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EFFECT OF PARTICLE CONTENT IN ANALYSIS OF CREEP IN AN ISOTROPIC UNIFORM COMPOSITE CYLINDER

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ABSTRACT

The following paper discusses the effect of particle content in analysis of creep in an isotropic uniform composite cylinder. The paper is a part of the series of papers published under the analysis of creep in an isotropic uniform composite cylinder.

INTRODUCTION

In applications such as pressure vessel for industrial gases or a media transportation of high-pressurized fluids and piping of nuclear reactors, the cylinder has to operate under severe mechanical and thermal loads, causing significant creep hence reduced service life (Gupta and Phatak, 2001; Tachibana and Iyoku, 2004; Hagihara and Miyazaki, 2008). As an example, in the high temperature engineering test reactor, the temperature reaches of the order of 900*oC* (Tachibana and Iyoku, 2004). The piping of reactor cooling system are subjected to high temperature and pressure and may be damaged due to high heat generated from the reactor core (Hagihara and Miyazaki, 2008). A number of studies pertaining to creep behaviour of the cylinder assume the cylinder to be made of monolithic material. However, under severe thermo mechanical loads cylinder made of monolithic materials may not perform well. The weight reduction achieved in engineering components, resulting from the use of aluminum/aluminum base alloys, is expected to save power and fuel due to a reduction in the payload of dynamic systems. However, the enhanced creep of aluminum and its alloys may be a big hindrance in such applications. Aluminum matrix composites offer a unique combination of properties, unlike many monolithic materials like metals and alloys, which can be tailored by modifying the content of reinforcement. Experimental studies on creep under uniaxial loading have demonstrated that steady state creep rate is reduced by several orders of magnitude in aluminum or its alloys reinforced with ceramic particles/whiskers like silicon carbide as compared to pure aluminum or its alloys (Nieh, 1984; Nieh *et al*, 1988). A significant improvement in specific strength and stiffness may also be attained in composites based on aluminum and aluminum alloys containing silicon carbide particles or whiskers. In addition, a suitable choice of variables such as reinforcement geometry, size and content of reinforcement in these composites can be used to make the cost-effective components with improved performance. With these forethoughts, it is decided to investigate the steady state creep in a cylinder made of Al-SiCp composite and subjected to high pressure and high temperature. A mathematical model has been developed to describe the steady state creep behaviour of the composite cylinder. The developed model is used to investigate the effect of material parameters viz particle size and particle content, and operating temperature on the steady state creep response of the composite cylinder.

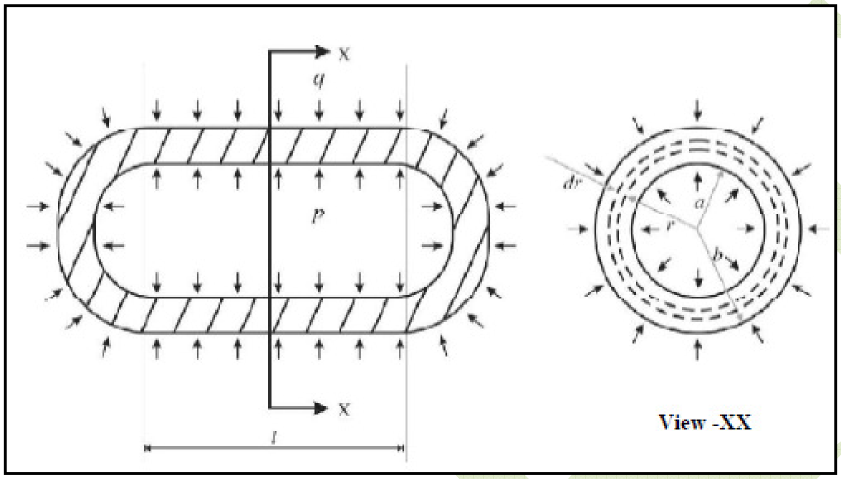

Fig. Schematic of closed end, thick-walled composite cylinder subjected to internal and external pressures.

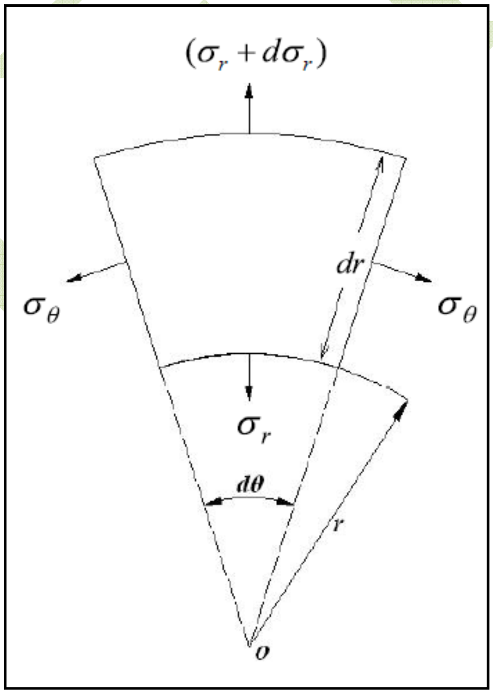

Fig. Free body diagram of an element of the composite cylinder

Effect of Particle Content

Figure given below shows the variation of stresses in composite cylinder containing different amount (*vol %*) of SiCp *i.e.* 10%, 20% and 30%.

