ID 1016

FINITE ELEMENT ANALYSIS FOR TENSILE PROPERTIES OF RANDOM SHORT Al_2O_3 FIBER REINFORCED ALUMINUM ALLOY COMPOSITE

Guozheng Kang[1] Qing Gao[1] Chuan Yang[2]
[1]*Department of Applied Mechanics and Engineering;* [2]*Department of Materials Engineering,*
Southwest Jiaotong University, Chengdu, Sichuan, China (610031)

SUMMARY: According to the schedule for overall effective properties of short fiber reinforced metal matrix composites and three-dimensional single fiber model, the tensile behaviors of δ-Al_2O_3 short fiber reinforced aluminum alloy composites were analyzed by three-dimensional elastic-plastic finite element method (FEM). The effects of various microstructural parameters on the tensile stress-strain curves were also considered. Finally, with the practical microstructural parameters and the distribution density function of the random short fiber's orientation taken into account, the initial stress-strain curve of δ-Al_2O_3/Al-5.5Zn was numerically simulated. The simulated stress-strain curve agreed very well with the measured one.

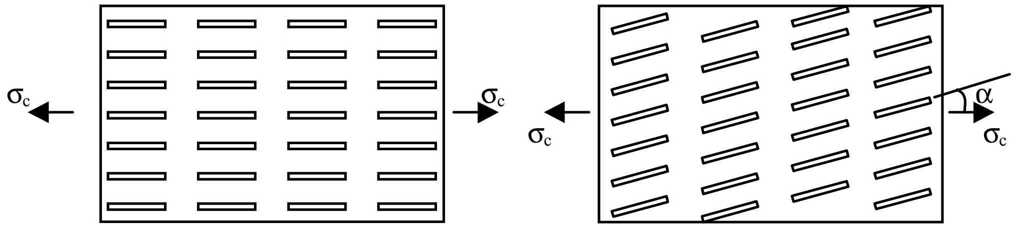
KEYWORDS: metal matrix composites, short fiber, tensile property, finite element

INTRODUCTION

The tensile behavior of aluminum alloy matrix composites reinforced by random short δ-Al_2O_3 fiber had been experimental characterized [1]. It was observed that the incorporation of short δ-Al_2O_3 fibers in matrix increased the elastic modulus, but decreased the proportional limit of reinforced matrix, and that current theories were not able to predict these effects accurately. Levy and Papazian [2] demonstrated that elastic-plastic analysis with the finite element models of short fiber reinforced metal matrix composites could be used for accurate prediction of tensile properties and could overcome the approximate treatments adopted in Eshelby-type models [3~4]. However, the random orientation of the fibers and the interfacial bond were not considered in their work. Takao, et al [4] concluded that the fiber's orientation angle α greater than 15° to 20° had a great effect on the composite stiffness. Thus, the fiber's orientation α that randomly ranged from 0° to 90° must be considered in the prediction of the tensile properties of the composites. It had been confirmed that the interfacial bond also greatly influenced the tensile properties of short fiber reinforced metal matrix composites [5], and should be taken into account, too. Thus, in this work, using the elastic-plastic finite element method, the initial stress-strain curves of the aligned or tilted short Al_2O_3 fiber reinforced aluminum alloy composites are initially analyzed. The effects of various microstructural variables such as fiber's aspect ratio and volume fraction, fiber's orientation, interfacial bond and matrix behavior on the initial stress-strain curves of composites are discussed in detail. Then, the initial stress-strain curve of squeeze casting δ-Al_2O_3/Al-5.5Zn composite is numerically simulated and compared with the measured one.

