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Design and Structural Analysis of Wind Turbine Blade by using Different Materials

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ABSTRACT

Wind power is the most successful forerunners of technological breakthroughs that could result in more efficient energy output. Because of the rapid advancement in the energy sector, there is a growing need to increase the energy efficiency and lifetime of wind turbines. A wind turbine installation consists of the following systems needed to capture the wind energy. They are turbine, which converts mechanical rotation into electrical power, other systems to start, stop and control the turbine. The majority of commercial turbines are of horizontal axis wind turbines. This makes this structure sensitive to over speed. This paper deals with the design and analysis of different composite materials of E-Glass, S-Glass, Armid, Epoxy Carbon and Graphene by considering the static conditions. ANSYS Workbench is used to perform a detailed study of a typical wind turbine blade. The composite materials are tested for Total deformation, Equivalent Von-Mises's stress, Maximum shear stress and strain energy and result values are noted. Design is done using CATIA V5 software and analysis is done by using Ansys Software.

Keywords: Wind Turbine Blade, Composite materials, CATIAV5, ANSYS 2020R1, Structural analysis.

INTRODUCTION

Blade is one of the major components of a wind turbine. it converts wind energy into mechanical energy. The aerodynamic performance is considered first in the optimal design of wind turbine blade, meanwhile, the blade is assumed to be a rigid body. However, when the wind turbine is in practical operating state the blade deformation resulted from load will influence its aerodynamic performance. Many Researchers (Tangler 2000, Veers et al. 2003) proposed the blades of medium and large wind turbine are mostly made of composite material, such as glass and carbon fiber. Sutherland and Mandrel (2004) investigated the effect of mean stress on the fatigue limit of the composite material by goodman diagram. The wind is solar power in mechanical form. A small part (around 2 %) of the energy of solar radiation on Earth is converted into kinetic energy of flowing air, the wind. Wind's velocity and direction depend on the imposed pressure gradients, plus certain other forces, plus the local geography. The wind is a free-flowing fluid stream. The most common type of lift-force wind turbines is the horizontal axis wind turbine - HAWT. The rotor axis lies horizontally, parallel to the air flow. The blades sweep a circular (or slightly conical) plane normal to the air flow, situated upwind (in front of the tower) or downwind (behind the tower). A wind turbine transforms the kinetic energy in the wind to mechanical energy in a shaft and finally into electrical energy in a generator. The main advantage of HAWTs is the good aerodynamic efficiency (if blades are properly designed) and versatility of applications. The maximum available energy, Pmax, is thus obtained if theoretically the wind speed could be reduced to zero: where m is the mass flow, Vo is the wind speed, ρ the density of the air and A the area where the wind speed has been reduced. The equation for the maximum available power is very important since it tells us that power increases with the cube of the wind speed and only linearly with density and area. The equation for the maximum available power is very important since it tells us that power increases with the cube of the wind speed and only linearly with density and area. The available wind speed at a given site is therefore often first measured over a period of time before a project is initiated. In practice one cannot reduce the wind speed to zero, so a power coefficient Cp is defined as the ratio between the actual power obtained and the maximum available power as given by the above equation. A theoretical maximum for Cp exists, denoted by the Betz limit2, 3, Cp max = 0.593. Modern wind turbines operate close to this limit, with Cp up to 0.5, and are therefore optimized. The byproduct of fossil fuel consumption is carbon dioxide, which has been named to be a primary constituent leading to Global Warming. The amount of carbon dioxide that someone or something produces is known as its "carbon footprint." The media has been focusing on this issue and many green movements have started to try and reduce our "carbon footprint." (Green Student U, 2008) There are only a few types of energy that do not produce carbon dioxide. These are nuclear power and renewable energy sources such as wind, solar and hydro power. Renewable energy sources are the cleanest from of these sources, because there is no waste formed as byproducts of these sources.

