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ANALYSIS OF FUNCTIONALLY GRADED THICK WALLED TRUNCATED CONE PRESSURE VESSEL WITH EXPONENTIALLY-VARYING PROPERTIES FOR DIFFERENT MATERIALS USING ANSYS 18.1

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Abstract - *Material properties and thickness of the pressure vessel are two very important parameters to control the maximum stress induced. Shells made up of functionally graded materials have significant stress reduction over the shells made up of homogeneous material. Therefore higher pressure is permissible for FGM shells. Many researchers have worked on limit speed and stress analysis of cylindrical shells by analytical as well as approximate methods. In current project work FGM cylindrical shells geometry model was converted into FE model by the discretization method that changes continuous material variation into stepwise variation. Material modelling, geometric modelling and finite element modelling is done for the shell and then numerical problem is solved using the finite element software ANSYS.*

Key Words: Functionally Graded Materials, Cylindrical shells, FE model, Material modelling, Geometric modelling, etc

1. INTRODUCTION

Functionally graded materials are a class of advanced composites which are formed of two or more constituent phases with a gradual and continuously variable chemical composition, microstructure and material properties. They were initially introduced by a group of Japanese scientists for the purpose of addressing the needs of aggressive environment of thermal shock in the space shuttle in 1984 [1]. Since then, due to FGMs outstanding advantages including a potential reduction of in-plane and transverse stresses through-the-thickness, an improved residual stress distribution, enhanced thermal properties, higher fracture toughness and reduced stress intensity factors, FGMs received much attention in both academic and engineering communities [2,3].

1.1 Theory of elasticity on hollow cylinders

Hollow cylinder is a three-dimensional (3D) structure bounded by two parallel curved surfaces (an inner surface and an outer one), which are respectively formed by the points at a fixed distance from the axis of the cylinder. Hollow cylinders are axisymmetric. To analyse the mechanical behaviours of them, cylindrical coordinate (r, θ, z) is always applied, where r, θ and z denote the radial, circumferential land axial coordinates respectively.
A summary of equations for hollow cylinders is made in this section, and the geometric equations, constitutive equations and equilibrium equations are mainly described. These equations associated with boundary conditions (and initial conditions) make up a complete set of equations of hollow cylinder theories.

2. LITERATURE SURVEY

A.M. Afsar et. al 2001 [8] developed a solution method for evaluating optimum material distributions have been developed to realize prescribed apparent fracture toughness in thick walled FGM circular pipes. Numerical results obtained for TiC/Al2O3 FGM pipes reveal that the apparent fracture toughness in the FGM pipes depend significantly on the material distribution and the apparent fracture toughness in the FGM pipes can be controlled within possible limits by choosing an optimum material distribution profile in the FGM pipes

Naki Tutuncu et. al 2001 [18] presented closed form solutions for stresses and displacements in a functionally graded cylindrical and spherical vessels subjected to internal pressure alone are obtained using the infinitesimal theory of elasticity. The material stiffness obeying a simple power law is assumed to vary through the wall thickness and Poisson's ratio is assumed constant. Stress distribution depending on an inhomogeneity constant are compared with those of homogeneous case.

Mohammad Zamani Nejad et al 2015 [16] obtained stresses in isotropic rotating thick-walled cylindrical pressure vessels made of functionally graded material as a function of radial direction by using the theory of elasticity. The pressure, inner radius and outer radius are considered constant. Material properties are considered as a function of the radius of the cylinder to a power law function and the Poisson's ratio is assumed as constant. The analytical solution of the Navier equation is obtained for the conditions of plane strain, plane stress and the cylinder with closed ends.

L.H. You 2005 [17] present an accurate method to carry out elastic analysis of thick-walled spherical pressure vessels subjected to internal pressure. Two kinds of pressure vessel are considered: one consists of two homogeneous layers near the inner and outer surfaces of the vessel and one functionally graded layer in the middle; the other consists of the functionally graded material only. The effects of Young's modulus of the outer layer, and Young's modulus and geometric size of the middle layer on the deformations and stresses in the vessels consisting of the three different layers are examined. A method to obtain an almost constant circumferential stress in the vessels consisting of the functionally graded material only is investigated.

Naki Tutuncu 2007 [4] obtained solutions for stresses and displacements in functionally-graded cylindrical vessels subjected to internal pressure alone are obtained using the infinitesimal theory of elasticity. The material is assumed to be isotropic with constant Poisson's ratio and exponentially-varying elastic modulus through the thickness.

Y.Z. Chen et. al 2008 [9] carried out elastic analysis for a thick cylinder made of functionally graded materials (FGMs). The property of FGMs is assumed to be exponential function form. The problem is reduced to solve an ordinary differential equation numerically result shows that the property of FGMs has a significant influence to the stress distribution along the radial direction.

