TCAC12k HTS SFP OSI/TC250 42% Fabric Prepreg Statistical Analysis Report

FAA Special Project Number SP4745WI-Q

NCAMP Report Number: NCP-RP-2010-076 N/C

Report Date: September 26, 2016

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

Fabrication Facility:
Advanced Composites Technologies
345 Coney Island Dr.
Sparks, NV 89431

Prepared by:

Elizabeth Clarkson, Ph.D

Reviewed by: (No longer available to sign)

Evelyn Lian Yeow Ng

Approved by:

Royal Lovingfoss

REVISIONS:

Rev	By	Date	Pages Revised or Added
N/C	Elizabeth Clarkson	10/27/2011	Document Initial Draft.
N/C	Elizabeth Clarkson	08/03/2015	Summary tables 3-1, 3-2, 3-3 and 3-4 on pages 33-36 were updated for strength values (WC-CTD, FC-RTD, IPS-ETW, OHT1, SBS1, ILT) and modulus values (WC-CTD, UNC2-ETW). Poisson's ratio values were updated for WT, WC, FC and removed for UNC1, 2, 3. Sections 4.3 (WC), 4.4 (FC), 4.5 (IPS), 4.13 (SBS1) and 4.20 (OHT1) were updated to reflect the changes to strength values. Tables 4-19 (UNC2 modulus), 4-40 (ILT) and 5-1 (outliers) were updated with new values.
N/C	Elizabeth Clarkson	9/29/2016	Document Initial Release.

Table of Contents

List of Figures

List of Tables

1. Introduction

This report contains statistical analysis of the TCAC 12k HTS40 F13 SFP OSI (193gsm)/TC250 42% fabric prepreg material property data published in NCAMP Test Report CAM-RP-2011-005 Rev A. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP4745WI-Q and also meet the requirements of NCAMP Standard Operating Procedure NSP 100; the test panels, test specimens, and test setups have been conformed by the FAA and the testing has been witnessed by the FAA.

B-Basis values, A-estimates, and B-estimates were calculated using a variety of techniques that are detailed in section two. The qualification material was procured to NCAMP Material Specification NMS 688/2 Rev B Release dated July 29, 2008. The panels were fabricated by Advanced Composites Technologies, 345 Coney Island Dr., Sparks NV 89431 in accordance with Process Specification NPS 81688 Rev C July 29, 2008. The NCAMP Test Plan NTP 6888Q2 Rev B July 29, 2008 was used for this qualification program. The testing was performed at the National Institute for Aviation Research (NIAR) in Wichita, Kansas.

Basis numbers are labeled as 'values' when the data meets all the requirements of CMH-17 Rev G. 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 is 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 Composite Materials Handbook 17 (CMH-17 Rev G).

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

The ronra5h5.9(r)-h -1.15 TD 0 2harperty dat29.2 -19r9.2 .00J 2995 0 TD .0002 Tc .002 Tw [atiodo7(y

Test Property	Symbol
Warp Compression Strength	F_1^{cu}
Warp Compression Modulus	E_1^c
Warp Compression Poisson’s Ratio	${}_{12}^{c}$
Warp Tension Strength	F_1^{tu}
Warp Tension Modulus	E_1^t
Warp Tension Poisson’s Ratio	${}_{12}^{t}$
Fill Compression Strength	F_2^{cu}
Fill Compression Modulus	E_2^c
Fill Compression Poisson’s Ratio	${}_{21}^{c}$
Fill Tension Strength	F_2^{tu}
Fill Tension Modulus	E_2^t
In Plane Shear Strength at 5% strain	$F_{12}^{s5\%}$
In Plane Shear Strength at 0.2% offset	$F_{12}^{s0.2\%}$

1.2 Pooling Across Environments

When pooling across environments was allowable, the pooled co-efficient of variation was used. ASAP (AGATE Statistical Analysis Program) 2008 version 1.0 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 using Stat17 version 5.

1.3 Basis Value Computational Process

The general form to compute engineering basis values is: basis value = $\bar{X} - kS$ 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 2.0.

1.4 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 Revision G. 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 AGATE Statistical Analysis Program (ASAP) when pooling across environments is permissible according to CMH-17 Rev G guidelines. If pooling is not permissible, a single point analysis using STAT-17 is performed for each environmental condition with sufficient test results. If the data does not meet the CMH-17 Rev G 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 ASAP Statistical Formulas and Computations

This section contains the details of the specific formulas ASAP 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.: $$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(X_i - \bar{X}\right)^2}$$ 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 data, 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. $$S_p = \sqrt{\frac{\sum_{i=1}^{k} \left(n_i - 1\right) S_i^2}{\sum_{i=1}^{k} \left(n_i - 1\right)}}$$ Equation 4

Where k refers to the number of batches 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.

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

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.

$$\text{Basis Values:} \quad \begin{aligned} A\text{-basis} &= \bar{X} - K_a S \\ B\text{-basis} &= \bar{X} - K_b S \end{aligned} \qquad \text{Equation 6}$$

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 Rev G. The approximation formulas are given below:

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

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

Where

r = the number of environments being pooled together

n_j = number of data values for environment j

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

$f = N - r$

$$q(f) \quad 1 \quad \frac{2.323}{\sqrt{f}} \quad \frac{1.064}{f} \quad \frac{0.9157}{f\sqrt{f}} \quad \frac{0.6530}{f^{2}}$$ Equation 9

$$b_B(f) \quad \frac{1.1372}{\sqrt{f}} \quad \frac{0.49162}{f} \quad \frac{0.18612}{f\sqrt{f}}$$

September 26, 2016

where t is the $1 - \frac{.05}{2n}$ quartile of a t distribution with $n-2$ degrees of freedom.

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 $z_{(1)}$, $z_{(2)}$,… $z_{(L)}$, 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:

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

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

$$a \quad (4g \quad 6)(k \quad 1) \quad (10 \quad 6g)S$$

$$b \quad (2g \quad 4)k^2 \quad 8Tk \quad (2g \quad 14T \quad 4)S \quad 8T \quad 4g \quad 6$$

$$c \quad (6T \quad 2g \quad 2)k^2 \quad (4T \quad 4g \quad 6)k \quad (2T \quad 6)S \quad 4T$$

$$d \quad (2T \quad 6)k^2 \quad 4Tk$$

$$S \quad \sum_{i \; 1}^{k} \frac{1}{n_i}$$

$$T \quad \sum_{i \; 1}^{n \; 1} \frac{1}{i}$$

$$g \quad \sum_{i \; 1}^{n \; 2} \sum_{j \; i \; 1}^{n \; 1} \frac{1}{(n \quad i)\, j}$$

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

$$OSL = \frac{1}{1 + e^{-0.48 + 0.78\ln(AD^*) + 4.58 AD^*}}, \quad AD^* = \left(1 + \frac{0.2}{\sqrt{n}}\right) AD \qquad \text{Equation 31}$$

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:

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

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 $x_{(1)}, ..., x_{(n)}$.

2.2.2 Computing Normal Distribution Basis values

Stat17 uses a table of values for the k-factors (shown in Table 2-1) when the sample size is less than 16 and a slightly different formula than ASAP to compute approximate k-values for the normal distribution when the sample size is 16 or larger.

Norm. Dist. k Factors for N<16		
N	B-basis	A-basis
2	20.581	37.094
3	6.157	10.553
4	4.163	7.042
5	3.408	5.741
6	3.007	5.062
7	2.756	4.642
8	2.583	4.354
9	2.454	4.143
10	2.355	3.981
11	2.276	3.852
12	2.211	3.747
13	2.156	3.659
14	2.109	3.585
15	2.069	3.520

Table 2-1: K factors for normal distribution

2.2.2.1 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 [illegible]

Stat17 solves these equations numerically for $\hat{\alpha}$ and $\hat{\beta}$ in order to compute basis values.

