

ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Structural Analysis of Bamboo and E-glass Fiber Reinforced Epoxy Composite for Wind Turbine Blade using Finite Element Method and CFD

A Thesis Submitted to the Addis Ababa University Institute Technology, School of GraduateStudies
In Partial Fulfillment of the Requirement for Degree of Master of Science In
Mechanical Engineering (Mechanical Design Stream)

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October 2020

Addis Ababa

Addis Ababa University

Addis Ababa Institute of Technology

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Declaration

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This is to certify that the thesis prepared by **Netsanet Berga**, entitled: **Structural Analysis of Bamboo and E-glass Fiber Reinforced Epoxy Composite for Wind Turbine Blade using Finite Element Method and CFD**, do here by declare this thesis is my original work and that it has not been submitted partially, or in full for a degree in any university/institution, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

Signature:_____

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Acknowledgement

My heartfelt thank goes to my advisor Araya Abera for his valuable advices, motivations, and guidance during my study. I would like to express my deep gratitude to Mr. Garbe Chukulu and Mr. Nahom Mekiso for their support and motivation. Finally, I would like to thank all of my families and friends those who were supporting and motivating me for the achievement of this thesis.

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Acronyms/ Abbreviation

FEM	Finite Element Method
FEA	Finite Element Analysis
ANSYS	Analysis System
FRP	Fiber Reinforced Plastics
CFD	Computational Fluid Dynamics
NACA	National Advisory Committee for America
HAWT	Horizontal Wind Turbine Blade
VAWT	Vertical Axis Wind Turbine Blade
BEM	Blade Element Momentum
GFRPs	Glass Fiber Reinforced Plastics
CFRPs	Carbon Fiber Reinforced Plastics

Abstract

As far as a wind power generation technology increases, selecting the better wind turbine blade material is becoming more and more important. Modeling and stress analysis of wind turbine blade are very essential for further design and the application of wind turbine blade. The aim of the thesis is to conduct static structural analysis of wind turbine blade for six different ratios of Bamboo to E-glass fiber reinforced epoxy composite. NACA0012 airfoil is used for horizontal axis wind turbine blade section, which is the same throughout the blade length. Based on the parameters of airfoil and the geometrical parameters of blade, the three-dimension modeling has done using CATIA software. Maximum wind speed is 35m/s. The pressure on the blade surface are determined by CFD using ANSYS Fluent software. Static structural analysis has performed using FEA using ANSYS software. According to the displacement solution of blade, the maximal displacement occurs in the blade and the stress concentration occurs in the center of the blade. Depending on the displacement, safety factor and stress the FEM analysis result was discussed. The FEM results were compared with the tensile strength of the material and the safe displacement. Based on static simulation result among the six ratios of Bamboo to E-glass fiber have a better strength is 70:30%. The selected Bamboo to E-glass ratio material compare and contrast with previous work of wind turbine blade material.

Key word: *FEM, CFD, Bamboo to E-glass Ratio, Strength, Displacement, Strain*

Chapter one

1. Introduction

One of unfulfilled human need is energy, to fulfil this desire human beings are explored many things. There are different source of energy including conventional energy, which is fossil fuel. In recent years, wind energy has noted the highest growth rate in comparison with other renewable energy sources. Among different type of renewable energy, wind energy is the second most important resource next to hydropower for power generation [1]. Wind energy is an important player in the world's energy market and it represents a mainstream energy source of new power generation. Wind energy is an abundant resource given by nature free of cost. Moreover, wind power is renewable clean energy with short construction periods; it has considered as one of the most viable sources of sustainable energy. It has significant advantage of quick results [2].

Wind is an indirect source of solar energy. It is caused by the uneven heating of the earth by the sun and the resulting redistribution of air to equalize energy in the atmosphere moving air from areas of high pressure to areas of lower pressure. Every hour the earth receives $1014kWh$ of solar energy, of which about 1-2% is converted into wind energy [2].

Due to great potential of wind energy source, i.e. the capacity is 18645MW, 4925MW, and 2005MW with wind speed of 7.5~8m/s, 8~8.8m/s, and more than 8.8m/s respectively at a height of 50m, Ethiopia has developed 51MW wind power with 34 turbine units of each 1500kW capacity (large size turbine blade types) from Adama wind farm projects phase1 [3]. The large sized wind turbine blades are made from fiber-reinforced plastics (FRP) owing to the materials' superior strength-to-weight ratio compared to wood and metals [1, 2, 4, and 5]. The major parts of a modern turbine cost (% of total): tower 22%, blades 18%, gearbox 14%, and generator 8% of the total cost. Unfortunately, most materials they used for blade construction are synthetic, which are non-biodegradable in their biological process. This causes synergetic effect on our eco-system. To alleviate this problems, now a day the progress of exploration of materials that are environmental friendly, '*natural plants'*, have been ongoing [6, 7].

1.1. Background of the study

The main components of the wind turbine to accept the wind energy is the wind turbine blades [8]. Since 1970s, most of wind turbines are producing with composite materials. Materials such as wood, steel, aluminum, glass-fiber-reinforced plastics (GFRPs) and carbon fiber reinforced plastics (CFRPs) have been used [2, 7].The choice of wind turbine blade

materials design usually depends on many parameters such as strength, weight, stiffness, price, fatigue properties, load bearing capacity (tensile strength)and the ability to withstand bending (flexural strength). In addition, the blades must be stiff enough to avoid hitting the towers when deflected by the wind loads. In view of these requirements, only materials with the very high strength, fatigue resistance and stiffness i.e. ,composites, are only choice in wind turbine blades design [1, 2, 4].

As of 2013, production of wind turbine blades are as large as 120 meters in diameter. Within 2001, an estimated 50 million kilograms of fiber glass laminate were used in wind turbine blades [7, 9]. However, problems encountered with the commonly used fiber composite materials like carbon and glass are rise in cost, non-renewable material, the pollution of the environment due to industrial process etc. are common in the globe [6, 7].One of the directions for solutions is to look for new material applications: recycling and reuse, sustainable production of products, or use of renewable resources.

For this purpose different researchers conduct on performance of new material [10] investigate the performance of bamboo and E-glass fiber reinforced epoxy composite, output shows it can have a potential to be used for wind turbine blade shell construction. The output of the result used as an input for this thesis.

The blade consists of two faces (suction and pressure side) joined together by adhesives and stiffened by many shear webs (I section) or by box beam (box spar). Wind turbine blade subjected to many types of loading like flap wise and edgewise bending, gravitational forces, tensional loading as well as loads due to pitch acceleration. Edgewise bending is caused by gravitational forces and torque of blade whereas flap wise bending is due wind pressure; the spar is the main component to endure the flap wise bending while edgewise bending is resisted by edges of blade [11]. So, wind turbine blade need different type of analysis before implementation of the selected new material such as structural, dynamic, fatigue life, cost effectiveness.

With the leaves become larger and the cost and quality of the blade are also increasing, which leads to an increase in the cost of design and experiment, so to find a reliable structure calculation method is very important. With the finite element method widely used in various fields, it is proved that the finite element method is a relatively reliable calculation method. Therefore, the blade structure analyzed using the finite element method is feasible.

ANSYS is one of the finite element analysis (FEA) software which is working on computer based numerical technique for calculating the strength and behavior of engineering structures. It can be used to compute deflection, stress, vibration, buckling behavior and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. It can analyze elastic deformation, or permanently bent out of shape plastic deformation. The computer is required because of the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made Finite Element Analysis available to many disciplines and companies. Useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained.

In the finite element method, a structure is broken down into many small simple blocks or elements. The behavior of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equations describing the behaviors of the individual elements are joined into an extremely large set of equations that describe the behavior of the whole structure. The computer can solve thislarge set of simultaneous equation. From the solution, the computer extracts the behavior of the individual elements. From this, it can get the stress and deflection of all the parts of the structure. The stresses will be compared to allowable values of stress for the materials to be used, to see if the structure is strong enough.

The aim of this thesis is to conduct structural analysis of Bamboo and E-glass fiber reinforced epoxy composite for wind turbine blade application. Therefore, in the present work, the CFD was performed by the model equation of large eddy simulation (LES) to get the critical load on wind turbine blades and FEM analysis of static structure was done on ANSYS Work bench by imputing experimental results material properties of six different Bamboo and E-glass ratio.

1.2.Statements of the problem

Wind turbine provides an alternative source of energy. Blade is an important part of wind turbine. Wind turbine blades are complex structures whose design depends on selection of the aerodynamic shape, structural configuration, material selection, and density of blade material.

The dynamic and mechanical properties of a wind turbine can be modified by changing fiber-loading ratio of the composite material of the blade. Hence, emphasis is given on the material

of the blade. The results of analysis of different fiber loading ratios of the composite material are compared to evaluate the best possible one suited for practical application. Moreover, airfoil shape taken is NACA 0012, this is cambered airfoil belongs to the four digit series of the NACA airfoil classification.

As literatures indicates, bamboo plant has a great potential that can be used as structural material because of its better mechanical properties and surplus resource in Ethiopia compared to other natural fibers[10]. Beside this fact, use of synthetic fibers has been polluting environment and its increased cost has been becoming a constraint for construction of modern wind turbine.

Therefore, it necessitated to perform structural analysis on wind turbine blade shell of different fiber loading ratios to validate its applicability for intended airfoil shape. Thus, the blade optimization is carried out by considering parameter like fiber loading ratios of the material, stresses, and deformation on the blade. Moreover, experimental results [10] of Bamboo and E-glass reinforced epoxy composite material was used as input to finite element analysis and optimization. The results of structural analysis have been compared and contrasted with other wind turbine blade materials, which are previously recommended by researchers.

1.3. Objective of the study

1.3.1 General objective

The general objective of this study is to conduct structural analysis on composite wind turbine blade shell

1.3.2. Specific objectives

The specific objectives of the study are to:

- Determine critical pressure value acting on the surface of horizontal wind turbine blade using CFD analysis for particular maximum wind velocity of 35m/s
- Perform static structural analysis on horizontal wind turbine blade for various loading ratios of bamboo and E-glass fiber reinforced epoxy composite
- Compare and select the optimum strength of horizontal wind turbine blade at different ratios of Bamboo to E-glass fiber based on static structural analysis result.

1.4. Significance of the study

The study is believed to optimize and making use of the potential resource of bamboo fiber for wind turbine blade shell construction. Use of bamboo fibers for the blade construction significantly decreases cost needed for blade construction and increases strength of the material. The study enables to determine best fiber loading ratio of bamboo to E-glass ratio to attain better strength. Moreover, the results of the analysis can be used as benchmark for other researches.

1.5. Scope of the study

The study focused on structural analysis of Bamboo and E-glass fiber reinforced epoxy composite for wind turbine blade application. 3D modeling was performed using CATIA version-5 software, the model was imported to ANSYS software for further CFD and static structural analysis. Computational fluid dynamics (CFD) analysis was performed to determine critical pressure acting on blade shell, which was used as input load for static structural analysis. Static structural analysis was used to select the optimum fiber-loading ratio for the construction of wind turbine blade shell. Eventually, the results of the study were compared with previously done research works.

1.6. Organization of the thesis

This work is organized in five chapters. The first chapter gives a brief description of wind turbine, the thesis background, problem statement, general and specific objectives, significance, and scope of the study. The second chapter presents literature review on introduction of wind turbine and its types, wind turbine blade, blade structure, and blade airfoil. Moreover, this chapter deals about load on wind turbine blade, aerodynamic load determination, structural analysis of wind turbine blade, and previous structural analysis results. Eventually, the previous work experimental analysis results of composite material were used as benchmark for wind turbine blade analysis. The third chapter deals with the selection of NACA standard aerofoil shape, computational fluid dynamics, and static structural analysis of Bamboo and E-glass fiber reinforced epoxy composite wind turbine blade shell. The fourth chapter explains about CFD and structural analysis results, and its discussion. The last chapter devoted to draw conclusions, recommendations, and future works.

Chapter Two

2. Literature Review

2.1. Wind Turbine

Power has been extracted from the wind over hundreds of years with historic designs, known as windmills, constructed from wood, cloth and stone for the purpose of pumping water or grinding corn. Historic designs, typically large, heavy and inefficient, were replaced in the 19th century by fossil fuel engines and the implementation of a nationally distributed power network. A greater understanding of aerodynamics and advances in materials, particularly polymers, has led to the return of wind energy extraction in the latter half of the 20th century. Wind power devices are now used to produce electricity, and commonly termed wind turbines. The orientation of the shaft and rotational axis determines the first classification of the wind turbine.

Wind turbine technology is one of the rapid growth sectors of renewable energy all over the world. As a core component of a wind turbine, it is a common view that the design and manufacturing of rotor blades represent about 20% of the total investment of the wind turbine [14]. Moreover, the performance of a wind turbine is highly dependent on the design of the rotor [15]. As well as rotor aerodynamic performance, the structure strength, stiffness and fatigue of the blade are also critical to the wind turbine system service life.

2.1.1 Wind turbine types

There are two types of wind turbines available on the market: Vertical axis and horizontal axis wind turbines [16].A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT). A vertical axis wind turbine (VAWT) has its shaft normal to the ground. The two configurations have instantly distinguishable rotor designs, each with its own favorable characteristics [17]. The discontinued mainstream development of the VAWT can be attributed to a low tip speed ratio and difficulty in controlling rotor speed. Difficulties in the starting of vertical turbines have also hampered development, believed until recently to be incapable of self-starting [18]. However, the VAWT requires no additional mechanism to face the wind and heavy generator equipment can be mounted on the ground, thus reducing tower loads. Therefore, the VAWT is not completely disregarded for future development. A novel V-shaped VAWT rotor design is currently under investigation which exploits these favourable attributes [19]. This design is currently unproven on a megawatt scale, requiring several years of development before it can be considered competitive. In addition to the problems associated with alternative designs, the popularity of the HAWT can be attributed to increased rotor control through pitch and

yaw control. The HAWT has therefore emerged as the dominant design configuration, capitalized by all of today's leading large scale turbine manufacturers. For this reason, this work also conducts structural analysis on horizontal wind turbine blade.

2.2. Wind Turbine Blade

Blades of a wind turbine are airfoils shaped. When the blades rotate through air they produce the aerodynamic force. They are the parts that are responsible of generating the lift [20]. The lift is a component of the aerodynamic force that the fluid, in this case wind, exerts on the blades while they are rotating [21]. It is perpendicular to the approaching flow direction [21]. And it is different from the drag force that is the other component of the aerodynamic force that is parallel to the direction of the flow [21]. Generally, the lift moves from bottom to top in an upward direction, but sometimes it can go in different directions with respect the right angles of the flow [21]. In other words, it is the force used to make the rotor of the wind turbine rotate that is produced when the blades face the wind properly [22].

In the wind turbine business, the blades play an important role when it comes to generating electricity. They are the major components that turn the rotor shaft. So the design of the blade matters a lot because it affects the efficiency of the wind turbine as a whole, thus affects the energy production. The blades efficiency depends on three factors: the weight, the length, and the strength. That is why it is crucial to conduct strength analysis, have longer and lighter blades as of to meet the production need.

2.2.1 Wind Turbine Blade Airfoil

For horizontal axis wind turbines, it is recommended to have a higher lift but lower drag aero foil. There are many kinds of airfoil including the general aviation airfoil, such as NACA (National Advisory Committee of America) series, which are still used in some wind turbines. However, with the development of wind turbines, the dedicated airfoil came about. The S series designed by NREL in USA, is mostly used in stall-regulated wind turbines for its gentle behavior in stall conditions; the FFA W series designed in Sweden and RIS series designed in Denmark, are preferable for lower Reynolds applications, and the DU series designed in Netherland, is popular in High Reynolds for large wind turbines. Each of these series has its own aero foil shape with different thickness to-chord ratio of 18%-40%. The thicker aero foil shapes are often located at the inner part (close to rotor center) of the blade while the thinner ones are set in the outer part of the blade due to ease of manufacturing and better strength and stiffness.

The simplest asymmetric foils are the NACA 4-digit series foils, which use the same formula as that used to generate the 00xx symmetric foils, but with the line of mean camber bent. The airfoil of NACA0012 was applied for this work to facilitate the modeling and analysis of the blade. This airfoil structure is relative simpler, the maximum relative thickness and the maximum camber relative position are both 0, and the maximum relative thickness is 12%

2.3. Load on Wind Turbine Blade

The main loads on the blades are generated by wind and gravity. Wind loads mainly induce both flapwise and edgewise bending. These loads have both a static and a dynamic component (variations in wind speed and natural wind shear) that induce fatigue on the blade material. Gravity loads mainly induce edgewise bending, when the blade is horizontal. The rotation of the blades cause alternating edge-wise bending and thus fatigue of the material.

The rotor blade is loaded in a combination of flapwise and edgewise loads. Basically the blades are exposed to three different load sources. One is the wind load that through the lift and drag on the aerodynamic profile loads the blade primarily in bending flapwise. The second load source is the gravity varying edgewise from tension/compression in leading edge and compression/tension in trailing edge. This is the main reason for the edgewise fatigue bending of the blade. Finally, the blades are exposed to centrifugal forces during the rotation. However, these longitudinal loads are relatively low and often not taken into account in the design. Furthermore, the design loads are divided into static loads and cyclic loads. International design recommendations specify both types of loads. Moreover, the blades will be subjected to a wide range of environmental conditions.

2.4. Wind Turbine Blade Aerodynamic Load Determination

For the aerodynamic component of wind turbine blade, the BEM (blade element momentum) model [24] has been extensively applied due to its efficiency and reasonable accuracy. The high efficiency of the BEM model also makes it suitable for design optimization, which generally involves a large number of design iterations. Based on the BEM model and different optimization strategies, a series of case studies has been performed to optimize the aerodynamic performance for both fixed speed [25, 26] and variable-speed wind turbine blades [27, 28]. However, the BEM model is incapable of providing detailed information on the flow field, such as flow visualization and wake development. This information is important for wind turbine designers to have a better understanding of the flow field around the blade and to further optimize the design. Obtaining detailed information on the flow field requires CFD (computational fluid dynamics) modelling [29], which has been receiving

greater attention in recent years due to the rapid advancement of computer technology. Compared to BEM model, the CFD model is more computationally expensive, but it is capable of accurately modelling complex 3D (three-dimensional) flow fields and representing realistic fluid dynamics more accurately [30-32]. Due to its high level of accuracy and flexibility, the CFD model is chosen to determine load on the surface of the blade in this study.

2.5. Structural Analysis of Wind Turbine Blade

For the structural analysis, beam models and FEA (finite element analysis) models are the two most common approaches referred in the literature [33, 34]. Beam models are 1D (one-dimensional) representations of 3D structures which discretise properties such as stiffness and mass into points along the 1D beam. They are computationally efficient and generally give reasonable results. Based on a nonlinear beam model, Wang et al. [35] developed a nonlinear aeroelastic model for wind turbine blades, taking account of both large blade deflections and geometric nonlinearities. The beam model is characterised by cross-sectional properties, such as mass per unit length and cross-sectional stiffness, which can be obtained by using specialized cross-sectional analysis models [36]. However, a beam model is incapable of providing some important information for the blade design, such as detailed stress distributions within the blade structure. In an FEA model, wind turbine composite blades are generally constructed using 3D composite shell elements, which are capable of describing composite layer characteristics throughout the shell thickness. FEA model has the advantages of being high-fidelity and capable of examining the detailed stress distributions within each layer of composite blade structure [37]. For this reason, FEA model is selected for structural analysis in this thesis.

2.6. Wind Turbine Blade Material in the past

Glass and carbon fibers: The stiffness of composites is determined by the stiffness of fibers and their volume content. Typically, E-glass fibers (i.e., borosilicate glass called electric glass or E-glass for its high electric resistance) are used as main reinforcement in the composites. With increasing the volume content of fibres in UD composites, the stiffness, tensile and compression strength increase proportionally, yet, at high volume content of fibers (after 65%), there might be dry areas without resin between fibers and the fatigue strength of the composite reduces [38]. Typically, the glass/epoxy composites for wind blades contain up to 75 weight % glass.

Many investigations toward the development of fibers, which are stronger than the usual E-glass fibers, have been carried out. The high strength fibers (which are still used seldom in practice, but represent a promising source of the composite materials improvement) include glass fibers with modified compositions (S-glass, R-glass, etc.), carbon fibers, basalt and aramid fibers. S-glass (i.e., high strength glass, S means “Strength” here) developed in the 1960s, shows 40% higher tensile and flexural strengths, and 10–20% higher compressive strength and flexural modulus, as compared to E-glass. The S-glass is much more expensive than E-glass. S2 glass was developed in the 1968 as a commercial version of S-glass. S glass and S2 glass fibers have the same composition (magnesium alumino-silicate). The main differences are in sizing (fiber coating) and certification procedure. The price of S2-glassis around 10 times of that of E-glass. R-Glass fibers, introduced in 1968, are produced with acalcium alumino-silicate glass with less silica and added oxides [39]. Some other special glasses developed by Owens Corning are ECRGLAS, Advantex and most recently WindStrandTM glass fibers. The WindStrandTM glass fibers show15 percent higher stiffness and up to 30 percent higher strength when compared to E-glass [40]

Carbon fibers are considered to be a very promising alternative to the glass fibers. They show much higher stiffness and lower density than the glass fibers, thus, allowing the thinner, stiffer and lighter blades. However, they have relatively low damage tolerance, compressive strength and ultimate strain, and are much more expensive than the E glass fibers [41,42]. Carbon fiber reinforced composites are sensitive to the fiber misalignment and waviness: even small misalignments lead to the strong reduction of compressive and fatigue strength. Carbon fiber composites are used by the companies Vestas (Aarhus, Denmark) and Siemens Gamesa (Zamudio, Spain), often in structural spar caps of large blades [41]

Aramid and basalt fibers. Further, an interesting alternative is using non-glass, high strength fibers first of all, aramid and basalt fibers. Aramid (aromatic polyamide) fibers demonstrate high mechanical strength, and are tough and damage tolerant, but have low compressive strength, low adhesion to polymer resins, absorb moisture, and degrade due to the ultraviolet radiation [30]. Basalt fibers show good mechanical properties, are 30% stronger, 15–20% stiffer and 8–10% lighter than E-glass, and cheaper than the carbon fibers [41]. The application of basalt fibers in small wind turbines have been demonstrated in [42,43], and the results were very encouraging. In the works [42,43], the basalt fibers were used as hybrids with carbon fibers

Hybrid composites. Hybrid reinforcements (E-glass/carbon, E-glass/aramid, etc.) represent an interesting alternative to the pure glass or pure carbon reinforcements. Ong and Tsai [44] demonstrated that the full replacement would lead to 80% weight savings, and cost increase by 150%, while a partial (30%) replacement would lead to only 90% cost increase and 50% weight reduction for 8 m turbine. The world currently longest wind turbine rotor blade, the 88.4 m long blade from LM Wind Power is made of carbon/glass hybrid composites [45] In a number of works, the strength and damage mechanisms of hybrid composites were studied [46–63]. It was reported, among others, that the incorporation of glass fibers in carbon.

