AXIS SYMMETRIC STRESS ANALYSIS OF INTERNALLY PRESSURIZED ROTATING CYLINDER WITH DIFFERENT MATERIALS BY USING ANSYS

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ABSTRACT:

The present paper is devoted to stress analysis of a homogeneous, orthotropic, internally pressurized rotating cylinder. Assuming the cylinder in plain strain condition and that the volume remains constant, finite element method is used to find out the stresses and displacement at each node of ISO parametric elements (Bi-linear and Quadratic). FEM results are then compared with the exact values, comparison is also done between different element numbers (for same element type) and between different element types (for same element number).Two materials taken in to account for the to check the structural deformations. The two materials are aluminum and structural steel to compare soft and hard materials by using simulation software ANSYS work bench 15.0. The reason for doing the comparison is to find out by how much the FEM results vary from the exact solution and to see how the FEM results converge to exact values by increasing the element number. Comparison also gives the brief idea about the two elements i.e which of the two elements gives better results for the same element number.

Keywords: *Axis symmetry, FEM, ANSYS*.

INTRODUCTION

The research on the determination of stresses and strains in a rotating thick hollow cylinder has never stopped because of their vast importance in the different fields of engineering (mechanical, electrical, civil, computer engineering, etc). Many standard and advanced textbooks like Ress, Timoshenko, Goodier and Uugural and Festes have pane strain and plane stress solutions in them for many years. Finite element is another important method of finding out the stresses and strains of any complex bodies for whom the exact solution has not been derived. Finite element method has made it possible tondesign any complex bodies.

Here, two iso-parametric (Bilinear and Quadrilateral Quadratic elements) elements are used for solving the problem. Results obtained by FEM are then compared with the exact values and the comparison is discussed.

Pressure vessels are important because many liquids and gases must be stored under high pressure. Special emphasis is placed upon the strength of the vessel to prevent explosions as a result of rupture. Codes for the safety of such vessels have been developed that specify the design of the container for specified conditions. Most pressure vessels are required to carry only low pressures and thus are constructed of tubes and sheets rolled to form cylinders. Some pressure vessels must carry high pressures, however, and the thickness of the vessel walls must increase in order to provide adequate strength. Interest in studying of the shell arises from the fifties of twentieth century. The assemblies, containing thin shells, find wide use in the modern engineering, especially in ships, aircraft and spacecraft industry. The shell vibrations and buckling modes are analyzed by means of numerical methods, to clarify qualitatively the critical loads and different buckling modes.

In today's aerospace and aircraft industries, structural efficiency is the main concern. Due to their high specific strength and light weight, fiber reinforced composites find a wide range of applications. Light weight compression load carrying structures form part of all aircraft, and space vehicle fuel tanks, air cylinders are some of the many applications.

In the present work, design analysis of fiber reinforced multi layered composite shell, with optimum fiber orientations; minimum mass under strength constraints for a cylinder with or without stiffeners under axial loading for static and buckling analysis on the pressure vessel has been studied. Cylindrical shells (see Fig.1.1) such as thin-walled laminated composite unstiffened vessels like deep submarine exploration housings and autonomous underwater vehicles are subjected to any combination of in plane, Out of plane and shear loads due to the high external hydrostatic pressure during their application. Due to the geometry of these structures, buckling is one of the most important failure criteria. Buckling failure mode of a stiffened cylindrical shell can further be subdivided into global buckling, local skin buckling and stiffener crippling. Global buckling is collapse of the whole structure, i.e. collapse of the stiffeners and the shell as one unit. Local skin buckling and the stiffeners crippling on the other hand are localized failure modes involving local failure of only the skin in the first case and the stiffeners in the second case.

