IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 6, Issue 9, September 2019

Creep Analysis of a Composite Cylinder - A Literature Review

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Abstract: This article reviews the problem of creep in cylinders made of Functionally Graded Materials (FGMs). Selected papers published in the English language including the phrase "creep analysis of composite cylinder" in the title, abstract, or key words were searched in science direct and Google scholar databases and reviewed. The literature provides evidence that in recent years the problem of creep in cylinders made of FGMs operating under high pressure and temperature has attracted the interest of many researchers. Creep behaviour of composites with tailored distribution of reinforcement is of importance in view of their applications at high temperature. It is observed that the rotating circular cylinders under internal pressure made of transversely isotropic material were on the safer side of the design as compared to rotating circular cylinders under internal pressure made of isotropic material.

Keywords: Creep analysis, Composite material, Composite cylinder, Functionally Graded Materials (FGM's)

I. INTRODUCTION

Composite materials (also called composition materials or shortened to composites) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. [24] Composite materials are generally used for buildings, bridges and structures such as boat hulls, race car bodies, shower stalls, bathtubs, and storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft in demanding environments.

A. *CREEP*

In materials science, creep is the tendency of a solid material to move slowly or deform permanently under the influence of stresses. It occurs as a result of long-term exposure to high levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near their melting point. Creep always increases with temperature.

The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that might otherwise lead to cracking. [25]

B. FUNCTIONALLY GRADED MATERIALS (FGMS)

Functionally Graded Materials (FGM's) are composite materials where the composition or the microstructure is varied so that certain variation of material properties is achieved. [23]

Functionally Graded Material (FGM) belongs to a class of advanced material characterized by variation in properties as the dimension varies. The overall properties of FMG are unique and different from any of the individual material that forms it. There is a wide range of applications for FGM and it is expected to increase as the cost of material processing and fabrication processes are reduced by improving these processes. [7]

Functionally graded materials (FGMs) are a new generation of engineered materials that are gaining interest in recent years. FGMs were initially designed as thermal barrier materials for aerospace structural applications and fusion reactors. [3, 21] FGMs also find applications in structural components operating under extremely high-temperature environments. [6] FGMs are the composite materials in which the content of reinforcement is gradually varied in some

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direction to achieve gradient in properties. Due to graded variation in the content of constituent materials, the properties of FGMs undergo smooth and continuous change from one surface to another, thus eliminating interface problems and diminishing thermal stress concentrations. As an example FGMs based on ceramic reinforcement in metal matrix, are able to withstand high-temperature environments due to better thermal resistance of ceramic constituents, while the metal constituents enhance their mechanical performance and reduce the possibility of catastrophic fracture. The application of concept of FGMs to Metals Matrix Composites (MMCs) has led to the development of components designed with the purpose of employing selective reinforcement in certain regions where enhanced properties like increased modulus, strength and /or wear resistance are required. [5, 20]

C. COMPOSITE CYLINDER

Under severe thermo-mechanical loads, cylinder made of monolithic materials may not perform well. The excellent mechanical properties like high specific strength and stiffness, and high temperature stability offered by metal matrix composites (MMCs), such as aluminium and aluminium alloy matrix composites reinforced with ceramics like silicon carbide, make them an appropriate material for applications involving high pressure and high operating temperature.

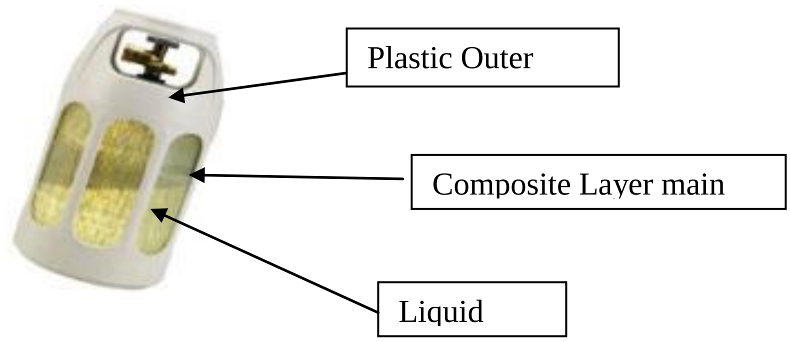

Fig. 1: Composite Cylinder for outdoor application. [28]

