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

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1. Introduction

This report contains the equivalency test results for Solvay (formerly Advanced Composites Group) MTM45-1/CF0525-36%RW (3K PW AS4 Fabric) “M” cure cycle compared to the original qualification panels produced using the “MH” cure cycle for the same material. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP3505WI-Q and also meet the requirements outlined in NCAMP Standard Operating Procedure NSP 100. The test panels, test specimens, and test setups have been conformed by the FAA and the testing has been witnessed by the FAA.

The material was procured to ACG Material Specification ACGM 1001–07 Revision I/R dated January 19, 2005. An equivalent NCAMP material specification NMS 451/7 has been created. NMS 451/7 contains specification limits that are derived from the qualification dataset using guidelines in section 6 of DOT/FAA/AR-03/19 and CMH-17 Volume 1 Rev. G section 8.4.1.

The mechanical testing was performed by ACG at their Tulsa, Oklahoma facility. The comparisons were performed according to CMH-17-1G section 8.4.1. The modified coefficient of variation (Mod CV) comparison tests were done in accordance with section 8.4.4 of CMH-17-1G. DMA test data was not available for an equivalency comparison.

The original qualification data was published in “MTM45-1 CF0525 Data MH Cure Cycle Values Only 2-18-10.pdf”. The qualification test panels were fabricated in accordance with Solvay (formerly Advanced Composites Group) process specification ACGP 1001-02 Revision E “MH” cure cycle. The equivalency data was published in “MTM45-1 CF0525 Data M Cure Cycle Values only 1-14-10.pdf”. The test panels were fabricated in accordance with ACG process specification ACGP 1001-02 Revision E “M” cure cycle.

Engineering basis values were reported in NCAMP Report NCP-RP-2009-037 N/C which details the standards and methodology used for computing basis values as well as providing the B-basis values and A- and B- estimates computed from the test results for the original qualification panels.

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

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 451/7. NMS 451/7 has additional requirements that are listed in its prepreg process control document (PCD), fiber specification, fiber PCD, and other raw material specifications and PCDs which impose essential quality controls on the raw materials and raw material manufacturing equipment and processes. *Aircraft companies and certifying agencies should assume that the material property data published in this report is not applicable when the material is not procured to NCAMP Material Specification NMS 451/7*. NMS 451/7 is a free, publicly available, non-proprietary aerospace industry material specification.

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

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

1.1 Symbols and Abbreviations

Test Property	Abbreviation
Warp Compression	WC
Warp Tension	WT
Fill Compression	FC
Fill Tension	FT
In-Plane Shear	IPS
Short Beam Strength	SBS
Open Hole Tension	OHT
Open Hole Compression	OHC
Interlaminar Tension	ILT
Curved Beam Strength	CBS
Compression After Impact	CAI
Cured Ply Thickness	CPT

Table 1-1 Test Property Abbreviations

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	−65º F	CTD
Room Temperature Dry	75º F	RTD
Elevated Temperature Dry	200º F	ETD
Elevated Temperature Wet	200º F	ETW

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.

Modified CV = $$CV^* = \begin{cases} .06 & if\ CV < .04 \\ \frac{CV}{2} + .04 & if\ .04 \le CV < .08 \\ CV & if\ CV \ge .08 \end{cases}$$ 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 27 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were seven additional tests performed with insufficient data. A comparison of the average cured ply thickness was also made. All tests were performed with an α level of 5%.

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

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

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

Table 3-1 "% Failed" Results Scale

Equivalency Test Results for Solvay (Formerly Advanced Composites Group) M Cure Cycle with MTM45-1/CF0525-36%RW (3K PW AS4 Fabric) MH Cure Cycle						
Test	Normalized Data	Property	Environmental Condition			
			CTD	RTD	ETD	ETW
Warp Compression	Yes	Strength		Failed by 1.2%		Pass
		Modulus		Pass		Pass
Warp Tension	Yes	Strength	Pass	Pass		
		Modulus	Pass	Pass with Mod CV		
Fill Compression	Yes	Strength		Failed by 6.5%	Pass	Pass
		Modulus		Pass	Failed by 0.1%	Failed by 9.0%
Fill Tension	Yes	Strength	Pass	Pass		Pass Insufficient Data
		Modulus	Failed by 0.03%	Failed by 4.2%		Failed by 3.4%
In-Plane Shear	No	0.2% Offset Strength	Pass Insufficient Data	Pass		
		5% Strain Strength		Pass		
		Modulus	Pass	Failed by 4.7%		
Short Beam Strength	No	Strength		Failed by 2.8%		Pass with Mod CV
Open Hole Compression	Yes	Strength		Pass		Pass with Mod CV Insufficient Data
Open Hole Tension	Yes	Strength	Pass	Pass Insufficient Data		
Interlaminar Tension	No	Strength		Pass Insufficient Data		
Curved Beam Strength	No	Strength		Pass Insufficient Data		
Compression After Impact	Yes	Strength		Pass Insufficient Data		
Cured Ply Thickness	NA	NA	Pass			

