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

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Elizabeth Clarkson, Ph.D.
National Center for Advanced Materials Performance (NCAMP)
National Institute for Aviation Research
Wichita State University
Wichita, KS 67260-0093

Testing Facility:
National Institute for Aviation Research
Wichita State University
1845 N. Fairmount
Wichita, KS 67260-0093

Test Panel Fabrication Facility:
Solvay (Formerly Advanced Composites Group)
5350 South 129th East Avenue
Tulsa, OK 74134-6703

Prepared by: Dr. Elizabeth Clarkson

Digitally signed by Dr. Elizabeth Clarkson
DN: cn=Dr. Elizabeth Clarkson, o=Wichita State University, ou=NCAMP, email=bclarkson@niar.wichita.edu, c=US
Date: 2018.08.22 11:49:21 -05'00'

Elizabeth Clarkson

Reviewed by: Jonathan Tisack

Digitally signed by Jonathan Tisack
DN: cn=Jonathan Tisack, o=NIAR, ou=NCAMP, email=jtisack@niar.wichita.edu, c=US
Date: 2018.08.22 12:42:51 -05'00'

Jonathan Tisack

Katherine Carney

Digitally signed by Katherine Carney
DN: cn=Katherine Carney, o=NIAR/NCAMP, ou=NIAR/NCAMP, email=kcarney@niar.wichita.edu, c=US
Date: 2018.09.06 15:26:23 -05'00'

Katherine Carney

Approved by: Royal Lovingfoss

Digitally signed by Royal Lovingfoss
DN: cn=Royal Lovingfoss, o=NIAR, ou=NCAMP, email=rlovingfoss@niar.wichita.edu, c=US
Date: 2018.09.10 09:01:28 -05'00'

Royal Lovingfoss

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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) "MH" cure cycle compared to the "M" 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 M 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 "M" cure cycle. An equivalent NCAMP Process Specification, NPS 81451 with cure "M" 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

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 $\bar{X} - k_n^{table\ 2.1} \cdot S$ where $\bar{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample.

The sample minimum must exceed $\bar{X} - k_n^{table\ 2.2} \cdot S$ where $\bar{X}$ 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 37 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) M Cure Cycle with MTM45-1/ 12K AS4 145gsm 32%RW Unidirectional MH Cure Cycle						
Test	**Normalized Data**	**Property**	**Environmental Condition**			
			CTD	RTD	ETD	ETW
Longitudinal Compression	**Yes**	**Modulus**		Pass		Pass
Longitudinal Tension	**Yes**	**Modulus**	Pass	Pass		
Transverse Compression	**No**	**Strength**		Failed by 0.6%		Pass with Mod CV
		Modulus		Failed by 5.1%		Pass
Transverse Tension	**No**	**Strength**	Failed by 19.3%	Failed by 16.6%		Pass
		Modulus	Pass	Failed by 1.0%		Pass
In-Plane Shear	**No**	**0.2% Offset Strength**	Pass	Pass		Pass
		5% Strain Strength	Pass Insufficient Data	Pass		Pass
		Modulus	Failed by 1.8%	Failed by 2.9%		Failed by 1.8%
Short Beam Strength	**No**	**Strength**	Pass	Pass	Failed by 1.4%	Failed by 2.5%
Unnotched Compression	**Yes**	**Strength**		Failed by 1.2%		Failed by 2.4%
		Modulus		Pass		Pass
Unnotched Tension	**Yes**	**Strength**	Pass	Pass		
		Modulus	Pass	Pass with Mod CV		
Open Hole Compression	**Yes**	**Strength**		Pass		Pass with Mod CV Insufficient Data
Open Hole Tension	**Yes**	**Strength**	Pass	Pass		
Interlaminar Tension	**No**	**Strength**		Failed by 12.2% Insufficient Data		
Curved Beam Strength		**Strength**		Failed by 13.1% Insufficient Data		
Compression After Impact	**Yes**	**Strength**		Failed by 9.0% Insufficient Data		
Cured Ply Thickness	**NA**	**NA**	Pass			
Dynamic Mechanical Analysis	**Onset Storage Modulus - Dry**		Failed by 16.5% Insufficient Data			
	Peak of Tangent Delta - Dry		Pass Insufficient Data			
	Onset Storage Modulus - Wet		Failed by 3.4% Insufficient Data			
	Peak of Tangent Delta - Wet		Failed by 4.0% Insufficient Data			

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.

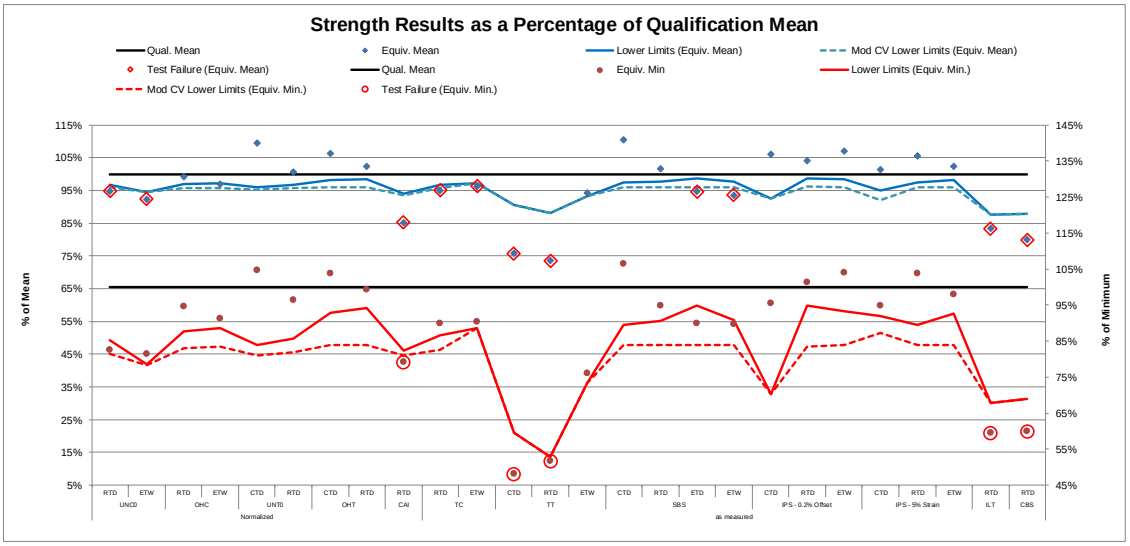

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

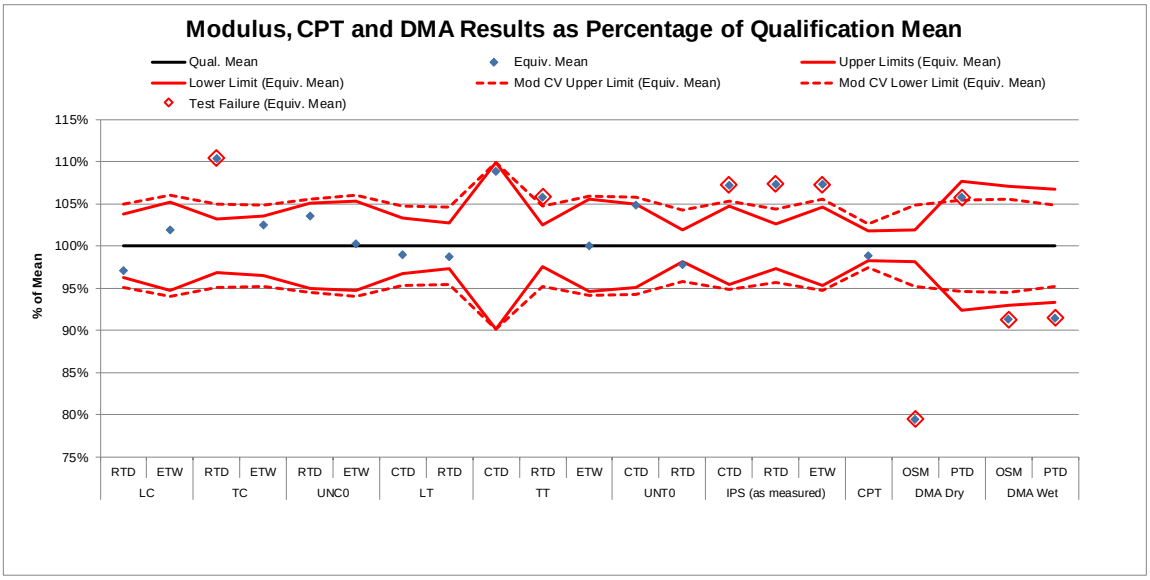

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

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 tests for both the RTD and ETW conditions. Statistics and analysis results are shown for the modulus data in Table 3-3.