Propane composite cylinders are high-strength containers made from a mixture of fibreglass or carbon fibres and a plastic resin, typically epoxy. The main body of the composite cylinder is translucent, which means that the user can easily see the liquid level in the cylinder and avoid unexpected fuel run-outs. The main body is protected by a hard plastic outer shell. [28]

D. FEATURES OF COMPOSITE CYLINDERS

A. *Lightweight*- Composite cylinders weigh 33-50 % less than steel cylinders that can hold an equivalent amount of propane, and are approximately the same weight as aluminium cylinders.
B. *Visible Gas Level*- The main body is translucent, which allows the user to see how much propane is inside.
C. *Non-rusting*- It will not rust, as can happen with a steel cylinder, since the cylinder is made from plastic and fiberglass.

II. LITERATURE REVIEW

Gupta et al. (1998) analyzed the thermo creep transition of non homogeneous thick walled circular cylinder under internal pressure by using Seth's Transition theory. This theory does not require any ad-hoc assumptions like yield criterion, incompressibility condition etc. It utilizes the concept of generalized strain measure. For a cylinder whose compressibility increased radially (K = -1) were subjected to pressure only, the circumferential stress was maximum at the outer surface. With the introduction of thermal effects, the circumferential stress was again maximum at the outer surface but thermal effects reduced the stresses as compared to pressure effects only.
For homogeneous compressible cylinders (K = 0) subjected to pressure only, the circumferential stress was maximum at outer surface but with the introduction of thermal effects the circumferential stress was again maximum at the outer surface but it reduced the stresses in as compared to the pressure effects only.
For a cylinder whose compressibility decreases radially (K = 1) the circumferential stress was maximum at the inner surface for incompressible material as compared to compressible material and it decreased with the introduction of thermal effects.

Therefore, the cylinders whose compressibility increased radially (K = -1) and cylinders made of homogeneous compressible material (K = 1) were safe to design.

Yang et al. (2000) proposed an analytical solution to obtain stresses in a FG layered cylinder by taking into account the elastic and creep behaviour of the material. The study considered a two layered cylinder with inner layer made of homogeneous material showing elastic behaviour while the outer layer was assumed to be made of an FGM having creeping material. It was concluded that for elastic material the solution was exact, whereas for creeping material the solution was asymptotic. The FEM calculations indicate that the fifth-order asymptotic solution may be used to calculate stresses for a long time creep. However, for a short time creep, the first order asymptotic solution yielded the approximate values of stresses.

Sharma S. (2004) analyzed the elastic-plastic transition of a non-homogeneous thick-walled circular cylinder under internal pressure using Seth's transition theory. For the homogeneous cylinders, high pressure was required for initial yielding than the non-homogeneous cylinders and this pressure goes on increasing when radii ratio increased. For a homogeneous cylinder where yielding took place at internal surface, it required a less percentage increase in pressure to become fully plastic than to its initial yielding and this percentage goes on increasing with the increased radii ratio. For the non-homogeneous cylinders, high percentage increase in pressure was required by the cylinders to become fully plastic as compared to the homogeneous cylinders. It was observed that circumferential stress was maximum at the external surface for a non-homogeneous circular cylinder and non-homogeneity increased the tangential stress at the external surface significantly.
It was concluded that the circular cylinders made of non-homogeneous material (non-homogeneity increases radially) was on the safer side of design. The more use of non-homogeneous material (non-homogeneity increased radially), was therefore beneficial for the manufacturing of circular cylinders to provide a longer service life than the cylinders made of homogeneous materials under identical conditions.

Muliana et al. (2006) analyzed creep behaviour, collapse of thick-section and layered composite structures using a nonlinear visco-elastic and multi-scale modeling framework. The thick section composites were manufactured by the pultrusion process and reinforced with alternating layers with unidirectional fibers. The creep analysis of axially compressed laminated cylinder under surface pressure was presented. The creep collapse analysis of different Fiber Reinforced Plastic (FRP) composite structures was studied using the combined micromechanical and structural FE model. It was shown that the compressive loading ratio, along with the residual stiffness of the structure after buckling could affect the creep behaviour and the magnitude of critical time for initiation of unstable response. The proposed models can be used to assess the service life of structures.

