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Solvay (Formerly Advanced Composites Group) MTM45-1/IM7-145-32%RW (12K IM7 UNI) LH cure cycle compared to MH cure cycle Equivalency Statistical Analysis Report

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1. Introduction

This report contains the equivalency test results for Solvay (formerly Advanced Composites Group) MTM45-1/IM7-145-32%RW (12K IM7 UNI) MH cure cycle compared to the “LH” 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 1001–06 Revision A dated January 19, 2005. An equivalent NCAMP material specification NMS 451/6 has been created for this material which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19.

The 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.

The qualification test panels were cured in accordance with ACG process specification ACGP 1001-02 Revision E “MH” cure cycle while the equivalency panels were cured in accordance with “LH” cure cycle. An equivalent NCAMP Process Specification, NPS 81451 with “LH” Cure Cycle, has been created. ACG Test Plan AI/TR/1392 Rev E was used for this equivalency program. However, there are some properties that were not executed in this equivalency testing:

- 0° Tension
  - CTD, RTD – Cure 2
  - ETW2 – Cure 1 and 2
- 0° Compression
  - RTD – Cure 2
  - ETW and ETW2 – Cure 1 and 2
- 90° Tension
  - ETW and ETW2 – Cure 1 and 2
- 90° Compression
  - ETW and ETW2 – Cure 1 and 2
- UNT0 Tension
  - ETW2 – Cure 1 and 2
- UNC0 Compression
  - RTD – Cure 2
  - ETW and ETW2 – Cure 1 and 2

- In-Plane Shear
  - Modulus: RTD – Cure 1 and 2
  - Strength + Modulus: CTD, ETW, and ETW2 – Cure 1 and 2
- Short Beam Strength
  - CTD, RTD, ETD – Cure 2
  - ETW and ETW2 – Cure 1 and 2
- Open Hole Tension
  - CTD and ETW2 – Cure 1 and 2
- Open Hole Compression
  - RTD – Cure 2
  - ETW and ETW2 – Cure 1 and 2
- Interlaminar Tension
  - RTD and ETW2 – Cure 2
- Compression After Impact
  - RTD and ETW2 – Cure 2

The material property data for the qualification panels is published in CAM-RP-2008-007 Rev B. The equivalency data is available in "MTM45-1 IM7-145 LH Cure Cycle Values 2-6-08.pdf". Engineering basis values were reported in NCAMP Report NCP-RP-2008-006 Rev A, which details the standards and methodology used for computing basis values as well as providing the B-basis values and A- and B- estimates computed from the test results for the original qualification panels.

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

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 451/6. NMS 451/6 has additional requirements that are listed in its prepreg process control document (PCD), fiber specification, fiber PCD, and other raw material specifications and PCDs which impose essential quality controls on the raw materials and raw material manufacturing equipment and processes. *Aircraft companies and certifying agencies should assume that the material property data published in this report is not applicable when the material is not procured to NCAMP Material Specification NMS 451/6*. NMS 451/6 is a free, publicly available, non-proprietary aerospace industry material specification.

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

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

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	OHT
Open Hole Compression	OHC
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

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

The results of the equivalency comparisons are listed as 'Pass', 'Fail', or 'Pass with Mod CV'. 'Pass with Mod CV' refers to cases where the equivalency fails unless the modified coefficient of variation method is used. A minimum of eight samples from two separate panels and processing cycles is required for strength properties and a minimum of four specimens for modulus comparison. If the sample does not have an adequate number of specimens, this will be indicated with 'Insufficient Data' after the Pass or Fail indication. A summary of all results is shown in Table 3-2.

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

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

Table 3-1 "% Failed" Results Scale

Equivalency Test Results for Solvay (Formerly Advanced Composites Group) MTM45-1/IM7-145-32%RW (12K IM7 UNI) MH Cure Cycle (qualification) with LH Cure Cycle (equivalency)					
Test	**Normalized Data**	**Property**	**Environmental Condition**		
			CTD	RTD	ETD
Longitudinal Compression	**Yes**	**Modulus**		Pass	
Longitudinal Tension	**Yes**	**Modulus**	Pass	Pass	
Transverse Compression	**No**	**Strength**		Failed by 8.8%	
		Modulus		Pass	
Transverse Tension	**No**	**Strength**	Failed by 37.8%	Failed by 39.3%	
		Modulus	Pass	Pass with Mod CV	
In-Plane Shear	**No**	**0.2% Offset Strength**		Pass	
		5% Strain Strength		Pass	
Short Beam Strength	**No**	**Strength**	Failed by 2.0% Insufficient Data	Pass with Mod CV Insufficient Data	Pass with Mod CV Insufficient Data
Unnotched Compression	**Yes**	**Strength**		Pass Insufficient Data	
	Yes	**Modulus**		Pass	
Unnotched Tension	**Yes**	**Strength**	Pass	Pass	
		Modulus	Failed by 1.7%	Pass with Mod CV	
Open Hole Compression	**Yes**	**Strength**		Failed by 11.6% Insufficient Data	
Open Hole Tension	**Yes**	**Strength**		Pass	
Cured Ply Thickness	**NA**	**NA**	Pass		
Dynamic Mechanical Analysis	**Onset Storage Modulus - Dry**		Pass with ±18°F RESULTS		
	Onset Storage Modulus - Wet		Failed by 6.3%		

Note: Not all tests indicated in the test plan were executed. See the introduction for details.

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.