Fig Cylindrical Pressure Vessel

LITERATURE REVIEW

Chan (1999). Figueiredo et al. (2008) proposed a numerical methodology in order to predict the elastic-plastic stress behaviour of functionally graded cylindrical vessels subjected to internal pressure. It was assumed that the structures undergo small strain and that the material properties of the graded layer are modeled by the modified rule of mixtures approximation. Furthermore, the plastic domain for ductile phases was defined through the von-Mises yield criterion. They proposed an iterative method for solving the nonlinear system, combining a finite element approximation and an incremental-iterative scheme. Haghpanah et al. (2009, 2010) extended the Variable Material Property (VMP) method developed by Jahed and Dubey (1997) for materials with varying elastic and plastic properties. In the VMP method, the linear elastic solution of a boundary value problem is used as a basis to generate the inelastic solution. Through iterative analysis, the VMP method was used to obtain the distribution of material parameters which were considered as field variables. The application of the VMP method, generally applied to homogeneous elastic-plastic materials (Jahed et al., 2001, 2005, 2006), was extended to materials with varying elastic-plastic properties in order to calculate the residual stresses in an autofrettaged FGM cylindrical vessel. Although there are several papers in the elastic analysis of FGM spherical pressure vessels in the literature (You et al., 2005; Dai et al., 2006; Chen and Lin, 2008), elastic-plastic stress analysis of FGM spherical pressure vessel is not such a customary study. Sadeghian and Ekhteraei (2011) studied the thermal stress analysis for an FGM spherical pressure vessel made of elastic–perfectly plastic and power law material model. Similar FGM cylindrical and spherical vessels, much of the studies on FGM rotating disk has been carried out numerically (Durodola and Attia, 2000; Bayat et al., 2008). Haghpanah et al. (2012) applied VMP method to solve for estimating the elasto-plastic stresses in a rotating disk with varying elastic and plastic properties in the radial direction. In this paper a new analytical method is proposed for predicting stress components of a strainhardening cylinder based on the von-Mises yield criterion under plane-stress conditions by assuming an isotropic material model. Results obtained from finite element analysis using the commercial software, ABAQUS (v 6.10), were used to validate the proposed analytical method. The method was further extended to obtain solutions for FGM spherical vessels and rotating disks. Elastic-plastic governing equations of functionally graded cylindrical and spherical pressure vessels and rotating disks are presented in the next section. Section 3 describes the material properties of the graded layer modelled by the modified rule of mixtures approximation. Solution procedures and results of the elastic-plastic analyses are presented in section 4. Finally in section 5 key conclusions are pointed out.

Materials have been pivot to the growth, prosperity, security and quality of life of human beings since the beginning of history. Without new materials and their efficient production, our world of modern devices, machines, automobiles, aircrafts and structural products could not exist. The increasing complexity of areas like construction, transport, environment, and energy demands products and industrial processes with improved quality, durability, functionality and structural properties of materials. This has inspired material engineers to come up with new materials at low cost to meet stringent and often conflicting property requirements, which conventional materials such as monolithic metals and their alloys cannot satisfy. To meet today‟s requirements, composite materials have shown great promise. Composites are the materials, which are tailored by combining two or more materials to get properties that are not attainable in any of its constituents alone. These materials contain dispersed fibers, particles or whiskers embedded in a matrix, which may be metallic, polymer or ceramic material. Composites are made from constituents, which can be grouped as (a) matrix (continuous phase) and (b) reinforcements (either continuous or discontinuous) in the form of particles, flakes, whiskers and short fibers (Alman, 2001). These combinations of materials can result in a newly synthesized material having unique and tailored properties such as low density, exceptional strength and stiffness, fatigue and corrosion resistance, high thermal conductivity and low coefficient of thermal expansion (Srivatsan et al, 1995). Due to their light weight, composites are being extensively used in manufacturing components of ground, space and aerospace vehicles. Composite technology provides us with the ability to create new multifunctional materials that can offer all the desirable characteristics required for a given application combined with low cost and near net-shape manufacturing processes, thereby expanding the vision for new materials and applications. On the basis of nature of matrix materials, the composites may be classified as metal matrix composites (MMCs), ceramic metal composites (CMCs) and polymer matrix composites (PMCs) (Aggarwal and Broatman, 1980).

Amongst the above mentioned composites, MMCs are the most important in present day material technology, as their development is pivotal to the growth of a number of leading technologies such as space, aerospace and shipbuilding technology. Metal matrix composites are based on metals or their alloys reinforced with fibers, particles or whiskers. A metal matrix composite combines into a single material a metallic base with a reinforcing constituent, which is usually non-metallic and is commonly a ceramic. Metal matrix composites containing particles are generally isotropic and are relatively cheap. Due to their superior stiffness, high strength at elevated temperatures and better creep characteristics, many of these composites are finding increasing application in components operating under elevated temperatures. In comparison to PMCs, MMCs can sustain higher service temperature, possess greater thermal and electrical conductivities and greater strength in shear and compression (Park et al, 1990). The increasing demand of ceramic like properties in metallic materials is mainly motivated by the need of weight reduction of dynamic systems operating under elevated temperatures, where PMCs are not capable enough. If the lighter

composites can replace components in motion, there exists a great possibility for further weight reduction of the surrounding components in an engineering system due to reduction of moving masses. Therefore, the MMCs are an attractive choice for variety of applications such as components of combustion engine, brake systems, stiff beams, load transfer elements in vehicles (support, personal and utility cars, rail transport), aerospace applications (turbine engines, helicopters, spacecrafts, airplanes, missile guidance systems), thermal management components in high power electronics, thermally cycled components (heat sinks, electronic packaging, mechanically loaded heat transfer elements) and machine components with high wear resistance but with low weight (textile machines, packaging machines, transmission system).

