Report No: NCP-RP-2010-010 Rev N/C
Report Date: June 22, 2018

Solvay (Formerly Advanced Composites Group) – MTM45-1 CF0526A-36% RW 3K Plain Weave G30-500 Fabric, 193 gsm Equivalency Statistical Analysis Report – LH Cure Cycle

FAA Special Project Number: SP3505WI-Q

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1. Introduction

This report contains the equivalency test results for Solvay (formerly Advanced Composites Group) MTM45-1 CF0526A-36%RW 3K Plain Weave G30-500 Fabric (also known as HTS40 E13 3k-70-PW), 193 gsm panels produced using the “LH” cure cycle compared to the original qualification panels of the same material which were produced using the “MH” cure cycle. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP3505WI-Q and also meet the requirements outlined in NCAMP Standard Operating Procedure NSP 100. The test panels, test specimens, and test setups have been conformed by the FAA and the testing has been witnessed by the FAA.

The material was procured to ACG Material Specification ACGM 1001–13 Revision A dated November 14, 2007. An equivalent NCAMP material specification NMS 451/13 Revision A dated September 26, 2012 has been created for this material which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19.

The Equivalency test panels were cured in accordance with ACG process specification ACGP 1001-02 Revision E using cure cycle “LH”. An equivalent NCAMP Process Specification, NPS 81451 with “LH” cure cycle, has been created. The ACG Test Plan AI/TR/1392 Revision E was used for this equivalency 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 NCAMP Test Report NCP-RP-2008-003 Rev D. The material property data for the equivalence panels is published in NCAMP Test Report CAM-RP-2010-003 Rev N/C. Engineering basis values were reported in NCAMP Report NCP-RP-2008-005 Rev A 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 451/13. NMS 451/13 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* 451/13. NMS 451/13 is a free, publicly available, non-proprietary aerospace industry material specification.

The use of NCAMP material and process specifications do 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.

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

Table 1-1 Test Property Abbreviations

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	−65º F	CTD
Room Temperature Dry	75º F	RTD
Elevated Temperature Dry	200º F	ETD
Elevated Temperature Wet	200º F	ETW
Elevated Temperature Wet	250º F	ETW2

Table 1-2 Environmental Conditions Abbreviations

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.

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

This is converted to percent by multiplying by 100%.

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

$$S^* = CV^* \cdot \bar{X} \qquad \text{Equation 2}$$

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

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

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 38 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were nine additional 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 3-2.

Failures in Table 3-2 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 3-1 gives a rough scale for the relative severity of those failures.

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

Table 3-1 "% Failed" Results Scale

Equivalency Test Results for Solvay (Formerly Advanced Composites Group) MTM45-1 CF0526A-36% RW 3K Plain Weave G30-500 Fabric, 193 gsm MH Cure Cycle (qualification) with LH Cure Cycle (equivalency)								
Test	**Normalized Data**	**Property**	**Environmental Condition**					
			CTD	**RTD**	**ETD**	**ETW**	**ETW2**	
Warp Compression	**Yes**	**Strength**		Failed by 3.7%		Failed by 20.3%	Failed by 23.9%	
		Modulus		Pass with Mod CV		Failed by 0.8%		
Warp Tension	**Yes**	**Strength**	Pass	Pass			Pass	
		Modulus	Pass	Failed by 0.8%				
Fill Compression	**Yes**	**Strength**		Pass	Pass	Pass	Pass	
		Modulus		Pass	Pass	Failed by 3.3%		
Fill Tension	**Yes**	**Strength**	Pass	Pass		Pass	Pass	
		Modulus	Pass	Pass		Pass with Mod CV		
In-Plane Shear	**No**	**0.2% Offset Strength**	Pass	Pass			Pass	
		5% Strain Strength	Pass Insufficient Data	Pass Insufficient Data			Pass Insufficient Data	
		Modulus	Failed by 3.8%	Failed by 5.3%			Failed by 17.6%	
Short Beam Strength	**No**	**Strength**	Failed by 1.0%	Pass			Pass	
Open Hole Compression	**Yes**	**Strength**		Pass with Mod CV		Pass Insufficient Data	Pass	
Open Hole Tension	**Yes**	**Strength**	Pass	Pass			Pass	
Interlaminar Tension	**No**	**Strength**		Pass Insufficient Data			Failed by 2.5% Insufficient Data	
Curved Beam Strength		**Strength**		Pass Insufficient Data			Failed by 9.7% Insufficient Data	
Compression After Impact	**Yes**	**Strength**		Failed by 6.5% Insufficient Data				
Cured Ply Thickness	**NA**	**NA**	Pass					
Dynamic Mechanical Analysis	**Onset Storage Modulus - Dry**		Pass with ±18°F RESULTS					
	Peak of Tangent Delta - Dry		Pass with ±18°F RESULTS					
	Onset Storage Modulus - Wet		Pass					
	Peak of Tangent Delta - Wet		Pass					

Table 3-2 Summary of Equivalency Test Results

A graphical presentation of all test results is 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.

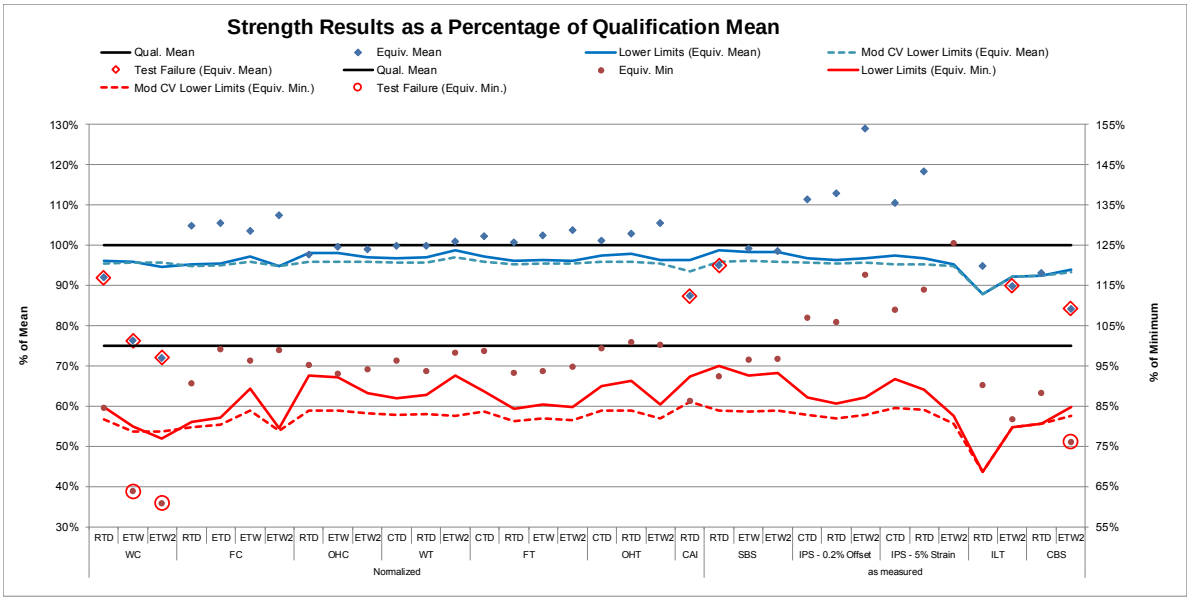

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

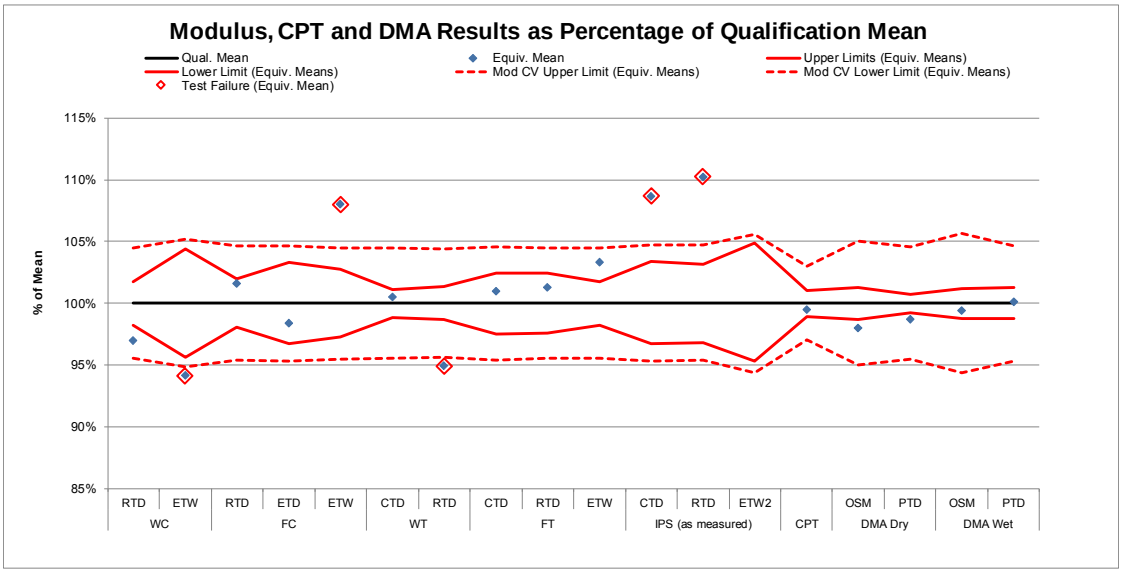

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Warp Compression (WC)

The WC data is normalized by cured ply thickness. The WC strength data failed for all three environmental conditions. Modified CV results were not provided for the ETW2 strength data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown.