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

Table 3-2 Summary of Equivalency Test Results

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

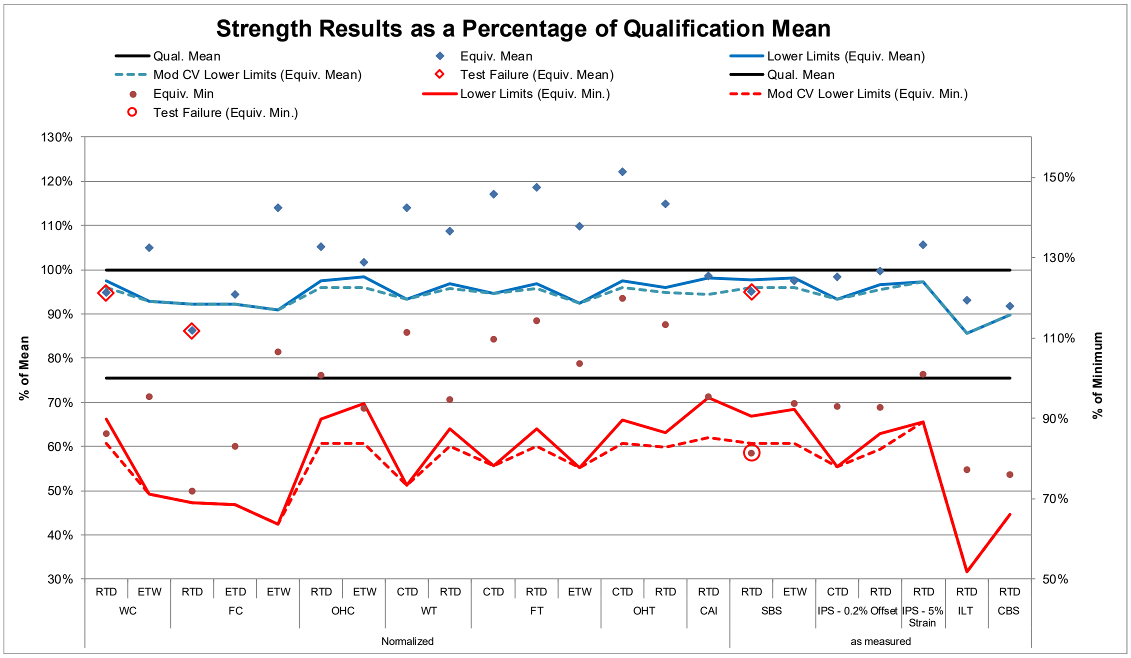

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

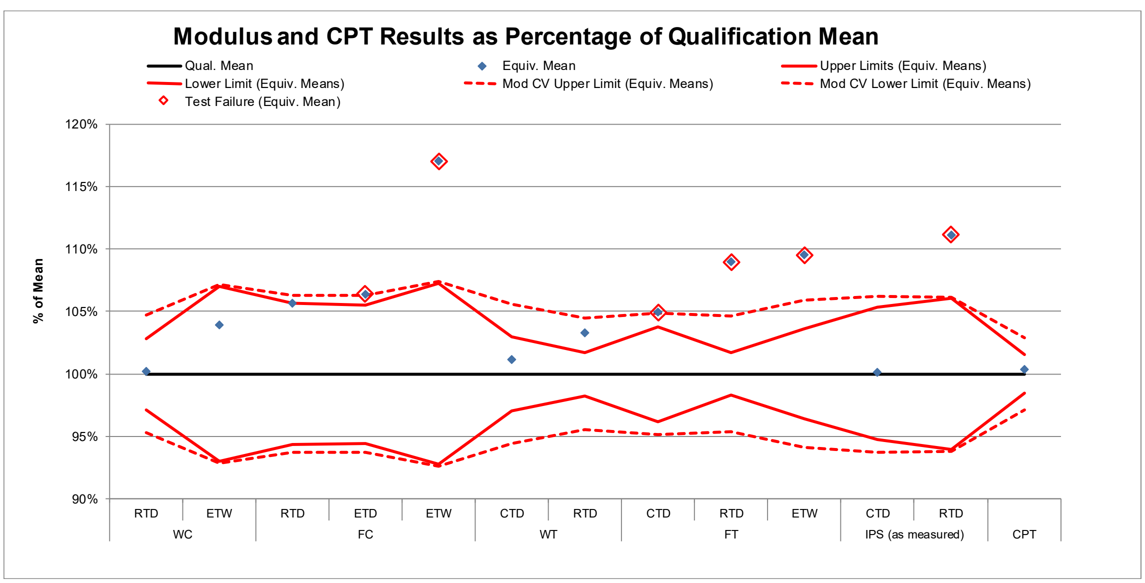

Figure 3-2 Summary of Modulus and CPT means and Equivalence limits

3.1 Warp Compression (WC)

The Warp Compression data is normalized by cured ply thickness. The WC normalized strength data passed the equivalency test for the ETW condition but not for the RTD condition. The WC normalized modulus data passed equivalency tests for both the RTD and ETW conditions. Modified CV results were not provided for the ETW strength data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for the strength data in Table 3-3 and for the modulus data in Table 3-4.

Warp Compression (WC) Strength	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079				
Mean Strength (ksi)	95.293	90.305	65.976	69.243
Standard Deviation	3.599	6.609	7.023	4.040
Coefficient of Variation %	3.777	7.318	10.645	5.835
Minimum	88.635	82.234	49.974	62.979
Maximum	101.770	103.762	79.385	75.321
Number of Specimens	18	8	20	8
RESULTS	FAIL		PASS	
Minimum Acceptable Equiv. Sample Mean	92.849		61.208	
Minimum Acceptable Equiv. Sample Min	85.575		47.014	
MOD CV RESULTS	FAIL		NA	
Modified CV %	6.000			
Minimum Acceptable Equiv. Sample Mean	91.411			
Minimum Acceptable Equiv. Sample Min	79.856			

Table 3-3 Warp Compression Strength Results

Warp Compression (WC) Modulus	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079				
Mean Modulus (Msi)	8.634	8.654	9.405	9.775
Standard Deviation	0.270	0.279	0.719	0.359
Coefficient of Variation %	3.132	3.229	7.642	3.677
Minimum	8.024	8.301	7.946	9.218
Maximum	9.009	9.055	10.587	10.257
Number of Specimens	16	8	13	6
RESULTS	PASS		PASS	
Passing Range for Modulus Mean	8.388 to 8.879		8.745 to 10.066	
Student's t-statistic	0.170		1.181	
p-value of Student's t-statistic	0.867		0.254	
MOD CV RESULTS	PASS with MOD CV		PASS with MOD CV	
Modified CV%	6.000		7.821	
Passing Range for Modulus Mean	8.225 to 9.043		8.731 to 10.080	
Modified CV Student's t-statistic	0.102		1.156	
p-value of Student's t-statistic	0.920		0.264	

Table 3-4 Warp Compression Modulus Results

The WC strength data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. The equivalency sample mean (90.305) is 97.26% of the minimum acceptable mean value (92.849) and the equivalency sample minimum (82.234) is 96.10% of the lowest acceptable minimum value (85.575). Under the assumption of the modified CV method, the equivalency sample mean is 98.79% of the minimum acceptable mean value (91.411) and the equivalency sample minimum value is acceptable.

Figure 3-3 illustrates the 0º Compression strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

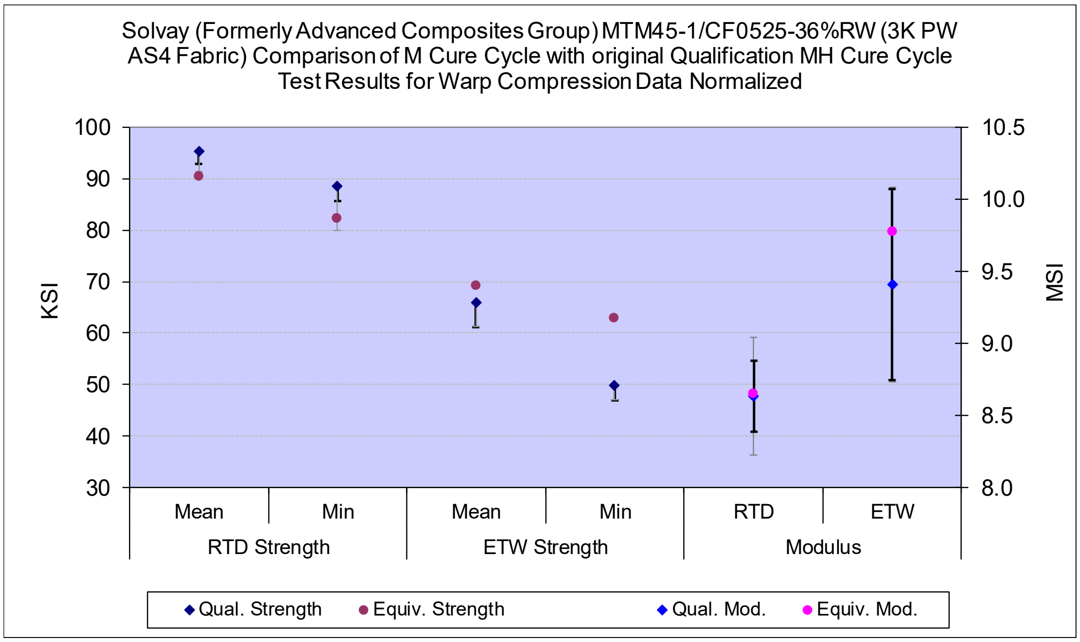

Figure 3-3 Warp Compression means, minimums and Equivalence limits

3.2 Warp Tension (WT)

The Warp Tension data is normalized by cured ply thickness. The WT normalized data passed all equivalency tests for the CTD and RTD conditions although the normalized modulus data in the RTD condition required the use of the modified CV method to pass equivalency. Modified CV results were not provided for the CTD strength data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for the strength data in Table 3-5 and for the modulus data in Table 3-6.

