On-Orbit Repair of RCC Structures

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On-orbit repair technologies for reinforced carbon-carbon composite (RCC) structures are critically needed for space shuttle return to flight (RTF) efforts. These technologies are also critically needed for the repair and refurbishment of thermal protection system of future Crew Entry Vehicles (CEV) of space exploration programs. GRABER (Glenn Adhesive Refractory for Bonding and Exterior Repair) has shown multiuse capability for in-space repair of both large repairs and small cracks in space shuttle Reinforced Carbon Carbon (RCC) leading edge material. The concept consists of preparing an adhesive paste and then applying the paste to the damaged/cracked area of the RCC composites with caulking gun. The adhesive paste cures at 100-120 C and transforms into a high temperature ceramic during vehicle re-entry conditions. Further development and testing are underway to optimize the materials properties and extend the application temperature.

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  - Frank Hui, George Raiche, and ArcJet Test Facility Staff
- **ATK Thiokol**
  - Dean Lester and Plasma Torch Testing Staff

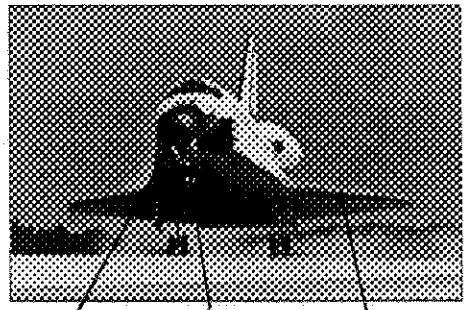
Outline

- Introduction
- RCC Repair Objectives
- On-Orbit Repair Technologies
- GRABER- Key Material Properties
- Testing and Characterization
  - ArcJet Testing
  - Plasma Torch Testing
  - Microstructural Characterization
- Summary and Conclusions

Thermal Protection System (TPS)
Damage Mechanisms

- Impact damage during ground handling
- Damage due to falling of ice or other objects during launch
- Micrometeoroid and orbital debris impact
- Damage caused by different factors during launch and reentry (weather, launch acoustics, shearing, etc.)

Leading Edge Structural Subsystem (LESS)
RCC Components Overview



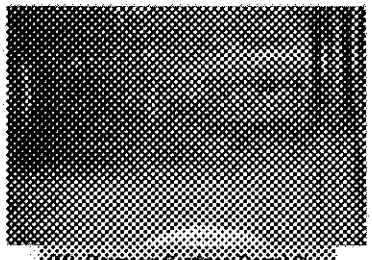
Nose Cap, Chin Panel, and Seals

Forward External Tank Attachment "Arrowhead" Plate

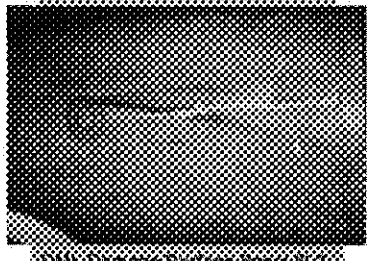
Wing Leading Edge Panels and Seals

[illegible]

Damage to Leading Edges During Testing



RCC Damage Surface Panel 9L



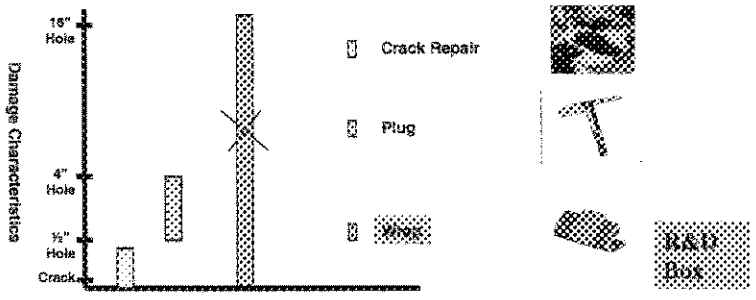
CMC Damage Surface Panel 9L2

[illegible]

RCC Repair Team Objectives

- Develop, certify, and deliver an Orbiter RCC Repair mod kit to repair catastrophic damage to the Leading Edge RCC subsystems (Nosecap, Chin panel, & Wing Leading Edge)
- Provide necessary products to XA to develop any required EVA tools (EVA)
- Provide support/products to MOD for on-orbit operational procedures development (MOD/OFTP)
- Provide a DTO kit & demonstrated RCC repair capability for STS 114

Repair Concept for WLE Damage and Location Limitations



Panel Location Limitations

- Crack Repair can accommodate cracks in the RCC acreage, but may have some restrictions on edges
- Plug can accommodate small scale holes provided adequate clearance behind damage to accommodate bolt length (expect restrictions on panel edges and wherever insulation is tight against the panel)

