IN-24

1593

P15

NASA Technical Memorandum 103682

METCAN Updates for High Temperature Composite Behavior: Simulation/Verification

H.-J. Lee, P.L.N. Murthy, and C.C. Chamis
Lewis Research Center
Cleveland, Ohio

(NASA-TM-103682) METCAN UPDATES FOR HIGH TEMPERATURE COMPOSITE BEHAVIOR: SIMULATION/VERIFICATION (NASA) 15 p N91-19229
CSCL 11D Unclas
G3/24 0001593

Prepared for the
36th International SAMPE Symposium and Exhibition
San Diego, California, April 15-18, 1991

NASA

METCAN UPDATES FOR HIGH TEMPERATURE COMPOSITE BEHAVIOR:

SIMULATION/VERIFICATION

H.-J. Lee, P.L.N. Murthy, and C.C. Chamis
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

The continued verification (comparisons with experimental data) of the METCAN (Metal Matrix Composite Analyzer) computer code is updated. Verification includes comparisons at room and high temperatures for two composites, SiC/Ti-15-3 and SiC/Ti-6-4. Specifically, verification of the SiC/Ti-15-3 composite includes comparisons of strength, modulus, and Poisson's ratio as well as stress-strain curves for four laminates at room temperature. High temperature verification includes comparisons of strength and stress-strain curves for two laminates. Verification of SiC/Ti-6-4 is for a transverse room temperature stress-strain curve and comparisons for transverse strength at three temperatures. Results of the verification indicate that METCAN can be used with confidence to simulate the high temperature nonlinear behavior of metal matrix composites.

E-5899

INTRODUCTION

High temperature metal matrix composites (HTMMC) offer great potential for use in advanced aerospace structural applications. The realization of this goal however, requires concurrent developments in (1) a technology base for fabricating HTMMC structural components, (2) experimental techniques for measuring thermal and mechanical characteristics, and (3) computational methods to predict their behavior. In the development of HTMMC's, it proves beneficial to initially simulate their behavior through computational methods. Besides providing an initial assessment of the HTMMC, this method helps to minimize the costly and time consuming experimental effort that would otherwise be required.

Recent research into computational methods for simulating the nonlinear behavior of high temperature metal matrix composites at NASA Lewis Research Center (refs. 1 and 2) has led to the development of the METCAN (Metal Matrix Composite Analyzer) computer code. METCAN treats material nonlinearity at the constituent (fiber, matrix, and interphase) level, where the behavior of the material is modelled using the dependence of a constituent's properties in a time-temperature-stress "material behavior space." The composite properties are synthesized from the constituent instantaneous properties by virtue of composite micromechanics, composite macromechanics, and laminate theory, which make up separate modules in the METCAN code. These modules of the METCAN code have been validated using three dimensional finite element analysis and verified for room temperature linear time independent loadings (ref. 1). Factors which affect the behavior of the composite properties include the fabrication process variables, in-situ fiber and matrix properties, bonding between the fiber and matrix, and/or the properties of an interphase between the fiber and the matrix. A unique aspect of the METCAN code is an integrated cyclic arrangement which defines the computational effort for each load increment as shown in figure 1. Another feature is the use of the multifactor interaction relationship to represent the various nonlinearities and their interactions in the constituents. Figure 2 illustrates the multifactor interaction relationship and the reasons for its selection. The computational sequence involved in the METCAN simulation is shown in figure 3. The METCAN simulation begins with processing and cool down, followed by heat up to the use temperature, and ends with the application of the load.

The objective of this paper is to describe the status of the ongoing effort to verify (compare with experimental data) METCAN. In addition to demonstrating the ability of METCAN to predict the high temperature nonlinear behavior of metal matrix composites, another goal of the METCAN verification is to validate the use of the multifactor interaction relationship to predict the nonlinear behavior induced by time and high-temperature dependence. More information regarding METCAN, as well as previous METCAN verification results, can be found in references 3 to 5.