The WC modulus data passed for the RTD condition with the use of the modified CV approach. The modulus data for the ETW conditions did not pass the equivalency test. ETW2 modulus data was not available for the MH cure cycle.

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	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Strength (ksi)	99.431	91.349	65.303	49.766	58.451	42.065
Standard Deviation	5.609	4.197	4.659	5.332	4.905	5.330
Coefficient of Variation %	5.641	4.594	7.135	10.714	8.392	12.671
Minimum	85.323	84.038	57.655	41.659	46.474	35.563
Maximum	108.069	96.922	75.378	56.324	64.558	50.878
Number of Specimens	21	8	26	11	18	9
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	95.622		62.596		55.306	
Minimum Acceptable Equiv. Sample Min	84.286		52.213		45.006	
MOD CV RESULTS	**FAIL**		**FAIL**			
Modified CV %	6.821		7.567		**NA**	
Minimum Acceptable Equiv. Sample Mean	94.826		62.431			
Minimum Acceptable Equiv. Sample Min	81.120		51.420			

Table 3-3 Warp Compression Strength Results

Warp Compression (WC) Modulus	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	8.321	8.069	8.329	7.839		8.548
Standard Deviation	0.183	0.140	0.356	0.746		0.538
Coefficient of Variation %	2.196	1.740	4.280	9.517	**NA**	6.299
Minimum	8.018	7.822	7.505	6.935		7.920
Maximum	8.671	8.237	9.220	9.668		9.364
Number of Specimens	21	8	26	11		9
RESULTS	**FAIL**		**FAIL**			
Passing Range for Modulus Mean	8.173 to 8.468		7.964 to 8.694			
Student's t-statistic	-3.509		-2.727			
p-value of Student's t-statistic	0.002		0.010			
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		**NA**	
Modified CV%	6.000		6.140			
Passing Range for Modulus Mean	7.949 to 8.692		7.899 to 8.758			
Modified CV Student's t-statistic	-1.392		-2.317			
p-value of Student's t-statistic	0.175		0.026			

Table 3-4 Warp Compression Modulus Results

The WC strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (91.349) is 95.53% of the minimum acceptable mean value (95.622) and the equivalency sample minimum (84.038) is 99.71% of the lowest acceptable minimum value (84.286). Under the assumption of the modified CV method, the equivalency sample mean is 96.33% of the minimum acceptable mean value (94.826) and the equivalency sample minimum value is acceptable.

The WC strength data for the ETW environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (49.766) is 79.71% of the minimum acceptable mean value (62.431) and the equivalency sample minimum (41.659) is 81.02% of the lowest acceptable minimum value (51.420).

The WC strength data for the ETW2 environment failed equivalence due to both the mean and minimum being too low. The modified CV method could not be used due to the CV of the ETW2 condition being greater than 8%. The equivalency sample mean (42.065) is 76.06% of the minimum acceptable mean value (55.306) and the equivalency sample minimum (35.563) is 79.02% of the lowest acceptable minimum value (45.006).

The WC modulus data for the RTD environment failed the equivalency test because the sample mean value (8.069) is below the lower acceptance limit (8.173). The equivalency sample mean value is 98.72% of the lower limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the RTD environment passed the equivalence test.

The WC modulus data for the ETW environment failed the equivalency test because the sample mean value (7.839) is below the lower acceptance limit (7.964). The equivalency sample mean value is 98.43% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 99.23% of the minimum acceptable mean value (7.899).

Figure 3-3 illustrates the 0º Compression 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.

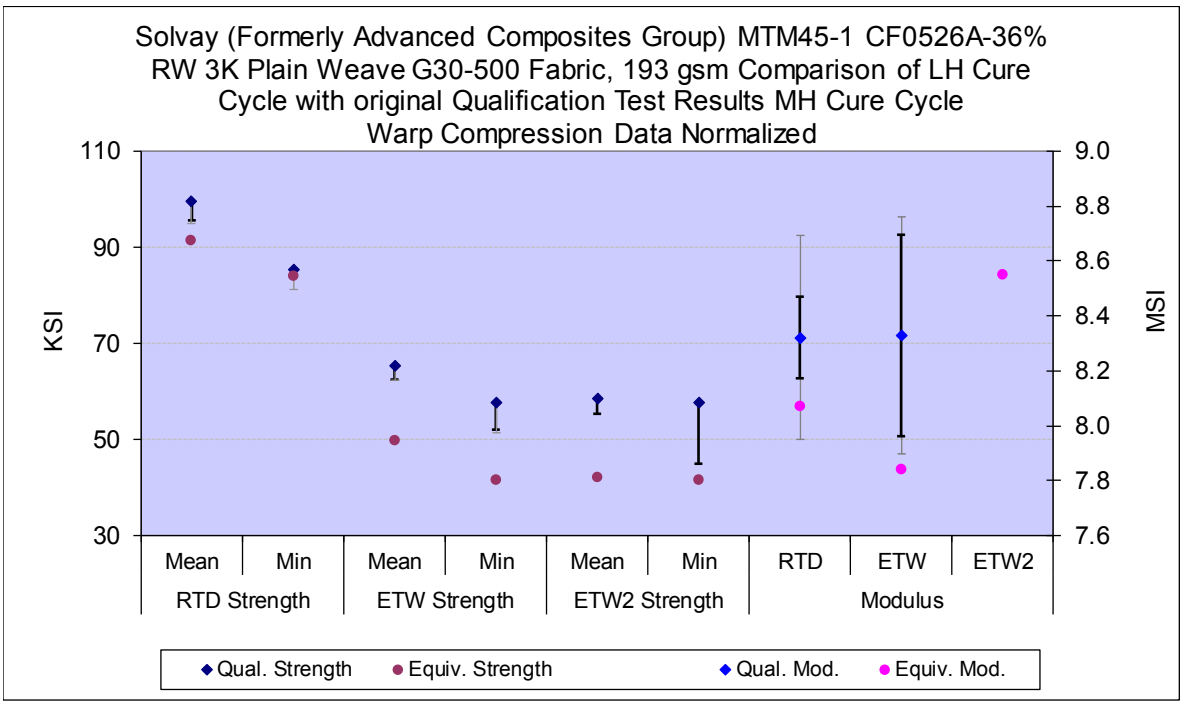

Figure 3-3 Warp Compression means, minimums and Equivalence limits

3.2 Warp Tension (WT)

The WT data is normalized by cured ply thickness. The WT strength data passed the equivalency tests for all the environmental conditions tested. The WT modulus data passed the equivalency test for the CTD condition but not for the RTD condition. ETW2 modulus data was not available for the MH cure cycle. 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 0.0079						
Mean Strength (ksi)	137.389	137.070	141.306	140.967	130.237	131.524
Standard Deviation	6.637	3.629	6.412	4.707	3.287	3.025
Coefficient of Variation %	4.831	2.647	4.538	3.339	2.524	2.300
Minimum	127.615	132.168	129.722	132.494	122.830	128.011
Maximum	147.996	142.355	150.835	149.164	137.018	140.520
Number of Specimens	19	8	28	8	21	15
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	132.882		136.952		128.597	
Minimum Acceptable Equiv. Sample Min	119.469		123.994		120.668	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.415		6.269		6.000	
Minimum Acceptable Equiv. Sample Mean	131.404		135.291		126.338	
Minimum Acceptable Equiv. Sample Min	113.591		117.389		107.486	

Table 3-5 Warp Tension Strength Results

Warp Tension (WT) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	9.367	9.409	9.241	8.770		10.120
Standard Deviation	0.113	0.141	0.162	0.084		1.357
Coefficient of Variation %	1.202	1.500	1.754	0.955	NA	13.405
Minimum	9.162	9.249	8.890	8.634		9.153
Maximum	9.582	9.646	9.534	8.864		14.291
Number of Specimens	19	8	28	8		15
RESULTS	**PASS**		**FAIL**			
Passing Range for Modulus Mean	9.262 to 9.472		9.120 to 9.363			
Student's t-statistic	0.827		-7.862			
p-value of Student's t-statistic	0.416		3.74E-09			
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		NA	
Modified CV%	6.000		6.000			
Passing Range for Modulus Mean	8.948 to 9.786		8.837 to 9.645			
Modified CV Student's t-statistic	0.208		-2.370			
p-value of Student's t-statistic	0.837		0.024			

Table 3-6 Warp Tension Modulus Results

The WT modulus data for the RTD environment failed the equivalency test because the sample mean value (8.770) is below the lower acceptance limit (9.120). The equivalency sample mean value is 96.17% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 99.24% of the minimum acceptable mean value (8.837).

