ISSN: 2394-3696
VOLUME 2, ISSUE 7, JULY-2015

ESTIMATION OF CREEP PARAMETERS IN AN ISOTROPIC UNIFORM COMPOSITE CYLINDER

Prof. Vyankatesh S. Kulkarni
Department of Mechanical Engineering,
Solapur University /BIT/Barshi/India

ABSTRACT

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.

SELECTION OF CREEP LAW

In aluminum based composites, undergoing steady state creep, the effective creep rate (e) is related to the effective stress ( ) through the well documented threshold stress (o) based creep law given by (Mishra and Pandey, 1990; Park *et al*, 1990; Mohamed *et al*, 1992; Pandey and Mishra, 1992; Gonzalez and Sherby, 1993; Pandey *et al*, 1994; Park and Mohamed, 1995; Cadek *et al*, 1995; Li and Mohamed, 1997; Li and Langdon, 1997, 1999; Yoshioka *et al*, 1998; Tjong and Ma, 2000; Ma and Tjong, 2001),

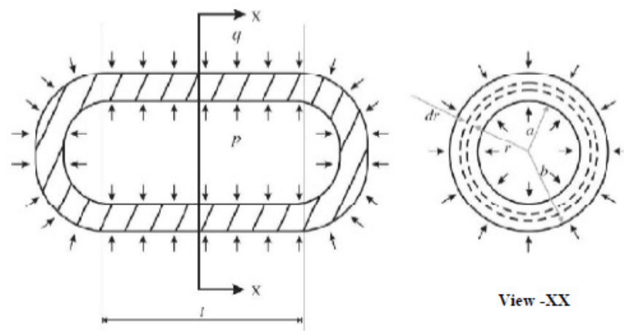
$$\dot{\varepsilon}_e = A'\left(\frac{\sigma_e - \sigma_o}{E}\right)^n \exp\left(\frac{-Q}{RT}\right)$$

where the symbols *A* , *n*, *Q*, *E*, *R* and *T* denote respectively the structure dependent parameter, true stress exponent, true activation energy, temperature-dependent young's modulus, gas constants and operating temperatures.

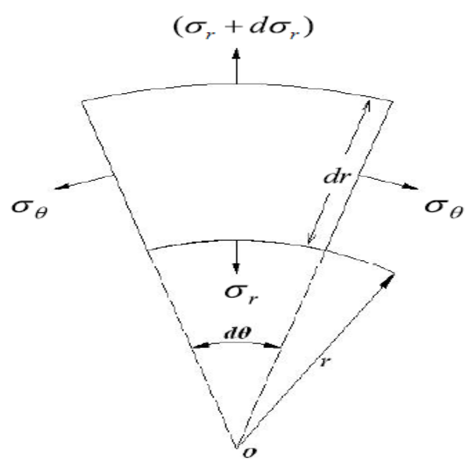
The values of true stress exponent (*n*) appearing in eqn above is usually selected as 3, 5 and 8, which correspond to three well-documented creep cases for metals and alloys:
(i) $n = 3$ for creep controlled by viscous glide processes of Dislocation,
(ii) $n = 5$ for creep controlled by high temperature dislocation climb (lattice diffusion), and
(iii) $n = 8$ for lattice diffusion-controlled creep with a constant structure (Tjong and Ma, 2000). Though, some of the research groups (Mishra and Pandey, 1990; Pandey and Mishra, 1992; Gonzalez and Sherby, 1993; Pandey *et al*, 1994) have used a true stress exponent of 8 to describe the steady state creep in Al-SiCp,w(subscript's' for particle and ;w; for whisker) composites but a number of other research groups (Park *et al*, 1990; Mohamed *et al*, 1992; Park and Mohamed, 1995; Cadek *et al*, 1995; Yoshioka *et al*, 1998; Li and Mohamed, 1997; Li and Langdon, 1997, 1999) have observed that a stress exponent of either ~3 or ~5, rather than 8, is a better choice to describe steady state creep data of discontinuously reinforced Al-SiC composites. Keeping this in view, a stress exponent of 5 is used to describe the steady state creep behaviour of Al-SiCp composite cylinder in this study.