METCAN VERIFICATION

Data for two metal matrix composites are examined in the current verification. They are:

(1) SiC/Ti-15-3 (ref. 6)
(2) SiC/Ti-6-4 (ref. 7)

SiC/Ti-15-3 verification includes comparisons of strength, modulus, and Poisson's ratio as well as stress-strain curves for four laminates at room temperature. High temperature verification includes comparisons of strength and stress-strain curves for two laminates. Verification of SiC/Ti-6-4 is for a transverse room temperature stress-strain curve and comparisons for transverse strength at three temperatures. The room temperature constituent material properties used as input initially for the two composites in METCAN are listed in table I.

ASSUMPTIONS MADE IN METCAN

Assumptions made in the verification are:

(1) Values of the exponents used in the multifactor interaction relationship are calculated from the constituent experimental data whenever possible. When there is lack of experimental data, default values are used. The default values have been established from studies conducted on other metal matrix composites (ref. 2).

(2) The in-situ matrix melting temperature in METCAN is set to a value close to the consolidation temperature. Since the consolidation temperature is the temperature at which the matrix has no strength remaining, the in-situ matrix melting temperature in METCAN must be close to the consolidation temperature of the composite to simulate this behavior. The temperature is 1800 °F for both matrices.

(3) The in-situ matrix strength in METCAN is determined through iterative comparisons with the experimental transverse composite strength, since it is assumed that the in-situ matrix will not realize the complete strength of the bulk matrix. Using the bulk matrix strength as an initial estimate of the in-situ matrix strength, the METCAN transverse composite strength prediction is compared to the experimental value. The process is repeated for different values of the in-situ matrix strength until a rough match is obtained between the METCAN prediction and the experimental transverse composite strength. The in-situ matrix strength turns out to be around 60 ksi for Ti-15-3 and 75 ksi for Ti-6-4.

The exponents mentioned in assumption (1) correspond to the exponents n, m, . . ., r, s in the multifactor interaction relationship shown in figure 2. For each increment of the computational simulation, various properties (P) for the fiber and matrix are determined by using the multifactor interaction relationship. The property (P) is a generic symbol representing any constituent material property (e.g., fiber and matrix modulus, strength, Poisson's ratio, etc.).

For this study, only the effects of the first two terms in the multifactor interaction relationship are considered, leading to a temperature and stress dependence of each property. This means that for each fiber and matrix combination, two exponents are required for each property to predict their behavior. From the available constituent experimental data, only the exponents for each matrix modulus, strength, and coefficient of thermal expansion (CTE) were determined. These exponents are listed in table II. Except for the modulus of Ti-15-3 (for which both exponents were determined), only the temperature dependent exponent for the three matrix properties were calculated. The stress dependent exponents for the three matrix properties, as well as the exponents for the other matrix and fiber properties are set to the default values of 0.50 for the matrix and 0.25 for the fiber. The significance of the exponents and the multifactor interaction relationship is the ability to simulate high temperature properties of the constituents from room temperature experimental data.

The assumptions in (2) and (3) result from the difficulty in obtaining in-situ properties of the constituents. The bulk properties serve as an initial estimate, but adjustments are sometimes necessary to accurately model the composite behavior. In assumption (3), the room temperature strength of the $[90]_8$ SiC/Ti-15-3 laminate and the room temperature transverse strength of SiC/Ti-6-4 are used to determine the in-situ matrix strength. Obviously, METCAN results for these two cases should match experimental values closely. Nonetheless, results for these two cases are included along with the comparisons of METCAN predictions and experimental data in the next two sections for completeness. It should also be noted that the values in assumptions (1) to (3) are determined only once and are kept fixed throughout the study for all the different laminates and temperatures.

SiC/Ti-15-3

METCAN predictions of room temperature elastic moduli, strengths, and Poisson's ratios for a fiber volume ratio (fvr) of 0.34 are compared with their respective experimental values for four laminates ($[0]_8$, $[90]_8$, $[90/0]_{2S}$, and

$[30/-30]_{2s}$) as shown in figures 4 to 6. Generally, differences between METCAN predictions and experimentally determined values for the aforementioned material properties are minimal.

The room temperature stress-strain behavior of these four laminates can be found in figures 7 to 10. For the most part, METCAN predictions of stress-strain behavior are in excellent agreement with experimental values. Figure 11 presents the stress-strain behavior of the $[0]_8$ laminate at high temperature (800 °F). The high temperature stress-strain behavior is similar to that of the room temperature curve. Comparisons between METCAN predicted and experimentally measured strengths at 800 °F for $[0]_8$ and $[90]_8$ laminates are shown in figure 12. Once again, good agreement exists between METCAN predictions and experimental values.

