

NASA/TM—2001-211125



Effect of Load Rate on Ultimate Tensile Strength of Ceramic Matrix Composites at Elevated Temperatures

Sung R. Choi
Ohio Aerospace Institute, Brook Park, Ohio

John P. Gyekenyesi
Glenn Research Center, Cleveland, Ohio

November 2001

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized data bases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301-621-0134
- Telephone the NASA Access Help Desk at 301-621-0390
- Write to:
NASA Access Help Desk
NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

NASA/TM—2001-211125



Effect of Load Rate on Ultimate Tensile Strength of Ceramic Matrix Composites at Elevated Temperatures

Sung R. Choi
Ohio Aerospace Institute, Brook Park, Ohio

John P. Gyekenyesi
Glenn Research Center, Cleveland, Ohio

Prepared for the
Finno-Ugric International Conference of Mechanics With Beda Symposium
sponsored by the Journal of Computational and Applied Mechanics
Budapest, Hungary, May 27–June 2, 2001

National Aeronautics and
Space Administration

Glenn Research Center

Acknowledgments

This work was supported in part by the UEET Program, NASA Glenn Research Center, Cleveland, Ohio.
The authors are grateful to R. Pawlik for the experimental work during the course of this work.

This report is a formal draft or working paper, intended to solicit comments and ideas from a technical peer group.

Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at <http://gltrs.grc.nasa.gov/GLTRS>

EFFECT OF LOAD RATE ON ULTIMATE TENSILE STRENGTH OF CERAMIC MATRIX COMPOSITES AT ELEVATED TEMPERATURES

Sung R. Choi
Ohio Aerospace Institute
Brook Park, Ohio 44142

John P. Gyekenyesi
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

ABSTRACT

Strength of three continuous fiber-reinforced ceramic composites, including SiC/CAS-II, SiC/MAS-5 and SiC/SiC, was determined as a function of test rate in air at 1100 to 1200 °C. All three composite materials exhibited a strong dependency of strength on test rate, similar to the behavior observed in many advanced monolithic ceramics at elevated temperatures. The application of the preloading technique as well as the prediction of life from one loading configuration (constant stress-rate) to another (constant stress loading) suggested that the overall macroscopic failure mechanism of the composites would be the one governed by a power-law type of damage evolution/accumulation, analogous to slow crack growth commonly observed in advanced monolithic ceramics. It was further found that constant stress-rate testing could be used as an alternative to life prediction test methodology even for composite materials, at least for short range of lifetimes and when ultimate strength is used as the failure criterion.

INTRODUCTION

The successful development and design of continuous fiber-reinforced ceramic composites (CFCCs) are dependent on a thorough understanding of basic properties such as fracture and delayed failure (slow crack growth, fatigue, or damage accumulation) behavior. Particularly, accurate evaluation of delayed failure behavior under specified loading/environment conditions is a prerequisite to ensure accurate life prediction of structural components.

This paper describes the effect of load rate on elevated-temperature ultimate tensile strength of three different Nicalon™ fiber-reinforced ceramic composites including SiC_f/calcium-aluminosilicate (CAS), SiC_f/magnesium-aluminosilicate (MAS) and SiC_f/silicon-carbide (SiC) ceramic composites. For each composite material, strength was determined in air as a function of test rate at elevated temperature of 1100 °C (SiC/CAS and SiC/MAS) or 1200 °C (SiC/SiC). This type of testing, when used for monolithic ceramics, is called "constant stress-rate" or "dynamic fatigue" testing [1 to 3]. The loading rate dependency of strength was analyzed with the power-law (damage) propagation, conventionally utilized for monolithic ceramics and glass. Preloading tests were conducted to better understand the governing failure mechanism(s) of the materials. Finally, the result of elevated-temperature constant stress ("static fatigue" or "stress rupture") testing was obtained for each material and compared with that of constant stress rate testing. This was done to further verify the overall failure mechanism of the material and to establish constant stress-rate testing as a means of life prediction test methodology for CFCCs. It should be noted that few studies on these subjects have been done for continuous fiber-reinforced ceramic composites [4], particularly at elevated temperatures.

