Effect of Heat Flux on Creep Stresses of Thick-Walled Cylindrical Pressure Vessels

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ABSTRACT
Assuming that the thermo-creep response of the material is governed by Norton's law, an analytical solution is presented for the calculation of time-dependent creep stresses and displacements of homogeneous thick-walled cylindrical pressure vessels. For the stress analysis in a homogeneous pressure vessel, having material creep behavior, the solutions of the stresses at a time equal to zero (i.e. the initial stress state) are needed. This corresponds to the solution of materials with linear elastic behavior. Therefore, using equations of equilibrium, stress-strain and strain-displacement, a differential equation for displacement is obtained and then the stresses at a time equal to zero are calculated. Using Norton's law in the multi-axial form in conjunction with the above-mentioned equations in the rate form, the radial displacement rate is obtained and then the radial, circumferential and axial creep stress rates are calculated. When the stress rates are known, the stresses at any time are calculated iteratively. The analytical solution is obtained for the conditions of plane strain and plane stress. The thermal loading is as follows: inner surface is exposed to a uniform heat flux, and the outer surface is exposed to an airstream. The heat conduction equation for the one-dimensional problem in polar coordinates is used to obtain temperature distribution in the cylinder. The pressure, inner radius and outer radius are considered constant. Material properties are considered as constant. Following this, profiles are plotted for the radial displacements, radial stress, circumferential stress and axial stress as a function of radial direction and time.

Keywords: Thick Cylindrical Pressure Vessel, Time-Dependent, Creep, Heat Flux.

1. Introduction

Axisymmetric component such as a cylindrical vessel is more often used as the basic process component in various structural and engineering applications such as pressure vessels (e.g. hydraulic cylinders, gun barrels, pipes, boilers, fuel tanks and gas turbines), accumulator shells, cylinders for aerospace industries, nuclear reactors and military applications, pressure vessel for industrial gases or a media transportation of high-pressurized fluids and piping of nuclear reactors [1, 2]. In most of these applications, the cylinder has to operate under severe mechanical and thermal loads, causing significant creep and thus reducing its service life [1, 2, 3, 4]. Therefore, the analysis of long term steady state creep deformations is very important in these applications. [1, 2].

Weir [5] investigated creep stresses in pressurized thick walled tubes. Bhatnagar and Gupta [6] obtained solution for an orthotropic thick-walled internally pressurized cylinder by using constitutive equations of anisotropy creep and Norton's creep law. Yang [7] obtained an analytical solution to calculate thermal stresses of thick cylindrical shells made od functionally graded materials with elastic and creep behavior. Creep damage simulation of thick-walled tubes using the theta projection concept investigated by Loghman and Wahab [8]. Gupta and Pathak [9] studied thermo creep analysis in a pressurized thick hollow cylinder. Assuming that the creep response of the material is governed by Norton's law, Zamani Nejad et. al. [10] presented a new exact closed form solution for creep stresses in isotropic and homogeneous thick spherical pressure vessels. In this paper all results have been obtained in nondimensional form. Hoseini et. al. [11] presented a new analytical solution for the steady state creep in rotating thick cylindrical shells subjected to internal and external pressure. In this paper the creep response of the material is governed by Norton's law and exact solutions for stresses are obtained under plane strain assumption. Wah [12] developed a theory for the collapse of cylindrical shells under steady-state creep and under external radial pressure and high temperature (300 to 500 F). Pai [13] studied the steady-state creep of a thick-walled orthotropic cylinder subjected to internal pressure. They observed that the creep anisotropy has a significant effect on the cylinder behavior particularly in terms of creep rates which may differ by an order of magnitude compared to an isotropic analysis. Sankaranarayanan [14] studied the steady creep behaviour of thin circular cylindrical shells subjected to combined lateral and axial pressures. The analysis is based on the Tresca criterion and the associated flow rule. Assuming that the total strain is consist of elastic and creep components, Murakami and Iwatsuki [15] investigated the transient creep analysis of circular cylindrical shells on the basis of the strain-hardening and time-hardening theories. Murakami and Suzuki [16] developed a numerical analysis of the steady state creep of a pressurized circular cylindrical shell on the basis of Mises' criterion and the power law of creep. Sim and Penny [17] studied the deformation behaviour of thick-walled tubes subjected to a variety of loadings during stress redistribution caused by creep. Murakami and Iwatsuki [18] investigated the steady state creep of simply supported circular cylindrical shells with open ends under internal pressure by using Nortons's law. Using finite-strain theory Bhatnagar and Arya [19] studied the creep bchaviour of a thick-walled cylinder under large strains. Murakami and Tanaka [20] investigated the creep buckling of clamped circular cylindrical shells subjected to axial compression combined with internal pressure with special emphasis on the concept of creep stability and the accuracy of the analysis. Jahed and Bidabadi [21] presented a general axisymmetric method for an inhomogeneous body for a disk with varying thickness. An approximation has been employed during their solution algorithm. It means that they avoid considering the differentiation constitutive terms of governing equations for creep analysis. Chen et al. [22] studied the creep behavior of a functionally graded cylinder under both internal and external pressures. They observed that an asymptotic solution can be derived on the basis of a Taylor series expansion if the properties of the graded material are axisymmetric and dependent on radial coordinate. In order to investigate creep performance of thick-walled cylindrical vessels or cylinders made of functionally graded materials, You et al. [23] proposed a simple and accurate method to determine stresses and creep strain rates in thick-walled cylindrical vessels subjected to internal pressure. Based on the power law constitutive equation, Altenbach et al. [24] presented the classical solution of the steady-state creep problem for a pressurized thick-walled cylinder. In this paper they applied an extended constitutive equation which includes both the linear and the power law stress dependencies. Singh and Gupta [25-28] developed a mathematical model to describe the steady-creep behaviour of functionally graded composite cylinders containing linearly varying silicon carbide particles in a matrix of pure aluminum involving threshold stress-based creep law. The model developed is used to investigate the effect of gradient in distribution of SiCp on the steady-state creep response of the composite cylinder. Assuming total strains to be the sum of elastic, thermal and creep strains, Loghman et al. [29] studied the time-dependent creep stress redistribution analysis of a thick-walled FGM cylinder placed in uniform magnetic and temperature fields and subjected to an internal pressure. Following Norton's law for material creep behavior and using equations of equilibrium, strain displacement and stress-strain relations in the rate form and considering Prandtl-Reuss relations for creep strain rate-stress equation, they obtained a differential equation for the displacement rate and then calculated the radial and circumferential creep stress rates. Sharma et al. [30] investigated the creep stresses in thick-walled circular cylinders under internal and external pressure, using transition theory, which is based on the concept of 'generalized principal strain measure'. Jamian et al. [31] investigated the creep analysis for a thick-walled cylinder made of functionally graded materials (FGMs) subjected to thermal and internal pressure. Singh and Gupta [32] studied the steady state creep behavior in a functionally graded thick composite cylinder subjected to internal pressure in the presence of residual stress. Hoffman's yield criterion is used, to describe the yielding of the cylinder material in order to account for residual stress. In this article, assuming that the thermo-creep response of the material is governed by Norton's law, an analytical solution is presented for the calculation of time-

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