Glenn Refractory Adhesive for Bonding and Exterior Repair (GRABER)

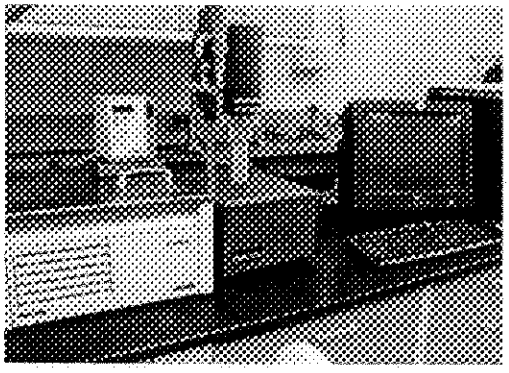
- Adhesive based on organic (Phenolics and Furan) based systems with a number of inorganic constituents.
- Viscosity and curing behavior (time, temperature) can be tailored to suit the needs.
- GRABER has been used to prepreg a wide variety of ceramic fiber weaves (C, SiO2, SiC).
- It bonds very well with a wide variety of surfaces and cures up to 120 C.

Multifunctionality of GRABER Based Materials

- **Crack Repair Materials**
  - Repair of cracks and damaged coatings
- **Adhesive and Sealants**
  - Bond and seal the edges in plug concept
- **Inner to Outer Mold Line (ITOM) Materials**
  - Filled Wing Concept
- **Flexible Prepregs**
  - New concepts for repair of large size damage
- **Manufacturing of Bulk Composites**
- **Repair of C/C Based Composites**
- **Functionally Graded Coatings for C/C Composites**

Reproducibility, Storage, and Shelf Life Characterization

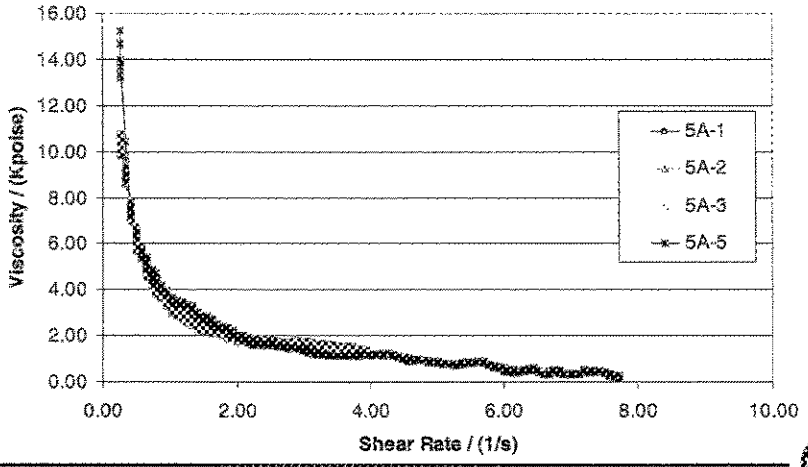
Brookfield PVS Rheometer Used for the Viscosity Measurements



The temperature control bath has capability from -20°C (- 4 F) to 180°C (356 F)

Reproducibility of GRABER 5A

Materials made at different times and in varying amounts show consistent viscosity



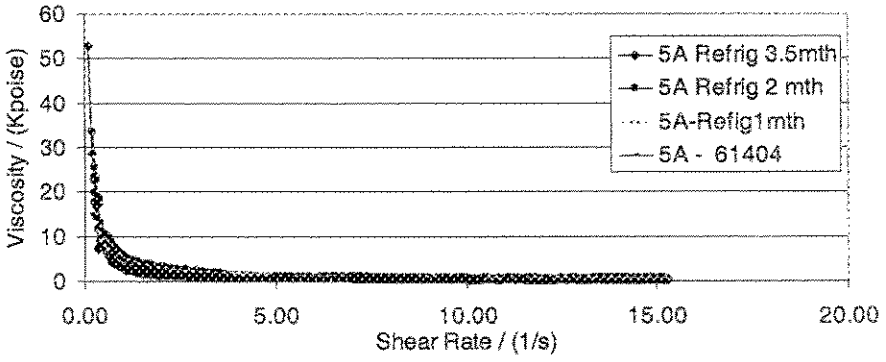
Effects of Storage Times & Temperatures

Materials	One Month		Two Months		>Three Months	
	0°C	-15°C	0°C	-15°C	0°C	-15°C
Graber-5	X	X	X	X		
Graber-5A	X	X	X	X	X	X
Graber-12A	X	X	X	X		

