Report No: NCP-RP-2020-010 Rev N/C
Report Date: February 8, 2021

Laminate Repair of Solvay (Formerly Cytec) 5320-1 T650 3k-PW fabric with 36% RC Qualification and Equivalency Statistical Analysis Report

NCAMP Project Number: NPN 031801

NCAMP Report Number: NCP-RP-2020-010 Rev N/C

Report Date: February 8, 2021

Elizabeth Clarkson, Ph.D.

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

Testing Facility:

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

Test Panel Fabrication Facility:

National Institute for Aviation Research - NCAT
Wichita State University
4004 North Webb Road
Wichita, KS 67226

Prepared by:

Dr. Elizabeth Clarkson

Digitally signed by Dr. Elizabeth Clarkson
DN: cn=Dr. Elizabeth Clarkson, o=Wichita State University, ou=NCAMP, email=bclarkson@niar.wichita.edu, c=US
Date: 2021.02.11 10:58:47 -06'00'

Elizabeth Clarkson

Reviewed by:

Jonathan Tisack

Digitally signed by Jonathan Tisack
DN: cn=Jonathan Tisack, o=NIAR, ou=NCAMP, email=jtisack@niar.wichita.edu, c=US
Date: 2021.02.11 10:51:56 -06'00'

Jonathan Tisack

Evelyn Lian

Digitally signed by Evelyn Lian
DN: cn=Evelyn Lian, o=NIAR/NCAMP, ou=NIAR/NCAMP, email=evelyn@niar.wichita.edu, c=US
Date: 2021.02.11 10:06:48 -06'00'

Evelyn Lian

Approved by:

Royal Lovingfoss

Digitally signed by Royal Lovingfoss
DN: cn=Royal Lovingfoss, o=WSU, ou=NIAR, email=rlovingfoss@niar.wichita.edu, c=US
Date: 2021.02.11 10:37:24 -06'00'

Royal Lovingfoss

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Scope

This report analyzes the test results for 3-batch qualification and a single batch equivalency of the laminate repair of Solvay 5320-1 T650 3k plain weave fabric prepreg using Solvay FM®300-2M Adhesive Film 0.06psf. The NCAMP Test Plan NTP 5325QR1 was used for this 3-batch qualification and a single batch equivalency of laminate repair program.

The laminate material property data have been generated with NCAMP oversight in accordance with NSP 100 NCAMP Standard Operating Procedures; the test panels and test specimens have been inspected by NCAMP Authorized Inspection Representatives (AIR) and the testing has been witnessed by NCAMP Authorized Engineering Representatives (AER). However, the data may not fulfill all the needs of any specific company's program; specific properties, environments, laminate architecture, and loading situations may require additional testing.

The use of NCAMP material and process specifications do 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 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.

Both qualification and equivalency material was procured to NCAMP Material Specification NMS 532/6 Rev A dated September 19, 2016. Both qualification and equivalency laminate repair test panels fabrication consisted of the parent test panels and repair test panels. Both qualification and equivalency laminate repair test panels were cured in accordance with NCAMP Process Specification NPS 85321 Rev C dated May 31, 2018 using baseline "C" cure cycle. The repair test panels are repaired to NCAMP Process Specification NPS 80530R using Solvay FM 300-2M Adhesive Film 0.06psf, which was procured to NMS 300/1. The NCAMP Test Plan NTP 5325QR1 was used for this 3-batch qualification and a single batch equivalency of laminate repair program. The testing was performed at the National Institute for Aviation Research (NIAR) in Wichita, Kansas.

B-Basis values, A-estimates, and B-estimates were calculated using a variety of techniques that are detailed in section two. Basis numbers are labeled as 'values' when the data meets all the requirements of CMH-17-1G. When those requirements are not met, they will be labeled as 'estimates.' When the data does not meet all requirements, the failure to meet these requirements is reported and the specific requirement(s) the data fails to meet is identified. The method used to compute the basis value is noted for each basis value provided. When appropriate, in addition to the traditional computational methods, values computed using the modified coefficient of variation method are also provided.

The material property data acquisition process is designed to generate basic material property data with sufficient pedigree for submission to Complete Documentation sections of the Composite Materials Handbook (CMH-17-1G).

Part fabricators that wish to utilize the material property data, allowables and specifications may be able to do so by demonstrating the capability to reproduce the original material properties; a process known as equivalency. More information about the equivalency process including the test statistics and its limitations can be found in section 6 of DOT/FAA/AR-03/19 and Section 8.4.1 of CMH-17-1G. The applicability of the equivalency process must be evaluated on a program-by-program basis by the applicant and certifying agency. The applicant and certifying agency must agree that the equivalency test plan, along with the equivalency process described in section 6 of DOT/FAA/AR-03/19 and Section 8.4.1 of CMH-17-1G, are adequate for the given program.

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 532/6 (Solvay 5320-1 T650 3k-PW) and NMS 300/1 (FM300-2M 0.06psf). NMS 532/6 and NMS 300/1 have 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 NMS 532/6 and NMS 300/1 and repaired according to NCAMP Process Specification NPS 80530R. NMS 532/6, NMS 300/1 and NPS 80530R are free, publicly available, non-proprietary aerospace industry material specification.

The data in this report is intended for general distribution to the public, either freely or at a price that does not exceed the cost of reproduction (e.g. printing) and distribution (e.g. postage).

1.2 Symbols and Abbreviations

Test Property	Abbreviation
Un-Notched Compression (Baseline)	UNC1
Un-Notched Compression Repair (Scarf Ratio 50:1)	UNCR50
Un-Notched Compression Repair (Scarf Ratio 30:1)	UNCR30
Compression After Impact (Scarf Ratio 50:1)	CAI150
Tension Repair (Scarf Ratio 50:1)	TR50
Tension Repair (Scarf Ratio 30:1)	TR30

Table 1-1: Test Property Abbreviations

Test Property	Symbol
Tension Repair Strength at Parent Laminate	F_p^{tu}
Tension Repair Strength at Repair Laminate	F_r^{tu}
Ultimate Joint Running Force per Repair Ply	N_j

Table 1-2: Test Property Symbols

Environmental Condition	Abbreviation	Temperature
Cold Temperature Dry	CTD	−65°F
Room Temperature Dry	RTD	70°F
Elevated Temperature Wet	ETW2	180°F

Table 1-3: 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 "Quasi-Isotropic"
2 refers to a 10/80/10 layup. This is also referred to as “Soft”
3 refers to a 50/40/10 layup. This is also referred to as “Hard”

EX: OHT1 is an open hole tension test with a 25/50/25 layup

Detailed information about the test methods and conditions used is given in NCAMP Test Report CAM-RP-2018-056.

1.3 Pooling Across Environments

When pooling across environments was allowable, the pooled co-efficient of variation was used. CMH17 STATS (CMH17 Approved Statistical Analysis Program) was used to determine if pooling was allowable and to compute the pooled coefficient of variation for those tests. In these cases, the modified coefficient of variation based on the pooled data was used to compute the basis values.

When pooling across environments was not advisable because the data was not eligible for pooling and engineering judgment indicated there was no justification for overriding the result, then B-Basis values were computed for each environmental condition separately, which are also provided by CMH17 STATS.

1.4 Basis Value Computational Process

The general form to compute engineering basis values is: $\text{basis value} = \overline{X} - kS$ where k is a factor based on the sample size and the distribution of the sample data. There are many different methods to determine the value of k in this equation, depending on the sample size and the distribution of the data. In addition, the computational formula used for the standard deviation, S, may vary depending on the distribution of the data. The details of those different computations and when each should be used are in section 2.

1.5 Modified Coefficient of Variation (CV) Method

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 variability as measured in the qualification program is often lower than the actual material variability because of several reasons. The materials used in the qualification programs are usually manufactured within a short period of time, typically 2-3 weeks only, which is not representative of the production material. Some raw ingredients that are used to manufacture the multi-batch qualification materials may actually be from the same production batches or manufactured within a short period of time so the qualification materials, although regarded as multiple batches, may not truly be multiple batches so they are not representative of the actual production material variability.

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%. The modified coefficient of variation (CV) method increases the measured coefficient of variation when it is below 8% prior to computing basis values. A higher CV will result in lower or more conservative basis values and lower specification limits. The use of the modified CV method is intended for a temporary period of time when there is minimal data available. When a sufficient number of production batches (approximately 8 to 15) have been produced and tested, the as-measured CV may be used so that the basis values and specification limits may be adjusted higher.

The material allowables in this report are calculated using both the as-measured CV and modified CV, so users have the choice of using either one. When the measured CV is greater than 8%, the modified CV method does not change the basis value. NCAMP recommended values make use of the modified CV method when it is appropriate for the data.

When the data fails the Anderson-Darling K-sample test for batch to batch variability or when the data fails the normality test, the modified CV method is not appropriate and no modified CV basis value will be provided. When the ANOVA method is used, it may produce excessively conservative basis values. When appropriate, a single batch or two batch estimate may be provided in addition to the ANOVA estimate.

In some cases a transformation of the data to fit the assumption of the modified CV resulted in the transformed data passing the ADK test and thus the data can be pooled only for the modified CV method.

NCAMP recommends that if a user decides to use the basis values that are calculated from as-measured CV, the specification limits and control limits be calculated with as-measured CV also. Similarly, if a user decides to use the basis values that are calculated from modified CV, the specification limits and control limits be calculated with modified CV also. This will ensure that the link between material allowables, specification limits, and control limits is maintained.

2. Background

Statistical computations are performed with CMH17 STATS. Pooling across environments will be used whenever it is permissible according to CMH-17-1G guidelines. If pooling is not permissible, the results of a single point analysis provided by CMH17 STATS is included instead. If the data does not meet CMH-17-1G requirements for a single point analysis, estimates are created by a variety of methods depending on which is most appropriate for the dataset available. Specific procedures used are presented in the individual sections where the data is presented.

2.1 CMH17 STATS Statistical Formulas and Computations

This section contains the details of the specific formulas CMH17 STATS uses in its computations.

2.1.1 Basic Descriptive Statistics

The basic descriptive statistics shown are computed according to the usual formulas, which are shown below:

Mean: $$\bar{X} = \sum_{i=1}^{n} \frac{X_i}{n}$$ **Equation 1**

Std. Dev.: $$S = \sqrt{\tfrac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}$$ **Equation 2**

% Co. Variation: $$\frac{S}{\bar{X}} \times 100$$ **Equation 3**

Where n refers to the number of specimens in the sample and X_i refers to the individual specimen measurements.

2.1.2 Statistics for Pooled Data

Prior to computing statistics for the pooled dataset, the data is normalized to a mean of one by dividing each value by the mean of all the data for that condition. This transformation does not affect the coefficients of variation for the individual conditions.

2.1.2.1 Pooled Standard Deviation

The formula to compute a pooled standard deviation is given below:

Pooled Std. Dev.: $$S_p = \sqrt{\frac{\sum_{i=1}^{k}(n_i - 1)S_i^2}{\sum_{i=1}^{k}(n_i - 1)}}$$ **Equation 4**

Where k refers to the number of batches, S_i indicates the standard deviation of i^{th} sample, and n_i refers to the number of specimens in the i^{th} sample.

2.1.2.2 Pooled Coefficient of Variation

Since the mean for the normalized data is 1.0 for each condition, the pooled normalized data also has a mean of one. The coefficient of variation for the pooled normalized data is the pooled standard deviation divided by the pooled mean, as in equation 3. Since the mean for the pooled normalized data is one, the pooled coefficient of variation is equal to the pooled standard deviation of the normalized data.

$$\text{Pooled Coefficient of Variation} = \frac{S_p}{1} = S_p$$ **Equation 5**

2.1.3 Basis Value Computations

Basis values are computed using the mean and standard deviation for that environment, as follows: The mean is always the mean for the environment, but if the data meets all requirements for pooling, S_p can be used in place of the standard deviation for the environment, S.

Basis Values:
$$A - basis = \bar{X} - K_a S$$
$$B - basis = \bar{X} - K_b S$$
Equation 6

2.1.3.1 K-factor computations

K_a and K_b are computed according to the methodology documented in section 8.3.5 of CMH-17-1G. The approximation formulas are given below:

$$K_a = \frac{2.3263}{\sqrt{q(f)}} + \sqrt{\frac{1}{c_A(f) \cdot n_j} + \left(\frac{b_A(f)}{2c_A(f)}\right)^2} - \frac{b_A(f)}{2c_A(f)}$$ **Equation 7**

$$K_b = \frac{1.2816}{\sqrt{q(f)}} + \sqrt{\frac{1}{c_B(f) \cdot n_j} + \left(\frac{b_B(f)}{2c_B(f)}\right)^2} - \frac{b_B(f)}{2c_B(f)}$$ **Equation 8**

Where

r = the number of environments being pooled together

n_j = number of data values for environment j

$$N = \sum_{j=1}^{r} n_j$$

$$f = N - r$$

$$q(f) = 1 - \frac{2.323}{\sqrt{f}} + \frac{1.064}{f} + \frac{0.9157}{f\sqrt{f}} - \frac{0.6530}{f^2}$$ **Equation 9**

$$b_B(f) = \frac{1.1372}{\sqrt{f}} - \frac{0.49162}{f} + \frac{0.18612}{f\sqrt{f}}$$ **Equation 10**

$$c_B(f) = 0.36961 + \frac{0.0040342}{\sqrt{f}} - \frac{0.71750}{f} + \frac{0.19693}{f\sqrt{f}}$$ **Equation 11**

$$b_A(f) = \frac{2.0643}{\sqrt{f}} - \frac{0.95145}{f} + \frac{0.51251}{f\sqrt{f}}$$ **Equation 12**

$$c_A(f) = 0.36961 + \frac{0.0026958}{\sqrt{f}} - \frac{0.65201}{f} + \frac{0.011320}{f\sqrt{f}}$$ **Equation 13**

2.1.4 Modified Coefficient of Variation

The coefficient of variation is modified according to the following rules:

Modified CV = $$CV^* = \begin{cases} .06 & \text{if } CV < .04 \\ \dfrac{CV}{2} + .04 & \text{if } .04 \le CV < .08 \\ CV & \text{if } CV \ge .08 \end{cases}$$ **Equation 14**

This is converted to percent by multiplying by 100%.

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

$$S^* = CV^* \cdot \overline{X}$$ **Equation 15**

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

$$S_p^* = \sqrt{\frac{\sum_{i=1}^{k}\left((n_i - 1)\left(CV_i^* \cdot \overline{X}_i\right)^2\right)}{\sum_{i=1}^{k}(n_i - 1)}}$$ **Equation 16**

The A-basis and B-basis values under the assumption of the modified CV method are computed by replacing S with S^*

2.1.4.1 Transformation of data based on Modified CV

In order to determine if the data would pass the diagnostic tests under the assumption of the modified CV, the data must be transformed such that the batch means remain the same while the standard deviation of transformed data (all batches) matches the modified standard deviation.

To accomplish this requires a transformation in two steps:

Step 1: Apply the modified CV rules to each batch and compute the modified standard deviation $S_i^* = CV^* \cdot \bar{X}_i$ for each batch. Transform the individual data values (X_{ij}) in each batch as follows:

$$X'_{ij} = C_i\left(X_{ij} - \bar{X}_i\right) + \bar{X}_i \quad \textbf{Equation 17}$$

$$C_i = \frac{S_i^*}{S_i} \quad \textbf{Equation 18}$$

Run the Anderson-Darling k-sample test for batch equivalence (see section 2.1.6) on the transformed data. If it passes, proceed to step 2. If not, stop. The data cannot be pooled.

Step 2: Another transformation is needed as applying the modified CV to each batch leads to a larger CV for the combined data than when applying the modified CV rules to the combined data (due to the addition of between batch variation when combining data from multiple batches). In order to alter the data to match S^*, the transformed data is transformed again, this time setting using the same value of C′ for all batches.

$$X''_{ij} = C'\left(X'_{ij} - \bar{X}_i\right) + \bar{X}_i \quad \textbf{Equation 19}$$

$$C' = \sqrt{\frac{SSE^*}{SSE'}} \quad \textbf{Equation 20}$$

$$SSE^* = (n-1)\left(CV^* \cdot \bar{X}\right)^2 - \sum_{i=1}^{k} n_i\left(\bar{X}_i - \bar{X}\right)^2 \quad \textbf{Equation 21}$$

$$SSE' = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(X'_{ij} - \bar{X}_i\right)^2 \quad \textbf{Equation 22}$$

Once this second transformation has been completed, the k-sample Anderson Darling test for batch equivalence can be run on the transformed data to determine if the modified co-efficient of variation will permit pooling of the data.

2.1.5 Determination of Outliers

All outliers are identified in text and graphics. If an outlier is removed from the dataset, it will be specified and the reason why will be documented in the text. Outliers are identified using the Maximum Normed Residual Test for Outliers as specified in section 8.3.3 of CMH-17-1G.

$$MNR = \frac{\max_{all\ i} \left| X_i - \overline{X} \right|}{S}, i = 1 \ldots n \qquad \textbf{Equation 23}$$

$$C = \frac{n-1}{\sqrt{n}} \sqrt{\frac{t^2}{n-2+t^2}} \qquad \textbf{Equation 24}$$

where t is the $1 - \frac{.05}{2n}$ quartile of a t distribution with n−2 degrees of freedom, n being the total number of data values.

