Final Test Report
for
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Fabrication, Characterization Testing, and Irradiation of Ceramic Polymer Composite Materials at 373 K

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Introduction

This report provides the results of the specimen fabrication and testing performed for Cryogenic Materials, Inc. by Composite Technology Development, Inc. (CTD). The test program consisted of short-beam shear, compression, leakage current, and dielectric breakdown testing of flat-plate composite laminates. All tests were performed at 373 K. Two different types of composite materials were tested. One set of specimens was fabricated by CTD and the other set was supplied by Cryogenic Materials, Inc. These composites both contained S-2 glass as the fiber, but were made with different matrix materials.

Specimen Fabrication

CTD fabricated one mechanical laminate (nominally 0.125" thick) and one electrical laminate (nominally 0.020" thick) from CTD-1202/S-2 glass. The laminates were both made by enclosing the S-2 glass fabric in flat plate molds and then performing a vacuum pressure impregnation (VPI) process to impregnate the fabric with CTD-1202 resin. The molds were then heated to 150°C for 2 hours to cure the resin to the green stage. Two similar laminates, made from SF-212/S-2 glass, were provided by Cryogenic Materials, Inc. All test specimens were subsequently machined from the fabricated laminates by Colorado WaterJet Company (Berthoud, CO).

Test Methods

Four different types of characterization tests were performed and are briefly described below. The test temperature for all tests was 373 K. Three tests were performed for each material and for each of the 4 test types.

Short-Beam Shear Testing

The short-beam shear testing was performed according to ASTM D2344. The nominal specimen size for the short-beam shear specimens was 1.100 x 0.250 x 0.125-in. thick. The tests were performed on a 1 kip load frame using a 3-point bend test fixture and a span-to-thickness ratio of 4. All specimens were oriented in the warp direction. Figure 1 shows the short-beam shear test setup. Deflection vs. load values were obtained as the specimen was loaded to failure at a load/displacement rate of 0.05 in/min.

Through-Thickness Compression Testing

The compression testing was performed according to ASTM D695. The nominal specimen size for the compression specimens was 0.250 x 0.250 x 0.125-in. thick. The testing was performed on a 20 kip load frame with the specimens loaded between two parallel plate load platens. Displacement taken from the test machine LVDT, load, and stress data were collected as the specimen was loaded to failure at a rate of 0.05 in/min.

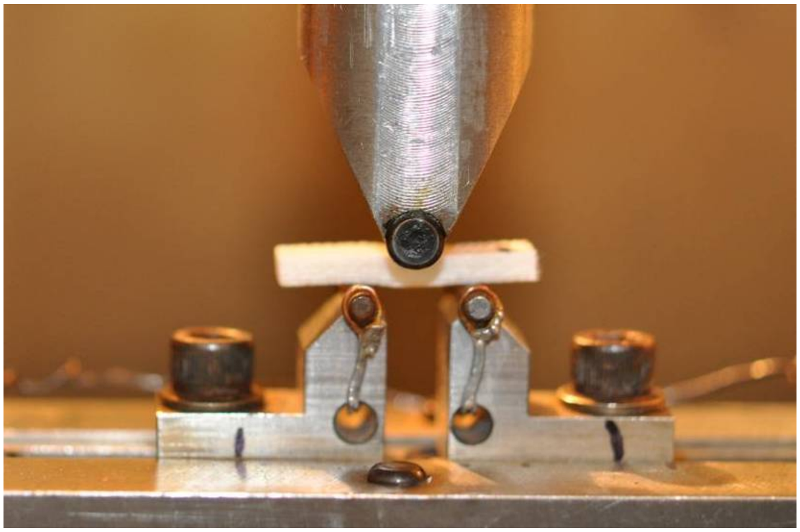

Figure 1. Short-beam shear setup.

Electrical Testing

The electrical testing was performed according to ASTM D149 and D3755. The electrical specimens were circular in cross section, nominally 1.375" in diameter and 0.020" thick. For both the dielectric breakdown test and the leakage current test the specimens were fixed between two 5/16" diameter electrodes and immersed in a high temperature oil bath at 373 K. Figure 2 shows the oil bath and the dielectric test fixture.

Leakage current testing was performed using a QuadTech hipot by ramping the voltage between the electrodes from 0 to 6 kVDC in 400 seconds. The leakage current was recorded on the QuadTech at 500 V intervals throughout the ramp.

Breakdown voltage testing was performed on the same leakage current electrical specimens. The dielectric breakdown was evaluated with a Hipotronics hipot, which is able to deliver higher voltages than the QuadTech, up to 120 kVDC. This test was performed by increasing the voltage between the electrodes at a rate of 6 kV/min until dielectric failure occurred. To ensure that the parts failed correctly and that the current did not arc around the specimen, the parts were re-tested after the initial failure to verify that they had fully broken down.

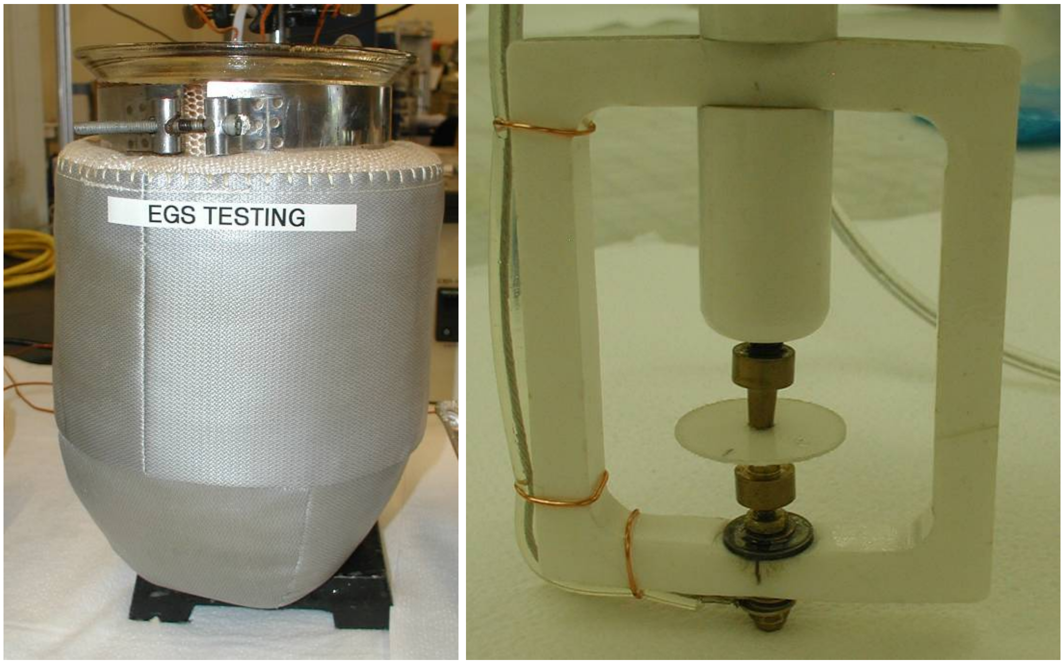

Figure 2. High temperature oil bath (left) and dielectric test fixture with 0.200" diameter electrodes (right).

Pre-Irradiation Test Results

All testing was performed as described above and according to the test plan. Individual test results for all test types and all materials are provided in Appendix A.

Mechanical Test Results

There was very little variability in both the short-beam shear and compression test data. In the SBS testing, CTD-1202 exhibited 109% higher flexural modulus and 33% higher shear strength than the SF-212 material, as shown in Figure 3.

In the through-thickness compression testing, the compression modulus of the two materials was very similar, with the difference falling within the data scatter. However, the compression strength of the CTD-1202 composite was 14% higher than the SF-212 material. The compression test results are shown in Figure 4.

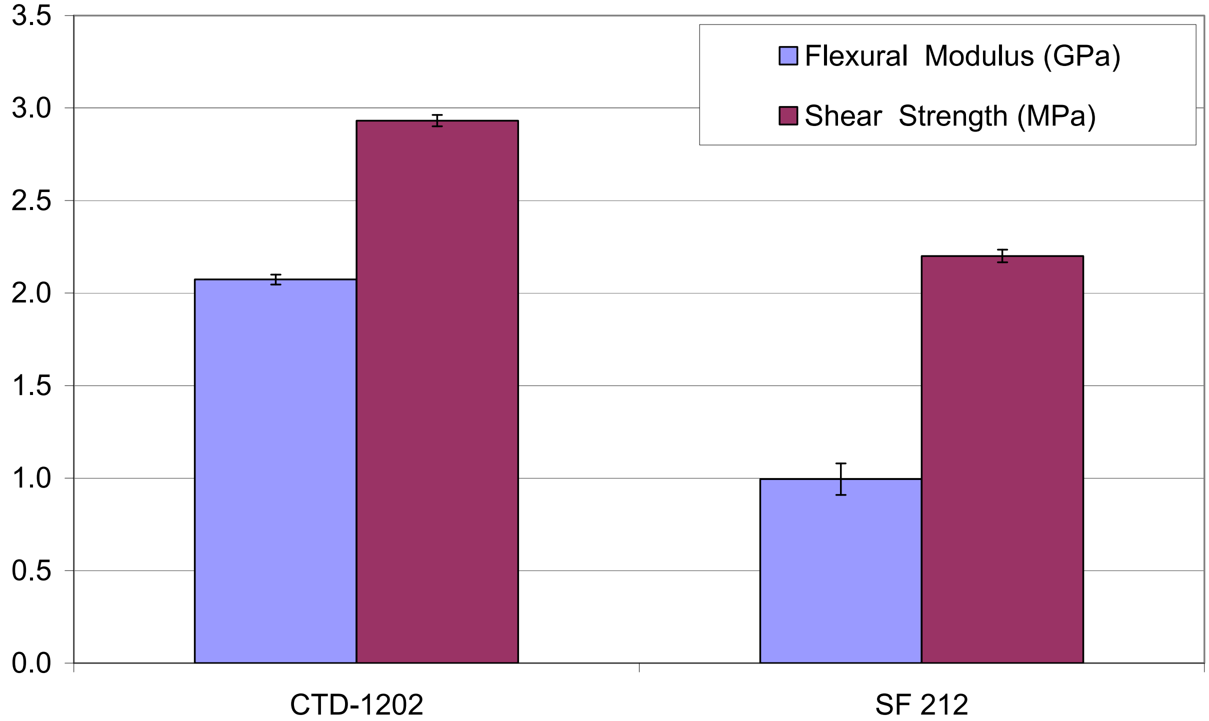

Figure 3. Flexural modulus and shear strength of CTD-1202/S-2 glass and SF-212/S-2 glass at 373 K

