Report No: NCP-RP-2010-001 Rev N/C
Report Date: March 21, 2019

Solvay (Formerly Advanced Composites Group) MTM45-1/CF0525-36%RW (3K PW AS4 Fabric) LH cure cycle compared to MH cure cycle Equivalency Statistical Analysis Report

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/CF0525-36%RW (3K PW AS4 Fabric) “LH” cure cycle compared to the original qualification panels produced using the “MH” cure cycle for the same material. 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 1001–07. An equivalent NCAMP material specification NMS 451/7 has been created. NMS 451/7 contains specification limits that are derived from the qualification dataset using guidelines in section 6 of DOT/FAA/AR-03/19 and CMH-17 Volume 1 Rev. G section 8.4.1.

The mechanical testing was performed by ACG at their Tulsa, Oklahoma facility. 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. DMA test data was not available for an equivalency comparison.

The original qualification data was published in “MTM45-1 CF0525 Data MH Cure Cycle Values Only 2-18-10.pdf”. The qualification test panels were fabricated in accordance with Solvay (formerly Advanced Composites Group) process specification ACGP 1001-02 Revision E “MH” cure cycle. The equivalency data was published in “MTM45-1 CF0525 Data LH Cure Cycle Values only 1-27-10.pdf”. The test panels were fabricated in accordance with ACG process specification ACGP 1001-02 Revision E “LH” cure cycle.

Engineering basis values were reported in NCAMP Report NCP-RP-2009-037 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 451/7. NMS 451/7 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 451/7*. NMS 451/7 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.

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
Interlaminar Tension	ILT
Curved Beam Strength	CBS
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

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

1 = “Quasi-Isotropic”
2 = “Soft”
3 = “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.

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

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 40 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were eight additional tests performed with insufficient data. A comparison of the average cured ply thickness 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) LH Cure Cycle with MTM45-1/CF0525-36%RW (3K PW AS4 Fabric) MH Cure Cycle							
Test	**Normalized Data**	**Property**	**Environmental Condition**				
			CTD	**RTD**	**ETD**	**ETW**	**ETW2**
Warp Compression	**Yes**	**Strength**		Failed by 0.8%		Pass	Pass
		Modulus		Pass		Pass	
Warp Tension	**Yes**	**Strength**	Pass	Pass			Failed by 8.6%
		Modulus	Pass	Pass with Mod CV			Failed by 4.6%
Fill Compression	**Yes**	**Strength**		Pass	Pass	Pass	Pass
		Modulus		Pass	Failed by 3.4%	Failed by 2.5%	
Fill Tension	**Yes**	**Strength**	Pass	Pass		Pass	Pass
		Modulus	Failed by 0.2%	Failed by 1.7%		Failed by 0.8%	
In-Plane Shear	**No**	**0.2% Offset Strength**	Pass	Failed by 0.2%			Pass
		5% Strain Strength	Failed by 4.2% Insufficient Data	Failed by 3.2%			Pass Insufficient Data
		Modulus	Pass	Pass			Pass
Short Beam Strength	**No**	**Strength**		Pass with Mod CV		Pass with Mod CV	Pass
Open Hole Compression	**Yes**	**Strength**		Pass		Failed by 0.8% Insufficient Data	Pass
Open Hole Tension	**Yes**	**Strength**	Pass	Pass			Pass
Interlaminar Tension	**No**	**Strength**		Pass Insufficient Data			Pass Insufficient Data
Curved Beam Strength	**No**	**Strength**		Pass Insufficient Data			Failed by 8.2% Insufficient Data
Compression After Impact	**Yes**	**Strength**		Failed by 0.5% Insufficient Data			
Cured Ply Thickness	**NA**	**NA**	Pass				

Note: DMA test data was not available for an equivalency comparison.

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.

