Report No: NCP-RP-2008-008 Rev N/C
Report Date: March 21, 2019

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

FAA Special Project Number: SP3505WI-Q

NCAMP Document: NCP-RP-2008-008 N/C

Report Date: March 21, 2019

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

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

NCP-RP-2008-008 Rev N/C report is for REFERENCE only, not to be used for Certification

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: 2019.03.21 11:33:33 -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: 2019.03.21 11:09:58 -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: 2019.03.21 11:20:35 -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: 2019.03.21 15:38:11 -05'00'

Royal Lovingfoss

TABLE OF CONTENTS

List of Tables

List of Figures

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 “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 1001–06 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.

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.

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 “M” cure cycle. An equivalent NCAMP Process Specification, NPS 81451 with “M” 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 1
- Open Hole Tension
    - CTD, RTD – Cure 2
- Open Hole Compression
    - RTD, ETW – Cure 1 and 2
- Interlaminar Tension
    - RTD – Cure 1
- Compression After Impact
    - RTD – Cure 1

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 M Cure Cycle Values 2-1-08.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	UNC
Unnotched Tension	UNT
Open Hole Tension	OHT
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

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 $\bar{X} - k_n^{table\ 2.1} \cdot S$ 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^*.

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

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

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

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

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

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

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

Table 3-1 "% Failed" Results Scale

Equivalency Test Results for Solvay (Formerly Advanced Composites Group) MTM45-1/IM7-145-32%RW (12K IM7 UNI) MH Cure Cycle (qualification) with M Cure Cycle (equivalency)

Test	Normalized Data	Property	Environmental Condition			
			CTD	RTD	ETD	ETW
Longitudinal Compression	Yes	Modulus		Pass		Failed by 7.0%
Longitudinal Tension	Yes	Modulus	Pass	Pass		
Transverse Compression	No	Strength		Failed by 39.7%		Failed by 32.8%
		Modulus		Pass		Pass
Transverse Tension	No	Strength	Failed by 12.8%	Failed by 14.2%		Pass
		Modulus	Failed by 2.9%	Failed by 10.0%		Failed by 2.9%
In-Plane Shear	No	0.2% Offset Strength	Pass	Failed by 8.8%		Pass
		5% Strain Strength	Failed by 3.5%	Failed by 4.6%		Failed by 0.4%
		Modulus	Failed by 0.2%	Failed by 9.8%		Failed by 9.4%
Short Beam Strength	No	Strength	Failed by 8.8%	Failed by 3.3% Insufficient Data	Failed by 8.7%	Pass
Unnotched Compression	Yes	Strength		Failed by 1.6%		Failed by 5.0% Insufficient Data
	Yes	Modulus		Pass		Pass
Unnotched Tension	Yes	Strength	Pass	Pass		
		Modulus	Pass	Pass		
Open Hole Tension	Yes	Strength	Pass Insufficient Data	Pass Insufficient Data		
Cured Ply Thickness	NA	NA	Pass with Mod CV			
Dynamic Mechanical Analysis	Onset Storage Modulus - Dry		Failed by 14.5%			
	Onset Storage Modulus - Wet		Failed by 0.4%			

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.

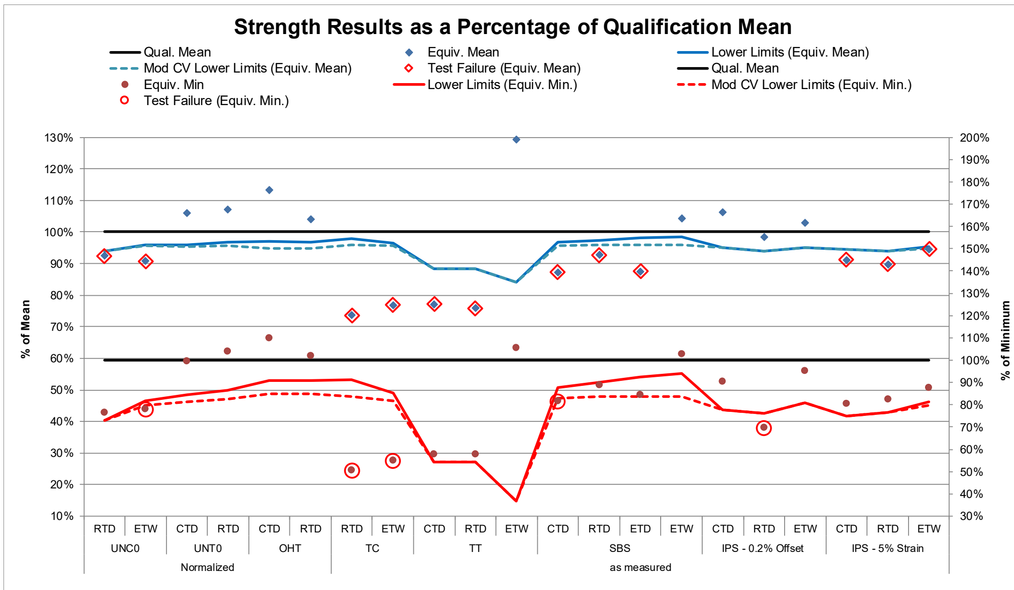

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

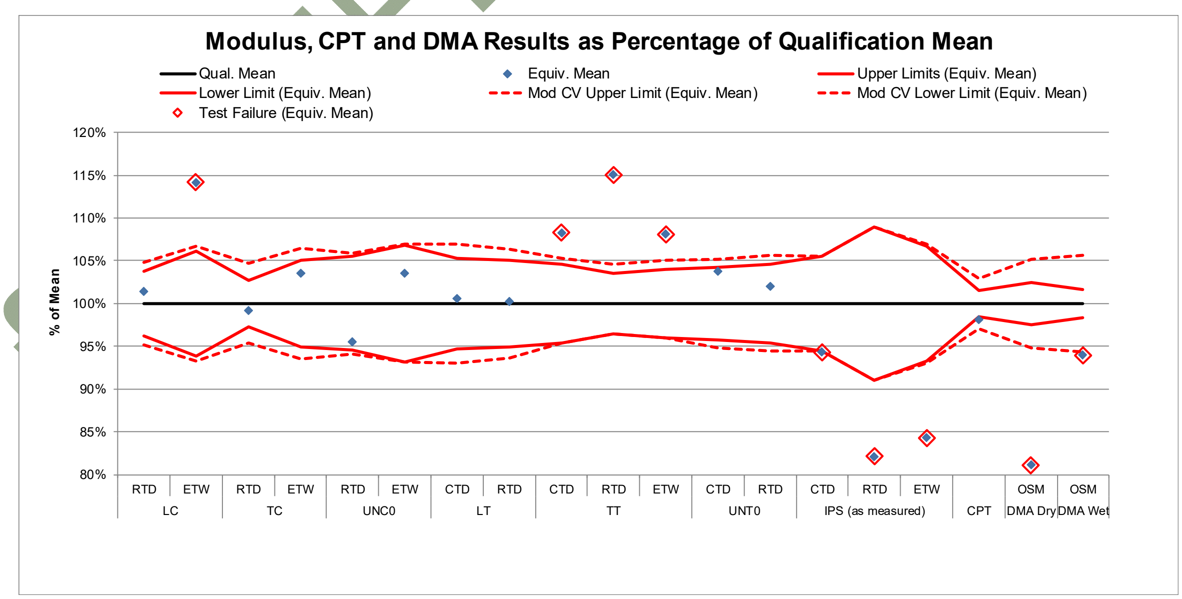

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Longitudinal Compression (LC)