Longitudinal Compression (LC) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	17.024	16.529	17.235	17.555
Standard Deviation	0.861	0.292	0.879	1.277
Coefficient of Variation %	5.059	1.764	5.102	7.277
Minimum	14.391	16.066	14.537	16.205
Maximum	18.894	16.916	18.368	20.230
Number of Specimens	18	8	17	8
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	16.374 to 17.675		16.333 to 18.137	
Student's t-statistic	-1.570		0.733	
p-value of Student's t-statistic	0.129		0.471	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.529		6.551	
Passing Range for Modulus Mean	16.192 to 17.856		16.192 to 18.279	
Modified CV Student's t-statistic	-1.228		0.634	
p-value of Student's t-statistic	0.231		0.533	

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.

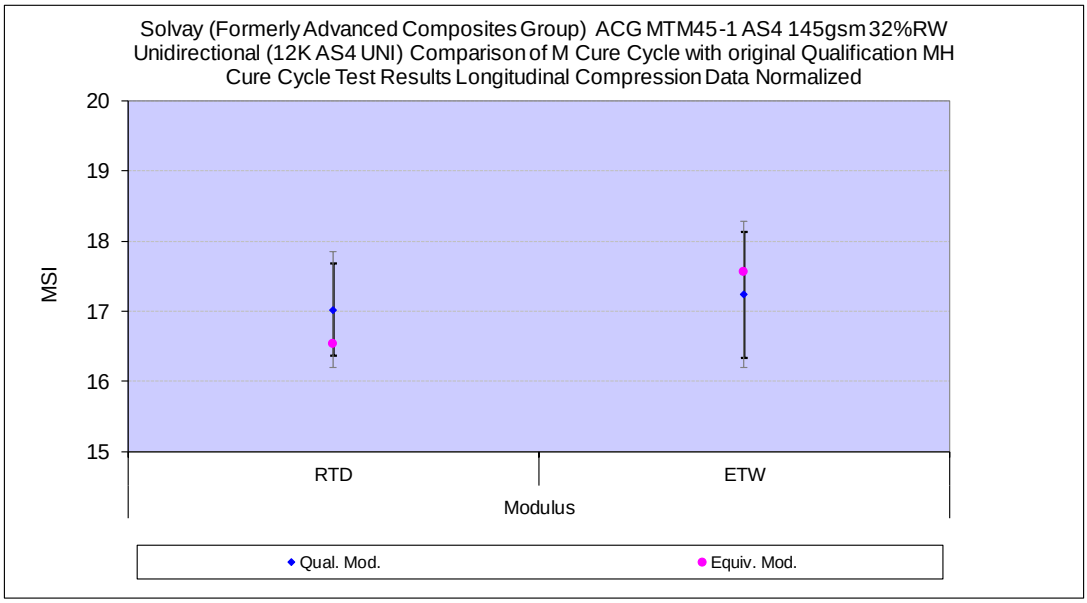

Figure 3-3 Longitudinal Compression Modulus means and Equivalence limits

3.2 Longitudinal Tension (LT)

The Longitudinal Tension data is normalized by cured ply thickness. 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 both the CTD and RTD conditions. 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)	18.744	18.534	18.513	18.270
Standard Deviation	0.779	0.496	0.619	0.441
Coefficient of Variation %	4.157	2.676	3.342	2.415
Minimum	17.550	17.814	17.530	17.593
Maximum	20.217	19.389	20.227	19.206
Number of Specimens	18	8	18	8
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	18.122 to 19.365		18.011 to 19.016	
Student's t-statistic	-0.695		-0.999	
p-value of Student's t-statistic	0.494		0.328	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.079		6.000	
Passing Range for Modulus Mean	17.870 to 19.617		17.667 to 19.359	
Modified CV Student's t-statistic	-0.494		-0.593	
p-value of Student's t-statistic	0.626		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.

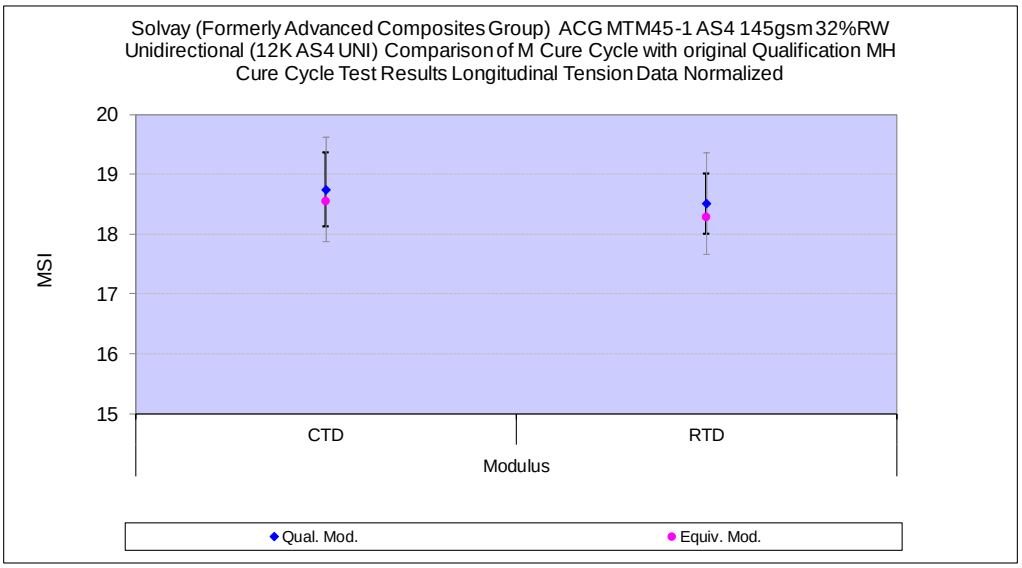

Figure 3-4 Longitudinal Tension Modulus means and Equivalence limits

3.3 Transverse Compression (TC)

The Transverse Compression data is not normalized. The TC data passed equivalency tests for both strength and modulus in the ETW condition, although the strength dataset required the use of the modified CV method. The TC data did not pass equivalency for either strength or modulus in the RTD condition. 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	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Strength (ksi)	26.810	25.472	14.956	14.397
Standard Deviation	1.321	1.300	0.637	0.571
Coefficient of Variation %	4.929	5.102	4.262	3.966
Minimum	23.888	24.131	13.438	13.527
Maximum	28.203	27.278	15.961	15.425
Number of Specimens	18	8	18	8
RESULTS	**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	25.912		14.523	
Minimum Acceptable Equiv. Sample Min	23.242		13.235	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**	
Modified CV %	6.465		6.131	
Minimum Acceptable Equiv. Sample Mean	25.633		14.334	
Minimum Acceptable Equiv. Sample Min	22.130		12.480	

Table 3-5 Transverse Compression Strength Results

Transverse Compression (TC) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Modulus (Msi)	1.246	1.375	1.181	1.210
Standard Deviation	0.037	0.061	0.046	0.049
Coefficient of Variation %	2.947	4.416	3.912	4.050
Minimum	1.198	1.295	1.109	1.114
Maximum	1.332	1.480	1.280	1.269
Number of Specimens	18	8	18	8
RESULTS	**FAIL**		**PASS**	
Passing Range for Modulus Mean	1.206 to 1.285		1.139 to 1.222	
Student's t-statistic	6.753		1.490	
p-value of Student's t-statistic	0.0000006		0.149	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**	
Modified CV%	6.000		6.000	
Passing Range for Modulus Mean	1.184 to 1.308		1.123 to 1.238	
Modified CV Student's t-statistic	4.289		1.074	
p-value of Student's t-statistic	0.00025		0.294	

Table 3-6 Transverse Compression Modulus Results

The TC 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 (25.472) is 98.30% of the minimum acceptable mean value (25.912). Under the assumption of the modified CV method, the equivalency sample mean is 99.37% of the minimum acceptable mean value (25.633).

The TC 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 (14.397) is 99.13% of the minimum acceptable mean value (14.523). Under the assumption of the modified CV method, the strength data from the ETW environment passed the equivalence test.

The TC modulus data for the RTD environment failed the equivalency test because the sample mean value (1.375) is above the upper acceptance limit (1.285). The equivalency sample mean value is 106.98% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 105.14% of the maximum acceptable mean value (1.308).

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.