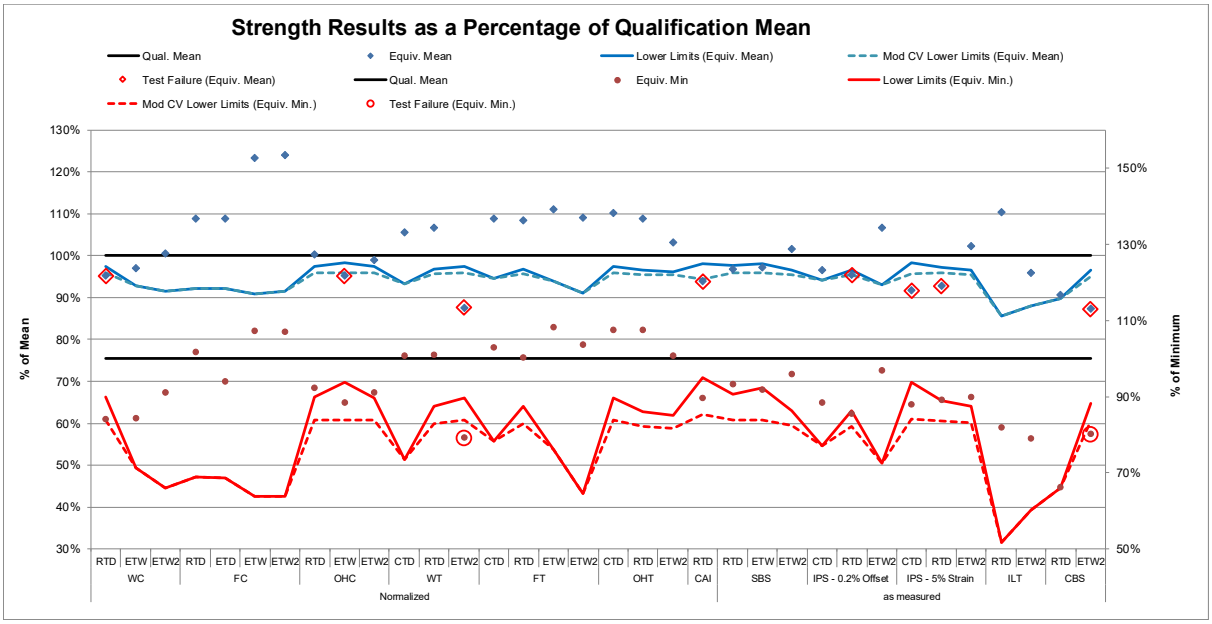

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

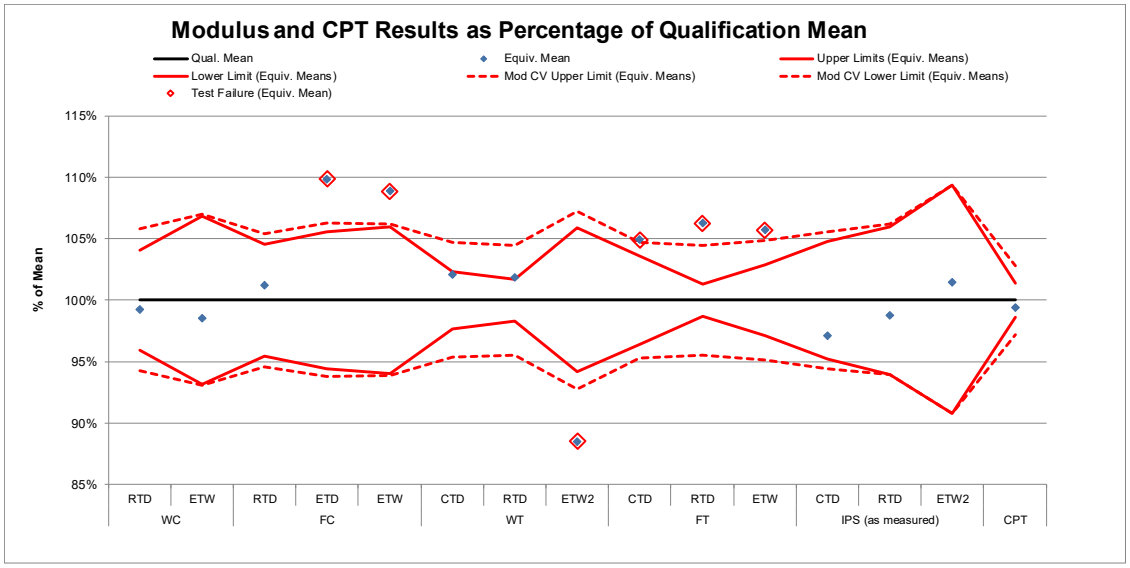

Figure 3-2 Summary of Modulus and CPT means and Equivalence limits

3.1 Warp Compression (WC)

The Warp Compression data is normalized by cured ply thickness. The WC normalized strength data passed equivalency tests for the ETW and ETW2 conditions but not for the RTD condition. The WC normalized modulus data passed equivalency tests for the RTD and ETW conditions. ETW2 modulus data was not available. Modified CV results were not provided for the ETW and 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. 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)	95.293	90.718	65.976	64.068	52.054	52.279
Standard Deviation	3.599	6.885	7.023	6.855	6.542	4.129
Coefficient of Variation %	3.777	7.590	10.645	10.700	12.568	7.898
Minimum	88.635	80.132	49.974	55.688	37.826	47.426
Maximum	101.770	100.744	79.385	74.644	65.368	58.589
Number of Specimens	18	8	20	8	20	8
RESULTS	**FAIL**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	92.849		61.208		47.612	
Minimum Acceptable Equiv. Sample Min	85.575		47.014		34.390	
MOD CV RESULTS	**FAIL**		**NA**		**NA**	
Modified CV%	6.000					
Minimum Acceptable Equiv. Sample Mean	91.411					
Minimum Acceptable Equiv. Sample Min	79.856					

Table 3-3 Warp Compression Strength Results

Warp Compression (WC) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079				
Mean Modulus (Msi)	8.634	8.568	9.405	9.264
Standard Deviation	0.270	0.556	0.719	0.493
Coefficient of Variation %	3.132	6.492	7.642	5.327
Minimum	8.024	8.015	7.946	8.620
Maximum	9.009	9.430	10.587	9.980
Number of Specimens	16	7	13	7
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	8.280 to 8.987		8.763 to 10.048	
Student's t-statistic	-0.387		-0.462	
p-value of Student's t-statistic	0.702		0.650	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		7.821	
Passing Range for Modulus Mean	8.135 to 9.133		8.751 to 10.060	
Modified CV Student's t-statistic	-0.275		-0.453	
p-value of Student's t-statistic	0.786		0.656	

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 (90.718) is 97.71% of the minimum acceptable mean value (92.849) and the equivalency sample minimum (80.132) is 93.64% of the lowest acceptable minimum value (85.575). Under the assumption of the modified CV method, the equivalency sample mean is 99.24% of the minimum acceptable mean value (91.411) and the equivalency sample minimum value is acceptable.

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.

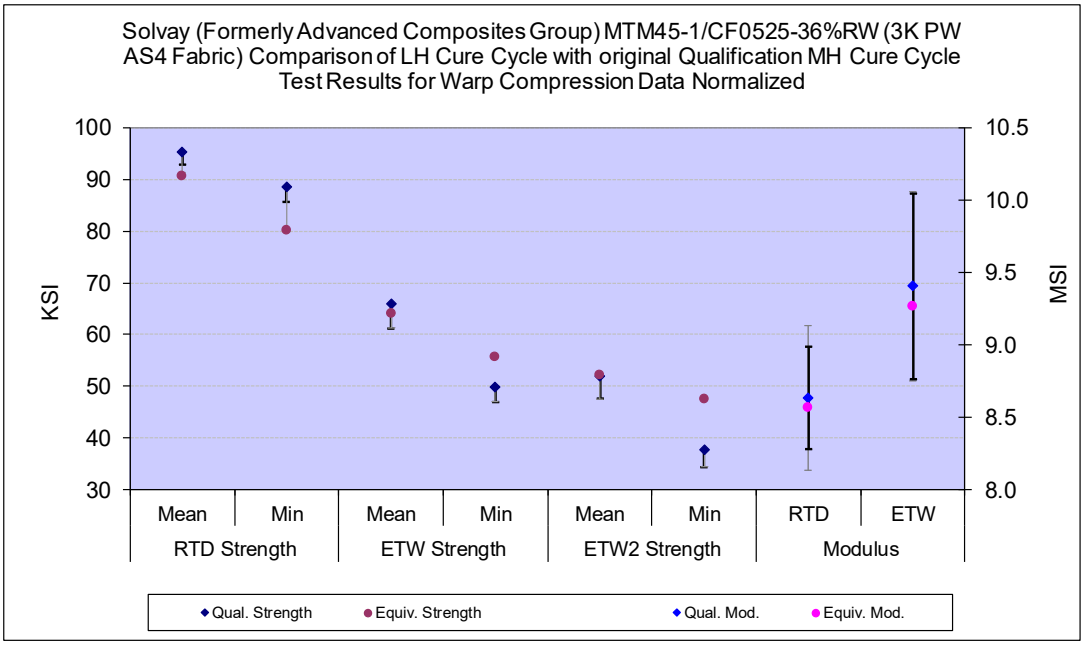

Figure 3-3 Warp Compression means, minimums and Equivalence limits

3.2 Warp Tension (WT)

The Warp Tension data is normalized by cured ply thickness. The WT normalized strength data passed equivalency tests for the CTD and RTD conditions but not for the ETW2 condition. The WT normalized modulus data passed equivalency tests for the CTD and RTD conditions but not for the ETW2 condition, and the RTD condition required the use of the modified CV approach to pass equivalency. Modified CV results were not provided for the CTD 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 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)	129.476	136.802	132.489	141.188	128.670	112.756
Standard Deviation	12.766	3.546	6.148	4.740	4.944	5.915
Coefficient of Variation %	9.860	2.592	4.641	3.357	3.843	5.246
Minimum	102.806	130.551	118.985	133.852	118.488	101.858
Maximum	146.565	141.925	142.328	148.048	136.269	119.397
Number of Specimens	21	8	22	8	18	8
RESULTS	**PASS**		**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	120.807		128.315		125.312	
Minimum Acceptable Equiv. Sample Min	95.007		115.889		115.320	
MOD CV RESULTS	**NA**		**PASS with MOD CV**		**FAIL**	
Modified CV%			6.320		6.000	
Minimum Acceptable Equiv. Sample Mean			126.804		123.428	
Minimum Acceptable Equiv. Sample Min			109.880		107.825	

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)	9.516	9.715	9.311	9.484	11.032	9.765
Standard Deviation	0.226	0.337	0.196	0.158	0.585	0.394
Coefficient of Variation %	2.374	3.469	2.108	1.671	5.307	4.037
Minimum	9.023	9.063	8.832	9.186	10.041	9.438
Maximum	10.026	10.061	9.671	9.698	12.366	10.323
Number of Specimens	21	8	22	8	18	4
RESULTS	**PASS**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	9.295 to 9.737		9.152 to 9.469		10.386 to 11.679	
Student's t-statistic	1.847		2.234		-4.089	
p-value of Student's t-statistic	0.076		0.034		0.001	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	6.000		6.000		6.653	
Passing Range for Modulus Mean	9.073 to 9.960		8.896 to 9.725		10.232 to 11.832	
Modified CV Student's t-statistic	0.920		0.855		-3.306	
p-value of Student's t-statistic	0.365		0.400		0.004	

Table 3-6 Warp Tension Modulus Results

The WT 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 (112.756) is 91.35% of the minimum acceptable mean value (123.428) and the equivalency sample minimum (101.858) is 94.47% of the lowest acceptable minimum value (107.825).