2.2.2.3.2 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 2.2.2.3.1, let

$$z_i = \left[x_i / \hat{\alpha}\right]^{\hat{\beta}}, \quad \text{for } i = 1, \ldots, n \qquad \text{Equation 38}$$

The Anderson-Darling test statistic is

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

and the observed significance level is

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

where

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

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

$$V_B = 3.803 \exp\left(1.79 - 0.516 \ln(n) + \frac{5.1}{n-1}\right) \quad \text{Equation 45}$$

$$V_A = 6.649 \exp\left(2.55 - 0.526 \ln(n) + \frac{4.76}{n}\right) \quad \text{Equation 46}$$

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 2-2: Weibull Distribution Basis Value Factors

2.2.2.4 Lognormal Distribution

A probability distribution for which the probability that an observation selected at random from this population falls between a and b $(0 < a < b < \infty)$ 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.

2.2.2.4.1 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 the linked equation above with linked equation below:

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

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 the linked equation above and the observed significance level (OSL) is computed using the linked equation 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 lognomal distribution. If $OSL \leq 0.05$, 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.

2.2.2.4.2 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

2.2.4 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

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

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

Denote the ratio of mean squares by

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

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

$$T = \frac{k_0 - \frac{k_1}{\sqrt{n c}} + (k_1 - k_0)\sqrt{\frac{u}{u + n c - 1}}}{1 - \frac{1}{\sqrt{n c}}} \qquad \text{Equation 60}$$

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.

2.3 Single Batch and Two Batch estimates using modified CV

This method has not been approved for use by the CMH-17 organization. Values computed in this manner are estimates only. It is used only when fewer than three batches are available and no valid B-basis value could be computed using any other method. The estimate is made using the mean of the data and setting the coefficient of variation to 8 percent if it was less than that. A modified standard deviation (S_{adj}) was computed by multiplying the mean by 0.08 and computing the A and B-basis values using this inflated value for the standard deviation.

$$\text{Estimated B-Basis} = \bar{X} - k_b S_{adj} = \bar{X} - k_b \cdot 0.08 \cdot \bar{X} \qquad \text{Equation 61}$$

2.4 Lamina Variability Method (LVM)

This method has not been approved for use by the CMH-17 organization. Values computed in this manner are estimates only. It is used only when the sample size is less than 16 and no valid B-basis value could be computed using any other method. The prime assumption for applying the LVM is that the intrinsic strength variability of the laminate (small) dataset is no greater than the strength variability of the lamina (large) dataset. This assumption was tested and found to be reasonable for composite materials as documented by Tomblin and Seneviratne [12].

To compute the estimate, the coefficients of variation (CVs) of laminate data are paired with lamina CV's for the same loading condition and environmental condition. For example, the 0º compression lamina CV CTD condition is used with open hole compression CTD condition. Bearing and in-plane shear laminate CV's are paired with 0º compression lamina CV's. However, if the laminate CV is larger than the corresponding lamina CV, the larger laminate CV value is used.

The LVM B-basis value is then computed as:

LVM Estimated B-Basis = $\bar{X}_1 \quad K_{N_1,N_2} \quad \bar{X}_1 \ \max \ CV_1, \tilde{CV}_2$ Equation 62

When used in conjunction with the modified CV approach, a minimum value of 8% is used for the CV.

Mod CV LVM Estimated B-Basis = $\bar{X}_1 \quad K_{N_1,N_2} \quad \bar{X}_1 \ \text{Max} \ 8\%, \tilde{CV}_1, CV_2$ Equation 63

With:

$\bar{X}_1$ the mean of the laminate (small dataset)
N_1 the sample size of the laminate (small dataset)
N_2 the sample size of the lamina (large dataset)
CV_1 is the coefficient of variation of the laminate (small dataset)
CV_2 is the coefficient of variation of the lamina (large dataset)
K_{N_1,N_2} is given in Table 2-5

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4.508	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3.827	3.607	0	0	0	0	0	0	0	0	0	0	0	0
5	3.481	3.263	3.141	0	0	0	0	0	0	0	0	0	0	0
6	3.273	3.056	2.934	2.854	0	0	0	0	0	0	0	0	0	0
7	3.134	2.918	2.796	2.715	2.658	0	0	0	0	0	0	0	0	0
8	3.035	2.820	2.697	2.616	2.558	2.515	0	0	0	0	0	0	0	0
9	2.960	2.746	2.623	2.541	2.483	2.440	2.405	0	0	0	0	0	0	0
10	2.903	2.688	2.565	2.484	2.425	2.381	2.346	2.318	0	0	0	0	0	0
11	2.856	2.643	2.519	2.437	2.378	2.334	2.299	2.270	2.247	0	0	0	0	0
12	2.819	2.605	2.481	2.399	2.340	2.295	2.260	2.231	2.207	2.187	0	0	0	0
13	2.787	2.574	2.450	2.367	2.308	2.263	2.227	2.198	2.174	2.154	2.137	0	0	0
14	2.761	2.547	2.423	2.341	2.281	2.236	2.200	2.171	2.147	2.126	2.109	2.093	0	0
15	2.738	2.525	2.401	2.318	2.258	2.212	2.176	2.147	2.123	2.102	2.084	2.069	2.056	0
16	2.719	2.505	2.381	2.298	2.238	2.192	2.156	2.126	2.102	2.081	2.063	2.048	2.034	2.022
17	2.701	2.488	2.364	2.280	2.220	2.174	2.138	2.108	2.083	2.062	2.045	2.029	2.015	2.003
18														

September 26, 2016

Laminate Strength Tests

B-basis	43.34		47.60		80.63				
Mean	48.65		53.24		91.10				
CV	6.00		6.00		6.64				
B-basis	44.01	39.36	47.61	63.49	79.07	NA:A	78.96	NA:I	8.46
Mean	49.32	43.48	53.25	70.82	89.54	83.05	92.14	114.08	9.30
CV	6.00	6.00	6.00	6.49	6.94	7.52	7.90	5.46	6.84
B-basis	46.77	24.55	47.28	38.44	77.76	NA:A	NA:A	79.22	3.55
Mean	52.08	28.65	52.92	45.81	88.23	50.82	76.32	92.35	4.51
CV	6.00	6.60	6.00	7.17	6.18	11.14	9.29	7.20	8.02
B-basis	39.24		43.84		52.21				
Mean	43.36		48.34		57.86				
CV	6.00		6.00		6.00				
B-basis	36.04	31.77	39.64	44.59	50.21	43.84	77.81	NA:I	
Mean	40.16	35.05	44.14	50.41	55.87	51.56	92.57	114.94	
CV	6.00	6.00	6.00	6.95	6.00	8.07	10.16	2.88	
B-basis	27.80	20.64	28.80	26.07	39.50	24.60	59.13	83.09	
Mean	31.92	23.92	33.31	31.83	45.16	28.73	74.02	95.22	
CV	6.00	6.00	6.00	8.78	6.00	7.38	8.98	6.45	
B-basis	47.43		52.00		98.71				
Mean	55.09		58.60		112.04				
CV	7.14		6.03		6.55				
B-basis	NA:A	42.12	53.38	65.18	102.70	75.08	77.94	NA:I	
Mean	57.11	46.73	59.99	72.37	116.03	86.42	90.68	106.38	
CV	6.82	6.12	6.52	6.21	6.26	6.65	7.21	6.27	
B-basis	58.43	27.77	55.67	40.64	92.88	NA:A	NA:A	71.53	
Mean	67.11	32.38	62.27	47.83	106.21	61.90	70.65	83.04	
CV	6.55	6.63	6.00	6.93	7.50	8.12	9.90	7.02	

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

Test data for fiber dominated properties was normalized according to nominal cured ply thickness. Both normalized and as measured statistics were included in the tables, but only the normalized data values were graphed. 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 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 computed using the ANOVA method, data from five batches is 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 2.1.4.1 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 in CMH17 Vol 1 Chapter 8 section 8.3.10.

