

High performance of finite element method applied to plastic analysis of reinforced materials with application in optoelectronic devices

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Finite element analysis of creeping short fiber composites is carried out in the second stage creep with application in microelectronic and optoelectronic/photonic devices. Prediction of the creep behavior is very significant for designing the optoelectronic and photonic composites with optical fibers. Study on the creep behavior is necessary for failure, fracture, fatigue, and creep resistance of the optoelectronic/photonic composites. The creep behavior of the short fiber composites is estimated by FEM. Study on the creep behavior is necessary for defect analysis and creep resistance of the short fiber composites. In this research work, prediction of the creep behavior of the short fiber composites is done under tensile axial stress by FEM. Application of the present research work is in design of the short fiber composites. Industrial application of the present method and findings is in shuttles, spaceships, and sensors. To accomplish to this aim, the available experimental results [9] are used for the FEM simulation.

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1. Introduction

Application of the optoelectronic composites is recently growing due to their applications in diverse industries. The increasing application of the optical fibers in the optoelectronic composites requires a methodical knowledge of their creep characteristics, creep resistances, and deformation mechanisms.

Recently, the creep of the short fiber composites has become to one of the essential problems in the industries. Metal matrix composites have many advantages such as high strength, high modulus and brilliant conductivities. The high temperature creep behavior of SiC whiskers reinforced aluminum alloys has been the main topic of studies that aimed at assessing the potential of these fibrous composites for using as materials in high temperature applications [1-10].

Several investigators have studied the creep behavior with considering the different methods [1-3]. Shear-lag theory applicable to discontinuous fiber composites has been presented [4-8].

For example, Cox [4] presented a stress transfer mechanism in the unidirectional long or short fiber composites, which is known as the shear lag model. The creep of dispersion reinforced aluminum based metal matrix composite has been experimentally investigated [9, 10]. The second stage creep of silicon carbide whisker/6061 aluminum composite at 573 K was experimentally analyzed [9]. The steady state creep

behavior of 6061 aluminum alloy and SiC/Al6061 composite has been analyzed experimentally and analytically by Morimoto et al. [9]. In which, occurrence of non-aligned fibers and creation of micro-cracks in the creeping composite are some difficulties during the experimental process.

According to many difficulties of the experimental methods, these methods have been also helpful for predicting the creep behavior approximately [11-24]. For instance, the creep behavior of the TiC-particulate-reinforced Ti alloy composite has been investigated at temperatures from 500 to 650°C and applied stresses from 230 to 430 MPa [12]. Up till now, numerous constitutive models have been presented to address viscoplastic behaviors of materials [25, 26].

As a different work, effects of atomic number and atomic weight have been studied on inelastic time dependent deformations [27]. Recently, a new method (a different insight) has been proposed to determine some unknowns such as displacement rate using special and well-behaved functions in order for analysis of the short fiber composites in the steady state creep semi-theoretically [28].

So, finite element method for analyzing the behavior of the creeping fibrous composites is required and vital, because, the happening of the creep in the fibrous composites can be dangerous. Consequently, the creep study becomes more essential in the diverse industries. That is, a novel model is proposed to predict the steady

state creep behavior of the short fiber composites with optical fibers using FEM instead of the expensive and time-consuming experimental method.

Main objective of this paper is the numerical study on the steady state creep of the short fiber composite to predict and analyze the creep behavior by FEM with application in nanocomposite analysis.

Also, FEM model is proposed for predicting the steady state creep behavior of the short fiber composites instead of the intricate and time-consuming experimental and analytical approaches.

2. Material and Method

An axisymmetric unit cell is assumed as a representative of the complete short fiber composite with a fiber with its surrounding matrix as two coaxial cylinders. The FEM model of the unit cell is schematically shown in Fig. 1.

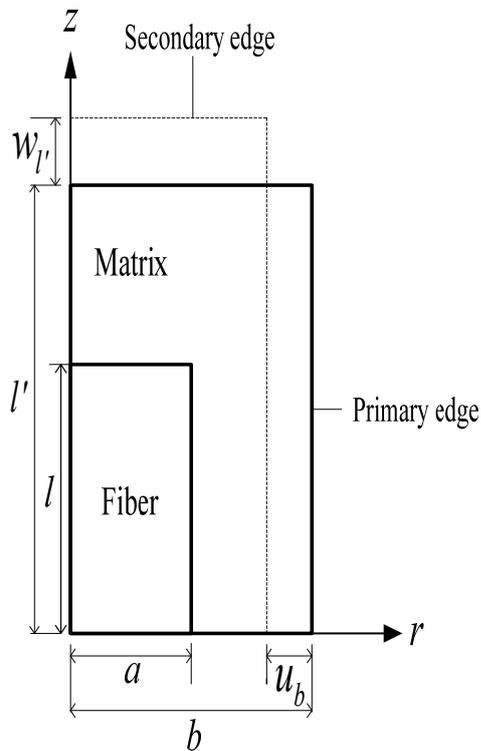


Fig. 1. Unit cell model for FEM simulation.