Generally, METCAN predictions of stress-strain behavior are in good agreement with experimental values, except for slight deviations. There are a number of possible explanations for the METCAN deviations from the experimental stress-strain behavior (figs. 7 to 11). First, there are the variabilities involved in the experimental measurements. Given the scatter of experimental values which occur from one specimen to another, it seems likely that most of the METCAN predictions will lie within the scatter of the experimental values. Another factor in the differences between METCAN predictions and experimental values may be the use of default values for some of the exponents in the multi-factor interaction relationship. Although these default exponents serve as a good initial estimate, adjustments to some of the exponents may be needed to better reflect the behavior of the composite.

SiC/Ti-6-4

METCAN predictions of transverse strengths for SiC/Ti-6-4 at three different temperatures (73°, 600°, and 800 °F) for a fvr = 0.34 are shown in figure 13. Differences between METCAN predictions and experimental results are minimal and the observed experimental degradation in strengths with increasing temperature is accurately predicted by METCAN. Examination of the room temperature stress-strain behavior (fig. 14) shows an almost exact match between METCAN and experiment.

CONCLUSIONS

The significant conclusion from the verification of the metal matrix composites examined, is that METCAN predictions are in good agreement with experimental data. Comparisons of METCAN generated values of moduli and Poisson's ratios at room temperature and strengths at room and high temperatures for the SiC/Ti-15-3 composite as well as comparisons of room and high temperature transverse strengths for the SiC/Ti-6-4 composite against experimental values resulted in minimal differences. Examination of the METCAN stress-strain predictions for both composites also produced good agreement with experimental values. The overall agreement between METCAN predictions and experimental data lends credence to the use of the integrated approach in METCAN and the multi-factor interaction relationship to represent nonlinear behavior. The results of the verification indicate that METCAN can be used with confidence to simulate the high temperature nonlinear behavior of metal matrix composites.

APPENDIX - SYMBOLS AND NOTATION

E	Young's modulus
fvr	fiber volume ratio
G	shear modulus
S	strength
T_C	consolidation temperature
T_m	melting temperature
α	coefficient of thermal expansion
ν	Poisson's ratio
ρ	weight density

<u>Subscripts</u>

11	direction along the fiber
22	direction transverse to the fiber

REFERENCES

1. D.A. Hopkins, and C.C. Chamis, "A Unique Set of Micromechanics Equations for High Temperature Metal Matrix Composites," NASA TM-87154, 1985.

2. C.C. Chamis, and D.A. Hopkins, "Thermoviscoplastic Nonlinear Constitutive Relationships for Structural Analysis of High Temperature Metal Matrix Composites," NASA TM-87291, 1985.

3. C.C. Chamis, P.L.N. Murthy, and D.A. Hopkins, "Computational Simulation of High Temperature Metal Matrix Composites Cyclic Behavior," NASA TM-102115, 1988.

4. P.L.N. Murthy, D.A. Hopkins, and C.C. Chamis, "Metal Matrix Composite Micromechanics: In-Situ Behavior Influence on Composite Properties," NASA TM-102302, 1989.

5. C.C. Chamis, J.J. Caruso, H.-J. Lee, and P.L.N. Murthy, METCAN Verification Status. NASA TM-103119, 1990.

6. Private communication from B.A. Lerch, NASA Lewis Research Center, Nov. 1989.

7. P.R. Nimmer, R.J. Bankert, E.S. Russell, and G.A. Smith, "Micromechanical Modeling of Fiber/Matrix Interface Effects in Transversely Loaded SiC/Ti-6-4 Metal Matrix Composites," The 13th Conference on Metal Matrix, Carbon, and Ceramic Matrix Composites, Pt. 2, J.D. Buckley, Editor, NASA CP-3054-Pt-2, 1990, pp. 493-514.