Storage Temperature Effects on GRABER 5A

Material Stored in a Refrigerator at 0 C

Materials stored for different times (1-3 months) had similar type of viscosity behavior as freshly prepared materials

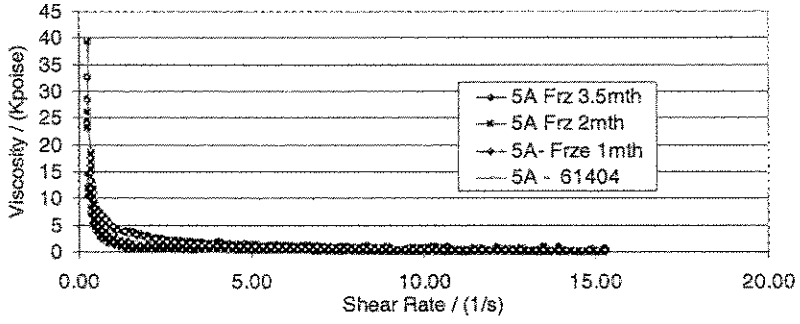


Material was Tested under Vacuum

Storage Effects on GRABER 5A

Material Stored in a Freezer at -15 C

Materials stored for different times (1-3 months) had similar type of viscosity behavior as freshly prepared materials



Material was Tested under Vacuum

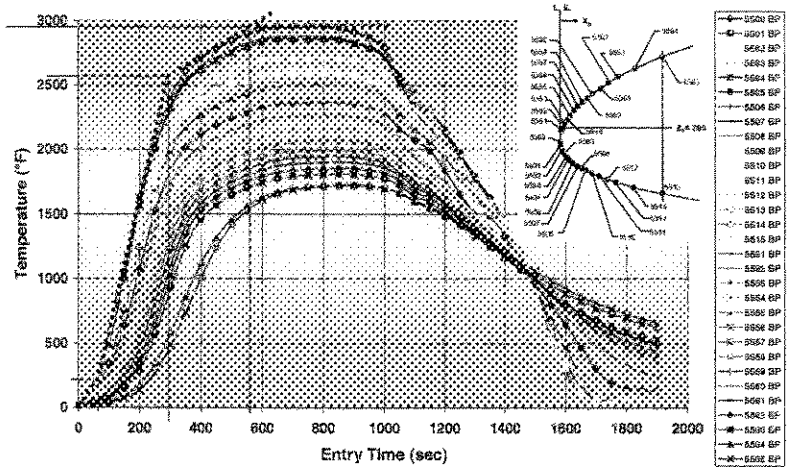
Crack Repair, ArcJet Testing, and Post Test Characterization

- GRABER 5 (0.035" and 0.062" wide cracks-ARC)
- GRABER 5A (0.035" and 0.062"-ARC)
- GRABER 12A (0.035"-JSC and 0.035" and 0.062"-ARC)

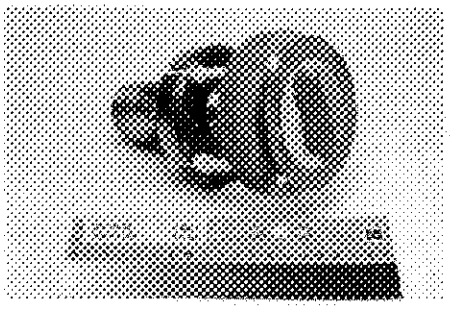
All SEVEN ArcJet Tests Were Successful

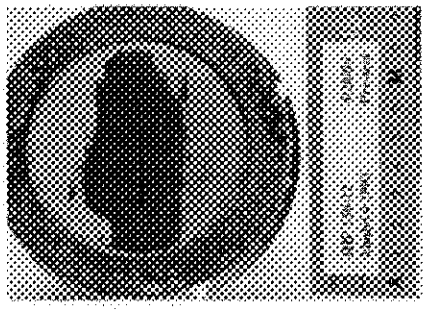
WLE Entry Temperature Profiles

Panel 9 (55% Span) Temperature Profile for Nom iSS EOM



ArcJet Testing of Repaired Specimens at ARC
Run 12 – Model 1993





ArcJet Testing of Repaired Specimens at ARC
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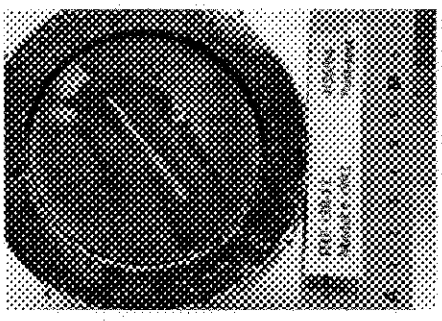
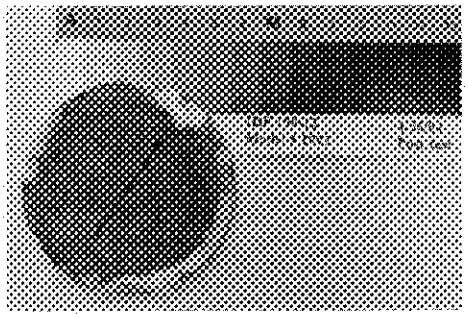
ArcJet Testing of Repaired Specimens at ARC
Run 12 – Model 1993

