Report No: NCP-RP-2019-001 Rev N/C
Report Date: July 18, 2018

Solvay (Formerly Advanced Composites Group) MTM45-1 / AS4145-32% RW Unitape (12K AS4 UNI) LH cure cycle compared to MH cure cycle Equivalency Statistical Analysis Report

FAA Special Project Number: SP3505WI-Q

NCAMP Document: NCP-RP-2019-001 Rev N/C

Report Date: July 18, 2018

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1. Introduction

This report contains the equivalency test results for Solvay (formerly Advanced Composites Group) MTM45-1/12K AS4 145gsm 32%RW Unidirectional (12K AS4 UNI) "LH" cure cycle compared to 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 1001-11. An equivalent NCAMP Material Specification NMS 451/11 which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19 has been created.

The original qualification data was published in "MTM45-1 AS4-145 CPT Normal Data MH Cure Cycle Values Only 7-16-09.pdf". The qualification test panels were fabricated in accordance with ACG process specification ACGP 1001-02 Revision B "MH" cure cycle. The equivalency data was published in "MTM45-1 AS4-145 CPT Normal Data LH Cure Cycle Values Only 2-1-08.pdf". The test panels were fabricated in accordance with ACG process specification ACGP 1001-02 Revision B using "LH" cure cycle. An equivalent NCAMP Process Specification, NPS 81451 with cure "LH" has been created. ACG Test Plan AI/TR/1392 Rev E was used for this equivalency program.

These tests were performed by Solvay (formerly Advanced Composites Group) in Tulsa Oklahoma. 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.

Engineering basis values were reported in NCAMP Report NCP-RP-2008-004 Rev N/C which details the standards and methodology used for computing basis values as well as providing the B-basis values and A- and B- estimates computed from the test results for the original qualification panels.

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

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 451/11. NMS 451/11 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 451/11. NMS 451/11 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
Longitudinal Compression	LC
Longitudinal Tension	LT
Transverse Compression	TC
Transverse Tension	TT
In-Plane Shear	IPS
Short Beam Strength	SBS
Unnotched Compression	UNC0
Unnotched Tension	UNT0
Open Hole Tension	OHT1
Open Hole Compression	OHC1
Interlaminar Tension	ILT
Curved Beam Strength	CBS
Compression After Impact	CAI
Cured Ply Thickness	CPT
Dynamic Mechanical Analysis	DMA

Table 1-1 Test Property Abbreviations

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	−65º 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:

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

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 53 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were an additional six 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) LH Cure Cycle with MTM45-1/ 12K AS4 145gsm 32%RW Unidirectional MH Cure Cycle							
Test	**Normalized Data**	**Property**	**Environmental Condition**				
			CTD	RTD	ETD	ETW	ETW2
Longitudinal Compression	**Yes**	**Modulus**		Pass with Mod CV		Pass with Mod CV	Failed by 3.2%
Longitudinal Tension	**Yes**	**Modulus**	Pass	Pass			Pass
Transverse Compression	**No**	**Strength**		Pass		Pass	Pass
		Modulus		Pass		Failed by 1.3%	Pass
Transverse Tension	**No**	**Strength**	Pass	Pass		Failed by 3.1% Insufficient Data	Failed by 0.7%
		Modulus	Failed by 4.2%	Pass with Mod CV		Pass	Pass
In-Plane Shear	**No**	**0.2% Offset Strength**	Pass	Pass		Pass	Pass
		5% Strain Strength	Failed by 0.5%	Pass		Pass	Pass
		Modulus	Pass	Pass		Failed by 0.1%	Pass
Short Beam Strength	**No**	**Strength**	Pass	Pass	Pass	Failed by 10.7%	Failed by 10.6%
Unnotched Compression	**Yes**	**Strength**		Pass		Pass	Pass
		Modulus		Failed by 2.9%		Pass	Pass with Mod CV
Unnotched Tension	**Yes**	**Strength**	Pass	Failed by 1.5%			Failed by 3.3%
		Modulus	Pass with Mod CV	Pass			Pass
Open Hole Compression	**Yes**	**Strength**		Pass		Pass with Mod CV Insufficient Data	Pass
Open Hole Tension	**Yes**	**Strength**	Pass	Pass			Pass
Interlaminar Tension	**No**	**Strength**		Pass Insufficient Data			Pass Insufficient Data
Curved Beam Strength		**Strength**		Pass Insufficient Data			Pass Insufficient Data
Compression After Impact	**Yes**	**Strength**		Failed by 7.5% Insufficient Data			
Cured Ply Thickness	**NA**	**NA**	Pass				
Dynamic Mechanical Analysis	**Onset Storage Modulus -**		Pass				
	Peak of Tangent Delta - Dry		Failed by 19.7%				
	Onset Storage Modulus -		Pass				
	Peak of Tangent Delta -		Failed by 1.6%				

Table 3-2 Summary of Equivalency Test Results

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

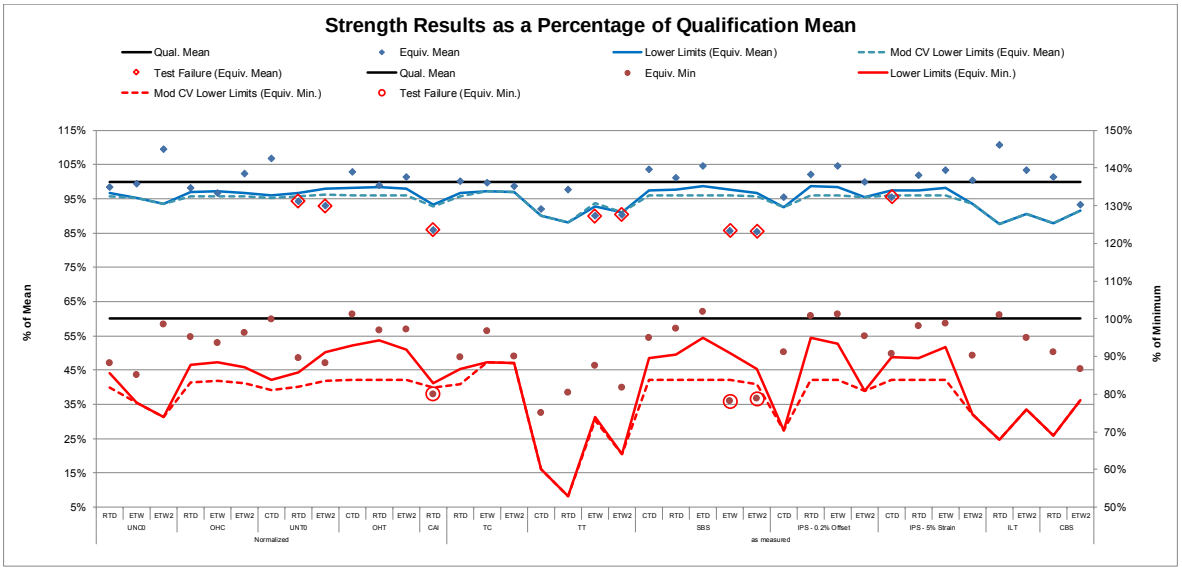

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

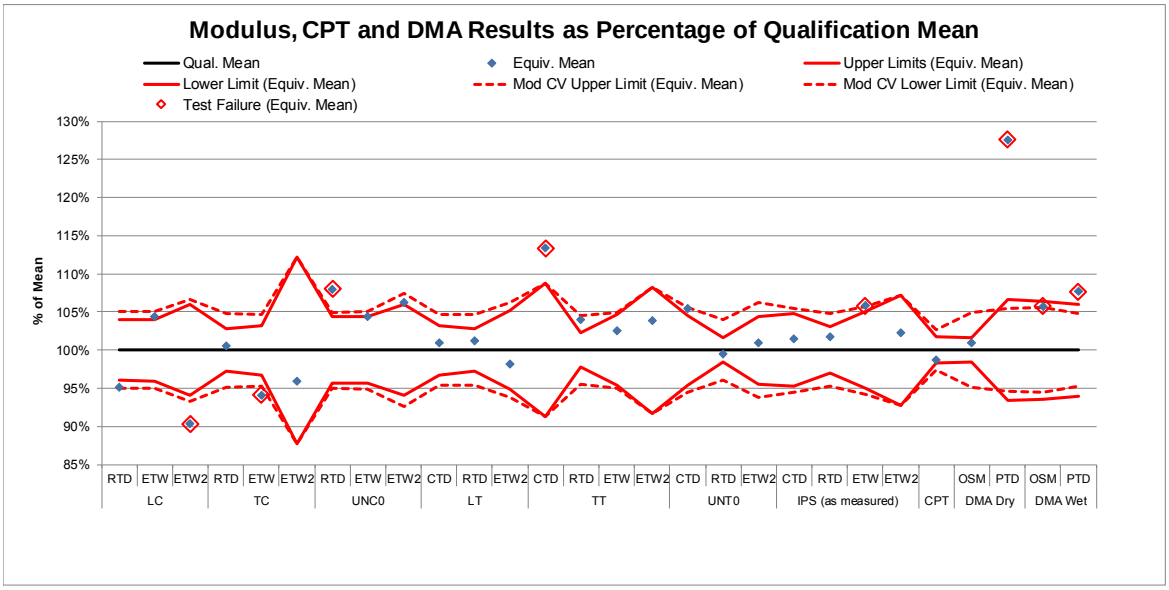

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Longitudinal Compression (LC)

The Longitudinal Compression modulus data is normalized by cured ply thickness. There is no LC strength data available other than the values computed using the backout formula applied to the UNC0 data. Rather than compare the results of the UNC0 derived LC strength values, the UNC0 strength data is directly compared in section 3.7. The LC normalized modulus data passed equivalency for the RTD and ETW conditions with the use of the modified CV method but failed for the ETW2 condition. Statistics and analysis results are shown for the modulus data in Table 3-3.

