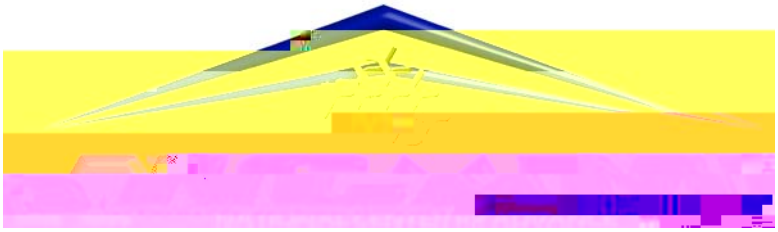

Equivalency Statistical Analysis for Laminate Repair Prepreg Batch of Solvay (Formerly Cytec) 5320-1 T650 3K-PW fabric with 36% RC

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1. Introduction

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.

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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
Compression After Impact	CAI
Cured Ply Thickness	CPT
Dynamic Mechanical Analysis	DMA

Table 1-1 Test Property Abbreviations

Environmental Condition	Temperature	Abbreviation
Cold Temperature Dry	ī65Ü Ñ5ęF	CTD
Room Temperature Dry	75Ü Ñ10ęF	RTD
Elevated Temperature Wet	250ÜÑ5ę F	ETW2

Table 1-2 Environmental Conditions Abbreviations

Tests with a number immediately after the abbreviation indicate the lay-up:

1 refers to a 25/50/25 layup. This is also referred to as ñQuasi-Isotropicò
2 refers to a 10/80/10 layup. This is also referred to as ñSoftò
3 refers to a 40/20/40 layup. This is also referred to as ñHardò

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, ñMaterial Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure.ò

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 óequivalentô materials.

2.2.1 Hypothesis Testing

This comparison is performed using the statistical methodology of hypothesis D 4 ъ T X Y em

2.2.2 Type I and Type II Errors

	Materials are equal	*Materials are not equal*
Conclude materials are equal	*Correct*	

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

The sample minimum must exceed $\bar{X} \quad k_n^{table\,2.2} \; S$ 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]

	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	977	7				

	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									

This is converted to percent by multiplying by 100%.

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

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

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

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

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 39 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. There were an additional two 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 Ŭ level of 5%.

The results of the equivalency comparisons are listed as ópassô, ófailô, or ópass with Mod CVô. ópass with Mod CVô 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

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

Table 3-2 "% Failed" Results Scale

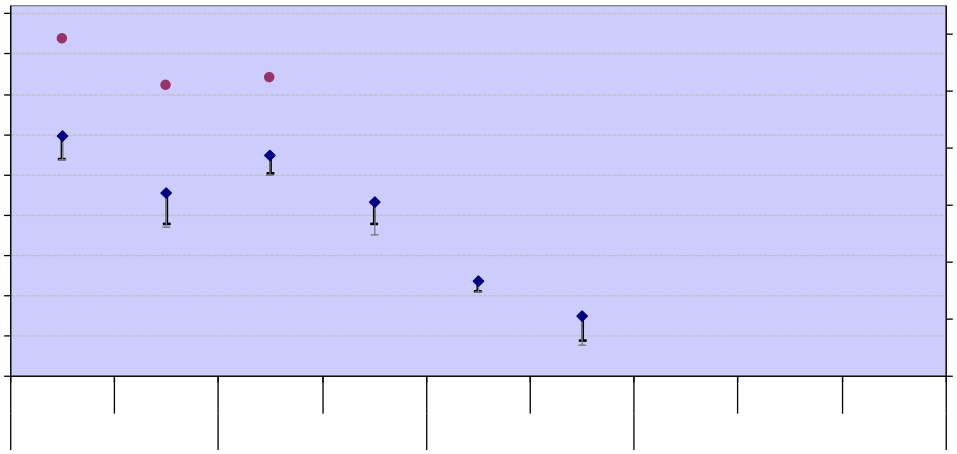
Graphical presentations of all te

3.1 Warp Compression (WC)

The WC data is normalized. Both the WC strength data and modulus data passed equivalency tests for all tested conditions. Statistics and analysis results are shown for the strength data in Table 3-3 and for the modulus data in Table 3-4.

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	107.485	131.625	102.675	122.163	71.411	77.107
Standard Deviation	8.031	5.028	6.262	3.855	4.953	6.368

Figure 3-3 illustrates the 0Ü 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.