The Longitudinal Compression data is normalized by cured ply thickness. The LC normalized modulus data passed for the RTD condition but failed equivalency for the ETW condition. 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		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	20.237	20.527	20.249	23.119
Standard Deviation	0.984	0.594	1.025	2.124
Coefficient of Variation %	4.864	2.892	5.062	9.189
Minimum	18.011	19.761	18.544	21.111
Maximum	21.751	21.421	22.215	27.146
Number of Specimens	23	8	18	9
RESULTS	**PASS**		**FAIL**	
Passing Range for Modulus Mean	19.477 to 20.997		19.014 to 21.485	
Student's t-statistic	0.781		4.785	
p-value of Student's t-statistic	0.441		0.00007	
MOD CV RESULTS	**PASS with MOD CV**		**FAIL**	
Modified CV%	6.432		6.531	
Passing Range for Modulus Mean	19.254 to 21.219		18.885 to 21.614	
Modified CV Student's t-statistic	0.604		4.332	
p-value of Student's t-statistic	0.551		0.0002	

Table 3-3 Longitudinal Compression Modulus Results

The LC modulus data for the ETW environment failed the equivalency test because the sample mean value (23.119) is above the upper acceptance limit (21.485). The equivalency sample mean value is 107.61% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 106.97% of the maximum acceptable mean value (21.614).

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.

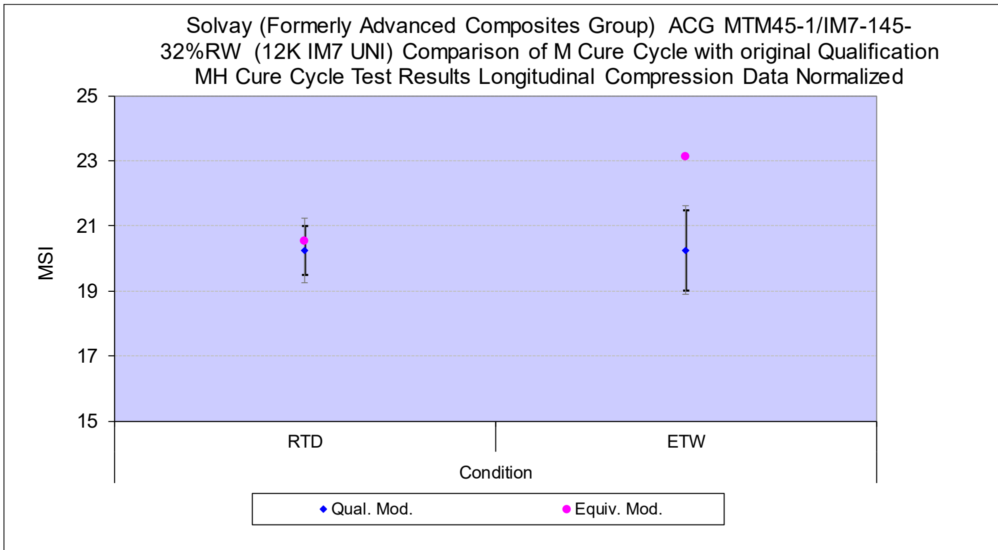

Figure 3-3 Longitudinal Compression Modulus means and Equivalence limits

3.2 Longitudinal Tension (LT)

The Longitudinal Tension data is normalized by cured ply thickness. The LT normalized modulus data passed equivalency tests 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 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. 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	23.499	22.899	22.947
Standard Deviation	1.124	0.609	1.210	0.360
Coefficient of Variation %	4.810	2.592	5.282	1.570
Minimum	21.961	22.934	21.459	22.498
Maximum	25.115	24.357	25.466	23.475
Number of Specimens	17	4	16	5
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	22.132 to 24.596		21.733 to 24.065	
Student's t-statistic	0.228		0.085	
p-value of Student's t-statistic	0.822		0.933	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.405		6.641	
Passing Range for Modulus Mean	21.742 to 24.986		21.440 to 24.359	
Modified CV Student's t-statistic	0.174		0.068	
p-value of Student's t-statistic	0.864		0.947	

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.

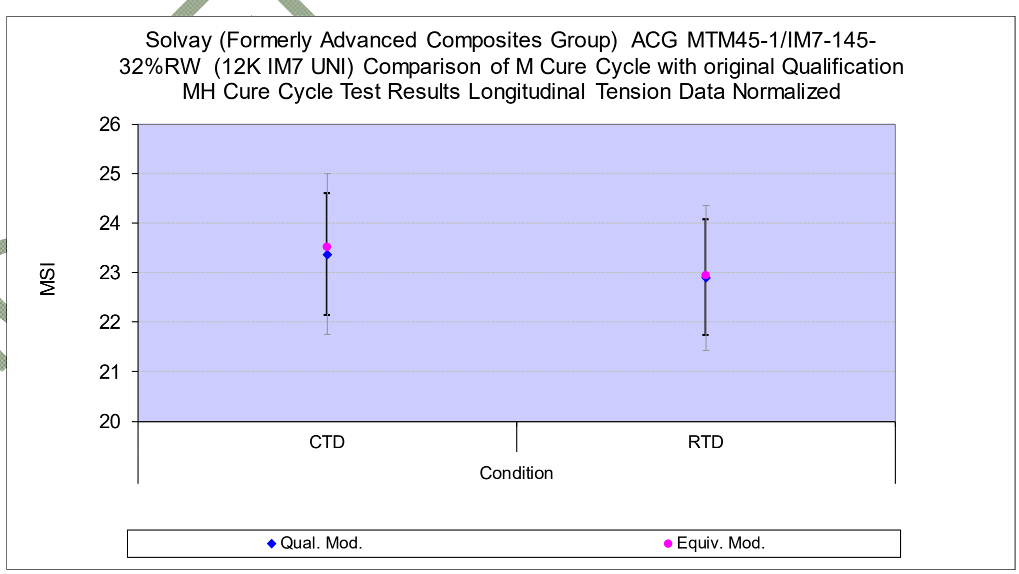

Figure 3-4 Longitudinal Tension Modulus means and Equivalence limits

3.3 Transverse (90°) Compression (TC)

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

Transverse Compression (TC) Strength	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Strength (ksi)	27.959	20.587	15.707	12.074
Standard Deviation	0.920	6.276	0.850	3.434
Coefficient of Variation %	3.292	30.485	5.414	28.440
Minimum	26.368	14.120	13.579	8.620
Maximum	29.299	27.181	17.065	15.908
Number of Specimens	18	8	18	9
RESULTS	**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	27.334		15.162	
Minimum Acceptable Equiv. Sample Min	25.474		13.376	
MOD CV RESULTS	**FAIL**		**FAIL**	
Modified CV %	6.000		6.707	
Minimum Acceptable Equiv. Sample Mean	26.820		15.032	
Minimum Acceptable Equiv. Sample Min	23.430		12.820	

Table 3-5 Transverse Compression Strength Results

Transverse Compression (TC) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Modulus (Msi)	1.222	1.211	1.087	1.125
Standard Deviation	0.037	0.037	0.051	0.057
Coefficient of Variation %	3.066	3.080	4.705	5.058
Minimum	1.162	1.157	0.956	1.075
Maximum	1.305	1.272	1.145	1.189
Number of Specimens	18	8	18	5
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	1.189 to 1.254		1.032 to 1.142	
Student's t-statistic	-0.646		1.444	
p-value of Student's t-statistic	0.525		0.163	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.352	
Passing Range for Modulus Mean	1.165 to 1.279		1.017 to 1.157	
Modified CV Student's t-statistic	-0.372		1.129	
p-value of Student's t-statistic	0.713		0.272	

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 (20.587) is 76.76% of the minimum acceptable mean value (26.820) and the equivalency sample minimum (14.120) is 60.26% of the lowest acceptable minimum value (23.430).

