N91-23068

PRACTICAL APPROACHES FOR APPLICATION OF RESISTANCE TYPE STRAIN GAGES ON HIGH TEMPERATURE COMPOSITES

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INTRODUCTION

The introduction of carbon/carbon and metal matrix composites as most probable candidate materials for extensive use on hypersonic flight vehicles generates the need to measure their mechanical properties under severe test environments. Surface mounted strain gages have historically provided the most widely used means for measuring strains and still appear to be the most straightforward and least expensive method for making the strain measurements associated with these materials.

Because of the extreme temperatures associated with the utilization of these high temperature composites, two basic problems occur when attempting to instrument the composites with strain gages. One is the difficulty in reliably attaching strain gages to the surfaces of the unique materials; the other is the inaccuracy often associated with strain gages at extreme temperatures.

This paper will address four areas of interest with respect to utilizing strain gages on carbon/carbon (with SiC surfaces) and titanium matrix composites. The four areas are as follows:

* Strain gage and adhesive combinations on carbon/carbon (C/C) at temperatures from -190 degrees C (-310 degrees F) to 540 degrees C (1004 degrees F).
* Half-bridge gaging for reducing apparent strain on C/C using poisson's ratio and bending configurations.
* Review of the "field installation" techniques developed for gaging a C/C hypersonic generic elevon.
* Results of initial strain gaging efforts on titanium matrix composites.

Current research in developing techniques for increasing the maximum temperature for strain gages on carbon/carbon will be reviewed.

STRAIN GAGE AND ADHESIVE COMBINATIONS FOR CARBON/CARBON

The primary difficulty in attaching strain gages to the surface of carbon/carbon is the arduous task of bonding the adhesive itself to the surface. To clarify this stated difficulty, it is important to note that, <u>for this paper, all references to carbon/carbon surfaces include a surface layer of silicon carbide (SiC) encapsulating the carbon/carbon</u> and it is the adherence to the silicon carbide that is difficult. This section of the paper discusses the techniques and materials developed for gaging carbon/carbon when testing at temperatures from -190 degrees C to 540 degrees C.

Plasma Sprayed Strain Gage Installations w/Ceramic Precoat

Early attempts at strain gaging C/C for testing at temperatures above 370 degrees C (700 degrees F) involved the application of the gage with various ceramic cements. Six different ceramics were tested and all showed various degrees of micro-cracking which destroyed the gage. The failures with ceramic cements and oxygen/acetylene flame spraying were followed by the development of a gaging technique employing plasma arc flame spraying. Initial efforts had the entire installation performed using only the plasma gun in conjunction with Alumina powders. This technique worked but the loss rate during installation was high. In order to decrease the loss rate during installation and to improve strain data reliability, the procedure was modified and the detailed gaging steps are as follows: Mask the areas to be gaged and micro-sandblast them using 50 micron grit aluminum oxide abrasive. Next, apply a .001" thick precoat of Omega CC ceramic cement (modified by adding an equal amount, by volume, of SiC powder to the Omega base powder). After curing, plasma spray a .002" thick layer of Alumina over the precoat. The gage is then placed on the Alumina and a very thin coat of a ceramic cement (Hitec's Yellow Cerro works well) is applied over the gage convolutes to protect them from the plasma spray operation. The thin coat of ceramic cement is cured, and the strain gage is plasma sprayed with aluminum oxide. Several high temperature strain gage types were tested with this method and all survived the 540 degrees C. However, the foil type high temperature gages were more prone to gage failure during thermal cycling due to gage grid shearing. Later testing revealed that an oxygen-acetylene gun can be substituted for the plasma gun and the bond obtained is sufficient to read strains at 540 degrees C. However, the shear strength of the oxygen-acetylene bond is lower than that obtained with the plasma.

High Temperature Gaging Using Ceramic Cement Only

While the plasma spray method of installing high temperature strain gages works well, there is another technique for providing strain gages on C/C for testing at 540 degrees C that does not require sophisticated gaging apparatus. It employs a ceramic cement which was not available when the plasma technique was developed. This ceramic cement supplied by Micro-Eng.II and called GC Ceramic does require careful application technique but when properly applied, a well bonded, reliable strain gage installation that is good to 540 degrees C and sometimes higher is achieved. With this ceramic, micro-cracking is greatly reduced and indiscernible at 540 degrees C. While data have been obtained at temperatures as high as 925 degrees C (1697 degrees F) with this cement it is not recommended above 540 degrees C on C/C with SiC surfaces because of the micro-cracking that occurs beyond this temperature. This ceramic works well with either wire or foil type high temperature strain gages. Following is a step-by-step procedure that has been utilized successfully with the GC ceramic cement on C/C specimens (w/SiC surfaces).