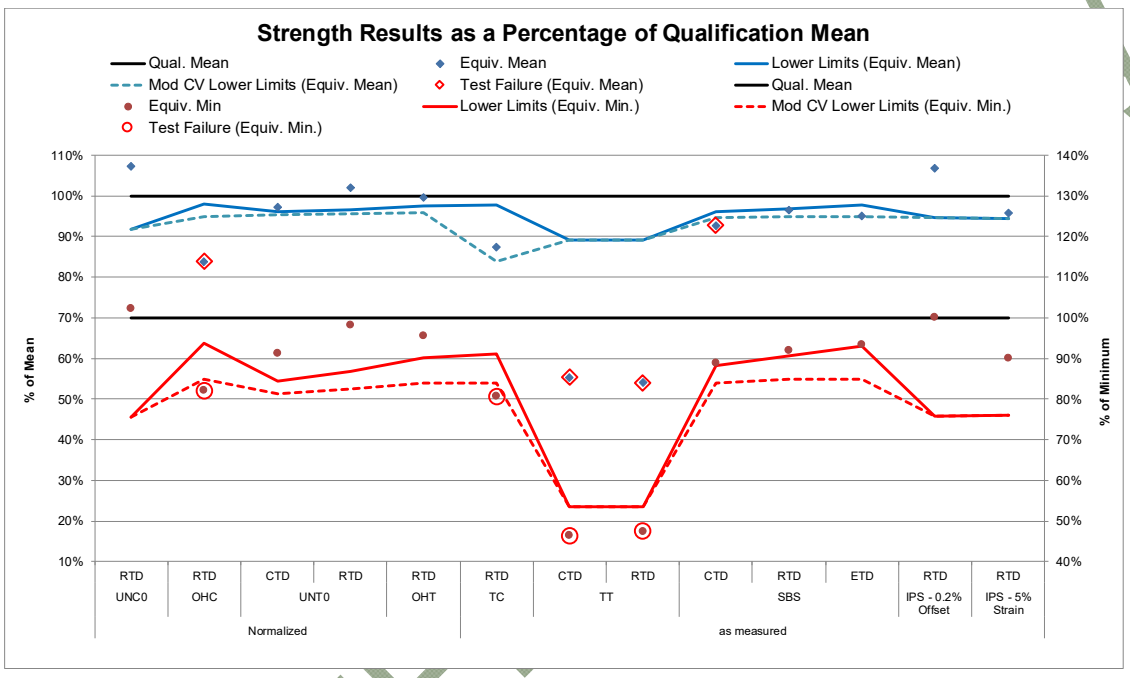

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

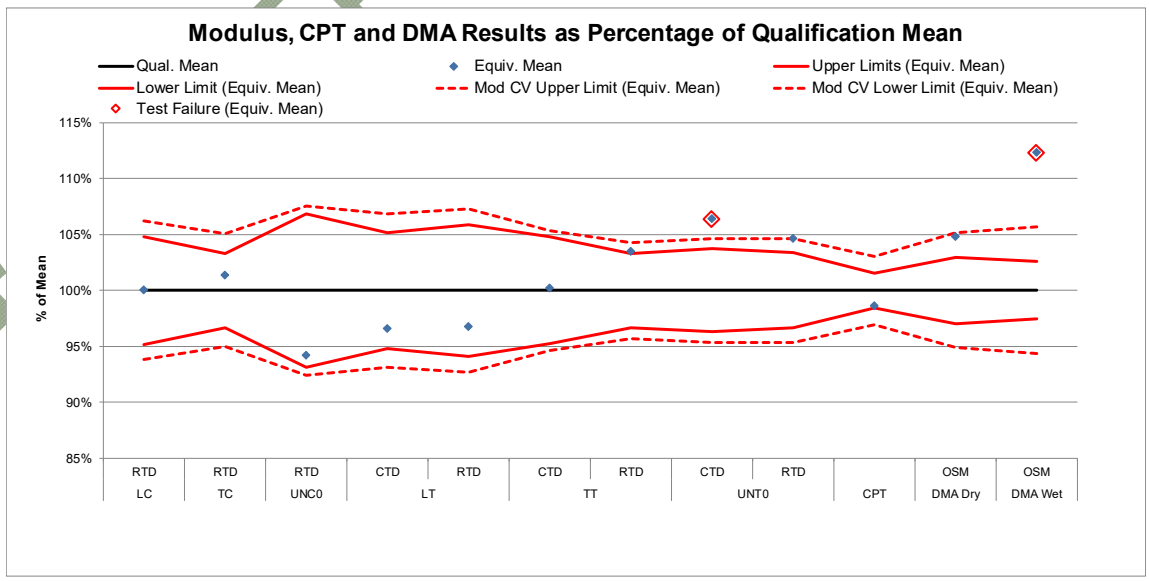

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Longitudinal Compression (LC)

The Longitudinal Compression data is normalized by cured ply thickness. The LC normalized modulus RTD data passed equivalency. 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. Statistics and analysis results are shown for the modulus data in Table 3-3.

Longitudinal Compression (LC) Modulus	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0055		
Mean Modulus (Msi)	20.237	20.234
Standard Deviation	0.984	0.825
Coefficient of Variation %	4.864	4.076
Minimum	18.011	18.928
Maximum	21.751	20.968
Number of Specimens	23	5
RESULTS	**PASS**	
Passing Range for Modulus Mean	19.262 to 21.212	
Student's t-statistic	-0.006	
p-value of Student's t-statistic	0.995	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.432	
Passing Range for Modulus Mean	18.979 to 21.495	
Modified CV Student's t-statistic	-0.004	
p-value of Student's t-statistic	0.997	

Table 3-3 Longitudinal Compression Modulus Results

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.

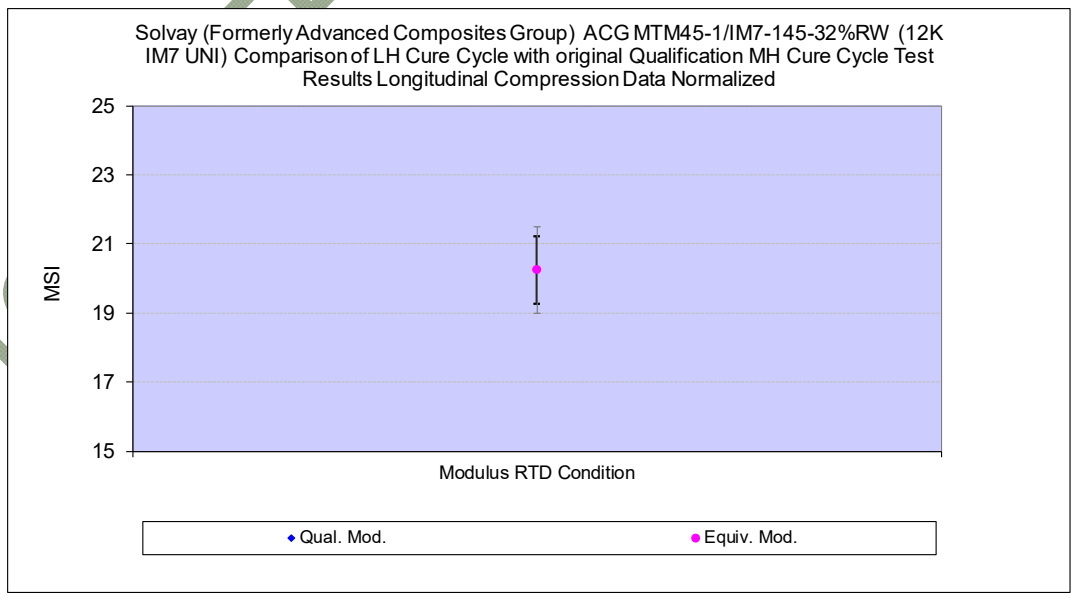

Figure 3-3 Longitudinal Compression Modulus means and Equivalence limits

3.2 Longitudinal Tension (LT)

The Longitudinal Tension data is normalized by cured ply thickness. The LT normalized modulus data passed equivalency for both the CTD and RTD conditions. There is no LT strength data available other than the values computed using the backout formula applied to the UNC0 data. Rather than compare the results of the UNT0 derived LT strength values, the UNT0 strength data is directly compared in section 3.8. Statistics and analysis results are shown for the modulus data in Table 3-4.

Longitudinal Tension (LT) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	23.364	22.564	22.899	22.144
Standard Deviation	1.124	0.306	1.210	0.791
Coefficient of Variation %	4.810	1.357	5.282	3.572
Minimum	21.961	22.217	21.459	20.987
Maximum	25.115	22.962	25.466	22.680
Number of Specimens	17	4	16	4
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	22.156 to 24.572		21.548 to 24.250	
Student's t-statistic	-1.387		-1.175	
p-value of Student's t-statistic	0.181		0.255	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.405		6.641	
Passing Range for Modulus Mean	21.761 to 24.968		21.225 to 24.573	
Modified CV Student's t-statistic	-1.045		-0.948	
p-value of Student's t-statistic	0.309		0.356	

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.