4.1 Warp (0º) Tension Properties (WT)

2

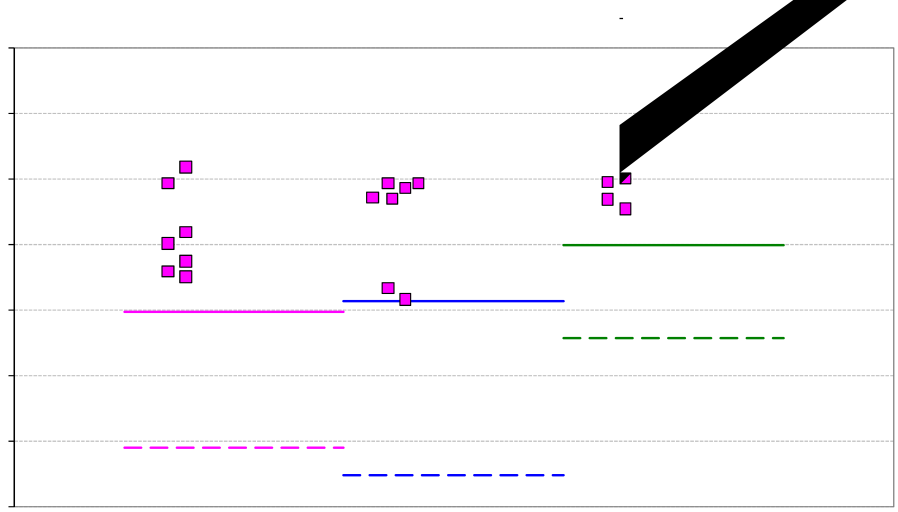
Statistics, estimates and basis values are given for strength data in Table 4-1 and for the modulus data in Table 4-2. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-1.

Only the as measured CTD data passed the ADK test. This means that all the other datasets will require an ANOVA analysis. In order for B-basis values computed using ANOVA, data from five batches are required. Since this dataset has only three batches, the basis values computed using ANOVA are considered estimates.

The as measured data from the RTD environment and the normalized data from the CTD and ETW environments passed the ADK test after the modified CV transformation. This means that modified CV B-basis values can be computed for the as measured RTD dataset and the normalized CTD and ETW datasets. Estimates computed using the modified CV method are provided for the normalized RTD dataset and the as measured ETW dataset. They are considered estimates because even after the modified CV transformation of the data, those datasets do not pass the ADK test.

Since the RTD environment is required to be included, pooling across the environments is not acceptable for the normalized data. However data from the CTD and RTD environments could be pooled to compute the modified CV basis values for the as measured data.

There was one outlier. In was on the high side of batch three of the ETW environment. It was an outlier only for batch three, not for the three batches pooled together. It was retained for this analysis.



Warp Tension Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	129.00	130.41	135.15	127.21	126.33	132.02
Stdev	9.81	9.03	5.44	12.11	8.70	7.23
CV	7.60	6.92	4.02	9.52	6.89	5.48
Mod CV	7.80	7.46	6.01	9.52	7.44	6.74
Min	110.30	111.70	125.54	105.39	106.47	119.41
Max	143.11	145.93	146.53	149.49	141.51	146.14
No. Batches	3	3	3	3	3	3
No. Spec.	21	19	23	21	19	23
Basis Values and/or Estimates						
B-basis Value				104.14		
B-Estimate	89.08	84.88	105.87		89.06	89.94
A-Estimate	60.60	52.41	84.96	87.70	62.49	59.89
Method	ANOVA	ANOVA	ANOVA	Normal	ANOVA	ANOVA
Modified CV Basis Values and/or Estimates						
B-basis Value	109.82		119.96	107.78	106.73	
B-Estimate		111.44				115.39
A-Estimate	96.16	97.99	109.10	94.39	93.38	103.49
Method	Normal	Normal	Normal	pooled	pooled	Normal

Table 4-1: Statistics, Basis values and/or Estimates for WT Strength Data

Warp Tension Modulus Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	8.76	8.94	8.85	8.62	8.66	8.64
Stdev	0.16	0.24	0.11	0.22	0.24	0.25
CV	1.84	2.63	1.30	2.57	2.74	2.94
Mod CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	8.52	8.71	8.63	8.15	8.34	8.17
Max	9.25	9.80	9.08	9.08	9.34	9.22
No. Batches	3	3	3	3	3	3
No. Spec.	21	19	24	21	19	24

Table 4-2: Statisticsfrom WT Modulus Data

4.3 Warp (0º) Compression Properties (WC)

Statistics, basis values and estimates are given for strength data in Table 4-5 and for the modulus data in Table 4-6. The normalized data, B-estimat

Env	CTD	RTD	ETD	ETW	CTD	RTD	ETD	ETW
Mean	102.29	101.26	84.41	64.80	102.36	100.14	82.77	66.25
Stdev	10.16	4.51	3.61	7.09	9.89	4.96	3.36	6.82
CV	9.94	4.46	4.27	10.94	9.66	4.96	4.06	10.30
Mod CV	9.94	6.23	6.14	10.94	9.66	6.48	6.03	10.30
Min	85.03	93.49	78.75	52.21	87.25	93.56	77.06	55.08
Max	120.29	109.31	91.95	81.72	121.06	110.23	88.86	81.52
No. Batches	3	3	3	3	3	3	3	3

4.4

Env	CTD	RTD	ETD	ETW	CTD	RTD	ETD	ETW
Mean	100.90	91.91	75.25	61.22	101.38	89.96	71.96	61.82
Stdev	11.17	13.07	12.15	7.81	11.59	12.98	12.44	8.43
CV	11.07	14.22	16.14	12.76	11.44	14.43	17.28	13.64
Mod CV	11.07	14.22	16.14	12.76	11.44	14.43	17.28	13.64
Min	84.86	68.22	54.92	46.42	81.31	66.58	51.41	44.71
Max	119.01	107.37	88.97	76.37	119.51	103.85	85.92	76.91
No. Batches	3	3	3	3	3	3	3	3
No. Spec.	18	21	19	22	18	21	19	22
B-Estimate	50.08	5.47	0.00	23.52	43.18	10.44	0.00	21.31
A-Estimate	13.86	0.00	0.00	0.00	1.67	0.00	0.00	0.00

4.6 Quasi Isotropic UnnotchedTension Properties (UNT1)

Statistics, basis values and estimates are given for UNT1 strength data in Table 4-10 and for the modulus data in Table 4-11. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-7.

The data from the CTD and RTD environments, both as measured and normalized, failed the ADK test, so they required an ANOVA analysis. In

4.7 "Soft" Unnotched Tension Properties (UNT2)