You et al. (2007) analyzed steady state creep in thick-walled cylinders made of arbitrary FGM and subjected to internal pressure. The stresses and strain rates were calculated by using Norton’s creep law. He used basic equation of axisymmetric, plane strain and steady state creep. The relative errors of radial, Circumferential and axial stresses and equivalent strain rate were calculated at the inner and outer radius of the cylinder with constant material properties. The difference in these values indicated the high accuracy of the proposed method.
Similarly, the stresses were calculated by using different material properties, and were compared which showed that tensile, circumferential and axial stresses goes up at the inner radius and goes down at the outer radius.

Sharma et al. (2008) obtained the Creep stresses for a transversely isotropic thick-walled rotating cylinder under internal pressure using Seth’s transition theory. Transition theory does not require any assumptions and thus poses and solved a more general problem. It utilized the concept of generalized principal strain measure and the asymptotic solution at transition points of the governing equations defining the deformed field. It was successfully applied to a large number of creep problems. Creep stresses and strain rates for a thick-walled circular rotating cylinder were calculated under internal pressure using transition theory.

With the increased angular speed, the circumferential stress increased at internal surface for transversely isotropic circular cylinder under internal pressure as compared to isotropic circular cylinder. With the increased measure, circumferential stress decreased at internal surface for transversely isotropic/ isotropic circular cylinder under internal pressure. With the increased angular speed, the creep rate had large value at the internal surface as compared to the cylinders made of transversely isotropic material and these values further increased at the internal surface with the increase in pressure. The value of creep rates decreased with the increase in strain.

Sharma et al. (2009) discussed the Thermo Elastic-Plastic Transition of Transversely Isotropic Thick-Walled Rotating Cylinder under Internal Pressure. Thick-walled circular cylinder made of isotropic material having thickness ratio = 4 yielded at the internal surface at high pressure as compared to cylinders made of transversely isotropic material. With the introduction of thermal effects and angular speed, the cylinder made of isotropic/ transversely isotropic material yielded at lower pressure. With increased angular speed and thermal effects much less pressure was required for initial yielding. It was observed that a thick-walled circular cylinder made of transversely isotropic material required high percentage increase in pressure to become fully plastic from. Its initial yielding and the percentage increased with the increase in temperature and angular speed. It means that at room temperature, thick-walled cylinders made of isotropic material is to withstand a greater pressure to initiate yielding at the internal surface as compared to cylinders made of transversely isotropic material. With the introduction of thermal effects and angular speed they yielded at a lower pressure, where as cylinders made of isotropic material required less percentage increase in pressure to become fully plastic state from its initial yielding. For fully plastic state, circumferential stress was maximum at external surface. Circumferential stress decreased with the increase in angular speed. It was observed that for fully plastic state, radial and circumferential stresses were independent of thermal effects.

Therefore, the circular cylinders under internal pressure made of transversely isotropic material were on the safer side of the design.

Sharma et al. (2009) observed the Elastic-plastic Transition of Transversely Isotropic Thick-walled Rotating Cylinder under Internal Pressure by using Seth's transition theory. Conditions assumed were:

a. the incompressibility conditions,
b. the deformation was small enough to make infinitesimal strain theory applicable, and
c. the yield criterion,

It was observed that the thick-walled circular cylinder made of isotropic material yields at high pressure as compared to cylinder made of transversely isotropic material whereas a thick-walled cylinder yielded at low pressure. With increased angular speed, less pressure is required for initial yielding of transversely isotropic material as compared to isotropic material. Thick walled circular cylinders made of transversely isotropic material required a high percentage increase in pressure to become fully plastic as compared to isotropic material from its initial yielding and this percentage increased with the increase in angular speed.
It was concluded that circular cylinders under internal pressure made of transversely isotropic material was on the safer side of the design as compared to the circular cylinder under internal pressure made of an isotropic material.

Singh et al. (2009) analyzed the effect of material parameters like size and content of the reinforcement and operating temperature on the stress and strain rates in the composite cylinder. He used threshold stress based creep law. The cylinder is a long, closed end, thick walled hollow made of Al-SiCp composite. Assumptions made were:
1) Material of the cylinder was incompressible, isotropic and had uniform distribution of SiCp in aluminium matrix.
2) Pressure was applied gradually and held constant during the loading history.
3) Steady state condition of stress was assumed.
4) Elastic deformations were small and are neglected as compared to creep deformations.