3.2 Warp Tension (WT)

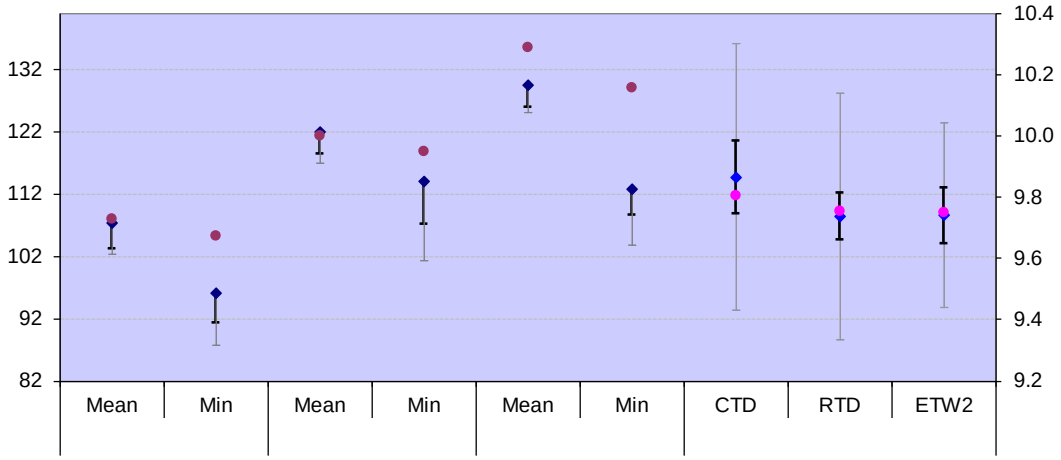
The WT data is normalized. Both the WT strength data and modulus data passed equivalency tests for all tested conditions. Statistics and analysis results are shown for the strength data in Table 3-5 and for the modulus data in Table 3-6.

Warp Tension (WT) Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	107.279	108.021	121.838	121.316	129.354	135.410
Standard Deviation	5.894	2.400	5.325	2.016	7.075	3.349
Coefficient of Variation %	5.494	2.222	4.371	1.662	5.469	2.473
Minimum	95.993	105.173	113.921	118.808	112.814	129.038
Maximum	121.054	111.779	131.605	124.669	137.556	140.538
Number of Specimens	21	8	22	9	22	16
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	103.277		118.424		125.934	
Minimum Acceptable Equiv. Sample Min	91.365		107.242		108.609	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	6.747		6.185		6.735	
Minimum Acceptable Equiv. Sample Mean	102.364		117.007		125.143	
Minimum Acceptable Equiv. Sample Min	87.736		101.181		103.809	

Table 3-5 Warp Tension Strength Results

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Modulus (Msi)	9.865	9.806	9.738	9.755	9.741	9.751
Standard Deviation	0.158	0.062	0.104	0.067	0.139	0.145
Coefficient of Variation %	1.606	0.637	1.065	0.688	1.432	1.483
Minimum	9.551	9.728	9.547	9.663	9.499	9.487
Maximum	10.063	9.908	9.966	9.902	9.9879.	.7
C 1.		3. ä .im c				

Figure 3-4 illustrates the 0Ü 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.



3.3 Fill Compression (FC)

The FC data is normalized. The normalized FC strength data and modulus data passed equivalency tests for all tested conditions. Modified CV results were not provided for the strength data because the coefficient of variation was above 8%

Figure 3-5 illustrates the 90Á 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

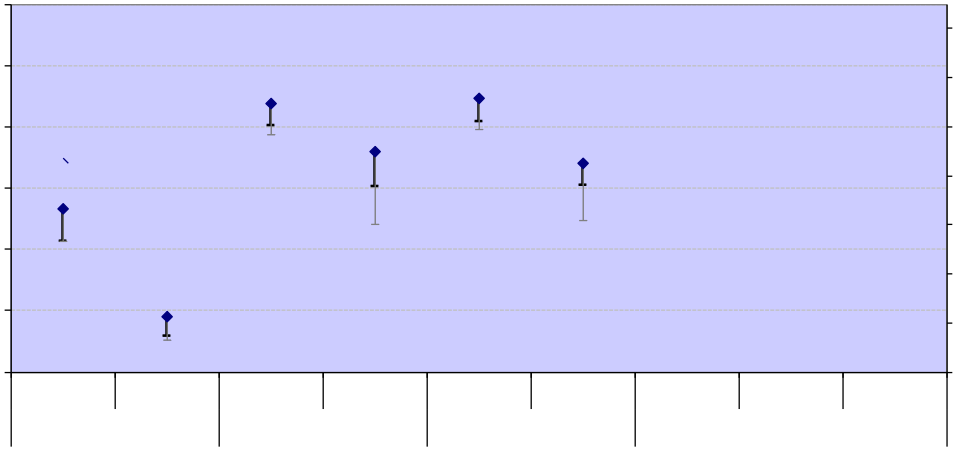
3.4 Fill Tension (FT)