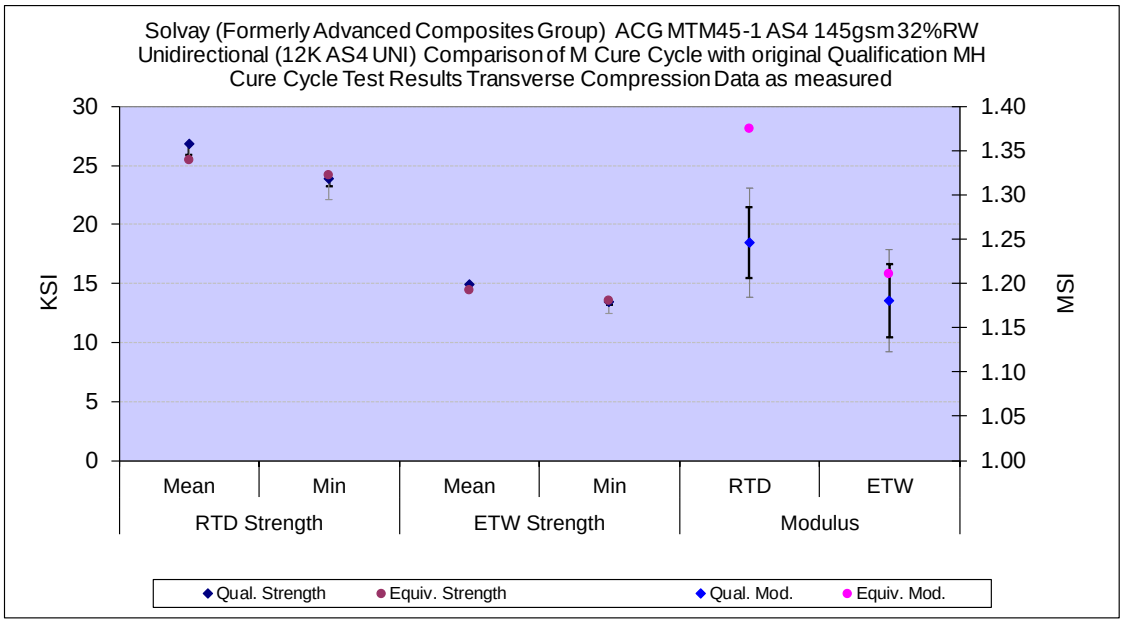

Figure 3-5 Transverse Compression means, minimums and Equivalence limits

3.4 Transverse Tension (TT)

The Transverse Tension data is not normalized. The TT strength data passed equivalency tests only for the ETW condition, failing for both the CTD and RTD conditions. The TT modulus data passed for both CTD and ETW conditions, but failed for the RTD condition. Modified CV results were not provided for the strength data because the coefficient of variation was above 8% for all conditions, which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for the strength data in Table 3-7 and for the modulus data in Table 3-8.

Transverse Tension (TT) Strength	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	7.100	5.376	6.916	5.083	3.985	3.756
Standard Deviation	1.049	1.316	1.208	0.901	0.393	0.438
Coefficient of Variation %	14.773	24.489	17.466	17.736	9.855	11.664
Minimum	5.542	3.410	5.629	3.574	3.291	3.029
Maximum	8.943	7.228	9.851	6.101	4.738	4.400
Number of Specimens	18	9	18	8	21	8
RESULTS	**FAIL**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	6.428		6.096		3.719	
Minimum Acceptable Equiv. Sample Min	4.225		3.655		2.925	

Table 3-7 Transverse Tension Strength Results

Transverse Tension (TT) Modulus	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Modulus (Msi)	1.254	1.364	1.151	1.218	0.992	0.992
Standard Deviation	0.134	0.166	0.035	0.012	0.070	0.042
Coefficient of Variation %	10.730	12.196	3.076	0.952	7.013	4.203
Minimum	1.078	1.092	1.099	1.204	0.891	0.934
Maximum	1.541	1.594	1.224	1.233	1.222	1.043
Number of Specimens	17	9	18	7	20	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Passing Range for Modulus Mean	1.129 to 1.378		1.123 to 1.180		0.938 to 1.046	
Student's t-statistic	1.839		4.831		-0.016	
p-value of Student's t-statistic	0.078		0.00007		0.987	
MOD CV RESULTS	**NA**		**FAIL**		**PASS with MOD CV**	
Modified CV%			6.000		7.506	
Passing Range for Modulus Mean			1.096 to 1.2064		0.934 to 1.050	
Modified CV Student's t-statistic			2.511		-0.015	
p-value of Student's t-statistic			0.020		0.988	

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 (5.376) is 83.63% of the minimum acceptable mean value (6.428) and the equivalency sample minimum (3.410) is 80.72% of the lowest acceptable minimum value (4.225). 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 (5.083) is 83.38% of the minimum acceptable mean value (6.096) and the equivalency sample minimum (3.574)

is 97.79% of the lowest acceptable minimum value (3.655). 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 (1.218) is above the upper acceptance limit (1.180). The equivalency sample mean value is 103.23% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.97% of the maximum acceptable mean value (1.206).

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.

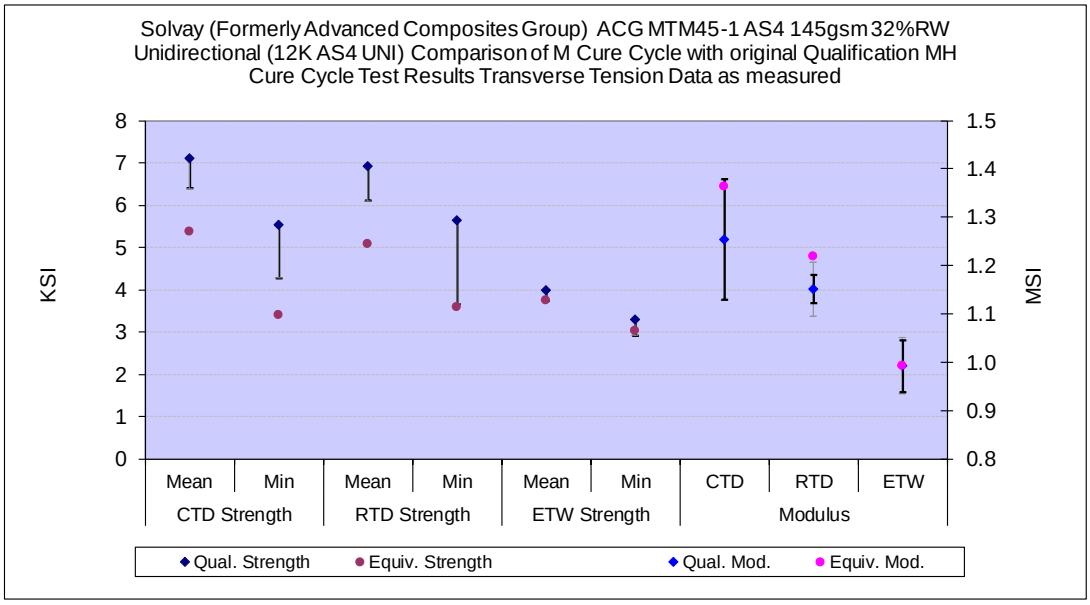

Figure 3-6 Transverse Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The SBS data passed equivalency tests for the CTD and RTD conditions but not for the ETD and ETW conditions. Statistics and analysis results for the SBS data are shown in Table 3-9.

Short Beam Strength (SBS)	CTD		RTD		ETD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured								
Mean Strength (ksi)	16.351	18.070	12.661	12.859	9.872	9.341	8.307	7.774
Standard Deviation	0.636	0.585	0.443	0.521	0.187	0.220	0.280	0.274
Coefficient of Variation %	3.892	3.235	3.500	4.054	1.898	2.358	3.374	3.522
Minimum	15.251	17.419	11.828	12.021	9.468	8.885	7.730	7.461
Maximum	17.395	18.915	13.380	13.455	10.175	9.536	8.848	8.201
Number of Specimens	18	8	18	8	18	8	18	8
RESULTS	**PASS**		**PASS**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	15.919		12.361		9.745		8.117	
Minimum Acceptable Equiv. Sample Min	14.632		11.465		9.366		7.551	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**		**FAIL**	
Modified CV %	6.000		6.000		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	15.685		12.146		9.470		7.969	
Minimum Acceptable Equiv. Sample Min	13.702		10.610		8.273		6.962	

Table 3-9 Lamina Short Beam Strength Results

The SBS strength data for the ETD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (9.341) is 95.86% of the minimum acceptable mean value (9.745) and the equivalency sample minimum (8.885) is 94.86% of the lowest acceptable minimum value (9.366). Under the assumption of the modified CV method, the equivalency sample mean is 98.64% of the minimum acceptable mean value (9.470) and the equivalency sample minimum value is acceptable.

