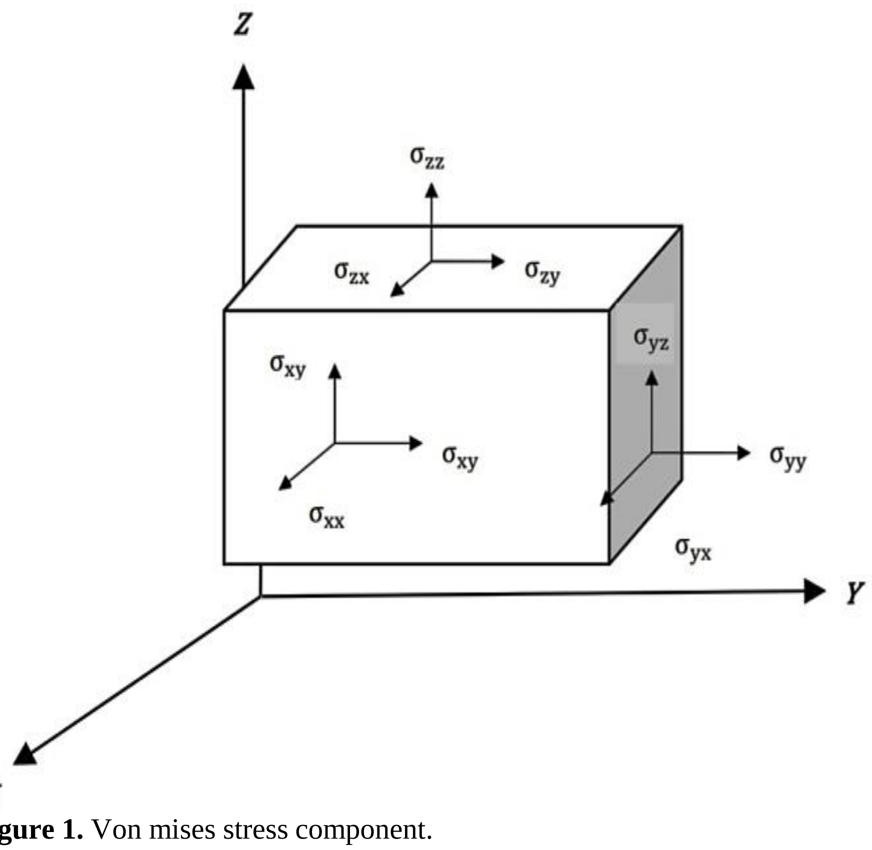

Figure 1. Von mises stress component.

The Von Mises Stress σ_{vm} equation is given by [1],

$$\sigma_{vm} = \sqrt{0.5\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + (\sigma_z - \sigma_x)^2 + 3(\tau^2{}_{xy} + \tau^2{}_{xx} + \tau^2{}_{yz})} \tag{1}$$

The Von Mises Stress σ_{vm} also can be expressed by [1],

$$\sigma_{vm} = \sqrt{0.5(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \tag{2}$$

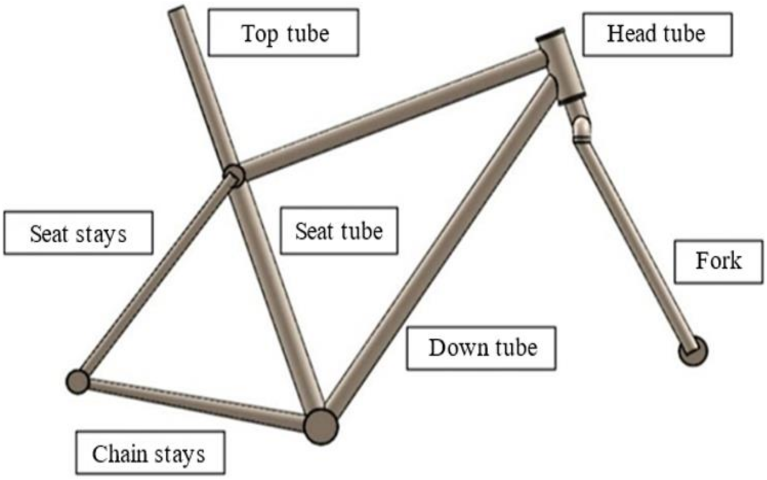

Figure 2. Components of bike frame.

