TESTING AND CHARACTERIZATION OF CMC COMBUSTOR LINERS

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ABSTRACT

Multiple combustor liner applications, both segmented and fully annular designs, have been configured for exposure in NASA's High Pressure Burner Rig (HPBR). The segmented liners were attached to the rig structure with SiC/SiC fasteners and exposed to simulated gas turbine conditions for nearly 200 hours. Test conditions included pressures of 6 atm, period necessary ?? gas velocity of 42 m/s, and gas temperatures near 1450°C. The temperatures of both the cooled and combustion-flow sides of the liners were measured using optical and contact measurement techniques. Minor weight loss was observed, but the liners remained structurally sound, although damage was noted in some fasteners.

INTRODUCTION

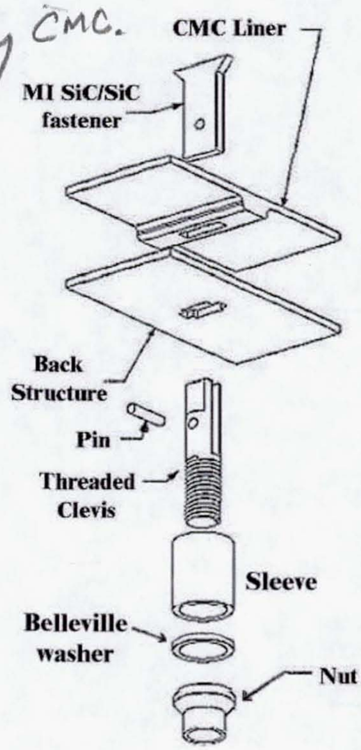
The use of ceramic matrix composites (CMCs) as combustor liners has the potential to improve gas turbine engine performance, through lower emissions and higher cycle efficiency, relative to today's superalloy hot section components. Evaluation of CMC components and sub-component features under gas turbine conditions is paramount in demonstrating the capabilities of these material systems in the complex thermal stress and environmentally aggressive engine environment. To date, only limited testing has been conducted on CMC combustor concepts and sub-elements of this type throughout the industry[1-3]. The combustion environment of the HPBR is an outstanding simulation of the turbine engine ~~that~~ and can economically deliver~~s~~ the gas compositions at pressures, gas velocities and temperatures required for ad~~ditiona~~l exposure of such research materials.

BACKGROUND

Under the High Speed Research/Enabling Propulsion Materials (HSR/EPM) Program, the Rich-burn, Quick-quench, Lean-burn (RQL) Sector Rig was lenn research center (GRC)

developed at NASA GRC to demonstrate the structural durability of SiC/SiC liners in a combustion environment. Designed by Pratt & Whitney, the RQL sector rig contained two rich zone liner cans that transitioned to a lean zone. Six different SiC/SiC components made up the combustion chamber[4], including the lean transition liners (LTLs) being discussed in this paper. The LTLs are curved plates, measuring approx 5.1 cm x 3.3 cm, covering a 60° arc of a 10.2 cm inner diameter. Two built-up regions of 12-ply thickness reinforce the locations of the attachment holes, ~~with 6-ply thickness in the remaining areas~~. The LTLs are fastened to the rig's metal back structure with SiC/SiC Miller attachments[5] as illustrated in Figure 1.

of 6-ply CMC.



Testing of LTLs under the HSR EPM Program[6-7] was limited due to operational and cost issues. Under the Efficient Engine Technology (UEET) Program, the HPBR was selected to continue certain sub-component feature and component level testing because of it's versatility in test fixturing and design. In the current effort the geometry of the LTL liners, their CMC attachments, and the HPBR configuration was adapted to accommodate continued testing.

Figure 1 – CMC panels fastened to metallic back structure using Miller attachment scheme.

MATERIAL

The combustor liners were manufactured by Honeywell Advanced Composites from a SiC/SiC developed ~~under~~ in the HSR EPM Program. A slurry-cast, melt infiltrated SiC matrix was reinforced with Sylramic™ SiC fibers. The fiber tows were woven into a 5-harness satin weave cloth using fiber tow spacings of 18 and 22 ends per inch, resulting in a nominal fiber volume fractions of 35% and 42%, respectively.