The SBS strength data for the ETW environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (7.774) is 95.77% of the minimum acceptable mean value (8.117) and the equivalency sample minimum (7.461) is 98.82% of the lowest acceptable minimum value (7.551). Under the assumption of the modified CV method, the equivalency sample mean is 97.55% of the minimum acceptable mean value (7.969) and the equivalency sample minimum value is acceptable.

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

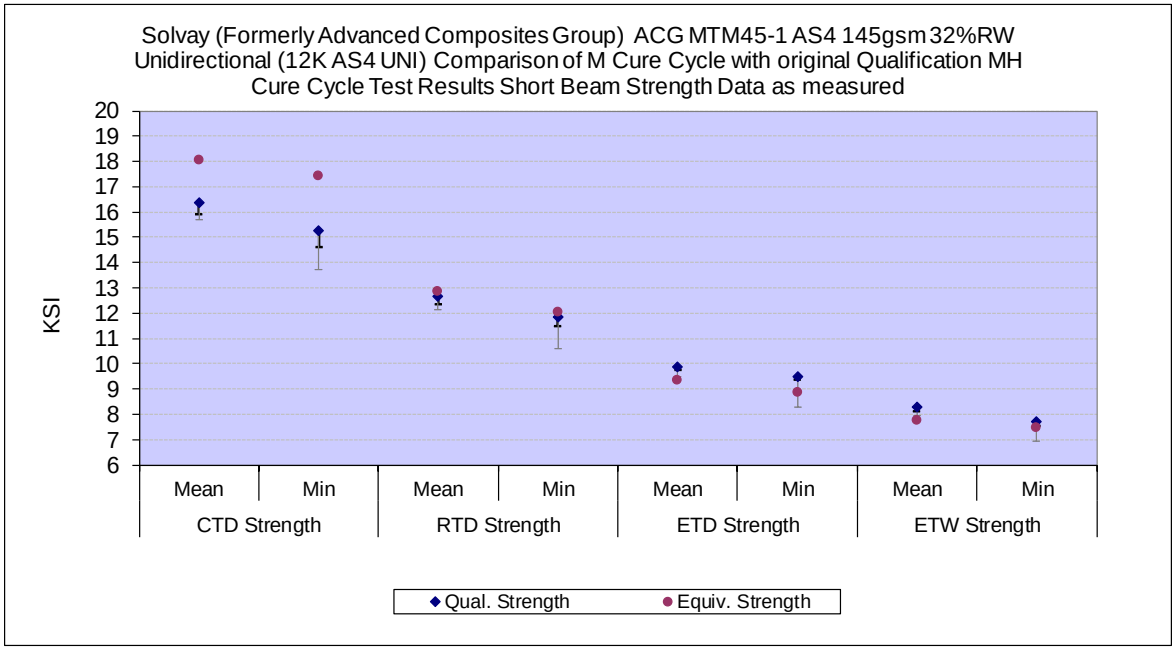

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS strength properties passed all equivalency tests for all three conditions tested. The IPS modulus datasets did not pass for any of the three conditions tested due to the modulus mean being too high. Statistics and analysis results are shown for 0.2% Offset Strength in Table 3-10, for Strength at 5% Strain in Table 3-11, and for Modulus in Table 3-12.

In-Plane Shear (IPS) 0.2% Offset Strength	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength 0.2% offset (ksi)	9.235	9.785	6.671	6.950	3.764	4.028
Standard Deviation	1.014	0.841	0.126	0.171	0.094	0.099
Coefficient of Variation %	10.982	8.598	1.884	2.461	2.491	2.462
Minimum	7.318	8.823	6.404	6.752	3.613	3.918
Maximum	10.888	11.441	6.850	7.319	3.918	4.204
Number of Specimens	19	8	18	9	19	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	8.546		6.590		3.700	
Minimum Acceptable Equiv. Sample Min	6.497		6.326		3.511	
MOD CV RESULTS	**NA**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%			6.000		6.000	
Minimum Acceptable Equiv. Sample Mean			6.414		3.611	
Minimum Acceptable Equiv. Sample Min			5.574		3.154	

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

In-Plane Shear (IPS) Strength at 5% Strain	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	**Insufficient Data**					
Mean Strength 5% Strain (ksi)	13.138	13.320	9.357	9.880	5.308	5.439
Standard Deviation	0.497	1.202	0.364	0.107	0.147	0.138
Coefficient of Variation %	3.783	9.025	3.890	1.082	2.768	2.537
Minimum	12.280	12.470	8.820	9.710	5.050	5.200
Maximum	14.280	14.170	9.860	10.030	5.620	5.590
Number of Specimens	14	2	18	8	19	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	12.488		9.110		5.209	
Minimum Acceptable Equiv. Sample Min	12.075		8.375		4.912	
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	12.107		8.976		5.092	
Minimum Acceptable Equiv. Sample Min	11.452		7.841		4.448	

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

In-Plane Shear (IPS) Modulus	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Modulus (Msi)	0.648	0.694	0.526	0.565	0.354	0.379
Standard Deviation	0.039	0.028	0.018	0.012	0.021	0.013
Coefficient of Variation %	6.089	4.017	3.412	2.198	5.892	3.307
Minimum	0.560	0.667	0.485	0.545	0.292	0.356
Maximum	0.710	0.755	0.556	0.576	0.378	0.391
Number of Specimens	19	9	18	9	19	8
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Passing Range for Modulus Mean	0.618 to 0.678		0.512 to 0.540		0.337 to 0.370	
Student's t-statistic	3.178		5.782		3.234	
p-value of Student's t-statistic	0.004		0.000005		0.003	
MOD CV RESULTS	**FAIL**		**FAIL**		**FAIL**	
Modified CV%	7.045		6.000		6.946	
Passing Range for Modulus Mean	0.614 to 0.682		0.503 to 0.549		0.335 to 0.373	
Modified CV Student's t-statistic	2.812		3.514		2.792	
p-value of Student's t-statistic	0.009		0.002		0.010	

Table 3-12 In-Plane Shear Modulus Results

The IPS modulus data for the CTD environment failed the equivalency test because the sample mean value (0.694) is above the upper acceptance limit (0.678). The equivalency sample mean value is 102.43% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 101.84% of the maximum acceptable mean value (0.682).

The IPS modulus data for the RTD environment failed the equivalency test because the sample mean value (0.565) is above the upper acceptance limit (0.540). The equivalency sample mean value is 104.61% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 102.92% of the maximum acceptable mean value (0.549).

The IPS modulus data for the ETW environment failed the equivalency test because the sample mean value (0.379) is above the upper acceptance limit (0.370). The equivalency sample mean value is 102.53% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 101.81% of the maximum acceptable mean value (0.373).

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.