The variation of particle size does not have a sizable effect on the stresses. The effective stress does not change on varying the particle size near the inner radius but it decreases towards the outer radius with increasing particle size. The effective strain decreased with decreasing SiCp particles size. The tangential and radial creep rates decreases due to finer SiCp particles. The increase in the amount of reinforcement particles increased the tangential and axial stresses near the inner radius and decreased near the outer radius.
The effective stress at the inner radius does not change with varying temperature but it decreased at the outer radius with the increase in temperature. With increased operating temperature the threshold stress (σ_o) decreased and the creep parameter M increased.
Sharma et al. (2010) analyzed the thermo creep transition of transversely isotropic thick- walled rotating cylinders under internal pressure by using Seth's transition theory. With the introduction of thermal effects, the circumferential stress was maximum at the internal surface for transversely isotropic/ isotropic circular cylinders under internal pressure. With the increased angular speed (without thermal effect), circumferential stress continuously increased at internal surface for transversely isotropic circular cylinders under internal pressure as compared to isotropic circular cylinders. With the increased measure, circumferential decreased at internal surface for transversely isotropic/ isotropic

circular cylinder under internal pressure. With the introduction of thermal effects, stresses at internal surface were decreasing with the increased measure n.
At room temperature, for thick-walled circular cylinders made of isotropic material under internal pressure, the creep rate have a large value at the internal surface as compared to cylinder made of transversely isotropic material for measure n = 1/3 and these values further increased at the internal surface with the increased pressure. For measure n = 1/7, the creep rates have lesser value at the internal surface as compared to measure n = 1/3. With the introduction of thermal effects, the creep rates were of lower value at the internal surface for thick-walled cylinder made of transversely isotropic / isotropic material under internal pressure. The value of creep rates decreased with the increase in strain.
Therefore, the rotating circular cylinders under internal pressure made of transversely isotropic material were on the safer side of the design as compared to rotating circular cylinders under internal pressure made of isotropic material.

Singh et al. (2010) analyzed the steady state behaviour in an isotropic functionally graded composite cylinder subjected to internal pressure. The cylinder is a long, closed end, thick-walled, hollow cylinder made of functionally graded Al-SiCp composite with silicon carbide particles decreased linearly from the inner to outer radius. Assumptions made were:

a) Material of the cylinder is locally isotropic and stresses at any point in the cylinder remains constant with time.
b) Elastic deformations are small, therefore, neglected as compared to creep deformation.

The results have been obtained for uniform and three different FGM cylinders. The creep parameter M increased with increasing radial distance and the threshold stress (σ_o) decreased linearly with increasing radial distance in the FGM cylinders whereas in uniform cylinders the creep parameters remains constant due to the same amount of SiCp.
The magnitude of radial stresses decreased throughout the cylinder with increase in particle gradient. The tangential stress remains tensile throughout and was increasing with the radius. The axial stress changes its nature from compressive (uniform cylinder) to tensile (FGM cylinder) at the inner radius. The effective stress decreased with increasing radial distance and the increased particle gradient in the composite cylinder led to increased effective stress near the inner radius and decreased near the outer radius. The strain rate in the FGM cylinder decreased with the radius and the decrease was observed in strain rate increase with further increase in particle gradient.

Hoseini et al. (2011) described a new analytical solution for the steady state creep in rotating thick walled cylinders. Exact solutions for stresses are obtained under plane strain assumption. The exact solution of creep stresses for a rotating thick hollow cylinders rotating at a constant angular velocity and were subjected to uniform pressure on the inner and outer surfaces obtained by Norton's power law and was used to derive general expressions for stresses and strain rates in the rotating thick cylinder.

Singh et al. (2011) studied the steady state creep in transversely isotropic functionally graded cylinder operating under internal and external pressure. The cylinder is made of an anisotropic 6061 Al – SiCw FGM.
Two cases were considered:

a) When cylinder was subjected to internal pressure alone.
b) When cylinder was subjected to both internal and external pressure.

