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Non-Steady Creep Analysis of FGM Rotating Disc Using GDQ Method

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Abstract. Considering primary and secondary regimes of creep, deformation of a rotating disc made of Al-SiC Functionally Graded Material (FGM) is investigated using Generalized Differential Quadrature Method (GDQ). Primary and secondary creep are described by Norton law in which creep parameters depended on volume fraction distribution of SiC reinforcement particles, temperature and particle size. All mechanical and thermal properties are functions of volume fraction percentage of SiC particles. Using equilibrium, constitutive and strain-displacement equations, displacement-based creep equation is obtained. This non-closed form equation is solved using GDQ method and a self-developed solution algorithm. Different graphs of creep strains and stresses are extracted using this presented method of creep analysis. Studies show that functionally distribution of particle content and prevailing temperature does not influence the stress fields considerably but obviously, the creep rates are depended on temperature level and percentage of reinforcing particles.

AMS subject classifications: 74A99

Key words: Primary and secondary creep, time, temperature, rotating disc, FGM, GDQ method.

1 Introduction

Rotating discs are an essential part of many industrial machines such as turbines, Pumps, compressors, aero engines and flywheels. Usually, these components are employed under high thermo-mechanical loadings. These conditions lead to activation of creep mechanisms and escalation of progressive time, temperature and stress dependent deformations. Creep process is accompanied by many different microstructural rearrangements including dislocation movements, aging of microstructures and grain boundary cavitation. These changes lead to progressive deformation, redistribution of stress and relaxation, local reduction of material strength and at last into creep rupture [1]. Experimental

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results show that in general, the augmentation of a second strong and stable phase into the material structure can restrict creep deformation. Metal Matrix Composites (MMCs) and Functionally Graded Materials (FGMs) are modern types of materials that could benefit such creep resistance characteristics. FGMs are engineered combination of two or more solid phases which are designed to fulfill specific thermal or mechanical characteristics. In addition to the creep resistance characteristics of FGMs, these materials show many outstanding merits such as low weight, high thermal and mechanical durability and strength. An important member of these types of structures are the FGM discs. Because of the widespread application of FGM discs in the severe thermo-mechanical conditions and subjectivity of creep phenomenon in these conditions, extensive researches have been done in this area some of them are mentioned in the following. Nearly the first researches in the creep of rotating discs dated back to the works published by whal et al. [2]. Assuming a power law pattern for the distribution of inhomogeneity and using different von-Misses and Teresca yield criterion, they have derived the creeping behavior of a rotating disc. These investigations continued by Ma et al. [3]. Evolutionary researches continued until Bhatnagar and Arya [4] investigated creep response of an orthotropic rotating disc. They observed that tangential stress at any radius and tangential creep rate at the inner radius decreases by increasing disc heterogeneity. Bhatnagar [5] extended this research into the variable thickness discs and creep responses using Norton creep law. Gupta et al. [6] found that a rotating disc with decreasing density and thickness in radial direction shows better creeping strength than a disc with constant density and thickness. Singh and ray [7] studied the steady state creep analysis of an isotropic FGM rotating disc made of Al-SiC composite. They used Norton's law for creep constitutive model. Creep parameters described in terms of temperature, particle size and volume fraction of SiC reinforcement particles were obtained according to the experimental data of pandey et al. [8]. Assuming various distribution patterns of SiC particles and thermal gradient and using finite element analysis ANSYS software, Gupta et al. [9] obtained steady state creep rates, stresses and strains of a rotating disc. Additional researches have been done by Singh and Ray in [10] and [11] to study the effects of particle distribution on the stress, creep strain and deformation fields. Gupta et al. [12] used the Sherby and Norton's creep laws to investigate the steady state creep behavior in FGM rotating discs made of linearly varying of SiC particles in the pure aluminum base and in presence of thermal gradients. They used the experimental data published by Whal et al. [2] to validate their results. Daghigh et al. carried out the initial thermo-elastic and time dependent creep evolution response of rotating ferritic steel disc (1/2Cr, 1/2Mo, 1/4V) using a long term creep constitutive equation [13]. They used a numerical procedure using Taylor series and Prandtl-Reuss relation to achieve the history of stresses and creep rates. Monfared et al. proposed an analytical formulation to study the steady state creep in short fiber composites using a complex variable method [14]. They used a plane stress model and determined the displacement rates with proper boundary conditions in the crept fibers. Kim developed a creep-rupture model of aluminum alloys using a time dependent cohesive zone law. He derived stress-rupture curves at various temperatures