Report No: NCP-RP-2009-001 Rev B
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# Solvay (Formerly ACG) MTM45-1/ Style 6781 S2 Glass Qualification Statistical Analysis Report

## FAA Special Project Number: SP3505WI-Q

## NCAMP Report Number: NCP-RP-2009-001 Rev B

## Report Date: July 8, 2019


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| N/C | Elizabeth Clarkson | 06/07/2011 | Yeow Ng | Document Initial Release |
| A | Elizabeth Clarkson | 07/19/2011 | Yeow Ng | Corrected Eq. 13 and changed CBS units to lbs in table 3.4 (it was incorrectly stated as ksi) |
| B | Elizabeth Clarkson | 05/01/2013 | Yeow Ng | Removed 'working draft' from all references to CMH17 Rev G. Decimals increased to 3 digits in all tables. ETW2 modulus values added for WC, FC, and UNC test results. Corrected revision of purchasing spec for material. Corrections made to tables 3-2, 3-3, 3-4 and 4-3. |
| B | Elizabeth Clarkson | 07/08/2019 | Royal Lovingfoss | Updated Table 3-3 – set the column width wider to display WC strength mean value at CTD condition. |
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# 1. Introduction

This report contains statistical analysis of ACG - MTM45-1/ Style 6781 S2 Glass material property data published in NCAMP Test Report CAM-RP-2009-001 Rev C. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP3505WI-Q and also meet the requirements outlined in NCAMP Standard Operating Procedure NSP 100. The test panels, test specimens, and test setups have been conformed by the FAA and the testing has been witnessed by the FAA.

B-Basis values and estimates were calculated using a variety of techniques that are detailed in section two. Qualification material was procured in accordance with ACG material specification ACGM 1001-12 Revision I/R dated March 10, 2005. An equivalent NCAMP Material Specification NMS 451/12 which contains specification limits that are derived from guidelines in DOT/FAA/AR-03/19 has been created. The qualification test panels were fabricated per ACGP1001-02 Revision E "MH" cure cycle. An equivalent NCAMP Process Specification NPS 81451 with baseline "MH" cure cycle has been created. The ACG Test Plan AI/TR/1392 Revision E was used for this qualification program.

Basis numbers are labeled as 'values' when the data meets all the requirements of CMH-17 Revision 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 along with the specific requirement(s) the data fails to meet. The method used to compute the basis value is noted for each basis value provided. When appropriate, in addition to the tradition 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 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 and accuracy of NCAMP material property data, material allowables, and specifications must be evaluated on case-by-case basis by aircraft companies and certifying agencies. NCAMP assumes no liability whatsoever, expressed or implied, related to the use of the material property data, material allowables, and specifications.

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 this 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 Rev G. The applicability of equivalency process must be evaluated on 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 Rev G are adequate for the given program.

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 451/12. NMS 451/12 may 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 NCAMP Material Specification NMS 451/12.* NMS 451/12 is a free, publicly available, non-proprietary aerospace industry material specification.

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).

## 1.1 Symbols and Abbreviations

| Test Property | Abbreviation |
|---|---|
| Warp Compression | WC |
| Warp Tension | WT |
| Fill Compression | FC |
| Fill Tension | FT |
| In-Plane Shear | IPS |
| Short Beam Strength | SBS |
| Unnotched Tension | UNT |
| Unnotched Compression | UNC |
| Open Hole Tension | OHT |
| Open Hole Compression | OHC |
| Filled Hole Tension | FHT |
| Filled Hole Compression | FHC |
| Pin Bearing | PB |
| Interlaminar Tension | ILT |
| Curved Beam Strength | CBS |
| Compression After Impact | CAI |

**Table 1-1: Test Property Abbreviations**

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

**Table 1-2: Test Property Symbols**

| Environmental Condition | Abbreviation |
|---|---|
| Cold Temperature Dry (−65°F) | CTD |
| Room Temperature Dry (75°F) | RTD |
| Elevated Temperature Dry (200°F) | ETD |
| Elevated Temperature Wet (200°F) | ETW |
| Elevated Temperature Wet (250°F) | ETW2 |

**Table 1-3: Environmental Conditions Abbreviations**

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

1 = “Quasi-Isotropic” 25/50/25
2 = “Soft” 10/80/10
3 = “Hard” 40/20/40

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

Detailed information about the test methods and conditions used is given in NCAMP Test Report CAM-RP-2009-001 Rev C.

## 1.2 Pooling Across Environments

When pooling across environments was allowable, the pooled co-efficient of variation was used. ASAP (**A**GATE **S**tatistical **A**nalysis **P**rogram) 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 (section 1.4) based on the pooled data was used to compute the basis values.

When pooling across environments was not allowable, (i.e. the data failed the Anderson-Darling test or normality tests and engineering judgment indicated there was no justification for overriding the result), B-Basis values were computed for each environment separately using Stat17 version 5.

## 1.3 Basis Value Computational Process

The general form to compute engineering basis values is: 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.

## 1.4 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 Rev 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 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 will 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 requirements of CMH-17 Rev G 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.:** $$S = \sqrt{\tfrac{1}{n-1} \sum_{i=1}^{n} \left( X_i - \bar{X} \right)^2}$$ **Equation 2**

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

Where $n$ refers to the number of specimens in the sample

### 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.

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

### 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.

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

#### 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:

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

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

Where

r = the number of environments being pooled together

$n_j$ = number of data values for environment j

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

$$f = N - r$$

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

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

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

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

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

### 2.1.4 Modified Coefficient of Variation

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

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

This is converted to percent by multiplying by 100%.

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

$$S^* = CV^* \cdot \bar{X} \qquad \text{Equation 15}$$

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

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

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 data 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

Outliers are identified using the Maximum Normed Residual Test for Outliers as specified in section 8.3.3 of CMH-17 Rev G.

$$MNR = \frac{\max\limits_{all\ i} \left| X_i - \bar{X} \right|}{S}, \; i = 1 \ldots n \quad \textbf{Equation 23}$$

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

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 $z_{(1)}, z_{(2)}, \ldots z_{(L)}$, 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:

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

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:

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

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.

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

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 $\sigma^2$.

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

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

where $x_{(i)}$ is the smallest sample observation, $\overline{x}$ 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

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

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

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. ASAP 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.

## 2.2 STAT-17

This section contains the details of the specific formulas STAT-17 uses in its computations.

The basic descriptive statistics, the maximum normed residual (MNR) test for outliers, and the Anderson Darling K-sample test for batch variability are the same as with ASAP – see sections 2.1.1, 2.1.3.1, and 2.1.5.

Outliers must be dispositioned before checking any other test results. The results of the Anderson Darling k-Sample (ADK) Test for batch equivalency must be checked. If the data passes the ADK test, then the appropriate distribution is determined. If it does not pass the ADK test, then the ANOVA procedure is the only approach remaining that will result in basis values that meet the requirements of CMH-17 Rev G.

### 2.2.1 Distribution tests

In addition to testing for normality using the Anderson-Darling test (see 2.1.7); Stat17 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 $x_{(1)}, ..., x_{(n)}$.

## 2.2.2 Computing Normal Distribution Basis values

Stat17 uses a table of values for the k-factors (shown in Table 2-1) and a slightly different formula than ASAP to compute approximate k-values for the normal distribution when the sample size is larger than 15.

| 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 $1.282\sqrt{n}$ 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.

#### 2.2.2.2 One-sided A-basis tolerance factors, $k_A$, for the normal distribution

The exact computation of $k_B$ 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 $k_B$ 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.

#### 2.2.2.3 Two-parameter Weibull Distribution

A probability distribution for which the probability that a randomly selected observation from this population lies between *a* and *b* $\left(0 < a < b < \infty\right)$ 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 2.2.2.3.1). Calculations specific to the goodness-of-fit test for the Weibull distribution are provided in section 2.2.2.3.2.

##### 2.2.2.3.1 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:

$$\hat{\alpha}\hat{\beta}\mathrm{n} - \frac{\hat{\beta}}{\hat{\alpha}^{\hat{\beta}-1}}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x}_{\mathrm{i}}^{\hat{\beta}} = 0$$ **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**

Stat17 solves these equations numerically for $\hat{\beta}$ and $\hat{\alpha}$ 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

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

The Anderson-Darling test statistic is

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

and the observed significance level is

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

where

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

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 ≤ 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.

### 2.2.2.3.3 Basis value calculations for the Weibull distribution

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

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

where

$$\hat{q} = \hat{\alpha}(0.10536)^{1/\hat{\beta}} \qquad \textbf{Equation 43}$$

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

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

V is the value in Table 2-2 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 2-2: 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 $\left(0 < a < b < \infty\right)$ 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.

#### 2.2.2.4.1 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:

$$z_{(i)} = \frac{\ln(\overline{x}_{(i)}) - \overline{x}_L}{s_L}, \quad \text{for } i = 1,\ldots,n$$ **Equation 47**

where $x_{(i)}$ is the $i^{th}$ smallest sample observation, $\overline{x}_L$ 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 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.

#### 2.2.2.4.2 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 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 be transformed back to the original units by applying the inverse of the log transformation.

## 2.2.3 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.

#### 2.2.3.1 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:

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

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 values are 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.