Warp Tension (WT) Strength	CTD Qual.	CTD Equiv.	RTD Qual.	RTD Equiv.
Data normalized with CPT 0.0079				
Mean Strength (ksi)	129.476	147.590	132.489	144.156
Standard Deviation	12.766	2.942	6.148	10.988
Coefficient of Variation %	9.860	1.994	4.641	7.622
Minimum	102.806	144.177	118.985	125.501
Maximum	146.565	153.212	142.328	155.694
Number of Specimens	21	8	22	8
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	120.807		128.315	
Minimum Acceptable Equiv. Sample Min	95.007		115.889	
MOD CV RESULTS	**NA**		**PASS with MOD CV**	
Modified CV %			6.320	
Minimum Acceptable Equiv. Sample Mean			126.804	
Minimum Acceptable Equiv. Sample Min			109.880	

Table 3-5 Warp Tension Strength Results

Warp Tension (WT) Modulus	CTD Qual.	CTD Equiv.	RTD Qual.	RTD Equiv.
Data normalized with CPT 0.0079				
Mean Modulus (Msi)	9.516	9.630	9.311	9.616
Standard Deviation	0.226	0.482	0.196	0.175
Coefficient of Variation %	2.374	5.006	2.108	1.819
Minimum	9.023	8.769	8.832	9.348
Maximum	10.026	10.188	9.671	9.889
Number of Specimens	21	6	22	8
RESULTS	**PASS**		**FAIL**	
Passing Range for Modulus Mean	9.235 to 9.798		9.149 to 9.472	
Student's t-statistic	0.830		3.869	
p-value of Student's t-statistic	0.414		0.001	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000	
Passing Range for Modulus Mean	8.988 to 10.045		8.895 to 9.726	
Modified CV Student's t-statistic	0.443		1.504	
p-value of Student's t-statistic	0.662		0.144	

Table 3-6 Warp Tension Modulus Results

The WT modulus data for the RTD environment failed the equivalency test because the sample mean value (9.616) is above the upper acceptance limit (9.472). The equivalency sample mean value is 101.52% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the RTD environment passed the equivalence test.

Figure 3-4 illustrates the 0º Tension strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

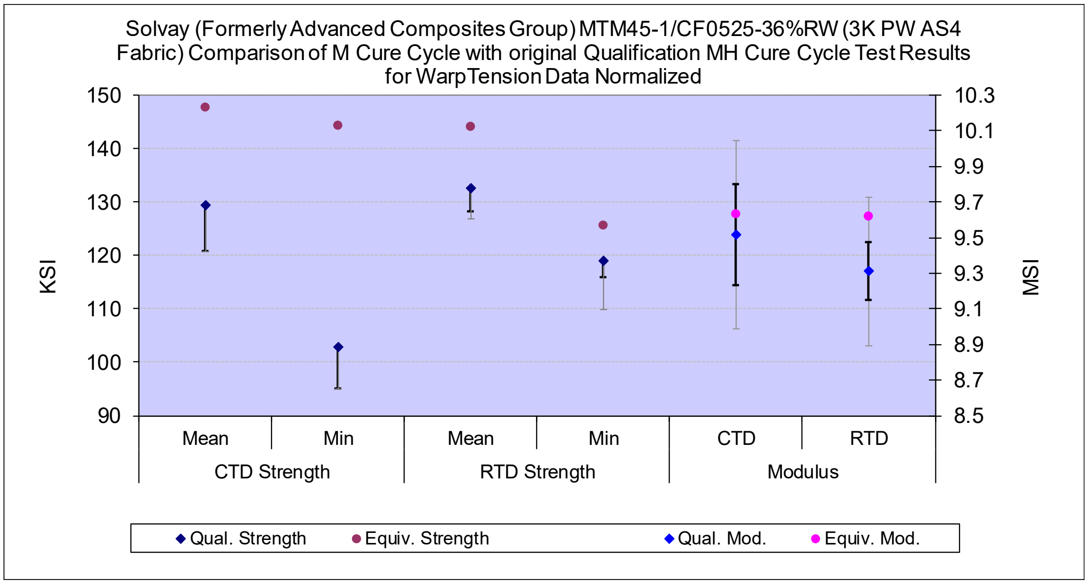

Figure 3-4 Warp Tension means, minimums and Equivalence limits

3.3 Fill Compression (FC)

The Fill Compression data is normalized by cured ply thickness. The FC normalized strength data passed equivalency tests for the ETD and ETW conditions but not the RTD condition. The FC normalized modulus data passed equivalency tests only for the RTD condition, not for the ETD or ETW conditions. Modified CV results were not provided for the strength data because in all cases the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. Statistics and analysis results are shown for the strength data in Table 3-7 and for the modulus data in Table 3-8.

Fill Compression (FC) Strength	RTD		ETD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Strength (ksi)	87.517	75.451	74.778	70.552	55.593	63.348
Standard Deviation	10.063	7.860	8.712	6.038	7.457	2.535
Coefficient of Variation %	11.498	10.418	11.651	8.558	13.413	4.002
Minimum	68.447	62.861	61.095	62.054	44.354	59.274
Maximum	102.287	88.315	88.262	79.065	72.240	66.985
Number of Specimens	24	8	18	8	20	8
RESULTS	FAIL		PASS		PASS	
Minimum Acceptable Equiv. Sample Mean	80.684		68.862		50.530	
Minimum Acceptable Equiv. Sample Min	60.347		51.255		35.460	

Table 3-7 Fill Compression Strength Results

Fill Compression (FC) Modulus	RTD		ETD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	8.046	8.499	8.319	8.851	8.689	10.168
Standard Deviation	0.461	0.723	0.479	0.557	0.653	0.783
Coefficient of Variation %	5.730	8.508	5.755	6.295	7.511	7.704
Minimum	7.414	7.642	7.415	7.972	7.450	8.795
Maximum	8.992	9.596	9.242	9.613	10.532	11.055
Number of Specimens	22	8	18	7	19	7
RESULTS	PASS		FAIL		FAIL	
Passing Range for Modulus Mean	7.590 to 8.501		7.858 to 8.780		8.062 to 9.317	
Student's t-statistic	2.036		2.386		4.864	
p-value of Student's t-statistic	0.051		0.026		0.00006	
MOD CV RESULTS	PASS with MOD CV		FAIL		FAIL	
Modified CV%	6.865		6.878		7.755	
Passing Range for Modulus Mean	7.539 to 8.553		7.796 to 8.843		8.048 to 9.331	
Modified CV Student's t-statistic	1.829		2.101		4.759	
p-value of Student's t-statistic	0.080		0.046		0.00008	

Table 3-8 Fill Compression Modulus Results

The FC 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 (75.451) is 93.51% of the minimum acceptable mean value (80.684). The modified CV method could not be used due to the CV of the RTD condition being greater than 8%.

The FC modulus data for the ETD environment failed the equivalency test because the sample mean value (8.851) is above the upper acceptance limit (8.780). The equivalency sample mean value is 100.81% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.09% of the maximum acceptable mean value (8.843).

The FC modulus data for the ETW environment failed the equivalency test because the sample mean value (10.168) is above the upper acceptance limit (9.317). The equivalency sample mean value is 109.14% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 108.98% of the maximum acceptable mean value (9.331).