TABLE I. - CONSTITUENT (FIBER/MATRIX) MATERIAL PROPERTIES USED IN METCAN

	Material Properties			
	Fiber		Matrix	
	SiC[a]	SiC[b]	Ti-15-3[a]	Ti-6-4[b]
ρ, lb/in.^{3}	0.110	0.108	0.172	0.170
T_m, °F	4870	4500	3000	3000
E_{11}, Mpsi	62	60	12	17
E_{22}, Mpsi	62	60	12	17
G_{12}, Mpsi	26	20	5	7
ν_{12}	0.19	0.30	0.32	0.30
α_{11}, ppm/°F	2.7	2.7	4.7	5.2
α_{22}, ppm/°F	2.7	2.7	4.7	5.2
S_{11}, ksi	500	500	130	131
S_{22}, ksi	500	500	130	131
S_{12}, ksi	300	250	78	78

[a]Private communication from B.A. Lerch, NASA Lewis Research Center.
[b]Reference 6.

TABLE II. - VALUES OF MATRIX EXPONENTS CALCULATED FROM EXPERIMENTAL DATA

[Default values for matrix exponents are 0.50 while the fiber exponents are 0.25.]

Exponent[a]	Matrix	
	Ti-15-3	Ti-6-4
Modulus - temperature	0.132	0.587
Modulus - stress	.423	(b)
Strength - temperature	.290	.902
CTE[c] - temperature	-.122	-.037

[a]See figure 2.
[b]Insufficient constituent experimental data to determine exponent.
[c]CTE = Coefficient of Thermal Expansion.

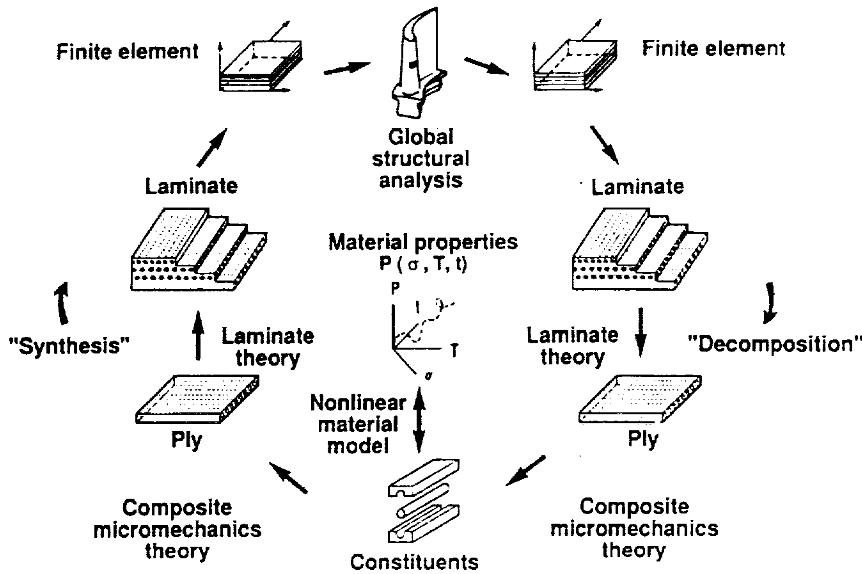
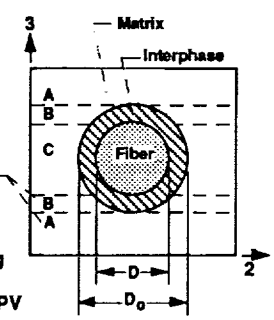


Figure 1.—Integrated approach to metal-matrix composite analysis.

$$\frac{P}{P_O} = \left[\frac{T_F - T}{T_F - T_O}\right]^n \left[\frac{S_F - \sigma}{S_F - \sigma_O}\right]^m \left[\frac{\dot{S}_F - \dot{\sigma}_O}{\dot{S}_F - \dot{\sigma}_O}\right]^{\ell} \left[\frac{\dot{T}_F - \dot{T}}{\dot{T}_F - \dot{T}_O}\right]^k \left[\frac{R_F - R}{R_F - R_O}\right]^p \ldots$$

$$\ldots \left[\frac{N_{MF} - N_M}{N_{MF} - N_{MO}}\right]^q \left[\frac{N_{TF} - N_R}{N_{TF} - N_{TO}}\right]^r \left[\frac{t_F - t}{t_F - t_O}\right]^s \ldots$$



Rationale:

- Gradual effects during most range, rapidly degrading near final stages
- Representative of the in situ behavior for fiber, matrix, interphase, coating
- Introduction of primitive variables (PV)
- Consistent in situ representation of all constituent properties in terms of PV
- Room–temperature values for reference properties
- Continuous interphase growth
- Simultaneous interaction of all primitive variables
- Adaptability to new materials
- Amenable to verification inclusive of all properties
- Readily adaptable to incremental computational simulation

Notations:

P – property; T – temperature; S – strength; R – metallurgical reaction; N – number of cycles: t – time; over dot – rate; subscripts: O – reference; F – final; M – mechanical; T – thermal

Figure 2.—Assumed multifactor interaction relationship to represent the various factors which influence in situ constituent materials behavior.

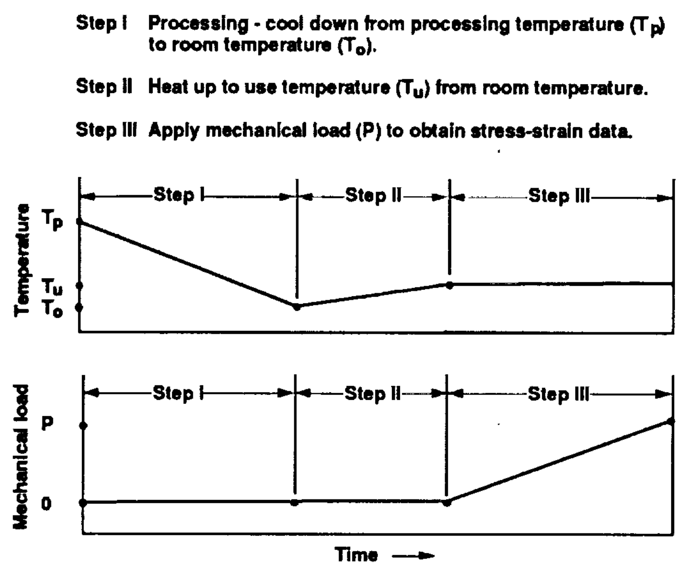


Figure 3.—Computational sequence for the METCAN simulation.

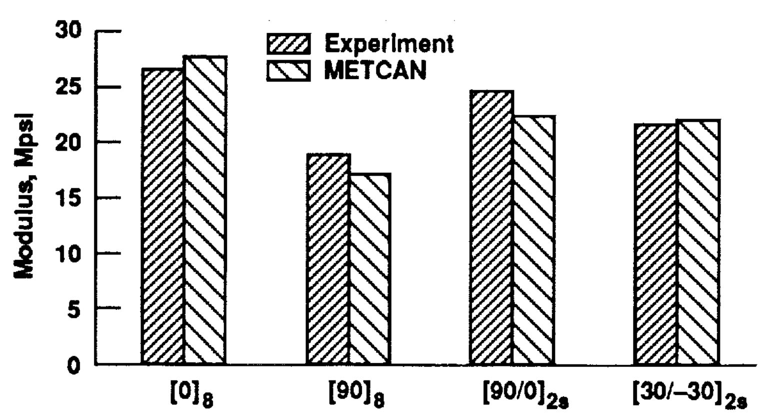


Figure 4.—METCAN predictions of room–temperature elastic moduli for SiC/Ti–15–3; fiber volume ratio, 0.34.

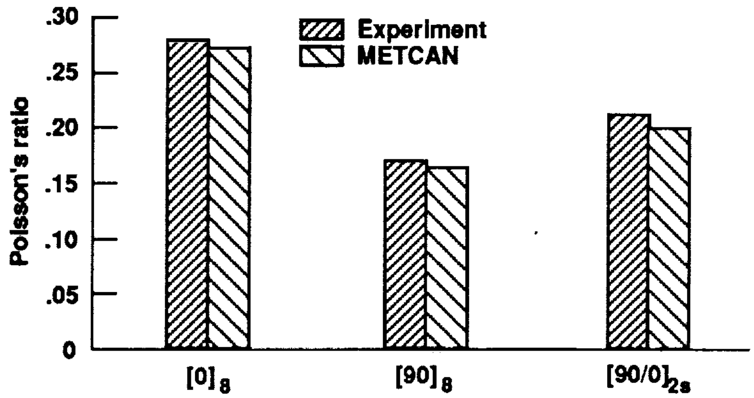


Figure 5.—METCAN predictions of room-temperature Poisson's ratio for SiC/Ti–15–3; fiber volume ratio, 0.34.