The WT modulus data for the RTD environment failed the equivalency test because the sample mean value (9.484) is above the upper acceptance limit (9.469). The equivalency sample mean value is 100.15% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the RTD environment passed the equivalence test.

The WT modulus data for the ETW2 environment failed the equivalency test because the sample mean value (9.765) is below the lower acceptance limit (10.386). The equivalency sample mean value is 94.02% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 95.43% of the minimum acceptable mean value (10.232).

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.

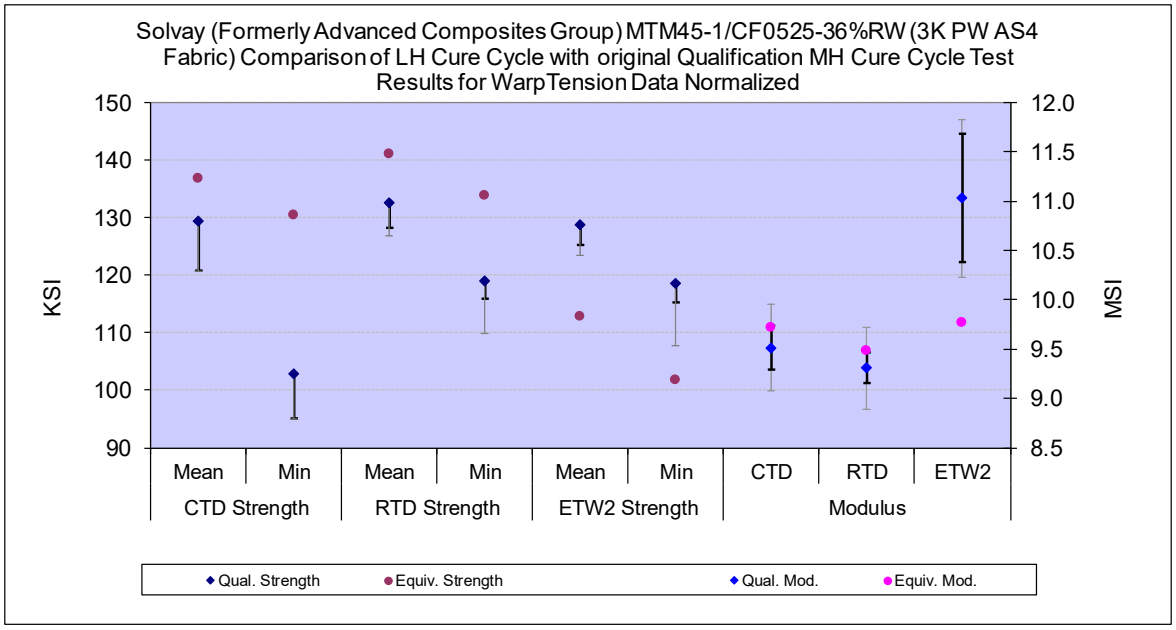

Figure 3-4 Warp Tension means, minimums and Equivalence limits

3.3 Fill Compression (FC)

The Fill Compression data is normalized by cured ply thickness. The FC normalized strength data passed equivalency tests for all four conditions tested. The FC normalized modulus data passed equivalency tests only for the RTD condition, not for the ETD or ETW conditions. ETW2 modulus data was not available. Modified CV results were not provided for the strength data because in all cases 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 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)	87.517	95.190	74.778	81.431	55.593	68.578	47.569	59.033
Standard Deviation	10.063	3.864	8.712	5.457	7.457	5.919	5.899	4.845
Coefficient of Variation %	11.498	4.059	11.651	6.702	13.413	8.631	12.402	8.206
Minimum	68.447	88.998	61.095	70.268	44.354	59.592	32.516	50.864
Maximum	102.287	101.005	88.262	87.040	72.240	75.259	59.361	66.901
Number of Specimens	24	8	18	8	20	8	19	8
RESULTS	**PASS**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	80.684		68.862		50.530		43.563	
Minimum Acceptable Equiv. Sample Min	60.347		51.255		35.460		31.640	

Table 3-7 Fill Compression Strength Results

Fill Compression (FC) Modulus	RTD		ETD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	8.046	8.146	8.319	9.139	8.689	9.459
Standard Deviation	0.461	0.098	0.479	0.642	0.653	0.130
Coefficient of Variation %	5.730	1.204	5.755	7.021	7.511	1.369
Minimum	7.414	8.021	7.415	8.357	7.450	9.261
Maximum	8.992	8.256	9.242	10.147	10.532	9.594
Number of Specimens	22	7	18	8	19	7
RESULTS	**PASS**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	7.682 to 8.410		7.853 to 8.785		8.170 to 9.208	
Student's t-statistic	0.564		3.629		3.060	
p-value of Student's t-statistic	0.578		0.001		0.005	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		**FAIL**	
Modified CV%	6.865		6.878		7.755	
Passing Range for Modulus Mean	7.610 to 8.482		7.799 to 8.840		8.153 to 9.225	
Modified CV Student's t-statistic	0.472		3.251		2.965	
p-value of Student's t-statistic	0.641		0.003		0.007	

Table 3-8 Fill Compression Modulus Results

The FC modulus data for the ETD environment failed the equivalency test because the sample mean value (9.139) is above the upper acceptance limit (8.785). The equivalency sample mean value is 104.02% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 103.39% of the maximum acceptable mean value (8.840).

The FC modulus data for the ETW environment failed the equivalency test because the sample mean value (9.459) is above the upper acceptance limit (9.208). The equivalency sample mean value is 102.72% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 102.53% of the maximum acceptable mean value (9.225).

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.

