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Abstract

A novel attachment approach for positioning sensor lead wires on silicon carbide-based monolithic ceramic and fiber reinforced ceramic matrix composite (FRCMC) components has been developed. This approach is based on an affordable, robust ceramic joining technology, named *ARCJoinT*, which was developed for the joining of silicon carbide-based ceramics and fiber reinforced composites. The *ARCJoinT* technique has previously been shown to produce joints with tailorable thickness and good high temperature strength. In this study, silicon carbide-based ceramic and FRCMC attachments of different shapes and sizes were joined onto silicon carbide fiber reinforced silicon carbide matrix (SiC/SiC) composites having flat and curved surfaces. Based on results obtained in previous joining studies, the joined attachments should maintain their mechanical strength and integrity at temperatures up to 1350 °C in air. Therefore, they can be used to position and secure sensor lead wires on SiC/SiC components that are being tested in programs that are focused on developing FRCMCs for a number of demanding, high temperature applications in aerospace and ground-based systems. This approach, which is suitable for installing attachments on large and complex shaped monolithic ceramic and composite components, should enhance the

durability of minimally intrusive high temperature sensor systems. The technology could also be used to reinstall attachments on ceramic components that were damaged in service.

Introduction

There has been a surge of interest in the development of silicon carbide-based monolithic ceramic and composite materials and components for demanding, high temperature applications. These materials are being considered for a number of applications in the aeronautics, chemical, energy, electronics, nuclear, and transportation industries. Current and potential applications include engine components, radiant heater tubes, heat exchangers, heat recuperators, components for land based turbines for power generation, fusion reactor components, furnace linings and bricks, and components for diffusion furniture (boats, tubes) in the microelectronics industry. Thorough characterization of material properties, including high temperature testing under simulated or actual operating conditions, is a high priority for programs involved in developing these SiC-based materials and components.

Members of the Sensors and Electronics Technology Branch at NASA Glenn Research Center (GRC) are developing minimally intrusive methods of monitoring the exposure conditions and the material response (such as surface temperature, strain, heat flux characteristics, etc.) of components that are being tested or operated in hostile, high temperature environments [1-4]. Their primary goal is to instrument the test article or operating component with sensors (e.g., thermocouples or strain gages) that are durable, but (1) have a minimal effect on the gas flow across the surface of the component and thermal conduction through the component, and (2) have minimal reactivity with the surface of the article. Therefore, the main thrust of this work has been the development of sensors in a thin film form for use on various advanced material test articles, including SiC/SiC composite components.

Under typical test conditions for SiC/SiC composites, these sensors must function at 1000 °C or higher under high velocity combustion gas flow for extended times in test rigs. In previous studies at NASA GRC, sheathed sensor lead wires have been bonded to the surface of the composite test article using an alumina-based refractory adhesive such as Aremco 503 cement. The cement initially prevents the lead wires from vibrating, moving, or detaching from the thin film sensors. The latter can occur within the welded joints that bond the lead wires to the thin film sensor wires. The cement is chemically compatible with the sheathed lead wires (cables) and the substrate material, and the bonded wires have a minimal effect on the high velocity gas flow within the test rig. However, heat conduction through the thickness of the test article is reduced by the presence of a poor thermal conductor on its surface. More importantly, at 1000 °C or higher, the adhesive cement degrades and begins cracking. This leads to detachment from the FRCMC component and can cause the welds connecting the sensor lead wires and the thin film wires to break, especially when high velocity combustion gases are flowing over the sensor lead wires. Thus, the use of these minimally intrusive methods in the long term characterization of SiC/SiC test components has been limited by lead wire attachment durability.

Therefore, there is a need for an improved attachment technique for securing sensor lead wires in place on SiC-based components/subcomponents that are being tested at temperatures to 1000 °C (or higher), to enhance the durability of minimally intrusive sensors. Based on the need for minimal intrusion, an alternative approach to attaching sensor lead wires to SiC/SiC components utilizing strongly-bonded monolithic SiC and SiC/SiC hoops was devised.

The joining of SiC-based ceramics (including FRCMCs) has been pursued within the Ceramics Branch at NASA GRC for several years [5-14], since joining is recognized as one of the enabling technologies for the use of these materials in demanding propulsion applications. An affordable, robust ceramic joining technology named *ARCJoinT* has been developed at NASA GRC for the joining of silicon carbide-based ceramics and fiber reinforced composites [5]. The *ARCJoinT* approach, which is a reaction forming technique, has previously been shown to produce joints with tailorable thickness and good high temperature strength. The formation of joints by this approach is also attractive since the thermomechanical properties of the joint interlayer can be tailored to be very close to those of the silicon carbide-base materials. Therefore, we initiated a study to investigate the bonding of SiC and SiC/SiC hoop attachments to SiC-based substrates using the *ARCJoinT* approach. The goals of this study were to determine our ability to join these attachments to test articles, to use the attachments to position and secure the sensor lead wires, and to evaluate the potential for improving sensor durability.