Fiber reinforced composites allows the improvement of their impact properties and tensile strain to failure of the carbon fibers. Manders and Bader [51] observed an enhancement of the failure strain of the carbon fiber reinforced phase when "carbon fiber is combined with less-stiff higher-elongation glass fiber in a hybrid composite". However, in [52], it was shown on the basis of computations that the dependency of the composite strength on the ratio glass/carbon is V-shaped, with a minimum at the content of the order of 60% carbon, i.e., the hybrid strength can be under some conditions be lower than the strength of both pure glass or pure carbon composites. This observation was confirmed experimentally in [54]. Thus, while the hybrid composites seem to be a very promising group of composites for wind energy, additional investigations are required for the optimal composition of the materials. A computational micromechanical model of hybrid glass/fiber composites, and the composite degradation process (first, failure of glass fibers and then failure of carbon fibers), as observed in numerical simulations in [52,53]

Natural fibers. In some cases, natural fibers can be used as well. The advantages of natural fibers, as sisal, flax, hemp, jute, are the low costs, availability and environmental friendliness. The disadvantages are the quality variations, high moisture uptake and low thermal stability of the raw fibers [55]. Holmes et al. [56,57] tested a novel bamboo-poplar epoxy laminate for wind turbine blades, and demonstrated that this material has high strength and stiffness, and can be used in wind blades instead of common composites. The high strength and durability of bamboo as well as its quick growth and broad availability make the bamboo to a very promising material for the wind energy applications

An interesting option for developing countries is small turbines, producible on-site, and made from "natural composites", i.e., from locally available timber [58]. In a series of investigations, a group of Nepali, Danish and Australian scientists studied the applicability of

different timbers for wind turbines, and demonstrated that the turbines with wooden blades represent a reliable and low cost option for the developing countries [59–61].

Bamboo fiber: Bamboo has many culms. There is a diversity between different culms on stiffness, strength and fracture toughness. The culm of a bamboo plant is a ligno-cellulosic natural functionally graded composite material. Fibers are densely located around the outer cortex and similarly on the top of the culm. As a result when we examine bamboo timber; from inner to the outer and from the bottom culm to the top, the mechanical strength of the bamboo is enlarge. The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%) [64].

The bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin. Therefore, a devised process should be adopted to extract the bamboo fibers for reinforcement of composite materials. However once proper method of fiber extraction is selected, the result obtained is comparable even with glass fiber [65]. These comparison result indicate that the mechanical properties of bamboo fiber is super higher than that of other natural fibres and also nearer to glass fiber characteristics.

Abiy Alen[10] perform fabrication and experimental tensile test, compressive test , In plane shear test, Flexural test and Failure mode for Bamboo and E-glass fibre reinforced Epoxy Matrix composite. Fibre to matrix ratio was 45%:55. The experimental test was performed for six different Bamboo to E-glass ratios keeping epoxy constant. This hybrid composite material is taken in this study for structural analysis for wind turbine blade.

2.7.Previous Work on Structural Analysis of Wind Turbine Blade

In number of works, structural analysis of composite wind turbine blade studied [66-71]. Duan and Zhao [66] used the finite element method to analyze the stress distribution of a 600 kW wind turbine blade and found that the maximum stress occurred at the root of wind blade. Yehet al. [67] evaluated the stress distribution and deflection of NREL 5MW wind blade with different structural stiffeners. Meng-Kao Yeh and Chen-Hsu Wang [68] use finite element method to analyze the stress of composite wind turbine blade along different pitch angle of blade and found that,at the 0^0 pitch angle the wind turbine blade is subjected to the largest combined load and therefore the stress is the largest; with the increasing pitch angle, the load gradually decreases and the stress is also smaller. The stress and displacement are the greatest when the wind blade is located at 120^0 angular position from its highest vertex.

Akhil P Mathew, Athul S, Barath P and Rakesh [69] conduct structural analysis for five different materials which are structural steel, Epoxy Carbon, S-glass, E-glass and Aluminum alloy to validate the strength of the blade and compare the material based on their Finite element analysis result of stress, deformation and mass and select Epoxy carbon as best material for windmill blade.

Ali Nawaz Mengall Saravanan Karuppanan and Azmi Abdul Wahab [70] perform structural analysis for Basalt fiber reinforced plastic and Glass fiber reinforced plastic blade using FEM and found that deflection and stress developed in Basalt fiber reinforced plastic blades were less as compared to Glass fiber reinforced plastic blade in same force condition, thickness and boundary condition.

V. Garcla, L. Vargas, A. Acuna, J.B. Sosa, E. Durazo, R. Ballesteros, and J. Ocampo[71]use finite element analysis to determine the suitability of basalt fiber as a substitute for E-glass in structural applications, which would improve the cost effectiveness of small wind turbine blades. To obtain the wind load pressure distribution over the blade, a computational aerodynamic analysis by CFD (computational fluid dynamics) was performed based on the blade's design and operating conditions. The result validating that basalt fibres are a viable alternative to substitute E-glass fibers. In this study structural analysis is conducted for wind turbine blade for hybrid composite material of Bamboo and E-glass reinforced fiber epoxy matrix using FEA.

As have discussed above different researchers conduct on the performance of new material to substitute wind turbine blade with new composite by different method. For this purpose different researchers conduct on performance of new material [10] investigate the performance of bamboo and E-glass fiber reinforced epoxy composite, output shows it can have a potential to be used for wind turbine blade shell construction. The output of the result used as an input for this thesis.

The aim of this thesis is to conduct static structural analysis of Bamboo and E-glass fiber reinforced epoxy composite for wind turbine blade application. Therefore, in the present work, the CFD was performed by the model equation of large eddy simulation (LES) to get the critical load on wind turbine blades and FEM analysis of static structure was done on ANSYS Work bench by imputing experimental results material properties of six different Bamboo and E-glass ratio.

Chapter Three

3. Materials and Method

3.1.Materials

The Materials used in this work is directly the experimental results of research work on bamboo and E-glass fiber reinforced epoxy composite [10]. Beside this, CATIA Version-5 and ANSYS softwares were used as tools for modeling, CFD simulation, and structural analysis.

3.2.Method Used

In order to meet the objective of this study the methods on figure 3.1 have been employed;

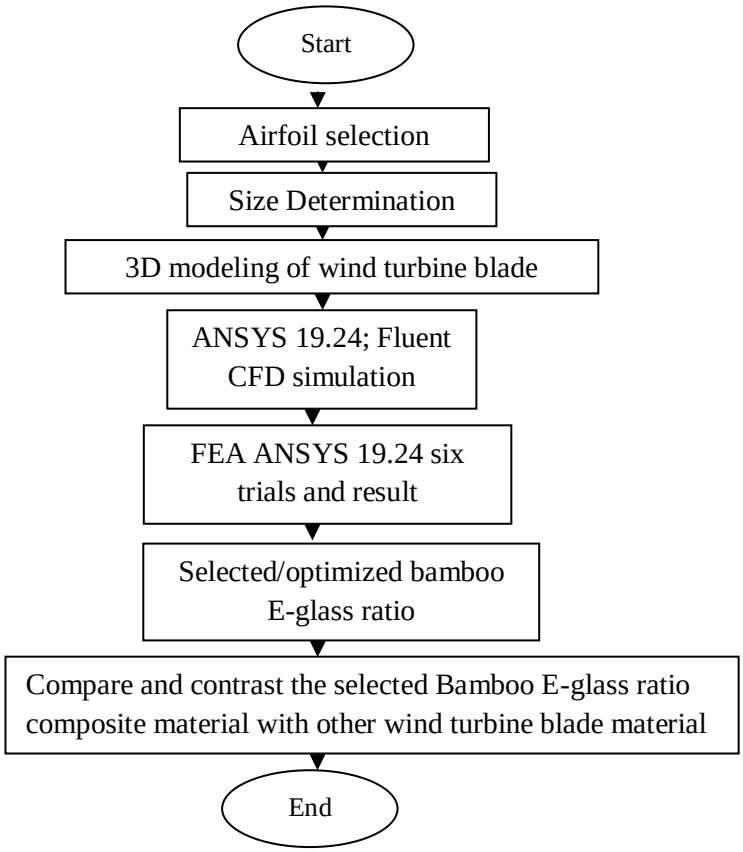


Figure 3.1: Work Flow Diagram

3.3.Airfoil Selection

The thesis selects airfoil from standard of NACA. The airfoil of NACA0012 was applied to facilitate the modeling and analysis of the blade. NACA0012 has selected for its simplicity for 3D modeling since it is symmetrical.

The NACA four-digit wing sections define the profile by: [72]

1. First digit describing maximum camber as percentage of the chord.
2. Second digit describing the distance of maximum camber from the airfoil leading edge in tenths of the chord.
3. Last two digits describing maximum thickness of the airfoil as percent of the chord. [73].

For this case, the NACA 0012 implies that: The NACA 0012 airfoil is symmetrical, the 00 indicating that it has no camber. The 12 indicates that the airfoil has a 12% thickness to chord length ratio: it is 12% as thick as it is long.

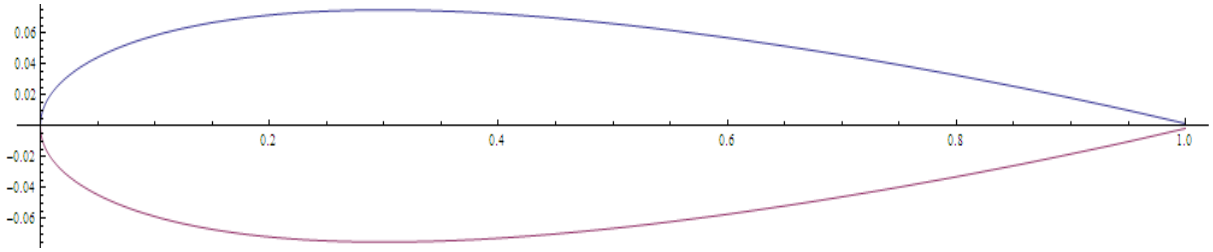


Figure 3.2 NACA0012 [74]

Equation for a symmetrical 4-digit NACA airfoil for 3D-modeling [74]

The formula for the shape of a NACA 00xx foil, with "xx" being replaced by the percentage of thickness to chord, is

$y_t=5t[0.2969\sqrt{x}-0.1260x-0.3516x^2+0.2843x^3-1.1015x^4]$……Eq.(1) [75, 76]

Where:

x, is the position along the chord from 0 to 1.00 (0 to 100%),

y_t, is the half thickness at a given value of *x* (centre line to surface),

t is the maximum thickness as a fraction of the chord (so *t* gives the last two digits in the NACA 4-digit denomination divided by 100).

Note that in this equation, at $x/c = 1$ (the trailing edge of the airfoil), the thickness is not quite zero. If a zero-thickness trailing edge is required, for example for computational work, one of the coefficients should be modified such that they sum to zero. Modifying the last coefficient (i.e. to −0.1036) will result in the smallest change to the overall shape of the airfoil. The leading edge approximates a cylinder with a radius of [77]

$$r = 1.1019\frac{t^2}{c} \quad \text{.....Eq. (2)}$$

Now the coordinates (x_U, y_U) of the upper airfoil surface and (x_L, y_L) of the lower airfoil surface are $x_U=x_L=x$, $y_U=+y_t$, $y_L=-y_t$

Beside this, CFD analysis on the blade is performed to determine critical load value and the strength analysis of the shell.The Airfoil models was first prepared and then imported into ANSYS where load and boundary conditions imposing, material properties defining, and meshing have been done as illustrated on figure 3.3. In the analysis domain, the air was made to flow at a constant velocity at 35m/s, and the temperature and density of the air was taken 300K, and 1.225 kg/m^3respectively. All wind turbines are designed for a maximum wind speed, called the survival speed, above which they will be damaged. The survival speed of commercial wind turbines is in the range of 30 m/s (144 km/h, 89 MPH) to 72 m/s (259 km/h, 161 MPH). The most common survival speed is 60 m/s (216 km/h, 134 MPH). Some have been designed to survive 80 metres per second (290 km/h; 180 mph) [78].35m/s is in this range.

3.4.Data Collection

Information is gathered from different sources; such as journals, books, websites written about physical and mechanical properties of fibers and matrix of composite materials that were used as an input for static structural analysis. The experimental results of bamboo to E-glass Fiber ratio were used as an input for structural analysis from previous research works [10].

Table 3.1Experimental Test Results of Bamboo to E-glass fiber reinforced composite (Adopted from reference [10])

Experimental Test and Stress Type		**Bamboo to E-glass Fibre ratio**					
Test Type	**Stress**	**100:0%**	**70:30%**	**50:50%**	**30:70%**	**15:85%**	**0:100%**
Tensile stress	Ultimate Tensile Strength (MPa)	187.73	414.72	513.52	520.56	534.11	557.29
	Failure Strength (MPa)	186.32	354.64	475.18	470.92	463.07	489.62
	Elongation at Break	4.59	5.96	5.99	7.32	7.49	7.09
Compressive Test	Maximum Compressive Strength (MPa)		134.73	146.20	119.26	114.13	116.65
	Failure Strength (MPa)		122.30	144.90	101.30	103.00	104.00
	Yield Strength (MPa)		64.20	68.30	28.5	54.20	27.60
	Failure Strain (%)		5.97	6.45	6.85	6.79	6.31
Young's Modulus	In Plane Shear Modulus (MPa)	1784.00	2866.00	3849.00	3346.00	3411.00	
	Tensile Modulus (MPa)	3211.00	9528.00	11588.00	9494.00	8657.00	10091.00
	Flexure Modulus (MPa)		6874.00	6929.00	6644.00	7681.00	5048.00
	Compressive Modulus (MPa)		2036.00	2357.00	1906.00	2630.00	2512.00
In plane Shear Stress	Maximum in plane shear strength (MPa)	18.18	69.71	84.31	97.55	94.21	
	Failure Strength(MPa)	17.79	65.24	82.45	91.96	93.94	
	Failure Strain (%)	1.34	4.95	4.18	5.27	4.81	
	Maximum Flexural Strength (MPa)		376.17	460.00	439.44	435.18	478.35
	Failure Strength (MPa)		346.20	435.54	439.44	406.27	437.47
	Failure Strain(%)		6.90	7.80	5.90	6.50	9.30

3.5.3D modeling of wind turbine blade

3D modeling of wind turbine blade was designed by using CATIA version-5 software. The model was imported to ANSYS software in order to perform Computational fluid dynamics (CFD), and Finite element analysis (FEA).For a full scale of wind turbine diameter 36m; NACA0012 airfoil was used to study various turbulent models. The following figure 3.2 shows the full scale mode of wind turbine developed by CATIA V5.

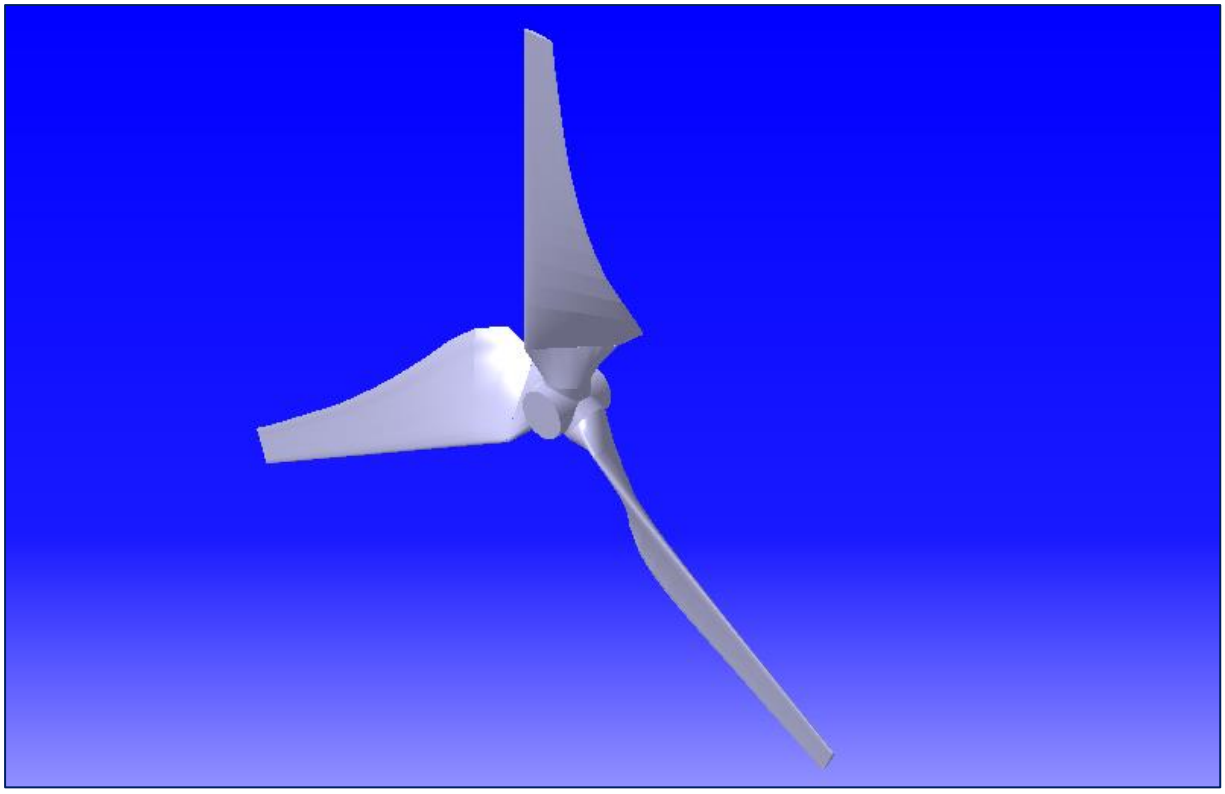
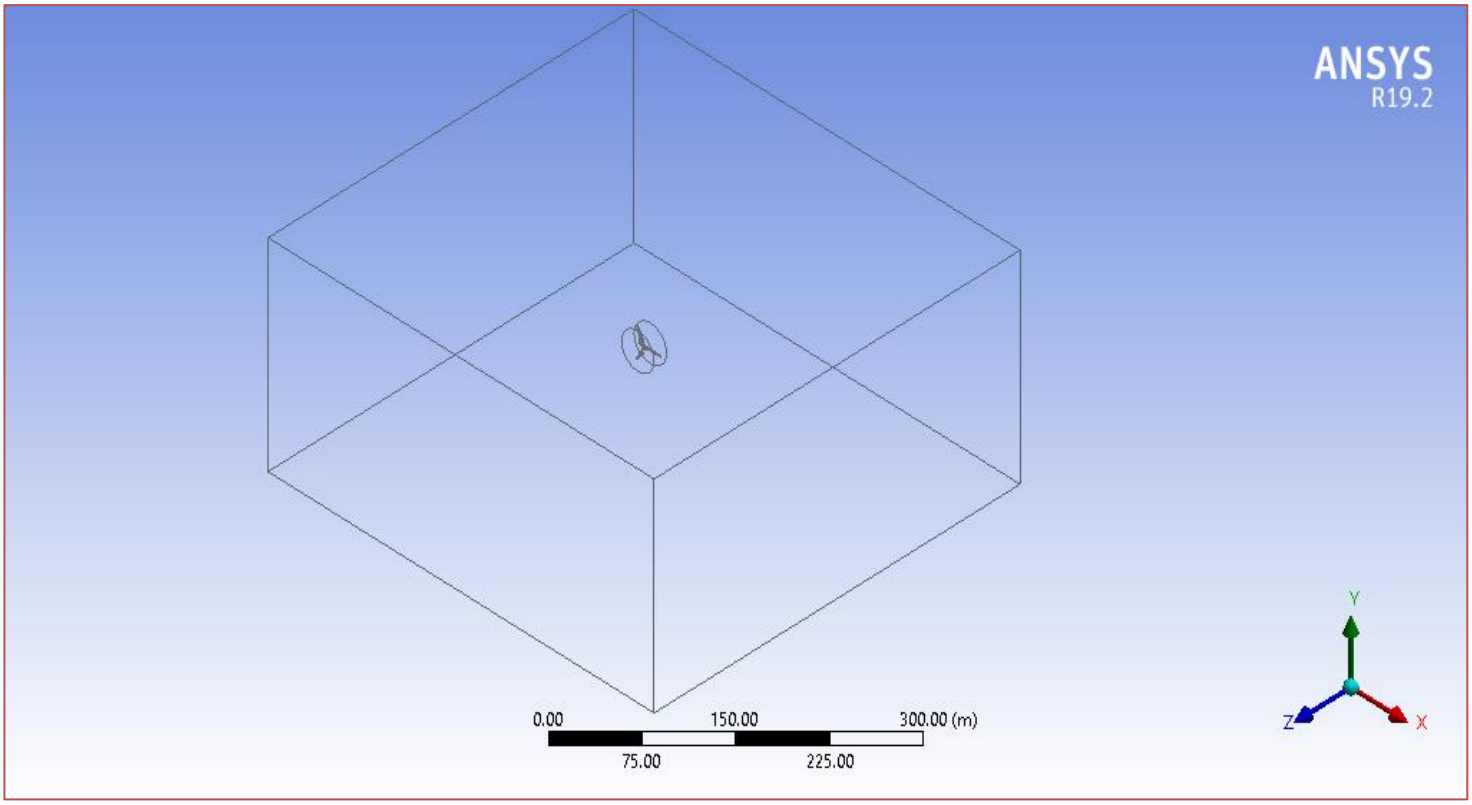
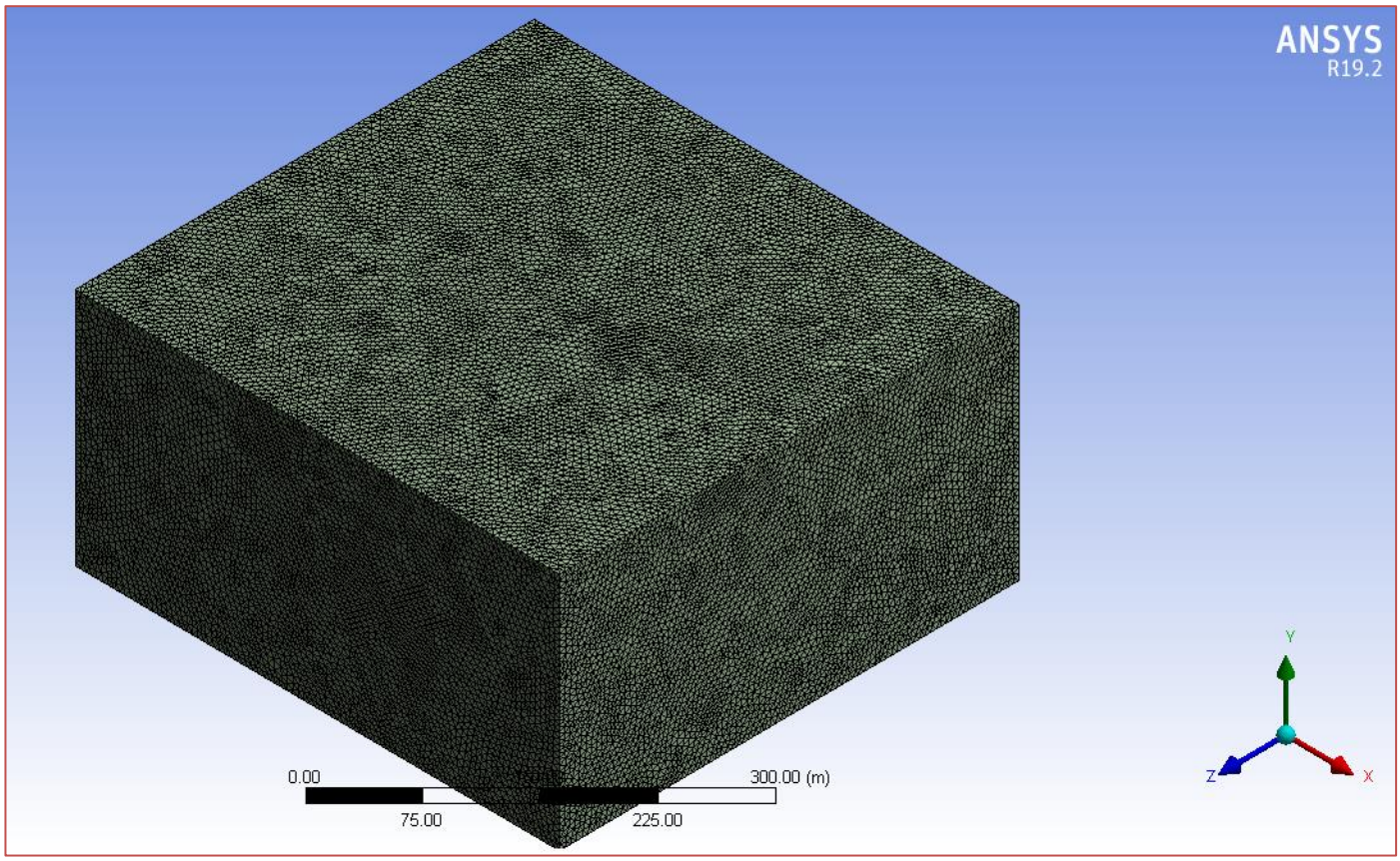