Rapid growth in technology has ushered in an era when it is possible to synthesize materials for components that exhibit graded-variation in properties. Typically, under severe environments such as high temperature or high thermal gradients, where conventional materials (metals or ceramics) may not survive alone. Thus, the concept of Functionally Graded Materials (FGMs) emerged and led to the development of superior heat resistant materials. FGMs are composites that are provided with heat-resistant ceramics on the high-temperature side and tough metals with high thermal conductivity on the low temperature side. In FGMs, the constituents or their contents vary with respect to position coordinates, which enable them to provide unique performance (Gupta et al, 2005). FGMs possess great potential for applications in components subjected to severe mechanical and thermal loadings due to their unique performance resulting from spatial tailoring of properties at microscopic level. FGMs have been developed as ultra-high temperature resistant materials for potential applications in aircrafts, space vehicles and other components exposed to elevated temperatures (Noda et al, 1998). In addition to excellent mechanical and thermal properties, they also possess the advantage of optimizing the use of costly dispersoids, since the content of dispersoids in FGMs varies from high temperature to low temperature region. The use of materials at high temperature is associated with number of problems like reduced life, oxidation, loss of strength and higher creep. Though, a number of materials have been developed with improved high-temperature properties, but ever increasing demands of modern technology need materials with even better high-temperature strength and oxidation resistance. For a long time, the principal high temperature applications were associated with steam power plants, oil refineries and chemical plants. The operating temperature in these systems seldom exceeds 50^{o}C. With the introduction of gas turbine engines, requirements developed for materials to operate at temperatures around 800oC under high stress as in turbine buckles. The need of more powerful engines has further pushed this limit to around 1000 oC (Dieter, 1988).

Further, weight reduction of a structural component is important for applications in space, aerospace and automobile industries. Aluminum and its alloys are extensively used in these applications for several years. However, the enhanced creep of aluminum and its alloys may not permit their application at elevated temperatures. From this point of view, components based on MMCs with aluminum/aluminum alloys reinforced with ceramic fibers, whiskers or particles are found to be extremely useful. Experimental studies pertaining to uniaxial creep have demonstrated that steady state creep rate in aluminum and its alloy reinforced with ceramic like silicon carbide is reduced by several orders of magnitude as compared to pure aluminum or its alloys (Nieh, 1984; Nieh et al, 1988).

The study of axisymmetric component such as cylinder is important due to their large scale structural and engineering applications, In most of these applications, cylinder is subjected to severe mechanical and thermal loads, causing significant creep and reducing its service life (Gupta and Pathak 2001; Tachibana and Iyoku 2004; Hagihara and Miyazaki 2008). However, the prediction of creep in many axisymmetric components, including pressure vessels, is extremely important and a quite complex task. Even the most elaborate finite element procedure yields results that are very time consuming and are not always reliable. The application of cylinder made from composite material under high stress and high temperature requires a thorough understanding of its creep characteristics and the prevailing creep mechanisms. Qualitative information pertaining to creep rate is also essential for predicting the useful life of cylindrical components operating under a given set of pressure and temperature. The availability of above mentioned information helps to modify, if required, the processing parameters of the cylinder material, tailor the cylinder design, or change the composition of material of the cylinder, so as to improve its creep resistance. The designers of cylindrical components, subjected to creep, are always interested in controlling the resulting creep deformation to enhance its service life. Therefore, studies concerning creep analysis help the designers to optimize the distribution of costly reinforcement in a composite cylindrical vessel, in order to control its creep response. The improved design will lead to a better safety of human beings associated with the application of pressure vessels.

In the recent years, a number of studies have been undertaken to investigate mechanical behaviour of functionally graded cylinders operating under thermo-mechanical loadings. Though, FGMs were originally intended to operate at elevated temperature, but most of the research work pertaining to functionally graded cylinders focus on its elastic behaviour (Arai et al, 1993; Pindera et al, 1994; Noda et al, 1998; Yang et al, 1999). In high-temperature environment, the time-dependent mechanism plays a vital role in determining the deformation of structure and is also responsible for ultimate failure. Unfortunately, owing to complexity of the problem, studies pertaining to determination of creep stresses and creep strains in cylinder made of FGMs are rather scant (Chen et al, 2007; You et al, 2009).