Experimental Procedures

Silicon carbide-based monolithic ceramic and FRCMC attachments of different shapes and sizes were joined onto SiC/SiC composites having flat and curved surfaces. The majority of the attachments evaluated in this study were semi-circular SiC hoops (Fig. 1) that could be used to position and secure sensor lead wires.

A schematic of the reaction forming process that was used to join the attachments to SiC/SiC panels and subelements is shown in Fig. 2. It has previously been demonstrated that joint thickness can be controlled using this process. The initial step in the joining process is the application of a carbonaceous mixture to the joint area. The applied mixture is cured at 110-120 °C for 10 to 20 minutes [8]. During curing, a moderately strong bond is developed between the attachment (in most cases, a semi-circular hoop) and the substrate. Next, silicon or a silicon-alloy in the form of a paste, slurry, or tape is applied to the joint regions, and the article is heated up to 1250-1425 °C (temperature required depends on the composition of the infiltrant) for 5-10 minutes. The silicon or silicon-alloy becomes molten and reacts with the carbon to form a joint consisting of silicon carbide grains and a minor (and typically controllable) amount of silicon. If a silicon-alloy is used, additional phases (as determined by the alloy composition) will be present. Joints formed between the attachments and the SiC/SiC substrates were characterized by optical microscopy of polished cross sections.

Following the joining of the attachments, the sensor lead wire cable can be slipped through the hoops (Fig. 3) and connected to thin film sensors. Any excess space between the lead wire assembly and the hoop can be filled with refractory cement or another nonreactive compound, if necessary, to prevent the assembly from moving.

The novel attachment concept was initially tested by heat treating lead wire cables (Nextel braided-sheath 3-Fe/Cr/Al conductors and 20 mil (0.5 mm) Pt-sheath Pt, Pt/Rh conductors) that had been placed through developmental attachments (SiC hoops) on small SiC/SiC panels. The 20 mil thermocouple lead wire cables were held within the hoops with cement, because the hoops were oversized. The panels, which were heated in air for up to 10 hrs at 1100 °C, were subsequently examined.

Results and Discussion

Fabrication and Joining of Attachment Hoops

Attachment hoops of various sizes (Fig. 1) were developed for securing lead wire cables. These hoops were fabricated from monolithic SiC tubes (of various diameters) or "corrugated" SiC/SiC composite panels. Carbon hoops can also be used to form attachments. In this case, additional silicon is applied to the joint region, and the carbon hoop is subsequently converted to silicon carbide (with some residual silicon) via the same reaction forming process. The advantage to using this approach is the relative ease of cutting and machining graphite (vs. SiC) into the required attachment shape. In addition, a carbon tube can be converted to SiC via reaction forming, and then machined to obtain SiC hoops of the desired size.

The use of a properly sized attachment should prevent the wires from moving, which reduces the risk of sensor failure occurring due to breakage of the weld between the lead wires and the wires connected to the thin film sensors. The smaller and/or thinner hoop attachments should minimize disruption of testing under simulated engine conditions due to their minimal contact with the test article (and thus, minimal effect on through thickness thermal conductivity), and by minimizing the disruption of high velocity combustion or cooling gas flow. Thus, the use of thin hoops having an inner radius slightly larger than the diameter of the sensor lead wire cable (Fig. 4) was selected as a preferred approach for further development in our attachment studies. An example of our ability to join these attachments to a curved surface is provided in Fig. 5. This capability is important, because most SiC/SiC components that are tested (such as combustor liners) have some curved surfaces.

Microstructure of Joints

A macroscopic view of the polished cross section of a joined attachment and the microstructure of one of the joints formed between this attachment and a melt infiltrated (MI) SiC/SiC FRCMC substrate are shown in Fig. 6 (a-c). This SiC attachment hoop was fabricated by cutting an 8 mm o.d. diameter Hexoloy-SA tube (wall thickness of 1.2 mm). The hoops were each approximately 1.9 mm wide. Polished cross sections of three hoops (and thus, six joint regions) were examined. The thickness' of the joints that were examined ranged from 40 to 360 μm. The average joint thickness was approximately 150 μm. The primary causes of the variation in joint thickness presumably were (1) differences in the amount of force used when positioning the attachment and forming the initial bond (prior to melt infiltration) resulting in differences in the amount of carbonaceous paste present in the joint region, and (2) the surface roughness of both the composite and the ends of the hoops. The additional silicon and silicon carbide material remaining around the base of each hoop (Fig. 6 b), which naturally forms a fillet, is not a concern because it probably increases the strength of the attachment. In 5 of the 6 joints that were evaluated, the microstructure primarily consisted of a fine mixture of silicon carbide grains (gray) and residual silicon (white) phase (Fig. 6 c,d). Some residual silicon-filled cracks or pores were also observed. However, the other joint (the sixth one) that was examined consisted primarily of silicon.