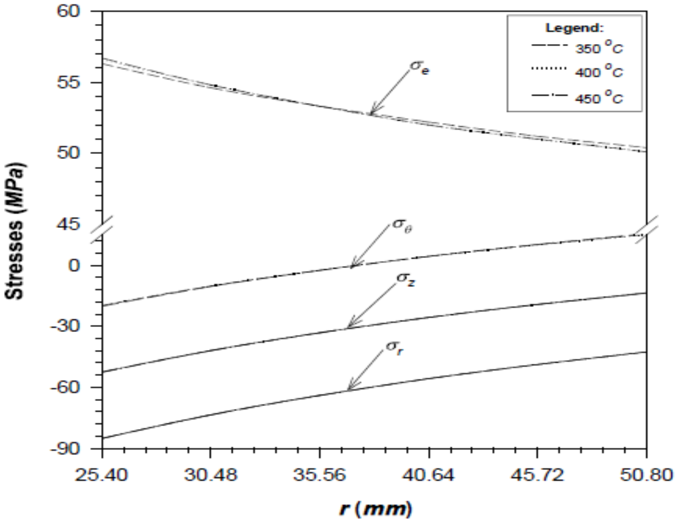

Fig. No 1Variation of creep stresses in composite cylinder for varying temperature (*V* = 20 *vol%*, *P* = 1.7*μm*).

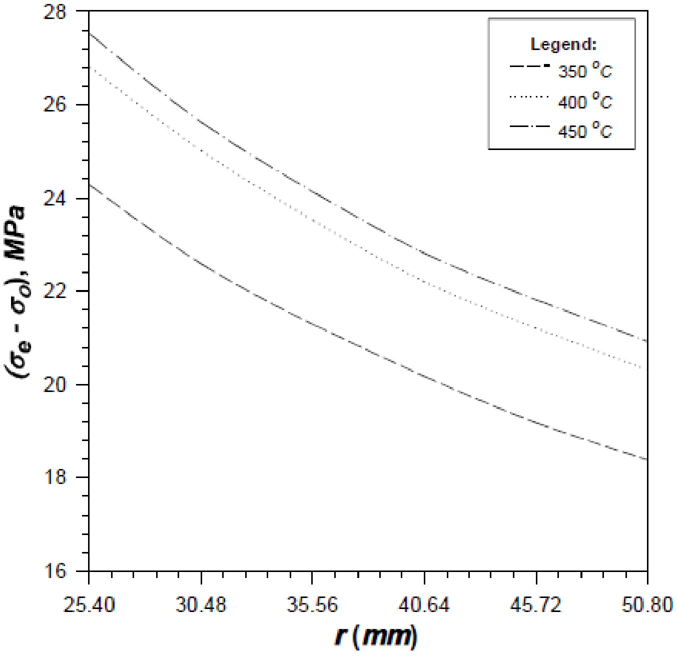

Fig No 2 Variation of stress difference in composite cylinder for varying operating temperature (*V* = 20 *vol%*, *P* = 1.7 *μm*).

The radial stress does not exhibit sizable variation on modifying the content of SiCp, except for a small increase observed somewhere in the middle region of the cylinder with increase in particle content from 10% to 30%. Unlike particle size, the increase in particle content induces some sizable variation in the tangential and axial stresses as observed in Fig. above by increasing the amount of SiCp from 10% to 30%, the tangential stress, compressive near the inner and tensile near the outer radius increases over the entire radius of the cylinder. The maximum increase observed in tangential stress is about 25% at the outer radius. The axial stress (compressive) increase in the content of SiCp from 10% to 30%. At the inner radius, the axial stress increases by about 4% but at the outer radius it decreases by about 12% with the increase in particle content from 10% to 30%. Unlike axial stress, the effective stress decreases near the inner radius but increases near the outer radius with the increase in amount of SiCp from 10% to 30%. The maximum decrease (at the inner radius) and increase (at the outer radius) observed respectively about 5% and 6%**.** The stress difference (σ_e-σ_0) had shown in Fig. 2, decreases significantly over the entire radial distance with increasing SiCp content from 10% to 30%. The decrease observed is relatively more towards the inner radius. As expected, the effective strain rate, Fig. 3, decreases significantly with the increase in amount of SiCp. The effective strain rate decreases by about four orders of magnitude throughout the cylinder on increasing the content of SiCp from 10% to 30%. The decrease observed in effective strain rate may be attributed to decrease in creep parameter *M* and increase in threshold stress (σo) with the increase in content of SiCp, as evident from Table 1. The impact of varying particle content on the tangential and radial creep rates is similar to those noticed for effective strain rate. By increasing the amount of SiCp in the composite cylinder, the inter-particle spacing decreases that causes the increase in threshold stress (Li and Langdon, 1999) but decrease in creep parameter *M* (Table 3.1). Both these factors are responsible for significant reduction in strain rates. Mishra and Pandey (1990) in their review of uniaxial creep data of Nieh (1984), Nieh *et al* (1988) and Morimoto *et al* (1988) have also noticed that creep rate in SiC (whisker) reinforced aluminum alloy (6061Al) composite could be significantly reduced by increasing the content of reinforcement. A similar effect of increasing SiC (particle) content on strain rate has been noticed by Pandey *et al* (1992) for Al-SiCp composite under uniaxial creep.

