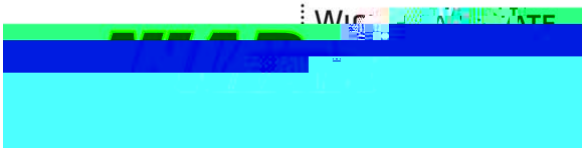

Report No: NCP-RP-2019-001 Rev N/C
Report Date: July 18, 2018

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

FAA Special Project Number: SP3505WI-Q

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

Report Date: July 18, 2018

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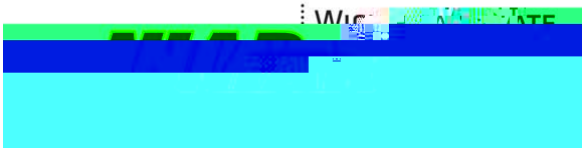

Report No: NCP-RP-2019-001 Rev N/C
Report Date: July 18, 2018

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Jonathan Tisack

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Jonathan Tisack **Katherine Carney**

Approved by:

Royal Lovingfoss

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List of Tables

1. Introduction

This report contains the equivalency test results for Solvay (formerly Advanced Composites Group) MTM45-1/12K AS4 145gsm 32%RW Unidirectional (12K AS4 UNI) “LH” cure cycle compared to the “MH” cure cycle for the same material. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP3505WI-Q and also meet the requirements outlined in NCAMP Standard Operating Procedure NSP 100. The test panels, test specimens, and test setups have been conformed by the FAA and the testing has been witnessed by the FAA.

The material was procured to ACG Material Specification ACGM 1001-11. An equivalent NCAMP Material Specification NMS 451/11 which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19 has been created.

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

These tests were performed by Solvay (formerly Advanced Composites Group) in Tulsa Oklahoma. The comparisons were performed according to CMH-17-1G section 8.4.1. The modified coefficient of variation (Mod CV) comparison tests were done in accordance with section 8.4.4 of CMH-17-1G.

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

The NCAMP shared material property database contains material property data of common usefulness to a wide range of aerospace projects. However, the data may not fulfill all the needs of a project. Specific properties, envir

property data published in this report is not applicable when the material is not procured to NCAMP Material Specification NMS 451/11. NMS 451/11 is a free, publicly available, non-proprietary aerospace industry material specification.

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

The applicability and accuracy of NCAMP material property data, material allowables, and specifications must be evaluated on case-by-case basis by aircraft companies and

2.2.2 Type I and Type II Errors

	Materials are equal	Materials are not equal
Conclude materials are equal	Correct Decision	

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 $\bar{X} - k_n^{table2.1} * S$ where $\bar{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample.

The sample minimum must exceed $\bar{X} - k_n^{table2.2} * S$ where $\bar{X}$ and S are,

Table 2-1 One-sided tolerance factor

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

This is converted to percent by multiplying by 100%.

CV^* is used to compute a modified standard deviation S^*.

$$S^* \quad CV^* \quad \bar{X} \qquad \sim \qquad \text{Equation 2}$$

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

$$S_p^* \quad \sqrt{\frac{\sum_{i=1}^{k} n_i \quad 1 \quad CV_i^* \quad \bar{X}_i^{\,2}}{\sum_{i=1}^{k} n_i \quad 1}} \qquad \sim \qquad \text{Equation 3}$$

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 t

3. Equivalency Test Results

There were a total of 53 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were an additional six tests performed with insufficient data. A comparison of the average cured ply thickness and DMA results was also made. All tests were performed with an . level of 5%.

