SUMMARY OF RESEARCH
FINAL REPORT

Title: High Temperature Mechanical Behavior of Ceramic Matrix composites

Type of report: Final

Name of principal investigator: John Hemann

Period covered by grant: 04/12/89 to 07/14/96

Name and address if the grantee's institution: Cleveland State University
1983 East 24th St.
Cleveland, Ohio 44115

Grant number: NCC 3-138

John Hemann

Sept 5, 1997

NEW TECHNOLOGY DISCLOSURE

NT CONTROL NO. *(Official use only)*

NASA Task Manager Contractor
Jon Salem

Task Manager or Grantee Principal Investigator
John Hemann
9/5/97

This form is used by NASA contractors, subcontractors, grantees, and grantee subcontractors when reporting patentable and non-patentable inventions, discoveries, improvements or innovations (including computer software) to NASA. Use of this report form is optional, however, an alternative format must at a minimum contain the information required herein.

When necessary, attach additional documentation to provide a full, detailed description.

1. TITLE
High Temperature Mechanical Behavior of Ceramic Matrix Composites

2. INNOVATOR(S) *(Name, Social Security No., and Home Address)**

3. EMPLOYER (Organization and division)
Cleveland State University

4. ADDRESS (Place of Performance)

1983 East 24th Street
Cleveland, Ohio 44115

5.NASA PRIME CONTRACT/GRANT NO.
NCC 3-138

6. CONTRACTOR DISCLOSURE NO. and TASK NO.

SECTION I - DESCRIPTION OF THE PROBLEM THAT MOVTIVATED THE TECHYNOLOGY DEVELOPMENT(Enter A.-General Description of Problem Objective; B.-Key or Unique Problem Characteristics; C.-Past History/Prior Techniques; D.-Limitations of Prior Techniques)

NA

SUMMARY OF RESEARCH

The research accomplishments under this grant were very extensive in the areas of the high temperature behavior of ceramics, ceramic composites and testing standards for these materials. Rather than try to summarize all this research I have enclosed research papers and reports which were completed with the funding provided by the grant. These papers and reports are listed below.

Choi, S.R. and Salem, J.A., "Strength and Fracture Toughness of Monolithic and SiC Whisker Reinforced Silicon Nitride," Advanced Composite materials.

Choi, S.R. and Salem, J.A., "Comparison of dynamic fatigue behavior between SiC whisker-reinforced composite and monolithic silicon nitrides," NASA Tech. Memo. 103707, 1991.

Salem, J.A., Choi, S.R., Sanders, W.A. and Fox, D.S., "Elevated temperature mechanical behavior of monolithic and SiC whisker-reinforced silicon nitrides," NASA Tech. Memo. 105245, 1991.

Choi, S.R. and Salem, J.A., "Strength, toughness and R-curve behavior of SiC whisker reinforced composite Si_3N_4 with reference to monolithic Si_3N_4," Journal of Material Science, 27, 1992.

Choi, S.R. and Salem, J.A., "Slow crack growth of indent cracks in glass with and without applied stress," Material Science and Engineering, A149, 1992.

Choi, S.R. and Tikare, V., "Crack healing behavior of hot pressed silicon nitride due to oxidation," Scripta Metallurgica, 26, 1992.

Choi, S.R., Chulya, A. and Salem, J.A., "Analysis of precracking parameters for ceramic single-edge-precracked-beam specimens," Fracture Mechanics of Ceramics, 10, 1992.

Salem, J.A., Choi, S.R., Freedman, M.R. and Jenkins, M.G., "Mechanical behavior and failure phenomenon of an in-situ toughened silicon nitride," Journal of Material Science, 27, 1992.

Choi, S.R., Salem,J.A. and Sanders, W.A., "Estimation of crack closure stresses for in-situ toughened silicon nitride with 8 wt% scandia," Journal of the American Ceramic Society, 75, 1992.

Choi, S.R., Chulya, A. and Salem, J.A., "Analysis of precracking parameters and fracture toughness for ceramic single-edge-precracked-beam specimens," NASA Tech. Memo. 105568, 1992.

Choi, S.R., Salem, J.A. and Hebsur, M.G.,"Evaluation of the fracture toughness of Nb-40Al-8Cr-1W-1Y-0.05B intermetallic material by indentation techniques," Journal of Material Science, 28, 1993.

Choi, S.R. and Salem, J.A., "Fracture toughness of PMMA as measured with indentation cracks," Journal of Materials Research, 8, 1993.

