CREEP ANALYSIS OF TRANSVERSELY ISOTROPIC FGM CYLINDER

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Abstract

It is revealed by several investigators that aluminum alloy matrix composites containing SiC whiskers or fibers have anisotropic properties, which is attributed to the different orientation of whiskers. In other words, creep properties obtained by conducting uniaxial test on specimens taken from the same composite material may differ depending on the orientation of specimens. In short fiber or whisker reinforced composites, material flow during processing such as forging and extrusion often leads to preferential alignment of short fibers or whiskers, resulting in anisotropic mechanical properties. As a result, the composite containing aligned fibers or whiskers exhibit different yield stresses in the direction of alignment and transverse direction.

The experimental studies also reveal that mechanical strength of composite depends on the direction considered, because of the orientation of whiskers that contribute to reinforcing the composite to different degrees depending on their alignment in the direction of application of force (Lederich and Sastry, 1982; Crove et al, 1985; McDanels, 1985). The comparison of analytical results reported for creep in isotropic thick-walled cylinder subjected to internal pressure with the experimental results show discrepancies, which has been attributed to the development of anisotropy during creep (Davis, 1960).

With these forethoughts, it is decided to investigate the consequence of anisotropy on the steady state creep behaviour of a long thick-walled circular cylinder made of FGM. For this purpose, the steady state creep is analyzed in a FGM cylinder composed of transversely isotropic 6061Al-SiCw composite, in which the SiC whiskers are assumed to align in the tangential direction. The content of SiCw in the FGM cylinder is assumed to decrease linearly from the inner to outer radius. The creep stresses and creep rates are estimated in the FGM cylinder for two different operating conditions: (i) cylinder subjected to internal pressure alone and (ii) The maximum SiCw content (Vmax) in the FGM cylinder is assumed as 20 vol% at the inner radius while keeping the average SiCw content (Vavg) as 15 vol%. The results are estimated for varying degree of anisotropy, characterized by the ratio of radial (or axial) and tangential yield strength of the FGM. As a benchmark, the results are also estimated for a similar cylinder but made of isotropic FGM.

Keywords: DISTRIBUTION OF REINFORCEMENT AND ESTIMATION OF CREEP PARAMETERS, Creep parameters of 6061Al- SiCp,w Composites, Comparison of creep parameters of Al-30 vol% SiCp and 6061Al-30 vol% SiCp (P = 1.23 µm; T = 288 oC; V = 30 vol%)

5.1 GENERAL

It is revealed by several investigators that aluminum/aluminum alloy matrix composites containing SiC whiskers or fibers have anisotropic properties, which is attributed to the different orientation of whiskers. In other words, creep properties obtained by conducting uniaxial test on specimens taken from the same composite material may differ depending on the orientation of specimens. In short fiber or whisker reinforced composites, material flow during processing such as forging and extrusion often leads to preferential alignment of short fibers or whiskers, resulting in anisotropic mechanical properties. As a result, the composite containing aligned fibers or whiskers exhibit different yield stresses in the direction of alignment and transverse direction.

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5.2 DISTRIBUTION OF REINFORCEMENT AND ESTIMATION OF CREEP PARAMETERS

The content of SiCw in the FGM cylinder is assumed to decrease linearly from the inner (*a)* to outer radius (*b*), similar to those described in chapter 4 for FG Al-SiCp cylinder. The content of SiCw, $V(r)$, at any radius r of the FGM cylinder may be estimated from Eqn. 4.1. Similarly the average and minimum SiCw contents in the FGM cylinder may be estimated respectively from Eqs. 4.4 and 4.5.

In order to obtain the values of creep parameters M and σ_o for FGM cylinder made of 6061Al-SiCw, the regression equations developed in chapter 4, which are applicable to AlSiCp composites, are modified. In order to account for the effect of changing matrix from Al to 6061Al on the creep parameters, the terms dM_1 and $d\sigma_{o_1}$ are added in Eqs. (4.6) and (4.7) respectively. The terms dM_1 and $d\sigma_{o_1}$ compensate the effect of incorporating SiC particles in 6061Al matrix, rather than pure Al matrix. To determine the values of dM_1 and $d\sigma_{o_1}$, the experimental creep data reported by Nieh *et al* (1988) for 6061Al-SiCp,w composites are represented on $\dot{\varepsilon}^{1/5}$ verses σ plots in Fig. 5.1 . The slope and intercepts of these graphs yield the values of creep parameters M and σ_o for 6061Al-SiCp,w, as reported in (Table 5.1).

Table 5.1: Creep parameters of 6061Al- SiCp,w Composites

Composite	Temperature (°C)	M (*s-1/5/MPa*)	*σo* (*MPa*)	Coefficient of correlation
6061Al-30 *vol%* SiCp	288	1.796E-03	35.94	0.981
6061Al-20 *vol%* SiCw	232	1.457E-03	88.34	0.972
6061Al-20 *vol%* SiCw	288	2.710E-03	61.90	0.905
6061Al-20 *vol%* SiCw	343	3.937E-03	41.73	0.980

The particle size of SiC in 6061Al-30 *vol%* SiCp composite, reported in Table 5.1, has not been mentioned in the study of Nieh *et al* (1988). However, they reported that 6061Al-20 *vol%* SiCw composite (Table 5.1) consists of cylindrical whisker having diameter 0.5 *µm* and an aspect ratio of 10. Therefore, the size of SiCp, which is assumed to be spherical, is estimated as 1.23 *µm*, by equating the volume of cylindrical SiCw (in 6061Al-20 *vol%* SiCw) and spherical SiCp (in 6061Al-30 *vol%* SiCp).

