Equivalency Statistical Analysis for Laminate Repair Prepreg Batch of Solvay (Formerly Cytec) 5320-1 T650 3K-PW fabric with 36% RC

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1. Introduction

This report contains the equivalency test results for the batch of Solvay (Formerly Cytec) 5320-1 T650 3K-PW fabric with 36% RC prepreg material used in the Laminate Repair qualification program. This one batch of prepreg material compared to the original qualification panels of the same material prior to the repair program. The lamina and laminate material property data have been generated with NCAMP oversight in accordance with NSP 100 NCAMP Standard Operating Procedures; the test panels and test specimens have been inspected by NCAMP Authorized Inspection Representatives (AIR) and the testing has been witnessed by NCAMP Authorized Engineering Representatives (AER).

The material was procured to NCAMP Material Specification NMS 532/6 which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19. The equivalency test panels were fabricated per NCAMP Process Specification NPS 85321 using baseline cure cycle ‘C’. The NCAMP Test Plan NTP 5325QR1 was used for the equivalency portion of this program.

The tests on the equivalency specimens were performed at the National Institute for Aviation Research (NIAR) in Wichita, Kansas. The comparisons were performed according to CMH-17-1G section 8.4.1. The modified coefficient of variation (Mod CV) comparison tests were done in accordance with section 8.4.4 of CMH-17-1G.

The material property data for the qualification panels is published in CAM-RP-2012-017 Rev NC. The material property data for the equivalency panels is published in NCAMP Test Report CAM-RP-2019-045 Rev N/C. Engineering basis values were reported in NCAMP Report NCP-RP-2012-023 Rev N/C which details the standards and methodology used for computing basis values as well as providing the B-basis values and A- and B- estimates computed from the test results for the original qualification panels.

The NCAMP shared material property database contains material property data of common usefulness to a wide range of aerospace projects. However, the data may not fulfill all the needs of a project. Specific properties, environments, laminate architecture, and loading situations that individual projects need may require additional testing.

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 532/6. NMS 532/6 has additional requirements that are listed in its prepreg process control document (PCD), fiber specification, fiber PCD, and other raw material specifications and PCDs which impose essential quality controls on the raw materials and raw material manufacturing equipment and processes. *Aircraft companies and certifying agencies should assume that the material property data published in this report is not applicable when the material is not procured to NCAMP Material Specification NMS 532/6*. NMS 532/6 is a free, publicly available, non-proprietary aerospace industry material specification.

The use of NCAMP material and process specifications does not guarantee material or structural performance. Material users should be actively involved in evaluating material performance and quality including, but not limited to, performing regular purchaser quality control tests, performing periodic equivalency/additional testing, participating in material change management activities, conducting statistical process control, and conducting regular supplier audits.

The applicability and accuracy of NCAMP material property data, material allowables, and specifications must be evaluated on case-by-case basis by aircraft companies and certifying agencies. NCAMP assumes no liability whatsoever, expressed or implied, related to the use of the material property data, material allowables and specifications.

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1.1 Symbols and Abbreviations

Test Property	Abbreviation
Warp Compression	WC
Warp Tension	WT
Fill Compression	FC
Fill Tension	FT
In-Plane Shear	IPS
Short Beam Strength	SBS
Open Hole Tension	OHT
Open Hole Compression	OHC
Compression After Impact	CAI
Cured Ply Thickness	CPT
Dynamic Mechanical Analysis	DMA

Table 1-1 Test Property Abbreviations

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	−65º ±5˚F	CTD
Room Temperature Dry	75º ±10˚F	RTD
Elevated Temperature Wet	250º±5˚ F	ETW2

Table 1-2 Environmental Conditions Abbreviations

Tests with a number immediately after the abbreviation indicate the lay-up:

1 refers to a 25/50/25 layup. This is also referred to as “Quasi-Isotropic”
2 refers to a 10/80/10 layup. This is also referred to as “Soft”
3 refers to a 40/20/40 layup. This is also referred to as “Hard”

EX: OHT1 is an open hole tension test with quasi-isotropic layup.

2. Background

Equivalence tests are performed in accordance with section 8.4.1 of CMH-17-1G and section 6.1 of DOT/FAA/AR-03/19, "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure."

2.1 Results Codes

Pass indicates that the test results are equivalent for that environment under both computational methods.

Fail indicates that the test results are NOT equivalent under both computational methods.

Pass with Mod CV indicates the test results are equivalent under the assumption of the modified CV method that the coefficient of variation is at least 6 but the test results fail without the use of the modified CV method.

2.2 Equivalency Computations

Equivalency tests are performed to determine if the differences between test results can be reasonably explained as due to the expected random variation of the material and testing processes. If so, we can conclude the two sets of tests are from 'equivalent' materials.

2.2.1 Hypothesis Testing

This comparison is performed using the statistical methodology of hypothesis testing. Two mutually exclusive hypotheses are set up, termed the null (H_0) and the alternative (H_1). The null hypothesis is assumed true and must contain the equality. For equivalency testing, they are set up as follows, with M_1 and M_2 representing the two materials being compared:

$$H_0 : M_1 = M_2$$
$$H_1 : M_1 \neq M_2$$

Samples are taken of each material and tested according to the plan. A test statistic is computed using the data from the sample tests. The probability of the actual test result is computed under the assumption of the null hypothesis. If that result is sufficiently unlikely then the null is rejected and the alternative hypothesis is accepted as true. If not, then the null hypothesis is retained as plausible.

2.2.2 Type I and Type II Errors

	Materials are equal	*Materials are not equal*
Conclude materials are equal	*Correct Decision*	*Type II error*
Conclude materials are not equal	*Type I error*	*Correct Decision*

Figure 2-1 Type I and Type II errors

As illustrated in Figure 2-1, there are four possible outcomes: two correct conclusions and two erroneous conclusions. The two wrong conclusions are termed type I and type II errors to distinguish them. The probability of making a type I error is specified using a parameter called alpha (α), while the type II error is not easily computed or controlled. The term 'sufficiently unlikely' in the previous paragraph means, in more precise terminology, the probability of the computed test statistic under the assumption of the null hypothesis is less than α.

For equivalency testing of composite materials, α is set at 0.05 which corresponds to a confidence level of 95%. This means that if we reject the null and say the two materials are not equivalent with respect to a particular test, the probability that this is a correct decision is no less than 95%.

2.2.3 Cumulative Error Probability

Each characteristic (such as Longitudinal Tension strength or In-Plane Shear modulus) is tested separately. While the probability of a Type I error is the same for all tests, since many different tests are performed on a single material, each with a 5% probability of a type I error, the probability of having one or more failures in a series of tests can be much higher.

If we assume the two materials are identical, with two tests the probability of a type I error for the two tests combined is $1 - .95^2 = .0975$. For four tests, it rises to $1 - .95^4 = 0.1855$. For 25 tests, the probability of a type I error on 1 or more tests is $1 - .95^{25} = 0.7226$. With a high probability of one or more equivalence test failures due to random chance alone, a few failed tests should be allowed and equivalence may still be presumed provided that the failures are not severe.

2.2.4 Strength and Modulus Tests

For strength test values, we are primarily concerned only if the equivalence sample shows lower strength values than the original qualification material. This is referred to as a 'one-sided' hypothesis test. Higher values are not considered a problem, though they may indicate a difference between the two materials. The equivalence sample mean and sample minimum values are compared against the minimum expected values for those statistics, which are computed from the qualification test result.

The expected values are computed using the values listed in Table 2-1 and Table 2-2 according to the following formulas:

> The mean must exceed $\overline{X} - k_n^{table\,2.1} \cdot S$ where $\overline{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample.
>
> The sample minimum must exceed $\overline{X} - k_n^{table\,2.2} \cdot S$ where $\overline{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample.

If either the mean or the minimum falls below the expected minimum, the sample is considered to have failed equivalency for that characteristic and the null hypothesis is rejected. The probability of failing either the mean or the minimum test (the α level) is set at 5%.

For Modulus values, failure occurs if the equivalence sample mean is either too high or too low compared to the qualification mean. This is referred to as a 'two-sided' hypothesis test. A standard two-sample two-tailed t-test is used to determine if the mean from the equivalency sample is sufficiently far from the qualification sample mean to reject the null hypothesis. The probability of a type I error is set at 5%.

These tests are performed with the HYTEQ spreadsheet, which was designed to test equivalency between two materials in accordance with the requirements of CMH-17-1G section 8.4.1: Tests for determining equivalency between an existing database and a new dataset for the same material. Details about the methods used are documented in the references listed in Section 5.

One-sided tolerance factors for limits on sample mean values									
n	α								
	0.25	**0.1**	**0.05**	**0.025**	**0.01**	**0.005**	**0.0025**	**0.001**	**0.0005**
2	0.6266	1.0539	1.3076	1.5266	1.7804	1.9528	2.1123	2.3076	2.4457
3	0.5421	0.8836	1.0868	1.2626	1.4666	1.6054	1.7341	1.8919	2.0035
4	0.4818	0.7744	0.9486	1.0995	1.2747	1.3941	1.5049	1.6408	1.7371
5	0.4382	0.6978	0.8525	0.9866	1.1425	1.2488	1.3475	1.4687	1.5546
6	0.4048	0.6403	0.7808	0.9026	1.0443	1.1411	1.2309	1.3413	1.4196
7	0.3782	0.5951	0.7246	0.8369	0.9678	1.0571	1.1401	1.2422	1.3145
8	0.3563	0.5583	0.6790	0.7838	0.9059	0.9893	1.0668	1.1622	1.2298
9	0.3379	0.5276	0.6411	0.7396	0.8545	0.9330	1.0061	1.0959	1.1596
10	0.3221	0.5016	0.6089	0.7022	0.8110	0.8854	0.9546	1.0397	1.1002
11	0.3084	0.4790	0.5811	0.6699	0.7735	0.8444	0.9103	0.9914	1.0490
12	0.2964	0.4593	0.5569	0.6417	0.7408	0.8086	0.8717	0.9493	1.0044
13	0.2856	0.4418	0.5354	0.6168	0.7119	0.7770	0.8376	0.9121	0.9651
14	0.2760	0.4262	0.5162	0.5946	0.6861	0.7488	0.8072	0.8790	0.9300
15	0.2673	0.4121	0.4990	0.5746	0.6630	0.7235	0.7798	0.8492	0.8985
16	0.2594	0.3994	0.4834	0.5565	0.6420	0.7006	0.7551	0.8223	0.8700
17	0.2522	0.3878	0.4692	0.5400	0.6230	0.6797	0.7326	0.7977	0.8440
18	0.2455	0.3771	0.4561	0.5250	0.6055	0.6606	0.7120	0.7753	0.8202
19	0.2394	0.3673	0.4441	0.5111	0.5894	0.6431	0.6930	0.7546	0.7984
20	0.2337	0.3582	0.4330	0.4982	0.5745	0.6268	0.6755	0.7355	0.7782
21	0.2284	0.3498	0.4227	0.4863	0.5607	0.6117	0.6593	0.7178	0.7594
22	0.2235	0.3419	0.4131	0.4752	0.5479	0.5977	0.6441	0.7013	0.7420
23	0.2188	0.3345	0.4041	0.4648	0.5359	0.5846	0.6300	0.6859	0.7257
24	0.2145	0.3276	0.3957	0.4551	0.5246	0.5723	0.6167	0.6715	0.7104
25	0.2104	0.3211	0.3878	0.4459	0.5141	0.5608	0.6043	0.6579	0.6960
26	0.2065	0.3150	0.3803	0.4373	0.5041	0.5499	0.5926	0.6451	0.6825
27	0.2028	0.3092	0.3733	0.4292	0.4947	0.5396	0.5815	0.6331	0.6698
28	0.1994	0.3038	0.3666	0.4215	0.4858	0.5299	0.5710	0.6217	0.6577
29	0.1961	0.2986	0.3603	0.4142	0.4774	0.5207	0.5611	0.6109	0.6463
30	0.1929	0.2936	0.3543	0.4073	0.4694	0.5120	0.5517	0.6006	0.6354