Statistics, basis values and estimates are given

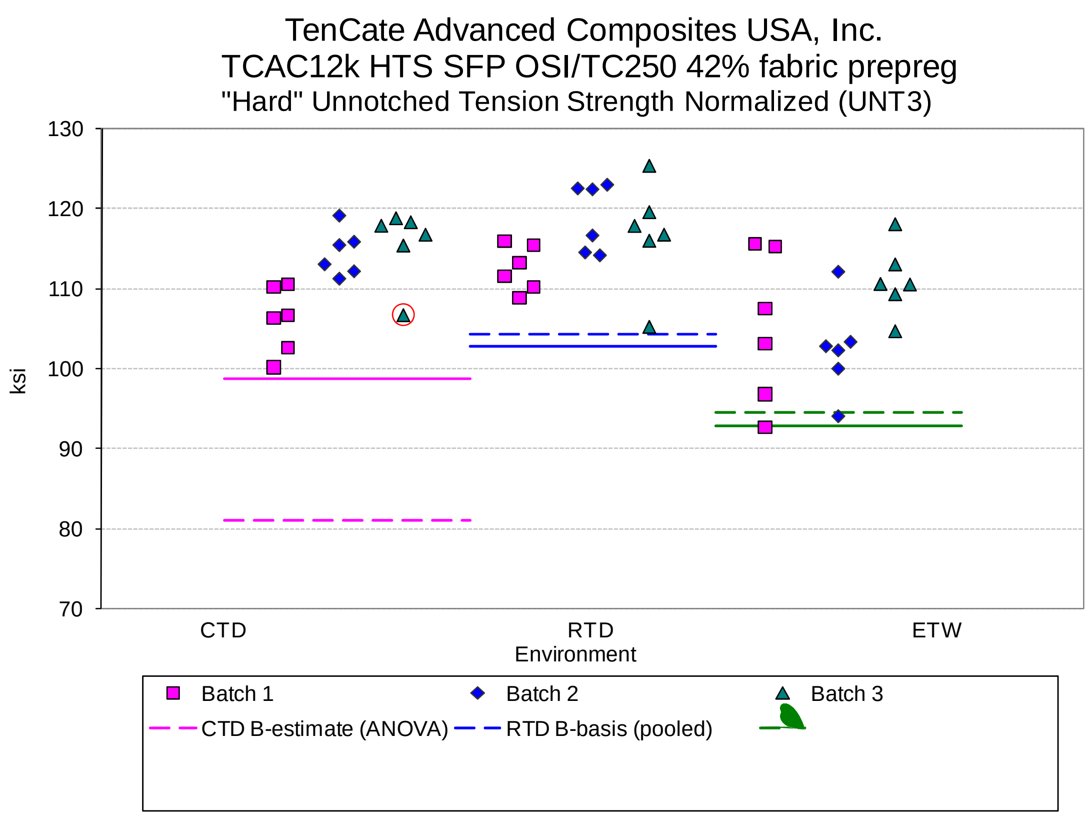
Unnotched Tension (UNT2) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	57.86	55.87	45.16	56.48	54.00	44.39
Stdev	1.60	1.72	1.32	1.88	1.68	1.40
CV	2.76	3.08	2.92	3.34	3.11	3.15
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	53.99	51.78	42.97	53.19	49.88	42.18
Max	59.75	58.58	48.18	60.75	56.51	46.72
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value		53.08	42.37	53.53	51.05	41.44
B-Estimate	50.29					
A-Estimate	44.89	51.18	40.47	51.56	49.08	39.47
Method	ANOVA	pooled	pooled	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	52.21	50.21	39.50	50.97	48.49	38.88
A-Estimate	48.43	46.44	35.72	47.29	44.81	35.20
Method	pooled	pooled	pooled	pooled	pooled	pooled

4.8 "Hard" Unnotched Tension Properties (UNT3)

Statistics, basis values and estimates are given for UNT3 strength data in Table 4-14 and for the modulus data in Table 4-15. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-9.

Both the as measured and normalized data from the CTD environment failed the ADK test, but passed with the modified CV transform. Pooling was appropriate for the RTD and ETW environments and for all three environments to compute the modified CV basis values.

There was one outlier. It was on the low side of batch three of the normalized data from the CTD environment. It was an outlier only for that batch, not when the three batches were combined. It was retained for this analysis.



Unnotched Tension (UNT3) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	112.04	116.03	106.21	110.38	113.07	104.54
Stdev	5.71	5.25	7.44	6.24	5.75	7.92
CV	5.09	4.53	7.00	5.65	5.08	7.58
Modified CV	6.55	6.26	7.50	6.83	6.54	7.79
Min	100.16	105.20	92.71	100.11	102.31	92.20
Max	119.06	125.34	118.04	119.28	123.52	118.97
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value		104.30	94.48		100.47	91.93
B-Estimate	81.04			81.98		
A-Estimate	58.93	96.32	86.50	61.75	91.89	83.35
Method	ANOVA	pooled	pooled	ANOVA	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	98.71	102.70	92.88	96.75	99.44	90.91
A-Estimate	89.81	93.80	83.98	87.65	90.35	81.81
Method	pooled	pooled	pooled	pooled	pooled	pooled

Table 4-14: Statistics, Bassi Values and/or Estimates for UNT3 Strength Data

Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	7.77	7.86	7.70	7.65	7.66	7.58
Stdev	0.14	0.16	0.14	0.23	0.19	0.24
CV	1.75	2.05	1.78	3.05	2.45	3.20
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	7.58	7.57	7.43	7.21	7.39	7.24
Max	8.12	8.17	7.86	8.00	7.98	8.07
No. Batches	3	3	3	3	3	3

4.9 Quasi Isotropic Unnotched Compression (UNC1)

Statistics, basis values and estimates are given for UNC1 strength data in Table 4-16 and for the modulus data in Table 4-17. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-10.

The data from the RTD and ETW environments, both as measured and normalized, failed the ADK test, so they required an ANOVA analysis. In order for B-basis values to be computed using the ANOVA method, data from five batches is required. Since this dataset has only three batches, the basis values computed using ANOVA are considered estimates. The as measured RTD dataset passes the ADK test after the modified CV transform is applied, but the other three datasets do not. Pooling was not appropriate due to these failures. A modified CV B-basis value was computed for the as measured data from the RTD environment. Estimates computed using the modified CV method are provided for the remaining datasets.

There were no outliers.

Env	RTD	ETW	RTD	ETW
Mean	83.05	50.82	81.97	51.84
Stdev	6.24	5.66	5.46	5.98
CV	7.52	11.14	6.66	11.53
Modified CV	7.76	11.14	7.33	11.53
Min	69.08	40.72	68.90	40.97
Max	91.94	62.14	89.62	63.74
No. Batches	3	3	3	3
No. Spec.	19	20	19	20
B-Estimate	45.94	18.84	57.77	17.69
A-Estimate	19.45	NA	40.52	NA
Method	ANOVA	ANOVA	ANOVA	ANOVA
B-basis Value			70.26	
B-Estimate	70.49	39.91		40.33
A-Estimate	61.59	32.16	61.95	32.14

Meth548 T195(32.14)]TJ .825.4(N)825487.5(8)]TJ .825raal(A)0(802.)-5567

4.10 “Soft” Unnotched Compression (UNC2)

Statistics, basis values and estimates are given for UNC2 strength data in Table 4-18 and for the modulus data in Table 4-19. The normalized data and B-basis values are shown graphically in Figure 4-11.

Unnotched Compression (UNC2) Strength Basis Values and Statistics				
	Normalized		As Measured	
Env	RTD	ETW	RTD	ETW
Mean	51.56	28.73	51.10	29.17
Stdev	4.16	1.94	4.32	2.29
CV	8.07	6.76	8.46	7.84
Modified CV	8.07	7.38	8.46	7.92
Min	40.61	24.31	39.93	24.06
Max	56.88	32.57	56.50	33.33
No. Batches	3	3	3	3
No. Spec.	19	19	19	19
Basis Values and/or Estimates				
B-basis Value	43.84	24.94	42.91	
B-Estimate				19.45
A-Estimate	36.34	22.25	35.09	12.52
Method	Weibull	Normal	Weibull	ANOVA
Modified CV Basis Values and/or Estimates				
B-basis Value	NA	24.60	44.85	22.91
A-Estimate	NA	21.66	40.58	18.64
Method	NA	Normal	pooled	pooled

Table 4-18: Statistics, Basis Values and/or Estimates for UNC2 Strength Data

Unnotched Compression (UNC2) Modulus Statistics				
	Normalized		As Measured	
Env	RTD	ETW	RTD	ETW
Mean	3.82	3.36	3.78	3.41
Stdev	0.16	0.16	0.19	0.19
CV	4.28	4.86	4.97	5.42
Modified CV	6.14	6.43	6.48	6.71
Min	3.43	3.12	3.41	3.17
Max	4.07	3.70	4.11	3.76
No. Batches	3	3	3	3
No. Spec.	19	18	19	18

Table 4-19: Statistics from UNC2 Modulus Data

4.11 “Hard” Unnotched Compression (UNC3)

4.12 Short Beam Strength (SBS) Data

The Short Beam Strength data is not normalized. Statistics, basis values and estimates are given for SBS strength data in Table 4-22. The data, B-estimates and B-basis values are shown graphically in Figure 4-13.