The TC strength data for the ETW environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (12.074) is 80.32% of the minimum acceptable mean value (15.032) and the equivalency sample minimum (8.620) is 67.24% of the lowest acceptable minimum value (12.820).

Figure 3-5 illustrates the 90º Compression strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

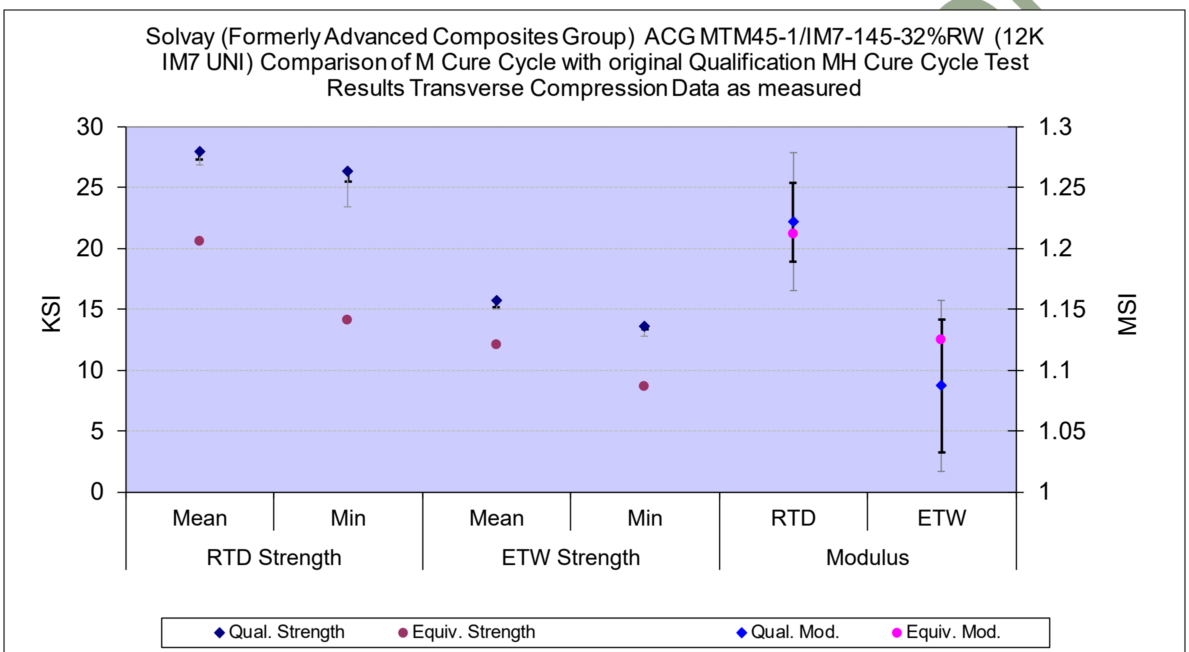

Figure 3-5 Transverse Compression means, minimums and Equivalence limits

3.4 Transverse (90°) Tension (TT)

The Transverse Tension data is not normalized. The TT strength data passed only the equivalency test for the ETW condition. It failed equivalency for all remaining equivalency tests. The mean strength values were too low and the mean modulus values were too high in the M cure cycle dataset. Modified CV results were not provided for the strength data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for strength in Table 3-7 and for modulus in Table 3-8.

Transverse Tension (TT) Strength	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	8.340	6.437	7.595	5.763	4.298	5.555
Standard Deviation	1.415	1.598	1.289	1.613	1.007	0.991
Coefficient of Variation %	16.970	24.831	16.975	27.989	23.440	17.841
Minimum	5.328	4.823	5.405	4.407	2.559	4.531
Maximum	10.422	8.469	9.521	8.592	5.288	6.698
Number of Specimens	18	8	21	8	19	8
RESULTS	FAIL		FAIL		PASS	
Minimum Acceptable Equiv. Sample Mean	7.379		6.719		3.614	
Minimum Acceptable Equiv. Sample Min	4.519		4.114		1.578	

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)	1.238	1.340	1.111	1.278	0.951	1.029
Standard Deviation	0.075	0.029	0.056	0.018	0.049	0.027
Coefficient of Variation %	6.074	2.173	5.085	1.415	5.117	2.663
Minimum	1.140	1.278	1.008	1.259	0.866	1.011
Maximum	1.451	1.374	1.236	1.312	1.028	1.095
Number of Specimens	22	8	23	9	19	8
RESULTS	FAIL		FAIL		FAIL	
Passing Range for Modulus Mean	1.181 to 1.294		1.071 to 1.150		0.913 to 0.989	
Student's t-statistic	3.724		8.633		4.175	
p-value of Student's t-statistic	0.001		1.25E-09		0.0003	
MOD CV RESULTS	FAIL		FAIL		FAIL	
Modified CV%	7.037		6.542		6.559	
Passing Range for Modulus Mean	1.173 to 1.303		1.060 to 1.161		0.904 to 0.999	
Modified CV Student's t-statistic	3.234		6.758		3.330	
p-value of Student's t-statistic	0.003		1.71E-07		0.003	

Table 3-8 Transverse Tension Modulus Results

The TT 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 (6.437) is 87.24% of the lowest acceptable mean value (7.379). 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 the sample mean value being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (5.763) is 85.77% of the lowest acceptable mean value (6.719). 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 CTD environment failed the equivalency test because the sample mean value (1.340) is above the upper acceptance limit (1.294). The equivalency sample mean value is 103.57% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 102.89% of the maximum acceptable mean value (1.303).

The TT modulus data for the RTD environment failed the equivalency test because the sample mean value (1.278) is above the upper acceptance limit (1.150). The equivalency sample mean value is 111.10% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 110.05% of the maximum acceptable mean value (1.161).

The TT modulus data for the ETW environment failed the equivalency test because the sample mean value (1.029) is above the upper acceptance limit (0.989). The equivalency sample mean value is 103.95% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 102.94% of the maximum acceptable mean value (0.999).