Longitudinal Compression (LC) Modulus	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Modulus (Msi)	17.024	16.196	17.235	17.997	19.625	17.721
Standard Deviation	0.861	0.492	0.879	0.506	1.077	0.940
Coefficient of Variation %	5.059	3.036	5.102	2.812	5.489	5.303
Minimum	14.391	15.566	14.537	17.099	17.822	16.825
Maximum	18.894	16.848	18.368	18.855	20.779	19.831
Number of Specimens	18	8	17	8	6	8
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	16.347 to 17.701		16.539 to 17.931		18.449 to 20.801	
Student's t-statistic	-2.524		2.263		-3.528	
p-value of Student's t-statistic	0.019		0.033		0.004	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	6.529		6.551		6.744	
Passing Range for Modulus Mean	16.171 to 17.877		16.364 to 18.107		18.312 to 20.938	
Modified CV Student's t-statistic	-2.004		1.808		-3.159	
p-value of Student's t-statistic	0.056		0.084		0.008	

Table 3-3 Longitudinal Compression Modulus Results

The LC modulus data for the RTD environment failed the equivalency test because the sample mean value (16.196) is below the lower acceptance limit (16.347). The equivalency sample mean value is 99.08% 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 LC modulus data for the ETW environment failed the equivalency test because the sample mean value (17.997) is above the upper acceptance limit (17.931). The equivalency sample mean value is 100.36% 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.

The LC modulus data for the ETW2 environment failed the equivalency test because the sample mean value (17.721) is below the lower acceptance limit (18.449). The equivalency sample mean value is 96.05% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 96.77% of the minimum acceptable mean value (18.312).

Figure 3-3 illustrates the 0º Compression 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.

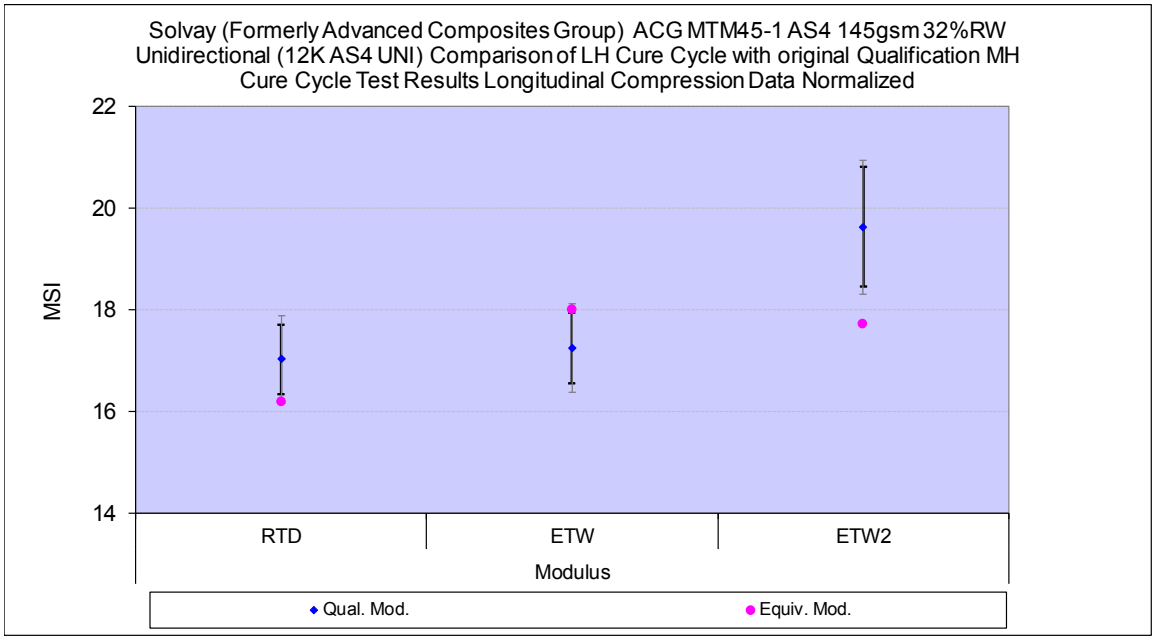

Figure 3-3 Longitudinal Compression Modulus means and Equivalence limits

3.2 Longitudinal Tension (LT)

The Longitudinal Tension data is normalized by cured ply thickness. There is no LT strength data available other than the values computed using the backout formula applied to the UNT0 data. Rather than compare the results of the UNT0 derived LT strength values, the UNT0 strength data is directly compared in section 3.8. The LT normalized modulus data passed equivalency tests for all three tested conditions. Statistics and analysis results are shown for the modulus data in Table 3-4.

Longitudinal Tension (LT) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Modulus (Msi)	18.744	18.930	18.513	18.734	21.900	21.512
Standard Deviation	0.779	0.419	0.619	0.516	1.117	1.084
Coefficient of Variation %	4.157	2.212	3.342	2.757	5.102	5.040
Minimum	17.550	18.261	17.530	18.081	19.511	20.294
Maximum	20.217	19.650	20.227	19.899	23.603	22.717
Number of Specimens	18	8	18	8	15	6
RESULTS	**PASS**		**PASS**		**PASS**	
Passing Range for Modulus Mean	18.135 to 19.352		17.995 to 19.031		20.779 to 23.021	
Student's t-statistic	0.633		0.879		-0.724	
p-value of Student's t-statistic	0.533		0.388		0.478	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.079		6.000		6.551	
Passing Range for Modulus Mean	17.880 to 19.608		17.658 to 19.369		20.534 to 23.267	
Modified CV Student's t-statistic	0.446		0.532		-0.594	
p-value of Student's t-statistic	0.660		0.600		0.559	

Table 3-4 Longitudinal Tension Modulus Results

Figure 3-4 illustrates the 0º Tension 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.

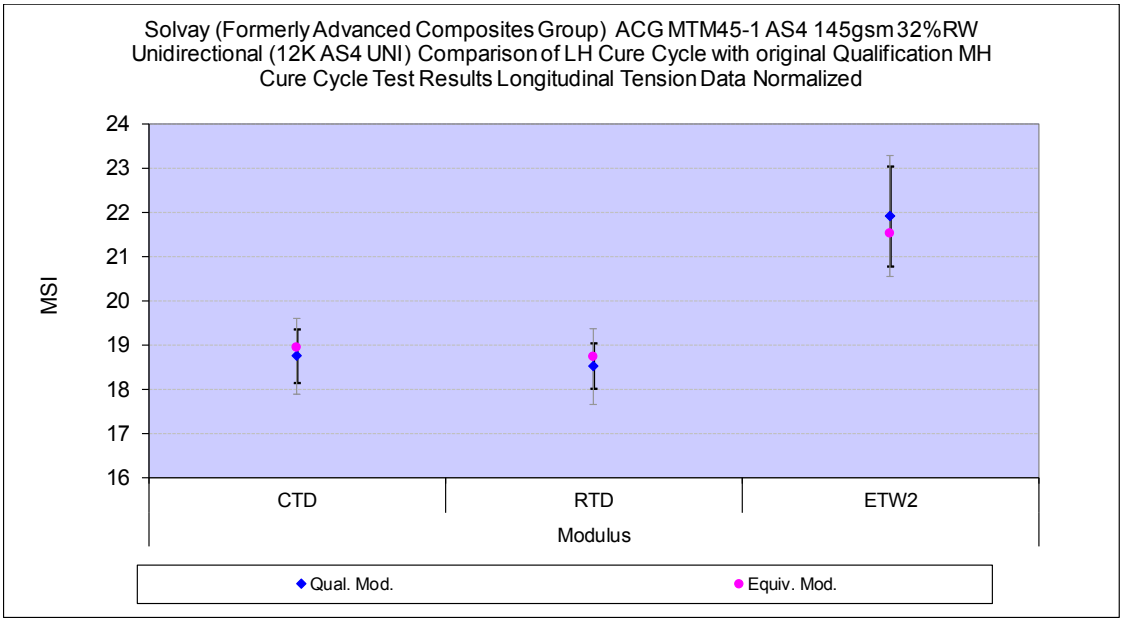

Figure 3-4 Longitudinal Tension Modulus means and Equivalence limits

3.3 Transverse Compression (TC)

The Transverse Compression data is not normalized. The TC as-measured strength data passed equivalency tests for all three tested conditions. The TC as-measured modulus data passed equivalency tests for the RTD and ETW2 conditions, but not the ETW condition. Modified CV results were not provided for the ETW2 modulus 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.

Transverse Compression (TC) Strength	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	26.810	26.873	14.956	14.911	12.302	12.152
Standard Deviation	1.321	1.380	0.637	0.305	0.532	0.531
Coefficient of Variation %	4.929	5.135	4.262	2.049	4.322	4.369
Minimum	23.888	24.050	13.438	14.466	11.294	11.071
Maximum	28.203	28.398	15.961	15.347	13.054	12.629
Number of Specimens	18	8	18	8	24	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	25.912		14.523		11.941	
Minimum Acceptable Equiv. Sample Min	23.242		13.235		10.867	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.465		6.131		6.161	
Minimum Acceptable Equiv. Sample Mean	25.633		14.334		11.788	
Minimum Acceptable Equiv. Sample Min	22.130		12.480		10.256	

Table 3-5 Transverse Compression Strength Results

Transverse Compression (TC) Modulus	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Modulus (Msi)	1.246	1.254	1.181	1.111	1.267	1.215
Standard Deviation	0.037	0.048	0.046	0.038	0.157	0.120
Coefficient of Variation %	2.947	3.802	3.912	3.395	12.401	9.885
Minimum	1.198	1.206	1.109	1.055	1.093	1.006
Maximum	1.332	1.351	1.280	1.160	1.446	1.363
Number of Specimens	18	8	18	8	7	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Passing Range for Modulus Mean	1.211 to 1.281		1.142 to 1.219		1.112 to 1.422	
Student's t-statistic	0.449		-3.747		-0.719	
p-value of Student's t-statistic	0.657		0.001		0.485	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		**NA**	
Modified CV%	6.000		6.000			
Passing Range for Modulus Mean	1.186 to 1.306		1.125 to 1.236			
Modified CV Student's t-statistic	0.266		-2.610			
p-value of Student's t-statistic	0.793		0.015			

Table 3-6 Transverse Compression Modulus Results

The TC modulus data for the ETW environment failed the equivalency test because the sample mean value (1.111) is below the lower acceptance limit (1.142). The equivalency sample mean value is 97.25% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 98.70% of the minimum acceptable mean value (1.125).