Wind Turbine Blade:

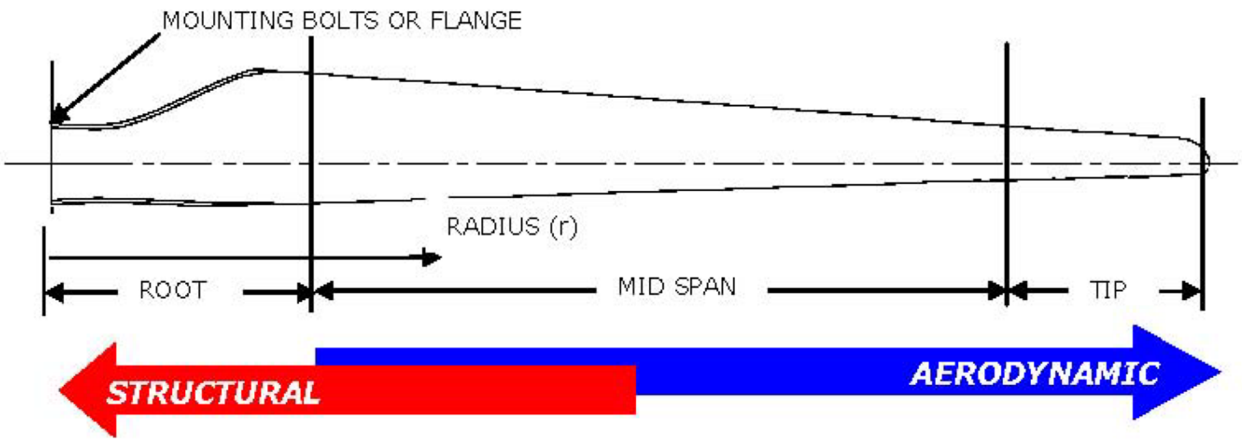

Fig. 1 Wind Turbine Blade

Wind turbine blade are usually constructed with high taper ratio and twisting angle. small wind turbine usually has one airfoil type, whereas large -scale wind turbine needs to be different airfoil along the blade radius. An airfoil should be selected with maximum lift to drag ratio and minimum pitching moment coefficient. Most optimization models concentrate on improving wind turbine blade performance by enhancing the taper ratio, aerodynamic twist, and geometric twist of the blade, however some of the optimization models improve the wind turbine performance by changing the airfoil shape.

LITERATURE REVIEW

Akhil P Mathew et al. [1] Studied the structural analysis of composite wind turbine blade in different materials (structural steel, epoxy carbon, E-glass). The design static analysis of composite wind mill blade had been carried out. In this work comparison between composite materials are made under same load condition. Stress, strain and deformation are calculated using Ansys. It was found that epoxy carbon is more suitable for wind mill blade. **Shiv N Prajapati et al. [2]** Conducted experiment on finite element structural analysis of wind turbine blade. The manufacturing cost of the wind turbine blade is about 15-20% of the wind turbine plant cost. So, it is likely to reduce the investment cost of the wind turbine blade by maximizing the service life of the wind turbine blades. The important aerodynamic parameters which decide the efficiency of the wind turbine blade are analyzed for the NACA 4420 airfoil. **A.J Sri Ganapathy et al. [3]** experimented Design and analysis of vertical axis wind turbine blade. The vertical blade design has high strength and lower material consumption to achieve the low cost of complete wind turbine rotor assembly which actually covers over 50 percent of total wind turbine costs. It reduces 40% of weight which is more reliable and easier to manufacture. The low cost of complete rotor assembly of a wind turbine covers 50% of overall cost. [4] Babu, **Sajja Ravi, et al [4]** used advanced soft computing tools for estimating the Thermo-Physical Properties of Water-Alumina Nanofluid" in the mechanical engineering field. Also **Rani, G. Jamuna, & Rao P. Gangadhara[5],** used ANSYS in the manufacturing of hydraulic press. **Amer et al. [6]** Studied the structural analysis of a composite wind turbine blade.

The design of the wind turbine blades must be structurally optimized with optimal blade thickness distribution and maximum power output. The wind turbine blades are manufactured using composites materials with carbon fiber reinforcements. these materials are having less cost, high strength and stiffness. **Mohammed Marouane Ichenia et al. [7]** Conducted experiment on Aerodynamics and Structural Analysis of Wind Turbine Blade. The design and development of such a wind turbine blade profile for domestic application by comparison with various profiles. This research work is for generating electricity at low wind speeds and that can be used to power the lighting requirements of a house. **Peter J. schubel and Richard J. Crossley [8]** Investigated the wind turbine blade design. The review provides a complete picture of wind turbine blade design and shows the dominance of modern turbines almost exclusive use of horizontal axis rotors. **Emily blace et al. [9]** conducted experiment on design of prototype wind turbine blade. The unique features of our various tested blade designs include but are not limited to: blade twist, pitch angle, winglets, and lightweight, optimized blades designed by Wisk wind will allow their turbine to achieve a low cut in speed and high-power output over a wide range of wind speeds. **P Sakthivel and G. P. Raja Mani [10]** conducted experiment on design and analysis of modified wind turbine blade. The main aim of this paper is to increase the wind power production. There are two electromagnetic induction generators which are preferred to share the loads through single shaft over straight level gears.