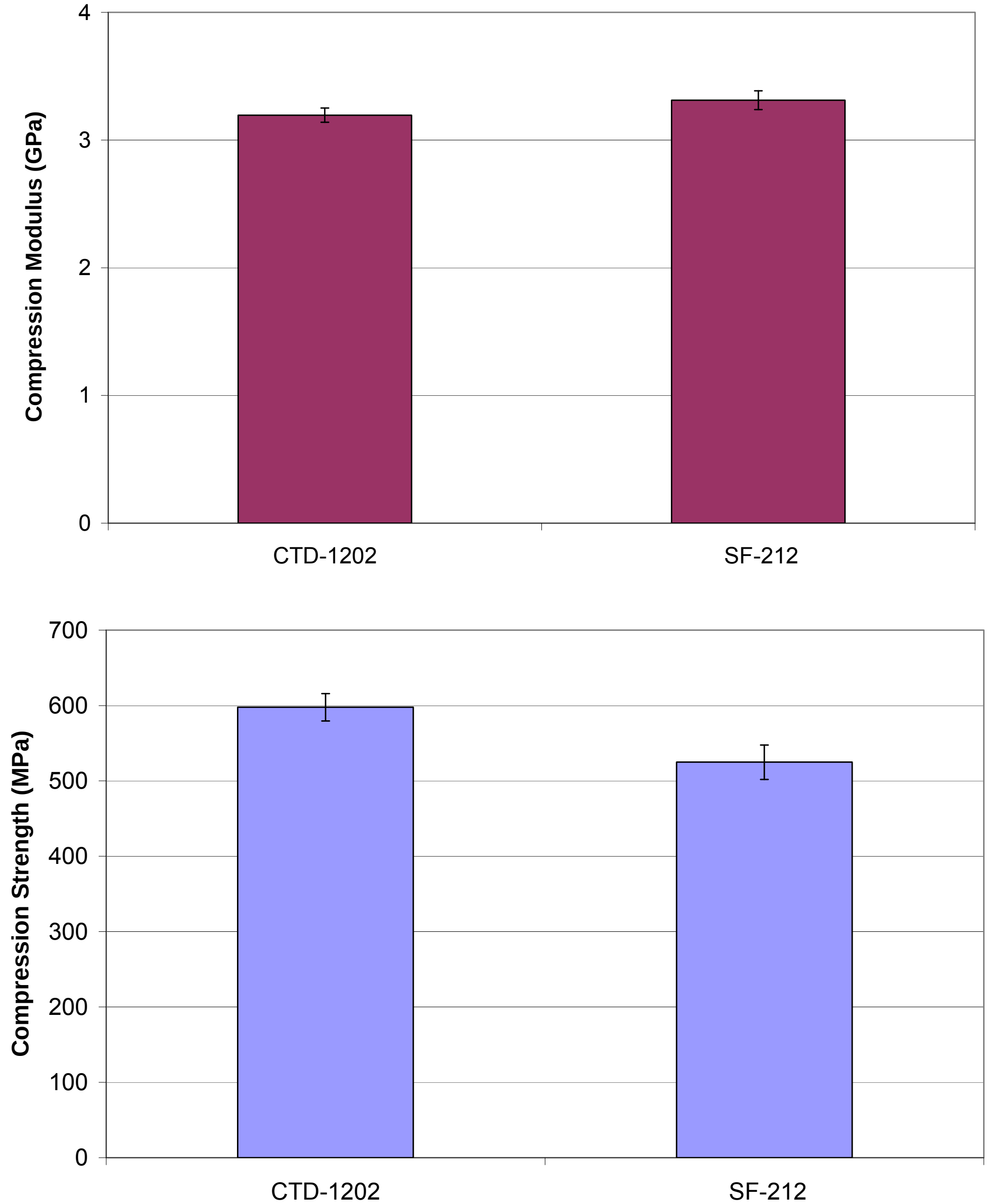

Figure 4. Through-thickness compression modulus and compression strength of CTD-1202/S-2 glass and SF-212/S-2 glass at 373 K

Electrical Test Results

In the leakage current testing, the leakage current was measured at zero amps for all test specimens on both materials. On the data sheets, this leakage current has been recorded as <0.1 μA, since this is the lower limit of current detection that the QuadTech hipot is able to measure.

The dielectric breakdown test results for the SF-212 specimens were reasonably consistent; however the breakdown results for the CTD-1202 laminate had a very large amount of scatter, as seen in Figure 5.

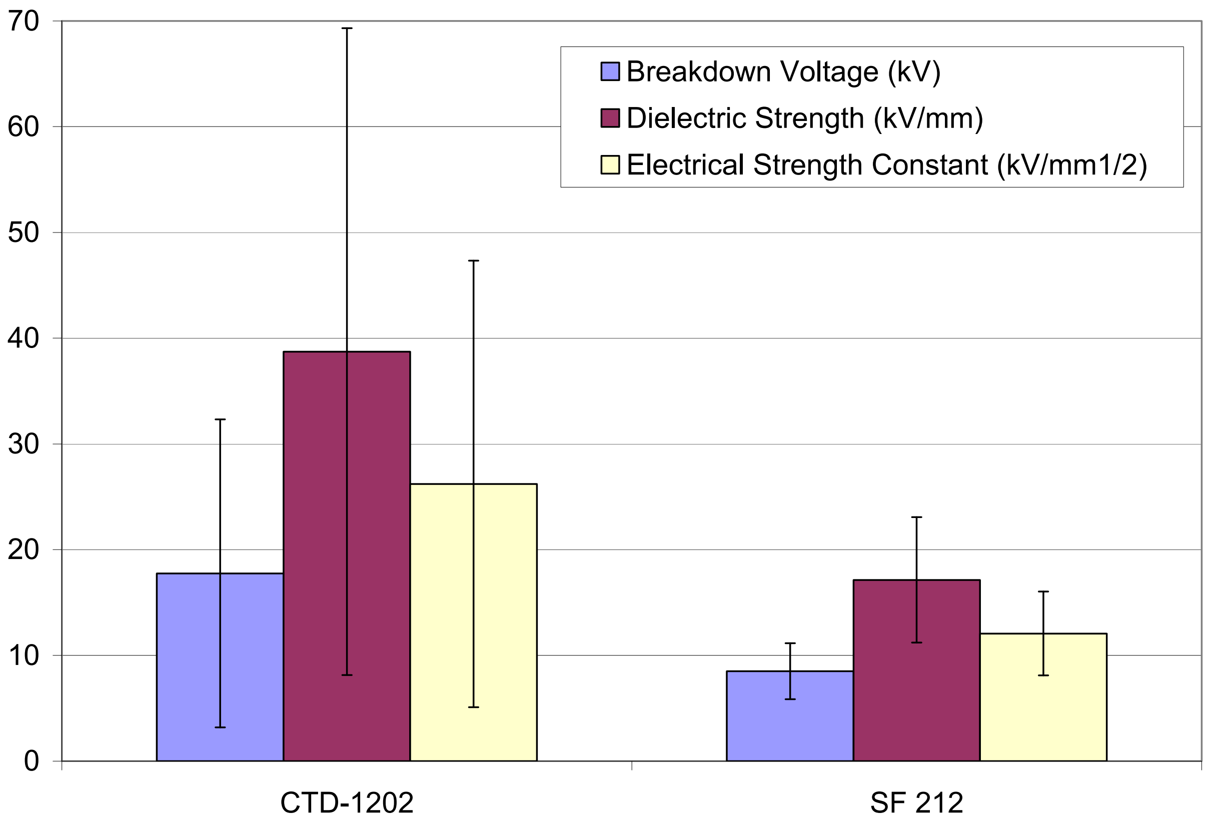

Figure 5. Dielectric breakdown test results of CTD-1202/S-2 glass and SF-212/S2-Glass at 373 K

To determine whether the initial test specimens for the CTD-1202 material were representative of the entire laminate, several additional CTD-1202 specimens were cut and tested. In addition, all dielectric specimens were further inspected and measured to determine fiber volume fraction, resin mass percentage, and density to see if any correlation between these properties could be made with the inconsistent dielectric breakdown results. These physical measurements and properties for the electrical test specimens for both materials are given in Tables 1 and 2. The same properties were measured for the additional test specimens taken from the CTD-1202 electrical laminate, with the results given in Table 3.

It was observed that the CTD-1202 specimen that tested the lowest in the first test had visible resin voids and thus a much lower resin mass percentage. The remainder of the laminate and most of the additional test specimens had much smoother, void-free surfaces.

Table 1. Physical measurements of CTD-1202 dielectric specimens.

Specimen	*Thickness*	*Mass*	*Fiber Volume Fraction*	*Resin Mass*	*Resin Mass*	*Density*
#	*(mm)*	*(g)*		*(g)*	%	*(g/cm³)*
Pre-Irradiation						
1	0.453	0.7472	0.532	0.1722	23.05%	1.722
2	0.467	0.7677	0.516	0.1927	25.11%	1.716
3	0.420	0.6839	0.574	0.1089	15.93%	1.700
Irradiation 1						
1	0.444	0.7376	0.543	0.1627	22.05%	1.734
2	0.458	0.7561	0.526	0.1812	23.96%	1.723
3	0.445	0.7367	0.542	0.1618	21.96%	1.728
4	0.453	0.7450	0.532	0.1701	22.83%	1.717
5	0.447	0.7430	0.539	0.1681	22.62%	1.735
6	0.438	0.7398	0.550	0.1649	22.29%	1.763
7	0.454	0.7480	0.531	0.1731	23.14%	1.720
Irradiation 2						
1	0.478	0.7747	0.504	0.1998	25.79%	1.692
2	0.456	0.7491	0.529	0.1742	23.25%	1.715
3	0.448	0.7438	0.538	0.1689	22.70%	1.733
4	0.450	0.7374	0.536	0.1625	22.03%	1.711
5	0.436	0.7331	0.553	0.1582	21.58%	1.755
6	0.466	0.7608	0.517	0.1859	24.43%	1.704
7	0.460	0.7513	0.524	0.1764	23.48%	1.705
Control						
1	0.416	0.7127	0.579	0.1378	19.33%	1.788
2	0.427	0.7151	0.564	0.1402	19.60%	1.748
3	0.444	0.7414	0.543	0.1665	22.45%	1.743
4	0.450	0.7456	0.536	0.1707	22.89%	1.730
5	0.434	0.7213	0.555	0.1464	20.29%	1.735
6	0.436	0.7194	0.553	0.1445	20.08%	1.722
7	0.403	0.6977	0.598	0.1228	17.60%	1.807

Table 2. Physical measurements of SF-212 dielectric specimens.

Specimen	*Thickness*	*Mass*	*Fiber Volume Fraction*	*Resin Mass*	*Resin Mass*	*Density*
#	*(mm)*	*(g)*		*(g)*	*%*	*(g/cm^3)*
Pre-Irradiation						
1	0.495	0.7575	0.487	0.1825	24.10%	1.597
2	0.522	0.7387	0.462	0.1637	22.17%	1.477
3	0.483	0.7289	0.499	0.1539	21.12%	1.575
Irradiation 1						
1	0.532	0.7778	0.453	0.2029	26.08%	1.526
2	0.478	0.7348	0.504	0.1599	21.76%	1.605
3	0.548	0.7772	0.440	0.2023	26.03%	1.480
4	0.514	0.7473	0.469	0.1724	23.07%	1.518
5	0.538	0.7778	0.448	0.2029	26.08%	1.509
6	0.568	0.8056	0.424	0.2307	28.63%	1.480
7	0.466	0.7287	0.517	0.1538	21.10%	1.632
Irradiation 2						
1	0.494	0.7297	0.488	0.1548	21.21%	1.542
2	0.509	0.7339	0.474	0.1590	21.66%	1.505
3	0.474	0.7650	0.508	0.1901	24.85%	1.685
4	0.531	0.7612	0.454	0.1863	24.47%	1.496
5	0.516	0.7409	0.467	0.1660	22.40%	1.499
6	0.516	0.7657	0.467	0.1908	24.91%	1.549
7	0.518	0.7484	0.465	0.1735	23.18%	1.508
Control						
1	0.564	0.7354	0.427	0.1605	21.82%	1.361
2	0.480	0.7397	0.502	0.1648	22.27%	1.609
3	0.596	0.7314	0.404	0.1565	21.39%	1.281
4	0.518	0.7712	0.465	0.1963	25.45%	1.554
5	0.540	0.7725	0.446	0.1976	25.58%	1.493
6	0.484	0.7266	0.498	0.1517	20.87%	1.567
7	0.446	0.6829	0.540	0.1080	15.81%	1.598

Table 3. Physical measurements of additional CTD-1202 dielectric specimens.

Specimen	Thickness	Area	Mass	Density	Fiber Mass	Fiber Volume Fraction	Resin Mass	Resin Mass
#	(mm)	(mm^2)	(g)	(g/cm^3)	(g)		(g)	%
1	0.433	457.74	0.3333	1.682	0.275	0.557	0.059	17.57%
2	0.479	457.31	0.3675	1.678	0.274	0.503	0.093	25.31%
3	0.440	447.42	0.3343	1.698	0.269	0.548	0.066	19.67%
4	0.396	366.08	0.2620	1.807	0.220	0.609	0.042	16.13%
5	0.550	266.01	0.2146	1.467	0.160	0.438	0.055	25.60%
6	0.442	248.51	0.1874	1.706	0.149	0.545	0.038	20.40%
7	0.469	257.12	0.2024	1.678	0.154	0.514	0.048	23.75%
8	0.451	247.62	0.1928	1.726	0.149	0.534	0.044	22.91%
9	0.424	439.46	0.3318	1.781	0.264	0.568	0.068	20.50%
10	0.398	295.58	0.2155	1.832	0.177	0.606	0.038	17.67%
11	0.462	224.25	0.1669	1.611	0.135	0.522	0.032	19.35%

The extra CTD-1202 specimens were smaller than the initial specimens because they were cut from the remainder of the dielectric laminate. Therefore, smaller electrodes, 0.200-in. in diameter, had to be used to prevent flashover during the dielectric breakdown testing. The two different electrodes used are shown in Figure 6.

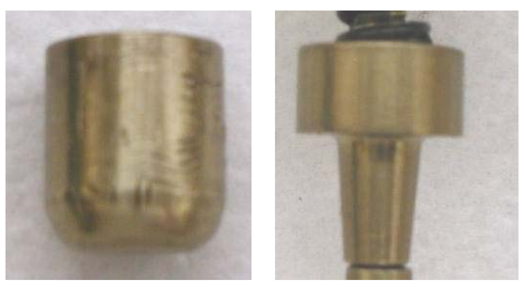

Figure 6. 5/16-in. diameter electrode used for the larger 3.125” diameter specimens (left) and 0.200-in. diameter electrode used for smaller, additional set of test specimens (right).