The FT data is normalized. The normalized FT strength data and modulus data passed equivalency tests for all tested conditions.

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		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077						
Mean Strength (ksi)	101.592	104.228	118.678	115.574	119.526	129.582
Standard Deviation	7.647	2.860	4.979	3.786	5.163	4.533
Coefficient of Variation %	7.527	2.744	4.196	3.276	4.320	3.498
Minimum	83.956	100.111	110.990	110.066	108.939	125.112
Maximum	115.184	108.229	127.331	121.855	126.636	136.500
Number of Specimens	21	8	21	8	21	8
RESULTS	**PASS**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	96.399		115.297		116.020	
Minimum Acceptable Equiv. Sample Min	80.944		105.234		105.586	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV %	7.764		6.098		6.160	
Minimum Acceptable Equiv. Sample Mean	96.236		113.764		114.527	
Minimum Acceptable Equiv. Sample Min	80.296		99.139		99.647	

Figure 3-6 illustrates the 90Á 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.



3.5 Lamina Short Beam Strength (SBS)

The SBS data is not normalized. The SBS data passed equivalency tests for all tested conditions.

3.6 In-Plane Shear (IPS)

The IPS data is not normalized. The IPS data passed all equivalency tests for the CTD and RTD conditions, although the strength at 5% strain data in the CTD condition required the use of the modified CV approach to pass equivalency. The IPS data in the ETW2 condition passed equivalency tests only for strength at 5% strain, not for 0.2% offset strength or modulus. The strength at 5% strain data in the CTD condition had insufficient data for the result to be considered conclusive.

Statistics and analysis results are shown for the 0.2% offset strength data in Table 3-12, the strength at 5% strain data in Table 3-13, and the modulus data in Table 3-14.

In-Plane Shear (IPS) 0.2% Offset Strength	CTD		RTD		ETW2	
	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Strength @ 0.2% offset (ksi)	11.504	11.536	8.299	8.322	3.760	3.523
Standard Deviation	0.179	0.196	0.134	0.052	0.159	0.066
Coefficient of Variation %	1.559	1.703	1.612	0.630	4.238	1.870
Minimum	11.011	11.169	8.095	8.230	3.545	3.434
Maximum	11.856	11.788	8.614	8.415	4.108	3.633
Number of Specimens	21	10	21	8	21	8
RESULTS	**PASS**		**PASS**		**FAIL**	
Minimum Acceptable Equiv. Sample Mean	11.395		8.209		3.652	
Minimum Acceptable Equiv. Sample Min	11.006		7.938		3.330	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	6.000		6.000		6.119	
Minimum Acceptable Equiv. Sample Mean	11.084		7.961		3.604	
Minimum Acceptable Equiv. Sample Min	9.587		6.955		3.139	

Table 3-12 In-Plane Shear 0.2% Offset Strength Results

In-Pl Ó¯

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured	**Insufficient Data**					
Mean Strength @ 5% Strain (ksi)	18.882	18.308	14.650	14.455	6.915	6.712
Standard Deviation	0.639	0.391	0.451	0.121	0.328	0.146
Coefficient of Variation %	3.382	2.137	3.081	0.835	4.737	2.182
Minimum	17.916	17.843	14.071	14.289	6.427	6.549
Maximum	19.882	18.761	15.577	14.700	7.487	6.968
Number of Specimens	17	5	21	8	19	8
RESULTS	**FAIL**		**PASS**		**PASS**	
Minimum Acceptable Equiv. Sample Mean	18.338		14.343		6.693	
Minimum Acceptable Equiv. Sample Min	17.268		13.431		6.031	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.369	
Minimum Acceptable Equiv. Sample Mean	17.917		14.053		6.616	
Minimum Acceptable Equiv. Sample Min	16.018		12.277		5.726	