Vedulla Manoj Kumar et al. [11]: Conducted experiment on modelling and analysis of wind turbine blade with advanced material by simulation. Wind turbine efficiency depends up on one of the important parameters as the speed of the blade. for a lighter blade a small wind force is enough to rotate it, where as a heavy blade will require large and steady wind loads. to improve the wind turbine performance the blade material is being changed from epoxy glass to epoxy carbon.

METHODOLOGY OF PROBLEM

Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provide the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

Introduction to Catia V5:
Catia is a process-centric computer-aided design/computer-assisted manufacturing/computer-aided engineering (CAD/CAM/CAE) system that fully uses next generation object technologies and leading-edge industry standards. Catia v5 is integrated with Dassault Systems Product Lifecycle Management (PLM) solutions. It allows the users to simulate their industrial design processes from initial concept to product design, analysis, assembly and also maintenance. In this software, it includes mechanical, and shape design, styling, product synthesis, equipment and systems engineering, NC manufacturing, analysis and simulation, and industrial plant design. It is very user-friendly software because Sold works Knowledge ware allows broad communities of user to easily capture and share know-how, rules, and other intellectual property assets.

Design:
CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify and validate complex innovative shapes from industrial design to Class-A surfacing with the ICEM surfacing technologies. CATIA supports multiple stages of product design whether started from scratch or from 2D sketches (blueprints).

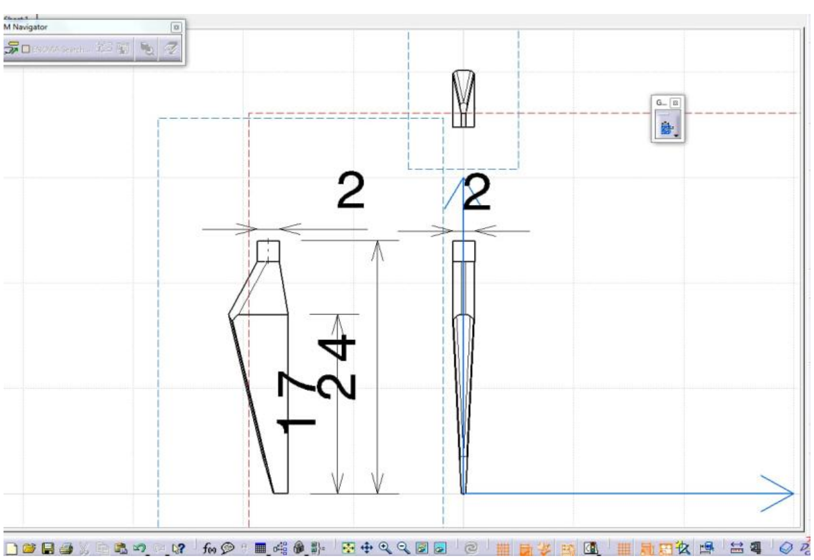

Fig.2 Design of blade

INTRODUCTION TO ANSYS:

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

SPECIFIC CAPABILITIES OF ANSYS:

Structural:

Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings, naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

- **Static Analysis** - Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.
- **Transient Dynamic Analysis** - Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.
- **Buckling Analysis** - Used to calculate the buckling loads and determine the buckling mode shape. Both linear (eigenvalue) buckling and nonlinear buckling analyses are possible.
  In addition to the above analysis types, several special-purpose features are available such as Fracture mechanics, Composite material analysis, Fatigue and both p-Method and Beam analyses.

Material selection: The durability and life of wind turbine blade can be increased, if the wind turbine blade has high stiffness, environmental loading resistance and low weight. These properties can be obtained by using advance composite material. The composite material has superior mechanical properties, lower weight and higher strength compared to many metals and alloys. In wind turbine blade long fiber reinforced polymers laminates are responsible for enduring strength and damage resistance, shape stability, while resin matrix is responsible for stiffness, fracture toughness and out of plane strength. In modern era, carbon fiber and E glass fiber material are mainly used for making blade. Carbon fiber has more promptly used in spar design comparing with E glass fiber, as it has high stiffness and density then carbon fiber. However, it has relatively lower damage tolerance, compressive strength and much more expensive. Therefore, carbon fiber is used for designing spar and E glass fiber is used for making outer periphery for good strength and lower cost of blade.

