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Effect of Particle Size on Creep Stresses in Thick-Walled Composite Cylinders Considering Plane Stress

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Abstract- In the present work the creep stresses in thick cylinders made of uniform composite were obtained in the presence of internal pressure by considering plane stress. The analysis was carried out by varying the particle size of silicon carbide in aluminum matrix. It was found that the stress in radial direction is negligibly affected with the increase in the size of SiC particles. However, the stress in tangential direction and effective stress increases near the inner radius and decreases near the outer radius with the increase in particle size. The tangential stress showed the increasing trend throughout the radius whereas the von Mises effective stress decreases throughout the entire radial distance.

Index Terms- Creep, Cylinder; Plane Stress.

1. INTRODUCTION

Thick-walled cylinders made of metal and concrete are widely used in components which are subjected to high pressure and temperature such as boilers, aerospace industry, gun barrels, nuclear reactor, hydraulic cylinder etc. (Arya and Bhatnagar, 1976; Becht, *et al*.2000; Singh and Gupta, 2009). Creep is important factor when the cylinder is subjected to high temperature and mechanical loading, the effect of creep is that it will decrease the service life of cylinder (Tachibana and Iyoku, 2004 and Hagihara and Miyazaki, 2008). Pai, 1967 has obtain solution for steady state creep of thick orthotropic cylinder subjected to internal pressure and found that anisotropy has a significant effect on cylinder behavior in terms of creep in comparison to isotropic analysis. Bhatnagar and Gupta, 1969 have done analysis of thick walled orthotropic cylinder and found that the effect of anisotropy is to reduce the stresses and the cylinder made of anisotropic material is safe as per design consideration. Bhatnagar el al. (1984) have done creep analysis of an internally pressurized orthotropic rotating cylinder and found that orthotropy of certain type results in lesser values of stress than for isotropic case thus reducing creep rates.

Under harsh environments when the material is subjected to high temperature and thermal, the conventional materials alone may not survive. Therefore, to utilize the energy resources efficiently we need advanced materials such as composites in comparison with conventional materials when subjected to severe thermo-mechanical loads. Various types of composites included in this category are metal matrix composites (MMCs) such as aluminium/aluminium alloys reinforced with silicon carbide and functionally graded materials (FGMs). Other advanced materials may include Ceramics composites and carbon-carbon composites (Lukkassen and Meidell, 2007). These materials can provide high resistance towards failure. Fukui and Yamanaka, 1992 have studied the elastic problem of thick-walled tubes of a functionally graded material (FGM) under internal pressure in the case of plane strain. Fukui et al, 1993, also analyzed the effects of the composition gradient in the radial direction on thermal stress for thick-walled tubes of functionally graded material (FGM) under uniform thermal loading. You et al. (2007) have investigated steady state creep of thick-walled cylindrical vessels made of functionally graded materials subjected to internal pressure using Norton's Law. This approach is employed to calculate stresses and creep strain rates in the thick-walled cylindrical vessels and also examined how variations of material parameters along the radial direction affect the stresses in the vessels. In the present work a mathematical model has been developed to study the effect of particle size on the steady state creep behavior of composite thick cylinder using Threshold's stress based law.

2. CREEP LAW AND PARAMETERS

The effective strain rate $\dot{\varepsilon}_e$, in aluminium based composites, undergoing steady state creep, is related to the effective stress, σ_e , through well documented threshold stress, σ_o , based creep law given by (Mishra and Pandey, 1990; Pandey et al. 1992).

$$\dot{\varepsilon}_e = [M(\sigma_e - \sigma_o)]^n \tag{1}$$

Where, M and σ_o are known as creep parameters and they are dependent upon material type, temperature (T), reinforcement size (P) and the reinforcement content (V). In present work, the value of stress exponent n is taken as 5 and values of M and σ_o have been drawn from the experimental study of Pandey *et al*, 1992.

Table 1: Creep parameters used (Pandey *et al*, 1992).

P (μm)	T ($°C$)	V (*Vol.* %)	M ($s^{-1/5}/MPa$)	σ_o (MPa)
1.7	350	10	0.00435	19.83
14.5			0.00872	16.50
45.9			0.00939	16.29

3. MATHEMATICAL EQUATIONS

Consider a thick composite cylinder made of Al-SiC$_P$ with internal radius "a" and external radius "b" and subjected to internal pressure "p". The coordinates axes θ, r and z are taken respectively along tangential, radial and axial directions of the cylinder.