If MNR > C, then the X_i associated with the MNR is considered to be an outlier. If an outlier exists, then the X_i associated with the MNR is dropped from the dataset and the MNR procedure is applied again. This process is repeated until no outliers are detected. Additional information on this procedure can be found in references 1 and 2.

2.1.6 The k-Sample Anderson Darling Test for Batch Equivalency

The k-sample Anderson-Darling test is a nonparametric statistical procedure that tests the hypothesis that the populations from which two or more groups of data were drawn are identical. The distinct values in the combined data set are ordered from smallest to largest, denoted $z_{(1)}, z_{(2)}, \ldots z_{(L)}$, where L will be less than n if there are tied observations. These rankings are used to compute the test statistic.

The k-sample Anderson-Darling test statistic is:

$$ADK = \frac{n-1}{n^2(k-1)} \sum_{i=1}^{k} \left[\frac{1}{n_i} \sum_{j=1}^{L} h_j \frac{\left(nF_{ij} - n_i H_j \right)^2}{H_j \left(n - H_j \right) - \frac{nh_j}{4}} \right] \qquad \textbf{Equation 25}$$

Where

n_i = the number of test specimens in each batch

$n = n_1+n_2+\ldots+n_k$

h_j = the number of values in the combined samples equal to $z_{(j)}$

H_j = the number of values in the combined samples less than $z_{(j)}$ plus ½ the number of values in the combined samples equal to $z_{(j)}$

F_{ij} = the number of values in the i^{th} group which are less than $z_{(j)}$ plus ½ the number of values in this group which are equal to $z_{(j)}$.

The critical value for the test statistic at 1−α level is computed:

$$ADC = 1 + \sigma_n \left[z_\alpha + \frac{0.678}{\sqrt{k-1}} - \frac{0.362}{k-1} \right] \qquad \textbf{Equation 26}$$

This formula is based on the formula in reference 3 at the end of section 5, using a Taylor's expansion to estimate the critical value via the normal distribution rather than using the t distribution with k-1 degrees of freedom.

$$\sigma_n^2 = VAR(ADK) = \frac{an^3 + bn^2 + cn + d}{(n-1)(n-2)(n-3)(k-1)^2}$$ **Equation 27**

With

$$a = (4g-6)(k-1) + (10-6g)S$$
$$b = (2g-4)k^2 + 8Tk + (2g-14T-4)S - 8T + 4g - 6$$
$$c = (6T+2g-2)k^2 + (4T-4g+6)k + (2T-6)S + 4T$$
$$d = (2T+6)k^2 - 4Tk$$
$$S = \sum_{i=1}^{k} \frac{1}{n_i}$$
$$T = \sum_{i=1}^{n-1} \frac{1}{i}$$
$$g = \sum_{i=1}^{n-2} \sum_{j=i+1}^{n-1} \frac{1}{(n-i)j}$$

The data is considered to have failed this test (i.e. the batches are not from the same population) when the test statistic is greater than the critical value. For more information on this procedure, see reference 3.

2.1.7 The Anderson Darling Test for Normality

Normal Distribution: A two parameter (μ, σ) family of probability distributions for which the probability that an observation will fall between *a* and *b* is given by the area under the curve between a and b:

$$F(x) = \int_a^b \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx$$ **Equation 28**

A normal distribution with parameters (μ, σ) has population mean μ and variance σ^2.

The normal distribution is considered by comparing the cumulative normal distribution function that best fits the data with the cumulative distribution function of the data. Let

$$z_{(i)} = \frac{x_{(i)} - \bar{x}}{s}, \quad \text{for i = 1,\ldots,n}$$ **Equation 29**

where $x_{(i)}$ is the smallest sample observation, $\bar{x}$ is the sample average, and s is the sample standard deviation.

The Anderson Darling test statistic (AD) is:

$$AD = \sum_{i=1}^{n} \frac{1-2i}{n} \left\{ \ln\left[F_0(z_{(i)})\right] + \ln\left[1 - F_0\left(z_{(n+1-i)}\right)\right] \right\} - n$$ **Equation 30**

Where F_0 is the standard normal distribution function. The observed significance level (OSL) is

$$OSL = \frac{1}{1+e^{-0.48+0.78\ln(AD^*)+4.58AD^*}}, \quad AD^* = \left(1+\frac{4}{n}-\frac{25}{n^2}\right)AD \qquad \textbf{Equation 31}$$

This OSL measures the probability of observing an Anderson-Darling statistic at least as extreme as the value calculated if, in fact, the data are a sample from a normal population. If OSL > 0.05, the data is considered sufficiently close to a normal distribution.

2.1.8 Levene's Test for Equality of Coefficient of Variation

Levene's test performs an Analysis of Variance on the absolute deviations from their sample medians. The absolute value of the deviation from the median is computed for each data value. $w_{ij} = \left| y_{ij} - \tilde{y}_i \right|$ An F-test is then performed on the transformed data values as follows:

$$F = \frac{\sum_{i=1}^{k} n_i \left(\bar{w}_i - \bar{w}\right)^2 /(k-1)}{\sum_{i=1}^{k}\sum_{j=1}^{n_i} {}_i\left(w_{ij} - \bar{w}_i\right)^2 /(n-k)} \qquad \textbf{Equation 32}$$

If this computed F statistic is less than the critical value for the F-distribution having k-1 numerator and n-k denominator degrees of freedom at the 1-α level of confidence, then the data is not rejected as being too different in terms of the co-efficient of variation. CMH-17 STATS provides the appropriate critical values for F at α levels of 0.10, 0.05, 0.025, and 0.01. For more information on this procedure, see references 4, and 5.

2.1.9 Distribution Tests

In addition to testing for normality using the Anderson-Darling test (see 2.1.7), CMH17 STATS also tests to see if the Weibull or Lognormal distribution is a good fit for the data.

Each distribution is considered using the Anderson-Darling test statistic which is sensitive to discrepancies in the tail regions. The Anderson-Darling test compares the cumulative distribution function for the distribution of interest with the cumulative distribution function of the data.

An observed significance level (OSL) based on the Anderson-Darling test statistic is computed for each test. The OSL measures the probability of observing an Anderson-Darling test statistic at least as extreme as the value calculated if the distribution under consideration is in fact the underlying distribution of the data. In other words, the OSL is the probability of obtaining a value of the test statistic at least as large as that obtained if the hypothesis that the data are actually from the distribution being tested is true. If the OSL is less than or equal to 0.05, then the assumption that the data are from the distribution being tested is rejected with at most a five percent risk of being in error.

If the normal distribution has an OSL greater than 0.05, then the data is assumed to be from a population with a normal distribution. If not, then if either the Weibull or lognormal distributions has an OSL greater than 0.05, then one of those can be used. If neither of these distributions has an OSL greater than 0.05, a non-parametric approach is used.

In what follows, unless otherwise noted, the sample size is denoted by n, the sample observations by $x_1, ..., x_n$, and the sample observations ordered from least to greatest by $x_{(1)}, ..., x_{(n)}$.

2.1.9.1 One-sided B-basis tolerance factors, k_B, for the normal distribution when sample size is greater than 15.

The exact computation of k_B values is $1/\sqrt{n}$ times the 0.95th quantile of the noncentral t-distribution with noncentrality parameter $1.282\sqrt{n}$ and n − 1 degrees of freedom. Since this in not a calculation that Excel can handle, the following approximation to the k_B values is used:

$$k_B \approx 1.282 + \exp\{0.958 - 0.520\ln(n) + 3.19/n\}$$ **Equation 33**

This approximation is accurate to within 0.2% of the tabulated values for sample sizes greater than or equal to 16.

2.1.9.2 One-sided A-basis tolerance factors, k_A, for the normal distribution

The exact computation of k_A values is $1/\sqrt{n}$ times the 0.95th quantile of the noncentral t-distribution with noncentrality parameter $2.326\sqrt{n}$ and n − 1 degrees of freedom (Reference 11). Since this is not a calculation that Excel can handle easily, the following approximation to the k_A values is used:

$$k_A \approx 2.326 + \exp\{1.34 - 0.522\ln(n) + 3.87/n\}$$ **Equation 34**

This approximation is accurate to within 0.2% of the tabulated values for sample sizes greater than or equal to 16.

2.1.9.3 Two-parameter Weibull Distribution

A probability distribution for which the probability that a randomly selected observation from this population lies between a and b $(0 < a < b < \infty)$ is given by

$$e^{-(a/\alpha)^\beta} - e^{-(b/\alpha)^\beta}$$ **Equation 35**

where α is called the scale parameter and β is called the shape parameter.

In order to compute a check of the fit of a data set to the Weibull distribution and compute basis values assuming Weibull, it is first necessary to obtain estimates of the population shape and scale parameters (Section 2.1.9.3.1). Calculations specific to the goodness-of-fit test for the Weibull distribution are provided in section 2.1.9.3.2.

2.1.9.3.1 Estimating Weibull Parameters

This section describes the *maximum likelihood* method for estimating the parameters of the two-parameter Weibull distribution. The maximum-likelihood estimates of the shape and scale parameters are denoted $\hat{\beta}$ and $\hat{\alpha}$. The estimates are the solution to the pair of equations:

$$\hat{\alpha}\hat{\beta}n - \frac{\hat{\beta}}{\hat{\alpha}^{\hat{\beta}-1}}\sum_{i=1}^{n} x_i^{\hat{\beta}} = 0$$ **Equation 36**

$$\frac{n}{\hat{\beta}} - n\ln\hat{\alpha} + \sum_{i=1}^{n}\ln x_i - \sum_{i=1}^{n}\left[\frac{x_i}{\hat{\alpha}}\right]^{\hat{\beta}}\left(\ln x_i - \ln\hat{\alpha}\right) = 0$$ **Equation 37**

CMH17 STATS solves these equations numerically for $\hat{\beta}$ and $\hat{\alpha}$ in order to compute basis values.

2.1.9.3.2 Goodness-of-fit test for the Weibull distribution

The two-parameter Weibull distribution is considered by comparing the cumulative Weibull distribution function that best fits the data with the cumulative distribution function of the data. Using the shape and scale parameter estimates from section 2.1.9.3.1, let

$$z_{(i)} = \left[x_{(i)}/\hat{\alpha}\right]^{\hat{\beta}}, \quad \text{for } i = 1,\ldots,n$$ **Equation 38**

The Anderson-Darling test statistic is

$$AD = \sum_{i=1}^{n}\frac{1-2i}{n}\left[\ln\left[1-\exp(-z_{(i)})\right] - z_{(n+1-i)}\right] - n$$ **Equation 39**

and the observed significance level is

$$OSL = 1/\left\{1+\exp[-0.10+1.24\ln(AD^*)+4.48AD^*]\right\}$$ **Equation 40**

where

$$AD^* = \left(1+\frac{0.2}{\sqrt{n}}\right)AD$$ **Equation 41**

This OSL measures the probability of observing an Anderson-Darling statistic at least as extreme as the value calculated if in fact the data is a sample from a two-parameter Weibull distribution. If OSL $\leq$ 0.05, one may conclude (at a five percent risk of being in error) that the population does not have a two-parameter Weibull distribution. Otherwise, the hypothesis that the population has a two-parameter Weibull distribution is not rejected. For further information on these procedures, see reference 6.

2.1.9.3.3 Basis value calculations for the Weibull distribution

For the two-parameter Weibull distribution, the B-basis value is

$$B = \hat{q}e^{\left(-V/\hat{\beta}\sqrt{n}\right)}$$ **Equation 42**

where

$$\hat{q} = \hat{\alpha}\left(0.10536\right)^{1/\hat{\beta}}$$ **Equation 43**

To calculate the A-basis value, substitute the equation below for the equation above.

$$\hat{q} = \hat{\alpha}(0.01005)^{1/\beta}$$ **Equation 44**

V is the value in Table 2-1 when the sample size is less than 16. For sample sizes of 16 or larger, a numerical approximation to the V values is given in the two equations immediately below.

$$V_B \approx 3.803 + \exp\left[1.79 - 0.516\ln(n) + \frac{5.1}{n-1}\right]$$ **Equation 45**

$$V_A \approx 6.649 + \exp\left[2.55 - 0.526\ln(n) + \frac{4.76}{n}\right]$$ **Equation 46**

This approximation is accurate within 0.5% of the tabulated values for n greater than or equal to 16.

Weibull Dist. K Factors for N<16		
N	B-basis	A-basis
2	690.804	1284.895
3	47.318	88.011
4	19.836	36.895
5	13.145	24.45
6	10.392	19.329
7	8.937	16.623
8	8.047	14.967
9	7.449	13.855
10	6.711	12.573
11	6.477	12.093
12	6.286	11.701
13	6.127	11.375
14	5.992	11.098
15	5.875	10.861

Table 2-1: Weibull Distribution Basis Value Factors

2.1.9.4 Lognormal Distribution

A probability distribution for which the probability that an observation selected at random from this population falls between a and b $\left(0 < a < b < \infty\right)$ is given by the area under the normal distribution between ln(a) and ln(b).

The lognormal distribution is a positively skewed distribution that is simply related to the normal distribution. If something is lognormally distributed, then its logarithm is normally distributed. The natural (base e) logarithm is used.

2.1.9.4.1 Goodness-of-fit test for the Lognormal distribution

In order to test the goodness-of-fit of the lognormal distribution, take the logarithm of the data and perform the Anderson-Darling test for normality from Section 2.1.7. Using the natural logarithm, replace Equation 29 above with Equation 47 below:

$$z_{(i)} = \frac{\ln\left(x_{(i)}\right) - \bar{x}_L}{s_L}, \quad \text{for } i = 1, \ldots, n \qquad \textbf{Equation 47}$$

where $x_{(i)}$ is the i[th] smallest sample observation, $\bar{x}_L$ and s_L are the mean and standard deviation of the $\ln(x_i)$ values.

The Anderson-Darling statistic is then computed using Equation 30 above and the observed significance level (OSL) is computed using Equation 31 above. This OSL measures the probability of observing an Anderson-Darling statistic at least as extreme as the value calculated if in fact the data are a sample from a lognormal distribution. If OSL ≤ 0.05, one may conclude (at a five percent risk of being in error) that the population is not lognormally distributed. Otherwise, the hypothesis that the population is lognormally distributed is not rejected. For further information on these procedures, see reference 6.

2.1.9.4.2 Basis value calculations for the Lognormal distribution

If the data set is assumed to be from a population with a lognormal distribution, basis values are calculated using the equation above in section 2.1.3. However, the calculations are performed using the logarithms of the data rather than the original observations. The computed basis values are then transformed back to the original units by applying the inverse of the log transformation.

2.1.10 Non-parametric Basis Values

Non-parametric techniques do not assume any particularly underlying distribution for the population the sample comes from. It does require that the batches be similar enough to be grouped together, so the ADK test must have a positive result. While it can be used instead of assuming the normal, lognormal or Weibull distribution, it typically results in lower basis values. One of following two methods should be used, depending on the sample size.

2.1.10.1 Non-parametric Basis Values for large samples

The required sample sizes for this ranking method differ for A and B basis values. A sample size of at least 29 is needed for the B-basis value while a sample size of 299 is required for the A-basis.

To calculate a B-basis value for $n > 28$, the value of r is determined with the following formulas:

For B-basis values:

$$r_B = \frac{n}{10} - 1.645\sqrt{\frac{9n}{100}} + 0.23 \qquad \textbf{Equation 48}$$

For A-Basis values:

$$r_A = \frac{n}{100} - 1.645\sqrt{\frac{99n}{10,000}} + 0.29 + \frac{19.1}{n}$$ **Equation 49**

The formula for the A-basis values should be rounded to the nearest integer. This approximation is exact for most values and for a small percentage of values (less than 0.2%), the approximation errs by one rank on the conservative side.

The B-basis value is the r_B^{th} lowest observation in the data set, while the A-basis value is the r_A^{th} lowest observation in the data set. For example, in a sample of size n = 30, the lowest (r = 1) observation is the B-basis value. Further information on this procedure may be found in reference 7.

2.1.10.2 Non-parametric Basis Values for small samples

The Hanson-Koopmans method (references 8 and 9) is used for obtaining a B-basis value for sample sizes not exceeding 28 and A-basis values for sample sizes less than 299. This procedure requires the assumption that the observations are a random sample from a population for which the logarithm of the cumulative distribution function is concave, an assumption satisfied by a large class of probability distributions. There is substantial empirical evidence that suggests that composite strength data satisfies this assumption.

The Hanson-Koopmans B-basis value is:

$$B = x_{(r)}\left[\frac{x_{(1)}}{x_{(r)}}\right]^k$$ **Equation 50**

The A-basis value is:

$$A = x_{(n)}\left[\frac{x_{(1)}}{x_{(n)}}\right]^k$$ **Equation 51**

where $x_{(n)}$ is the largest data value, $x_{(1)}$ is the smallest, and $x_{(r)}$ is the r^{th} largest data value. The values of r and k depend on n and are listed in Table 2-2. This method is not used for the B-basis value when $x_{(r)} = x_{(1)}$.

The Hanson-Koopmans method can be used to calculate A-basis values for n less than 299. Find the value k_A corresponding to the sample size n in Table 2-3. For an A-basis value that meets all the requirements of CMH-17-1G, there must be at least five batches represented in the data and at least 55 data points. For a B-basis value, there must be at least three batches represented in the data and at least 18 data points.