### 2.2.4 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 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 2-3. 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 2-4. For a publishable A-basis value according to CMH-17 Rev G, 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 2-3: 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 2-4: A-Basis Hanson-Koopmans Table**

### 2.2.5 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.

#### 2.2.5.1 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 $\left(n_i, \bar{x}_i, s_i^2\right)$ 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:

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

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

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

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

Next, the mean sums of squares are computed:

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

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

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

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

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

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

Two k-factors are computed using the methodology of section 2.2.2 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

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

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

$$T = \frac{k_0 - \frac{k_1}{\sqrt{n'}} + (k_1 - k_0)\sqrt{\frac{u}{u+n'-1}}}{1 - \frac{1}{\sqrt{n'}}} \qquad \textbf{Equation 60}$$

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 batchs 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.

**Estimated B-Basis =** $\bar{X} - k_b S_{adj} = \bar{X} - k_b \cdot 0.08 \cdot \bar{X}$ **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 =** $\bar{X}_1 - K_{(N_1,N_2)} \cdot \bar{X}_1 \cdot \max\left(CV_1, CV_2\right)$ **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 =** $\bar{X}_1 - K_{(N_1,N_2)} \cdot \bar{X}_1 \cdot Max\left(8\%, CV_1, CV_2\right)$ **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)

$CV_2$ is the coefficient of variation of the lamina (large dataset)

$K_{(N_1,N_2)}$ is given in Table 2-5

| | N1 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N1+N2-2 | 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 | 2.686 | 2.473 | 2.348 | 2.265 | 2.204 | 2.158 | 2.122 | 2.092 | 2.067 | 2.046 | 2.028 | 2.012 | 1.999 | 1.986 |
| 19 | 2.673 | 2.459 | 2.335 | 2.251 | 2.191 | 2.144 | 2.108 | 2.078 | 2.053 | 2.032 | 2.013 | 1.998 | 1.984 | 1.971 |
| 20 | 2.661 | 2.447 | 2.323 | 2.239 | 2.178 | 2.132 | 2.095 | 2.065 | 2.040 | 2.019 | 2.000 | 1.984 | 1.970 | 1.958 |
| 21 | 2.650 | 2.437 | 2.312 | 2.228 | 2.167 | 2.121 | 2.084 | 2.053 | 2.028 | 2.007 | 1.988 | 1.972 | 1.958 | 1.946 |
| 22 | 2.640 | 2.427 | 2.302 | 2.218 | 2.157 | 2.110 | 2.073 | 2.043 | 2.018 | 1.996 | 1.978 | 1.962 | 1.947 | 1.935 |
| 23 | 2.631 | 2.418 | 2.293 | 2.209 | 2.148 | 2.101 | 2.064 | 2.033 | 2.008 | 1.987 | 1.968 | 1.952 | 1.938 | 1.925 |
| 24 | 2.623 | 2.410 | 2.285 | 2.201 | 2.139 | 2.092 | 2.055 | 2.025 | 1.999 | 1.978 | 1.959 | 1.943 | 1.928 | 1.916 |
| 25 | 2.616 | 2.402 | 2.277 | 2.193 | 2.132 | 2.085 | 2.047 | 2.017 | 1.991 | 1.969 | 1.951 | 1.934 | 1.920 | 1.907 |
| 26 | 2.609 | 2.396 | 2.270 | 2.186 | 2.125 | 2.078 | 2.040 | 2.009 | 1.984 | 1.962 | 1.943 | 1.927 | 1.912 | 1.900 |
| 27 | 2.602 | 2.389 | 2.264 | 2.180 | 2.118 | 2.071 | 2.033 | 2.003 | 1.977 | 1.955 | 1.936 | 1.920 | 1.905 | 1.892 |
| 28 | 2.597 | 2.383 | 2.258 | 2.174 | 2.112 | 2.065 | 2.027 | 1.996 | 1.971 | 1.949 | 1.930 | 1.913 | 1.899 | 1.886 |
| 29 | 2.591 | 2.378 | 2.252 | 2.168 | 2.106 | 2.059 | 2.021 | 1.990 | 1.965 | 1.943 | 1.924 | 1.907 | 1.893 | 1.880 |
| 30 | 2.586 | 2.373 | 2.247 | 2.163 | 2.101 | 2.054 | 2.016 | 1.985 | 1.959 | 1.937 | 1.918 | 1.901 | 1.887 | 1.874 |
| 40 | 2.550 | 2.337 | 2.211 | 2.126 | 2.063 | 2.015 | 1.977 | 1.946 | 1.919 | 1.897 | 1.877 | 1.860 | 1.845 | 1.832 |
| 50 | 2.528 | 2.315 | 2.189 | 2.104 | 2.041 | 1.993 | 1.954 | 1.922 | 1.896 | 1.873 | 1.853 | 1.836 | 1.820 | 1.807 |
| 60 | 2.514 | 2.301 | 2.175 | 2.089 | 2.026 | 1.978 | 1.939 | 1.907 | 1.880 | 1.857 | 1.837 | 1.819 | 1.804 | 1.790 |
| 70 | 2.504 | 2.291 | 2.164 | 2.079 | 2.016 | 1.967 | 1.928 | 1.896 | 1.869 | 1.846 | 1.825 | 1.808 | 1.792 | 1.778 |
| 80 | 2.496 | 2.283 | 2.157 | 2.071 | 2.008 | 1.959 | 1.920 | 1.887 | 1.860 | 1.837 | 1.817 | 1.799 | 1.783 | 1.769 |
| 90 | 2.491 | 2.277 | 2.151 | 2.065 | 2.002 | 1.953 | 1.913 | 1.881 | 1.854 | 1.830 | 1.810 | 1.792 | 1.776 | 1.762 |
| 100 | 2.486 | 2.273 | 2.146 | 2.060 | 1.997 | 1.948 | 1.908 | 1.876 | 1.849 | 1.825 | 1.805 | 1.787 | 1.771 | 1.757 |
| 125 | 2.478 | 2.264 | 2.138 | 2.051 | 1.988 | 1.939 | 1.899 | 1.867 | 1.839 | 1.816 | 1.795 | 1.777 | 1.761 | 1.747 |
| 150 | 2.472 | 2.259 | 2.132 | 2.046 | 1.982 | 1.933 | 1.893 | 1.861 | 1.833 | 1.809 | 1.789 | 1.770 | 1.754 | 1.740 |
| 175 | 2.468 | 2.255 | 2.128 | 2.042 | 1.978 | 1.929 | 1.889 | 1.856 | 1.828 | 1.805 | 1.784 | 1.766 | 1.750 | 1.735 |
| 200 | 2.465 | 2.252 | 2.125 | 2.039 | 1.975 | 1.925 | 1.886 | 1.853 | 1.825 | 1.801 | 1.781 | 1.762 | 1.746 | 1.732 |

**Table 2-5: B-Basis factors for small datasets using variability of corresponding large dataset**

# 3. Summary Tables

The basis values for all tests are summarized in the following tables. The recommended B-basis values all meet the requirements of CMH-17 Rev G and are compiled in Table 3-1 and Table 3-2. However, not all test data meets those requirements. All B-basis values and B-estimates of basis values are shown in the Table 3-3 and Table 3-4. When the data does not meet the requirements of CMH-17 Rev G, the basis values 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 computed without that modification are presented for all tests. The modified CV basis values are recommended for use when available.

## 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 3-1and Table 3-2 of recommended values.

1. Recommended values are NEVER estimates. Only B-basis values that meet all requirements of CMH-17 Rev G 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 Rev G recommends that no less than five batches be used when computing basis values with the ANOVA method.
5. Caution is recommended with B-basis values calculated from STAT17 when the B-basis value is 90% or more of the average value. Basis values of 90% or more of the mean value imply that the CV is unusually low and may not be conservative. Such values will be indicated.
6. If the data appear questionable (e.g. when the CTD-RTD-ETW trend of the basis values are 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 ACG - MTM45-1/ Style 6781 S2 Glass

**All B-basis values in this table meet the standards for publication in CMH-17G Handbook**
**Values are for normalized data unless otherwise noted**

### Lamina Strength Tests

| Environment | Statistic | WT | WC | FT | FC | SBS* | IPS* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.2% Offset | 5% Strain |
| CTD (-65°F) | B-basis | 84.675 | 92.394 | 79.525 | 78.047 | 10.925 | 6.402 | 10.856 |
| | Mean | 92.341 | 102.884 | 90.056 | 85.807 | 12.510 | 7.250 | 12.293 |
| | CV | 6.000 | 7.362 | 6.000 | 6.975 | 6.339 | 6.000 | 6.000 |
| RTD (75°F) | B-basis | 73.792 | 72.942 | NA:A | 61.268 | 8.791 | 4.808 | 8.090 |
| | Mean | 81.458 | 83.433 | 80.501 | 69.072 | 9.789 | 5.445 | 9.161 |
| | CV | 6.000 | 6.885 | 4.733 | 6.864 | 6.490 | 6.000 | 6.000 |
| ETD (200°F) | B-basis | | | | 51.982 | 6.836 | | |
| | Mean | | | | 59.702 | 7.876 | | |
| | CV | | | | 8.118 | 6.779 | | |
| ETW (200°F) | B-basis | 49.997 | 47.798 | NA:A | 39.962 | 6.064 | 2.981 | 4.977 |
| | Mean | 57.663 | 58.289 | 57.225 | 47.865 | 6.577 | 3.376 | 5.636 |
| | CV | 6.000 | 7.029 | 4.002 | 6.002 | 6.280 | 6.000 | 6.000 |
| ETW2 (250°F) | B-basis | 49.845 | NA:A | 49.057 | 33.189 | 4.486 | 2.353 | 4.034 |
| | Mean | 57.511 | 50.971 | 55.319 | 41.092 | 5.140 | 2.665 | 4.569 |
| | CV | 6.000 | 9.214 | 6.000 | 6.648 | 6.528 | 6.000 | 6.000 |

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,
Shaded empty boxes indicate that no test data is available for that property and condition.
* Data is as measured rather than normalized
** indicates the Stat17 B-basis value is greater than 90% of the mean value.