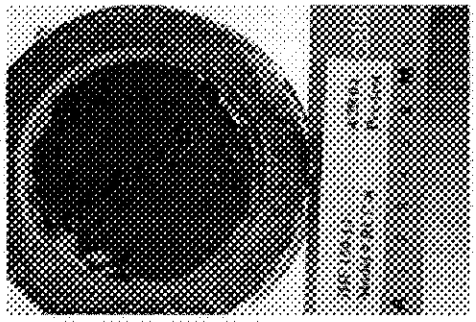


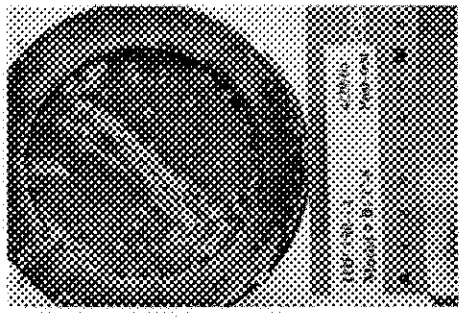
Post Test- Front Side



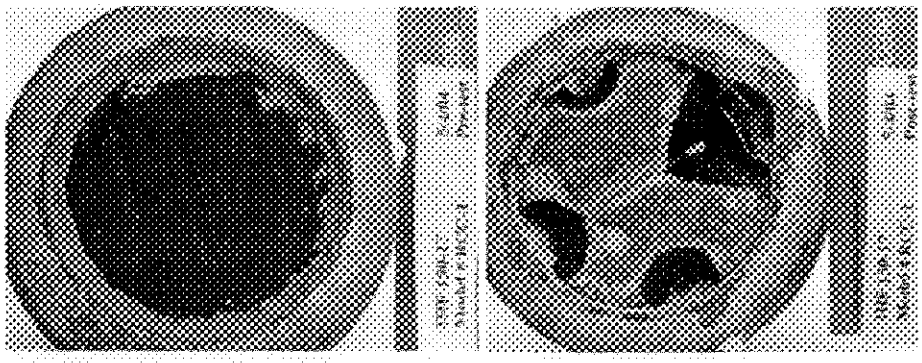
Post Test- Back Side

ArcJet Testing of Repaired Specimens at ARC
Run 14 – Model RCC 8





ArcJet Testing of Repaired Specimens at ARC
Run 17 – Model RCC 1

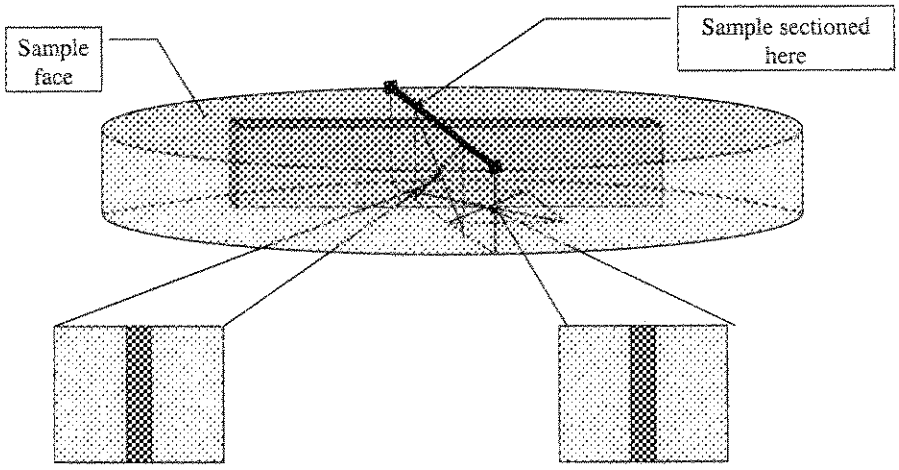