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

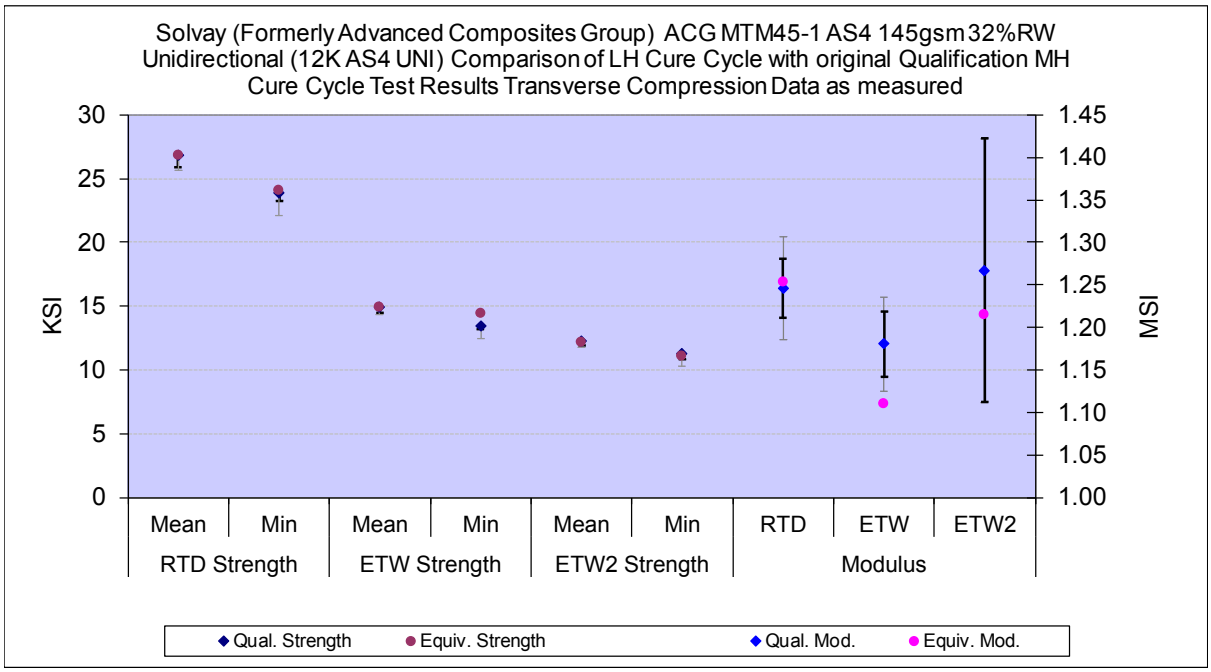

Figure 3-5 Transverse Compression means, minimums and Equivalence limits

3.4 Transverse Tension (TT)

The Transverse Tension data is not normalized. The TT as-measured strength data passed equivalency for the CTD and RTD conditions but not for the ETW or ETW2 conditions. The TT as-measured modulus data passed for the RTD, ETW and ETW2 conditions, although the RTD condition required the use of the modified CV method to pass equivalency. The TT modulus data did not pass equivalency for the CTD condition. Modified CV results were not provided for the strength data in any condition or the modulus data for the CTD and ETW2 conditions because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. The TT ETW strength dataset had only seven test results available, so the results are considered inconclusive. Statistics and analysis results are shown for the strength data in Table 3-7 and for the modulus data in Table 3-8.

Transverse Tension (TT) Strength	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured					Insufficient Data			
Mean Strength (ksi)	7.100	6.537	6.916	6.753	3.985	3.588	3.260	2.946
Standard Deviation	1.049	0.833	1.208	0.728	0.393	0.129	0.434	0.171
Coefficient of Variation %	14.773	12.741	17.466	10.778	9.855	3.592	13.318	5.801
Minimum	5.542	5.327	5.629	5.562	3.291	3.490	2.677	2.666
Maximum	8.943	8.109	9.851	7.770	4.738	3.825	4.043	3.178
Number of Specimens	18	8	18	8	21	7	18	8
RESULTS	**PASS**		**PASS**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	6.388		6.096		3.701		2.965	
Minimum Acceptable Equiv. Sample Min	4.268		3.655		2.944		2.088	

Table 3-7 Transverse Tension Strength Results

Transverse Tension (TT) Modulus	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured								
Mean Modulus (Msi)	1.254	1.421	1.151	1.197	0.992	1.017	0.942	0.978
Standard Deviation	0.134	0.117	0.035	0.011	0.070	0.014	0.102	0.038
Coefficient of Variation %	10.730	8.267	3.076	0.934	7.013	1.395	10.783	3.895
Minimum	1.078	1.246	1.099	1.176	0.891	0.986	0.800	0.922
Maximum	1.541	1.555	1.224	1.210	1.222	1.032	1.209	1.027
Number of Specimens	17	9	18	8	20	9	15	8
RESULTS	**FAIL**		**FAIL**		**PASS**		**PASS**	
Passing Range for Modulus Mean	1.144 to 1.363		1.125 to 1.178		0.944 to 1.041		0.863 to 1.020	
Student's t-statistic	3.145		3.510		1.075		0.975	
p-value of Student's t-statistic	0.004		0.002		0.292		0.341	
MOD CV RESULTS	**NA**		**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV%			6.000		7.506			
Passing Range for Modulus Mean			1.100 to 1.203		0.940 to 1.044			
Modified CV Student's t-statistic			1.826		1.005			
p-value of Student's t-statistic			0.080		0.324			

Table 3-8 Transverse Tension Modulus Results

The TT strength data for the ETW environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (3.588) is 96.94% of the minimum acceptable mean value

(3.701). The modified CV method could not be used due to the CV of the ETW condition being greater than 8%.

The TT 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 (2.946) is 99.34% of the minimum acceptable mean value (2.965). The modified CV method could not be used due to the CV of the ETW2 condition being greater than 8%.

The TT modulus data for the CTD environment failed the equivalency test because the sample mean value (1.421) is above the upper acceptance limit (1.363). The equivalency sample mean value is 104.22% of the upper limit of acceptable values. The modified CV method could not be used due to the CV of the CTD condition being greater than 8%.

The TT modulus data for the RTD environment failed the equivalency test because the sample mean value (1.197) is above the upper acceptance limit (1.178). The equivalency sample mean value is 101.59% 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.

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

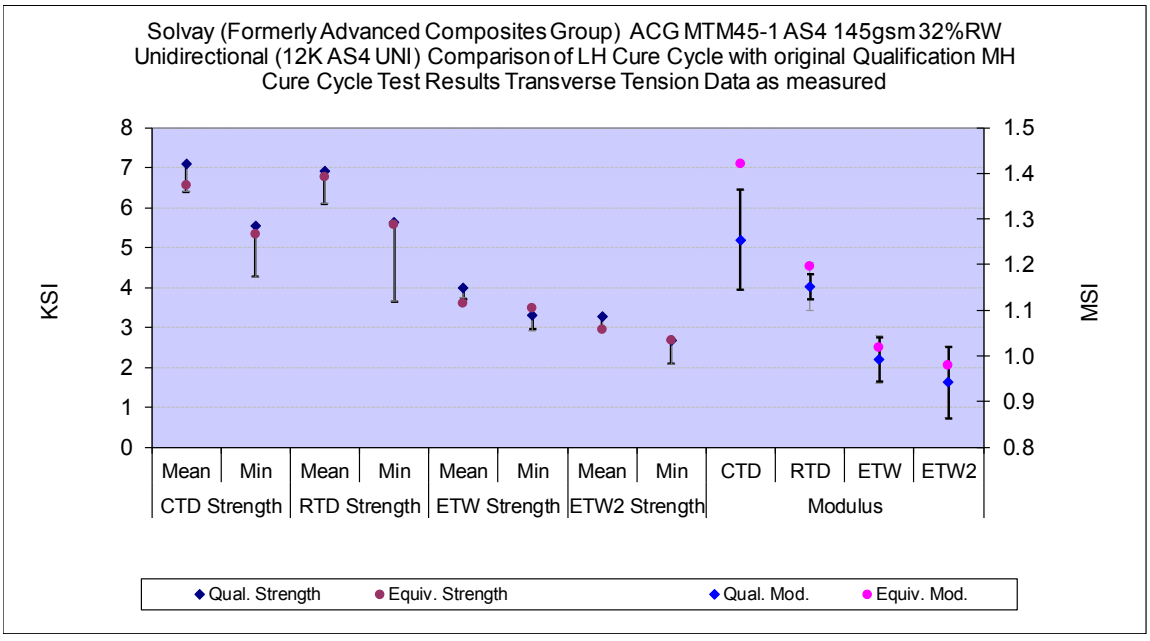

Figure 3-6 Transverse Tension means, minimums and Equivalence limits

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 of the dry test conditions, CTD, RTD and ETD, but failed for the wet test conditions, ETW and ETW2.

Statistics and analysis results for the SBS data are shown in Table 3-9.