B-Basis Hanson-Koopmans Table		
n	r	k
2	2	35.177
3	3	7.859
4	4	4.505
5	4	4.101
6	5	3.064
7	5	2.858
8	6	2.382
9	6	2.253
10	6	2.137
11	7	1.897
12	7	1.814
13	7	1.738
14	8	1.599
15	8	1.540
16	8	1.485
17	8	1.434
18	9	1.354
19	9	1.311
20	10	1.253
21	10	1.218
22	10	1.184
23	11	1.143
24	11	1.114
25	11	1.087
26	11	1.060
27	11	1.035
28	12	1.010

Table 2-2: B-Basis Hanson-Koopmans Table

A-Basis Hanson-Koopmans Table					
n	k	n	k	n	k
2	80.00380	38	1.79301	96	1.32324
3	16.91220	39	1.77546	98	1.31553
4	9.49579	40	1.75868	100	1.30806
5	6.89049	41	1.74260	105	1.29036
6	5.57681	42	1.72718	110	1.27392
7	4.78352	43	1.71239	115	1.25859
8	4.25011	44	1.69817	120	1.24425
9	3.86502	45	1.68449	125	1.23080
10	3.57267	46	1.67132	130	1.21814
11	3.34227	47	1.65862	135	1.20620
12	3.15540	48	1.64638	140	1.19491
13	3.00033	49	1.63456	145	1.18421
14	2.86924	50	1.62313	150	1.17406
15	2.75672	52	1.60139	155	1.16440
16	2.65889	54	1.58101	160	1.15519
17	2.57290	56	1.56184	165	1.14640
18	2.49660	58	1.54377	170	1.13801
19	2.42833	60	1.52670	175	1.12997
20	2.36683	62	1.51053	180	1.12226
21	2.31106	64	1.49520	185	1.11486
22	2.26020	66	1.48063	190	1.10776
23	2.21359	68	1.46675	195	1.10092
24	2.17067	70	1.45352	200	1.09434
25	2.13100	72	1.44089	205	1.08799
26	2.09419	74	1.42881	210	1.08187
27	2.05991	76	1.41724	215	1.07595
28	2.02790	78	1.40614	220	1.07024
29	1.99791	80	1.39549	225	1.06471
30	1.96975	82	1.38525	230	1.05935
31	1.94324	84	1.37541	235	1.05417
32	1.91822	86	1.36592	240	1.04914
33	1.89457	88	1.35678	245	1.04426
34	1.87215	90	1.34796	250	1.03952
35	1.85088	92	1.33944	275	1.01773
36	1.83065	94	1.33120	299	1.00000
37	1.81139				

Table 2-3: A-Basis Hanson-Koopmans Table

2.1.11 Analysis of Variance (ANOVA) Basis Values

ANOVA is used to compute basis values when the batch to batch variability of the data does not pass the ADK test. Since ANOVA makes the assumption that the different batches have equal variances, the data is checked to make sure the assumption is valid. Levene's test for equality of variance is used (see section 2.1.8). If the dataset fails Levene's test, the basis values computed are likely to be conservative. Thus this method can still be used but the values produced will be listed as estimates.

2.1.11.1 Calculation of basis values using ANOVA

The following calculations address batch-to-batch variability. In other words, the only grouping is due to batches and the k-sample Anderson-Darling test (Section 2.1.6) indicates that the batch to batch variability is too large to pool the data. The method is based on the one-way analysis of variance random-effects model, and the procedure is documented in reference 10.

ANOVA separates the total variation (called the sum of squares) of the data into two sources: between batch variation and within batch variation.

First, statistics are computed for each batch, which are indicated with a subscript $\left(n_i, \overline{x}_i, s_i^2\right)$ while statistics that were computed with the entire dataset do not have a subscript. Individual data values are represented with a double subscript, the first number indicated the batch and the second distinguishing between the individual data values within the batch. k stands for the number of batches in the analysis. With these statistics, the Sum of Squares Between batches (SSB) and the Total Sum of Squares (SST) are computed:

$$SSB = \sum_{i=1}^{k} n_i \overline{x}_I^2 - n\overline{x}^2 \qquad \textbf{Equation 52}$$

$$SST = \sum_{i=1}^{k} \sum_{j=1}^{n_i} x_{ij}^2 - n\overline{x}^2 \qquad \textbf{Equation 53}$$

The within-batch, or error, sum of squares (SSE) is computed by subtraction

$$SSE = SST - SSB \qquad \textbf{Equation 54}$$

Next, the mean sums of squares are computed:

$$MSB = \frac{SSB}{k-1} \qquad \textbf{Equation 55}$$

$$MSE = \frac{SSE}{n-k} \qquad \textbf{Equation 56}$$

Since the batches need not have equal numbers of specimens, an 'effective batch size,' is defined as

$$n' = \frac{n - \frac{1}{n}\sum_{i=1}^{k} n_i^2}{k-1} \qquad \textbf{Equation 57}$$

Using the two mean squares and the effective batch size, an estimate of the population standard deviation is computed:

$$S = \sqrt{\frac{MSB}{n'} + \left(\frac{n'-1}{n'}\right) MSE} \qquad \textbf{Equation 58}$$

Two k-factors are computed using the methodology of section 8.3.5 of CMH-17-1G using a sample size of n (denoted k_0) and a sample size of k (denoted k_1). Whether this value is an A- or B-basis value depends only on whether k_0 and k_1 are computed for A or B-basis values.

Denote the ratio of mean squares by

$$u = \frac{MSB}{MSE} \quad \text{Equation 59}$$

If u is less than one, it is set equal to one. The tolerance limit factor is

$$T = \frac{k_0 - \frac{k_1}{\sqrt{n'}} + \left(k_1 - k_0\right)\sqrt{\frac{u}{u + n' - 1}}}{1 - \frac{1}{\sqrt{n'}}} \quad \text{Equation 60}$$

The basis value is $\bar{x} - TS$.

The ANOVA method can produce extremely conservative basis values when a small number of batches are available. Therefore, when less than five (5) batches are available and the ANOVA method is used, the basis values produced will be listed as estimates.

2.2 Equivalence Tests

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."

2.2.1 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.

2.2.2 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.

2.2.2.1 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.

2.2.2.2 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%.

2.2.2.3 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.

2.2.2.4 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 2-4 and Table 2-5 according to the following formulas:

> The mean must exceed $\overline{X} - k_n \cdot S$ where $\overline{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample and k_n comes from Table 2-4.
>
> The sample minimum must exceed $\overline{X} - k_n \cdot S$ where $\overline{X}$ and S are, respectively, the mean and the standard deviation of the qualification sample and k_n comes fromnTable 2-5.

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 7.

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 2-4: 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 2-5: One-sided tolerance factors for limits on sample minimum values

2.2.2.5 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 = $$CV^* = \begin{cases} .06 & if\ CV < .04 \\ \dfrac{CV}{2} + .04 & if\ .04 \le CV < .08 \\ CV & if\ CV \ge .08 \end{cases}$$ **Equation 61**

This is converted to percent by multiplying by 100%.

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

$$S^* = CV^* \cdot \bar{X} \qquad \textbf{Equation 62}$$

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

$$S_p^* = \sqrt{\frac{\sum_{i=1}^{k}\left((n_i - 1)\left(CV_i^* \cdot \bar{X}_i\right)^2\right)}{\sum_{i=1}^{k}(n_i - 1)}} \qquad \textbf{Equation 63}$$

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. Summary of Results

The basis values for all tests are summarized in the following tables. The NCAMP recommended B-basis values meet all requirements of CMH-17-1G. However, not all test data meets those requirements. The summary tables provide a complete listing of all computed basis values and estimates of basis values. Data that does not meet the requirements of CMH-17-1G are shown in shaded boxes and labeled as estimates. Basis values computed with the modified coefficient of variation (CV) are presented whenever possible. Basis values and estimates computed without that modification are presented for all tests.

3.1 NCAMP Recommended B-basis Values

The following rules are used in determining what B-basis value, if any, is included in tables Table 3-1 of recommended values.

1. Recommended values are NEVER estimates. Only B-basis values that meet all requirements of CMH-17-1G are recommended.
2. Modified CV basis values are preferred. Recommended values will be the modified CV basis value when available. The CV provided with the recommended basis value will be the one used in the computation of the basis value.
3. Only normalized basis values are given for properties that are normalized.
4. ANOVA B-basis values are not recommended since only three batches of material are available and CMH-17-1G recommends that no less than five batches be used when computing basis values with the ANOVA method.
5. Basis values of 90% or more of the mean value imply that the CV is unusually low and may not be conservative. Caution is recommended with B-Basis values calculated from CMH-17 STATS when the B-basis value is 90% or more of the average value. Such values will be indicated.
6. If the data appear questionable (e.g. when the CTD-RTD-ETW trend of the basis values is not consistent with the CTD-RTD-ETW trend of the average values), then the B-basis values will not be recommended.

NCAMP Recommended B-basis Values for
Solvay 5320-1 T650 3k-PW fabric with 36% RC / FM300-2M 0.06psf Adhesive Film Repair
All B-basis values in this table meet the standards for publication in CMH-17G Handbook
Values are for normalized data unless otherwise noted

Laminate Strength and Ultimate Joint Running Force per Repair Ply

Environment	Statistic	UNC1 Norm [ksi]	UNCR50		UNCR30		CAI150		TR30			TR50		
			Strength [ksi] norm.	Joint Running Force per Repair Ply [lb/in/ply] as-meas.	Strength [ksi] norm.	Joint Running Force per Repair Ply [lb/in/ply] as-meas.	Strength [ksi] norm.	Joint Running Force per Repair Ply [lb/in/ply] as-meas.	Strength at Parent Laminate [ksi] norm.	Strength at Repair Laminate [ksi] norm.	Joint Running Force per Repair Ply [lb/in/ply] as-meas.	Strength at Parent Laminate [ksi] norm.	Strength at Repair Laminate [ksi] norm.	Joint Running Force per Repair Ply [lb/in/ply] as-meas.
CTD (-65°F)	B-basis	NA:A	77.95	600.2	NA:I	NA:I	31.53	242.8	NA:I	NA:I	NA:I	67.11	65.54	483.2
	Mean	90.59	87.15	671.1	90.04	693.3	34.92	268.9	74.21	73.64	546.8	76.83	75.15	553.3
	CV	5.954	7.610	7.610	6.207	6.207	6.000	6.000	7.482	6.895	6.617	6.678	6.870	6.803
RTD (70°F)	B-basis	71.26	73.53	566.2	NA:I	NA:I	28.94	222.8	NA:I	NA:I	NA:I	82.48	80.22	585.5
	Mean	79.76	82.74	637.1	82.49	635.2	32.32	248.9	90.61	89.11	656.9	92.19	89.83	655.6
	CV	6.126	6.000	6.000	6.681	6.681	6.110	6.110	3.425	3.206	2.409	6.000	6.000	6.000
ETW2 (180°F)	B-basis	58.30	55.68	428.8	NA:I	NA:I	25.61	197.2	NA:I	NA:I	NA:I	NA:A	NA:A	NA:A
	Mean	66.80	64.76	498.6	58.47	450.2	28.91	222.6	58.92	59.18	422.0	74.35	72.41	528.1
	CV	6.628	6.000	6.000	2.456	2.456	6.023	6.023	10.76	12.52	11.91	26.27	26.06	24.81

Notes: The modified CV B-basis value is recommended when available.
The CV provided corresponds with the B-basis value given.
NA implies that tests were run but data did not meet NCAMP recommended requirements.
"NA: A" indicates ANOVA with 3 batches, "NA: I" indicates insufficient data,

Table 3-1: NCAMP Recommended B-basis values for Strength and Ultimate Joint Running Force per Repair Ply Properties

Prepreg Material: Solvay 5320-1 T650 3k-PW fabric with 36% RC
Material Specification: NMS 532/6 (Solvay 5320-1 T650 3k-PW)
NMS 300/1 (FM300-2M 0.06psf)
Process Specification: NPS 85321 Baseline Cure Cycle (Parent)
NPS 80530R Baseline Cure Cycle (Repair)
Fabric: T650 3k PW **Resin:** Cycom 5320-1

Solvay 5320-1 T650 3k-PW fabric with 36% RC / FM300-2M 0.06psf Adhesive Film Repair

UNC1 Baseline
Tg(dry): 390.43°F **Tg(wet):** 320.95°F
Tg METHOD: DMA (ASTM D7028)

Scarf Ratio 50:1 (Tg(dry): / Tg(wet):)
Parent Section: 394.46°F 318.74°F
Repair Section: 384.96°F 311.46°F
Scarf Section, Adhesive: 289.84°F 226.04°F
Scarf Section, Laminate: 391.86°F 320.86°F

Scarf Ratio 30:1 (Tg(dry): / Tg(wet):)
Parent Section: 393.40°F 322.71°F
Repair Section: 381.75°F 316.11°F
Scarf Section, Adhesive: 287.64°F 228.93°F
Scarf Section, Laminate: 390.70°F 321.91°F

LAMINATE MECHANICAL PROPERTY B-BASIS SUMMARY
Normalizing by parent material $CPT_{5320\text{-}1\ 3k\text{-}PW}$=0.0077 in

Values shown in shaded boxes do not meet CMH-17G requirements and are estimates only**
These values may not be used for certification unless specifically allowed by the certifying agency

				CTD (-65°F)			RTD (70°F)			ETW2 (180°F)		
Test Type	**Scarf Ratio**	**Property**	**Normalization**	B-Basis	Modified CV B-basis	Mean	B-Basis	Modified CV B-basis	Mean	B-Basis	Modified CV B-basis	Mean
Unnotched Compression (UNC1) Baseline	NA	Strength [ksi]	As-Measured	53.76	NA	90.26	72.46	69.83	79.81	44.52	NA	66.57
			Normalized	58.29	NA	90.59	73.06	71.26	79.76	49.76	58.30	66.80
Compression After Impact (CAI150)	50:1	Strength [ksi]	As-Measured	28.71	29.74	33.01	25.16	27.04	30.31	24.25	24.32	27.50
			Normalized	32.69	31.53	34.92	28.09	28.94	32.32	25.52	25.61	28.91
		N_j [lb/in/ply]	As-Measured	251.7	242.8	268.9	216.3	222.8	248.9	196.5	197.2	222.6
Tensile Repair (TR50)	50:1	Strength at Parent Laminate [ksi]	As-Measured	66.07	62.94	72.03	79.14	76.02	85.10	NA	NA	68.57
			Normalized	70.16	67.11	76.83	85.53	82.48	92.19	NA	NA	74.35
		Strength at Repair Laminate [ksi]	As-Measured	61.97	61.40	70.46	79.35	73.87	82.92	NA	NA	66.79
			Normalized	68.82	65.54	75.15	83.50	80.22	89.83	NA	NA	72.41
		N_j [lb/in/ply]	As-Measured	492.1	483.2	553.3	624.1	585.5	655.6	NA	NA	528.1
		Modulus I [Msi] As-Measured	As-Measured	NA		6.958	NA		6.702	NA		6.577
			Normalized			7.422			7.261			7.122
		Modulus II [Msi] As-Measured	As-Measured	NA		6.921	NA		6.733	NA		6.634
			Normalized			7.382			7.295			7.184
Tensile Repair (TR30)	30:1*	Strength at Parent Laminate [ksi]	As-Measured	NA		70.03	NA		84.13	NA		54.17
			Normalized			74.21			90.61			58.92
		Strength at Repair Laminate [ksi]	As-Measured	NA		69.51	NA		82.74	NA		54.41
			Normalized			73.64			89.11			59.18
		N_j [lb/in/ply]	As-Measured	NA		546.8	NA		656.9	NA		422.0
		Modulus I [Msi]	As-Measured	NA		6.820	NA		6.737	NA		6.586
			Normalized			7.224			7.254			7.169
		Modulus II [Msi]	As-Measured	NA		6.866	NA		6.605	NA		6.672
			Normalized			7.273			7.114			7.264
Un-Notched Compression (UNCR50)	50:1	Strength [ksi]	As-Measured	71.43	74.12	82.80	62.72	68.94	77.62	50.75	52.39	60.94
			Normalized	78.04	77.95	87.15	73.62	73.53	82.74	59.96	55.68	64.76
		N_j [lb/in/ply]	As-Measured	600.9	600.2	671.1	566.9	566.2	637.1	461.7	428.8	498.6
Un-Notched Compression (UNCR30)	30:1*	Strength [ksi]	As-Measured	NA		85.65	NA		77.35	NA		54.25
			Normalized			90.04			82.49			58.47
		N_j [lb/in/ply]	As-Measured	NA		693.3	NA		635.2	NA		450.2

* No basis values available for 30:1 scarf ratio due to insufficient data
**CMH-17G requirements reguarding the minimum number of batches and specimens needed for the computed basis value to be published in the CMH-17 Handbook have not been met.

Table 3-2: Summary of Basis Value Results

A summary of the equivalency comparison results is given in Table 3-3. Equivalency comparisons were made between the UNC1 strength data and the UNCR50 and UNCR30 data; these are shown in sections 4.2 and 4.3 respectively. Equivalence of these datasets is not expected, they are provided for informational purposes only, and are not included in the summary table here or in section 5.