The data from the CTD environment failed the ADK test, so it required an ANOVA analysis. In order for B-basis values to be computed using the ANOVA method, data from five batches is required. Since this dataset has only three batches, the basis values computed using ANOVA are considered estimates. Pooling was appropriate for the RTD, ETD and ETW environments. Estimates computed using the modified CV method are provided for the CTD dataset, but these are considered estimates due to the failure of the ADK test after the modified CV transform.

There were no outliers.

Short Beam Strength (SBS) Basis Values and Statistics				
Env	CTD	RTD	ETD	ETW
Mean	10.44	9.36	6.77	4.36
Stdev	0.84	0.45	0.34	0.34
CV	8.03	4.82	5.05	7.73
Mod CV	8.03	6.41	6.53	7.87
Min	8.99	8.37	6.19	3.72
Max	12.10	10.02	7.37	4.94
No. Batches	3	3	3	3
No. Spec.	18	18	18	22
Basis Values and/or Estimates				
B-basis Value		8.70	6.11	3.71
B-Estimate	5.81			
A-Estimate	2.51	8.26	5.66	3.27
Method	ANOVA	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates				
B-basis Value		8.54	5.95	3.56
B-Estimate	8.78			
A-Estimate	7.61	8.00	5.40	3.01
Method	Normal	pooled	pooled	pooled

Table 4-22: Statistics, Basis Values and/or Estimates for SBS Strength Data

Laminate Short Beam Strength (SBS1) Basis Values and Statistics		
Env	RTD	ETW
Mean	9.30	4.51
Stdev	0.53	0.36
CV	5.69	8.02
Modified CV	6.84	8.02
Min	8.29	3.96
Max	10.23	5.09
No. Batches	3	3
No. Spec.	16	16
Basis Values and/or Estimates		
B-basis Value	8.46	3.67
A-Estimate	7.89	3.10
Method	pooled	pooled
Modified CV Basis Values and/or Estimates		
B-Estimate	8.34	3.55
A-Estimate	7.69	2.90
Method	pooled	pooled

Table 4-23: Statistics, Basis Values and/or Estimates for SBS1 Strength Data

ou

Open Hole Tension (OHT1) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	48.65	49.32	52.08	47.09	46.76	50.02
Stdev	1.83	1.26	1.89	2.20	1.41	1.84
CV	3.75	2.56	3.63	4.67	3.02	3.68
Modified CV	6.00	6.00	6.00	6.34	6.00	6.00
Min	44.61	47.47	48.84	41.76	44.39	47.23
Max	52.50	51.60	55.87	51.76	49.42	53.69
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value		46.39	49.15		43.76	47.03
B-Estimate	43.18			41.23		
A-Estimate	39.29	44.40	47.16	37.06	41.73	45.00
Method	ANOVA	pooled	pooled	ANOVA	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	43.34	44.01	46.77	41.90	41.57	44.83
A-Estimate	39.79	40.46	43.22	38.44	38.10	41.37
Method	pooled	pooled	pooled	pooled	pooled	pooled

Table 4-24: Statistics, Basis Values and/or Estimates for OHT1 Strength Data

4.15 “Soft” Open Hole Tension Properties (OHT2)

Statistics, basis values and estimates are gi

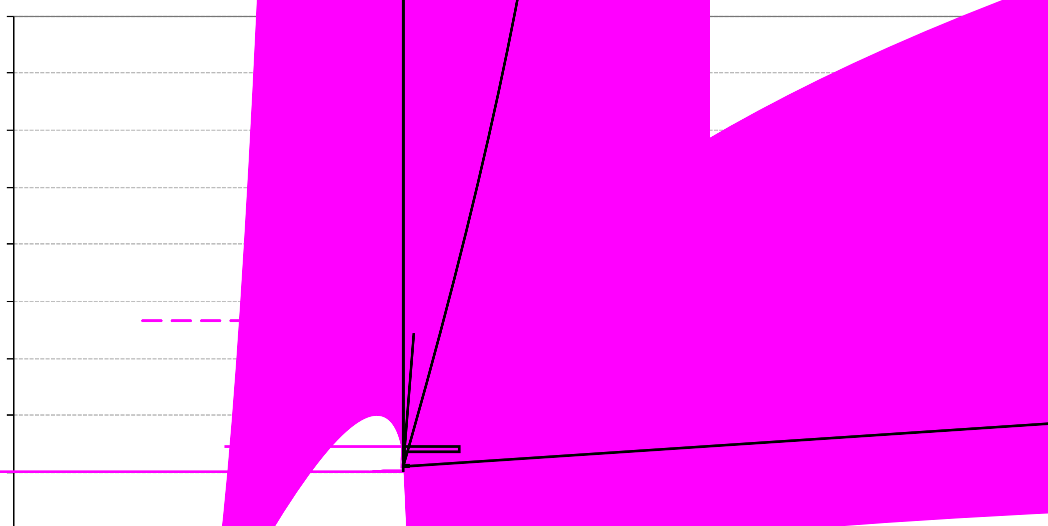
				As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	43.36	40.16	31.92	41.86	38.55	30.66
Stdev	1.48	1.41	0.77	1.31	1.28	0.80
CV	3.41	3.50	2.42	3.13	3.32	2.61
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	41.29	37.52	30.52	38.99	36.10	29.27
Max	45.91	42.79	32.97	44.46	40.59	32.07
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
B-basis Value	40.44	37.39	30.40	39.82	36.51	28.62
A-Estimate	38.38	35.42	29.32	38.45	35.15	27.26
Method	Normal	Normal	Normal	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	39.24	36.04	27.80	37.89	34.59	26.70
A-Estimate	36.49	33.29	25.05	35.25	31.94	24.05
Method	pooled	pooled	pooled	pooled	pooled	pooled

4.16 "Hard" Open Hole Te[illegible]roperties (OHT3)

Statistics, basis values and [illegible]es are given for OHT3 strength data in Table 4-26. The normalized data, B-estimate[illegible]-basis values are shown graphically in Figure 4-17.

The data from the RTD env[illegible]t, both as measured and normalized, and the normalized data from the ETW environment [illegible]e ADK test, so they required an ANOVA analysis. In order for B-basis values to be co[illegible]g the ANOVA method, data from five batches is required. Since this dataset has only [illegible]tches, the basis values computed using ANOVA are considered estimates. Afte[illegible]g the modified CV transform, the as measured data from the RTD environment and the [illegible]ed data from the ETW environment passed the ADK test, but the normalized data from th[illegible]nvironment did not. The as measured data from the three environments could be poo[illegible]mpute the modified CV basis values, but the normalized data could not due to the failure [illegible] test. Modified CV basis values using the single point meth[illegible] ETW environments. Estimates computed using the modifi[illegible] normalized RTD dataset.

