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Metal Matrix Composite Micromechanics: In-Situ Behavior Influence on Composite Properties

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METAL MATRIX COMPOSITE MICROMECHANICS:

IN-SITU BEHAVIOR INFLUENCE ON COMPOSITE PROPERTIES

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ABSTRACT

Recent efforts in computational mechanics methods for simulating the nonlinear behavior of metal matrix composites have culminated in the implementation of the Metal Matrix Composite Analyzer (METCAN) computer code. In METCAN material nonlinearity is treated at the constituent (fiber, matrix, and interphase) level where the current material model describes a time-temperature-stress dependency of the constituent properties in a "material behavior space." The composite properties are synthesized from the constituent instantaneous properties by virtue of composite micromechanics and macromechanics models. The behavior of metal matrix composites depend on 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 matrix. The present paper focuses on various aspects of in-situ property influence on composite behavior. Specifically, the influence of in-situ matrix strength and the interphase degradation on the unidirectional composite stress-strain behavior is examined. These types of studies provide insight into micromechanical behavior that may be helpful in resolving discrepancies between experimentally observed composite behavior and predicted response.

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SYMBOLS AND NOTATION

subscripts 11	Direction along the fiber
subscripts 22,33	Directions transverse to the fiber
subscripts f,m,c	Fiber, Matrix, and Composite
subscripts o,F	Reference and Final values
D_f	Diameter of the fiber
E	Young's Modulus
G	Shear Modulus
S	Strengths
T_M	Melting temperature
T_0	Room temperature
T	Current or use temperature
N_{TF}	Thermal cyclic limit
N_{MF}	Mechanical cyclic limit
$N_{T,M}$	Thermal and Mechanical cycles
P	Property
R	Reaction
$\dot{S}$	Stress rate
t	Time
α	Thermal expansion coefficient
ν	Poisson's Ratio
ρ	Weight density
σ	Stress
$\dot{\sigma}$	Stress rate

INTRODUCTION

High temperature metal matrix composites (HTMMC) are emerging as materials with potentially high payoffs in aerospace structural applications. Realization of these payoffs depends on the parallel and synergistic development of: (1) a technology base for fabricating HTMMC structural components, (2) experimental techniques for measuring their thermal and mechanical characteristics, and (3) computational methodologies for predicting their nonlinear behavior in complex service environments. In fact, it might be argued that the development of computational methodologies should precede the others because the structural integrity and durability of HTMMC can be computationally simulated, and the potential payoff for a specific application can be assessed, at least qualitatively. In this way, it is possible to minimize the costly and time consuming experimental effort that would otherwise be required in the absence of a predictive capability.

Recent research at NASA Lewis is directed towards the development of a computational capability to predict the nonlinear behavior of HTMMC. This capability is schematically depicted in figure 1. As seen in this figure, the capability consists of several computational modules encompassing the material constitutive behavior (bottom), composite micro/macro mechanics (sides), and the finite element analysis of structural components (top). The left part of the figure represents the synthesis of composite thermal/mechanical property variables, while the right part represents the decomposition of composite response variables. In the synthesis, the properties needed for structural analysis are generated while in the decomposition the local stresses needed to update the constituent instantaneous properties are calculated. The local stresses are used to calculate the ply microstresses (the stresses in the constituents). The dependence of the constituent material properties on temperature, stress, and several additional factors is defined in a "material behavior space" as depicted at the bottom center of the figure. The simulation (synthesis and decomposition) is performed using an incremental-iterative nonlinear analysis where convergence is enforced at every scale (ply, laminate, and structure) of the simulation. A detailed description of this multi-scale simulation strategy is given in reference [1]. A stand alone computer code has been developed to expedite the computational simulation process from the constituent materials level up to the laminate level. This simulation capability is encircled with the dashed line in figure 1. The stand-alone computer code is identified as METCAN for Metal Matrix Composite Analyzer.

CONSTITUENT MULTI-FACTOR MATERIAL MODEL

The various factors, which influence the constituent material behavior and ultimately the HTMMC behavior, are incorporated through a multi-factor interaction relationship shown in figure 2 where the rationale for adopting this type of relationship is summarized. Additional discussion on this relationship and its application can be found in reference [2]. Because of the unique representation of the unit cell with different intralaminar subregions, the model has a utility for studying the influences of the individual constituent in-situ behavior on the global response. In the present effort the in-situ matrix strength and the interphase mechanical properties are selected for the parametric studies.