Figure 3-4 illustrates the 0º Tension 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.

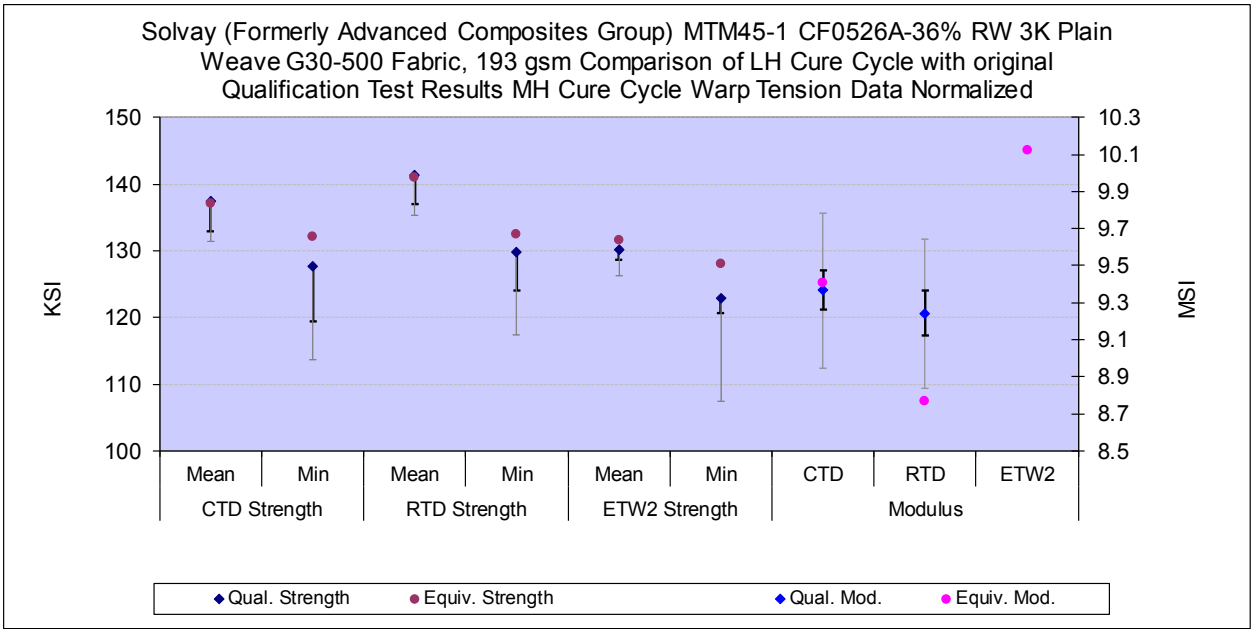

Figure 3-4 Warp Tension means, minimums and Equivalence limits

3.3 Fill Compression (FC)

The FC data is normalized by cured ply thickness. The FC strength data passed the equivalency tests for all four environmental conditions tested. The FC modulus data passed the equivalency tests for the RTD and ETD conditions, but not the ETW condition. ETW2 modulus data was not available for the MH cure cycle. 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	RTD		ETD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079								
Mean Strength (ksi)	88.677	92.933	75.424	79.548	58.307	60.410	51.854	55.759
Standard Deviation	6.210	6.985	4.981	4.057	2.323	2.899	3.938	2.689
Coefficient of Variation %	7.003	7.516	6.604	5.100	3.984	4.798	7.594	4.823
Minimum	80.354	80.342	65.296	74.720	53.132	56.103	44.472	51.271
Maximum	101.805	100.862	82.640	86.653	63.701	63.786	59.977	59.082
Number of Specimens	18	8	18	8	18	8	19	8
RESULTS	**PASS**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	84.460		72.042		56.730		49.180	
Minimum Acceptable Equiv. Sample Min	71.910		61.975		52.035		41.221	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	7.501		7.302		6.000		7.797	
Minimum Acceptable Equiv. Sample Mean	84.160		71.684		55.932		49.108	
Minimum Acceptable Equiv. Sample Min	70.716		60.554		48.861		40.937	

Table 3-7 Fill Compression Strength Results

Fill Compression (FC) Modulus	RTD		ETD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079								
Mean Modulus (Msi)	8.204	8.335	8.215	8.081	7.894	8.523		8.647
Standard Deviation	0.160	0.235	0.340	0.217	0.277	0.141		0.344
Coefficient of Variation %	1.944	2.824	4.142	2.686	3.512	1.660	NA	3.980
Minimum	7.933	8.026	7.659	7.778	7.455	8.250		8.284
Maximum	8.578	8.715	8.792	8.503	8.465	8.675		9.232
Number of Specimens	18	8	18	8	18	8		8
RESULTS	**PASS**		**PASS**		**FAIL**			
Passing Range for Modulus Mean	8.042 to 8.366		7.944 to 8.486		7.678 to 8.109			
Student's t-statistic	1.673		-1.020		6.032			
p-value of Student's t-statistic	0.107		0.318		0.000003			
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**		**NA**	
Modified CV%	6.000		6.071		6.000			
Passing Range for Modulus Mean	7.824 to 8.584		7.833 to 8.597		7.538 to 8.250			
Modified CV Student's t-statistic	0.714		-0.724		3.648			
p-value of Student's t-statistic	0.482		0.476		0.001			

Table 3-8 Fill Compression Modulus Results

The FC modulus data for the ETW environment failed the equivalency test because the sample mean value (8.523) is above the upper acceptance limit (8.109). The equivalency sample mean value is 105.10% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 103.31% of the maximum acceptable mean value (8.250).

Figure 3-5 illustrates the 90º Compression 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.

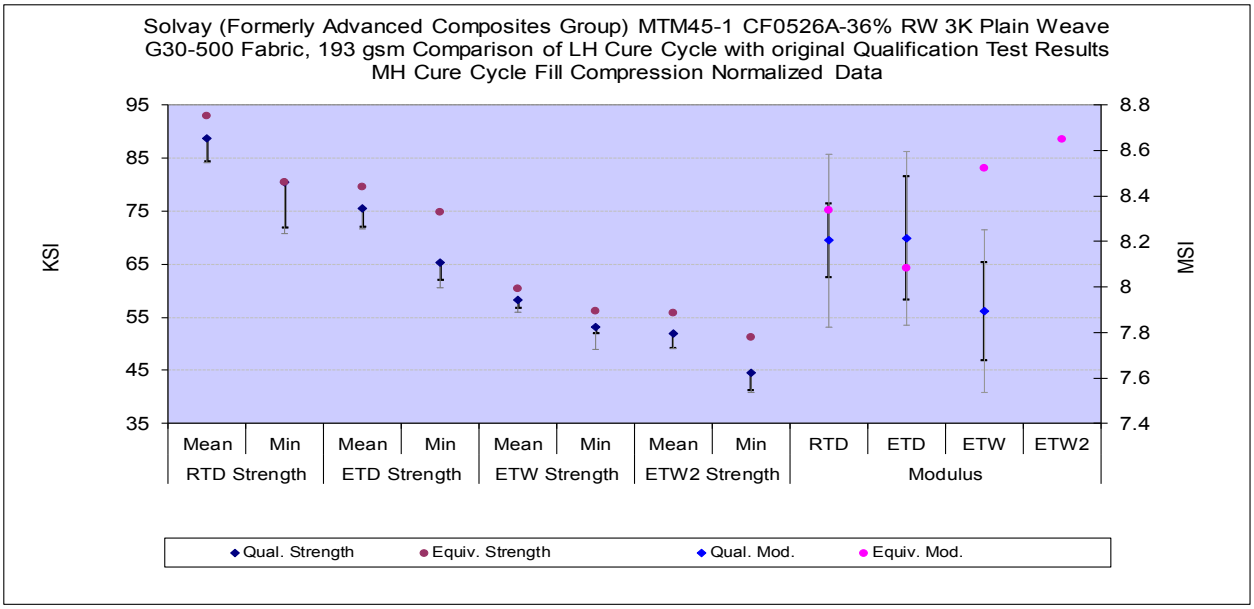

Figure 3-5 Fill Compression means, minimums and Equivalence limits

3.4 Fill Tension (FT)

The FT data is normalized by cured ply thickness. The FT strength data passed the equivalency tests for all four environmental conditions tested. The FT modulus data passed for all three conditions where data was available to compare, although the ETW condition passed only with the use of the modified CV approach. ETW2 modulus data was not available for the MH cure cycle. 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		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079								
Mean Strength (ksi)	125.639	128.393	128.257	129.199	117.184	120.060	110.443	114.670
Standard Deviation	5.232	3.330	7.500	4.489	6.342	5.949	6.282	4.537
Coefficient of Variation %	4.165	2.593	5.848	3.475	5.412	4.955	5.688	3.957
Minimum	118.178	123.984	111.989	119.645	108.885	109.781	101.609	104.596
Maximum	133.107	134.798	137.325	134.408	129.016	127.683	122.766	118.824
Number of Specimens	18	8	18	8	19	8	18	8
RESULTS	**PASS**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	122.086		123.164		112.878		106.177	
Minimum Acceptable Equiv. Sample Min	111.511		108.006		100.061		93.481	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.082		6.924		6.706		6.844	
Minimum Acceptable Equiv. Sample Mean	120.450		122.227		111.849		105.310	
Minimum Acceptable Equiv. Sample Min	105.006		104.280		95.967		90.034	