Tikare, V. and Choi, S.R., "Combined mode I and mode II fracture of monolithic ceramics," Journal of the American Ceramic Society, 76, 1993.

Choi, S.R. and Tikare, V., "Crack healing of alumina with a residual glassy phase: strength, fracture toughness and fatigue," Materials Science and Engineering, A171, 1993.

Choi, S.R. and Salem, J.A., "Thermal Shock Behavior of Silicon Nitride Flexure Beam Specimens with Indentation Cracks," Journal of the American Ceramic Society, 77, 1994.

Choi, S.R., Salem, J.A. and Palko, J.L., "Comparison of tension and flexure to determine fatigue life prediction parameters at elevated temperatures," ASTM STP 1201, 1994.

Choi, S.R. and Salem, J.A., "Crack-growth resistance of in-situ toughened silicon nitride," Journal of the American Ceramic Society, 77, 1994.

Choi, S.R. and Salem, J.A., "Error identified as hystersis in flexure testing of advanced ceramics," Scripta Materialia, 35, 1996.

Choi, S.R. and Salem, J.A., "Effect of preloading on fatigue strength in dynamic fatigue testing of ceramic materials at elevated temperatures," Ceramic Engineering Science Proceedings, 16, 1996.

Choi, S.R. and Salem, J.A., "Preloading technique in dynamic fatigue testing of gass and ceramics with an indentator flaw system," Journal of the American Ceramic Society, 79, 1996.

Choi, S.R. and Salem, J.A., "Cyclic fatigue of brittle materials with an indented-induced flaw system," Material Science and Engineering, A208, 1996.

Choi, S.R., Salem, J.A. and Gyekenyesi, J.P., "Fatigue strength as a function of preloading in dynamic fatigue testing of glass and ceramics," Transactions of the ASME, 1996.

Choi, S.R., Nemeth, N.N., Salem, J.A., Powers, L.M. and Gyekenyesi, J.P., "High temperature slow crack growth of Si_3N_4 specimens subjected to uniaxial and biaxial dynamic loading conditions," Ceramic Engineering Science Proceedings, 16, 1996.

SECTION II-TECHNICALLY COMPLETE AND EASILY UNDERSTANDABLE DESCRIPTION OF NEW TECHNOLOGY THAT WAS DEVELOPMED TO SOLVE THE PROBLEM OR MEET THE OBJECTIVE (Enter as appropriate A.-Specific description of item; B.-State of development; C.-Operation as a unit; D.-Functional operation; E.-Supportive theory; F.-Engineering specification; G.-Peripheral equipment; H.-Drawings, graphs, etc.; I.-Parts or ingredients lists; and J.-Maintenance, reliability, safety factors)

SECTION III-UNIQUE OR NOVEL FEATURES OF THE TECHNOLOGY AND THE RESULTS (ORBENEFITS) OF ITS APPLICATION (Enter as appropriate A.-Novel or unique features; B.-Development or conceptual problems; C.-Operating characteristics, test data; D.-Analysis of capabilities;

SECTION IV-SPECULATION REGARDING USEFUL NON-AEROSPACE APPLICATIONS OF THE INNOVATION OR TECHNOLOGY

SECTION IV (Continued)

SECTION V-ADDITIONAL DOCUMENTATION (Include or list below any pertinent documentation which aids in the understanding or application of the new technology. IF NOT TOO BULKY OR DIFFICULT TO REPREODUCE, INCLUDE COPIES WITHTHIS REPORT. For those references or additional documentation available but NOT included in this report *due to their being nonessential to a basic understanding of the new technology and which may be costly to reproduce or handle) complete item 1, below)

A. AVAILABLE DOCUMENTS (Check and complete)			
	☐ 1. PAPERS, ARTICLES	☐ 4. ASSEMBLY/MFG.DRAWINGS	☐ 7. TEST DATA
	☐ 2. CONTRACTOR REPORTS	☐ 5. PARTS OR INGRED LIST	☐ 8. SEMBLY/MFG.PROCED
	☐ 3. ENGINEERING SPECS.	☐ 6. OPERATING MANUALS	☐ 9. COMPUTER TAPES/CARDS
	☐ 10. OTHER (SPECIFY)		

B. INCIDATE THE DATES OR THE APPROXIMATE TIME PERIOD DURING WHICH THIS TECHNOLOGY WAS DEVELOPED *(I.E. CONCEIVED, CONSTRUCTED, TESTED, ETC.)*