NUMERICAL CALCULATIONS

Based on the analysis presented in previous section, a computer program has been developed to calculate the steady state creep response of the composite cylinder for various combinations of size and content of the reinforcement (SiCp), and operating temperature. For the purpose of numerical computation, the inner and outer radii of the cylinder are taken 25.4 *mm* and 50.8 *mm* respectively, and the internal and external pressures are assumed as 85.25 *MPa* and 42.6 *MPa* respectively. The dimensions of cylinder and the operating pressure chosen in this study are similar to those used in earlier work (Johnson *et al*, 1961) on thick walled cylinder made of aluminum alloy (RR59). The radial, tangential and axial stresses at different radial locations of the cylinder are calculated respectively from equations obtained above. The distributions of radial and tangential strain rates in the cylinder are computed from eqn above respectively. The creep parameters *M* and $_o$ required during the computation process are taken from Table 1 for the desired combination of particle size, particle content and operating temperature.



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



Free body diagram of an element of the composite cylinder.

CREEP ANALYSIS OF COMPOSITE CYLINDER

Considering a long thick-walled cylinder made of Al-SiCp with closed end and having inner and outer radii *a* and *b* respectively. The cylinder is subjected to internal pressure *p* and external pressure *q*, Fig. above The axes r, θ and *z* are taken respectively taken along radial, tangential and axial direction of the cylinder. For the purpose of analysis following assumptions are made in the present work:

I. Material of the cylinder is incompressible, isotropic and has uniform distribution of SiCp in aluminum matrix.
II. Pressure is applied gradually on the cylinder and held constant during the loading history.
III. Stresses at any point in the cylinder remain constant with time *i.e.* steady state condition of stress is assumed.
IV. Elastic deformations are small and are neglected as compared to creep deformations.

The geometric relationships between radial $\acute{\varepsilon}_r$ and tangential $\acute{\varepsilon}_\theta$ strain rates are,

$$\dot{\varepsilon}_r = \frac{d\dot{u}_r}{dr}$$

$$\dot{\varepsilon}_\theta = \frac{\dot{u}_r}{r}$$

Where $Ur = \frac{du}{dt}$ the radial displacement rate and u is the radial displacement.

Eliminating r u from Eqs above we get the deformation compatibility equation given by,

$$r\frac{d\dot{\varepsilon}_\theta}{dr} = \dot{\varepsilon}_r - \dot{\varepsilon}_\theta$$

The boundary conditions for a cylinder subjected to both internal and external pressures are,

(i) At $r = a,\ \sigma_r = -p$

(ii) At $r = b,\ \sigma_r = -q$

The negative sign of r in above equations implies the compressive nature of radial stress. The equilibrium equation for a thick-walled cylindrical vessel subjected to uniform internal and external pressures may be obtained by considering the equilibrium of forces acting on an element of the composite cylinder, confined between radius r and $r + dr$ as shown in figure above The axial length of the cylinder is assumed to be l.

By considering equilibrium of forces along the radial direction, we get,

$$(\sigma_r + d\sigma_r)(r + dr)d\theta\, l - \sigma_r r d\theta\, l - 2\sigma_\theta dr l \sin\frac{d\theta}{2} = 0$$

In deriving the above equilibrium equation the weight of the cylinder is ignored in comparison to external loads acting on the cylinder. The Eqn obtained may be simplified by neglecting the higher order terms and noting that dθ is very small *i.e.* dθ/2 = dθ/2 Therefore, the equilibrium equation becomes,

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

Under the assumption of incompressibility, one may write,

$$\dot{\varepsilon}_r + \dot{\varepsilon}_\theta + \dot{\varepsilon}_z = 0$$

Where έz is the axial strain rate.

The present analysis assumes that material of the cylinder is isotropic and yields according to von-Mises yield criterion (von Mises, 1913). The effective stress for isotropic material may be expressed as,

$$f(\sigma_{ij}) = \frac{1}{4}[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2]$$

where $f(\sigma_{ij})$ is the potential function and σ_{11}, σ_{22} and σ_{33} are the principal stresses.