All eleven of the additional dielectric test specimens shown in Table 3 were tested for dielectric breakdown at 373 K. The results of the secondary testing gave similar averages to the initial testing for the breakdown voltage, dielectric strength, and electrical strength constant, but the data was much more consistent and is shown in Figure 7 compared to the initial dielectric breakdown results. Based on the results of the additional dielectric breakdown testing, it was concluded that the CTD-1202 composite exhibited approximately 144% higher dielectric strength than the SF-212 composite.

Several things were concluded from the additional testing performed on the CTD-1202 composite material:

1. Extremely low or high breakdown strengths were not observed as in the first round of testing, with the majority of specimens exhibiting breakdown strengths around 37-38 KV/mm.

2. The breakdown strength does not seem to be dependent upon the resin mass content, as was initially thought from the first 3 tests that were conducted. In the additional tests, resin content ranged from 16% up to almost 26%, but the breakdown strength for both the high and low were almost identical. See Figure 8.

3. The lowest breakdown strength that was measured during the additional testing was on a specimen that had a noted surface void area, exhibiting a breakdown strength of 26.5, which is twice what the lowest breakdown strength was during the first round of testing. Additionally, a second specimen with a noted surface void tested significantly higher at 37.7 KV/mm.

4. Comparing the average breakdown strengths between the first test series and the second test series on the CTD-1202 system, there is very little difference. However, the data scatter is significantly reduced.

5. Testing only 3 samples for dielectric breakdown is not a statistically reliable number of test samples in order to ensure that one understands the electrical characteristics of a material. Therefore, for both irradiation test levels and the control testing, the sample size will be increased to 7 specimens to alleviate this problem.

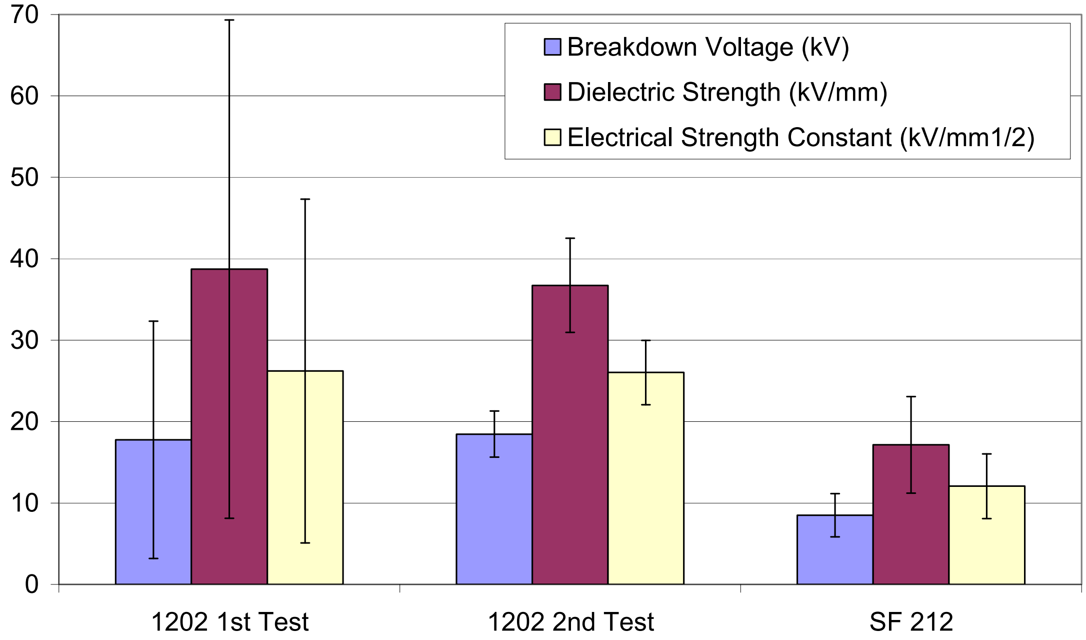

Figure 7. Summary chart of all dielectric breakdown data.

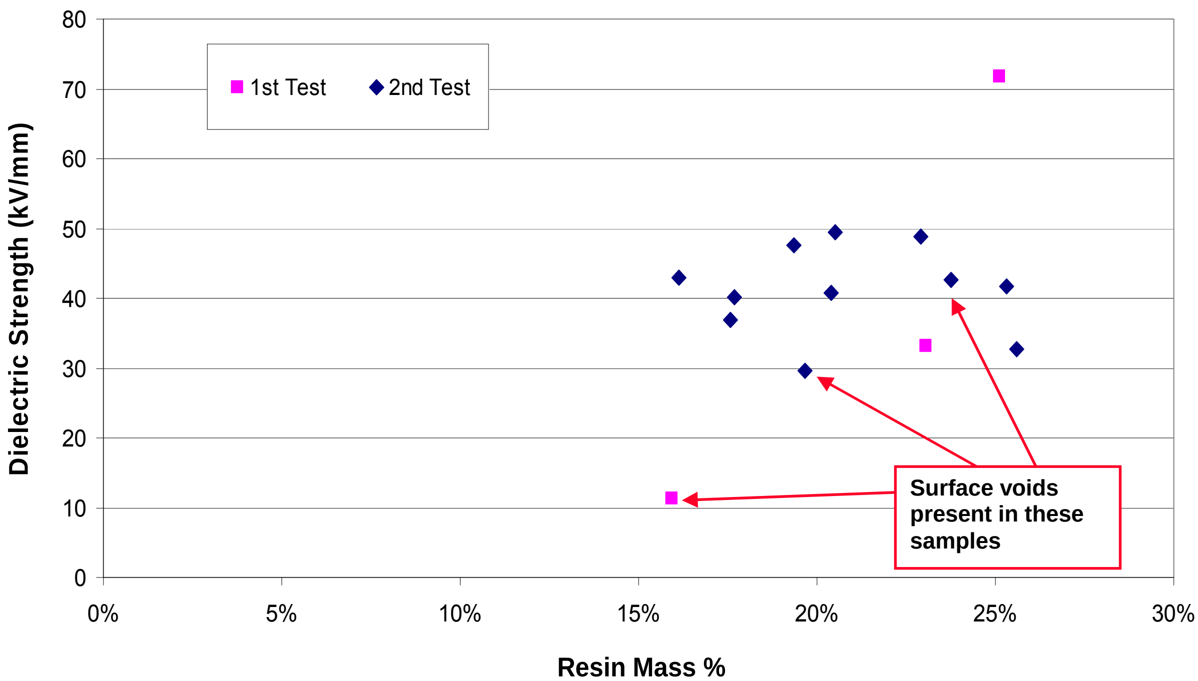

Figure 8. Resin mass % vs. dielectric strength of additional CTD-1202 electrical specimens.

Irradiation at MIT

Two sets of specimens were sent to the MIT Nuclear Reactor Laboratory for irradiation in the 2PH1 facility. Each set of specimens included 3 short-beam shear, 4 compression, and 7 dielectric specimens of both materials. Four Kapton FPC dielectric specimens were also included in each group. Each specimen was weighed, measured, and labeled prior to shipping to MIT. A third set of control specimens remained at CTD during this time.

The two sets of specimens were irradiated at fluences of $5x10^{22}$ n/m^2 (28 hours) and $5x10^{23}$ n/m^2 (278 hours), respectively. After irradiation, the specimens were returned to CTD for testing. When the specimens arrived at CTD they were removed from their packaging, visually inspected, and re-measured and re-weighed to determine if there were any changes in mass or dimension as a result of the radiation exposure.

As seen in Figures 9 and 10, both the inorganic composite and Kapton films exhibited a change in color after irradiation. The inorganic composite specimens changed from white to a gray/white color whereas the Kapton films changed from gold to brown.

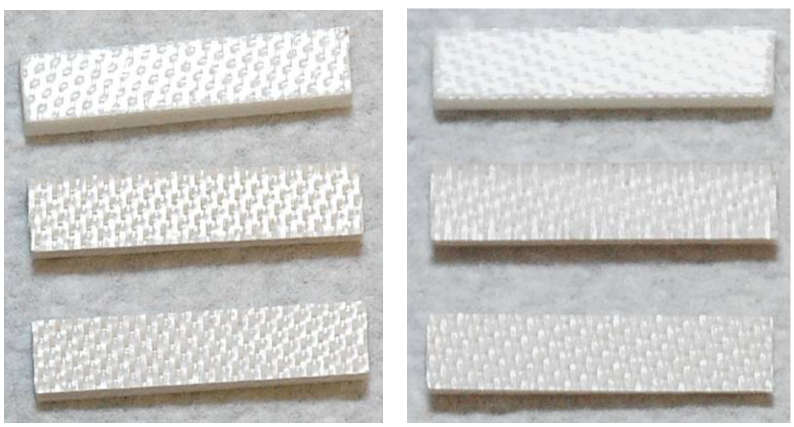

Figure 9. SF-212 (left) and CTD-1202 (right) short-beam shear specimens. From the top the specimens are: control, $5x10^{22}$ n/m^2 irradiation, $5x10^{23}$ n/m^2 irradiation.

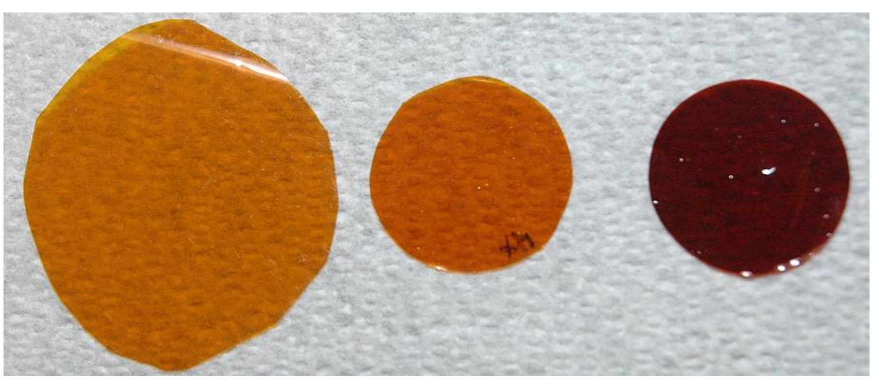

Figure 10. Kapton dielectric specimens. From left to right are examples of the control, $5x10^{22}$ n/m^2 irradiation, and $5x10^{23}$ n/m^2 irradiation specimens.

After visual inspection, the weight and dimensions of the composites were measured. During this work, the compression specimens were found to be very fragile after the 5×10^{23} n/m^2 irradiation. The specimens were handled with tweezers, and while handling one CTD-1202 specimen and three SF-212 specimens delaminated prior to testing. This left three CTD-1202 compression specimens and only one SF-212 compression specimen for mechanical testing.

Figure 11 shows the change in thickness between the initial measurements and the measurements taken after irradiation. As seen below, the thickness of the Kapton films increased 14-18% after irradiation, whereas the thicknesses of the SF-212 and CTD-1202 changed by less than ±3.5%. The change in the Kapton films is considered to be significant, but the changes in the inorganic composites are thought to be measurement error given the small differences observed in this work.