A limited amount of predicted results has been generated using the METCAN code in order to verify/validate the multifactor interaction relationship with experimental data. These results can be found in reference [3]. Some of the concerns with the HTMMC performance are the low experimentally measured transverse strengths, low thermal fatigue life and fabrication induced residual thermal stresses due to the coefficient of thermal expansion mismatch between the fiber and matrix. The unanticipated poor performance observed from these materials could be due to a lack of knowledge of proper in-situ constituent behavior, improper consolidation between the constituents, or an interphase growth due to a chemical reaction between the fiber and matrix leading to a weak bond between the constituents. To understand the causes of poor HTMMC performance, one needs insight into the composite behavior sensitivity to in-situ constituent properties. Such insight can be readily gained either by performing routine parametric studies using computational simulation or by conducting costly experiments.

In the present work the METCAN computer code is used to study the behavior at room and high temperature of SiC/Ti-15-3-3-3 (where SiC stands for Silicon Carbide fiber and Ti-15-3-3-3 stands for an alloy of Titanium with 15% Vanadium, 3% Aluminum, 3% Chromium, and 3% Tin) metal matrix composite. The motivation in selecting this particular composite for the study is provided by the wide recognition it has already received as a viable candidate for some of the high temperature applications associated with the National Aerospace Plane (NASP). Also, additional experimental testing is currently underway at NASA Lewis Research Center which will provide an opportunity for the verification/validation of the METCAN code. The specific objectives for the present work are: (1) to study the influence of the in-situ matrix strength on the room/high temperature response of unidirectional metal matrix composites, and (2) to study the influence of the interphase and its degradation on the room/high temperature response of unidirectional metal matrix composites.

CASES STUDIED

The metal matrix system, SiC/Ti-15-3-3-3 , is selected as the candidate for the present study. All the numerical results are obtained for a unidirectional laminate made of the above mentioned metal matrix composite. The fiber volume fraction is chosen to be 0.40 throughout the study. The nominal properties of SiC fiber and Ti-15-3-3-3 matrix used in the present study are given in Table I. Also presented in Table I are the room temperature composite properties predicted by METCAN. The study is divided into two parts; for the first part no interphase is taken into account, for the second part a distinct interphase is assumed. In the first part of the study, three different values for the in-situ matrix strength are used in the analysis. The in-situ strength values considered are 100% of the reference (room temperature) matrix strength, 50% of the reference strength, and 25% of the reference strength. Thus the matrix normal strengths chosen are 130, 65, and 32.5 ksi (tensile and compressive) respectively. The matrix shear strengths chosen are 91, 45.5, and 22.8 ksi respectively. For the second part of the study an interphase with a thickness equal to one percent of the fiber diameter is assumed to exist. Three sets of mechanical properties for the interphase are considered in the study, as follows: (1) interphase properties are the same as the matrix properties, (2) interphase properties are 50% of the matrix properties, and (3) interphase properties are 25% of the matrix properties. In this manner, the effect of interphase degradation on the composite behavior can be assessed.

The uniaxial stress-strain behavior of the metal matrix composite is examined as an indicator of composite response and is obtained at two different use temperatures; ambient or room temperature (70° F) and elevated temperature (1200° F). The composite stress-strain response is examined under five separate monotonic loading conditions; longitudinal tension, longitudinal compression, transverse tension, transverse compression and in-plane shear. To account for the composite residual stresses induced by the processing conditions, the cool-down history from the consolidation temperature (zero stress state) to room temperature (70° F) is simulated prior to the application of mechanical loading in all the cases studied. For the high temperature stress-strain behavior, heat-up from room temperature to 1200°F is simulated, as well, prior to the application of mechanical loading. The data necessary to plot the stress-strain behavior under different loading conditions is generated using METCAN. The thermal/mechanical load is applied incrementally until global failure is indicated. For each step the local cumulative microstresses in each region are checked against the respective strength limits. When a particular stress exceeds the limit the corresponding stiffness (modulus) is set to a low value (0.01 psi) to effectively represent zero stiffness. For example, if the local stress in matrix region A (σ_{m11A}) exceeds its allowable strength limit, then the value for modulus E_{m11A} is set to 0.01 psi. The incremental analysis is continued in this manner until the damage accumulated is sufficient enough to cause global failure of the structure. In the present study global failure is considered to occur at that point in the loading history where: (1) further load increase would cause an order of magnitude increase in strain, or (2) an abrupt change occurs in the slope of the stress-strain curve.