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

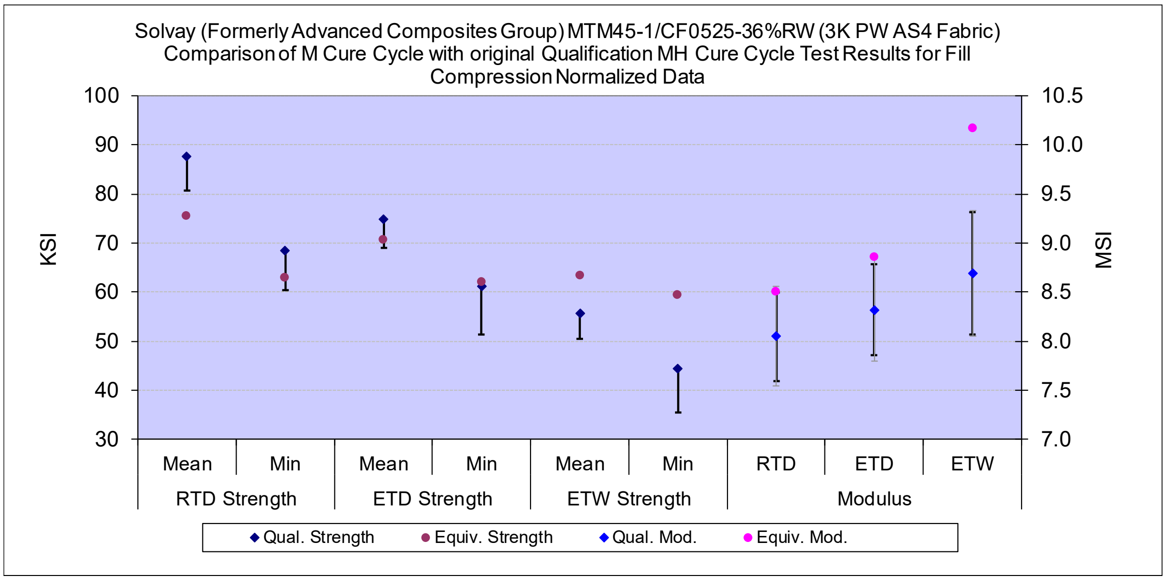

Figure 3-5 Fill Compression means, minimums and Equivalence limits

3.4 Fill Tension (FT)

The Fill Tension data is normalized by cured ply thickness. The FT normalized strength data passed equivalency tests for all three conditions tested. The FT normalized modulus data did not pass equivalency tests for any of the three conditions tested, in all three cases due to the modulus mean being too high. Modified CV results were not provided for the CTD or ETW 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 were insufficient specimens in the ETW strength data for the results to be considered conclusive. Statistics and analysis results are shown for the strength data in Table 3-9 and for the modulus data in Table 3-10.

Fill Tension (FT) Strength	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079					Insufficient Data	
Mean Strength (ksi)	124.005	145.295	124.793	147.966	119.653	131.495
Standard Deviation	9.984	4.719	5.786	3.172	10.551	10.324
Coefficient of Variation %	8.051	3.248	4.637	2.143	8.818	7.851
Minimum	91.457	136.019	115.303	142.594	97.804	123.966
Maximum	135.857	151.032	134.156	152.057	135.045	149.416
Number of Specimens	20	8	18	8	19	5
RESULTS	PASS		PASS		PASS	
Minimum Acceptable Equiv. Sample Mean	117.225		120.864		110.658	
Minimum Acceptable Equiv. Sample Min	97.048		109.170		92.974	
MOD CV RESULTS	NA		PASS with MOD CV		NA	
Modified CV %			6.318			
Minimum Acceptable Equiv. Sample Mean			119.439			
Minimum Acceptable Equiv. Sample Min			103.504			

Table 3-9 Fill Tension Strength Results

Fill Tension (FT) Modulus	CTD		RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079						
Mean Modulus (Msi)	9.157	9.608	8.854	9.647	8.904	9.750
Standard Deviation	0.445	0.269	0.143	0.231	0.305	0.276
Coefficient of Variation %	4.865	2.801	1.619	2.398	3.431	2.831
Minimum	8.290	9.113	8.585	9.165	8.472	9.430
Maximum	10.322	9.931	9.113	9.827	9.349	9.971
Number of Specimens	21	8	18	8	17	5
RESULTS	FAIL		FAIL		FAIL	
Passing Range for Modulus Mean	8.810 to 9.504		8.701 to 9.006		8.585 to 9.222	
Student's t-statistic	2.666		10.754		5.551	
p-value of Student's t-statistic	0.013		1.17E-10		0.00002	
MOD CV RESULTS	FAIL		FAIL		FAIL	
Modified CV%	6.432		6.000		6.000	
Passing Range for Modulus Mean	8.709 to 9.605		8.447 to 9.261		8.380 to 9.427	
Modified CV Student's t-statistic	2.067		4.024		3.372	
p-value of Student's t-statistic	0.048		0.0005		0.003	

Table 3-10 Fill Tension Modulus Results

The FT modulus data for the CTD environment failed the equivalency test because the sample mean value (9.608) is above the upper acceptance limit (9.504). The equivalency sample mean value is 101.09% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 100.03% of the maximum acceptable mean value (9.605).

The FT modulus data for the RTD environment failed the equivalency test because the sample mean value (9.647) is above the upper acceptance limit (9.006). The equivalency sample mean value is 107.12% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 104.17% of the maximum acceptable mean value (9.261).

The FT modulus data for the ETW environment failed the equivalency test because the sample mean value (9.750) is above the upper acceptance limit (9.222). The equivalency sample mean value is 105.73% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 103.43% of the maximum acceptable mean value (9.427).

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

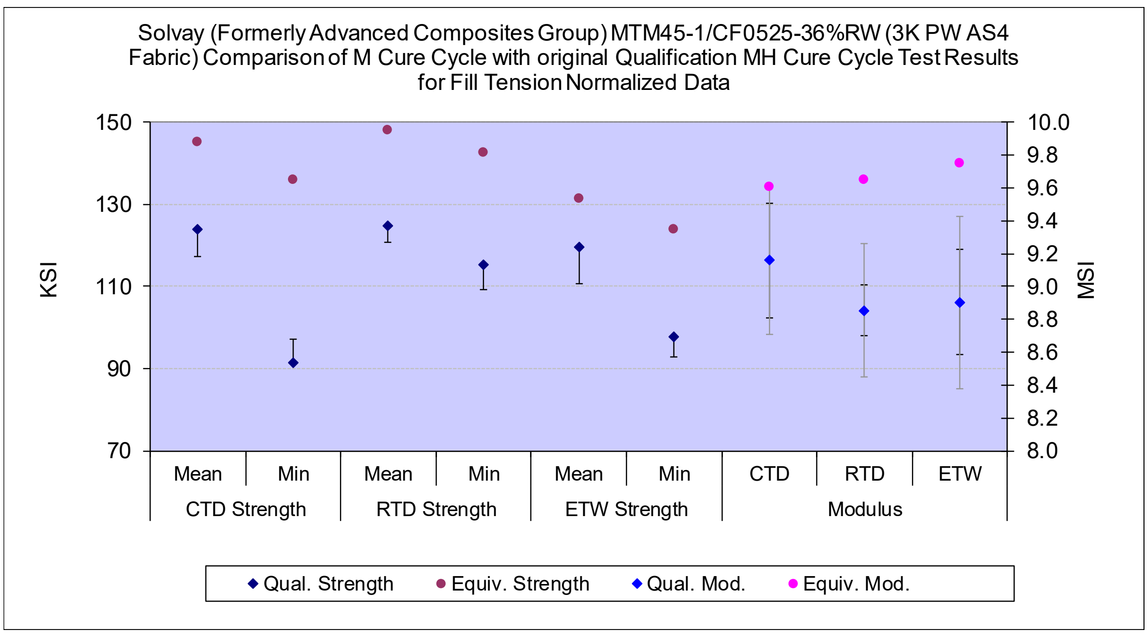

Figure 3-6 Fill Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The SBS data passed equivalency tests only for the ETW condition and only with the use of the modified CV method. Statistics and analysis results for the SBS data are shown in Table 3-11.