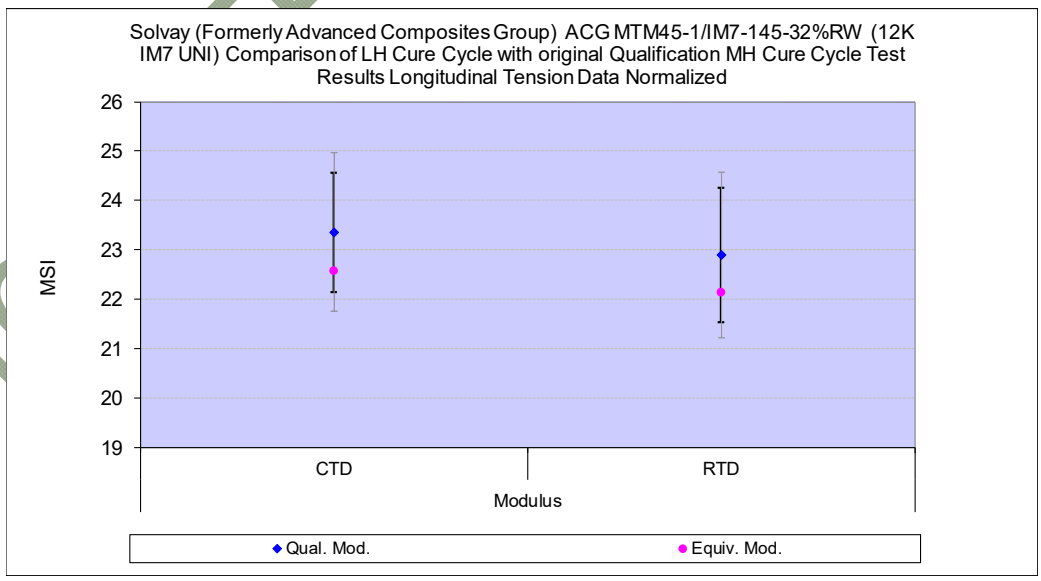

Figure 3-4 Longitudinal Tension Modulus means and Equivalence limits

3.3 Transverse Compression (TC)

The Transverse Compression data is not normalized. The TC data has results only for the RTD condition. The strength data failed equivalency tests while the modulus data passed. Statistics and analysis results are shown for strength in Table 3-5 and for modulus in Table 3-6.

Transverse Compression (TC) Strength	RTD	
	Qual.	Equiv.
Data as measured		
Mean Strength (ksi)	27.959	24.470
Standard Deviation	0.920	1.154
Coefficient of Variation %	3.292	4.718
Minimum	26.368	22.586
Maximum	29.299	25.850
Number of Specimens	18	8
RESUTTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	27.334	
Minimum Acceptable Equiv. Sample Min	25.474	
MOD CV RESUTTS	**FAIL**	
Modified CV%	6.000	
Minimum Acceptable Equiv. Sample Mean	26.820	
Minimum Acceptable Equiv. Sample Min	23.430	

Table 3-5 Transverse Compression Strength Results

Transverse Compression (TC) Modulus	RTD	
	Qual.	Equiv.
Data as measured		
Mean Modulus (Msi)	1.222	1.238
Standard Deviation	0.037	0.062
Coefficient of Variation %	3.066	5.002
Minimum	1.162	1.136
Maximum	1.305	1.304
Number of Specimens	18	8
RESUTTS	**PASS**	
Passing Range for Modulus Mean	1.181 to 1.262	
Student's t-statistic	0.819	
p-value of Student's t-statistic	0.421	
MOD CV RESUTTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for Modulus Mean	1.160 to 1.283	
Modified CV Student's t-statistic	0.536	
p-value of Student's t-statistic	0.597	

Table 3-6 Transverse Compression Modulus Results

The TC 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 (24.470) is 91.24% of the minimum acceptable mean value (26.820) and the equivalency sample minimum (22.586) is 96.40% of the lowest acceptable minimum value (23.430).

Figure 3-9 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.

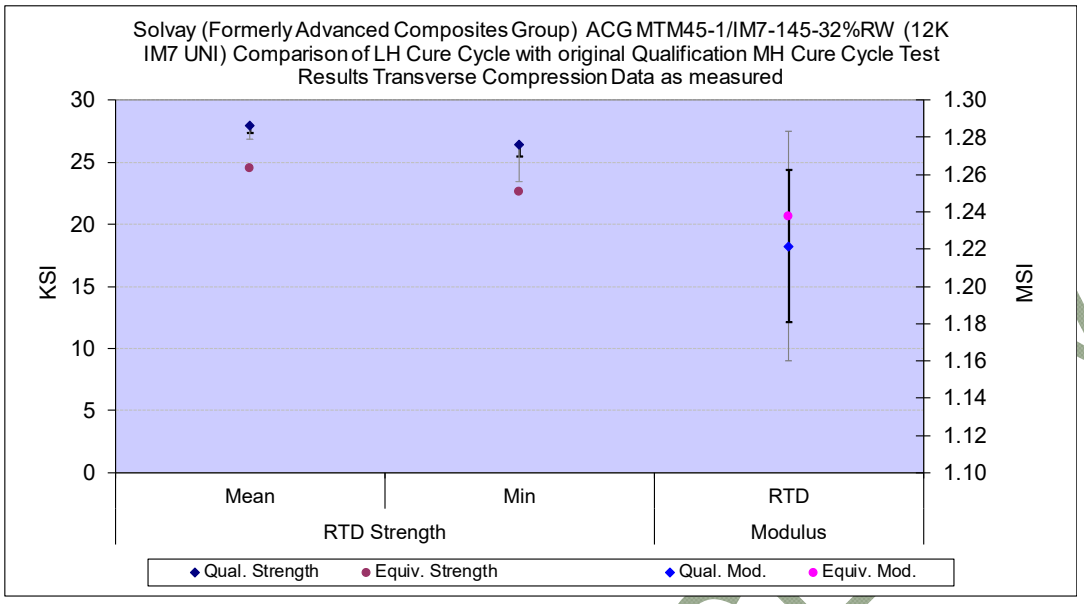

Figure 3-5 Transverse Compression means, minimums and Equivalence limits

3.4 Transverse Tension (TT)

The Transverse Tension data is not normalized. The TT strength data does not pass the equivalency tests for either CTD or RTD conditions. Modified CV results were not provided for the strength data because the coefficients of variation were above 8% which means that the modified CV results were no different from the results shown. The modulus data passes equivalency tests for both conditions, although the RTD condition required the use of the modified CV method. Statistics and analysis results are shown for strength in Table 3-7 and for modulus in Table 3-8.

Transverse Tension (TT) Strength	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Strength (ksi)	8.340	4.620	7.595	4.107
Standard Deviation	1.415	0.465	1.289	0.276
Coefficient of Variation %	16.970	10.056	16.975	6.721
Minimum	5.328	3.878	5.405	3.617
Maximum	10.422	5.383	9.521	4.535
Number of Specimens	18	9	21	9
RESUTTS	**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	7.433		6.768	
Minimum Acceptable Equiv. Sample Min	4.461		4.061	

Table 3-7 Transverse Tension Strength Results

Transverse Tension (TT) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Modulus (Msi)	1.238	1.240	1.111	1.150
Standard Deviation	0.075	0.067	0.056	0.008
Coefficient of Variation %	6.074	5.407	5.085	0.663
Minimum	1.140	1.072	1.008	1.141
Maximum	1.451	1.302	1.236	1.161
Number of Specimens	22	9	23	10
RESUTTS	**PASS**		**FAIL**	
Passing Range for Modulus Mean	1.179 to 1.297		1.074 to 1.148	
Student's t-statistic	0.096		2.151	
p-value of Student's t-statistic	0.924		0.039	
MOD CV RESUTTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.037		6.542	
Passing Range for Modulus Mean	1.171 to 1.304		1.063 to 1.158	
Modified CV Student's t-statistic	0.085		1.674	
p-value of Student's t-statistic	0.933		0.104	

Table 3-8 Transverse Tension Modulus Results

The TT strength data for the CTD environment failed equivalence due to both the mean and minimum being too low. The equivalency sample mean (4.620) is 62.15% of the minimum acceptable mean value (7.433) and the equivalency sample minimum (3.878) is 86.94% of the lowest acceptable minimum value (4.461). The modified CV method could not be used due to the CV of the CTD condition being greater than 8%.