Table 2-1 One-sided tolerance factors for limits on sample mean values

One-sided tolerance factors for limits on sample minimum values									
n	α								
	0.25	**0.1**	**0.05**	**0.025**	**0.01**	**0.005**	**0.0025**	**0.001**	**0.0005**
2	1.2887	1.8167	2.1385	2.4208	2.7526	2.9805	3.1930	3.4549	3.6412
3	1.5407	2.0249	2.3239	2.5888	2.9027	3.1198	3.3232	3.5751	3.7550
4	1.6972	2.1561	2.4420	2.6965	2.9997	3.2103	3.4082	3.6541	3.8301
5	1.8106	2.2520	2.5286	2.7758	3.0715	3.2775	3.4716	3.7132	3.8864
6	1.8990	2.3272	2.5967	2.8384	3.1283	3.3309	3.5220	3.7603	3.9314
7	1.9711	2.3887	2.6527	2.8900	3.1753	3.3751	3.5638	3.7995	3.9690
8	2.0317	2.4407	2.7000	2.9337	3.2153	3.4127	3.5995	3.8331	4.0011
9	2.0838	2.4856	2.7411	2.9717	3.2500	3.4455	3.6307	3.8623	4.0292
10	2.1295	2.5250	2.7772	3.0052	3.2807	3.4745	3.6582	3.8883	4.0541
11	2.1701	2.5602	2.8094	3.0351	3.3082	3.5005	3.6830	3.9116	4.0765
12	2.2065	2.5918	2.8384	3.0621	3.3331	3.5241	3.7054	3.9328	4.0969
13	2.2395	2.6206	2.8649	3.0867	3.3558	3.5456	3.7259	3.9521	4.1155
14	2.2697	2.6469	2.8891	3.1093	3.3766	3.5653	3.7447	3.9699	4.1326
15	2.2975	2.6712	2.9115	3.1301	3.3959	3.5836	3.7622	3.9865	4.1485
16	2.3232	2.6937	2.9323	3.1495	3.4138	3.6007	3.7784	4.0019	4.1633
17	2.3471	2.7146	2.9516	3.1676	3.4306	3.6166	3.7936	4.0163	4.1772
18	2.3694	2.7342	2.9698	3.1846	3.4463	3.6315	3.8079	4.0298	4.1902
19	2.3904	2.7527	2.9868	3.2005	3.4611	3.6456	3.8214	4.0425	4.2025
20	2.4101	2.7700	3.0029	3.2156	3.4751	3.6589	3.8341	4.0546	4.2142
21	2.4287	2.7864	3.0181	3.2298	3.4883	3.6715	3.8461	4.0660	4.2252
22	2.4463	2.8020	3.0325	3.2434	3.5009	3.6835	3.8576	4.0769	4.2357
23	2.4631	2.8168	3.0463	3.2562	3.5128	3.6949	3.8685	4.0873	4.2457
24	2.4790	2.8309	3.0593	3.2685	3.5243	3.7058	3.8790	4.0972	4.2553
25	2.4941	2.8443	3.0718	3.2802	3.5352	3.7162	3.8889	4.1066	4.2644
26	2.5086	2.8572	3.0838	3.2915	3.5456	3.7262	3.8985	4.1157	4.2732
27	2.5225	2.8695	3.0953	3.3023	3.5557	3.7357	3.9077	4.1245	4.2816
28	2.5358	2.8813	3.1063	3.3126	3.5653	3.7449	3.9165	4.1328	4.2897
29	2.5486	2.8927	3.1168	3.3225	3.5746	3.7538	3.9250	4.1409	4.2975
30	2.5609	2.9036	3.1270	3.3321	3.5835	3.7623	3.9332	4.1487	4.3050

Table 2-2 One-sided tolerance factors for limits on sample minimum values

2.2.5 Modified Coefficient of Variation

A common problem with new material qualifications is that the initial specimens produced and tested do not contain all of the variability that will be encountered when the material is being produced in larger amounts over a lengthy period of time. This can result in setting basis values that are unrealistically high.

The modified Coefficient of Variation (CV) used in this report is in accordance with section 8.4.4 of CMH-17-1G. It is a method of adjusting the original basis values downward in anticipation of the expected additional variation. Composite materials are expected to have a CV of at least 6%. When the CV is less than 8%, a modification is made that adjusts the CV upwards.

$$\textbf{Modified CV} = CV^* = \begin{cases} .06 & \text{if } CV < .04 \\ \dfrac{CV}{2} + .04 & \text{if } .04 \le CV < .08 \\ CV & \text{if } CV \ge .08 \end{cases} \qquad \textbf{Equation 1}$$

This is converted to percent by multiplying by 100%.

CV^* is used to compute a modified standard deviation S^*.

$$S^* = CV^* \cdot \overline{X} \qquad \textbf{Equation 2}$$

To compute the pooled standard deviation based on the modified CV:

$$S_p^* = \sqrt{\frac{\sum_{i=1}^{k}\left((n_i - 1)\left(CV_i^* \cdot \overline{X}_i\right)^2\right)}{\sum_{i=1}^{k}(n_i - 1)}} \qquad \textbf{Equation 3}$$

The A-basis and B-basis values under the assumption of the modified CV method are computed by replacing S with S^*.

When the basis values have been set using the modified CV method, we can use the modified CV to compute the equivalency test results.

3. Equivalency Test Results

There were a total of 39 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were an additional two tests performed with insufficient data. A comparison of the average cured ply thickness and DMA results was also made. All tests were performed with an α level of 5%.

The results of the equivalency comparisons are listed as 'Pass', 'Fail', or 'Pass with Mod CV'. 'Pass with Mod CV' refers to cases where the equivalency fails unless the modified coefficient of variation method is used. A minimum of eight samples from two separate panels and processing cycles is required for strength properties and a minimum of four specimens for modulus comparison. If the sample does not have an adequate number of specimens, this will be indicated with 'Insufficient Data' after the Pass or Fail indication. A summary of all results is shown in Table 3-1.

Failures in Table 3-1 are reported as "Failed by _._%". This percentage was computed by taking the ratio of the equivalency mean or minimum value to the modified CV limit for that value. Table 3-2 gives a rough scale for the relative severity of those failures.

<table>
<tr><th colspan="6">Equivalency Test Results for FAA Laminate Repair Study compared with Solvay (Formerly Cytec) 5320-1 T650 3k-PW fabric with 36% RC</th></tr>
<tr><th rowspan="2">Test</th><th rowspan="2">Normalized Data</th><th rowspan="2">Property</th><th colspan="3">Enviromental Condition</th></tr>
<tr><th>CTD</th><th>RTD</th><th>ETW2</th></tr>
<tr><td rowspan="2">Warp Compression</td><td rowspan="2">Yes</td><td>Strength</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Modulus</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td rowspan="2">Warp Tension</td><td rowspan="2">Yes</td><td>Strength</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Modulus</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td rowspan="2">Fill Compression</td><td rowspan="2">Yes</td><td>Strength</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Modulus</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td rowspan="2">Fill Tension</td><td rowspan="2">Yes</td><td>Strength</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Modulus</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td rowspan="3">In-Plane Shear</td><td rowspan="3">No</td><td>0.2% Offset Strength</td><td>Pass</td><td>Pass</td><td>Failed by 2.23%</td></tr>
<tr><td>5% Strain Strength</td><td>Pass with Mod CV Insufficient Data</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Modulus</td><td>Pass</td><td>Pass</td><td>Failed by 1.08%</td></tr>
<tr><td>Short Beam Strength</td><td>No</td><td>Strength</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td>Open Hole Compression 1</td><td>Yes</td><td>Strength</td><td></td><td>Pass</td><td>Pass</td></tr>
<tr><td>Open Hole Tension 1</td><td>Yes</td><td>Strength</td><td></td><td>Pass</td><td>Pass</td></tr>
<tr><td>Compression After Impact 1</td><td>Yes</td><td>Strength</td><td></td><td>Pass Insufficient Data</td><td></td></tr>
<tr><td>Cured Ply Thickness</td><td>NA</td><td>NA</td><td colspan="3">Pass</td></tr>
<tr><td rowspan="4">Dynamic Mechanical Analysis</td><td colspan="2">Onset Storage Modulus - Dry</td><td colspan="3">Failed by 0.06%</td></tr>
<tr><td colspan="2">Peak of Tangent Delta - Dry</td><td colspan="3">Pass with ±18°F RESULTS</td></tr>
<tr><td colspan="2">Onset Storage Modulus - Wet</td><td colspan="3">Pass with ±18°F RESULTS</td></tr>
<tr><td colspan="2">Peak of Tangent Delta - Wet</td><td colspan="3">Pass with ±18°F RESULTS</td></tr>
</table>

Table 3-1 Summary of Equivalency Test Results

Description	Modulus	Strength
Mild Failure	% fail $\leq$ 4%	% fail $\leq$ 5%
Mild to Moderate Failure	4% < % fail $\leq$ 8%	5% < % fail $\leq$ 10%
Moderate Failure	8% < % fail $\leq$ 12%	10%< % fail $\leq$ 15%
Moderate to Severe Failure	12% < % fail $\leq$ 16%	15% < % fail $\leq$ 20%
Severe Failure	16% < % fail $\leq$ 20%	20% < % fail $\leq$ 25%
Extreme Failure	20% < % fail	25% < % fail

Table 3-2 "% Failed" Results Scale

Graphical presentations of all test results are shown in Figure 3-1 and Figure 3-2. In order to show different tests on the same graphical scale, all values are plotted as a percentage of the corresponding qualification mean. Figure 3-1 shows the strength means in the upper part of the chart using left axis and the strength minimums in the lower part of the chart using the right axis. This was done to avoid overlap of the two sets of data and equivalency criteria. Figure 3-2 shows the equivalency means plotted with the upper and lower equivalency criteria.