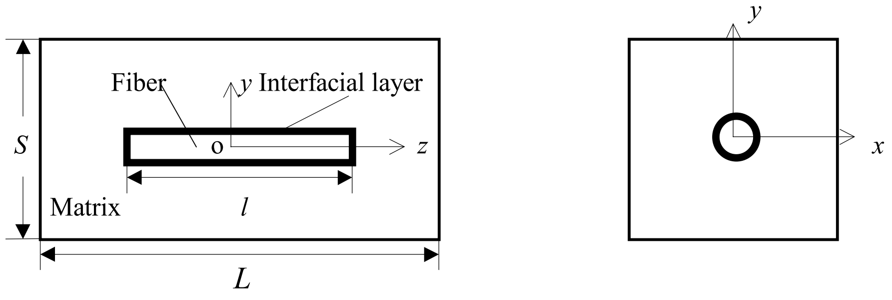
FEM MODEL

In our work, the composites reinforced by aligned and tilted short fibers were modeled to be a regular arrangement, as shown in Fig. 1. The three-dimensional single fiber model of aligned short fiber reinforced metal matrix composites shown in Fig. 2 was used. In order to discuss the effects of interface on the tensile properties of the short fiber composites, an interfacial layer was inserted into the model, as shown in Fig. 2. The FEM code was ANSYS R5.5 /Multiphysics. The sizes of model are：$\pi ld^2/4LS^2=V_f$, $(L-l)=(S-d)$. Where, V_f is fiber's volume fraction, d is fiber's diameter. Due to the fiber's approximate in-plane two-dimensional distribution of squeeze casting short fiber composites [1], fiber's orientation can be represented by the angle α between fiber's long axis and loading direction z. The mesh of FEM is not shown here, and the 20-nodes block element is adopted. The detail was described in Reference[1]. For the tilted fibers, the model of finite element analysis was the same as that shown in Fig. 2, but the load condition was obtained by coordinate system transformation and became to be $\sigma_L = \sigma_c \cos^2\alpha$, $\sigma_T = \sigma_c \sin^2\alpha$, $\tau_{LT} = \sigma_c \cos\alpha \sin\alpha$.



a) Aligned fiber model b) Tilted fiber model

Fig.1 the models of short fiber reinforced composites



a) Longitudinal Section b) Transverse Section

Fig. 2 The three-dimensional single fiber model of the composites

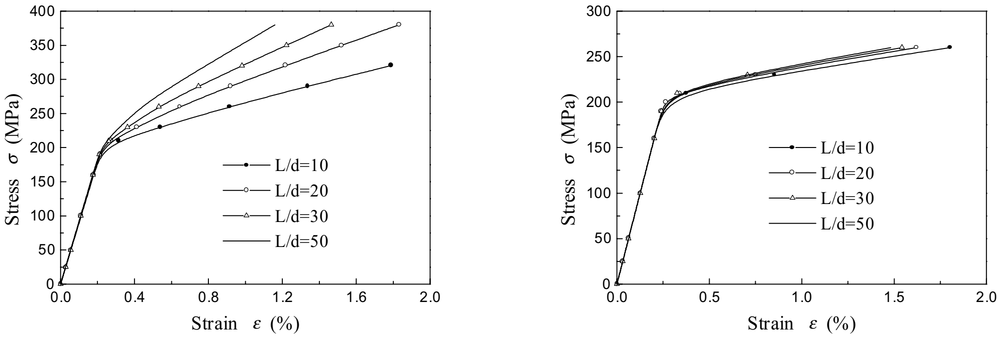
According to the schedule for overall effective properties of short fiber reinforced metal matrix composites used in Reference [6], the tensile properties of short fiber composites could be modeled by FEM. With the different microstructural parameters taken into account, the relation between the composite's tensile properties and its microstructures was discussed. In the calculation, the fiber was taken as an elastic material with the elastic modulus E_f of 300GPa and Poisson's ratio v_f of 0.20; the matrix was a bi-linear material with the elastic modulus E_m of 70GPa and Poisson's ratio v_m of 0.33and yielded by the Von-Mises rule.