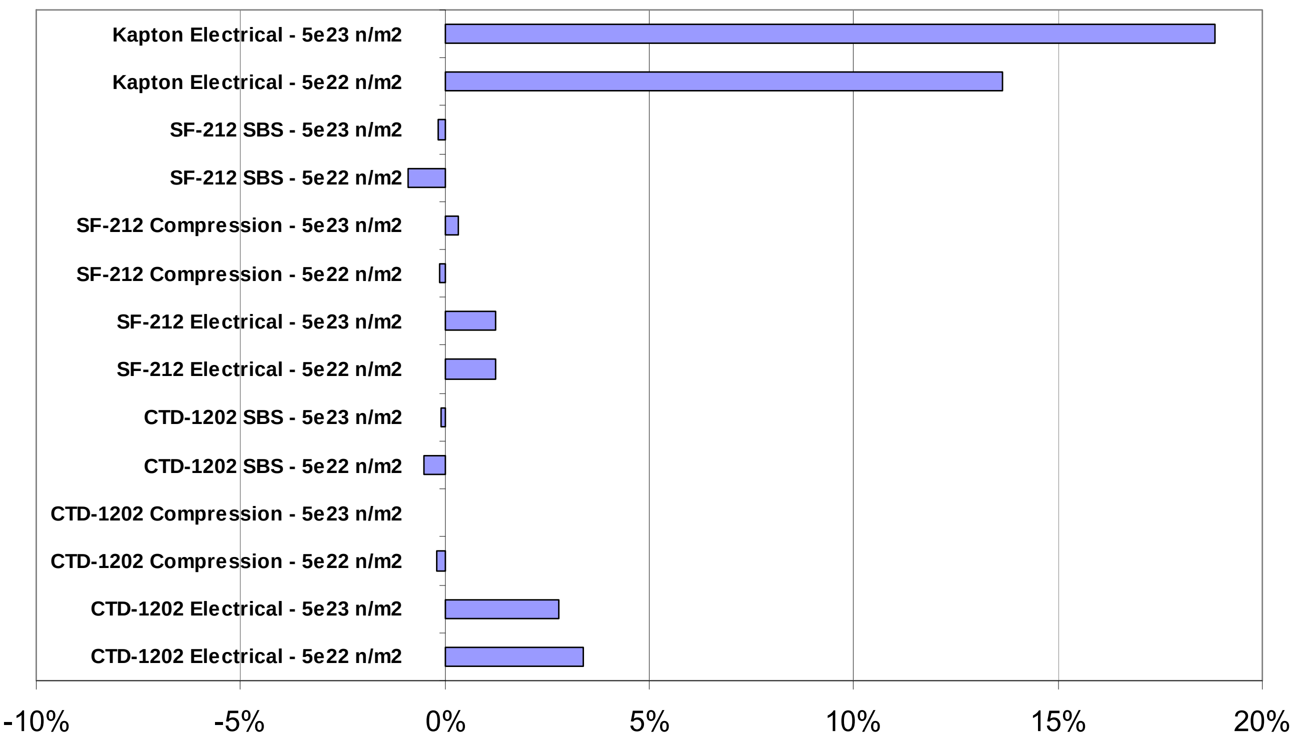

Figure 11. Percent change in thickness after irradiation.

The change in mass of the specimens after irradiation is shown in Figure 12. In each instance, the change in mass was found on the order of ±3%. Given the relatively small initial masses of the specimens, and the resolution of the analytical balance used in this work, it is difficult to draw conclusions on the effects of reactor irradiation on sample mass. The one consistent trend that is observed is that mass loss does not seem to be an issue for any of the composite specimens until they have been exposed to the higher radiation level.

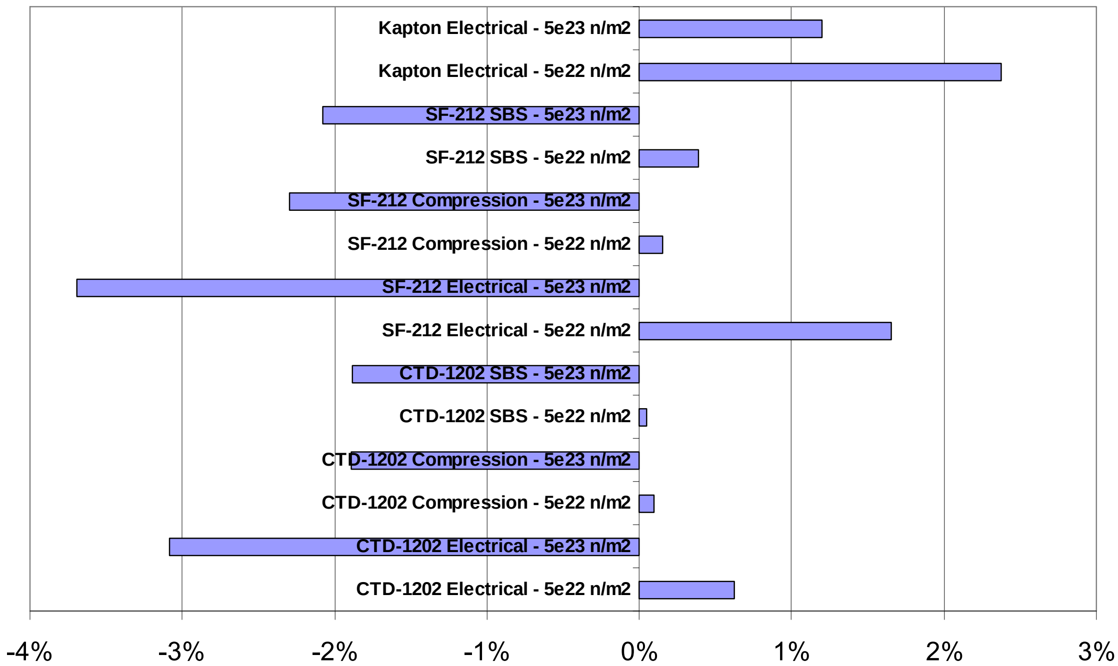

Figure 12. Percent change in mass after irradiation.

Post-Irradiation Test Results

Mechanical and electrical testing of the irradiated materials was performed at 373 K using the same procedures as described previously, but with additional safety precautions to contain the irradiated materials after failure. The following sections summarize the results of the testing. Complete data summaries for each test are provided in Appendix B.

Mechanical Test Results

Mechanical testing included measurement of the through-thickness compression and short-beam shear properties of the insulation materials after irradiation. Un-irradiated control specimens from the same laminates were also tested at this time. As seen in Figure 13, the compression modulus values for the CTD-1202 control specimens, as well as the materials exposed to a fast neutron fluence of 5 x 10^{22} n/m^2, were higher than those observed for the SF-212 composites. However, both materials exhibited a 60-65% decrease in compression modulus after irradiation at 5 x 10^{23} n/m^2. It should be noted that all of the modulus values shown in Figure 13 were determined using three extensometers, whereas the initial modulus values reported for these materials (Figure 4) were estimated using the LVDT output from the test machine.

The relative trends observed for the compression modulus values were also observed in the compression strengths (Figure 14). In these tests, the compression strength of the control specimens were very similar to those of the materials irradiated at 5 x 10^{22} n/m^2, but the higher radiation exposure resulted in a significant decrease in strength. As previously noted, one of the CTD-1202 specimens and three of the SF-212 compression specimens delaminated during handling prior to testing, so the reduction in strength in these materials was anticipated based on that observation.

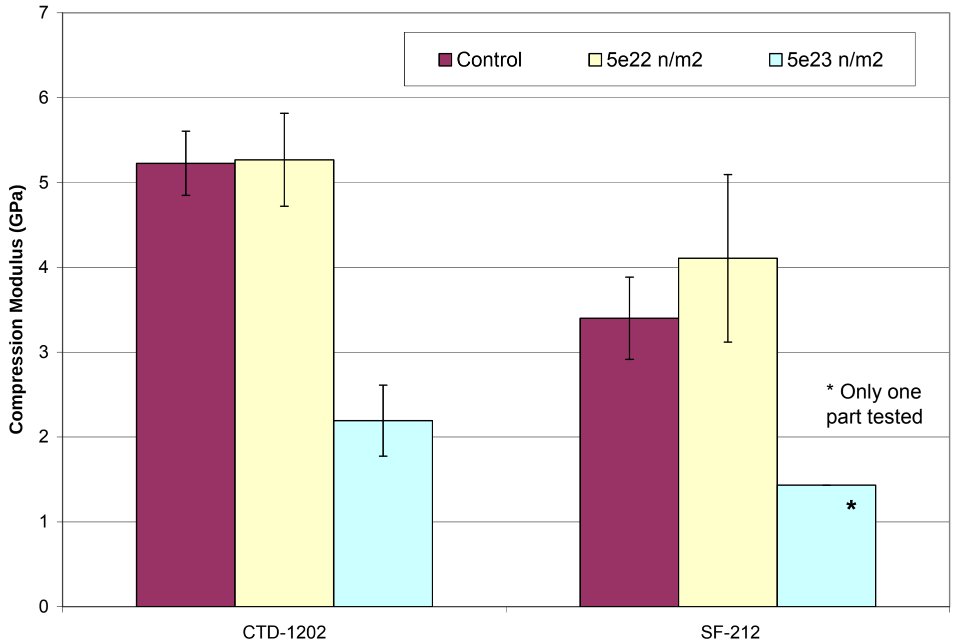

Figure 13. Through-thickness compression modulus of CTD-1202/S-2 glass and SF-212/S-2 glass at 373 K.

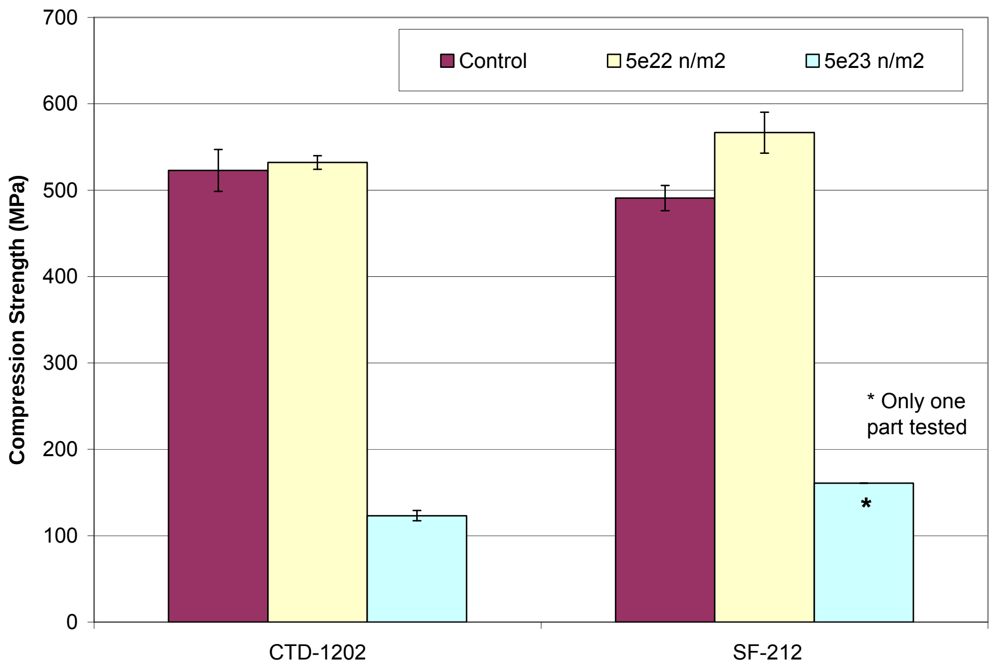

Figure 14. Through-thickness compression strength of CTD-1202/S-2 glass and SF-212/S-2 glass at 373 K.

Next, the short-beam shear strength and flexural modulus values of the irradiated materials were determined. As shown in Figure 15, the flexural modulus of the CTD-1202 laminate decreased by approximately 45% after the $5x10^{22}$ n/m^2 irradiation, and by 85% after the $5x10^{23}$ n/m^2 irradiation. The flexural modulus of the SF-212 material also decreased by approximately 80% after exposure to the higher fluence, although an increase in modulus was observed after the lower fluence. The initial increase in flexural modulus for the SF-212 material may be attributable to radiation-induced embrittlement, but more testing would need to be performed to verify that.

The radiation exposure also resulted in a decrease in shear strength for both inorganic composite materials (Figure 16). In this testing, the shear strength of the CTD-1202 composites decreased by about 40% after the $5x10^{22}$ n/m^2 irradiation, and by approximately 70% after the $5x10^{23}$ n/m^2 irradiation. Similarly, the shear strength of the SF-212 ,material decreased by 13% after the $5x10^{22}$ n/m^2 irradiation, and by 75% after the $5x10^{23}$ n/m^2 irradiation. Thus, while neither material exhibited high initial shear strengths, the performance of both was degraded by exposure to the high neutron fluence used in this investigation.