**Table 3-1: NCAMP recommended B-basis values for lamina test data**

## NCAMP Recommended B-basis Values for ACG - MTM45-1/ Style 6781 S2 Glass

**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 Tests

| Lay-up | ENV | Statistic | OHT | OHC | FHT | FHC | UNT | UNC | PB 2% Offset | LSBS* |
|---|---|---|---|---|---|---|---|---|---|---|
| 25/50/25 | CTD (-65˚F) | B-basis | 35.070 | | 36.268 | | 64.047 | | | |
| | | Mean | 38.931 | | 41.071 | | 72.416 | | | |
| | | CV | 6.000 | | 6.000 | | 6.000 | | | |
| | RTD (75˚F) | B-basis | 28.200 | 32.741 | NA:I | NA:I | 58.383** | 62.489 | 74.025 | 8.027 |
| | | Mean | 32.064 | 37.020 | 34.467 | 56.053 | 63.704 | 70.765 | 82.726 | 9.456 |
| | | CV | 6.000 | 6.000 | 1.969 | 2.256 | 6.000 | 6.000 | 6.005 | 4.960 |
| | ETW2 (250˚F) | B-basis | 21.490 | 20.732 | | 30.132 | NA:I | NA:A | 55.005 | 4.708** |
| | | Mean | 24.336 | 23.478 | | 35.208 | 46.686 | 39.732 | 63.819 | 5.107 |
| | | CV | 6.000 | 6.000 | | 7.485 | 1.701 | 5.611 | 7.612 | 6.009 |
| 10/80/10 | CTD (-65˚F) | B-basis | 33.527 | | | | | | | |
| | | Mean | 37.967 | | | | | | | |
| | | CV | 6.000 | | | | | | | |
| | RTD (75˚F) | B-basis | NA:I | NA:I | | | | | | |
| | | Mean | 30.844 | 31.557 | | | | | | |
| | | CV | 1.179 | 1.713 | | | | | | |
| | ETW2 (250˚F) | B-basis | NA:I | 17.464 | | | | | | |
| | | Mean | 20.076 | 20.142 | | | | | | |
| | | CV | 0.678 | 6.822 | | | | | | |
| 40/20/40 | CTD (-65˚F) | B-basis | 39.528 | | | | | | | |
| | | Mean | 44.694 | | | | | | | |
| | | CV | 6.000 | | | | | | | |
| | RTD (75˚F) | B-basis | NA:I | NA:I | | | | | | |
| | | Mean | 38.334 | 41.079 | | | | | | |
| | | CV | 2.367 | 1.278 | | | | | | |
| | ETW2 (250˚F) | B-basis | NA:I | 22.866 | | | | | | |
| | | Mean | 25.999 | 26.053 | | | | | | |
| | | CV | 1.923 | 6.276 | | | | | | |

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,
Shaded empty boxes indicate that no test data is available for that property and condition.
* Data is as measured rather than normalized
** indicates the Stat17 B-basis value is greater than 90% of the mean value.

**Table 3-2: Recommended B-basis values for laminate test data**

## 3.2 Lamina and Laminate Summary Tables

**ACG - MTM45-1/ 6781 S2 Glass Lamina Properties Summary**

| | |
|---|---|
| **Material:** | Advanced Composites Group - MTM45-1/ Style 6781 S2 Glass |
| **Prepreg:** | MTM45-1/6781-35%RW |
| **Fiber:** | JPS Glass (fabric)/AGY (fiber): SCG75 1/0 1.0Z 636 7636 |
| **Resin:** | MTM45-1 |
| **Material Specificaton:** | NCAMP Material Specification NMS 451/12 Material Specification |
| **Process Specification:** | NCAMP Process Specification NPS 81451 with baseline “MH” cure cycle |

**Tg(dry):** 391.47 °F **Tg(wet):** 341.86 °F **Tg METHOD: DMA (SRM 18-94)**

| | | | |
|---|---|---|---|
| **Date of fiber manufacture** | October 2005 - November 2005 | **Date of testing** | 07/11/2007 - 03/2009 |
| **Date of resin manufacture** | November 2005 - January 2006 | **Date of data submittal** | 3/27/2009 |
| **Date of prepreg manufacture** | November 2005 - January 2006 | **Date of analysis** | December 2008 - June 2009 |
| **Date of composite manufacture** | April 2006-September 2006 | | |

**LAMINA MECHANICAL PROPERTY B-BASIS SUMMARY**

**Data reported: As measured followed by normalized values in parentheses, normalizing tply: 0.0101 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 | | | RTD | | | ETD | | | ETW | | | ETW2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B-Basis | Modified CV B-basis | Mean | B-Basis | Modified CV B-basis | Mean | B-Basis | Modified CV B-basis | Mean | B-Basis | Modified CV B-basis | Mean | B-Basis | Modified CV B-basis | Mean |
| $F_1^{tu}$ (ksi) | 83.557 (88.033) | 81.970 (84.675) | 90.047 (92.341) | 67.589 (77.151) | 71.839 (73.792) | 79.916 (81.458) | | | | 53.432 (53.355) | 48.034 (49.997) | 56.111 (57.663) | 40.017 (43.043) | NA (49.845) | 56.182 (57.511) |
| $E_1^t$ (Msi) | | | 4.208 (4.315) | | | 4.136 (4.216) | | | | | | 3.798 (3.902) | | | 3.684 (3.772) |
| $F_2^{tu}$ (ksi) | 83.243 (83.609) | 77.856 (79.525) | 88.167 (90.056) | 51.835 (55.468) | 68.922 70.512 | 78.918 (80.501) | | | | 43.412 (46.278) | 49.282 50.531 | 56.073 (57.225) | 46.776 (47.580) | 47.975 (49.057) | 54.098 (55.319) |
| $E_2^t$ (Msi) | | | 4.058 (4.143) | | | 3.991 (4.071) | | | | | | 3.690 (3.766) | | | 3.533 (3.617) |
| $F_1^{cu}$ (ksi) | 61.357 (93.623) | (85.133) (92.394) | 100.033 (102.884) | 73.622 (74.172) | 72.453 (72.942) | 81.406 (83.433) | | | | 48.897 (49.028) | 47.729 (47.798) | 56.681 (58.289) | 18.164 (23.752) | NA NA | 49.767 (50.971) |
| $E_1^c$ (Msi) | | | 4.230 (4.350) | | | 4.117 (4.220) | | | | | | 3.980 (4.091) | | | 3.923 (4.020) |
| $\nu_{12}^c$ | | | 0.140 | | | 0.138 | | | | | | 0.116 | | | 0.101 |
| $F_2^{cu}$ (ksi) | 49.924 (79.019) | NA (78.047) | 83.226 (85.807) | 57.753 (62.245) | NA (61.268) | 67.078 (69.072) | 44.086 (52.949) | NA (51.982) | 57.852 (59.702) | 33.897 (40.951) | 39.935 (39.962) | 46.146 (47.865) | 35.369 (34.179) | 34.357 (33.189) | 39.821 (41.092) |
| $E_2^c$ (Msi) | | | 4.115 (4.245) | | | 3.901 (4.017) | | | 3.819 (3.943) | | | 3.815 (3.958) | | | 3.915 (4.038) |
| $\nu_{21}^c$ | | | 0.133 | | | 0.129 | | | 0.115 | | | 0.108 | | | 0.098 |
| $F_{12}^{s5\%}$ (ksi) | 11.246 | 10.856 | 12.293 | 8.322 | 8.090 | 9.161 | | | | 4.981 | 4.977 | 5.636 | 3.563 | 4.034 | 4.569 |
| $F_{12}^{s0.2\%}$ (ksi) | 7.070 | 6.402 | 7.250 | 5.159 | 4.808 | 5.445 | | | | 3.078 | 2.981 | 3.376 | 2.306 | 2.353 | 2.665 |
| $G_{12}^s$ (Msi) | | | 0.711 | | | 0.553 | | | | | | 0.341 | | | 0.268 |
| SBS (ksi) | 10.925 | NA | 12.510 | 8.791 | NA | 9.789 | 7.023 | 6.836 | 7.876 | 6.064 | NA | 6.577 | 4.151 | 4.486 | 5.140 |

**Table 3-3: Summary of Test Results for Lamina Data**

| | | |
|---|---|---|
| **Material:** | Advanced Composites Group - MTM45-1/ Style 6781 S2 Glass | **ACG MTM45-1/ 6781 S2 Glass Laminate Properties Summary** |
| **Prepreg:** | MTM45-1/6781-35%RW | |
| **Fiber:** | JPS Glass (fabric)/AGY (fiber): SCG75 1/0 1.0Z 636 7636 | |
| **Resin:** | MTM45-1 | |
| **Material Specificaton:** | NCAMP Material Specification NMS 451/12 Material Specification | |
| **Process Specification:** | NCAMP Process Specification NPS 81451 with baseline “MH” cure cycle | |