1. Availability of the materials.
2. Suitability of materials for the working condition in service.
3. The cost of materials.
4. Physical and chemical properties of material.
5. Mechanical properties of material.

RESULTS AND DISCUSSION

The Horizontal-Axis Wind Turbine (HAWT) is 43.2 meters long and starts with a cylindrical shape at the root and then transitions to the airfoils S818, S825 and S826 for the root, body and tip, respectively. This wind blade also has pitch to vary as a function of radius, giving it a twist and the pitch angle at the blade tip is 4 degrees. Accordingly, the stress limit of the blade is determined by the strength of the E-glass used in the skin of the blade. The turbulent wind flows towards the negative z-direction at 12 m/s which is a typical rated wind speed for a turbine at this size. This incoming flow is assumed to make the blade rotate at an angular velocity of-2.22 rad/s about the z-axis. The tip speed ratio is therefore equal to 8 which is a reasonable value for a large wind turbine. The blade root is offset from the axis of rotation by 1 meter. The process of CFD simulation begins with the creation of a three-dimensional domain and its proper discretization. We define the velocity at the inlet of 12 m/s with turbulent intensity of 5% and turbulent viscosity ratio of 10 and the Pressure of 1 atm in order to validate the present simulation. As mentioned in the beginning of this work, the aerodynamic performance of wind turbines are primarily a function of the steady state aerodynamics that is discussed. The analysis presented provides a method for determining average loads on a wind turbine. However, a number of important steady state and dynamic effects that cause increased loads or decreased power production from those expected with the BEM theory presented here, especially increased transient loads.

Table .1 Properties of materials

Material	Stress (Pa)	Deformation(mm)	Strain
E-Glass	4.428	3.0138e-8	0.00056226
S-Glass	4.410	2.7540e-8	0.0005139
Armid	4.376	2.5216e-8	0.00047368
Epoxy Carbon	4.411	2.0612e-8	0.0003843
Graphene	4.446	1.9796e-8	0.00037007

Ansys Results of Graphen Material:

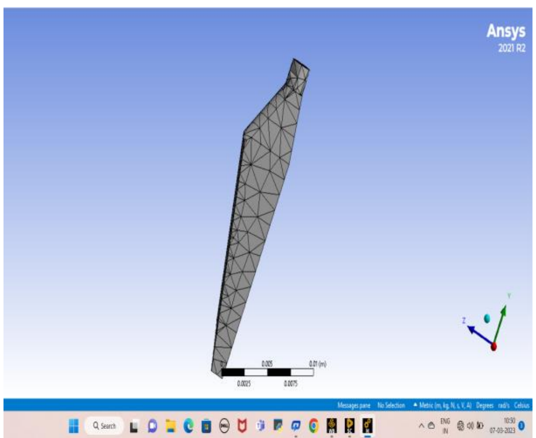

Fig.3 Meshing of wind turbine blade

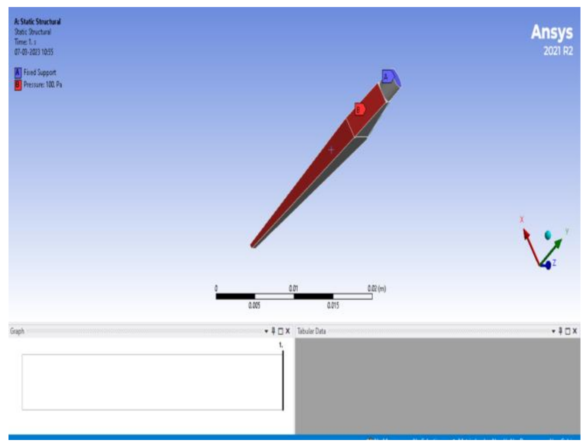

Fig.4 Applying atm. Pressure to the wind turbine blade

Structural Analysis of wind turbine Blade:

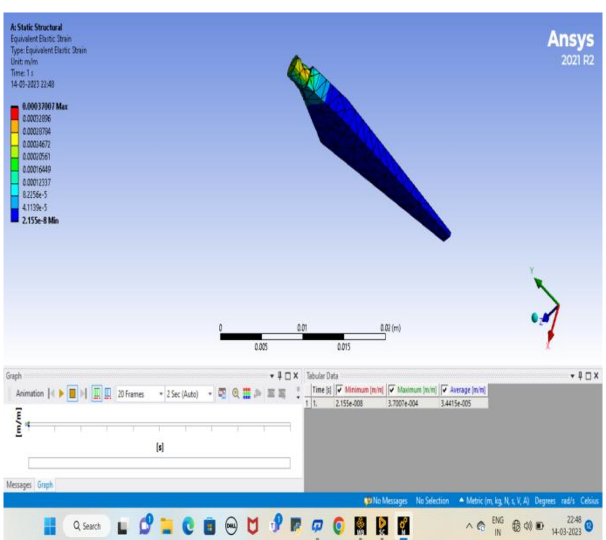

Fig.5 Von-Mises Stress in wind turbine blade

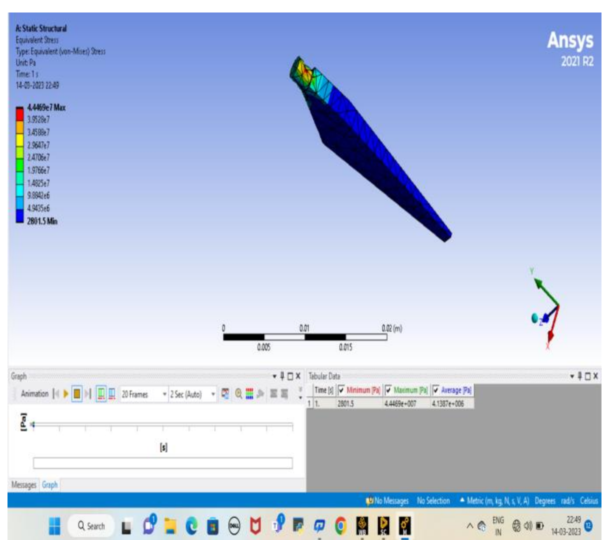

Fig.6 Von-Mises Strain in wind turbine blade

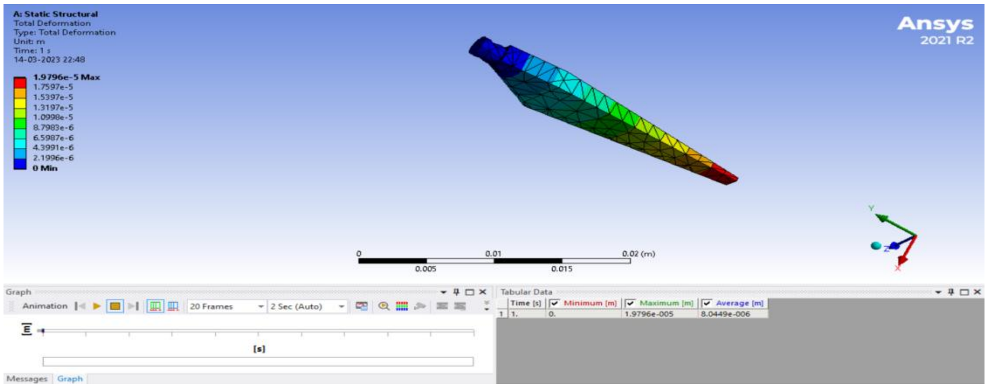

Fig.7 Total Deformation in wind turbine blade

Graphical Results:

Von Mises Stress:

observed that in case of equivalent (von-mises) stress, Wind Turbine Blade disc made of designs and various materials S-Glass, E-Glass, Armid, Epoxy Carbon finally Graphene is found to have stress of (Pa) shown below figure.

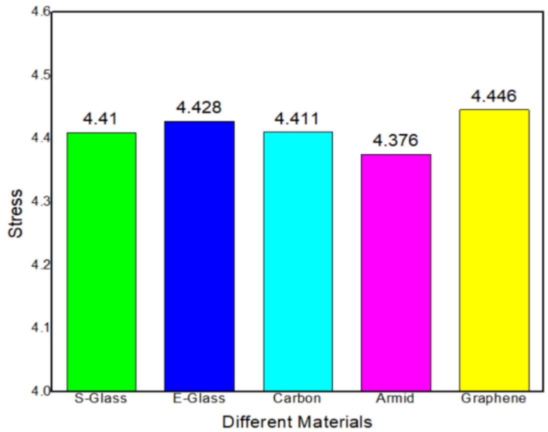

Fig. 8 Von Mises stress

Von-**Mises Strain:**

We observed that in case of equivalent (von-mises) stress, Wind Turbine Blade disc made of designs and various materials S-Glass, E-Glass, Armid, Epoxy Carbon finally Graphene is found to have stress of (Pa) shown below figure.