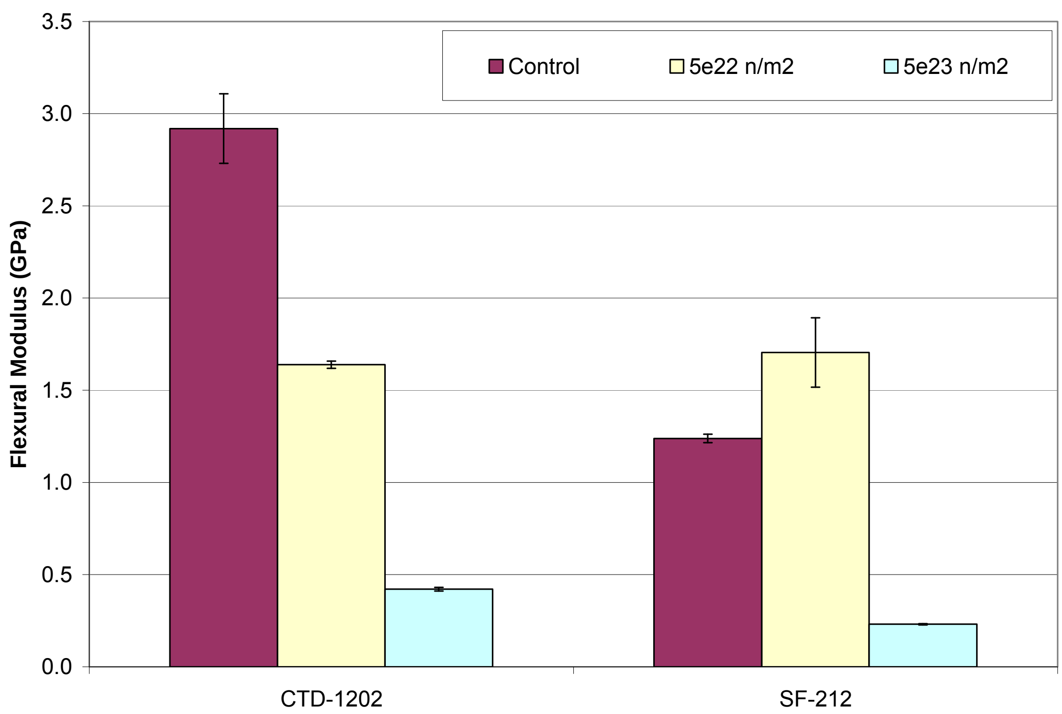

Figure 15. Flexural modulus of CTD-1202/S-2 glass and
SF-212/S-2 glass at 373 K.

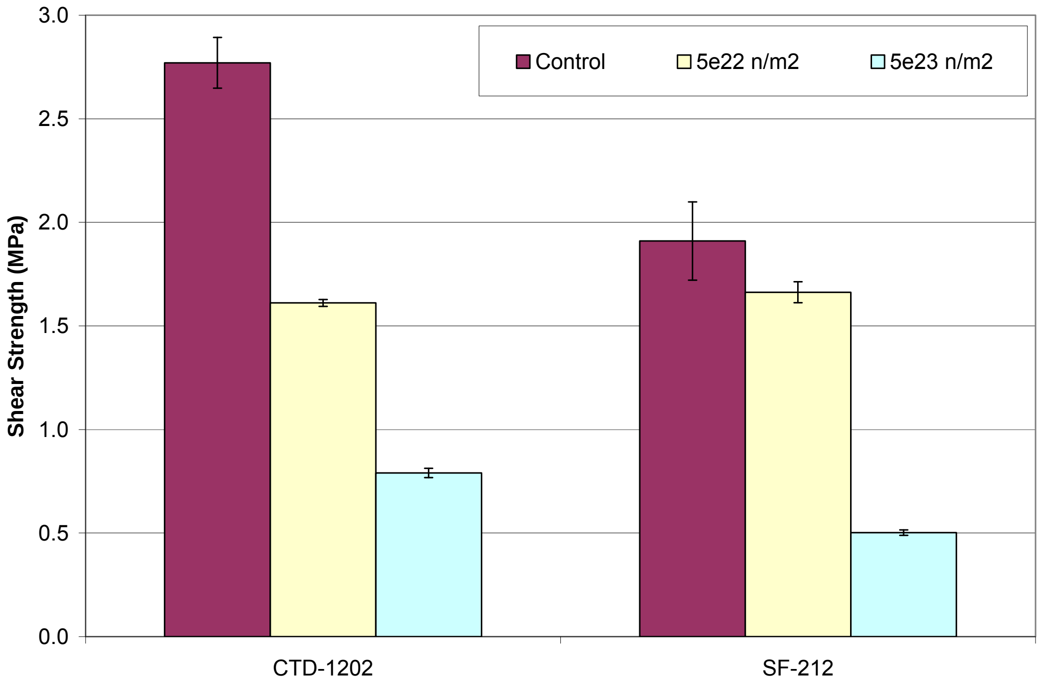

Figure 16. Shear strength of CTD-1202/S-2 glass and
SF-212/ S-2 glass at 373 K.

Electrical Test Results

As shown in Figures 17 through 19, the control specimens for both the CTD-1202 and SF-212 materials appear to have higher dielectric strengths than the pre-irradiation specimens. However, it should be noted that only three pre-irradiation specimens were tested, whereas seven specimens were tested for each of the other test conditions. Moreover, the standard deviations observed during the pre-irradiation testing are relatively high. Given the larger number of control samples, these average values are likely more representative of the dielectric breakdown strengths of the two candidate materials and provide a better estimate of initial performance to which the irradiated materials can be compared.

As seen below, the dielectric strength of the CTD-1202 composites was initially twice that of the SF-212 material. After irradiation, however, the breakdown strengths of both materials decreased significantly. These decreases were found to be at least 40% after irradiation at $5x10^{22}$ n/m^2, and at least 50% after exposure to a fast neutron fluence of $5x10^{23}$ n/m^2.

In addition, Figures 20 and 21 show the average leakage current for each inorganic material at applied voltages of 0 to 6 kV. The CTD-1202 composites exhibit a slightly higher leakage current after the lower irradiation, but the differences seen here are within the standard deviations between the two sample sets. The leakage current values for the SF-212 material irradiated at the higher fluence show a significant increase as compared to the materials exposed to the lower fluence.

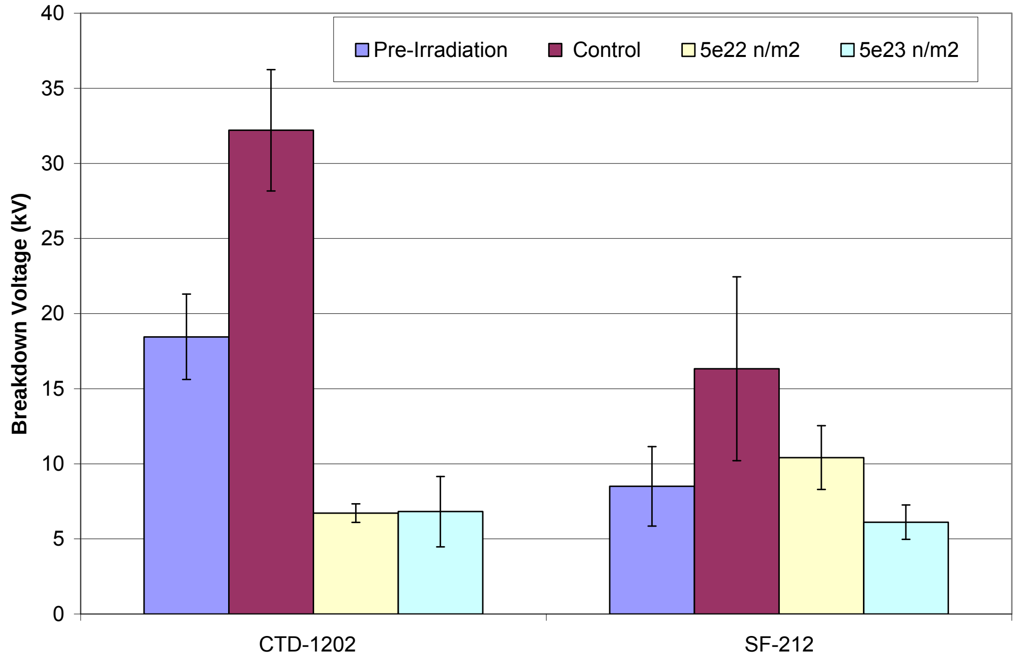

Figure 17. Breakdown voltage of CTD-1202/S-2 glass and SF-212/ S-2 glass at 373 K.

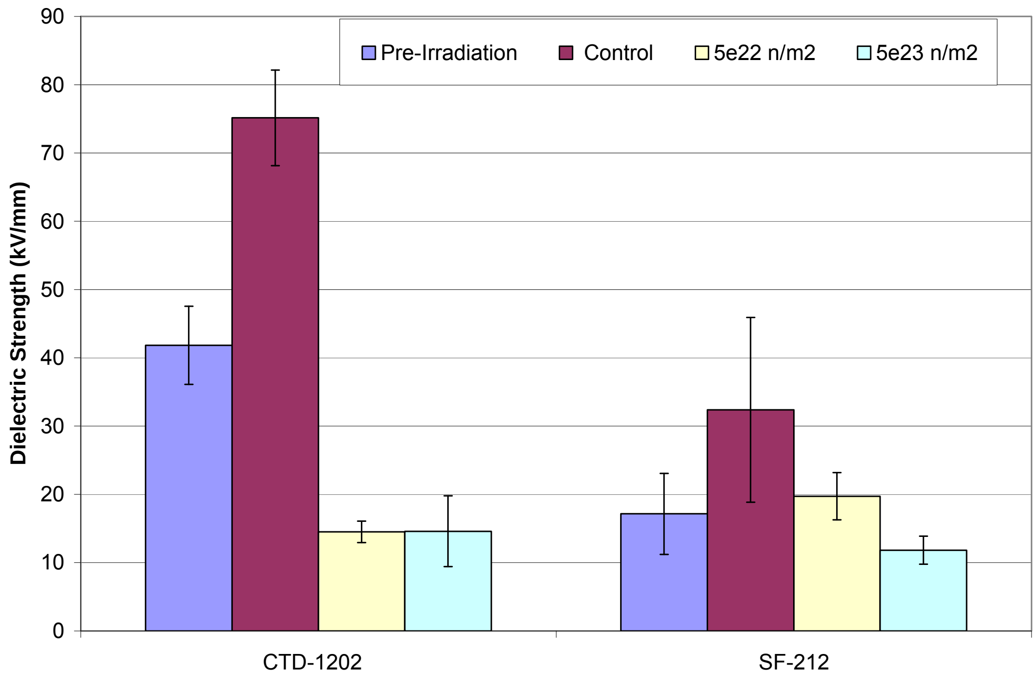

Figure 18. Dielectric strength of CTD-1202/S-2 glass and SF-212/ S-2 glass at 373 K.

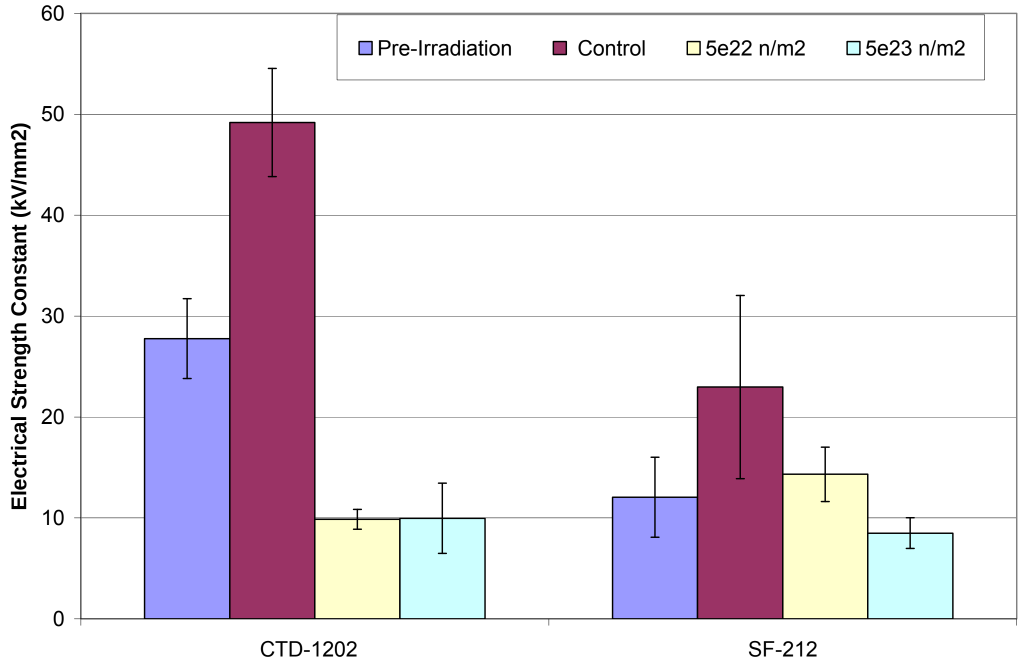

Figure 19. Electrical strength constant of CTD-1202/S-2 glass and SF-212/ S-2 glass at 373 K.