Short Beam Strength (SBS)	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Strength (ksi)	10.414	9.889	6.297	6.137
Standard Deviation	0.365	0.905	0.178	0.210
Coefficient of Variation %	3.505	9.153	2.831	3.414
Minimum	9.807	8.479	6.065	5.902
Maximum	10.991	10.826	6.624	6.517
Number of Specimens	18	8	18	8
RESULTS	**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	10.166		6.176	
Minimum Acceptable Equiv. Sample Min	9.429		5.815	
MOD CV RESULTS	**FAIL**		**PASS with MOD CV**	
Modified CV%	6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	9.990		6.040	
Minimum Acceptable Equiv. Sample Min	8.727		5.277	

Table 3-11 Lamina Short Beam Strength Results

The SBS data for the RTD environment failed equivalence due to both the sample mean and sample minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (9.889) is 98.99% of the minimum acceptable mean value (9.990) and the equivalency sample minimum (8.479) is 97.16% of the lowest acceptable minimum value (8.727).

The SBS 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 (6.137) is 99.38% of the minimum acceptable mean value (6.176). Under the assumption of the modified CV method, the strength data from the ETW environment passed the equivalence test.

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

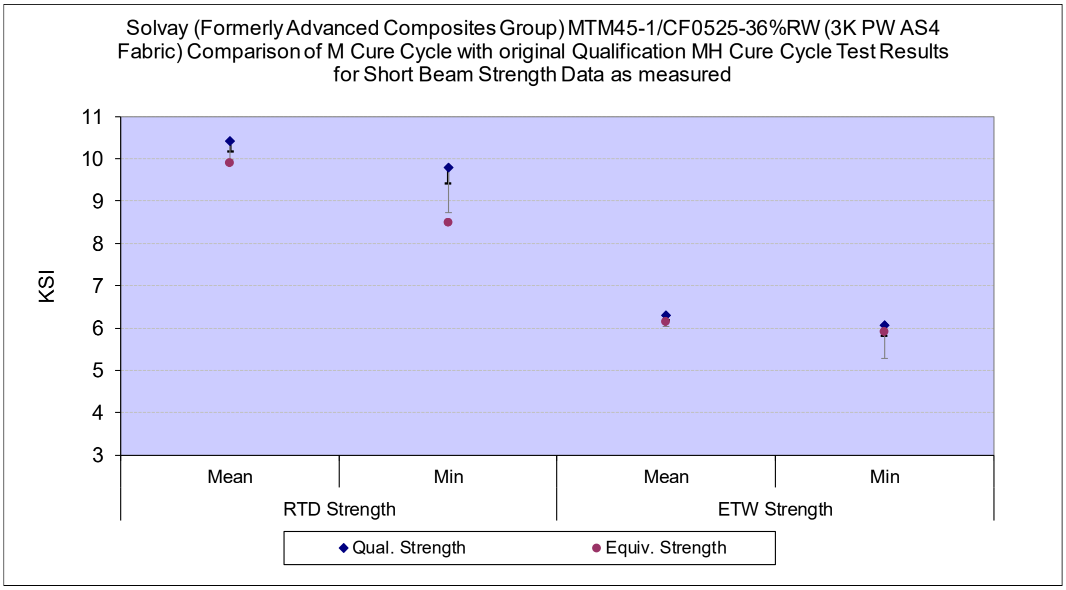

Figure 3-7 Lamina Short Beam Strength means, minimums and Equivalence limits

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS strength data passed all equivalency tests. The IPS modulus data passed equivalency tests for the CTD condition but not the RTD condition. There was no Strength at 5% Strain data available for the M cure cycle in the CTD condition. Modified CV results were not provided for the 0.2% Offset CTD dataset because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown. There were insufficient specimens in the IPS 0.2% Offset Strength dataset for the CTD condition for the results to be considered conclusive. Statistics and analysis results are shown for the 0.2% Offset Strength and Strength at 5% Strain data in Table 3-12, and for the Modulus data in Table 3-13.

In-Plane Shear (IPS) Strength	0.2% Offset				5% Strain	
	CTD		RTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data					
Mean Strength (ksi)	7.852	7.719	5.999	5.984	9.948	10.507
Standard Deviation	0.664	0.401	0.307	0.336	0.403	0.292
Coefficient of Variation %	8.458	5.200	5.121	5.612	4.055	2.780
Minimum	6.865	7.305	5.462	5.560	9.348	10.041
Maximum	9.141	8.149	6.549	6.514	10.910	10.821
Number of Specimens	23	6	24	8	19	8
RESULTS	PASS		PASS		PASS	
Minimum Acceptable Equiv. Sample Mean	7.333		5.790		9.674	
Minimum Acceptable Equiv. Sample Min	6.127		5.170		8.859	
MOD CV RESULTS	NA		PASS with MOD CV		PASS with MOD CV	
Modified CV%			6.561		6.027	
Minimum Acceptable Equiv. Sample Mean			5.732		9.541	
Minimum Acceptable Equiv. Sample Min			4.936		8.329	

Table 3-12 In-Plane Shear Strength Results

In-Plane Shear (IPS) Modulus	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured				
Mean Modulus (Msi)	0.627	0.628	0.541	0.601
Standard Deviation	0.034	0.050	0.041	0.034
Coefficient of Variation %	5.411	7.934	7.519	5.663
Minimum	0.563	0.554	0.472	0.560
Maximum	0.715	0.692	0.600	0.655
Number of Specimens	23	7	24	8
RESULTS	PASS		FAIL	
Passing Range for Modulus Mean	0.594 to 0.661		0.508 to 0.573	
Student's t-statistic	0.054		3.769	
p-value of Student's t-statistic	0.958		0.001	
MOD CV RESULTS	PASS with MOD CV		FAIL	
Modified CV%	6.706		7.760	
Passing Range for Modulus Mean	0.588 to 0.666		0.507 to 0.574	
Modified CV Student's t-statistic	0.046		3.672	
p-value of Student's t-statistic	0.963		0.001	

Table 3-13 In-Plane Shear Modulus Results

The IPS modulus data for the RTD environment failed the equivalency test because the sample mean value (0.601) is above the upper acceptance limit (0.573). The equivalency sample mean value is 104.82% of the upper limit of acceptable values. Under the assumption of the modified CV method, the equivalency sample mean is 104.66% of the maximum acceptable mean value (0.574).