	Qual.	Equiv.	Qual.	Equiv.	Qual.	Equiv.
Data as measured						
Mean Modulus (Msi)	0.852	0.847	0.735	0.726	0.386	0.365
Standard Deviation	0.020	0.015	0.012	0.012	0.017	0.006
Coefficient of Variation %	2.387	1.829	1.664	1.651	4.359	1.626
Minimum	0.820	0.827	0.711	0.717	0.358	0.357
Maximum	0.881	0.868	0.759	0.755	0.422	0.374
Number of Specimens	21	10	21	8	21	8
RESULTS	**PASS**		**PASS**		**FAIL**	
Passing Range for Modulus Mean	0.837 to 0.867		0.725 to 0.746		0.374 to 0.399	
Student's t-statistic	-0.877		-0.870		-0.528	
p-value of Student's t-statistic	0.800		0.800		0.179	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FAIL**	
Modified CV%	0.818 to 0.886		0.703 to 0.768		0.369 to 0.404	
Passing Range for Modulus Mean	-0.340		-0.560		-2.515	
p-value of Student's t-statistic	0.736		0.580		0.018	

Figure 3-8 illustrates the IPS 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.

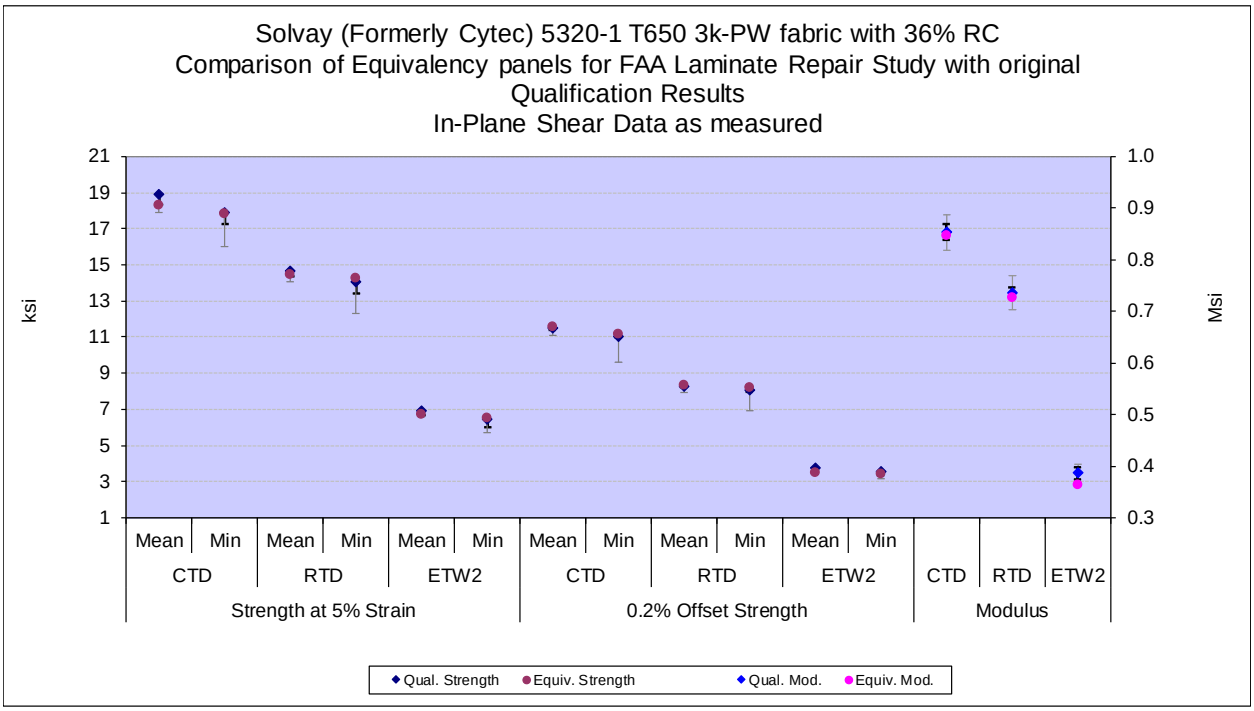


Figure 3-8 In-Plane Shear means, minimums and Equivalence limits

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

The OHT1 data is normalized. The OHT1 strength data passed equivalency tests for all tested conditions. Statistics and analysis results for the OHT1 strength data are shown in Table 3-15.