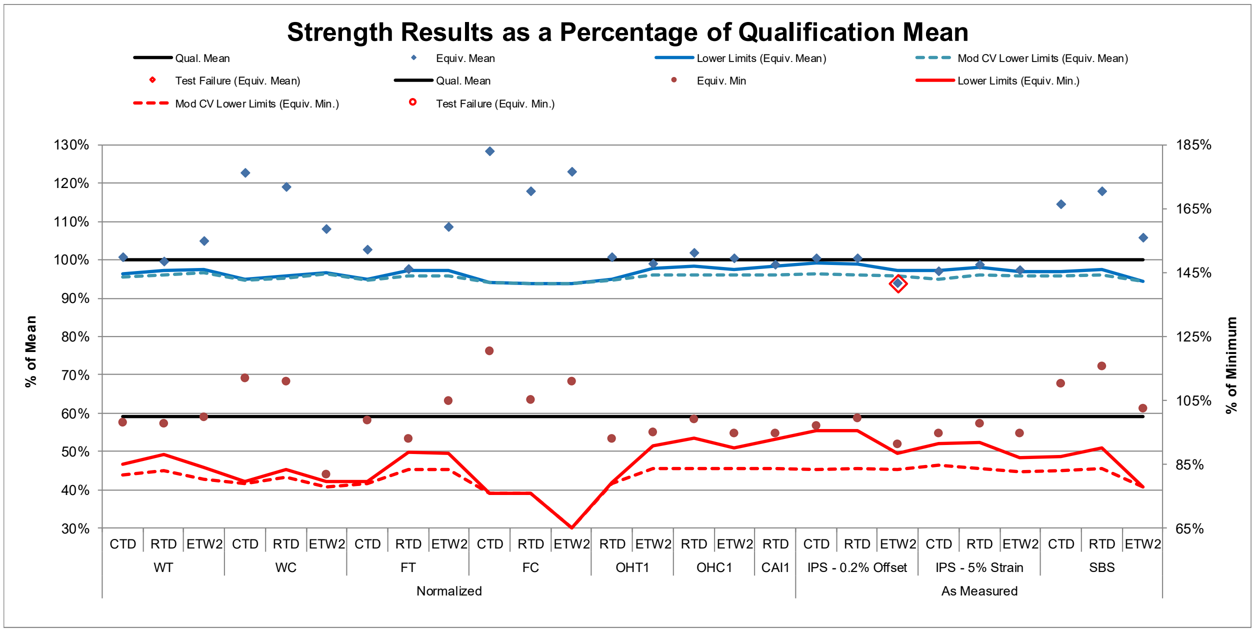

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

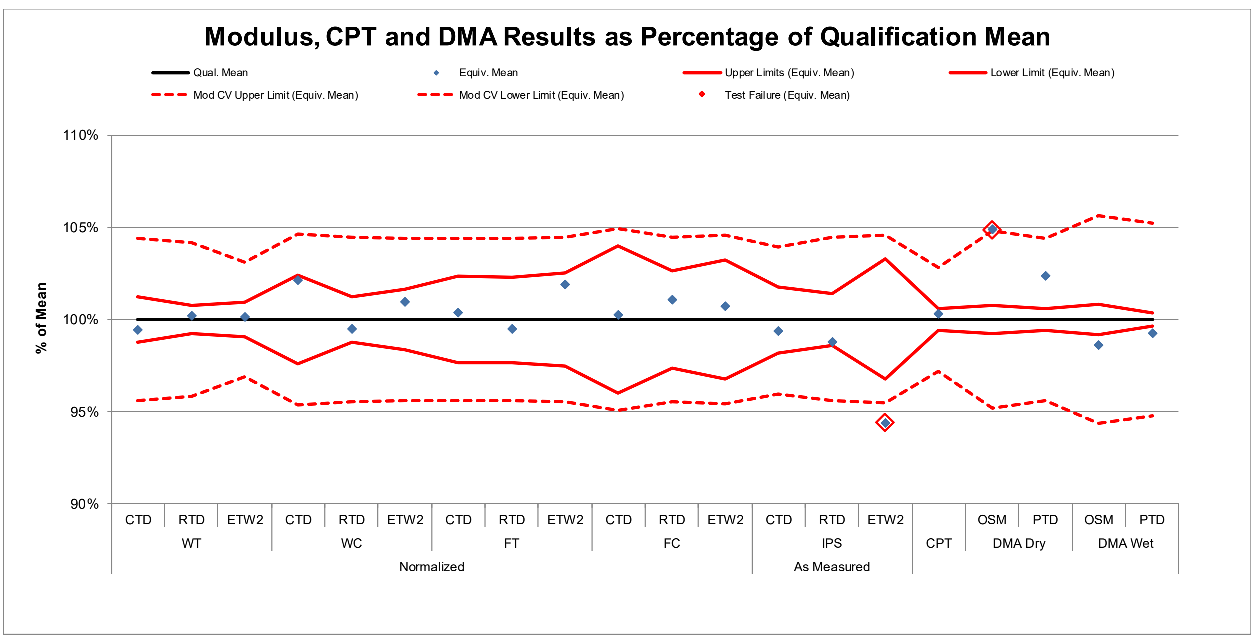

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Warp Compression (WC)

The WC data is normalized. Both the WC strength data and modulus data passed equivalency tests for all tested conditions. Statistics and analysis results are shown for the strength data in Table 3-3 and for the modulus data in Table 3-4.

Warp Compression (WC) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	107.485	131.625	102.675	122.163	71.411	77.107
Standard Deviation	8.031	5.028	6.262	3.855	4.953	6.368
Coefficient of Variation %	7.472	3.820	6.099	3.156	6.936	8.258
Minimum	93.342	120.146	91.296	113.701	62.710	58.374
Maximum	125.370	136.498	118.856	125.890	81.372	85.809
Number of Specimens	28	8	25	8	32	16
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	102.032		98.423		69.016	
Minimum Acceptable Equiv. Sample Min	85.801		85.768		56.886	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.736		7.049		7.468	
Minimum Acceptable Equiv. Sample Mean	101.839		97.760		68.833	
Minimum Acceptable Equiv. Sample Min	85.035		83.132		55.773	

Table 3-3 Warp Compression Strength Results

Warp Compression (WC) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Modulus (Msi)	8.815	8.999	9.030	8.981	8.840	8.922
Standard Deviation	0.237	0.281	0.120	0.158	0.189	0.086
Coefficient of Variation %	2.687	3.125	1.328	1.761	2.135	0.959
Minimum	8.437	8.667	8.759	8.856	8.371	8.830
Maximum	9.315	9.627	9.205	9.239	9.193	9.043
Number of Specimens	21	8	21	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	8.602 to 9.027		8.918 to 9.142		8.696 to 8.983	
Student's t-statistic	1.778		-0.907		1.174	
p-value of Student's t-statistic	0.087		0.372		0.251	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Passing Range for Modulus Mean	8.408 to 9.221		8.627 to 9.433		8.449 to 9.231	
Modified CV Student's t-statistic	0.928		-0.251		0.430	
p-value of Student's t-statistic	0.362		0.804		0.670	

Table 3-4 Warp Compression Modulus Results

Figure 3-3 illustrates the 0º Compression strength means and minimum values and modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

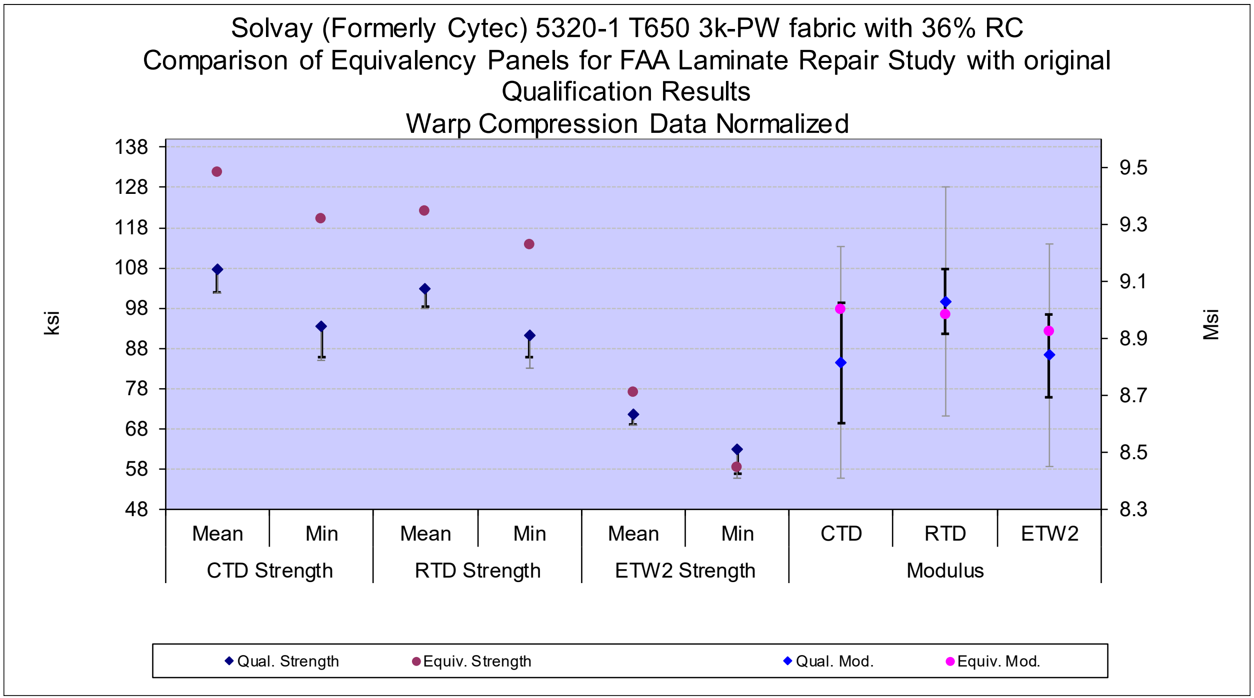

Figure 3-3 Warp Compression means, minimums and Equivalence limits

3.2 Warp Tension (WT)

The WT data is normalized. Both the WT strength data and modulus data passed equivalency tests for all tested conditions. Statistics and analysis results are shown for the strength data in Table 3-5 and for the modulus data in Table 3-6.

