Creep response of a variable thickness Al-SiC$_p$ composite disc under different temperatures

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Abstract

The study deals with the analysis of steady state creep in a composite (Al-SiC$_p$) disc having radially decreasing thickness. The yielding of the disc material is described by Tresca's criterion and creep behavior by a threshold stress-based law. The performance of the disc is evaluated under three different temperatures. The increase in operating temperature of the disc is noticed to cause a significant enhancement in the creep strain rates but the effect on creep stresses has been observed to be negligible.

Keywords. Rotating disc, Creep, Composite, variable thickness

I. Introduction

Rotating disc have a number of important applications like disc brakes, jet engines, turbine discs, grinding wheels etc. [1, 2]. In most of these applications, disc has to endure large thermal and mechanical loads for considerable periods of time, which makes it vulnerable to creep [3-5]. In such applications the use of ceramic induced metal matrix composites has been recommended by a number of researchers [3, 6]. In addition, radially decreasing thickness profiles for the disc have been found to minimize creep stresses and strain rates [7-9]. Creep strain rates were studied for Al-SiCp composite samples at different temperatures under uniaxial loading [10]. It was found that the creep rates increase with increase in temperature. The effect of varying operating temperature upon the creep stresses and strain rates on a constant thickness rotating composite disc was studied by [11]. It was observed that the effect of temperature on stresses was almost negligible. But the strain rates were significantly increased with the increase in temperature.

Literature reveals that the studies related to the effect of temperature on the creep performance of a rotating disc have been mostly done on constant thickness discs but that done on variable thickness discs have been scant. Therefore, it was decided to carry out the creep analysis in a rotating Al-SiCp composite disc having radially decreasing thickness governed by a hyperbolic function. The disc has been subjected to three different temperatures throughout for the creep analysis. It has been observed that upon increasing the temperature in the disc, the increase in stresses is only negligible, but the strain rates (both radial and tangential) increase significantly.

II. Disc thickness profile and operating conditions

Thickness (t) of the disc is assumed to vary in a hyperbolic manner (Fig. 1) as,

$$t(r) = t_b \left[r/b \right]^k \tag{1}$$

Where, t_b is the disc thickness at the outer radius, k is disc thickness index of the hyperbolic disc, r is the radius of the disc and b is the outer radius of disc, respectively. The average thickness t_{avg} of the disc is kept equal to 25.4 mm.

The disc is assumed to undergo steady state creep as per threshold stress based law [8] under plane stress conditions. Elastic deformation of the disc is ignored, and material of the disc is assumed to be incompressible and isotropic. Disc is assumed to yield according to Tresca criterion [8].

III. Mathematical formulation

The disc is assumed to be made of Al-SiC composite and is subjected to steady state creep [8]. Using threshold stress based law and creep constitutive equations [8], the expressions derived for radial and tangential creep strain rates are given below,

$$\dot{\varepsilon}_r = \frac{\left[M \left\{ \sigma_{eff} - \sigma_0 \right\} \right]^5}{2\sigma_{eff}} (2\sigma_r - \sigma_t) \tag{2}$$

$$\dot{\varepsilon}_t = \frac{\left[M \left\{ \sigma_{eff} - \sigma_0 \right\} \right]^5}{2\sigma_{eff}} (2\sigma_t - \sigma_r) \tag{3}$$

Where, σ_{eff} : effective stress, σ_t: is tangential stress, σ_r : radial stress, σ_0 : threshold stress, M: material dependent creep parameter.

The values of creep parameters $M(r)$ and $\sigma_0(r)$ can be obtained from the earlier developed regression equations [8], as given below,

$$M = 0.025234 - \frac{14.0267}{T(r)} \tag{4}$$

$$\sigma_0 = 45.7642 - 0.023\, T(r) \tag{5}$$

where T is the operating temperature (in kelvin).

According to Tresca yield criterion as applied to the rotating disc [8],

$$\sigma_{eff} = \sigma_t \tag{6}$$

Force equilibrium equation of a variable thickness rotating disc, having angular velocity ω and variable thickness $t(r)$ [7], can be written as,

$$\frac{d}{dr}[rt(r)\sigma_r] - t(r)\sigma_t + \rho(r)\omega^2 r^2 t(r) = 0 \tag{7}$$

Where ρ is the density of disc material.