The results of the equivalency comparisons are listed as ‘Pass’, ‘Fail’, or ‘Pass with Mod

			CTD	RTD	ETD	ETW	ETW2
Longitudinal Compression	**Yes**	**Modulus**		Pass with Mod CV			

Table 3-2 Summary of Equivalency Test Results

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

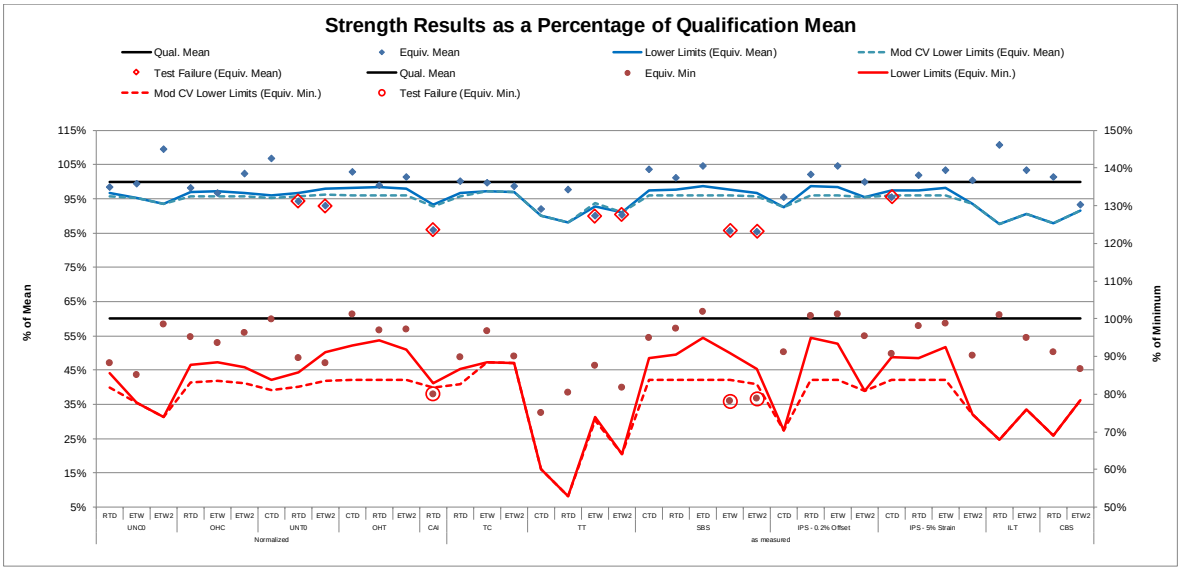

Figure 3-1 Summary of Strength means and minimums compared to their respective Equivalence limits