Overall, given the microstructural appearance of some of the joints formed in this study between the attachments and a SiC/SiC substrate, we currently expect the joints to have high temperature strengths that are much greater than the stresses that the joint region will be subjected to during testing. This is being determined in a concurrent study in which a burner rig is being used to evaluate the durability of the sensor assembly. To ensure optimum performance, our new goal is to identify a reproducible technique for forming joints similar to the one shown in Fig. 6d, because in a previous study [9], Hexoloy-SA SiC specimens containing butt joints that had been formed using the same process (and which exhibited similar joint microstructures and a thickness of 50 μm) had an average flexural strength of 265 MPa at 1350 °C. Therefore, additional attachments are being formed using modified approaches, for subsequent microstructural evaluation.

Evaluation of Stability and Durability

Heat treatments of subelements (small SiC/SiC panels) with wires secured on the surface (using the novel positioning approach) at 1100 °C for up to 10 hrs did not appear to degrade either type of sheathed lead wires (Nextel braided-sheath 3-Fe/Cr/Al conductors and 20 mil (0.5 mm) Pt-sheath Pt, Pt/Rh conductors) or affect the SiC hoops. The latter remained in place, and there was no detectable reaction between the substrate or hoops and the cables. Under similar test conditions, the cement that has typically been used to secure the lead wires would crack and debond. As mentioned earlier, adhesive degradation at 1000 °C has allowed cables to detach from test articles and vibrate, which led to sensor failure. Thus, the projected excellent high temperature strength and stability of the attachments and joints should make it possible to obtain better sensor durability than has previously been achieved through the practice of using refractory, adhesive cement to secure lead wire assemblies.

Conclusions

An approach was developed wherein a reaction forming method has been successfully used to join hoop-shaped monolithic SiC and SiC/SiC composite attachments to both flat and curved surfaces of SiC/SiC composite subelements. These attachments, which were developed for positioning and securing sensor lead wire cables on large and complex shaped monolithic SiC or SiC/SiC composite test components, are expected to maintain their integrity up to 1350 °C in air. Thus, this approach is being further evaluated to determine the potential for obtaining enhanced durability, minimally intrusive, high temperature sensor systems for use during testing conducted for programs that are focused on developing ceramic materials for a number of demanding, high temperature applications in aerospace and ground-based systems. The approach has widespread application. It will be of use to the Propulsion Instrumentation Working Group, which addresses the development and application of sensors for high temperature evaluation of Aeropropulsion components/machinery.

Other Potential Applications of This Technology

The technology could also be used to reinstall attachments on ceramic components that were damaged in service. With modifications, this approach could be used for installing attachments on silicon nitride-based materials, or to repair silicon-based CMCs.

Future Work

The processing, testing, and characterization of attachments joined using modified approaches will continue, in order to allow us to optimize the microstructure and performance of the joints. We intend to use this approach to attach different types of lead wire cables to various SiC-based substrates. Given that melt infiltrated (MI) SiC/SiC components are being considered for many propulsion applications, we want to fully consider possible interactions between the constituents of this particular FRCMC and the lead wire cables. The lead wires typically used in testing at NASA GRC have Inconel, platinum, or braided Nextel fiber sheaths. The lead wires within the cables consist of Pt, Pt-Rh, and Fe-Cr-Al high temperature conductors. Thus, we are currently evaluating the need for environmental barriers (coatings, protective sheath, etc.) that would prevent reactions between thermocouple sheath materials or lead wires and the silicon, silica, or SiC present in the attachments or the silicon-based substrate (monolithic SiC or SiC/SiC composite test article). The results of this study will be presented in a subsequent paper, that will further address the environmental durability/stability of the sensor assembly and attachments. As part of that study, testing of MI SiC/SiC panels (Fig. 7) instrumented with thin film thermocouples will be performed in a Mach 0.3 burner rig to evaluate the durability of the sensor assembly up to 1200 °C. If this testing indicates improved results, the technology could then be applied to the testing of subcomponents.

Additional effort will be expended on developing a "portable" joining technique for attaching the hoops to SiC/SiC components. This is a challenging task. However, the ability to use an effective localized heating source would make the approach more flexible by removing the need for a furnace. This could make it easier to work with larger articles, and would provide a means of incorporating or repairing various types of attachments "in the field."