The equilibrium Eq.(2) of cylinder is given as (Gupta and Pathak, 2001)

$$r\frac{d\sigma_r}{dr} = \sigma_\theta - \sigma_r \tag{2}$$

Where σ_r , σ_θ represents the stress in radial and tangential directions.

The generalized constitutive Eq.(3–5) for creep in an isotropic composite (Gupta et al. 2005),considering plane stress are given as,

$$\dot{\varepsilon}_r = \frac{d\dot{u}_r}{dr} = \frac{\dot{\varepsilon}_e}{2\sigma_e}\,[2\sigma_r - \sigma_\theta] \tag{3}$$

$$\dot{\varepsilon}_\theta = \frac{\dot{u}_r}{r} = \frac{\dot{\varepsilon}_e}{2\sigma_e}\,[2\sigma_\theta - \sigma_r] \tag{4}$$

$$\dot{\varepsilon}_z = -\frac{\dot{\varepsilon}_e}{2\sigma_e}\,[\sigma_r + \sigma_\theta] \tag{5}$$

Following Von-Mises yield criterion (Dieter, 1988), the effective stress is given by Eq.(6),

$$\sigma_e = \frac{1}{\sqrt{2}}[(\sigma_\theta - \sigma_z)^2 + (\sigma_z - \sigma_r)^2 + (\sigma_r - \sigma_\theta)^2]^{\frac{1}{2}} \tag{6}$$

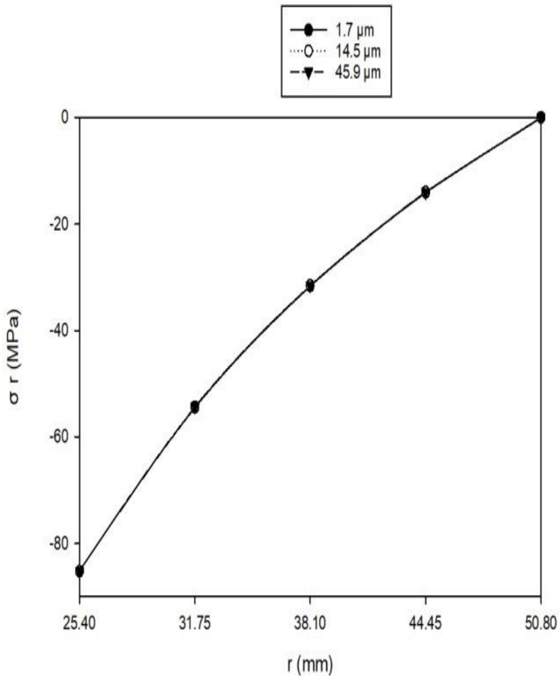
Equilibrium equation along with constitutive Eqs. have been solved to obtain creep stresses namely radial, tangential and effective stresses are obtained.

4. RESULTS AND DISCUSSION

Figure:1(a)-(c) shows the effect of variation of particle size from 1.7μm to 45.9μm on the creep stresses in a thick cylinder made of aluminium SiC particles. The radial stress shown in figure 1(a) remains compressive all over the radius having its maximum value of 85.25MPa at inner radius and zero at outer radius, as per imposed boundary conditions. Table 2 shows the variation of radial stress for different particle size.

Table 2: Variation of Radial Stress for different particle size.

r (mm)	σ_r MPa (1.7 µm)	σ_r MPa (14.5 µm)	σ_r MPa (45.9µm)
25.40	-85.25	-85.25	-85.25
31.75	-54.47	-54.39	-54.38
38.10	-31.63	-31.54	-31.54
44.45	-14.05	-14.00	-14.00
50.80	0.00	0.00	0.00