Glenn Research Center at Lewis Field

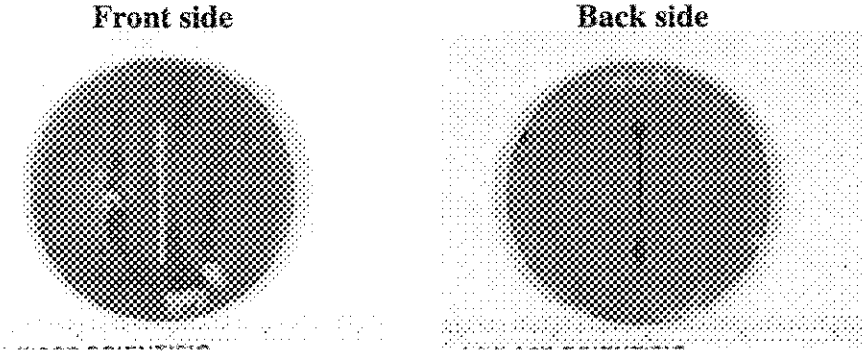
ArcJet Testing of Repaired Specimens at ARC
Run 17 – Model RCC-1

Glenn Research Center at Lewis Field

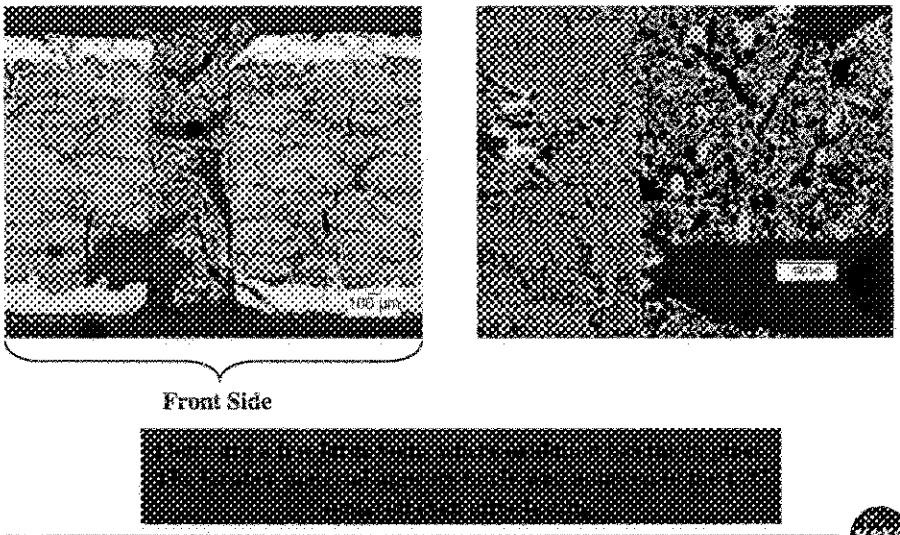
Arcjet Sample Description and Preparation



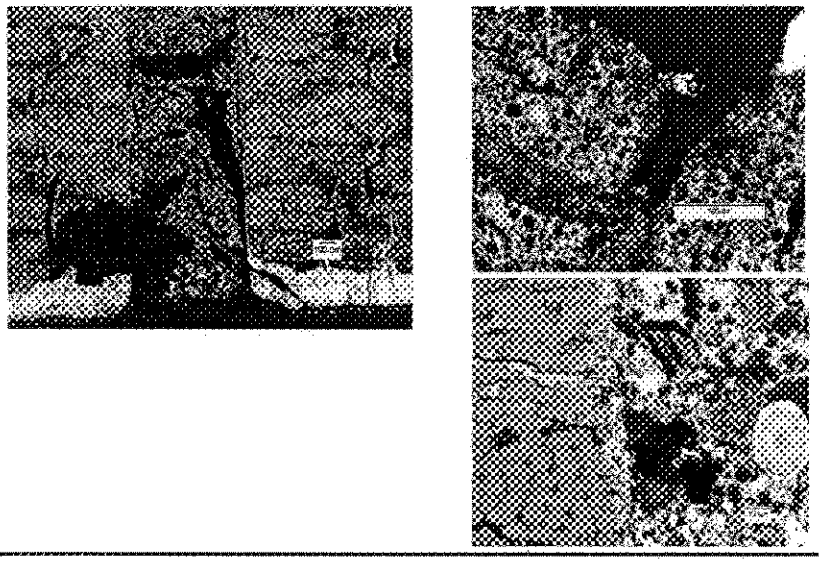
ArcJet Sample 1993, Graber 5A, 0.035" Crack Width



