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On the use of the transformation matrix for visco plastic flow in reinforced materials employing experimental data with application in microelectronic and optoelectronic/photonic devices

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A mathematically based formulation is presented for analyzing the visco plastic flow in the reinforced materials using experimental data with application in microelectronic and optoelectronic/photonic devices. Predicting the creep behavior is very important for designing the optoelectronic and photonic composites with optical fibers. Study on the creep behavior is essential for failure, fracture, fatigue, and creep resistance of the optoelectronic/photonic composites. The mathematical model is based on the transformation matrix. Creep flow in short fiber composites is considered as a visco plastic flow for analyzing. In this paper, the composite creep strain rate behavior is predicted by transformation matrix analytically. That is, the composite creep strain rate behavior is approximately predicted by affecting the transformation matrix on the experimental data for the matrix creep strain rate. One of the important applications of the present work is in the short fiber composite design. Finally, excellent similarities are found between the obtained mathematical results and the experimental data.

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1. Introduction

Application of the optoelectronic/photonic composites is newly growing due to their applications in diverse industries. Accordingly, an exact study on the micro-creep behavior and its mechanisms for the materials is significant and crucial, because, the creep in the electrical and optoelectronic/photonic systems (devices), and optical fibers may be very hazardous. The creep in the mentioned systems may generate the serious disturbances in the advanced systems. The increasing application of the optical fibers in the optoelectronic/photonic composites requires a methodical knowledge of their creep characteristics, creep resistances, and deformation mechanisms. In the recent years, the visco plastic flow and creep deformations of the short fiber composites with optical fibers have been analyzed in the scientific societies and some industries.

Therefore, creep investigations become more significant in the industries.

A lot of researchers have studied the second stage creep behavior by analytical, experimental, and FE methods. Now and then, the experimental methods are difficult and sometimes impossible for predicting the composite creep strain rate behavior. So, because of some difficulties of the experimental methods, the present analytical method is proposed for predicting these behaviors instead of the experimental methods. Newly, widespread studies were done to predict the steady state creep behavior of the composites by various methods.

Finite element method, FEM, is the one of the strong methods for modeling the creep problems [1-3]. For instance, the creep deformation behavior of the metal-matrix composites was studied by a continuum mechanics treatment utilizing finite element techniques by Dragon and Nix [1].

Also, advanced analytical shear-lag model applicable to discontinuous fiber composites was proposed [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 studied experimentally [9-12].

The creep rupture of a silicon-carbide reinforced aluminum composite was investigated by Nieh [9]. The second stage creep of silicon carbide whisker/6061 aluminum composite at 573 K was experimentally studied by Morimoto et al. [10]. The efficiency of densification process in preparation of carbon-carbon composites has been studied by Klučáková [12].

As a different research work regarding the optical fiber, a simple arrangement with optical fiber and homogeneous-type nematic liquid crystal SLM has been presented [13].

Moreover, a novel method has been presented to predict the micro-creep behavior of the short fiber composites with application in microelectronic and optoelectronic/photonic devices based on energy formulation, equilibrium and fundamental equations with considering geometric relations [14].

Also, an important study of a recently developed 2D optical code division multiple access (2D-OCDMA) code transmission named Time Hopping Odd Double Weight (THODW) utilizing plastic optical fiber (POF) has been proposed. In which, the unique properties of POF have attracted attention for its potential to be used in transmitting signals within homes or buildings [15].

Solitons in optical metamaterials has been studied by the aid of mapping method. At which, there are two types of nonlinear media taken into consideration. They are Kerr law and parabolic law nonlinearity. The constraint conditions, on the parameters, that need to hold for the solitons to exist, have been also listed [16].

L-Histidinium Maleate was synthesized and subsequently high-quality single crystals were grown from aqueous solution by slow cooling technique. In which, the grown crystals were under powder X-ray diffraction to confirm the crystallinity [17].

In the present work, an analytically based formulation is proposed to analyze the visco plastic flow in the reinforced materials using experimental data with application in microelectronic and optoelectronic/photonic composite devices.

That is, a novel analytical model is presented for prediction of the steady state creep behavior of the short fiber composites with optical fibers using transformation matrix technique in place of the expensive and time-consuming experimental method. In which, the composite creep strain rate behavior is approximately predicted by affecting the transformation matrix on the experimental data for the matrix creep strain rate.

For validating the present analytical method and obtained results, the results of the present analytical and experimental methods are compared with together by experimental data for a creeping metal matrix composite MMC.

Metal matrix composite is chosen to validate the obtained results due to the inaccessibility to the experimental data of the creeping optoelectronic/photonic composites.