Table 1. Mechanical Properties of Carbon Fiber [6].

Mechanical Properties	Carbon Fiber
Tensile Strength	2068.43 Mpa OR 300 Ksi
Tensile Modulus	15 Msi
Shear Modulus	0.6 Msi
Density	1.55 gm/cm^3

Material: Carbon Fiber.
Tube Thickness of bicycle: 2.246 Inch [6].

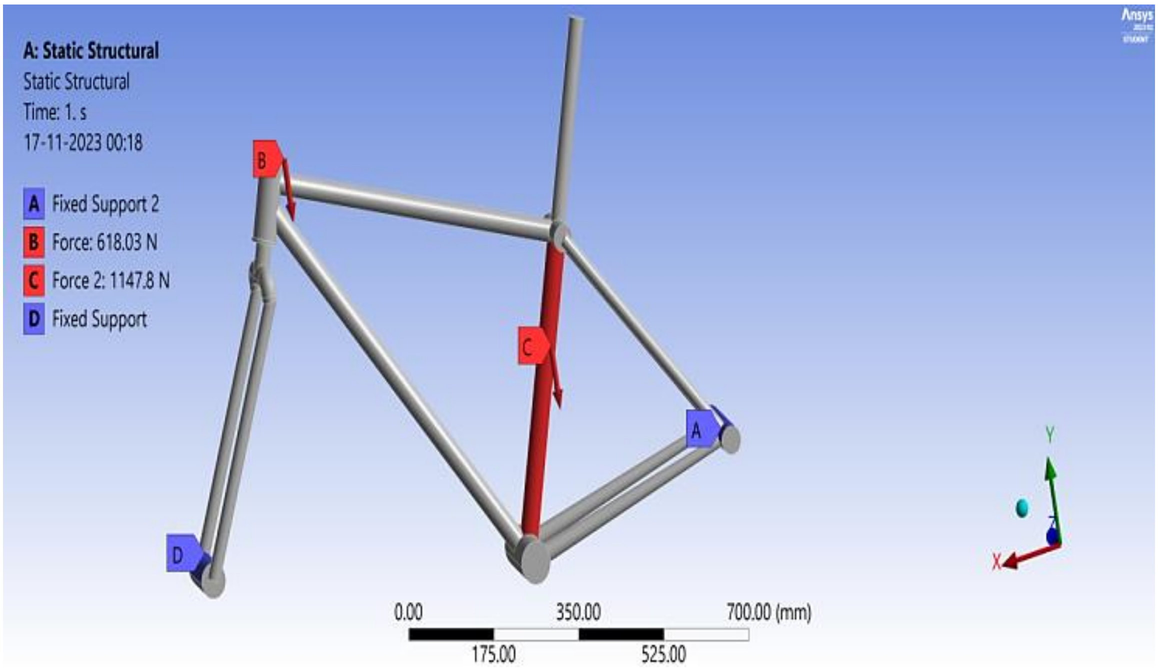

Figure 3. Static Structural of bike frame.

The Static Structural (Figures 2 & 3, Table 1) of bike frame Fixed support are provided A and D while B and C forces are applied structural element of bike. The Analysis is to determine the structural response of the bike frame under the applied forces. The Total force is applied to the frame is 1765.8 N (180Kg). The force is divided into two components Force B is 1147.8 N applied to the middle seat tube and Force C is 618.03 N applied to the front Tube (Handle) of the Frame.