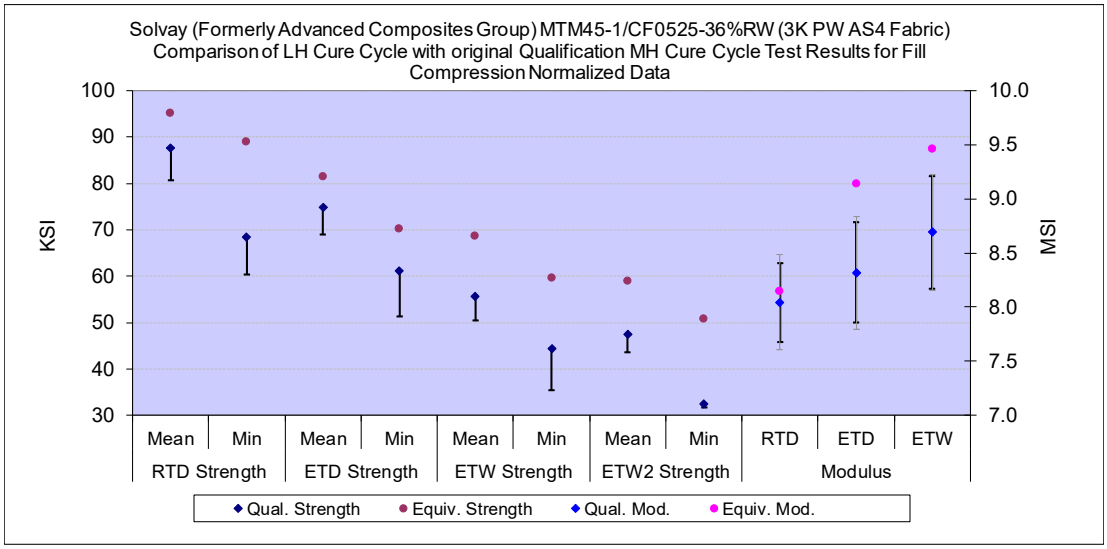

Figure 3-5 Fill Compression means, minimums and Equivalence limits

3.4 Fill Tension (FT)

The Fill Tension data is normalized by cured ply thickness. The FT normalized strength data passed equivalency tests for all four conditions tested. The FT normalized modulus data did not pass equivalency tests for the CTD, RTD or ETW conditions, in all three cases due to the modulus mean being too high. ETW2 modulus data was not available. Modified CV results were not provided for the CTD, ETW or 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. 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)	124.005	135.071	124.793	135.212	119.653	132.849	112.917	123.102
Standard Deviation	9.984	6.310	5.786	6.237	10.551	3.339	14.843	4.724
Coefficient of Variation %	8.051	4.672	4.637	4.613	8.818	2.514	13.145	3.838
Minimum	91.457	127.596	115.303	125.119	97.804	129.541	83.718	117.034
Maximum	135.857	144.475	134.156	146.297	135.045	140.133	135.193	129.848
Number of Specimens	20	8	18	8	19	8	19	8
RESULTS	**PASS**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	117.225		120.864		112.489		102.838	
Minimum Acceptable Equiv. Sample Min	97.048		109.170		91.165		72.840	
MOD CV RESULTS	**NA**		**PASS with MOD CV**		**NA**		**NA**	
Modified CV%			6.318					
Minimum Acceptable Equiv. Sample Mean			119.439					
Minimum Acceptable Equiv. Sample Min			103.504					

Table 3-9 Fill Tension Strength Results

Fill Tension (FT) Modulus	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	9.157	9.609	8.854	9.409	8.904	9.412
Standard Deviation	0.445	0.089	0.143	0.099	0.305	0.165
Coefficient of Variation %	4.865	0.926	1.619	1.057	3.431	1.751
Minimum	8.290	9.510	8.585	9.278	8.472	9.235
Maximum	10.322	9.780	9.113	9.528	9.349	9.637
Number of Specimens	21	8	18	8	17	7
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	8.828 to 9.486		8.738 to 8.969		8.648 to 9.159	
Student's t-statistic	2.818		9.898		4.124	
p-value of Student's t-statistic	0.009		5.99798E-10		0.0004	
MOD CV RESULTS	**FAIL**		**FAIL**		**FAIL**	
Modified CV%	6.432		6.000		6.000	
Passing Range for Modulus Mean	8.723 to 9.591		8.459 to 9.249		8.472 to 9.335	
Modified CV Student's t-statistic	2.137		2.903		2.440	
p-value of Student's t-statistic	0.042		0.008		0.023	

Table 3-10 Fill Tension Modulus Results

The FT modulus data for the CTD environment failed the equivalency test because the sample mean value (9.609) is above the upper acceptance limit (9.486). The equivalency sample mean value is 101.30% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.19% of the maximum acceptable mean value (9.591).

The FT modulus data for the RTD environment failed the equivalency test because the sample mean value (9.409) is above the upper acceptance limit (8.969). The equivalency sample mean value is 104.90% of the upper limit of acceptable values.

Under the assumption of the modified CV method, the equivalency sample mean is 101.74% of the maximum acceptable mean value (9.249).

The FT modulus data for the ETW environment failed the equivalency test because the sample mean value (9.412) is above the upper acceptance limit (9.159). The equivalency sample mean value is 102.76% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.82% of the maximum acceptable mean value (9.335).

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.

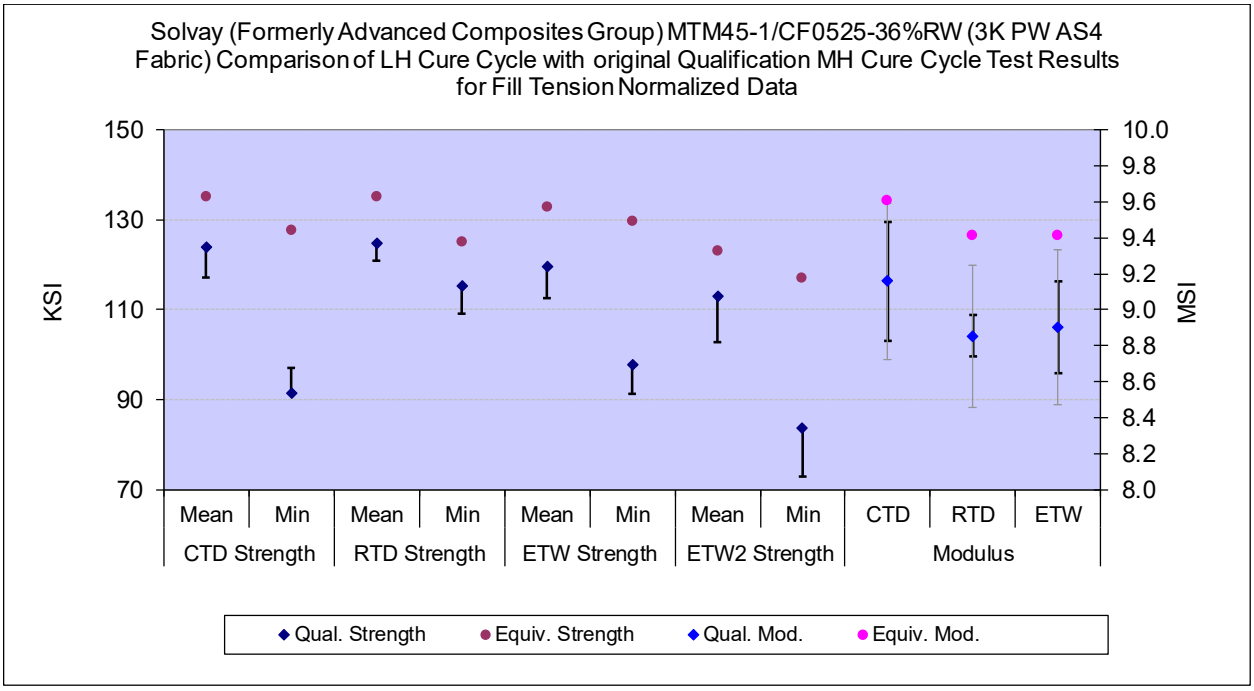

Figure 3-6 Fill Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The Short Beam Strength data passed equivalency tests for all three conditions, but the RTD and ETW conditions required the use of the modified CV method to pass. 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)	10.414	10.071	6.297	6.127	4.958	5.035
Standard Deviation	0.365	0.272	0.178	0.329	0.252	0.147
Coefficient of Variation %	3.505	2.705	2.831	5.373	5.091	2.916
Minimum	9.807	9.723	6.065	5.786	4.366	4.757
Maximum	10.991	10.417	6.624	6.542	5.319	5.209
Number of Specimens	18	8	18	8	18	8
RESULTS	**FAIL**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	10.166		6.176		4.787	
Minimum Acceptable Equiv. Sample Min	9.429		5.815		4.277	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.546	
Minimum Acceptable Equiv. Sample Mean	9.990		6.040		4.738	
Minimum Acceptable Equiv. Sample Min	8.727		5.277		4.082	

Table 3-11 Lamina Short Beam Strength Results

The SBS 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 (10.071) is 99.07% of the minimum acceptable mean value (10.166). Under the assumption of the modified CV method, the strength data from the RTD environment passed the equivalence test.