Equivalency Test Results for Solvay 5320-1 T650 3k-PW fabric with 36% RC / FM300-2M 0.06psf Adhesive Film Repair

				Condition		
Scarf Ratio	**Test Type**	**Data**	**Property**	**CTD (-65°F)**	**RTD (70°F)**	**ETW2 (180°F)**
30:1 compared with 50:1	Tensile Repair (TR30)	Normalized	F_p^{tu} [ksi]	Pass	Pass	Failed by 5.66%
			F_r^{tu} [ksi]	Pass	Pass	Failed by 2.86%
			Modulus I [Msi]	Pass with Mod CV	Pass	Pass
			Modulus II [Msi]	Pass with Mod CV	Pass with Mod CV	Pass
		As-Measured	N_j [lb/in/ply]	Pass	Pass	Failed by 5.86%
30:1 compared with 50:1	Un-Notched Compression (UNCR30)	Normalized	Strength [ksi]	Pass	Pass	Failed by 5.87%
		As-Measured	N_j [lb/in/ply]	Pass	Pass	Failed by 5.87%

Table 3-3: Summary of Equivalency Results

4. Individual Test Summaries, Statistics, Basis Values and Graphs

Test data for fiber dominated properties was normalized according to nominal cured ply thickness. Test failures, outliers and explanations regarding computational choices were noted in the accompanying text for each test.

All individual specimen results are graphed for each test by batch and environmental condition with a line indicating the recommended basis values for each environmental condition. The data is jittered (moved slightly to the left or right) in order for all specimen values to be clearly visible. The strength values are always graphed on the vertical axis with the scale adjusted to include all data values and their corresponding basis values. The vertical axis may not include zero. The horizontal axis values will vary depending on the data and how much overlapping there was of the data within and between batches. When there was little variation, the batches were graphed from left to right. The environmental conditions were identified by the shape and color of the symbol used to plot the data. Otherwise, the environmental conditions were graphed from left to right and the batches were identified by the shape and color of the symbol.

When a dataset fails the Anderson-Darling k-sample (ADK) test for batch-to-batch variation, an ANOVA analysis is required. In order for B-basis values to be computed using the ANOVA method, data from five batches are required. Since this qualification dataset has only three batches, the basis values computed using ANOVA are considered estimates only. However, the basis values resulting from the ANOVA method using only three batches may be overly conservative. The ADK test is performed again after a transformation of the data according to the assumptions of the modified CV method (see section 2.1.4 for details). If the dataset still passes the ADK test at this point, modified CV basis values are provided. If the dataset does not pass the ADK test after the transformation, estimates may be computed using the modified CV method per the guidelines of CMH-17-1G section 8.3.10.

4.1 Un-Notched Compression Baseline (UNC1)

The UNC1 data is normalized. Data is available only for strength. Test results are available from three environmental conditions, CTD, RTD and ETW2. These tests provide a baseline for equivalency comparison to the UNCR50 and UNCR30 test data presented in the next section.

The CTD and ETW2 conditions failed the Anderson Darling k-sample test (ADK test) for batch to batch variability, which means that pooling across environments was not acceptable and CMH-17-1G guidelines required using the ANOVA analysis. With fewer than five batches, these are considered estimates. The CTD datasets, both normalized and as-measured, and the as-measured ETW2 dataset did not pass the ADK test after they were transformed according to the assumptions of the modified CV method, so modified CV basis values could not be provided for those datasets. The normalized ETW2 dataset did pass the ADK test after applying the modified CV transformation and the RTD and ETW2 normalized datasets met all requirements for pooling to compute the modified CV basis values.

There were no statistical outliers.

Statistics, estimates and basis values are given for the UNC1 strength data in Table 4-1. The normalized specimen strength data, B-estimates and B-basis values are shown graphically in Figure 4-1.

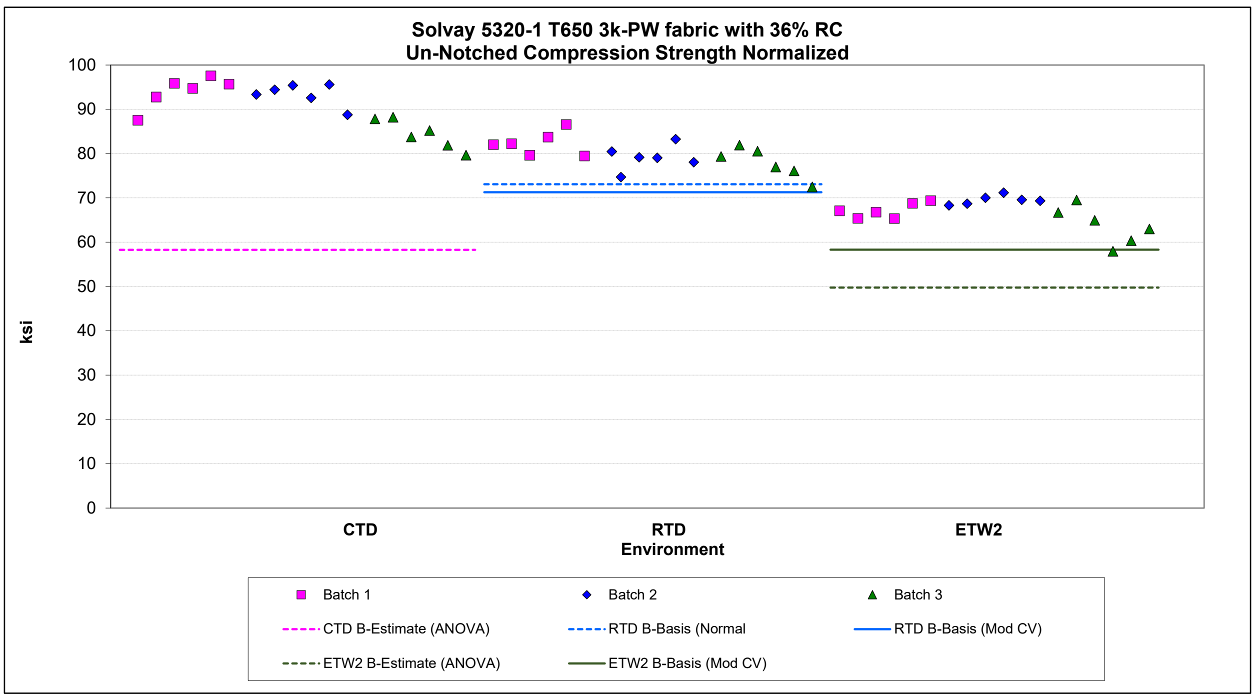

Figure 4-1: Batch plot for UNC1 Strength

Un-Notched Compression (UNC1) Strength Basis Values and Statistics [ksi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	90.59	79.76	66.80	90.26	79.81	66.57
Stdev	5.394	3.391	3.511	6.006	3.719	4.086
CV	5.954	4.252	5.257	6.654	4.660	6.138
Mod CV	6.977	6.126	6.628	7.327	6.330	7.069
Min	79.66	72.46	57.96	78.02	71.14	56.62
Max	97.52	86.57	71.19	97.39	86.39	71.82
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and Estimates						
B-Basis Value		73.06			72.46	
B-Estimate	58.29		49.76	53.76		44.52
A-Estimate	35.24	68.32	37.61	27.72	67.26	28.79
Method	ANOVA	Normal	ANOVA	ANOVA	Normal	ANOVA
Modified CV Basis Values and Estimates						
B-Basis Value	NA	71.26	58.30	NA	69.83	NA
A-Estimate		65.49	52.53		62.78	
Method		pooled	pooled		Normal	

Table 4-1: Statistics and Basis values for UNC1 Strength Data

4.2 Un-Notched Compression Repair with scarf ratio of 50:1 (UNCR50)

The UNCR50 data was normalized with parent material CPT. Data is available for the Ultimate Joint Running Force per Repair Ply (as-measured only) and Strength both normalized and as-measured. Test results are available for three environmental conditions, CTD, RTD and ETW2. Basis values and estimates are computed for each condition. Equivalency tests were made comparing the UNCR50 data to the UNC1 data presented in the previous section.

The as-measured RTD and ETW2 conditions for Strength properties failed the Anderson Darling k-sample test (ADK test) for batch to batch variability, which means that pooling across environments was not acceptable and CMH-17-1G guidelines required using the ANOVA analysis. With fewer than five batches, these are considered estimates. Both datasets passed the ADK test after they were transformed according to the assumptions of the modified CV method, so modified CV basis values could be provided. The normal distribution could be used for the as-measured CTA dataset and for all three conditions for Ultimate Joint Running Force per Repair Ply and normalized Strength dataset. Pooling was acceptable for the CTA & RTA conditions for the normalized Strength data and the Ultimate Joint Running Force data. Pooling was acceptable for all three conditions for Strength (both normalized and as-measured) and Ultimate Joint Running Force per Repair Ply with the use of the modified CV basis value computations.

There was one statistical outlier. The lowest value in batch one of the as-measured ETW2 Strength dataset was an outlier for batch one, but not for the ETW2 condition and not for the normalized dataset. It was retained for this analysis.

Statistics, estimates and basis values are given for the UNCR50 strength data in Table 4-2 and for the Ultimate Joint Running Force per Repair Ply data in Table 4-3. The normalized specimen Strength data, B-estimates and the B-basis values are shown graphically in Figure 4-2 and for the as-measured Ultimate Joint Running Force per Repair Ply data in Figure 4-3.

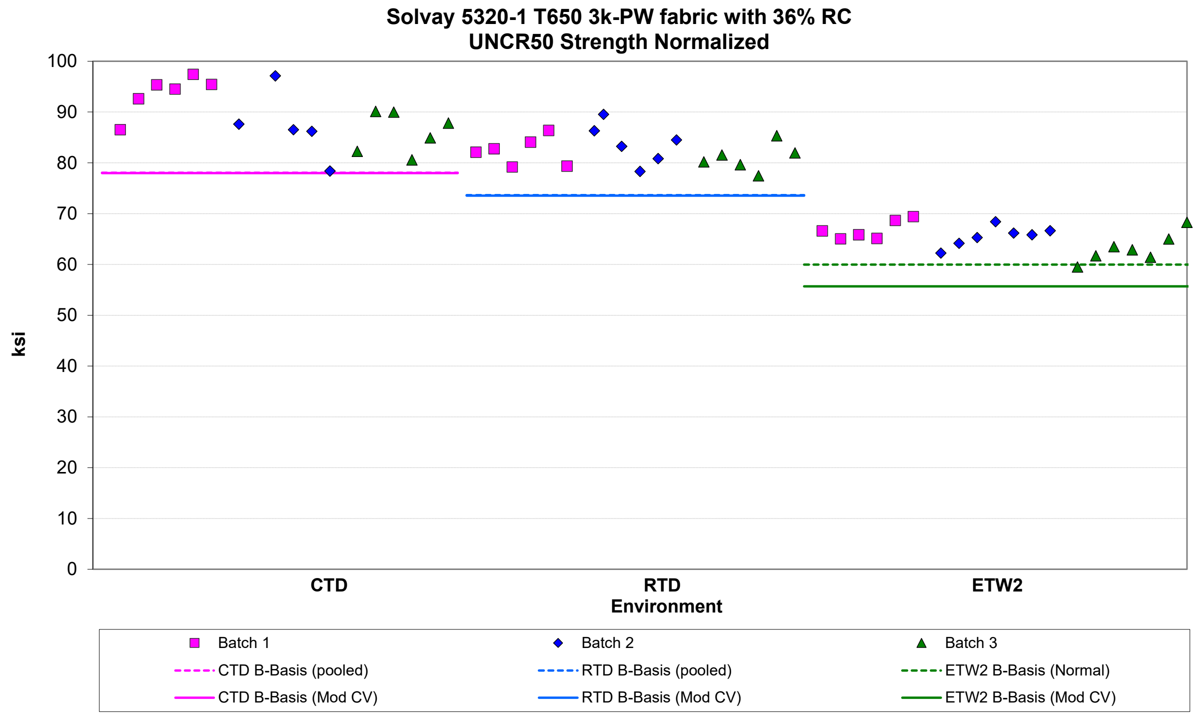

Figure 4-2: Batch Plot for UNCR50 Strength Normalized

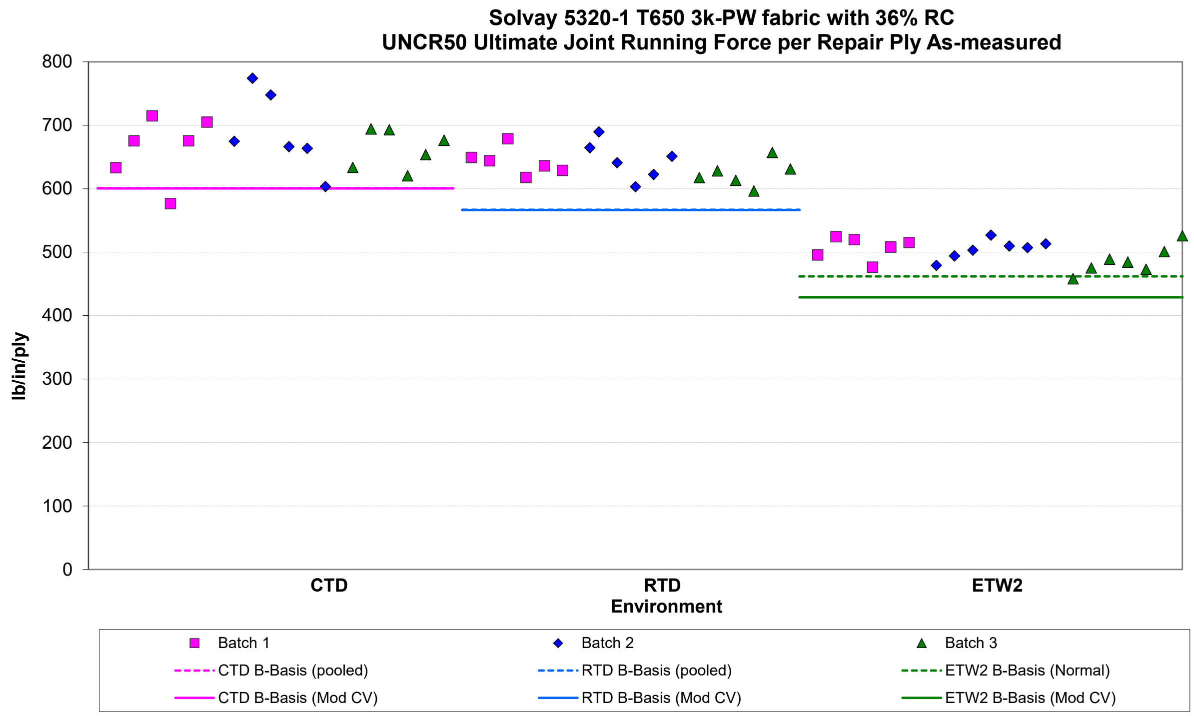

Figure 4-3: Batch Plot for UNCR50 Ultimate Joint Running Force per Repair Ply As-measured

Un-Notched Compression Repair (UNCR50) Strength Basis Values and Statistics [ksi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	87.15	82.74	64.76	82.80	77.62	60.94
Stdev	6.293	3.237	2.516	5.761	3.319	2.336
CV	7.220	3.913	3.885	6.957	4.276	3.833
Mod CV	7.610	6.000	6.000	7.479	6.138	6.000
Min	74.86	77.46	59.50	72.62	71.14	56.28
Max	100.50	89.53	68.40	95.93	83.84	64.94
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	21	18	18	21
Basis Values and Estimates						
B-Basis Value	78.04	73.62	59.96	71.43		
B-Estimate					62.72	50.75
A-Estimate	71.84	67.42	56.55	63.37	52.10	43.48
Method	pooled	pooled	Normal	Normal	ANOVA	ANOVA
Modified CV Basis Values and Estimates						
B-Basis Value	77.95	73.53	55.68	74.12	68.94	52.39
A-Estimate	71.82	67.41	49.53	68.35	63.17	46.59
Method	pooled	pooled	pooled	pooled	pooled	pooled

Table 4-2: Statistics and Basis Values for UNCR50 Strength Data

Un-Notched Compression Repair (UNCR50) Ultimate Joint Running Force per Repair Ply Basis Values and Statistics [lb/in/ply]			
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	671.1	637.1	498.6
Stdev	48.45	24.93	19.37
CV	7.220	3.913	3.885
Mod CV	7.610	6.000	6.000
Min	576.4	596.4	458.2
Max	773.9	689.4	526.7
No. Batches	3	3	3
No. Spec.	18	18	21
Basis Values and Estimates			
B-Basis Value	600.9	566.9	461.7
A-Estimate	553.2	519.2	435.4
Method	pooled	pooled	Normal
Modified CV Basis Values and Estimates			
B-Basis Value	600.2	566.2	428.8
A-Estimate	553.0	519.1	381.4
Method	pooled	pooled	pooled

Table 4-3: Statistics and Basis Values for UNCR50 Ultimate Joint Running Force per Repair Ply As-measured Data

The equivalency test results for the UNC1 normalized strength datasets with the corresponding data from the UNCR50 normalized strength test results are shown in Table 4-4. The CTD and ETW2 repair results were significantly lower than the UNC1 results. The RTD repair results passed the equivalency test for the normalized dataset.