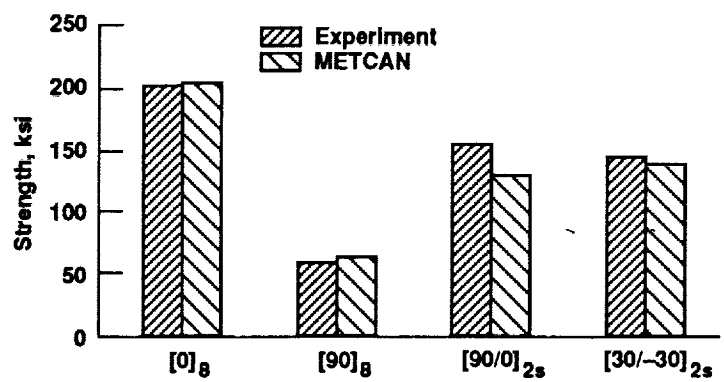


Figure 6.—METCAN predictions of room-temperature strengths for SiC/Ti–15–3; fiber volume ratio, 0.34.

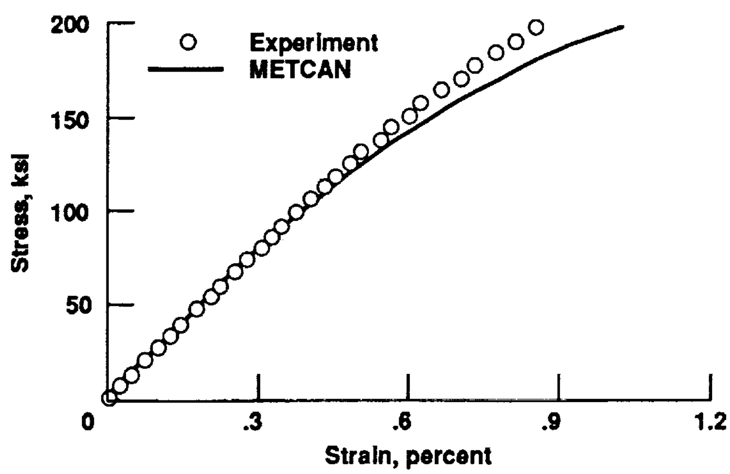


Figure 7.—SiC/Ti–15–3 stress–strain for [0]$_8$ at 70 °F; fiber volume ratio, 0.34.

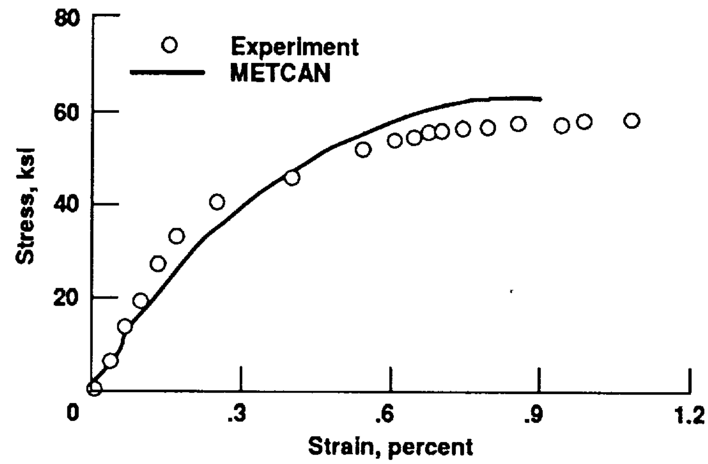


Figure 8.—SiC/Ti-15-3 stress-strain for $[90]_8$ at 70 °F; fiber volume ratio, 0.34.