Finally, the obtained analytical results are also validated and verified through comparison with the experimental data. In which, a good agreement is found between the obtained analytical and available experimental results.

2. Material and method

Now, an axisymmetric unit cell is considered as a representative of the complete short fiber composite with a fiber with its surrounding matrix as two coaxial cylinders. The unit cell model shown in Fig. 1 is used to model a short fiber composite. Also, a full fiber/matrix interface is considered.

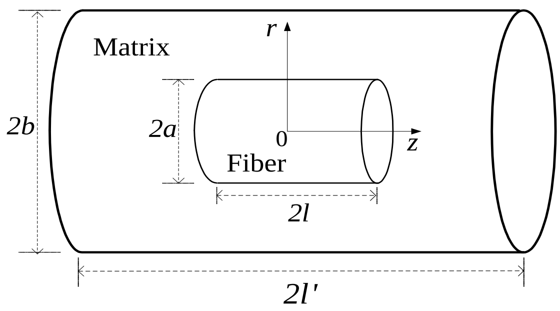

Fig. 1. Presenting the unit cell model.

In the mentioned model, it is 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 introduced by f and $s=l/a$ respectively. In addition, $k = l'a/lb$ is supposed as a parameter related to the geometry of the unit cell. An axial tensile stress, $\sigma_0 = \sigma_{applied}$, is also equally 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),

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

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

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

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

Where 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. Also parameters of σ_r, σ_θ, σ_z, and τ_{rz} are the radial, circumferential, axial, and shear stress components, respectively. In this section, new mathematical and analytical model based on transformation matrix is presented for predicting the composite creep strain rate behavior.

One of the abilities of this model is in analytical modeling instead of the time consuming and costly experimental methods. In addition, this approach is very simple for determination of the composite creep strain rate behavior. The obtained analytical results are then verified by the experimental data of Morimoto et al., [10]. Interestingly, proper agreements are found between the analytical and experimental predictions.

This model is based on the rotation principle and transformation matrix which effect on the experimental data of the creeping matrix strain rates. The result of this transformation is resulted to determination of the composite creep strain rates as the following,

$$\left[x_1 \quad x_2\right]_{1\times 2}\begin{bmatrix}\sigma_{applied}\\ \dot{\varepsilon}_{creeping\ matrix}\end{bmatrix}_{2\times 1}=\left[R_{composite\ creep\ strain\ rate}\right]_{1\times 1}= \left[\dot{\varepsilon}_{composite\ creep\ strain\ rate}\right]_{1\times 1} \quad (4)$$

In which, $\left[x_1 \quad x_2\right]_{1\times 2}$ is the transformation matrix which convert the values of the experimental creep strain rate in the matrix to the composite creep strain rate values. The parameter of x_1 and x_2 are the constants only for an applied tensile stress value. The parameter of $\dot{\varepsilon}_{creeping\ matrix}$ is related to the creep strain rate in a specific $\sigma_{applied}$. At the end, the matrix of $\left[R_{composite\ creep\ strain\ rate}\right]_{1\times 1}$ is the composite creep strain rate value in a specific $\sigma_{applied}$. For example, for $\sigma_{applied}=50\,MPa$, have,

$$\left[10^{-11} \quad -0.0088\right]_{1\times 2}\begin{bmatrix}50\\ 4.8\times 10^{-8}\end{bmatrix}_{2\times 1}=\left[7.76\times 10^{-11}\right]_{1\times 1} \quad (5)$$

Consequently, we may use transformation matrix model to predict the composite creep strain rate values ($\dot{\varepsilon}_{composite\ creep\ strain\ rate}$) by effect of the transformation matrix on the experimental data of the creeping matrix strain rate values. In the following, the creep strain rate behavior in the matrix (*Al 6061*), the experimental data for the composite creep strain rate behavior [10], and the composite creep strain rate behavior obtained by the present analytical method respectively are presented (Eqs. (6-8)).

$$\dot{\varepsilon}^{Al\ 6061}_{creeping\ matrix}=2\times 10^{-11}\left[Exp\left(0.156\times\sigma_{applied}\right)\right] \quad (6)$$

$$\dot{\varepsilon}^{Al6061,SiC15\%,experimental}_{composite\ creep\ strain\ rate}=10^{-15}\left[Exp\left(0.2255\times\sigma_{applied}\right)\right] \quad (7)$$

$$\dot{\varepsilon}^{Al6061,SiC15\%,Present\ analytical\ work}_{composite\ creep\ strain\ rate}=2\times 10^{-15}\left[Exp\left(0.225\times\sigma_{applied}\right)\right] \quad (8)$$

3. Result and discussion

To validate and verify the present solution method, the $SiC_f\,/\,Al_m$ composite is selected as a case study, and the obtained results are compared with the experimental results. For the composite used here $SiC_f\,/\,Al_m$, the volume fraction of fibers is *0.15* and the fibers have an aspect ratio of *7.4* and *k = 0.76*, which are in accordance with the suggestions made in [10].