EXPERIMENTAL PROCEDURE

All the matrices of the three test composites were reinforced by ceramic-grade Nicalon™ fibers with a fiber volume fraction of about 0.39. The nominal fiber diameters ranged from 10 to 15 μm . The three composite materials included Nicalon™ unidirectionally (1D) fiber-reinforced calcium aluminosilicate (designated SiC/CAS-II), Nicalon™ crossply (2D) magnesium aluminosilicate (designated SiC/MAS-5), and Nicalon™ plain-woven (2D) silicon carbide composites. SiC/CAS-II and SiC/MAS-5 were fabricated by Corning, Inc., through hot-pressing followed by ceraming of the composites by a thermal process. The designation “-5” in SiC/MAS-5 indicates that the matrix was doped with 5 vol% fraction of borosilicate glass. The silicon carbide matrix in the SiC/SiC composites was fabricated by the DuPont Company through chemical vapor infiltration (CVI) into the fiber perform. SiC/CAS-II and SiC/MAS-5 laminates were 18 and 16 plies thick, respectively, with a nominal thickness of about 3 mm. The plain-woven laminates of the SiC/SiC composite were supplied 12 plies (normally 3.5 mm) thick. More detailed information regarding the test composite materials can be found elsewhere [5]. The SiC/CAS-II material has been used in a previous, preliminary study on test rate-effect on tensile strength [6]. The dogboned tensile test specimens measuring 152.4 mm (length) \times 12.7 mm (width) were machined from the composite laminates, with the gage section of about 30 mm long, 10 mm wide and 3.0 to 3.5 mm thick (as-furnished). The design of the dogboned tensile test specimen was the result of previous finite element analysis [7].

Monotonic tensile testing was conducted in air at 1100 °C for both SiC/CAS-II and SiC/MAS-5 and at 1200 °C for SiC/SiC, using a servohydraulic test frame (Model 8501, Instron, Canton, MA). A total of three to four different loading rates (in load control), corresponding to stress rates ranging within 50 to 0.005 MPa/s, were employed with typically 3 test specimens tested at each loading rate. Detailed experimental procedure on tensile testing and related induction-heating equipment can be found elsewhere [5]. Preloading or accelerated testing technique, applied primarily to monolithic ceramics and glass [8], was also conducted at test temperatures using 0.5 MPa/s (for SiC/CAS-II) or 0.005 MPa/s (for SiC/MAS-5 and SiC/SiC) in an attempt to better understand the governing failure mechanism of the materials. Predetermined preloads, corresponding to about 80 to 90 percent of the failure strength determined at 0.5 or 0.005 MPa/s with zero preload (regular testing), were applied quickly to the test specimens prior to testing and their corresponding strengths were measured. Typically two to three test specimens were used in preload testing. Tensile testing was performed in accordance with ASTM Test Standard, ASTM C 1359 [9].

Constant stress (“static fatigue” or “stress rupture”) tensile testing was also performed in air for the three composite materials using the same test specimens, test fixture, test frame and same test temperatures that were used for monotonic tensile testing. The limited availability of test materials confined the testing to four to nine test specimens, depending on material. Four different static loads were applied to test specimens and their corresponding times to failure were determined.

RESULTS

Constant Stress-Rate Testing

The results of monotonic tensile strength testing with different test rates are presented in Fig. 1, where *ultimate strength* was plotted as a function of *applied stress rate* for each composite material using log-log scales. Each solid line in the figure indicates a best-fit regression line based on the log (*ultimate strength*) versus log (*applied stress rate*) relation. The decrease in ultimate strength with decreasing stress rate, which represents a susceptibility to damage accumulation or delayed failure, was significant for all the composite materials. The strength degradation was about 51, 31 and 62 percent, respectively, for SiC/CAS-II, SiC/MAS-5 and SiC/SiC