The strain rate increment (έij *d)* is related to the potential function through the associated flow rule as given below,

$$d\varepsilon_{ij} = d\lambda \frac{\partial f(\sigma_{ij})}{\partial \sigma_{ij}}$$

Where *d* is the proportionality factor that must depend on *σij dσ ij* and *έij* apart from strain history because of strain hardening (Back fen, 1972). Using the yield criterion given by Eqn below one may obtain the following constitutive equations in terms of principal strain increments

$d\acute{\varepsilon}_{11}$ $d\acute{\varepsilon}_{22}$ $d\acute{\varepsilon}_{33}$ and principal stresses $\sigma_{11}\sigma_{22}$ σ_{33}

$$\begin{Bmatrix} d\varepsilon_{11} = \left[\sigma_{11} - \frac{(\sigma_{22} + \sigma_{33})}{2}\right] d\lambda \\ d\varepsilon_{22} = \left[\sigma_{22} - \frac{(\sigma_{11} + \sigma_{33})}{2}\right] d\lambda \\ d\varepsilon_{33} = \left[\sigma_{33} - \frac{\sigma_{11} + \sigma_{22}}{2}\right] d\lambda \end{Bmatrix}$$

The von-Mises effective stress σ_e and effective strain rate increment dέe are given by,

$$\sigma_e = \frac{1}{\sqrt{2}}[(\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + (\sigma_{11} - \sigma_{22})^2]^{1/2}$$

$$d\varepsilon_e = \frac{\sqrt{3}}{2}[(d\varepsilon_{11} - d\varepsilon_{22})^2 + (d\varepsilon_{22} - d\varepsilon_{33})^2 + (d\varepsilon_{33} - d\varepsilon_{11})^2]^{1/2}$$

The effective strain increment $d\acute{\varepsilon}_e$ may be obtained by substituting the values of $d\acute{\varepsilon}_{11}$ $d\acute{\varepsilon}_{22}$ $d\acute{\varepsilon}_{33}$ and correlating the resulting equation with the effective stress given by Eqn to obtain,

$$d\varepsilon_e = \sigma_e d\lambda$$

Using equations obtained above we get,

$$\begin{Bmatrix} d\varepsilon_{11} = \dfrac{d\varepsilon_e}{\sigma_e}\left[\sigma_{11} - \dfrac{(\sigma_{22}+\sigma_{33})}{2}\right] \\ d\varepsilon_{22} = \dfrac{d\varepsilon_e}{\sigma_e}\left[\sigma_{22} - \dfrac{(\sigma_{11}+\sigma_{33})}{2}\right] \\ d\varepsilon_{33} = \dfrac{d\varepsilon_e}{\sigma_e}\left[\sigma_{33} - \dfrac{\sigma_{11}+\sigma_{22}}{2}\right] \end{Bmatrix}$$

Integrating the above set of equations we obtain,

$$\begin{Bmatrix} \dot{\varepsilon}_{11} = \dfrac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_{11} - \sigma_{22} - \sigma_{33}] \\ \dot{\varepsilon}_{22} = \dfrac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_{22} - \sigma_{11} - \sigma_{33}] \\ \dot{\varepsilon}_{33} = \dfrac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_{33} - \sigma_{11} - \sigma_{22}] \end{Bmatrix}$$

The set of equations obtained are termed as constitutive equations for creep in an isotropic material in principal stress space. The generalized constitutive equations for creep in an isotropic composite takes the following form when reference frame is along the principal directions of r, θ and z.

$$\dot{\varepsilon}_r = \frac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_r - \sigma_\theta - \sigma_z]$$

$$\dot{\varepsilon}_\theta = \frac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_\theta - \sigma_z - \sigma_r]$$

$$\dot{\varepsilon}_z = \frac{\dot{\varepsilon}_e}{2\sigma_e}[2\sigma_z - \sigma_r - \sigma_\theta]$$

Where $\acute{\varepsilon}_r$ $\acute{\varepsilon}_\theta$ $\acute{\varepsilon}_z$ and σ_r σ_θ σ_z are the strain rates and the stresses respectively along *r*, θ and *z* directions, as indicated by the subscripts.