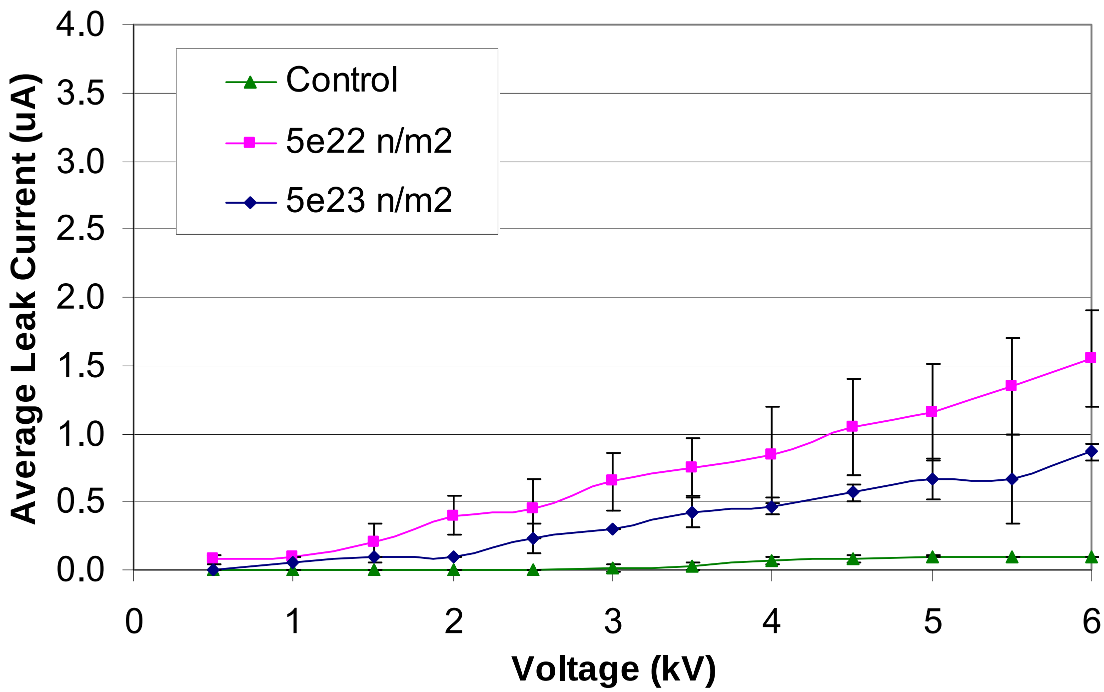

Figure 20. CTD-1202/S-2 glass leakage current measurements at 373 K.

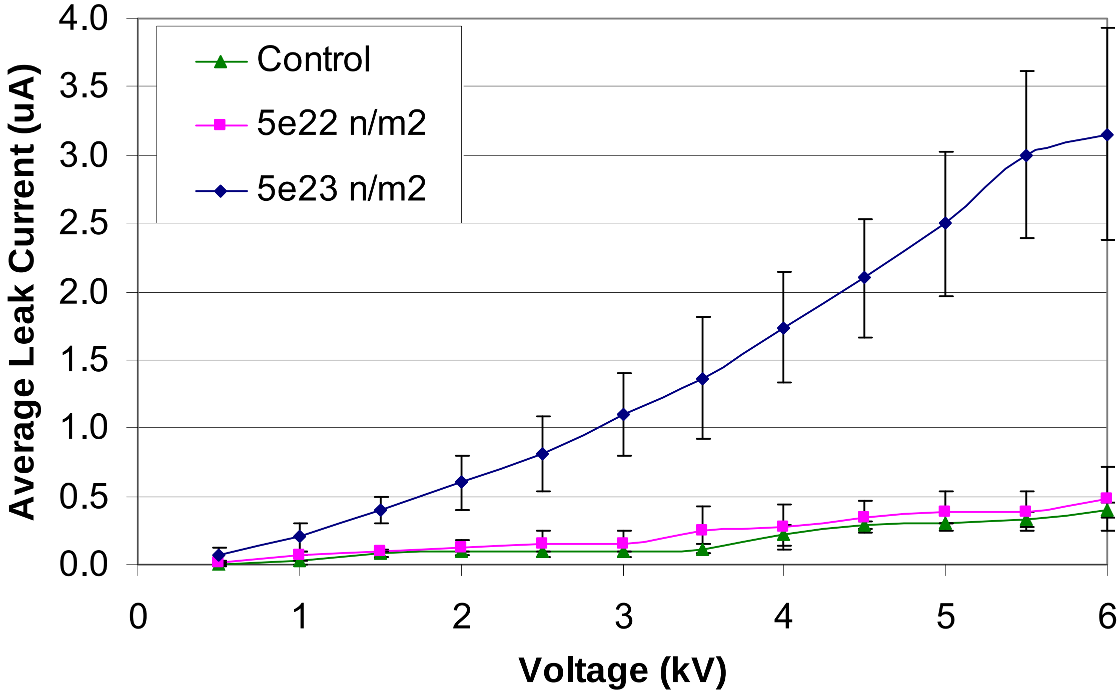

Figure 21. SF-212/S-2 glass leakage current measurements at 373 K.

Finally, the dielectric breakdown properties and leakage current behavior of the Kapton specimens, before and after irradiation, are presented in Table 4 and Figure 22, respectively. As seen below, the breakdown voltages and corresponding dielectric strength values decreased 30-40% after irradiation at 5 x 10^{22} n/m^2, however there was no additional degradation as a result of the higher fluence. The relatively high dielectric breakdown strengths reported in Table 4 are also indicated by the low leakage currents observed for these materials. As seen in Figure 23, the leakage currents were below 0.5 μA at applied voltages up to 6 kV for both the un-irradiated and irradiated specimens.

Table 4. Average thickness and dielectric strength characteristics of Kapton films before and after reactor irradiation.

Kapton Film Property	**Irradiation Condition**		
	Control	**5 x 10^{22} n/m^2**	**5 x 10^{23} n/m^2**
Thickness (mm)	0.029	0.057	0.060
Breakdown Voltage (kV)	17.9	13.5	13.7
Dielectric Strength (kV/mm)	364.7	237.3	231.4
Electrical Strength Constant (kV/mm$^{1/2}$)	80.7	56.5	56.2

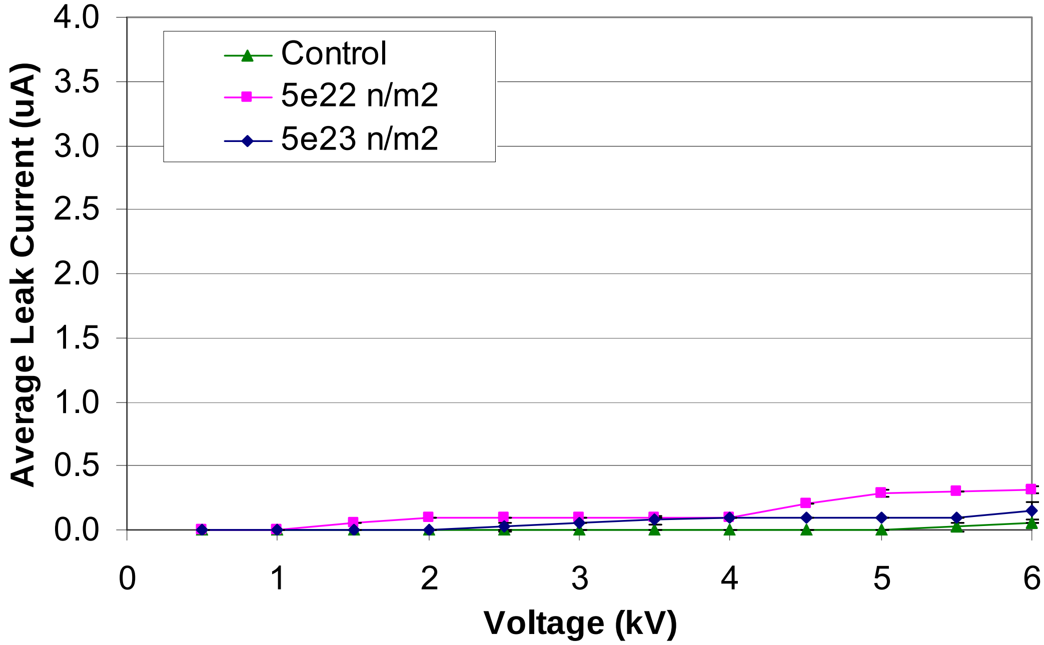

Figure 22. Kapton leakage current measurements at 373 K.

APPENDIX A

PRE-IRRADIATION MECHANICAL AND ELECTRICAL TEST RESULTS

Shear Test Results - ASTM D 2344

TEST CONDITIONS

Customer:	**Cryogenic Materials, Inc.**	***Load Frame:***	**1 Kip**
Matrix System:	**CTD-1202, SF 212**	***Load / Displacement Rate:***	**0.05 in/min**
Reinforcement:	**S2-Glass**	***Test Fixture:***	**3 point bend**
Specimen Type:	**0.125" x 0.250" x 1.1"**		
Material Reference:	**358001**		
CTD Program #:	**7258**		
Customer:	**Cryogenic Materials, Inc.**	***Test Temperature:***	**373 K**
Test Date:	**6/25/2009**	***Temperature Hold Time:***	**5 Minutes**

SBS TESTING, PRE-IRRADIATION TEST RESULTS

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	First Failure Ultimate Load (lbs)	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1240	0.2480	1.098	0.4920	3.97	17.6	17.9	0.3	0.4	I
2	0.1230	0.2490	1.098	0.4920	4.00	17.4	20.0	0.3	0.4	I
3	0.1230	0.2480	1.097	0.4920	4.00	17.1	17.5	0.3	0.4	I

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.30	0.43
Std. Dev.	0.00	0.00
CV:	0.01	0.01

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	2.07	2.93
Std. Dev.	0.03	0.03
CV:	0.01	0.01

SF 212

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	First Failure Ultimate Load (lbs)	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1270	0.2500	1.096	0.5040	3.97	13.3	13.3	0.1	0.3	I
2	0.1250	0.2500	1.099	0.5040	4.03	13.3	13.3	0.2	0.3	I
3	0.1250	0.2500	1.101	0.5040	4.03	13.5	13.5	0.2	0.3	I

Failure Mode:
I = Interlaminar Shear
MI = Multiple Interlaminar Shear
D = Diagonal Shear/Compression
C = Compressive Failure
T = Tensile Failure

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.14	0.32
Std. Dev.	0.01	0.00
CV:	0.09	0.02

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	0.99	2.20
Std. Dev.	0.09	0.03
CV:	0.09	0.02

Compression Test Results – ASTM D695

TEST CONDITIONS

Customer:	Cryogenic Materials, Inc.	***Test Date:***	***6/26/2009***
CTD Program #:	***7258***	***Load Frame:***	***20 Kip***
Material Reference:	***358001 & SF212***	***Load / Displacement Rate:***	***.050 in/min***
Matrix System:	***CTD 1202 & SF 212***	***Load Range Card:***	***20 Kip***
Reinforcement:	***S2- Glass***	***Stroke Range Card:***	***6 in.***
ASTM Reference:	***D695 (SACMA SRM-1)***	***Load Cell:***	***20 Kip***
Specimen Type:	***0.250" X 0.250" X .125"***	***Strain Measurement:***	***MTS LVDT***
Test Fixture:	***SRM-1***	***Strain Gage type:***	
Test Temperature:	***373K***	***Temperature Controller:***	***Custom Thermal Chamber***
Temperature hold time:	***5 minutes***	***Temperature Sensor:***	***Type K Thermocouple***
Specimen Conditioning:	***NA***		

TEST RESULTS

Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)	Notes
CTD-1202 -1	0.121	0.248	0.248	0.0615	83.7	5148	0.462	
-2	0.122	0.247	0.249	0.0615	88.6	5449	0.456	
-3	0.122	0.248	0.249	0.0618	87.8	5420	0.472	
				Average	**86.7**	**5339.0**	**0.463**	
				Std. Dev.:	**2.6**	**166.0**	**0.008**	
				CV:	**0.03**	**0.03**	**0.017**	
SF-212 -1	0.131	0.249	0.249	0.0620	76.5	4746	0.478	
-2	0.128	0.250	0.247	0.0618	72.6	4485	0.471	
-3	0.129	0.249	0.250	0.0623	79.2	4931	0.492	**
				Average	**76.1**	**4720.7**	**0.480**	
				Std. Dev.:	**3.3**	**224.1**	**0.011**	
				CV:	**0.04**	**0.05**	**0.022**	

Notes ** - Compressed to 820 lbs, test engineer aborted due to low temp. condition (approx. 95C, 368K); Specimen was heated and test re-run @ 100C w/ failure @ 4931 lbs