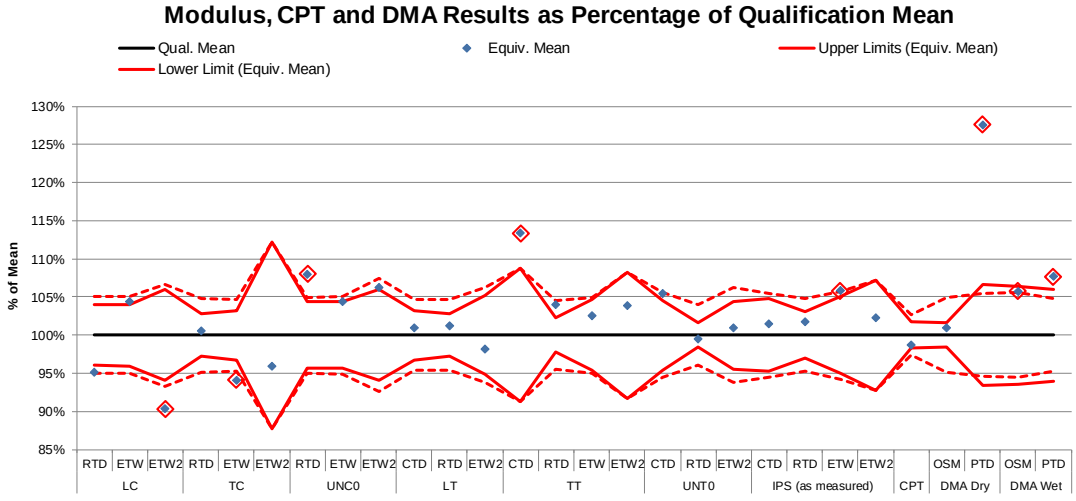

Figure 3-2 Summary of Modulus, CPT, and DMA means and Equivalence limits

3.1 Longitudinal Compression (LC)

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

Longitudinal Compression (LC)	RTD		ETW		ETW2	
Modulus	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055						
Mean Modulus (Msi)	17.024	16.196	17.235	17.997	19.625	17.721
Standard Deviation	0.861	0.492	0.879	0.506	1.077	0.940
Coefficient of Variation %	5.059	3.036	5.102	2.812	5.489	5.303
Minimum	14.391	15.566	14.537	17.099	17.822	16.825
Maximum	18.894	16.848	18.368	18.855	20.779	19.831
Number of Specimens	18	8	17	8	6	8
RESULTS	FAIL		FAIL		FAIL	
Passing Range for Modulus Mean	16.347 to 17.701		16.539 to 17.931		18.449 to 20.801	
Student's t-statistic	-2.524		2.263		-3.528	
p-value of Student's t-statistic						
MOD CV RESULTS						
Modified CV%			6.551		6.744	
Passing Range for Modulus Mean			16.364 to 18.107			
Modified CV Student's t-statistic			1.808			
p-value of Student's t-statistic			0.084		0.008	1.551

Table 3-3 Longitudinal Compression Modulus Results

The LC modulus data for the RTD environment failed the equivalency test because the sample mean value (16.196) is below the lower acceptance limit (16.347). The equivalency sample mean value is 99.08% of the lower limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the RTD environment passed the equivalence test.

The LC modulus data for the ETW environment failed the equivalency test because the sample mean value (17.997) is above the upper acceptance limit (17.931). The equivalency sample mean value is 100.36% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the ETW environment passed the equivalence test.

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

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

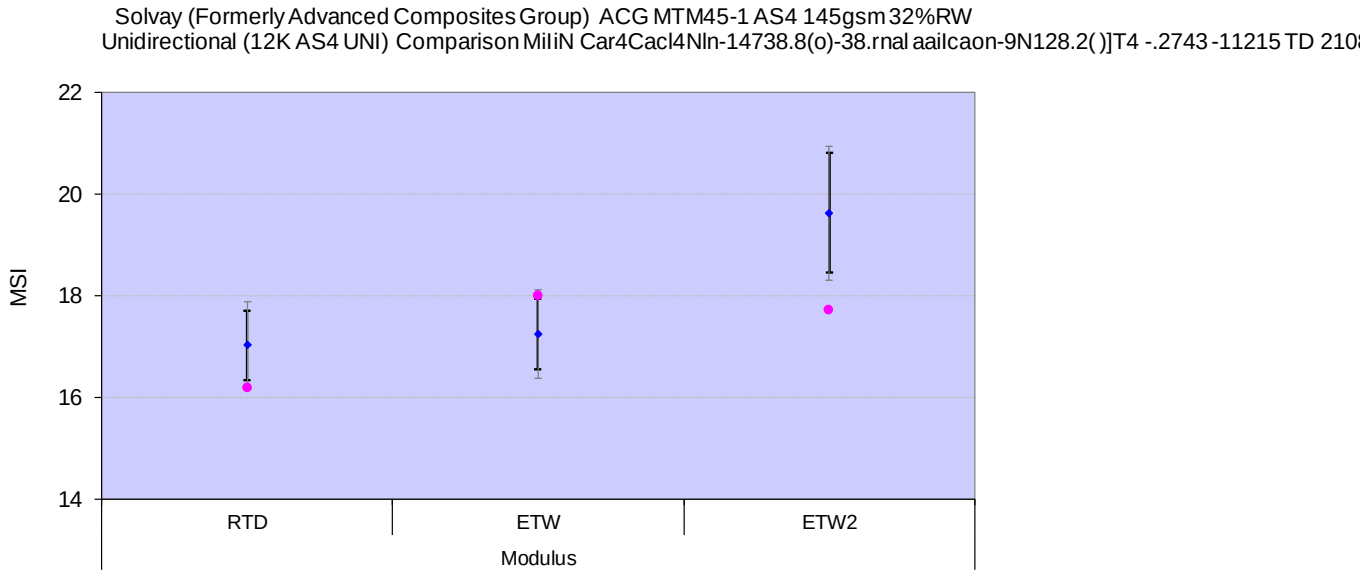

Figure 3-3 Longitudinal Compression Modulus means and Equivalence limits

3.2 Longitudinal Tension (LT)

The Longitudinal Tension data is normalized by cured ply thickness. There is no LT strength data available other than the values computed using the backout formula applied to the UNT0 data. Rather than comp