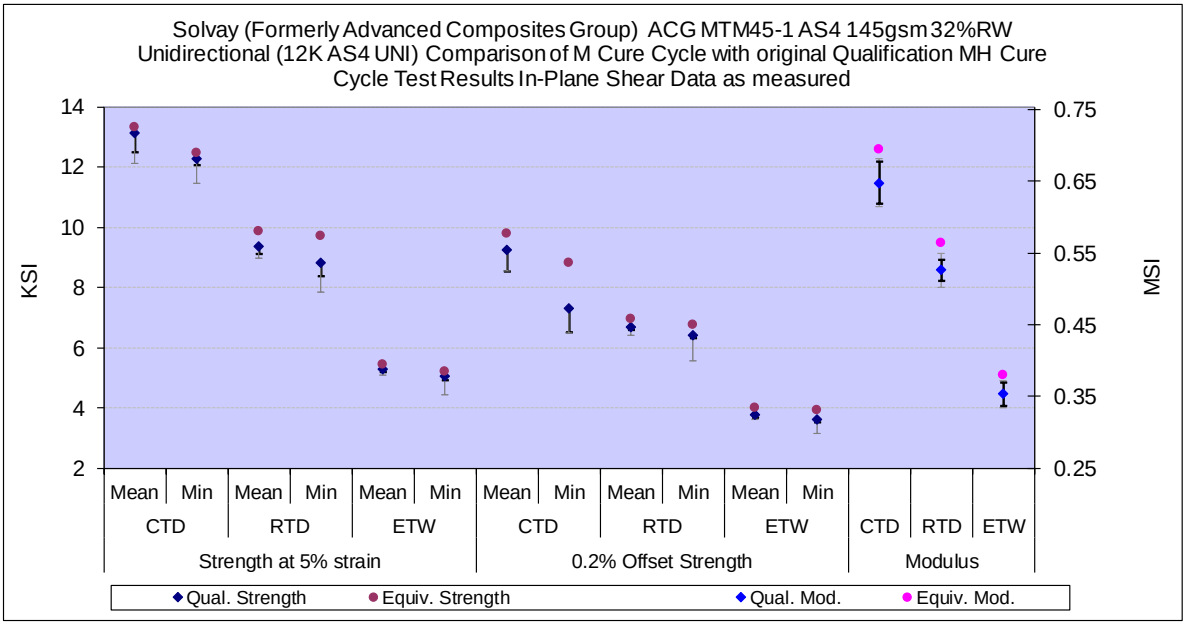

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The Unnotched Compression data is normalized by cured ply thickness. The UNC0 strength data did not pass equivalency tests for either the RTD or ETW conditions but the UNC0 modulus data passed equivalency tests for both conditions tested. 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	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Strength (ksi)	107.573	102.021	76.185	70.340
Standard Deviation	5.715	8.759	6.085	5.186
Coefficient of Variation %	5.313	8.586	7.987	7.373
Minimum	97.654	88.840	63.870	62.057
Maximum	117.799	116.165	94.269	75.307
Number of Specimens	24	10	24	8
RESULTS	**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	104.093		72.053	
Minimum Acceptable Equiv. Sample Min	91.701		59.755	
MOD CV RESULTS	**FAIL**		**FAIL**	
Modified CV %	6.656		7.994	
Minimum Acceptable Equiv. Sample Mean	103.213		72.049	
Minimum Acceptable Equiv. Sample Min	87.687		59.742	

Table 3-13 Unnotched Compression 0 Strength Results

Unnotched Compression (UNC0) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	9.015	9.330	9.676	9.694
Standard Deviation	0.555	0.678	0.548	0.709
Coefficient of Variation %	6.161	7.269	5.666	7.314
Minimum	8.209	8.239	8.697	8.692
Maximum	10.719	10.521	10.603	10.610
Number of Specimens	24	10	20	8
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	8.561 to 9.469		9.163 to 10.188	
Student's t-statistic	1.411		0.073	
p-value of Student's t-statistic	0.168		0.942	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	7.081		6.833	
Passing Range for Modulus Mean	8.517 to 9.513		9.096 to 10.256	
Modified CV Student's t-statistic	1.286		0.064	
p-value of Student's t-statistic	0.208		0.949	

Table 3-14 Unnotched Compression 0 Modulus Results

The UNC0 strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (102.021) is 98.01% of the minimum acceptable mean value (104.093) and the equivalency sample minimum (88.840) is 96.88% of the lowest acceptable minimum value (91.701). Under the assumption of the modified CV method, the equivalency sample mean is 98.85% of the minimum acceptable mean value (103.213) and the equivalency sample minimum value is acceptable.

The UNC0 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 (70.340) is 97.62% of the minimum acceptable mean value

(72.053). Under the assumption of the modified CV method, the equivalency sample mean is 97.63% of the minimum acceptable mean value (72.049).

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.

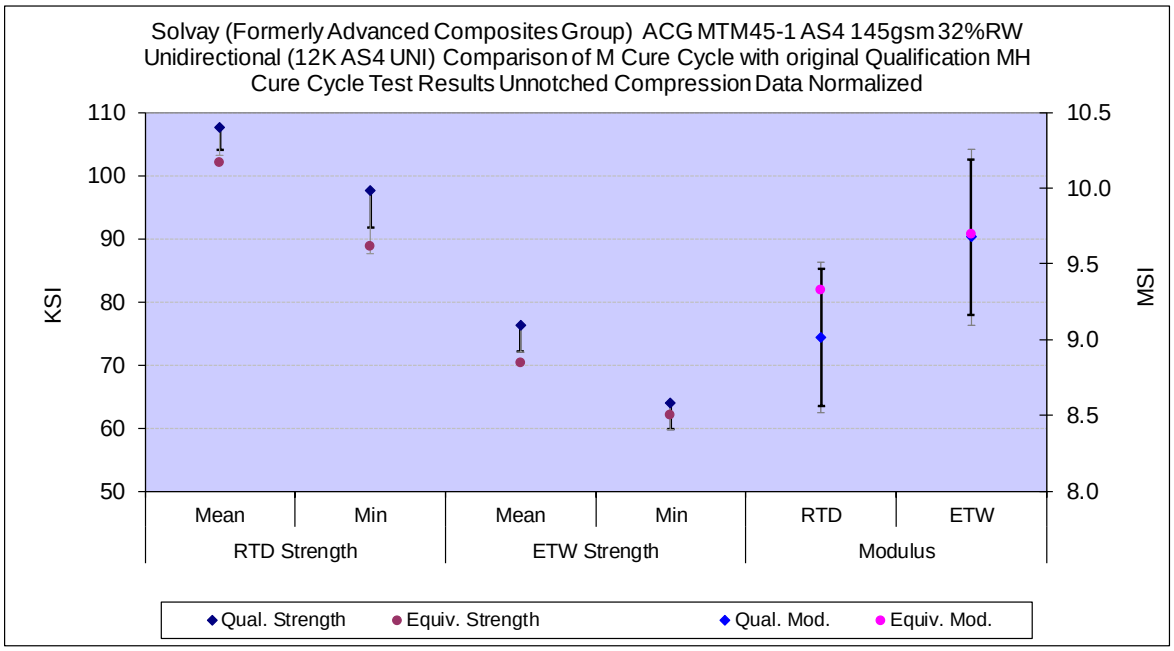

Figure 3-9 Unnotched Compression 0 means, minimums and Equivalence limits

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

The Unnotched Tension data is normalized by cured ply thickness. The UNT0 data passed all equivalency tests for both strength and modulus in both the CTD and RTD conditions, although the modulus RTD dataset 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	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Strength (ksi)	141.409	154.714	144.688	145.690
Standard Deviation	8.488	3.691	7.554	4.147
Coefficient of Variation %	6.003	2.386	5.221	2.846
Minimum	124.829	148.134	120.235	139.424
Maximum	157.668	159.157	154.907	151.929
Number of Specimens	21	8	19	9
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	135.645		139.845	
Minimum Acceptable Equiv. Sample Min	118.490		123.982	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	7.001		6.610	
Minimum Acceptable Equiv. Sample Mean	134.686		138.557	
Minimum Acceptable Equiv. Sample Min	114.677		118.471	

Table 3-15 Unnotched Tension 0 Strength Results

Unnotched Tension (UNT0) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	10.073	10.562	9.897	9.671
Standard Deviation	0.536	0.666	0.219	0.260
Coefficient of Variation %	5.323	6.305	2.212	2.687
Minimum	9.170	9.751	9.528	9.369
Maximum	11.202	11.520	10.405	10.202
Number of Specimens	20	8	23	9
RESULTS	**PASS**		**FAIL**	
Passing Range for Modulus Mean	9.580 to 10.567		9.712 to 10.082	
Student's t-statistic	2.035		-2.491	
p-value of Student's t-statistic	0.052		0.019	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.662		6.000	
Passing Range for Modulus Mean	9.498 to 10.649		9.474 to 10.319	
Modified CV Student's t-statistic	1.744		-1.092	
p-value of Student's t-statistic	0.093		0.284	

Table 3-16 Unnotched Tension 0 Modulus Results

The UNT0 modulus data for the RTD environment failed the equivalency test because the sample mean value (9.671) is below the lower acceptance limit (9.712). The equivalency sample mean value is 99.58% 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.

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.