Supposed that a cylindrical fiber with a radius a and a length $2l$ is inserted in a coaxial cylindrical matrix with an outer radius b and a length $2l'$. The volume fraction and aspect ratio of the fiber are presented by f and $s=l/a$ respectively. Additionally, $k=l'a/lb$ is considered as a parameter in relation with the geometry of the unit cell.

An applied axial tensile loading " σ_0 ", is uniformly applied on the end faces of the unit cell (at $z = \pm l'$). The creep behavior of the matrix is described by an exponential law as the following in Eq. (1),

$$\dot{\epsilon}_e = A \exp\left(\frac{\sigma_e}{B}\right) \quad (1)$$

In which, A and B are the steady state creep constants of the matrix material and the equivalent stress σ_e and the equivalent strain rate $\dot{\epsilon}_e$ are given by following formulation,

$$\sigma_e = \frac{1}{\sqrt{2}} \sqrt{(\sigma_r - \sigma_\theta)^2 + (\sigma_\theta - \sigma_z)^2 + (\sigma_z - \sigma_r)^2 + 6\tau_{rz}^2} \quad (2)$$

$$\dot{\epsilon}_e = \frac{\sqrt{2}}{3} \sqrt{(\dot{\epsilon}_r - \dot{\epsilon}_\theta)^2 + (\dot{\epsilon}_\theta - \dot{\epsilon}_z)^2 + (\dot{\epsilon}_z - \dot{\epsilon}_r)^2 + 6\dot{\epsilon}_{rz}^2} \quad (3)$$

Where, the parameters " $\dot{\epsilon}_r, \dot{\epsilon}_\theta, \dot{\epsilon}_z$, and $\dot{\epsilon}_{rz}$ " are the strain rate components in the directions indicated by subscripts. In addition, the parameters " $\sigma_r, \sigma_\theta, \sigma_z$, and τ_{rz} " are the radial, circumferential, axial, and shear stress components, respectively.

One of the important advantages of the present model is in fast and simple prediction and analysis of such problems instead of the time consuming and complex experimental and analytical methods.

Additionally, the present approach is very simple for prediction of the composite creep strain rate behavior with optical fibers. The obtained results are next validated by the experimental data of Morimoto et al., [9].

One of the advantages of the FEM is in accurate modeling of the creeping unit cell in place of the time consuming and difficult analytical and experimental methods. The analysis with assisting FEM is very easy for predicting the composite creep behavior.

To compare the obtained results, the finite element numerical calculations of steady state creep behavior of the mentioned fibrous composite are also done using the finite element commercial code of ANSYS. Axisymmetric unit cell model is assumed for FEM creep analysis.

The axisymmetry approach with nonlinear quadratic element of plane 185 is used for FEM prediction. This element is a higher order eight-node element and has creep modeling capability.

3. Result and discussion

For predicting the creep behavior of the short fiber composite by the FEM, the SiC_f/Al_m composite is chosen as a case study. Volume fraction of fibers is 0.15 and the fibers have an aspect ratio of 7.4 and $k = 0.76$ [9]. Furthermore, for the creeping the matrix, the constants are the values of $A = \exp(-24.7)$ and $B = 6.47$ considering " $\sigma_0 = 80 \text{ MPa}$ " at 573 K . The results obtained from the FEM are schematically shown in Figs. 2 and 3.

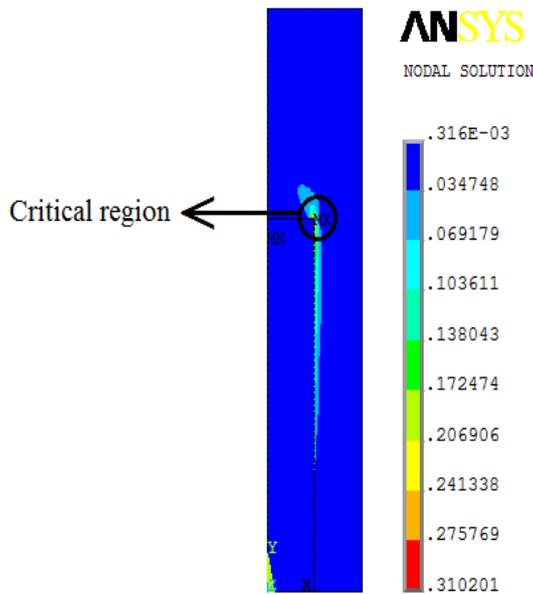


Fig. 2. Equivalent total mechanical strain in creeping unit cell by nodal solution.