1. Micro-sandblast the areas to be strain gaged.
2. Apply a basecoat of GC ceramic cement to a thickness of .001 inches.
3. Air dry for a minimum of 30 minutes.
4. Slowly apply heat using a heat gun until the specimen temperature reaches 100 degrees C (212 degrees F) to 110 degrees C (230 degrees F) and hold for two minutes.
5. Cool to room temperature, inspect and then cure at 150 degrees C (300 degrees F) for one-half hour.
6. Cool and install the gage as follows:
    a. place the gage on the basecoat and apply a minimum amount of GC ceramic in the open areas of the gage carrier frame. This coat should be sufficient to hold the gage convolutes in place, but thin enough to be able to still see most of the convolutes.

b. cure the cement as in steps 3, 4, and 5. Cool to room temperature.

c. Under a microscope, carefully remove the gage carrier frame and eliminate any loose particles or tape adhesive residue.

d. fill all remaining open areas making certain that the cement "wets" these areas. This is important in preventing voids.

7. Cure as in steps 3, 4, and 5.
8. Next, another layer of GC is applied to fill any low areas, helping to provide a uniform ceramic surface.
9. Cure as in steps 3, 4, and 5.
10. After cooling, use a fine aluminum oxide stone to carefully hone any high areas.
11. Now, apply a final overcoat of the GC ceramic cement still maintaining a low ceramic profile.
12. Cure as in steps 3, 4, and 5.
13. Finally, take the specimen to 315 degrees C (600 degrees F) and hold for one-half hour.
14. Cool and microscopically inspect the installation. The entire installation should not be more than .008" to .010" thick.

HALF-BRIDGE GAGING FOR REDUCING APPARENT STRAIN ON CARBON/CARBON

While a fair degree of success has been realized in achieving a good bond for strain gages on C/C, the ability to accurately measure strains at temperatures above 370 degrees C (700 degrees F) is reduced by several factors. The steep slope of the apparent strain curve associated with high temperature strain gages (roughly 30 micro-strain/degree C w/BCL-3 gages on C/C), a degree of uncertainty in the repeatability of the apparent strain curve, the drift rate of the gage at high temperatures, and the often difficult task of accurately measuring the temperature, all contribute to the inaccuracies in high temperature strain measurements. Though half-bridge gaging configurations will be limited to certain applications, the data generated on C/C when half-bridges have been tested warrant serious consideration of this technique where possible. The BCL-3 strain gage has two features which make it desirable for half-bridge gaging. One, the scatter in total apparent strain from gage to gage is typically less than 500 micro-strain from a total of 17000 micro-strain at 540 degrees C, and, two, the variation in drift rate at high temperatures is negligible from gage to gage. Therefore, when a given test scenario will allow for two of these gages to be placed in adjacent legs of the bridge circuit with both gages being subjected to the temperature change, the resulting total apparent strain and drift rate are dramatically reduced. Figure 1 shows two typical apparent strain runs to 540 degrees C when half-bridge gaging is employed. One curve is generated with a bending half-bridge, the other with a poisson's ratio half-bridge. As shown, neither curve exceeded 250 micro-strain, yet, a single gage typically shows 17000 micro-strain at 540 degrees C on carbon/carbon with this type of gage.

Gage Selection For Testing At 540 Degrees C On Carbon/Carbon

Several gage types have been tested on C/C at 540 degrees C with two types out-performing the others. These are, the Batelle-Columbus-Laboratories gage type BCL-3 and the "Chinese Gage" distributed by Hitec Products and Micro-Engineering II. Both of these gages are manufactured from the same basic alloy and both have similar characteristics. One BCL-3 gage has been subjected to twenty temperature excursions to 540 degrees C on a C/C specimen with loads applied and is still functioning. The "Chinese Gage" has been successfully tested on C/C specimens at 540 degrees C as part of a NASA, Langley Research Center and General Dynamics joint venture.

"FIELD INSTALLATION" TECHNIQUES FOR GAGING A CARBON/CARBON ELEVON

A test program to be commenced this winter at NASA's Ames Dryden Flight Research Facility will require the installation of approximately 300 strain gages on an elevon constructed of carbon/carbon. This elevon is to be subjected to a series of load tests at room temperature followed by elevated temperature testing. Strain gage data at room temperature are essential and tentatively strain data will be obtained at elevated temperatures. A technique has been developed that will allow the elevon to be tested at a temperature of 200 degrees C (390 degrees F) as well as room temperature using conventional gaging materials. The technique, simple and straightforward, is described here. Also, later in the program, an attempt will be made to install high temperature gages using a ceramic cement for testing at 540 degrees C. That gaging technique is also reviewed here.