Short Beam Strength (SBS)	CTD		RTD		ETD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured										
Mean Strength (ksi)	16.351	16.940	12.661	12.811	9.872	10.333	8.307	7.115	6.830	5.837
Standard Deviation	0.636	0.818	0.443	0.436	0.187	0.238	0.280	0.416	0.335	0.295
Coefficient of Variation %	3.892	4.832	3.500	3.406	1.898	2.304	3.374	5.843	4.910	5.061
Minimum	15.251	15.517	11.828	12.321	9.468	10.052	7.730	6.485	6.348	5.380
Maximum	17.395	18.030	13.380	13.717	10.175	10.717	8.848	7.597	7.459	6.245
Number of Specimens	18	8	18	8	18	8	18	8	18	8
RESULTS	**PASS**		**PASS**		**PASS**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	15.919		12.361		9.745		8.117		6.602	
Minimum Acceptable Equiv. Sample Min	14.632		11.465		9.366		7.551		5.925	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**		**FAIL**	
Modified CV%	6.000		6.000		6.000		6.000		6.455	
Minimum Acceptable Equiv. Sample Mean	15.685		12.146		9.470		7.969		6.531	
Minimum Acceptable Equiv. Sample Min	13.702		10.610		8.273		6.962		5.640	

Table 3-9 Lamina Short Beam Strength Results

The SBS 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 (7.115) is 89.29% of the minimum acceptable mean value (7.969) and the equivalency sample minimum (6.485) is 93.15% of the lowest acceptable minimum value (6.962).

The SBS 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 (5.837) is 89.38% of the minimum acceptable mean value (6.531) and the equivalency sample minimum (5.380) is 95.40% of the lowest acceptable minimum value (5.640).

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.

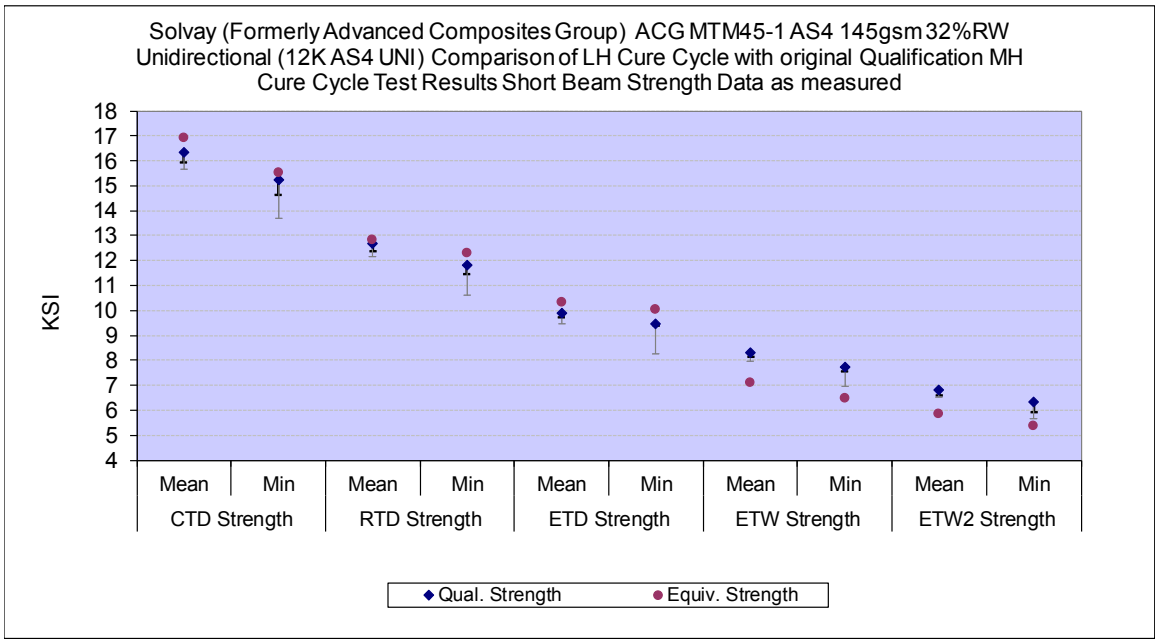

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS 0.2% Offset Strength data passed equivalency tests in all four tested conditions, and the Strength at 5% Strain data passed for the RTD, ETW and ETW2 conditions but not for the CTD condition. The IPS modulus data passed for the CTD, RTD and ETW2 conditions but not for the ETW condition. Modified CV results were not provided for 0.2% Offset Strength in the CTD condition or for Strength at 5% Strain and Modulus in the ETW2 condition because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown.

Statistics and analysis results are shown for the 0.2% Offset Strength data in Table 3-10, for the Strength at 5% Strain data in Table 3-11, and for the Modulus data in Table 3-12.

In-Plane Shear (IPS) 0.2% Offset Strength	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured								
Mean Strength 0.2% offset (ksi)	9.235	8.822	6.671	6.812	3.764	3.941	3.313	3.313
Standard Deviation	1.014	0.312	0.126	0.086	0.094	0.102	0.232	0.114
Coefficient of Variation %	10.982	3.541	1.884	1.256	2.491	2.577	7.001	3.452
Minimum	7.318	8.409	6.404	6.720	3.613	3.807	3.027	3.157
Maximum	10.888	9.327	6.850	6.920	3.918	4.094	3.801	3.479
Number of Specimens	19	8	18	8	19	8	24	9
RESULTS	**PASS**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	8.546		6.585		3.700		3.165	
Minimum Acceptable Equiv. Sample Min	6.497		6.331		3.511		2.678	
MOD CV RESULTS	**NA**		**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %			6.000		6.000		7.501	
Minimum Acceptable Equiv. Sample Mean			6.399		3.611		3.154	
Minimum Acceptable Equiv. Sample Min			5.590		3.154		2.632	

Table 3-10 In-Plane Shear 0.2% Offset Strength Results

In-Plane Shear (IPS) Strength at 5% Strain	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured								
Mean Strength 5% Strain (ksi)	13.138	12.545	9.357	9.536	5.308	5.480	4.645	4.661
Standard Deviation	0.497	0.384	0.364	0.269	0.147	0.225	0.438	0.319
Coefficient of Variation %	3.783	3.060	3.890	2.820	2.768	4.100	9.425	6.853
Minimum	12.280	11.910	8.820	9.170	5.050	5.240	4.170	4.190
Maximum	14.280	13.100	9.860	9.840	5.620	5.890	5.530	5.270
Number of Specimens	14	8	18	8	19	8	15	8
RESULTS	**FAIL**		**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	12.800		9.110		5.209		4.348	
Minimum Acceptable Equiv. Sample Min	11.796		8.375		4.912		3.463	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV %	6.000		6.000		6.000			
Minimum Acceptable Equiv. Sample Mean	12.603		8.976		5.092			
Minimum Acceptable Equiv. Sample Min	11.010		7.841		4.448			

Table 3-11 In-Plane Shear Strength at 5% Strain Results

In-Plane Shear (IPS) Modulus	CTD		RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured								
Mean Modulus (Msi)	0.648	0.658	0.526	0.535	0.354	0.3741	0.328	0.335
Standard Deviation	0.039	0.024	0.018	0.019	0.021	0.020	0.030	0.026
Coefficient of Variation %	6.089	3.589	3.412	3.462	5.892	5.329	9.278	7.860
Minimum	0.560	0.624	0.485	0.493	0.292	0.340	0.271	0.270
Maximum	0.710	0.690	0.556	0.555	0.378	0.395	0.395	0.358
Number of Specimens	19	8	18	8	19	8	24	9
RESULTS	**PASS**		**PASS**		**FAIL**		**PASS**	
Passing Range for Modulus Mean	0.617 to 0.679		0.510 to 0.542		0.336 to 0.372		0.304 to 0.351	
Student's t-statistic	0.653		1.185		2.362		0.645	
p-value of Student's t-statistic	0.520		0.248		0.026		0.524	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**		**NA**	
Modified CV%	7.045		6.000		6.946			
Passing Range for Modulus Mean	0.612 to 0.683		0.501 to 0.551		0.333 to 0.3739			
Modified CV Student's t-statistic	0.574		0.757		2.081			
p-value of Student's t-statistic	0.571		0.457		0.048			

Table 3-12 In-Plane Shear Modulus Results

The IPS strength at 5% strain data for the CTD environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (12.545) is 98.01% of the minimum acceptable mean value (12.800). Under the assumption of the modified CV method, the equivalency sample mean is 99.54% of the minimum acceptable mean value (12.603).

The IPS modulus data for the ETW environment failed the equivalency test because the sample mean value (0.3741) is above the upper acceptance limit (0.372). The equivalency sample mean value is 100.71% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.06% of the maximum acceptable mean value (0.3739).

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.