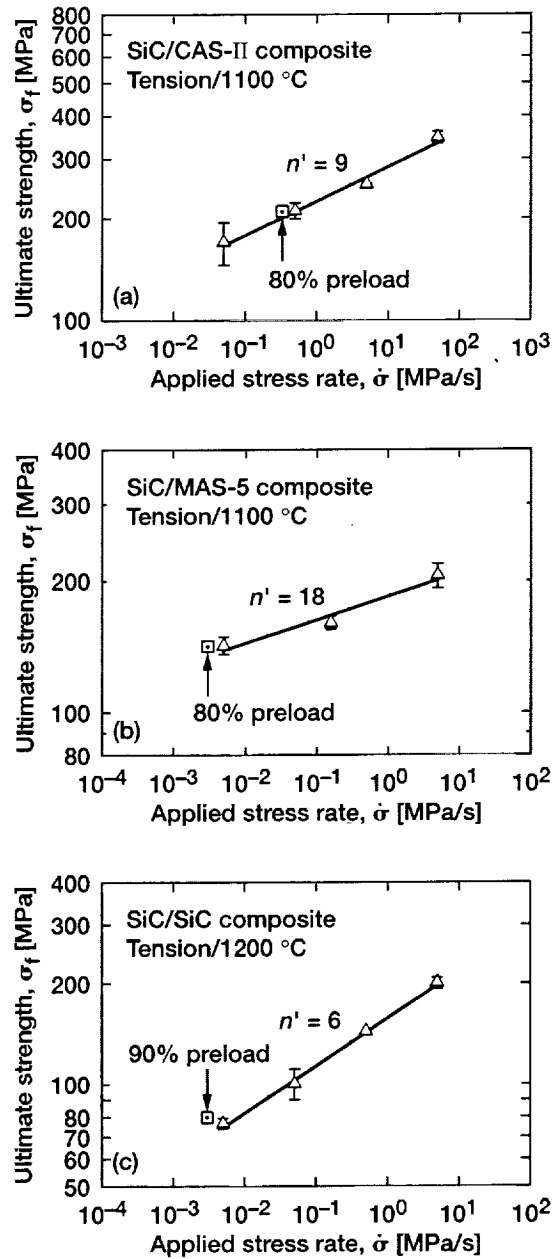


Figure 1.—Results of ultimate tensile strength as a function of stress rate for (a) SiC/CAS-II, (b) SiC/MAS-5, and (c) SiC/SiC composites at elevated temperatures in air. The solid lines represent the best-fit regression lines. Error bar indicates ± 1.0 standard deviation. The results of preloading tests are also included.

when stress rate decreased from the highest to the lowest. Fracture patterns for the SiC/CAS-II composite showed some fiber pullout with jagged faceted matrix cracking often propagating along the test-specimen length, as shown in Fig. 2. For a given stress rate, however, the difference in strength between different fracture patterns was not obvious. No appreciable difference in the mode of failure was observed for SiC/MAS-5 and SiC/SiC, where most specimens tested at either high or low stress rate exhibited relatively flat fracture surfaces (see Fig. 2), possibly called *brittle fracture*.

Preload Testing

The results of preloading tests are also shown in Fig. 1, where the ultimate strength with 80 to 90 percent preloads is compared with that in regular testing with zero preload. The difference in strength between two preloads (0 and 80 to 90 percent) was negligibly small for each material: 211 MPa (for 0 percent preload) and 209 MPa (for a 85 percent preload) for SiC/CAS-II; 142 MPa (0 and 80 percent preload) for SiC/MAS-5; 77 MPa (0 percent) and 80 MPa (90 percent) for SiC/SiC. Hence, the maximum strength difference, exhibited by SiC/SiC, amounts to only about 4 percent. This indicates that any significant damage that would control ultimate strength of the material did not occur before the applied loads up to 80 to 90 percent of fracture load. Conversely, the damage to control final failure would have occurred when applied load or test time was greater than 80 to 90 percent of fracture load or total test time. The theory explaining results of preload testing will be described in the discussion section.

Constant Stress ("Stress Rupture") Testing

A summary of results of constant stress or stress rupture testing at elevated temperatures is presented in Fig. 3, where *time to failure* was plotted against *applied stress* for each composite material using log-log scales. A significant decrease in time to failure with increasing applied stress, which represents a susceptibility to damage accumulation or delayed failure, was evident for all the composite materials tested. Each solid line in Fig. 3 indicates a prediction made based on the constant stress-rate data (Fig. 1), which will be discussed in a later section. The mode of fracture in constant stress testing was very similar to that in constant stress-rate testing. Brittle failure was exemplified for SiC/MAS-5 (2D) and SiC/SiC (2D), while somewhat jagged matrix cracking was observed for SiC/CAS-II (1D).

DISCUSSION

The strength dependency on test rate exhibited by the three composite materials (Fig. 1) is very similar to that observed in advanced monolithic ceramics at ambient or elevated temperatures. The strength degradation with decreasing stress rate has been known to be due to slow crack growth (delayed failure or fatigue) of an initial crack, typically governed by the following empirical power-law relation [1 to 3]

$$v = \alpha(K_I/K_{IC})^n \quad (1)$$

where v , K_I and K_{IC} are crack velocity, mode I stress intensity factor and fracture toughness, respectively. α and n are called slow crack growth (SCG) parameters. Based on this power-law relation, the strength (σ_f) can be derived as a function of applied stress rate ($\dot{\sigma}$) [1 to 3].