3.3 Transverse Compression (TC)

The Transverse Compression data is not normalized. The TC as-measured strength data passed equivalency tests for all three tested conditions. The TC as-measured modulus data passed equivalency tests for the RTD and ETW2 conditions, but not the ETW condition. Modified CV results were not provided for the ETW2 modulus data because the coefficient of variation was above 8% which means that the modified CV results were no different from the results shown.

Statistics and analysis results are shown for the strength data in Table 3-5 and for the modulus data in Table 3-6.

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength (ksi)	26.810	26.873	14.956	14.911	12.302	12.152
Standard Deviation	1.321	1.380	0.637	0.305	0.532	0.531
Coefficient of Variation %	4.929	5.135	4.262	2.049	4.322	4.369
Minimum	23.888	24.050	13.438	14.466	11.294	11.071
Maximum	28.203	28.398	15.961	15.347	13.054	12.629
Number of Specimens	18	8	18	8	24	8
RESULTS						

Table 3-5 Transverse Compression Strength Results

Table 3-6 Transverse Compression Modulus Results

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

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

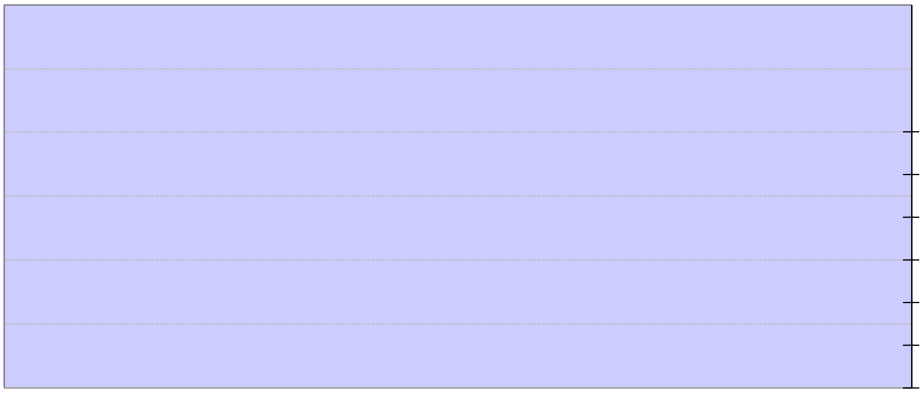

Figure 3-5 Transverse Compression means, minimums and Equivalence limits

3.4 Transverse Tension (TT)

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

		Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured									
	Mean Strength (ksi)								

Table 3-7 Transverse Tension Strength Results

Table 3-8 Transverse Tension Modulus Results

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

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

The TT strength data for the ETW2 environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The equivalency sample mean (2.946) is 99.34% of the minimum acceptable mean value (2.965). The modified CV method could not be used due to the CV of the ETW2 condition being greater than 8%.

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

The TT modulus data for the RTD environment failed the equivalency test because the sample mean value (1.197) is above the upper acceptance limit (1.178). The equivalency sample mean value is 101.59% of the upper limit of acceptable values. Under the assumption of the modified CV method, the modulus data from the RTD environment passed the equivalence test.

