FEM STUDY ON CREEPING FIBROUS COMPOSITE SiC/Al WITH APPLICATION IN ELECTRONIC, ELECTROMECHANICAL, AND ELECTRICAL COMPOSITE DEVICES

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Creep can be dangerous for electromechanical, electronic and electrical connections, networks and devices. Recently, the metal matrix composites (MMC's) are generally used for designing the electromechanical and electrical systems and devices due to their advantages. Therefore, analysis of the creep behavior is necessary and important for safe designing the fibrous composite devices. For achieving to this purpose, a numerical model is developed by FEM for predicting the micro-creep behavior of the fibrous composites with application in electromechanical, electronic, and electrical composite devices and systems. In present FEM model, determination of the creep behavior is easier than the available methods. So, predicting the creep behavior is noteworthy in order to design the electromechanical, electronic, and electrical composite devices and systems. For instance, electrical disconnection in the some systems may be because of the creep phenomenon. Also, analyzing the creep behavior is required for failure, fracture, and creep resistance of the electromechanical, electronic, and electrical composite devices and systems. Finally, the creep behavior is numerically predicted for a metal matrix composite (*SiC/Al6061*) by FEM.

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1. Introduction

Creep may create a turbulence and damage in the electromechanical, electronic, and electrical composite devices and systems. So, all electrical and electromechanical connections and networks are disconnected by happening the creep phenomenon in these composite devices and systems. The use of the electromechanical and electrical composite devices is recently growing due to their applications in different industries. As an important application, the creep in shuttles and spaceships may be very dangerous. So, analysis of the micro-creep behavior and its mechanisms for the materials is necessary, because, the creep of the electromechanical and electronic composite systems and devices can be very dangerous. Also, creep in these systems can generate the serious disturbances in the advanced systems.

A lot of researchers have analyzed the steady state creep behavior by various methods. Lately, the high temperature creep behavior of *SiC* whiskers reinforced aluminum alloys has been very important topic of studies that aimed at assessing the potential of these fibrous composites for utilizing as materials in high temperature applications [1-11]. So, FEM analysis of the creeping fibrous composites behavior is important and vital, because, the happening of the creep in the

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fibrous composites may be hazardous. Therefore, the creep study becomes more necessary in the various industries. Numerous studies have been done for analyzing the creep behavior considering the special methods [1-3]. The transient creep behavior of a metal matrix composite containing a dilute concentration of randomly oriented spheroidal inclusions was explicitly derived from the constitutive equation of the matrix, in which, the mentioned model can account for the influence of inclusion shape, elastic inhomogeneity between both phases, and the volume fraction of inclusions [1]. Shear-lag theory applicable to discontinuous fiber composites has been proposed [4-8]. For instance, Cox [4] proposed 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 [9-11]. The second stage creep of silicon carbide whisker/6061 aluminum composite at 573 K was experimentally analyzed [9]. An experimental study [11] is carried out, which includes testing of three strengthened beams and one control under short-term loading for evaluation of their failure loads, and long-term testing of another set of beams under different levels of sustained loads for a period of one year. Analysis of the creep deformation in non-reinforced regions of the creeping short fiber composites has been carried out under tensile stress using the virtual fiber method [12]. Also, the effect of atomic number and atomic weight on time-dependent inelastic deformation in metals has been analyzed semi-analytically [13].

In the present paper, a micromechanical creep model for a fibrous composite is numerically (FEM) simulated for predicting and preventing probable dangers of the creep phenomenon with application in electromechanical, electronic and electrical composite devices. A metal matrix composite (*SiC/Al6061*) is chosen for predicting the creep behavior by FEM.

2. Material and method

Here, an axisymmetric unit cell is assumed to simulate a complete short fiber composite shown in Fig. 1. In the mentioned model 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 respectively introduced by f and $s = l/a$. In addition, $k = l'a/lb$ is considered as a parameter related to the geometry of the unit cell.