Table 3-9 Fill Tension Strength Results

Fill Tension (FT) Modulus	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079								
Mean Modulus (Msi)	9.071	9.156	8.883	8.993	8.636	8.923		9.483
Standard Deviation	0.272	0.216	0.284	0.090	0.192	0.118		0.365
Coefficient of Variation %	2.996	2.363	3.194	1.000	2.225	1.319	NA	3.846
Minimum	8.599	8.861	8.035	8.852	8.258	8.758		9.069
Maximum	9.395	9.380	9.178	9.107	8.868	9.128		10.088
Number of Specimens	18	8	18	8	19	8		8
RESULTS	**PASS**		**PASS**		**FAIL**			
Passing Range for Modulus Mean	8.846 to 9.297		8.669 to 9.097		8.485 to 8.788			
Student's t-statistic	0.774		1.065		3.890			
p-value of Student's t-statistic	0.447		0.298		0.001			
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV%	6.000		6.000		6.000			
Passing Range for Modulus Mean	8.657 to 9.486		8.487 to 9.279		8.251 to 9.022			
Modified CV Student's t-statistic	0.420		0.575		1.529			
p-value of Student's t-statistic	0.678		0.571		0.139			

Table 3-10 Fill Tension Modulus Results

The FT modulus data for the ETW environment failed the equivalency test because the sample mean value (8.923) is above the upper acceptance limit (8.788). The equivalency sample mean value is 101.53% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the ETW environment passed the equivalence test.

Figure 3-6 illustrates the 90º Tension 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.

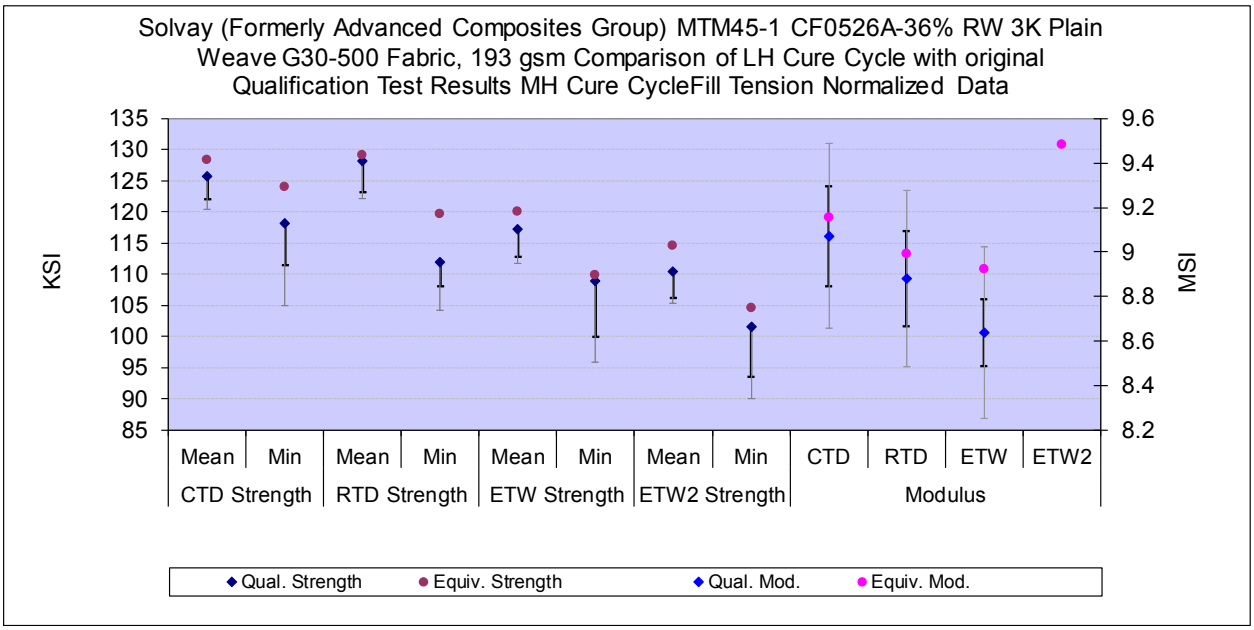

Figure 3-6 Fill Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The SBS data passed for both the ETW and ETW2 environmental conditions, but not the RTD condition. Statistics and analysis results for the SBS data are shown in Table 3-11.

Short Beam Strength (SBS)	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	10.293	9.777	6.532	6.470	5.241	5.158
Standard Deviation	0.194	0.145	0.178	0.120	0.132	0.088
Coefficient of Variation %	1.888	1.485	2.729	1.852	2.515	1.704
Minimum	9.957	9.509	6.219	6.308	4.995	5.065
Maximum	10.583	9.957	6.973	6.654	5.510	5.326
Number of Specimens	20	8	18	9	18	8
RESULTS	**FAIL**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	10.161		6.418		5.151	
Minimum Acceptable Equiv. Sample Min	9.768		6.043		4.885	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	9.874		6.281		5.027	
Minimum Acceptable Equiv. Sample Min	8.626		5.458		4.392	

Table 3-11 Lamina Short Beam Strength Results

The SBS strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (9.777) is 96.22% of the minimum acceptable mean value (10.161) and the equivalency sample minimum (9.509) is 97.35% of the lowest acceptable minimum value (9.768). Under the assumption of the modified CV method, the equivalency sample mean is 99.02% of the minimum acceptable mean value (9.874) and the equivalency sample minimum value is acceptable.

Figure 3-7 illustrates the Short Beam 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.

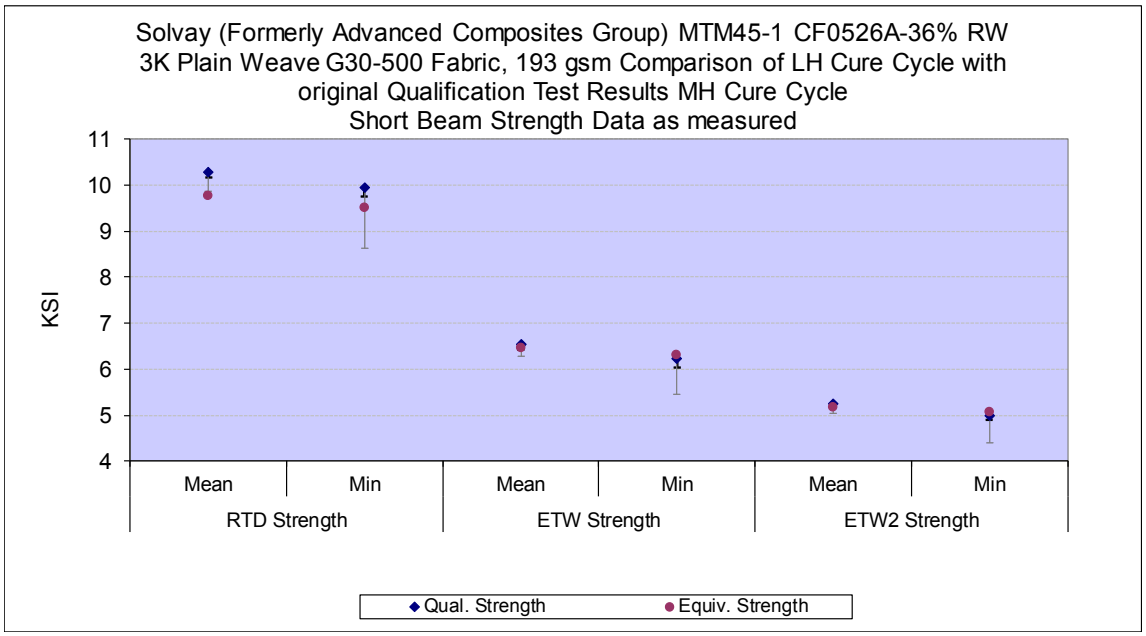

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS strength data passes all equivalency tests. However, the strength at 5% strain datasets for all three conditions have insufficient data for the results to be considered conclusive. The IPS modulus data fails the equivalency test for all three environment conditions tested due to the mean modulus value being too high.