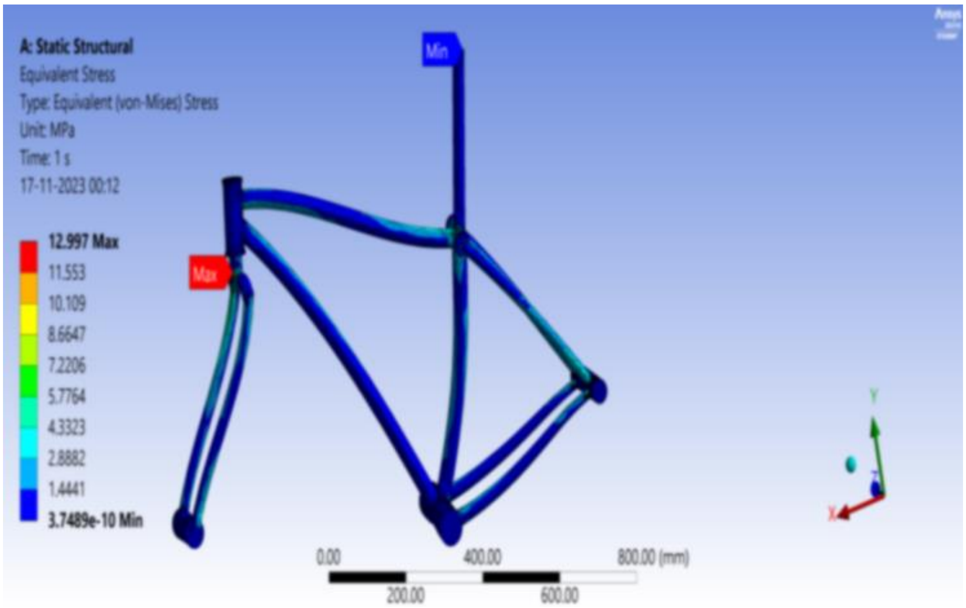

Figure 4a. Minimum Stress.

The Equivalent (von mises) stress is a used to yielding of materials under various stresses condition. we have mechanical properties of carbon fiber material according to Mechanical Properties (Table 1) This mechanical properties we had Taken in ANSYS Software and Analysis it. In this case, stress values range from very low 3.7489e-10 MPa to higher values up to 12.997 MPa in different areas of the frame [17].

The stress distribution varies across different parts of the frame. The minimum stresses are observed in certain areas while higher stresses are concentrated in specific regions. stress lower value are 3.7489e-10 MPa which is very minimum stress is happening on Front head tube, seat tube, top tube, down tube, Seat stay and Fork zone area while some stress as we can See at 4.3323 MPa which is lower stress impact zone of tube frame. (Figure 4a) The higher stress impact on front head tube joint zone area is 5.7764 MPa to 12.997 MPa as we can see (Figure 4b). Stress is dependent on the force applied. Increase in force leads to an increase in stress (Figure 5). This is consistent with the fundamental relationship between force, stress and material properties [18].

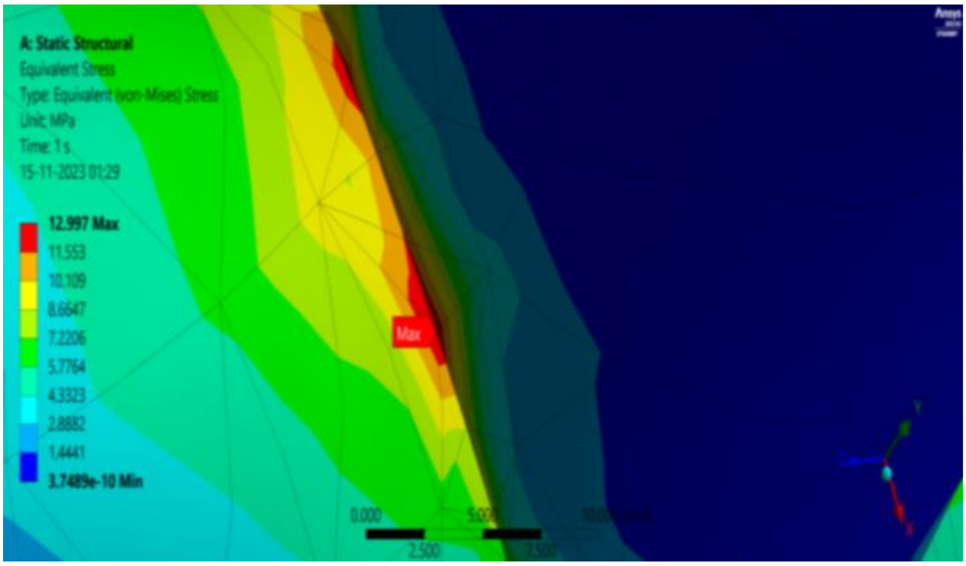

Figure 4.b. Maximum Stress.