	Qual.	Equiv.	Qual.	Equiv.
Data normalized with CPT 0.0077				
Mean Strength (ksi)	43.645	43.951	48.634	48.089
Standard Deviation	3.342	1.943	1.669	1.408
Coefficient of Variation %	7.657	4.420	3.432	2.929
Minimum	37.877	40.550	46.035	46.157
Maximum	49.687	46.590	53.216	49.744
Number of Specimens	19	8	19	8

RESULTS

3.9 “25/50/25” Compression After Impact 1 (CAI1)

The CAI1 data is normalized. The CAI1 strength data passed equivalency tests for the RTD condition but has insufficient data for the results to be considered conclusive. Statistics and analy ᵀ ɔ ᴀ Й p ® ᵀ M ᵐ ᴀ mM ᵐ ᵡ l MqqeA ˎ ž M ᵀ ᵐ ᴰ l ɹ ȳ te l M v ᵐ ƥ M ɔ ƥ] M ɣ

3.10 Cured Ply Thickness (CPT)

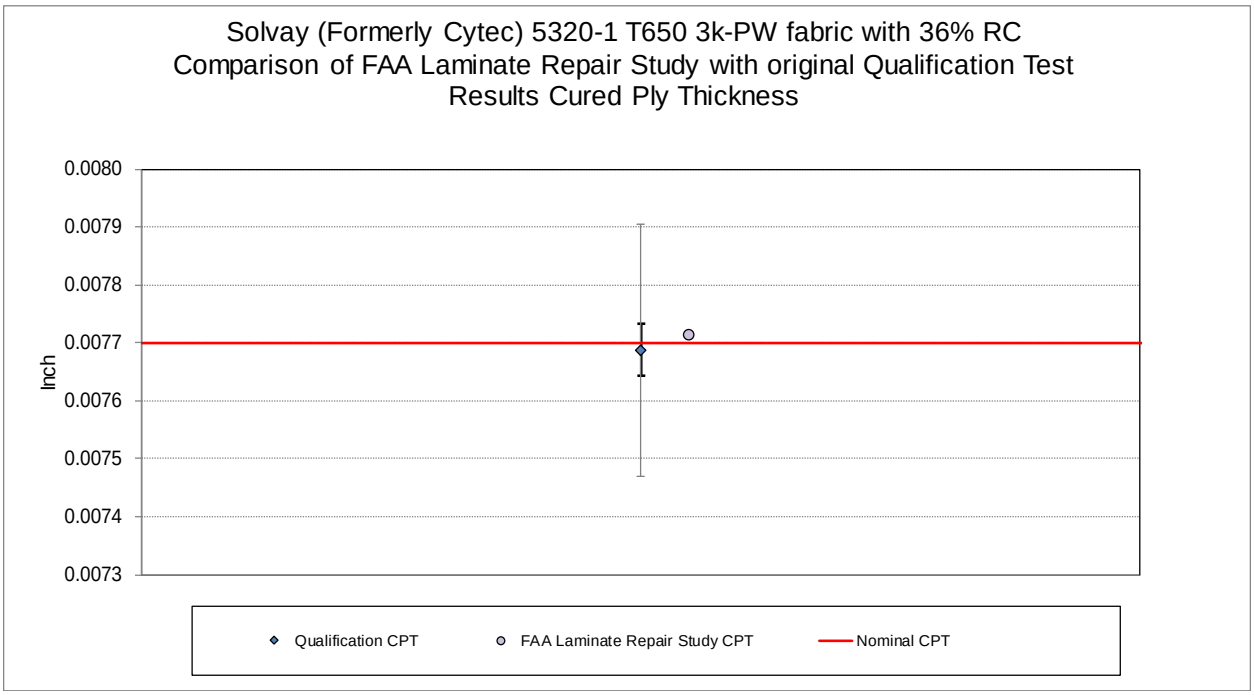


Figure 3-12 CPT means, 95% standard error bars and nominal value

3.11 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 Ñ18ÁF. This equivalency criterion for evaluating glass transition temperature is not a statistically-based criterion but is generally more stringent than that based on Ŭ=5% with modified coefficient of variation but less stringent that that based on Ŭ=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 DMA dry data sets were slightly above the upper acceptance limits while the DMA wet data sets were slightly below the lower acceptance limits. However, the DMA data passed equivalency tests for both the dry Peak of Tangent Delta and th

The Peak of Tangent Delta for wet data failed the equivalency test because the sample mean value (341.500) is below the lower acceptance limit (342.826). The equivalency sample mean is 99.61% of the lower limit of acceptable values. With the allowable range set to Ñ18ÁF, the Peak of Tangent Delta for DMA wet data passed the equivalency test.