Warp Tension (WT) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	107.279	108.021	121.838	121.316	129.354	135.410
Standard Deviation	5.894	2.400	5.325	2.016	7.075	3.349
Coefficient of Variation %	5.494	2.222	4.371	1.662	5.469	2.473
Minimum	95.993	105.173	113.921	118.808	112.814	129.038
Maximum	121.054	111.779	131.605	124.669	137.556	140.538
Number of Specimens	21	8	22	9	22	16
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	103.277		118.424		125.934	
Minimum Acceptable Equiv. Sample Min	91.365		107.242		108.609	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.747		6.185		6.735	
Minimum Acceptable Equiv. Sample Mean	102.364		117.007		125.143	
Minimum Acceptable Equiv. Sample Min	87.736		101.181		103.809	

Table 3-5 Warp Tension Strength Results

Warp Tension (WT) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Modulus (Msi)	9.865	9.806	9.738	9.755	9.741	9.751
Standard Deviation	0.158	0.062	0.104	0.067	0.139	0.145
Coefficient of Variation %	1.606	0.637	1.065	0.688	1.432	1.483
Minimum	9.551	9.728	9.547	9.663	9.499	9.487
Maximum	10.063	9.908	9.966	9.902	9.987	9.971
Number of Specimens	21	8	22	9	24	16
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	9.746 to 9.985		9.661 to 9.815		9.648 to 9.833	
Student's t-statistic	-1.019		0.443		0.229	
p-value of Student's t-statistic	0.317		0.661		0.820	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Passing Range for Modulus Mean	9.430 to 10.300		9.335 to 10.141		9.438 to 10.044	
Modified CV Student's t-statistic	-0.279		0.085		0.070	
p-value of Student's t-statistic	0.782		0.933		0.945	

Table 3-6 Warp Tension Modulus Results

Figure 3-4 illustrates the 0º Tension strength means and minimum values and modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

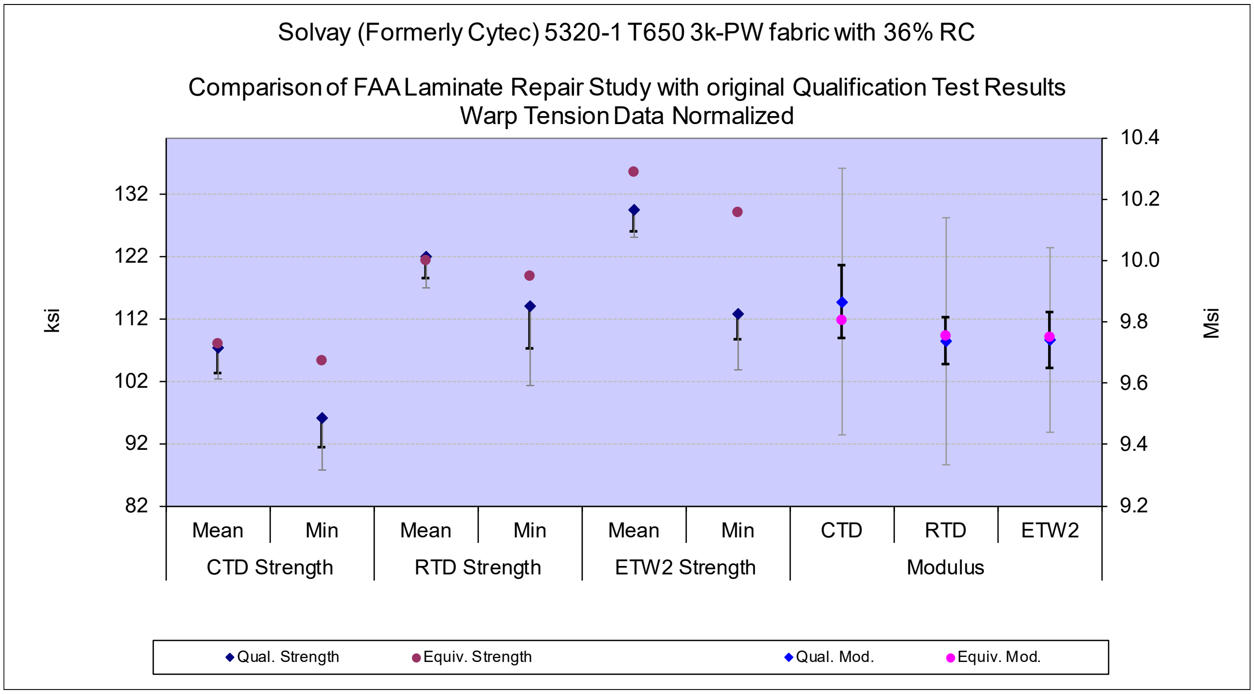

Figure 3-4 Warp Tension means, minimums and Equivalence limits

3.3 Fill Compression (FC)

The FC data is normalized. The normalized FC strength data and modulus data passed equivalency tests for all tested conditions. Modified CV results were not provided for the strength data because the coefficient of variation was above 8% for all three conditions, which meant that the modified CV results were no different from the results shown.

Statistics and analysis results are shown for the strength data in Table 3-7 and for the modulus data in Table 3-8.

Fill Compression (FC) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	100.115	128.457	98.149	115.460	62.660	77.026
Standard Deviation	8.862	3.646	8.788	6.765	7.559	4.793
Coefficient of Variation %	8.852	2.838	8.954	5.859	12.064	6.223
Minimum	83.271	120.568	81.915	103.014	51.634	69.438
Maximum	117.161	131.594	116.024	121.397	77.482	85.356
Number of Specimens	24	8	23	8	22	14
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	94.098		92.182		58.758	
Minimum Acceptable Equiv. Sample Min	76.187		74.422		40.820	

Table 3-7 Fill Compression Strength Results

Fill Compression (FC) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Modulus (Msi)	8.868	8.889	8.680	8.773	8.732	8.792
Standard Deviation	0.476	0.140	0.306	0.129	0.383	0.094
Coefficient of Variation %	5.369	1.579	3.521	1.474	4.381	1.071
Minimum	8.083	8.740	8.203	8.665	7.938	8.659
Maximum	9.734	9.115	9.162	9.057	9.244	8.909
Number of Specimens	21	8	21	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	8.514 to 9.223		8.449 to 8.911		8.448 to 9.016	
Student's t-statistic	0.121		0.819		0.431	
p-value of Student's t-statistic	0.905		0.420		0.670	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.684		6.000		6.190	
Passing Range for Modulus Mean	8.429 to 9.307		8.294 to 9.067		8.333 to 9.131	
Modified CV Student's t-statistic	0.098		0.490		0.306	
p-value of Student's t-statistic	0.923		0.628		0.762	

Table 3-8 Fill Compression Modulus Results

Figure 3-5 illustrates the 90° Compression strength means and minimum values and modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

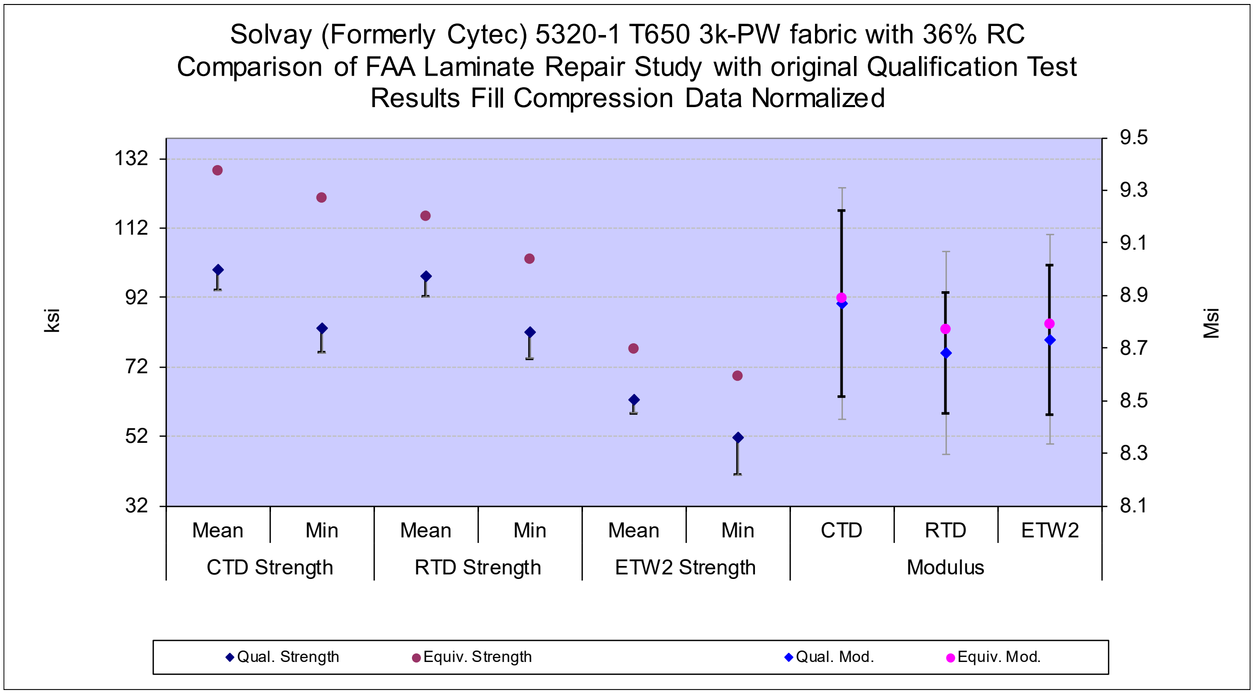

Figure 3-5 Fill Compression means, minimums and Equivalence limits

3.4 Fill Tension (FT)

The FT data is normalized. The normalized FT strength data and modulus data passed equivalency tests for all tested conditions.

Statistics and analysis results are shown for the strength data in Table 3-9 and for the modulus data in Table 3-10.