Figure 3.2: 3D Modeling of Large Scale Wind Turbine of NACA0012

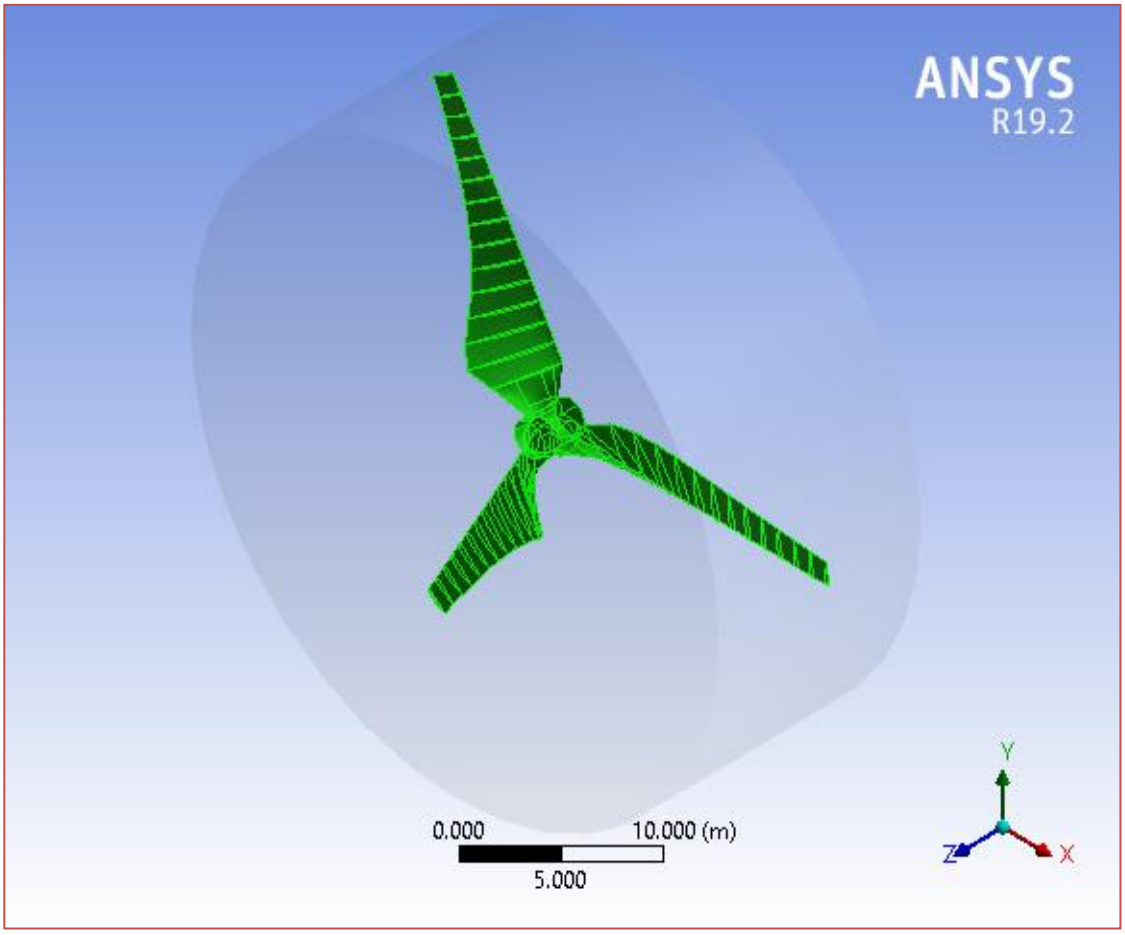
3.6. CFD Simulation

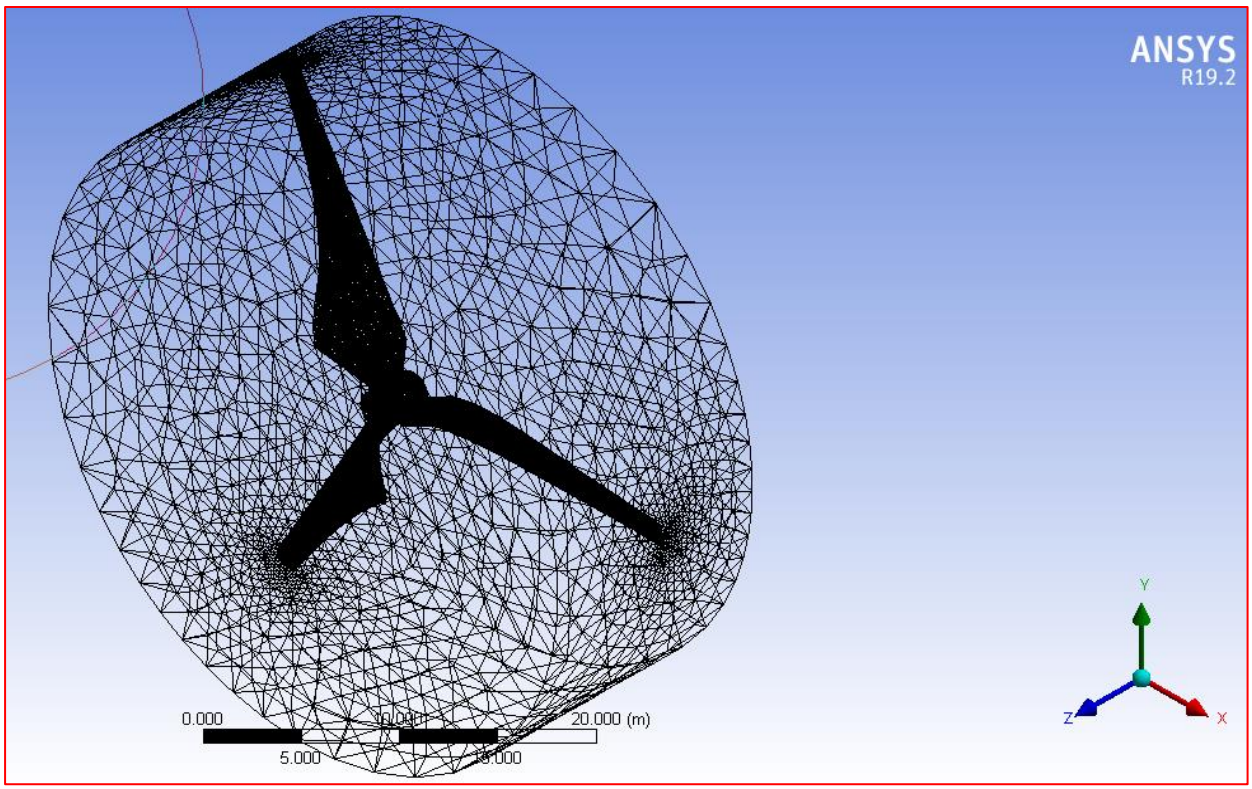
3.6.1 CFD Simulation Boundary Conditions





(a) Stationary Domain and its discritization





(b): Rotor Domain and its discritization

Figure 3.3: Computatioal Domain and Discritization

3.6.2 Fluid Flow Solver Type and Material Used

This is the general concept that has to be considered depending on simulation type. The step followed as;

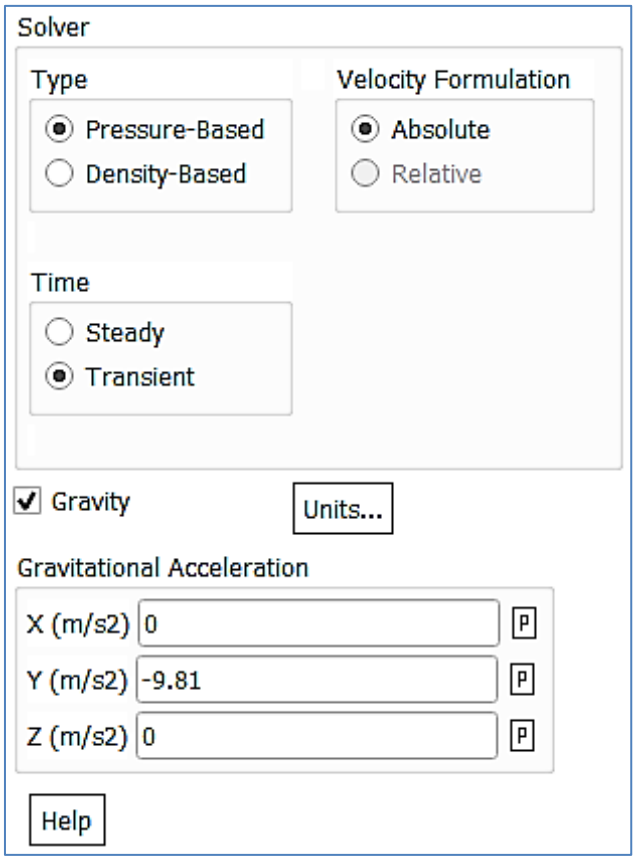


Figure 3.4Fluid flow solver type

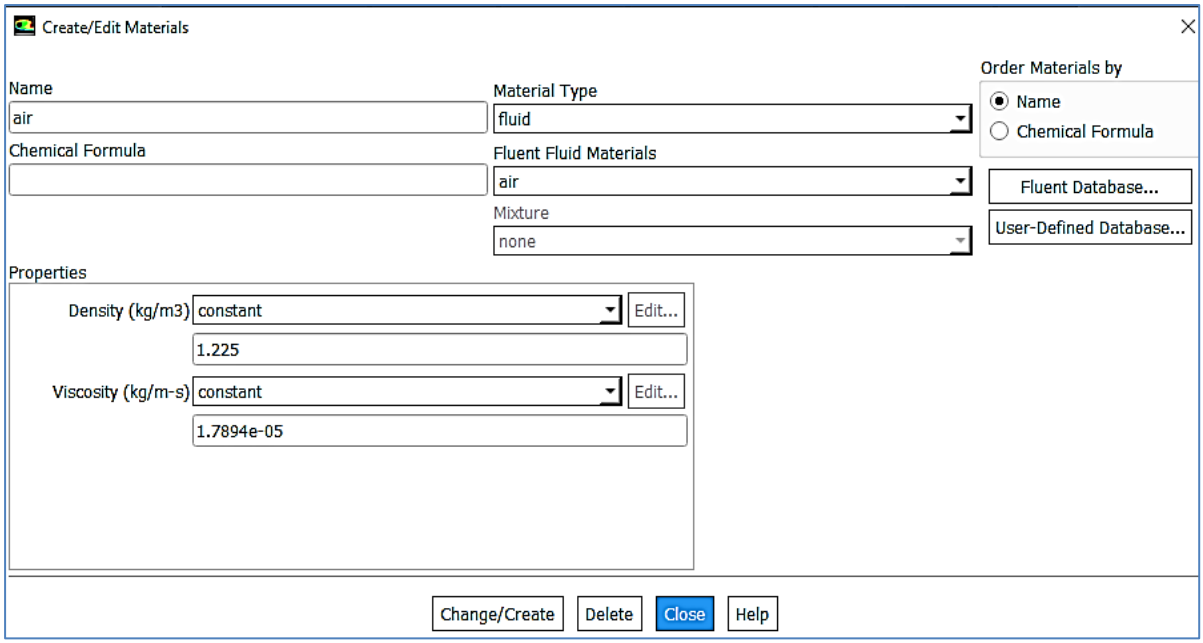


Figure 3. 5: Properties of Air

3.6.3 Cell Zone Boundary Conditions

Under the cell zone condition in order to make collision between flowing air and rotor blade we give the input rotational speed to the rotary that is 35m/s wind speed converted into 2 rad/s and the diameter of the blade is 36m.

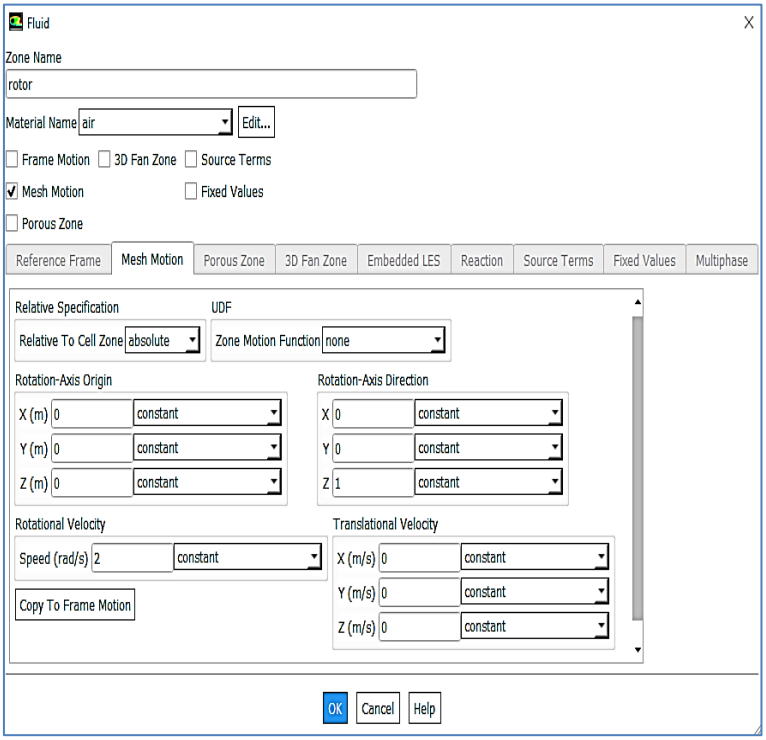


Figure 3. 6 Cell Zone Boundary Conditions

3.6.4 Viscous Model (Simulation Model)

For full time simulation model of viscous fluid the large eddy simulation (LES)was selected with the sub grid of **Smagorisky-Lilly equation**. For the detail, the following steps were used:

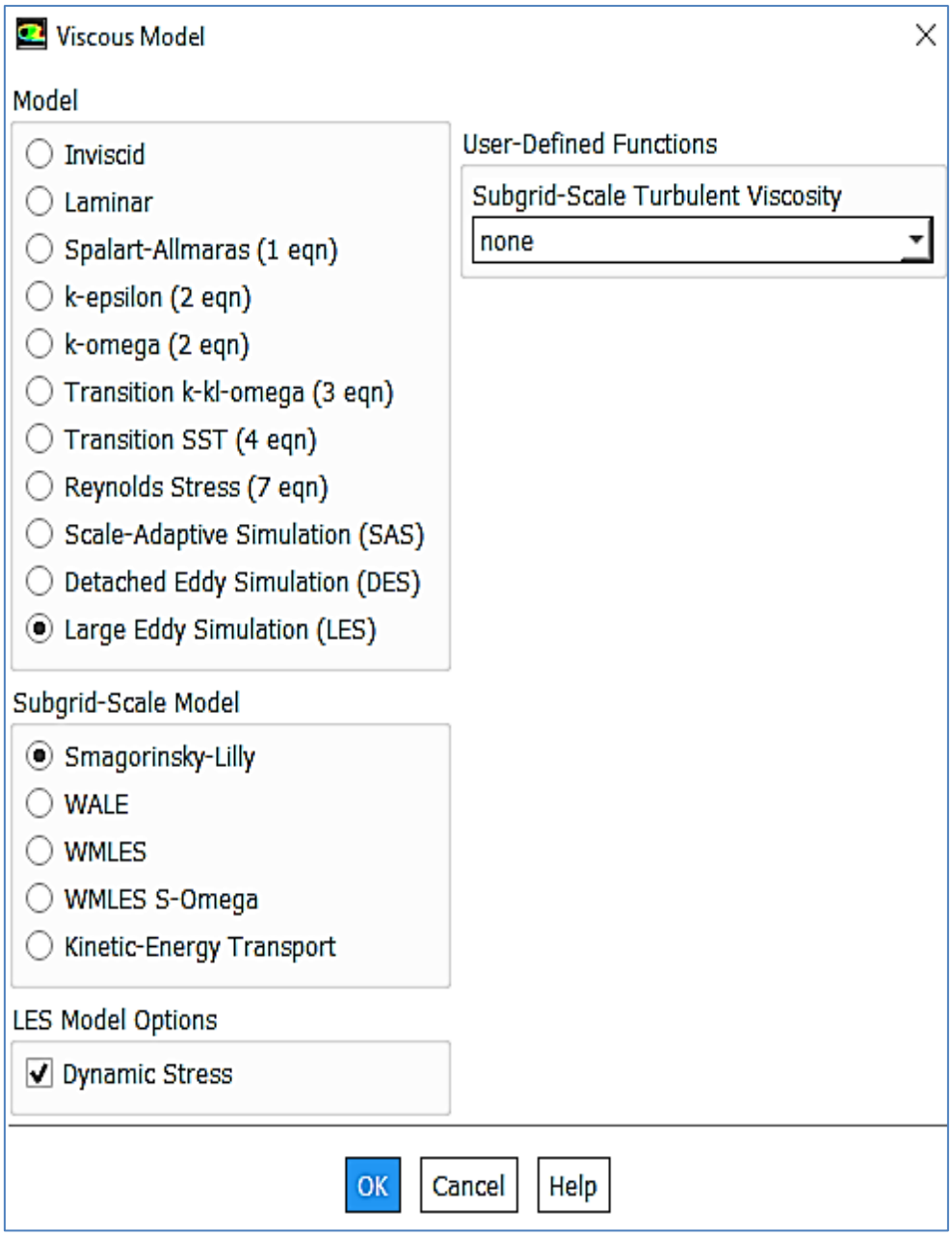
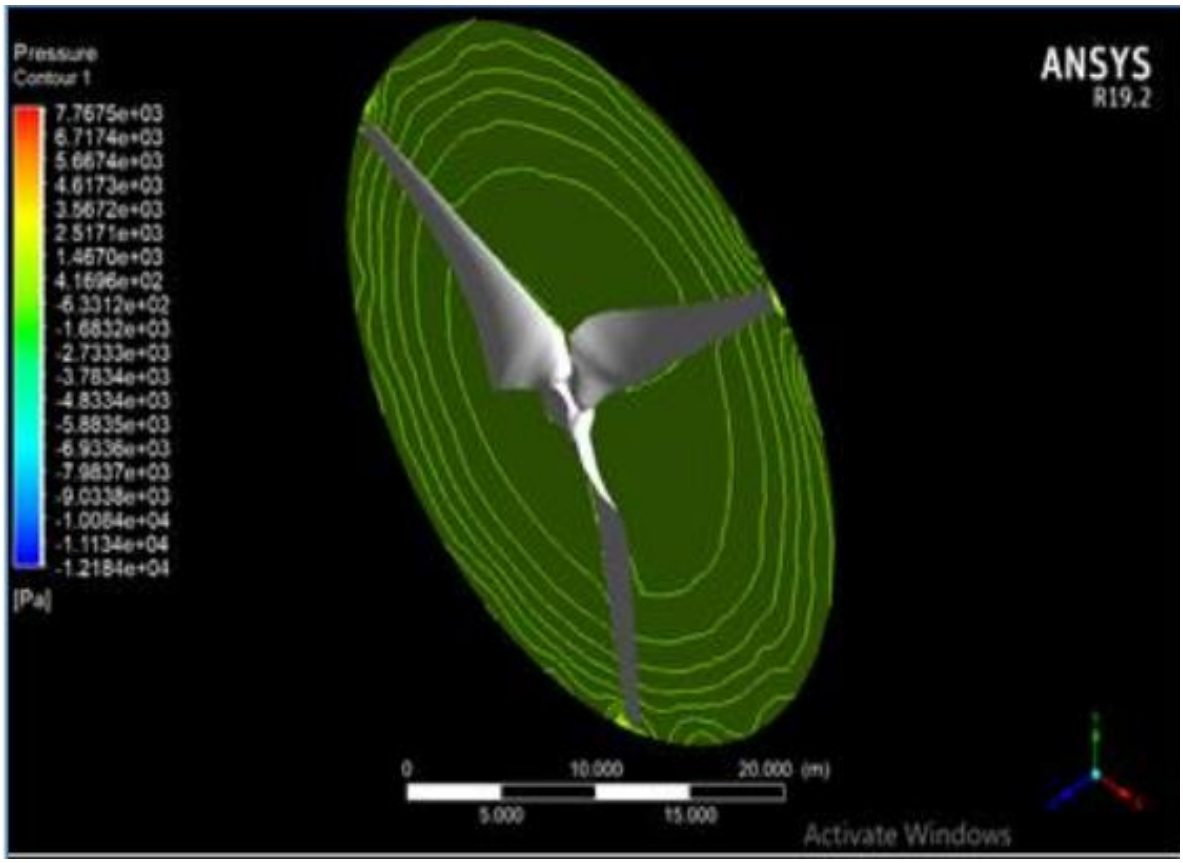
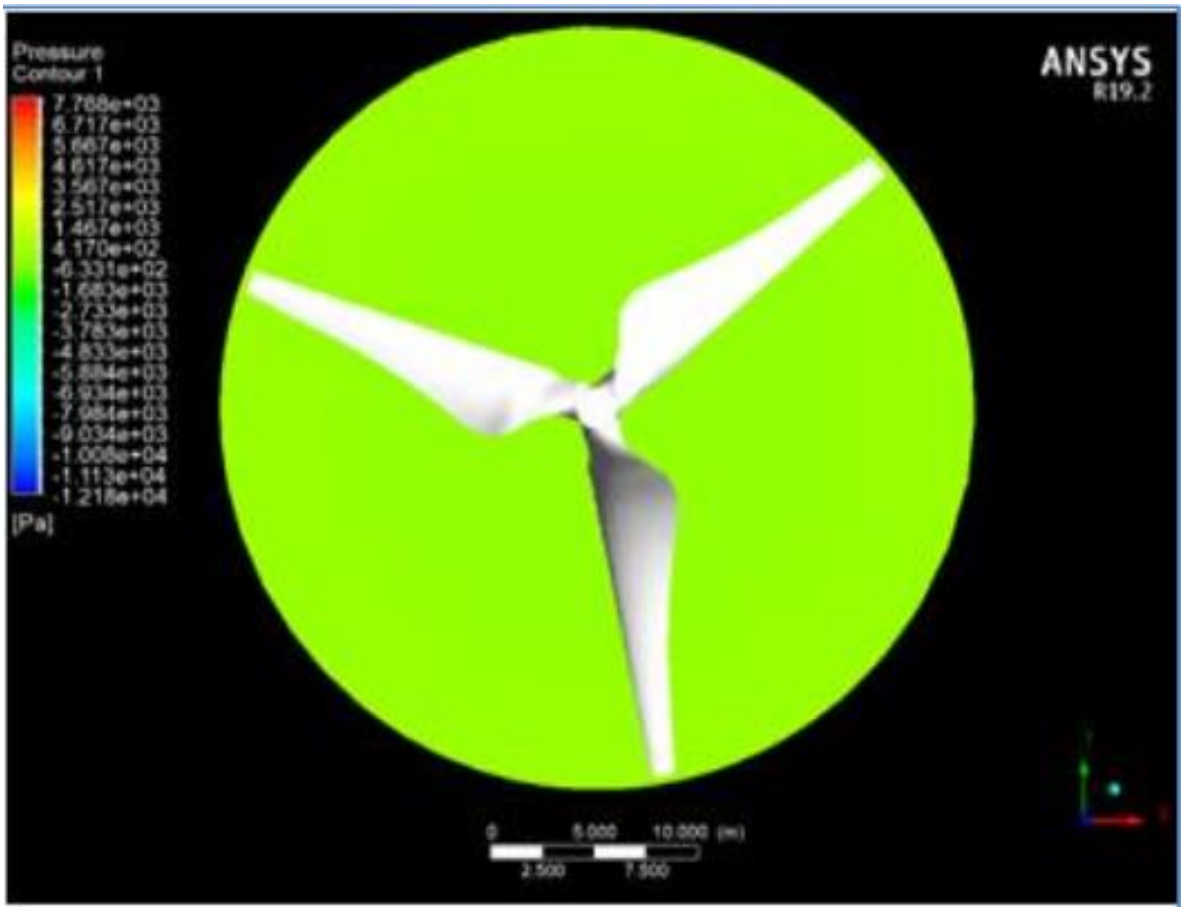
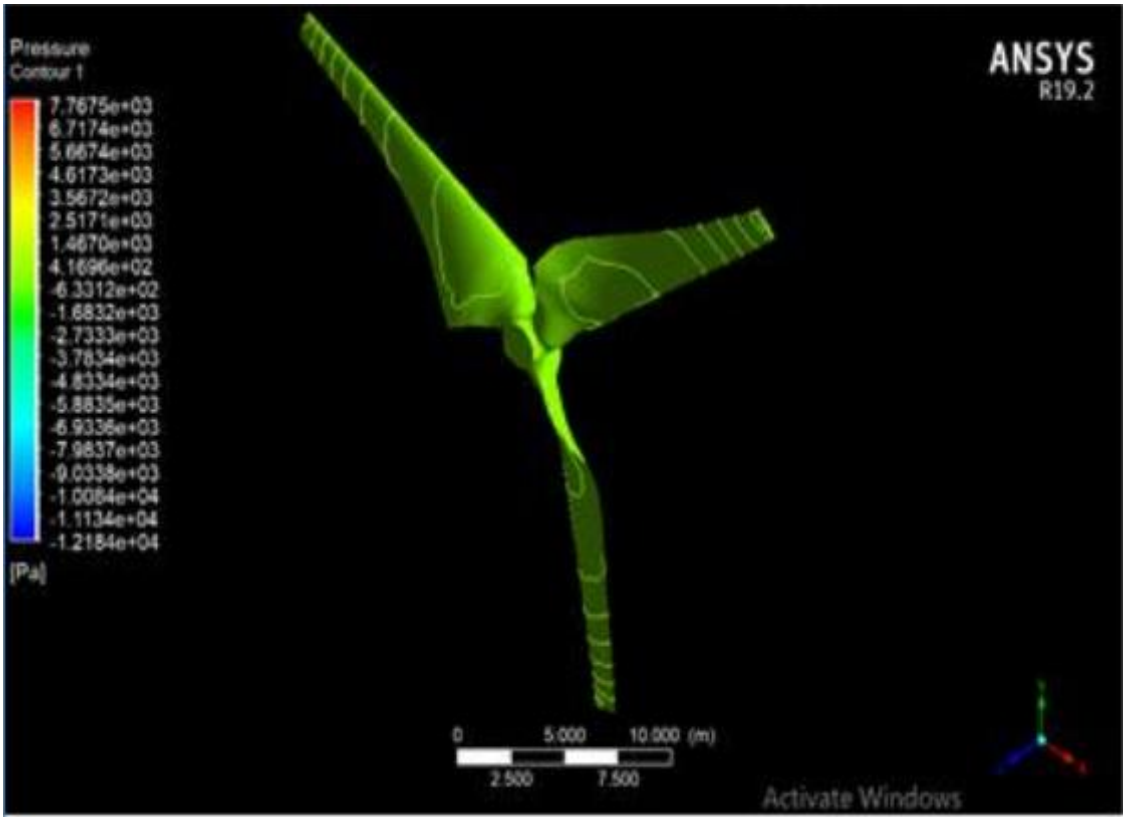