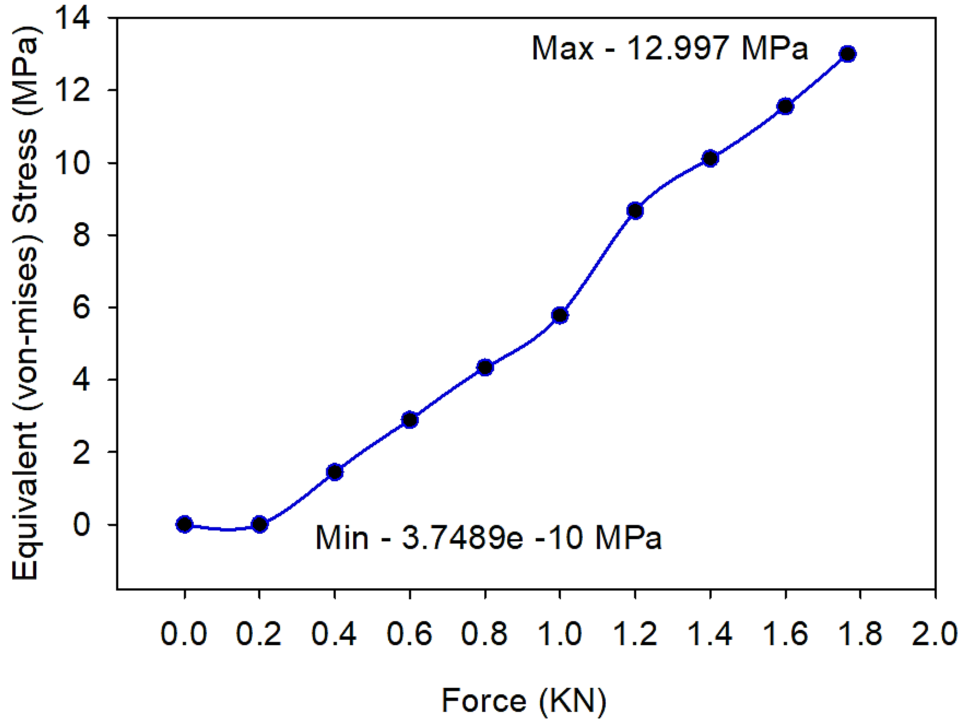

Figure 5. Equivalent (von-mises) Stress vs Force.

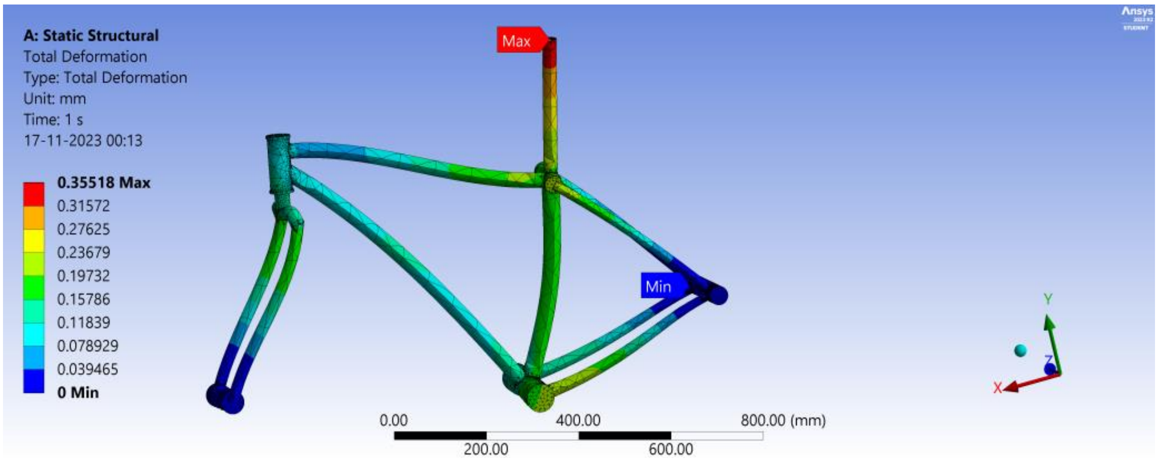

Figure 6. Total Deformation.