RESULTS AND DISCUSSIONS

In this section, the initial stress-strain curves of aligned or tilted short fiber reinforced composites are initially analyzed and discussed. Then, the initial stress-strain curve of squeeze casting δ-Al_2O_3/Al-5.5Zn composite is numerically simulated using the method that is similar to the laminate analogical theory developed by Johnson and Brit [7]. In the prediction, the practical distribution density function of fiber orientation measured in Reference [1] is used. On Comparison with the measured result, the reasonability of the simulation is examined. Since the elastic modulus of random short fiber reinforced aluminum alloy composites had been systematically analyzed in Reference [8], for the initial stress-strain curve of the composite, two parameters, proportional limit σ_p and hardening rate n, are discussed in this paper.

Effects of Fiber's Aspect Ratio and Volume Fraction

With different aspect ratio L/d, the stress-strain curves of aligned short fiber composites were modeled under a longitudinal or transverse loading. In the calculation, the fiber volume fraction V_f was taken as 10%. For longitudinal loading (equivalent to the fiber's orientation angle α=0°), with the increment of the L/d, the proportional limit σ_p remains almost unchanged, but the hardening rate n increases, as shown in Fig. 2. This is resulted from the fact that with the increasing of L/d the stress concentration in the matrix at fiber's end does not changed, but the matrix stress decreases. When L/d>30, the further increment of L/d has little effect on the initial modulus, but a great effect on the hardening rate n. However, for transverse loading (equivalent to the fiber's orientation angle α=90°), the L/d has little effect on the stress-strain curve. This means that the effects of L/d on the initial stress-strain curves have a significant dependence on the fiber's orientation.



a) Longitudinal

b) Transverse

Fig. 3 The simulated initial stress-strain curves with different fiber's aspect ratios L/d

The initial stress-strain curves of the composites also were calculated with different fiber volume fraction V_f and a constant aspect ratio L/d=20. From the calculated results, it is also concluded that the proportional limit σ_p and hardening rate n increase significantly when the V_f increases, which is in good agreement with the established work [2].

Effects of Fiber's Orientation

Using the finite element model shown in former section, the stress-strain curves were simulated with the different fiber's orientations. The results are shown in Fig. 4. Here, V_f=10%, L/d=20. It is shown that, with the variation of α, the initial modulus and hardening rate n increase obviously. When $\alpha \le 60°$, the initial modulus and hardening rate n decrease with the increasing of α; when $\alpha > 60°$, they increase with the increasing of α. This means that the most adverse fiber's orientation is α=60°, not α=90°. However, the proportional limit σ_p has a little change when the fiber's orientation varies.

Effects of Interfacial Bond

The interfacial bond can be represented by the mechanical properties of interfacial layer that is shown in Fig.2. Reference [9] has shown that the effect of the elastic modulus of interfacial layer E_i on the stress transfer of short fiber composite is much greater than that of plastic behavior of interfacial layer. Thus only the variation of E_i is considered here. The stress-strain curves were predicted with the different E_i. The simulated results are shown in Fig. 5. Here, V_f=10%, L/d=20. With the increment of E_i, the longitudinal modulus and proportional limit σ_p of composite increase. In the meantime, the hardening rate n also has an obvious enhancement, as shown in Fig. 5. It can be seen that the effect of interfacial layer modulus E_i on the tensile properties of composite is also highly dependent on the fiber's orientation. The effect of E_i on the transverse stress-strain curve is greater than that of E_i on the longitudinal one.

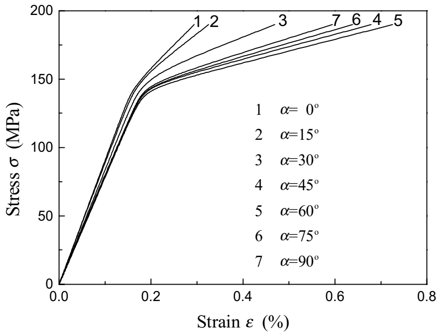


Fig. 4 Simulated initial stress-strain curves with different fiber's orientations α

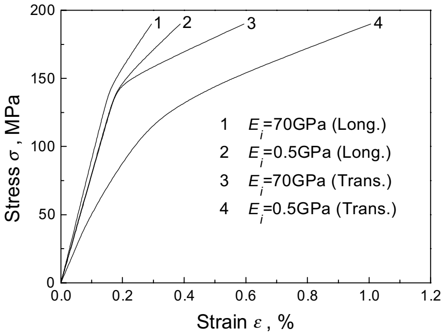


Fig. 5 Simulated initial stress-strain curves with different interfacial moduli E_i

Effects of Matrix Plastic Parameters

In the above-mentioned calculation, the matrix with a yield strength σ_{my} of 150MPa and a hardening modulus H'_m of 2.0GPa was used.