Figure 3-6 illustrates the 90º Tension strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

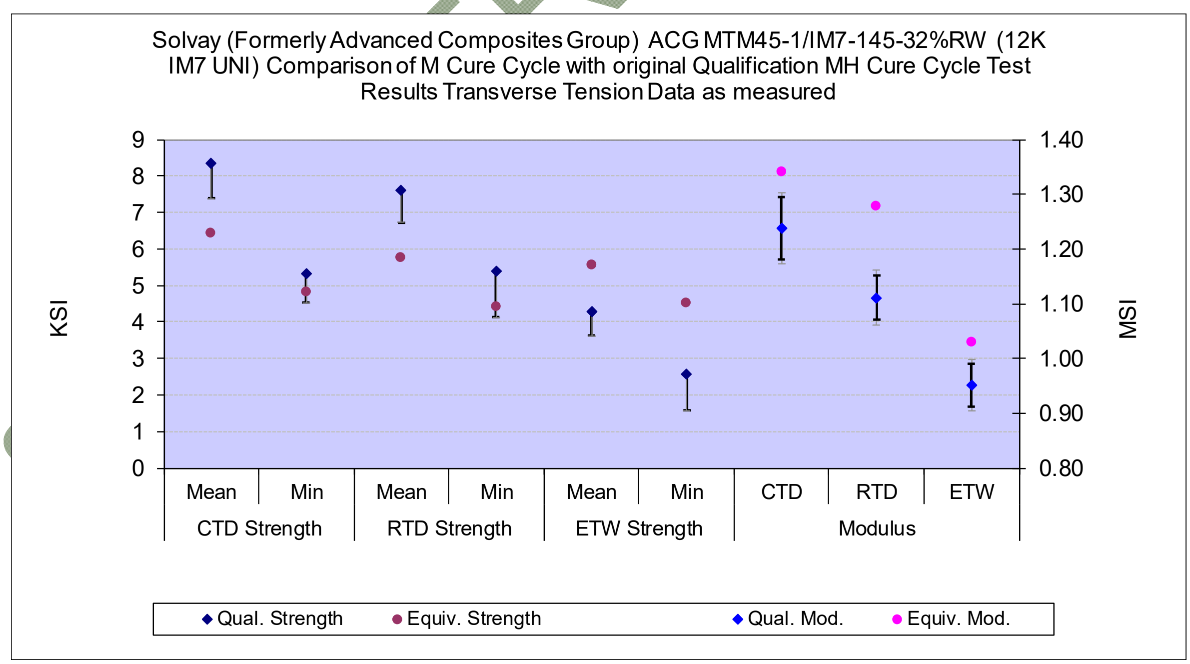

Figure 3-6 Transverse Tension means, minimums and Equivalence limits

3.5 Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The SBS data passed the equivalency test for the ETW environment but failed equivalency tests for the other environments (CTD, RTD, and ETD). There was insufficient data for the RTD condition from the qualification sample, so that result is not considered conclusive. 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			Insufficient Data					
Mean Strength (ksi)	20.854	18.201	14.466	13.423	11.152	9.770	8.540	8.913
Standard Deviation	0.967	0.601	0.542	0.408	0.309	0.197	0.191	0.097
Coefficient of Variation %	4.638	3.303	3.750	3.038	2.768	2.013	2.238	1.088
Minimum	18.954	17.029	13.851	12.868	10.586	9.414	8.329	8.774
Maximum	22.386	18.993	15.180	14.124	11.569	9.977	9.124	9.041
Number of Specimens	14	8	6	8	13	8	18	8
RESULTS	**FAIL**		**FAIL**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	20.197		14.098		10.942		8.410	
Minimum Acceptable Equiv. Sample Min	18.242		13.001		10.318		8.024	
MOD CV RESULTS	**FAIL**		**FAIL**		**FAIL**		**PASS with MOD CV**	
Modified CV%	6.319		6.000		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	19.959		13.877		10.697		8.192	
Minimum Acceptable Equiv. Sample Min	17.296		12.122		9.345		7.156	

Table 3-9 Lamina Short Beam Strength Results

The SBS data for the CTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (18.201) is 90.12% of the minimum acceptable mean value (20.197) and the equivalency sample minimum (17.029) is 93.35% of the lowest acceptable minimum value (18.242). Under the assumption of the modified CV method, the equivalency sample mean is 91.19% of the minimum acceptable mean value (19.959) and the equivalency sample minimum is 98.45% of the lowest acceptable minimum value (17.296).

The SBS data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (13.423) is 95.21% of the minimum acceptable mean value (14.098) and the equivalency sample minimum (12.868) is 98.98% of the lowest acceptable minimum value (13.001). Under the assumption of the modified CV method, the equivalency sample mean is 96.73% of the minimum acceptable mean value (13.877) and the equivalency sample minimum value is acceptable.

The SBS data for the ETD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (9.770) is 89.29% of the minimum acceptable mean value (10.942) and the equivalency sample minimum (9.414) is 91.24% of the lowest acceptable minimum value (10.318). Under the assumption of the modified CV method, the equivalency sample mean is 91.33% of the minimum acceptable mean value (10.697) 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.

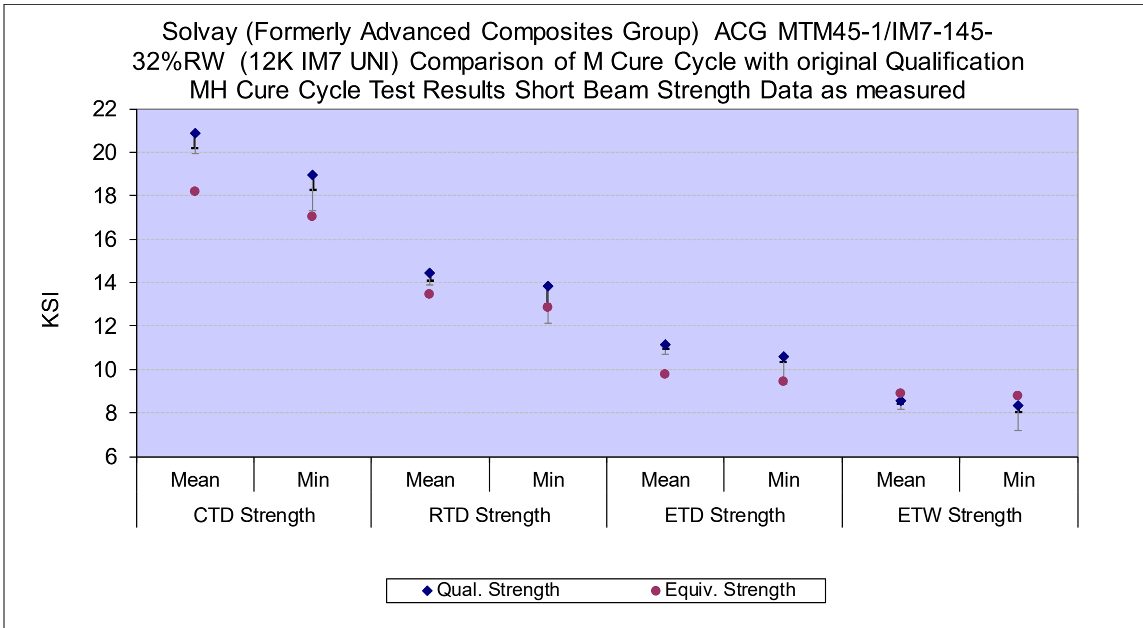

Figure 3-7 Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The 0.2% offset strength data passed equivalency for the CTD and ETW conditions but not for the RTD condition. The strength at 5% strain data and the modulus data both failed equivalency for all three environmental conditions tested.