Fill Tension (FT) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	101.592	104.228	118.678	115.574	119.526	129.582
Standard Deviation	7.647	2.860	4.979	3.786	5.163	4.533
Coefficient of Variation %	7.527	2.744	4.196	3.276	4.320	3.498
Minimum	83.956	100.111	110.990	110.066	108.939	125.112
Maximum	115.184	108.229	127.331	121.855	126.636	136.500
Number of Specimens	21	8	21	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	96.399		115.297		116.020	
Minimum Acceptable Equiv. Sample Min	80.944		105.234		105.586	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.764		6.098		6.160	
Minimum Acceptable Equiv. Sample Mean	96.236		113.764		114.527	
Minimum Acceptable Equiv. Sample Min	80.296		99.139		99.647	

Table 3-9 Fill Tension Strength Results

Fill Tension (FT) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Modulus (Msi)	9.770	9.805	9.678	9.627	9.519	9.700
Standard Deviation	0.311	0.068	0.304	0.057	0.315	0.164
Coefficient of Variation %	3.180	0.690	3.144	0.593	3.314	1.687
Minimum	9.288	9.656	9.187	9.562	9.070	9.527
Maximum	10.330	9.875	10.180	9.721	10.153	10.037
Number of Specimens	21	8	22	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	9.540 to 9.999		9.454 to 9.903		9.277 to 9.761	
Student's t-statistic	0.316		-0.474		1.534	
p-value of Student's t-statistic	0.754		0.639		0.137	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Passing Range for Modulus Mean	9.339 to 10.201		9.252 to 10.104		9.094 to 9.944	
Modified CV Student's t-statistic	0.169		-0.249		0.874	
p-value of Student's t-statistic	0.867		0.805		0.390	

Table 3-10 Fill Tension Modulus Results

Figure 3-6 illustrates the 90° Tension strength means and minimum values and modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

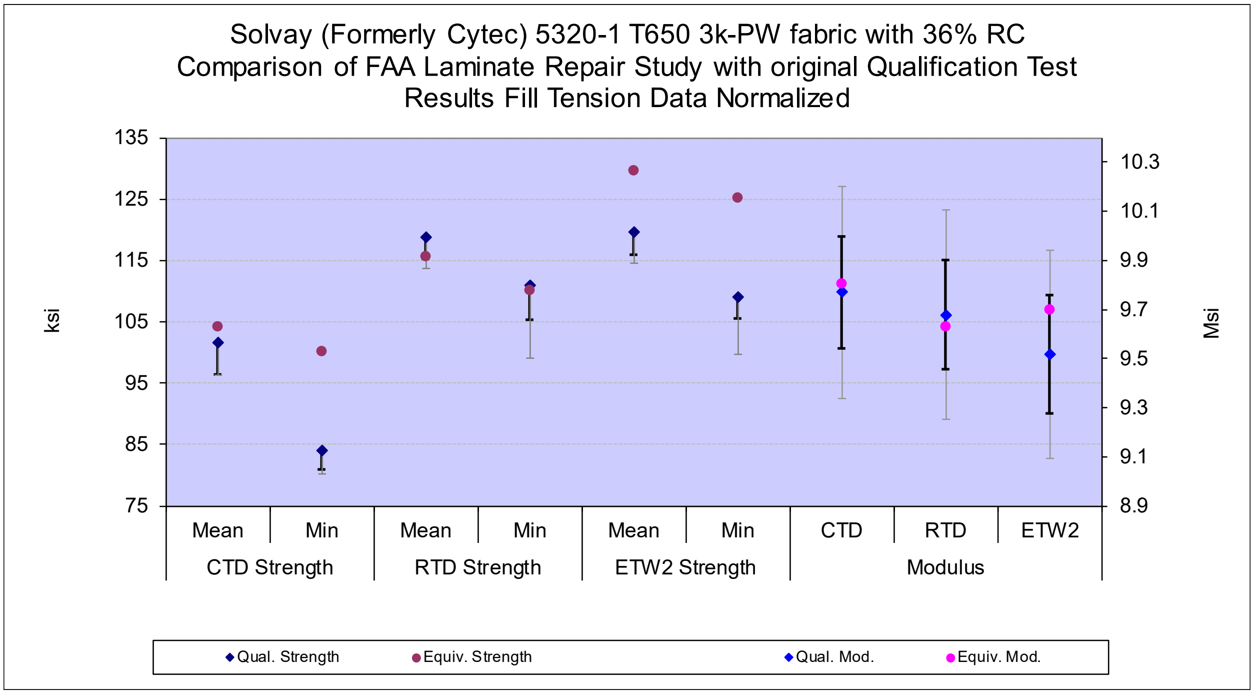

Figure 3-6 Fill Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The SBS data is not normalized. The SBS data passed equivalency tests for all tested conditions. Modified CV results were not provided for the ETW2 condition because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results for the SBS data are shown in Table 3-11.

Short Beam Strength (SBS)	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	12.538	14.356	11.035	12.983	6.580	6.945
Standard Deviation	0.582	0.434	0.407	0.223	0.533	0.210
Coefficient of Variation %	4.640	3.022	3.691	1.715	8.103	3.026
Minimum	11.703	13.810	9.931	12.760	5.804	6.739
Maximum	13.712	15.070	11.871	13.433	7.452	7.391
Number of Specimens	21	8	21	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	12.143		10.759		6.218	
Minimum Acceptable Equiv. Sample Min	10.967		9.935		5.140	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV%	6.320		6.000			
Minimum Acceptable Equiv. Sample Mean	12.000		10.586			
Minimum Acceptable Equiv. Sample Min	10.399		9.247			

Table 3-11 Lamina Short Beam Strength Results

Figure 3-7 illustrates the SBS means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

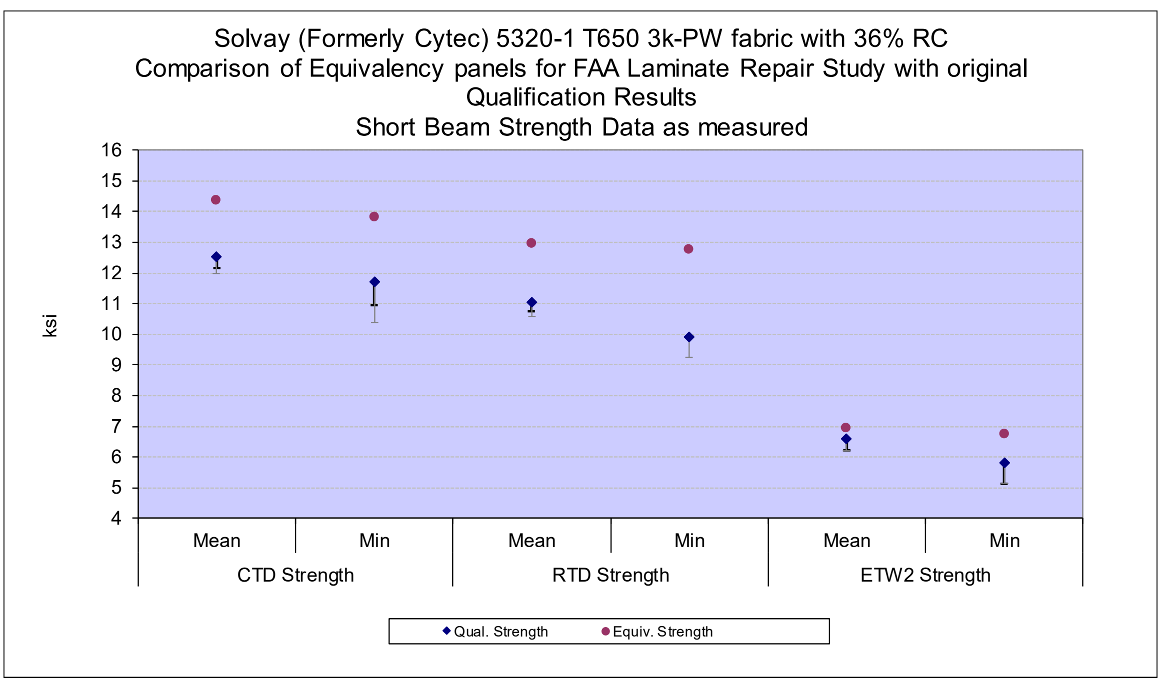

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The IPS data is not normalized. The IPS data passed all equivalency tests for the CTD and RTD conditions, although the strength at 5% strain data in the CTD condition required the use of the modified CV approach to pass equivalency. The IPS data in the ETW2 condition passed equivalency tests only for strength at 5% strain, not for 0.2% offset strength or modulus. The strength at 5% strain data in the CTD condition had insufficient data for the result to be considered conclusive.

Statistics and analysis results are shown for the 0.2% offset strength data in Table 3-12, the strength at 5% strain data in Table 3-13, and the modulus data in Table 3-14.

In-Plane Shear (IPS) 0.2% Offset Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength @ 0.2% offset (ksi)	11.504	11.536	8.299	8.322	3.760	3.523
Standard Deviation	0.179	0.196	0.134	0.052	0.159	0.066
Coefficient of Variation %	1.559	1.703	1.612	0.630	4.238	1.870
Minimum	11.011	11.169	8.095	8.230	3.545	3.434
Maximum	11.856	11.788	8.614	8.415	4.108	3.633
Number of Specimens	21	10	21	8	21	8
RESULTS	**PASS**		**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	11.395		8.209		3.652	
Minimum Acceptable Equiv. Sample Min	11.006		7.938		3.330	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	6.000		6.000		6.119	
Minimum Acceptable Equiv. Sample Mean	11.084		7.961		3.604	
Minimum Acceptable Equiv. Sample Min	9.587		6.955		3.139	

Table 3-12 In-Plane Shear 0.2% Offset Strength Results

In-Plane Shear (IPS) Strength at 5% Strain	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data					
Mean Strength @ 5% Strain (ksi)	18.882	18.308	14.650	14.455	6.915	6.712
Standard Deviation	0.639	0.391	0.451	0.121	0.328	0.146
Coefficient of Variation %	3.382	2.137	3.081	0.835	4.737	2.182
Minimum	17.916	17.843	14.071	14.289	6.427	6.549
Maximum	19.882	18.761	15.577	14.700	7.487	6.968
Number of Specimens	17	5	21	8	19	8
RESULTS	**FAIL**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	18.338		14.343		6.693	
Minimum Acceptable Equiv. Sample Min	17.268		13.431		6.031	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.369	
Minimum Acceptable Equiv. Sample Mean	17.917		14.053		6.616	
Minimum Acceptable Equiv. Sample Min	16.018		12.277		5.726	

Table 3-13 In-Plane Shear Strength at 5% Strain Results

In-Plane Shear (IPS) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Modulus (Msi)	0.852	0.847	0.735	0.726	0.386	0.365
Standard Deviation	0.020	0.015	0.012	0.012	0.017	0.006
Coefficient of Variation %	2.387	1.829	1.664	1.651	4.359	1.626
Minimum	0.820	0.827	0.711	0.717	0.358	0.357
Maximum	0.881	0.868	0.759	0.755	0.422	0.374
Number of Specimens	21	10	21	8	21	8
RESULTS	**PASS**		**PASS**		**FAIL**	
Passing Range for Modulus Mean	0.837 to 0.867		0.725 to 0.746		0.374 to 0.399	
Student's t-statistic	-0.777		-1.770		-3.528	
p-value of Student's t-statistic	0.443		0.088		0.002	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	6.000		6.000		6.179	
Passing Range for Modulus Mean	0.818 to 0.886		0.703 to 0.768		0.369 to 0.404	
Modified CV Student's t-statistic	-0.340		-0.560		-2.515	
p-value of Student's t-statistic	0.736		0.580		0.018	

Table 3-14 In-Plane Shear Modulus Results

The IPS 0.2% offset strength data for the ETW2 environment failed the equivalency test due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (3.523) is 96.48% of the minimum acceptable mean value (3.652). Under the assumption of the modified CV method, the equivalency sample mean is 97.77% of the minimum acceptable mean value (3.604).