References

[1] J. Lei, L. Martin, and H. Will, International Gas Turbine & Aeroengine Congress & Exhibition, Orlando, FL, ASME 97-GT-458.

[2] J. Lei, M.D. Cuy, and S.P. Wnuk, "Attachment of Free Filament Thermocouples for Temperature Measurements on CMC," NASA-TM 107488 (1997), Glenn Research Center, Cleveland, OH.

[3] L. Martin and R. Holanda, "Applications of Thin Film Thermocouples for Surface Temperature Measurement," NASA-TM 106714 (1994), Glenn Research Center, Cleveland, OH.

[4] R. Holanda, "Development of Thin Film Thermocouples on Ceramic Materials for Advanced Propulsion System Applications," NASA-TM 106017 (1992), Glenn Research Center, Cleveland, OH.

[5] M. Singh, Scripta Materialia, 37, 8 (1997) 1151-1154.

[6] M. Singh, Industrial Heating, September 1997, 91-93.

[7] M. Singh and J.D. Kiser, in 'Physics & Process Modeling and Other Propulsion R&T Conference', NASA CP-10193, 5:1-10 (1997).

[8] M. Singh, J.D. Kiser and S.C. Farmer, Ceramic Engineering and Science Proceedings, 18, 3, (1997) 161-166.

[9] M. Singh, J. Mater. Sci. Letters, 17 (1998) 459-461.

[10] M. Singh, in "Joining of Advanced and Specialty Materials," ASM International, Materials Park, OH (1998) 1-5.

[11] M. Singh, "Key Engineering Materials," 164 (1999) 415-420.

[12] M. Singh, in Proceedings of "9th CIMTEC-World Ceramics Congress", Florence, Italy (1998).

[13] M. Singh, Advanced Materials and Processes, 10 (1998) 89-90.

[14] M. Singh, J. Mater. Sci., 33, 24 (1998) 5781-5787.

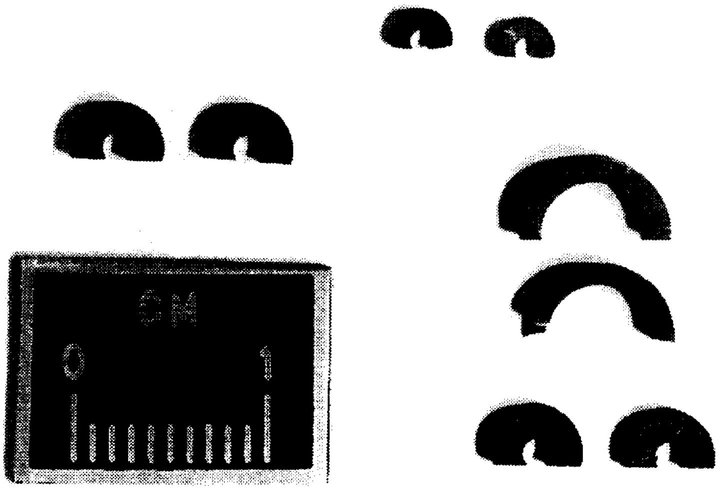

Figure 1.—SiC hoop attachments of various sizes.

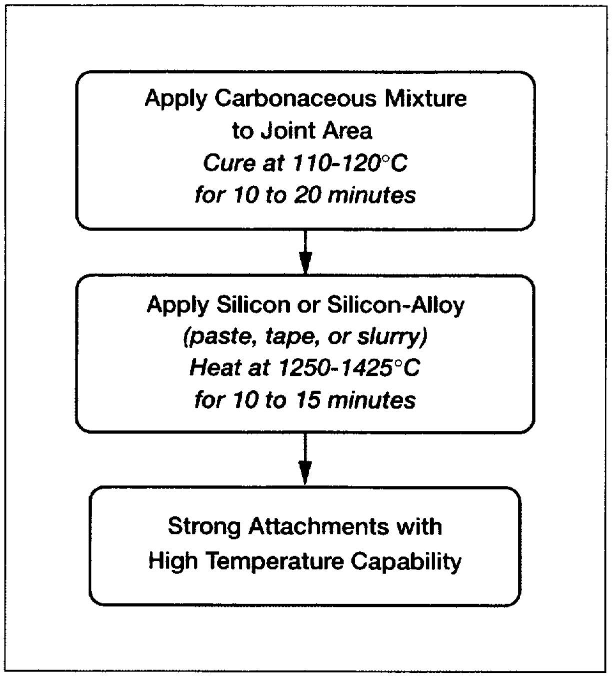

Figure 2.—Schematic of the Reaction Forming Joining Process that was used to attach SiC hoops.