RESULTS AND DISCUSSION

The results of the study are shown as stress (ksi) versus strain (%) curves in figures 3-12. Each figure contains two sets of curves. The solid lines represent room temperature stress-strain response whereas the dashed lines represent high temperature (1200° F) response. Each set consists of three curves (A,B,C) that represent the three different cases of in-situ matrix strength in figs. 3-7 and the three different sets of properties assumed for the interphase in figs. 8-12.

Influence of in-situ matrix strength on unidirectional composite behavior

Figures 3 and 4 show the behavior under longitudinal tension and compression loading respectively of a unidirectional SiC/Ti-15-3-3-3 composite. The curves show an initial negative (compressive) strain at zero load due to the processing induced residual strains. From these results the following observations are made:

(1) The room/high temperature plots show similar trends. Both sets start at different initial compressive strains. The initial strain in room temperature predictions is due to processing. Additional strains due to heat-up are also present in the second set which corresponds to the 1200° F stress-strain predictions. Here, the heating has alleviated the initial residual strain due to processing. Both cases show a slight decrease in the ultimate strength at 1200° F.

(2) For each set, the ultimate strength in tension/compression is reached at approximately the same strain level. However, the stress level at failure is substantially smaller for the tensile loading case than it is for the compressive loading case. Also to be noted is the higher strength predictions in compression than in tension. The primary reason for this is that the fiber allowable strength in tension is assumed to be 500 ksi whereas its compressive strength is assumed to be 650 ksi (Table I). The present model does not account for the fiber microbuckling failure mode which

may actually be the governing failure mode in compression. The fiber microbuckling will reduce the compresive strength substantially and therefore, the compressive strength predicted by the present model may be overly optimistic.

(3) About 10 to 20 percent reduction in the composite longitudinal strength resulted as a consequence of the in-situ matrix strength degradation. The behavior of the composite is essentially fiber dominated for this type of loading. This explains why the composite strength does not show degradation in the same proportion as the matrix strength degradation.

(4) The initial tangent modulus for all three cases of each temperature set appears to be the same for the longitudinal compression loading behavior. There appears to be a slight decrease in the initial tangent modulus (of the room temperature set) for the longitudinal tension loading. Also, the behavior in longitudinal compression exhibits more pronounced reduction in initial tangent modulus due to the increase in use temperature.

Based upon the above observations it can be concluded that in the absence of an interphase the longitudinal strength of the unidirectional composite exhibits only about a 10 to 20 percent loss even though the matrix strength has been reduced drastically. Hence, one can infer that if experimentally observed strengths are substantially lower than those predicted, then it is more than likely that fibers were damaged during the processing of the composite. Also, a fiber microbuckling failure mode needs to be incorporated into the model in order to obtain more realistic compressive strengths.

Figures 5 and 6 show the behavior of the composite under transverse tension and compression loading. Following is a list of significant observations that can be made from the results.

(1) Similar to the longitudinal loading case, the room/high temperature stress-strain behaviors show similar trends, however, the reduction in strength is quite substantial due to transverse

loading. Both the ultimate strength and strain suffer severe degradation due to an increase in the use temperature except for case C of figure 5. This is due to the matrix dominance on composite behavior and matrix sensitivity to elevated temperature.

(2) The strain and the ultimate stress at which global failure occurs show drastic reduction with the decrease in matrix strength. This is due to the matrix dominated behavior of the unidirectional composite in transverse tension/compression. As with the longitudinal tension/compression loading cases, the stress limits predicted are much higher for the loading in compression as opposed to the loading in tension.

(3) The reduction in composite transverse strength is almost in the same proportion as the reduction in matrix strength.

(4) The initial tangent modulus also shows significant reduction with the reduction in the strength of matrix for the room temperature curves.

An important general conclusion from the above observations is that the transverse response is very sensitive to the in-situ matrix strength variations. Hence, one can expect a significant scatter in experimental data for transverse strengths as well as extremely low values for the composite strength in the transverse direction. Therefore, the in-situ matrix properties must be known precisely in order to correlate experimental data and predictions with acceptable accuracy.

The behavior of the composite in in-plane shear loading is depicted in figure 7. It is seen from the figure that the ultimate stress and strain are reduced significantly with reduction in matrix strength as well as with the increase in use temperature. The initial tangent modulus appears to be unaffected by the reduced matrix strength. However, with the increase in use temperature this initial tangent modulus does show significant degradation. All the plots start at zero strain where no load is applied. This is to be expected because there is no residual shear strain present due to the processing induced residual stresses. Note that the same general conclusion mentioned above for transverse tension/compression applies to the composite behavior in in-plane shear as well, namely that in-plane shear is very sensitive to in-situ matrix strength degradations.