C. LIST THE FIRST PUBLICATION OR PUBLIC DISCLOSURE OF THE NEW TECHNOLOGY, AND DATES

D. LIST THE DATES AND ANY PARTICULARLY PERTINENT PAGE NUMBERS OF OTHER PUBLICATION SWHICH ARE AVAILABLE BUT NOT ATTACHED

E. DEGREE OF TECHNOLOGICAL SIGNIFICANCE (Check in your best judgment the statement which best expresses the degree of technological significance of this technology)

☐ 1. MODIFICATION TO EXISTING TECHNOLOGY ☐ UBSTANTIAL ADVANCE IN THE ART ☐ MAJOR BREAKTHROUGH

KEYWORDS (list 5-10 words)

SIGNATURES(S) OF INNOVATOR(S)	DATE

NASA GRANTEE
NEW TECHNOLOGY REPORT

NASA requires each research grantee, research contractor and research subcontractor to report new technology to the NASA Technology Utilization Office. The required reports and corresponding schedules are as follows:

Title of Report	Form Number	Timetable
Individual Disclosure	NASA 666A	The grantee discloses each discovery of new technology individually, at the time of its discovery
Interim Report	LeRC-GNTR	For multi-year grants, the grantee summarizes the previous year's disclosures on an annual basis. The first Interim New Technology (NT) Report is due exactly 12 months from the effective date of the grant.
Final Report	LeRC-GNTR	The grantee submits a cumulative summary of all disclosed discoveries. This Final NT Report is submitted immediately following the grant's technical period of performance.

Grantee Name and Address:
John Hemann
Cleveland State University
1983 East 24th Street
Cleveland, Ohio 44115

Report Submitted by: John Hemann
Telephone Number: (216) 687-3630

NASA Grant Title: High Temperature Mechanical Behavior of Ceramic Matrix Composites

NASA Grant Number: NCC 3-138

NASA Project Manager: Jon Salem

Grant Completion Date: 07/14/96

Today's Date: 9/5/97

New technology may be either reportable items or subject inventions.

A reportable item is any invention or discovery, whether or not patentable, that was conceived or first actually reduced to practice during the performance of the grant, contract or subcontract. Large business contractors and subcontractors must disclose reportable items as they are discovered and submit a noncumulative list of these new technology items on an annual basis[ref.: Interim NT Report] and a cumulative list at the completion of the grant, contract or subcontract period [ref.: Final NT Report].

A subject invention is any invention or discover, whether or not patentable, that was conceived or first actually reduced to practice during the performance of the grant, contract or subcontract. Grantee, small business contractors and subcontractors must, at a minimum, disclose subject inventions as they are discovered and submit a cumulative list of these new technology items on an annual basis[ref.: Interim NT Report] and list at the completion of the grant, or subcontract period [ref.: Final NT Report].

Grantees, small business contractors and small business subcontractor are only required to disclose and report patentable items (subject inventions). We request, however, that small business contractors and subcontractors disclose both patentable and nonpatentable (reportable) items, both of which are automatically evaluated for publication as NASA *Tech Brief* awards.

PLEASE COMPLETE THE REVERSE SIDE OF THIS FORM AND MAIL TO THE FOLLOWING ADDRESS:

NASA LEWIS RESEARCH CENTER
ATTN: KAREN GRASSE
TECHNOLOGY UTILIZATION OFFICE; MAIL STOP 7-3
CLEVELAND, OHIO 44134

I General Information

1. Type of Report ☐ Interim ☒ Final

2. Size of Business: ☐ Small ☐ Large ☒ Nonprofit Organization

3. Have any nonpatentable new technology items resulted from work performed under this grant during this reporting period?
   ☐ yes ☒ no

4. Have any patentable new technology items resulted from work performed under this grant during this reporting period?
   ☐ yes ☒ no

5. Are new technology items (nonpatentable or patentable) being disclosed with this report?
   ☐ yes ☒ no

II New Technology Items

Please provide the title(s) of all new and previously disclosed new technology items conceived or first actually reduced to practice under the is grant. If this is an interim report, previously disclosed items need not be mentioned.

	Title	Internal Docket Number	Patent Appl. Filed	Patentable Item	Nonpatentable Item
1.			☐	☐	☐
2.			☐	☐	☐
3.			☐	☐	☐
4.			☐	☐	☐

III Subcontractors

Please complete the following section listing all research subcontractors participating to date. Include each subcontractor's name, address, contract person, and telephone number. If this is an interim report, previously noted subcontractors need not be mentioned.

Use of the forms identified on the reverse side of this page is optional; however, an alternate must at a minimum contain the information required by these forms.