The von Mises yield criterion given by Eqn. above, when reference frame is along principal directions of *r*, and *z*, becomes,

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

For a cylinder made of incompressible material and having closed ends, the plain strain condition exists *i.e.* $\acute{\varepsilon}_z = 0$ (Bhatnagar and Arya, 1974; Popov, 2001). Therefore, under plain strain condition, the radial displacement rate may be obtained as,

$$\dot{u}_r = \frac{C}{r}$$

Where *C* is a constant of integration now we get,

$$\dot{\varepsilon}_r = -\frac{C}{r^2}$$

$$\dot{\varepsilon}_\theta = \frac{C}{r^2}$$

Under plain strain condition, $\acute{\varepsilon}_z=0$ Eqn gives,

$$\sigma_z = \frac{\sigma_r + \sigma_\theta}{2}$$

Therefore, the axial stress at any point in the cylinder is arithmetic mean of the radial and tangential stresses at the corresponding location the effective stress in the cylinder is given by,

$$\sigma_e = \frac{\sqrt{3}}{2}(\sigma_\theta - \sigma_r)$$

Using Eqs above we get,

$$\sigma_\theta - \sigma_r = \frac{4}{3}\left(\frac{\sigma_e C}{\dot{\varepsilon}_e r^2}\right)$$

Substituting $\acute{\varepsilon}e$ and σ_e respectively from above equations into above equation and simplifying, we get,

$$\sigma_\theta - \sigma_r = \frac{I_1}{r^{2/n}} + I_2$$

Where,

$$I_1 = \left[\frac{4}{3}\right]^{\frac{n+1}{2n}} \cdot \left(\frac{C^{1/n}}{M}\right) \quad \text{and} \quad I_2 = \frac{2}{\sqrt{3}}\sigma_o .$$

After integrating the resulting equation, we get,

$$\sigma_r = -\frac{n}{2} \cdot \frac{I_1}{r^{2/n}} + I_2 \ln r + C_1$$

Where *C1* is another constant of integration. Using the boundary conditions the values of *C1* and *I1* are obtained as,

$$C_1 = \frac{n}{2} I_1 b^{-2/n} - I_2 \ln b - q$$

$$I_1 = \frac{2}{n} X$$

Where

$$X = \frac{\left[p - q - I_2 \ln(b/a)\right]}{(a^{-2/n} - b^{-2/n})}$$

The values of *C1* and *I1* obtained above are substituted to get the radial stress,

$$\sigma_r = -\left[X\left(r^{-2/n} - b^{-2/n}\right) + I_2 \ln(b/r) + q\right]$$

The tangential stress is obtained as

$$\sigma_\theta = X\left[b^{-2/n} - \left(1 - \frac{2}{n}\right) \cdot r^{-2/n}\right] + I_2\left[1 - \ln(b/r)\right] - q$$

And the axial stress is obtained as,

$$\sigma_z = X\left[b^{-2/n} - \left(1 - \frac{1}{n}\right) r^{-2/n}\right] - I_2\left[\ln(b/r) - 0.5\right] - q$$

The radial and tangential strain rates in the composite cylinder are obtained in terms of effective strain rate,

$$\dot{\varepsilon}_\theta = -\dot{\varepsilon}_r = 0.87\,\dot{\varepsilon}_e$$

Therefore, the radial and tangential strain rates in the composite cylinder are 87% of the effective strain rate at the corresponding radial location.

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 ^{o}C
Creep parameters estimated: $M = 3.271\times10^{-4}\ s^{-1/5}/MPa$, σ_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 equations above 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 obtained equation to estimate the effective strain rates ( ) *e* at the corresponding radial locations. The effective stresses and effective strain rates thus estimated at the inner radius σ_e = 189.83MPa and $\acute{\varepsilon}_e$ = 2.168x10^{-8} s^{-1} and at the outer radius σ_e = 116 MPa $\acute{\varepsilon}_e$ = 1.128x10^{-9} s^{-1} of the copper cylinder are substituted in creep law, 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 Fig. 3 verifies the accuracy of analysis presented and software developed in the current study.

The creep law given may alternatively be expressed as,

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

$$\text{where } M = \frac{1}{E}\left(A' \exp\frac{-Q}{RT}\right)^{1/n} \text{ and the stress exponent } n = 5.$$