**Tg(dry):** 391.47 °F **Tg(wet):** 341.86 °F **Tg METHOD : DMA (SRM 18-94)**

| | | | |
|---|---|---|---|
| **Date of fiber manufacture** | October 2005 - November 2005 | **Date of testing** | 07/11/2007 - 03/2009 |
| **Date of resin manufacture** | November 2005 - January 2006 | **Date of data submittal** | 3/27/2009 |
| **Date of prepreg manufacture** | November 2005 - January 2006 | **Date of analysis** | December 2008 - June 2009 |
| **Date of composite manufacture** | April 2006-September 2006 | | |

**LAMINATE MECHANICAL PROPERTY B-BASIS SUMMARY**

**Data reported as normalized used a normalizing $t_{ply}$ of 0.0101 in**

Values shown in shaded boxes do not meet CMH17 Rev G requirements and are estimates only

These values may not be used for certification unless specifically allowed by the certifying agency

| Test | Property | Test Condition | Unit | Quasi Isotropic 25/50/25 B-basis | Quasi Isotropic 25/50/25 Mod. CV B-basis | Quasi Isotropic 25/50/25 Mean | "Soft" 10/80/10 B-basis | "Soft" 10/80/10 Mod. CV B-basis | "Soft" 10/80/10 Mean | "Hard" 40/20/40 B-basis | "Hard" 40/20/40 Mod. CV B-basis | "Hard" 40/20/40 Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OHT (normalized) | Strength | CTD | ksi | 37.910 | 35.070 | 38.931 | 36.832 | 33.527 | 37.967 | 38.608 | 39.528 | 44.694 |
| | | RTD | ksi | 31.040 | 28.200 | 32.064 | 28.826 | 25.682 | 30.844 | 35.880 | 32.056 | 38.334 |
| | | ETW | ksi | 23.224 | 20.341 | 24.430 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | 21.442 | 21.490 | 24.336 | 18.535 | 16.789 | 20.076 | 23.959 | 21.648 | 25.999 |
| OHC (normalized) | Strength | RTD | ksi | 34.227 | 32.741 | 37.020 | 27.748 | 26.275 | 31.557 | 36.121 | 34.204 | 41.079 |
| | | ETW | ksi | 22.966 | 21.898 | 26.299 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | 22.519 | 20.732 | 23.478 | 17.927 | 17.464 | 20.142 | 23.742 | 22.866 | 26.053 |
| UNT (normalized) | Strength | CTD | ksi | 68.086 | 64.047 | 72.416 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 3.422 | --- | --- | --- | --- | --- | --- |
| | Strength | RTD | ksi | 58.383 | NA | 63.704 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 3.129 | --- | --- | --- | --- | --- | --- |
| | Strength | ETW2 | ksi | 43.101 | 39.041 | 46.686 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 2.778 | --- | --- | --- | --- | --- | --- |
| UNC (normalized) | Strength | RTD | ksi | 67.838 | 62.489 | 70.765 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 3.299 | --- | --- | --- | --- | --- | --- |
| | Poisson's Ratio | | | --- | --- | 0.298 | --- | --- | --- | --- | --- | --- |
| | Strength | ETW | ksi | 40.864 | 38.963 | 46.794 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 3.092 | --- | --- | --- | --- | --- | --- |
| | Poisson's Ratio | | | --- | --- | 0.353 | --- | --- | --- | --- | --- | --- |
| | Strength | ETW2 | ksi | 27.817 | 34.462 | 39.732 | --- | --- | --- | --- | --- | --- |
| | Modulus | | Msi | --- | --- | 3.285 | --- | --- | --- | --- | --- | --- |
| | Poisson's Ratio | | | --- | --- | 0.362 | --- | --- | --- | --- | --- | --- |
| FHT (normalized) | Strength | CTD | ksi | 39.511 | 36.268 | 41.071 | --- | --- | --- | --- | --- | --- |
| | | RTD | ksi | 32.212 | 28.699 | 34.467 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FHC (normalized) | Strength | RTD | ksi | 49.287 | 46.672 | 56.053 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | 30.483 | 30.132 | 35.208 | --- | --- | --- | --- | --- | --- |
| Pin Bearing (normalized) | 2% Offset Strength | RTD | ksi | 75.707 | 74.025 | 82.726 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | 56.709 | 55.005 | 63.819 | --- | --- | --- | --- | --- | --- |
| LSBS (as meas) | Strength | RTD | ksi | 8.027 | NA | 9.456 | --- | --- | --- | --- | --- | --- |
| | | ETW | ksi | 5.561 | 5.312 | 6.380 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | 4.708 | NA | 5.107 | --- | --- | --- | --- | --- | --- |
| CAI (normalized) | Strength | RTD | ksi | --- | --- | 31.866 | --- | --- | --- | --- | --- | --- |
| ILT (as meas) | Strength | RTD | ksi | --- | --- | 6.130 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | ksi | --- | --- | 2.601 | --- | --- | --- | --- | --- | --- |
| CBS (as meas) | Strength | RTD | lbs | --- | --- | 251.245 | --- | --- | --- | --- | --- | --- |
| | | ETW2 | lbs | --- | --- | 102.965 | --- | --- | --- | --- | --- | --- |

**Table 3-4: Summary of Test Results for Laminate Data**

# 4. Lamina Test Results, 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 0 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 section 8.3.10 of CMH-17 Rev G.

## 4.1 Warp (0º) Tension Properties (WT)

The as measured and the normalized ETW2 data and the as measured RTD data did not pass the Anderson-Darling k-sample test (ADK test) for batch-to-batch variation. This means those datasets require the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. The normalized ETW2 data does pass the ADK test with the modified CV transform, so modified CV values are provided for that datasets. The as measured ETW2 data does not pass the ADK test even after the modified CV transform and it does not pass the normality test so no modified CV basis values or estimates can be provided.

The normalized CTD, RTD and ETW data could be pooled. Although the CTD and RTD data fail the normality test, the pooled dataset for those three conditions passes the normality test. There was one outlier, before pooling the batches but not after, in the as measured data from the RTD environment. It was on the low side of batch one. It was retained for this analysis.

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

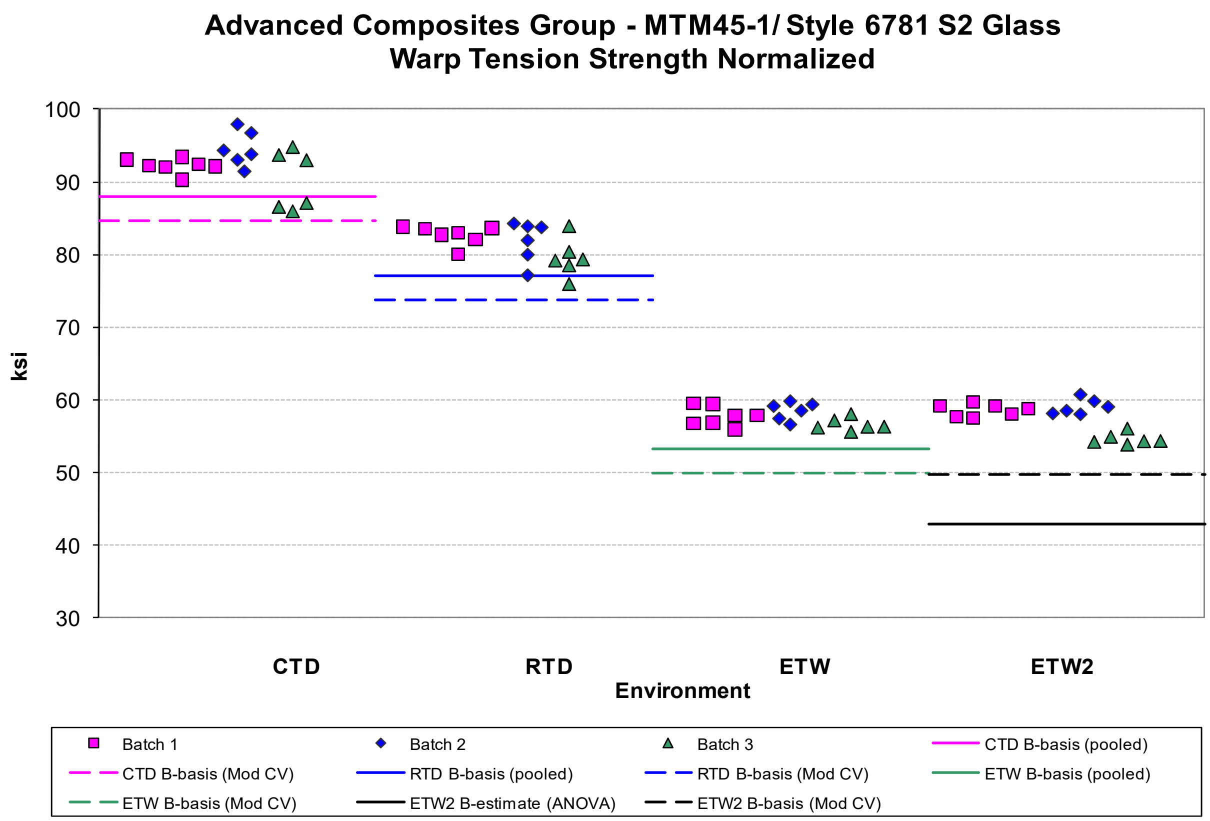


**Figure 4-1: Batch Plot for WT Strength normalized**

| Warp Tension Strength Basis Values and Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 92.341 | 81.458 | 57.663 | 57.511 | 90.047 | 79.916 | 56.111 | 56.182 |
| Stdev | 3.119 | 2.547 | 1.361 | 2.158 | 3.129 | 2.523 | 1.375 | 2.365 |
| CV | 3.377 | 3.127 | 2.360 | 3.751 | 3.475 | 3.157 | 2.450 | 4.209 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.105 |
| Min | 85.975 | 75.979 | 55.670 | 53.912 | 83.317 | 74.104 | 53.748 | 52.218 |
| Max | 98.000 | 84.330 | 59.868 | 60.784 | 94.341 | 82.985 | 58.827 | 59.223 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 88.033 | 77.151 | 53.355 | | 83.557 | | 53.432 | |
| B-estimate | | | | 43.043 | | 67.589 | | 40.017 |
| A-estimate | 85.145 | 74.263 | 50.468 | 32.714 | 76.620 | 58.796 | 51.530 | 28.477 |
| Method | pooled | pooled | pooled | ANOVA | Weibull | ANOVA | Normal | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 84.675 | 73.792 | 49.997 | 49.845 | 81.970 | 71.839 | 48.034 | NA |
| A-estimate | 79.594 | 68.712 | 44.917 | 44.765 | 76.556 | 66.425 | 42.620 | NA |
| Method | pooled | pooled | pooled | pooled | pooled | pooled | pooled | NA |