The SBS data for the ETW environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (6.127) is 99.22% of the minimum acceptable mean value (6.176) and the equivalency sample minimum (5.786) is 99.50% of the lowest acceptable minimum value (5.815). Under the assumption of the modified CV method, the strength data from the ETW environment passed the equivalence test.

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.

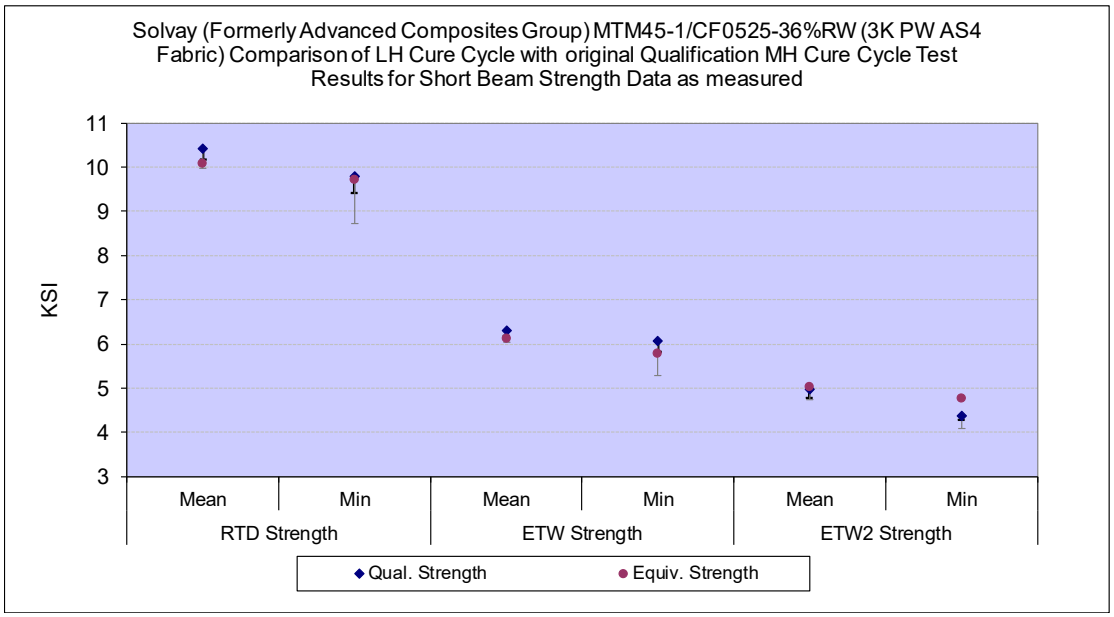

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS Strength at 5% Strain data passed equivalency tests only for the ETW2 condition, and failed for the CTD and RTD conditions. The IPS 0.2% Offset Strength data passed equivalency tests for both the CTD and ETW2 conditions, but not for the RTD condition. The IPS modulus data passed equivalency tests for all three conditions tested. Modified CV results were not provided for the 0.2% Offset Strength CTD and ETW2 datasets or for the Modulus ETW2 dataset because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. There were insufficient specimens in the IPS Strength at 5% Strain CTD and ETW2 datasets for the results to be considered conclusive.

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)	7.852	7.583	5.999	5.721	2.630	2.808
Standard Deviation	0.664	0.535	0.307	0.430	0.267	0.179
Coefficient of Variation %	8.458	7.061	5.121	7.522	10.152	6.392
Minimum	6.865	6.943	5.462	5.138	2.354	2.547
Maximum	9.141	8.418	6.549	6.405	3.473	2.975
Number of Specimens	23	8	24	8	21	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	7.401		5.790		2.449	
Minimum Acceptable Equiv. Sample Min	6.059		5.170		1.909	
MOD CV RESULTS	**NA**		**FAIL**		**NA**	
Modified CV %			6.560			
Minimum Acceptable Equiv. Sample Mean			5.732			
Minimum Acceptable Equiv. Sample Min			4.936			

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**	
Mean Strength 5% Strain (ksi)	13.250	12.144	9.948	9.234	4.473	4.574
Standard Deviation	0.316	0.446	0.403	0.228	0.212	0.407
Coefficient of Variation %	2.384	3.671	4.055	2.467	4.740	8.891
Minimum	12.749	11.660	9.348	8.866	4.143	4.019
Maximum	13.788	12.820	10.910	9.494	4.948	4.960
Number of Specimens	11	7	19	8	18	7
RESULTS	**FAIL**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	13.021		9.674		4.319	
Minimum Acceptable Equiv. Sample Min	12.412		8.859		3.910	
MOD CV RESULTS	**FAIL**		**FAIL**		**PASS with MOD CV**	
Modified CV %	6.000		6.027		6.370	
Minimum Acceptable Equiv. Sample Mean	12.674		9.541		4.266	
Minimum Acceptable Equiv. Sample Min	11.141		8.329		3.717	

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)	0.627	0.609	0.541	0.534	0.309	0.313
Standard Deviation	0.034	0.040	0.041	0.031	0.033	0.037
Coefficient of Variation %	5.411	6.570	7.519	5.833	10.606	11.688
Minimum	0.563	0.557	0.472	0.477	0.254	0.270
Maximum	0.715	0.688	0.600	0.566	0.380	0.385
Number of Specimens	23	8	24	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	0.597 to 0.657		0.508 to 0.573		0.280 to 0.337	
Student's t-statistic	-1.232		-0.434		0.318	
p-value of Student's t-statistic	0.228		0.668		0.753	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV%	6.706		7.760			
Passing Range for Modulus Mean	0.592 to 0.662		0.508 to 0.574			
Modified CV Student's t-statistic	-1.052		-0.422			
p-value of Student's t-statistic	0.301		0.676			

Table 3-14 In-Plane Shear Modulus Results

The IPS 0.2% Offset strength dataset for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (5.721) is 98.80% of the minimum acceptable mean value (5.790) and the equivalency sample minimum (5.138) is 99.40% of the lowest acceptable minimum value (5.170). Under the assumption of the modified CV method, the equivalency sample mean is 99.81% of the minimum acceptable mean value (5.732) and the equivalency sample minimum value is acceptable.

The IPS strength at 5% strain dataset for the CTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (12.144) is 93.27% of the minimum acceptable mean value (13.021) and the equivalency sample minimum (11.660) is 93.94% of the lowest acceptable minimum value (12.412). Under the assumption of the modified CV method, the equivalency sample mean is 95.82% of the minimum acceptable mean value (12.674) and the equivalency sample minimum value is acceptable.

The IPS strength at 5% strain dataset 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 (9.234) is 95.45% of the minimum acceptable mean value (9.674). Under the assumption of the modified CV method, the equivalency sample mean is 96.78% of the minimum acceptable mean value (9.541).

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.