There were two outliers. T[illegible] CTD data was an outlier for both the normalized and as me[illegible]was an outlier only after pooling the three batches together wh[illegible]tlier both before and after pooling the data from the three ba[illegible] batch three of the as measured ETW data was an outlier f[illegible]ata from the three batches combined. Both outliers were retaine[illegible]



Open Hole Tension (OHT3) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	55.09	57.11	67.11	54.05	55.05	65.50
Stdev	3.46	3.89	3.43	3.67	3.31	3.00
CV	6.28	6.82	5.11	6.80	6.01	4.58
Modified CV	7.14	7.41	6.55	7.40	7.01	6.29
Min	48.85	50.78	58.94	47.58	50.45	60.52
Max	65.34	62.82	72.55	64.57	60.47	71.01
No. Batches	3	3	3	3	3	3
No. Spec.	19	18	18	19	18	18
Basis Values and/or Estimates						
B-basis Value	48.35			46.89		59.57
B-Estimate		35.34	52.54		37.80	
A-Estimate	43.56	19.81	42.15	41.81	25.49	55.37
Method	Normal	ANOVA	ANOVA	Normal	ANOVA	Normal
Modified CV Basis Values and/or Estimates						
B-basis Value	47.43		58.43	47.03	47.99	58.44
B-Estimate		48.76				
A-Estimate	41.99	42.85	52.29	42.31	43.28	53.73
Method	Normal	Normal	Normal	pooled	pooled	pooled

Filled Hole Tension (FHT1) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	53.24	53.25	52.92	51.66	51.03	50.78
Stdev	1.42	1.41	1.39	1.51	1.47	1.43
CV	2.66	2.65	2.63	2.93	2.89	2.82
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	50.38	50.20	50.05	48.54	47.61	47.68
Max	56.05	55.21	55.10	54.50	52.92	53.26
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value	50.75	50.76	50.43	49.05	48.42	48.17
A-Estimate	49.09	49.10	48.77	47.31	46.68	46.43
Method	pooled	pooled	pooled	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	47.60	47.61	47.28	46.23	45.60	45.35
A-Estimate	43.83	43.84	43.51	42.60	41.97	41.72
Method	pooled	pooled	pooled	pooled	pooled	pooled

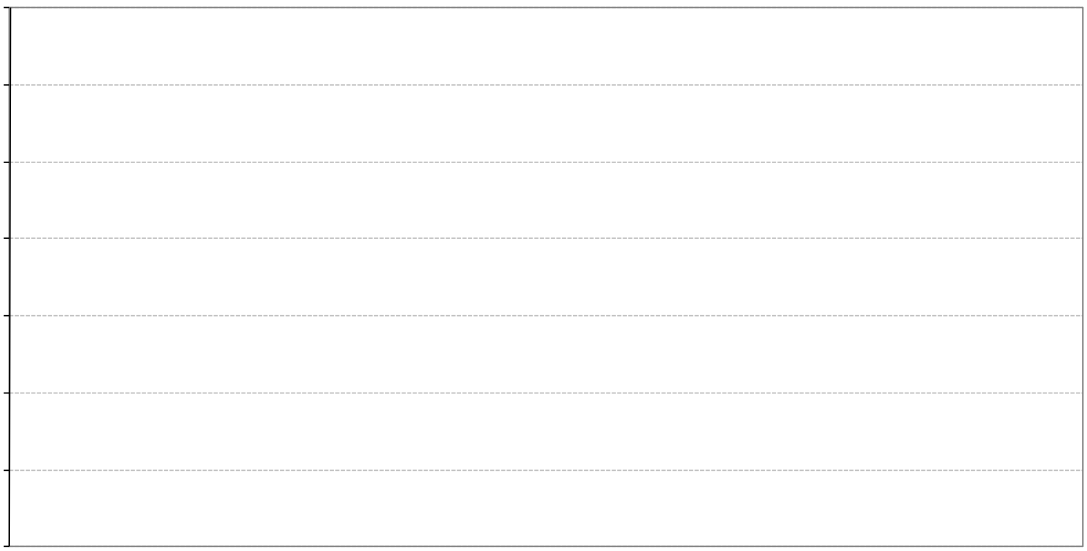
Table 4-27: Statistics, Basis Values and/or Estimates for FHT1 Strength Data

4.18 "Soft" Filled Hole Tension (FHT2)

Statistics, basis values and estimates are given for FHT2 strength data in Table 4-28. The normalized data and the B-basis values are shown graphically in Figure 4-19.

The FHT2 data had no test failure. Pooling across all environments was acceptable.

There was one outlier. It was the lowest value of batch two in the RTD environment. It was an outlier for the as measured data only after pooling the data from the three batches together. It was an outlier for the normalized data only for batch two and not for the combined data from the three batches. It was retained for this analysis.



Filled Hole Tension (FHT2) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	48.34	44.14	33.31	46.68	42.03	31.95
Stdev	1.13	1.48	0.84	1.42	1.34	0.83
CV	2.33	3.34	2.51	3.05	3.20	2.61
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	46.27	40.47	32.12	43.55	38.45	30.83
Max	50.67	47.20	34.85	48.84	44.74	33.58
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value	46.26	42.06	31.22	44.51	39.85	29.77
A-Estimate	44.87	40.67	29.84	43.05	38.40	28.32
Method	pooled	pooled	pooled	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	43.84	39.64	28.80	42.36	37.71	27.63
A-Estimate	40.83	36.63	25.79	39.48	34.82	24.74
Method	pooled	pooled	pooled	pooled	pooled	pooled

...9

...n data in Table 4-29. T...
...sti... ...phically in Figure 4-20.

...a data ... from the ETW environme...
...nd norm... ...ired an ANOVA analysis. ...
...alues to be... ..., data from five batches is requ...
...ataset has ... ...mputed using ANOVA are
...ed estimates ... ...D and RTD environments could...
..., all three of thos...
...cceptable.

...n batch two of the
...ed RTD data were
...n two o... ...or the data combined from all three batches.
...th outliers were retai...

Filled Hole Tension (FHT3) Strength Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW	CTD	RTD	ETW
Mean	58.60	59.99	62.27	57.02	57.56	60.15
Stdev	2.38	3.02	2.34	2.51	3.31	2.75
CV	4.07	5.04	3.76	4.40	5.76	4.58
Modified CV	6.03	6.52	6.00	6.20	6.88	6.29
Min	53.75	54.44	57.06	52.81	51.72	54.18
Max	62.53	65.29	65.27	61.84	62.64	64.25
No. Batches	3	3	3	3	3	3
No. Spec.	18	18	18	18	18	18
Basis Values and/or Estimates						
B-basis Value	53.64	55.03		52.07		
B-Estimate			50.41		42.19	45.05
A-Estimate	50.27	51.65	41.95	48.56	31.23	34.27
Method	pooled	pooled	ANOVA	Normal	ANOVA	ANOVA
Modified CV Basis Values and/or Estimates						
B-basis Value	52.00	53.38	55.67	50.35	50.90	53.49
A-Estimate	47.59	48.97	51.26	45.91	46.45	49.05
Method	pooled	pooled	pooled	pooled	pooled	pooled

4.20 Quasi Isotropic Open Hole Compression (OHC1)

Statistics, B-basis values and estimates are given for OHC1 strength data in Table 4-30. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-21.

Two data points from one of the batch A panels were removed from this dataset and the analysis of it after review and discussi

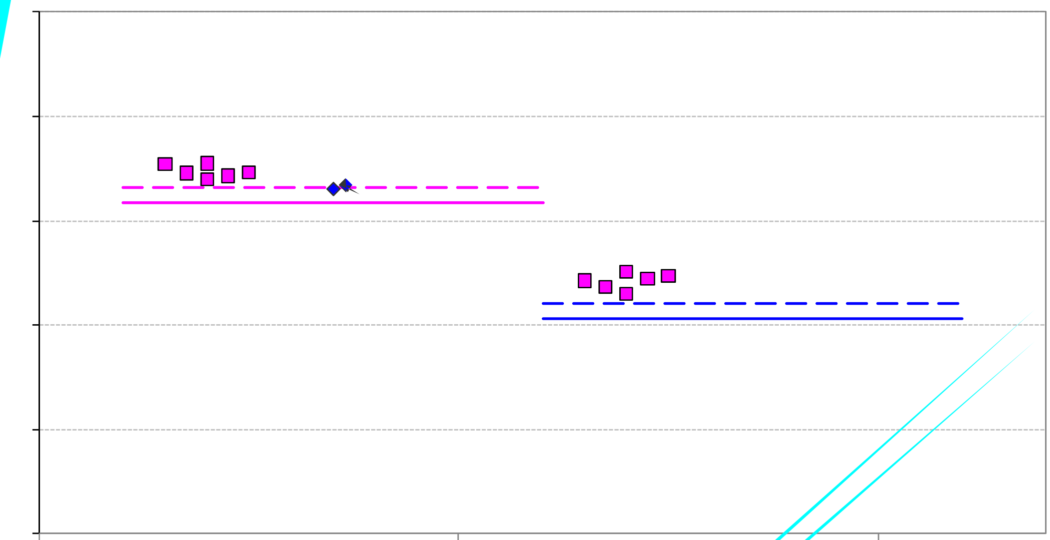
Env	RTD	ETW	RTD	ETW
Mean	43.48	28.65	41.98	27.98
Stdev	1.47	1.49	1.42	1.51
CV	3.39	5.19	3.38	5.40
Modified CV	6.00	6.60	6.00	6.70
Min	40.95	25.37	38.63	25.31
Max	46.03	31.69	43.96	30.97
No. Batches	3	3	3	3
No. Spec.	18	19	18	19
B-basis Value	40.57	21.05	39.18	20.96
A-Estimate	38.50	15.63	37.19	15.95
Method	Normal	ANOVA	Normal	ANOVA
B-basis Value	39.36	24.55	37.96	23.98
A-Estimate	36.56	21.75	35.23	21.25