A.T. Kalali et. al 2013 [13] in this work the analysis results obtained for the vessel material ceramic/metal functionally graded material indicate the possibility of formation and growth of the plastic region within the wall thickness from the external surface of the FGM vessels whereas in a cylindrical (spherical) vessels made of homogeneous materials, plasticity starts essentially from the inner surface.

Shildip D. Urade et al. 2014 [5] designed a multilayer pressure vessel to work under high pressure condition the stress analysis of multi-layer pressure vessel made of a homogeneous and isotropic material and subjected to internal pressure is considered. The hoop stresses for 1, 2 & 3-layerpressure vessel is calculated theoretically. The modelling of pressure vessel is carried out in CATIA V5 and this model is imported in ANSYS Workbench where stress analysis is carried out. The shrink fit is applied during the CAD modelling of multilayer pressure vessel. Both theoretical and FE results are compared and effect of multi-layering on stresses induced and the volume requirement to sustain the given pressure is calculated. Also optimization of number of layers is carried out for multi-layering the pressure vessel. From calculations it is observed that as the numbers of layers increases, the hoop stresses decreases.

M. Z. Nejad et. al. [7] Stresses and the displacements in thick-walled spherical shells made of functionally graded materials subjected to internal shells made of functionally graded materials subjected to internal and external pressure are developed by an analytical method. The mechanical properties, except Poisson's ratio, are assumed to obey the exponential variations throughout the thickness. The displacement and stresses distributions were compared with the solutions of the finite element method (FEM) and good agreement was found. The presented results show that the material inhomogeneity has a significant influence on the mechanical behaviors of thick hollow spherical structures made of functionally graded materials with exponential
varying properties.

Zewu Wang et al. [10] in this paper investigation of the optimization design of the material distribution properties for an FGM hollow vessel subjected to internal pressure. By constructing an exponential function and determining the material properties, the general analytical solution of the stresses of the FGM pressure vessel was given based on the Euler-Cauchy formula. And then, an optimization model for obtaining the optimal material distribution of FGM vessel was proposed coupling the general finite element (FE) code. The discrepancy between the analytical solution and the numerical solution was about 2%, which verified the reliability of the proposed models, and the optimization results also proved the feasibility of proposed optimization scheme because of arriving at the optimal solution in a few iterations.

3. PROBLEM FORMULATION & VALIDATION

In an FGM the variation of material properties is usually attained by adjusting the volume fractions of two or more compatible constituents, and the material used is in the base paper assumed to be functionally graded in the radial direction. Thus, variations in the material properties such as Young's modulus and Poisson's ratio may be arbitrary functions of the radial coordinate. In the base paper Young's modulus with exponentially-varying properties and constant Poisson's ratio is considered as the variation of Poisson's ratio ν is small for engineering materials.
Modulus of elasticity of FGM pressure vessel follow the exponential law

$$E(r) = E_o e^{\alpha(r-1)}$$

Where $r = r'/R$, r' is the radial radius, r is the normalized radial radius, and α is the elastic graded factor of the FGM. E is the modulus of elasticity, and E_o is the modulus of elasticity of the external wall.

The dimensions of the pressure vessel as taken in base paper are R_i = 74 mm, R_o = 80.082 mm, height = 400 mm and that of a spherical head are (R_i = 74 mm, R_o = 77.542 mm). Two primary materials are Al_2O_3 alumina for ceramic and stainless steel for metal, respectively. And E_o=200 GPa, ν = 0.3, and exponent factor is α = 1.5. The internal pressure is 12 MPa. The complete problem of the base paper was solved in ANSYS APDL, in this project also ANSYS APDL 18.1 is used. Geometry model was converted into FE model by the discretization method that changes continuous material variation into stepwise variation. In ANSYS APDL elements are prior defined and a database is available with the software of the same having different degree of freedom and material properties like creep, swelling, warping magnitude, etc. In this work axisymmetric 8-node plane element Plane82 was selected as selected in the base paper. Considering the symmetry of the pressure vessel in the axial direction as well as longitudinal only one fourth portion of the material was constructed.

Since, the work is based on FGM therefore instead of using GUI ANSYS Parametric Design Language is used as it easier to assign the mechanical properties of materials, etc.