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

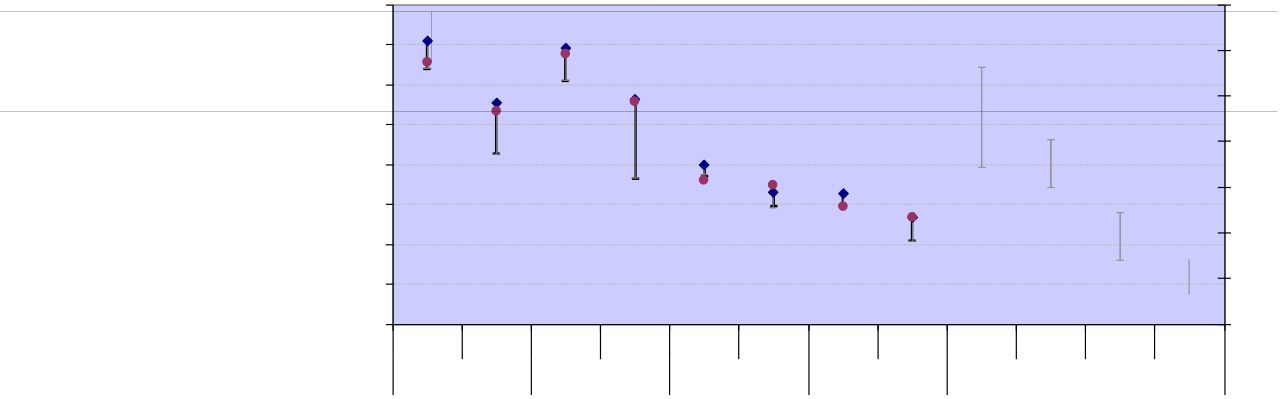

Figure 3-6 Transverse Tension means, minimums and Equivalence limits

3.5 Lamina Short Beam Strength (SBS)

The Short Beam Strength data is not normalized. The Short Beam Strength data passed equivalency tests for all three of the dry test conditions, CTD, RTD and ETD, but failed for the wet test conditions, ETW and ETW2.

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

					ETD		ETW		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured										
Mean Strength (ksi)	16.351	16.940	12.661	12.811	9.872	10.333	8.307	7.115	6.830	5.837
Standard Deviation	0.636	0.818	0.443	0.436	0.187	0.238	0.280	0.416	0.335	0.295
Coefficient of Variation %	3.892	4.832	3.500	3.406	1.898	2.304	3.374	5.843	4.910	5.061
Minimum	15.251	15.517	11.828	12.321	9.468	10.052	7.730	6.485	6.348	5.380
Maximum	17.395	18.030	13.380	13.717	10.175	10.717	8.848	7.597	7.459	6.245
Number of Specimens	18	8	18	8	18	8	18	8	18	8
RESULTS					**PASS**		**FAIL**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean					9.745		8.117		6.602	
Minimum Acceptable Equiv. Sample Min					9.366		7.551		5.925	
MOD CV RESULTS					**PASS with MOD CV**		**FAIL**			
Modified CV %					6.000		6.000			
Minimum Acceptable Equiv. Sample Mean					9.470		7.969		6.531	
Minimum Acceptable Equiv. Sample Min							6.962		5.64848 0 0 6.8421 110.52 524.76 Tm -.0449 49.5.	

Table 3-9 Lamina Short Beam Strength Results

The SBS strength data for the ETW environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (7.115) is 89.29% of the minimum acceptable mean value (7.969) and the equivalency sample minimum (6.485) is 93.15% of the lowest acceptable minimum value (6.962).

The SBS strength data for the ETW2 environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (5.837) is 89.38% of the minimum acceptable mean value (6.531) and the equivalency sample minimum (5.380) is 95.40% of the lowest acceptable minimum value (5.640).

Figure 3-7 illustrates the Short Beam Strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with

rror bars with

3.6 In-Plane Shear (IPS)

The In-Plane Shear data is not normalized. The IPS 0.2% Offset Strength data passed equivalency tests in all four tested condi

Table 3-12 In-Plane Shear Modulus Results

The IPS strength at 5% strain data for the CTD environment failed equivalence due to the sample mean being below the acceptance limit. The sample minimum value is

3.7 “50/0/50” Unnotched Compression 0 (UNC0)