EXPERIMENTAL PROCEDURES

The High Pressure Burner Rig[8] at NASA GRC ~~Glenn Research Center~~ is a high-velocity, pressurized combustion test rig used for high-temperature environmental durability studies of advanced materials and components. The facility, shown in Figure 2, burns jet fuel and air in controlled ratios, simulating combustion gas chemistries, temperatures, pressures, and gas velocities representative of today's gas turbine engines. Operating conditions include 1.0 kg/sec combustion and secondary cooling airflow capability, equivalence ratios of 0.5-1.0 with typically 10% H_2O vapor pressure, gas temperatures ranging 700-1650°C, test pressures ranging 4-12 atmospheres, and gas velocities ranging 10-30 m/s.

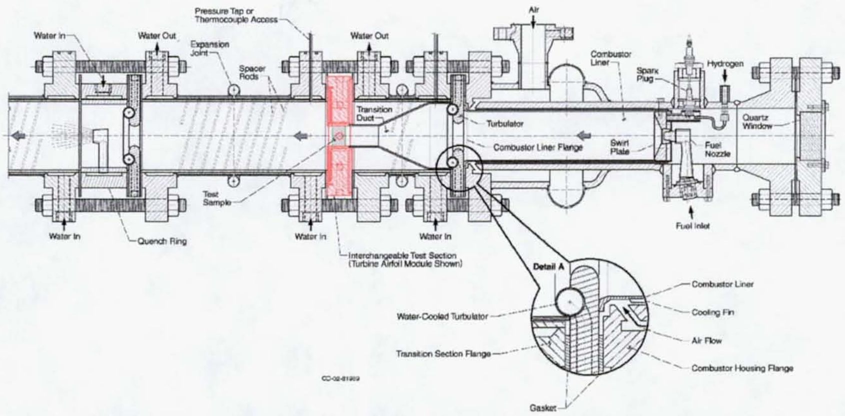
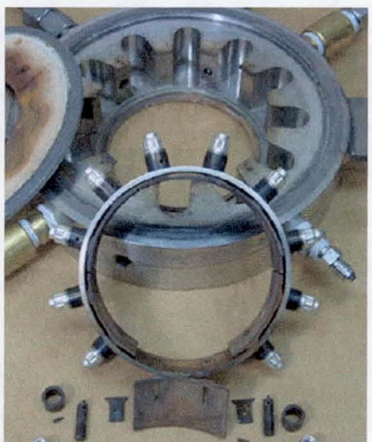


Figure 2 – Schematic of the High Pressure Burner Rig.

A water-cooled test module was designed ~~to fit into the existing flanges,~~ to ~~allow for~~ provide separate gas and backside cooling paths, ~~and provide~~ enabling access to ~~obtain~~ surface and substrate ~~temperatures~~ ~~measurement~~ measurements using optical and contact measurement techniques ~~to be obtained~~. The hardware assembly for testing the Lean Transition Liners ~~testing~~ is shown in Figure 3~~a~~ Figure 3(a). ~~The setup shows a~~ A set of ~~6~~ six LTLs are attached to an impingement ring that recesses into the main water-cooled ring and is secured with a retaining cover plate (Figure 3b). Cooling air is manifolded thr~~u~~ough supply lines into the area behind the impingement ring that was machined to accommodate the Miller Attachments and distributed evenly onto the liners through holes in the impingement plate.



(a)

(b)

Figure 3 – Test ~~setup after 148 hrs~~ assembly shows (a) assembly of parts including Miller attachments and (b) LTLs installed in test rig with pyrometer access port.