Influence of interphase property degradation on unidirectional composite behavior

The influence of interphase property degradation on the behavior of a unidirectional SiC/Ti-15-3-3-3 composite in longitudinal tension/compression is shown in figures 8 and 9 respectively. The differences among curves A, B and C appear to be minor. The residual strain due to processing is seen to be different for each case A, B and C. This results in a slight lateral shift of the response. Higher use temperature has alleviated the residual strain significantly. The ultimate strength in compression is seen to be higher than in tension. This is due to the higher fiber strength assumed in compression than in tension. The reduction in the ultimate strength due to the interphase degradation is negligible.

Figures 10 and 11 show the influence of the interphase degradation on the transverse stress-strain response in tension/compression respectively. The ultimate strength exhibits substantial reduction due to the degradation in the interphase properties. Also, the behavior in transverse compression appears to be affected much more severely than the transverse tension. The higher use temperature has primarily resulted in substantial reductions in the ultimate strengths for case A. Cases B and C show degradation due to higher use temperature only for tension loading. In addition, there is a significant reduction in the initial tangent modulus due to higher use temperature in the case of transverse compression loading.

The behavior due to in-plane shear loading is shown in figure 12. Here, it is seen that the interphase has almost negligible influence on the response. The ultimate strain shows a minimal increase with the interphase degradation. The higher use temperature response shows similar trends with significant reductions in the overall shear modulus and the ultimate in-plane shear strength.

The interphase in metal matrix composites can be caused by a chemical reaction between fiber and matrix, or by an intentional introduction of a compliant coating on the fiber which can be thought of as an interphase for the present discussion. Based on the results in figures 8-12, it can be concluded that the longitudinal and in-plane shear behavior of the composite is not significantly affected. The transverse behavior is drastically altered due to the interphase degradation. Hence, a low transverse strength observed experimentally may be indicative of a weak interphase or improper consolidation between the fiber and matrix.

SUMMARY

Based on the computational studies performed with METCAN for the SiC/Ti-15-3-3-3 unidirectional composite the following conclusions are reached:

(1) The in-situ matrix strength substantially influences the transverse tensile/compressive strengths. For the range of matrix strengths considered, the reduction in composite transverse strengths is in direct proportion to the reduction in matrix strength.

(2) The longitudinal tensile/compressive strength of the composite exhibits about a 10 to 20 percent reduction due to the reduction in matrix strength, for the range considered.

(3) The in-plane shear strength is severely reduced due to the in-situ matrix strength variations. A maximum of 50 percent reduction in in-plane shear strength occurs for the range of in-situ matrix strengths considered.

(4) The influence of the interphase degradation on the longitudinal tension/compression and in-plane shear behavior is negligible.

(5) The behavior in transverse tension/compression is affected drastically by the interphase degradation. Both the ultimate strength and strain reduce substantially.

(6) The primary effect of higher use temperature specific to interphase degradation cases is a reduction in composite strength with the exception of the behavior under transverse compression loading where the reduction in strength occurs only for case A curves. For compression and in-plane shear loading a reduction in the initial tangential modulus occurs, as well as the reduction in the ultimate strength.

(7) In general, degradation in in-situ matrix strength and the presence of a weak interphase dramatically affect the matrix dominated composite behavior and have negligible effects on the fiber dominated composite behavior.

REFERENCES

1. Hopkins, D. A., 1984, "Nonlinear Analysis of High-Temperature Multilayered Fiber Composite Structures," NASA TM-83754.

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

3. Chamis, C. C., Murthy, P. L. N., and Hopkins, D. A., 1988, "Computational Simulation of High Temperature Metal Matrix Composites Cyclic Behavior," Presented at the ASTM Symposium on Thermal and Mechanical Behavior of Ceramic and Metal Matrix Composites, Atlanta, Georgia.

TABLE I. Nominal Constituent Properties and Predicted Composite Properties at Room Temperature