Figure 3. 7: Viscous Fluid

3.6.5 CFD Simulation Results







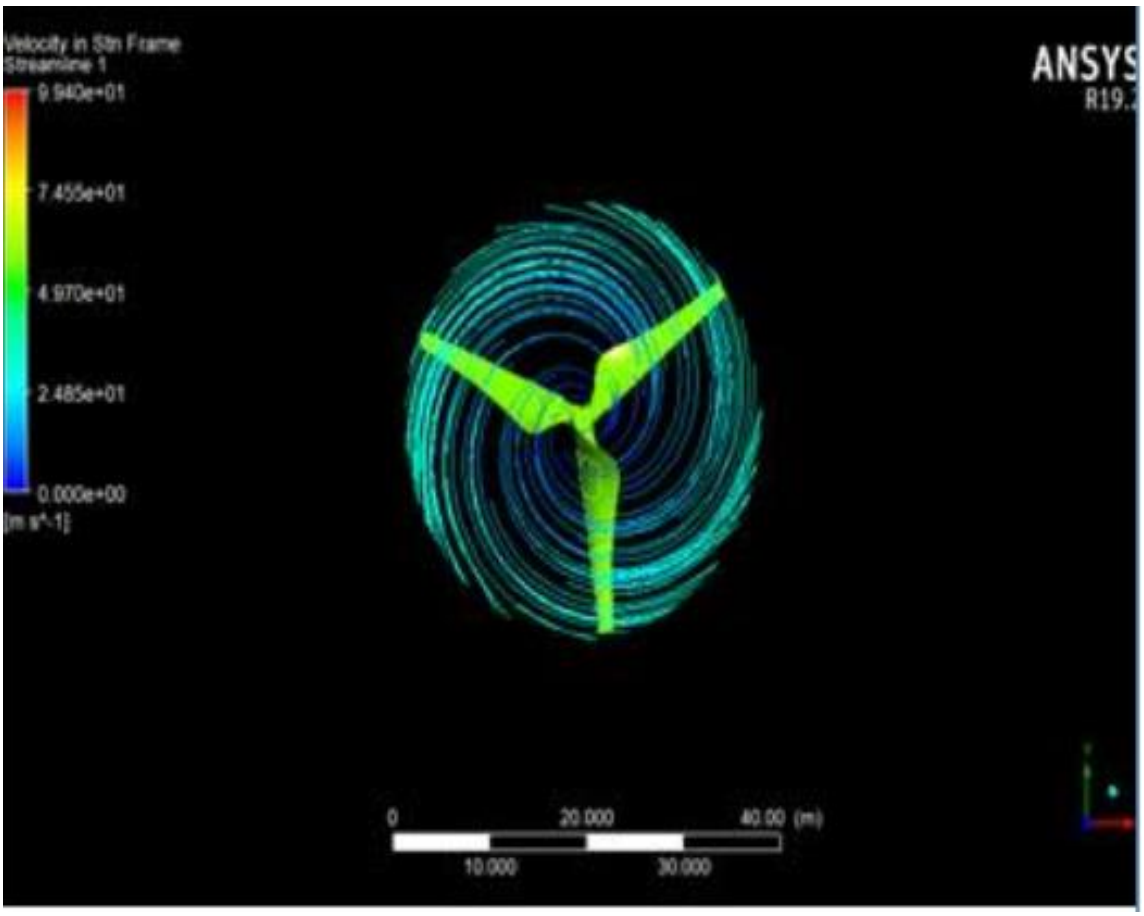
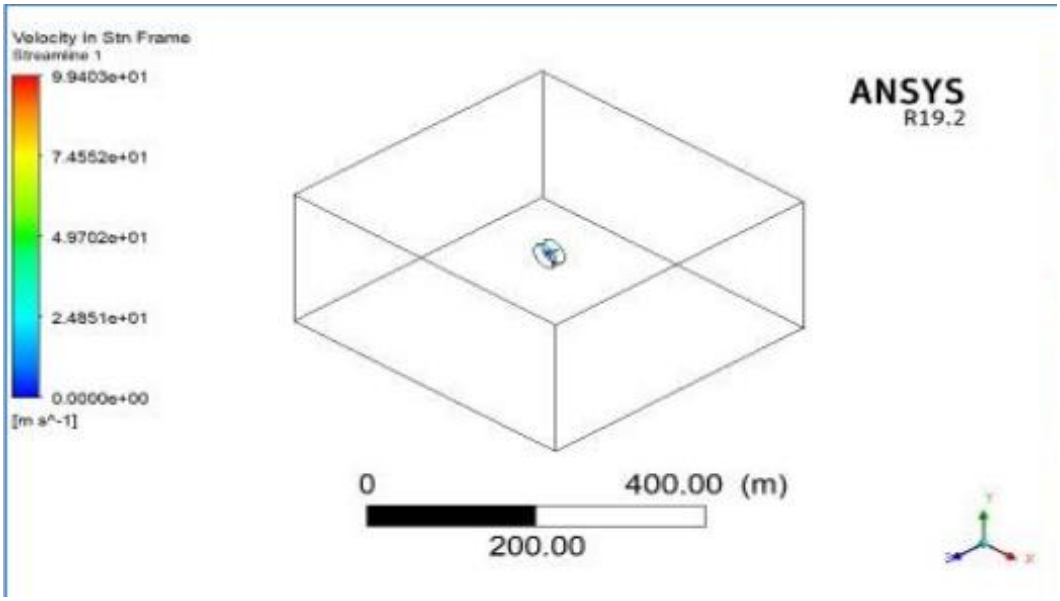
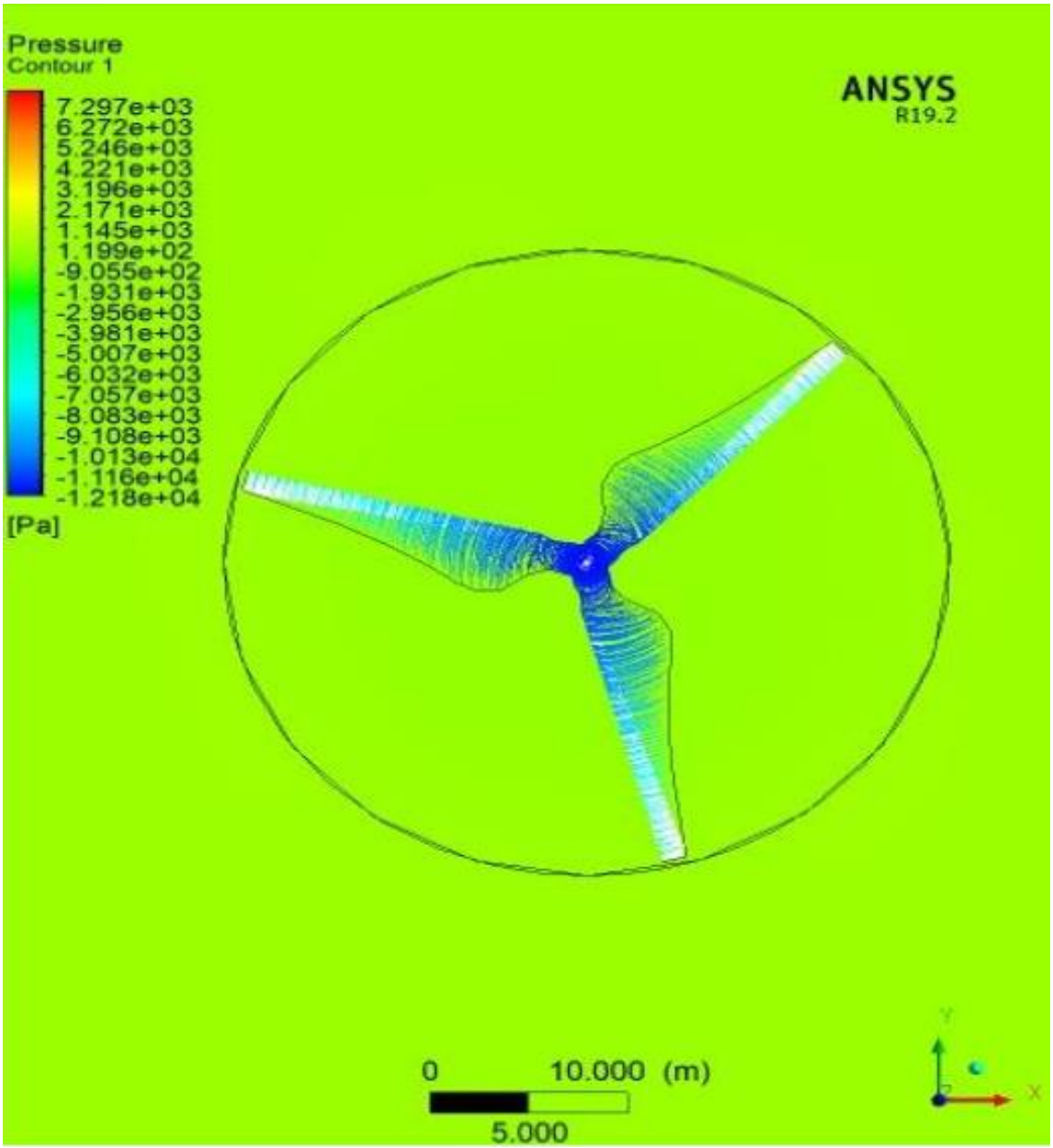


Figure 3.8a, b, c &d: CFD Simulation of Conture Pressure on blade and its profile


Velocity in Stn Frame
Streamline 1
9.9403e+01
7.4552e+01
4.9702e+01
2.4851e+01
0.0000e+00
[m s^-1]
ANSYS
R19.2
0
400.00 (m)
200.00


Pressure
Contour 1
7.297e+03
6.272e+03
5.246e+03
4.221e+03
3.196e+03
2.171e+03
1.145e+03
1.199e+02
-9.055e+02
-1.931e+03
-2.956e+03
-3.981e+03
-5.007e+03
-6.032e+03
-7.057e+03
-8.083e+03
-9.108e+03
-1.013e+04
-1.116e+04
-1.218e+04
[Pa]
ANSYS
R19.2
0
10.000 (m)
5.000

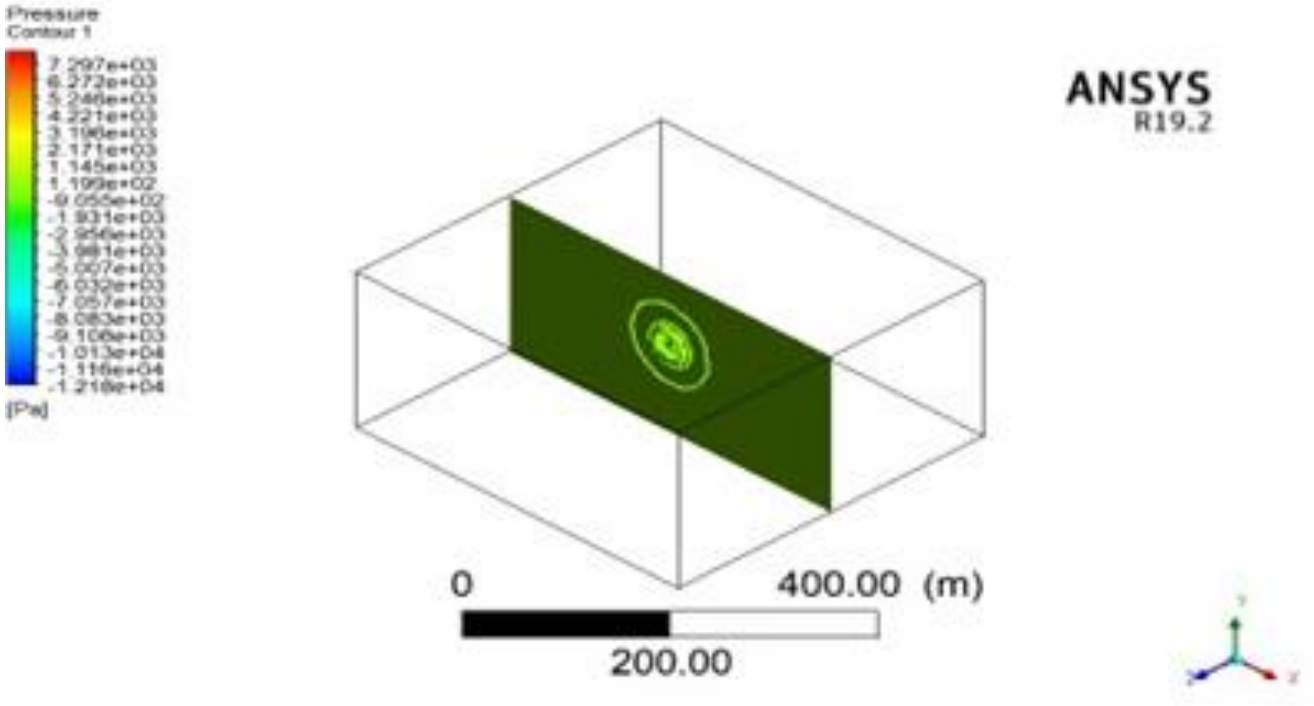


Figure 3.9: CFD Simulation of Conture Pressure mapped on to the blade through the static structural analysis chamber

3.7.Finite Element Analysis Using ANSYS 19.24 software

The CFD result was occasionally mapped into static structural analysis section for testing all ratios of trials founded from experimental data [10]. The following figure shows the mapping style of CFD pressure result to the static structural chamber.

3.8.ANSYS Static Structural analysis Boundary Condition

3.8.1 Model Discretization for static structural Analysis

The thickness distribution is calculated in terms of the chord where the total thickness of the blade at any position will be a percentage of the chord length at that position. Table 3.3 and Figure 3.10 below show the thickness distribution for the blade.

Table 3.2: Blade thickness variation versus surface number of wind turbine axisNACA0012

Blade tickes	Blade Number (step)
0.009	1
0.018	2
0.027	3
0.036	4
0.045	5
0.054	6
0.063	7
0.072	8
0.081	9
0.09	10
0.099	11
0.108	12
0.117	13
0.126	14
0.135	15