We have obtained results (Figure 6) indicating at minimum deformation is 0 mm at stress 3.7489e-10 MPa this minimum deformation is bottom fork, and bottom seat stays of tube zone and maximum deformation is 0.35518 mm at stress is 12.997 MPa which deformation is happening on middle top seat tube of frame. The material is deformed minimum to maximum due to stresses or forces is occurs on the frame. This material deformation depends on yield strength of material.

Figure 7 The directional deformation on the axis refers to the displacement or deformation of a structure along the Y-Axis /Vertical plane (Figure 8) and X-Axis /Horizontal Plane (Figures 9 & 10). because of applied forces. This is the directional deformation along the y-axis and x-axis. Positive values typically indicate Material is deform in the positive direction while negative values indicate displacement in the negative direction. This deformation is due to forced impact on vertically or horizontally plane. The Force has the same impact on plane, but values are obtained different in horizontal and vertical plane. In Y-Axis The material is maximum deform bottom fork tube and bottom rear seat stays is 0.0004677 mm which is very minor and minimum deformation is -0.18721 which is also minor, While in X-axis Plane The material deform maximum is -0.21475 mm which is very minor top seat of tube and minimum material is deform top fork tube. The material will deform compression of forces on bike structural elements.

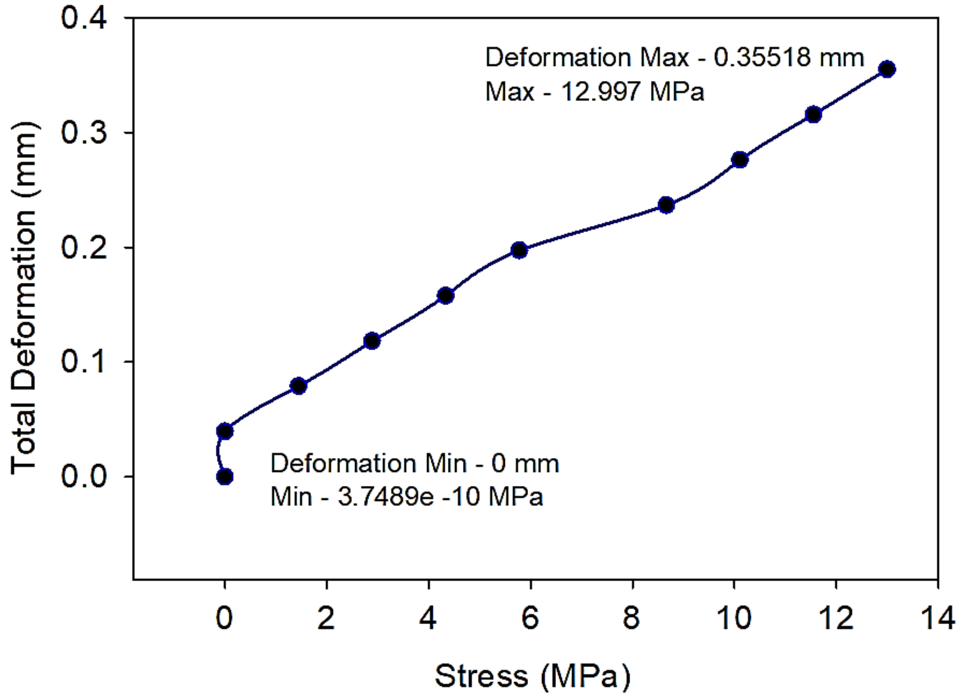

Figure 7. Total Deformation vs Stress.