Statistics and analysis results are shown for the 0.2% offset strength data in Table 3-12, for the strength at 5% strain data in Table 3-13, and for 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)	8.267	9.200	6.119	6.904	3.248	4.188
Standard Deviation	0.397	0.241	0.327	0.276	0.155	0.208
Coefficient of Variation %	4.799	2.623	5.341	3.995	4.784	4.957
Minimum	7.577	8.835	5.654	6.484	2.981	3.817
Maximum	8.908	9.516	6.695	7.305	3.521	4.434
Number of Specimens	18	8	26	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	7.997		5.897		3.142	
Minimum Acceptable Equiv. Sample Min	7.196		5.237		2.828	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.399		6.670		6.392	
Minimum Acceptable Equiv. Sample Mean	7.907		5.842		3.107	
Minimum Acceptable Equiv. Sample Min	6.838		5.017		2.687	

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**		**Insufficient Data**		**Insufficient Data**	
Mean Strength 5% Strain (ksi)	14.077	15.561	10.772	12.755	5.671	7.507
Standard Deviation	0.455	0.211	0.454	0.264	0.374	0.270
Coefficient of Variation %	3.229	1.356	4.210	2.067	6.588	3.591
Minimum	13.015	15.328	9.991	12.266	5.142	7.120
Maximum	14.571	15.824	11.591	12.962	6.370	7.829
Number of Specimens	13	6	26	6	19	7
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	13.722		10.418		5.400	
Minimum Acceptable Equiv. Sample Min	12.897		9.594		4.680	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.105		7.294	
Minimum Acceptable Equiv. Sample Mean	13.418		10.259		5.371	
Minimum Acceptable Equiv. Sample Min	11.884		9.064		4.574	

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)	0.661	0.718	0.557	0.614	0.340	0.423
Standard Deviation	0.027	0.022	0.020	0.024	0.018	0.024
Coefficient of Variation %	4.016	3.121	3.669	3.909	5.162	5.627
Minimum	0.622	0.685	0.525	0.576	0.318	0.387
Maximum	0.713	0.747	0.602	0.645	0.377	0.457
Number of Specimens	18	8	26	8	21	8
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	0.639 to 0.683		0.539 to 0.574		0.324 to 0.357	
Student's t-statistic	5.307		6.616		10.279	
p-value of Student's t-statistic	0.00002		1.85E-07		7.83E-11	
MOD CV RESULTS	**FAIL**		**FAIL**		**FAIL**	
Modified CV%	6.008		6.000		6.581	
Passing Range for Modulus Mean	0.630 to 0.692		0.531 to 0.583		0.321 to 0.359	
Modified CV Student's t-statistic	3.794		4.452		8.749	
p-value of Student's t-statistic	0.001		0.0001		2.30E-09	

Table 3-14 In-Plane Shear Modulus Results

The IPS modulus data for the CTD environment failed the equivalency test because the sample mean value (0.718) is above the upper acceptance limit (0.683). The equivalency sample mean value is 105.13% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 103.78% of the maximum acceptable mean value (0.692).

The IPS modulus data for the RTD environment failed the equivalency test because the sample mean value (0.614) is above the upper acceptance limit (0.574). The equivalency sample mean value is 106.85% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 105.29%of the maximum acceptable mean value (0.583).

The IPS modulus data for the ETW2 environment failed the equivalency test because the sample mean value (0.423) is above the upper acceptance limit (0.357). The equivalency sample mean value is 118.57% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 117.61%of the maximum acceptable mean value (0.359).

Figure 3-8 illustrates the In-Plane Shear 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.

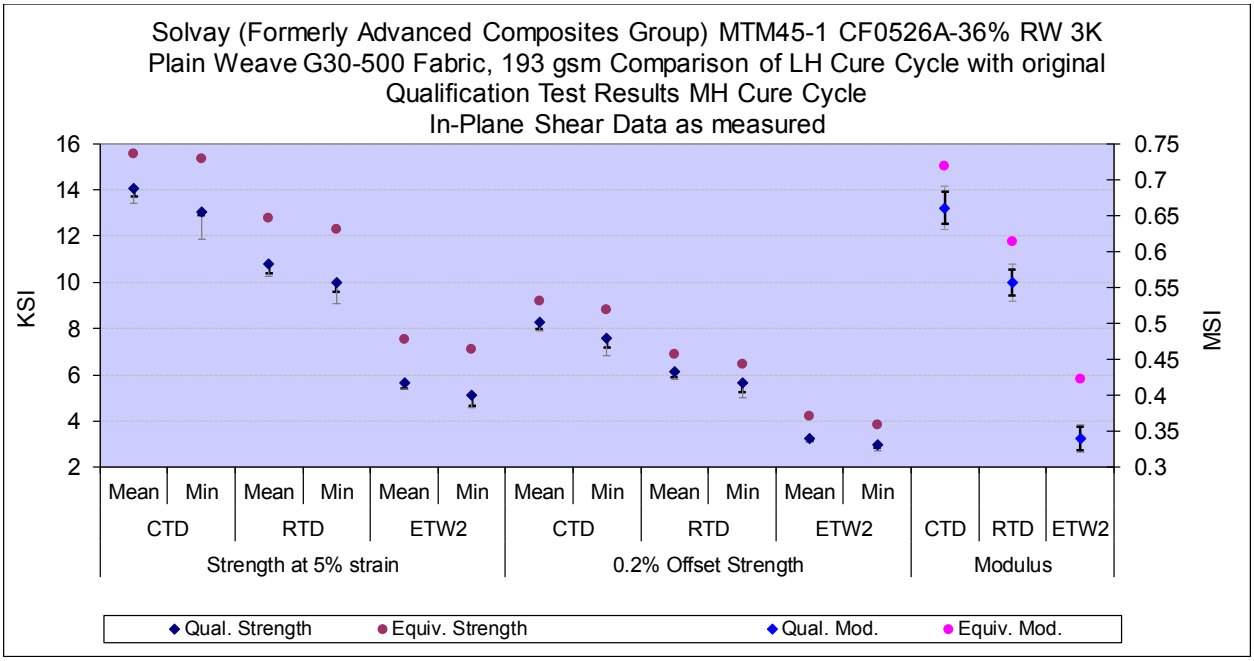

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The OHT1 data is normalized by cured ply thickness. The Open Hole Tension normalized strength data passes all equivalency tests. Statistics and analysis results for the OHT1 strength data are shown in Table 3-15.

Open Hole Tension (OHT1) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Strength (ksi)	51.269	51.862	52.164	53.668	51.214	53.983
Standard Deviation	1.897	0.560	1.701	0.644	2.770	1.409
Coefficient of Variation %	3.700	1.079	3.260	1.200	5.410	2.611
Minimum	47.691	50.886	48.549	52.577	46.921	51.297
Maximum	55.038	52.886	54.717	54.867	54.947	55.562
Number of Specimens	18	8	18	8	18	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	49.981		51.009		49.333	
Minimum Acceptable Equiv. Sample Min	46.147		47.573		43.734	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000		6.705	
Minimum Acceptable Equiv. Sample Mean	49.180		50.039		48.883	
Minimum Acceptable Equiv. Sample Min	42.963		43.713		41.943	

Table 3-15 Open Hole Tension 1 Strength Results

Figure 3-9 illustrates the Open Hole Tension 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.

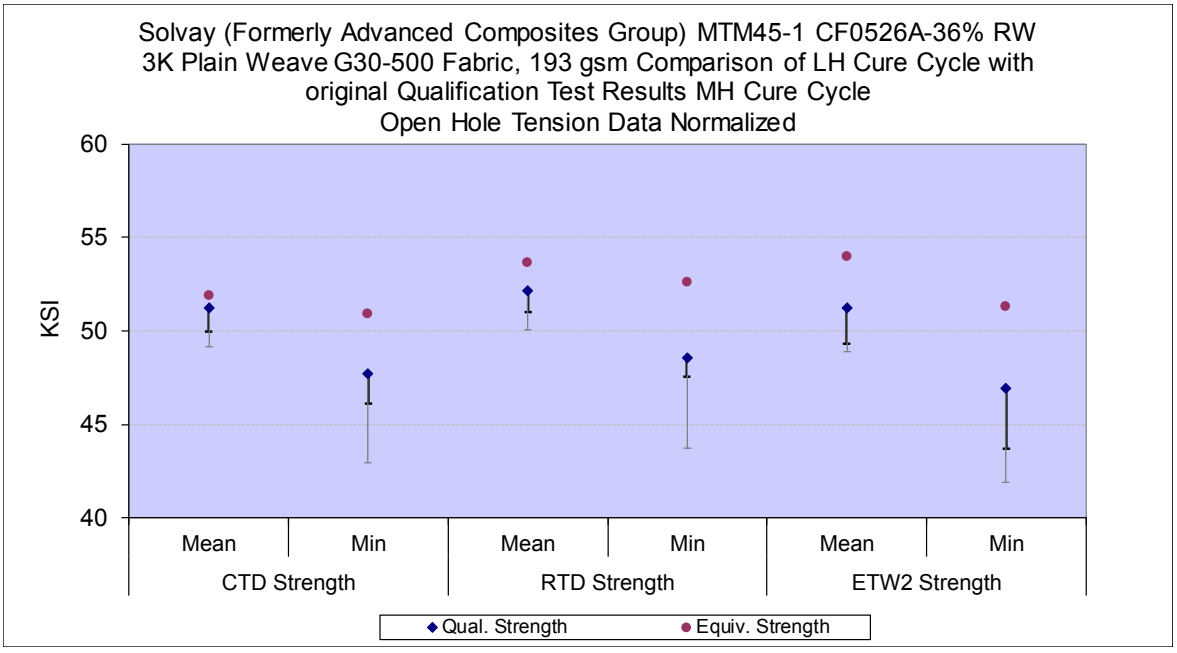

Figure 3-9 Open Hole Tension means, minimums and Equivalence limits

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

The OHC1 data is normalized by cured ply thickness. The Open Hole Compression data passes all equivalency tests, although the RTD data requires the use of the modified CV approach and the ETW condition has insufficient data for the result to be considered conclusive. Statistics and analysis results for the OHC1 strength data are shown in Table 3-16.