SiC Fiber		Ti-15-3-3-3 Matrix		Composite	
ρ_f	.11 lb/in^3	ρ_m	.172 lb/in^3	ρ_c	.147 lb/in^3
E_f	62 Mpsi	E_m	12.3 Mpsi	E_{c11}	31.2 Mpsi
ν_f	.3 in/in	ν_m	.32 in/in	E_{c22}	18.5 Mpsi
G_f	23.8 Mpsi	G_m	4.7 Mpsi	E_{c33}	18.5 Mpsi
α_f	1.8 ppm	α_m	4.5 ppm	G_{c12}	7.7 Mpsi
T_{Mf}	4870 deg. F	T_{Mm}	1800 deg. F	G_{c23}	6.9 Mpsi
S_{f11T}	500 ksi	S_{mT}	130 ksi	G_{c13}	7.7 Mpsi
S_{f11C}	650 ksi	S_{mC}	130 ksi	ν_{c12}	.31 in/in
S_{f22T}	500 ksi	S_{mS}	91 ksi	ν_{c23}	.33 in/in
S_{f22C}	650 ksi			ν_{c13}	.31 in/in
S_{f12S}	300 ksi			α_{c11}	2.9 ppm
D_f	5.6 mils			α_{c22}	3.2 ppm
				α_{c33}	3.2 ppm

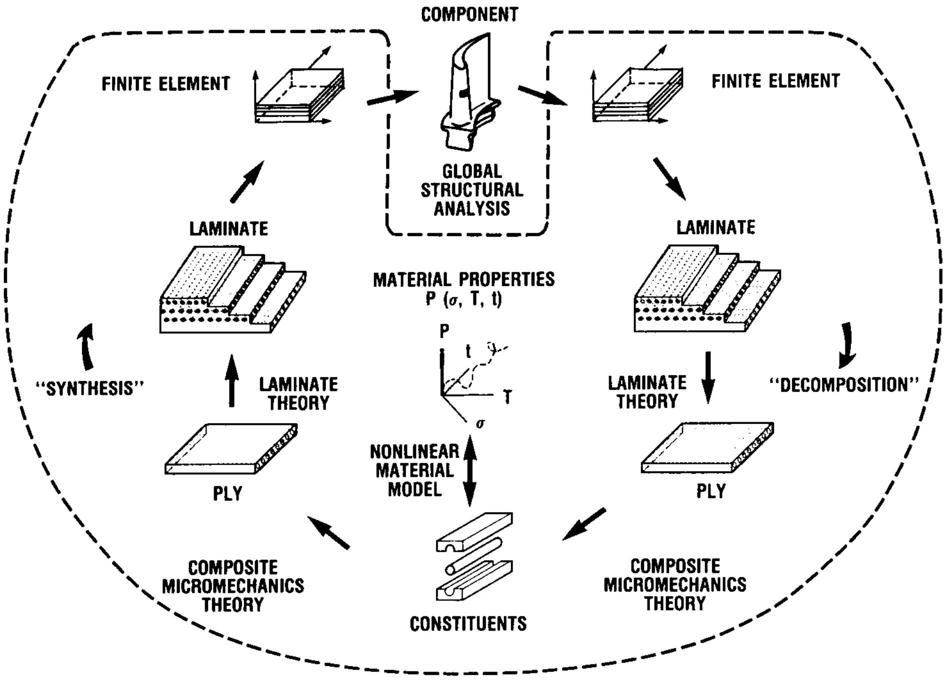
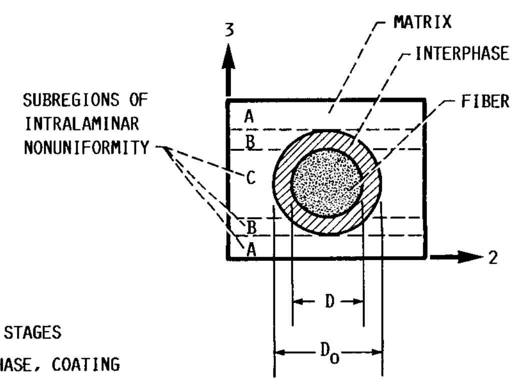


Figure 1. - Integrated multi-scale approach to metal matrix composite analysis.

$$\frac{P}{P_0} = \left[\frac{T_F - T}{T_F - T_0}\right]^n \left[\frac{S_F - \sigma}{S_F - \sigma_0}\right]^m \left[\frac{\dot{S}_F - \dot{\sigma}_0}{\dot{S}_F - \dot{\sigma}}\right]^{\ell} \left[\frac{\dot{T}_F - \dot{T}}{\dot{T}_F - \dot{T}_0}\right]^k \left[\frac{R_F - R}{R_F - R_0}\right]^p \ldots$$

$$\ldots \left[\frac{N_{MF} - N_M}{N_{MF} - N_{MO}}\right]^q \left[\frac{N_{TF} - N_T}{N_{TF} - N_{TO}}\right]^r \left[\frac{t_F - t}{t_F - t_0}\right]^s \ldots .$$



RATIONALE:

- GRADUAL EFFECTS DURING MOST RANGE, RAPIDILY 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

Figure 2. - Multifactor interaction relationship for in-situ constistuent material behavior.