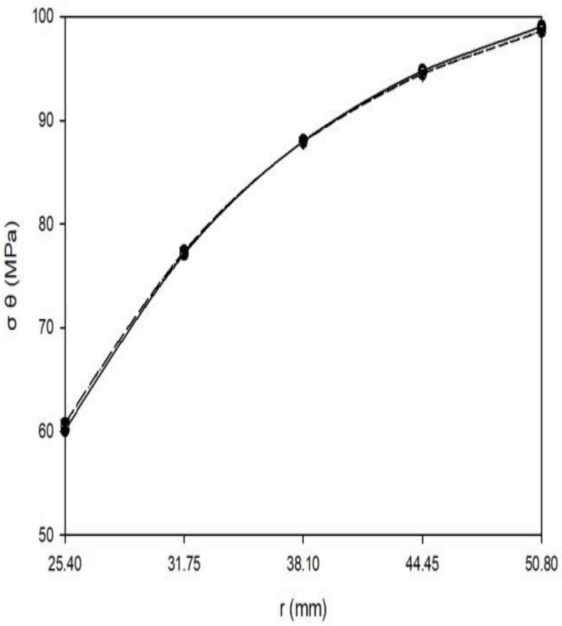


1(a)

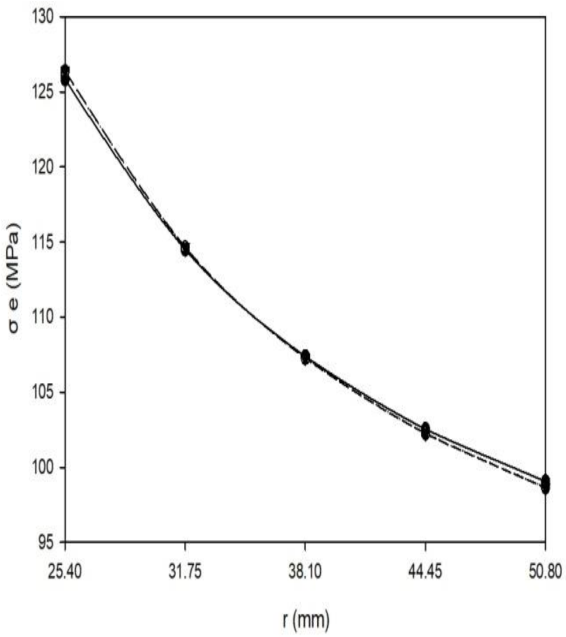
The stress in tangential direction as shown in figure 1(b) remains tensile and goes on increasing towards outer radius. The tangential stress at inner radius with particle size 1.7μm is 60.14MPa and with particle size 45.9μm is 60.78MPa whereas at outer radius the tangential stress with particle size 1.7μm is 99.05MPa and with particle size 45.9μm is 98.62MPa. Table 3 shows the variation of tangential stress for different particle size.

Table 3: Variation of Tangential Stress for different particle size.

r (mm)	σ_θ MPa (1.7 µm)	σ_θMPa (14.5 µm)	σ_θMPa (45.9µm)
25.40	60.14	60.74	60.78
31.75	77.15	77.38	77.40
38.10	88.02	87.97	87.97
44.45	94.79	94.54	94.52
50.80	99.05	98.64	98.62



1(b)



1(c)

Fig.1(a)-(c). Variation of creep stress in cylinder.

It is clear from figure 1(a) and 1(b) that variation of particle size from 1.7µm to 45.9µm has marginal effect on the stress in radial and tangential direction of thick walled cylinder made of aluminium matrix with SiC particles.

However, in case of effective stress as shown in figure 1(c) it has been observed that, the effective stress for coarser particle size is marginally higher in comparison with finer particle size at inner radius and it decreases towards outer radius. At outer radius the effective stress for coarser particle size is marginally less than finer particle size. The effective stress with 1.7μm at inner radius is found as 125.84MPa and at outer radius it is 99.05MPa whereas with 45.9μm the stress at inner radius is 126.40MPa and at outer radius is 98.62MPa. Table 4 shows the variation of effective stress for different particle size.

Table 3: Variation of Tangential Stress for different particle size

r (mm)	σ_e MPa (1.7 µm)	σ_e MPa (14.5 µm)	σ_e MPa (45.9µm)
25.40	125.84	126.36	126.39
31.75	114.50	114.65	114.66
38.10	107.38	107.27	107.26
44.45	102.53	102.25	102.24
50.80	99.05	98.64	98.62

5. Conclusion

From present study it has been concluded that,

1. The stress in the radial direction is negligibly affected with the increase in the size of SiC particles.
2. The tangential stress and effective stresses increases near the inner radius and decreases near the outer radius with the increase in particle size.
3. The stress in the tangential direction increases throughout the radius of the cylinder. However, the von Mises effective stress decreases throughout.

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