Open Hole Compression (OHC1) Strength	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079			Insufficient Data			
Mean Strength (ksi)	41.707	40.755	31.460	31.315	28.915	28.601
Standard Deviation	1.151	0.845	0.915	1.493	1.260	0.911
Coefficient of Variation %	2.759	2.073	2.908	4.767	4.357	3.186
Minimum	40.200	39.691	30.259	29.268	27.028	27.200
Maximum	45.064	42.102	32.364	33.403	31.343	30.013
Number of Specimens	18	8	6	8	18	8
RESULTS	**FAIL**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	40.926		30.839		28.060	
Minimum Acceptable Equiv. Sample Min	38.601		28.990		25.513	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000		6.179	
Minimum Acceptable Equiv. Sample Mean	40.008		30.178		27.702	
Minimum Acceptable Equiv. Sample Min	34.951		26.364		24.091	

Table 3-16 Open Hole Compression 1 Strength Results

The OHC1 strength data for the RTD environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (40.755) is 99.58% of the minimum acceptable mean value (40.962). Under the assumption of the modified CV method, the strength data from the RTD environment passed the equivalence test.

Figure 3-10 illustrates the Open Hole Compression 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.

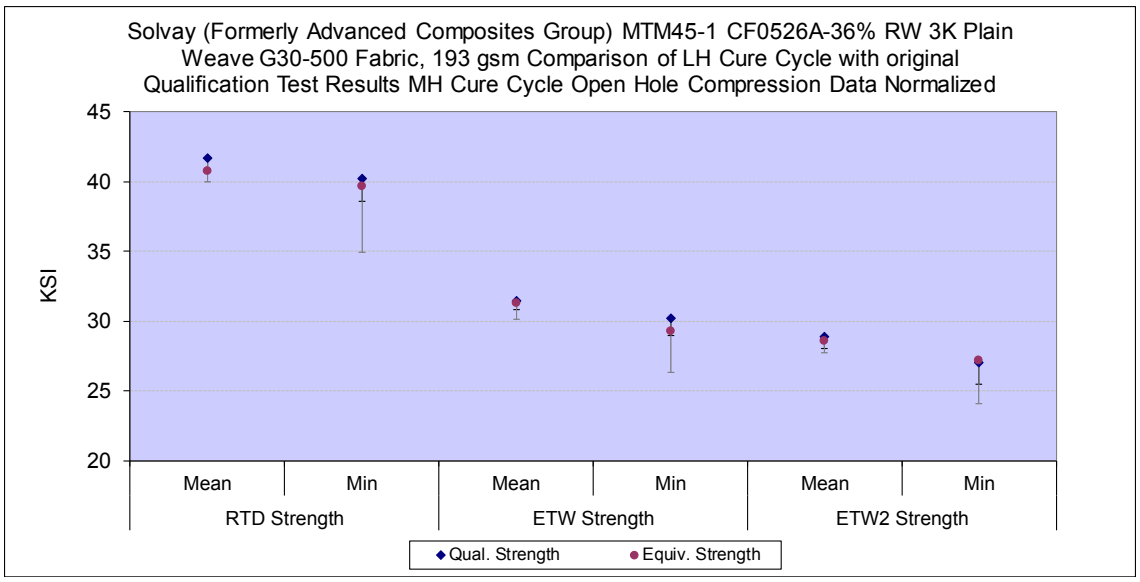

Figure 3-10 Open Hole Compression means, minimums and Equivalence limits

3.9 Interlaminar Tension (ILT) and Curved Beam Strength (CBS)

The Interlaminar Tension and Curved Beam Strength data are not normalized. The ILT and CBS strength data passed equivalency tests for the RTD condition but not for the ETW2 condition. There was insufficient data for these results to be considered conclusive. Modified CV results were not provided for the ILT strength data 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 are shown for the ILT data in Table 3-17 and for the CBS data in Table 3-18.

Interlaminar Tension (ILT) Strength	RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data	
Mean Strength (ksi)	6.596	6.253	2.699	2.424
Standard Deviation	0.850	0.425	0.224	0.214
Coefficient of Variation %	12.885	6.796	8.289	8.839
Minimum	5.911	5.953	2.479	2.204
Maximum	8.131	6.876	2.984	2.650
Number of Specimens	6	4	6	4
RESULTS	**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	5.790		2.487	
Minimum Acceptable Equiv. Sample Min	4.521		2.153	

Table 3-17 Interlaminar Tension Strength Results

Curved Beam Strength (CBS)	RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data	
Mean Strength (ksi)	259.361	241.598	110.697	93.161
Standard Deviation	20.507	13.086	6.960	6.568
Coefficient of Variation %	7.907	5.416	6.287	7.050
Minimum	238.105	228.866	103.744	84.259
Maximum	297.144	255.853	122.994	98.520
Number of Specimens	6	4	6	4
RESULTS	**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	239.907		104.095	
Minimum Acceptable Equiv. Sample Min	209.282		93.701	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**	
Modified CV %	7.953		7.144	
Minimum Acceptable Equiv. Sample Mean	239.793		103.195	
Minimum Acceptable Equiv. Sample Min	208.987		91.386	

Table 3-18 Curved Beam Strength Results

The ILT strength data for the ETW2 environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (2.424) is 97.47% of the minimum acceptable mean value (2.487). The modified CV method could not be used due to the CV of the ETW condition being greater than 8%.

The CBS strength data for the ETW2 environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (93.161) is 90.28% of the minimum acceptable mean value (103.195) and the equivalency sample minimum (84.259) is 92.20% of the lowest acceptable minimum value (91.386).

Figure 3-11 illustrates the Interlaminar Tension and Curved Beam Strength means and minimum values for the qualification sample and the equivalency sample. Due to the large CV of the qualification sample, the modified CV approach does not change the limits.

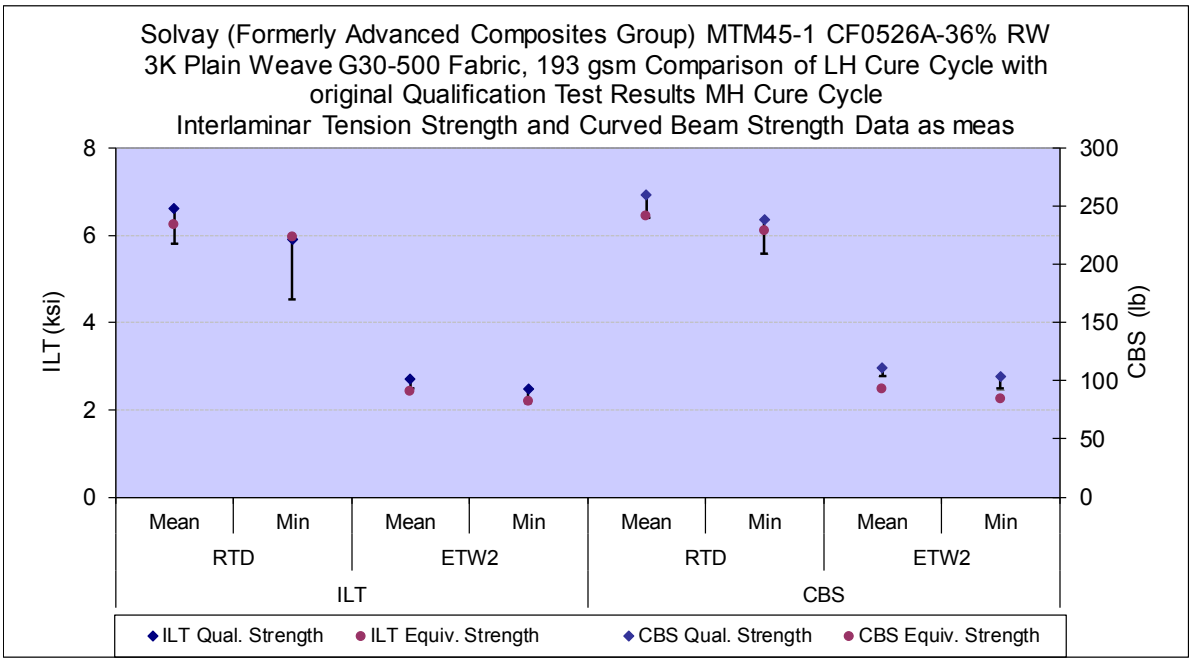

Figure 3-11 Interlaminar Tension and Curved Beam Strength means, minimums and Equivalence limits

3.10 Compression After Impact 1 (CAI1)

The CAI1 data is normalized by cured ply thickness. The Compression After Impact normalized strength data was only tested at the RTD condition. The strength data failed the equivalency test, but there was insufficient data for the results to be considered conclusive. Statistics and analysis results for CAI strength data are shown in Table 3-19.