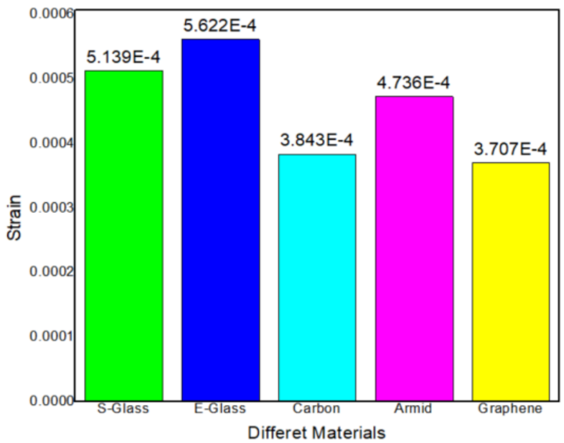

Fig. 9 Von Mises strain

Total Deformation Graph:

we can observe that in case of equivalent Total deformation, Wind Turbine Blade disc made of designs and various materials S-Glass, E-Glass, Armid, Epoxy Carbon finally Graphene is found to have least deformation of shown below figure.

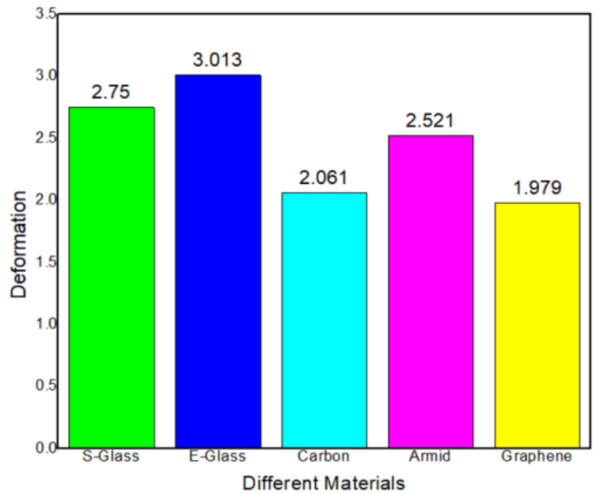

Fig. 10 Total Deformation

CONCLUSIONS

- It is observed from the results the (Graphene) is the best product which increases the life as we compare the results with other materials.
- It can be concluded that the material is the best output for model as Graphene
- Finally it is concluded that the Graphene material is the best output for model.

REFERENCES

[1]. Akhil P Mathew, Athul S "Structural Analysis of composite Wind Turbine Blade", 5(6), 2018.
[2]. Bent F. Sorensen, John Holmes, "Blade material Testing Method and structural design", 2010.
[3]. P Sakthivel and G.P Raja Mani "Design and Analysis of Modified wind turbine Blade", 7 (1) 2019.
[4]. Sajja Ravi, K.P.V. Krishna Varma, and Kunapuli Siva Satya Mohan. "Artificial Neural Network Technique for Estimating the Thermo-Physical Properties of Water-Alumina Nanofluid". Ecological Engineering & Environmental Technology 23 no. 2 (2022): 97-106. doi:10.12912/27197050/145583.
[5]. Rani, G. Jamuna, Rao P. Gangadhara, Konuru Srinivasa Rao, and M. Ravi Teja. "Design and Optimization of 200 Ton H-Type Hydraulic Press." In *E3S Web of Conferences*, vol. 309, p. 01155. EDP Sciences, 2021.
[6]. Vipin Kumar Singh, Tiju.T. Thomas "Structural design of a wind turbine",5, 2013.
[7]. Peter J. Shuble and Richard J. Crossley "Wind Turbine Blade design",6(6) 2012.
[8]. Shiv N Prajapati, Manish Kumar "A Finite Element Structural Analysis of Wind Turbine Blade",2(7) 2017.
[9]. A.J Sri Ganapathy, S Sudan "Design and Analysis of Vertical Axis Wind Turbine Blade",2(5) 2020.
[10]. C. Amer and M. Sahni "Structural Analysis of a Composite Wind Turbine Blade",8, 2017.Benham Thyagarajan "Structural Analysis of a wind Turbine Blade", 2013.
[11]. J.P. Baird, S.F Pender, "Optimization of a vertical axis wind turbine for small scale applications", 1983.