Selection Of Strain Gages And Gaging Materials For Testing To 200 Degrees C

This program requires strain gaging for testing at room temperature and at elevated temperatures if possible. Since this will be a fairly lengthy program in terms of time required for testing, it was decided to utilize an adhesive that has proven itself to be excellent for long term reliability. Hopefully, this adhesive could be applied to the surface and the gage in a manner consistent with techniques applicable for structural component gaging. Several adhesives were tested in conjunction with Micro-Measurements, Inc. encapsulated series WK-00, WK-03, and WK-06 gages. The first two adhesive types tested bonded well but the gage failed during repeated excursions to 200 degrees C. These adhesives were Micro-Measurements, Inc. M-BOND GA-2 and M-BOND GA-61. The third adhesive, M-BOND AE-15, worked well initially and gage type WK-00-500BH-350 had generated the smallest apparent strains in early tests. Consequently, a C/C specimen was instrumented with one of these gages on each side placed back to back. The specimen was then subjected to ten apparent strain runs to 200 degrees C. Apparent strains were repeatable for both gages on all of the runs, gage output drift at 200 degrees C was zero after two hours, and bending strain data at 200 degrees C was repeatable within two percent. Because of the ease of installation and the success with the M-BOND AE-15 in conjunction with the WK-00-500BH-350 strain gage, no further effort was made to find another combination of gage and adhesive for the temperature range of 25 degrees C to 200 degrees C.

Gaging Procedure Followed For Testing Carbon/Carbon At 200 Degrees C

In order to simulate, to a degree, the gaging scenario that will be required for the carbon/carbon elevon gaging, the gages were pre-wired and installed without the benefit of a microscope which is typically used during the installation. Following are the steps performed in gaging the C/C specimens discussed above.

1. Micro-sandblast areas to be gaged using 50 micron grit aluminum oxide. Also, sandblast spots for bonding lead wires, including thermocouples.

2. Using clean, dry air, blow away sandblasting residue.
3. In areas where gages are to be attached, apply a coat of M-BOND AE-15. This "precoat" should be thick enough to allow for sanding (after curing) in order to provide a relatively flat surface for the strain gage.
4. Slowly raise the temperature to 65 degrees C (150 degrees F) and hold for four hours. Use heat lamps or vacuum pad heaters to achieve the required cure temperature.
5. Following this cure, sand the AE-15 using a sanding block and 180 grit sandpaper. Sand away the precoat until the peaks of the SiC are reached. Remove the residue with clean air or pressurized freon.
6. Install the pre-wired gages using "Rumble Strain Gage Vacuum Pads" as per standard vacuum pad gage installation procedures.
7. Cure the installation for four hours at 65 degrees C as in Step 4.

Tentative Gaging Procedure For A Carbon/Carbon Elevon For Testing At Temperatures To 540 Degrees C

While the entire testing program for the elevon has not yet been finalized, a gaging procedure has been developed which will provide some degree of strain measurement at temperatures of 540 degrees C and perhaps higher. The procedure, though not described in detail here, is similar to that described earlier in the paper under the sub-heading "High Temperature Gaging Using Ceramic Cement Only".

INITIAL GAGING EFFORTS ON TITANIUM MATRIX COMPOSITES

This area of research has just recently been initiated at NASA's Langley Research Center as part of a joint effort with McDonnell Douglas, St. Louis, MO. While this effort includes research in developing techniques and strain gaging materials that will perform accurately and reliably at temperatures up to 815 degrees C (1500 degrees F) on metal matrix composites, the initial thrust of the research was in the cryogenic region.