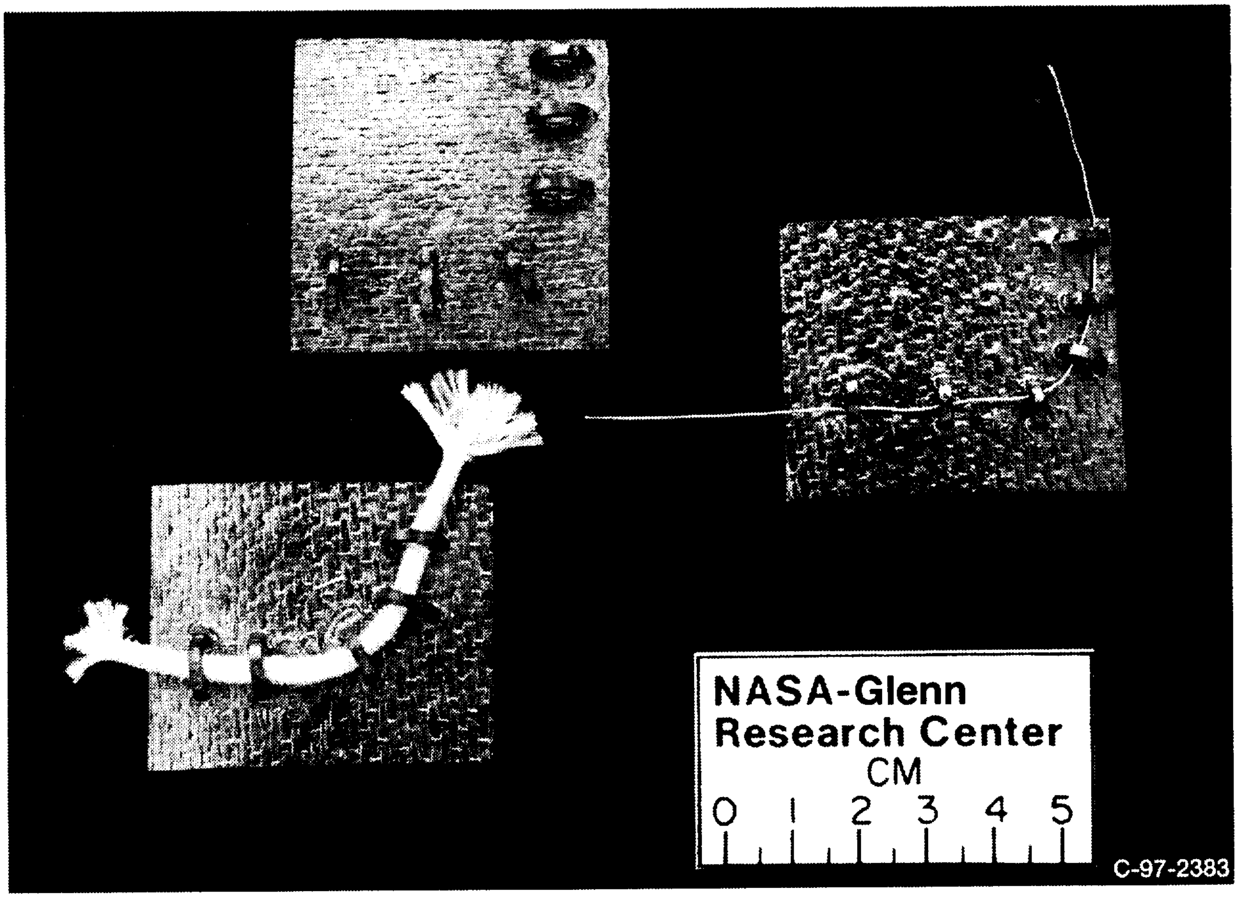

Figure 3.—SiC hoops joined to SiC/SiC composite panels. These attachments are for positioning and securing sensor lead wires.