The magnitude of creep stresses and creep rates in a FGM cylinders subjected to internal pressure alone were higher as compared to the FGM cylinder subjected to both internal and external pressure.
Also, the presence of both internal and external pressure reduced the inhomogenity in the stress (axial) and strain rates as compared to the presence of internal pressure only.
It also studied the effect of anisotropy on the maximum and minimum value of stresses in FGM cylinder.

a) In an anisotropic FGM cylinder having ($\alpha < 1$), radial stresses increased in the middle region and tangential stresses reduced near inner radius but increased near outer radius, as compared to an isotropic FGM cylinder ($\alpha = 1$).
b) The axial and effective stresses in an anisotropic FGM cylinder ($\alpha < 1$) were lower than in an isotropic FGM cylinder ($\alpha = 1$).
c) The effect observed in an anisotropic cylinder having $\alpha > 1$ was opposite to that of an anisotropic cylinder having $\alpha < 1$.
d) An anisotropic FGM cylinder has relatively higher strength in the tangential direction as compared to the radial and axial direction which leads to lower strain rates over the entire radius.
e) With increased extent of anisotropic, the inhomogenity in creep stresses reduced but the inhomogenity in creep rates increased.

Therefore, the chances of distortion in FGM cylinder having α >1 were more as compared to FGM cylinder having α <1.

Sharma et al. (2012) obtained the creep transition in non homogeneous thick walled circular cylinder under internal and external pressure by using transition theory which is based on the concept of generalized principal strain measure. For circular cylinder under external pressure, stresses were compressible in nature and were maximum at internal surface. For cylinder without external pressure, circumferential stress again was of compressible nature and increased with the increase in measure. For the cylinder whose external pressure has been increased and is more than that of internal pressure, circumferential stresses were maximum at the internal surface and were high as compared to the cylinder whose external pressure is zero. Circumferential stresses were increasing for the cylinder whose internal pressures have been increased without external pressure. The increased external pressure also increases circumferential stresses significantly.

Therefore, Circular cylinders with external pressure (without internal pressure or less internal pressure as compared to external pressure) and with nonlinear measure (N = 5) were on the safer side of the design because circumferential stresses were less for cylinder with above mentioned parameters as compared to other cases.

Singh et al. (2013) studied the steady state creep behaviour in a functionally graded thick composite cylinders subjected to internal pressure in the presence of residual stresses. Hoffman's Yield criterion was used to describe the yielding of the cylinder material in order to account for residual stresses and compared the result with a similar cylinder but yielding was according to Von Mises criterion.
The cylinder is made of FG 6061 Al-SiCw composite material. The steady state creep stresses and strain rates were calculated for the given composite cylinder having residual stresses. Then yielding by Hoffman yield criterion was described. The results obtained were then compared with a similar cylinder but without residual stress.
Since, the FG cylinder were similar in dimensions the value of creep parameters in both the cylinders were same. The value of creep parameters M increased with increasing radial distance and the Threshold stress (σ_o) decreased linearly with increasing radial distance. The radial stresses were compressive and higher at inner radius and zero at outer radius. Its magnitude changes a little due to the presence of thermal residual stresses.
The tangential stress was tensile throughout and increased with increasing radius and reaches maximum value near the outer radius. But in presence of residual stress, the tangential stress increased near the inner radius and decreased near towards the outer radius.
The axial stress changed its nature from compressive to tensile on moving from inner to outer radius and due to the presence of residual stress the magnitude of tensile axial stress decreased (at outer radius) and the magnitude of compressive stress increased (at inner radius).
The effective stress observed increased value due to the presence of residual stress. The effective strain rate and the tangential strain rate also observed a higher value due to the presence of residual stress and the maximum difference in tangential strain rate is observed at the outer radius between the two cylinders.

III. CONCLUSION

In this paper we have discussed about the creep analysis of composite cylinder, in recent years the problem of creep in cylinders made of FGMs operating under high pressure and temperature has attracted the interest of many researchers. Creep behaviour of composites with tailored distribution of reinforcement is of importance in view of their applications at high temperature. It is observed that the rotating circular cylinders under internal pressure made of transversely isotropic material were on the safer side of the design as compared to rotating circular cylinders under internal pressure made of isotropic material.

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