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

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

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

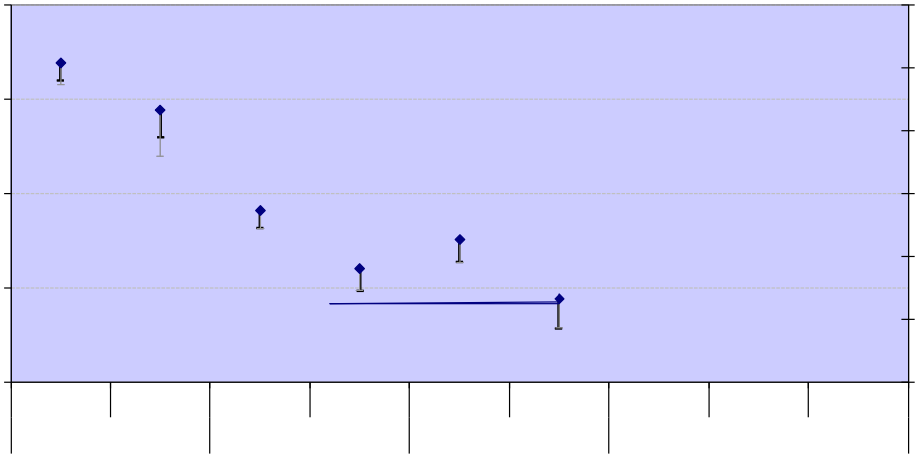

Figure 3-9 Unnotched Compression 0 means, minimums and Equivalence limits

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

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

Table 3-15 Unnotched Tension 0 Strength Results

Table 3-16 Unnotched Tension 0 Modulus Results

The UNT0 strength data for the RTD environment failed equivalence due to the sample

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

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

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0055 0.23a						

Table 3-18 Open Hole Compression 1 Strength Results

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

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

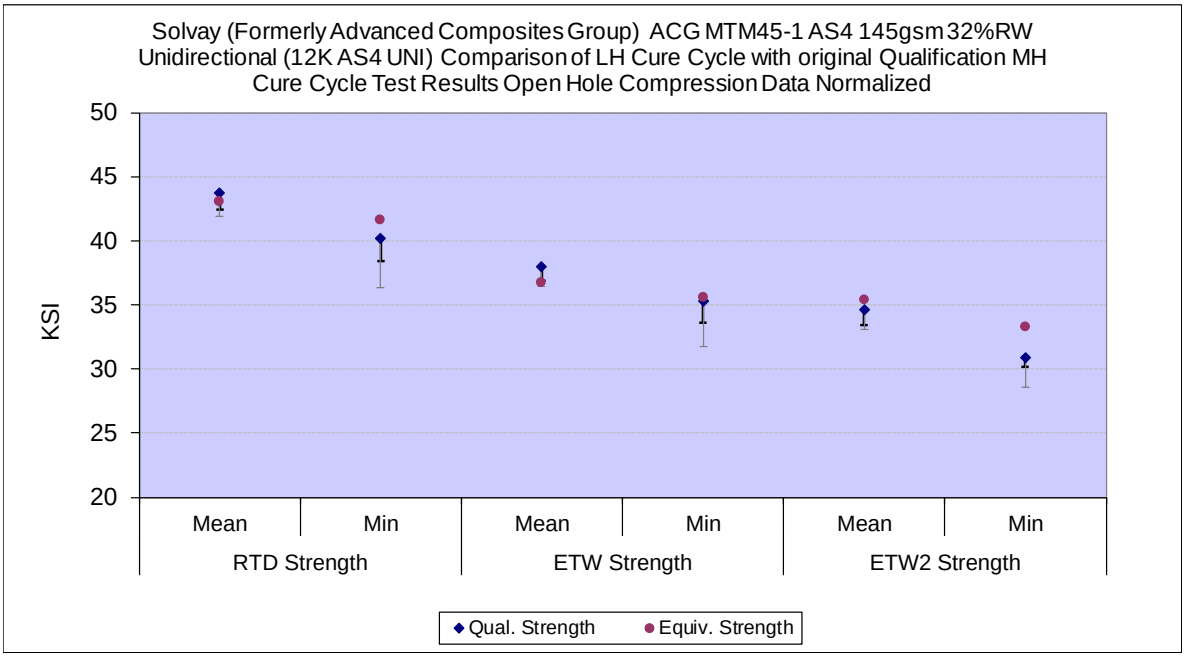

Figure 3-12 Open Hole Compression 1 means, minimums and Equivalence limits

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

The Interlaminar Tension and Curved Beam Strength data are not normalized. The ILT

3.12 Compression After Impact (CAI)

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

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

Table 3-20 Compression After Impact Strength Results

The CAI strength data for the RTD environment failed equivalence due to both the mean and minimum being too low. Under the assumption of the modified CV method, the equivalency sample mean (26.720) is 92.52% of the minimum acceptable mean value (28.880) and the equivalency sample minimum (24.878) is 97.98% of the lowest acceptable minimum value (25.392).