$$\sigma_f = D[\dot{\sigma}]^{1/n+1} \quad (2)$$

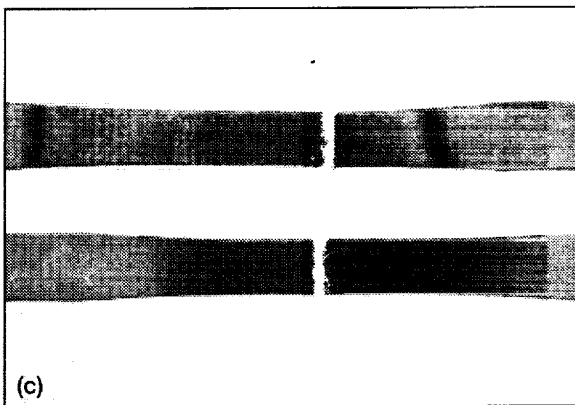
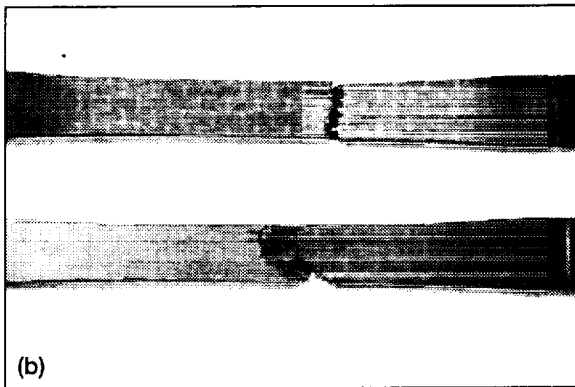
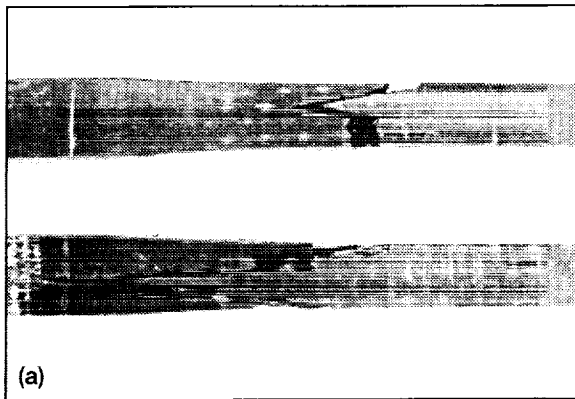


Figure 2.—Fracture patterns for (a) SiC/CAS-II, (b) SiC/MAS-5, and (c) SiC/SiC composites subjected to elevated-temperature tensile testing. The upper and lower pictures for a given composite material indicate the specimens tested at the lowest and the highest load rates, respectively.

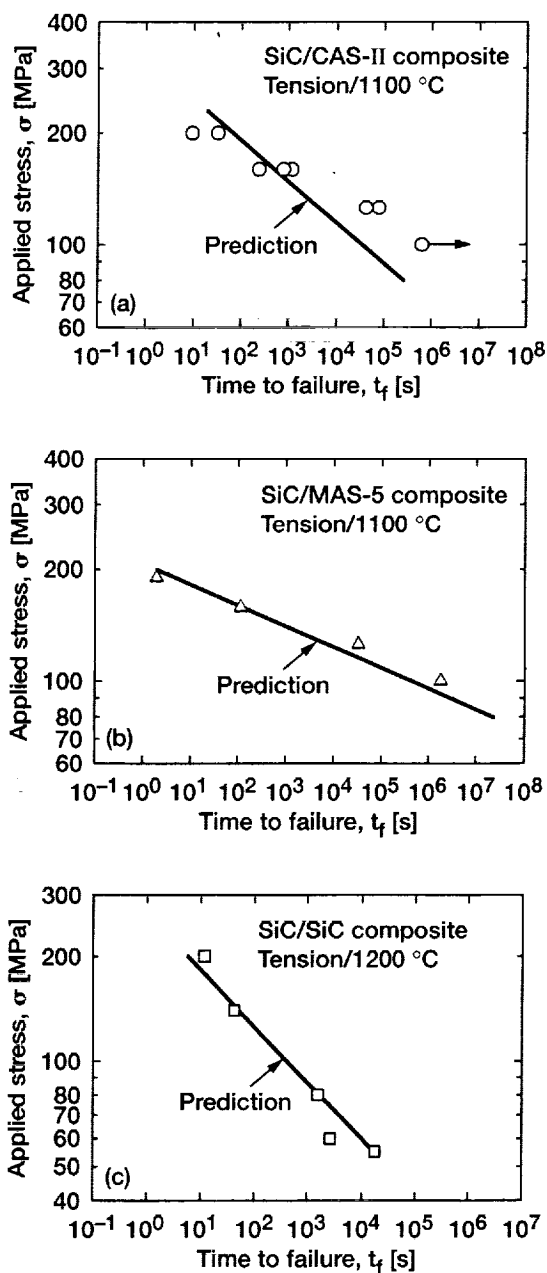


Figure 3.—Results of constant stress (“static fatigue” or “stress rupture”) testing for (a) SiC/CAS-II, (b) SiC/MAS-5, and (c) SiC/SiC composites at elevated temperatures in air. The solid lines represent the predictions made based on the results of constant stress-rate testing (Figure 1).