The IPS strength at 5% strain data for the CTD environment failed the equivalency test due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (18.308) is 99.84% of the minimum acceptable mean value (18.338). Under the assumption of the modified CV method, the strength data from the CTD environment passed the equivalency test.

The IPS modulus data for the ETW2 environment failed the equivalency test because the sample mean value (0.365) is below the lower acceptance limit (0.374). The equivalency sample mean value is 97.57% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 98.92% of the minimum acceptable mean value (0.369).

Figure 3-8 illustrates the IPS strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

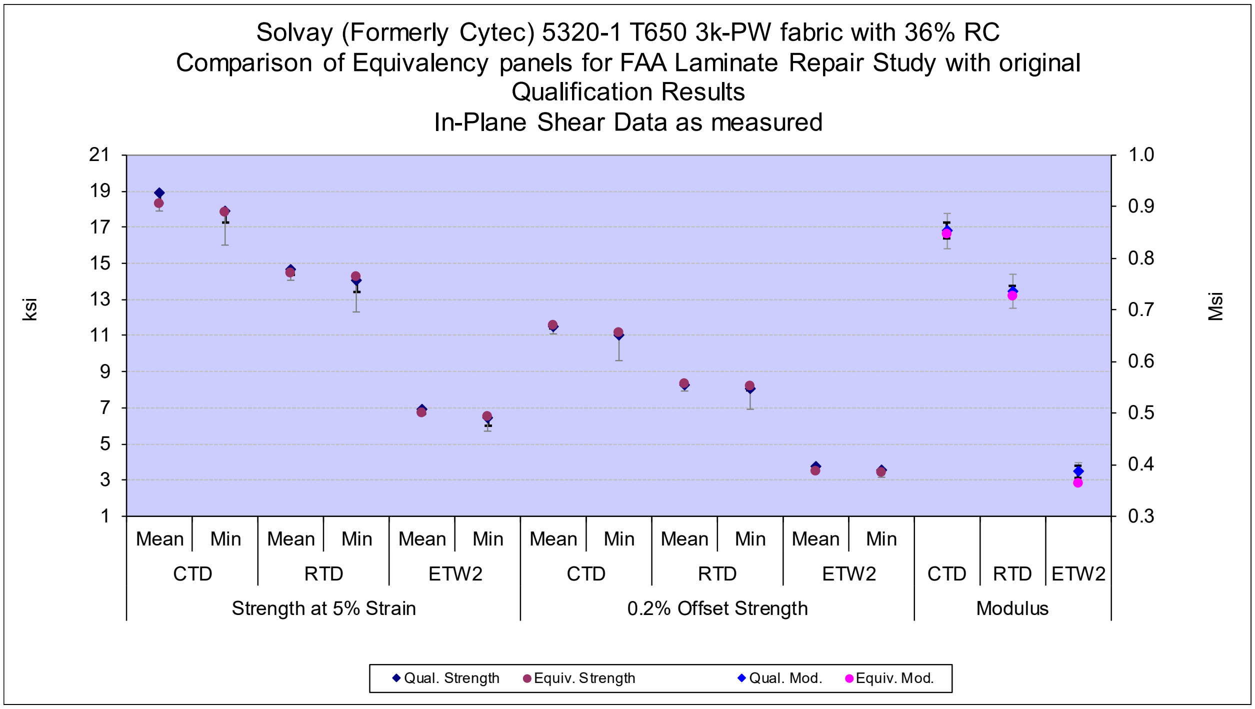

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

3.7 "25/50/25" Open Hole Tension 1 (OHT1)

The OHT1 data is normalized. The OHT1 strength data passed equivalency tests for all tested conditions. Statistics and analysis results for the OHT1 strength data are shown in Table 3-15.

Open Hole Tension 1 (OHT1) Strength	RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077				
Mean Strength (ksi)	43.645	43.951	48.634	48.089
Standard Deviation	3.342	1.943	1.669	1.408
Coefficient of Variation %	7.657	4.420	3.432	2.929
Minimum	37.877	40.550	46.035	46.157
Maximum	49.687	46.590	53.216	49.744
Number of Specimens	19	8	19	8
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	41.376		47.501	
Minimum Acceptable Equiv. Sample Min	34.622		44.128	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.829		6.000	
Minimum Acceptable Equiv. Sample Mean	41.325		46.653	
Minimum Acceptable Equiv. Sample Min	34.420		40.755	

Table 3-15 Open Hole Tension 1 Strength Results

Figure 3-9 illustrates the OHT1 strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

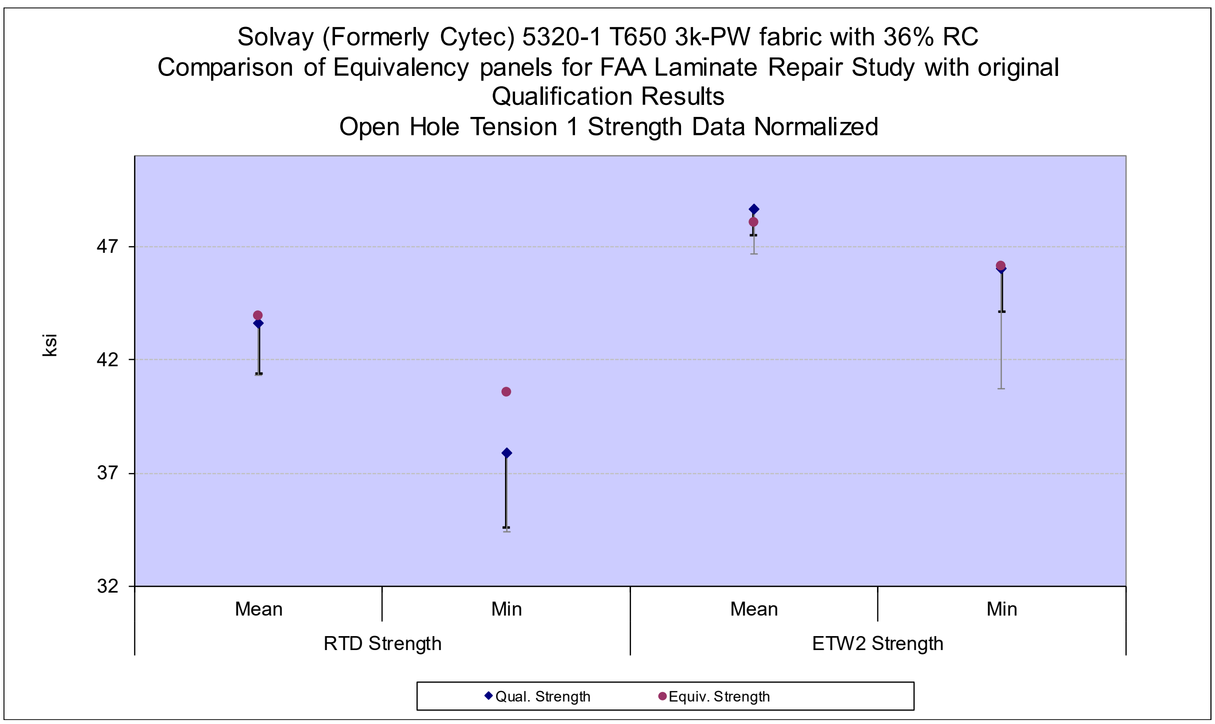

Figure 3-9 Open Hole Tension 1 means, minimums and Equivalence limits

3.8 "25/50/25" Open Hole Compression 1 (OHC1)

The OHC1 data is normalized. The OHC1 strength data passed equivalency tests for all tested conditions. Statistics and analysis results for the OHC1 strength data are shown in Table 3-16.

Open Hole Compression 1 (OHC1) Strength	RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077				
Mean Strength (ksi)	48.077	48.841	34.342	34.424
Standard Deviation	1.204	0.839	1.269	1.311
Coefficient of Variation %	2.504	1.718	3.696	3.808
Minimum	46.044	47.549	31.311	32.504
Maximum	49.978	50.365	36.496	36.655
Number of Specimens	21	8	22	8
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	47.260		33.480	
Minimum Acceptable Equiv. Sample Min	44.827		30.915	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	46.118		32.943	
Minimum Acceptable Equiv. Sample Min	40.289		28.779	

Table 3-16 Open Hole Compression 1 Strength Results

Figure 3-10 illustrates the OHC1 strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

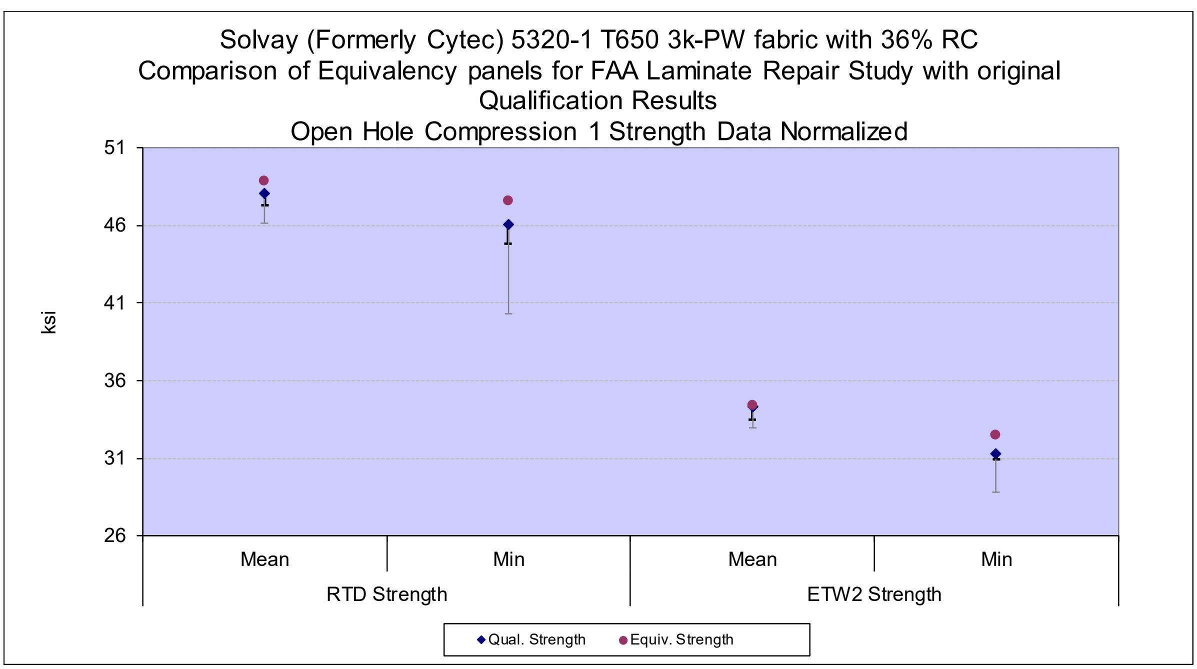

Figure 3-10 Open Hole Compression 1 means, minimums and Equivalence limits

3.9 "25/50/25" Compression After Impact 1 (CAI1)

The CAI1 data is normalized. The CAI1 strength data passed equivalency tests for the RTD condition but has insufficient data for the results to be considered conclusive. Statistics and analysis results for the CAI1 strength data are shown in Table 3-17.