Compression After Impact (CAI) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0079	Insufficient Data	
Mean Strength (ksi)	33.844	29.576
Standard Deviation	1.126	0.354
Coefficient of Variation %	3.326	1.197
Minimum	31.920	29.218
Maximum	35.229	29.926
Number of Specimens	8	3
RESULTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	32.620	
Minimum Acceptable Equiv. Sample Min	31.228	
MOD CV RESULTS	**FAIL**	
Modified CV%	6.000	
Minimum Acceptable Equiv. Sample Mean	31.637	
Minimum Acceptable Equiv. Sample Min	29.125	

Table 3-19 Compression After Impact 1 Strength Results

The CAI1 strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (29.576) is 90.67% of the minimum acceptable mean value (32.620) and the equivalency sample minimum (29.218) is 93.56% of the lowest acceptable minimum value (31.228). Under the assumption of the modified CV method, the equivalency sample mean is 93.49% of the minimum acceptable mean value (31.637) and the equivalency sample minimum value is acceptable.

Figure 3-12 illustrates the Compression After Impact 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.

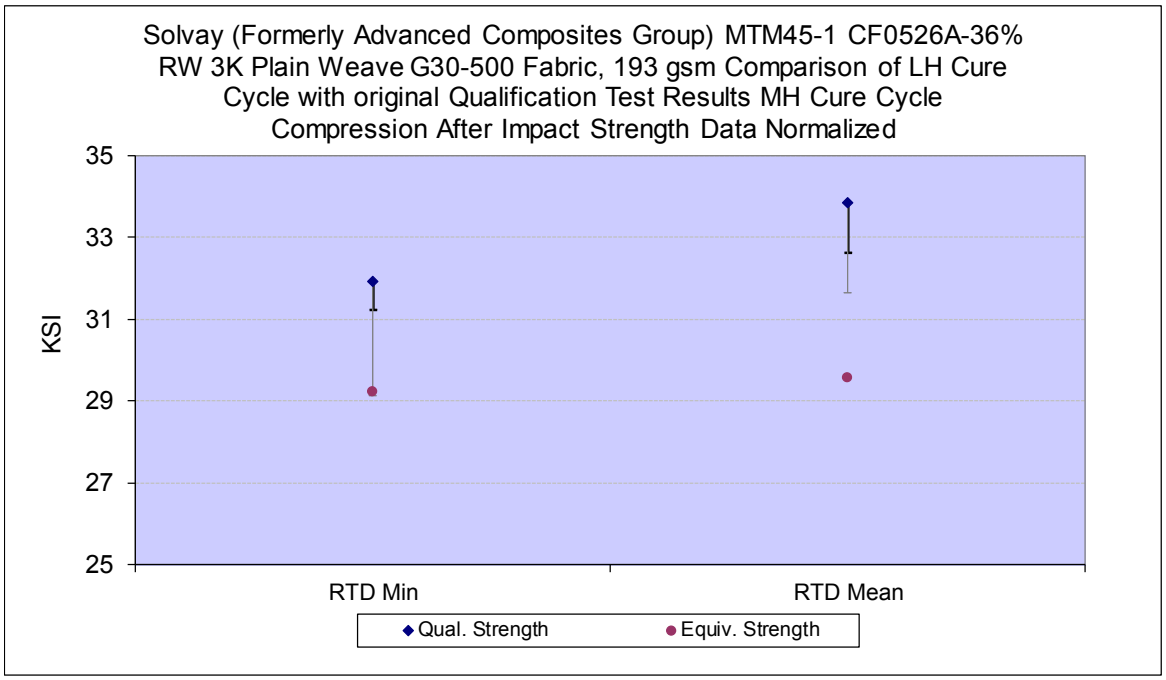

Figure 3-12 Compression After Impact 1 means, minimums and Equivalence limits

3.11 Dynamic Mechanical Analysis (DMA)

DMA is compared for two measurements, the onset of storage modulus and the peak of tangent delta, taken under both wet and dry conditions. These are each 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. The DMA data from the LH cure cycle failed equivalency 95% t-tests in the dry condition, but passed equivalency with the use of the ±18°F criteria.

Statistics for both the original qualification material and the equivalency sample are shown in Table 3-20. The average DMA values from both the qualification sample and the equivalency sample are shown in Figure 3-13. 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.

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)	360.358	353.202	397.585	392.428	320.424	318.578	385.610	385.860
Standard Deviation	6.594	3.191	3.950	3.475	5.610	2.982	6.909	3.531
Coefficient of Variation %	1.830	0.904	0.994	0.886	1.751	0.936	1.792	0.915
Minimum	352.724	350.078	392.288	387.752	313.754	314.960	376.412	380.012
Maximum	380.984	358.286	408.416	396.752	345.344	322.718	408.254	389.660
Number of Specimens	34	9	34	9	34	9	34	9
RESULTS	**FAIL**		**FAIL**		**PASS**		**PASS**	
Passing Range for DMA Mean	355.754 to 364.961		394.661 to 400.509		316.485 to 324.362		380.771 to 390.449	
Student's t-statistic	-3.139		-3.562		-0.946		0.104	
p-value of Student's t-statistic	0.003		0.001		0.350		0.917	
Range = ±18°F RESULTS	**PASS Range = ±18°F**		**PASS Range = ±18°F**		**PASS Range = ±18°F**		**PASS Range = ±18°F**	
Passing Range for DMA Mean	342.358 to 378.358		379.585 to 415.585		302.424 to 338.424		367.610 to 403.610	

Table 3-20 DMA Results

The Onset Storage Modulus for dry data failed the equivalency test because the sample mean value (353.202) is below the lower acceptance limit (355.754). The equivalency sample mean is 99.28% of the lower limit of acceptable values. With the allowable range set to ±18°F, the DMA dry data from Onset Storage Modulus passed the equivalency test.

The Peak of Tangent Delta for dry data failed the equivalency test because the sample mean value (392.428) is below the lower acceptance limit (394.661). The equivalency sample mean is 99.43% of the lower limit of acceptable values. With the allowable range set to ±18°F, the DMA dry data from Peak of Tangent Delta passed the equivalency test.