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

| Warp Tension Modulus Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 4.315 | 4.216 | 3.902 | 3.772 | 4.208 | 4.136 | 3.798 | 3.684 |
| Stdev | 0.043 | 0.024 | 0.038 | 0.028 | 0.061 | 0.056 | 0.070 | 0.059 |
| CV | 0.988 | 0.570 | 0.971 | 0.743 | 1.457 | 1.353 | 1.839 | 1.590 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 |
| Min | 4.243 | 4.185 | 3.807 | 3.721 | 4.098 | 3.994 | 3.653 | 3.604 |
| Max | 4.412 | 4.265 | 3.968 | 3.825 | 4.337 | 4.230 | 3.924 | 3.773 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |

Table 4-2: Statistics from WT modulus data

## 4.2 Warp (0º) Compression Properties (WC)

The as measured CTD and the as measured and normalized ETW2 data did not pass the Anderson-Darling k-sample test (ADK test) for batch-to-batch variation. This means those datasets require the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. These data sets did not pass with the modified CV transform of the data, so modified CV values are not provided for those datasets. An override of the ADK test results was not deemed appropriate due to the same batch (3) having the lowest mean value in all cases. Estimates based on the normal distribution and using the modified CV method are provided. Since the ETW2 datasets had a CV greater than 8%, the modified CV method could not be applied. Instead, estimates computed using normal distribution are provided for that condition.

The as measured RTD and ETW data could be pooled and for the normalized data, CTD, RTD and ETW could be pooled. There were no outliers.

Statistics, estimates and basis values are given for the WC strength data in Table 4-3. Statistics for the modulus data are given in Table 4-4. The normalized data, B-estimates and B-basis values and estimates are shown graphically in Figure 4-2.

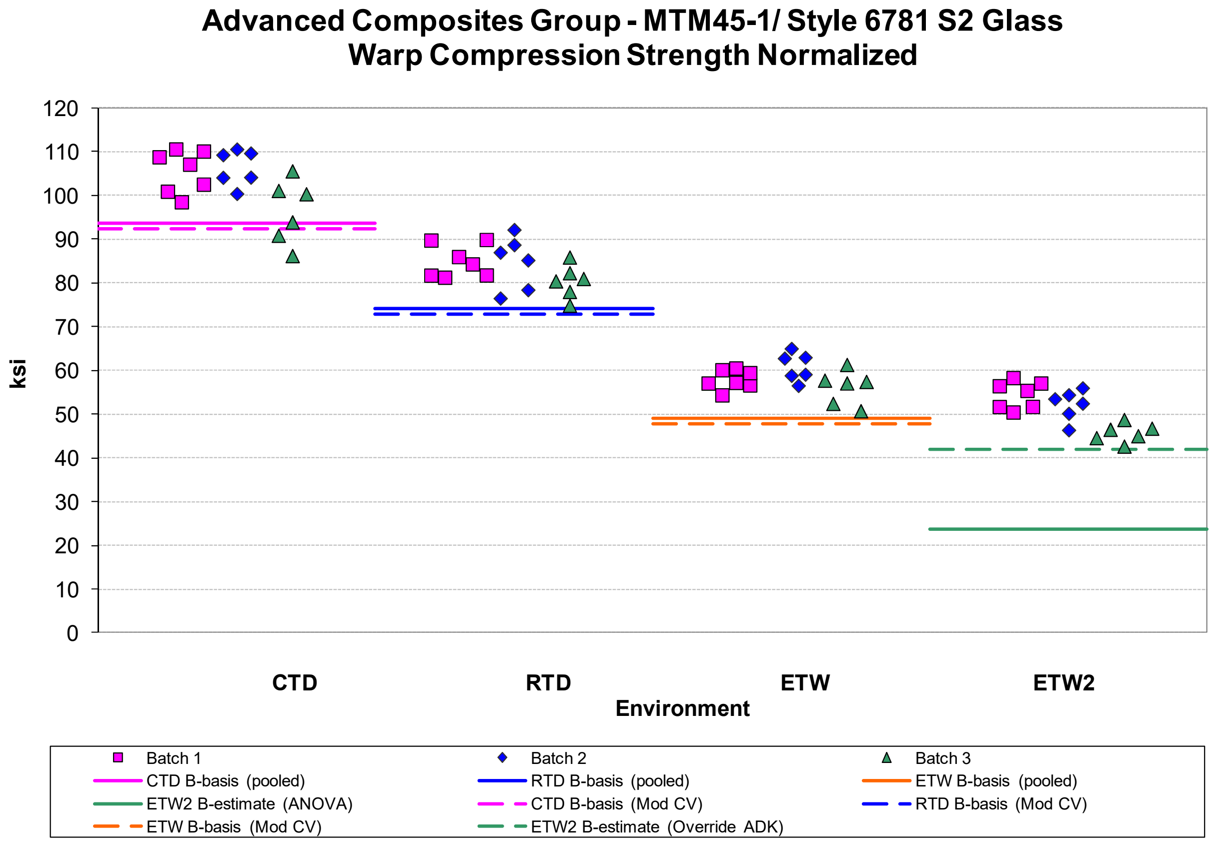


**Figure 4-2: Batch Plot for WC Strength normalized**

| Warp Compression Strength Basis Values and Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 102.884 | 83.433 | 58.289 | 50.971 | 100.033 | 81.406 | 56.681 | 49.767 |
| Stdev | 6.918 | 4.814 | 3.531 | 4.696 | 7.287 | 5.018 | 3.475 | 5.108 |
| CV | 6.724 | 5.770 | 6.058 | 9.214 | 7.285 | 6.164 | 6.130 | 10.263 |
| Mod CV | 7.362 | 6.885 | 7.029 | 9.214 | 7.642 | 7.082 | 7.065 | 10.263 |
| Min | 86.228 | 74.867 | 50.738 | 42.675 | 83.174 | 72.168 | 48.980 | 41.055 |
| Max | 110.577 | 92.168 | 64.994 | 58.342 | 110.032 | 90.015 | 62.312 | 58.007 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 93.623 | 74.172 | 49.028 | | | 73.622 | 48.897 | |
| B-estimate | | | | 23.752 | 61.357 | | | 18.164 |
| A-estimate | 87.415 | 67.964 | 42.820 | 4.328 | 33.762 | 68.304 | 43.579 | NA |
| Method | pooled | pooled | pooled | ANOVA | ANOVA | pooled | pooled | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 92.394 | 72.942 | 47.798 | | | 72.453 | 47.729 | |
| B-estimate | | | | | 85.133 | | | |
| A-estimate | 85.361 | 65.909 | 40.765 | | 74.568 | 66.337 | 41.612 | |
| Method | pooled | pooled | pooled | | Normal | pooled | pooled | |
| Override of ADK test | | | | | | | | |
| B-estimate | | | | 41.817 | | | | 39.811 |
| A-estimate | | | | 35.327 | | | | 32.752 |
| Method | | | | Normal | | | | Normal |

Table 4-3: Statistics, Basis Values and/or Estimates for WC Strength

| Warp Compression Modulus Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 4.350 | 4.220 | 4.091 | 4.020 | 4.230 | 4.117 | 3.980 | 3.923 |
| Stdev | 0.157 | 0.094 | 0.076 | 0.179 | 0.208 | 0.127 | 0.134 | 0.224 |
| CV | 3.611 | 2.225 | 1.867 | 4.456 | 4.914 | 3.083 | 3.360 | 5.714 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.228 | 6.457 | 6.000 | 6.000 | 6.857 |
| Min | 4.050 | 4.073 | 3.951 | 3.860 | 3.903 | 3.930 | 3.775 | 3.712 |
| Max | 4.556 | 4.354 | 4.203 | 4.707 | 4.537 | 4.351 | 4.184 | 4.734 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |

Table 4-4: Statistics from WC modulus data

## 4.3 Fill (90º) Tension Properties (FT)

The Fill Tension data is not suitable for pooling so single point analysis methods must be used. The analysis results for the normalized and as measured data were the same. Only the CTD data passed the ADK test. The RTD, ETW and ETW2 datasets did not pass the ADK test and require the ANOVA method to compute basis values, but with data from only three batches, these values are considered estimates and may result in overly conservative basis values. The ETW2 data failed the ADK test but passed with the modified CV transformation, so modified CV basis values are provided for the ETW2 data. The RTD and ETW data failed the ADK test even after the modified CV transform, but they did pass the normality test with that transform so B-estimates are provided for the RTD and ETW conditions.