The creep parameters *M* and σ_o for Al-SiCp composite are calculated from Eqs. (4.6) and (4.7), developed in chapter 4, by taking P = 1.23 *µm*, V = 30 *vol%* and T = 288 ^oC. The creep parameters, thus obtained, for Al-30 *vol%* SiCp composite are compared with those reported for 6061Al-30 *vol%* SiCp in Table 5.1. The comparison of these parameters is given in Table 5.2.

Table 5.2: Comparison of creep parameters of Al-30 *vol%* SiCp and 6061Al-30 *vol%* SiCp (P = 1.23 *µm*; T = 288 ^oC; V = 30 *vol%*)

M^{Al} ($s^{-1/5}$/MPa)	M^{6061Al} ($s^{-1/5}$/MPa)	$dM_1 = M^{6061Al} - M^{Al}$	σ_o^{Al} (MPa)	σ_o^{6061Al} (MPa)	$d\sigma_{o_1} = \sigma_o^{6061Al} - \sigma_o^{Al}$
-2.314E-03	1.795E-03	0.004109	44.65	35.94	8.71

The creep parameters *M* and σ_o for 6061Al-SiCp composites can now be obtained as below by adding the values of terms dM_1 and $d\sigma_{o_1}$, reported in Table 5.2, in Eqs. (4.6) and (4.7) respectively.

$$M = 0.02876 - \frac{0.00879}{P} - \frac{14.02666}{T} + \frac{0.03224}{V(r)} + dM_1 \qquad (5.1)$$

$$\sigma_o = -0.084\,P - 0.023\,T + 1.185\,(V(r)) + 22.207 + d\sigma_{o_1} \qquad (5.2)$$

In order to obtain the creep parameters *M* and σ_o for 6061Al-SiCw composites we have further added the terms dM_2 and $d\sigma_{o2}$ respectively to Eqs.(5.1) and (5.2), which are applicable for 6061Al-SiCp composites. The additions of dM_2 and $d\sigma_{o2}$ compensate the effect of incorporating SiCw, rather than SiCp, in a matrix of 6061Al. This procedure of finding the creep parameters of 6061AlSiCw composite has been followed due to limited experimental creep data available for whisker reinforced composites. The creep parameters *M* and σ_o have been calculated for 6061Al-20 *vol%* SiCp from Eqs. (5.1) and (5.2) by taking P = 1.23 *µm*, V = 20 *vol%* and T = 288 ^oC. The creep parameter, thus obtained, for 6061Al-20 *vol%* SiCp composite are compared with those estimated for 6061Al20 *vol%* SiCw in Table 5.3.

Table 5.3: Comparison of creep parameters of 6061Al-20 *vol%* SiCp and 6061Al-20 *vol%* SiCw (P = 1.23 *µm*; T = 288 ^oC; V = 20 *vol%*)

M^p ($s^{-1/5}$/MPa)	M^w ($s^{-1/5}$/MPa)	$dM_2 = M^w - M^p$	σ_o^p (MPa)	σ_o^w (MPa)	$d\sigma_{o_2} = \sigma_o^w - \sigma_o^p$
2.332E-03	2.710E-03	3.78E-04	41.5	61.90	20.40

Finally, the creep parameters *M* and σ_o for 6061Al-SiCw composites can be obtained from the following equations, obtained by adding the values of terms dM_2 and $d\sigma_o2$, reprted in Table 5.3, in Eqs. (5.1) and (5.2).

$$M = 0.02876 - \frac{0.00879}{P} - \frac{14.02666}{T} + \frac{0.03224}{V(r)} + dM_1 + dM_2 \qquad (5.3)$$

$$\sigma_o = -0.084P - 0.0232T + 1.1853(V(r)) + 22.207 + d\sigma_{o_1} + d\sigma_{o_2} \qquad (5.4)$$

In a FGM cylinder, with known SiCw gradient, both the creep parameters *M* and σ_o will be functions of radial distance (*r*) alone. The values of *M* and σ_o for 6061Al-SiCw, at a given radial distance (*r*), could be estimated from Eqs. (5.3) and (5.4) by substituting the content, *V(r)*, of SiCw at that location.

CONCLUSION

With radial distance in FGM cylinders. The values of creep parameters in both isotropic and transversely isotropic (referred as anisotropic in this study) cylinders are equal. The value of parameter M increases with increasing radial distance as shown in The increase observed in M may be attributed to decrease particle content V(r), on On the other hand, the threshold stress (o) shown FGM cylinder. The threshold stress is higher in locations having more amount of SiCw reinforcement compared to locations having lower SiCw content.

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