4. Summary of Results

All the equivalency comparisons are conducted with Type I error probability (Ŭ) 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

4.2 Failures

The FAA Laminate Repair Study material has sufficient test results for comparison with the original qualification material test results on a total of 39 different test types and conditions, not including the cured ply thickness or the DMA comparison.

Using the modified CV method, there were two failures. Both failures were for IPS properties (0.2% offset strength and modulus) in the ETW2 condition.

1. In-Plane Shear Modulus for the ETW2 condition failed by 1.08%
2. In-Plane Shear 0.2% Offset Stren

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 two or more failures is 58.71%. Figure 4-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 39 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 ñnot equivalentò with a 95% level of confidence if there were five or more failures out of 39 independent tests.

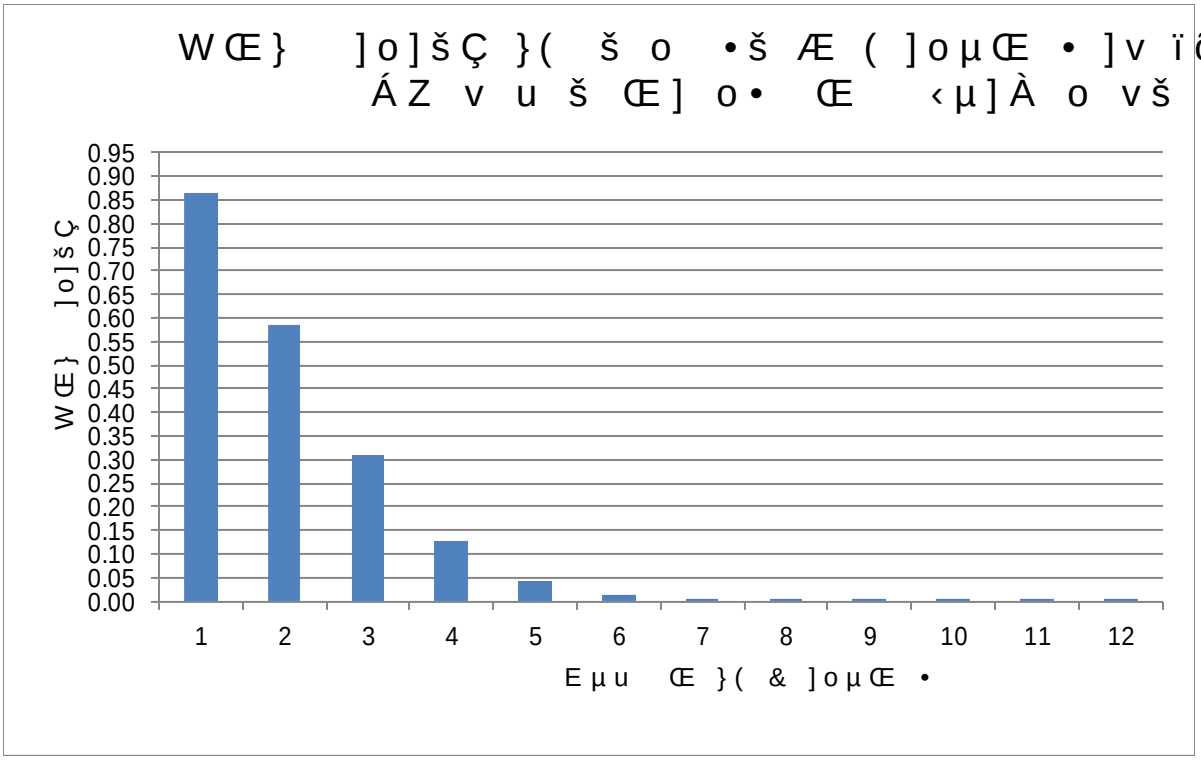


Figure 4-1 Probability of Number of Failures

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, ñ*Material Qualification and Equivalency for polymer Matrix Composite Material Systems: Updated Procedure*ò, 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