Compression After Impact 1 (CAI1) Strength	RTD	
	Qual.	**Equiv.**
Data normalized with CPT	**Insufficient Data**	
Mean Strength (ksi)	33.442	32.943
Standard Deviation	0.898	0.721
Coefficient of Variation %	2.684	2.188
Minimum	32.800	31.583
Maximum	35.405	34.104
Number of Specimens	7	8
RESULTS	**PASS**	
Minimum Acceptable Equiv. Sample Mean	32.833	
Minimum Acceptable Equiv. Sample Min	31.019	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV %	6.000	
Minimum Acceptable Equiv. Sample Mean	32.080	
Minimum Acceptable Equiv. Sample Min	28.025	

Table 3-17 Compression After Impact 1 Strength Results

Figure 3-11 illustrates the CAI1 strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

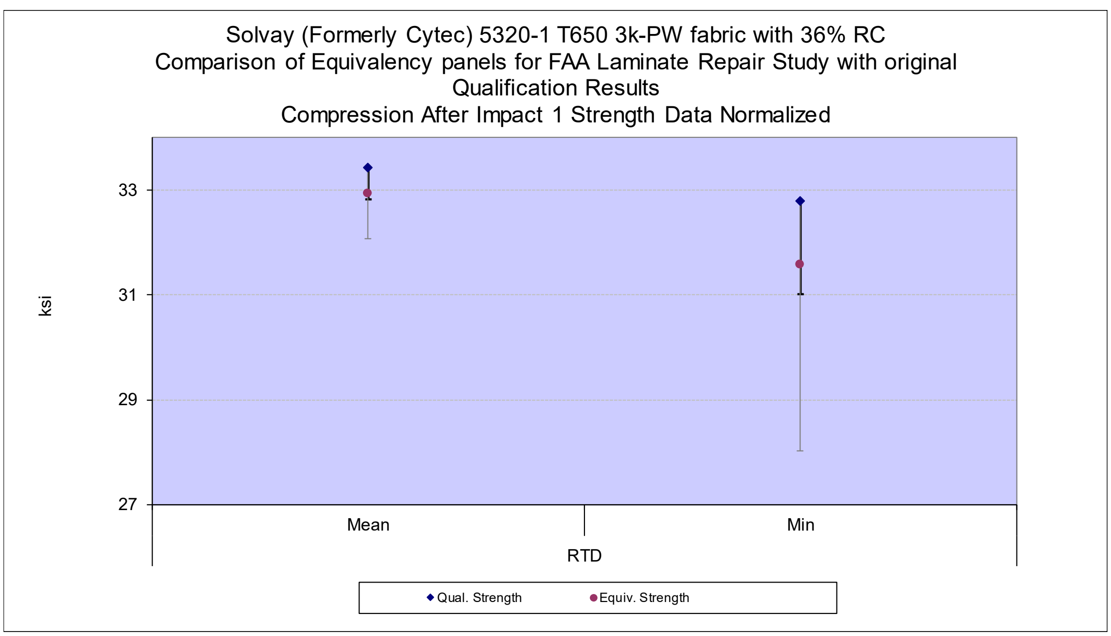

Figure 3-11 Compression After Impact 1 means, minimums and Equivalence limits

3.10 Cured Ply Thickness (CPT)

The Cured Ply Thickness can be considered equivalent according to the results of a pooled two-sample double-sided t-test at a 95% confidence level. Statistics for both the original qualification material and the FAA Laminate Repair Study equivalency sample are shown in Table 3-18.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness (inch)	0.007687	0.007712
Standard Deviation	0.00009	0.00009
Coefficient of Variation %	1.18507	1.12481
Minimum	0.00739	0.00756
Maximum	0.00792	0.00784
Number of Specimens	167	18
RESULTS	**PASS**	
Passing Range for CPT Mean	0.007643 to 0.007732	
Student's t-statistic	1.097	
p-value of Student's t-statistic	0.274	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.007472 to 0.007903	
Modified CV Student's t-statistic	0.226	
p-value of Student's t-statistic	0.821	

Table 3-18 Cured Ply Thickness Results

Figure 3-12 illustrates the average CPT for both the qualification sample and the equivalency sample with 95% standard error bars. The limits for equivalency samples are shown are error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

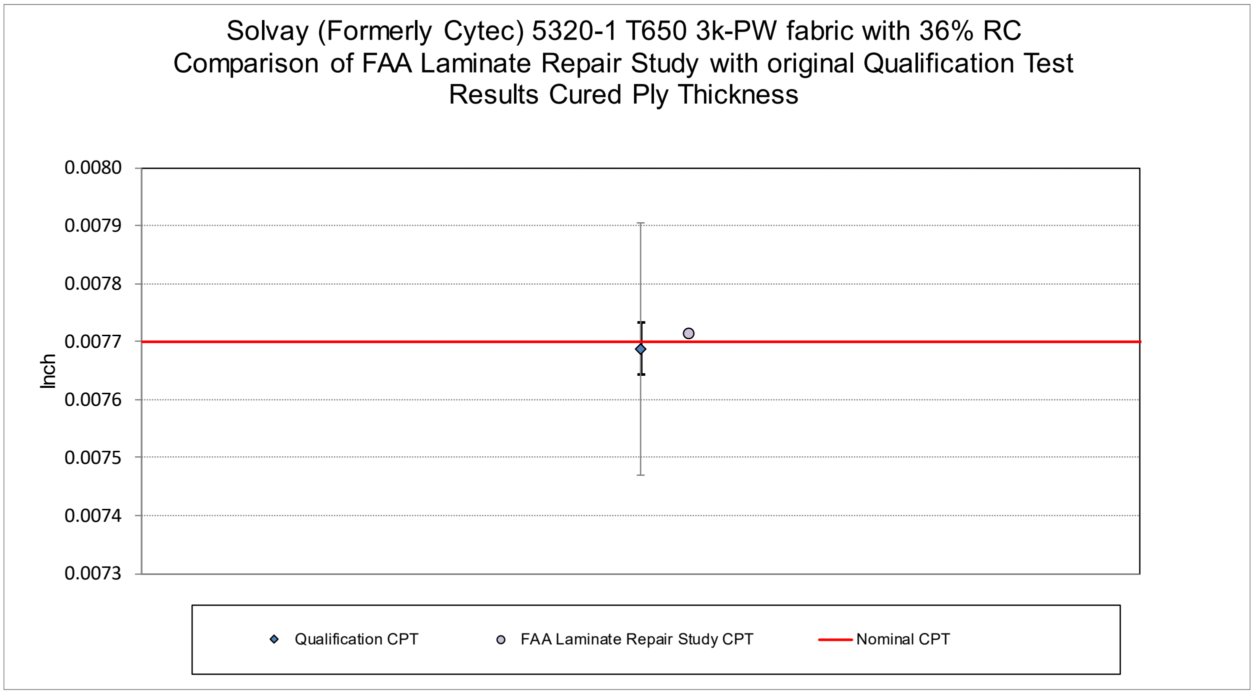

Figure 3-12 CPT means, 95% standard error bars and nominal value

3.11 Dynamic Mechanical Analysis (DMA)

DMA is compared for two measurements, the onset of storage modulus and the peak of tangent delta for both dry and wet conditions. These are tested for equivalency using a pooled two-sample double-sided t-test at a 95% confidence level. The modified CV method is not applied to DMA, but an additional analysis is also made with the allowable range for DMA being set to ±18°F. This equivalency criterion for evaluating glass transition temperature is not a statistically-based criterion but is generally more stringent than that based on α=5% with modified coefficient of variation but less stringent that that based on α=5% with as-measured coefficient of variation. This criterion is added to the test on Tg to aid the decision making process because the statistically-based methods are often too stringent (when as-measured coefficient of variation is used) or too lax (when modified coefficient of variation is used).

The DMA dry data sets were slightly above the upper acceptance limits while the DMA wet data sets were slightly below the lower acceptance limits. However, the DMA data passed equivalency tests for both the dry Peak of Tangent Delta and the wet conditions for both Onset Storage Modulus and Peak of Tangent Delta with the use of the ±18°F criteria. Statistics for both the original qualification material and the equivalency sample are shown in Table 3-19.

Dynamic Mechanical Analysis (DMA)	Onset Storage Modulus - Dry		Peak of Tangent Delta - Dry		Onset Storage Modulus - Wet		Peak of Tangent Delta - Wet	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Mean (°F)	374.801	393.026	411.645	421.413	318.622	314.206	344.135	341.500
Standard Deviation	5.348	4.910	3.847	5.350	3.124	7.643	1.677	3.658
Coefficient of Variation %	1.427	1.249	0.934	1.269	0.980	2.433	0.487	1.071
Minimum	363.146	383.306	402.062	412.538	312.962	294.152	341.168	333.302
Maximum	386.546	400.514	422.600	431.366	323.546	323.384	347.090	345.740
Number of Specimens	48	18	48	18	48	18	48	18
RESULTS	**FAIL**		**FAIL**		**FAIL**		**FAIL**	
Passing Range for DMA Mean	371.910 to 377.692		409.272 to 414.018		315.992 to 321.252		342.826 to 345.444	
Student's t-statistic	12.595		8.224		-3.355		-4.022	
p-value of Student's t-statistic	5.53E-19		1.30E-11		0.001		0.0002	
Range = ±18°F RESULTS	**FAIL**		**PASS Range = ±18°F**		**PASS Range = ±18°F**		**PASS Range = ±18°F**	
Passing Range for DMA Mean	356.801 to 392.801		393.645 to 429.645		300.622 to 336.622		326.135 to 362.135	

Table 3-19 DMA Results

The Onset Storage Modulus for dry data failed the equivalency test because the sample mean value (393.026) is above the upper acceptance limit (377.692). The equivalency sample mean is 104.06% of the upper limit of acceptable values. With the allowable range is set to ±18°F, the equivalency sample mean is 100.06% of the minimum mean value (392.801).