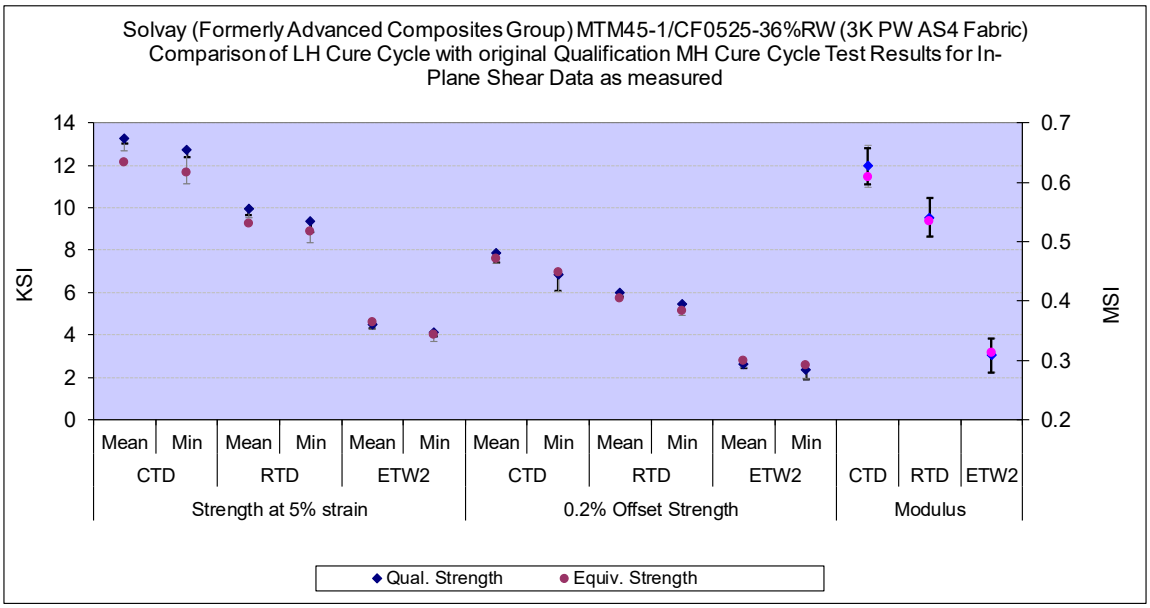

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The Open Hole Tension data is normalized by cured ply thickness. The Open Hole Tension normalized strength data passed equivalency tests for all three conditions tested. 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)	51.411	56.702	53.112	57.810	52.533	54.188
Standard Deviation	1.972	0.894	2.750	0.534	2.910	0.893
Coefficient of Variation %	3.836	1.578	5.178	0.924	5.539	1.647
Minimum	47.027	55.251	48.868	57.061	47.714	52.938
Maximum	53.622	58.126	57.024	58.707	56.454	55.756
Number of Specimens	18	8	18	8	19	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	50.072		51.245		50.557	
Minimum Acceptable Equiv. Sample Min	46.087		45.687		44.677	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.589		6.769	
Minimum Acceptable Equiv. Sample Mean	49.317		50.736		50.118	
Minimum Acceptable Equiv. Sample Min	43.083		43.663		42.931	

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.

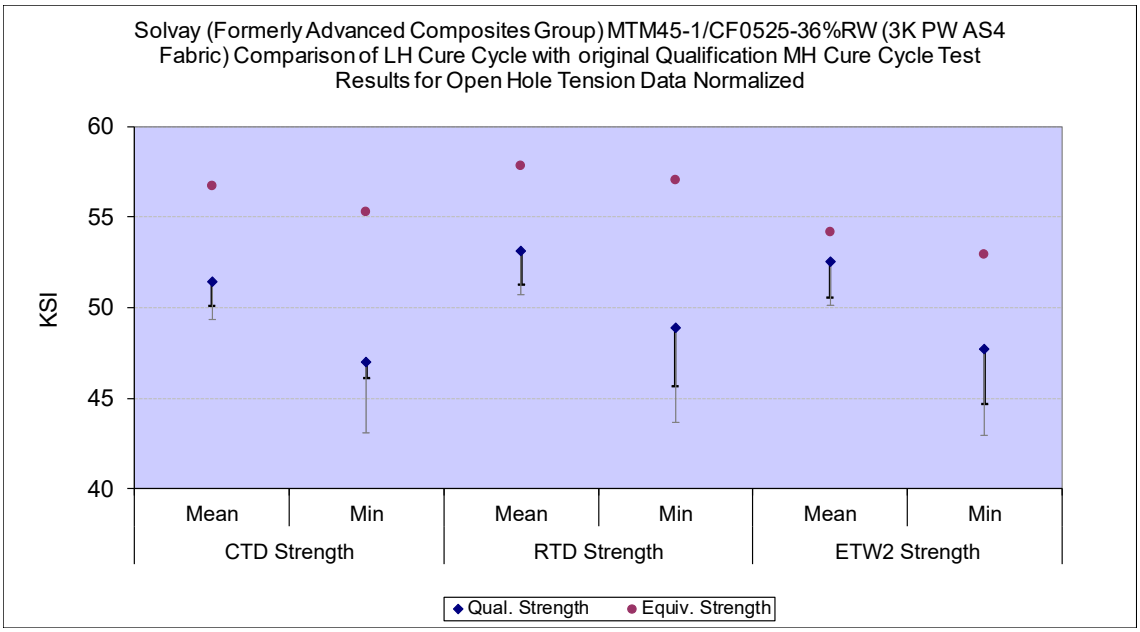

Figure 3-9 Open Hole Tension means, minimums and Equivalence limits

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

The Open Hole Compression data is normalized by cured ply thickness. The Open Hole Compression normalized strength data passed equivalency tests for the RTD and ETW2 conditions but not for the ETW condition. There were insufficient specimens in the OHC1 ETW strength dataset 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)	41.461	41.552	33.419	31.809	29.286	28.958
Standard Deviation	1.560	2.965	0.771	1.129	1.112	1.139
Coefficient of Variation %	3.762	7.136	2.307	3.549	3.798	3.933
Minimum	38.150	38.234	32.334	29.577	27.433	26.704
Maximum	43.728	46.739	34.248	32.975	31.199	30.353
Number of Specimens	18	8	6	8	18	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	40.402		32.895		28.531	
Minimum Acceptable Equiv. Sample Min	37.249		31.337		26.284	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	39.772		32.058		28.093	
Minimum Acceptable Equiv. Sample Min	34.744		28.005		24.542	

Table 3-16 Open Hole Compression 1 Strength Results

The OHC1 strength data for the ETW environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (31.809) is 96.70% of the minimum acceptable mean value (32.895) and the equivalency sample minimum (29.577) is 94.38% of the lowest acceptable minimum value (31.337). Under the assumption of the modified CV method, the equivalency sample mean is 99.22% of the minimum acceptable mean value (32.058) and the equivalency sample minimum value is acceptable.

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.