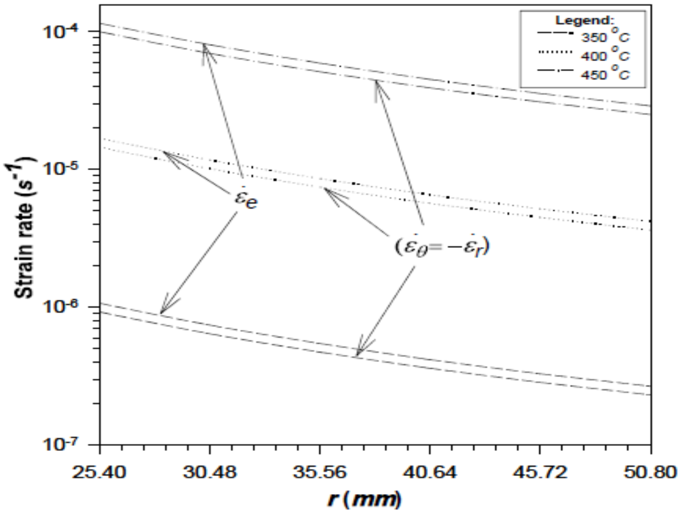

Fig No. 3Variation of strain rates in composite cylinder for varying operating temperature (*V* = 20 *vol%*, *P* = 1.7*μm*).

Table.No.1 Creep parameters for Al-SiCp composites (Pandey et al, 1992)

P (μm)	T (°C)	V (vol %)	M ($s^{-1/5}/MPa$)	σ_o (MPa)	Coefficient of correlation
1.7	350	10	4.35×10^{-3}	19.83	0.945
14.5			8.72×10^{-3}	16.50	0.999
45.9			9.39×10^{-3}	16.29	0.998
1.7	350	10	4.35×10^{-3}	19.83	0.945
		20	2.63×10^{-3}	32.02	0.995
		30	2.27×10^{-3}	42.56	0.945
1.7	350	20	2.63×10^{-3}	32.02	0.995
	400		4.14×10^{-3}	29.79	0.974
	450		5.92×10^{-3}	29.18	0.916

RESULTS AND DISCUSSION

Numerical calculations have been carried out to obtain the steady state creep response of the composite cylinder for different particle size, particle content and operating temperature.

VALIDATION

Before discussing the results obtained, it is necessary to check the accuracy of analysis carried out and the computer program developed. To accomplish this task, the tangential, radial and axial stresses have been computed from the current analysis for a copper cylinder, the results for which are available in literature (Johnson *et al*, 1961). The dimensions of the cylinder, operating pressure and temperature, and the values of creep parameters used for the purpose of validation are summarized in Table 2.

Table no.2 Summary of data used for validation (Johnson et al)

Cylinder Material : Copper

Cylinder dimensions: $a = 25.4\ mm$, $b = 50.8\ mm$.

Internal Pressure = $23.25\ MPa$, External Pressure = 0

Operating Temperature = $250\ ^oC$

Creep parameters estimated: $M = 3.271 \times 10^{-4}\ s^{-1/5}/MPa$, $\sigma_o = 11.32\ MPa$

To estimate the values of parameters *M* and o for copper cylinder, firstly σ_e have been calculated at the inner and outer radii of the cylinder by substituting the values of σ_e σ_r σ_θ σ_z in Eqn. we obtained at these locations, as reported in The study of Johnson *et al* (1961). The values of stresses σ_r σ_θ and σ_z and the tangential strain rate $\acute{\varepsilon}_\theta$ reported by Johnson *et al* (1961) at the inner and outer radii are substituted in Eqn. we obt to estimate the effective strain rates (σ_0) *e* at the corresponding radial locations. The effective stresses and effective strain rates thus estimated at the inner radius $\sigma_e = 189.83$MPa and $\acute{\varepsilon}_e = 2.168\text{x}10^{-8}$ s^{-1} and at the outer radius $\sigma_e = 116$ MPa $\acute{\varepsilon}_e = 1.128\text{x}10^{-9}$ s^{-1} of the copper cylinder are substituted in creep law, Eqn. we obtained, to obtain the creep parameters *M* and o for copper cylinder as given in Table 2. These creep parameters have been used in the developed software to compute the distribution of tangential strain rate in the copper cylinder. The tangential strain rates, thus obtained, have been compared with those reported by Johnson *et al* (1961). A nice agreement is observed in Figures above verifies the accuracy of analysis presented and software developed in the current study.

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