Modified CV results were not provided for the CTD datasets for strength at 5% strain and modulus, or for the RTD datasets for all three properties, because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for the 0.2% offset strength data in Table 3-10, for the strength at 5% strain data in Table 3-11, and for the modulus data in Table 3-12.

In-Plane Shear (IPS) 0.2% Offset Strength	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength 0.2% offset (ksi)	7.738	8.217	5.896	5.804	3.530	3.632
Standard Deviation	0.617	0.808	0.517	0.757	0.251	0.237
Coefficient of Variation %	7.980	9.833	8.767	13.037	7.118	6.513
Minimum	6.662	6.990	4.762	4.106	3.076	3.368
Maximum	9.080	9.380	6.990	6.495	3.892	3.953
Number of Specimens	38	10	20	8	19	8
RESULTS	**PASS**		**FAIL**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	7.362		5.545		3.359	
Minimum Acceptable Equiv. Sample Min	6.023		4.501		2.851	
MOD CV RESULTS	**PASS with MOD CV**		**NA**		**PASS with MOD CV**	
Modified CV%	7.990				7.559	
Minimum Acceptable Equiv. Sample Mean	7.362				3.348	
Minimum Acceptable Equiv. Sample Min	6.021				2.809	

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						
Mean Strength 5% Strain (ksi)	13.000	11.859	9.634	8.651	5.475	5.179
Standard Deviation	1.176	1.123	0.839	0.675	0.379	0.356
Coefficient of Variation %	9.047	9.472	8.709	7.806	6.930	6.867
Minimum	10.560	10.460	7.959	7.940	4.679	4.800
Maximum	14.526	13.030	11.034	9.380	6.015	5.620
Number of Specimens	18	10	18	8	18	8
RESULTS	**FAIL**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	12.284		9.064		5.218	
Minimum Acceptable Equiv. Sample Min	9.734		7.368		4.451	
MOD CV RESULTS	**NA**		**NA**		**FAIL**	
Modified CV%					7.465	
Minimum Acceptable Equiv. Sample Mean					5.198	
Minimum Acceptable Equiv. Sample Min					4.372	

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)	0.632	0.596	0.525	0.431	0.358	0.302
Standard Deviation	0.053	0.026	0.048	0.070	0.025	0.032
Coefficient of Variation %	8.437	4.448	9.144	16.152	7.109	10.753
Minimum	0.542	0.563	0.419	0.266	0.321	0.256
Maximum	0.751	0.637	0.621	0.488	0.402	0.346
Number of Specimens	38	10	20	8	19	8
RESULTS	FAIL		FAIL		FAIL	
Passing Range for Modulus Mean	0.597 to 0.667		0.478 to 0.572		0.334 to 0.382	
Student's t-statistic	-2.067		-4.110		-4.841	
p-value of Student's t-statistic	0.044		0.0004		0.00006	
MOD CV RESULTS	NA		NA		FAIL	
Modified CV%					7.554	
Passing Range for Modulus Mean					0.333 to 0.383	
Modified CV Student's t-statistic					-4.659	
p-value of Student's t-statistic					0.00009	

Table 3-12 In-Plane Shear Modulus Results

The IPS 0.2% Offset strength data for the RTD environment failed equivalence due to the minimum sample value being below the acceptance limit. The sample mean value is acceptable. The equivalency sample minimum (4.106) is 91.23% of the lowest acceptable minimum value (4.501). The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The IPS Strength at 5% Strain data for the CTD environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (11.859) is 96.54% of the minimum acceptable mean value (12.284). The modified CV method could not be used due to the CV of the CTD condition being greater than 8%.

The IPS Strength at 5% Strain 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 (8.651) is 95.45% of the minimum acceptable mean value (9.064). The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The IPS Strength at 5% Strain 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 (5.179) is 99.25% of the minimum acceptable mean value (5.218). Under the assumption of the modified CV method, the equivalency sample mean is 99.63% of the minimum acceptable mean value (5.198).

The IPS modulus data for the CTD environment failed the equivalency test because the sample mean value (0.596) is below the lower acceptance limit (0.597). The equivalency sample mean value is 99.84% of the lower limit of acceptable values. The modified CV method could not be used due to the CV of the CTD condition being greater than 8%.

The IPS modulus data for the RTD environment failed the equivalency test because the sample mean value (0.431) is below the lower acceptance limit (0.478). The equivalency sample mean value is 90.17% of the lower limit of acceptable values. The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The IPS modulus data for the ETW environment failed the equivalency test because the sample mean value (0.302) is below the lower acceptance limit (0.334). The equivalency sample mean value is 90.32% of the lower limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 90.57% of the minimum acceptable mean value (0.333).

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.

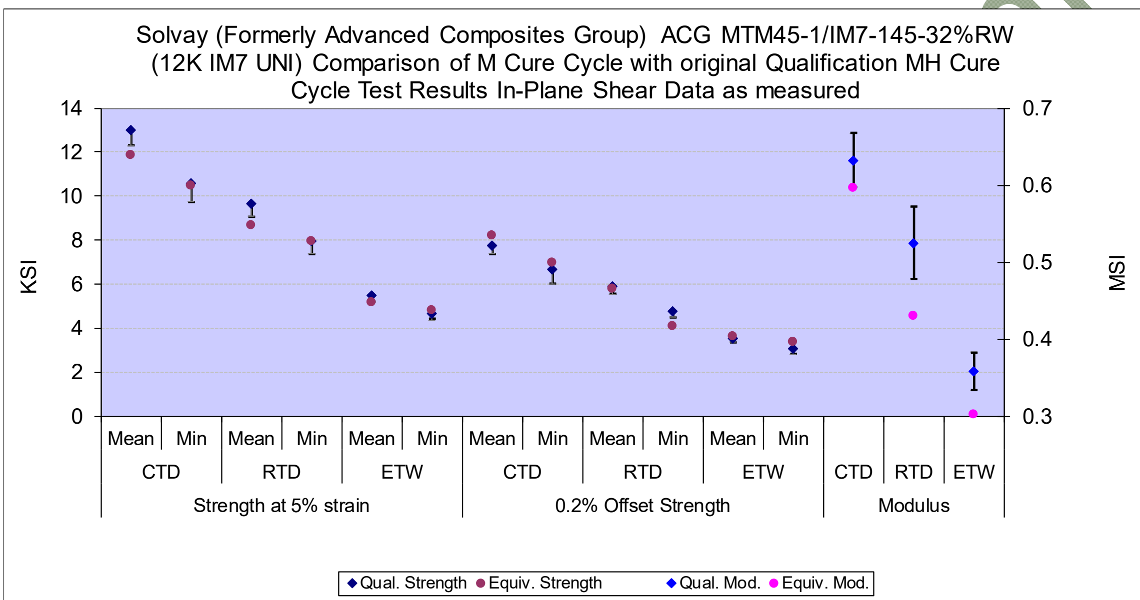

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The Unnotched Compression 0 data is normalized by cured ply thickness. The UNC0 normalized modulus data passed the equivalency test for both the RTD and ETW environments, while the UNC0 strength data did not pass for either environment. Modified CV results were not provided for the RTD strength data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. There was insufficient data from the qualification sample for the ETW strength test, so those results are not considered conclusive. 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			Insufficient Data	
Mean Strength (ksi)	99.647	92.222	83.272	75.610
Standard Deviation	9.660	7.549	5.514	6.277
Coefficient of Variation %	9.694	8.186	6.622	8.302
Minimum	82.622	76.155	76.373	64.935
Maximum	114.340	99.926	88.911	88.100
Number of Specimens	8	10	6	10
RESULTS	FAIL		FAIL	
Minimum Acceptable Equiv. Sample Mean	93.766		79.914	
Minimum Acceptable Equiv. Sample Min	72.821		67.958	
MOD CV RESULTS	NA		FAIL	
Modified CV %			7.311	
Minimum Acceptable Equiv. Sample Mean			79.565	
Minimum Acceptable Equiv. Sample Min			66.364	