The mathematical modeling of composite shells involves the theory of lamina and laminate analysis. Laminate is a collection of lamina arranged in specified manner. In order to analyze the response of a laminated composite, it is necessary to predict the behavior of individual lamina. Buckling load calculations of shells without stiffeners involve the load-strain and moment-curvature relations through the laminate analysis and that of the shells with stiffeners require the force and moment interaction relations of the stiffeners and the shell, in order to determine the stiffness contribution of the stiffeners to the total structure. The object of buckling analysis is to estimate the maximum pressure that the composite shell can withstand before it becomes elastically unstable "Windenburg and Trilling Equation" is used to determine composite shell critical buckling pressure. The design philosophy of a composite shell is to avoid failure during a predetermined service life. Failure of a shell depends principally on the type of application involved. Composite laminates containing fiber reinforced thermosetting polymers do not exhibit gross yielding, yet they are also not classic brittle materials. Under a static tensile load, many laminates show non-linear characteristics attributes to sequential ply failures. The current design practice in aerospace industry, marine industries use the first ply failure approach. The crack appearing in the failed ply may make the neighboring plies susceptible to mechanical and environmental damage. The design criteria for fiber reinforced composite shell uses the same design criteria as those for metals. They are as follows: 1) Must sustain the ultimate design load in static testing. 2) Fatigue life must be equal or exceed the projected vehicle life.

A precise analysis of creep in composite cylinder would lead to develop a better understanding of the materials and operating parameters responsible for controlling the stresses and strain rates in the cylinders subjected to severe thermo-mechanical loadings. Although, much research has gone into the analysis of FGMs, engineers and other professionals engaged in the design process of FGMs lack a unified framework to make decisions regarding choice of the best possible combination of existing material ingredients and their composition profiles. The problem investigated in this work may provide guidelines to the designers of cylindrical pressure vessel, composed of either uniform composites or functionally graded materials, and will also lead to generate a reliable design code. The results obtained in the proposed work will open up the possibility of using functionally graded composite for above mentioned applications. The study undertaken will also help in identifying the ways to improve the creep behaviour of FGM cylinder by employing tailored inhomogenity in the distribution of costly reinforcement without altering their total content. The study will prepare a ground for exploring the possibility of employing different types of composite cylinder on the basis of their creep behaviour. The present work is limited to only steady state creep behaviour of the composite cylinder. Since 30-40% of the life of the component subjected to creep is spent in this regime only.

MODEL & MESHING

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted in the aerospace, automotive, shipbuilding, and other industries.

Computer Aided Three dimensional Interactive Application(CATIA) is well known software for 3-d designing and modeling for complex shapes.Commonly referred to as a 3D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAX), including conceptualization, design (CAD), engineering (CAE) and manufacturing (CAM). CATIA facilitates collaborative engineering across disciplines around its 3DEXPERIENCE platform, including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering.

CATIA facilitates the design of electronic, electrical, and distributed systems such as fluid and HVAC systems, all the way to the production of documentation for manufacturing.

MESHING

- The Figure shown is the meshed model of rigid flange coupling in the ANSYS analysis for the static structural process. To analyse, the FEM triangular type of mesh is used for the rigid flange coupling in the ANSYS environment.
- The number of elements used in this meshing is 71441and the number of nodes is 122228.In this process regular type of meshing is done to analyse the process.
- Using the working condition of the coupling a relative rotational movement between the shafts comes into picture consequently.
- The determination of the shear stress along the contact region is essential. So, the model is meshed and then analysed to get the detail and authentic result of the stresses of the contact region.

ANALYSIS

REDUCING THE DESIGN AND MANUFACTURING COSTS USING ANSYS (FEA):

The ANSYS program allows engineers to construct computer models or transfer CAD models of structures, products, components, or systems, apply loads or other design performance conditions and study physical responses such as stress levels, temperature distribution or the impact of lector magnetic fields.

In some environments, prototype testing is undesirable or impossible. The ANSYS program has been used in several cases of this type including biomechanical applications such as high replacement intraocular lenses. Other representative applications range from heavy equipment components, to an integrated circuit chip, to the bit-holding system of a continuous coal-mining machine.

ANSYS design optimization enables the engineers to reduce the number of costly prototypes, tailor rigidity and flexibility to meet objectives and find the proper balancing geometric modifications.