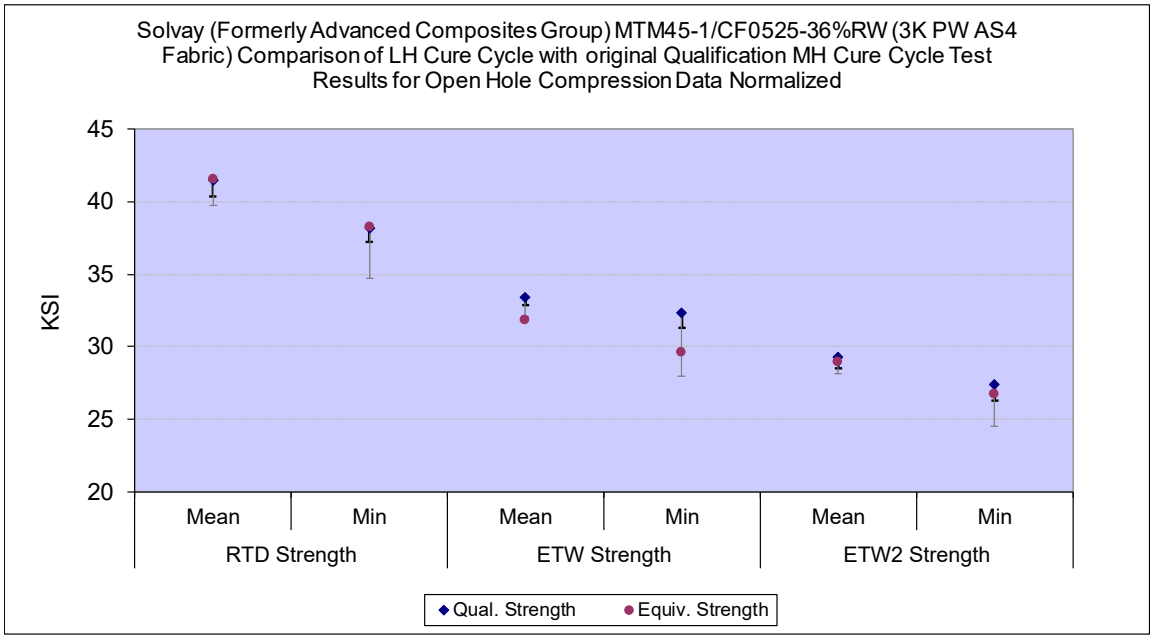

Figure 3-10 Open Hole Compression means, minimums and Equivalence limits

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

The Interlaminar Tension and Curved Beam Strength data are not normalized. The ILT strength data passed equivalency tests for both the RTD and ETW2 conditions. The CBS data passed equivalency tests for the RTD condition but not the ETW2 condition. Modified CV results were not provided for the ILT strength data from either condition and the CBS data for the RTD condition because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown.

There was insufficient data for these results to be considered conclusive. Statistics and analysis results are shown for the ILT and CBS data in Table 3-17.

Interlaminar Tension (ILT) Strength and Curved Beam Strength (CBS)	Interlaminar Tension (ILT) Strength				Curved Beam Strength (CBS)			
	RTD		ETW2		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data		Insufficient Data		Insufficient Data	
Mean Strength (ksi)	5.224	5.762	3.771	3.615	220.889	200.140	159.237	139.019
Standard Deviation	0.969	1.256	0.579	0.517	28.857	44.294	7.208	11.211
Coefficient of Variation %	18.552	21.794	15.347	14.299	13.064	22.131	4.527	8.065
Minimum	4.282	4.278	3.169	2.981	188.373	146.309	147.149	127.647
Maximum	6.960	7.249	4.613	4.373	265.883	252.550	168.423	158.689
Number of Specimens	7	6	7	6	7	6	7	6
RESULTS	**PASS**		**PASS**		**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	4.467		3.319		198.357		153.609	
Minimum Acceptable Equiv. Sample Min	2.707		2.268		145.956		140.520	
MOD CV RESULTS	**NA**		**NA**		**NA**		**FAIL**	
Modified CV%							6.263	
Minimum Acceptable Equiv. Sample Mean							151.450	
Minimum Acceptable Equiv. Sample Min							133.339	

Table 3-17 Interlaminar Tension Strength and Curved Beam Strength Results

The CBS 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 (139.019) is 91.79% of the minimum acceptable mean value (151.450) and the equivalency sample minimum (127.647) is 95.73% of the lowest acceptable minimum value (133.339).

Figure 3-11 illustrates the Interlaminar Tension and Curved 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.

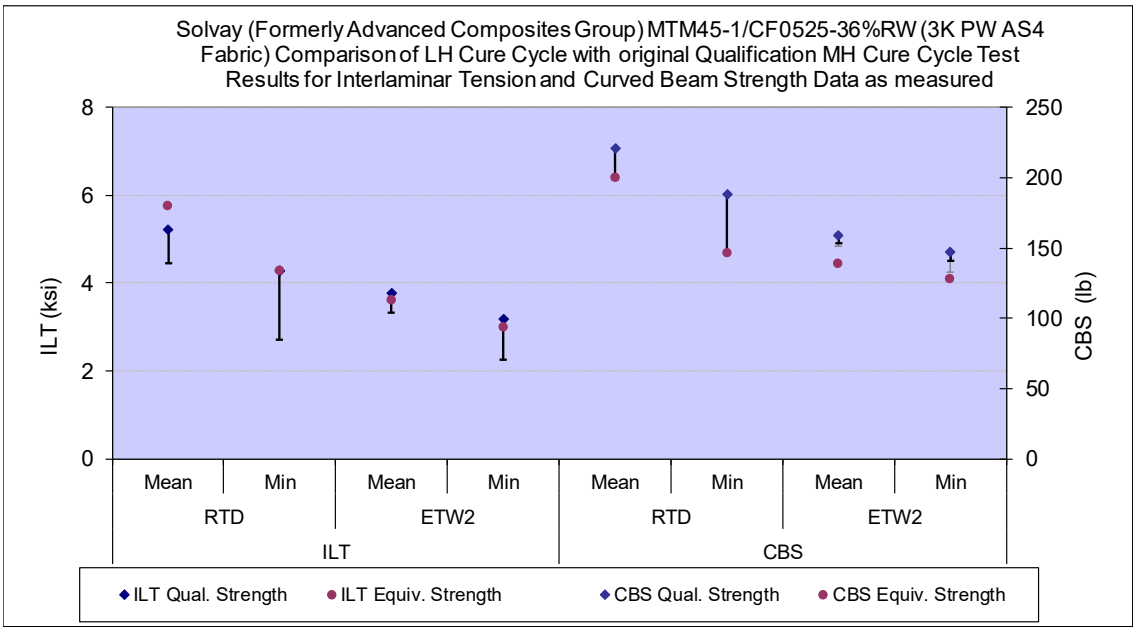

Figure 3-11 Interlaminar Tension and Curved Beam Strength means, minimums and Equivalence limits

3.10 Compression After Impact 1 (CAI1)

The Compression After Impact data is normalized by cured ply thickness. The Compression After Impact normalized strength data did not pass equivalency for the RTD condition. There was insufficient data for the result to be considered conclusive. Statistics and analysis results for CAI strength data are shown in Table 3-18.

Compression After Impact (CAI) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0079	Insufficient Data	
Mean Strength (ksi)	34.435	32.322
Standard Deviation	0.698	1.038
Coefficient of Variation %	2.028	3.213
Minimum	33.522	30.909
Maximum	35.763	33.344
Number of Specimens	8	4
RESULTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	33.773	
Minimum Acceptable Equiv. Sample Min	32.730	
MOD CV RESULTS	**FAIL**	
Modified CV %	6.000	
Minimum Acceptable Equiv. Sample Mean	32.475	
Minimum Acceptable Equiv. Sample Min	29.390	

Table 3-18 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 (32.322) is 95.70% of the minimum acceptable mean value (33.773) and the equivalency sample minimum (30.909) is 94.43% of the lowest acceptable minimum value (32.730). Under the assumption of the modified CV method, the equivalency sample mean is 99.53% of the minimum acceptable mean value (32.475) 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.