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)	11.108	10.608	10.933	11.321
Standard Deviation	0.726	0.489	0.864	0.635
Coefficient of Variation %	6.537	4.606	7.898	5.607
Minimum	10.158	9.889	9.227	10.565
Maximum	12.238	11.277	12.423	12.757
Number of Specimens	8	10	12	8
RESULTS	PASS		PASS	
Passing Range for Modulus Mean	10.500 to 11.715		10.183 to 11.684	
Student's t-statistic	-1.744		1.086	
p-value of Student's t-statistic	0.100		0.292	
MOD CV RESULTS	PASS with MOD CV		PASS with MOD CV	
Modified CV%	7.269		7.949	
Passing Range for Modulus Mean	10.457 to 11.759		10.179 to 11.687	
Modified CV Student's t-statistic	-1.627		1.081	
p-value of Student's t-statistic	0.123		0.294	

Table 3-14 Unnotched Compression 0 Modulus Results

The UNC0 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 (92.222) is 98.35% of the minimum acceptable mean value (93.766). The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The UNC0 strength data for the ETW environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (75.610) is 95.03% of the minimum acceptable mean value (79.565) and the equivalency sample minimum (64.935) is 97.85% of the lowest acceptable minimum value (66.364).

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.

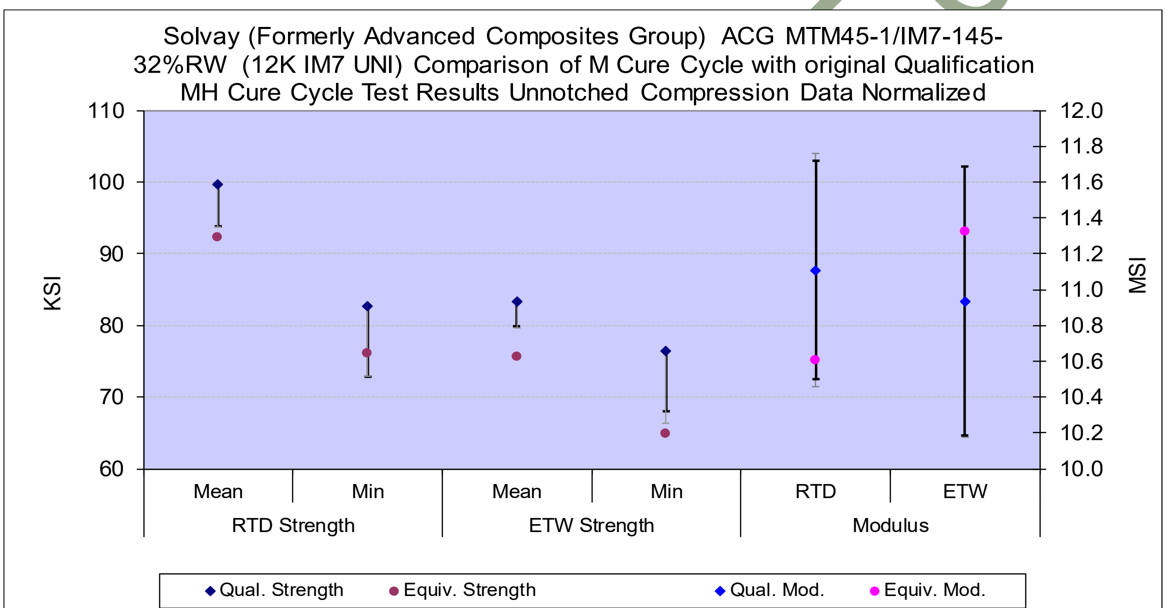

Figure 3-9 Unnotched Compression 0 means, minimums and Equivalence limits

3.8 “50/0/50” Unnotched Tension 0 (UNT0)

The Unnotched Tension 0 data is normalized by cured ply thickness. The UNT0 normalized data passed all equivalency tests. 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)	184.307	195.654	181.547	194.745
Standard Deviation	10.716	7.127	8.964	3.295
Coefficient of Variation %	5.814	3.643	4.937	1.692
Minimum	165.012	183.453	167.358	189.048
Maximum	202.157	204.755	200.537	198.537
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 3-15 Unnotched Tension 0 Strength Results

Unnotched Tension (UNT0) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055				
Mean Modulus (Msi)	11.623	12.064	11.624	11.859
Standard Deviation	0.604	0.426	0.520	0.836
Coefficient of Variation %	5.201	3.528	4.476	7.049
Minimum	9.923	11.511	10.692	9.836
Maximum	12.533	12.807	12.332	12.310
Number of Specimens	18	8	20	8
RESULTS	**PASS**		**PASS**	
Passing Range for Modulus Mean	11.133 to 12.112		11.090 to 12.158	
Student's t-statistic	1.862		0.906	
p-value of Student's t-statistic	0.075		0.373	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.600		6.238	
Passing Range for Modulus Mean	11.022 to 12.224		10.973 to 12.274	
Modified CV Student's t-statistic	1.517		0.744	
p-value of Student's t-statistic	0.142		0.464	

Table 3-16 Unnotched Tension 0 Modulus Results

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.