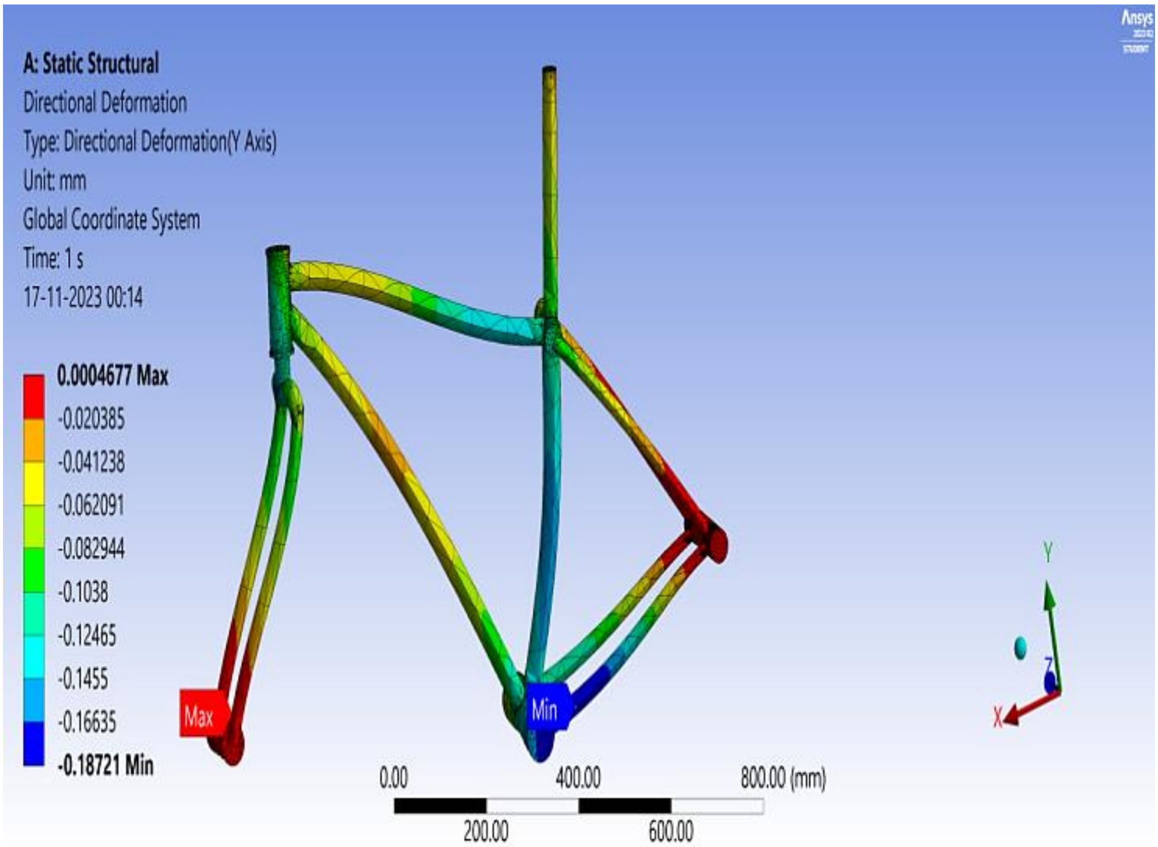

Figure 8. Directional Deformation Y-Axis.