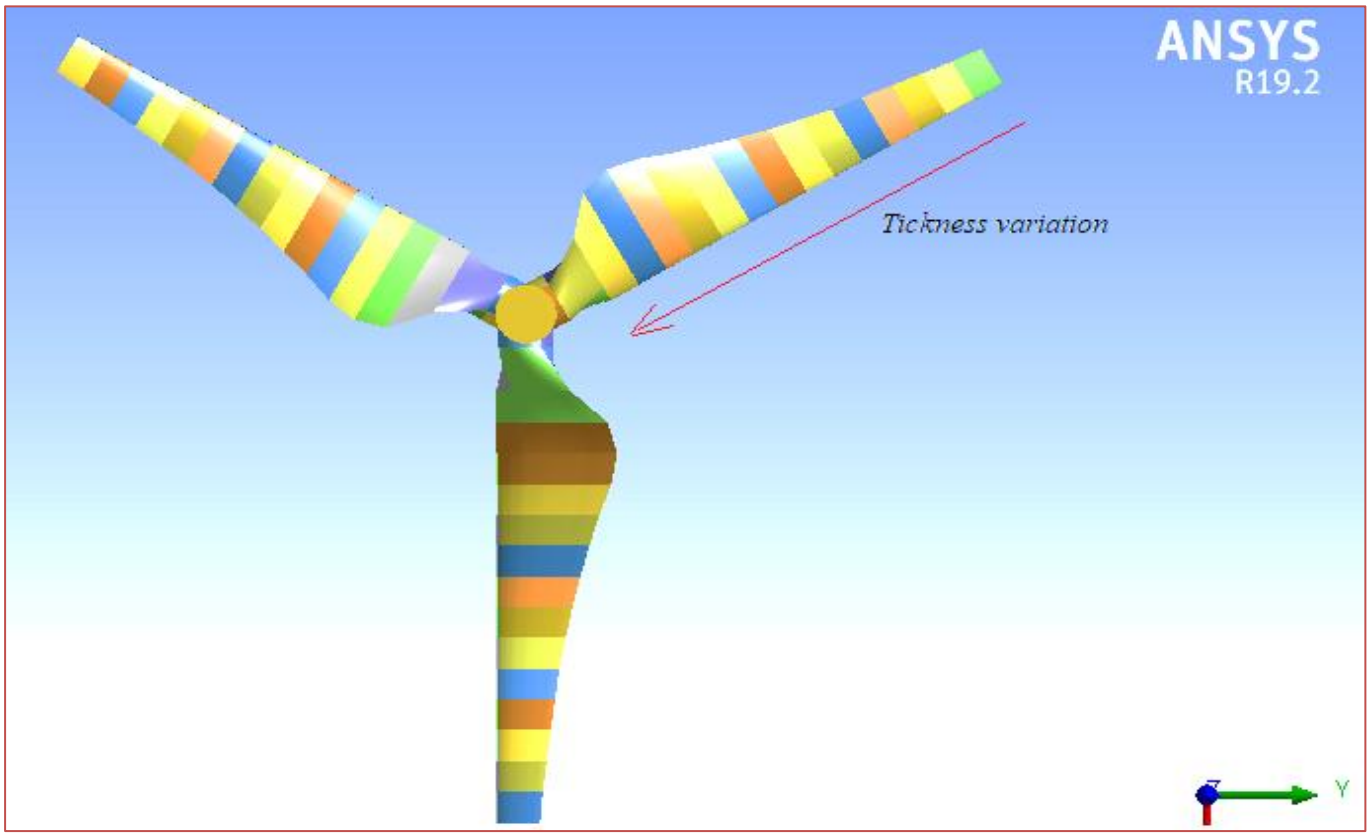
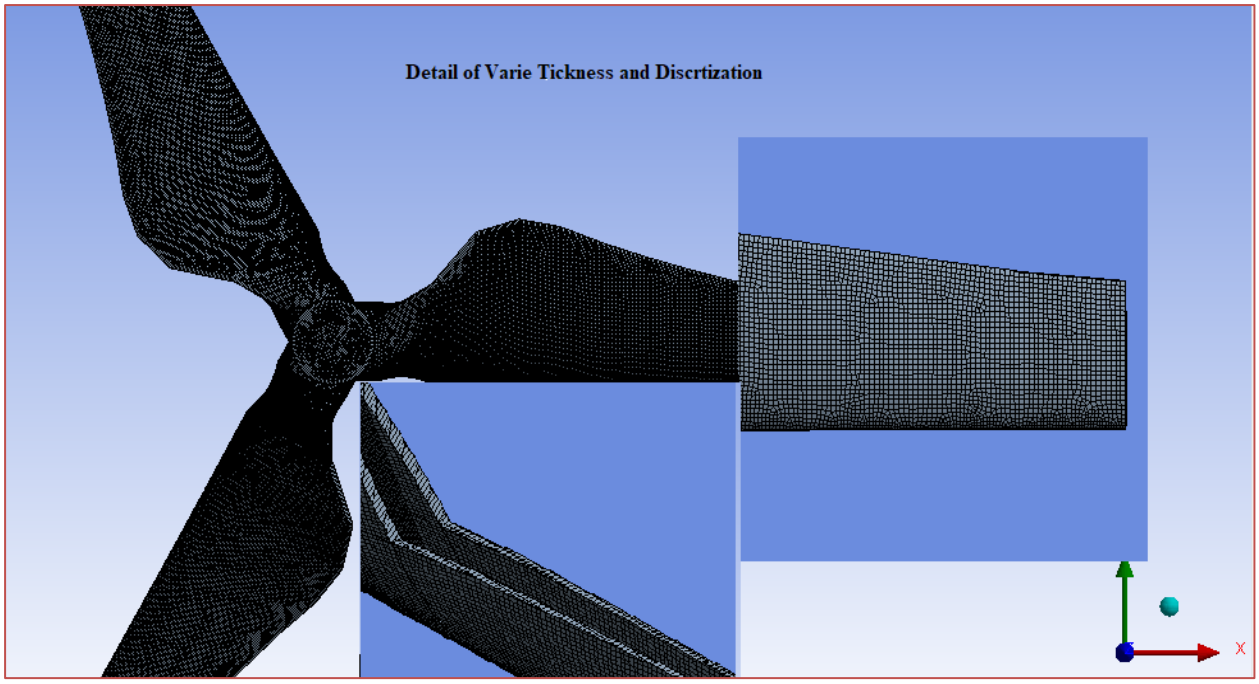
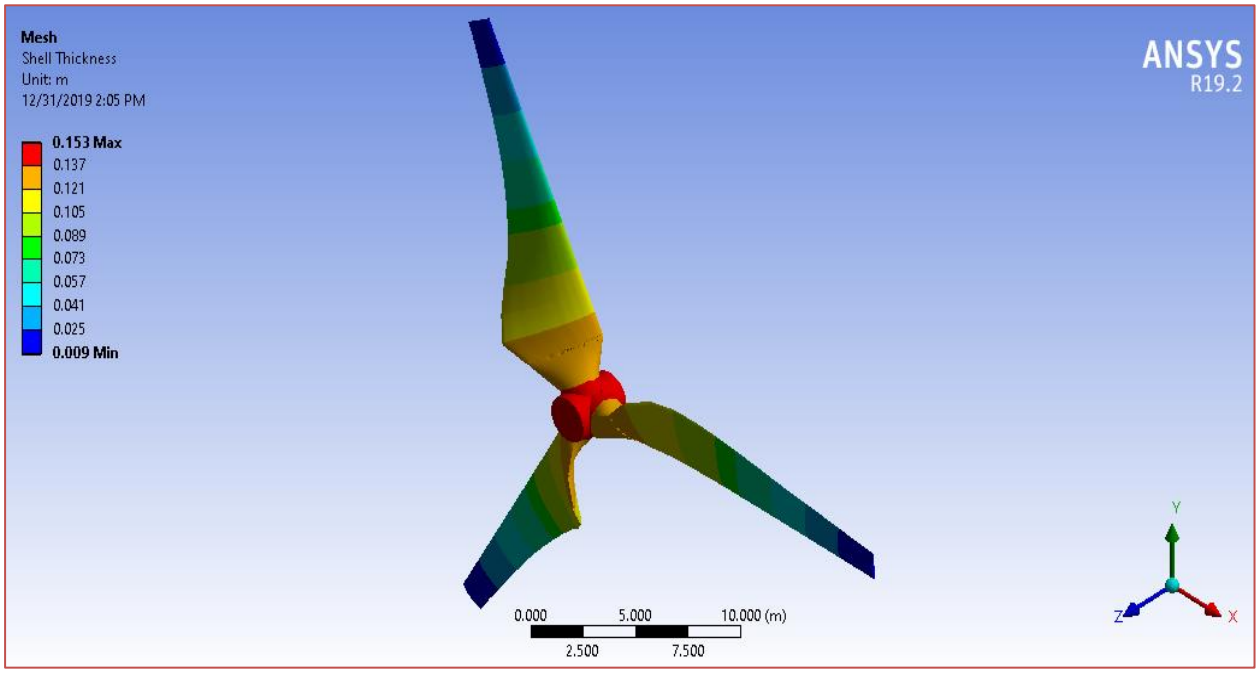


Figure 3.10: Thickness Distribution for the blade



(a)



(b)

Figure 3. 11: a Represents Mesh Generated for Turbine Blade, and b Represents Shell Thickness of the turbine blade

3.8.2 ANSYS Structural Analysis Material Input Data

The material properties of bamboo to E-glass ratio were taken from experimental results of previous research work [10] as it was described in the table 3.1. The properties of the materials were imposed on 3D model of wind turbine blade for performing static structural analysis.

3.9. Selection of Optimum Fiber Ratio for Bamboo to E-Glass

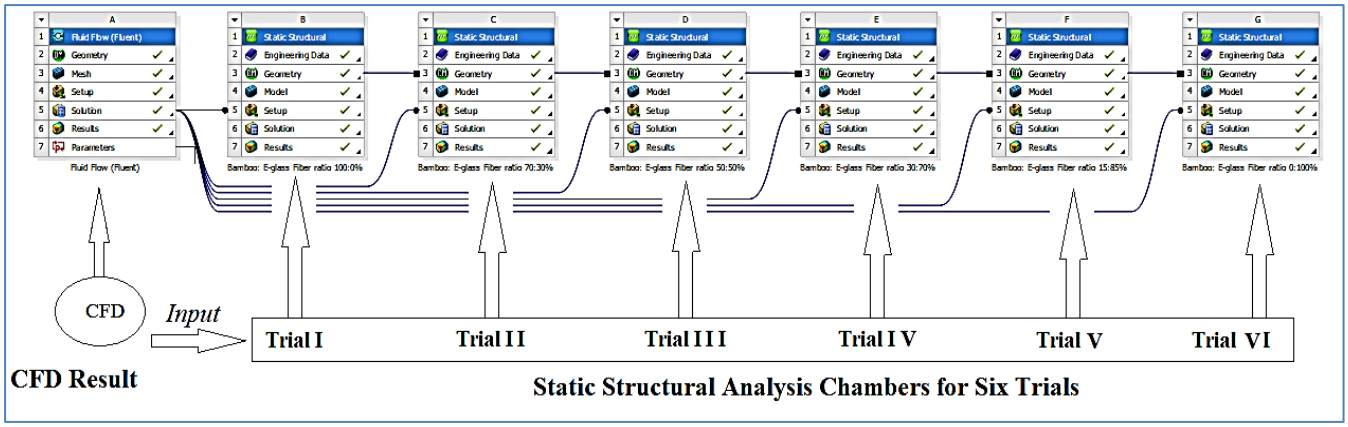
After carrying out the static structural analysis, the equivalent stress, displacement, and safety factor have been compared with each other and the best fiber-loading ratio was selected by interpreting the resulting mechanical properties for each trials.

Chapter Four

4. Results and Discussions

4.1. Computational Fluid Dynamics Mapped (CFD) Result from Simulation

The following figure 4.1 shows the CFD surface pressure result was mapped from ANSYS Fluent workbench to each six static structural analysis as shown on figure 4.1 below.



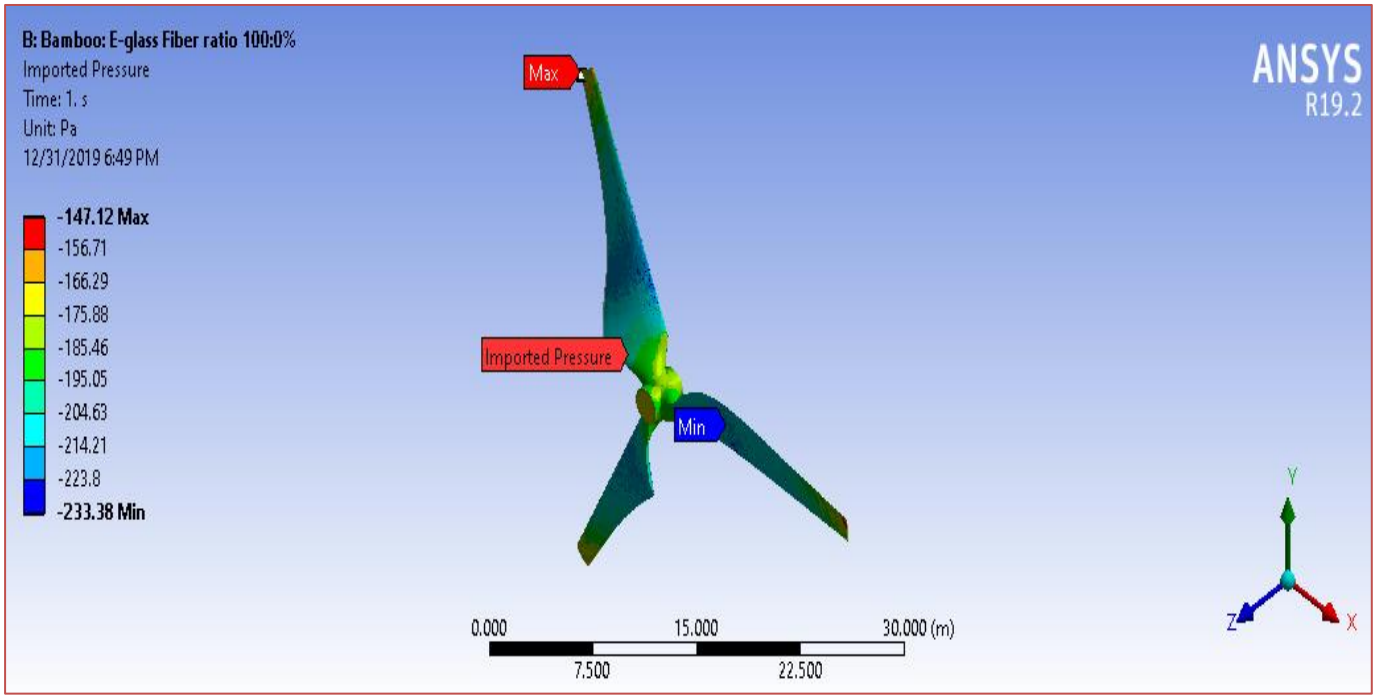
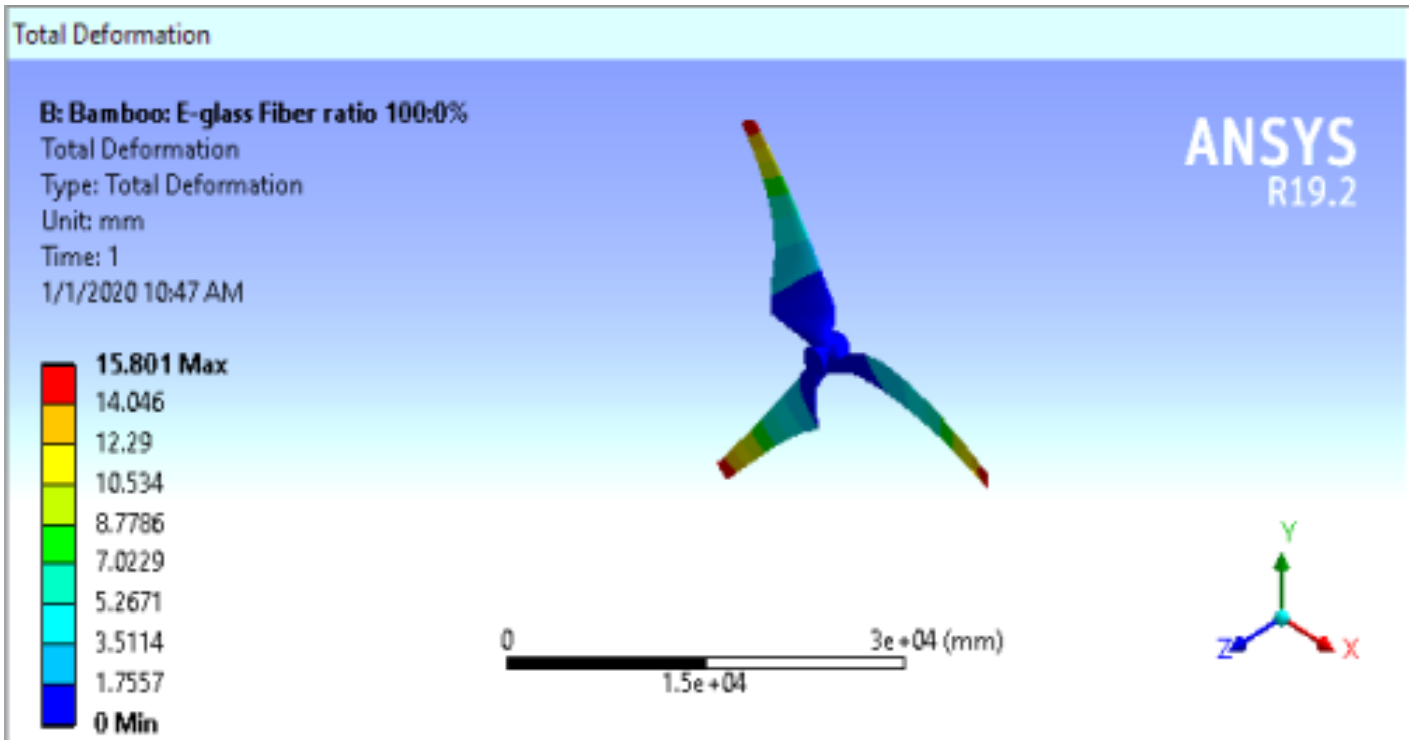
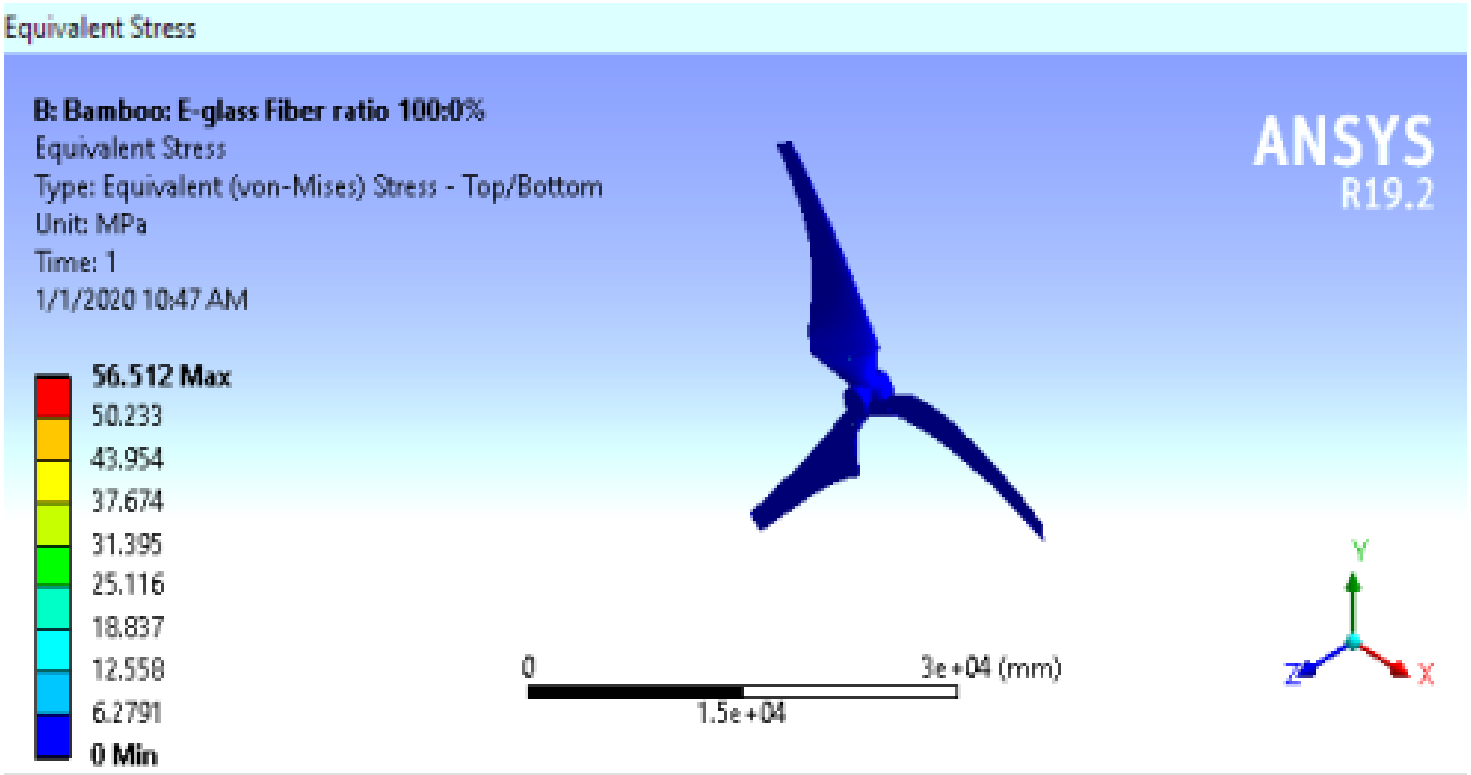


