NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 7, JULY-2015

EFFECT OF TEMPERATURE IN ANALYSIS OF CREEP IN AN ISOTROPIC UNIFORM COMPOSITE CYLINDER

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ABSTRACT

The following paper discusses the effect of temperature 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 behavior 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.

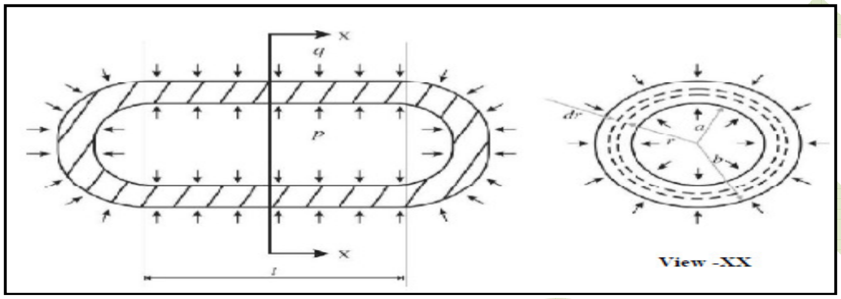

Fig. Schematic of closed end, thick-walled composite cylinder subjected to internal and external pressures.

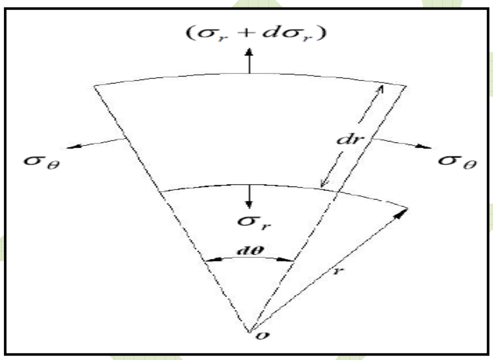

Fig. Free body diagram of an element of the composite cylinder

EFFECT OF TEMPERATURE

The creep in a material is significantly influenced by the operating temperature. Therefore, this section brings out the effect of varying operating temperature on the stresses and strain rates in a thick cylinder made of aluminum matrix composite reinforced with 20 *vol%* of SiCp. Figure 1 shows the variation of radial, tangential, axial and effective stresses in a composite cylinder operating at three different temperatures *i.e.* 350 *oC*, 400 *oC* and 450 *o C*. Similar to the effect observed for particle size (Fig. 2), the radial, tangential and axial stresses do not exhibit sizable variation with the increase in operating temperature from 350 *oC* to 450 *oC*. The effect of temperature on the stresses is not significant, except for a slight variation noticed for effective stress. With the decrease in operating temperature from 450 *oC* to 350 *oC*, the compressive value of tangential stress increases a little (around 2.5%) near the inner radius. It is interesting to observe that in the middle of cylinder, the nature of tangential stress changes from compressive to tensile. Further, this tensile value of tangential stress increases on moving towards the outer radius of cylinder with the decrease in operating temperature from 450 *oC* to 350 *oC*. The maximum increase observed is around 3%. The variation of axial stress is similar to that observed for radial stress. It remains compressive throughout the cylinder, with maximum value at the inner radius and minimum value at the outer radius. On the other hand, the effective stress, near the inner radius, decreases marginally with the decrease in temperature from 450 o*C* to 350 o*C*; but it exhibits a marginal increase towards the outer radius with the decrease in temperature. The stress difference (σe-σ0) shown in Fig. 3.13, decreases throughout the cylinder with decreasing temperature. The maximum decrease observed in stress difference is around 12% over the entire radius when the operating temperature decreases from 450 *oC* to 350 *oC*. The effective, radial and tangential strain rates in the cylinder decreases by about two orders of magnitude with the decrease in operating temperature from 450 *oC* to 350 *oC*. With decrease in operating temperature, the threshold stress o increases and the creep parameter *M* decreases (Table 1), as a result of which the strain rates in the composite cylinder decrease to a significant extent. The effect of temperature on the creep rate observed in this study are similar to those reported by Pandey *et al* (1992) for Al- SiCp composites under uniaxial creep

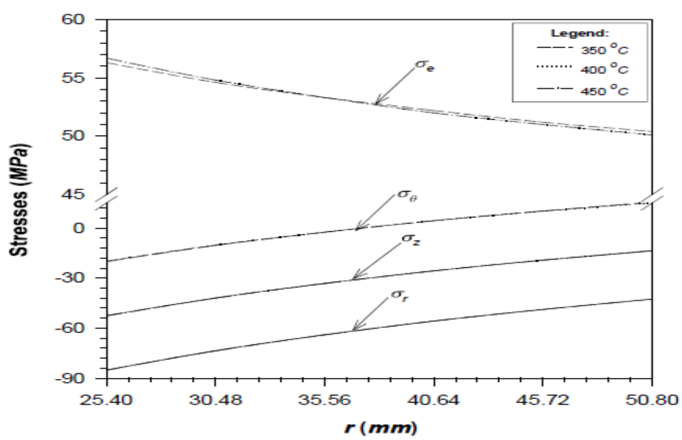

Fig no 1 Variation of creep stresses in composite cylinder for varying temperature (*V* = 20 *vol%*, *P* = 1.7*µm*).