Testing was performed in phases to gather the different information to fully document the test. Initial intent was to ~~checkout~~ test the hardware, determine the backside cooling required to protect the impingement ring, and ~~setup~~ establish a baseline cycle. Calibration runs ~~established~~ indicated adequate cooling flows, maintaining the metal temperatures typically below 400°C at maximum (stoichiometric) conditions. The cycle chosen was a 30 minute transient with 15 minutes of dwell time at 1425-1475°C gas temperature and gas velocities near 42 m/sec. ~~Next,~~ A 1.3 cm hole was then added to the impingement ring to allow a 2-color optical pyrometer to monitor one LTL backside temperature, and a smaller 0.3 cm hole was used for a contact thermocouple measurement. Both thermocouple and pyrometer acknowledged that the substrate temperatures varied with cooling flow. For example, during the dwell time, the substrate temperature varied between 800°C and 915°C for the maximum and minimum cooling flows, respectively. A third configuration monitored the surface temperatures. For this, an additional 1.3 cm hole was added to the LTL positioned over the pyrometer port to allow viewing the hot side of the opposite LTL. This is the configuration ~~is also~~ shown in Figure 3(b).

Finally, an additional fiber optic pyrometer was added to monitor the backside temperature and compare with the 2-color pyrometer. Calibrated for SiC/SiC materials, the fiber optic consists ~~if~~ of a sapphire tip directed perpendicular (90 degrees) to the LTL backside at a focal length of approximately 1/16 in using the 1/8 in diameter hole previously used for the contact thermocouple. The pyrometers displayed ~~fairly good~~ reasonable agreement over the entire range. Figure 4 illustrates the baseline cycle using data taken throughout the testing. The maximum temperatures at the surface ~~(925-985°C)~~ and at the substrate ~~(855-915°C)~~ ~~temperatures achieved~~ were 925-985°C and 855-915°C, respectively, at 1425-1475°C gas temperatures. The material temperatures varied slightly with backside cooling, as expected, and the gradient through the LTL remained essentially the same (55-70°C).

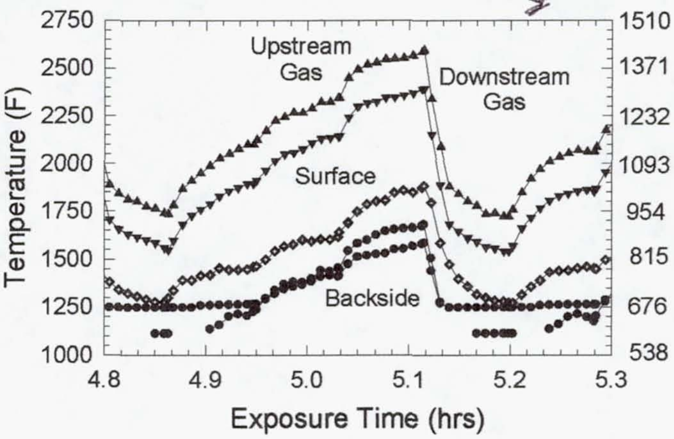


Figure 4 – Baseline HPBR cycle used to expose the LTLs.

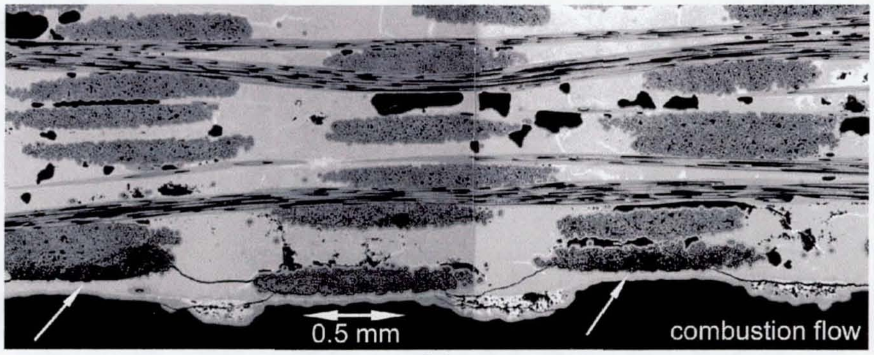
RESULTS AND DISCUSSION

A total of 97.7 hrs (174 cycles) were accumulated during the initial ~~run~~ testing on the original set of (6) LTLs and their attachments. Inspections at 5.7, 13.2, 44.7, and 97.7 hrs indicating no visual signs of deterioration. Subsequent testing to acquire the substrate temperature data increased the exposure~~s~~ time to 148.1 hours and 260 cycles, after which a significant amount of rust was noted on the LTLs. This was attributed to ~~the service air that had contained some water during the time of the~~ entrained water in the service ~~flow~~ air supply used for cooling.