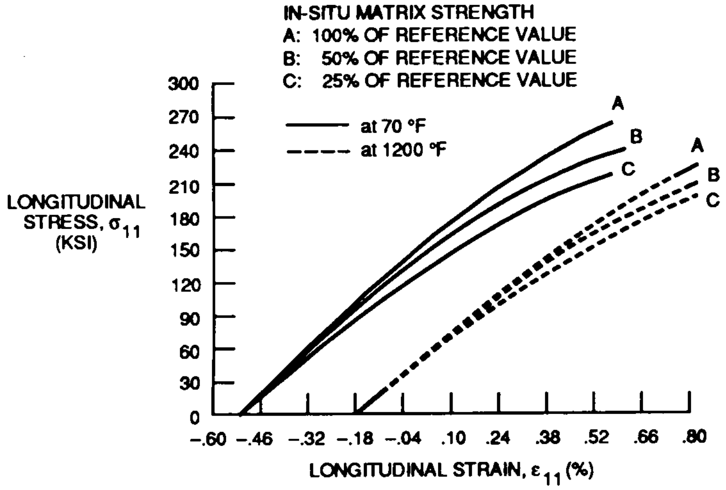


Figure 3. - Influence of in-situ matrix strength on the response of SiC/Ti-15-3-3-3 unidirectional composite in longitudinal tension.

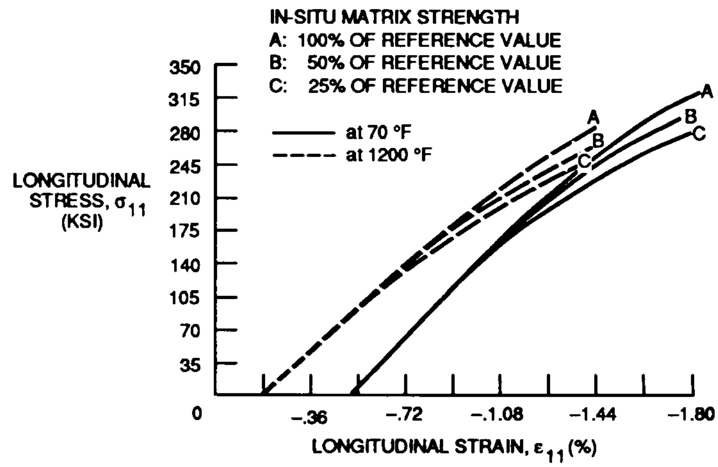


Figure 4. - Influence of in-situ matrix strength on the response of SiC/Ti-15-3-3-3 unidirectional composite in longitudinal compression.

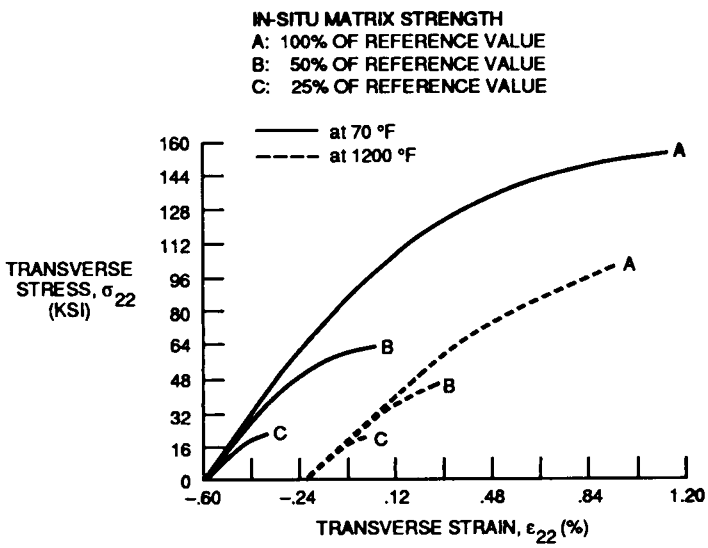


Figure 5. - Influence of in-situ matrix strength on the response of SiC/Ti-15-3-3-3 unidirectional composite in transverse tension.