	Compression Modulus (GPa)	
	CTD-1202	SF-212
Average	3.2	3.3
Std. Dev.:	0.1	0.1
CV:	0.02	0.02

	Compression Strength (MPa)	
	CTD-1202	SF-212
Average	597.7	524.9
Std. Dev.:	18.1	22.8
CV:	0.03	0.04

Dielectric Test Results

TEST CONDITIONS

Matrix System:	**CTD-1202, SF 212**	*Test Fixture:*	**Dielectric Fixture**
Reinforcement:	**S2-Glass**	*Electrode Size:*	**5/16"**
Material Reference:	**358002**		
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**6/24/2009**		

DIELECTRIC TESTING, PRE-IRRADIATION TEST RESULTS

CTD-1202

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant (kV/mm$^{1/2}$)	Leakage Current (μA)
1	0.453	15	33.11	22.29	< 0.1
2	0.467	33.5	71.73	49.02	< 0.1
3 *	0.42	4.751	11.31	7.33	< 0.1
Average	0.447	17.75	38.72	26.21	< 0.1
Std Dev	0.02	14.57	30.60	21.12	

SF 212

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant (kV/mm$^{1/2}$)	Leakage Current (μA)
1	0.495	7.5	15.15	10.66	< 0.1
2	0.522	6.5	12.45	9.00	< 0.1
3	0.483	11.5	23.81	16.55	< 0.1
Average	0.500	8.50	17.14	12.07	< 0.1
Std Dev	0.02	2.65	5.93	3.97	

NOTES: * Voids present in resin

Dielectric Test Results

TEST CONDITIONS

Matrix System:	**CTD-1202**	*Test Fixture:*	**Dielectric Fixture**
Reinforcement:	**S2-Glass**	*Electrode Size:*	**0.20"**
Material Reference:	**358002**		
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**7/3/2009**		

DIELECTRIC TESTING, PRE-IRRADIATION TEST RESULTS

CTD-1202

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant (kV/mm$^{1/2)}$
1	0.433	16	36.95	24.32
2	0.479	20	41.75	28.90
3 *	0.440	13	29.55	19.60
4	0.396	17	42.93	27.01
5	0.457	18	39.39	26.63
6	0.442	18	40.72	27.07
7 *	0.469	20	42.64	29.20
8	0.451	22	48.78	32.76
9	0.424	21	49.53	32.25
10	0.398	16	40.20	25.36
11	0.462	22	47.62	32.37
Average	0.441	18.45	41.82	27.77
Std Dev	0.03	2.84	5.72	3.95

NOTES: * Voids present in resin

APPENDIX B

POST-IRRADIATION MECHANICAL AND ELECTRICAL TEST RESULTS

Thickness and Mass Changes for Irradiated Specimens

Specimen Type	**Irradiation Level** (n/m^2)	**Thickness Change (%)**	**Mass Change (%)**
CTD-1202 Electrical	5×10^{22}	3.4	0.6
CTD-1202 Electrical	5×10^{23}	2. 8	-3.1
CTD-1202 Compression	5×10^{22}	-0.2	0.1
CTD-1202 Compression	5×10^{23}	0.0	-1.9
CTD-1202 SBS	5×10^{22}	-0.5	0.1
CTD-1202 SBS	5×10^{23}	-0.1	-1.9
SF-212 Electrical	5×10^{22}	1.2	1.7
SF-212 Electrical	5×10^{23}	1.2	-3.7
SF-212 Compression	5×10^{22}	-0.1	0.2
SF-212 Compression	5×10^{23}	0.3	-2.3
SF-212 SBS	5×10^{22}	-0.9	0.4
SF-212 SBS	5×10^{23}	-0.2	-2.1
Kapton Electrical	5×10^{22}	13.7	2.4
Kapton Electrical	5×10^{23}	18.9	1.2

Shear Test Results - ASTM D 2344, Control

TEST CONDITIONS

Customer:	**Cryogenic Materials, Inc.**	***Load Frame:***	**20 Kip**
Matrix System:	**CTD-1202, SF 212**	***Load / Displacement Rate:***	**0.05 in/min**
Reinforcement:	**S2-Glass**	***Test Fixture:***	**3 point bend**
Specimen Type:	**0.125" x 0.250" x 1.1"**		
Material Reference:	**358001**		
CTD Program #:	**7258**		
Customer:	**Cryogenic Materials, Inc.**	***Test Temperature:***	**373 K**
Test Date:	**11/18/2009**	***Temperature Hold Time:***	**5 Minutes**

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Ultimate Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1225	0.2480	1.097	0.6225	5.08	17.1	0.42	0.4	I
2	0.1225	0.2480	1.096	0.6225	5.08	15.9	0.40	0.4	I
3	0.1215	0.2485	1.097	0.6225	5.12	15.7	0.45	0.4	I

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.42	0.40
Std. Dev.	0.03	0.02
CV:	0.06	0.04

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	2.92	2.77
Std. Dev.	0.19	0.12
CV:	0.06	0.04

SF 212

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1260	0.2490	1.100	0.6225	4.94	5.5	0.016	0.1	I
2	0.1280	0.2485	1.097	0.6225	4.86	12.6	0.182	0.3	I
3	0.1280	0.2490	1.099	0.6225	4.86	11.0	0.177	0.3	I

Failure Mode:
I = Interlaminar Shear
MI = Multiple Interlaminar Shear
D = Diagonal Shear/Compression
C = Compressive Failure
T = Tensile Failure

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.13	0.23
Std. Dev.	0.09	0.09
CV:	0.75	0.38

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	0.86	1.58
Std. Dev.	0.65	0.59
CV:	0.75	0.38

Excluding specimen #1:

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.18	0.28
Std. Dev.	0.00	0.03
CV:	0.02	0.10

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	1.24	1.91
Std. Dev.	0.02	0.19
CV:	0.02	0.10

Shear Test Results - ASTM D 2344, Irradiation $5x10^{22}$ n/m^2

TEST CONDITIONS

Customer:	**Cryogenic Materials, Inc.**	***Load Frame:***	**20 Kip**
Matrix System:	**CTD-1202, SF 212**	***Load / Displacement Rate:***	**0.05 in/min**
Reinforcement:	**S2-Glass**	***Test Fixture:***	**3 point bend**
Specimen Type:	**0.125" x 0.250" x 1.1"**		
Material Reference:	**358001**		
CTD Program #:	**7258**		
Customer:	**Cryogenic Materials, Inc.**	***Test Temperature:***	**373 K**
Test Date:	**11/20/2009**	***Temperature Hold Time:***	**5 Minutes**

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1229	0.2485	1.083	0.6224	5.06	9.4	0.235	0.23	I
2	0.1218	0.2493	1.083	0.6224	5.11	9.4	0.241	0.23	I
3	0.1224	0.2498	1.083	0.6224	5.09	9.6	0.237	0.24	I

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.24	0.23
Std. Dev.	0.00	0.00
CV:	0.01	0.01

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	1.64	1.61
Std. Dev.	0.02	0.02
CV:	0.01	0.01

SF 212

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1269	0.2494	1.083	0.6224	4.91	10.2	0.265	0.24	I
2	0.1285	0.2501	1.083	0.6224	4.85	10.0	0.216	0.23	I
3	0.1291	0.2492	1.083	0.6224	4.82	10.7	0.261	0.25	I

Failure Mode:
I = Interlaminar Shear
MI = Multiple Interlaminar Shear
D = Diagonal Shear/Compression
C = Compressive Failure
T = Tensile Failure

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.25	0.24
Std. Dev.	0.03	0.01
CV:	0.11	0.03

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	1.70	1.66
Std. Dev.	0.19	0.05
CV:	0.11	0.03

Shear Test Results - ASTM D 2344, Irradiation $5x10^{23}$ n/m^2

TEST CONDITIONS

Customer:	**Cryogenic Materials, Inc.**	***Load Frame:***	**20 Kip**
Matrix System:	**CTD-1202, SF 212**	***Load / Displacement Rate:***	**0.05 in/min**
Reinforcement:	**S2-Glass**	***Test Fixture:***	**3 point bend**
Specimen Type:	**0.125" x 0.250" x 1.1"**		
Material Reference:	**358001**		
CTD Program #:	**7258**		
Customer:	**Cryogenic Materials, Inc.**	***Test Temperature:***	**373 K**
Test Date:	**11/20/2009**	***Temperature Hold Time:***	**5 Minutes**

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1228	0.2486	1.083	0.6224	5.07	4.6	0.062	0.113	I
2	0.1226	0.2487	1.083	0.6224	5.08	4.6	0.062	0.112	I
3	0.1243	0.2483	1.083	0.6224	5.01	4.9	0.059	0.118	I

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.06	0.11
Std. Dev.	0.00	0.00
CV:	0.02	0.03

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	0.42	0.79
Std. Dev.	0.01	0.02
CV:	0.02	0.03

SF 212

Specimen #	Thickness (in)	Width (in)	Length (in)	Span (in)	Span Ratio	Max Load (lbs)	Flex. Modulus (Msi)	Apparent Shear Strength (ksi)	Failure Mode
1	0.1292	0.2488	0.043	0.6224	4.82	3.1	0.033	0.1	I
2	0.1285	0.2482	0.043	0.6224	4.84	3.2	0.034	0.1	I
3	0.1276	0.2495	0.043	0.6224	4.88	3.1	0.033	0.1	I

Failure Mode:
I = Interlaminar Shear
MI = Multiple Interlaminar Shear
D = Diagonal Shear/Compression
C = Compressive Failure
T = Tensile Failure

	Flexural Modulus (Msi)	Shear Strength (ksi)
Average	0.03	0.07
Std. Dev.	0.00	0.00
CV:	0.02	0.03

	Flexural Modulus (GPa)	Shear Strength (MPa)
Average	0.23	0.50
Std. Dev.	0.00	0.01
CV:	0.02	0.03

Compression Test Results, Control

TEST CONDITIONS

Customer:	***Cryogenic Materials, Inc.***	***Test Date:***	***11/18/2009***
CTD Program #:	***7258***	***Load Frame:***	***20 Kip***
Material Reference:	***358001 & SF-212***	***Load / Displacement Rate:***	***0.00033 in/s***
Matrix System:	***CTD 1202 & SF-212***	***Load Range Card:***	***20 Kip***
Reinforcement:	***S2- Glass***	***Stroke Range Card:***	***6 in.***
ASTM Reference:	***D695 (SACMA SRM-1)***	***Load Cell:***	***20 Kip***
Specimen Type:	***0.250" X 0.250" X .125"***	***Strain Measurement:***	***3 Extensometers***
Test Fixture:	***SRM-1***	***Strain Gage type:***	
Test Temperature:	***373K***	***Temperature Controller:***	***NA***
Temperature hold time:	***5 minutes***	***Temperature Sensor:***	***Type K T/C***
Specimen Conditioning:	***NA***		

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)
CTD-1202 -1	0.119	0.247	0.247	0.0610	76.7	4682	0.697
-2	0.119	0.246	0.246	0.0605	80.3	4862	0.829
-3	0.119	0.249	0.247	0.0615	72.4	4454	0.745
-4	0.118	0.249	0.248	0.0616	73.8	4547	0.761
				Average	**75.8**	**4636.3**	**0.758**
				Std. Dev.:	**3.5**	**177.0**	**0.055**
				CV:	**0.05**	**0.04**	**0.072**

SF-212

Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)
SF-212 -1	0.126	0.249	0.252	0.0627	70.4	4418.0	0.388
-2	0.128	0.249	0.248	0.0618	69.3	4278.0	0.526
-3	0.127	0.247	0.248	0.0611	70.8	4326.3	0.525
-4	0.127	0.247	0.246	0.0608	74.2	4508.0	0.534
				Average	**71.2**	**4382.6**	**0.493**
				Std. Dev.:	**2.1**	**101.8**	**0.070**
				CV:	**0.03**	**0.02**	**0.143**

	Compression Modulus (GPa)	
	CTD-1202	SF-212
Average	5.2	3.4
Std. Dev.:	0.4	0.5
CV:	0.07	0.14

	Compression Strength (MPa)	
	CTD-1202	SF-212
Average	522.8	490.7
Std. Dev.:	24.2	14.6
CV:	0.05	0.03