ArcJet Sample 1993 (150-12), Graber 5A, 0.035" Crack Width

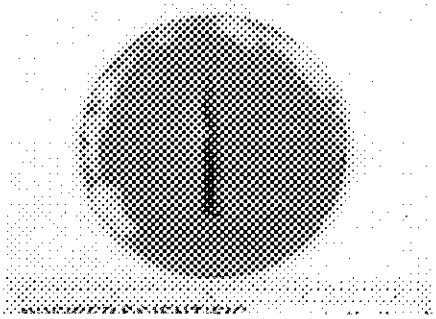


ArcJet Sample 1993 (150-12), Graber 5A, 0.035" Crack Width

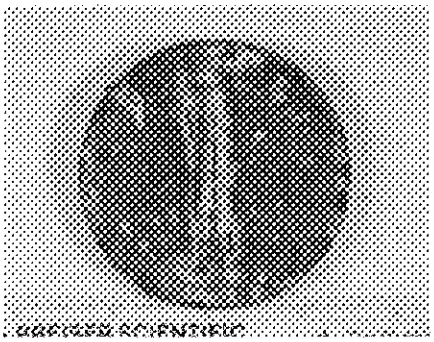


ArcJet Sample 150-14, RCC-8, GRABER 12A, 0.062" Crack Width

Back side

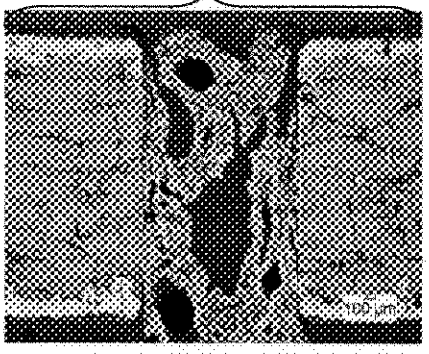


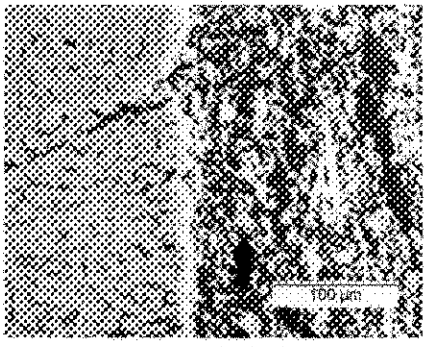
Front side



ArcJet Sample 150-14, RCC-8, GRABER 12A, 0.062" Crack Width

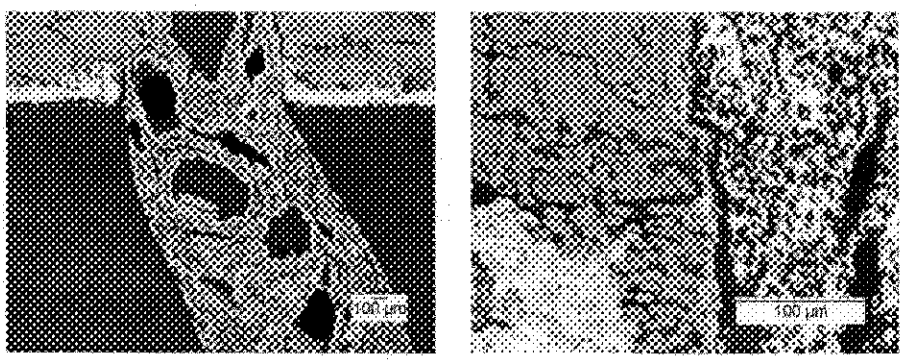
Front Side





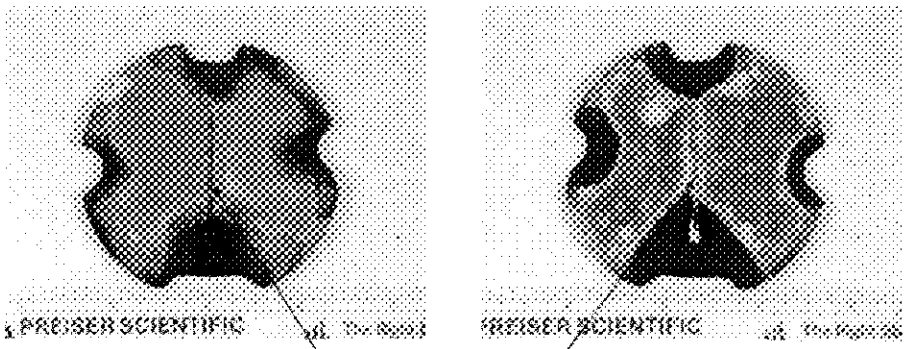
There are large voids within the Graber material. The bonding between the Graber material and the CAC substrate looks good as seen on the right.