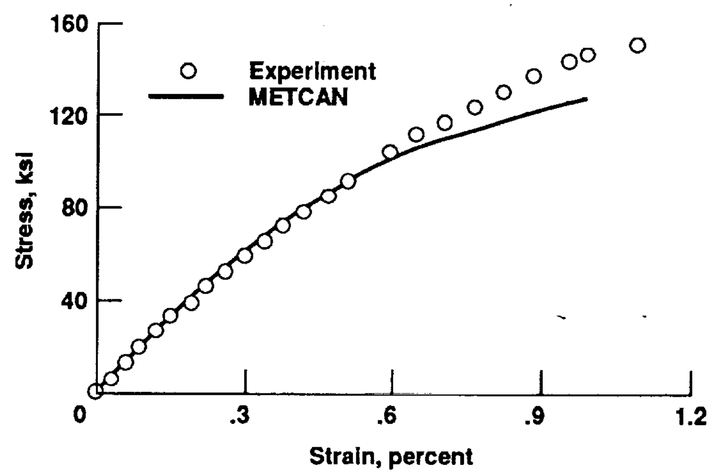


Figure 9.—SiC/Ti-15-3 stress-strain for $[90/0]_{2s}$ at 70 °F; fiber volume ratio, 0.34.

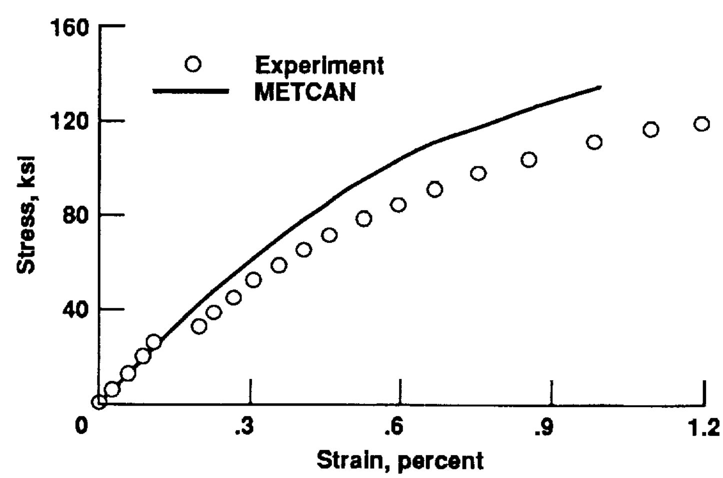


Figure 10.—SiC/Ti-15-3 stress-strain for $[30/-30]_{2s}$ at 70 °F; fiber volume ratio, 0.34.

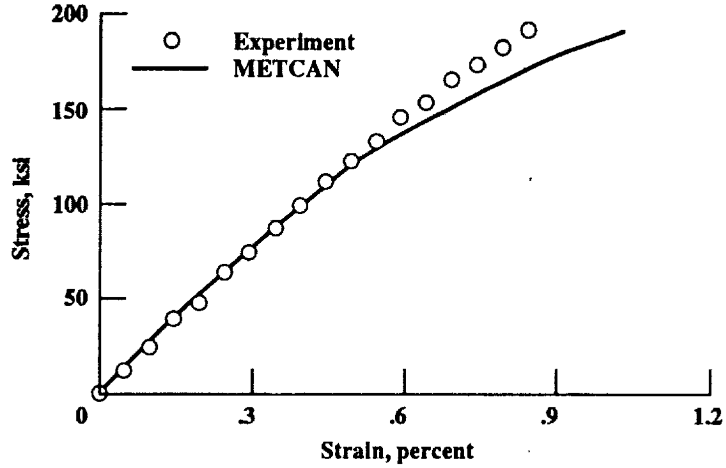


Figure 11.—SiC/Ti–15–3 stress–strain for [0] at 800 °F; fiber volume ratio, 0.34.

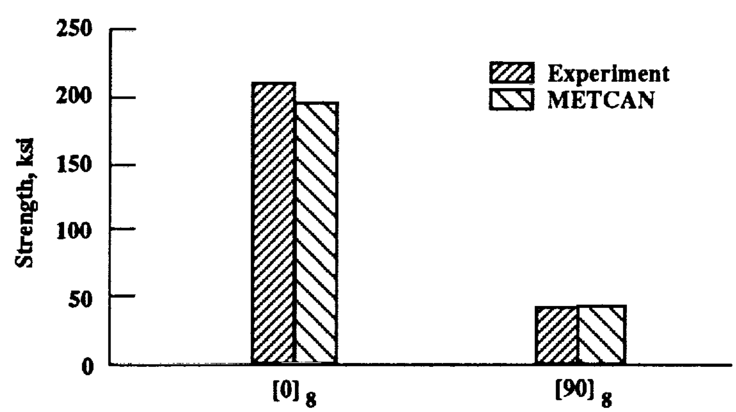


Figure 12.—METCAN predictions of high–temperature (800 °F) strengths for SiC/Ti–15–3; fiber volume ratio, 0.34.