Compression Test Results, Irradiation $5x10^{22}$ n/m^2

TEST CONDITIONS

Customer:	***Cryogenic Materials, Inc.***	***Test Date:***	***11/19/2009***
CTD Program #:	***7258***	***Load Frame:***	***20 Kip***
Material Reference:	***358001 & SF-212***	***Load / Displacement Rate:***	***.050 in/min***
Matrix System:	***CTD 1202 & SF-212***	***Load Range Card:***	***20 Kip***
Reinforcement:	***S2- Glass***	***Stroke Range Card:***	***6 in.***
ASTM Reference:	***D695 (SACMA SRM-1)***	***Load Cell:***	***20 Kip***
Specimen Type:	***0.250" X 0.250" X .125"***	***Strain Measurement:***	***MTS LVDT***
Test Fixture:	***SRM-1***	***Strain Gage type:***	
Test Temperature:	***373K***	***Temperature Controller:***	***Custom Thermal Chamber***
Temperature hold time:	***5 minutes***	***Temperature Sensor:***	***Type K Thermocouple***
Specimen Conditioning:	***NA***		

CTD-1202							
Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)
CTD-1202 -1	0.122	0.250	0.245	0.0612	77.9	4767	0.874
-2	0.122	0.248	0.251	0.0622	75.6	4698	0.697
-3	0.122	0.249	0.249	0.0621	77.1	4786	0.768
-4	0.121	0.246	0.250	0.0616	78.0	4804	0.716
				Average	**77.1**	**4763.8**	**0.764**
				Std. Dev.:	**1.1**	**46.4**	**0.079**
				CV:	**0.01**	**0.01**	**0.104**

SF-212							
SF-212 -1	0.126	0.253	0.249	0.0630	81.0	5102	0.555
-2	0.128	0.250	0.253	0.0631	82.7	5222	0.482
-3	0.128	0.250	0.249	0.0622	86.6	5390	0.541
-4	0.129	0.249	0.250	0.0624	78.4	4891	0.805
				Average	**82.2**	**5151.1**	**0.596**
				Std. Dev.:	**3.4**	**209.8**	**0.143**
				CV:	**0.04**	**0.04**	**0.240**

	Compression Modulus (GPa)	
	CTD-1202	SF-212
Average	5.27	4.11
Std. Dev.:	0.55	0.99
CV:	0.10	0.24

	Compression Strength (MPa)	
	CTD-1202	SF-212
Average	531.9	566.6
Std. Dev.:	7.8	23.7
CV:	0.01	0.04

Compression Test Results, Irradiation $5x10^{23}$ n/m^2

TEST CONDITIONS

Customer:	***Cryogenic Materials, Inc.***	***Test Date:***	***11/19/2009***
CTD Program #:	***7258***	***Load Frame:***	***20 Kip***
Material Reference:	***358001 & SF-212***	***Load / Displacement Rate:***	***.050 in/min***
Matrix System:	***CTD 1202 & SF-212***	***Load Range Card:***	***20 Kip***
Reinforcement:	***S2- Glass***	***Stroke Range Card:***	***6 in.***
ASTM Reference:	***D695 (SACMA SRM-1)***	***Load Cell:***	***20 Kip***
Specimen Type:	***0.250" X 0.250" X .125"***	***Strain Measurement:***	***MTS LVDT***
Test Fixture:	***SRM-1***	***Strain Gage type:***	
Test Temperature:	***373K***	***Temperature Controller:***	***Custom Thermal Chamber***
Temperature hold time:	***5 minutes***	***Temperature Sensor:***	***Type K Thermocouple***
Specimen Conditioning:	***NA***		

CTD-1202

Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)	Notes
CTD-1202 -1	0.122	0.249	0.247	0.0615	17.6	1081.2	0.309	
-2	0.121	0.248	0.248	0.0615				*
-3	0.122	0.246	0.248	0.0609	18.8	1146.8	0.383	
-4	0.122	0.248	0.251	0.0622	17.2	1068.8	0.263	
				Average	**17.9**	**1098.9**	**0.318**	
				Std. Dev.:	**0.9**	**41.9**	**0.061**	
				CV:	**0.05**	**0.04**	**0.191**	

SF-212

Specimen #	Thickness (in)	Width (in)	Length (in)	X-Section Area (in²)	Ultimate Strength (ksi)	Maximum Load (lbs)	Compressive Modulus (Msi)	Notes
SF-212 -1								*
-2								*
-3								*
-4	0.126	0.251	0.249	0.0625	23.3	1459	0.208	
				Average	**23.3**	**1458.8**	**0.208**	

Notes * Specimens delaminated prior to testing

	Compression Modulus (GPa)	
	CTD-1202	SF-212
Average	2.19	1.43
Std. Dev.:	0.42	0.00
CV:	0.19	0.00

	Compression Strength (MPa)	
	CTD-1202	SF-212
Average	123.2	160.8
Std. Dev.:	5.9	0.0
CV:	0.05	0.00

Dielectric Test Results, Control

TEST CONDITIONS

Matrix System:	**CTD-1202, SF 212**	***Test Fixture:***	**Dielectric Fixture**
Reinforcement:	**S2-Glass**	***Electrode Size:***	**.2"**
Material Reference:	**358002**		
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/19/2009**		

CTD-1202

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.41	27.85	67.93	43.49
2	0.422	34.15	80.92	52.57
3	0.446	35.81	80.29	53.62
4	0.449	34.66	77.19	51.73
5	0.427	30.15	70.61	46.14
6	0.437	36.44	83.39	55.12
7	0.402	26.39	65.65	41.62
Average	0.428	32.21	75.14	49.19
Std Dev	0.02	4.04	7.01	5.35

SF 212

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.562	13.06	23.24	17.42
2	0.476	26.84	56.39	38.90
3	0.599	8.44	14.09	10.91
4	0.52	16.23	31.21	22.51
5	0.535	19.82	37.05	27.10
6	0.479	18.55	38.73	26.80
7	0.438	11.39	26.00	17.21
Average	0.516	16.33	32.39	22.98
Std Dev	0.06	6.12	13.53	9.09

Dielectric Test Results, Irradiation $5x10^{22}$ n/m^2

TEST CONDITIONS

Matrix System:	**CTD-1202, SF 212**	*Test Fixture:*	**Dielectric Fixture**
Reinforcement:	**S2-Glass**	*Electrode Size:*	**.2"**
Material Reference:	**358002**		
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/19/2009**		

CTD-1202				
Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant (kV/mm$^{1/2}$)
1	0.482	5.906	12.25	8.51
2	0.47	6.75	14.36	9.85
3	0.452	7.87	17.41	11.71
4	0.458	6.76	14.76	9.99
5	0.459	6.78	14.77	10.01
6	0.465	6.75	14.52	9.90
7	0.458	6.17	13.47	9.12
Average	0.463	6.71	14.51	9.87
Std Dev	0.01	0.62	1.57	0.99

SF 212				
Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant (kV/mm$^{1/2}$)
1	0.532	9.04	16.99	12.39
2	0.493	7.78	15.78	11.08
3	0.553	10.91	19.73	14.67
4	0.514	10.16	19.77	14.17
5	0.54	14.39	26.65	19.58
6	0.565	11.36	20.11	15.11
7	0.488	9.28	19.02	13.28
Average	0.526	10.42	19.72	14.33
Std Dev	0.03	2.13	3.45	2.70

Dielectric Test Results, Irradiation $5x10^{23}$ n/m^2

TEST CONDITIONS

Matrix System:	**CTD-1202, SF 212**	*Test Fixture:*	**Dielectric Fixture**
Reinforcement:	**S2-Glass**	*Electrode Size:*	**.2"**
Material Reference:	**358002**		
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/20/2009**		

CTD-1202

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.482	3.738	7.76	5.38
2	0.469	6.37	13.58	9.30
3	0.463	10.73	23.17	15.77
4	0.462	9.06	19.61	13.33
5	0.457	5.97	13.06	8.83
6	0.479	5.46	11.40	7.89
7	0.47	6.38	13.57	9.31
Average	0.469	6.82	14.59	9.97
Std Dev	0.01	2.34	5.17	3.48

SF 212

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1				
2	0.518	7.24	13.98	10.06
3	0.478	5.522	11.55	7.99
4	0.544	7.22	13.27	9.79
5	0.521	6.82	13.09	9.45
6	0.518	5.42	10.46	7.53
7	0.523	4.46	8.53	6.17
Average	0.517	6.11	11.81	8.50
Std Dev	0.02	1.15	2.06	1.53

Dielectric Test Results, Kapton

TEST CONDITIONS

Matrix System:	**Kapton FPC (HPPST)**	***Test Fixture:***	**Dielectric Fixture**
Reinforcement:	**None**	***Electrode Size:***	**.2"**
Material Reference:			
CTD Program #:	**7258**		
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/20/2009**		

Control

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.049	17.87	364.69	80.73
2	0.049	17.87	364.69	80.73
Average	0.049	17.87	364.69	80.73
Std Dev	0.00	0.00	0.00	0.00

Irradiation $5x10^{22}$ n/m^2

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.059	13.59	230.34	55.95
2	0.055	13.49	245.27	57.52
3	0.058	12.62	217.59	52.40
4	0.055	14.08	256.00	60.04
Average	0.057	13.45	237.30	56.48
Std Dev	0.00	0.61	16.84	3.20

Irradiation $5x10^{23}$ n/m^2

Specimen #	Insulation Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Electrical Strength Constant ($kV/mm^{1/2}$)
1	0.067	15.19	226.72	58.68
2	0.059	8.51	144.24	35.04
3	0.058	15.06	259.66	62.53
4	0.054	15.92	294.81	68.51
Average	0.060	13.67	231.36	56.19
Std Dev	0.01	3.46	64.39	14.67

Leakage Current Test Results

TEST CONDITIONS

Matrix System:	**CTD-1202**	***Test Fixture:***	**Dielectric Fixture**
Reinforcement:	**S-2 Glass**	***Electrode Size:***	**.2"**
Material Reference:	**358002**	***Ramp time:***	**180 s**
CTD Program #:	**7258**	***Test Meter:***	***QuadTech Guardian 1030***
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/19/2009**		

Applied Voltage (KVDC)	Average Leak Current (μA)		
	Control	$5x10^{22}$ n/m^2	$5x10^{23}$ n/m^2
0.5	0.00	0.08	0.00
1.0	0.00	0.10	0.05
1.5	0.00	0.20	0.10
2.0	0.00	0.40	0.10
2.5	0.00	0.45	0.23
3.0	0.02	0.65	0.30
3.5	0.02	0.75	0.43
4.0	0.07	0.85	0.47
4.5	0.08	1.05	0.57
5.0	0.10	1.15	0.67
5.5	0.10	1.35	0.67
6.0	0.10	1.55	0.87

Leakage Current Test Results

TEST CONDITIONS

Matrix System:	**SF-212**	***Test Fixture:***	**Dielectric Fixture**
Reinforcement:	**S-2 Glass**	***Electrode Size:***	**.2"**
Material Reference:	**None**	***Ramp time:***	**180 s**
CTD Program #:	**7258**	***Test Meter:***	***QuadTech Guardian 1030***
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/19/2009**		

Applied Voltage (KVDC)	Average Leak Current (μA)		
	Control	$5x10^{22}$ n/m^2	$5x10^{23}$ n/m^2
0.5	0.00	0.01	0.07
1.0	0.03	0.07	0.20
1.5	0.08	0.10	0.40
2.0	0.10	0.13	0.60
2.5	0.10	0.15	0.82
3.0	0.10	0.15	1.10
3.5	0.12	0.25	1.37
4.0	0.22	0.28	1.73
4.5	0.28	0.35	2.10
5.0	0.30	0.39	2.50
5.5	0.33	0.39	3.00
6.0	0.40	0.48	3.15

Leakage Current Test Results

TEST CONDITIONS

Matrix System:	**Kapton**	*Test Fixture:*	**Dielectric Fixture**
Reinforcement:	**None**	*Electrode Size:*	**.2"**
Material Reference:	**N/A**	*Ramp time:*	**180 s**
CTD Program #:	**7258**	*Test Meter:*	***QuadTech Guardian 1030***
Test Temperature:	**373 K**		
Test Condition:	**Synthetic Oil**		
Test Date:	**11/20/2009**		

Applied Voltage (KVDC)	Average Leak Current (μA)		
	Control	$5x10^{22}$ n/m^2	$5x10^{23}$ n/m^2
0.5	0.00	0.00	0.00
1.0	0.00	0.00	0.00
1.5	0.00	0.05	0.00
2.0	0.00	0.10	0.00
2.5	0.00	0.10	0.03
3.0	0.00	0.10	0.05
3.5	0.00	0.10	0.08
4.0	0.00	0.10	0.10
4.5	0.00	0.20	0.10
5.0	0.00	0.28	0.10
5.5	0.03	0.30	0.10
6.0	0.05	0.32	0.15