ArcJet Sample 150-14, RCC-8, GRABER 12A, 0.062" Crack



Backside

ArcJet Sample 150-11, RCC-1,GRABER 5, 0.062" Crack Width

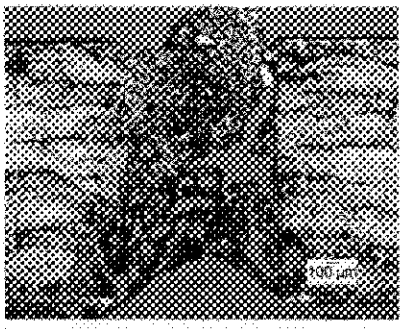


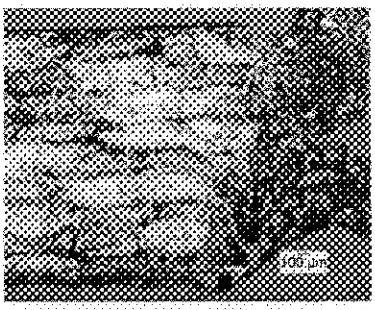
Back side

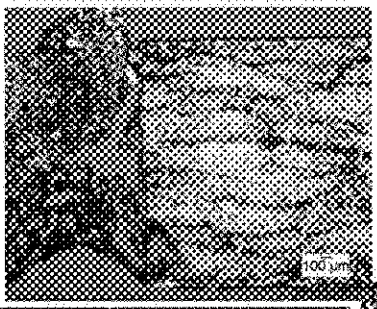
Front side

Crack filled with Graber material

ArcJet Sample 150-11, RCC-1,GRABER 5, 0.062" Crack



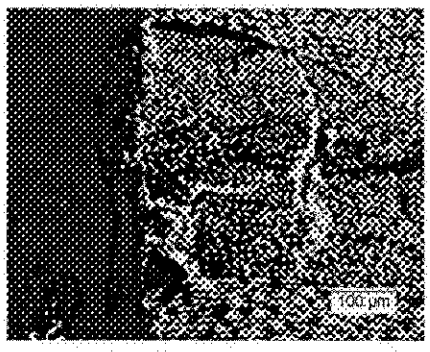


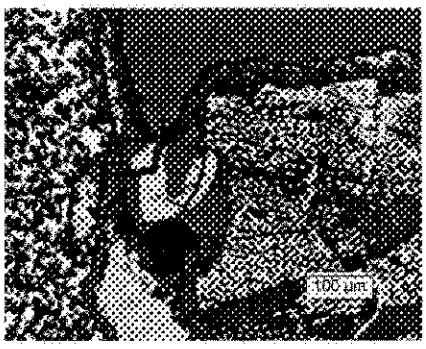


Front Side

It appears as the sample had partially recrystallized at advanced stage. There is only a skeleton left of the Uvarov material which appears to be a glassy phase.

ArcJet Sample 150-11, RCC-1,GRABER 5, 0.062" Crack Width



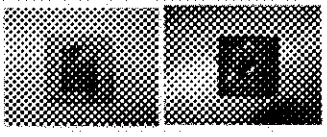
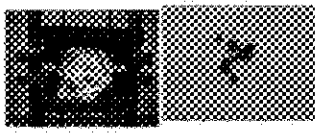
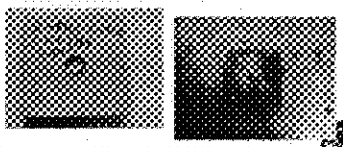


These higher magnification images show more clearly the glassy phase left of the Uvarov material. You can also see the degradation of the SiC matrix.

Applications of GRABER in Other Repair Concepts

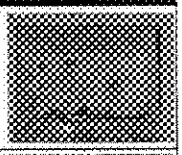
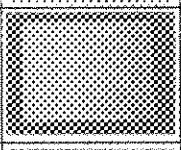
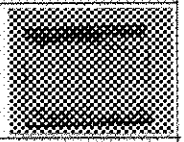
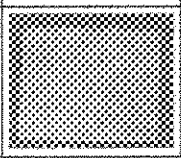
Plug Repair Development