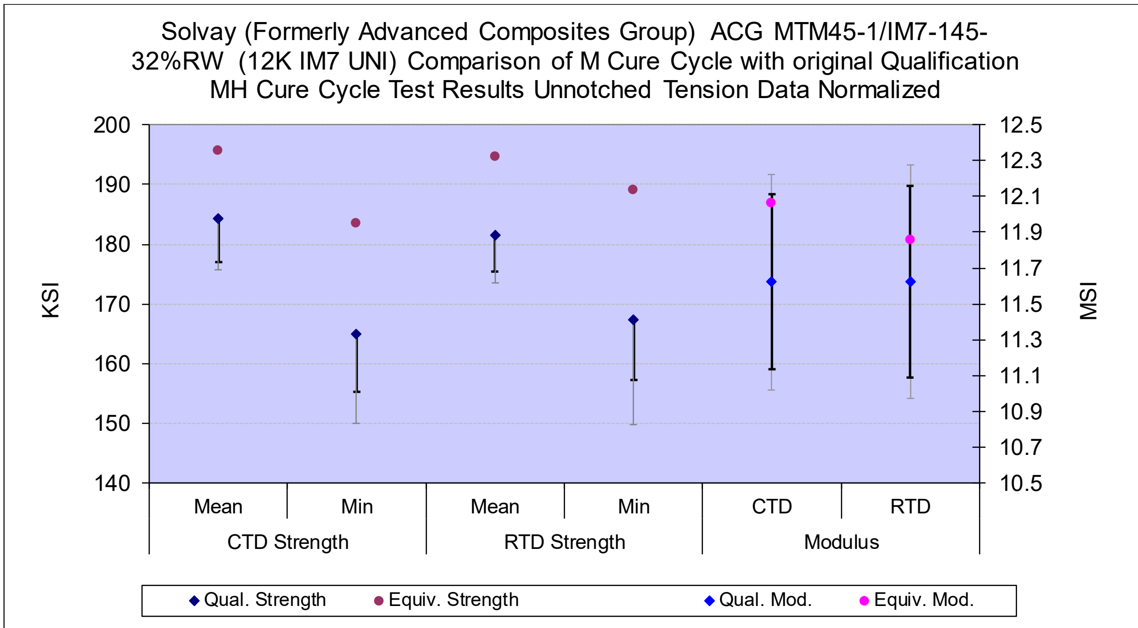

Figure 3-10 Unnotched Tension 0 means, minimums and Equivalence limits

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 passed the equivalency test for both the CTD and RTD environments. However there was insufficient data for these tests, so the results are not considered conclusive. 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	Insufficient Data		Insufficient Data	
Mean Strength (ksi)	66.592	75.457	68.014	70.731
Standard Deviation	2.378	1.849	2.495	1.638
Coefficient of Variation %	3.571	2.450	3.668	2.316
Minimum	62.521	73.342	64.644	69.282
Maximum	70.751	77.814	73.185	73.379
Number of Specimens	18	5	19	5
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	64.565		65.887	
Minimum Acceptable Equiv. Sample Min	60.579		61.705	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	63.186		64.535	
Minimum Acceptable Equiv. Sample Min	56.489		57.695	

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.

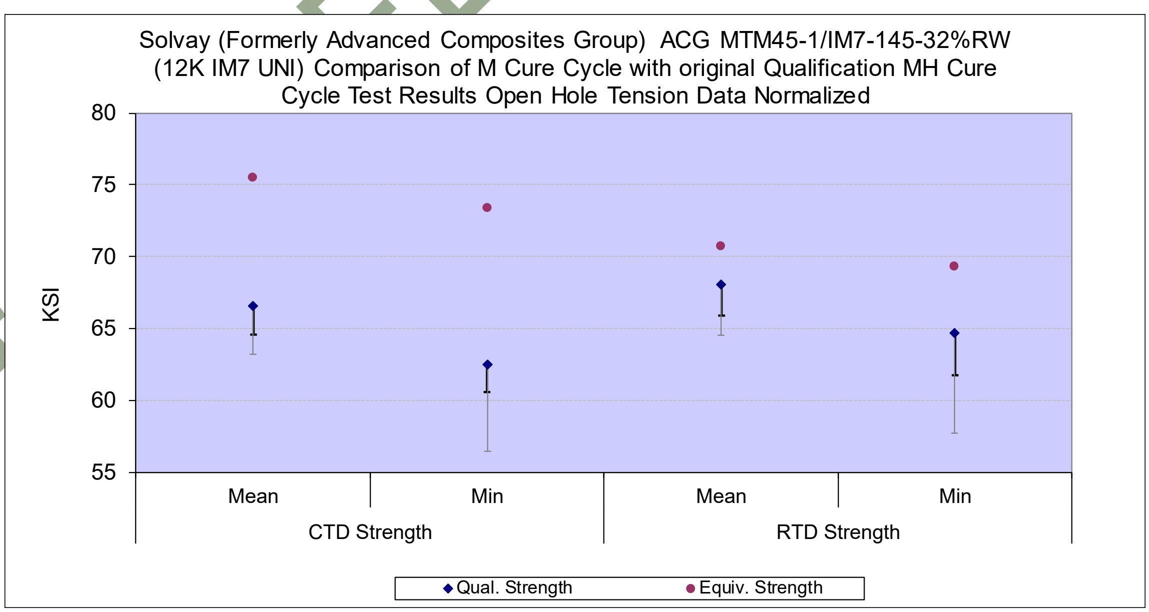

Figure 3-11 Open Hole Tension 1 means, minimums and Equivalence limits

3.10 Cured Ply Thickness (CPT)

The Cured Ply Thickness cannot be considered equivalent according to the results of a pooled two-sample double-sided t-test at a 95% confidence level. The CPT data failed the equivalency test because the average CPT (0.005494) is below the lower acceptance limit (0.005684). The equivalency average CPT is 99.71% of the lower limit of acceptable values. Under the assumption of the modified CV method, the CPT data passed the equivalency test.

Statistics for both the original qualification material MH cure cycle and equivalency M cure cycle samples are shown in Table 3-18. The average CPT with 95% standard error bars is shown in Figure 3-12. The longer, lighter colored error bars are for the modified CV computations.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.005599	0.005494
Standard Deviation	0.00017	0.00018
Coefficient of Variation %	3.04460	3.22398
Minimum	0.00496	0.00518
Maximum	0.00602	0.00585
Number of Specimens	482	16
RESULTS	**FAIL**	
Passing Range for CPT Mean	0.005514 to 0.005684	
Student's t-statistic	-2.413	
p-value of Student's t-statistic	0.016	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.005433 to 0.005765	
Modified CV Student's t-statistic	-1.239	
p-value of Student's t-statistic	0.216	

Table 3-18 Cured Ply Thickness Results

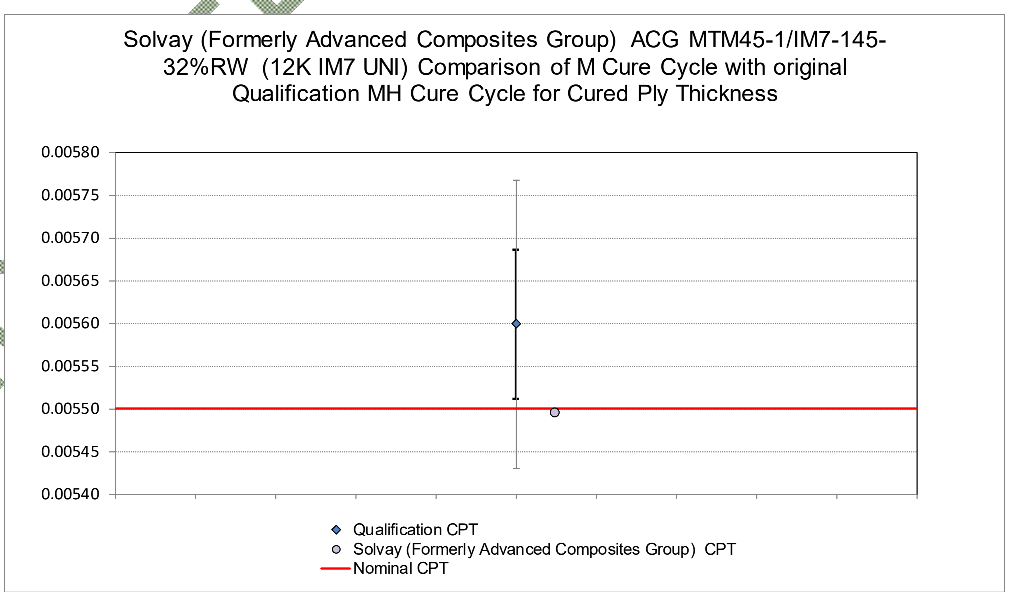

Figure 3-12 CPT means, 95% standard error bars and nominal value

3.11 Dynamic Mechanical Analysis (DMA)

DMA measurement are 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 3-19.