There were two outliers for the normalized data, one of which was also an outlier for the as measured data. They were both from batch two, both on the high side and both were outliers before but not after pooling the three batches. One was in the CTD environment and it was the only outlier in the as measured data. The other was in the ETW2 environment.

Statistics, estimates and basis values are given for the FT strength data in Table 4-5. Statistics for the modulus data are shown in Table 4-6. The normalized data, B-estimates and B-basis values for the data are shown graphically Figure 4-3.

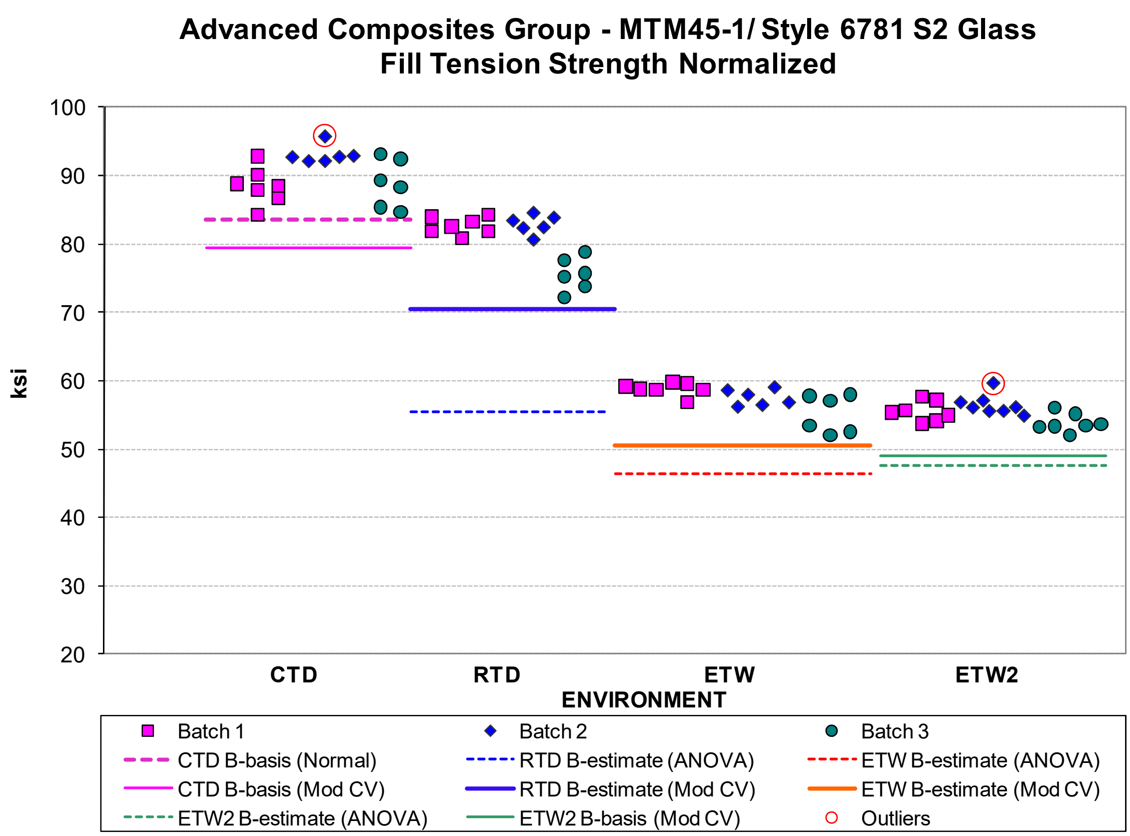


**Figure 4-3: Batch Plot for FT Strength normalized**

| Fill Tension Strength Basis Values and Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 90.056 | 80.501 | 57.225 | 55.319 | 88.167 | 78.918 | 56.073 | 54.098 |
| Stdev | 3.309 | 3.810 | 2.290 | 1.744 | 2.526 | 3.944 | 2.482 | 1.720 |
| CV | 3.674 | 4.733 | 4.002 | 3.152 | 2.866 | 4.998 | 4.427 | 3.179 |
| Mod CV | 6.000 | 6.367 | 6.001 | 6.000 | 6.000 | 6.499 | 6.213 | 6.000 |
| Min | 84.239 | 72.214 | 52.091 | 52.032 | 82.984 | 70.917 | 50.785 | 50.795 |
| Max | 95.810 | 84.598 | 59.769 | 59.615 | 92.947 | 83.630 | 59.080 | 57.269 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 22 | 19 | 19 | 19 | 22 |
| Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 83.609 | | | | 83.243 | | | |
| B-estimate | | 55.468 | 46.278 | 47.580 | | 51.835 | 43.412 | 46.776 |
| A-estimate | 79.030 | 37.598 | 38.471 | 42.055 | 79.747 | 32.500 | 34.380 | 41.547 |
| Method | Normal | ANOVA | ANOVA | ANOVA | Normal | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 79.525 | | | 49.057 | 77.856 | | | 47.975 |
| B-estimate | | 70.512 | 50.531 | | | 68.922 | 49.282 | |
| A-estimate | 72.057 | 63.429 | 45.786 | 44.587 | 70.546 | 61.833 | 44.467 | 43.603 |
| Method | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |

**Table 4-5: Statistics, Basis Values and/or Estimates for FT Strength data**

| Fill Tension Modulus Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 4.143 | 4.071 | 3.766 | 3.617 | 4.058 | 3.991 | 3.690 | 3.533 |
| Stdev | 0.053 | 0.054 | 0.071 | 0.081 | 0.083 | 0.080 | 0.083 | 0.098 |
| CV | 1.274 | 1.323 | 1.876 | 2.230 | 2.046 | 2.013 | 2.260 | 2.780 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 |
| Min | 4.068 | 4.005 | 3.673 | 3.469 | 3.926 | 3.861 | 3.534 | 3.365 |
| Max | 4.267 | 4.186 | 3.922 | 3.783 | 4.181 | 4.107 | 3.855 | 3.720 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 24 | 19 | 19 | 19 | 24 |

**Table 4-6: Statistics, Basis Values and/or Estimates for FT Modulus data**

## 4.4 Fill (90º) Compression Properties (FC)

The as measured CTD and ETW datasets did not pass the Anderson-Darling k-sample test (ADK test) for batch-to-batch variation. This means those datasets required the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. The ETW data passes the ADK test after the modified CV transform, so modified CV values are provided for that dataset.

The normalized data could be pooled. The only test failure was the ETD data which failed the normality test, but the pooled dataset did not so pooling was acceptable. The ETW and ETW2 datasets have only 16 specimens each. This is insufficient to produce data values using the single point method, but it is a sufficiently large sample when pooling can be used, so the normalized data, which is pooled, meet CMH-17 Rev G standards while the as measured data, which uses the single point method, must be considered estimates for those conditions.

The as measured data could not be pooled due to non-normality of the pooled dataset. Modified CV basis values could not be provided for the CTD, RTD and ETD datasets due to the non-normality of the datasets for those three conditions.

There was one outlier. It was in the ETD data, batch one on the high side and it was an outlier in both the normalized and as measured datasets. It was an outlier before pooling the three batches but not after. It was retained for this analysis.

Statistics and basis values are given for the FC strength data in Table 4-7. Statistics for the modulus data are given in Table 4-8. The normalized data and the B-basis values are shown graphically in Figure 4-4.