3 0 3T /TT6 1219 178.460er 3483 0 3 [illegible]

4.21 “Soft” Open Hole Compression (OHC2)

Statistics, basis values and estimates are given for OHC2 strength data in Table 4-31. The normalized data and B-basis values are shown graphically in Figure 4-22.

There were no test failures and pooling was acceptable. There was one outlier. It was the highest value in batch three of the normalized ETW data. It was an outlier only for batch three, not when the three batches were combined. It was retained for this analysis.



Env	RTD	ETW	RTD	ETW
Mean	35.05	23.92	33.97	23.42
Stdev	1.23	0.77	1.07	0.75
CV	3.50	3.23	3.14	3.21
Modified CV	6.00	6.00	6.00	6.00
Min	33.01	22.61	32.21	22.02
Max	37.75	25.15	36.19	24.99
No. Batches	3	3	3	3
No. Spec.	18	18	18	18
B-basis Value	33.18	22.05	32.29	21.73
A-Estimate	31.91	20.78	31.15	20.59

Env	RTD	ETW	RTD	ETW
Mean	46.73	32.38	45.12	31.59
Stdev	1.98	1.70	1.91	1.88
CV	4.24	5.26	4.23	5.97
Modified CV	6.12	6.63	6.11	6.98
Min	43.18	29.07	41.57	28.36
Max	50.12	36.87	47.62	36.76
No. Batches	3	3	3	3
No. Spec.	18	18	18	18
B-basis Value	43.36	29.01	41.67	28.14
A-Estimate	41.07	26.72	39.31	25.79
Method	pooled	pooled	pooled	pooled
B-basis Value	42.12	27.77	40.57	27.05
A-Estimate	38.99	24.64	37.47	23.95
Method	pooled	pooled	pooled	pooled

Filled Hole Compression (FHC1) Strength Basis Values and Statistics				
	Normalized		As Measured	
Env	RTD	ETW	RTD	ETW
Mean	70.82	45.81	67.86	44.37
Stdev	3.53	2.91	3.30	2.76
CV	4.98	6.34	4.86	6.23
Modified CV	6.49	7.17	6.43	7.11
Min	65.05	39.43	63.32	38.12
Max	76.76	50.71	75.64	48.87
No. Batches	3	3	3	3
No. Spec.	18	17	18	17
Basis Values and/or Estimates				
B-basis Value			61.35	
B-Estimate	56.19	31.71		31.03
A-Estimate	45.77	21.67	56.74	21.52
Method	ANOVA	ANOVA	Normal	ANOVA
Modified CV Basis Values and/or Estimates				
B-basis Value	63.49	38.44	60.88	37.35
A-Estimate	58.50	33.45	56.11	32.60
Method	pooled	pooled	pooled	pooled

4.24 “Soft” Filled Hole Compression (FHC2)

Filled Hole Com pression (FHC2) Stren gth Basis Values and				
	Normalized		As Measured	
Env	RTD	ETW	RTD	ETW
Mean	50.41	31.83	48.68	30.75
Stdev	2.97	2.80	3.14	2.78
CV	5.89	8.78	6.45	9.03
Modified CV	6.95	8.78	7.23	9.03
Min	43.21	26.99	40.37	25.05
Max	54.77	35.92	52.78	34.45
No. Batches	3	3	3	3
No. Spec.	16	18	16	18
Basis Values and/or Estimates				
B-Estimate	44.37	17.46	42.29	18.34
A-Estimate	40.10	7.21	37.79	9.50
Method	Normal	ANOVA	Normal	ANOVA
Modified CV Basis Values and/or Estimates				
B-basis Value	44.59	26.07	42.86	24.99
A-Estimate	40.67	22.14	38.94	21.06
Method	pooled	pooled	pooled	pooled

*An override of the ATK test result for the ETW condition was recommended by CMH-17 Data Review Working group. It is listed as a B-basis value rather than a B-estimate for that reason.

Table 4-34: Statistics, Basi

4.25

Env	RTD	ETW	RTD	ETW
Mean	72.37	47.83	70.13	46.08
Stdev	3.21	2.80	3.25	2.86
CV	4.43	5.86	4.63	6.20
Modified CV	6.21	6.93	6.32	7.10
Min	67.50	42.29	66.57	41.12
Max	77.91	53.26	77.21	52.52
No. Batches	3	3	3	3

4.26 Quasi Isotropic Single Shear Bearing (SSB1)

Statistics, basis values and estimates are given for the SSB1 strength data in Table 4-36. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-27.

The two percent offset strength data from the ETW environment, both as measured and normalized, failed the ADK test so they required an ANOVA analysis. In order for B-basis values to be computed using the ANOVA method, data from five batches is required. Since this dataset has only three batches, the basis values computed using ANOVA are considered estimates. After applying the modified CV transform, neither of those datasets passed the ADK test so pooling across the environments was not acceptable. Due to these failures modified CV B-basis values for the ETW environment could not be provided. Estimates based on the modified CV method are provided instead.

The two percent offset strength normalized data from the RTD environment failed the normality test. The lognormal distribution had the best fit for that dataset, so basis values were computed assuming the lognormal distribution and modified CV basis values could not be computed.

There was data from only one batch for ultimate strength in the RTD environment, therefore only estimates are provided. The modified CV basis values were computed using the single batch method.

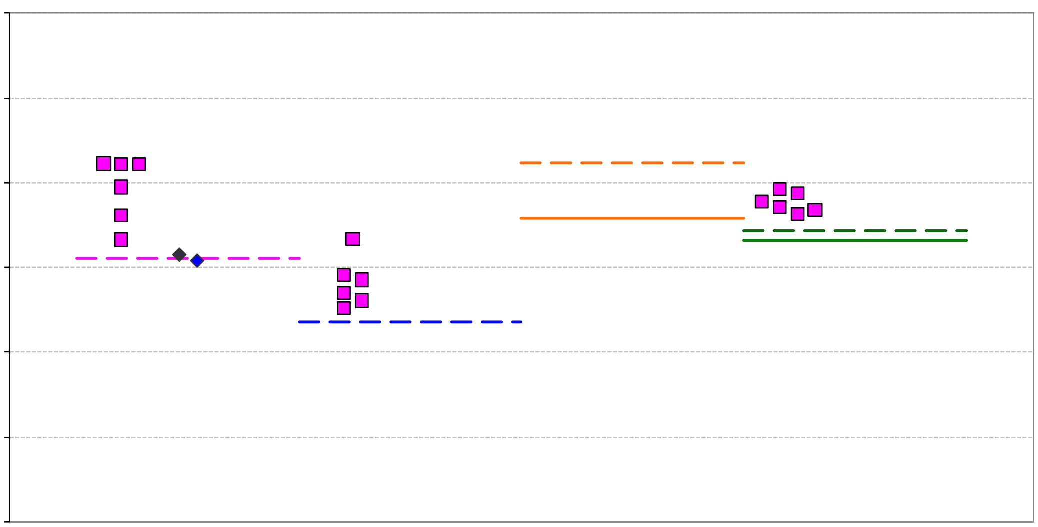
4.27 “Soft” Single Shear Bearing (SSB2)

Statistics, basis values and estimates are given for the SSB2 strength data in Table 4-37. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-28.