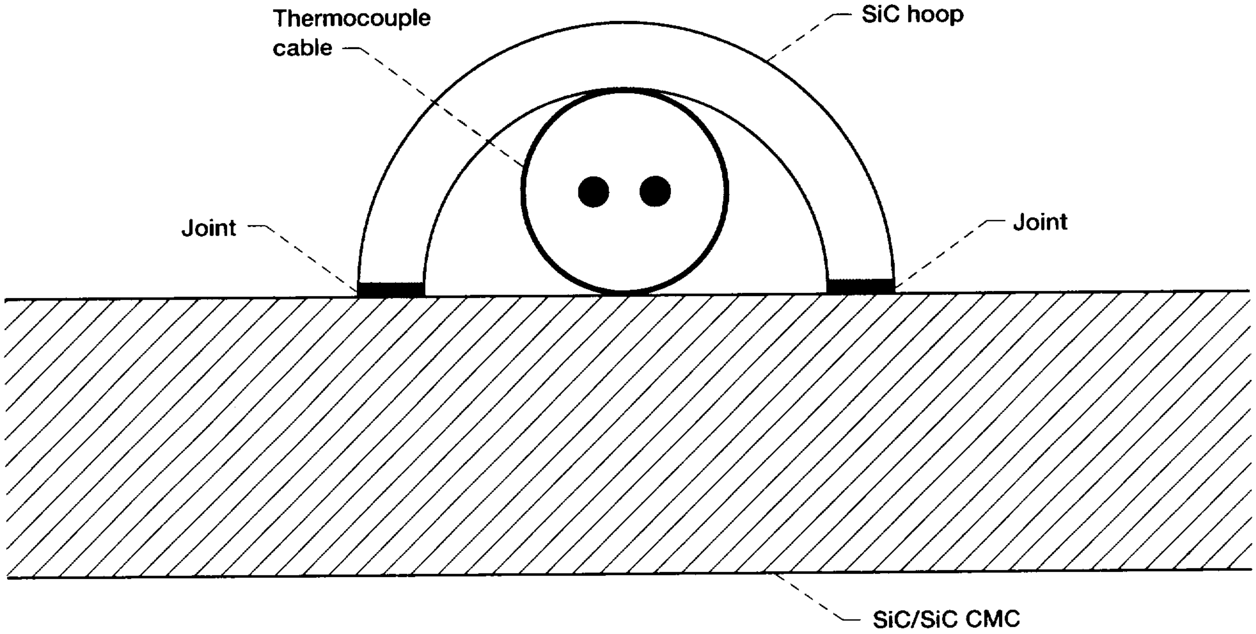

Figure 4.—Schematic showing a cross sectional view of the thin SiC hoop attachment approach for positioning lead wired cables on SiC/SiC CMC subcomponents.