Gaging And Testing Of Titanium Matrix Composite Specimen

Initial testing of a titanium matrix composite specimen, type: SCS-6/BETA 21S [0/90/0] involved strain gaging the specimen utilizing standard NASA-LaRC gaging procedures with conventional foil strain gages and gaging materials. The specimen was subjected to temperatures from -190 degrees C (-310 degrees F) to 260 degrees C (500 degrees F). The purpose of the test was to obtain baseline data at room temperature, at -190 degrees C, and at 260 degrees C. Two single gages of the same type were installed back-to-back with the only difference being in the self-temperature-compensation (STC) number of each gage. One gage was a WK-03-250BG-350 and the other was a WK-06-250BG-350. Cantilever bending loads were applied to the specimen at 25 degrees C, -185 degrees C, and at 265 degrees C. The strain variation at those temperatures is shown for each gage in Figure 2. Gage factor change has been accounted for at each temperature and, as shown, each gage generated identical strain levels at its respective temperature. Apparent strain runs were made through the temperature range of -190 degrees C to 265 degrees C. A typical run is shown in Figure 3 with outputs recorded at 50 degree C intervals. Note that the WK-06 gage generates less strain cryogenically but drops off dramatically above room temperature. The WK-03 gage while generating -1400 micro-strain at -190 degrees C is relatively flat from 25 degrees C to 265 degrees C.

Apparent strains were not corrected for change in gage factor as a function of temperature change. Research and development efforts are ongoing in this area, specifically, gages and bonding material combinations that will function at 815 degrees C.

CURRENT EFFORTS IN GAGING CARBON/CARBON FOR USE AT 815 DEGREES C AND HIGHER

Even though high temperature strain gages have been successfully attached to C/C (with SiC surfaces) and survived to temperatures of 1100 degrees C (2012 degrees F), there are problems to be overcome at these very high temperatures. These include, survival of the gage when thermal cycling is involved, resistance leakage to ground, and repeatability of apparent strain curves. Current efforts are being directed toward developing a technique that will provide a reliable strain gage on C/C at 815 degrees C. Good initial results are being obtained utilizing two new techniques and each is briefly discussed here.

Carbon/Carbon Gaged And Tested At 815 Degrees C Utilizing Plasma And Oxygen-Acetylene Powder Gun

A means of obtaining a good bond between the gaging ceramic and the silicon carbide surface has been obtained utilizing a combination of plasma arc flame spraying and oxygen-acetylene flame spraying. A combination of ceramic spray powders was also used. The basecoat was $3Al_2O_3$-$2SiO_2$ (Mulite powder), plasma sprayed. This was followed by Al_2O_3 (Alumina powder) which was oxygen-acetylene flame sprayed and was utilized to secure the gage to the basecoat of Mulite. The gage was then oversprayed with more Mulite using the plasma gun. Importantly, the bond was enhanced by first sandblasting the surface with a very coarse (24 grit) aluminum oxide abrasive. This abrasive, while effective in roughening the surface, may cause microscopic damage to the substrate. This damage possibility is currently being investigated at Langley.

Cantilever bending strain data, repeatable within four percent, were obtained at 815 degrees C using this method in combination with a Battelle-Columbus-Laboratories type: BCL-3 strain gage. Though this installation functioned well for several cycles at 815 degrees C, it failed during the second excursion to 930 degrees C (1706 degrees F). An inspection revealed micro-cracking of the Mulite.

Strain Data Obtained At 1100 Degrees Celsius On A Carbon/Carbon Specimen

A carbon/carbon specimen furnished by General Dynamics, Fort Worth, TX, was strain gaged and tested at temperatures up to 1100 degrees C. This specimen differed from all others tested to date, in that it had a very rough chemically vapor deposited (cvd) coating of silicon carbide added to the existing silicon carbide surface. The gaging approach was similar to that described above with a few exceptions. Half-bridge gaging was utilized to reduce apparent strain and Alumina was the only spray powder used. Figure 4 plots the bending strains at 1100 degrees C obtained during two excursions to that temperature. Unfortunately, the specimen did not have a surface sealant and since the tests were conducted in air the specimen delaminated after two runs to 1100 degrees C. Figure 5 is a photo of the specimen after the second excursion to the loadings test temperature. The delamination is visible throughout the length of the specimen. The strain gages are still functional.

CONCLUDING REMARKS

Strain gaging any material for testing at extreme temperatures, whether its at -190 degrees C or at 815 degrees C, requires the utilization of the appropriate strain gages, gaging materials, installation accessories, and gaging configuration in order to provide the maximum accuracy and reliability for a given test requirement. The task of determining the optimum means and materials for strain gaging high temperature composites such as carbon/carbon and titanium matrix composites is particularly difficult. The maximum test temperature, the maximum strain level, type of test (dynamic, static, both) are but a few of the factors that will help in determining the gaging approach. The strain gaging of these composites for cryogenic and elevated temperature testing is relatively new. As these materials are made available to the strain gage community, improved approaches and techniques will be forthcoming.