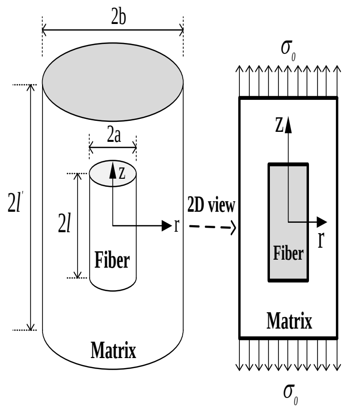

Fig. 1. Unit cell model.

Also, an axial load σ_0 is equally applied on the end faces of the unit cell (at $z = \pm l'$). The steady state condition is supposed. Small elastic deformations are neglected compared to the creep plastic deformations. The fiber and matrix have respectively elastic and plastic behaviors during the creep analysis. Material properties are assumed to be constant under applied load and temperature. The behavior of the creeping matrix is presented by an exponential law as given in Eq. (1).

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

In which, *A* and *B* are the creep constants, and obtained from reference of [9]. Also, σ_e and $\dot{\varepsilon}_e$ are equivalent stress and equivalent strain rate of the creeping matrix respectively. The equivalent stress σ_e is given by the following (Eq. (2)),

$$\sigma_e = \frac{\sqrt{2}}{2}\left[\left(\sigma_r - \sigma_\theta\right)^2 + \left(\sigma_\theta - \sigma_z\right)^2 + \left(\sigma_z - \sigma_r\right)^2 + 6\tau_{rz}{}^2\right]^{\frac{1}{2}} \tag{2}$$

The parameters of "σ_r, σ_θ , σ_z" and "τ_{rz}" are the stress components in the directions indicated by subscripts. In addition, $\dot{\varepsilon}_e$ is the equivalent strain rate and is described by Eq. (3), as the following,

$$\dot{\varepsilon}_e = \frac{\sqrt{2}}{3}\left[\left(\dot{\varepsilon}_r - \dot{\varepsilon}_\theta\right)^2 + \left(\dot{\varepsilon}_\theta - \dot{\varepsilon}_z\right)^2 + \left(\dot{\varepsilon}_z - \dot{\varepsilon}_r\right)^2 + 6\dot{\varepsilon}_{rz}^2\right]^{\frac{1}{2}} \tag{3}$$

In which, the parameters of "$\dot{\varepsilon}_r, \dot{\varepsilon}_\theta, \dot{\varepsilon}_z$" and "$\dot{\varepsilon}_{rz}$" are the strain rate components in the directions indicated by subscripts. Moreover, boundary conditions are given by the following,

$$\dot{u}\left(0,z\right)\Big|^{l\le z\le l'} = 0 \tag{4}$$

$$\dot{u}\left(b,z\right)\Big|^{0\le z\le l'} = \dot{u}_b \tag{5}$$

$$\dot{w}\left(r,0\right)\Big|^{a\le r\le b} = 0 \tag{6}$$

$$\dot{w}\left(b,l\right)\Big|^{a\le r\le b} = -2l\dot{u}_b / b \tag{7}$$

$$\tau_{rz}\left(0,z\right)\Big|^{0\le z\le l'} = \tau_{rz}\left(b,z\right)\Big|^{0\le z\le l'} = 0 \tag{8}$$

$$\tau_{rz}\left(r,0\right)\Big|^{0\le r\le b} = \tau_{rz}\left(r,l'\right)\Big|^{0\le r\le b} = 0 \tag{9}$$

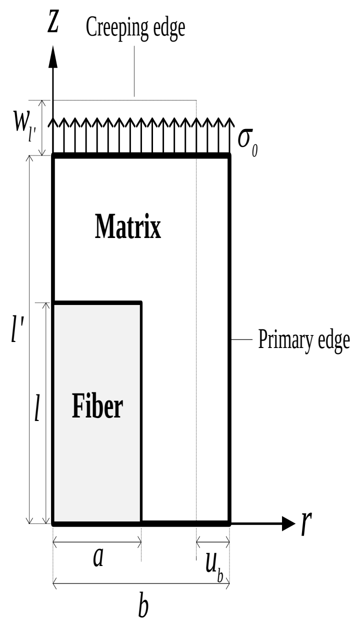

Fig. 2. Schematic of the unit cell edges in the steady state creep.