Figure 4. 1: Surface pressure mapped result

4.2.Static Structural Simulation Results

Trial I: Simulation Results from Bamboo: E-Glass Fiber Ratio 100%:0%





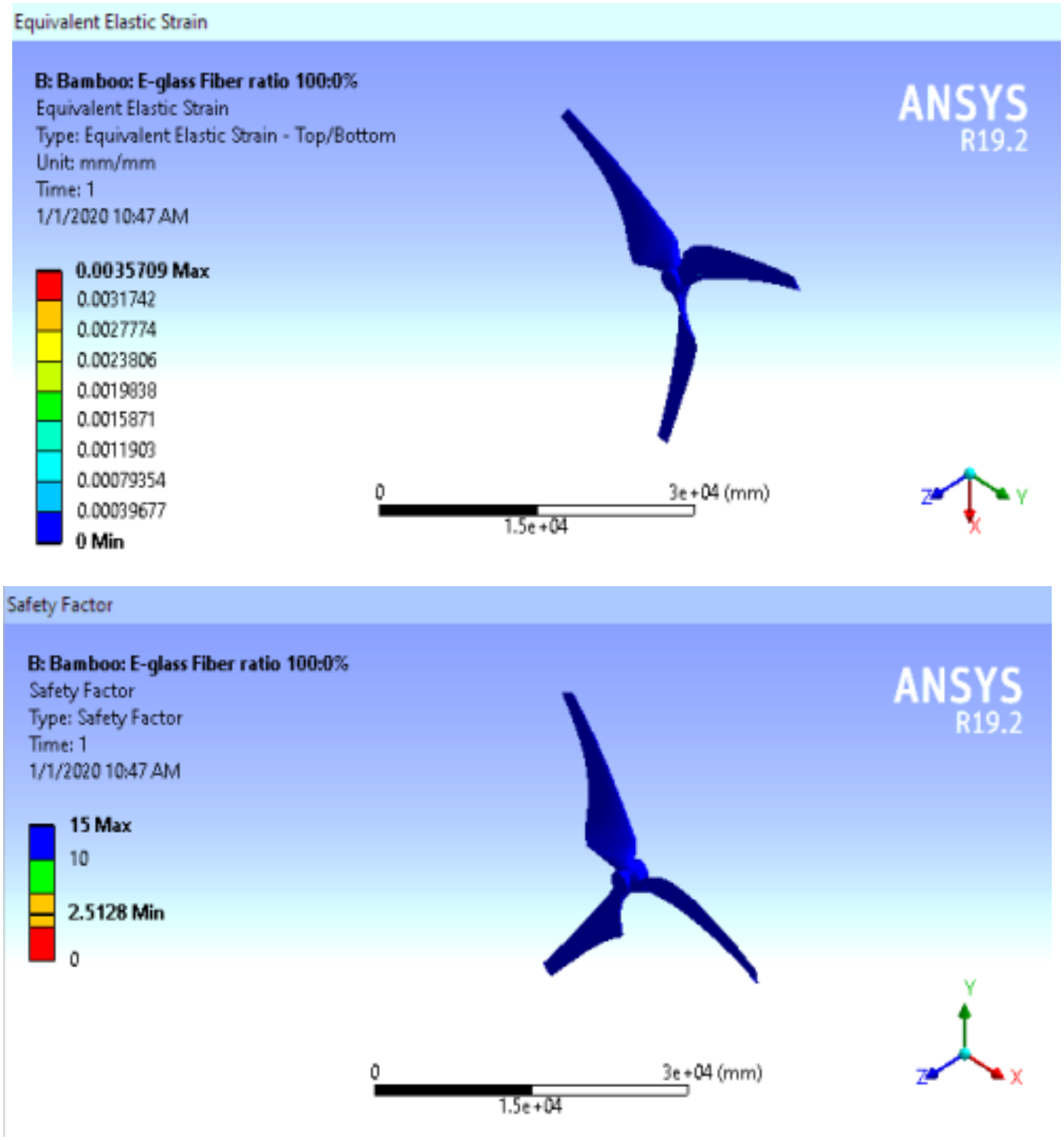
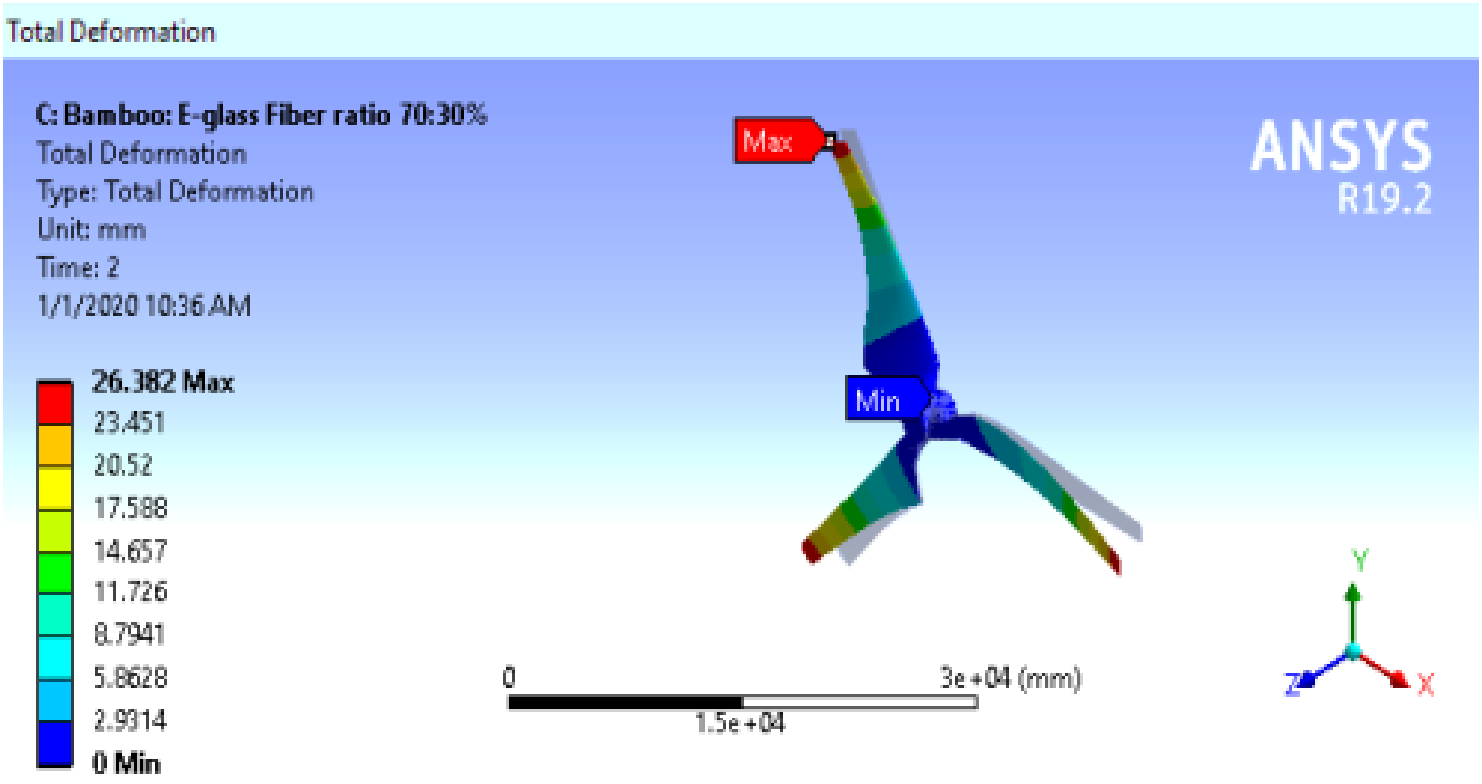
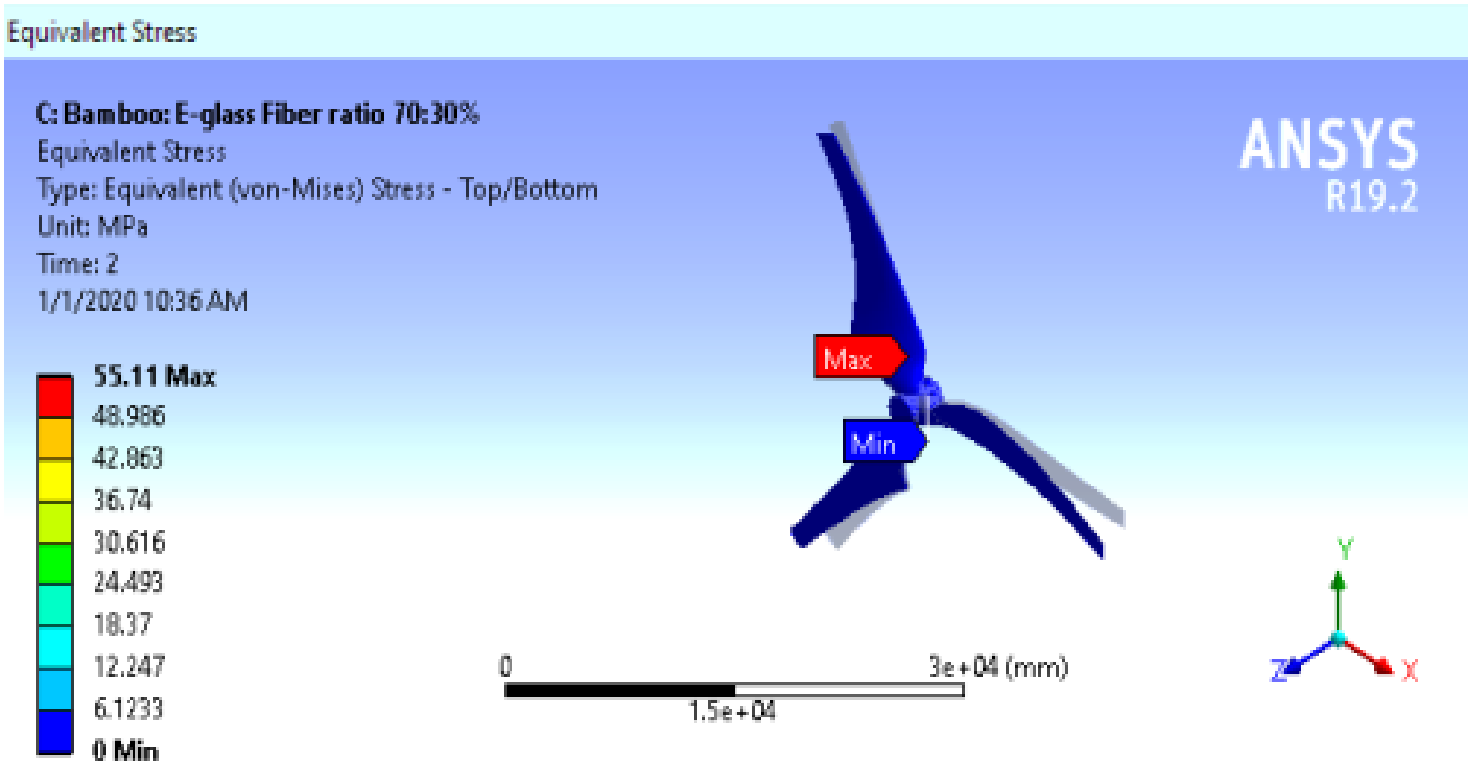
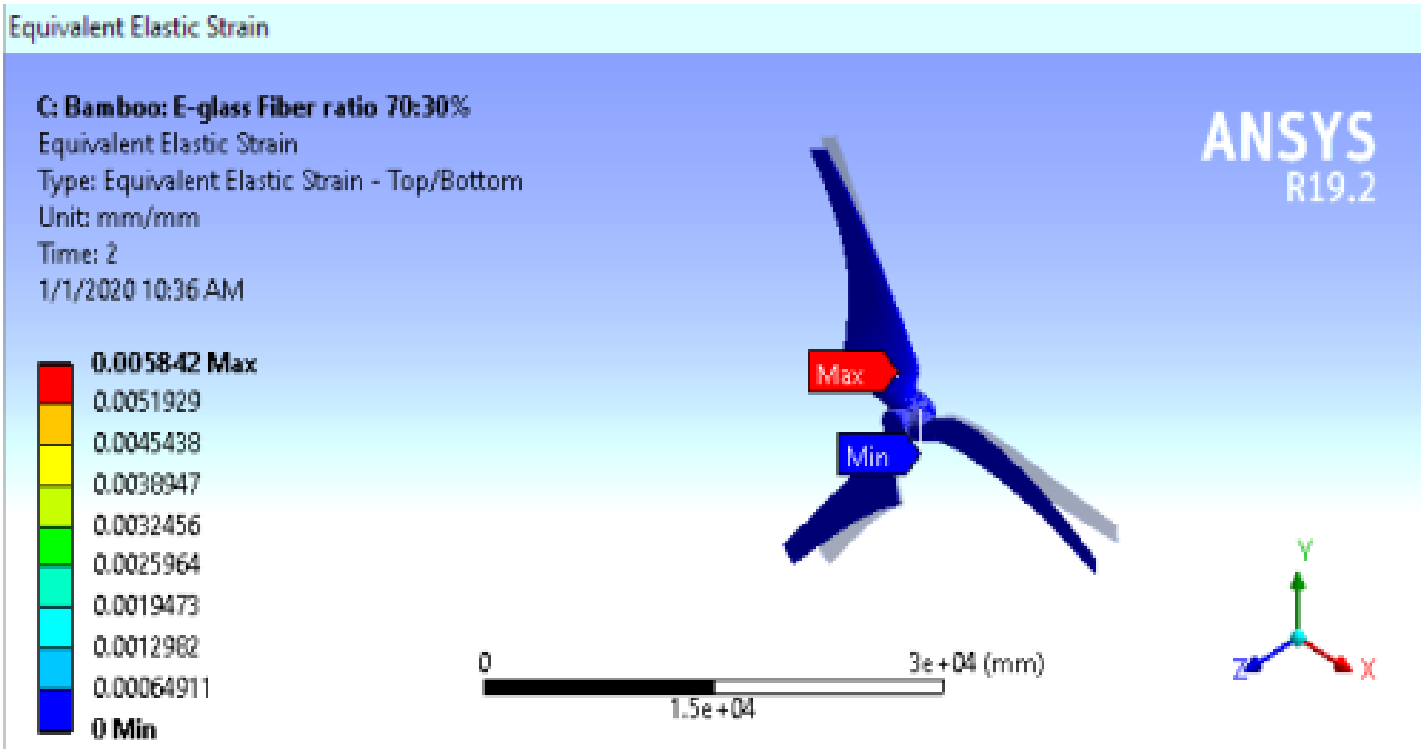


Figure 4.2: Simulation Result from Bamboo: E-Glass Fiber Ratio 100%:0%

Trial II: Simulation Result from Bamboo: E-Glass Fiber Ratio 70%:30%







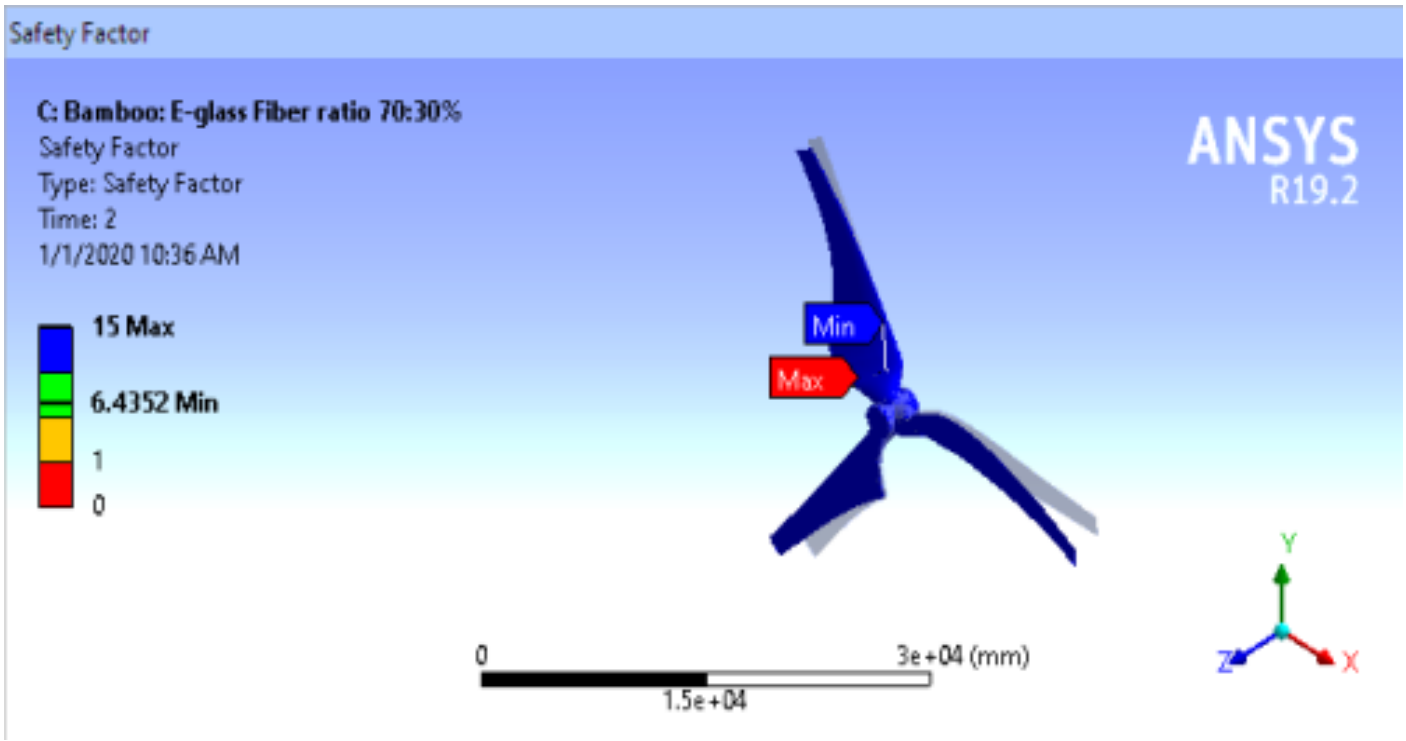
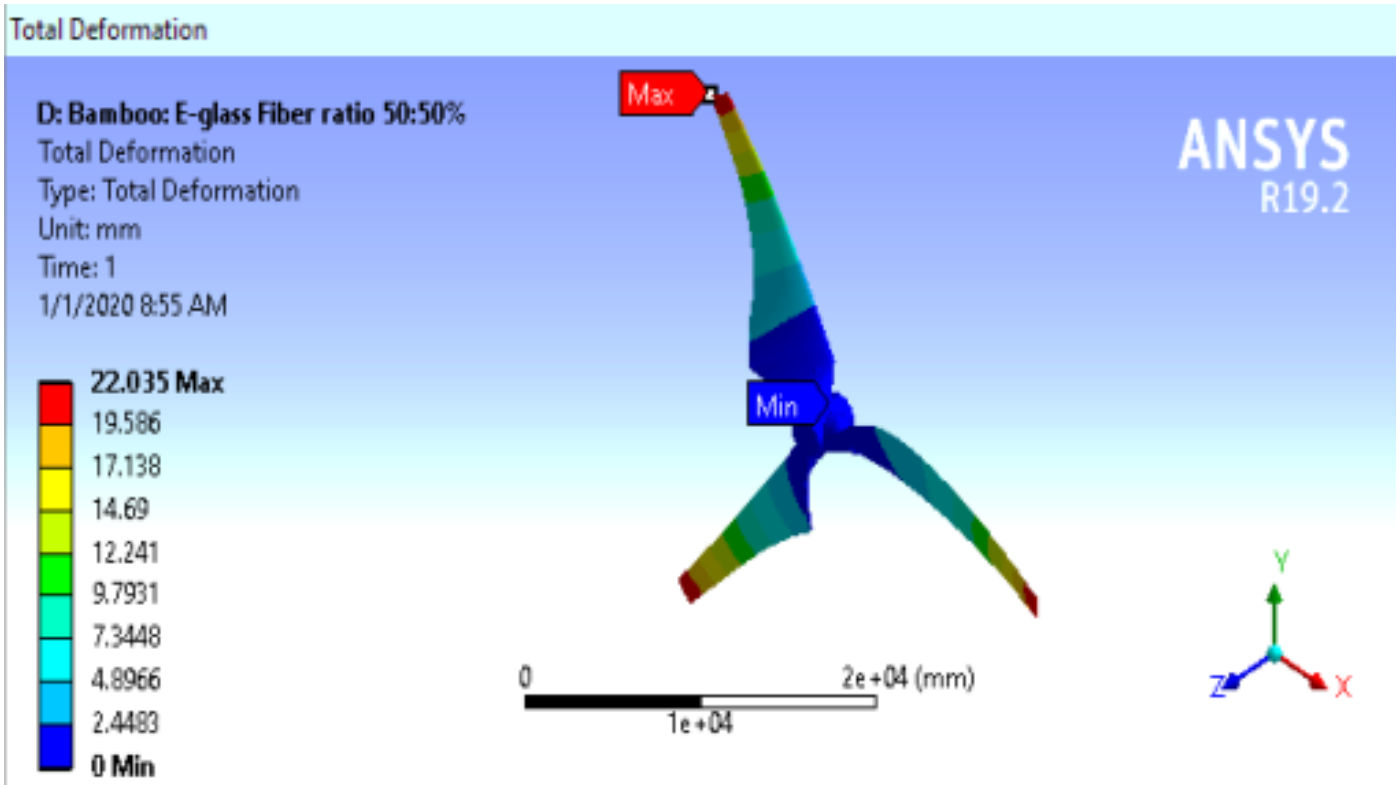
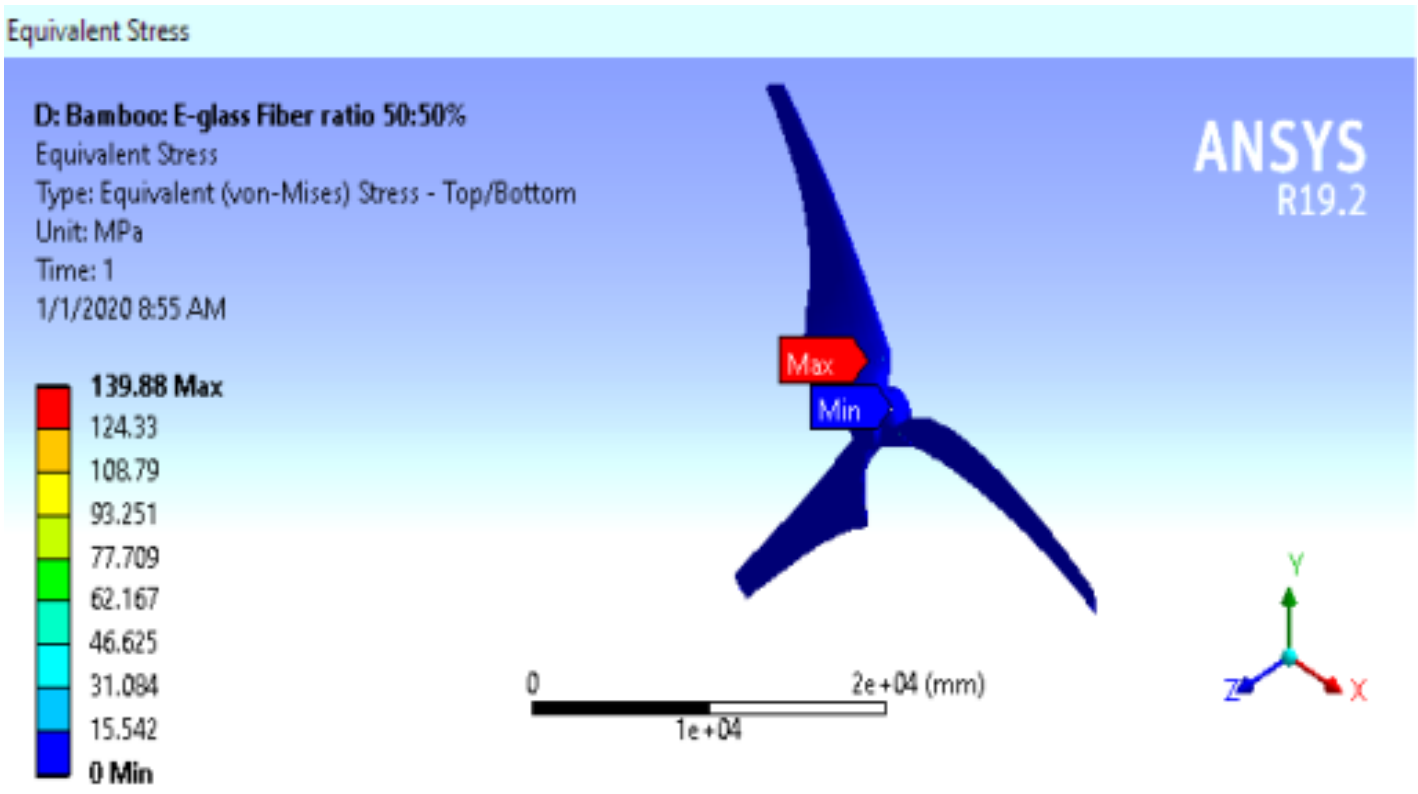
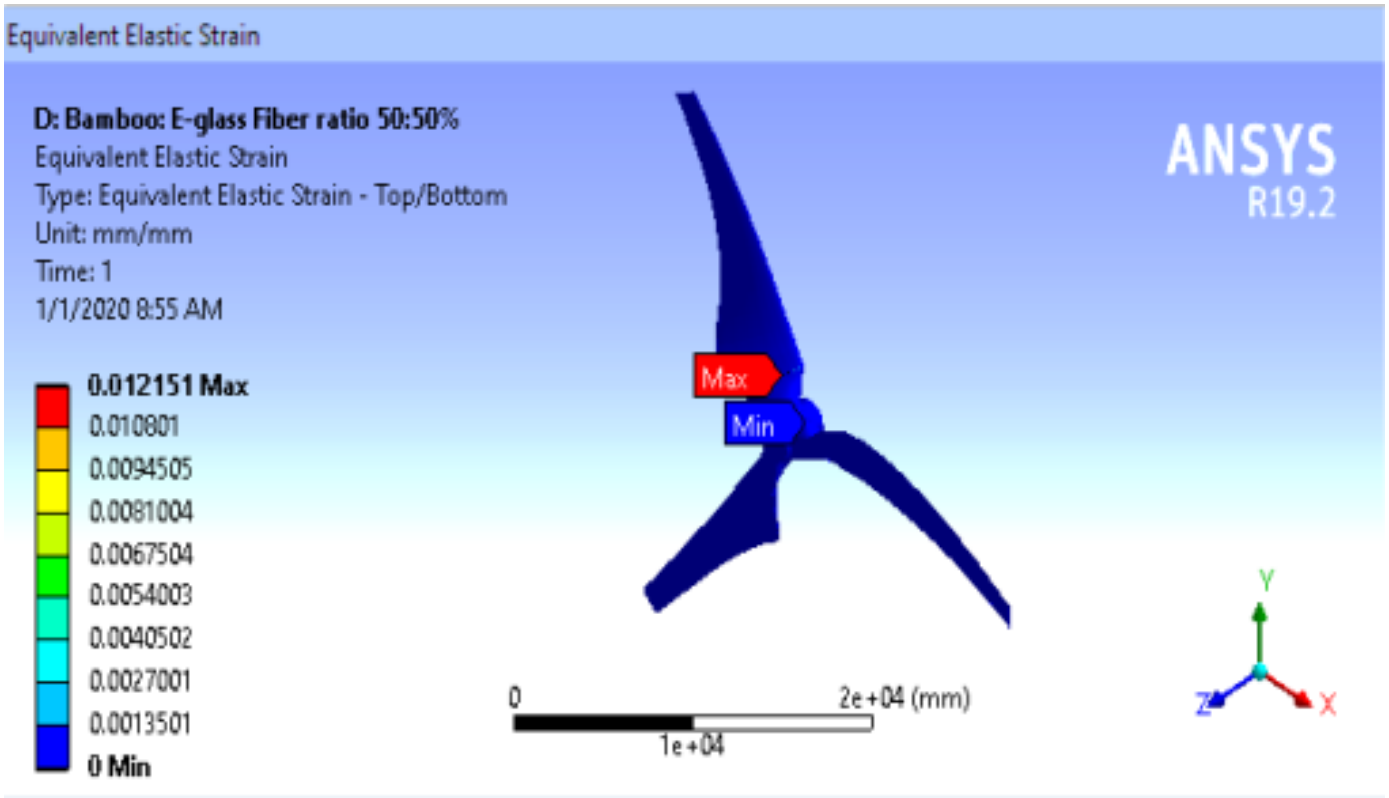