While reliable strain gage installations on C/C have been demonstrated at temperatures from -190 degrees C to 540 degrees C and while current research indicates that strain data at 815 degrees C is readily achievable, the desired goal of routinely measuring strain at 1100 degrees C on C/C using surface mounted strain gages is still not obtainable.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Mr. Fred Lamm (senior strain gage technician, Modern Machine & Tool Co. Inc.) for his art, skill, patience, and assistance throughout this effort.

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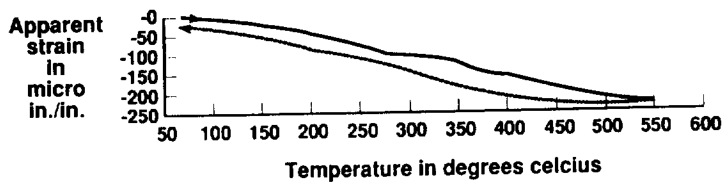
BCL GAGES
Apparent Strain Curves

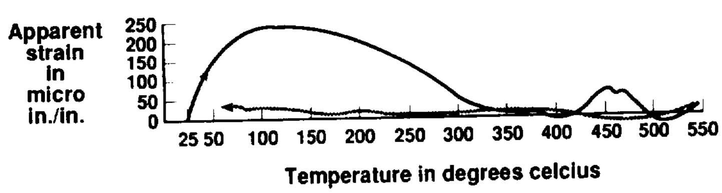
CARBON/CARBON SPECIMEN
Bending half-bridge apparent strain
11th apparent strain run to 540°c



Beam supported vertically with no tare load applied

Beam no. 1211-F   Gage type : BCL-3   Installation: Micro-Eng.II, GC Ceramic

CARBON/CARBON SPECIMEN
Poisson's ratio half bridge
3rd apparent strain run to 540°c



Specimen supported vertically with no tare load applied
This data assumes a G.F. of 2.15 @ 540°c and a Poisson's ratio of .5