Figure 3-8 illustrates the In-Plane Shear strength means and minimum values and the modulus means for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

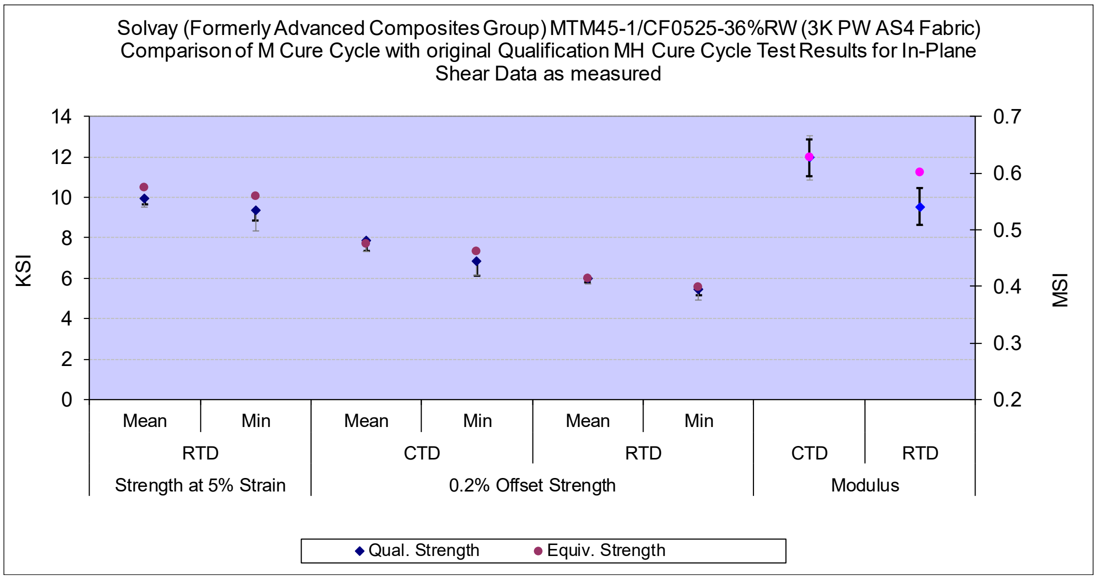

Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The Open Hole Tension data is normalized by cured ply thickness. The Open Hole Tension normalized strength data passed equivalency tests for both conditions tested. There was insufficient data in the RTD condition for the results to be considered conclusive. Statistics and analysis results for the OHT1 strength data are shown in Table 3-14.

Open Hole Tension (OHT1) Strength	CTD		RTD	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079			Insufficient Data	
Mean Strength (ksi)	51.411	62.759	53.112	60.968
Standard Deviation	1.972	0.951	2.750	0.680
Coefficient of Variation %	3.836	1.515	5.178	1.116
Minimum	47.027	61.566	48.868	60.205
Maximum	53.622	63.890	57.024	61.963
Number of Specimens	18	8	18	6
RESULTS	**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	50.072		50.965	
Minimum Acceptable Equiv. Sample Min	46.087		45.971	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.000		6.589	
Minimum Acceptable Equiv. Sample Mean	49.317		50.380	
Minimum Acceptable Equiv. Sample Min	43.083		44.025	

Table 3-14 Open Hole Tension 1 Strength Results

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

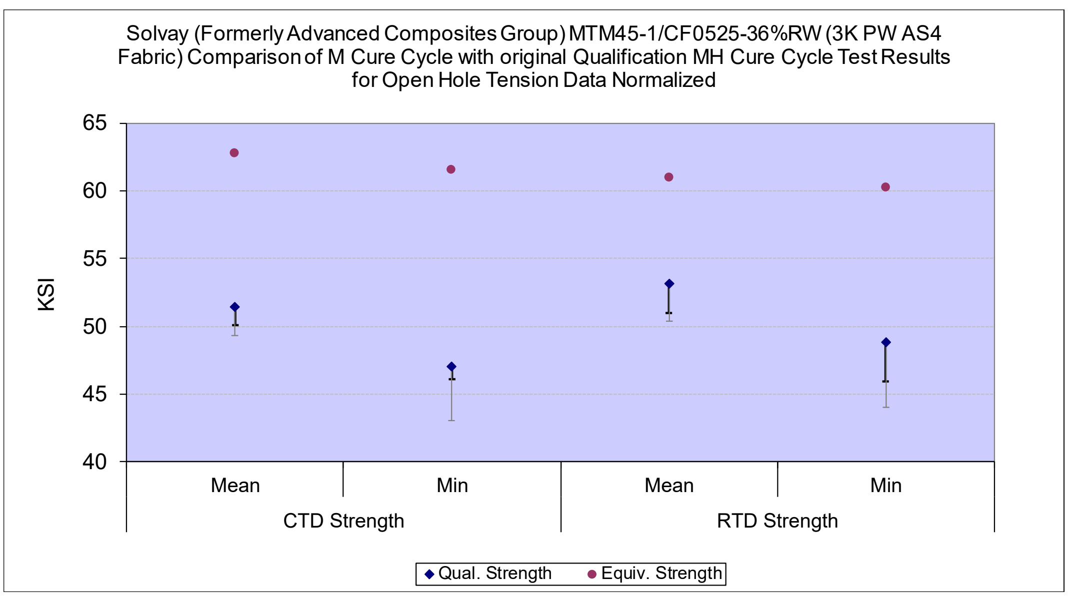

Figure 3-9 Open Hole Tension means, minimums and Equivalence limits

3.8 “25/50/25” Open Hole Compression 1 (OHC1)

The Open Hole Compression data is normalized by cured ply thickness. The Open Hole Compression normalized strength data passed equivalency tests for both the RTD and ETW conditions although the ETW condition required the use of the modified CV method to pass. There was insufficient data in the ETW condition for the results to be considered conclusive. Statistics and analysis results for the OHC1 strength data are shown in Table 3-15.

Open Hole Compression (OHC1) Strength	RTD		ETW	
	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0079			Insufficient Data	
Mean Strength (ksi)	41.461	43.612	33.419	33.974
Standard Deviation	1.560	1.520	0.771	1.561
Coefficient of Variation %	3.762	3.485	2.307	4.594
Minimum	38.150	41.729	32.334	30.937
Maximum	43.728	46.262	34.248	36.164
Number of Specimens	18	8	6	8
RESULTS	**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	40.402		32.895	
Minimum Acceptable Equiv. Sample Min	37.249		31.337	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	39.772		32.058	
Minimum Acceptable Equiv. Sample Min	34.744		28.005	

Table 3-15 Open Hole Compression 1 Strength Results

The OHC1 strength data for the ETW environment failed equivalence due to the minimum sample value being below the acceptance limit. The sample mean value is acceptable. The equivalency sample minimum (30.937) is 98.72% of the lowest acceptable minimum value (31.337). Under the assumption of the modified CV method, the strength data from the ETW environment passed the equivalence test.