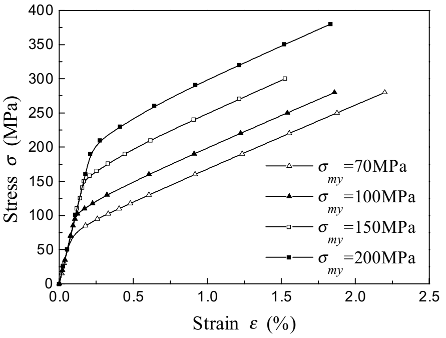


Fig. 6 Simulated initial stress-strain curves with the different σ_{my}

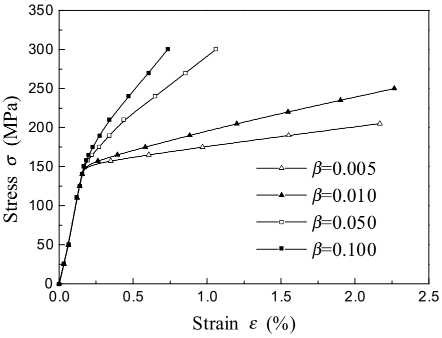


Fig. 7 Simulated initial stress-strain curves with the different H'_m ($\beta = H'_m/E_m$)

In order to discuss the effects of the matrix yield strength, the initial stress-strain curves of the aligned short fiber composites was modeled with different σ_{my} under the longitudinal loading. In the calculation, the hardening modulus of the matrix H'_m was remained as a constant value of 2.0GPa and V_f=10%, L/d=20. The results are shown in Fig. 6. It is shown that the variation of matrix yield strength has no effect on the elastic proportion of the stress-strain curves, but has a significant effect on the plastic behavior of the composites. The composite's proportional limit σ_p is considerably enhanced due to the increment of the σ_{my}, but the hardening rate *n* remains almost unchanged. This means that the variation of the σ_{my} mainly influences the proportional limit of the composites. Keeping matrix yield strength as a constant value of 150MPa, the initial stress-strain curves of the composites were simulated with the different H'_m. The simulated stress-strain curves are shown in Fig. 7. It can be seen that the variation of the H'_m has a significant effect only on the plastic behavior of the composites. The composite's hardening rate *n* increases considerably with the increment of the H'_m, but the proportional limit σ_p remains unchanged.

Prediction for Stress-Strain Curve of δ-Al_2O_3/Al-5.5Zn

With the practical microstructural variables, the initial stress-strain curve of the δ-Al_2O_3/Al-5.5Zn composite with fiber volume fraction of 10% was predicted by FEM. The matrix was assumed to be a bi-linear material with a yield strength σ_{my} of 60.0MPa and a tangential modulus H'_m of 2.0GPa. The interfacial bond was considered to be perfect and the interfacial modulus E_i was taken to be equal to the matrix modulus (=70GPa). The fiber aspect ratio was equal to 20. The distribution of fiber's orientation of squeeze casting δ-Al_2O_3/Al-5.5Zn measured in Reference [1] was used here. The elastic modulus and Poisson ratio of fiber and matrix was 300GPa, 0.20 and 70GPa, 0.33, respectively. The predicted and measured curves are shown in Fig. 8. It is concluded that the prediction is reasonable. The apparent deviation takes place only in the proportional limit. This is resulted from the thermal residual stress produced in the manufacture of composite is not considered in the prediction.