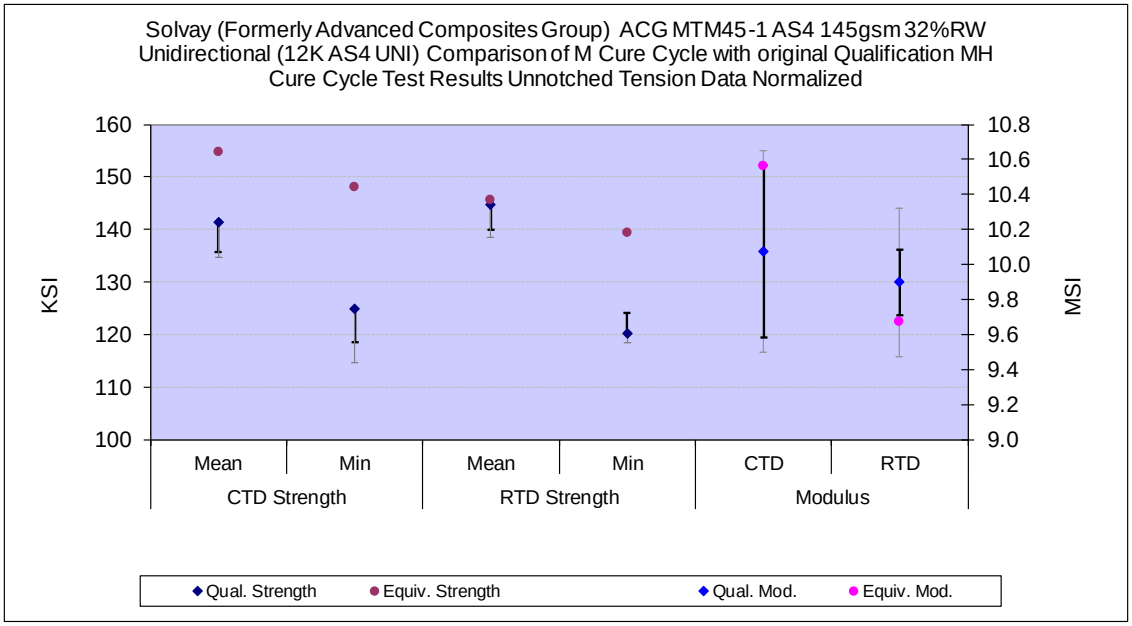

Figure 3-10 Unnotched Tension 0 means, minimums and Equivalence limits

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

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

Open Hole Tension (OHT1) Strength	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Strength (ksi)	57.485	61.134	57.388	58.753
Standard Deviation	1.509	1.121	1.236	1.329
Coefficient of Variation %	2.625	1.833	2.154	2.262
Minimum	54.426	59.702	54.448	57.054
Maximum	60.395	62.783	59.478	60.540
Number of Specimens	18	8	18	8
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	56.460		56.549	
Minimum Acceptable Equiv. Sample Min	53.410		54.050	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	55.143		55.050	
Minimum Acceptable Equiv. Sample Min	48.172		48.091	

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.

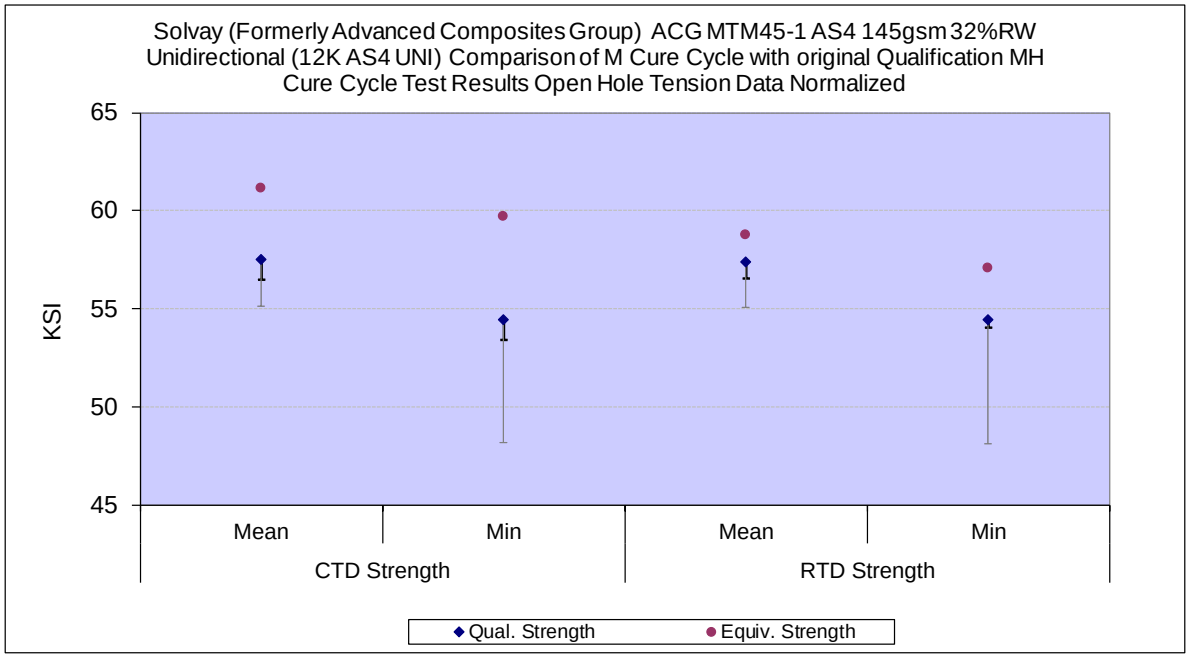

Figure 3-11 Open Hole Tension 1 means, minimums and Equivalence limits

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

The Open Hole Compression data is normalized by cured ply thickness. The OHC1 strength data passed equivalency tests for both the RTD and ETW conditions although the ETW condition required the use of the modified CV method. The ETW condition had insufficient data in the qualification sample for the result to be considered conclusive. Statistics and analysis results for the OHC1 strength data are shown in Table 3-18.

Open Hole Compression (OHC1) Strength	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055			Insufficient Data	
Mean Strength (ksi)	43.760	43.364	37.991	36.807
Standard Deviation	1.998	1.165	1.609	1.560
Coefficient of Variation %	4.567	2.686	4.236	4.238
Minimum	40.190	41.409	35.322	34.634
Maximum	48.108	44.928	39.897	39.157
Number of Specimens	18	8	6	8
RESULTS	**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	42.403		36.898	
Minimum Acceptable Equiv. Sample Min	38.364		33.646	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.283		6.118	
Minimum Acceptable Equiv. Sample Mean	41.893		36.413	
Minimum Acceptable Equiv. Sample Min	36.336		31.715	

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 (36.807) is 99.75% 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.

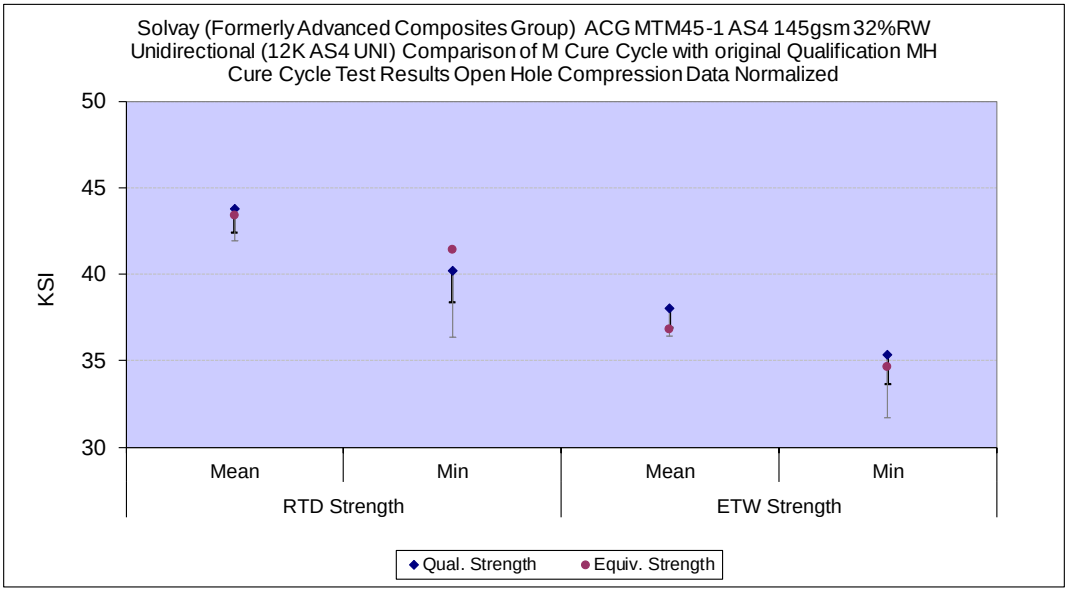

Figure 3-12 Open Hole Compression 1 means, minimums and Equivalence limits

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

The Interlaminar Tension and Curved Beam Strength data are not normalized. Modified CV results were not provided because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. The ILT and CBS data did not pass equivalency tests, however, there was insufficient data for the result to be considered conclusive. 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		Curved Beam Strength	
	RTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data	
Mean Strength (ksi)	6.891	5.741	287.343	229.515
Standard Deviation	0.909	1.339	36.594	46.645
Coefficient of Variation %	13.186	23.328	12.735	20.323
Minimum	5.386	4.101	227.963	172.094
Maximum	8.041	7.229	335.803	281.546
Number of Specimens	6	4	6	4
RESULTS	FAIL		FAIL	
Minimum Acceptable Equiv. Sample Mean	6.029		252.629	
Minimum Acceptable Equiv. Sample Min	4.672		197.979	

Table 3-19 Interlaminar Tension and Curved Beam Strength Results

The ILT strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (5.741) is 95.22% of the minimum acceptable mean value (6.029) and the equivalency sample minimum (4.101) is 87.77% of the lowest acceptable minimum value (4.672). The modified CV method could not be used due to the CV being greater than 8%.