In the present study, free-free boundary conditions are assumed for the disc as in case of disc mounted on a splined shaft [12], as given by,

$$\textit{(i)}\ \sigma_r = 0 \ \ at\ r = r_a \ \ \& \ \ \textit{(ii)}\ \sigma_r = 0 \ \ at\ r = r_b \tag{8}$$

The equilibrium equation Eq. (7) is solved using Eqs. (2) & (3) as per the procedure followed in an earlier published work [8].

IV. Results and discussions

Based upon the formulation described in section 3, steady state creep stresses and strain rates in three composite discs having different temperature values throughout (Table-1) are analysed. The dimensions and parameters used in the study are summarized in Table 2. The temperature of the disc D2 is chosen to be the mean of the temperatures of the other two discs.

Table 1. Hyperbolicl thickness (k = -0.286) composite discs with different temperature values

Disc notation	Temperature of the disc (K)
D1	573
D2	623
D3	673

Table 2. Disc dimensions and parameters

Disc dimension and parameters
r_a = 31.75 mmr_b = 152.4 mmt_a = 35 mmt_b = 22.34 mm t_{avg} = 25.4 mm k = -0.286Disc RPM*:* 15000 SiC content = 20%

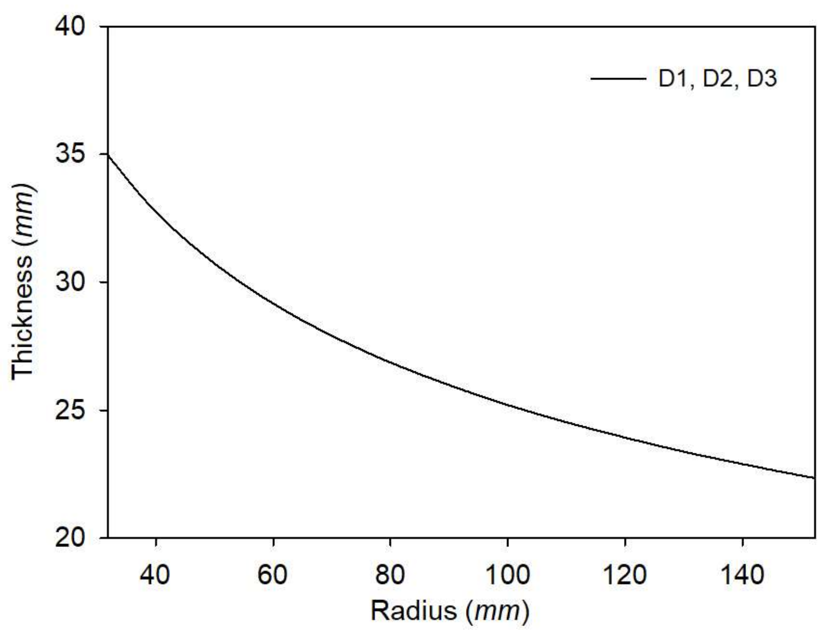

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Figure 1: Thickness variation in the disc

As can be seen from Figs. 2 and 3, the effect of increase in temperature on the stresses induced in the disc is almost negligible. Radial stress in disc D3 has a slightly higher value throughout, w.r.t. disc D1 (Fig 2). The difference in the maximum radial stress in discs D1 and D3 is 0.14 MPa. The maximum radial stress lies somewhere in the middle of the disc (as is evident from the magnified view shown in Fig 2).