ISSN: 2394-3696
VOLUME 2, ISSUE 7, JULY-2015

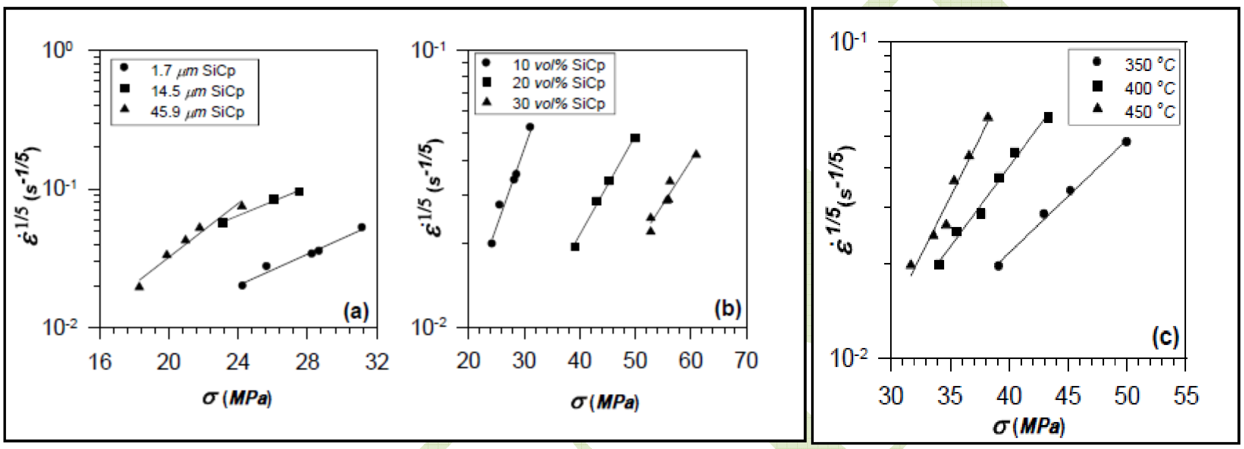
The creep parameters *M* and o given in above are dependent on the type of material and are also affected by the temperature (*T*) of application. In a composite, the dispersed size (*P*) and the content of dispersed (*V*) are the Primary material variables affecting these parameters. In the present study, the values of *M* and o have been extracted from the uniaxial creep results reported for Al-SiCp by Pandey *et al* (1992). Though, Pandey *et al* (1992) used a stress exponent of 8 to describe steady state creep in these composites. But due to the objections raised by several researchers (Park *et al*, 1990; Mohamed *et al*, 1992; Park and Mohamed, 1995; Cadek *et al*, 1995; Li and Mohamed 1997; Yoshioka *et al*, 1998; Li and Langdon, 1997, 1999), we have chosen a stress exponent of 5 to describe steady state creep in Al-SiCp composite.

In order to extract the values of creep parameters for Al-SiCp, the individual set of creep data reported by Pandey *et al* (1992) have been plotted as $\in^{-1/5}$versus σ on linear scales as shown in Figs. 3.1(a)-(c). From the slope and Intercepts of these graphs, the values of creep parameters *M* and o have been obtained and are reported in Table 3.1. This approach of determining the threshold. Stress (o) is known as linear extrapolation technique (Lagneborg and Bergman, 65 1976). To avoid variation due to systematic error, if any, in the experimental results, the creep results from a single source have been used. The $\in^{-1/5}$versus σ plots corresponding to the observed experimental data points of Al-SiCp composites (Pandey *et al*, 1992), for various combinations of particle size, particle content and operating temperature, exhibit an excellent Linearity as evident from Figs.3 The coefficient of correlation for these plots has been reported in excess to 0.916 as given in Table 1. In the light of these results, the choice of stress exponent *n* = 5, to describe the steady state creep behaviour of Al-SiCp composite, is justified.

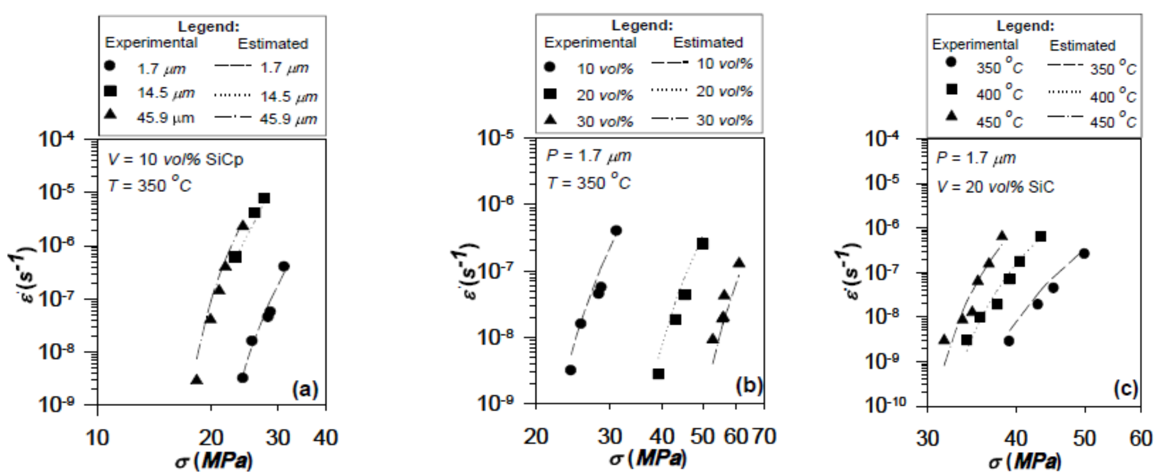
Table.No.1 Creep parameters for Al-SiCp composites (Pandey et al, 1992)