Where $\dot{u}_b$ in Eq. (5) is the radial displacement rate on the outer surface of the unit cell (at $r = b$, see Fig. 2). Also, the boundary conditions on the fiber/matrix interface (i.e. at $r = a, 0 \le z \le l$) are as the following,

$$\dot{u}(a,z) = 0 \tag{10}$$

$$\dot{w}(a,z) = 0 \tag{11}$$

3. Results and discussions

To verify and predict the creep behavior, the short fiber composite *SiC/Al6061* is chosen as a case study. The steady state creep behavior of the fibrous composite "*SiC/Al6061*" is experimentally studied at 573 *K* under constant stress 80 MPa [9]. For the composite used here (*SiC/Al6061*), the volume fraction (*f*) of fibers is *15%* and the fibers have an aspect ratio (*s*) of *7.4* and $k = 0.76$ [9]. Also, the steady state creep constants of the matrix material, *A* and *B*, in Eq. (1) are considered as $A = exp\ (-24.7)$ and $B = 6.47$ [9]. The following figures show the creep behavior of the fibrous composite (*SiC/Al6061*).

In addition, axisymmetric unit cell model is assumed for FEM creep analysis. The predicted creep behaviors are presented by FEM in the following figures (see Figs. 3-6).

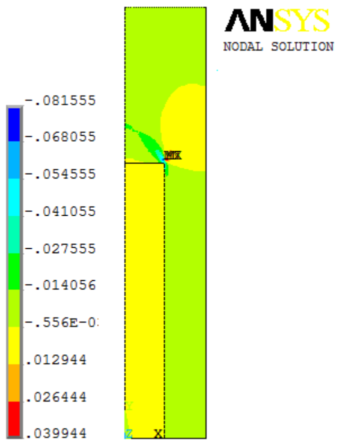

Fig. 3. X-component of total mechanical strain (with considering a =1, X= r, Y= z, Z= θ)

Fig. 3 shows distribution of the total mechanical strain in X-direction in the steady state creep of the unit cell. This nodal solution shows that the values of total mechanical strain in X-direction are critical at $r=a$, $z=l$. That is, this region should be considered to composite design, because, the electrical current and magnetic field may vary and change with possible debonding in the mentioned region.

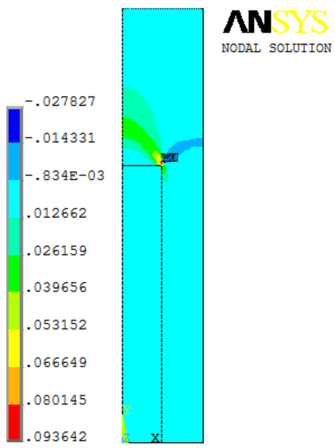

Fig. 4. Y-component of total mechanical strain (with considering a =1, X= r, Y= z, Z= θ).

Fig. 4 shows the distribution of the total mechanical strain in Y-direction in the steady state creep of the unit cell. Maximum values of the total mechanical strain in Y-direction are seen in the regions nearing the fiber end.

That is, the mentioned regions are critical and dangerous, because, unwelcome and undesired electrical connections and disturbances may happen due to the creep of the matrix in this region.

So, we can control these behaviors for preventing the unwelcome occurrences.