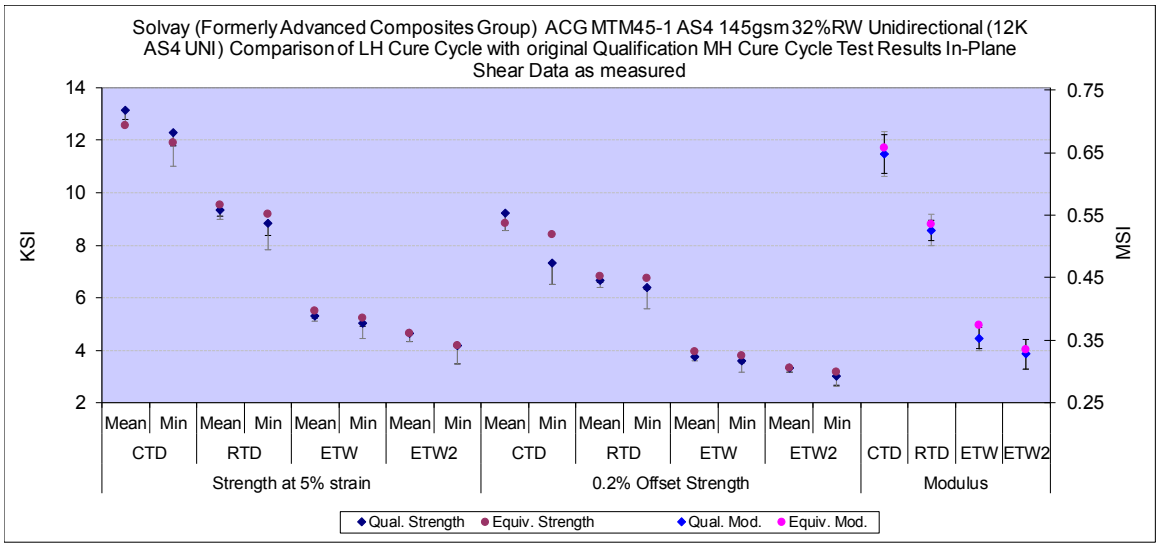

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

3.7 "50/0/50" Unnotched Compression 0 (UNC0)

The Unnotched Compression data is normalized by cured ply thickness. The UNC0 normalized strength data passed equivalency tests for all three conditions tested. The UNC0 modulus data passed equivalency tests for the ETW and ETW2 conditions but not the RTD condition, with the ETW2 dataset requiring the use of the modified CV method to pass. 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.

Statistics and analysis results are shown for strength in Table 3-13 and for modulus in Table 3-14.

Unnotched Compression (UNC0) Strength	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Strength (ksi)	107.573	105.930	76.185	75.764	70.048	76.674
Standard Deviation	5.715	5.672	6.085	7.560	6.774	4.082
Coefficient of Variation %	5.313	5.354	7.987	9.979	9.671	5.323
Minimum	97.654	94.925	63.870	64.909	57.622	69.051
Maximum	117.799	113.486	94.269	87.198	87.904	82.984
Number of Specimens	24	9	24	10	24	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	103.909		72.479		65.448	
Minimum Acceptable Equiv. Sample Min	91.907		59.285		51.757	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV %	6.656		7.994			
Minimum Acceptable Equiv. Sample Mean	102.983		72.476			
Minimum Acceptable Equiv. Sample Min	87.946		59.272			

Table 3-13 Unnotched Compression 0 Strength Results

Unnotched Compression (UNC0) Modulus	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Modulus (Msi)	9.015	9.739	9.676	10.095	9.986	10.609
Standard Deviation	0.555	0.235	0.548	0.423	0.472	0.329
Coefficient of Variation %	6.161	2.417	5.666	4.188	4.725	3.098
Minimum	8.209	9.301	8.697	9.564	9.522	10.241
Maximum	10.719	10.030	10.603	10.847	10.706	11.069
Number of Specimens	24	9	20	9	5	5
RESULTS	**FAIL**		**PASS**		**FAIL**	
Passing Range for Modulus Mean	8.622 to 9.408		9.252 to 10.099		9.393 to 10.579	
Student's t-statistic	3.754		2.030		2.424	
p-value of Student's t-statistic	0.001		0.052		0.042	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.081		6.833		6.362	
Passing Range for Modulus Mean	8.566 to 9.464		9.181 to 10.170		9.248 to 10.724	
Modified CV Student's t-statistic	3.290		1.738		1.949	
p-value of Student's t-statistic	0.003		0.094		0.087	

Table 3-14 Unnotched Compression 0 Modulus Results

The UNC0 modulus data for the RTD environment failed the equivalency test because the sample mean value (9.739) is above the upper acceptance limit (9.408). The equivalency sample mean value is 103.51% of the upper limit of acceptable values.

Under the assumption of the modified CV method, the equivalency sample mean is 102.91% of the maximum acceptable mean value (9.464).

The UNC0 modulus data for the ETW2 environment failed the equivalency test because the sample mean value (10.609) is above the upper acceptance limit (10.579). The equivalency sample mean value is 100.29% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the ETW2 environment passed the equivalence test.

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

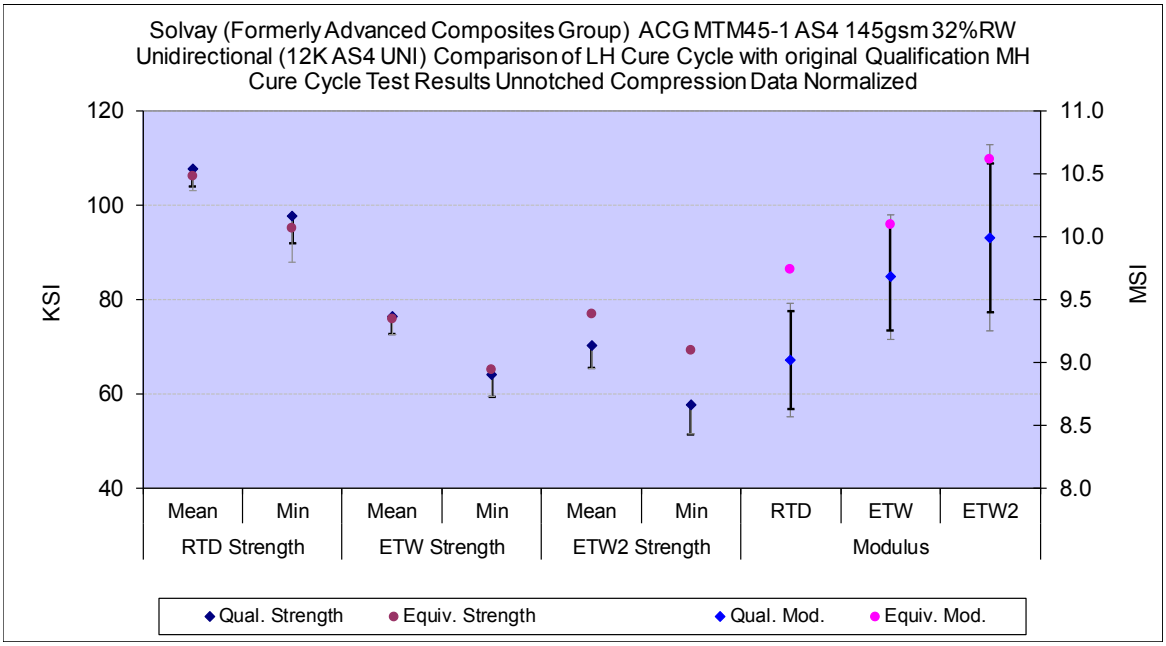

Figure 3-9 Unnotched Compression 0 means, minimums and Equivalence limits

3.8 "50/0/50" Unnotched Tension 0 (UNT0)

The Unnotched Tension data is normalized by cured ply thickness. The UNT0 normalized strength data passed equivalency tests only for the CTD condition, not for the RTD or ETW2 conditions. The UNT0 normalized modulus data passed equivalency tests for all three conditions tested although the CTD condition required the use of the modified CV method. Statistics and analysis results are shown for strength in Table 3-15 and for modulus in Table 3-16.

Unnotched Tension (UNT0) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Strength (ksi)	141.409	150.980	144.688	136.513	133.733	124.389
Standard Deviation	8.488	5.674	7.554	4.579	4.285	5.488
Coefficient of Variation %	6.003	3.758	5.221	3.354	3.204	4.412
Minimum	124.829	141.268	120.235	129.579	122.496	117.994
Maximum	157.668	158.361	154.907	142.605	141.492	131.740
Number of Specimens	21	8	19	9	18	9
RESULTS	**PASS**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	135.645		139.845		130.986	
Minimum Acceptable Equiv. Sample Min	118.490		123.982		121.987	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**		**FAIL**	
Modified CV %	7.001		6.610		6.000	
Minimum Acceptable Equiv. Sample Mean	134.686		138.557		128.589	
Minimum Acceptable Equiv. Sample Min	114.677		118.471		111.739	

Table 3-15 Unnotched Tension 0 Strength Results

Unnotched Tension (UNT0) Modulus	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Modulus (Msi)	10.073	10.627	9.897	9.851	10.975	11.082
Standard Deviation	0.536	0.415	0.219	0.170	0.387	0.486
Coefficient of Variation %	5.323	3.901	2.212	1.721	3.530	4.382
Minimum	9.170	9.985	9.528	9.538	10.359	10.517
Maximum	11.202	11.045	10.405	10.086	11.391	11.769
Number of Specimens	20	7	23	10	9	6
RESULTS	**FAIL**		**PASS**		**PASS**	
Passing Range for Modulus Mean	9.612 to 10.534		9.738 to 10.056		10.488 to 11.462	
Student's t-statistic	2.474		-0.583		0.474	
p-value of Student's t-statistic	0.021		0.564		0.643	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.662		6.000		6.000	
Passing Range for Modulus Mean	9.513 to 10.633		9.504 to 10.290		10.294 to 11.656	
Modified CV Student's t-statistic	2.036		-0.236		0.339	
p-value of Student's t-statistic	0.052		0.815		0.740	

Table 3-16 Unnotched Tension 0 Modulus Results

The UNT0 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 (136.513) is 97.62% of the minimum acceptable mean value (139.845). Under the assumption of the modified CV method, the equivalency sample mean is 98.53% of the minimum acceptable mean value (138.557).

The UNT0 strength data for the ETW2 environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean

(124.389) is 94.96% of the minimum acceptable mean value (130.986) and the equivalency sample minimum (117.994) is 96.73% of the lowest acceptable minimum value (121.987). Under the assumption of the modified CV method, the equivalency sample mean is 96.73% of the minimum acceptable mean value (128.589) and the equivalency sample minimum value is acceptable.

The UNT0 modulus data for the CTD environment failed the equivalency test because the sample mean value (10.627) is above the upper acceptance limit (10.534). The equivalency sample mean value is 100.88% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the CTD environment passed the equivalence test.