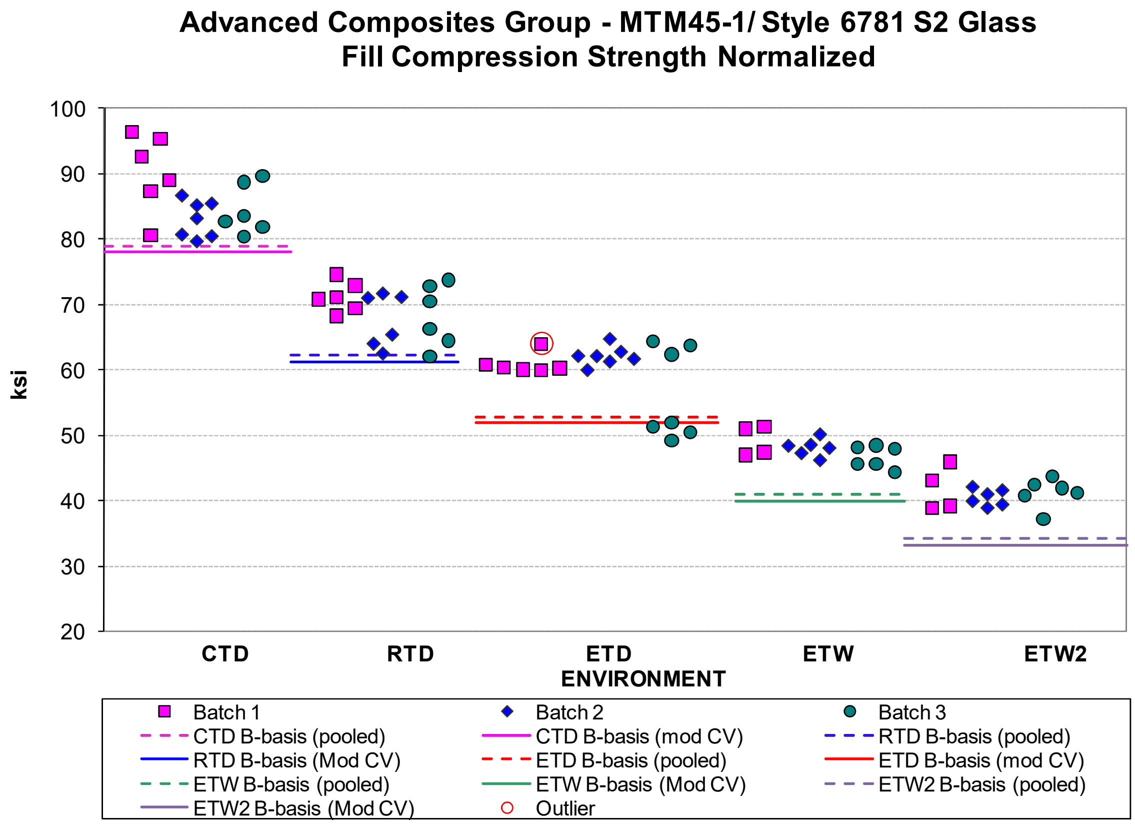


**Figure 4-4: Batch Plot for FC Strength normalized**

| Fill Compression Strength Basis Values and Statistics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | | As Measured | | | | |
| Env | CTD | RTD | ETD | ETW | ETW2 | CTD | RTD | ETD | ETW | ETW2 |
| Mean | 85.807 | 69.072 | 59.702 | 47.865 | 41.092 | 83.226 | 67.078 | 57.852 | 46.146 | 39.821 |
| Stdev | 5.105 | 3.956 | 4.846 | 1.917 | 2.176 | 5.860 | 4.135 | 5.032 | 2.417 | 2.188 |
| CV | 5.950 | 5.727 | 8.118 | 4.005 | 5.296 | 7.041 | 6.164 | 8.698 | 5.237 | 5.495 |
| Mod CV | 6.975 | 6.864 | 8.118 | 6.002 | 6.648 | 7.521 | 7.082 | 8.698 | 6.619 | 6.747 |
| Min | 79.760 | 62.086 | 49.180 | 44.339 | 37.151 | 76.858 | 59.927 | 46.818 | 41.907 | 35.902 |
| Max | 96.419 | 74.638 | 64.792 | 51.358 | 45.921 | 95.905 | 73.686 | 63.355 | 50.764 | 45.446 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 18 | 20 | 16 | 16 | 19 | 18 | 20 | 16 | 16 |
| Basis Values and/or Estimates | | | | | | | | | | |
| B-basis Value | 79.019 | 62.245 | 52.949 | 40.951 | 34.179 | | 57.753 | 44.086 | | |
| B-estimate | | | | | | 49.924 | | | 33.897 | 35.369 |
| A-estimate | 74.546 | 57.777 | 48.470 | 36.494 | 29.722 | 26.159 | 48.705 | 30.963 | 25.168 | 32.228 |
| Method | pooled | pooled | pooled | pooled | pooled | ANOVA | Weibull | Non-Parametric | ANOVA | Normal |
| Modified CV Basis Values and/or Estimates | | | | | | | | | | |
| B-basis Value | 78.047 | 61.268 | 51.982 | 39.962 | 33.189 | | NA | NA | | |
| B-estimate | | | | | | NA | | | 39.935 | 34.357 |
| A-estimate | 72.933 | 56.160 | 46.862 | 34.867 | 28.094 | NA | NA | NA | 35.565 | 30.512 |
| Method | pooled | pooled | pooled | pooled | pooled | NA | NA | NA | Normal | Normal |

**Table 4-7: Statistics, Basis Values and/or Estimates for FC Strength data**

| Fill Compression Modulus Statistics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | | As Measured | | | | |
| Env | CTD | RTD | ETD | ETW | ETW2 | CTD | RTD | ETD | ETW | ETW2 |
| Mean | 4.245 | 4.017 | 3.943 | 3.958 | 4.038 | 4.115 | 3.901 | 3.819 | 3.815 | 3.915 |
| Stdev | 0.184 | 0.085 | 0.064 | 0.052 | 0.205 | 0.202 | 0.120 | 0.111 | 0.107 | 0.243 |
| CV | 4.344 | 2.122 | 1.632 | 1.313 | 5.089 | 4.911 | 3.074 | 2.896 | 2.799 | 6.212 |
| Mod CV | 6.172 | 6.000 | 6.000 | 6.000 | 6.544 | 6.455 | 6.000 | 6.000 | 6.000 | 7.106 |
| Min | 3.769 | 3.815 | 3.812 | 3.890 | 3.708 | 3.611 | 3.682 | 3.654 | 3.687 | 3.526 |
| Max | 4.436 | 4.138 | 4.049 | 4.068 | 4.455 | 4.400 | 4.068 | 3.954 | 3.988 | 4.344 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 18 | 20 | 16 | 16 | 19 | 18 | 20 | 16 | 16 |

Table 4-8: Statistics from FC Modulus data

## 4.5 In-Plane Shear Properties (IPS)

For the strength at 5% strain measurements, all four environments fail the ADK test but pass with the modified CV transform.

This means those datasets require the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. All datasets did pass the normality test, and passed the ADK test under the modified CV transformation. While the pooled dataset passes Levene's test, the transformed pooled dataset does not, so pooling is not appropriate for the modified CV basis values.

For the 0.2% offset strength measurements, the CTD dataset passes the ADK test while the other three environments do not. As with the 5% strain measurements, all environments pass the ADK test with the modified CV transformation. This means the RTD, ETW and ETW2 datasets require the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. As with the 5% strain data, all datasets pass the normality test, and passed the ADK test under the modified CV transformation. After transformation of the data to fit the assumptions of the modified CV method, the pooled dataset does not pass Levene's test, so pooling is not appropriate for the modified CV basis values.

There were two outliers for the 0.2% offset strength data, one was on the low side of batch one in the CTD environment; this was an outlier before but not after pooling the three batches together. The other outlier was one the low side of batch two in the ETW2 environment. This was an outlier both before and after pooling the three batches together. Both outliers were retained for this analysis.

There were two outliers for the strength at 5% strain data. One was on the high side of batch one in the ETW environment; this was an outlier before but not after pooling the three batches together. The other outlier was one the high side of batch three in the ETW2 environment. This was an outlier both before and after pooling the three batches together. Both outliers were retained for this analysis.

Statistics, estimates and basis values are given for the IPS strength data in Table 4-9. Statistics for the modulus data are given in Table 4-10. The data, B-estimates and B-basis values for the 5% strain strength data are shown graphically in Figure 4-5 and for the 0.2% offset strength data in Figure 4-6 .