where D is another SCG parameter associated with inert strength, n and crack geometry. Equation (2) can be expressed in a more convenient form by taking logarithms of both sides

$$\log \sigma_f = \frac{1}{n+1} \log \dot{\sigma} + \log D \quad (3)$$

Constant stress-rate (“dynamic fatigue”) testing based on Eqs. (2) or (3) has been established as ASTM Test Methods (C1368 [2] and C1465 [3]) to determine SCG parameters of advanced monolithic ceramics at ambient and elevated temperatures. It has been recommended to use units of MPa for σ_f and MPa/s for $\dot{\sigma}$ [2 to 3]. As can be seen in Fig. 1, the data fit to Eq. (3) is very reasonable with the coefficients of correlation (r_{coef}) all greater than 0.980, indicating that the damage evolution/accumulation or delayed failure of the composite materials would be adequately described by the power-law type relation, Eq. (1). Assuming this, the *apparent* parameters n' and D' for the composites were determined using a linear regression analysis based on Eq. (3) with the data in Fig. 1. Values of $n' = 9.0$ and $D' = 226$, $n' = 18$ and $D' = 185$, and $n' = 6$ and $D' = 158$ were obtained for SiC/CAS-II, SiC/MAS-5 and SiC/SiC, respectively (The prime was used here for composite materials to distinguish them from monolithic ceramic counterparts.). It is noteworthy that the value of n' , a measure of susceptibility to damage, was very low for both SiC/CAS-II and SiC/SiC, but intermediate for SiC/MAS-5. Typical monolithic silicon nitrides and silicon carbides at high temperatures at ≥ 1200 °C exhibit $n \geq 20$. Hence, compared with monolithic ceramics, the SiC/CAS-II and SiC/SiC composites exhibited a significantly higher susceptibility to damage evolution/accumulation.

The preload or accelerated test technique has been developed for monolithic ceramics in order to save test time in constant stress-rate testing [8]. Based on *the power-law SCG* relation of Eq. (1) with some mathematical manipulation, strength of a test specimen under a preload (α_p) was derived as a function of preloading factor [8,2, and 3];

$$\sigma_{fp} = \sigma_f \left(1 + \alpha_p^{n+1}\right)^{\frac{1}{n+1}} \quad (4)$$

where σ_{fp} is strength with a preload and α_p ($0 \leq \alpha_p \leq 1$) is a preloading factor (or percentage of preload) in which a preload stress (applied to the test specimen) is normalized with respect to the strength with zero preload. Equation (4) indicates that strength with a preload is sensitive to the magnitude of preload particularly at lower n and higher α_p values. A theoretical prediction of ultimate strength as a function of preload, based on Eq. (4) with estimated values of n' from Fig. 1, is shown in Fig. 4. The prediction (solid lines) is in excellent agreement with the experimental data for all the three composite materials tested, as seen in the figure. This result obtained for the composite materials is also analogous to that observed in advanced monolithic ceramics and glass [8]. Damage, mainly SCG, of monolithic ceramics occurs substantially close to 90 percent of total failure time because of their higher n (≥ 20) value [8]. The applicability of the preloading analysis for the composite materials strongly suggests that major damage evolution/accumulation process would be the one governed by the power-law relation (Eq. (1)) and that the damage would have occurred after a long incubation time, at least after 80 percent of total test time.

For the case that a single delayed failure mechanism (SCG) is predominant, a life prediction (for monolithic ceramics) from one loading configuration to another can be made analytically or numerically, depending on the complexity of loading configurations concerned. A prediction

