AFRL-RX-WP-TP-2009-4157

# THROUGH THICKNESS MODULUS (E33) OF CERAMIC MATRIX COMPOSITES : MECHANICAL TEST METHOD CONFIRMATION (PREPRINT)

**G. Ojard, T. Barnett, A. Calomino, Y. Gowayed, U. Santhosh, J. Ahmaad,
R. Miller, and R. John**

**Pratt & Whitney**

**JANUARY 2008**

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**AIR FORCE RESEARCH LABORATORY
MATERIALS AND MANUFACTURING DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE**

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



**1. REPORT DATE** ***(DD-MM-YY)***
January 2008

**2. REPORT TYPE**
Journal Article Preprint

**3. DATES COVERED** ***(From - To)***
01 January 2008 – 01 January 2008

**4. TITLE AND SUBTITLE**
THROUGH THICKNESS MODULUS (E33) OF CERAMIC MATRIX COMPOSITES : MECHANICAL TEST METHOD CONFIRMATION (PREPRINT)

**5a. CONTRACT NUMBER**
F33615-03-D-2354-0004

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
62102F

**6. AUTHOR(S)**
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**5d. PROJECT NUMBER**
4347

**5e. TASK NUMBER**
53

**5f. WORK UNIT NUMBER**
43475314

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Pratt & Whitney
400 Main Street
East Hartford, CT 06108

Southern Research Institute, Birmingham, AL
NASA-Glenn Research Center, Cleveland, OH
Auburn University, Auburn, AL
Research Applications, Inc., San Diego, CA

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Air Force Research Laboratory
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base, OH 45433-7750
Air Force Materiel Command
United States Air Force

**10. SPONSORING/MONITORING AGENCY ACRONYM(S)**
AFRL/RXLMN

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)**
AFRL-RX-WP-TP-2009-4157

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited.

**13. SUPPLEMENTARY NOTES**
Presented at the 32nd International Conference & Exposition on Advanced Ceramics & Composites, Jan 27 – Feb 1, 2008, Daytona Beach, FL.
PAO Case Number and clearance date: WPAFB-07-0727, 17 December 2007.
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**14. ABSTRACT**
Considering the interest in and challenges of using ceramic matrix composites, a full understanding of the physical properties is needed to continue to move the technology forward. A property of interest to the design process is the through thickness modulus of the composite and most high performance CMC material systems are produced extremely thin hindering generation of test specimens that can easily be instrumented and tested in the through-thickness direction. Past work by the authors has shown that a stacked disk method could measure the through thickness modulus at various temperatures with sufficient accuracy. Due to the nature of the stacked disk, several testing issues were present and a model material system was chosen to alleviate testing concerns. A monolithic ceramics system was used to verify the test method by using the material in its monolithic state deploying the same stacked disk method. Results and conclusions of this verification effort will be discussed.

**15. SUBJECT TERMS**
ceramic matrix composites, material properties, monolithic, stacked disk method

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT: | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON (Monitor) |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | Reji John |
| Unclassified | Unclassified | Unclassified | SAR | 10 | **19b. TELEPHONE NUMBER** *(Include Area Code)* N/A |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std. Z39-18

Mechanical Properties and Processing of Ceramic Binary, Ternary and Composite Systems,
Ceramic Engineering and Science Proceedings, Volume 29, Issue 2, 2008, Jonathan Salem, Greg Hilmas, and
William Fahrenholtz, editors; Tatsuki Ohji and Andrew Wereszczak, volume editors,
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# THROUGH THICKNESS MODULUS (E33) OF CERAMIC MATRIX COMPOSITES: MECHANICAL TEST METHOD CONFIRMATION

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## ABSTRACT

Considering the interest in and challenges of using ceramic matrix composites, a full understanding of the physical properties is needed to continue to move the technology forward. A property of interest to the design process is the through thickness modulus of the composite. Most high performance CMC material systems are produced in a relatively thin state that hinders generation of test specimens that can easily be instrumented and tested in the through-thickness direction. Past work by the authors has shown that a stacked disk method could measure the through thickness modulus at various temperatures with sufficient accuracy. Due to the nature of the stacked disk, several testing issues were present and a model material system was chosen to alleviate testing concerns. A monolithic ceramic system was used to verify the test method by using the material in its monolithic state deploying the same stacked disk method. Results and conclusions of this verification effort will be discussed.