The TT strength data for the RTD environment failed equivalence due to both the mean and minimum being too low. The equivalency sample mean (4.107) is 60.68% of the minimum acceptable mean value (6.768) and the equivalency sample minimum (3.617) is 89.08% of the lowest acceptable minimum value (4.061). The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The TT modulus data for the RTD environment failed the equivalency test because the sample mean value (1.150) is above the upper acceptance limit (1.148). The equivalency sample mean value is 100.18% 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 3-10 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.

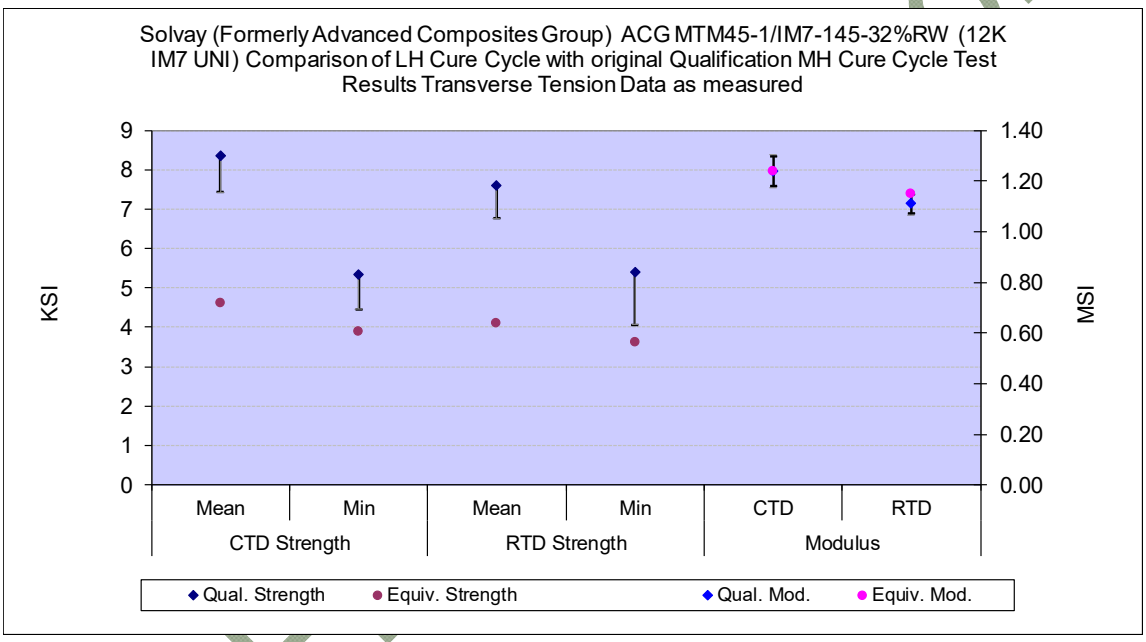

Figure 3-6 Transverse Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The SBS data failed for the CTD condition and the RTD and ETD conditions passed only with the use of the modified CV method. The SBS data lacked sufficient specimens for the results to be considered conclusive. Statistics and analysis results for the SBS data are shown in Table 3-9.

Short Beam Strength (SBS)	CTD		RTD		ETD	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data		Insufficient Data	
Mean Strength (ksi)	20.854	19.336	14.466	13.953	11.152	10.603
Standard Deviation	0.967	0.754	0.542	0.382	0.309	0.164
Coefficient of Variation %	4.638	3.902	3.750	2.737	2.768	1.544
Minimum	18.954	18.559	13.851	13.310	10.586	10.425
Maximum	22.386	20.441	15.180	14.269	11.569	10.818
Number of Specimens	14	5	6	5	13	5
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	20.029		14.004		10.888	
Minimum Acceptable Equiv. Sample Min	18.408		13.094		10.371	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.319		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	19.730		13.726		10.581	
Minimum Acceptable Equiv. Sample Min	17.522		12.271		9.460	

Table 3-9 Lamina Short Beam Strength Results

The SBS strength data for the CTD environment failed equivalence due to the sample mean value being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (19.336) is 96.54% of the lowest acceptable mean value (20.029). Under the assumption of the modified CV method, the equivalency sample mean is 98.00% of the lowest acceptable mean value (19.730).

The SBS strength data for the RTD environment failed equivalence due to the sample mean value being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (13.953) is 99.64% of the lowest acceptable mean value (14.004). Under the assumption of the modified CV method, the strength data from the RTD environment passed the equivalence test.

The SBS strength data for the ETD environment failed equivalence due to the sample mean value being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (10.603) is 97.37% of the lowest acceptable mean value (10.888). Under the assumption of the modified CV method, the strength data from the ETD 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.

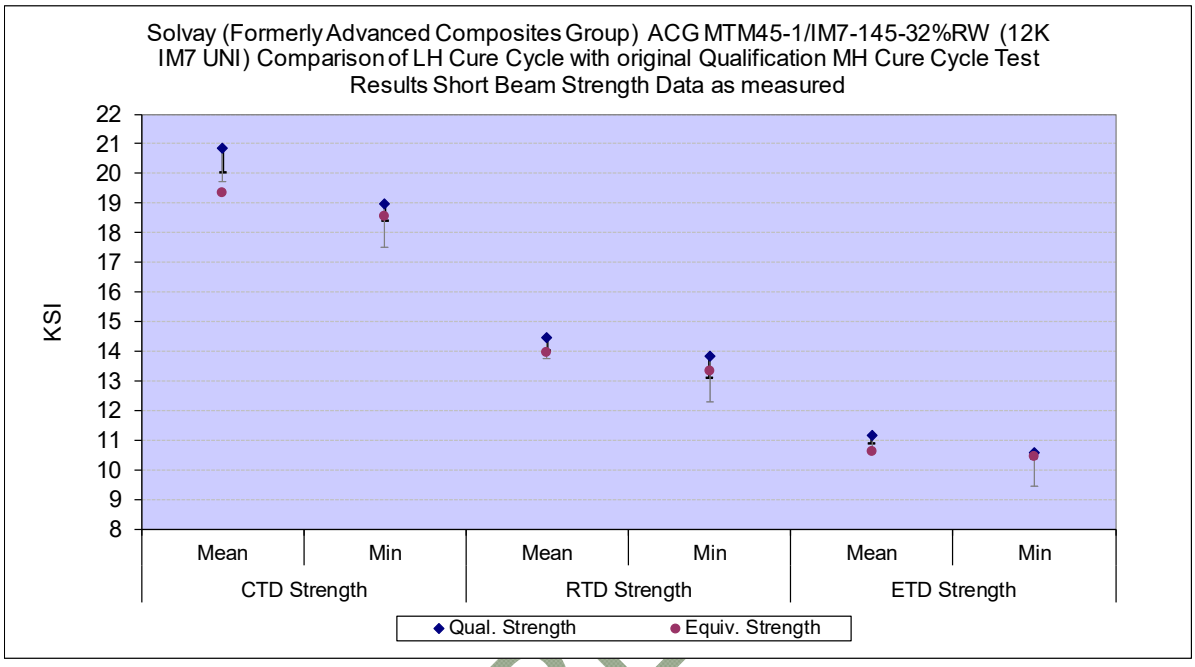

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS strength data passed for both 0.2% Offset Strength and Strength at 5% Strain. Modified CV results were not provided because the coefficients of variation were above 8% which means that the modified CV results were no different from the results shown. Modulus data was not available. Statistics and analysis results are shown in Table 3-10.