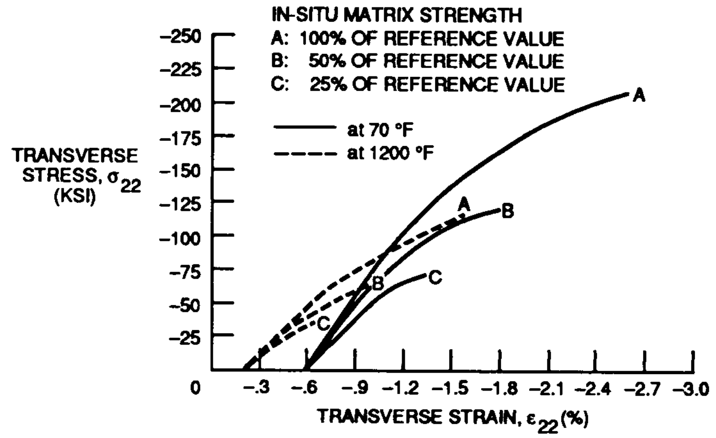


Figure 6. - Influence of in-situ matrix strength on the response of SiC/Ti-15-3-3-3 unidirectional composite in transverse compression.

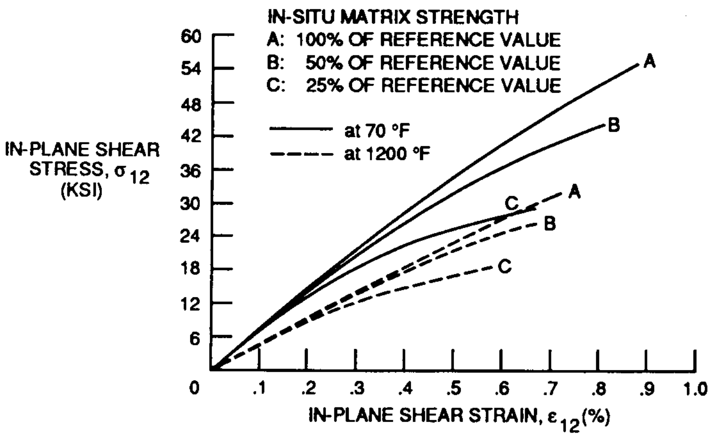


Figure 7. - Influence of in-situ matrix strength on the response of SiC/Ti-15-3-3-3 unidirectional composite in in-plane shear.

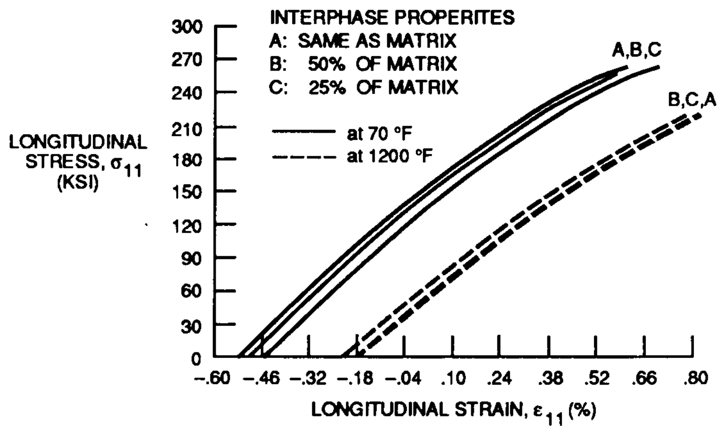


Figure 8. - Influence of interphase property degradation on the response of SiC/Ti-15-3-3-3 unidirectional composite in longitudinal tension.

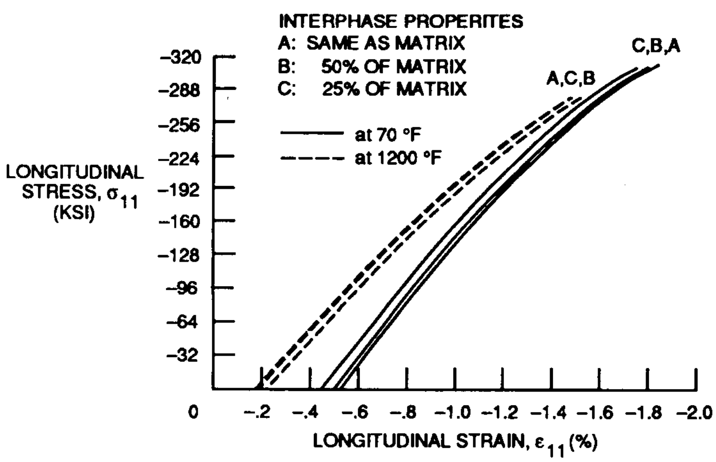


Figure 9. - Influence of interphase property degradation on the response of SiC/Ti-15-3-3-3 unidirectional composite in longitudinal compression.