Figure 3-14 illustrates the Compression After Impact strength means and minimum values for the qualification sample and the equivalency sample. The limits for equivalency samples are shown as error bars with the qualification data. The longer, lighter colored error bars are for the modified CV computations.

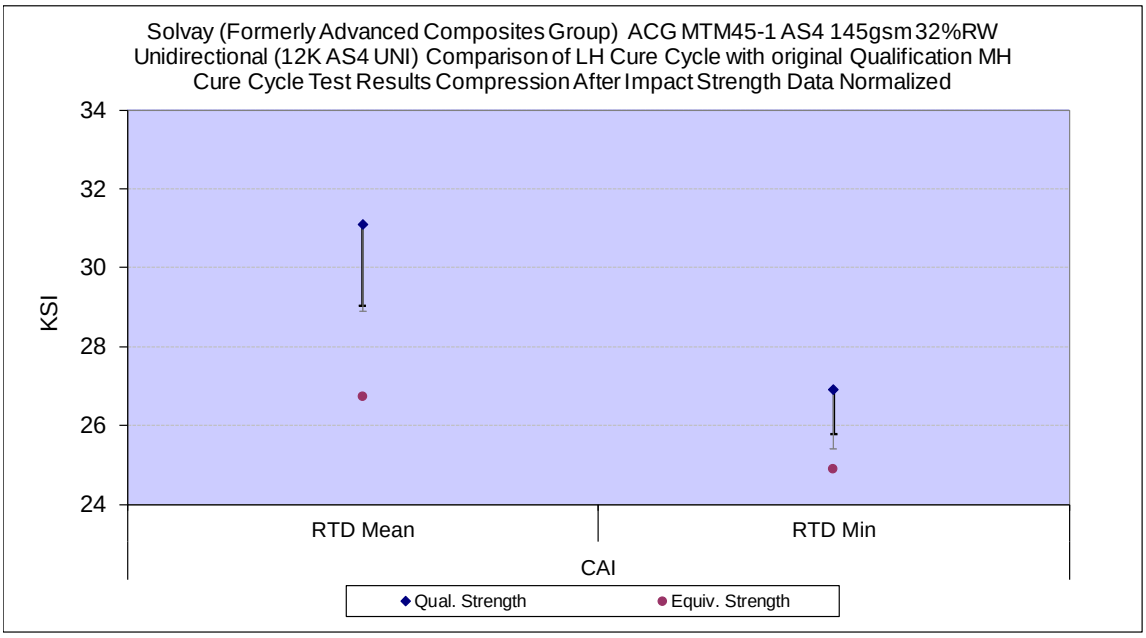

Figure 3-14 Compression After Impact means, minimums and Equivalence limits

3.13 Cured Ply Thickness (CPT)

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

Table 3-21 Cured Ply Thickness Results