In-Plane Shear (IPS) Strength Properties RTD condition	0.2% Offset Strength		Strength at 5% Strain	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Strength (ksi)	5.896	6.302	9.634	9.223
Standard Deviation	0.517	0.241	0.839	0.436
Coefficient of Variation %	8.767	3.832	8.709	4.728
Minimum	4.762	5.908	7.959	8.680
Maximum	6.990	6.567	11.034	9.650
Number of Specimens	20	10	18	9
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	5.582		9.096	
Minimum Acceptable Equiv. Sample Min	4.461		7.334	

Table 3-10 In-Plane Shear Strength Results

Figure 3-8 illustrates the In-Plane Shear 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.

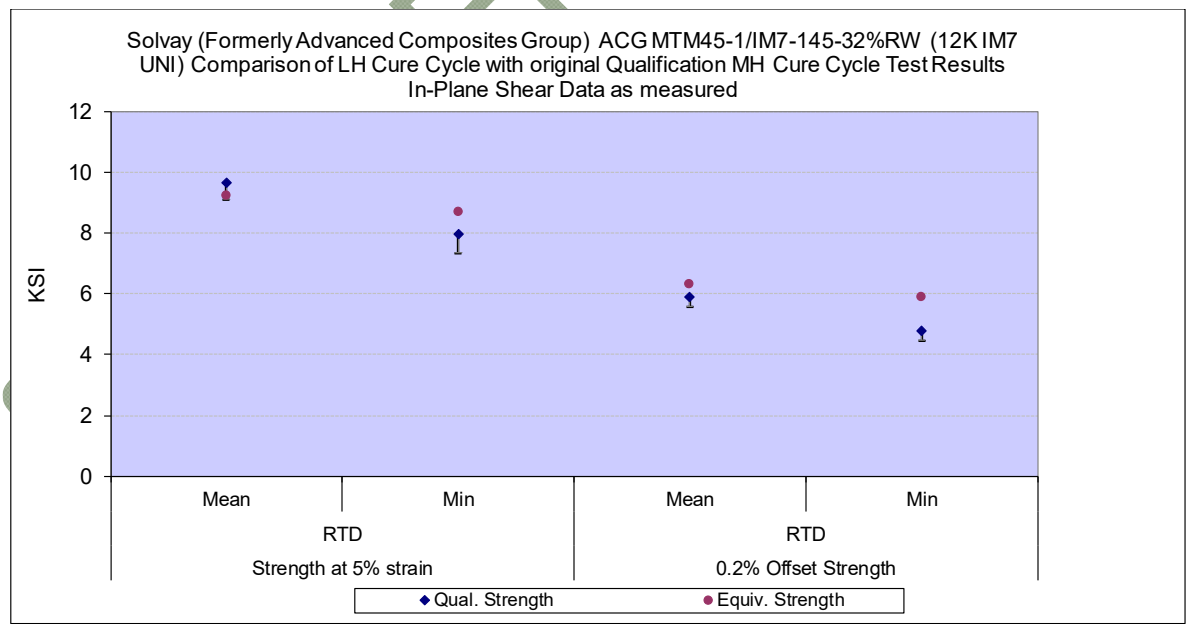

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The Unnotched Compression 0 data is normalized by cured ply thickness. The UNC0 normalized data passed equivalency tests for both strength and modulus in the RTD condition. However, there was data from only five specimens available, which is considered insufficient to draw conclusions for strength properties but adequate for modulus. Modified CV results were not provided for strength 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 3-11 and for modulus in Table 3-12.

Unnotched Compression (UNC0) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0055	Insufficient Data	
Mean Strength (ksi)	99.647	106.950
Standard Deviation	9.660	3.263
Coefficient of Variation %	9.694	3.051
Minimum	82.622	102.104
Maximum	114.340	110.955
Number of Specimens	8	5
RESULTS	**PASS**	
Minimum Acceptable Equiv. Sample Mean	91.413	
Minimum Acceptable Equiv. Sample Min	75.222	

Table 3-11 Unnotched Compression 0 Strength Results

Unnotched Compression (UNC0) Modulus	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0055		
Mean Modulus (Msi)	11.108	10.457
Standard Deviation	0.726	0.307
Coefficient of Variation %	6.537	2.935
Minimum	10.158	10.109
Maximum	12.238	10.813
Number of Specimens	8	5
RESULTS	**PASS**	
Passing Range for Modulus Mean	10.345 to 11.871	
Student's t-statistic	-1.878	
p-value of Student's t-statistic	0.087	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	7.269	
Passing Range for Modulus Mean	10.267 to 11.949	
Modified CV Student's t-statistic	-1.704	
p-value of Student's t-statistic	0.116	

Table 3-12 Unnotched Compression 0 Modulus Results

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.

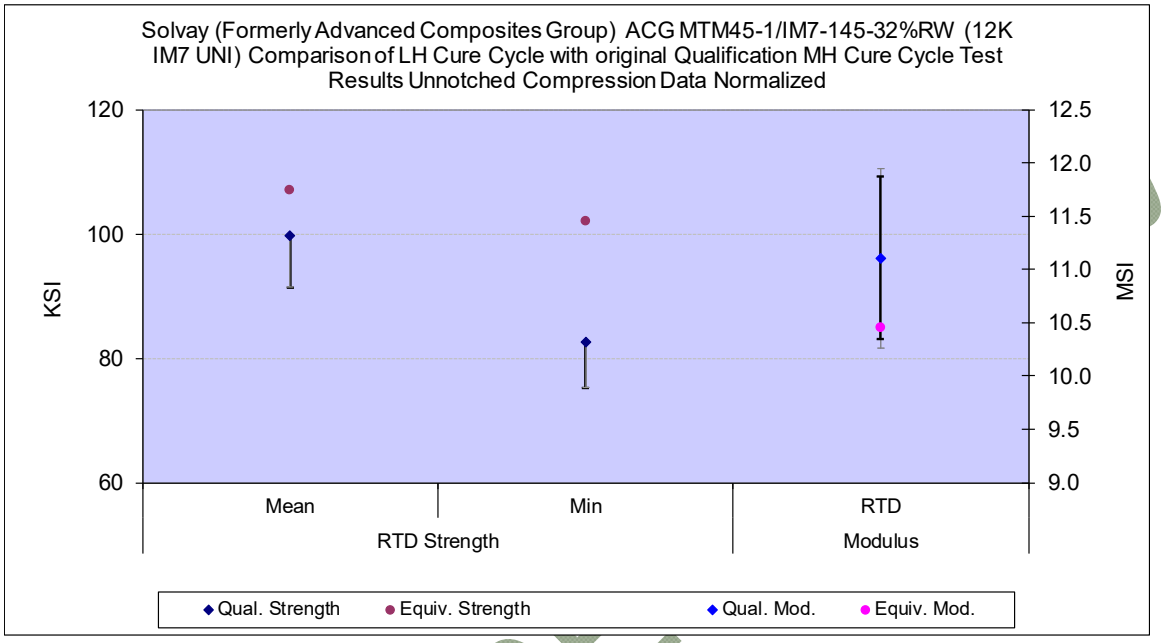

Figure 3-9 Unnotched Compression 0 means, minimums and Equivalence limits

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

The Unnotched Tension 0 data is normalized by cured ply thickness. The UNT0 normalized data passes all equivalency tests for strength. The UNT0 modulus data does not pass the equivalency test for the CTD condition, but does pass the equivalency test for the RTD condition with the use of the modified CV method. Statistics and analysis results are shown for strength in Table 3-13 and for modulus in Table 3-14.

