

5.2 PROTECTIVE SHEATH OVER CONVENTIONAL CERAMIC FIBER BURNER

Open weave preforms were used by a number of the composite manufacturers to make "screens" with large open area fractions separated by "ligaments" of nearly fully-dense matrix. A photograph of a typical screen is shown as Figure 5-2. The open weave screen geometry lends itself well to use as either a reinforcement structure for existing ceramic fiber burners or as a reverberatory screen used to increase radiant efficiency. The reinforcement or protective sheath concept is discussed in this section. The reverberatory screen concept is discussed in the following section.

As a protective sheath, the CFCC screen serves as a high emissivity, impact resistant outer shell to provide increased protection for the more fragile ceramic fiber pad underneath. If successfully implemented, the protective sheath would give the lower cost and flashback resistant ceramic fiber burner much greater durability. The constituents of the ceramic fiber pad could be cast directly onto the CFCC screen, which would replace the perforated metal substructure used for more conventional ceramic fiber burners. By increasing the ruggedness of the ceramic fiber burner, the CFCC protective sheath would be addressing one of the major perceived shortcomings of the current product.

A laboratory prototype burner was constructed from a 3M Siconex screen and standard Alzeta ceramic fiber materials as shown in Figure 5-3. Simple open-ended cylindrical screens were fabricated by 3M and purchased by Alzeta. These screens were used as casting forms as part of the Pyrocore manufacturing process, with the ceramic fiber mat being vacuum cast onto the inside of the ceramic composite screen. The burners were of relatively small dimensions, and a means was devised for sealing the ends of the burner, while simultaneously joining to a standard pipe fitting, for mounting to the fuel/air train. The method used would probably not be suitable for a large volume product. In tests described in Section 6, this burner concept featured significantly improved durability and damage resistance relative to standard ceramic fiber burner products both before and after extensive life testing in a high temperature environment.

The fundamental difficulty associated with this concept is the necessity of joining the ceramic sheath to a flange or pipe thread fitting to allow the burner to be connected with a gas-tight seal to an incoming premix line. As stated above, the technique used for

TABLE 6-6 COMBUSTION ENVIRONMENT TESTING
PRE/POST-EXPOSURE TENSILE TESTING
RESULTS, AVERAGE VALUES

Sample ID	As-Received Amercom	As-Received Dow Corning	As-Received DuPont	Post-Test DuPont
Number of Samples	8	9	11	11
Tensile Strength, MPa (Standard Deviation)	432.2 (62.0)	292.0 (20.7)	271.2 (43)	236.8 (31.7)
Strain to Failure (Standard Deviation)	1.10% (0.26%)	0.76% (0.05%)	0.35% (0.17%)	0.27% (0.14%)
Modulus, GPa (Standard Deviation)	84.34 (17.9)	40.67 (2.1)	161.18 (18.7)	139.69 (11.0)
Toughness, Area Under $\sigma - \epsilon$ Curve, MPa (Standard Deviation)	3.12 (1.15)	1.06 (0.14)	0.66 (0.42)	0.39 (0.24)

Figure 6-26(a) presents a photomicrograph of a typical as-received tensile fracture. These samples had the most consistent cross sectional area, averaging 0.815 mm², and appeared to have the highest fiber volume fraction. Unfortunately, the "exposed" samples split along the long axis of the tow during the combustion environment exposure. This longitudinal cracking can be seen in Figure 6-27(a). These longitudinal cracks exposed the fibers to the combustion atmosphere and allowed the interface material to volatilize.

The Amercom samples retained their shape in spite of the longitudinal cracking, but overall strength was greatly diminished and the samples were found to be very brittle at the conclusion of the exposure testing. All of the Amercom post-exposure samples subsequently failed during removal from the combustion test apparatus or during preparation for tensile tests. A cursory examination of the tows revealed relatively little matrix infiltration into the interior of the tow creating a composition and density gradient that may have caused the splitting during the thermal stress cycling.

for the pre-exposure DuPont samples was 0.447 mm². These samples appeared to be well infiltrated with minimal voids around the fibers. The tensile properties as shown in Table 6-6 were in good agreement with typical values obtained for multi-ply samples.⁷⁻⁸

An average strength for the unexposed samples of 271 MPa was obtained with a standard deviation of 43.4 MPa, the lowest value of the three specimen groups evaluated. Strain to failure was also lower with an average value of 0.35 percent, about half that of the Dow Corning samples and one third that of the Amercom samples. The average modulus value was higher than both the Amercom or Dow Corning samples at 161 GPa with a standard deviation of 18.7 GPa. The average strain energy density value obtained by integrating the average stress/strain curve was found to be 0.66 MPa, 66 percent of the 1 MPa requirement defined in Section 5.

Post-exposure samples had an average strength of 236.8 MPa with a standard deviation of 31.7 Pa. This is 13 percent lower than the unexposed sample average, but much greater than the retained strength of other composites tested. A typical stress-strain curve for the DuPont samples before and after the combustion exposure test is presented in Figure 6-25(c). Figure 6-26(d) shows the surface appearance of a typical DuPont Lanxide sample tow. Figures 6-27(c) and 6-27(d) are photomicrographs of a post exposure tensile fracture; showing the carbon interface to be intact and unaffected by the combustion environment.

Summary of Tensile Test Program

Results of the combustion environment exposure and tensile tests indicate that additional process development is required to extend the life of CFCCs at typical combustion conditions. The test program described above resulted in the complete destruction of the Dow Corning samples in 1300 hours and significantly reduced the strength of the Amercom samples over the same time period. The DuPont samples survived the test program, but long term exposure resulted in a noticeable decrease in all mechanical properties. Typical combustion applications will require a 20,000 to 25,000 hour component life, as opposed to the 1300 hour test described here.

The mechanism of failure for the Dow Corning (PIP) samples appears to be oxidation of the matrix. The Amercom samples apparently failed due to incomplete infiltration and resultant high thermal stress levels. The DuPont samples performed best,