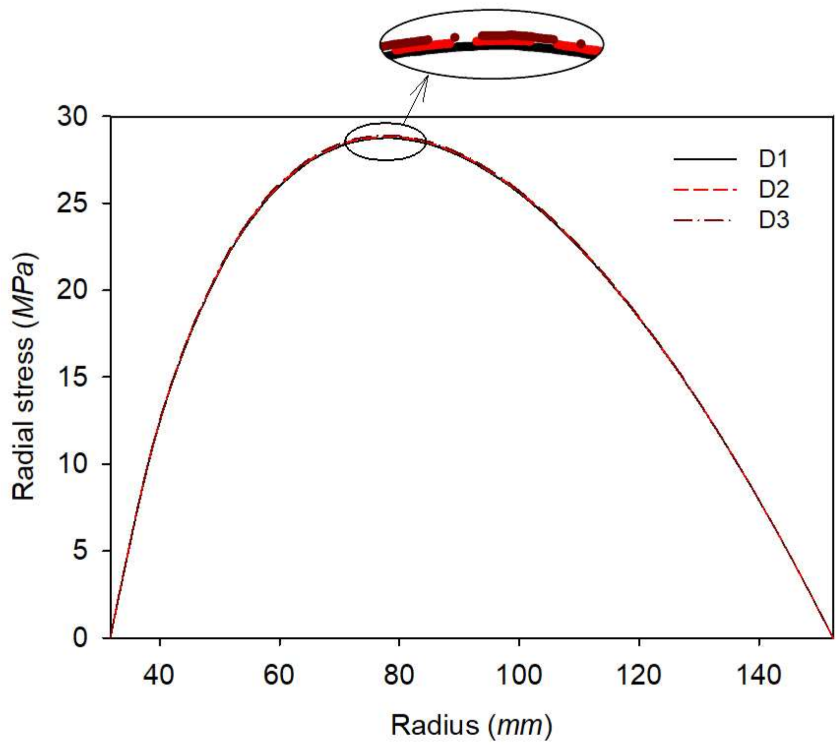

Figure 2: Effect of temperature variation on radial stress

As observed in Fig. 3, as the disc temperature increases (573 K to 673 K) tangential stress increases at the inner radius but decreases at the outer radius. The 'maximum tangential stress' in disc D3 is observed to be 0.46 MPa higher than the maximum value in disc D1.

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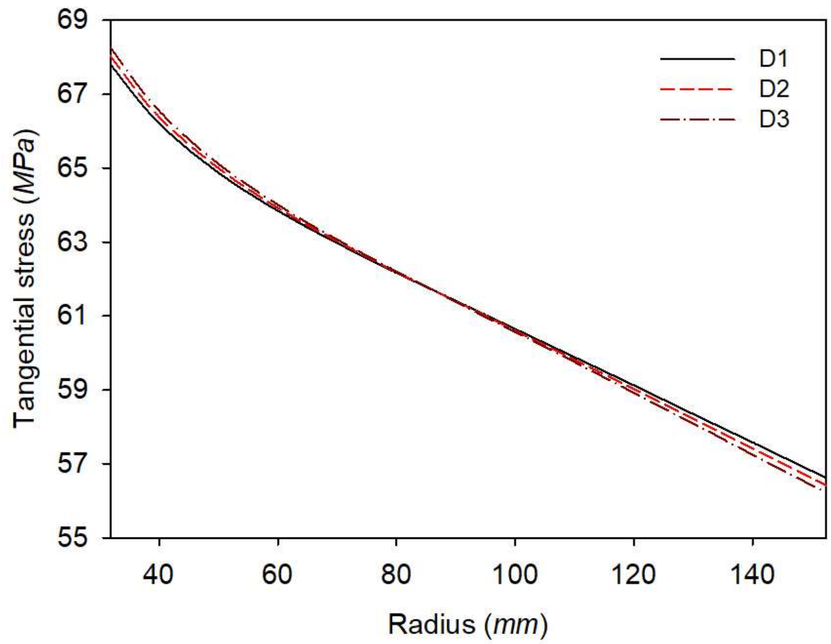

Figure 3: Effect of temperature variation on tangential stress

In all the three discs considered, as the radius is increased, the value of radial strain rate decreases, becomes minimum near the middle of the disc, and then increases again (Fig. 4). On the other hand, the tangential strain rate values go on decreasing in the radial direction (Fig. 5). But the maximum value of both the strain rates is observed to occur at the inner radius. As the disc temperature increases, the value of both the strain rates increases throughout the disc. The maximum value of both the strain rates decreases by about four orders of magnitude with increase in temperature.