Also, for the creeping the matrix, the constants are the values of $A=exp(-24.7)$ and $B=6.47$.

As mentioned before, one of the advantages of the present method is in the use of the mathematical modeling instead of time consuming and costly experimental methods. In this research, the purpose of the creep analysis is in the proper composite design.

That is, creep behavior must be studied to prevent the failure and defect in the creeping short fiber composites. The comparison of the present analytical and experimental predictions is carried out in Fig. 2.

The results obtained from the present method are presented in the Fig. 2. As mentioned before (inaccessibility to the experimental data of the creeping optoelectronic/photonic composites), for comparing the results of the present method, the *SiC/6061Al* composite is selected as a case study and also the obtained analytical and experimental results are compared with together.

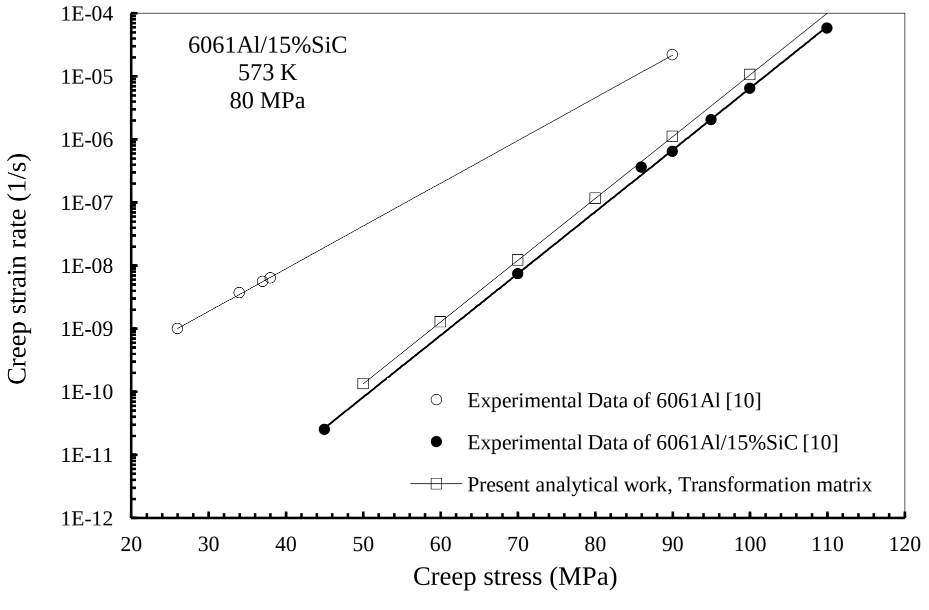

Fig. 2. Comparison of the present analytical and experimental results (Morimoto et al. [10]).

Fig. 2 shows a good agreement between the present analytical and experimental results for second stage creep of the short fiber composite. Also, it is seen that the values of the composite creep strain rate ($\dot{\varepsilon}_{composite\ creep\ strain\ rate}$) increase with increasing the stress values.

In which, the composite creep strain rate behavior is ascending along with the smooth and uniform gradients. Based on this behavior, we can control the composite creep strain rate behavior because of the smooth gradients.

The finite element (FEM) analysis of the creep strain rate is schematically shown in Fig. 3. This FEM analysis and solution may be helpful for better designing the microelectronic and optoelectronic/photonic composite devices with optical fibers.

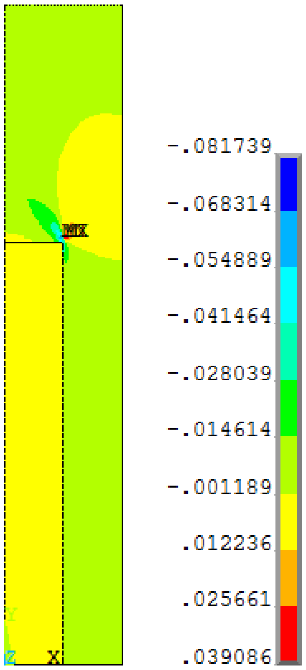

Fig. 3. Presenting the contour nodal solution data of the creep strain rate in r-direction

Also, Fig. 3 presents graphically the complete distribution of the creep strain rate in r-direction using the contour nodal solution data in the unit cell. This distribution can be beneficial for better designing the fibrous composites with optical fibers.