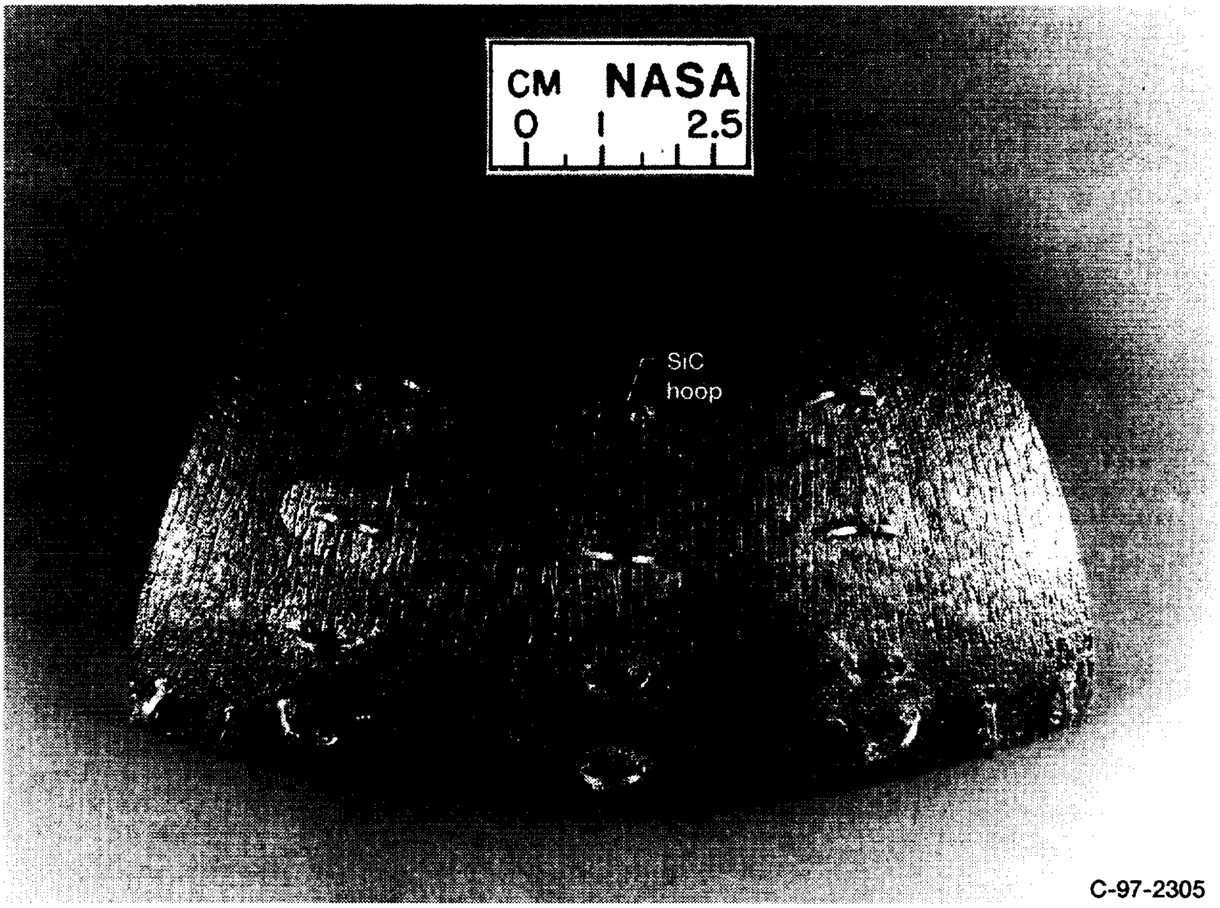

Figure 5.—Demonstration of our ability to attach (via reaction joining) SiC hoops for positioning and securing sensor lead wires on a SiC/SiC composite subelement having a curved surface.

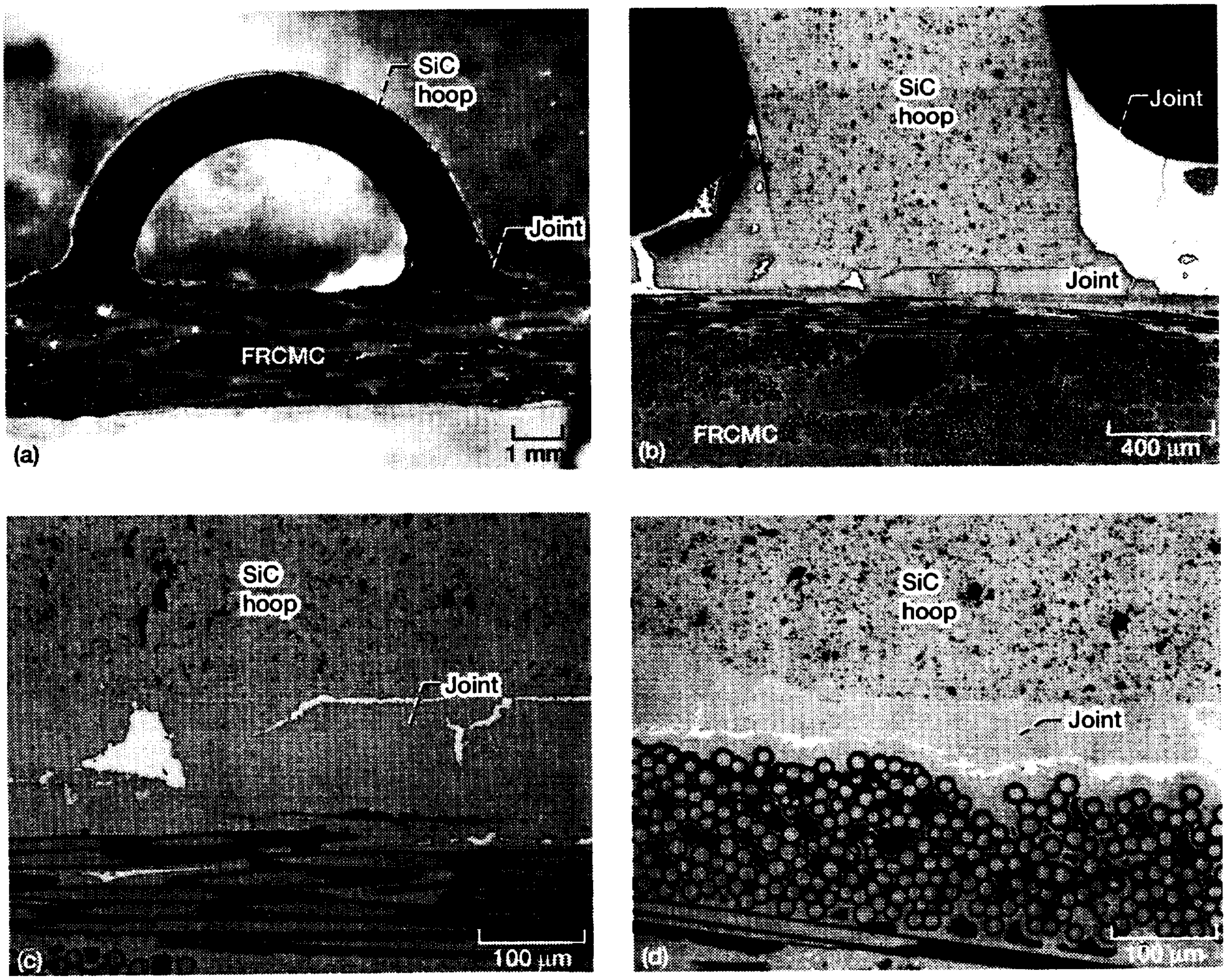

Figure 6.—(a) Polished cross section of a SiC hoop joined to a SiC/SiC panel; (b,c) microstructure of a reaction formed joint between the attachment (SiC hoop) and SiC/SiC substrate shown in (a) and (d). This joint microstructure exhibits the characteristics (composition, thickness, uniformity) that we feel will yield optimum results.