Competitive companies look for ways to produce the highest quality product at the lowest cost. ANSYS (FEA) can help significantly by reducing the design and manufacturing costs and by giving engineers added confidence in the products they design. FEA is most effective when used at the conceptual design stage. It is also useful when used later in manufacturing process to verify the final design before prototyping.

Program availability:

The ANSYS program operates on 486 and Pentium based PCs running on Wndows95 or Windows NT and workstations and super computers primarily running on UNIX operating system. ANSYS Inc. continually works with new hardware platforms and operating systems.

TYPES OF STRUCTURAL ANALYSIS:

Structural analysis is the most common application of the finite element method. The term structural (or structure) implies civil engineering structures such as bridges and buildings, but also naval, aeronautical and mechanical structures such as ship hulls, aircraft bodies and machines housings as well as mechanical components such as pistons, machine parts and tools.

There are seven types of structural analyses available in ANSYS. One can perform the following types of structural analyses. Each of these analysis types are discussed in detail as follows.

1. Static analysis
2. Modal analysis
3. Harmonic analysis
4. Transient dynamic analysis
5. Spectrum analysis
6. Buckling analysis
7. Explicit dynamic analysis

STRUCTURAL STATIC ANALYSIS:

A static analysis calculates the effects of steady loading condition on a structure, while ignoring inertia and damping effects such as those caused by time varying loads. A static analysis can, however include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes.)

PROCEDURE FOR ANSYS ANALYSIS:

Static analysis is used to determine the displacements, stresses, strains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain).

A static analysis can be either linear or nonlinear. In our present work we consider linear static analysis.

The procedure for static analysis consists of these main steps:

1. Building the model.
2. Obtaining the solution.
3. Reviewing the results.

PROCESSOR:

It is a powerful user-friendly post-processing program using interactive colour graphics. It has extensive plotting features for displaying the results obtained from the finite element analysis. One picture of the analysis results (i.e. the results in a visual form) can often reveal in seconds what would take an engineer hour to asses from a numerical output, say in tabular form. The engineer may also see the important aspects of the results that could be easily missed in a stack of numerical data.

Employing state of art image enhancement techniques, facilities viewing of:

- Contours of stresses, displacements, temperatures, etc.
- Deform geometric plots
- Animated deformed shapes
- Time-history plots
- Solid sectioning

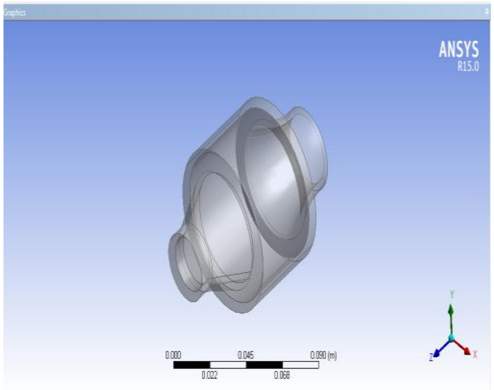

Figure shows a static structural design of a Internally Pressurized Rotating Cylinder.

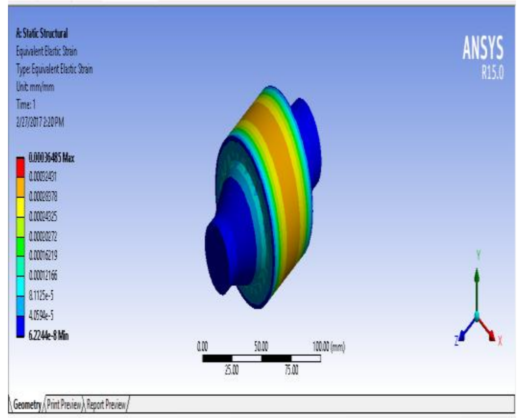

Figure shows a static structural design of equivalent elastic strain.

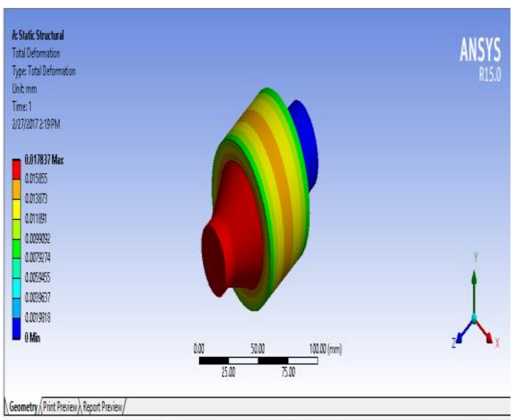

Figure shows a static structural design total deformation.