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

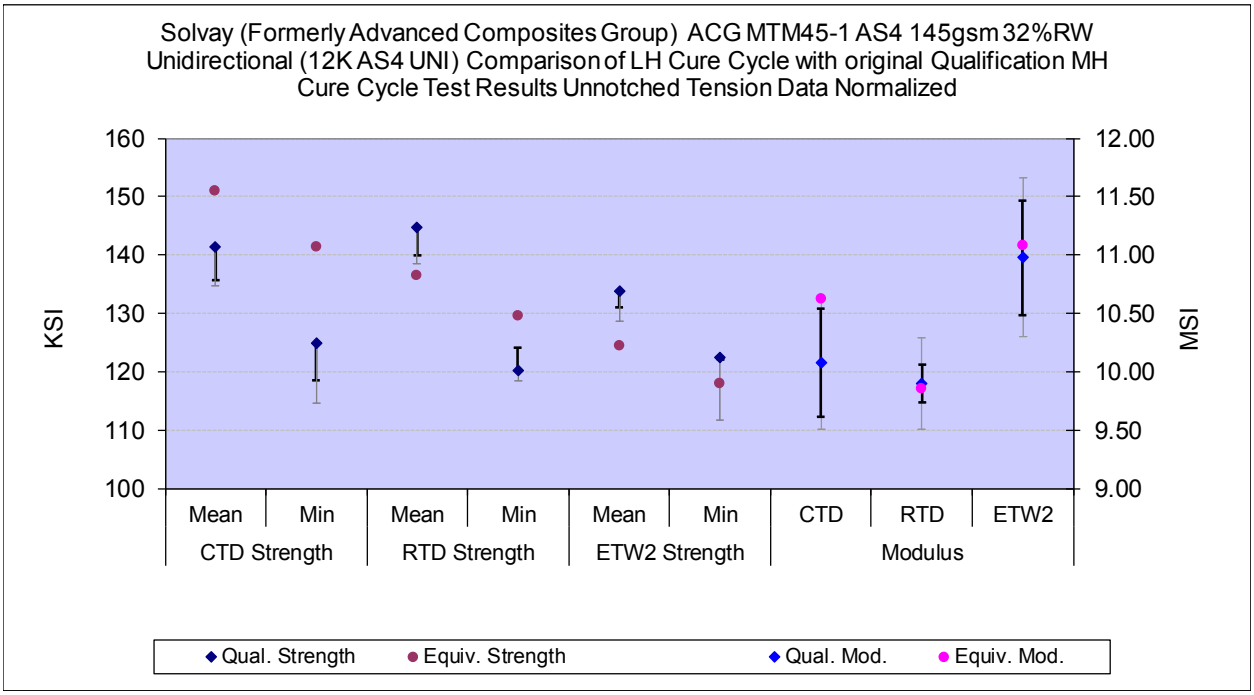

Figure 3-10 Unnotched Tension 0 means, minimums and Equivalence limits

3.9 "25/50/25" Open Hole Tension 1 (OHT1)

The Open Hole Tension data is normalized by cured ply thickness. The OHT1 normalized strength data passed equivalency tests for all three tested conditions. Statistics and analysis results for the OHT1 strength data are shown in Table 3-17.

Open Hole Tension (OHT1) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Strength (ksi)	57.485	59.158	57.388	56.756	54.959	55.728
Standard Deviation	1.509	1.044	1.236	1.217	1.661	1.827
Coefficient of Variation %	2.625	1.764	2.154	2.144	3.023	3.279
Minimum	54.426	58.207	54.448	55.596	52.589	53.362
Maximum	60.395	61.542	59.478	59.350	60.048	58.728
Number of Specimens	18	8	18	8	18	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	56.460		56.549		53.831	
Minimum Acceptable Equiv. Sample Min	53.410		54.050		50.473	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	55.143		55.050		52.720	
Minimum Acceptable Equiv. Sample Min	48.172		48.091		46.056	

Table 3-17 Open Hole Tension 1 Strength Results

Figure 3-11 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.

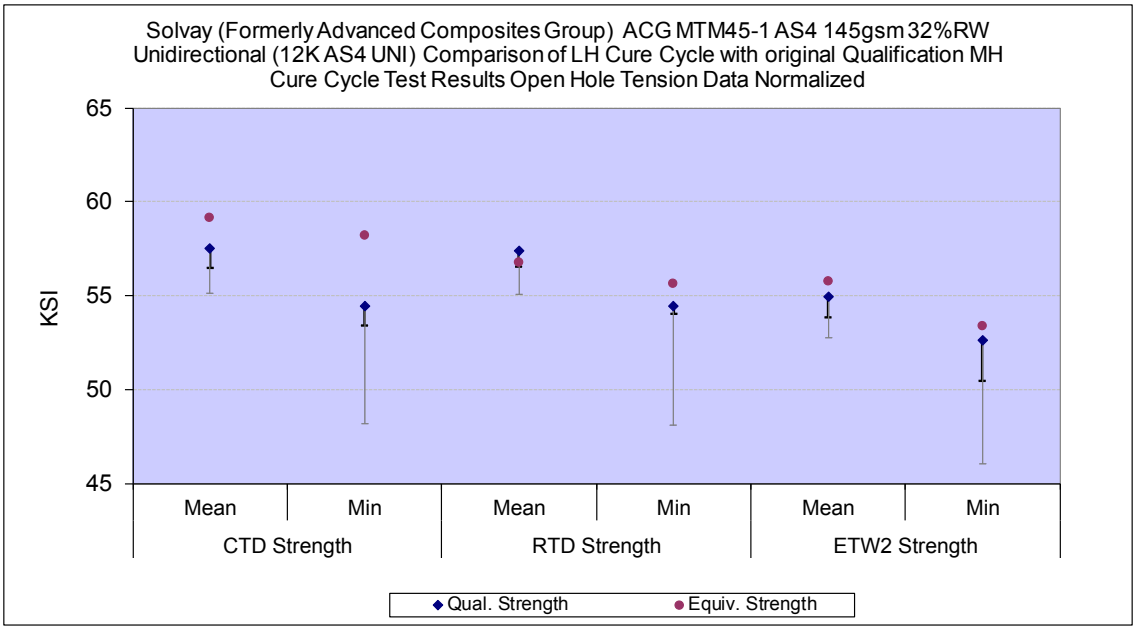

Figure 3-11 Open Hole Tension 1 means, minimums and Equivalence limits

3.10 "25/50/25" Open Hole Compression 1 (OHC1)

The Open Hole Compression data is normalized by cured ply thickness. The OHC1 normalized strength data passed equivalency tests for all three tested conditions although the ETW condition required the use of the modified CV method. The ETW condition had test values from only six specimens available in the qualification dataset, which is insufficient to meet the requirements of CMH-17-1G, so that result is not considered conclusive. Statistics and analysis results for the OHC1 strength data are shown in Table 3-18.

Open Hole Compression (OHC1) Strength	RTD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055			Insufficient Data			
Mean Strength (ksi)	43.760	43.019	37.991	36.731	34.571	35.391
Standard Deviation	1.998	1.147	1.609	1.133	1.639	1.097
Coefficient of Variation %	4.567	2.666	4.236	3.084	4.741	3.101
Minimum	40.190	41.614	35.322	35.529	30.876	33.253
Maximum	48.108	44.699	39.897	38.531	37.802	36.584
Number of Specimens	18	8	6	8	18	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	42.403		36.898		33.458	
Minimum Acceptable Equiv. Sample Min	38.364		33.646		30.146	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.283		6.118		6.370	
Minimum Acceptable Equiv. Sample Mean	41.893		36.413		33.076	
Minimum Acceptable Equiv. Sample Min	36.336		31.715		28.625	

Table 3-18 Open Hole Compression 1 Strength Results

The OHC1 strength data for the ETW environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (36.731) is 99.55% of the minimum acceptable mean value (36.898). Under the assumption of the modified CV method, the strength data from the ETW environment passed the equivalence test.

Figure 3-12 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.

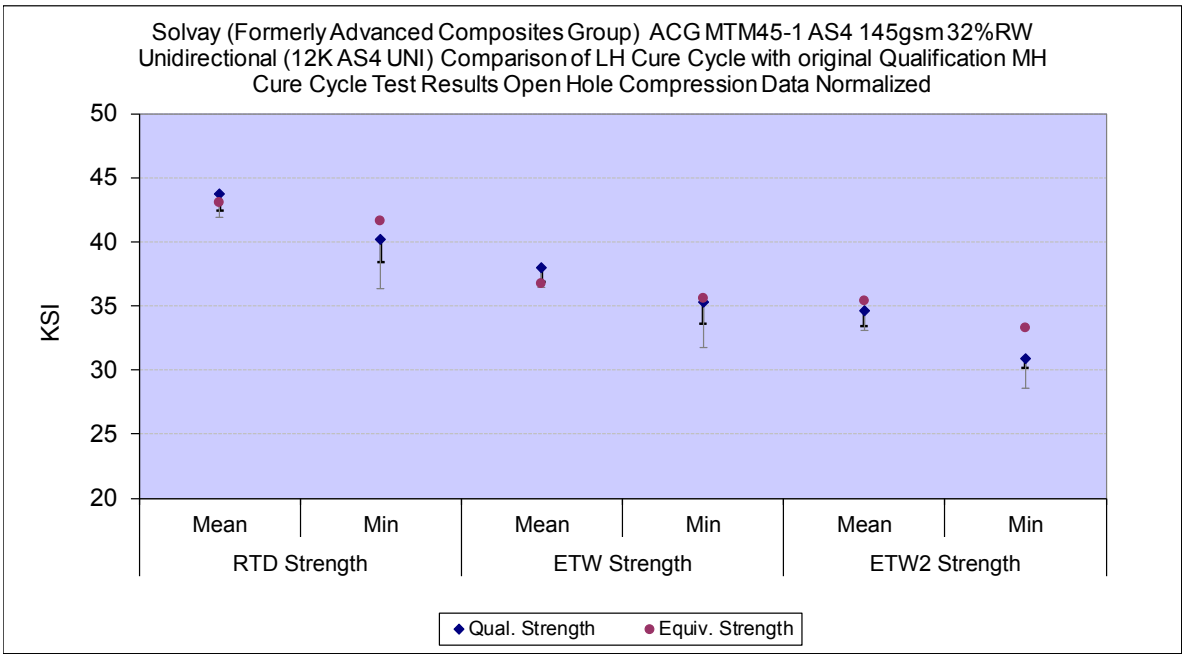

Figure 3-12 Open Hole Compression 1 means, minimums and Equivalence limits

3.11 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 both the RTD and ETW2 conditions. There was insufficient data for these results to be considered conclusive. Modified CV results were not provided because the coefficient of variation was above 8% for all test properties and conditions, which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for both the ILT and the CBS data in Table 3-19.