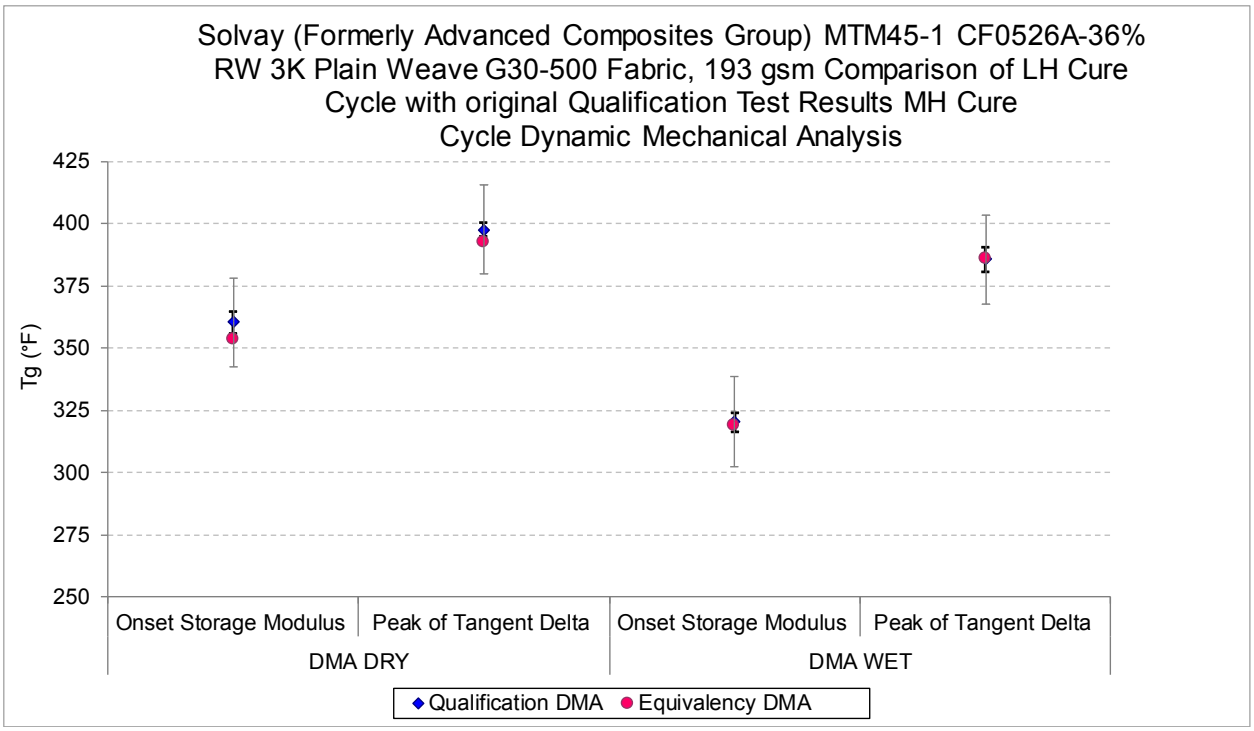

Figure 3-13 DMA Means and Equivalence limits

3.12 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. Both the MH (original qualification) and LH (equivalency) cure cycles are shown in Table 3-21. The average CPT with 95% standard error bars is shown in Figure 3-14. The longer, lighter colored error bars are for the modified CV computations.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.008056	0.008014
Standard Deviation	0.00017	0.00011
Coefficient of Variation %	2.05131	1.43258
Minimum	0.00762	0.00783
Maximum	0.00855	0.00828
Number of Specimens	133	16
RESULTS	**PASS**	
Passing Range for CPT Mean	0.007972 to 0.008140	
Student's t-statistic	-0.988	
p-value of Student's t-statistic	0.325	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.007816 to 0.008297	
Modified CV Student's t-statistic	-0.346	
p-value of Student's t-statistic	0.730	

Table 3-21 Cured Ply Thickness Results

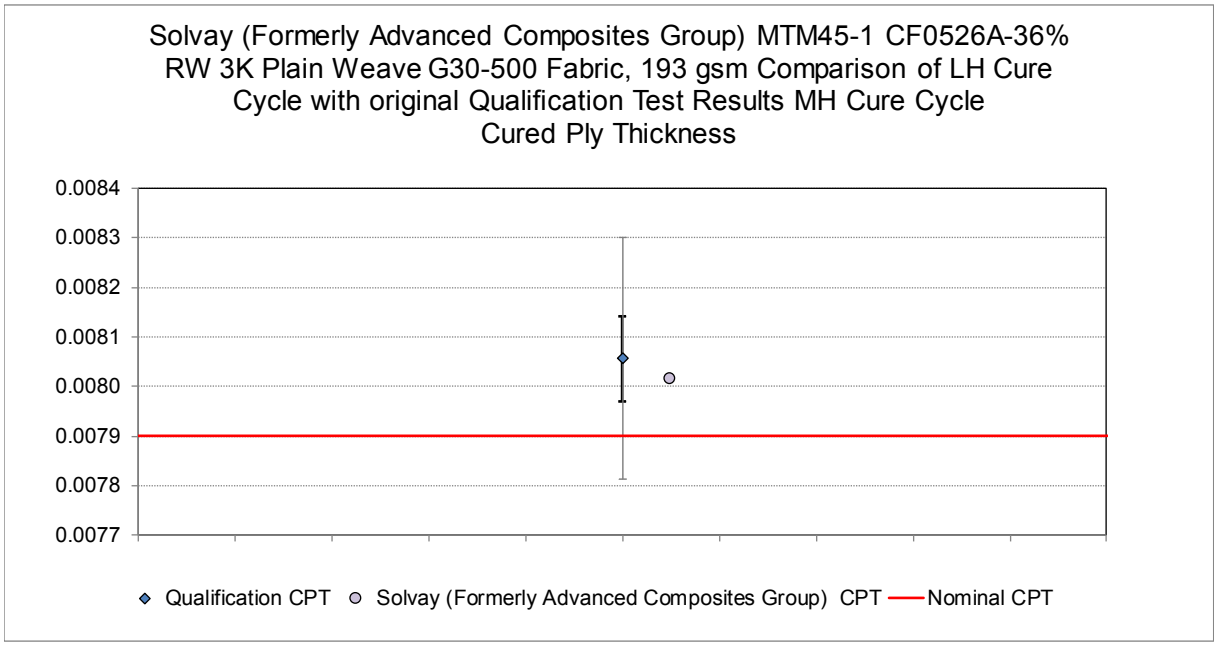

Figure 3-14 CPT means, 95% standard error bars and nominal value

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 LH Cure Cycle material has sufficient test results for comparison with the original qualification material test results on a total of 38 different test types and conditions, not including the cured ply thickness and DMA tests.

Using the modified CV method, there were ten failures total. The Warp Compression strength failures in both ETW conditions and the In-Plane Shear Modulus in the ETW2 condition being classified as severe failures according to the scale presented Table 3-1.

1. Warp Compression Strength for the RTD condition failed by 3.7%.
2. Warp Compression Strength for the ETW condition failed by 20.3%.
3. Warp Compression Strength for the ETW2 condition failed by 23.9%.
4. Warp Compression Modulus for the ETW condition failed by 0.8%
5. Warp Tension Modulus for the RTD condition failed by 0.8%
6. Fill Compression Modulus for the ETW condition failed by 3.3%.
7. In-Plane Shear Modulus for the CTD condition failed by 3.8%
8. In-Plane Shear Modulus for the RTD condition failed by 5.3%
9. In-Plane Shear Modulus for the ETW2 condition failed by 17.6%
10. Short Beam Strength for the CTD condition failed by 1.0%

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

Ten failures out of 38 test conditions gives the LH cure cycle a pass rate of 73.68% 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 1.90 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 ten or more failures is 0.0010%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 38 independent tests. If the two materials were equivalent, the probability of getting four 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 38 independent tests.

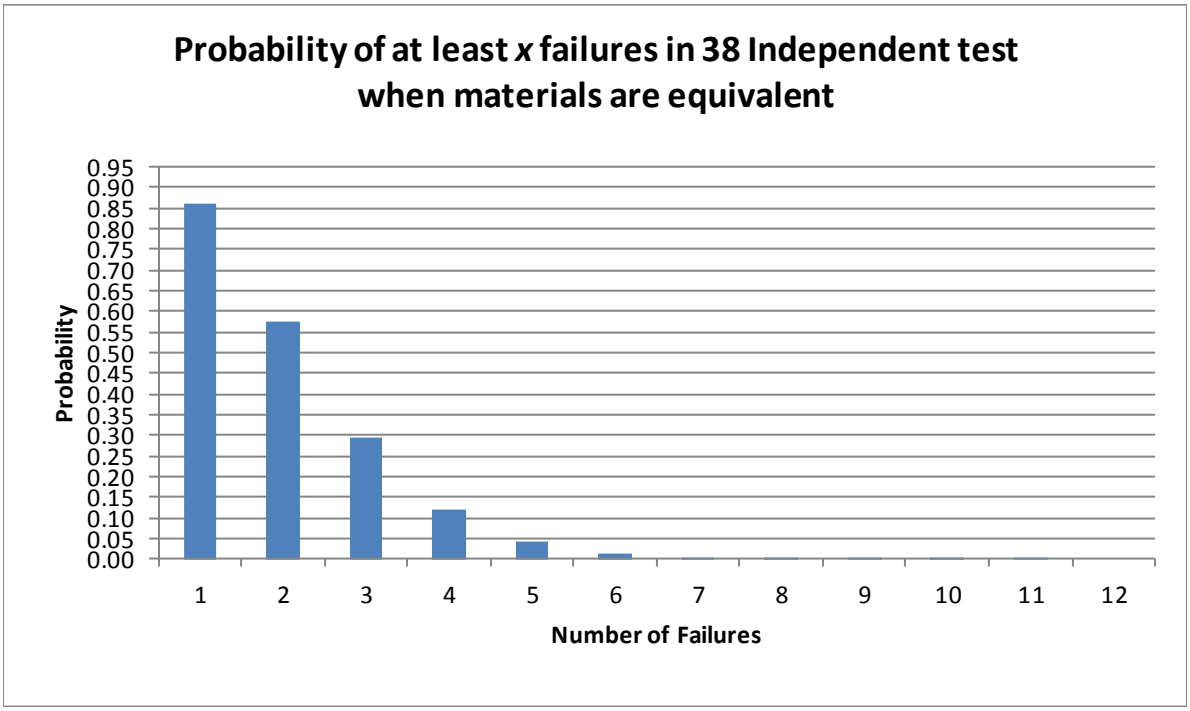

Figure 4-1 Probability of Number of Failures

5. References

1. CMH-17 Rev G, Volume 1, 2012. SAE International, 400 Commonwealth Drive, Warrendale, PA 15096
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
3. Vangel, Mark, "Lot Acceptance and Compliance Testing Using the Sample Mean and an Extremum", Technometrics, Vol 44, NO. 3, August 2002, pp. 242-249