The CBS data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (229.515) is 90.85% of the minimum acceptable mean value (252.629) and the equivalency sample minimum (172.094) is 86.93% of the lowest acceptable minimum value (197.979). The modified CV method could not be used due to the CV being greater than 8%.

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.

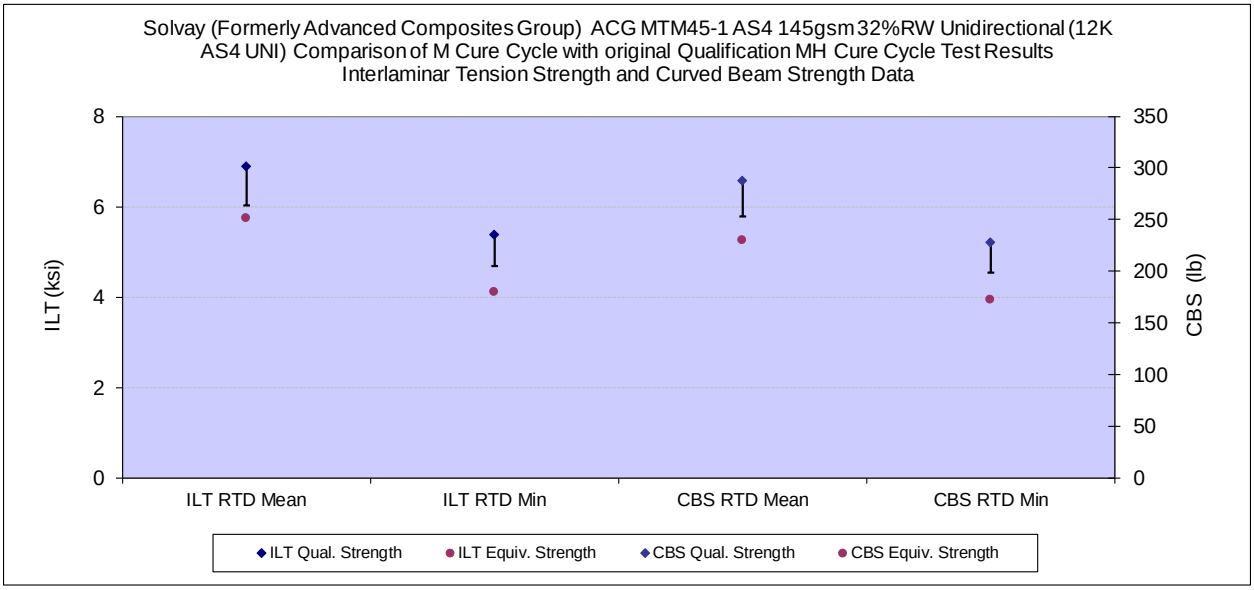

Figure 3-13 Interlaminar Tension and Curved Beam Strength means, minimums and Equivalence limits

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 the equivalency test 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	26.479
Standard Deviation	2.183	2.050
Coefficient of Variation %	7.021	7.741
Minimum	26.898	24.607
Maximum	33.553	29.600
Number of Specimens	7	5
RESULTS	**FAIL**	
Minimum Acceptable Equiv. Sample Mean	29.234	
Minimum Acceptable Equiv. Sample Min	25.575	
MOD CV RESULTS	**FAIL**	
Modified CV%	7.510	
Minimum Acceptable Equiv. Sample Mean	29.104	
Minimum Acceptable Equiv. Sample Min	25.190	

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 (26.479) is 90.98% of the minimum acceptable mean value (29.104) and the equivalency sample minimum (24.607) is 97.69% of the lowest acceptable minimum value (25.190).

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.

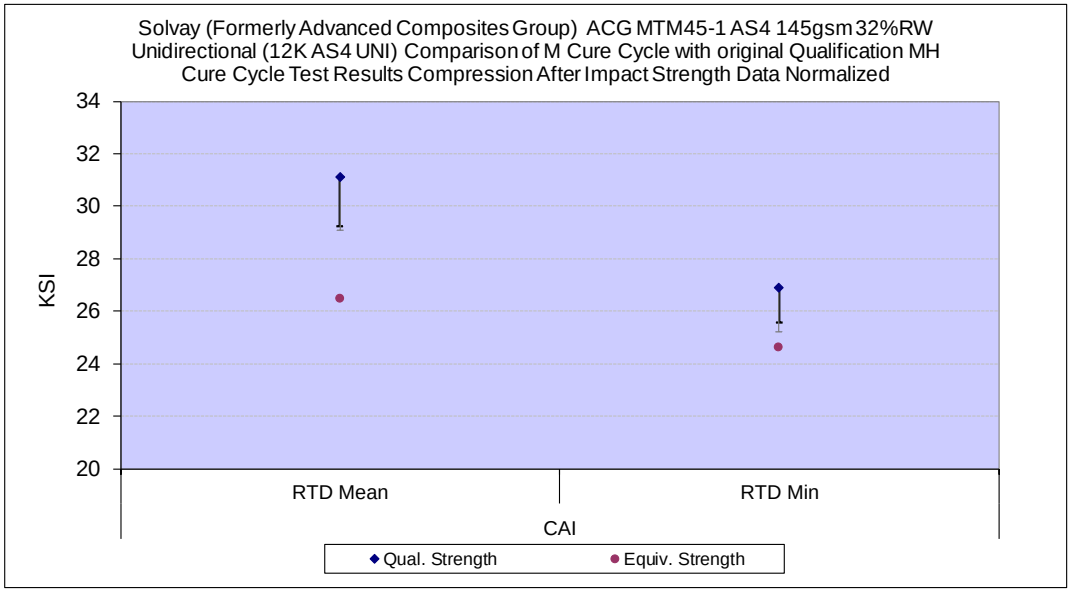

Figure 3-14 Compression After Impact means, minimums and Equivalence limits

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 M 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	0.005413
Standard Deviation	0.00021	0.00010
Coefficient of Variation %	3.76079	1.81878
Minimum	0.00458	0.00525
Maximum	0.00588	0.00573
Number of Specimens	40	22
RESULTS	**PASS**	
Passing Range for CPT Mean	0.005384 to 0.005571	
Student's t-statistic	-1.382	
p-value of Student's t-statistic	0.1720	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.005334 to 0.005622	
Modified CV Student's t-statistic	-0.897	
p-value of Student's t-statistic	0.373	

Table 3-21 Cured Ply Thickness Results

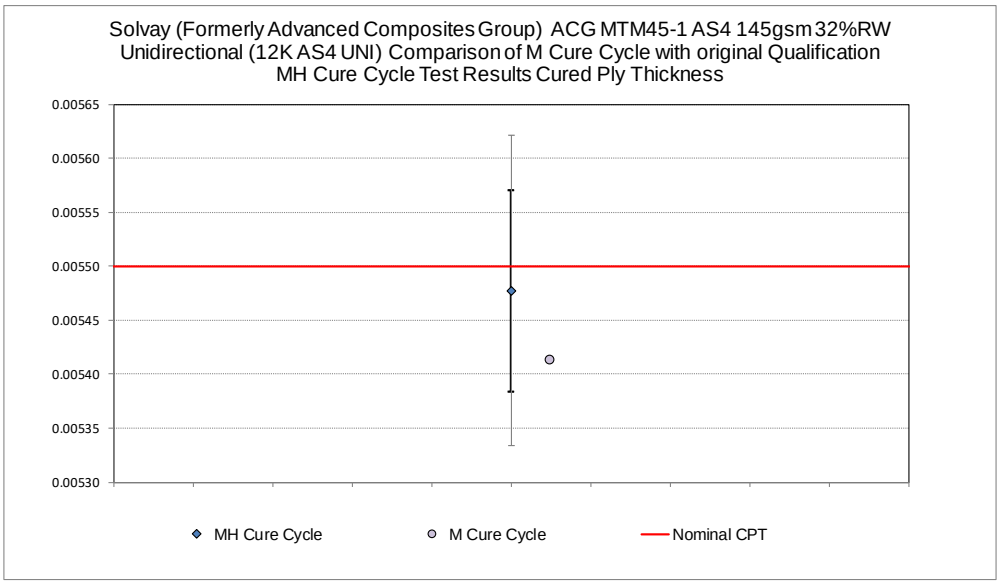

Figure 3-15 CPT means, 95% standard error bars and nominal value

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).