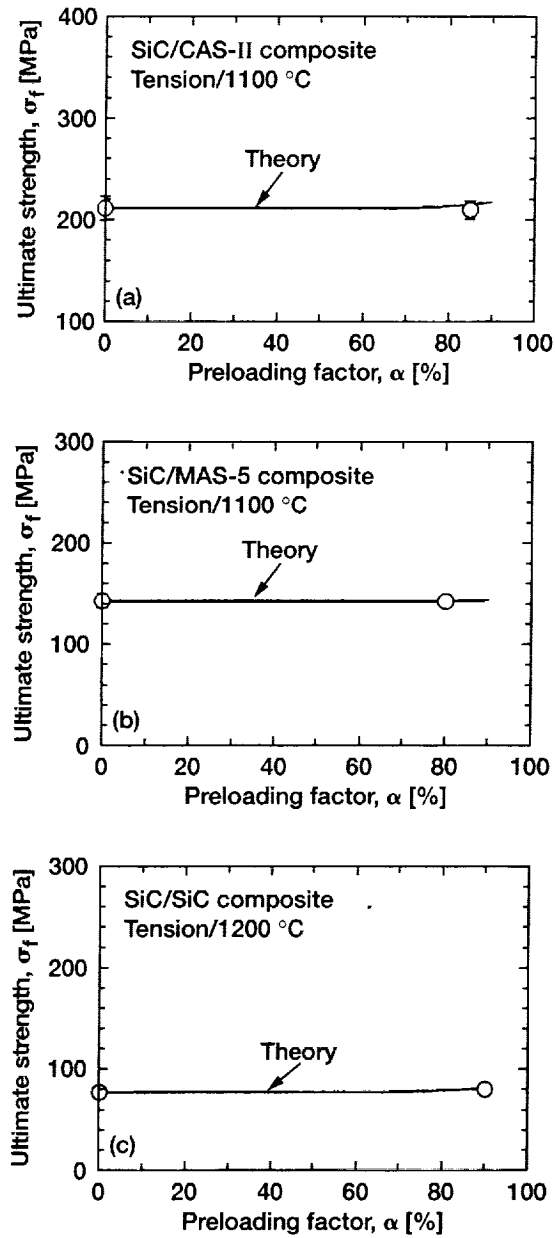


Figure 4.—Result of preloading tests (ultimate strength as a function of preloading) for (a) SiC/CAS-II, (b) SiC/MAS-5, and (c) SiC/SiC composites at elevated temperatures in air. A theoretical line based on Equation (4) [8] is included for comparison for each composite material.

of life in constant stress loading can be made based on Eq. (1) using constant stress-rate testing data as follows:

$$t_f = \left[\frac{D^{n+1}}{n+1} \right] \sigma^{-n} \quad (5)$$

where t_f and σ are time to failure and applied stress, respectively. Use of Eq. (5) together with n' and D' determined in constant stress-rate testing allows one to predict life in constant stress loading. The results thus predicted are presented in Fig. 3 as solid lines. Except for some discrepancy in the SiC/CAS-II composite, the overall prediction is in reasonable agreement with experimental data, at least for short periods of life. This indicates that the governing failure mechanism of SiC/MAS-5 and SiC/SiC was identical in both constant stress rate testing and constant stress testing. Since the prediction (Eq. (5)) was made based on the power-law relation, it is certain that the distinct failure mechanism of the two composite materials would be governed by the power-law type of damage evolution/accumulation (or SCG or delayed failure).