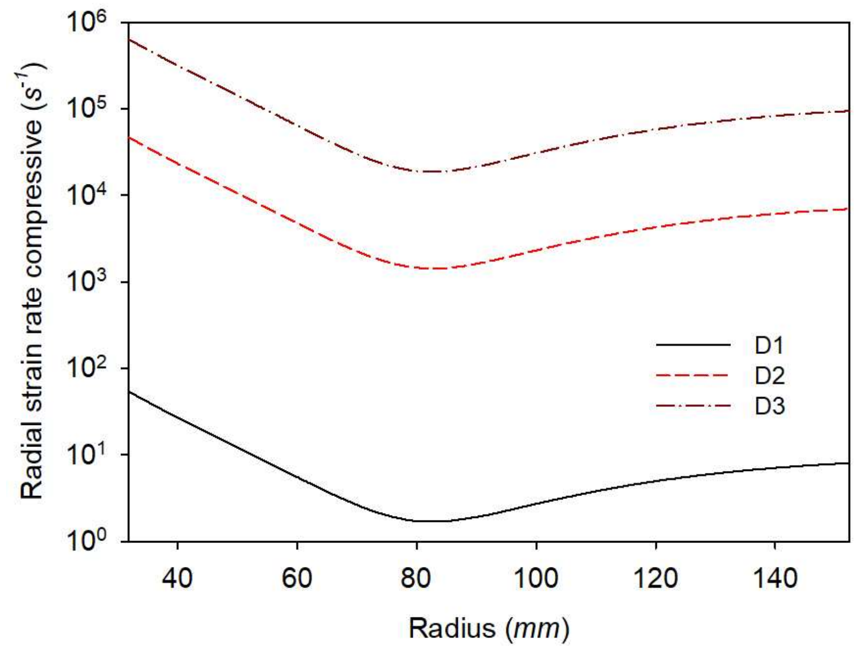

Figure 4: Effect of temperature variation on radial strain rate

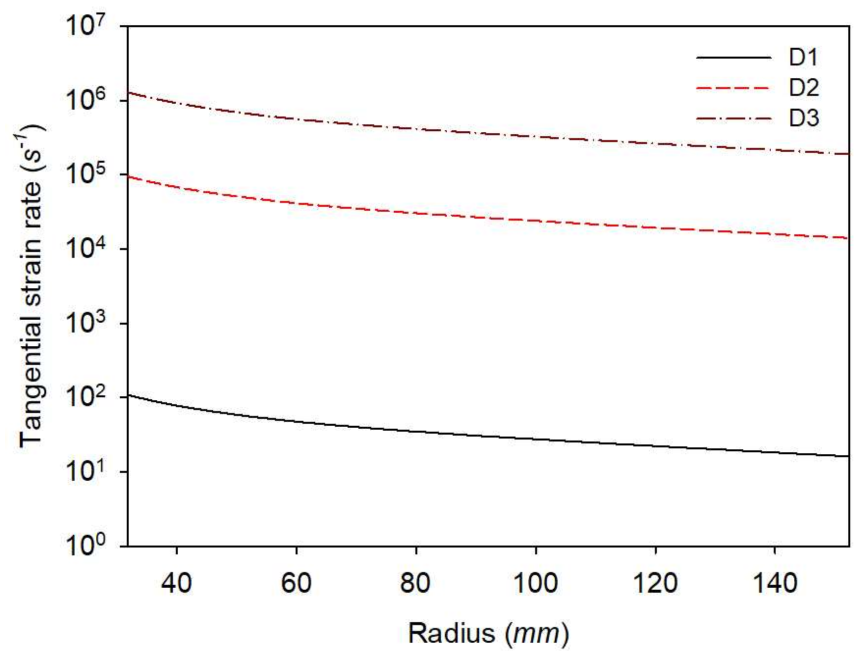

Figure 5: Effect of temperature variation on tangential strain rate

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V. Conclusions

Following conclusions have been drawn from the present study:

- The disc having the lowest temperature exhibits superior creep response.

Upon increasing the disc temperature:

- A negligible increase in stresses occur throughout the disc except in case of tangential stress which decreases at the outer radius by a small amount.
- Both the radial and tangential creep strain rates increase throughout the disc.

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