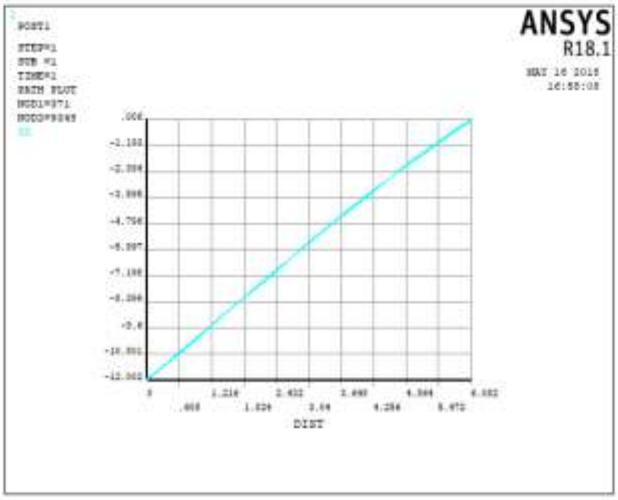

Fig 3.1: Radial stress of cylindrical part of the FGM pressure pressure vessel

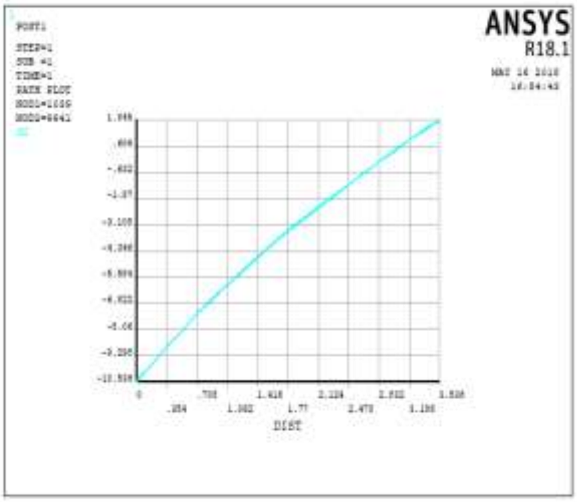

Fig 3.2: Radial stress of spherical part of the FGM pressure vessel

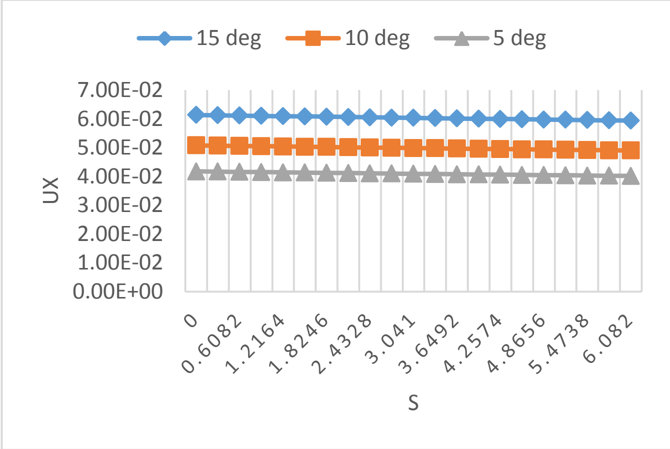

Fig 3.3: Comparison of radial displacement for 5°, 10°, 15° truncated cone pressure vessel

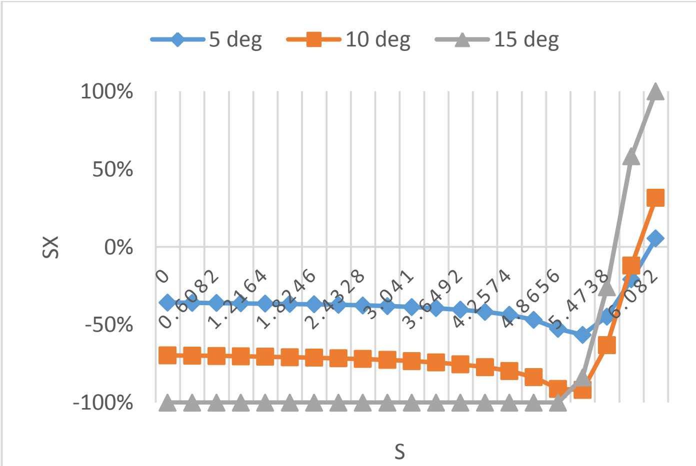

Fig 3.4: Comparison of radial stress for 5°, 10°, 15° truncated cone pressure vessel

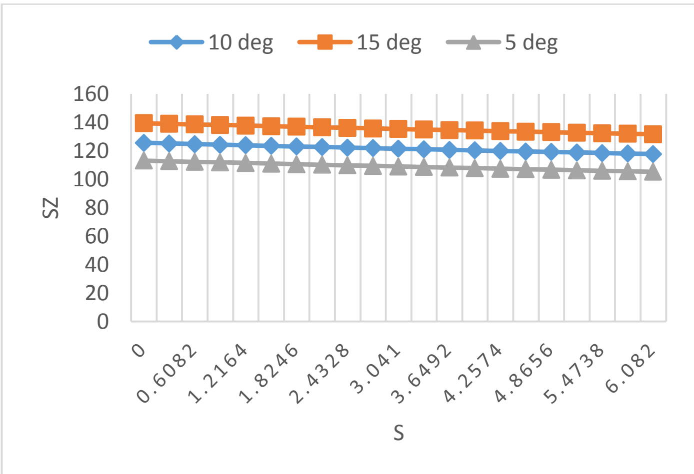

Fig 3.5: Comparison of circumferential stress for 5°, 10°, 15° truncated cone pressure vessel