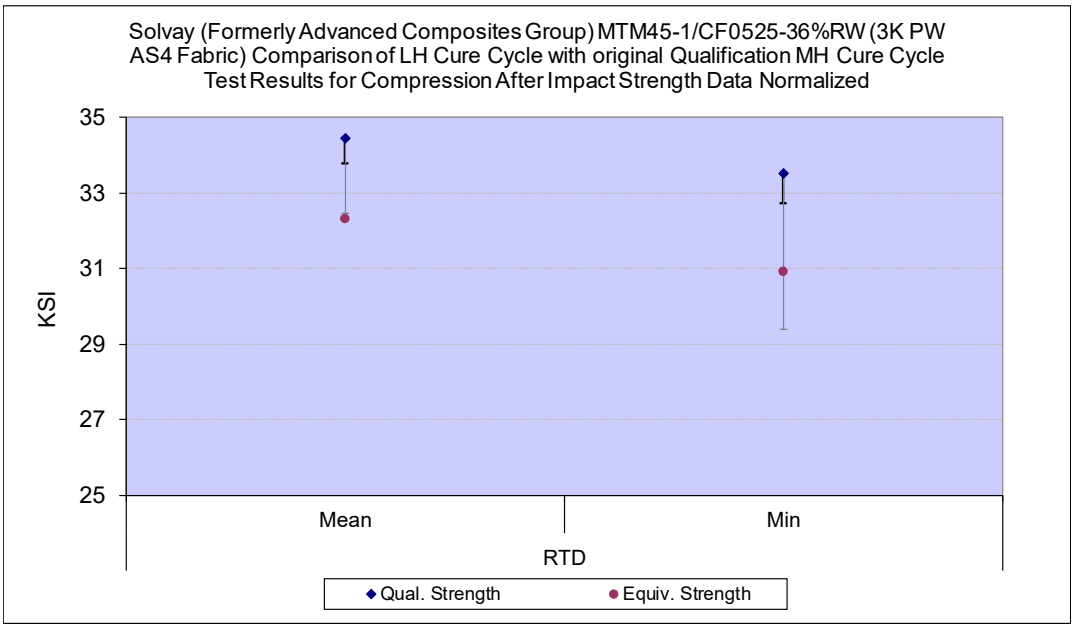

Figure 3-12 Compression After Impact 1 means, minimums and Equivalence limits

3.11 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 MH cure cycle qualification sample and the LH cure cycle equivalency sample are shown in Table 3-19.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.008193	0.008144
Standard Deviation	0.00024	0.00012
Coefficient of Variation %	2.97370	1.51258
Minimum	0.00758	0.00799
Maximum	0.00964	0.00850
Number of Specimens	146	18
RESULTS	**PASS**	
Passing Range for CPT Mean	0.008078 to 0.008309	
Student's t-statistic	-0.841	
p-value of Student's t-statistic	0.402	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.007963 to 0.008424	
Modified CV Student's t-statistic	-0.421	
p-value of Student's t-statistic	0.674	

Table 3-19 Cured Ply Thickness Results

Figure 3-12 illustrates the Cured Ply Thickness mean values for the qualification sample and the equivalency sample. The average CPT with 95% standard error bars is shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations. The nominal value used for computing normalized values is shown as a horizontal red line in the graph.

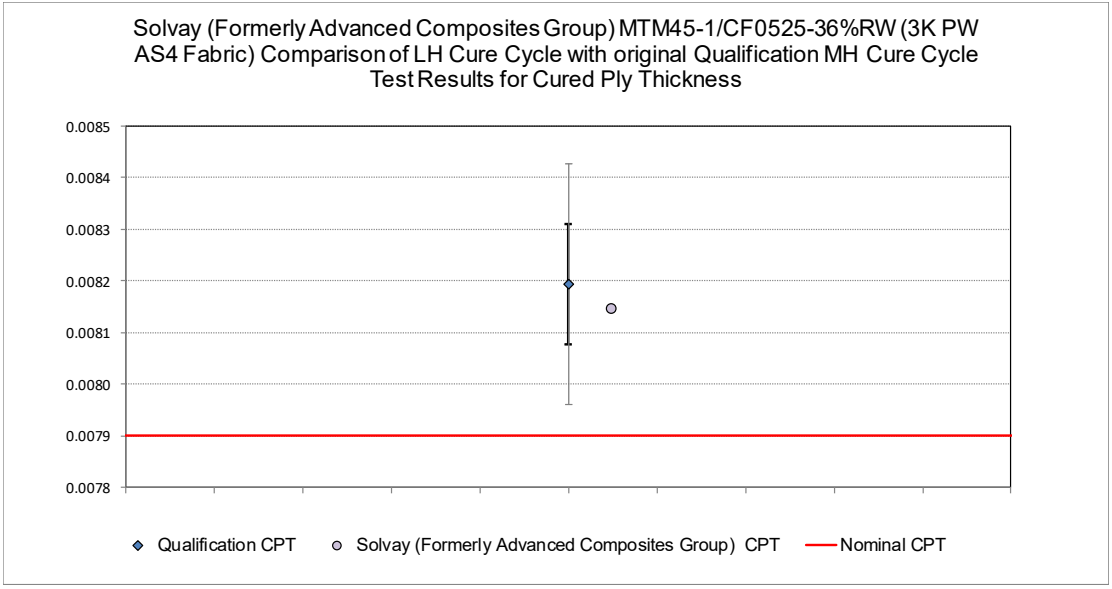

Figure 3-13 CPT means, 95% standard error bars and nominal value

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 CPT test is not included in this part of the analysis because the results of multiple other tests may be dependent or correlated with that test.

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 sample has sufficient test results for comparison with the original qualification material test results on a total of 40 different test types and conditions, not including the cured ply thickness comparison.

Using the modified CV method, there were ten failures.

1. Warp Compression strength for the RTD condition failed by 0.8%
2. Warp Tension strength for the ETW2 condition failed by 8.6%
3. Warp Tension modulus for the ETW2 condition failed by 4.6%
4. Fill Compression modulus for the ETD condition failed by 3.4%
5. Fill Compression modulus for the ETW condition failed by 2.5%
6. Fill Tension modulus for the CTD condition failed by 0.2%
7. Fill Tension modulus for the RTD condition failed by 1.7%
8. Fill Tension modulus for the ETW condition failed by 0.8%
9. In-Plane Shear 0.2% Offset Strength for the RTD condition failed by 0.2%
10. In-Plane Shear Strength at 5% Strain for the RTD condition failed by 3.2%

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 40 tests gives the LH cure cycle a pass rate of 75% 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 2.0 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 0.002%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 40 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 40 independent tests.

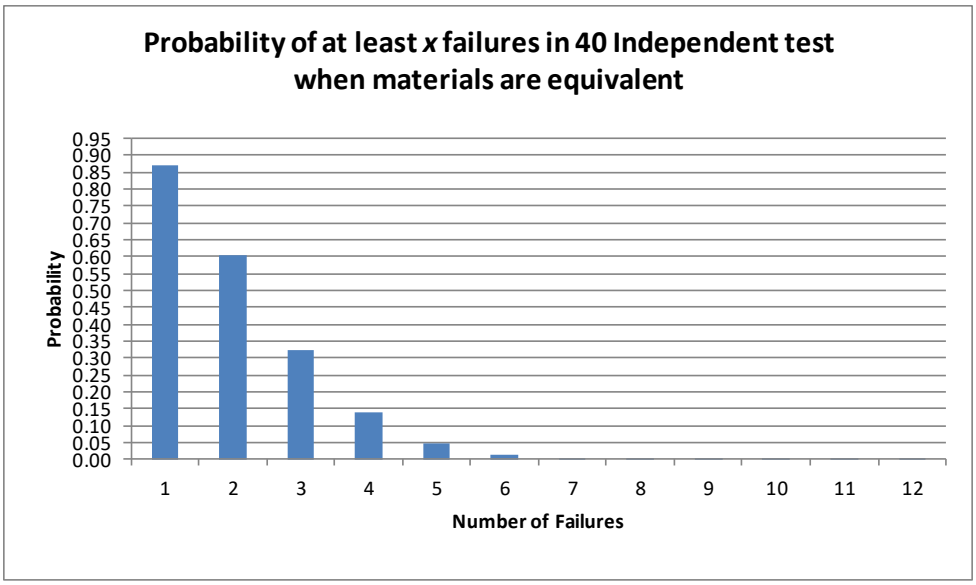

Figure 4-1 Probability of Number of Failures

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