Unnotched Tension (UNT0) Strength	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Strength (ksi)	184.307	179.119	181.547	185.256
Standard Deviation	10.716	5.097	8.964	5.948
Coefficient of Variation %	5.814	2.845	4.937	3.211
Minimum	165.012	168.554	167.358	178.312
Maximum	202.157	185.308	200.537	197.023
Number of Specimens	18	8	19	8
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	177.031		175.460	
Minimum Acceptable Equiv. Sample Min	155.373		157.345	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.907		6.469	
Minimum Acceptable Equiv. Sample Mean	175.663		173.573	
Minimum Acceptable Equiv. Sample Min	149.935		149.839	

Table 3-13 Unnotched Tension 0 Strength Results

Unnotched Tension (UNT0) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	11.623	12.365	11.624	12.162
Standard Deviation	0.604	0.198	0.520	0.210
Coefficient of Variation %	5.201	1.599	4.476	1.723
Minimum	9.923	12.062	10.692	11.787
Maximum	12.533	12.759	12.332	12.364
Number of Specimens	18	9	20	8
RESULTS	**FAIL**		**FAIL**	
Passing Range for Modulus Mean	11.193 to 12.052		11.230 to 12.018	
Student's t-statistic	3.561		2.811	
p-value of Student's t-statistic	0.002		0.009	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**	
Modified CV%	6.600		6.238	
Passing Range for Modulus Mean	11.083 to 12.163		11.083 to 12.165	
Modified CV Student's t-statistic	2.832		2.045	
p-value of Student's t-statistic	0.009		0.051	

Table 3-14 Unnotched Tension 0 Modulus Results

The UNT0 modulus data for the CTD environment failed the equivalency test because the sample mean value (12.365) is above the upper acceptance limit (12.052). The equivalency sample mean value is 102.60% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 101.67% of the maximum acceptable mean value (12.163).

The UNT0 modulus data for the RTD environment failed the equivalency test because the sample mean value (12.162) is above the upper acceptance limit (12.018). The equivalency sample mean value is 101.20% 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 3-10 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.

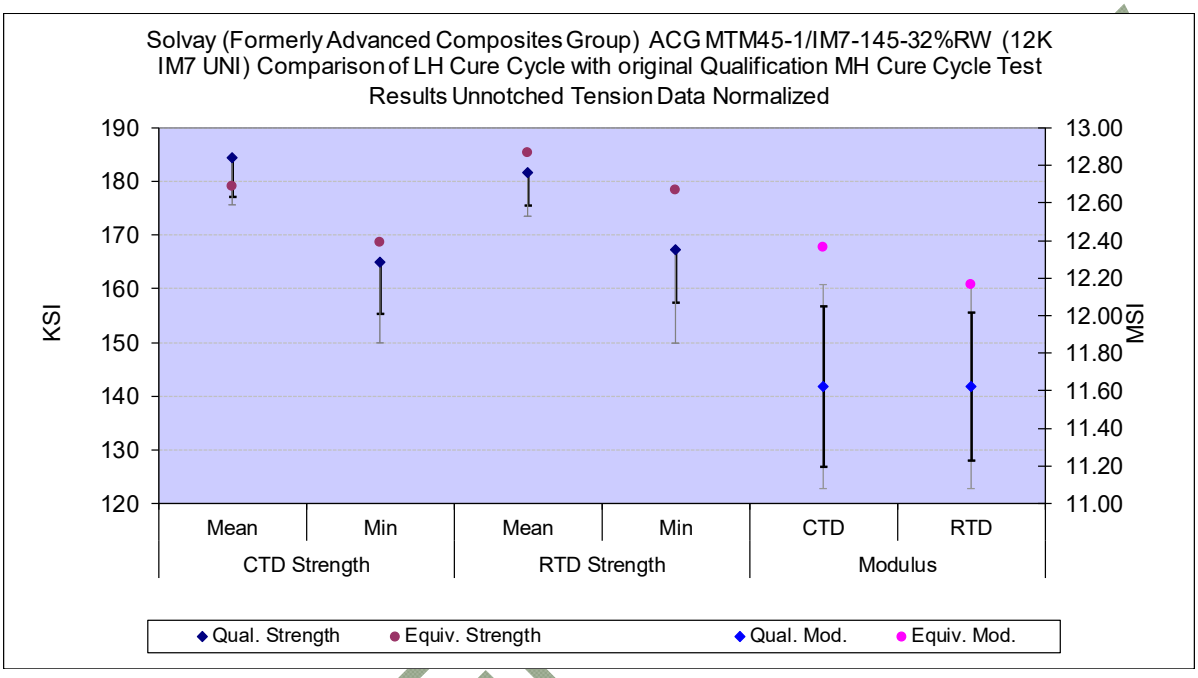

Figure 3-10 Unnotched Tension 0 means, minimums and Equivalence limits

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

The Open Hole Tension 1 data is normalized by cured ply thickness. The OHT1 normalized strength data passes equivalency tests for the RTD condition. Statistics and analysis results for the OHT1 strength data are shown in Table 3-15.

Open Hole Tension (OHT1) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0055		
Mean Strength (ksi)	68.014	67.767
Standard Deviation	2.495	3.365
Coefficient of Variation %	3.668	4.966
Minimum	64.644	65.033
Maximum	73.185	75.414
Number of Specimens	19	8
RESULTS	**PASS**	
Minimum Acceptable Equiv. Sample Mean	66.320	
Minimum Acceptable Equiv. Sample Min	61.278	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV %	6.000	
Minimum Acceptable Equiv. Sample Mean	65.243	
Minimum Acceptable Equiv. Sample Min	56.995	

Table 3-15 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.