Only the Dry Peak of Tangent Delta dataset passed the equivalency test. There was insufficient data for the results to be considered conclusive. 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	293.818	329.927	348.918	326.389	297.862	377.131	344.926
Standard Deviation	6.033	3.775	21.879	7.078	18.191	19.265	20.432	16.270
Coefficient of Variation %	1.631	1.285	6.632	2.028	5.573	6.468	5.418	4.717
Minimum	362.300	290.822	298.544	343.976	298.538	285.176	349.148	333.614
Maximum	382.586	298.058	392.000	357.026	391.952	320.030	430.856	363.572
Number of Specimens	145	3	145	3	26	3	26	3
RESULTS	FAIL		PASS		FAIL		FAIL	
Passing Range for DMA Mean	363.022 to 376.874		304.860 to 354.995		303.528 to 349.250		351.917 to 402.345	
Student's t-statistic	-21.723		1.497		-2.560		-2.621	
p-value of Student's t-statistic	1.37E-47		0.136		0.016		0.014	
Range = ±18°F RESULTS	FAIL		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 dry data failed the equivalency test because the sample mean value (293.818) is below the lower acceptance limit (363.022). The equivalency sample mean is 80.94% of the lower limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 83.48% of the minimum mean value (351.948).

The Onset Storage Modulus for wet data failed the equivalency test because the sample mean value (297.862) is below the lower acceptance limit (303.528). The equivalency sample mean is 98.13% of the lower limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 96.59% of the minimum mean value (308.389).

The Peak of Tangent Delta for wet data failed the equivalency test because the sample mean value (344.926) is below the lower acceptance limit (351.917). The equivalency sample mean is 98.01% of the lower limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 96.04% of the minimum mean value (359.131).

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.

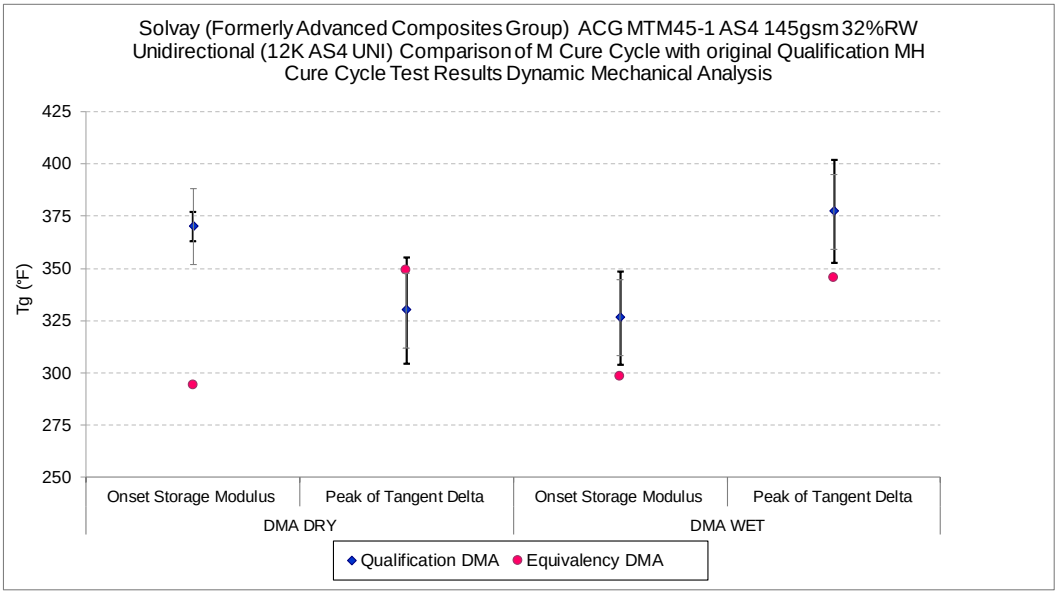

Figure 3-16 DMA Means and Equivalence limits

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 M cure cycle panels have sufficient test results for comparison with the original qualification material test results on a total of 37 different test types and conditions, not including the cured ply thickness or the DMA comparison. Using the modified CV method, there were twelve failures.

1. Transverse Compression Strength for the RTD condition failed by 0.6%
2. Transverse Compression Modulus for the RTD condition failed by 5.1%
3. Transverse Tension Strength for the CTD condition failed by 19.3%
4. Transverse Tension Strength for the RTD condition failed by 16.6%
5. Transverse Tension Modulus for the RTD condition failed by 1.0%
6. In-Plane Shear Modulus for the CTD condition failed by 1.8%
7. In-Plane Shear Modulus for the RTD condition failed by 2.9%
8. In-Plane Shear Modulus for the ETW condition failed by 1.8%
9. Short Beam Strength for the ETD condition failed by 1.4%
10. Short Beam Strength for the ETW condition failed by 2.5%
11. Unnotched Compression Strength for the RTD condition failed by 1.2%
12. Unnotched Compression Strength for the ETW condition failed by 2.4%

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

Twelve failures out of 37 test conditions gives the M cure cycle a pass rate of 67.57% for these tests. If the equivalency sample came from a material identical to the original qualification material and all tests were independent of all other tests, the expected pass rate would be 95%. This equates to 1.85 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 twelve or more failures is less than 0.0001%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 37 independent tests. If the two materials were equivalent, the probability of getting five or more failures is less than 5%. This means that the material could be considered as "not equivalent" with a 95% level of confidence if there were five or more failures out of 37 independent tests.

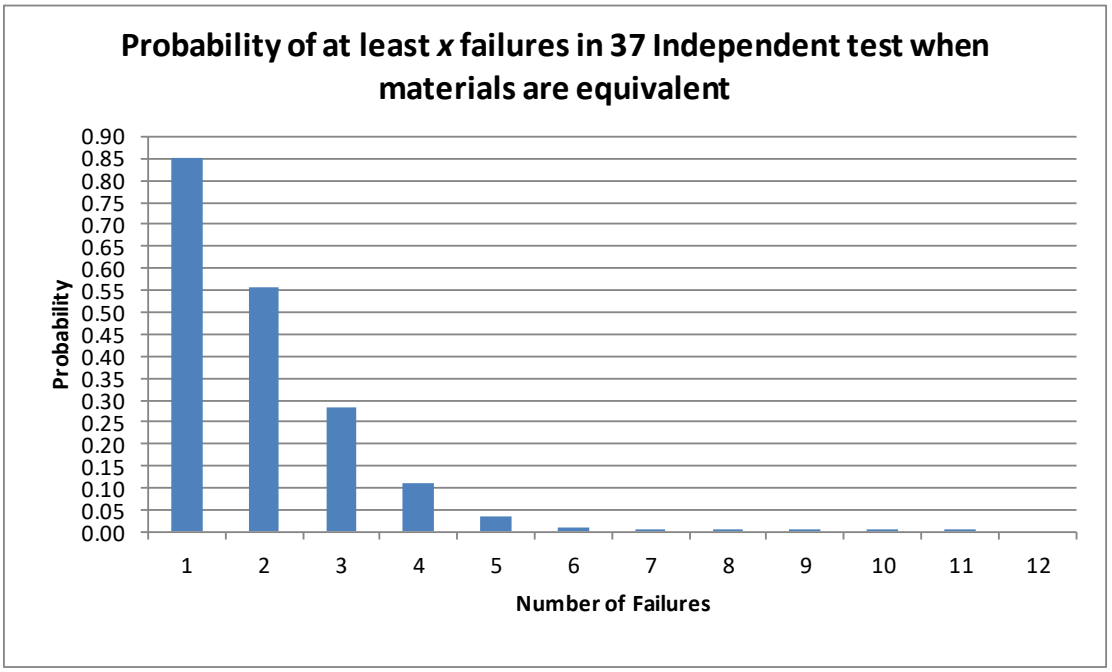

Figure 4-1 Probability of Number of Failures

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