## INTRODUCTION

Ceramic matrix composites are considered for advanced engineering applications such as aggressive gas turbine engine applications and thermal protection systems due to the fact that the mechanical properties are relatively constant with temperatures up to the maximum use temperature (1). This is especially the case for turbine and combustor applications where there are high temperatures and possibly high stresses (2,3). These potential applications look to ceramic matrix composites due to the high temperature capability promised in strength at temperature with reduced or no cooling air requirements coupled with a lower density material. This can be seen in the wide breadth of work considering ceramic matrix composites in multiple applications (4).

As designs progress and become more challenging, there is a need to fully understand the physical properties of the material. A specific property of interest is the through thickness elastic modulus ($E_{33}$). This property is based on interactions between the fiber, fiber interface coating and the matrix as well as porosity as the material is pulled or compressed in the through thickness direction (z direction or 33 direction). The authors have documented a test method that can measure this property as a function of temperature (5). Since that time, a model material was used to review the test method arrive at, which relied upon testing a stack of discs greater than 25 mm in height. This was done to assure that the method is robust.

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## PROCEDURE

### Material – CMC

Melt Infiltrated In-Situ BN SiC/SiC composite (MI SiC/SiC) is the material that was documented in the past work (5). The MI SiC/SiC system has a stochiometric SiC (Sylramic™) fiber in a multiphase matrix of SiC deposited by chemical vapor deposition followed by slurry casting of SiC particulates with a final melt infiltration of Si. The specific MI SiC/SiC tested had 36% volume fraction fibers using a 5 HS weave at 20 EPI with a cross ply lay-up. A cross section of the material is shown in Figure 1.

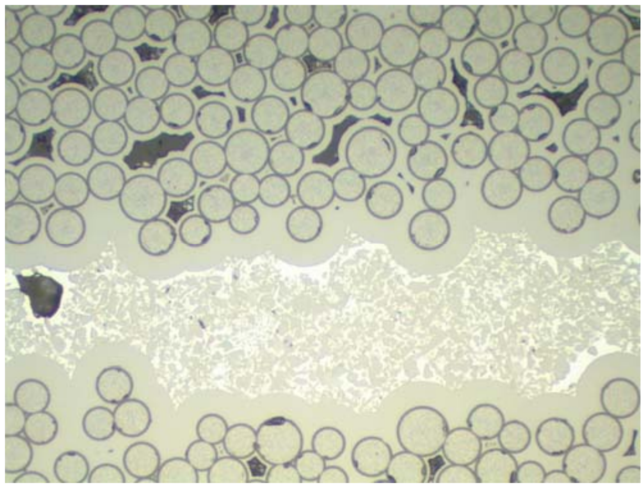

**Figure 1. Cross sections of Melt Infiltrated In-Situ BN SiC/SiC Composite**

### Material – Monolithic (Test Material)

The material chosen as a test material is MACOR. MACOR is a machinable glass ceramic and is a fluorine rich glass with a composition approaching trisilicic fluorphlogopite mica ($KMg_3AlSi_3O_{10}F_2$) (6). The material was acquired in a rod form.

### Method

The past method relied upon a stacked disk method (5). Enough disks were machined for one sample to allow an overall stack height greater than 27 mm. By having a stack greater than 25 mm, flags could be placed onto the stack to allow extensometry to be used over an 18-20 mm gage section. This would allow strain to be measured during compression.

For the MACOR material, the material was machined into disks as was the case for the CMC as well as leaving a solid rod of material greater than 25 mm in height for testing in compression as a comparison (where the interfaces from stacking would not be present).

All disks machined for this effort (CMC and MACOR) were machined with a center hole so that a centering rod of graphite could be used. The rod was machined shorter than the disk height so that it would not interfere or influence the measurement. This is shown in Figure 2.

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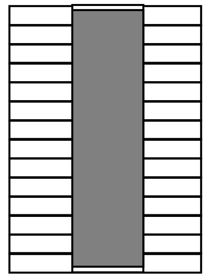

**Figure 2. Schematic of stacked disks (method) with centering hole (rod)**

RESULTS

The work done on the MI SiC/SiC system in the past paper is summarized in Figure 3 showing the modulus data as a function of temperature. The ultrasonic value (at room temperature) falls within the two experiments done on the CMC.