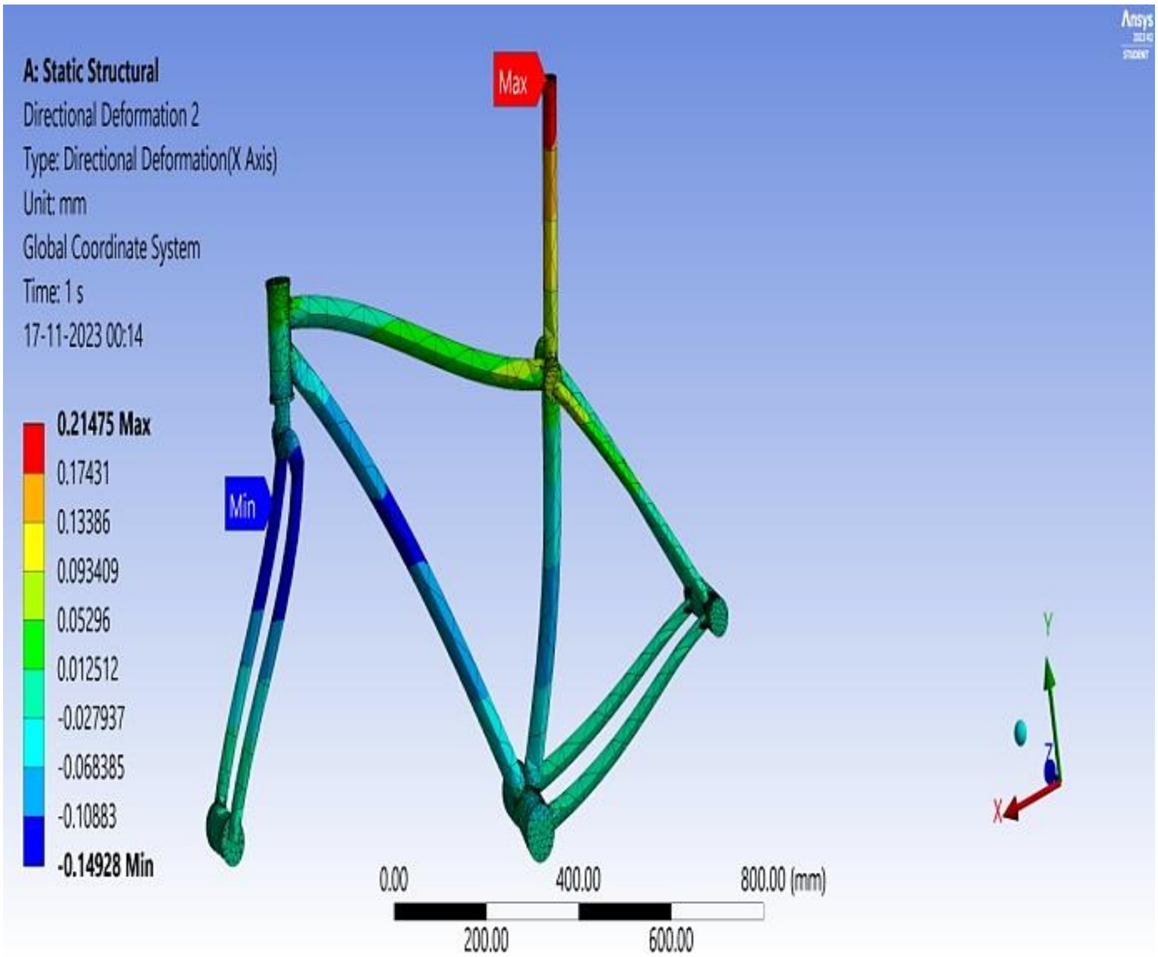

Figure 9. Directional Deformation X-Axis.