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

The accuracy of creep response of the composite cylinder, to be estimated in subsequent sections, will depend on the accuracy associated with the prediction of creep parameters *M* and o for various combinations of material parameters and operating temperature. To accomplish this task, the creep parameters given in Table 1 have been substituted in the constitutive creep model, to estimate the strain rates corresponding to the experimental stress values reported by Pandey *et al* (1992) for Al-SiCp composite corresponding to various combinations of material parameters and temperature as given in Table 1. The estimated strain rates have been compared with the strain rates observed experimentally by Pandey *et al* (1992). Figs. 3 show an excellent agreement between the strain rates estimated and those observed experimentally, to inspire confidence in the creep parameters estimated in this study.



Variation of $\dot{\varepsilon}^{1/5}$ versus σ in Al-SiCp composite for different (a) particle sizes of SiCp, (b) *vol%* of SiCp and (c) temperatures (Pandey *et al*, 1992).



Comparison of experimental (Pandey *et al*, 1992) and estimated strain rates in Al-SiCp composite for different (a) particle sizes of SiCp, (b) *vol%* of SiCp and (c) temperatures

REFERENCES

1. Abrinia, K., Naee, H., Sadeghi, F., and Djavanroodi, F. (2008) *new analysis for the FGM thick cylinders under combined pressure and temperature loading, American J. of Applied Sci., 5 (7): 852–859.*

2. Aggarwal, B.D., and Broatman, L.J. (1980*) Analysis and performance of fiber composites, John Wiley, USA.*

3. Akira, M., and Watabane, R. (1997) *Concept and P/M fabrication of functionally gradient materials, Ceramics Int., 23: 73–83.*

4. Alman, D.E. (2001) *Properties of metal matrix composites, in: ASM Handbook, 21: Composites, ASM International, Metals Park, Ohio, 838–858.*

5. Altenbach, H., Gorash, Y., and Naumenko, K. (2008) *Steady-state creep of a pressurized thick cylinder in both the linear and the power law ranges,Acta Mech., 195: 263–274.*

6. Anne, G., Hecht-Mijic, S., Richter, H., Van der Biest, O., and Vleugels, J. (2006) *Strength and residual stresses of functionally graded Al2O3/ZrO2 discs prepared by Electrophoretic deposition, Scripta Materialia, 54: 2053–2056*

7. Arai, Y., Kobayashi, H., and Tamura, M. (1990) *Analysis on residual stress and deformation of functionally gradient materials and its optimum design, Proc. 1st Int. Symposium on FGM, Sendai.*

8. Arai, Y., Kobayashi, H., and Tamura, M. (1993*) Elastic-plastic thermal stress analysis for optimum material design of functionally graded material, Trans. Jpn. Soc.Mech. Engg. (in Japanese), A59: 849.*

9. Boyle, J.T., and Spence, J. (1983) *Stress analysis for creep, London: Butterworth.*

10. Buttlar, W.G., Wagoner, M., You Z., and Brovold, S.T. (2004*) Simplifying the hollow cylinders tensile test procedure through volume-based strain, J. of Association of Asphalt Paving Technologies (AAPT), 73: 367–400.*

11. Cadek, J., and Sustek, V. (1994) *Comment on "Steady state creep behavior of silicon carbide reinforced aluminium composite" discussion, Scr. Metall. Mater., 30(3): 277–282.*

12. Cadek, J., Oikawa, H., and Sustek, V. (1994b) *High temperature creep behaviour of silicon carbide particulate-reinforced aluminium, High Temp. Mater. Processes, 13: 327–338.*