Dynamic Mechanical Analysis (DMA)	Onset Storage Modulus - Dry		Onset Storage Modulus - Wet	
	Qual.	Equiv.	Qual.	Equiv.
Mean (°F)	349.064	283.002	317.106	297.917
Standard Deviation	18.799	3.281	8.796	7.279
Coefficient of Variation %	5.386	1.159	2.774	2.443
Minimum	321.734	279.158	306.794	289.940
Maximum	386.222	286.232	348.782	307.238
Number of Specimens	22	20	17	20
RESULTS	FAIL		FAIL	
Passing Range for DMA Mean	340.443 to 357.686		311.743 to 322.469	
Student's t-statistic	-15.486		-7.264	
p-value of Student's t-statistic	1.71E-18		1.75E-08	
Range = ±18°F RESULTS	FAIL		FAIL	
Passing Range for DMA Mean	331.064 to 367.064		299.106 to 335.106	

Table 3-19 DMA Results

The Onset Storage Modulus for dry data failed the equivalency test because the sample mean value (283.002) is below the lower acceptance limit (340.443). The equivalency sample mean is 83.13% of the lower limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 85.48% of the minimum acceptable mean value (331.064).

The Onset Storage Modulus for wet data failed the equivalency test because the sample mean value (297.917) is below the lower acceptance limit (311.743). The equivalency sample mean is 95.56% of the lower limit of acceptable values. With the allowable range set to ±18°F, the equivalency sample mean is 99.60% of the minimum acceptable mean value (299.106).

Figure 3-13 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.

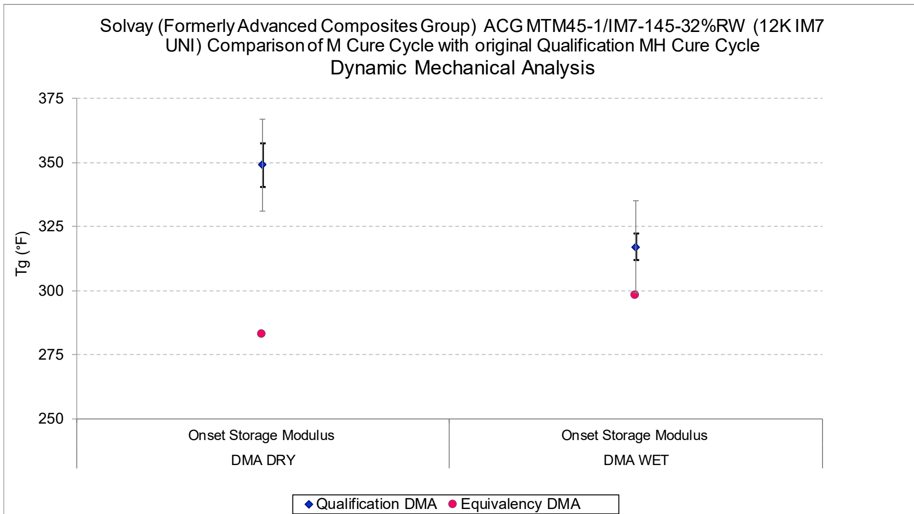

Figure 3-13 DMA Means and Equivalence limits

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 33 different test types and conditions, not including the cured ply thickness or the DMA comparison. Using the modified CV method, there were 18 failures.

1. Longitudinal Compression Modulus for the ETW condition failed by 7.0%
2. Transverse Compression Strength for the RTD condition failed by 39.7%
3. Transverse Compression Strength for the ETW condition failed by 32.8%
4. Transverse Tension Strength for the CTD condition failed by 12.8%
5. Transverse Tension Strength for the RTD condition failed by 14.2%
6. Transverse Tension Modulus for the CTD condition failed by 2.9%
7. Transverse Tension Modulus for the RTD condition failed by 10.0%
8. Transverse Tension Modulus for the ETW condition failed by 2.9%
9. In-Plane Shear 0.2% Offset Strength failed for the RTD condition by 8.8%
10. In-Plane Shear Strength at 5% Strain failed for the CTD condition by 3.5%
11. In-Plane Shear Strength at 5% Strain failed for the RTD condition by 4.6%
12. In-Plane Shear Strength at 5% Strain failed for the ETW condition by 0.4%
13. In-Plane Shear Modulus failed for the CTD condition by 0.2%
14. In-Plane Shear Modulus failed for the RTD condition by 9.8%
15. In-Plane Shear Modulus failed for the ETW condition by 9.4%
16. Short Beam Strength failed for the CTD condition by 8.8%
17. Short Beam Strength failed for the ETD condition by 8.7%
18. Unnotched Compression Strength failed for the RTD condition by 1.6%

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

Eighteen failures out of 33 tests and conditions gives the "M" cure cycle a pass rate of 45.45% 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 1.65 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 eighteen 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 33 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 33 independent tests.

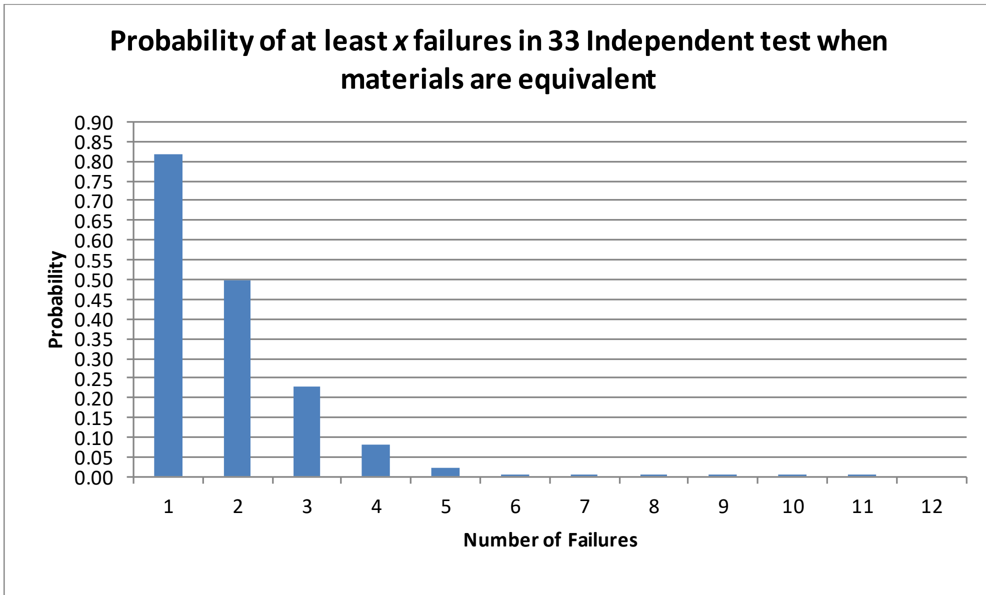

Figure 4-1 Probability of Number of Failures

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