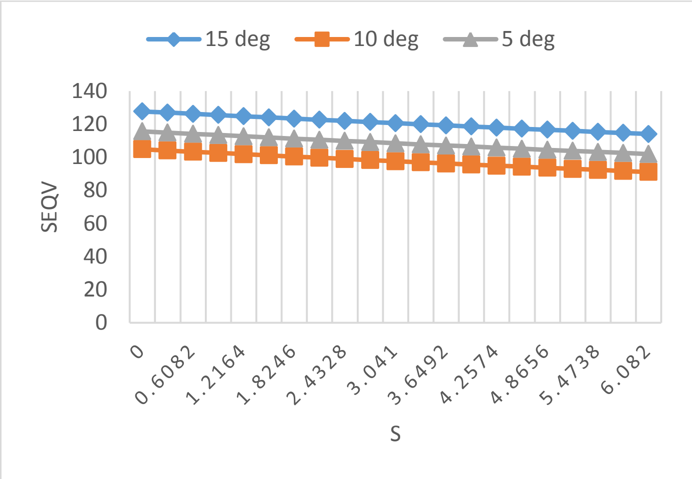

Fig 3.6: Comparison of von mises stress for 5°, 10°, 15° truncated cone pressure vessel

4. RESULT

Fig 3.3 reveals that radial displacement increases with increase in angle of beta and in fig 3.4 radial stress increases as the angle of beta increases. Also, the circumferential stress shown in Fig. 3.5 increases with the increase of the angle of beta and in fig 3.6 von mises stress increase with the increase in angle of beta.

Different metals like ASTM A516, 2014 T6 alloy, Ti-5Al-2.5Sn used for fabrication of pressure vessel is studied under FGM. Since stress is not dependent on material but strain is a dependent variable on material therefore, by varying different metal deformation or strain will change. A comparative analysis will help to choose the best material as per application from low pressure vessel to high pressure vessel and also economical.

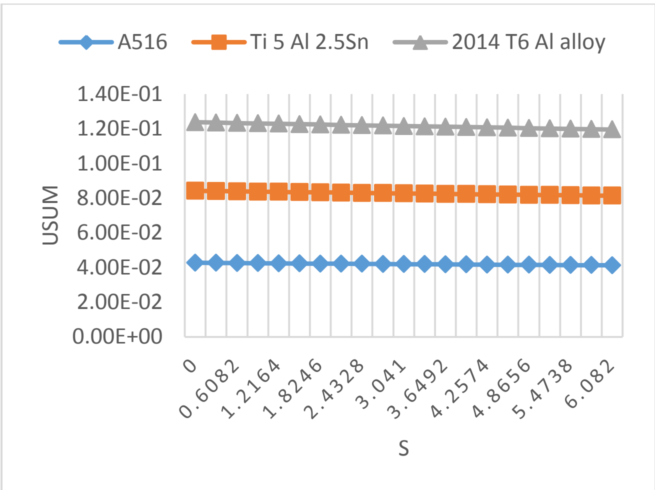

Fig 3.7: Comparison of displacement vector sum for 5°, 10°, 15° truncated cone pressure vessel

In the comparison data least deformation is noticed by ASTM A516 therefore the best material to handle maximum pressure in a pressure vessel is ASTM A516 whereas in comparison to that Ti-5Al-2.5Sn is a good alternative for low pressure vessels and 2014 T6 Al alloy can be used for low pressure vessels for economical means.

5. CONCLUSIONS

In this project work pressure vessel made up of functionally graded material is analysed. The pressure vessel has exponentially varying material properties and subjected to mechanical body load in the form of internal pressure. Truncated cone pressure vessel with three beta angle 5°, 10°, 15° are considered for fix-free boundary condition. Finite element modelling is done and numerical problem is analysed by the help of ANSYS Mechanical APDL 18.1 and a comparison is made for all truncated cone profiles and different material. The results obtained may be concluded as:

1. Von mises stress obtained is maximum near the inner radius zone for fix-free boundary condition. On the basis of which it is suggested that the disk should have higher strength in this region.
2. In all the cases of beta radial displacement, radial stress and circumferential stress is increasing with the increase in angle of beta.
3. ASTM A516 is found with least displacement compared with 2014 T6 alloy, Ti-5Al-2.5Sn.

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