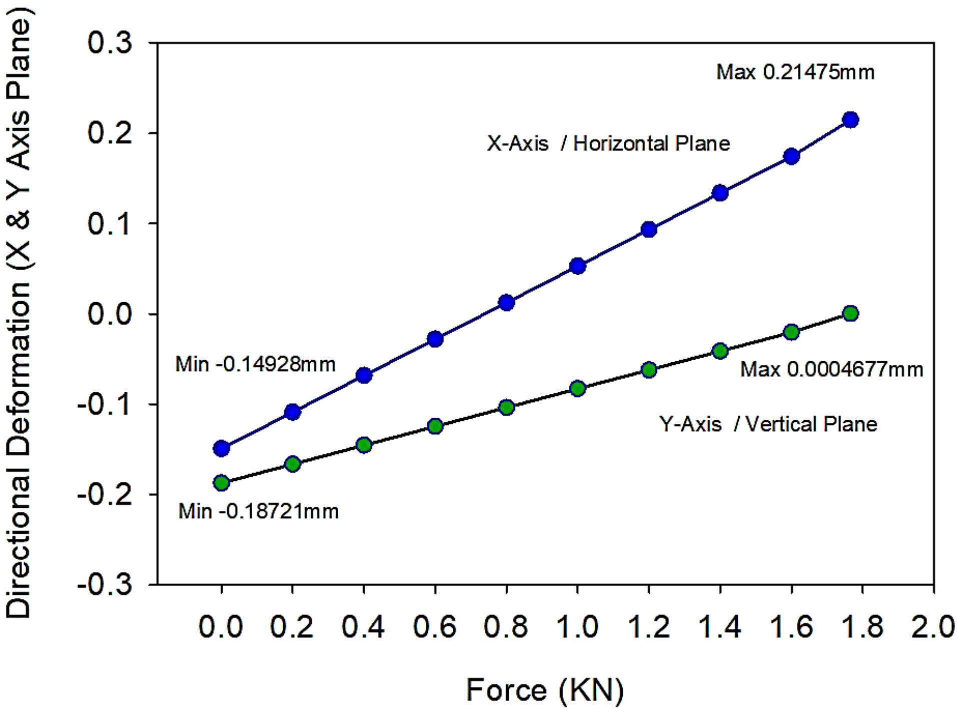

Figure 10. Directional Deformation (X & Y Axis Plane) vs Force.

CARBON FIBER MATERIAL

A Carbon Fiber is a polymer and is sometimes known as graphite fiber [9]. It's popular for its exceptional high tensile strength. Carbon Fiber is significantly lighter than traditional materials like steel and aluminium. It is about 70% lighter than steel and 40% lighter than Aluminium [9] This lightweight nature allows for bicycle manufacturers to design frames that suggest high strength and stiffness without compromise on weight and contributing to enhanced overall bike performance which means it can survive higher loads and defend against deformation. One of the most major advantages of carbon fibre is low density [13] it builds extremely lightweight. This Mechanical property is valuable in industries where weight decrease is critical such as a aerospace and automotive industry [19].

Carbon fiber is superb strength and corrosion resistance. It is suitable for use in insensitive environment as compared to non-polymer material like metals. It's contributing to the durability of structures and components. Carbon fiber can be molded into different shapes and sizes and for create complex flexibility and aerodynamic structures.

MANUFACTURING PROCESS OF CARBON FIBER

The 90% of carbon fibres material are made from Polyacrylonitrile (PAN) [9, 19]. The other 10% are produced from rayon or petroleum pitch. These materials are organic polymers with long molecular chains bound together by carbon atoms. The precursor is drawn into long strands or fibres and heated to a high temperature without contact to oxygen. This process is called as carbonization it's left non-carbon atoms and interlock the chains of carbon atoms before carbonization fibres are chemically altered to convert linear atomic bonding to a more thermally stable ladder bonding. This is achieved by heating the fibres in the existence of oxygen. Stabilization reactions are complex, process involves controlling heat to avoid overheating.

The Carbonizing stabilize fibers are heated to excessive temperatures (1,830°F to 5,500°F) [9] in a furnace fill with oxygen open gas mixture. The lack of oxygen prevents burning and fiber lose non carbon atoms in the form of gases. Carbon crystals form align parallel to the fiber axis. once carbonization the fiber surface is oxidized slightly to develop bonding properties. Various gases or liquids such as air carbon dioxide, sodium hypochlorite or nitric acid can be used for oxidation. It's increase chemical bonding and create a roughen surface for better mechanical bonding [9]. Protecting fiber for the period of handling and processing coating is applied is called as sizing. Coating materials such as epoxy, polyester, nylon, and urethane are preferred for adhesives used in composite materials [9, 19]. Coated Fibers are wound in spindle and load into turning machine. These fibres are twisted into yarns of various sizes which can be used in the production of composite materials.

CONCLUSION

As per Research it's conclude that the analysis of the Carbon Fiber material for the bike frame using Finite Element Analysis (ANSYS) software reveals that the maximum stress is reached 12.997 MPa which is below the tensile strength 2068.43 MPa from (Table 1) Mechanical Properties of Carbon Fiber Material. This indicates That the carbon Fiber material sufficient strength to endure the applied loads without approaching its yield point or facing failure and very Minimum Deformation of material. The carbon Fiber Bike Frame can be considered structurally suitable for its intended purpose providing Durability and Reliability to Rider.

Declaration of Interest

We Authors declare that there is no conflict of interest regarding the publication of this manuscript.

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