Unnotched Compression Strength	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	UNC1	UNCR50	UNC1	UNCR50	UNC1	UNCR50
Data normalized with Parent Material CPT 0.0077						
Mean Strength (ksi)	90.59	87.15	79.76	82.74	66.80	64.76
Standard Deviation	5.394	6.293	3.391	3.237	3.511	2.516
Coefficient of Variation %	5.954	7.220	4.252	3.913	5.257	3.885
Minimum	79.66	74.86	72.46	77.46	57.96	59.50
Maximum	97.52	100.50	86.57	89.53	71.19	68.40
Number of Specimens	18	18	18	18	18	21
RESULTS	FLAG		PASS		FLAG	
Minimum Acceptable Equiv. Sample Mean	88.13		78.21		65.31	
Minimum Acceptable Equiv. Sample Min	74.57		69.69		56.20	
MOD CV RESULTS	FLAG		PASS with MOD		FLAG	
Modified CV%	6.977		6.126		6.628	
Minimum Acceptable Equiv. Sample Mean	87.71		77.53		64.93	
Minimum Acceptable Equiv. Sample Min	71.82		65.25		53.43	

Table 4-4: Equivalency Comparison of UNC1 with UNCR50 Strength Normalized Data

The UNCR50 strength data for the CTD environment failed the equivalency test due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The UNCR50 sample mean (87.15) is 98.89% of the minimum acceptable mean value (88.13). Under the assumption of the modified CV method, the UNCR50 sample mean is 99.37% of the minimum acceptable mean value (87.71).

The UNCR50 strength data for the ETW2 environment failed the equivalency test due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The UNCR50 sample mean (64.76) is 99.15% of the minimum acceptable mean value (65.31). Under the assumption of the modified CV method, the UNCR50 sample mean is 99.74% of the minimum acceptable mean value (64.93).

Figure 4-4 illustrates the Un-Notched Compression normalized strength means and minimum values for the UNC1 sample and the UNCR50 sample. The limits for equivalency are shown as error bars with the UNC1 data. The longer, lighter colored error bars are for the modified CV computations.

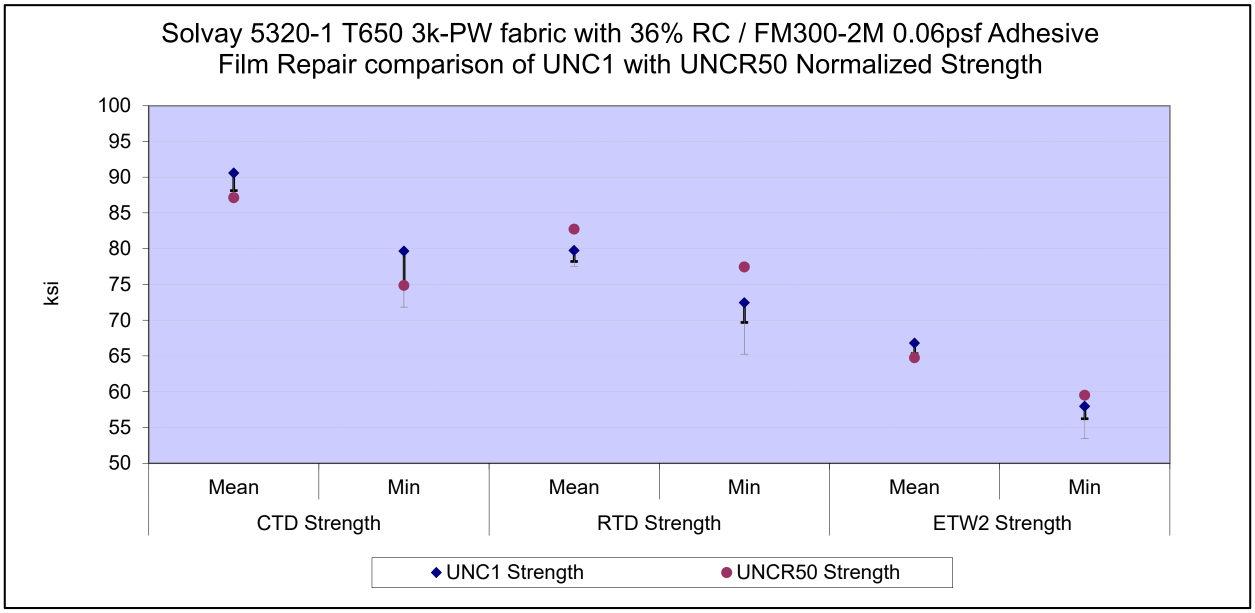

Figure 4-4: UNC1 and UNCR50 Strength means, minimums and Equivalence limits

4.3 Un-Notched Compression Repair with scarf ratio of 30:1 (UNCR30)

The UNCR30 data was normalized with parent material CPT. Data is available for the Ultimate Joint Running Force per Repair Ply (as-measured only) and Strength (normalized and as-measured). Test results are available from three environmental conditions, CTD, RTD and ETW2. Equivalency tests were made comparing the UNCR30 strength data to both the UNC1 data and the UNCR50 data and the Ultimate Joint Running Force per Repair Ply to the UNCR50 data. Equivalency results were consistently low for the UNCR30 data for all comparisons of the ETW2 condition.

The equivalency test results for the UNC1 normalized Strength datasets with the corresponding data from the UNCR30 normalized Strength test results are shown in Table 4-5. The equivalency test results comparing the UNCR50 normalized datasets with the corresponding data from the UNCR30 normalized test results are shown for strength in Table 4-6 and for the Ultimate Joint Running Force per Repair Ply results in Table 4-7.

Unnotched Compression Strength	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	UNC1	UNCR30	UNC1	UNCR30	UNC1	UNCR30
Data normalized with Parent Material CPT 0.0077						
Mean Strength (ksi)	90.59	90.04	79.76	82.49	66.80	58.47
Standard Deviation	5.394	5.589	3.391	5.512	3.511	1.436
Coefficient of Variation %	5.954	6.207	4.252	6.681	5.257	2.456
Minimum	79.66	82.95	72.46	75.21	57.96	56.41
Maximum	97.52	98.69	86.57	90.25	71.19	60.17
Number of Specimens	18	8	18	8	18	8
RESULTS	**PASS**		**PASS**		**FLAG**	
Minimum Acceptable Equiv. Sample Mean	86.93		77.45		64.41	
Minimum Acceptable Equiv. Sample Min	76.03		70.60		57.32	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FLAG**	
Modified CV %	6.977		6.126		6.628	
Minimum Acceptable Equiv. Sample Mean	86.30		76.44		63.79	
Minimum Acceptable Equiv. Sample Min	73.52		66.56		54.84	

Table 4-5: Equivalency Comparison of UNC1 with UNCR30 Strength Normalized Data

Unnotched Compression Strength	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	UNCR50	UNCR30	UNCR50	UNCR30	UNCR50	UNCR30
Data normalized with Parent Material CPT 0.0077						
Mean Strength (ksi)	87.15	90.04	82.74	82.49	64.76	58.47
Standard Deviation	6.293	5.589	3.237	5.512	2.516	1.436
Coefficient of Variation %	7.220	6.207	3.913	6.681	3.885	2.456
Minimum	74.86	82.95	77.46	75.21	59.50	56.41
Maximum	100.50	98.69	89.53	90.25	68.40	60.17
Number of Specimens	18	8	18	8	21	8
RESULTS	**PASS**		**PASS**		**FLAG**	
Minimum Acceptable Equiv. Sample Mean	82.88		80.54		63.05	
Minimum Acceptable Equiv. Sample Min	70.16		74.00		57.96	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**FLAG**	
Modified CV %	7.610		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	82.65		79.37		62.12	
Minimum Acceptable Equiv. Sample Min	69.25		69.34		54.27	

Table 4-6: Equivalency Comparison of UNCR50 with UNCR30 Strength Normalized Data

Un-Notched Compression Repair Ultimate Joint Running Force per Repair Ply	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	UNCR50	UNCR30	UNCR50	UNCR30	UNCR50	UNCR30
Mean (lb/in/ply)	671.1	693.3	637.1	635.2	498.6	450.2
Standard Deviation	48.45	43.03	24.93	42.44	19.37	11.06
Coefficient of Variation %	7.220	6.207	3.913	6.681	3.885	2.456
Minimum	576.4	638.7	596.4	579.1	458.2	434.4
Maximum	773.9	759.9	689.4	694.9	526.7	463.3
Number of Specimens	18	8	18	8	21	8
RESULTS	**PASS**		**PASS**		**FLAG**	
Minimum Acceptable Equiv. Sample Mean	638.2		620.2		485.5	
Minimum Acceptable Equiv. Sample Min	540.3		569.8		446.3	
MOD CV RESULTS	**PASS with MOD**		**PASS with MOD**		**FLAG**	
Modified CV%	7.610		6.000		6.000	
Minimum Acceptable Equiv. Sample Mean	636.4		611.1		478.3	
Minimum Acceptable Equiv. Sample Min	533.2		533.9		417.8	

Table 4-7: Equivalency Comparison of UNCR50 with UNCR30 Ultimate Joint Running Force per Repair Ply As-measured Data

The UNCR30 strength data for the ETW2 environment failed the equivalency test with the UNC1 data due to the both the sample mean and sample minimum being below the acceptance limit. The UNCR30 sample mean (58.47) is 90.77% of the minimum acceptable mean value (64.41). The UNCR30 sample minimum (56.41) is 98.42% of the acceptable sample minimum value (57.32). Under the assumption of the modified CV method, the UNCR30 sample mean is 91.66% of the minimum acceptable mean value (63.79) while the sample minimum was acceptable.

The UNCR30 strength data for the ETW2 environment failed the equivalency test with the UNCR50 data due to both the sample mean and the sample minimum being below the acceptance limit. The UNCR30 sample mean (58.47) is 92.74% of the minimum acceptable mean value (63.05). The UNCR30 sample minimum (56.41) is 97.32% of the minimum acceptable minimum value (57.96). Under the assumption of the modified CV method, the UNCR30 sample mean is 94.13% of the minimum acceptable mean value (62.12) while the sample minimum was acceptable.

The UNCR30 Ultimate Joint Running Force per Repair Ply data for the ETW2 environment failed the equivalency test with the UNCR50 data due to both the sample mean and the sample minimum being below the acceptance limit. The UNCR30 sample mean (450.2) is 92.74% of the minimum acceptable mean value (485.5). The UNCR30 sample minimum (434.4) is 97.32% of the minimum acceptable minimum value (446.3). Under the assumption of the modified CV method, the UNCR30 sample mean is 94.13% of the minimum acceptable mean value (478.3) while the sample minimum was acceptable.

Figure 4-5 illustrates the Un-Notched Compression strength means and minimum values for the UNC1 sample and the UNCR30 sample. The limits for equivalency are shown as error bars with the UNC1 data. The longer, lighter colored error bars are for the modified CV computations.

Figure 4-6 illustrates the Un-Notched Compression strength means and minimum values for the UNCR50 sample and the UNCR30 sample. Figure 4-7 illustrates the Un-Notched Compression Ultimate Joint Running Force per Repair Ply means and minimum values for the UNCR50 sample and the UNCR30 sample. The limits for equivalency are shown as error bars with the UNCR50 data. The longer, lighter colored error bars are for the modified CV computations.

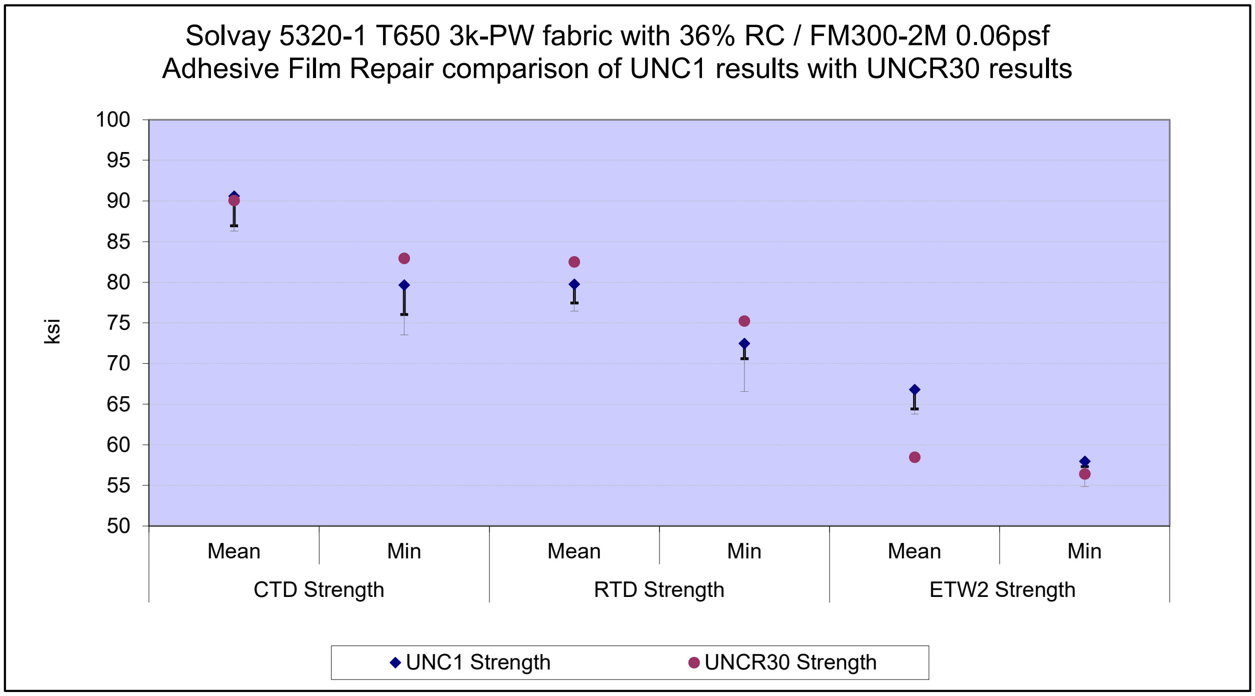

Figure 4-5: UNC1 and UNCR30 Strength means, minimums and Equivalence Limits

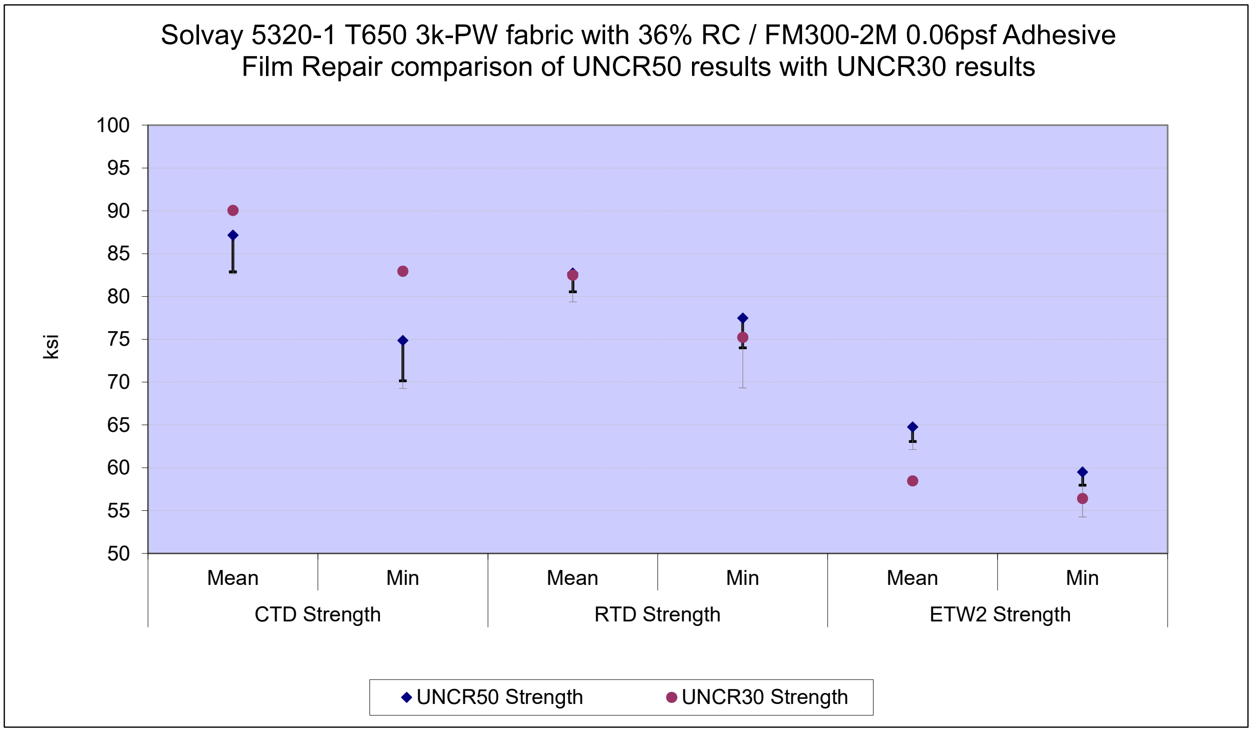

Figure 4-6: UNCR50 and UNCR30 Strength means, minimums and Equivalence Limits

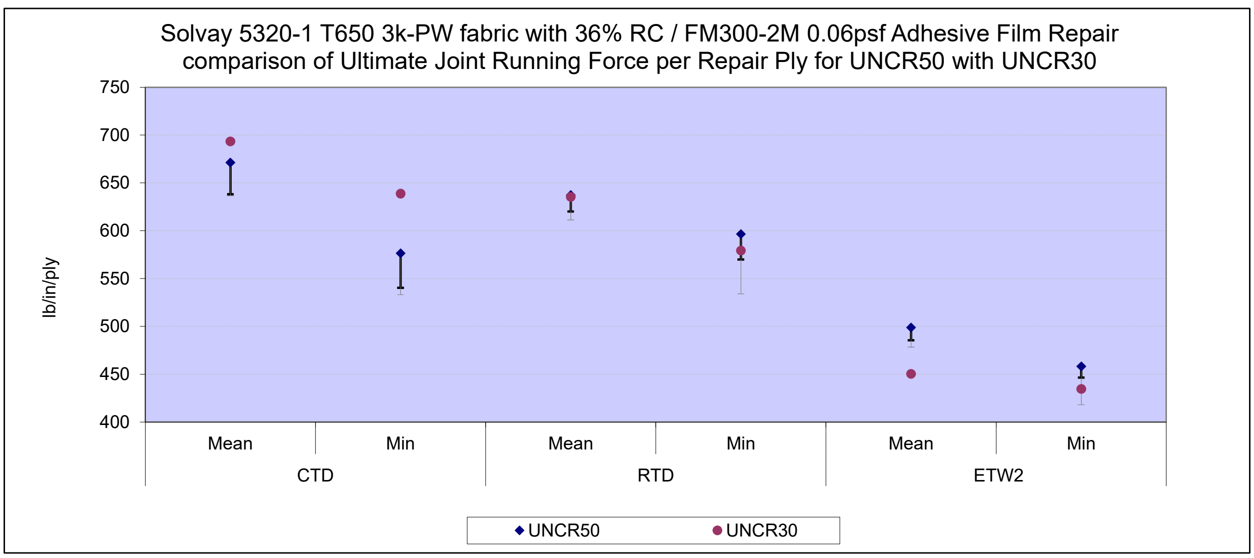

Figure 4-7: UNCR50 and UNCR30 Ultimate Joint Running Force per Repair Ply means, minimums and Equivalence Limits