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

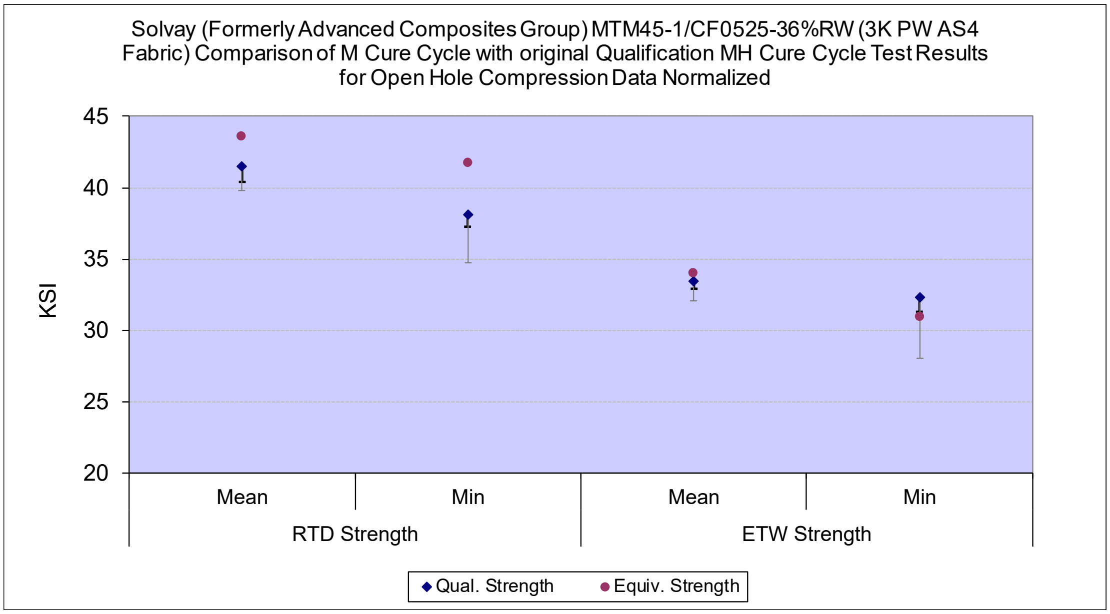

Figure 3-10 Open Hole Compression means, minimums and Equivalence limits

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

The Interlaminar Tension and Curved Beam Strength data are not normalized. The ILT and CBS strength data passed equivalency tests for the RTD condition. 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. There was insufficient data for these results to be considered conclusive. Statistics and analysis results are shown for the ILT and CBS data in Table 3-16.

Interlaminar Tension (ILT) Strength and Curved Beam Strength (CBS) RTD Condition	ILT		CBS	
	Qual.	Equiv.	Qual.	Equiv.
Data as measured	Insufficient Data		Insufficient Data	
Mean Strength (ksi)	5.224	4.863	220.889	202.687
Standard Deviation	0.969	0.608	28.857	26.019
Coefficient of Variation %	18.552	12.499	13.064	12.837
Minimum	4.282	4.039	188.373	168.057
Maximum	6.960	5.912	265.883	244.158
Number of Specimens	7	6	7	6
RESULTS	PASS		PASS	
Minimum Acceptable Equiv. Sample Mean	4.467		198.357	
Minimum Acceptable Equiv. Sample Min	2.707		145.956	

Table 3-16 Interlaminar Tension Strength and Curved Beam Strength Results

Figure 3-11 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.

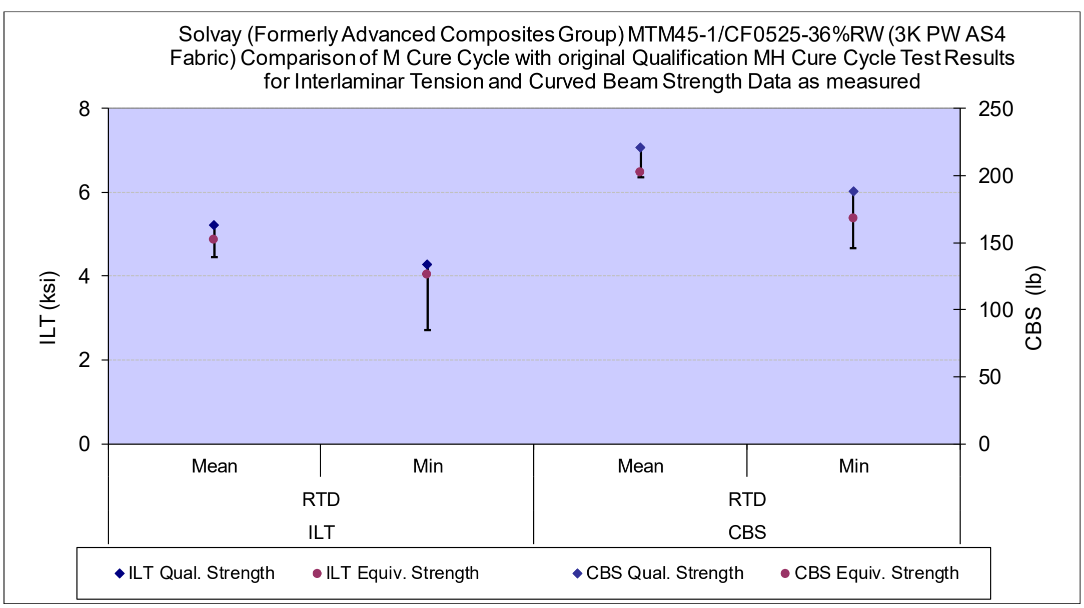

Figure 3-11 Interlaminar Tension and Curved Beam Strength means, minimums and Equivalence limits

3.10 Compression After Impact (CAI)

The Compression After Impact data is normalized by cured ply thickness. The Compression After Impact normalized strength data passed equivalency for the RTD condition. There was insufficient data for the result to be considered conclusive. Statistics and analysis results for CAI strength data are shown in Table 3-17.

Compression After Impact (CAI) Strength	RTD	
	Qual.	Equiv.
Data normalized with CPT 0.0079	Insufficient Data	
Mean Strength (ksi)	34.435	33.923
Standard Deviation	0.698	0.877
Coefficient of Variation %	2.028	2.584
Minimum	33.522	32.857
Maximum	35.763	34.995
Number of Specimens	8	4
RESULTS	**PASS**	
Minimum Acceptable Equiv. Sample Mean	33.773	
Minimum Acceptable Equiv. Sample Min	32.730	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV %	6.000	
Minimum Acceptable Equiv. Sample Mean	32.475	
Minimum Acceptable Equiv. Sample Min	29.390	

Table 3-17 Compression After Impact 1 Strength Results

Figure 3-12 illustrates the Compression After Impact strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

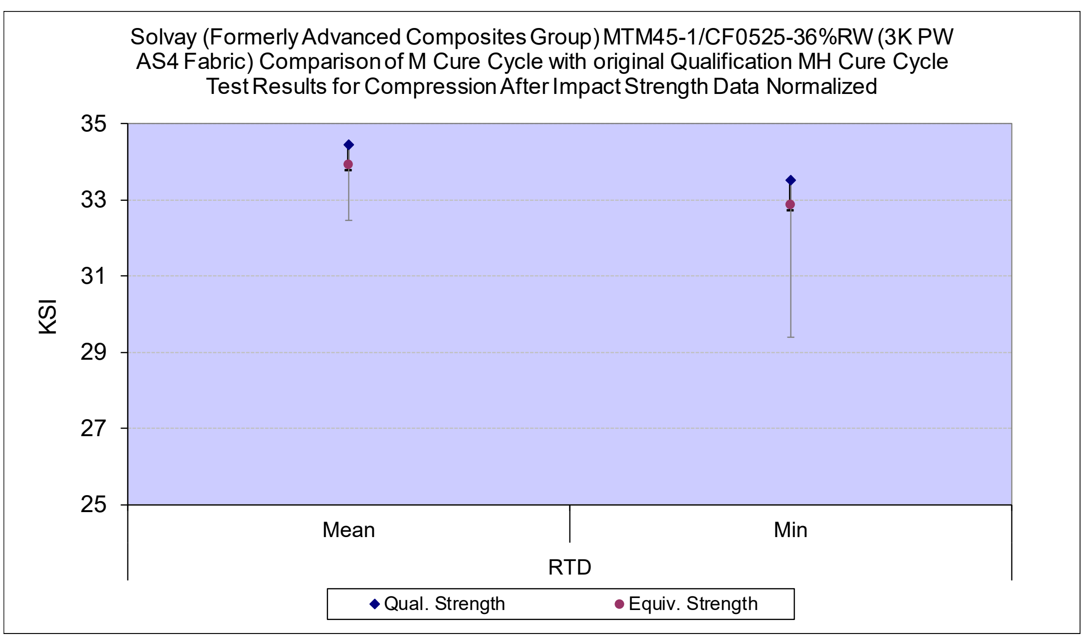

Figure 3-12 Compression After Impact 1 means, minimums and Equivalence limits

3.11 Cured Ply Thickness (CPT)

The Cured Ply Thickness can be considered equivalent according to the results of a pooled two-sample double-sided t-test at a 95% confidence level. Statistics for both the original MH cure cycle qualification sample and the M cure cycle equivalency sample are shown in Table 3-18.