13. Cadek, J., Oikawa, H., and Sustek, V. (1995) *Thershold creep behavior of discontinuous aluminium and aluminium alloy matrix composites: An overview, Mater. Sci.Engng. A190:9–21.*

14. Cadek, J., Sustek, V., and Pahutova, M. (1994a) *Is creep in discontinuous metal matrix composites lattice diffusion controlled?, Mater. Sci. Engg., A174: 141–147.*

15. Cederbaum, G., and Heller, R.A. (1989) *Dynamic deformation of orthotropic cylinders, J. Pressure Vessel Technol., 111(2): 97–101.*

16. Chan, S.H. (2001) *Performance and emissions characteristics of a partially insulated gasoline engine, Int. J. of Thermal Sci., 40: 255–261.*

17. Ishikawa, H., and Hata, K. (1980) *Thermoelastoplastic creep stress analysis for a thick- walled tube, Int. J. Solids and Structures, 16: 291–299.*

18. Ivosevic, M., Knight, R., Kalidindi, S. R., Palmese, G. R., and Sutter, J. K. (2006) *Solid particle erosion resistance of thermally sprayed functionally graded coatings for polymer matrix composites, Surf. Coat. Technol., 200: 5145–515*

19. Jabbari, M., Sohrabpour, S., and Eslami, M.R. (2002) *Mechanical and thermal stresses in a functionally graded due to radially symmetric load, Int. J. of Pressure Vessels and Piping, 79: 493–497.*

20. Johnson, A.E., Henderson, J., and Khan, B. (1961) *Behaviour of metallic thick-walled cylindrical vessels or tubes subjected to high internal or external pressures at elevated temperatures, Proc Instn Mech Engrs., 175(25): 1043–1069.*

21. Jolly, M.R. (1990*) The Foundry man, Nov., 509.*

22. Kang, C.G., and Rohatgi, P.K. (1996) *Transient thermal analysis of solidification in a centrifugal casting for composite materials containing particle segregation, Metallurgical and Mater.Trans. B, 27(2): 277–285.*

23. Khoshgoftar, M.J, Ghorbanpour, A.A., and Arefi, M. (2009) *Thermo elastic analysis of a thick walled cylinder made of functionally graded piezoelectric material, Smart Mater. Structures, 18(11): Article No.115007.*

24. Kieback, B., Neubrand, A., and Riedal, H. (2003) *Processing techniques of functionally graded materials, Mater. Sci. Engg., A362: 81–105.*

25. Park, K.T., Lavernia, E.J., and Mohamed, F.A. (1990) *High temperature creep of silicon carbide particulate reinforced aluminum, Acta Metall Mater., 38(11): 2149–2159.*

26. Pattnayak, D.K., Bapat, B.P., and RamaMohan, T.R. (2001) *Techniques for the synthesis of functionally graded materials, Proc. National Seminar on Functionally Graded Materials FGM-2001, DRDO, Ambernath, India, 86–93.*

27. Peng, L.M., Zhu, S.J., Ma, Z.Y., Bi, J., Chen, H.R., and Wang, F.G. (1998) *Creep behavior in an Al–Fe–V–Si alloy and SiC whisker-reinforced Al–Fe–V–Si composite, J. Mater. Sci., 33(23): 5643–5652.*

28. Perry, J., and Aboudi, J. (2003) *Elasto-plastic stresses in thick walled cylinders. ASME J. Pressure Vessel Technol., 125(3): 248–252.*

29. Peters, S.T. (1998) *Handbook of composites, 2nd Edition. Chapman and Hall, London, UK, 905–956.*

30. Pickel, W., Jr., Sidebowom, O.M., and Boresia, P. (1971) *Evaluation of creep laws and flow criteria for two metals subjected to step load and temperature changes, Expert. Mechanics, 11(5): 202–209.*

31. Pindera, M.J., Arnold, S.M., Aboudi, J., and Hui, D. (1994) *Special Issue: Use of composites in functionally graded materials, Composites Engng., 4: 1–150.*

32. Popov, E.P. (2001) *Engineering mechanics of solids, Singapore: Pearson Education.*

33. Povirk, G.L., Needleman, A., and Nutt, S.R. (1991) *an analysis of the effect of residual stress on deformation and damage mechanisms in Al-SiC composites, Mater. Sci. and Engg. A132: 31–38.*