Beam no. 1208-B   Gage type : BCL-3   Installation: Micro-Eng.II, GC Ceramic

Figure 1

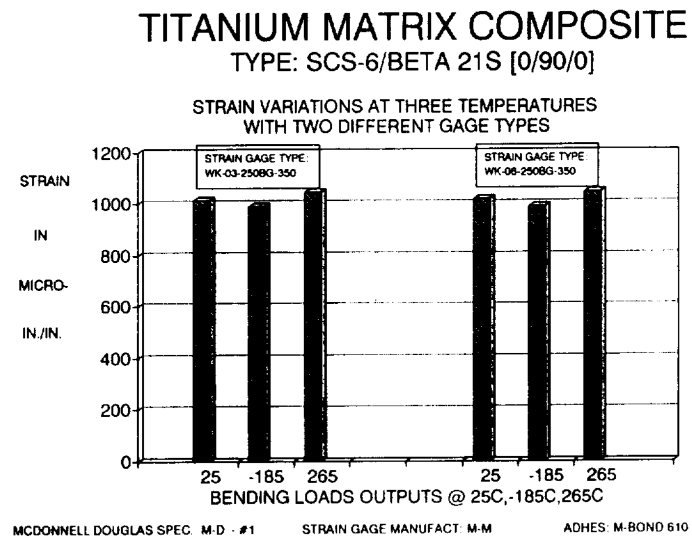


Figure 2

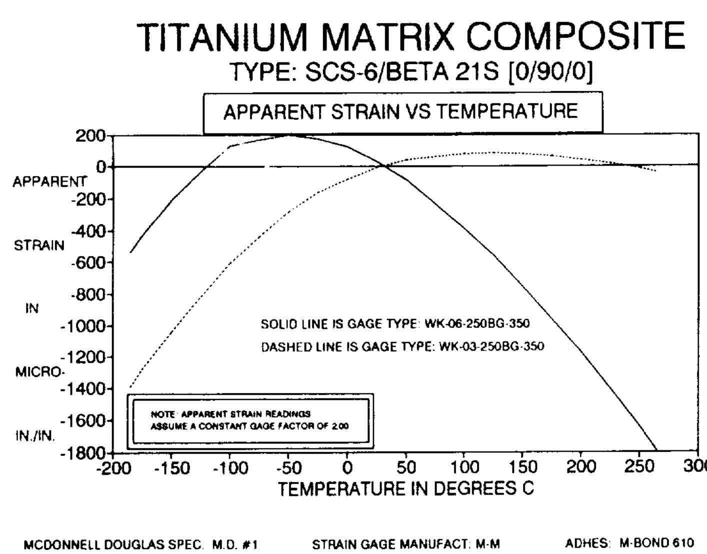


Figure 3

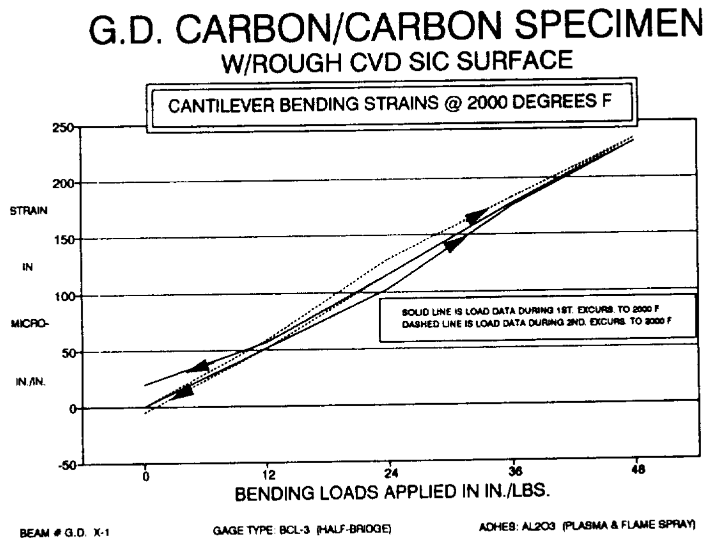


Figure 4

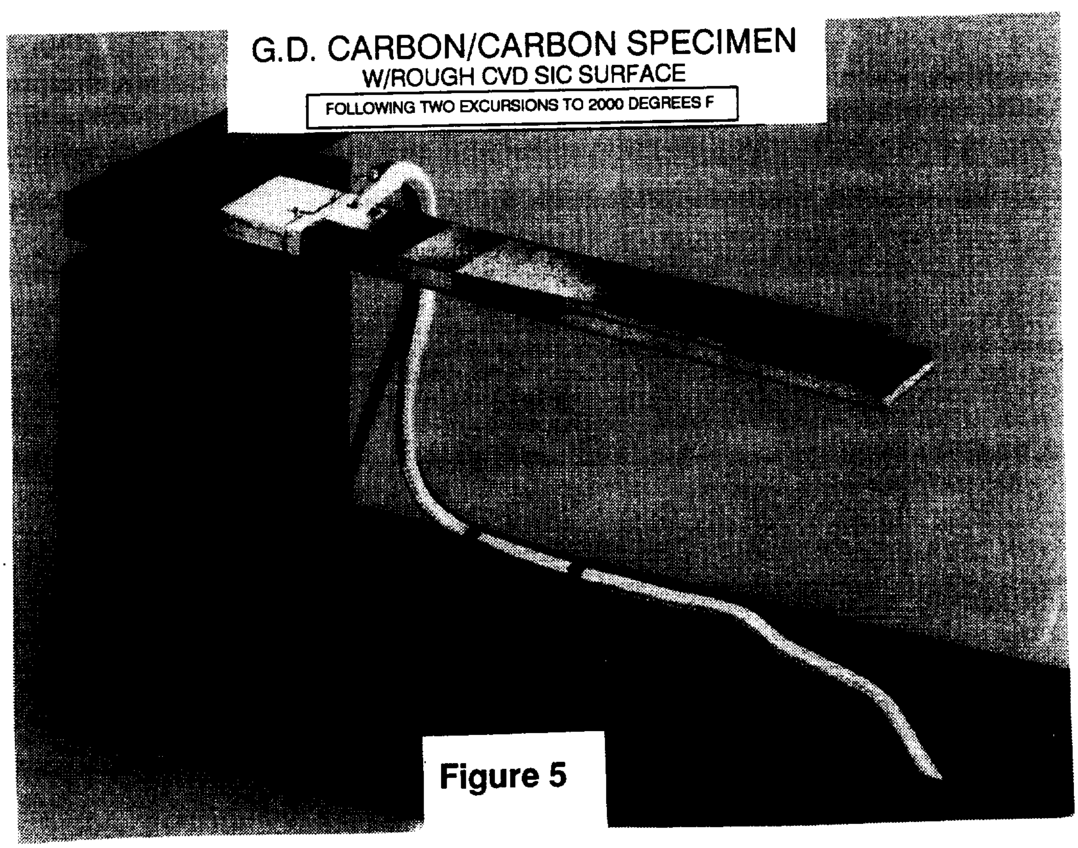


Figure 5

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