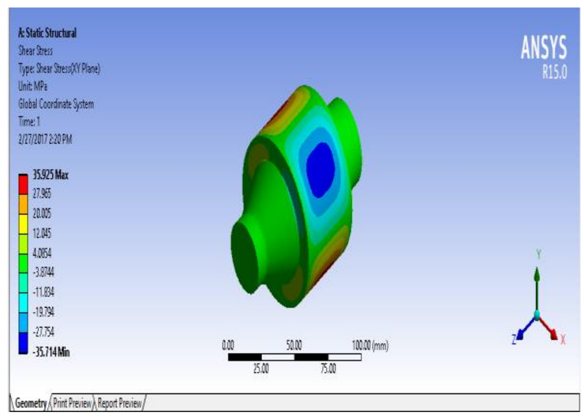

Figure shows a static structural design of shear stress analysis in XYplane

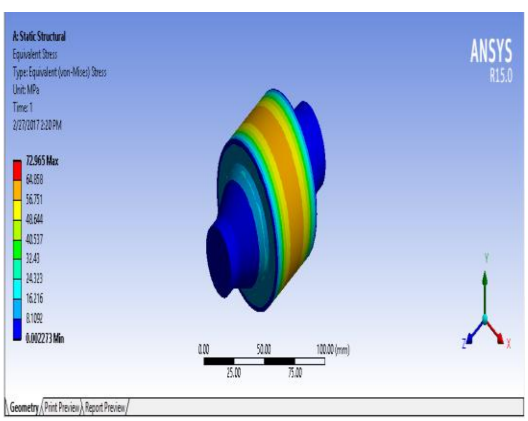

Figure shows a static structural design of equivalent stress analysis.

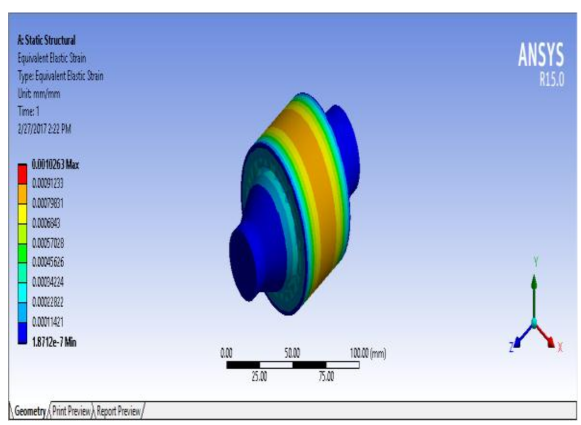

Figure shows a static structural design of equivalent elastic strain at a given pressure.

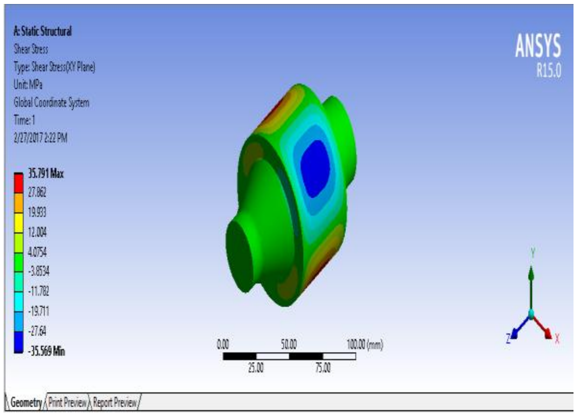

Figure shows a static structural design of shear stress on XYplane at a pressure of 5.6Mpa.

CONCLUSIONS

This project work involves the comparison of conventional steel and Composite material cylindrical pressure vessel under static loading conditions the model is preferred of in Catia V5 R20 and then analysis is perform through ANSYS 15.0 from the result obtained it will be concluded that the development of a composite cylindrical pressure vessel having constant cross sectional area, where the stress level at any station in the Composite pressure vessel is considered drop and rise due to the orientation of composite, has proved to be very effective. Taking weight into consideration, we can The deformation is tending to reduce for the axis symetric composite orientation so as the Equivalent Stress. The Lamina stacking sequence is appropriate which is free from extension – bending, coupling which reduces the effective stiffness of the lamina, since the laminates are symmetric. Appropriate number of plies needed in each orientation and thickness of the shell is safe from static and buckling analysis is concerned. The comparison plots obtain desired results for stresses and deformations with lamina orientations for the chosen composite materials.

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