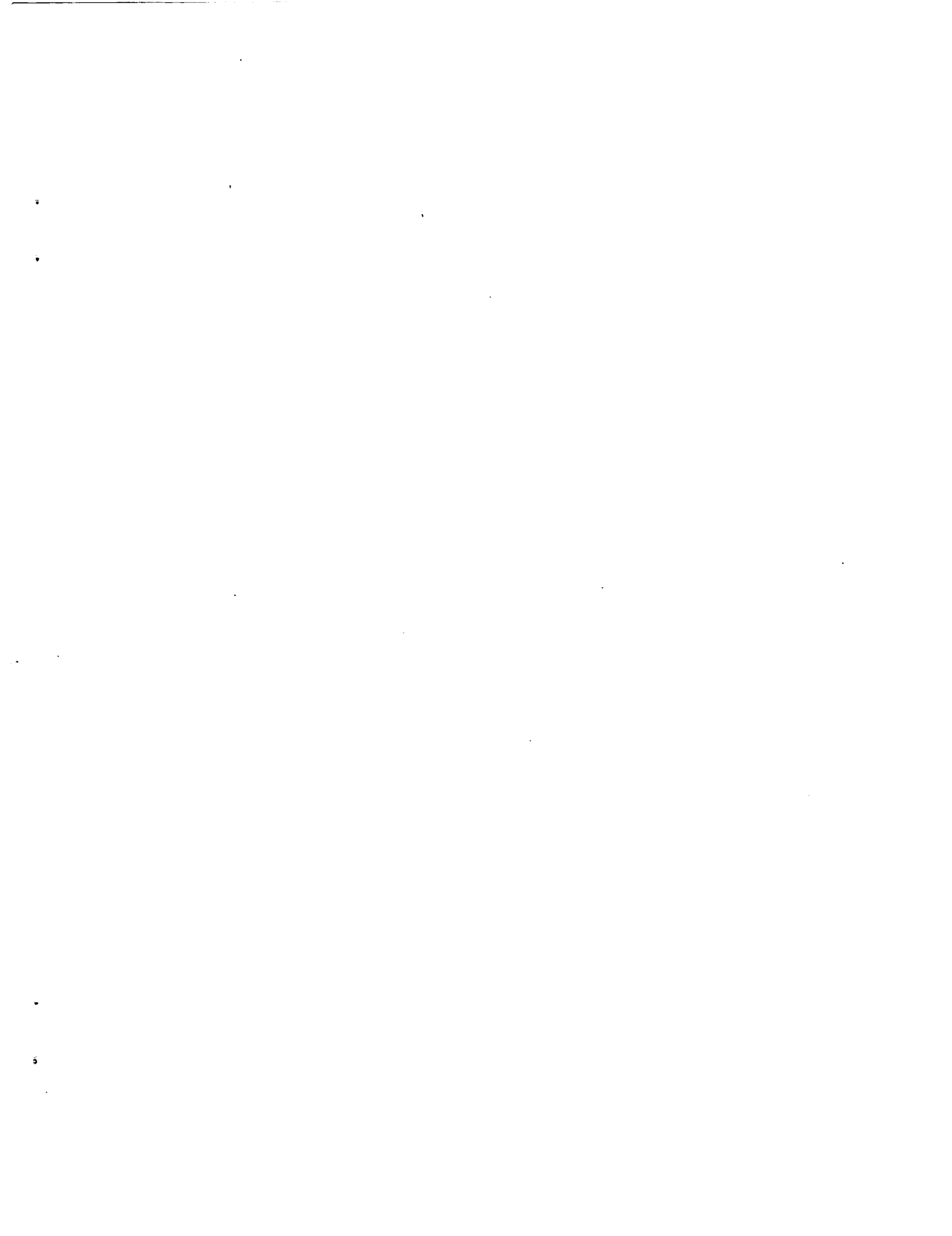
The strength dependency on test rate, the applicability of preloading technique and the reasonable life prediction from one loading configuration (constant stress-rate testing) to another (constant stress or stress rupture testing) all support that the damage evolution/accumulation of the composite materials tested was controlled by a process very similar to the power-law type of SCG of monolithic ceramics, and that the failure mechanism was almost independent of loading configuration either in monotonically increased or in constant loading. This indicates that the constant stress-rate testing, commonly utilized in determining life prediction parameters of monolithic ceramics, could be applicable even to composite materials. The merit of constant stress rate testing is enormous in terms of simplicity and test economy (short test time) over other stress rupture or cyclic fatigue testing, especially for short lifetimes. A continuing effort to establish a database in constant stress rate testing at elevated temperatures is in progress using more ceramic matrix composites. A more detailed study regarding microscopic failure mechanisms [4, 10 to 13] associated with matrix/fiber interaction, matrix cracking and its effect on slow crack growth, and delayed failure of sustaining fibers near fracture, etc. is needed. Finally, the results of this work also suggest that care must be exercised when characterizing elevated-temperature strength of composite materials. This is due to that fact that elevated-temperature strength has a relative meaning if a material exhibits rate dependency: the strength simply depends on which test rate one chooses (Fig. 1). Therefore, at least two test rates (high and low) are recommended to better characterize the high-temperature strength behavior of a composite material.

CONCLUSIONS

Elevated-temperature strength of three continuous fiber-reinforced ceramic composites, including SiC/CAS-II, SiC/MAS-5 and SiC/SiC, exhibited a strong dependency on test rate, similar to the behavior observed in many advanced monolithic ceramics at elevated temperatures. The applicability of the preloading technique as well as the predictability of life from one loading configuration (constant stress-rate) to another (constant stress loading) suggested that the distinct, overall failure mechanism of the composite materials would be a process primarily governed by a power-law type of damage evolution/accumulation, analogous to the mechanism observed in monolithic counterparts. It was further found that constant stress-rate testing could be utilized as a means of life prediction test methodology even for composites when short lifetimes are expected.