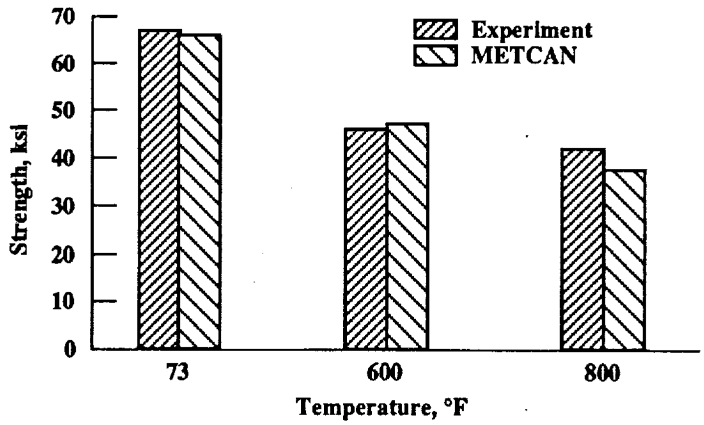


Figure 13.—METCAN predictions of transverse strength of SiC/Ti–6–4; fiber volume ratio, 0.34.

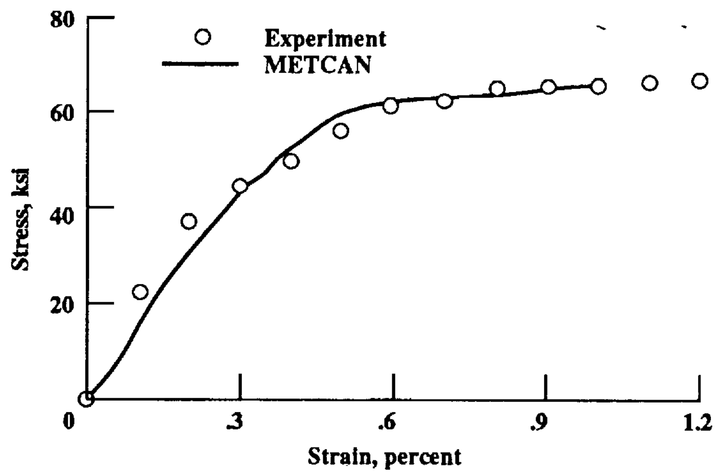


Figure 14.—Transverse stress–strain of SiC/Ti–6–4 at 73 °F; fiber volume ratio, 0.34.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-103682	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle METCAN Updates for High Temperature Composite Behavior: Simulation/Verification		5. Report Date
		6. Performing Organization Code
7. Author(s) H.-J. Lee, P.L.N. Murthy, and C.C. Chamis		8. Performing Organization Report No. E-5899
		10. Work Unit No. 510-10-50
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the 36th International SAMPE Symposium and Exhibition, San Diego, California, April 15-18, 1991.

16. Abstract

The continued verification (comparisons with experimental data) of the METCAN (Metal Matrix Composite Analyzer) computer code is updated. Verification includes comparisons at room and high temperatures for two composites, SiC/Ti-15-3 and SiC/Ti-6-4. Specifically, verification of the SiC/Ti-15-3 composite includes comparisons of strength, modulus, and Poisson's ratio as well as stress-strain curves for four laminates at room temperature. High temperature verification includes comparisons of strength and stress-strain curves for two laminates. Verification of SiC/Ti-6-4 is for a transverse room temperature stress-strain curve and comparisons for transverse strength at three temperatures. Results of the verification indicate that METCAN can be used with confidence to simulate the high temperature nonlinear behavior of metal matrix composites.

17. Key Words (Suggested by Author(s)) Metal matrix composite; Verification; Strength; Modulus; In-situ; Constituent; Nonlinear behavior; High temperature	18. Distribution Statement Unclassified – Unlimited Subject Category 24

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	14	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161