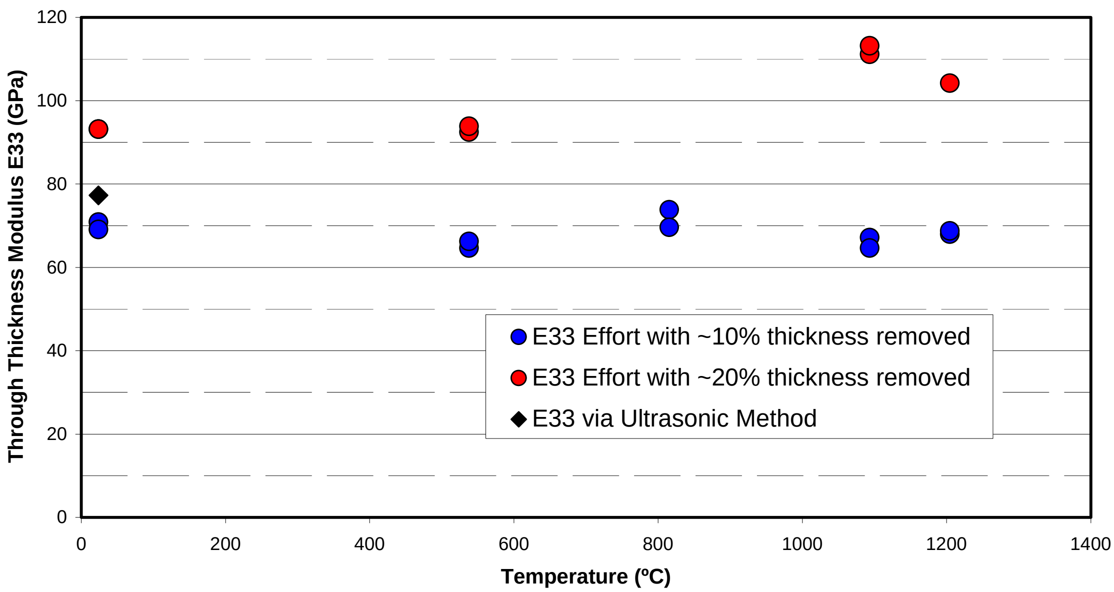


**Figure 3. Through Thickness Modulus values versus temperature for MI SiC/SiC**

The stress-strain for the CMC testing is shown in Figure 4. This figure shows that removing the surface asperities removes the initial compliance from the test. This also results in a higher modulus value since there is less porosity affecting the results.

The results from the MACOR rod and stacked disks are shown in Figure 5. As expected, the sold rod does not have the compliance issue seen in the stacked effort. The modulus value determined from the solid rod was found to be 66.6 GPa and the modulus value from stacked disk method was found to be 66.0 GPa. The literature value is published as 66.9 GPa (6).

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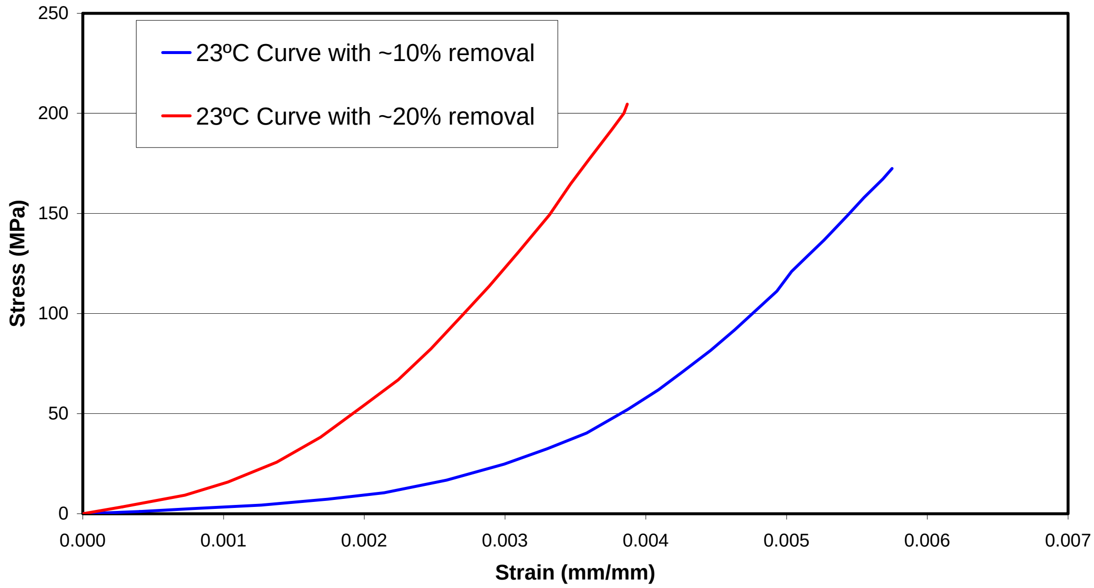