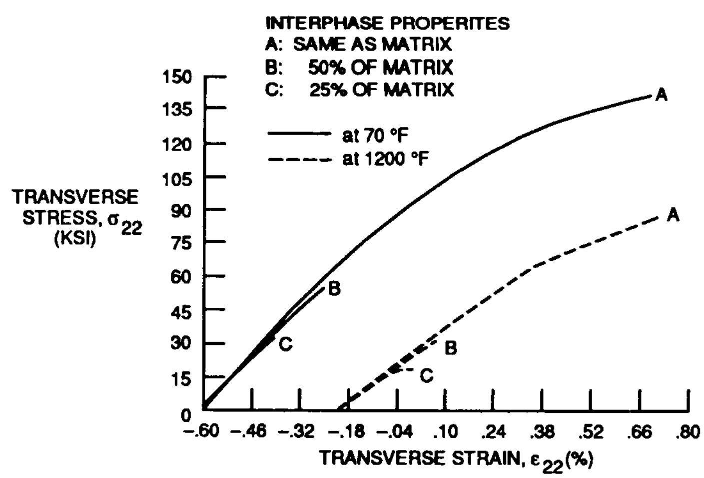


Figure 10. - Influence of interphase property degradation on the response of SiC/Ti-15-3-3-3 unidirectional composite in transverse tension.

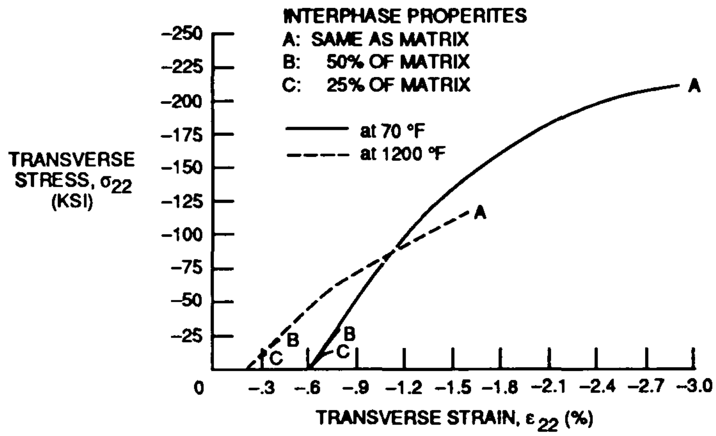


Figure 11. - Influence of interphase property degradation on the response of SiC/Ti-15-3-3-3 unidirectional composite in transverse compression.

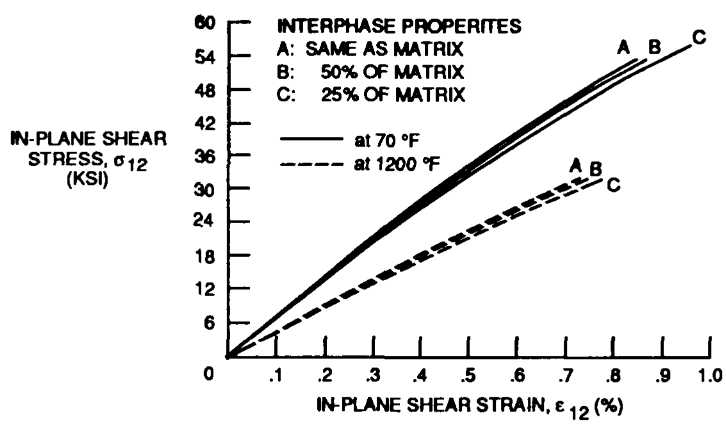


Figure 12. - Influence of interphase property degradation on the response of SiC/Ti-15-3-3-3 unidirectional composite in in-plane shear.

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16. Abstract

Recent efforts in computational mechanics methods for simulating the nonlinear behavior of metal matrix composites have culminated in the implementation of the Metal Matrix Composite Analyzer (METCAN) computer code. In METCAN material nonlinearity is treated at the constituent (fiber, matrix, and interphase) level where the current material model describes a time-temperature-stress dependency of the constituent properties in a ''material behavior space.'' The composite properties are synthesized from the constituent instantaneous properties by virtue of composite micromechanics and macromechanics models. The behavior of metal matrix composites depend on 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 matrix. The present paper focuses on various aspects of in-situ property influence on composite behavior. Specifically, the influence of in-situ matrix strength and the interphase degradation on the unidirectional composite stress-strain behavior is examined. These types of studies provide insight into micromechanical behavior that may be helpful in resolving discrepancies between experimentally observed composite behavior and predicted response.

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