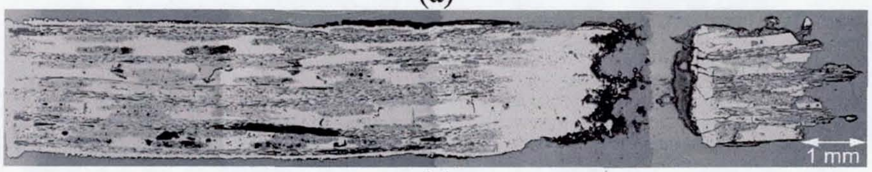
~~run~~. Otherwise, the LTLs appeared structurally sound. The ~~and all~~ attachments were ~~in~~ intact and remained free-floating as designed. In addition, the main ring, impingement ring, and retaining cover all displayed good durability. Shown earlier, the photographs shown in Figure 2 were taken at this juncture of the testing. The LTLs were weighed afterwards and found to have little to no weight change ~~gain~~, varying between +39.6 mg and -3.0 mg. Any anticipated weight loss due to recession[9] appears to be masked by the rust that was deposited.

one word

During the final ~~runs to acquire the~~ testing surface and fiber optic data, an additional 30.7 hours and 22 cycles of exposure were logged, bringing the total exposure to 178.8 hours and 282 cycles. The Miller attachments were all changed prior to the last 12.9 hours (4 cycles), and a few were sheared while being disassembled. A water leak in the main ring during those last 12.9 hours resulted in additional rust and contaminants to be deposited on the LTLs. Otherwise, the LTLs again appeared structurally sound and varied with respect to weight change with a range of both positive (+112 mg) and negative (-385 mg) values. As before, much of the anticipated weight loss due to recession was likely masked by the rust that ~~was~~ had been deposited during testing.



(a)



(b)

Figure 5 – Cross-sections of a) LTL and b) Miller attachment.

Figure 5 above shows the microstructure of the internal areas of one LTL and fastener after exposure. On the combustion side of the LTL in Figure 5(a), some fiber tows are either missing or depleted (as shown by arrows), and micro-cracking is seen throughout the matrix bridging the outermost individual fiber tows. This agrees well with damage found in the LTLs tested in the RQL Sector Rig, as well as SiC/SiC coupons tested in the High Pressure Burner Rig.[6] In Figure 5(b), the fastener appears similar to the LTL, and the matrix has been significantly depleted at the combustion-exposed end of the fastener (at photo right) and is

add space

discontinuous to the left of that area. Here, the cross-section has been polished back near the sharp corner forming the "Y" (see Figure 1) where material was also degraded.

CONCLUSIONS

Testing of these Lean Transition Liners in the HPBR continues to provide invaluable experience and further the insight into the development of CMCs as gas turbine components. Like other work throughout industry to develop and test CMC turbine shrouds, combustor liners, and combustor cans[1-3], these current configurations place such sub-element and component features in a realistic gas turbine environment under ~~a~~ stressed conditions. Thus, an extremely economical test, as compared with full-scale engine testing, has been developed for reproducing SiC recession on a complex part and evaluating the structural integrity of component and fastener designs. This affords certain liberties to be taken with respect to higher risk configurations. In addition, further testing of ~~EBC~~ environmental barrier coated coated parts is planned not only on these segmented liners, but on a fully annular liner. ~~fabricated using a~~ Nicalon-fiber reinforced ~~CVI~~ chemical vapor infiltrated SiC matrix composite, ~~has also been obtained and is being configured for testing.~~

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