**Figure 4. Stress-strain data at 24ºC for modulus determination shown in Figure 3**

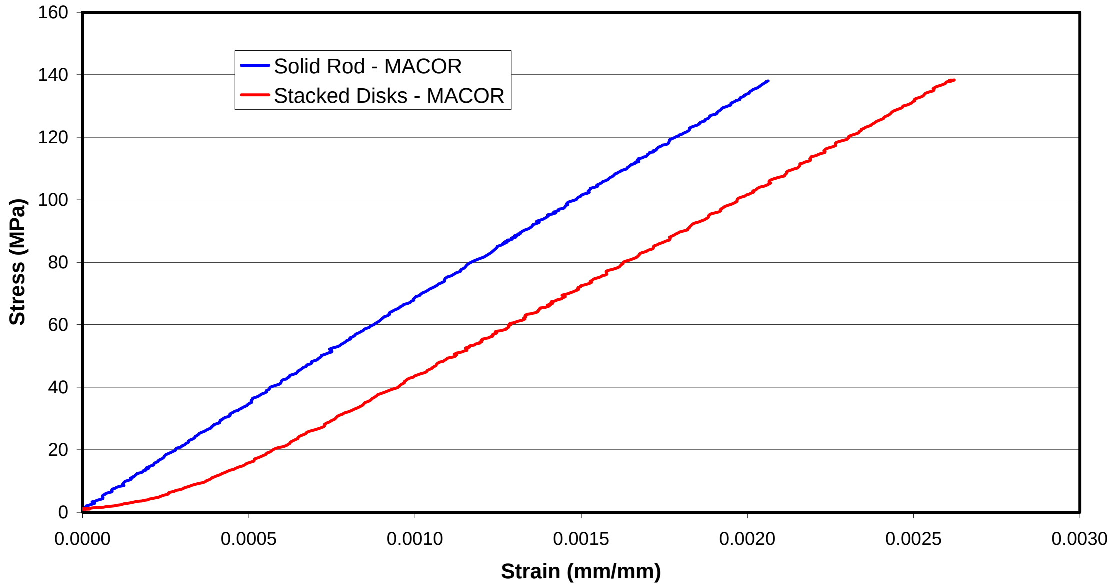


**Figure 5. Stress-strain data at 24ºC for the MACOR material (solid and stacked disks)**

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## DISCUSSION

The testing done on the MACOR material shows that the use of a stacked disk does not affect the resulting determination of modulus. It does show that there is concern about taking into account the initial compliance of the stack. For the stacked MACOR experiment, it is clear that the stress-strain data up to 40 MPa needs to be excluded in any analysis of the modulus from this experiment. The testing of the CMC shows that an even higher stress level is required before looking into what the modulus value is. This was set as being 160 MPa for the CMC based on past work (5). Figure 4 clearly shows that the slope of the curves is leveling off at this stress level.

The MACOR differs from the CMC in that when it was machined into disks and then ground, there is not as much surface asperity to remove. This is clearly not the case for the CMC system studied. The surface is not uniform initially due to the 5 HS weave used in fabricating the ply. Once the plys are stacked (in this case all material was 8 ply thick), several CVI runs are done applying more material to the surface. As can be seen in Figure 4, as more material is removed, the initial compliance of the stack is reduced. This is due to removing the surface asperities. A balance must be struck between how much material is removed before the material is no longer representative of the CMC.

## CONCLUSIONS

The method proposed of stacking disks of CMC material to determine the through thickness modulus of the material has been verified. It was found that stacking a known material to determine modulus and comparing that to a solid rod of material (for modulus) showed excellent agreement. Testing on a known material confirmed the need to look at the data outside of the initial compliance seen in the stress-strain data. Additional work should be taken on CMC systems to quantify the scatter seen in the method by looking at multiple samples within a given material system.

## ACKNOWLEDGMENTS

The Materials & Manufacturing Directorate, Air Force Research Laboratory under contract F33615-01-C-5234 and contract F33615-03-D-2354-D04 sponsored portions of this work

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