4.4 Tension Repair with Scarf Ratio of 50:1 (TR50)

The TR50 data was normalized with parent material CPT. Data is available for Strength at Parent Laminate (normalized and as-measured), Strength at Repair Laminate (normalized and as-measured), Ultimate Joint Running Force per Repair Ply (as-measured only), Modulus I (normalized and as-measured) and Modulus II (normalized and as-measured). Test results are available from three environmental conditions, CTD, RTD and ETW2. Basis values and estimates are computed for each condition for the strength and force properties but not for the modulus. Equivalency tests comparing the TR50 data to the TR30 data are presented in the next section.

The ETW2 condition datasets all failed the Anderson Darling k-sample test (ADK test) for batch to batch variability, which means that pooling across environments was not acceptable and CMH-17-1G guidelines required using the ANOVA analysis. With fewer than five batches, these would be considered estimates, but for these datasets, there were no computed basis values above zero. None of the ETW2 datasets passed the ADK test after the datasets were transformed according to the assumptions of the modified CV method, so modified CV basis values could not be provided.

The Strength at Parent Laminate CTD and RTD datasets, both normalized and as-measured, and the normalized Strength at Repair Laminate met all requirements for pooling. The Strength at Repair Laminate as-measured datasets failed the normality test and Levene's test for pooling, but passed them after the datasets were transformed according to the assumptions of the modified CV method, so pooling was acceptable for computing the modified CV basis values. The Ultimate Joint Running Force per Repair Ply failed the normality test for pooling, but passed after the datasets were transformed according to the assumptions of the modified CV method, so pooling was acceptable for computing the modified CV basis values.

There were two statistical outliers. The lowest value in batch three for the CTD condition was an outlier for both the Strength at Parent Laminate (CTD condition only, normalized and as-measured) and the Strength at Repair Laminate (Batch three only, as-measured only). The lowest value in batch two of the RTD condition was an outlier for Modulus I, both batch two and the RTD condition for the as-measured data, batch two only for the normalized data. Both outliers were retained for this analysis.

Statistics, basis values and estimates are given for the TR50 Strength at Parent Laminate and at Repair Laminate data in Table 4-8, for the TR50 Ultimate Joint Running Force per Repair Ply data in Table 4-10, and for the TR50 Modulus I and Modulus II data in Table 4-11. The normalized specimen Strength data, B-estimates and B-basis values are shown graphically for the TR50 strength data in Figure 4-8 and for the as-measured Ultimate Joint Running Force per Repair Ply data in Figure 4-9.

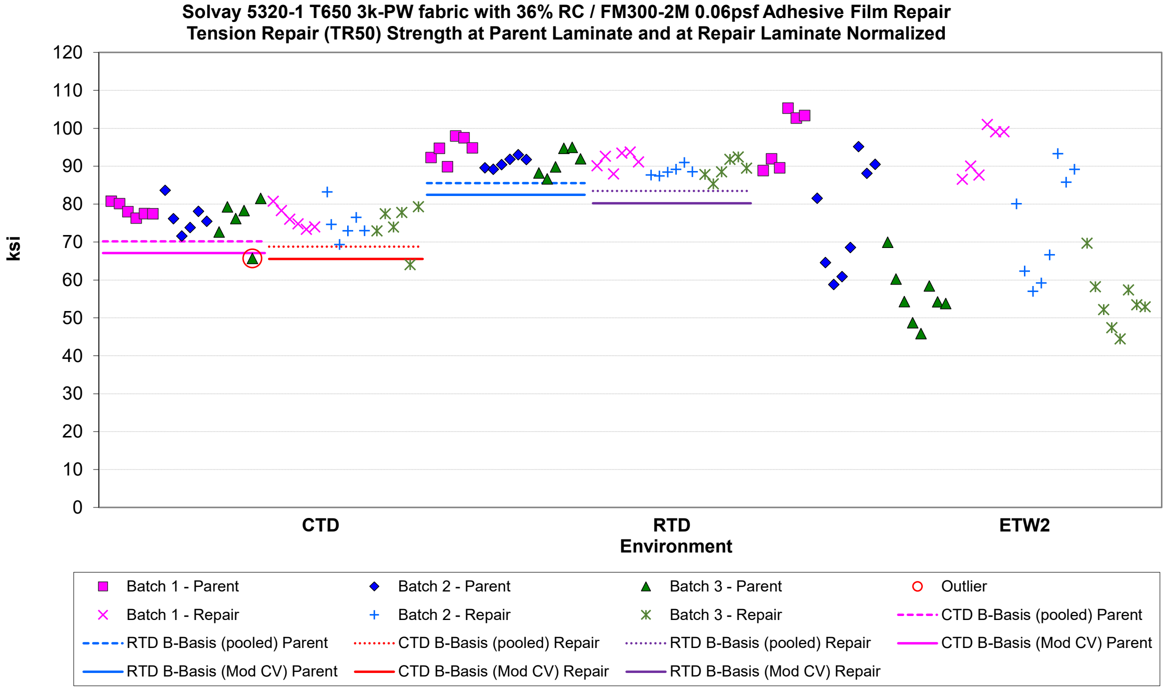

Figure 4-8: Batch plot for TR50 Strength at Parent Laminate and Strength at Repair Laminate Normalized

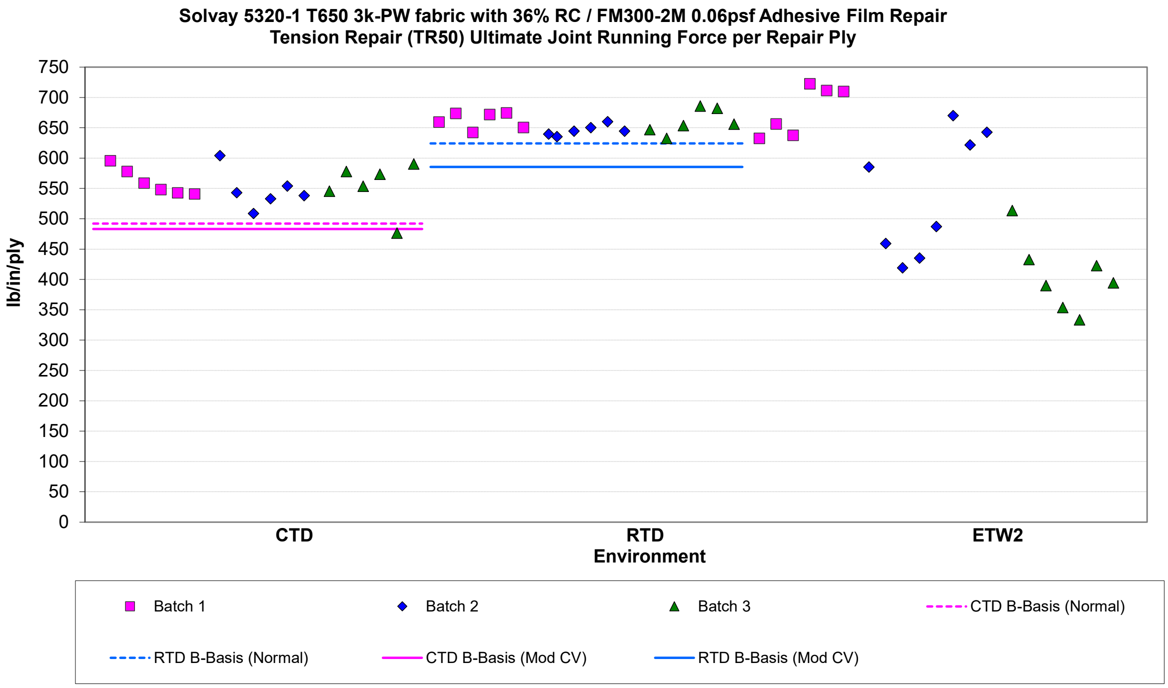

Figure 4-9: Batch plot for TR50 Ultimate Joint Running Force per Repair Ply As-measured

Tension Repair (TR50) Strength at Parent Laminate Basis Values and Statistics [ksi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	76.83	92.19	74.35	72.03	85.10	68.57
Stdev	4.115	3.136	19.53	3.962	2.383	17.61
CV	5.356	3.402	26.27	5.501	2.800	25.68
Mod CV	6.678	6.000	26.27	6.750	6.000	25.68
Min	65.70	86.64	45.88	61.32	80.61	42.82
Max	83.67	97.99	105.3	78.64	88.82	95.50
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	22	18	18	22
Basis Values and Estimates						
B-Basis Value	70.16	85.53	NA	66.07	79.14	NA
A-Estimate	65.63	81.00		62.02	75.09	
Method	pooled	pooled		pooled	pooled	
Modified CV Basis Values and Estimates						
B-Basis Value	67.11	82.48	NA	62.94	76.02	NA
A-Estimate	60.50	75.87		56.77	69.84	
Method	pooled	pooled		pooled	pooled	

Table 4-8: Statistics and Basis Values for TR50 Strength at Parent Laminate Data

Tension Repair (TR50) Strength at Repair Laminate Basis Values and Statistics [ksi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	75.15	89.83	72.41	70.46	82.92	66.79
Stdev	4.313	2.358	18.87	4.299	1.811	17.03
CV	5.740	2.625	26.06	6.101	2.184	25.50
Mod CV	6.870	6.000	26.06	7.050	6.000	25.50
Min	64.04	85.35	44.46	59.77	79.41	41.49
Max	83.23	93.79	101.0	78.22	85.65	91.59
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	22	18	18	22
Basis Values and Estimates						
B-Basis Value	68.82	83.50	NA	61.97	79.35	NA
A-Estimate	64.51	79.19		55.96	76.81	
Method	pooled	pooled		Normal	Normal	
Modified CV Basis Values and Estimates						
B-Basis Value	65.54	80.22	NA	61.40	73.87	NA
A-Estimate	59.00	73.68		55.24	67.71	
Method	pooled	pooled		pooled	pooled	

Table 4-9: Statistics and Basis Values for TR50 Strength at Repair Laminate Data

Tension Repair (TR50) Ultimate Joint Running Force per Repair Ply Basis Values and Statistics [lb/in/ply]			
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	553.3	655.6	528.1
Stdev	31.01	15.95	131.0
CV	5.605	2.433	24.81
Mod CV	6.803	6.000	24.81
Min	476.5	632.6	333.3
Max	603.8	685.6	722.6
No. Batches	3	3	3
No. Spec.	18	18	22
Basis Values and Estimates			
B-Basis Value	492.1	624.1	NA
B-Estimate	448.7	601.8	
A-Estimate	Normal	Normal	
Modified CV Basis Values and Estimates			
B-Basis Value	483.2	585.5	NA
A-Estimate	435.5	537.8	
Method	pooled	pooled	

Table 4-10: Statistics and Basis Values for TR50 Ultimate Joint Running Force per Repair Ply As-measured Data

Tension Repair (TR50) Modulus I Statistics [Msi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	7.422	7.261	7.122	6.958	6.702	6.577
Stdev	0.1668	0.1920	0.1270	0.1647	0.1528	0.0890
CV	2.247	2.645	1.783	2.368	2.280	1.353
Mod CV	6.000	6.000	6.000	6.000	6.000	6.000
Min	7.190	6.781	6.963	6.696	6.284	6.427
Max	7.625	7.597	7.358	7.261	6.958	6.747
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	22	18	18	22

Table 4-11: Statistics from TR50 Modulus I Data

Tension Repair (TR50) Modulus II Statistics [Msi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	7.382	7.295	7.184	6.921	6.733	6.634
Stdev	0.1077	0.1805	0.1463	0.1306	0.1745	0.1005
CV	1.458	2.474	2.036	1.888	2.592	1.514
Mod CV	6.000	6.000	6.000	6.000	6.000	6.000
Min	7.158	7.009	6.924	6.680	6.499	6.443
Max	7.540	7.574	7.456	7.192	7.051	6.805
No. Batches	3	3	3	3	3	3
No. Spec.	18	17	22	18	17	22

Table 4-12: Statistics from TR50 Modulus II Data

4.5 Tension Repair with Scarf Ratio of 30:1 (TR30)

The TR30 data was normalized with parent material CPT. Data is available for Strength at Parent Laminate (normalized and as-measured), Strength at Repair Laminate (normalized and as-measured), Ultimate Joint Running Force per Repair Ply (as-measured only), Modulus I (normalized and as-measured) and Modulus II (normalized and as-measured). Test results are available from three environmental conditions, CTD, RTD and ETW2. Equivalency tests were made comparing the TR30 data to the TR50 data for all five properties.

The three strength and force properties failed equivalency tests for the ETW2 condition, but passed for the CTD and RTD conditions. There is no modified CV computation for the ETW2 condition because the CV for that condition was above 8%, so no modification is made. The Modulus I CTD and the Modulus II CTD and RTD properties required the use of the modified CV method to pass equivalency.

The equivalency test results for the TR30 results compared with the TR50 results are shown for the Strength at Parent Laminate normalized in Table 4-13, for the Strength at Repair Laminate normalized in Table 4-14, for Ultimate Joint Running Force per Repair Ply as-measured in Table 4-15, for Modulus I normalized in Table 4-16, and for Modulus II normalized in Table 4-17.