Figure 4.3: Simulation Result from Bamboo: E-Glass Fiber Ratio 70%:30%

Trial III: Simulation Result from Bamboo: E-Glass Fiber Ratio 50%:50%







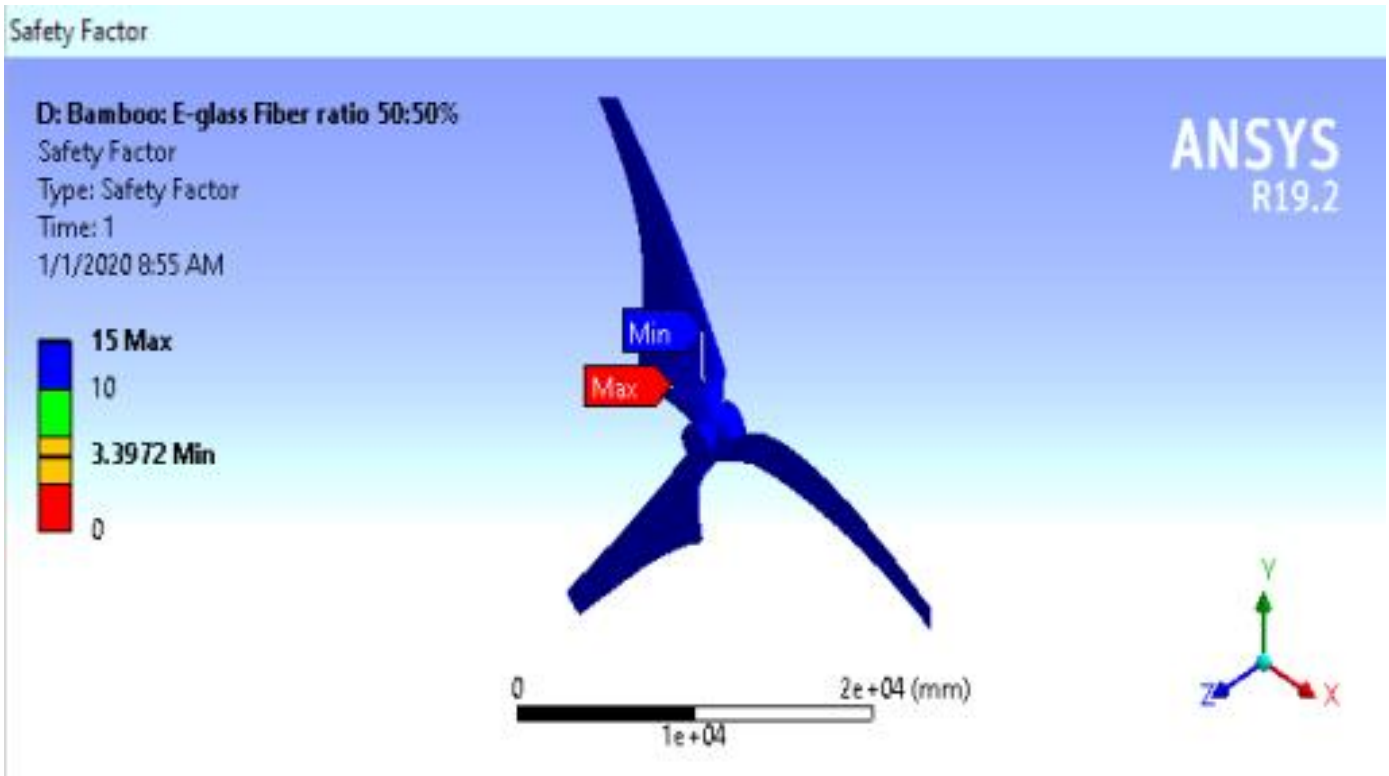
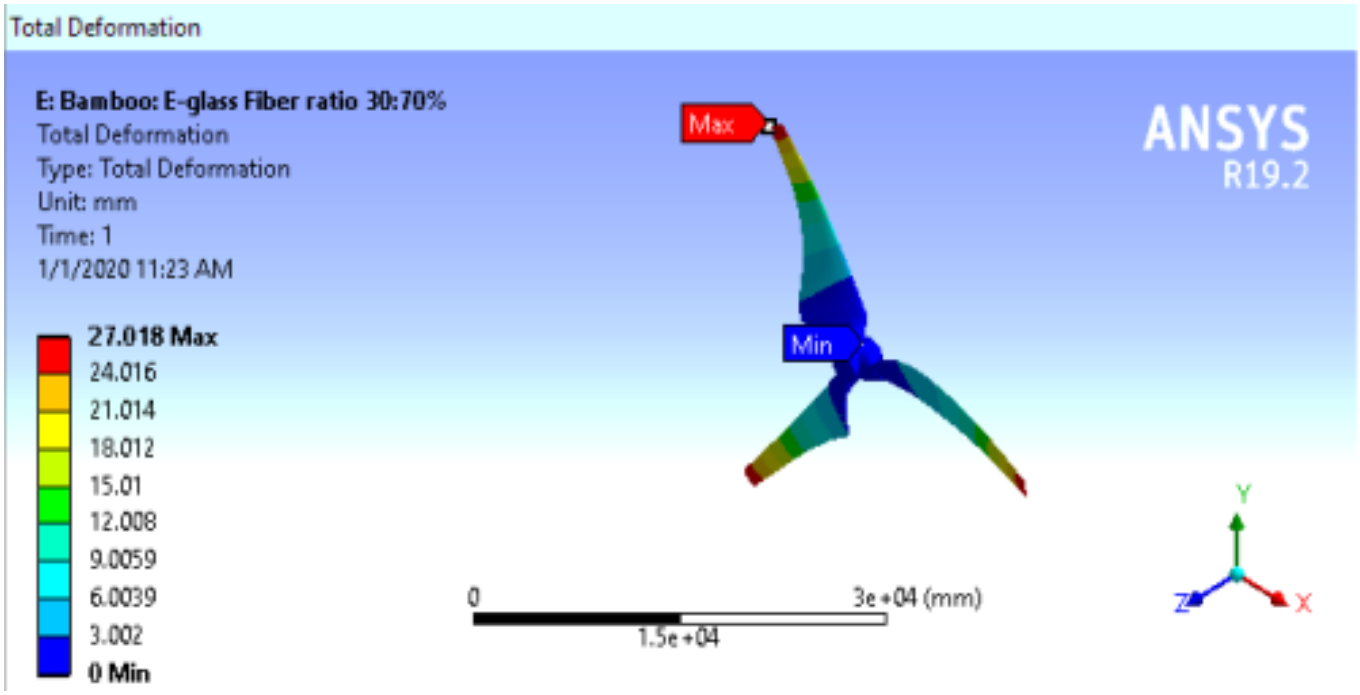
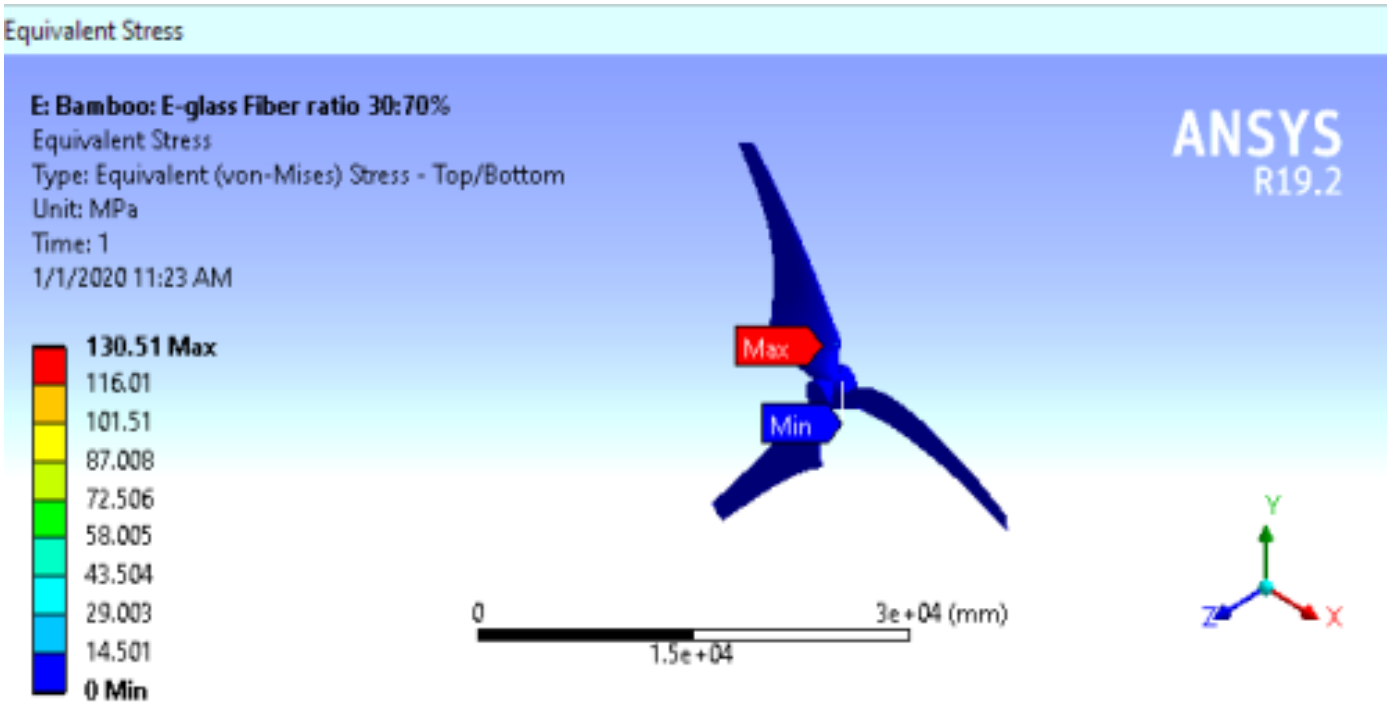
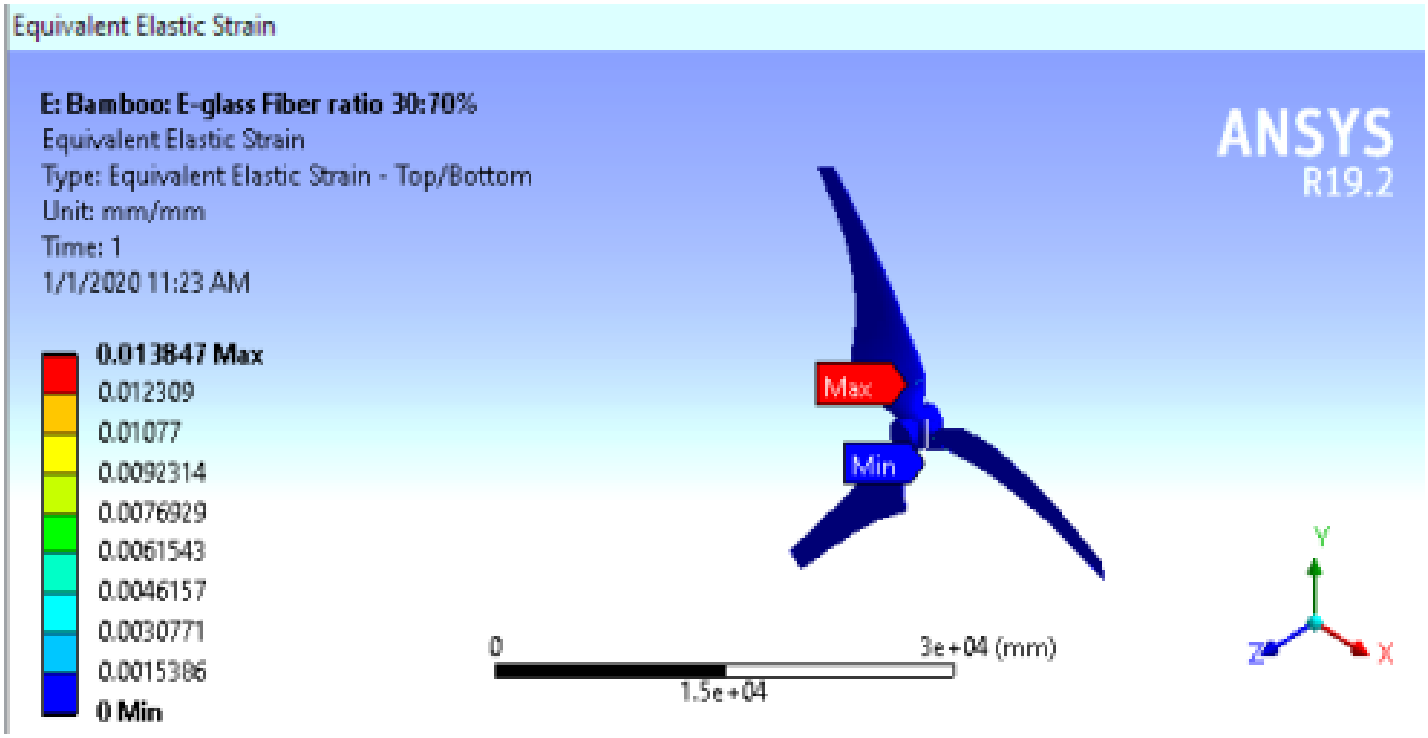


Figure 4.4: Simulation Result from Bamboo: E-Glass Fiber Ratio 50%:50%

Trial IV: Simulation Result from Bamboo: E-Glass Fiber Ratio 30%:70%







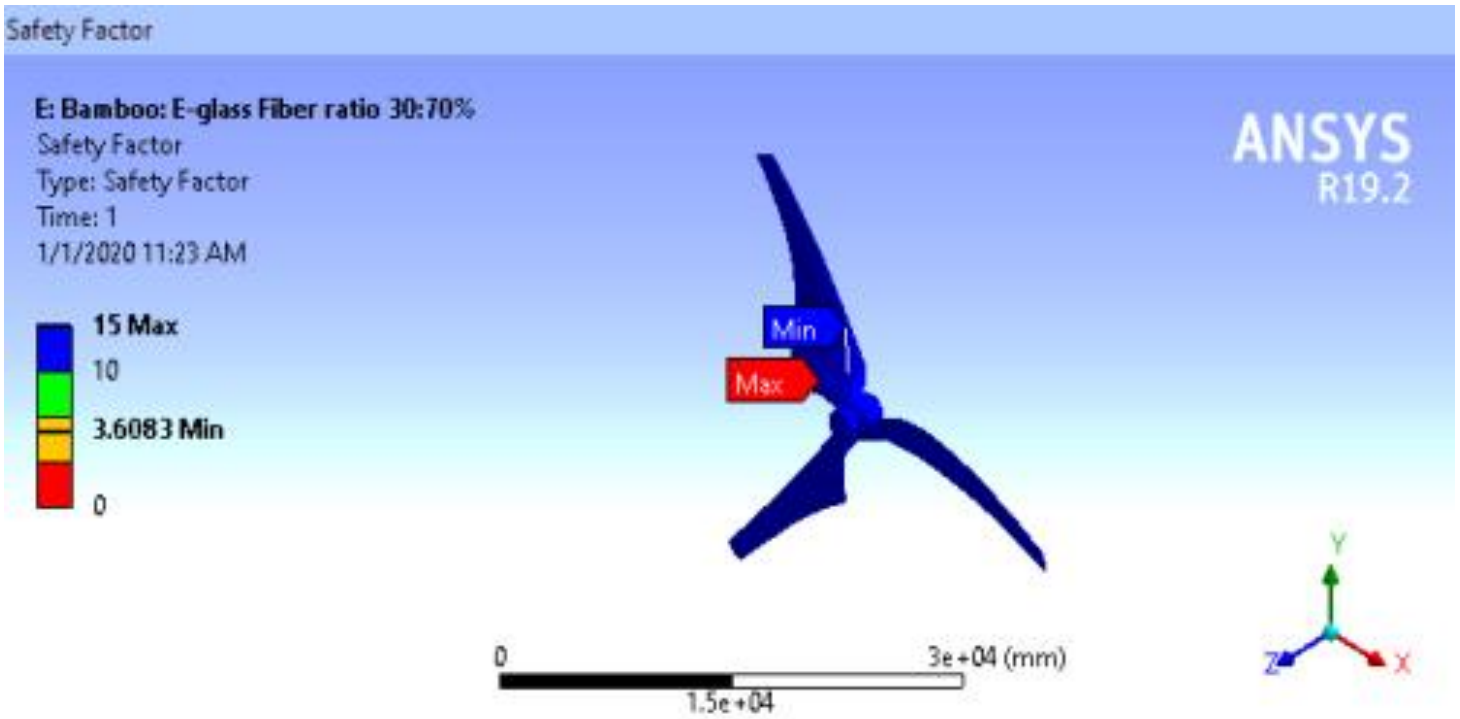
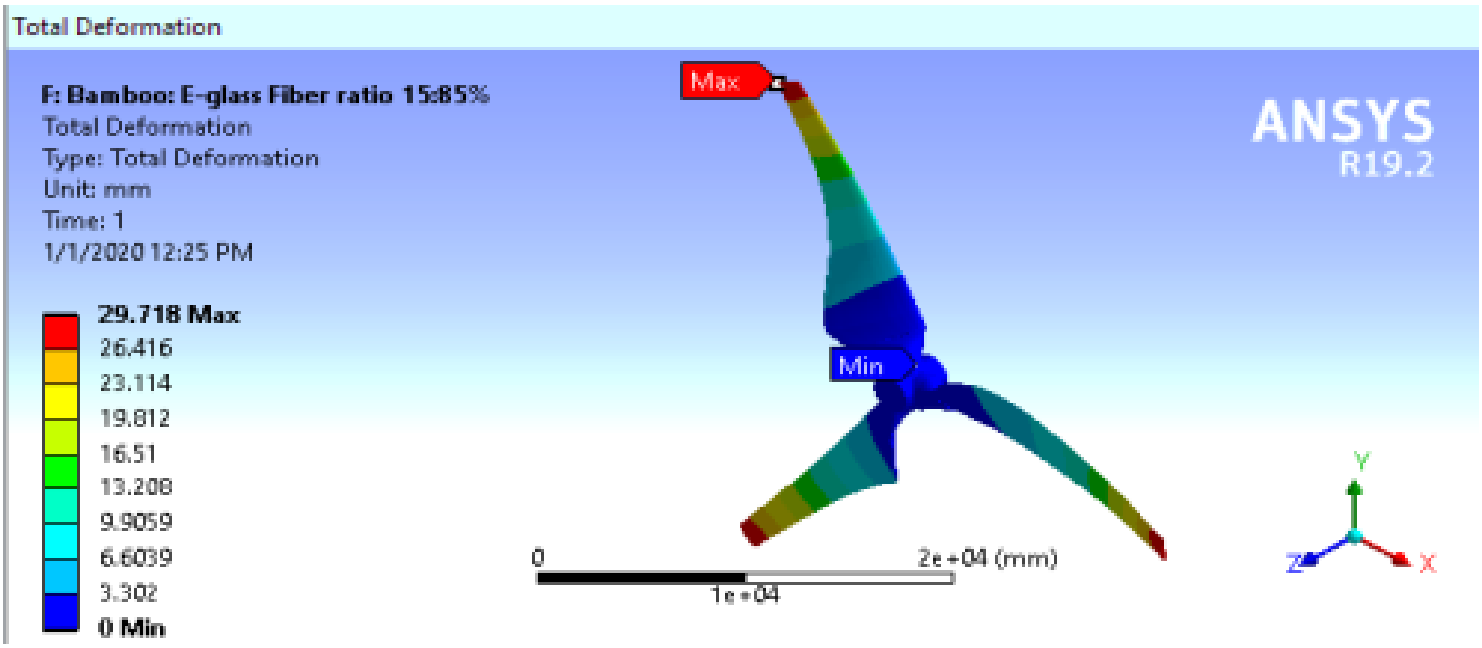
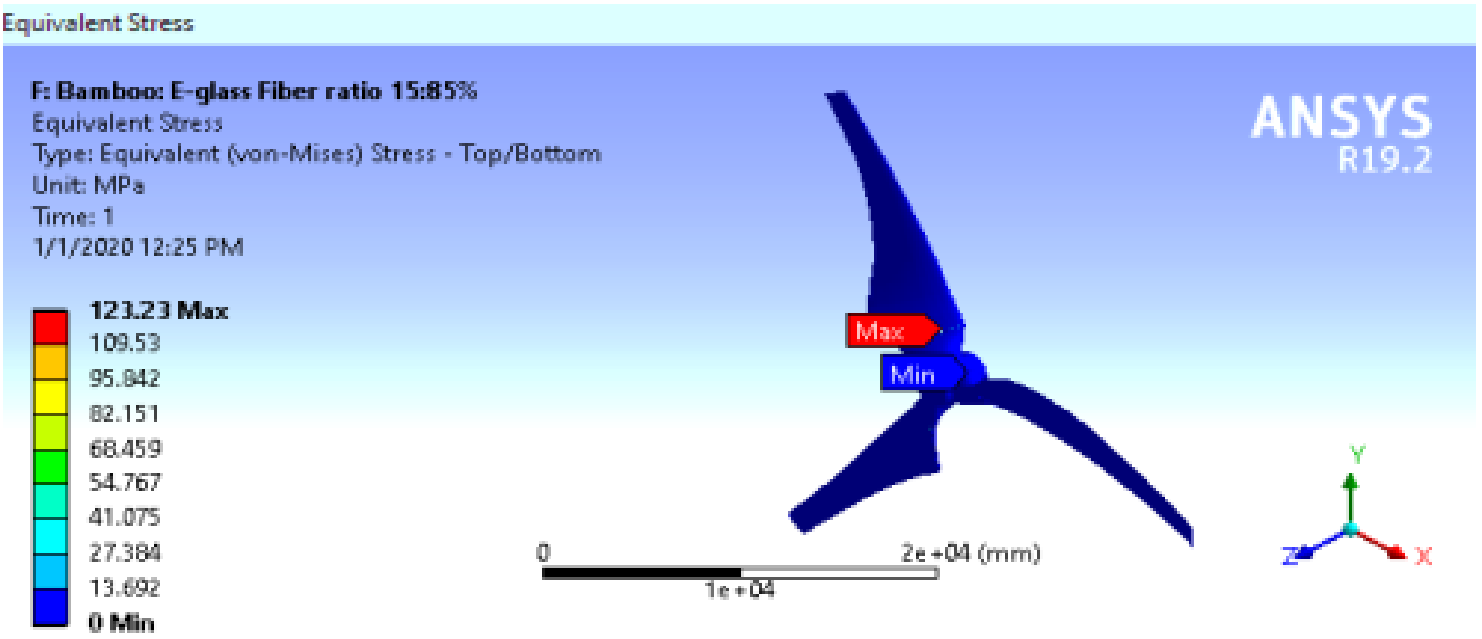
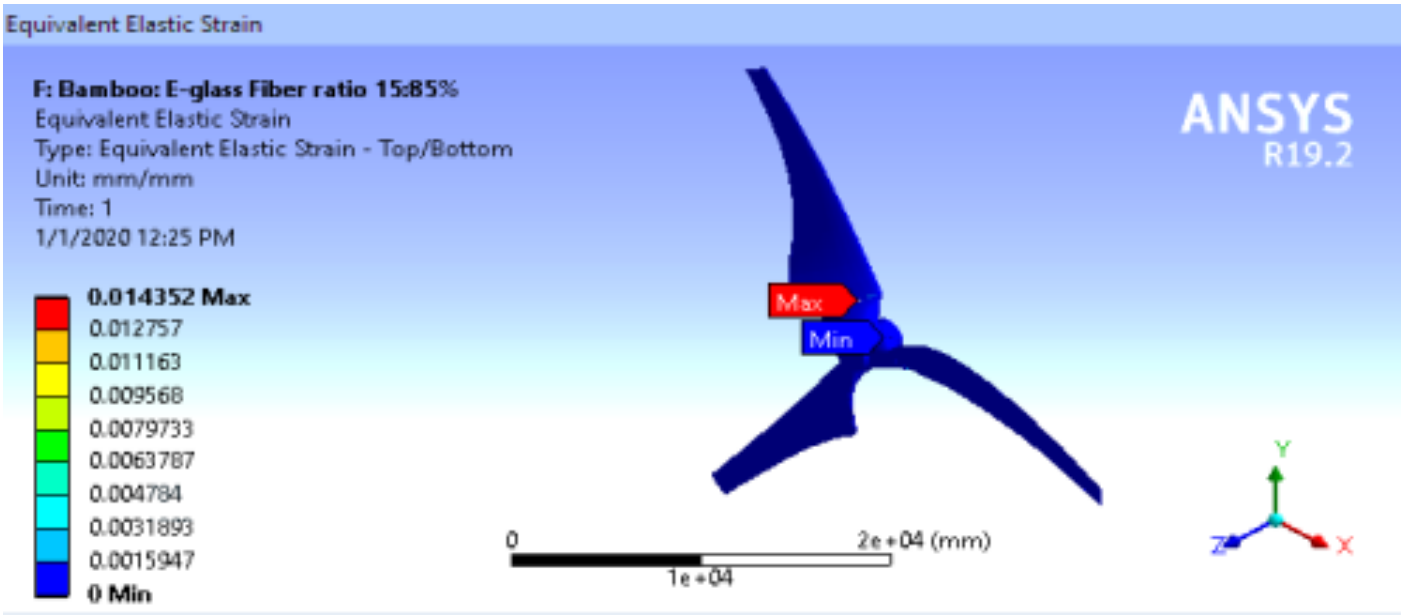