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)	6.891	7.625	3.895	4.022	287.343	291.644	163.190	152.267
Standard Deviation	0.909	0.566	0.386	0.390	36.594	26.458	14.482	12.748
Coefficient of Variation %	13.186	7.427	9.899	9.699	12.735	9.072	8.874	8.372
Minimum	5.386	6.965	3.278	3.701	227.963	262.129	137.844	141.332
Maximum	8.041	8.312	4.459	4.550	335.803	324.121	181.140	170.256
Number of Specimens	6	4	6	4	6	4	6	4
RESULTS	PASS		PASS		PASS		PASS	
Minimum Acceptable Equiv. Sample Mean	6.029		3.530		252.629		149.453	
Minimum Acceptable Equiv. Sample Min	4.672		2.954		197.979		127.826	

Table 3-19 Interlaminar Tension and Curved Beam Strength Results

Figure 3-13 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.

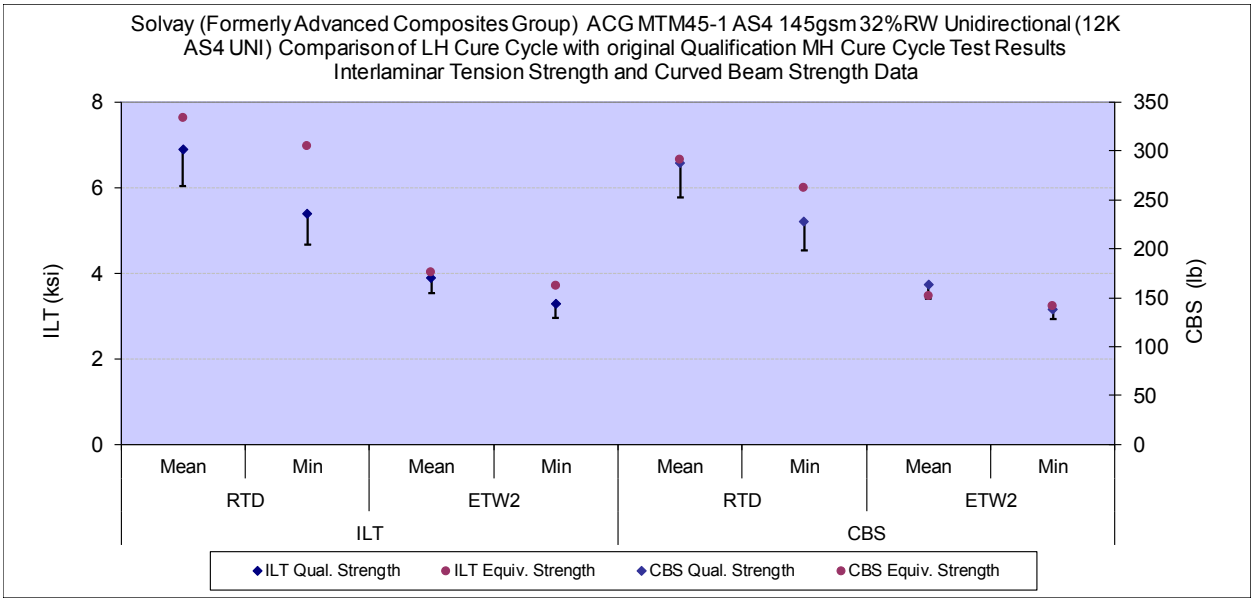

Figure 3-13 Interlaminar Tension and Curved Beam Strength means, minimums and Equivalence limits

3.12 Compression After Impact (CAI)

The Compression After Impact data is normalized by cured ply thickness. The CAI normalized strength data did not pass equivalency tests for the RTD condition. There was insufficient data for the result to be considered conclusive. Statistics and analysis results for the CAI strength data are shown in Table 3-20.

Compression After Impact (CAI) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0055	Insufficient Data	
Mean Strength (ksi)	31.095	26.720
Standard Deviation	2.183	1.992
Coefficient of Variation %	7.021	7.456
Minimum	26.898	24.878
Maximum	33.553	28.483
Number of Specimens	7	4
RESULTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	29.024	
Minimum Acceptable Equiv. Sample Min	25.764	
MOD CV RESULTS	**FAIL**	
Modified CV%	7.510	
Minimum Acceptable Equiv. Sample Mean	28.880	
Minimum Acceptable Equiv. Sample Min	25.392	

Table 3-20 Compression After Impact Strength Results

The CAI strength data for the RTD 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 (26.720) is 92.52% of the minimum acceptable mean value (28.880) and the equivalency sample minimum (24.878) is 97.98% of the lowest acceptable minimum value (25.392).

Figure 3-14 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.

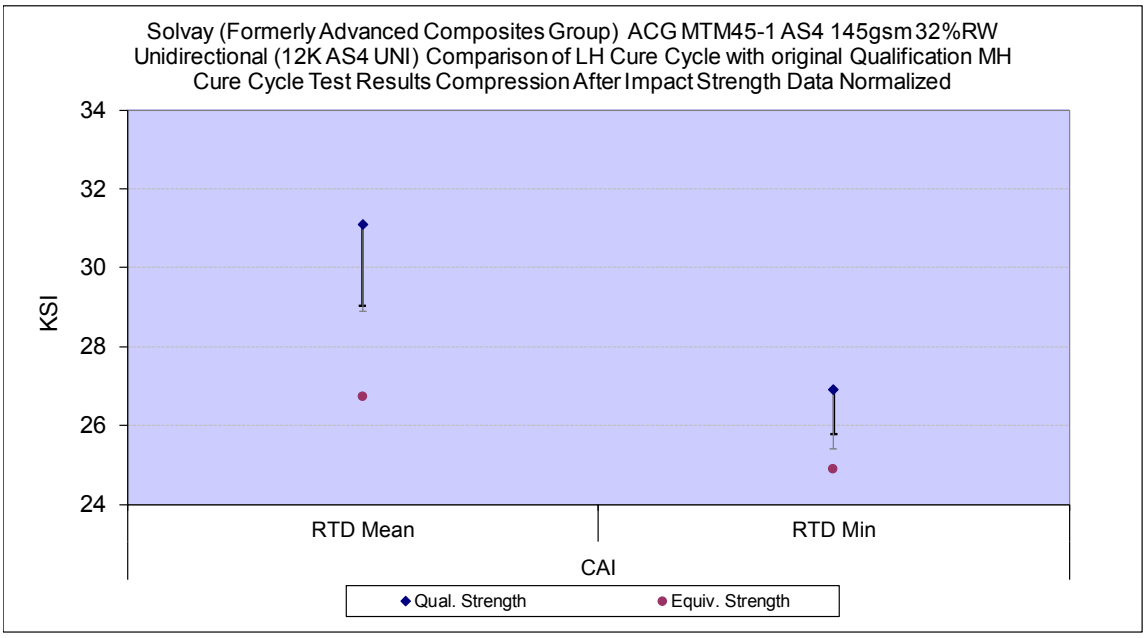

Figure 3-14 Compression After Impact means, minimums and Equivalence limits

3.13 Cured Ply Thickness (CPT)

The Cured Ply Thickness can be considered equivalent according to the results of a pooled two-sample double-sided t-test at a 95% confidence level. Statistics for both the original qualification material MH cure cycle and the LH cure cycle equivalency sample are shown in Table 3-21. The average CPT with 95% standard error bars is shown in Figure 3-15. The longer, lighter colored error bars are for the modified CV computations.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.005478	0.005406
Standard Deviation	0.00021	0.00011
Coefficient of Variation %	3.76079	1.97649
Minimum	0.00458	0.00522
Maximum	0.00588	0.00565
Number of Specimens	40	22
RESULTS	**PASS**	
Passing Range for CPT Mean	0.005383 to 0.005572	
Student's t-statistic	-1.526	
p-value of Student's t-statistic	0.13214	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.005333 to 0.005622	
Modified CV Student's t-statistic	-0.996	
p-value of Student's t-statistic	0.323	