The distribution of the creep principal stress behavior is graphically shown in Fig. 4. Consequently, we can basically 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 with application in microelectronic and optoelectronic/photonic composite devices.

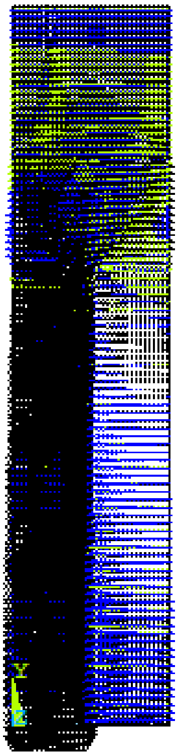

Fig. 4. The behavior of the creeping unit cell by vector plot (principal stress).

4. Summary and conclusion

In the present research work, a mathematically based formulation was introduced for analyzing the visco plastic flow in the reinforced materials using experimental data with application in microelectronic and optoelectronic/photonic devices. The new insight is proposed to predict the composite creep strain rate behavior ($\dot{\varepsilon}_{composite\ creep\ strain\ rate}$) of the short fiber composites with optical fibers using transformation matrix technique instead of the costly and time-consuming experimental method. At which, the composite creep strain rate behavior is approximately predicted by affecting the transformation matrix on the experimental data for the matrix creep strain rate. At the end, suitable agreements are found between the present analytical and experimental method results for second stage creep of the short fiber composite.

One of the advantages of the present method is in the application of the mathematical models instead of time consuming and costly experimental methods, and complex methods. Eventually, we can rely on the present method for predicting the composite creep strain rates ($\dot{\varepsilon}_{composite\ creep\ strain\ rate}$) in short fiber composites.

In addition, the composite creep strain rate behavior is ascending along with the soft and uniform gradients. Thus, we can control the composite creep strain rate behavior due to the smooth gradients. Thus, predicting the creep strain rate behavior of the short fiber composites with optical fibers is very important for better designing composites in the creep of the optoelectronic/photonic composite devices.

References

[1] T. L., Dragon, W. D. Nix, Acta. Metall. Mater., **38**(10), 1941 (1990).

[2] H. Ismar, F. Schröter, F., Streicher, Compos. Sci. Technol. **60**(11), 2129 (2000).

[3] K. J. Kim, W. R. Yu, M. S. Kim, Compos. Sci. Technol. **68**(7-8) 1688 (2008).

[4] H. L. Cox, Br. J. Appl. Phys. **3**, 72 (1952).

[5] S. T. Mileiko, Steady state creep of a composite with short fibres. J. Mater. Sci., **5,** 254 (1970).

[6] H. Fukuda, T. W. Chou, J. Compos. Mater., **1**(15), 79 (1981).

[7] M. McLean, Compos. Sci. Technol., **23,** 37 (1985).

[8] J. Zhang, Compos. Sci. Technol. **63**(13), 1877 (2003).

[9] T.G. Nieh, Metall. Trans. A., **15,** 139 (1984).

[10]T. Morimoto, T. Yamaoka, H. Lilholt, M. Taya, J. Eng. Mater. Technol., **110**, 70 (1988).

[11] A. Greasly, Mater. Sci. Technol. **11,** 163 (1995).

[12] M. Klučáková, Int. J. Phys. Sci., **1**(3), 121 (2006).

[13] S. Lei, L. Chen, Y. Hu B. Wang, Q. Lin, J. Optoelectron. Adv. Mater., **16**(9-10), 1003 (2014).

[14] V. Monfared, S. Daneshmand, Optoelectron. Adv. Mater., **9**(3-4), 410 (2015).

[15] A.Z.G. Zahid, M. Singh, P.S. Menon, F. N. Hasoon, H. Bakarman, A.A.A. Bakar, M.A.M. Ali, Optoelectron. Adv. Mat. – Rapid Commun., **9**(3-4), 362-366 (2015).

[16] E.V. Krishnan, M.AL Ghabshi, Q. Zhou, K.R. Khan, M.F. Mahmood, Y. XU, A. Biswas, M. Belic, J. Optoelectron. Adv. Mater., **17**(3-4) 511 (2015).

[17] H. Arul, R. Ezhil Vizhi, D. Rrajan Babu, J. Optoelectron. Adv. Mater., **17** (3-4) 270 (2015).

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