The Peak of Tangent Delta for dry data failed the equivalency test because the sample mean value (421.413) is above the upper acceptance limit (414.018). The equivalency sample mean is 101.79% of the upper limit of acceptable values. With the allowable range set to ±18°F, the Peak of Tangent Delta for DMA dry data passed the equivalency test.

The Onset Storage Modulus for wet data failed the equivalency test because the sample mean value (314.206) is below the lower acceptance limit (315.992). The equivalency sample mean is 99.43% of the lower limit of acceptable values. With the allowable range set to ±18°F, the Onset Storage Modulus for DMA wet data passed the equivalency test.

The Peak of Tangent Delta for wet data failed the equivalency test because the sample mean value (341.500) is below the lower acceptance limit (342.826). The equivalency sample mean is 99.61% of the lower limit of acceptable values. With the allowable range set to ±18°F, the Peak of Tangent Delta for DMA wet data passed the equivalency test.

Figure 3-13 illustrates the average Tg values determined from DMA for both the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the range equal to ±18°F computations.

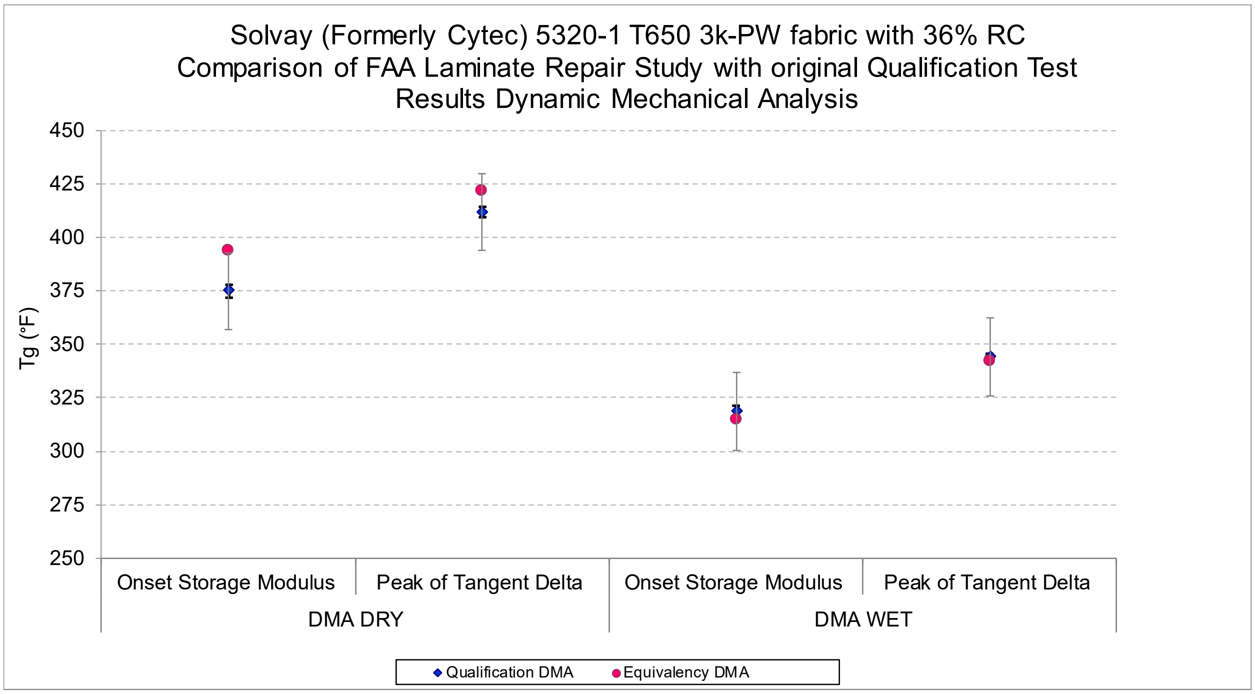

Figure 3-13 DMA Means and Equivalence limits

4. Summary of Results

All the equivalency comparisons are conducted with Type I error probability (α) of 5% in accordance with FAA/DOT/AR-03/19 report and CMH-17-1G section 8.4.1. It is common to obtain a few or even several failures in a typical equivalency program involving multiple independent property comparisons. In theory, if the equivalency dataset is truly identical to the qualification dataset, we expect to obtain approximately 5% failures. Since the equivalency test panels were fabricated by a different company, the test panel quality is expected to differ at least marginally; so, we expect to obtain slightly higher failure rates than 5% because the equivalency dataset may not be truly identical to the qualification dataset. However, a failure rate that is significantly higher than 5% is an indication that equivalency should not be assumed and some retesting is justified.

In addition to the frequency of failures, the severity of the failures (i.e. how far away from the pass/fail threshold) and any pattern of failures should be taken into account when making a determination of overall equivalency. Severity of failure can be determined using the graphs accompanying the individual test results. Whether or not a pattern of failures exists is a subjective evaluation to be made by the original equipment manufacturer or certifying agency. The question of how close is close enough is often difficult to answer, and may depend on specific application and purpose of equivalency. NCAMP does not make a judgment regarding the overall equivalence; the following information is provided to aid the original equipment manufacturer or certifying agency in making that judgment.

4.1 The assumption of Independence

The following computations are based on the assumption that the tests are independent. The DMA and CPT tests are not included in this part of the analysis because the results of multiple other tests may be dependent or correlated with those tests.

While the tests are all conducted independently, measurements for strength and modulus are made from a single specimen. For the In-Plane Shear tests, both the 0.2% offset strength and the strength at 5% strain as well as the modulus measurements are made on a single specimen. While modulus measurements are generally considered to be independent of the strength measurements, the IPS strength measurements are expected to be positively correlated.

However the computations can be considered conservative. If the tests are not independent and a failure in IPS 0.2% offset strength is correlated with a failure in IPS 5% strain strength, the probability of both failures occurring together should be higher than predicted with the assumption of independence, thus leading to a conservative overall judgment about the material.

4.2 Failures

The FAA Laminate Repair Study material has sufficient test results for comparison with the original qualification material test results on a total of 39 different test types and conditions, not including the cured ply thickness or the DMA comparison.

Using the modified CV method, there were two failures. Both failures were for IPS properties (0.2% offset strength and modulus) in the ETW2 condition.

1. In-Plane Shear Modulus for the ETW2 condition failed by 1.08%
2. In-Plane Shear 0.2% Offset Strength for the ETW2 condition failed by 2.23%

Those properties that did not pass equivalency tests should be evaluated regarding the needs of the application to determine if the test results for this equivalency sample will be sufficient for their design/build purposes.

4.3 Pass Rate

Two failures out of 39 tests and conditions gives the equivalency panels for the FAA Laminate Repair Study a pass rate of 94.87% for these tests. If the equivalency sample came from a material identical to the original qualification material and all tests were independent of all other tests, the expected pass rate would be 95%. This equates to 1.95 failures.

4.4 Probability of Failures

If the equivalency sample came from a material with characteristics identical to the original qualification material and all tests were independent of all other tests, the chance of having two or more failures is 58.71%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 39 independent tests. If the two materials were equivalent, the probability of getting five or more failures is less than 5%. This means that the material could be considered as "not equivalent" with a 95% level of confidence if there were five or more failures out of 39 independent tests.

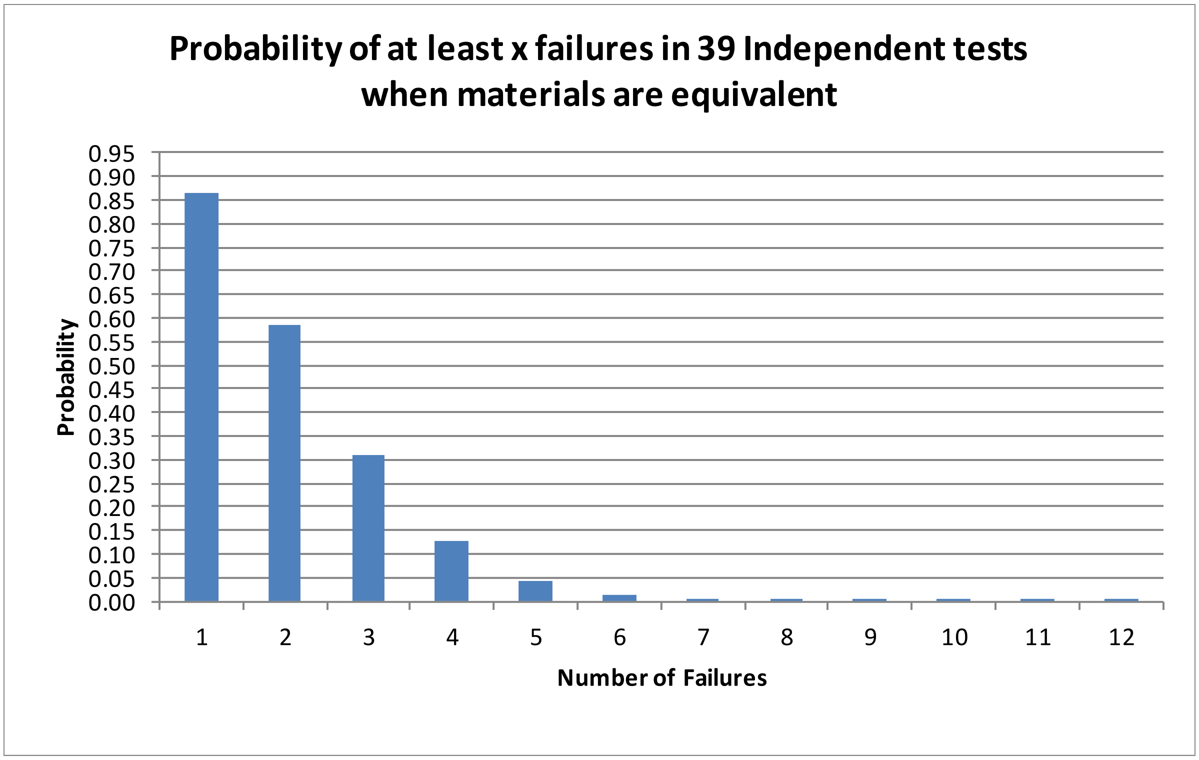

Figure 4-1 Probability of Number of Failures

5. References

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2. John Tomblin, Yeow C. Ng, and K. Suresh Raju, "*Material Qualification and Equivalency for polymer Matrix Composite Material Systems: Updated Procedure*", National Technical Information Service (NTIS), Springfield, Virginia 22161
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