Torch Screening Tests for RCC Repair Candidates @ ATK Thiokol Propulsion

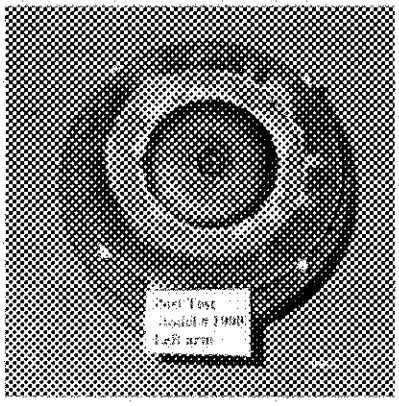
Silica Cloth/Graber 1 Hi Nicolon –S UF3364 SCV 2x 2 RCC Analog	133 Btu/ft²-sec 4min 13 sec to failure shown in post test photo.	Flat Plate with Hole Repair	
Platinum Rhodium crucible lid backed by RCC analog ***Room Temperature emmisivity 0.05***	136 Btu/ft²-sec ~1second	Free standing sample backed by RCC analog	
Silica Cloth/Graber 1 UF3364 SCV 2x 2 RCC Analog	129 Btu/ft²-sec , no burn through at 15 min	Flat Plate with Hole Repair	

Plug Repair Development

Torch Screening Tests for RCC Repair Candidates @ ATK Thiokol Propulsion

Graber-1 impreg. silica cloth bonded with UF-3364 SCV B-1 ***Full duration, patch was adhesively attached***	~130 Btu/ft²-sec 15 min, full duration	Flat Plate with Hole Repair		
HPC Coated Mo., Panel #43 ***Stopped Test – low heat flux.***	Start ~130 Btu/ft²-sec End ~87 Btu/ft²-sec 5 min until oxygen ran out	Free Standing Metal Disk		
HPC Coated Mo., Panel #44 ***Coating failure @...***	~130 Btu/ft²-sec ~5 min to failure	Free Standing Metal Disk		

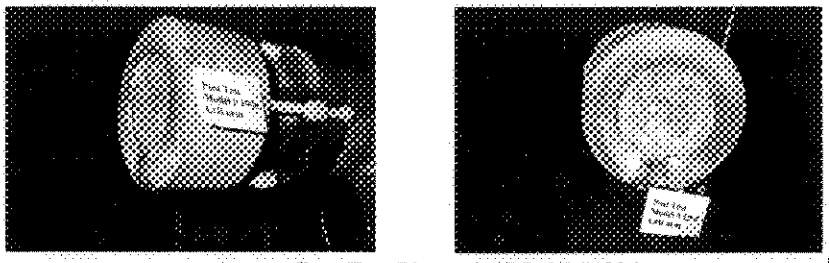
Sealants for Plug Repair Development



- **Analogue RCC Plug Sealed with GRABER 5A Crack Sealant**
- **Survived the ArcJet Testing at JSC**

Testing of GRABER-5 for ITOM at JSC Arc Jet Facility

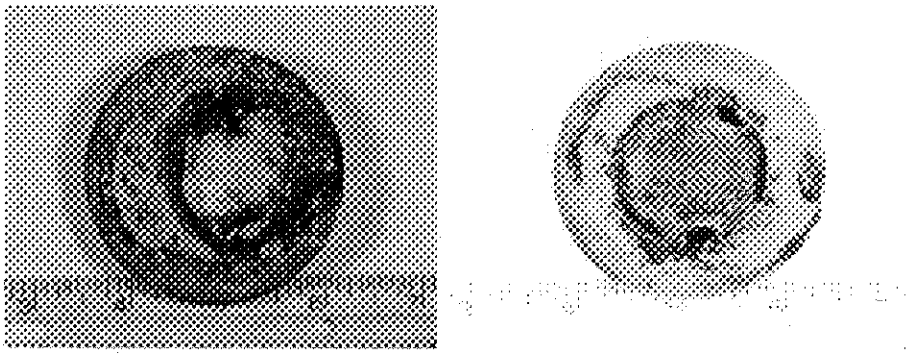
- Graber 5 Material was tested at JSC ARMSEF 1/9/04 in support of IFB team
  - 2700F and 2960F test points (based on RCC Calibration model)
- During the first 200 seconds at the 2700F test point, dramatic surface reactions were observed and the surface temperature did not stabilize and reach steady state
- After 200 seconds at the 2960F test point, the surface temperatures dropped significantly and stabilized, however, non-uniform temperature distributions across the surface were observed.
- The pressure readings on the backside showed no indications of flow through the material at any point during the test



Post Test Photos for Model #1906
Graber 5

Post Test Analysis of GRABER 5 (Model 1908)

Macrographs of 1908 after ArcJet Testing



Front Side

Back Side

Summary and Conclusions

- GRABER-based materials have multiuse capability and multifunctionality for a wide variety of repair applications.
- This system can be easily modified to obtain adhesive materials with desired properties (viscosity, composition, curing behavior, etc.).
- The material has long self life. Normal storage and handling techniques can be used.
- These materials are affordable since the cost of raw constituents is very low (few dollars a pound)
- Excellent plasma performance in ArcJet testing conditions at various facilities.