Tension Repair Strength at Parent Laminate	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	TR50	TR30	TR50	TR30	TR50	TR30
Data normalized with Parent Material CPT 0.0077						
Mean Strength (ksi)	76.83	74.21	92.19	90.61	74.35	58.92
Standard Deviation	4.115	5.552	3.136	3.104	19.53	6.337
Coefficient of Variation %	5.356	7.482	3.402	3.425	26.27	10.76
Minimum	65.70	65.89	86.64	86.48	45.88	51.06
Maximum	83.67	83.33	97.99	94.72	105.34	70.44
Number of Specimens	18	8	18	8	22	10
RESULTS	PASS		PASS		FLAG	
Minimum Acceptable Equiv. Sample Mean	74.03		90.06		62.46	
Minimum Acceptable Equiv. Sample Min	65.72		83.73		20.10	
MOD CV RESULTS	PASS with MOD CV		PASS with MOD CV		NA	
Modified CV%	6.678		6.000			
Minimum Acceptable Equiv. Sample Mean	73.34		88.44			
Minimum Acceptable Equiv. Sample Min	62.98		77.26			

Table 4-13: Equivalency Comparison of TR30 with TR50 Strength at Parent Laminate Normalized Data

Tension Repair Strength at Repair Laminate	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	TR50	TR30	TR50	TR30	TR50	TR30
Data normalized with Parent Material CPT 0.0077						
Mean Strength (ksi)	75.15	73.64	89.83	89.11	72.41	59.18
Standard Deviation	4.313	5.077	2.358	2.857	18.87	7.408
Coefficient of Variation %	5.740	6.895	2.625	3.206	26.06	12.52
Minimum	64.04	66.11	85.35	84.69	44.46	50.32
Maximum	83.23	81.62	93.79	92.66	101.02	71.38
Number of Specimens	18	8	18	8	22	10
RESULTS	**PASS**		**PASS**		**FLAG**	
Minimum Acceptable Equiv. Sample Mean	72.22		88.23		60.92	
Minimum Acceptable Equiv. Sample Min	63.50		83.46		20.00	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**NA**	
Modified CV%	6.870		6.000			
Minimum Acceptable Equiv. Sample Mean	71.64		86.17			
Minimum Acceptable Equiv. Sample Min	61.21		75.28			

Table 4-14: Equivalency Comparison of TR30 with TR50 Strength at Repair Laminate Normalized Data

Tension Repair Ultimate Joint Running Force per Repair Ply	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	TR50	TR30	TR50	TR30	TR50	TR30
Data as measured						
Mean (lb/in/ply)	553.3	546.8	655.6	656.9	528.1	422.0
Standard Deviation	31.01	36.18	15.95	15.82	131.0	50.25
Coefficient of Variation %	5.605	6.617	2.433	2.409	24.81	11.91
Minimum	476.5	487.2	632.6	631.9	333.3	360.7
Maximum	603.8	598.2	685.6	679.7	722.6	509.5
Number of Specimens	18	8	18	8	22	10
RESULTS	**PASS**		**PASS**		**FLAG**	
Minimum Acceptable Equiv. Sample Mean	532.3		644.8		448.3	
Minimum Acceptable Equiv. Sample Min	469.6		612.6		164.2	
MOD CV RESULTS	**PASS with MOD**		**PASS with MOD**		**NA**	
Modified CV%	6.803		6.000			
Minimum Acceptable Equiv. Sample Mean	527.8		628.9			
Minimum Acceptable Equiv. Sample Min	451.7		549.4			

Table 4-15: Equivalency Comparison of TR30 with TR50 Ultimate Joint Running Force per Repair Ply As-measured Data

Tension Repair Modulus I	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	TR50	TR30	TR50	TR30	TR50	TR30
Data normalized with Parent Material CPT 0.0077						
Mean Modulus (Msi)	7.422	7.224	7.261	7.254	7.122	7.169
Standard Deviation	0.167	0.178	0.192	0.162	0.127	0.105
Coefficient of Variation %	2.247	2.461	2.645	2.232	1.783	1.463
Minimum	7.190	7.019	6.781	7.041	6.963	6.979
Maximum	7.625	7.487	7.597	7.565	7.358	7.286
Number of Specimens	18	8	18	8	22	10
RESULTS	**FLAG**		**PASS**		**PASS**	
Passing Range for Modulus Mean	7.273 to 7.571		7.099 to 7.422		7.028 to 7.216	
Student's t-statistic	-2.743		-0.084		1.019	
p-value of Student's t-statistic	0.011		0.934		0.316	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Passing Range for Modulus Mean	7.083 to 7.761		6.930 to 7.591		6.840 to 7.404	
Modified CV Student's t-statistic	-1.206		-0.041		0.340	
p-value of Student's t-statistic	0.240		0.968		0.736	

Table 4-16: Equivalency Comparison of TR30 with TR50 Modulus I Normalized Data

Tension Repair Modulus II	CTD (−65˚F)		RTD (70˚F)		ETW2 (180˚F)	
	TR50	TR30	TR50	TR30	TR50	TR30
Data normalized with Parent Material CPT 0.0077						
Mean Modulus (Msi)	7.382	7.273	7.295	7.114	7.184	7.264
Standard Deviation	0.108	0.136	0.181	0.230	0.146	0.077
Coefficient of Variation %	1.458	1.876	2.474	3.237	2.036	1.065
Minimum	7.158	7.089	7.009	6.849	6.924	7.125
Maximum	7.540	7.452	7.574	7.557	7.456	7.383
Number of Specimens	18	8	17	8	22	10
RESULTS	**FLAG**		**FLAG**		**PASS**	
Passing Range for Modulus Mean	7.280 to 7.485		7.120 to 7.470		7.083 to 7.285	
Student's t-statistic	-2.206		-2.148		1.607	
p-value of Student's t-statistic	0.037		0.042		0.119	
MOD CV RESULTS	**PASS with MOD CV**		**PASS with MOD CV**		**PASS with MOD CV**	
Modified CV%	6.000		6.000		6.000	
Passing Range for Modulus Mean	7.049 to 7.716		6.952 to 7.638		6.901 to 7.467	
Modified CV Student's t-statistic	-0.678		-1.095		0.573	
p-value of Student's t-statistic	0.504		0.285		0.571	

Table 4-17: Equivalency Comparison of TR30 with TR50 Modulus II Normalized Data

The TR30 Strength at Parent Laminate data for the ETW2 environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The TR30 sample mean (58.92) is 94.34% of the minimum acceptable mean value (62.46). The modified CV method is not applicable due to the coefficient of variation for the TR50 sample being above 8%.

The TR30 Strength at Repair Laminate data for the ETW2 environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The TR30 sample mean (59.18) is 97.14% of the minimum acceptable mean value (60.92). The modified CV method is not applicable due to the coefficient of variation for the TR50 sample being above 8%.

The TR30 Ultimate Joint Running Force per Repair Ply data for the ETW2 environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The sample minimum value is acceptable. The TR30 sample mean (422.0) is 94.14% of the minimum acceptable mean value (448.3). The modified CV method is not applicable due to the coefficient of variation for the TR50 sample being above 8%.

The TR30 Modulus I data for the CTD environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The TR30 sample mean (7.224) is 99.93% of the minimum acceptable mean value (7.273). With the use of modified CV method, the sample mean is acceptable.

The TR30 Modulus II data for the CTD environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The TR30 sample mean (7.273) is 99.90% of the minimum acceptable mean value (7.280). With the use of modified CV method, the sample mean is acceptable.

The TR30 Modulus II data for the RTD environment failed the equivalency test with the TR50 data due to the sample mean being below the acceptance limit. The TR30 sample mean (7.114) is 99.91% of the minimum acceptable mean value (7.120). With the use of modified CV method, the sample mean is acceptable.

Figure 4-10 illustrates the Tension Repair Strength at Parent and at Repair Laminate means and minimum values for the TR50 sample and the TR30 sample. Figure 4-11 illustrates the Tension Repair Ultimate Joint Running Force per Repair Ply means and minimum values for the TR50 sample and the TR30 sample. Figure 4-12 illustrates the Tension Repair Modulus I and Modulus II mean values for the TR50 sample and the TR30 sample. The limits for equivalency are shown as error bars with the TR50 data. The longer, lighter colored error bars are for the modified CV computations.

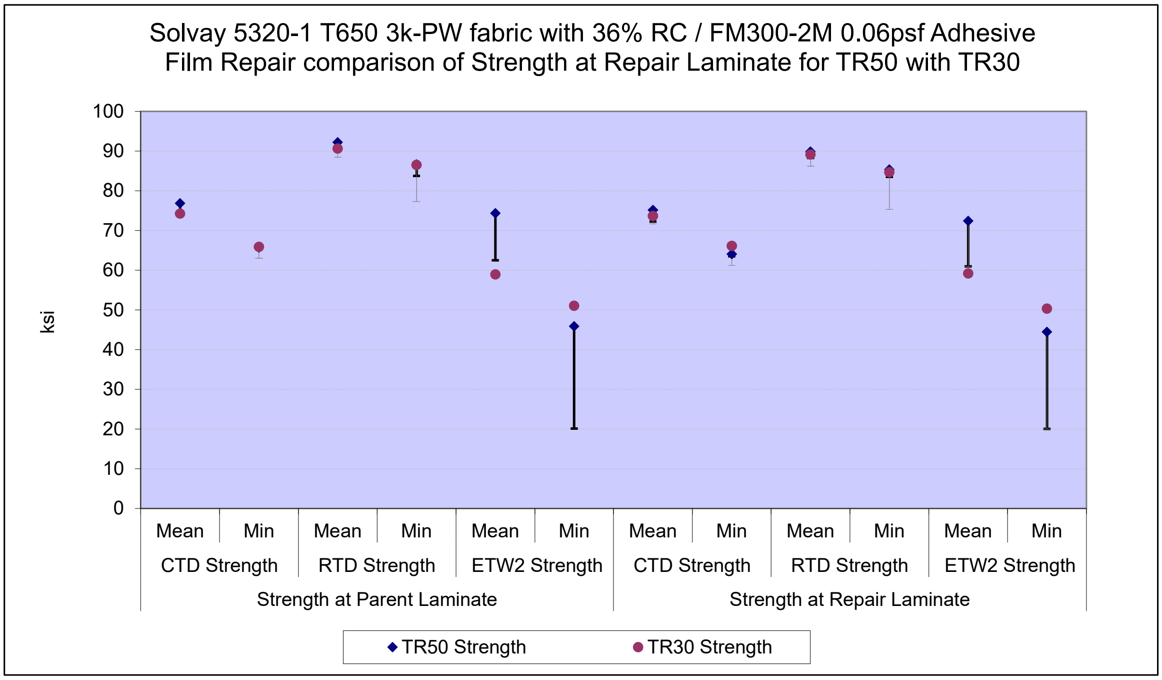

Figure 4-10: TR30 with TR50 normalized Strength at Parent and Repair Laminate means, minimums and Equivalence limits

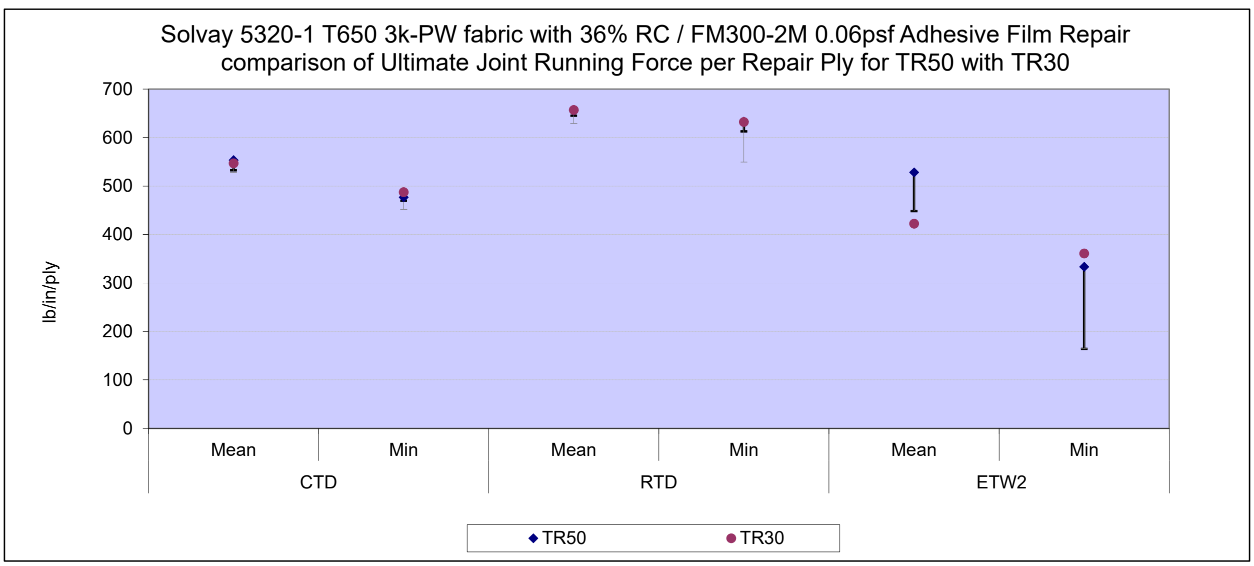

Figure 4-11: TR30 with TR50 Joint Running Force as-measured per Repair Ply means, minimums and Equivalence limits

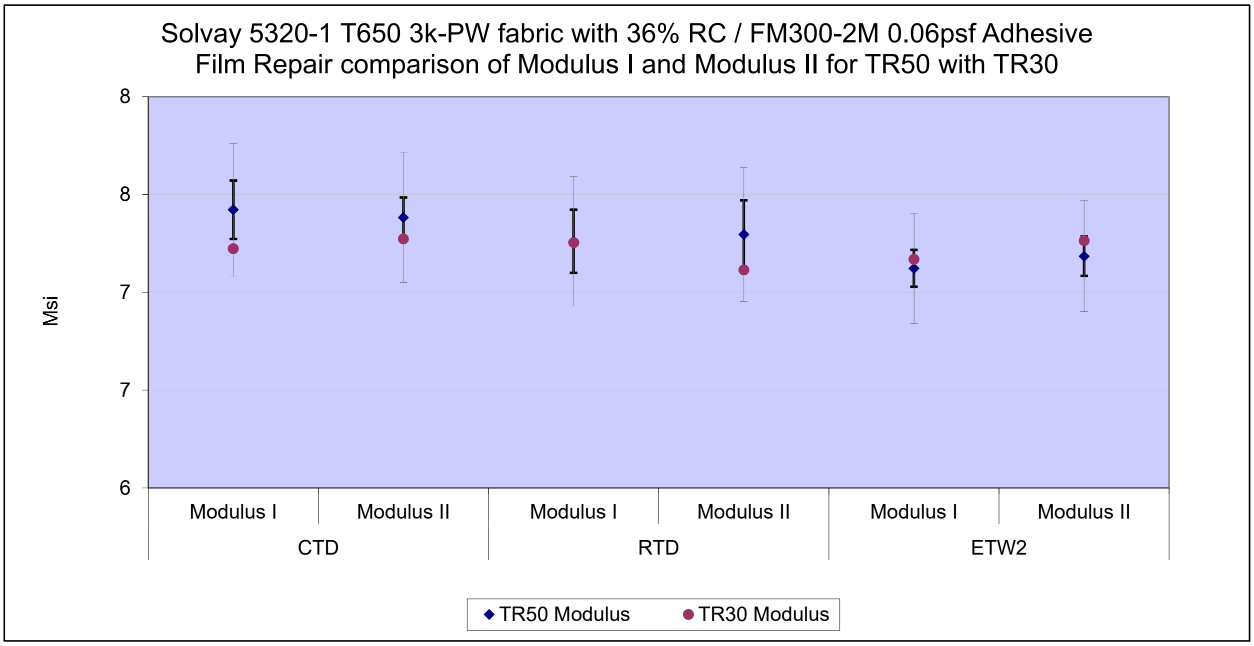

Figure 4-12: TR30 with TR50 Modulus I and Modulus II normalized means and Equivalence limits

4.6 Compression After Impact Repair with Scarf Ratio of 50:1 (CAI150)

The CAI150 data was normalized with parent material CPT. Data is available for Strength (normalized and as-measured) and Ultimate Joint Running Force per Repair Ply (as-measured only). Test results are available from three environmental conditions, CTD, RTD and ETW2. Basis values and estimates are computed for each condition.

While the CTD normalized strength data and as-measured Ultimate Joint Running Force per Repair Ply data passed the Anderson Darling k-sample test (ADK test) for batch to batch variability, the other datasets did not. The datasets that failed this diagnostic test meant that pooling across environments was not acceptable and CMH-17-1G guidelines required using the ANOVA analysis. With fewer than five batches, these are considered estimates. All datasets passed the ADK test after the data was transformed according to the assumptions of the modified CV method, so modified CV basis values could be provided. Pooling was acceptable for the modified CV basis value computations.

There was one statistical outlier. The lowest value in batch two of the ETW2 as-measured Strength dataset was an outlier for batch two, but not for the ETW2 condition and not for the normalized dataset. It was retained for this analysis.

Statistics, basis values and estimates are given for the CAI150 strength data in Table 4-18. The normalized specimen Strength data, B-estimates and B-basis values are shown graphically in for Strength in Figure 4-13 and for Ultimate Joint Running Force per Repair Ply in Figure 4-14: Batch Plot for CAI150 Ultimate Joint Running Force per Repair Ply As-measured.