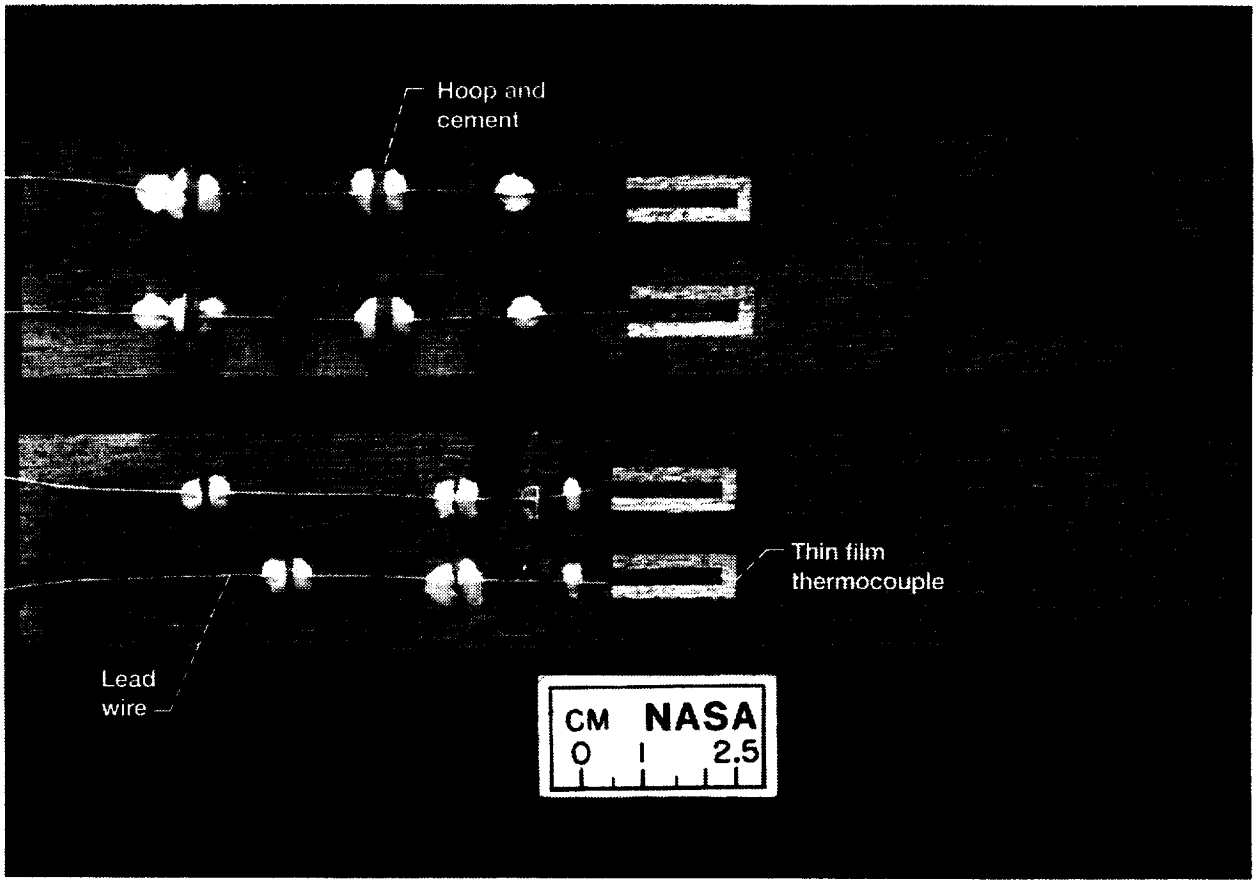

Figure 7.—SiC/SiC panels instrumented with thin film thermocouples. Lead wire cables were secured with joined SiC/SiC (top) and SiC (bottom) attachments and refractory cement. Several SiC hoops were damaged during a sand-blasting step (nonstandard) that was used to remove a previous thin film thermocouple.

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13. ABSTRACT ***(Maximum 200 words)***

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14. SUBJECT TERMS

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