Cured Ply Thickness (CPT)	Qual.	Equiv.
Average Cured Ply Thickness	0.008193	0.008223
Standard Deviation	0.00024	0.00033
Coefficient of Variation %	2.97370	3.97105
Minimum	0.00758	0.00793
Maximum	0.00964	0.00944
Number of Specimens	146	18
RESULTS	**PASS**	
Passing Range for CPT Mean	0.008068 to 0.008318	
Student's t-statistic	0.468	
p-value of Student's t-statistic	0.640	
MOD CV RESULTS	**PASS with MOD CV**	
Modified CV%	6.000	
Passing Range for CPT Mean	0.007958 to 0.008429	
Modified CV Student's t-statistic	0.249	
p-value of Student's t-statistic	0.804	

Table 3-18 Cured Ply Thickness Results

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

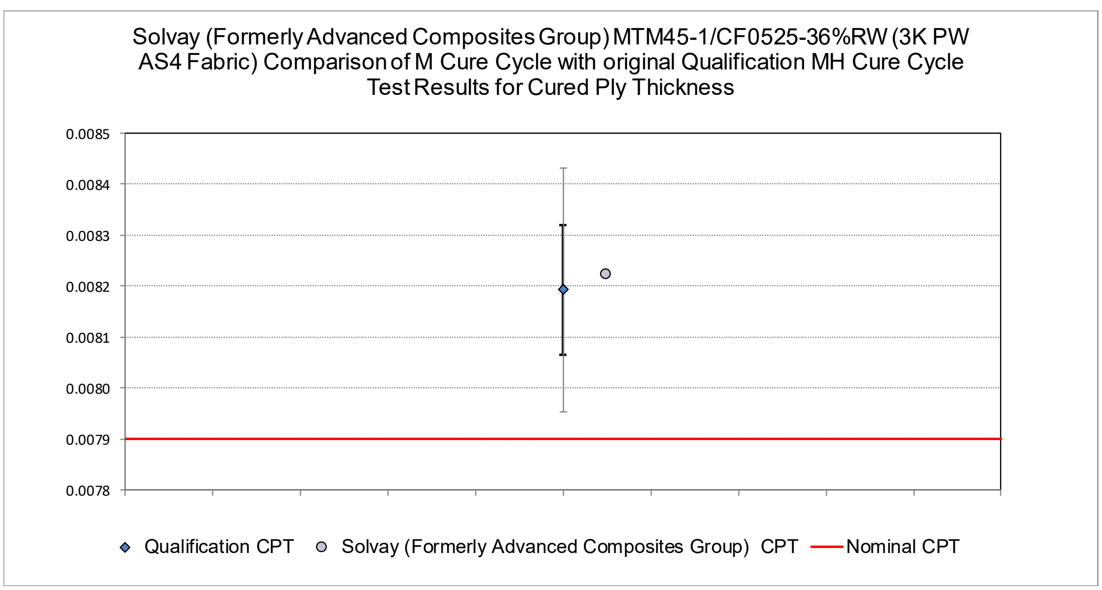

Figure 3-13 CPT means, 95% standard error bars and nominal value

4. Summary of Results

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

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

4.1 The assumption of Independence

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

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

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

4.2 Failures

The M Cure Cycle sample has sufficient test results for comparison with the original qualification material test results on a total of 27 different test types and conditions, not including the cured ply thickness comparison.

Using the modified CV method, there were nine failures.

1. Warp Compression strength for the RTD condition failed by 1.2%
2. Fill Compression strength for the RTD condition failed by 6.5%
3. Fill Compression modulus for the ETD condition failed by 0.1%
4. Fill Compression modulus for the ETW condition failed by 9.0%
5. Fill Tension modulus for the CTD condition failed by 0.03%
6. Fill Tension modulus for the RTD condition failed by 4.2%
7. Fill Tension modulus for the ETW condition failed by 3.4%
8. In-Plane Shear modulus for the RTD condition failed by 4.7%
9. Short Beam Strength for the RTD condition failed by 2.8%

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

Nine failures out of 27 tests gives the M cure cycle a pass rate of 66.67% 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 1.35 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 nine or more failures is 0.0004%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 27 independent tests. If the two materials were equivalent, the probability of getting four or more failures is less than 5%. This means that the material could be considered as “not equivalent” with a 95% level of confidence if there were four or more failures out of 27 independent tests.

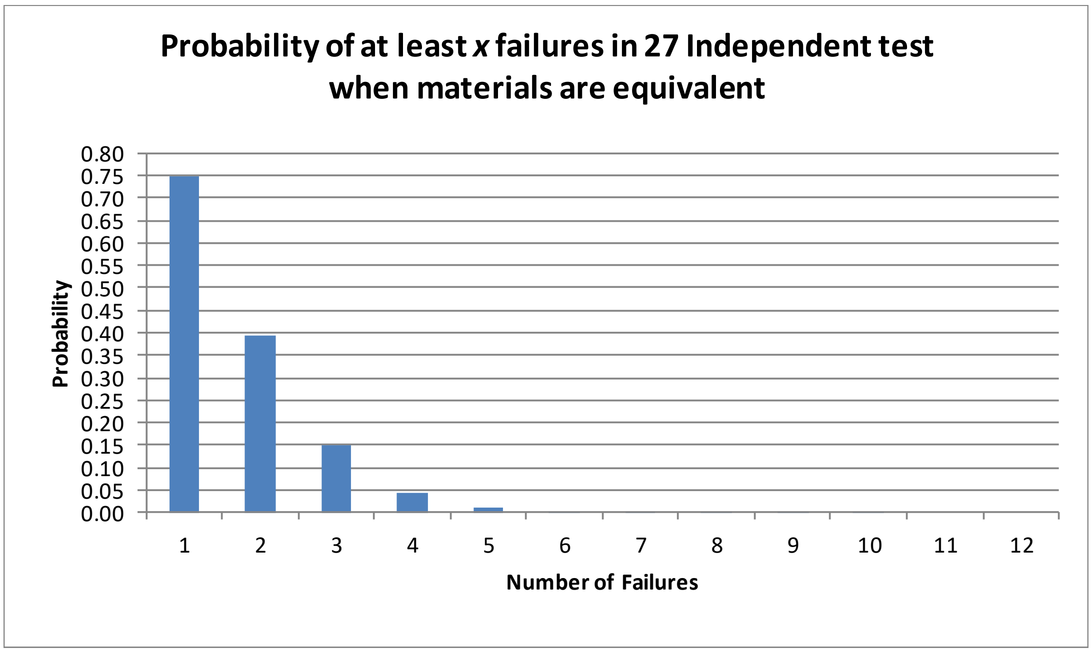

Figure 4-1 Probability of Number of Failures

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
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