There were no test failures in the two percent offset strength data. Pooling across the environments was acceptable. The coefficient of variation was large, so the modified CV method would not alter it and modified CV basis values are not provided.

There was data from only one batch for ultimate strength in the RTD environment, therefore only estimates are provided. The modified CV basis values were computed using the single batch method.

There was one outlier. It was on the low side of batch two of the normalized two percent offset strength data from the ETW environment. It was an outlier only for batch two, not for the combined data from all three batches. It was retained for this analysis.



Property								
Env	RTD	ETW	RTD	ETW	RTD	ETW	RTD	ETW
Mean	92.57	74.02	114.94	95.22	94.99	73.52	122.80	94.62

4.28 “Hard” Single Shear Bearing (SSB3)

Statistics, basis values and estimates are given for the SSB3 strength data in Table 4-39. The normalized data, B-estimates and B-basis values are shown graphically in Figure 4-29.

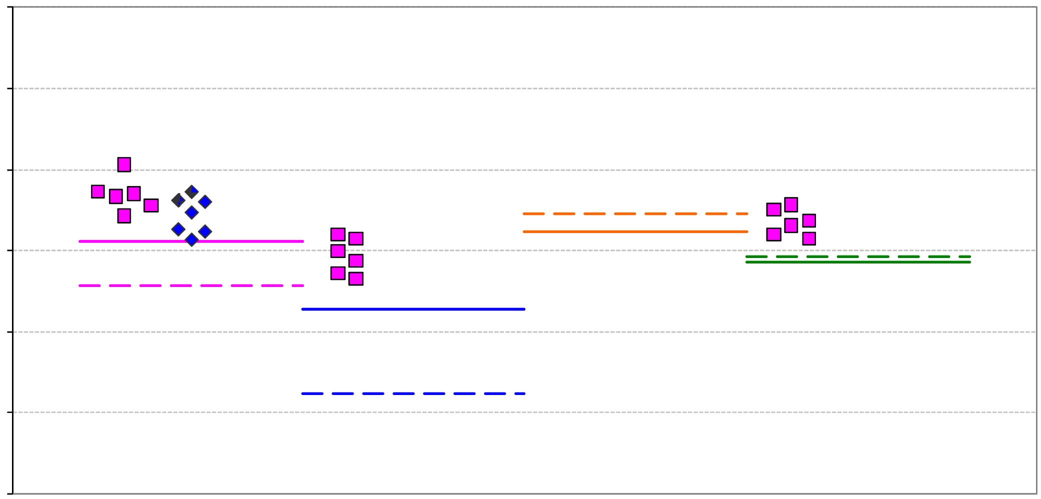
There were no test failures in the two percent offset strength data as measured. Pooling across the environments was acceptable.

The two percent offset strength normalized data from the both the RTD and ETW environments failed the ADK test so they required an ANOVA analysis. In order for B-basis values to be computed using the ANOVA method, data from five batches is required. Since this dataset has only three batches, the basis values computed using ANOVA are considered estimates.

After applying the modified CV transform, the environment passed the ADK test for the 2% offset strength normalized data from the RTD environment but not the ETW environment and modified CV basis values were computed for that environment. Estimates of the modified CV basis values are provided for the normalized 2% offset strength ETW data.

There was data from only one batch for ultimate strength in the RTD environment, therefore only estimates are provided. The modified CV basis values were computed using the single batch method.

There was one outlier. It was on the low side of batch two of the normalized two percent offset strength data from the ETW environment. It



4.29 Compression After Impact (CAI)

Basis values are not computed for this property. Testing is done only for the RTD condition. Summary statistics are presented in Table 4-39 and the data are displayed graphically in Figure 4-30. There were no outliers. Only one batch of material was tested.

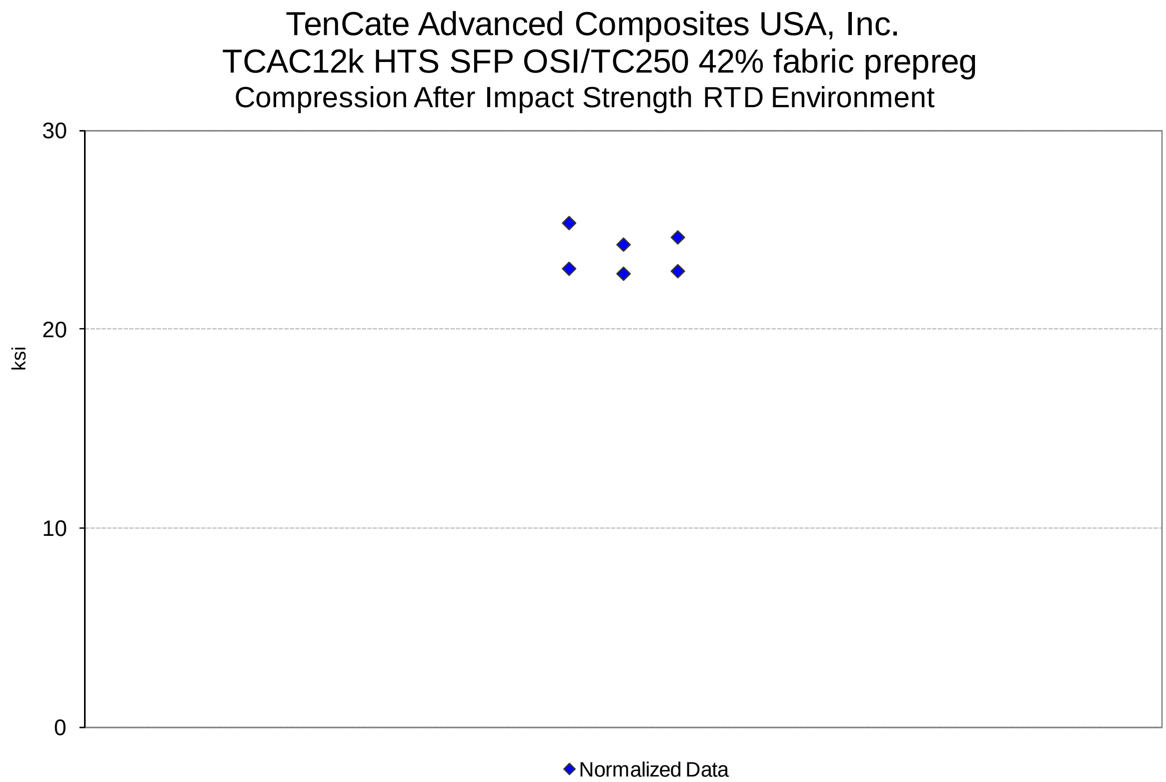


Figure 4-30: Plot for Compression After Impact normalized strength

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

The ILT and CBS data is not normalized. Only one batch of material was tested. Basis values are not computed for these properties. However the summary statistics are presented in Table 4-40 and the data are displayed graphically in Figure 4-31.

5. Outliers

Outliers were identified according to the standards documented in section 2.1.5, which are in accordance with the guidelines developed in CMH-17 Rev G chapter 8. An outlier may be an outlier in the normalized data, the as measured data, or both. A specimen may be an outlier for the batch only (before pooling the three batches within a condition together) or for the condition (after pooling the three batches within a condition together) or both.

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 themo9T4(r r2ut of 100 specim)8.7(e)-.528to the expected random

6. 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,” 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 Qualifciation 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