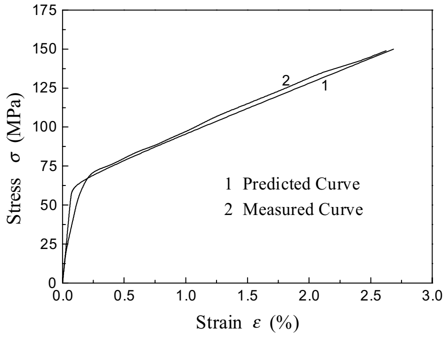


Fig. 8 The predicted and measured stress-strain curves of δ-Al_2O_3/Al-5.5Zn

CONCLUSIONS

The initial tensile stress-strain curves of short fiber reinforced aluminum alloy composites have a close relation to the microstructural characteristics, such as fiber aspect ratio, fiber's orientation, interfacial bond and matrix properties. The fiber's orientation is an important factor in random short fiber composites. When $\alpha \leq 60°$, the initial modulus and hardening rate *n* decrease with the increasing of α; when $\alpha > 60°$, they increase with the increasing of α. The effect of the interfacial bond and fiber aspect ratio has close relation to the fiber's orientation. The effect of E_i on the transverse properties is greater than that on the longitudinal ones; the effect of *l/d* on the longitudinal properties is greater than that on the transverse ones. A good interfacial bond is expected for improving the mechanical properties of the composites. The variation of matrix's yield strength σ_{my} and hardening modulus H'_m have no effect on the elastic proportion of the stress-strain curves, but significantly influence the plastic behavior of the composites. The matrix's yield strength σ_{my} mainly influences the proportional limit of the composites, and the hardening modulus H'_m has effect only on the composite's hardening rate n.

With the practical microstructure parameters of the squeeze casting δ-Al_2O_3/Al-5.5Zn composite, its initial tensile stress-strain curve is predicted by FEM reasonably. The predicted curve agrees very well with the measured one.

ACKNOWLEDGEMENT

Financially supported by Theoretical Research Fund of Southwest Jiaotong University, Contract No.1999XJ04.

REFERENCES

1. Kang, G.Z., " A Meso-mechanical Analysis for the Mechanical Behavior of Short Fiber Reinforced Metal Matrix Composites", Dissertation of Southwest Jiaotong Univ., Chengdu, 1997

2. Levy, A. and Papazian J.M., "Tensile Properties of Short Fiber Reinforced SiC/Al Composites: II. Finite Element Analysis", *Metall. Trans. A*, 1990, Vol.21, pp411

3. Taya, M. and Arsenault, R.J., "A Comparison between a Shear-lag Type Model and Eshelby Type Model in Predicting the Mechanical Properties of a Short Fiber Composite", *Scripta Metall.*, 1987, Vol.21, pp349

4. Takao, Y., et al, "Effective Longitudinal Young's Modulus of Misoriented Short Fiber Composites", *ASME J. Appl. Mech.*, 1982, Vol.49, pp536

5. Kang, G.Z., et al, "Interfacial Effects on Mechanical Behavior of Short Fiber Reinforced Metal Matrix Composites", *Acta Materiae Compositae Sinica*, 1999, Vol.16, No.1, pp40

6. Chen, H.R. and Su. X. F., "The Effect of Imperfect Interphase on Overall Average Mechanical Properties and Local Stress Fields of Multiphase Composite Materials", *Composites*, 1995, Vol.26, pp347

7. Johnson, W.S. and Birt, M.J., "Comparison of Some Micromechanics Models for Discontinuously Reinforced Metal Matrix Composites", *J. Comp. Tech. & Res.*, 1991, Vol.13, No.3, pp161

8. Kang, G.Z., et al, "Finite Element Method Based on the Energy Equivalence for Predicting the Elastic Modulus of δ-Al_2O_3/Al Composites", *Acta Materiae Compositae Sinica*, 1999, Vol.16, No.2, pp87

9. Kang, G.Z., Gao, Q. and Liu, S.K., "The Effects of Interfaces on Stress Transfer in Short Fiber Reinforced Metal Matrix Composites", *J. Southwest Jiaotong Univ.*, 1998, Vol.6, No.1, pp47