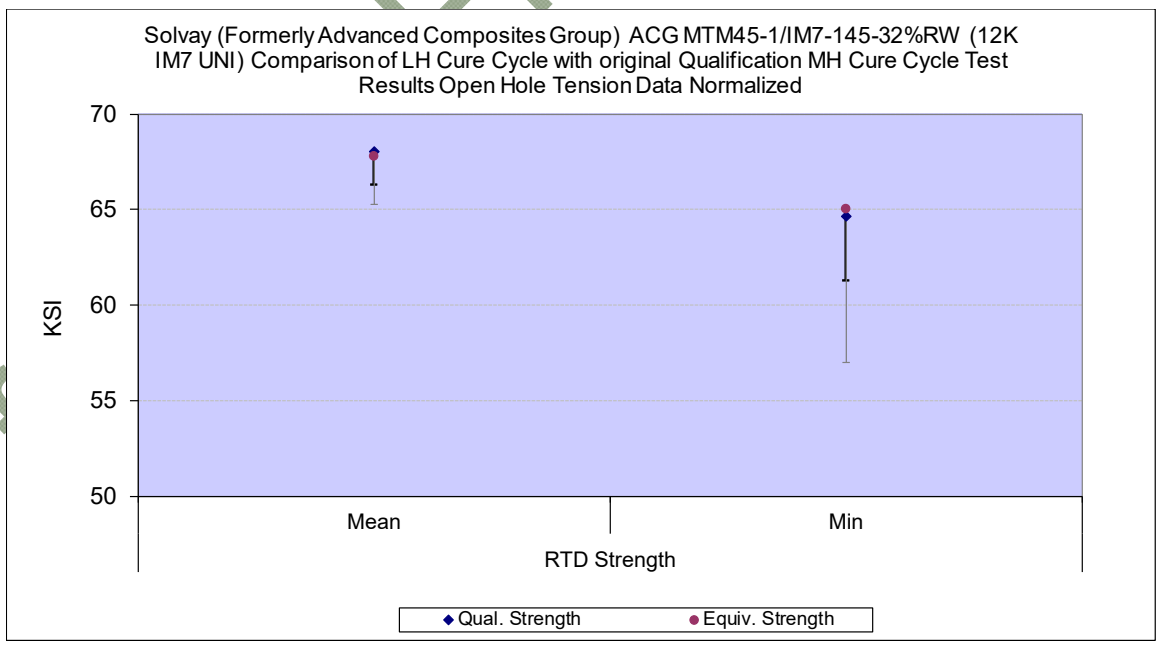

Figure 3-11 Open Hole Tension 1 means, minimums and Equivalence limits

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

The Open Hole Compression 1 data is normalized by cured ply thickness. The OHC1 normalized strength data failed the equivalency tests for the RTD condition, but with data available from only five specimens this is considered insufficient for the results 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	
	Qual.	Equiv.
Data normalized with CPT 0.0055	Insufficient Data	
Mean Strength (ksi)	42.867	35.945
Standard Deviation	1.046	0.462
Coefficient of Variation %	2.440	1.287
Minimum	41.351	35.233
Maximum	45.098	36.372
Number of Specimens	18	5
RESULTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	41.975	
Minimum Acceptable Equiv. Sample Min	40.222	
MOD CV RESULTS	**FAIL**	
Modified CV %	6.000	
Minimum Acceptable Equiv. Sample Mean	40.674	
Minimum Acceptable Equiv. Sample Min	36.363	

Table 3-16 Open Hole Compression 1 Strength Results

The OHC strength data for the RTD environment failed the equivalency test due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (35.945) is 88.37% of the minimum acceptable mean value (40.674) and the equivalency sample minimum (35.233) is 96.89% of the lowest acceptable minimum value (36.363).

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.

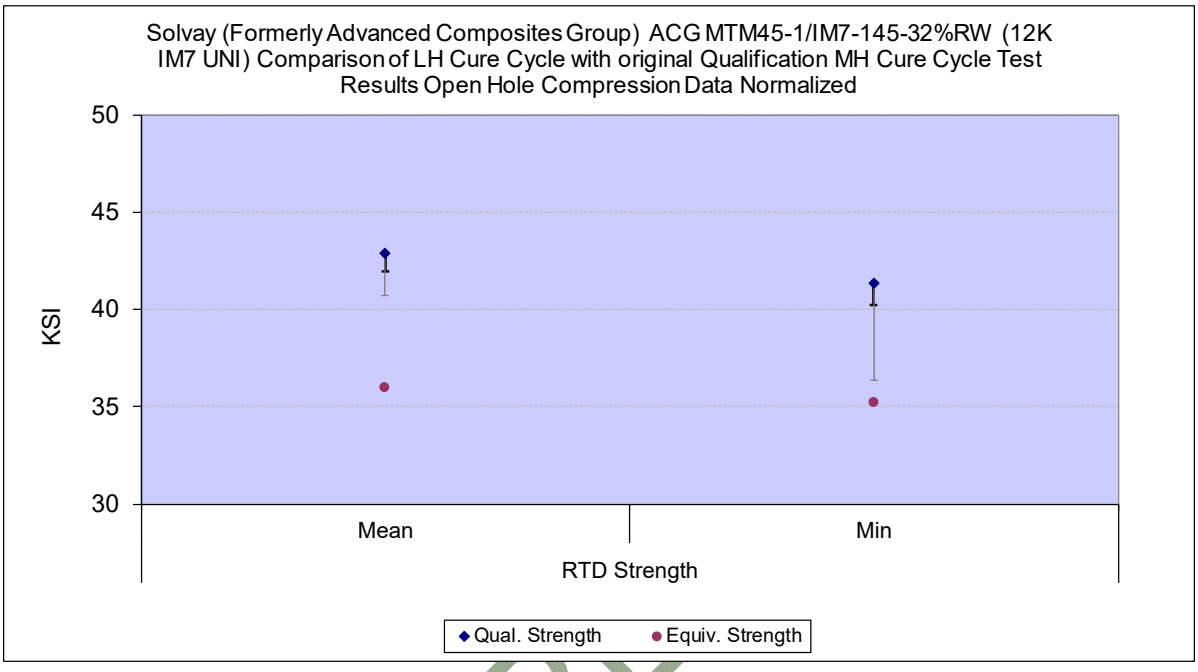

Figure 3-12 Open Hole Compression 1 means, minimums and Equivalence limits

3.11 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 equivalency LH cure cycle are shown in Table 3-17.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.005599	0.005519
Standard Deviation	0.00017	0.00007
Coefficient of Variation %	3.04460	1.19386
Minimum	0.00496	0.00543
Maximum	0.00602	0.00563
Number of Specimens	482	15
RESULTS	**PASS**	
Passing Range for CPT Mean	0.005512 to 0.005686	
Student's t-statistic	-1.817	
p-value of Student's t-statistic	0.070	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.005428 to 0.005769	
Modified CV Student's t-statistic	-0.924	
p-value of Student's t-statistic	0.356	

Table 3-17 Cured Ply Thickness Results

Figure 3-13. 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.

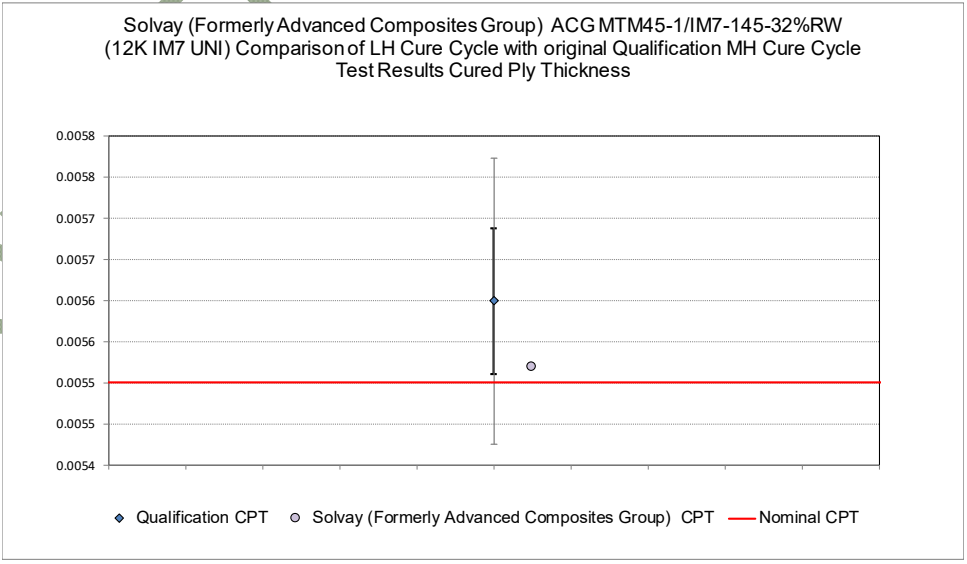

Figure 3-13 CPT means, 95% standard error bars and nominal value

3.12 Dynamic Mechanical Analysis (DMA)

DMA is compared for the measurement of the onset of storage modulus in 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).