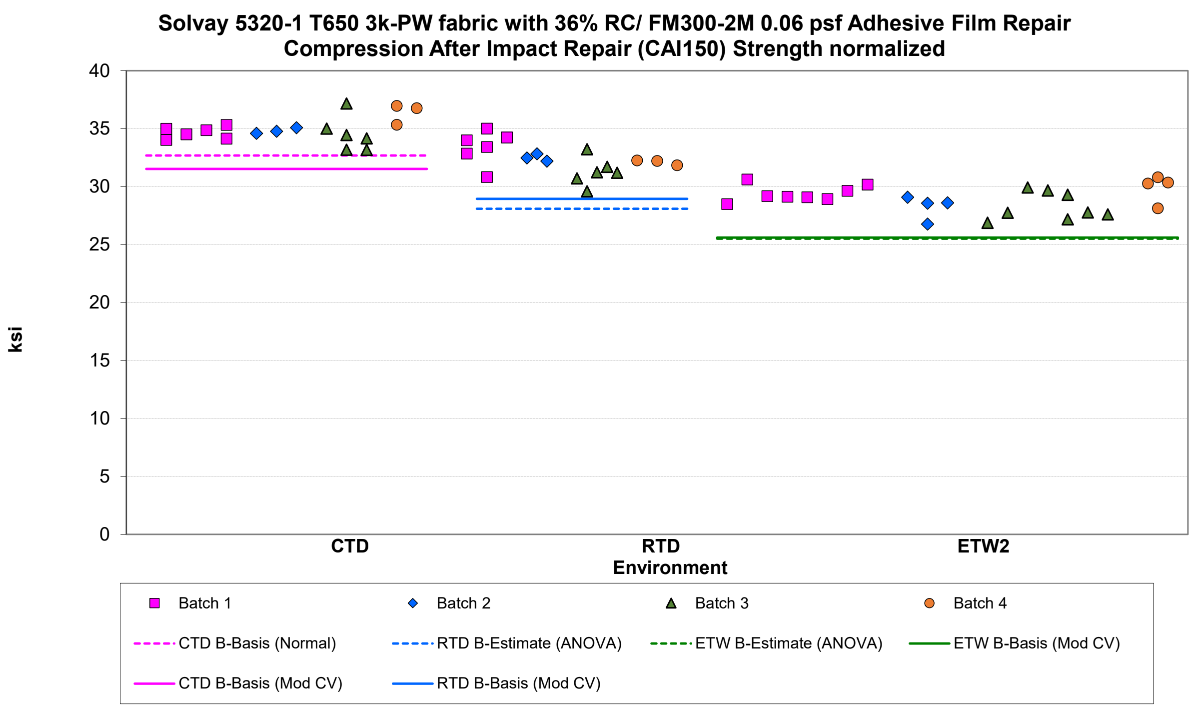

Figure 4-13: Batch Plot for CAI150 Strength normalized

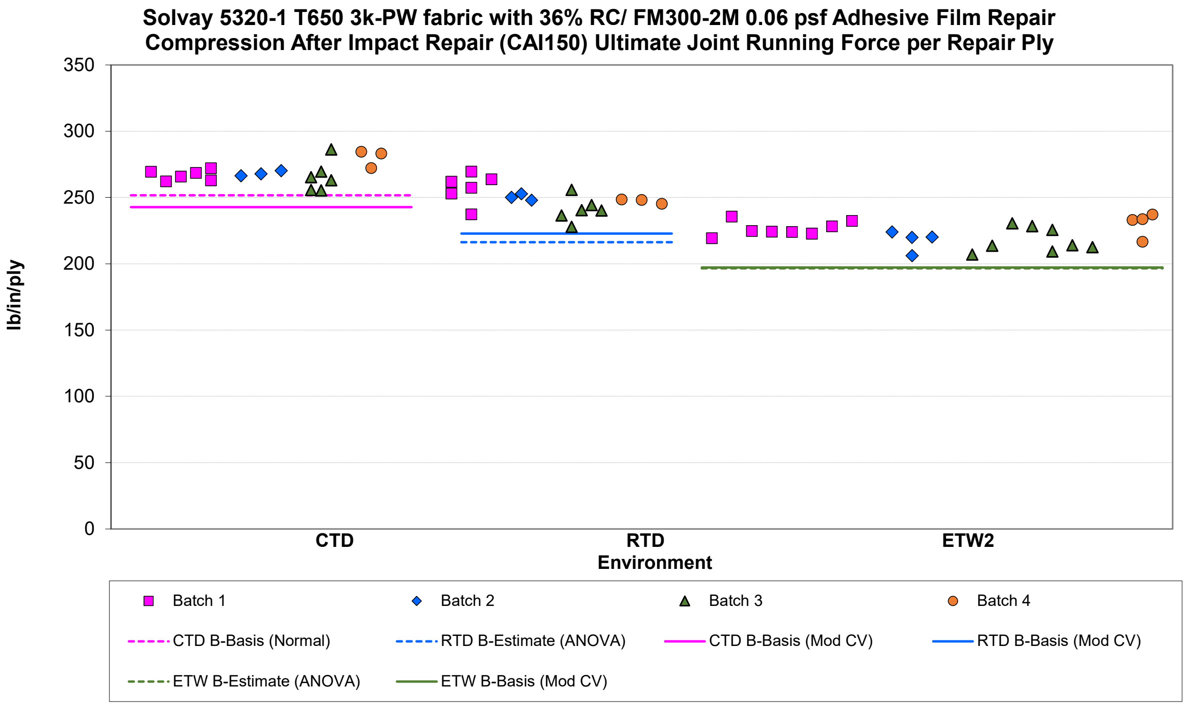

Figure 4-14: Batch Plot for CAI150 Ultimate Joint Running Force per Repair Ply As-measured

Compression After Impact Repair (CAI150) Strength Basis Values and Statistics [ksi]						
	Normalized			As-measured		
Env	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)	CTD (−65˚F)	RTD (70˚F)	ETW2 (180˚F)
Mean	34.92	32.32	28.91	33.01	30.31	27.50
Stdev	1.126	1.364	1.170	1.333	1.539	1.080
CV	3.225	4.221	4.046	4.039	5.079	3.927
Mod CV	6.000	6.110	6.023	6.019	6.539	6.000
Min	33.16	29.58	26.76	30.99	27.40	25.55
Max	37.18	34.99	30.81	36.15	33.36	30.01
No. Batches	4	4	4	4	4	4
No. Spec.	18	18	24	18	18	24
Basis Values and Estimates						
B-Basis Value	32.69					
B-Estimate		28.09	25.52	28.71	25.16	24.25
A-Estimate	31.12	25.14	23.15	25.71	21.57	21.97
Method	Normal	ANOVA	ANOVA	ANOVA	ANOVA	ANOVA
Modified CV Basis Values and Estimates						
B-Basis Value	31.53	28.94	25.61	29.74	27.04	24.32
A-Estimate	29.29	26.69	23.35	27.58	24.87	22.13
Method	pooled	pooled	pooled	pooled	pooled	pooled

Table 4-18: Statistics and Basis Values for CAI150 Strength Data

Compression After Impact Repair (CAI150) Ultimate Joint Running Force per Repair Ply Basis Values and Statistics [lb/in/ply]			
	As-measured		
Env	CTD (−65°F)	RTD (70°F)	ETW2 (180°F)
Mean	268.9	248.9	222.6
Stdev	8.672	10.503	9.006
CV	3.225	4.221	4.046
Mod CV	6.000	6.110	6.023
Min	255.3	227.8	206.1
Max	286.3	269.4	237.2
No. Batches	4	4	4
No. Spec.	18	18	24
Basis Values and Estimates			
B-Basis Value	251.7		
B-Estimate		216.3	196.5
A-Estimate	239.6	193.6	178.3
Method	Normal	ANOVA	ANOVA
Modified CV Basis Values and Estimates			
B-Basis Value	242.8	222.8	197.2
A-Estimate	225.5	205.5	179.8
Method	pooled	pooled	pooled

Table 4-19: Statistics and Basis Values for CAI150 Joint Running Force per Repair Ply As-measured Data

5. Summary of Equivalency Test 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.

There were a total of 21 different tests of equivalence run with sufficient data according to the recommendations of CMH-17-1G. 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 5-1.

Failures in Table 5-1 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.
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. Table 5-2 gives a rough scale for the relative severity of those failures.

Equivalency Test Results for Solvay 5320-1 T650 3k-PW fabric with 36% RC / FM300-2M 0.06psf Adhesive Film Repair						
				Condition		
Scarf Ratio	Test Type	Data	Property	CTD (-65°F)	RTD (70°F)	ETW2 (180°F)
30:1 compared with 50:1	Tensile Repair (TR30)	Normalized	F_p^{tu} [ksi]	Pass	Pass	Failed by 5.66%
			F_r^{tu} [ksi]	Pass	Pass	Failed by 2.86%
			Modulus I [Msi]	Pass with Mod CV	Pass	Pass
			Modulus II [Msi]	Pass with Mod CV	Pass with Mod CV	Pass
		As-Measured	N_j [lb/in/ply]	Pass	Pass	Failed by 5.86%
30:1 compared with 50:1	Un-Notched Compression (UNCR30)	Normalized	Strength [ksi]	Pass	Pass	Failed by 5.87%
		As-Measured	N_j [lb/in/ply]	Pass	Pass	Failed by 5.87%

Table 5-1: Summary of Equivalency Test Results

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

Table 5-2: "% Failed" Results Scale

5.1 The assumption of Independence

The following computations are based on the assumption that the tests are independent. While the tests are all conducted independently, measurements for strength and modulus are made from a single specimen. For the Tension Repair tests, five different property measurements are made on a single specimen. The different property measurements may not be independent of one another on the same specimen. However the computations can be considered conservative as the probability of failures occurring together should be higher than predicted with the assumption of independence, thus leading to a conservative overall judgment about the material.

5.2 Failures

The FAA Laminate Repair Study material has sufficient test results for comparison on a total of 21 different test types and conditions.

Using the modified CV method, there were five failures.

1. Strength at Parent Laminate Tensile Repair (TR30) compared with Tensile Repair (TR50) for the ETW2 condition failed by 5.66%
2. Strength at Repair Laminate Tensile Repair (TR30) compared with Tensile Repair (TR50) for the ETW2 condition failed by 2.86%
3. Ultimate Joint Running Force per Repair Ply Tensile Repair (TR30) compared with Tensile Repair (TR50) for the ETW2 condition failed by 5.86%
4. Un-Notched Compression Strength Repair (UNCR30) compared with Un-Notched Compression Strength Repair (UNCR50) for the ETW2 condition failed by 5.87%
5. Un-Notched Compression Ultimate Joint Running Force per Repair Ply (UNCR30) compared with Un-Notched Compression Ultimate Joint Running Force per Repair Ply (UNCR50) for the ETW2 condition failed by 5.87%

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.

5.3 Pass Rate

Five failures out of 21 tests and conditions gives the equivalency panels for the FAA Laminate Repair Study a pass rate of 76.19% 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 1.05 failures.

5.4 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 five or more failures is 0.32%. Figure 5-1 illustrates the probability of getting one or more failures, two or more failures, etc. for a set of 21 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 21independent tests.

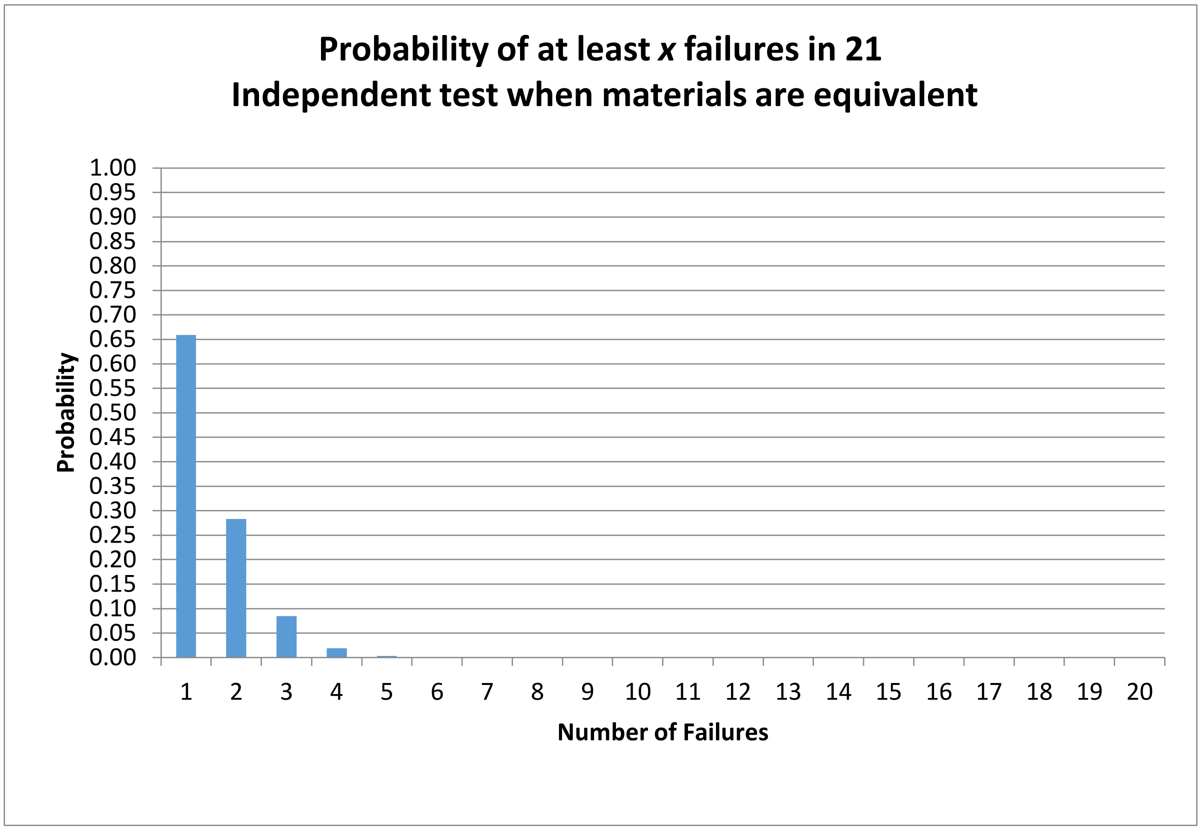

Figure 5-1: Probability of Number of Failures

6. Outliers

Approximately 5 out of 100 specimens will be identified as outliers due to the expected random variation of the data. This test is used only to identify specimens to be investigated for a cause of the extreme observation. Outliers that have an identifiable cause are removed from the dataset as they inject bias into the computation of statistics and basis values. Specimens that are outliers for the condition and in both the normalized and as-measured data are typically more extreme and more likely to have a specific cause and be removed from the dataset than other outliers. Specimens that are outliers only for the batch, but not the condition and specimens that are identified as outliers only for the normalized data or the as-measured data but not both, are typical of normal random variation.

All outliers identified were investigated to determine if a cause could be found. Outliers with causes were removed from the dataset and the remaining specimens were analyzed for this report. Information about specimens that were removed from the dataset along with the cause for removal is documented in the material property data report, NCAMP Test Report CAM-RP-2018-056.

Outliers for which no causes could be identified are listed in Table 6-1. These outliers were included in the analysis for their respective test properties.

Test	Condition	Batch	Specimen Number	Property	Normalized Specimen Value	As Measured Specimen Value	High/ Low	Batch Outlier	Condition Outlier
CAI150	ETW	2	NTP5325QR1-SOL-S36-NIAR-CAI150-B-C1-4-ETW-1	Strength	Not an Outlier	25.554	Low	Yes	No
TR50	CTD	3	NTP5325QR1-SOL-S36-NIAR-TR50-C-C4-1-CTD-2	Strength at Parent Laminate	65.70	61.321	Low	No	Yes
				Strength at Repair Laminate	Not an Outlier	59.770	Low	Yes	No
TR50	RTD	2	NTP5325QR1-SOL-S36-NIAR-TR50-B-C3-1-RTD-2	Modulus I	6.78	6.28	Low	Yes	Yes - as meas No - norm
UNCR50	ETW	1	NTP5325QR1-SOL-S36-NIAR-UNCR50-A-C2-1-ETW2-1	Strength	Not an Outlier	59.78	Low	Yes	No

Table 6-1: List of Outliers

7. References

1. Snedecor, G.W. and Cochran, W.G., *Statistical Methods*, 7th ed., The Iowa State University Press, 1980, pp. 252-253.
2. Stefansky, W., "Rejecting Outliers in Factorial Designs," *Technometrics*, Vol. 14, 1972, pp. 469-479.
3. Scholz, F.W. and Stephens, M.A., "K-Sample Anderson-Darling Tests of Fit," *Journal of the American Statistical Association*, Vol. 82, 1987, pp. 918-924.
4. Lehmann, E.L., *Testing Statistical Hypotheses*, John Wiley & Sons, 1959, pp. 274-275.
5. Levene, H., "Robust Tests for Equality of Variances," in *Contributions to Probability and Statistics*, ed. I. Olkin, Palo, Alto, CA: Stanford University Press, 1960.
6. Lawless, J.F., *Statistical Models and Methods for Lifetime Data*, John Wiley & Sons, 1982, pp. 150, 452-460.
7. *Metallic Materials and Elements for Aerospace Vehicle Structures*, MIL-HDBK-5E, Naval Publications and Forms Center, Philadelphia, Pennsylvania, 1 June 1987, pp. 9-166,9-167.
8. Hanson, D.L. and Koopmans, L.H., "Tolerance Limits for the Class of Distribution with Increasing Hazard Rates," *Annals of Math. Stat.*, Vol 35, 1964, pp. 1561-1570.
9. Vangel, M.G., "One-Sided Nonparametric Tolerance Limits," *Communications in Statistics: Simulation and Computation*, Vol. 23, 1994, p. 1137.
10. Vangel, M.G., "New Methods for One-Sided Tolerance Limits for a One-Way Balanced Random Effects ANOVA Model," *Technometrics*, Vol 34, 1992, pp. 176-185.
11. Odeh, R.E. and Owen, D.B., *Tables of Normal Tolerance Limits, Sampling Plans and Screening*, Marcel Dekker, 1980.
12. Tomblin, John and Seneviratne, Waruna, *Laminate Statistical Allowable Generation for Fiber-Reinforced Composites Material: Lamina Variability Method,* U.S. Department of Transportation, Federal Aviation Administration, May 2006.
13. Tomblin, John, Ng, Yeow and Raju, K. Suresh, *Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure,* U.S. Department of Transportation, Federal Aviation Administration, September 2003.
14. CMH-17 Rev G, Volume 1, 2012. SAE International, 400 Commonwealth Drive, Warrendale, PA 15096
15. Vangel, Mark, "Lot Acceptance and Compliance Testing Using the Sample Mean and an Extremum", Technometrics, Vol 44, NO. 3, August 2002, pp. 242-249