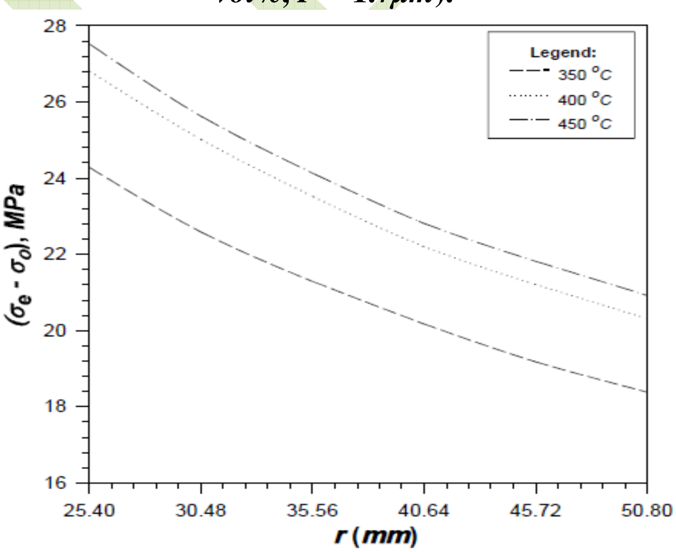

Fig No. 2 Variation of stress difference in composite cylinder for varying operating temperature (*V* = 20 *vol%*, *P* = 1.7 *µm*).

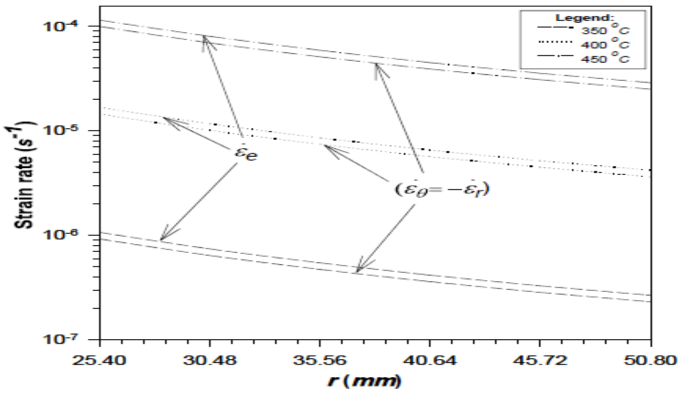

Fig no 3 Variation of strain rates in composite cylinder for varying operating temperature (*V* = 20 *vol%*, *P* = 1.7*μm*).

SELECTION OF MATERIAL PARAMETERS

It is evident from the above discussion that the creep stresses in a thick composite cylinder do not vary significantly by varying size and content of reinforcement (SiCp) as compared to the variation observed in strain rates. From The point of view of designing composite pressure vessel, operating under elevated temperature, the strain rates are considered to be primary design parameters. In order to reduce the steady state creep rates in the composite Cylinder, working under a given set of operating conditions (*i.e.* operating pressure and temperature) any of the following three options could be employed: (i) using finer size of reinforcement (SiCp) without varying its content, (ii) incorporating higher amount of dispersoids (SiCp) without altering its size, and (iii) simultaneously decreasing the size and increasing the amount of SiCp reinforcement. The selection of optimum size and content of the reinforcement in a composite pressure vessel, working under a given set of operating conditions, can be decided by simultaneously optimizing the cost of composite and the value of maximum strain rate in the composite cylinder for different combinations of particle size and particle content within the specified range.

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: $M = 3.271\times10^{-4}\ s^{-1/5}/MPa$, $\sigma_o = 11.32\ MPa$

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 know to estimate the effective strain rates at the corresponding radial locations. The effective stresses and effective strain rates thus estimated at the inner radius σ_e = 189.83MPa and $\acute{\varepsilon}_e = 2.168\text{x}10^{-8}\ s^{-1}$ and at the outer radius σ_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 3.2. 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.

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: 5145–5151.*

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.*

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