REFERENCES

1. Evans, A.G., "Slow Crack Growth in Brittle Materials under Dynamic Loading Condition," *Int. J. Fracture*, Vol. 10, 1974, pp. 251-259.
2. ASTM C 1368, "Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Ambient Temperature," *Annual Book of ASTM Standards*, Vol. 15.01, American Society for Testing and Materials, West Conshohocken, PA, 2001.
3. ASTM C 1465, "Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Elevated Temperatures," *Annual Book of ASTM Standards*, Vol. 15.01, American Society for Testing and Materials, West Conshohocken, PA, 2001.
4. Sorenson, B.F. and Holmes, J.W., "Effect of Loading Rate on the Monotonic Tensile Behavior of a Continuous-Fiber-Reinforced Glass-Ceramic Matrix Composite," *J. Am. Ceram. Soc.*, Vol. 79, No. 2, 1996, pp. 313-320.
5. Worthem, D.W., "Thermomechanical Fatigue Behavior of Three CFCC's," NASA CR-195441, NASA Glenn Research Center, Cleveland, OH, 1995.
6. Choi, S.R. and Gyekenyesi, J.P., "Effect of Loading Rate on Strength of Nicalon™/CAS CFCC at Elevated Temperature," in *Proc. of the 7th Annual International Conference on Composite Materials*, Edited D. Hui, Denver, CO, July 2-9, 2000, pp. 299-300.
7. Worthem, D.W., "Flat Tensile Specimen Design for Advanced Composites," NASA CR-185261, NASA Glenn Research Center, Cleveland, OH, 1990.
8. (a) Choi, S.R. and Gyekenyesi, J.P., "Fatigue Strength as a Function of Preloading in Dynamic Fatigue Testing of Glass and Ceramics," *ASME Trans., J. Eng. Gas Turbines and Power*, Vol. 119, No. 3, 1977, pp. 493-499; (b) Choi, S.R. and Salem, J.A., "Effect of Preloading on Fatigue Strength in Dynamic Fatigue Testing of Ceramic Materials at Elevated Temperatures," *Ceram. Eng. Sci. Proc.*, Vol. 16, No. 4, 1995, pp. 87-94.
9. ASTM C 1359, Standard Test Method for Monotonic Tensile Strength Testing of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Specimens at Elevated Temperatures," *Annual Book of ASTM Standards*, Vol. 15.01, American Society for Testing and Materials, West Conshohocken, PA, 2001.
10. Curtin, W.C. and Halverson, H.G., "High Temperature Deformation and Failure in Oxide/Oxide Composites," *HITEMP Review: Advanced High Temperature Engine Materials Technology Project*, NASAS/CP-1999-208915/VOL2, Paper 48, NASA Glenn Research Center, Cleveland, OH, 1999.
11. Lewinsohn, C.A., Henager, C.H., and Johns, R.H., "Environmentally Induced Time-Dependent Failure Mechanism in CFCCS at Elevated Temperatures," *Ceram. Eng. Sic. Proc.*, Vol. 19, No. 4, 1998, pp. 11-18.
12. Henager, C.H., and Jones, R.H., "Subcritical Crack Growth in CVI Silicon Carbide Reinforced with Nicalon Fibers: Experiment and Model," *J. Am. Ceram. Soc.*, Vol. 77, No. 9, 1994, pp. 2381-94.
13. Spearing, S.M., Zok, F.W., and Evans, A.G., "Stress Corrosion Cracking in a Unidirectional Ceramic-Matrix Composite," *J. Am. Ceram. Soc.*, Vol. 77, No. 2, 1994, pp. 562-70.



REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE November 2001	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Effect of Load Rate on Ultimate Tensile Strength of Ceramic Matrix Composites at Elevated Temperatures			5. FUNDING NUMBERS WU-714-04-30-00	
6. AUTHOR(S) Sung R. Choi and John P. Gyekenyesi				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER E-12975	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-2001-211125	
11. SUPPLEMENTARY NOTES Prepared for the Finno-Ugric International Conference of Mechanics With Beda Symposium sponsored by the Journal of Computational and Applied Mechanics, Budapest, Hungary, May 27-June 2, 2001. Sung R. Choi, Ohio Aerospace Institute, 22800 Cedar Point Road, Brook Park, Ohio 44142; and John P. Gyekenyesi, NASA Glenn Research Center. Responsible person, John P. Gyekenyesi, organization code 5920, 216-433-3210.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Categories: 39 and 27 Available electronically at http://gltrs.grc.nasa.gov/GLTRS This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Strength of three continuous fiber-reinforced ceramic composites, including SiC/CAS-II, SiC/MAS-5 and SiC/SiC, was determined as a function of test rate in air at 1100 to 1200 °C. All three composite materials exhibited a strong dependency of strength on test rate, similar to the behavior observed in many advanced monolithic ceramics at elevated temperatures. The application of the preloading technique as well as the prediction of life from one loading configuration (constant stress-rate) to another (constant stress loading) suggested that the overall macroscopic failure mechanism of the composites would be the one governed by a power-law type of damage evolution/accumulation, analogous to slow crack growth commonly observed in advanced monolithic ceramics. It was further found that constant stress-rate testing could be used as an alternative to life prediction test methodology even for composite materials, at least for short range of lifetimes and when ultimate strength is used as the failure criterion.				
14. SUBJECT TERMS Ceramic matrix composites; Mechanical testing; Elevated-temperature testing; Delayed failure; Life prediction testing; Life prediction; Ultimate testing strength; Slow crack growth/damage accumulation analysis			15. NUMBER OF PAGES 16	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	