Figure 4.5: Simulation Result from Bamboo: E-Glass Fiber Ratio 30%:70%

Trial V: Simulation Result from Bamboo: E-Glass Fiber Ratio 15%:85%







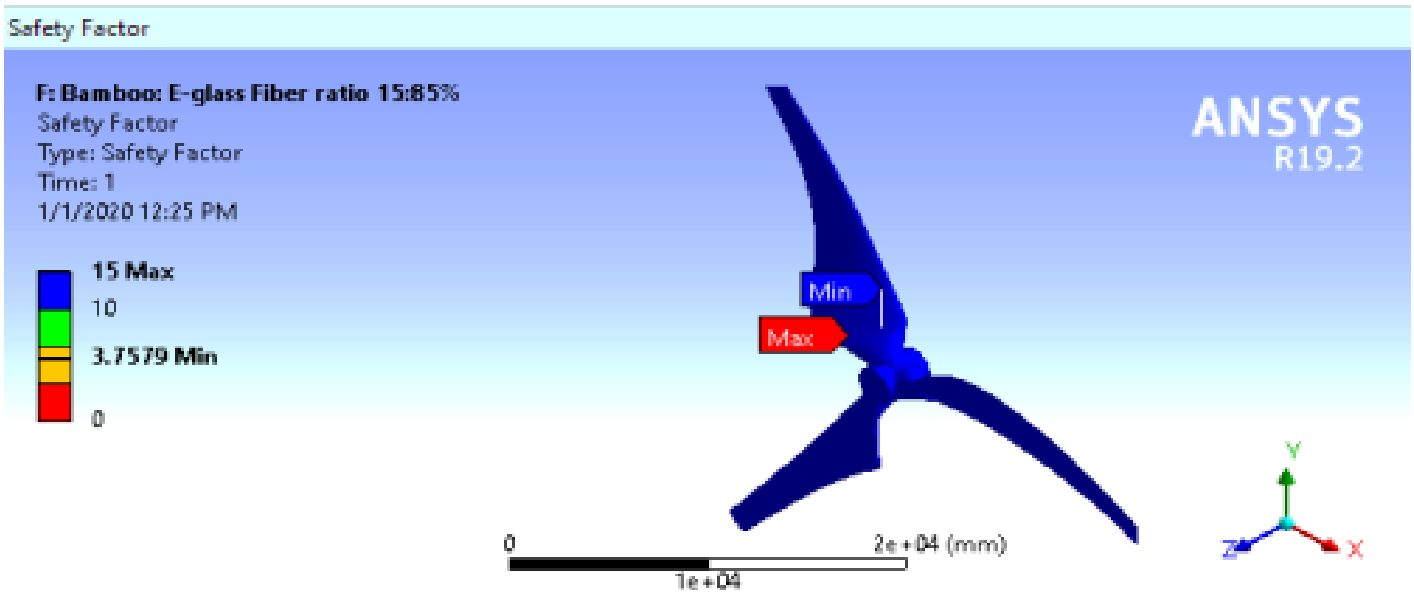
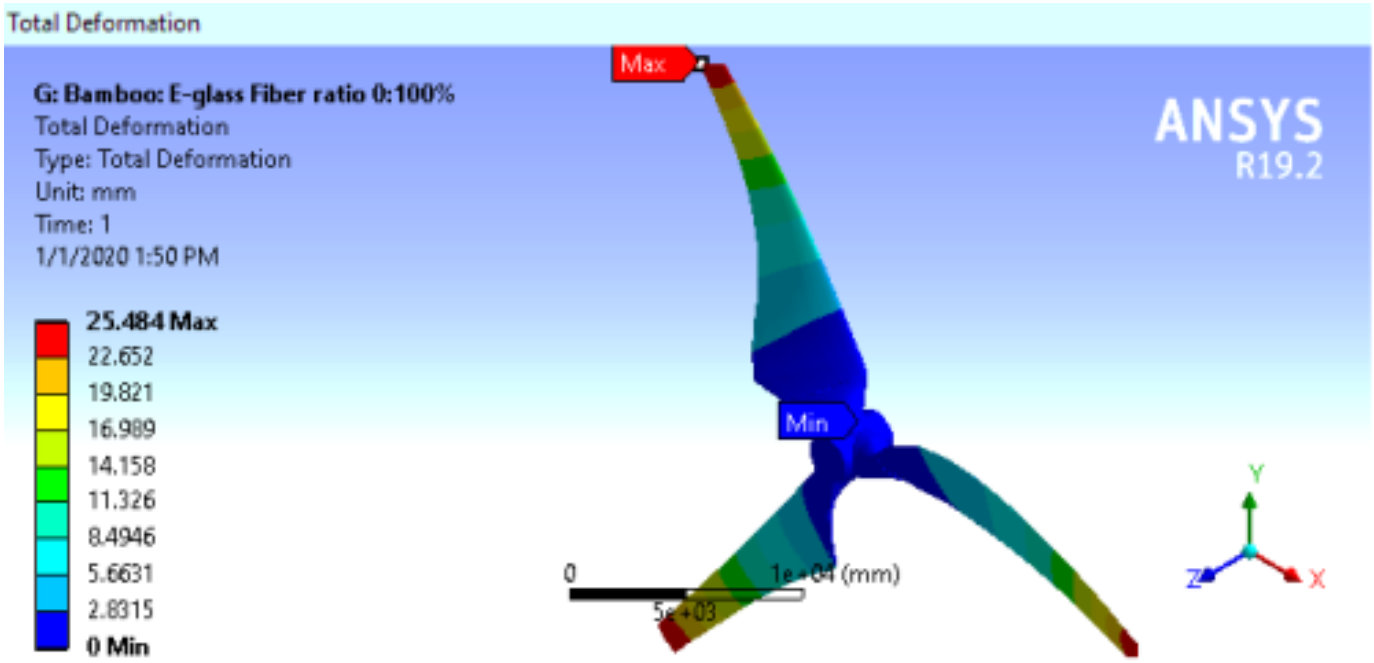
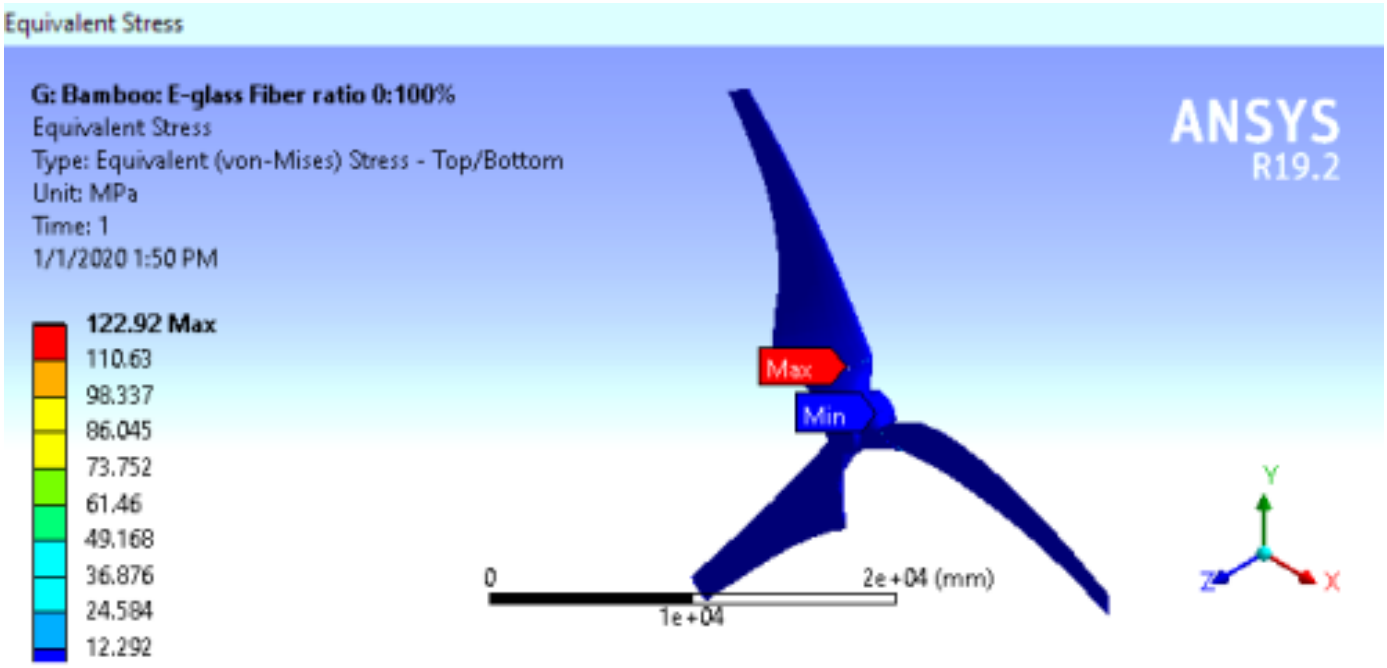
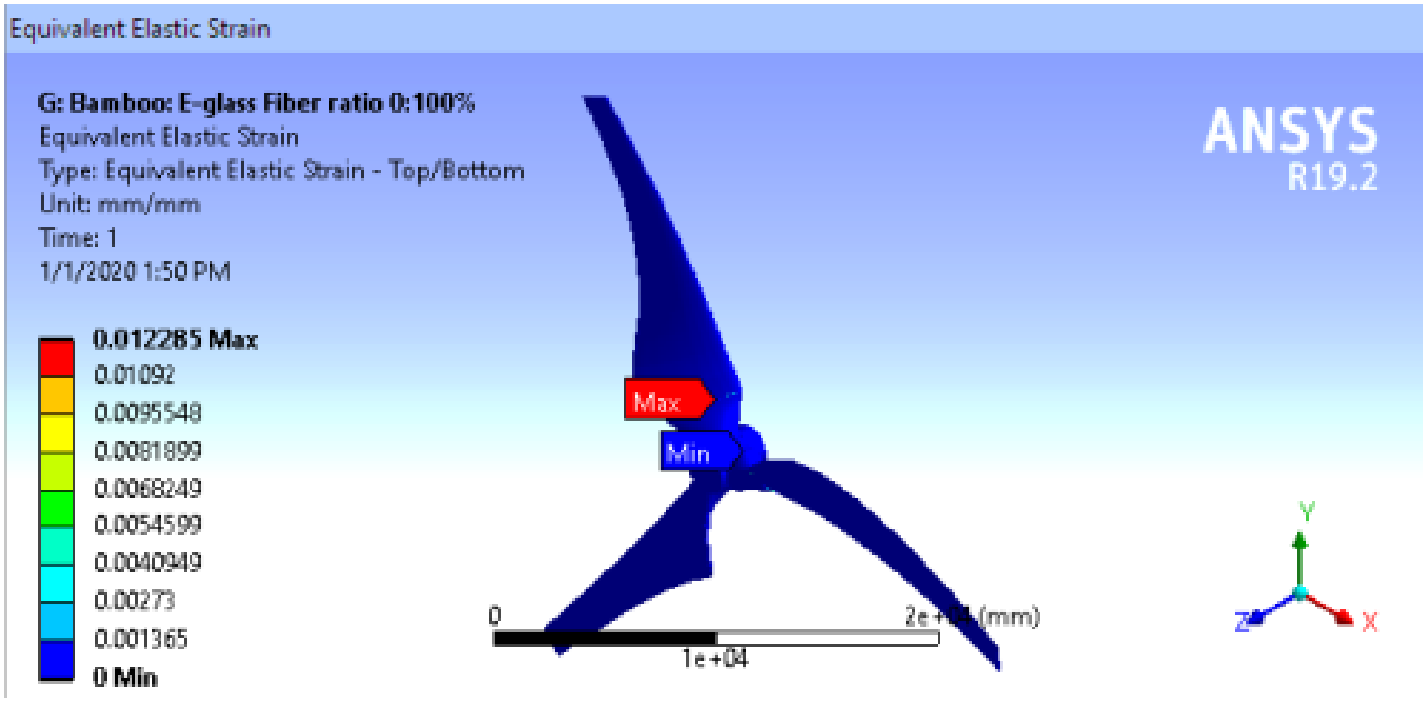


Figure 4.6: Simulation Result from Bamboo: E-Glass Fiber Ratio 15%:85%

Trial VI: Simulation Result from Bamboo: E-Glass Fiber Ratio 0%:100%







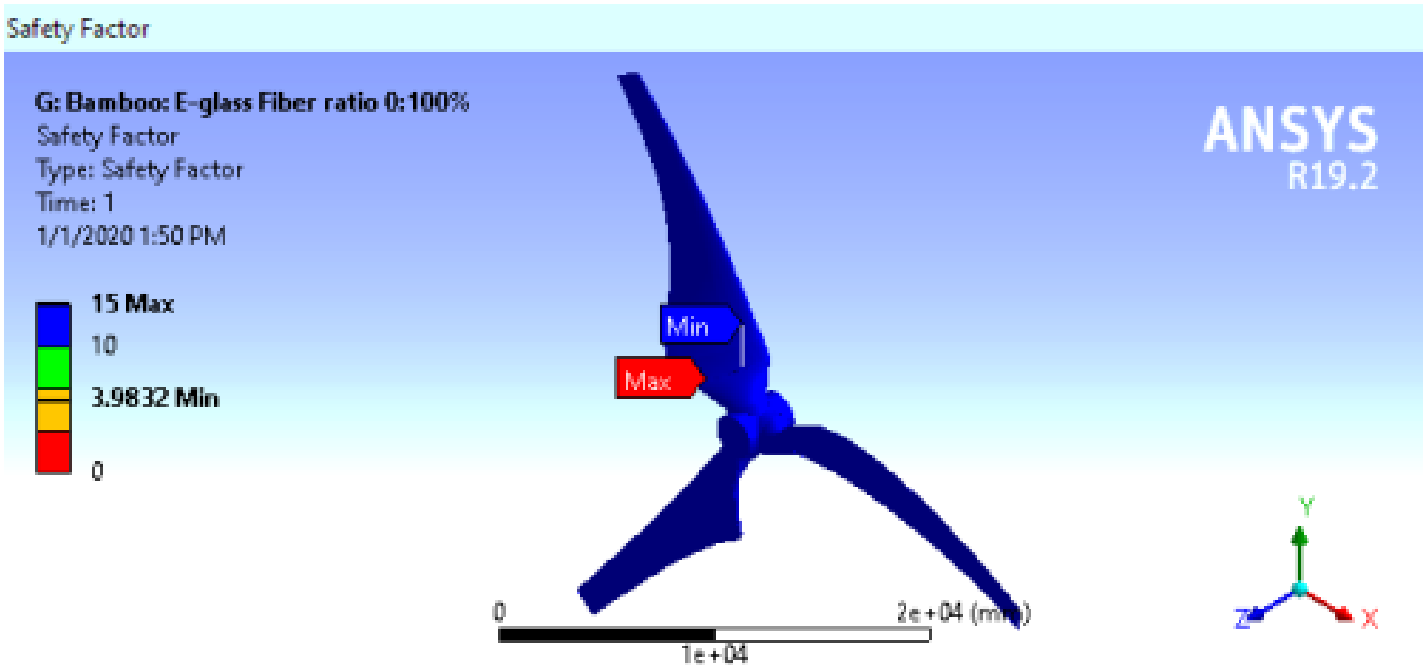


Figure 4.7: Simulation Result from Bamboo: E-Glass Fiber Ratio 0%:100%

4.3.Discussions

It is known that, the CFD result was determined by using ANSYS Fluent software. The CFD pressure result was used to determine the load at the surface of the blade by the form of iteration. The load used to apply is the surface pressure that applied for all six bamboo to E-glass fiber ratios. All gives different results of stress, deformation, and safety factors. Therefore, static structural analysis results the stresses, strains and deformation values are shown below in table 4.1.

Table 4. 1: Stress, Strain, Deformation, and Safety Factor

Bamboo: E-glass Fiber Ratio%	Total Deform(mm).(Maximum)	Strain(mm/mm).(Maximum)	Von Mis Stress((Mpa))(Maximum)	Safety Factor(minimum)
100:0	15.80	0.003570	56.510	2.5120
70:30	26.382	0.005842	55.056	6.4352
50:50	22.035	0.012150	139.88	3.3932
30:70	27.018	0.013840	130.51	3.6083
15:85	29.710	0.014300	123.23	3.7579
0:100	25.484	0.012280	122.92	3.9832

The result obtained from six different compositions of bamboo e-glass fiber shows, as the composition of bamboo decreases instead by increasing the amount of e-glass fiber reinforce, the stress induced on the material is large on the 100%:0% when it is compared with the 70%:30% and also the deformation and strain level also increased. But the safety factor is larger than the first trial of 2.51, while the second trial is 6.435. The increased deformations, safety factor, strain and decreasing of induced stress shows that, the material can withstand the load by deformable behavior. Means it cannot crush under the given loads, because it has elastic behavior due to the addition of 30% e-glass fiber composition. So the region of 70%:30% better than this of 100% Bamboo, due it has low elastic behavior.

Further when we continue to discuss the next trial 50%:50% with 70%:30%, the strain, stress level continuous to increase and but deformation and safety factor decreases. This shows that as the amount of glass fiber increased insignificantly the more stress become induced through the material.

From the above table, the trial result 50%:50%-15%:85%, as the amount of bamboo decreases, deformation, strain, safety factor continuous to increase and induced stress decreases. On this region the cause of decreasing the induction stress increase safety factor.

But it is not better than this of second trial that contain low deformation, better absorbing deformation after the load subjected to it.

The less displacement material for blade was selected as best safety factor.But 70%:30% has large deformation when it compared with 50%:50%. Although it have high safety factor, low stress induced, low strain value. So our selection must by compromising all factors, the better material 70%:30%.

The result of (Akhil P. Mathew, Athul S., Barath P. and Rakesh S., 2018)shows that for blade length of 10.7m, with wind speed of 10m/s the blade deformed 65.601mm, 26.448mm, 73.923mm, 221.3mm and 220.17mm for material Epoxy carbon, Structural steel, Aluminium alloy, E-glass and S-glass respectively. And maximum induced stress induced in the material of Epoxy carbon, Structural steel, Aluminium alloy, E-glass and S-glass is 189.42Mpa, 168.63Mpa, 169.04Mpa, 183.93Mpa and 177.66Mpa respectively. with mass in kg of 132.95, 705.18, 248.83, 179.66 and 179.66 respectively for a materials of Epoxy carbon, Structural steel, Aluminium alloy, E-glass and S-glass. When the result of the study compared with finding of this study for Bamboo to E-glass of 70%:30% ratio the deformation and stress developed in Bamboo to E-glass ratio of 70%:30% blades were less. So the Bamboo to E-glass of 70%:30% ratio reinforced fiber epoxy matrix has better strength than Epoxy carbon, Structural steel, Aluminum alloy, E-glass and S-glass material.

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Chapter Five

5. Conclusions and Recommendations

5.1. Conclusion

The NACA0012 airfoil data was applied to create the three-dimension model of the wind turbine blade using CATIA. Then CFD analysis performed to get the critical load on the blade with maximum wind speed of 35m/s. Then finite element analysis was conducted for static structural analysis using ANSYS for six Bamboo to E-glass ratio of the blade. Based on the static simulation result analysis it can be concluded that, among six Bamboo to E-glass ratios 70%:30% have better strength.

5.2. Recommendation

Based on the result of finite element structural analysis Bamboo and E-glass fiber reinforced Epoxy matrix hybrid composite is a promising wind turbine blade. However, prior to the implementation of Bamboo and E-glass fiber reinforced epoxy matrix as the new composite material for wind turbine blades, dynamic analysis, fatigue life, cost effectiveness analysis and experimental investigation is needed, especially when dealing with their fatigue behavior in order to utilize the benefits associated with the material.

5.3. Future Work

The researcher intended to give the idea on future work from different aspects, working on natural materials as composite has several advantages. From this point of views, regarding Bamboo to E-glass fiber Ratio several things can be made and improved in the future in which this study couldn't address.

So the following research areas are recommended for future studies.

- Finding the total cost effectiveness by using material science theory.
- Studying the dynamic load analysis and Fatigue life using FEM Analysis.
- Design of Bamboo to E-glass fiber material using ANSYS ACP

Appendix

Appendix 1: Rotor and Stationary Domain Definition

Name	***ROTOR DOMAIN***	***STATIONARY DOMAIN***
State	Meshed	Meshed
Graphics Properties		
Visible	Yes	Yes
Transparency	0.1	
Definition		
Suppressed	No	
Coordinate System	Default Coordinate System	
Behavior	None	
Reference Frame	Lagrangian	
Material		
Assignment		
Fluid/Solid	Defined By Geometry (**Fluid**)	
Bounding Box		
Length X	36.662 m	436.66 m
Length Y	36.662 m	211.66 m
Length Z	14. m	414. m
Properties		
Volume	14722 m³	3.8249e+007 m³
Centroid X	-4.2024e-007 m	2.0778e-015 m
Centroid Y	2.3103e-007 m	-12.505 m
Centroid Z	3.4561e-006 m	3.1166e-015 m
Statistics		
Nodes	111531	133398
Elements	614101	703374
Mesh Metric	Skewness	
Min	6.07661815666627E-04	7.6890857822387E-04
Max	0.84313348911184	0.735727218913075
Average	0.2330863141008	0.233124060611221
Standard Deviation	0.10192142145813	0.101849098611875

Appendix 2: Model Mesh (B, C, D, E, F and G or for six trials)

Object Name	*Mesh*
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	5.e-002 m
Sizing	
Use Adaptive Sizing	No
Growth Rate	Default (1.2)
Mesh Defeaturing	Yes
Defeature Size	Default (2.5e-004 m)
Capture Curvature	Yes
Curvature Min Size	Default (5.e-004 m)
Curvature Normal Angle	Default (30.0°)
Capture Proximity	No
Bounding Box Diagonal	42.26 m
Average Surface Area	1.8829 m²
Minimum Edge Length	5.3543e-006 m
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	2
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (4.5e-004 m)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Statistics	
Nodes	137299
Elements	150211

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