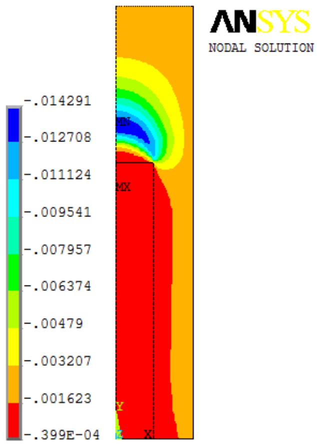

Fig. 5. Z-component of total mechanical strain (with considering a =1, X= r, Y= z, Z= θ).

Fig. 5 shows the distribution of the total mechanical strain in Z-direction in the steady state creep of the unit cell. The maximum values of the total mechanical strain in Z-direction are seen in the regions nearing the fiber. That is to say, this mentioned regions are hazardous and unsafe, because, unwelcome and undesired electrical connections and disturbances may occur due to the creep of the matrix in this region. As a result, the electrical connections may disconnect in the critical regions because of the creep phenomenon. Thus, we must control these behaviors by FEM predictions in order for preventing the unwelcome events.

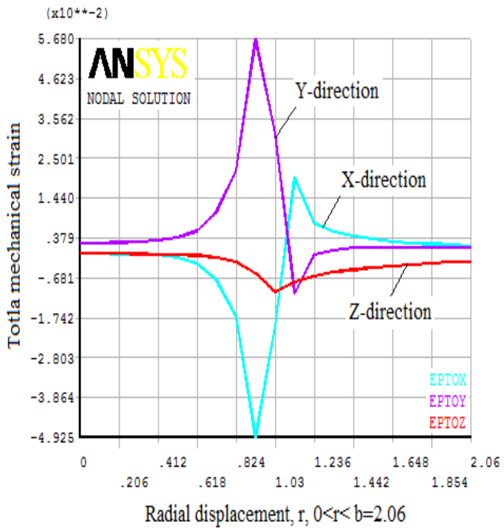

Fig. 6. Graphs of the total mechanical strain behaviors (at 0<r< b=2.06, z =l, a =1, X= r, Y= z, Z= θ).

According to Figs. 6, the nonlinear trends are observed in the total mechanical strain behaviors at the regions of "$0<r< b$, $z =l$" in the steady state creep of the short fiber composites. That is, the nonlinear behavior with variable slope and gradient is seen in the total mechanical strain behaviors at the mentioned regions. These nonlinear behaviors are because of the nature of the tensile steady state creep. So, we can control the creep displacement rates and total mechanical strain behaviors in the electromechanical, electronic, and electrical composite devices and systems using the present FEM predictions. Also, with this creep prediction, we can prevent from dangerous and undesirable events arising from the creep phenomenon in the electromechanical, electronic, and electrical composite devices and systems. Finally, creep in the electromechanical, electronic, and electrical composite devices and systems may be dangerous and unwelcome, and desirable happenings may occur in these system and devices. Particularly, creep in the small electronic systems (small electrical devices) is very important such as computer and electronic systems in the shuttles and spaceships.

4. Conclusions

In the present research work, to analyze the micromechanical creep behavior in the electromechanical, electronic, and electrical composite devices and systems, a FEM simulation was done for predicting the creep behavior of the short fiber composites. In accordance with the obtained predictions, the below conclusions may be concluded,

The mechanical strain and creep displacement rates are controllable in the electromechanical, electronic, and electrical composite devices and systems by FEM predictions. Furthermore, with helping the creep behavior predictions, we can prevent from dangerous and unwanted events arising from the happening the creep phenomenon in the mentioned systems and devices.

Variable slope and gradient is considered in the total mechanical strain behaviors at the regions of "$0<r< b, z =l$". Thus, these behaviors are controllable at the critical regions. For example, electrical disconnection in the some systems can be because of the creep.

Nonlinear behavior with variable gradients are seen in the regions of "$0<r< b, z =l$".

The nonlinear behaviors may be because of the nature of the tensile second stage creep.

Finally, prediction of the total mechanical strain behaviors is required and important in order for better designing the fibrous composites in the creep of the micromechanical creep behavior in the electromechanical, electronic, and electrical composite devices and systems .

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