Fig. 2 graphically shows that the marked regions nearing the fiber end (at $r=a$ and $z=l$) in the creeping matrix are critical. That is, creep rupture and creep debonding may occur in the mentioned region. So, this unwanted happening must be controlled and considered in short fiber composite design. On the other hand, distribution of the creep equivalent total mechanical strain is schematically shown in Fig. 2. So, we may simply design and optimize the creeping fibrous composite. With these contour plots and distributions, we can control the creep behavior of the creeping short fiber composites. This distribution (Fig. 2) may be helpful for better designing the fibrous composites with optical fibers.

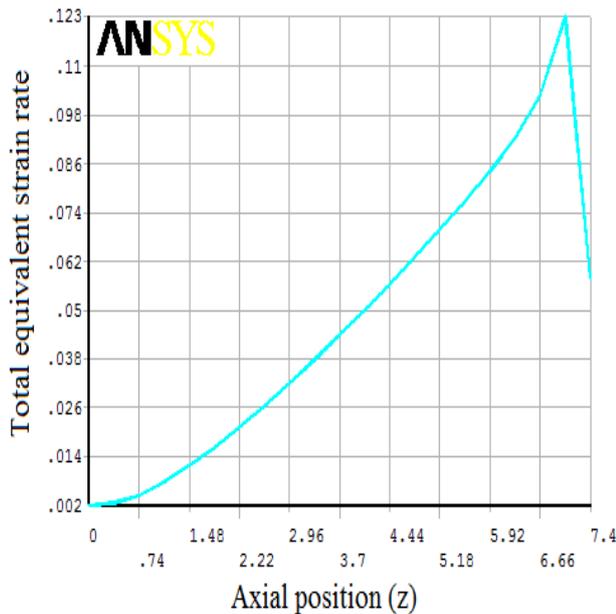


Fig. 3. Behavior of total mechanical equivalent creep strain at $r = a + \delta, 0 < z < l$ in creeping unit cell by nodal solution

The parameter of “ δ ” is a small positive value (small enough). Fig. 3 schematically proves that the regions nearing the fiber end (at $r = a + \delta$ and $z=l$) in the creeping matrix are critical and must be reinforced for preventing undesirable events. In a word, the creep rupture and creep debonding may happen in the mentioned region. Thus, this unwelcome occurrence must be controlled and considered in short fiber composite designing. In addition, the general behavior of the creep strain-mechanical trend is graphically presented in Fig. 3. With helping this behavior, we may simply design the short fiber composite. Also, we can control the creep behavior of the short fiber composites.

Fig. 4 shows the validation of FEM results. Also, ascending behavior is seen in the composite creep strain rate with constant slope and gradient. That is, this behavior with the mentioned trend is controllable. This diagram is beneficial for designing and optimizing the creeping short fiber composites

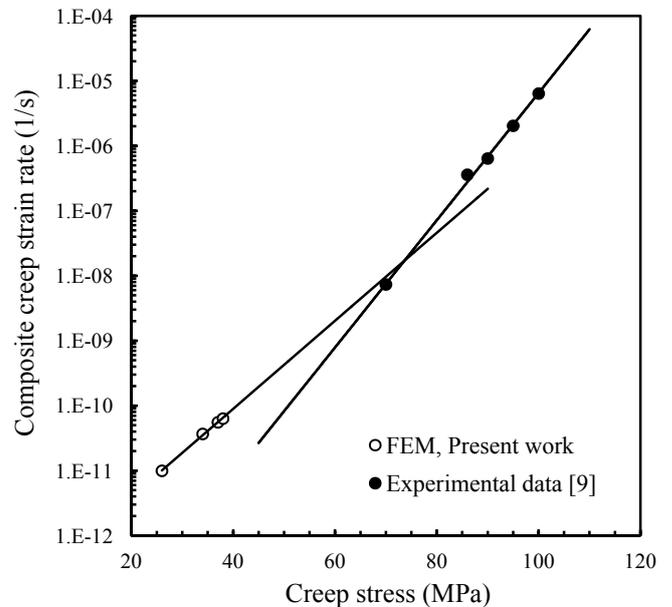


Fig. 4. Comparison of the experimental data [9] and FEM results

4. Summary and Conclusion

This paper presents FEM study to predict the behavior of the short fiber composites in the steady state creep with application in microelectronic and optoelectronic/photonic devices, and nanocomposites. The short fiber composite creep behavior was studied under tensile axial stress by FEM. One of the major applications of the present paper is in the short fiber composite designing and optimizing with application in optical fibers, sensors, and spaceships. Distribution of the total creep strain rate (contour nodal solution) in the unit cell can help us to avoid the creep rupture and debonding in the creeping fibrous composites. Also, critical regions were obtained in the fibrous

composites (at fiber end: $r = a + \delta$ and $z=f$). One of the main advantages of the present FEM work is in the application of the FEM instead of time consuming and complex experimental and analytical approaches. Finally, we can rely on the FEM predictions for predicting the creep behavior in short fiber composites.

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