Statistics for both the original qualification material and the equivalency sample are shown in Table 3-18.

Dynamic Mechanical Analysis (DMA)	Onset Storage Modulus - Dry		Onset Storage Modulus - Wet	
	Qual.	Equiv.	Qual.	Equiv.
Mean (°F)	349.064	365.897	317.106	356.116
Standard Deviation	18.799	13.524	8.796	12.689
Coefficient of Variation %	5.386	3.696	2.774	3.563
Minimum	321.734	349.772	306.794	345.848
Maximum	386.222	377.330	348.782	370.490
Number of Specimens	22	20	17	12
RESULTS	**FAIL**		**FAIL**	
Passing Range for DMA Mean	338.758 to 359.370		308.939 to 325.273	
Student's t-statistic	3.301		9.801	
p-value of Student's t-statistic	0.002		2.18E-10	
Range = ±18°F RESULTS	**PASS Range = ±18°F**		**FAIL**	
Passing Range for DMA Mean	331.064 to 367.064		299.106 to 335.106	

Table 3-18 DMA Results

The Onset Storage Modulus for dry data failed the equivalency test because the sample mean value (365.897) is above the upper acceptance limit (359.370). The equivalency sample mean is 101.82% of the upper limit of acceptable values. With the allowable range set to ±18°F, the DMA dry data from Onset Storage Modulus passed the equivalency test.

The Onset Storage Modulus for wet data failed the equivalency test because the sample mean value (356.116) is above the upper acceptance limit (325.273). The equivalency sample mean is 109.48% of the upper limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 106.27% of the maximum mean value (335.106).

Figure 3-14 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.

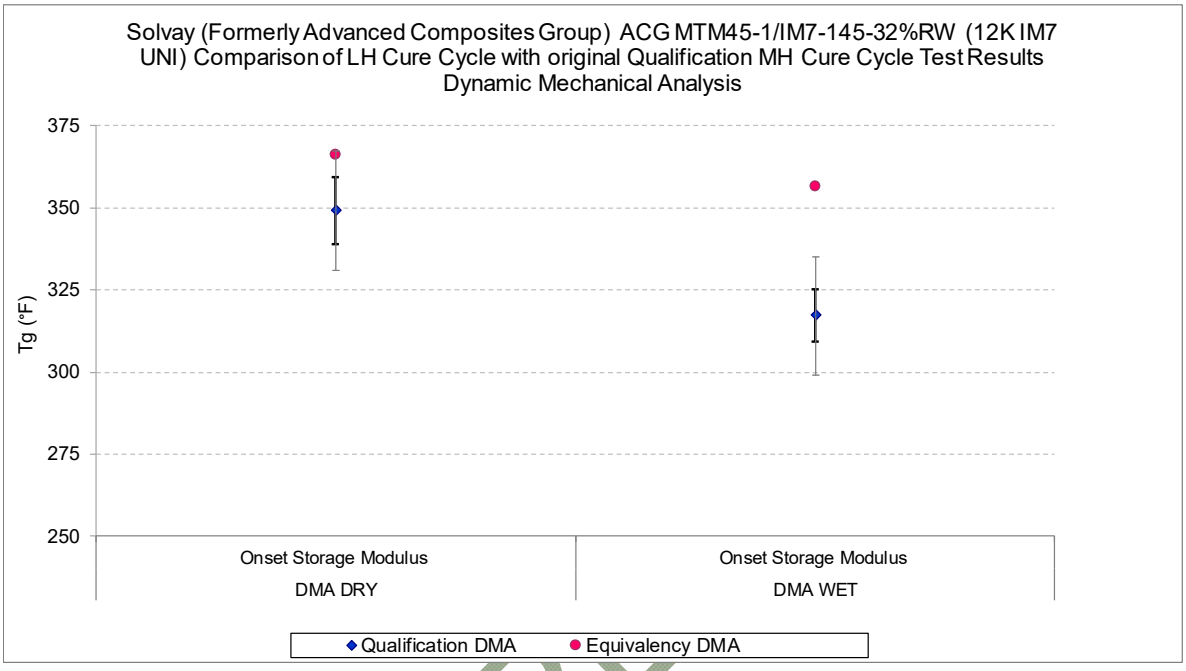

Figure 3-14 DMA Means and Equivalence limits

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 17 different test types and conditions, not including the cured ply thickness or the DMA comparison.

Using the modified CV method, there were four failures.

1. Transverse Compression Strength for the RTD condition failed by 8.8%
2. Transverse Tension Strength for the CTD condition failed by 37.8%
3. Transverse Tension Strength for the RTD condition failed by 39.3%
4. Unnotched Tension Modulus for the CTD condition failed by 1.7%

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

Four failures out of 17 test conditions gives the “LH” cure cycle a pass rate of 76.47% 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 0.85 expected 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 four or more failures is 0.88%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 17 independent tests. If the two materials were equivalent, the probability of getting four or more failures is less than 5%. This means that the material could be considered as "not equivalent" with a 95% level of confidence if there were four or more failures out of 17 independent tests.

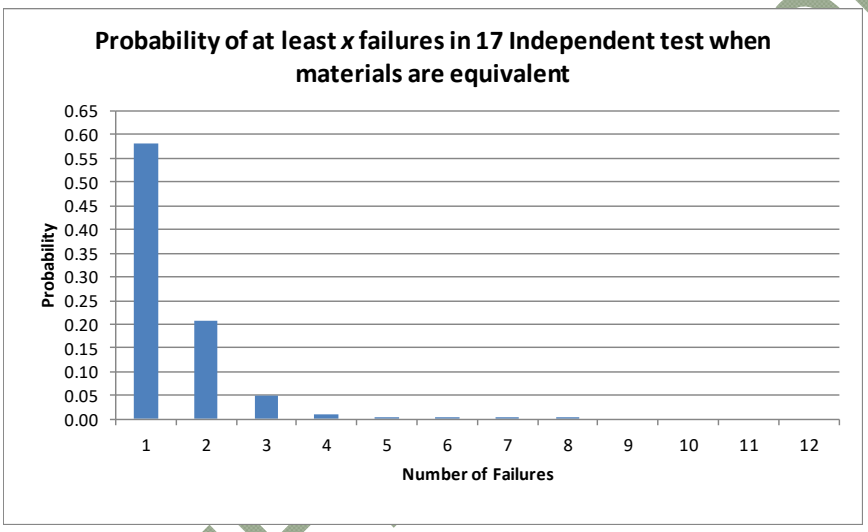

Figure 4-1 Probability of Number of Failures

5. References

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