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

3.14 Dynamic Mechanical Analysis (DMA)

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

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

Table 3-22 DMA Results

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

he mcy

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

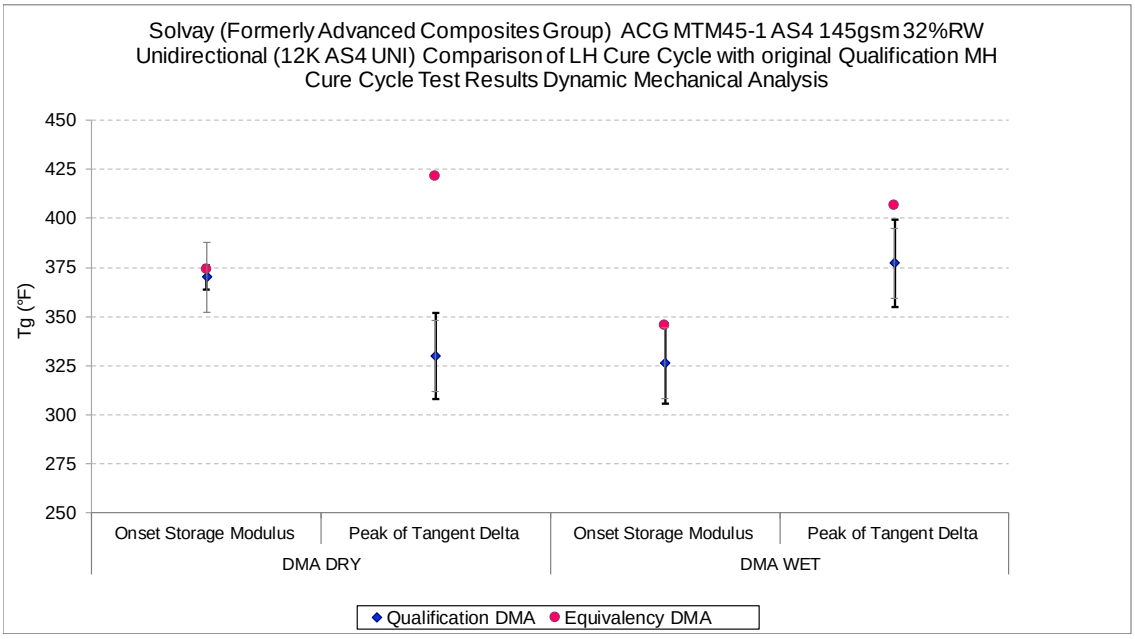

Figure 3-16 DMA Means and Equivalence limits

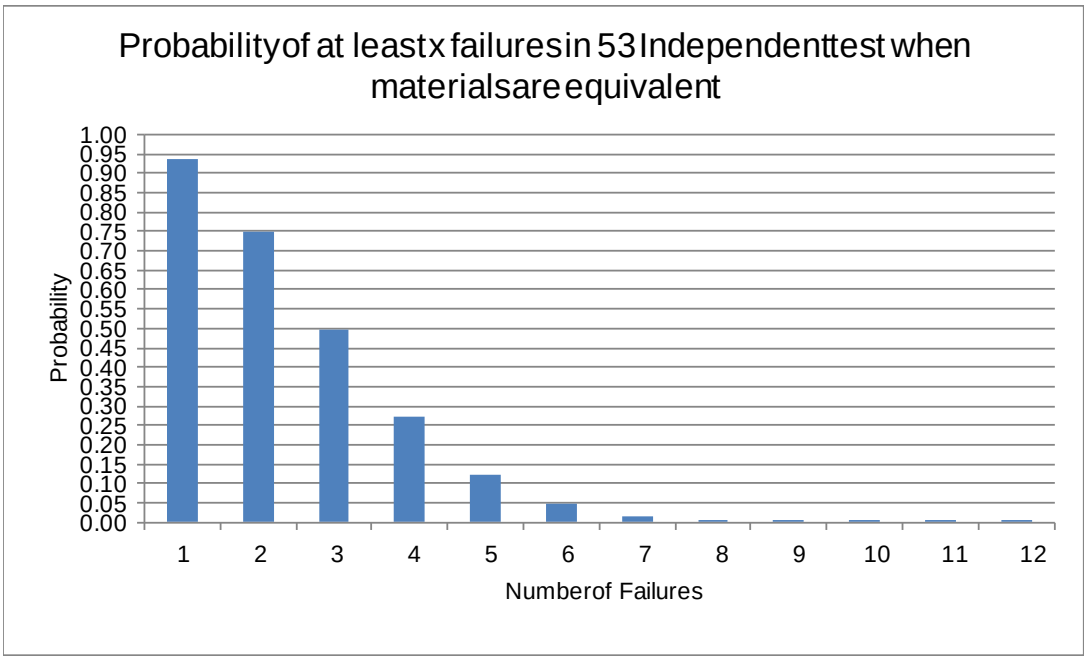

Figure 4-1 Probability of Number of Failures

5. References

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