Table 3-21 Cured Ply Thickness Results

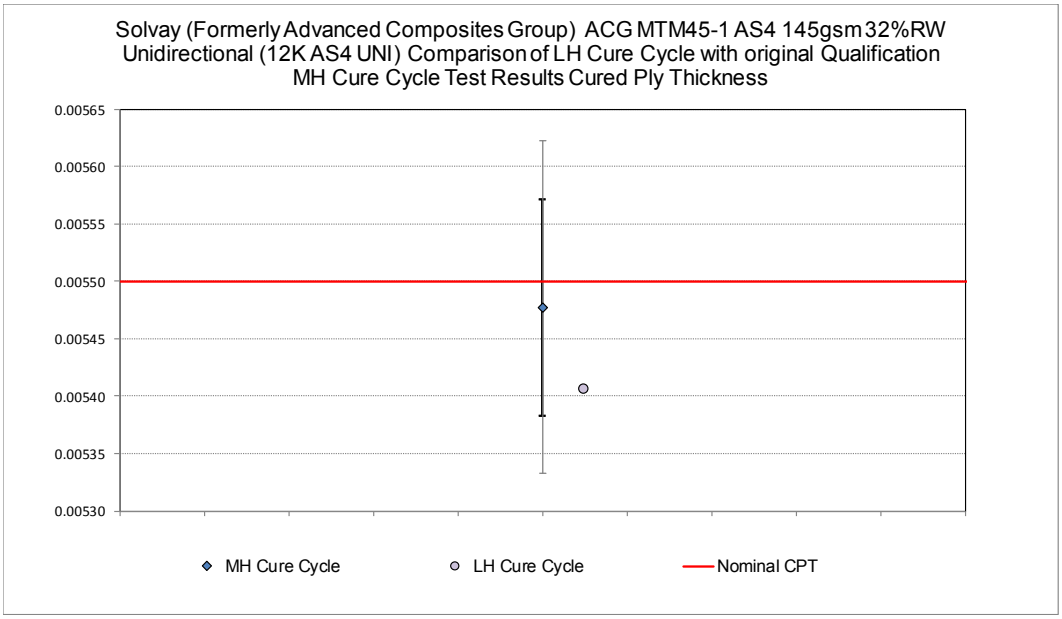

Figure 3-15 CPT means, 95% standard error bars and nominal value

3.14 Dynamic Mechanical Analysis (DMA)

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

The Onset of Storage Modulus datasets pass equivalency tests while the Peak of Tangent Delta datasets do not. Statistics for both the original qualification material and the equivalency sample are shown in Table 3-22.

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)	369.948	373.475	329.927	420.950	326.389	345.106	377.131	406.033
Standard Deviation	6.033	2.680	21.879	5.131	18.191	24.879	20.432	22.212
Coefficient of Variation %	1.631	0.718	6.632	1.219	5.573	7.209	5.418	5.470
Minimum	362.300	370.394	298.544	414.566	298.538	324.074	349.148	379.616
Maximum	382.586	376.880	392.000	425.540	391.952	372.788	430.856	425.756
Number of Specimens	145	4	145	4	26	4	26	4
RESULTS	**PASS**		**FAIL**		**PASS**		**FAIL**	
Passing Range for DMA Mean	363.954 to 375.942		308.224 to 351.631		305.464 to 347.315		354.434 to 399.827	
Student's t-statistic	1.163		8.288		1.832		2.608	
p-value of Student's t-statistic	0.247		6.62E-14		0.078		0.014	
Range = ±18°F RESULTS	**PASS Range = ±18°F**		**FAIL**		**FAIL**		**FAIL**	
Passing Range for DMA Mean	351.948 to 387.948		311.927 to 347.927		308.389 to 344.389		359.131 to 395.131	

Table 3-22 DMA Results

The Onset Storage Modulus for wet data passed the 95% t-test for equivalency but failed the equivalency test with the allowable range set to ±18°F. The equivalency sample mean (345.106) was 100.21% of the qualification mean value + 18°F (344.389).

The Peak of Tangent Delta for dry data failed the equivalency test because the sample mean value (420.950) is above the upper acceptance limit (351.631). The equivalency sample mean is 119.71% of the upper limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 120.99% of the maximum mean value (347.927).

The Peak of Tangent Delta for wet data failed the equivalency test because the sample mean value (406.033) is above the upper acceptance limit (399.827). The equivalency sample mean is 101.55% of the upper limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 102.76% of the maximum mean value (395.131).

Figure 3-16 illustrates the average DMA values for both the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the range equal to ±18°F computations.

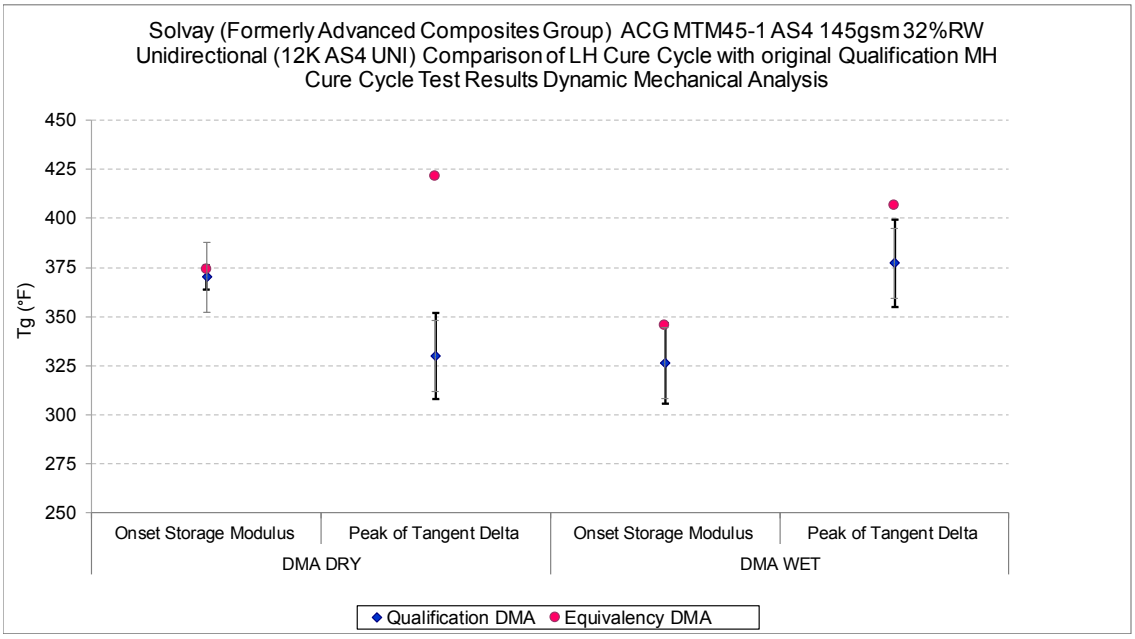

Figure 3-16 DMA Means and Equivalence limits

4. Summary of Results

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

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

4.1 The assumption of Independence

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

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

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

4.2 Failures

The LH cure cycle panels have sufficient test results for comparison with the original qualification material test results on a total of 53 different test types and conditions, not including the cured ply thickness or the DMA comparison.

Using the modified CV method, there were eleven failures. Seven of the failures were in ETW or ETW2 condition while only four were in dry conditions. Six of the failures were for strength properties while five were for modulus.

1. Longitudinal Compression Modulus for the ETW2 condition failed by 3.2%
2. Transverse Compression Modulus for the ETW condition failed by 1.3%
3. Transverse Tension Strength for the ETW2 condition failed by 0.7%
4. Transverse Tension Modulus for the CTD condition failed by 4.2%
5. In-Plane Shear Strength at 5% Strain for the CTD condition failed by 0.5%
6. In-Plane Shear Modulus for the ETW condition failed by 0.1%
7. Short Beam Strength for the ETW condition failed by 10.7%
8. Short Beam Strength for the ETW2 condition failed by 10.6%
9. Unnotched Compression Modulus for the RTD condition failed by 2.9%
10. Unnotched Tension Strength for the RTD condition failed by 1.5%
11. Unnotched Tension Strength for the ETW2 condition failed by 3.3%

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

Eleven failures out of 53 test conditions gives the LH cure cycle a pass rate of 79.25% 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 2.65 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 eleven or more failures is 0.0053%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 53 independent tests. If the two materials were equivalent, the probability of getting six 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 six or more failures out of 53 independent tests.

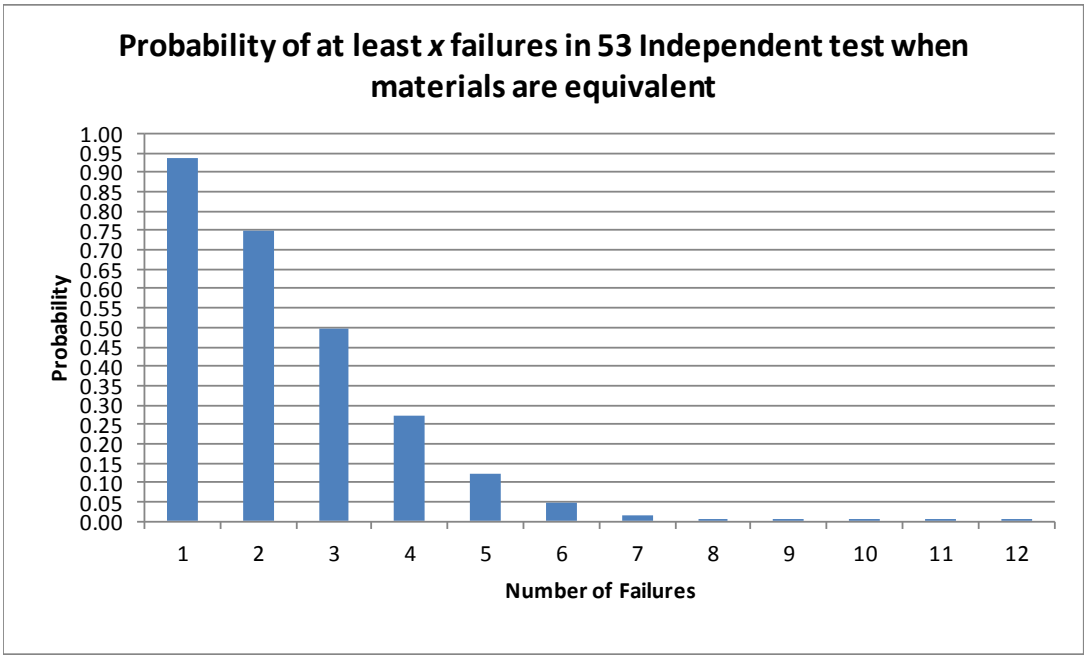

Figure 4-1 Probability of Number of Failures

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