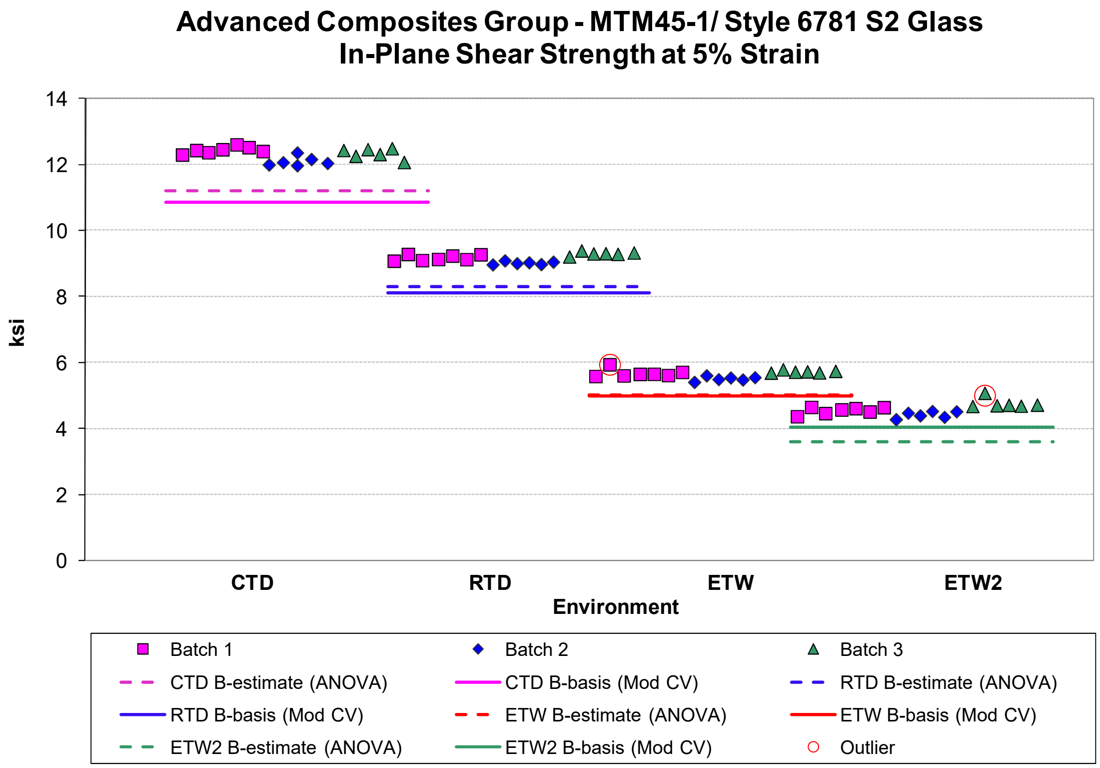


**Figure 4-5: Batch plot for IPS 5% Shear Strain**

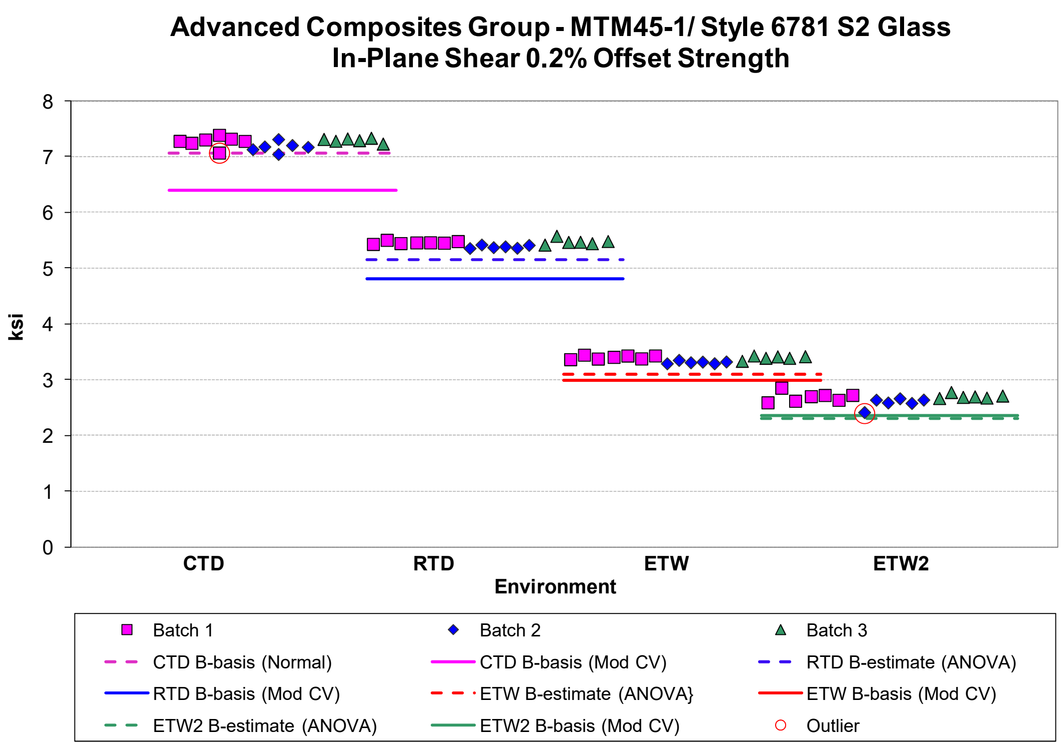


**Figure 4-6: Batch plot for IPS 0.2% Offset Strength**

| In-Plane Shear Strength Basis Values and Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Strength at 5% Strain | | | | 0.2% Offset Strength | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 12.293 | 9.161 | 5.636 | 4.569 | 7.250 | 5.445 | 3.376 | 2.665 |
| Stdev | 0.194 | 0.132 | 0.123 | 0.181 | 0.092 | 0.053 | 0.050 | 0.090 |
| CV | 1.579 | 1.441 | 2.183 | 3.972 | 1.273 | 0.974 | 1.487 | 3.360 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 |
| Min | 11.965 | 8.963 | 5.401 | 4.270 | 7.047 | 5.360 | 3.293 | 2.418 |
| Max | 12.598 | 9.385 | 5.936 | 5.072 | 7.390 | 5.579 | 3.448 | 2.855 |
| No. Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | | | | | 7.070 | | | |
| B-estimate | 11.246 | 8.322 | 4.981 | 3.563 | | 5.159 | 3.078 | 2.306 |
| A-estimate | 10.499 | 7.722 | 4.514 | 2.845 | 6.943 | 4.955 | 2.865 | 2.050 |
| Method | ANOVA | ANOVA | ANOVA | ANOVA | Normal | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values | | | | | | | | |
| B-basis Value | 10.856 | 8.090 | 4.977 | 4.034 | 6.402 | 4.808 | 2.981 | 2.353 |
| A-estimate | 9.836 | 7.330 | 4.509 | 3.656 | 5.801 | 4.357 | 2.701 | 2.132 |
| Method | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |

Table 4-9: Statistics, Basis Values and/or Estimates for IPS Strength data

| In-Plane Shear Modulus Statistics | | | | |
|---|---|---|---|---|
| Env | CTD | RTD | ETW | ETW2 |
| Mean | 0.711 | 0.553 | 0.341 | 0.268 |
| Stdev | 0.016 | 0.006 | 0.005 | 0.010 |
| CV | 2.256 | 1.067 | 1.500 | 3.679 |
| Mod CV | 6.000 | 6.000 | 6.000 | 6.000 |
| Min | 0.690 | 0.543 | 0.332 | 0.244 |
| Max | 0.763 | 0.563 | 0.349 | 0.288 |
| No. Batches | 3 | 3 | 3 | 3 |
| No. Spec. | 19 | 19 | 19 | 19 |

Table 4-10: Statistics from IPS Modulus data

## 4.6 Short Beam Strength Properties (SBS)

The ETW2 data did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means that dataset requires the ANOVA method to compute basis values which may result in overly conservative basis values. However, the ETW2 data does pass the normality test, and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset.

The CTD, RTD, ETW2 and pooled datasets fail the Anderson Darling normality test both before and after the modified CV transform. This means that pooling across environments is not appropriate and that the modified CV method cannot be used with those datasets. There were no outliers.

Statistics, estimates and basis values are given for the SBS data in Table 4-11. The data, B-estimates and B-basis values are shown in Figure 4-7.

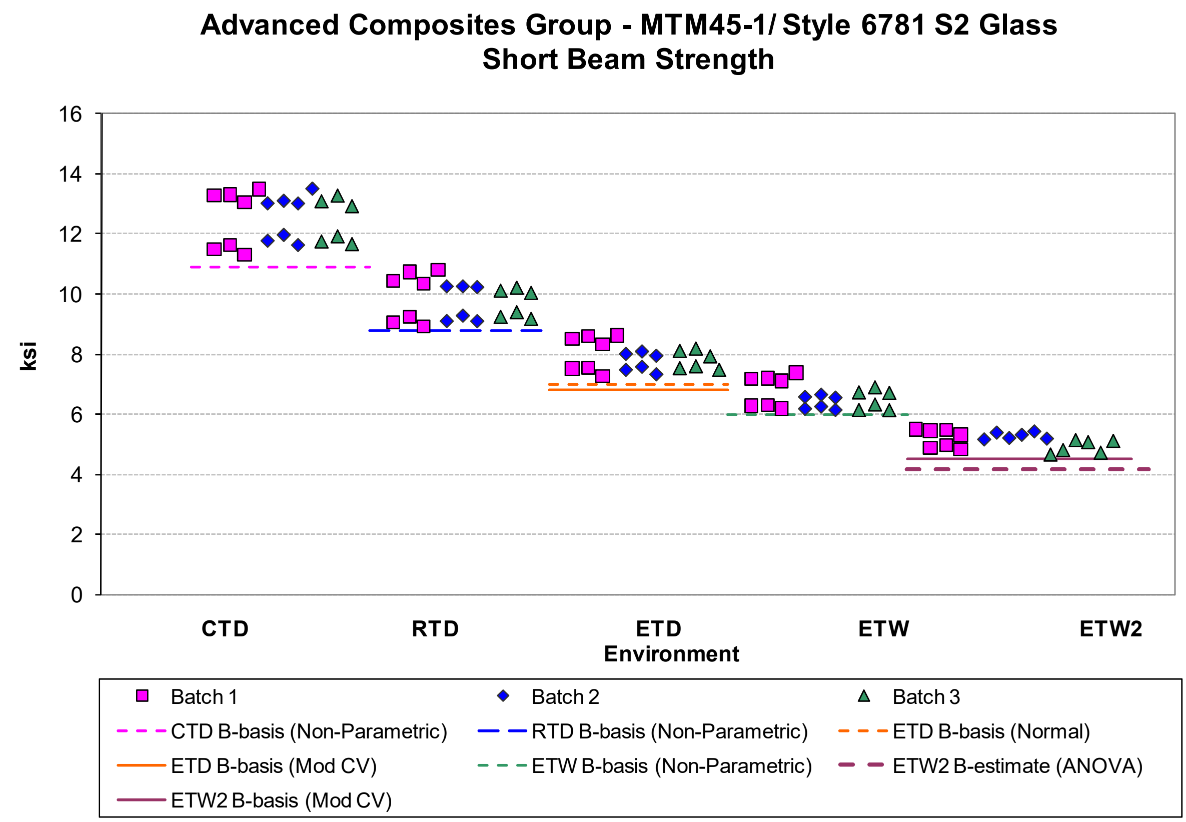


**Figure 4-7: Batch plot for SBS Strength**

| Short Beam Strength (SBS) as measured (ksi) | | | | | |
|---|---|---|---|---|---|
| Env | CTD | RTD | ETD | ETW | ETW2 |
| Mean | 12.510 | 9.789 | 7.876 | 6.577 | 5.140 |
| Stdev | 0.793 | 0.635 | 0.438 | 0.413 | 0.260 |
| CV | 6.339 | 6.490 | 5.557 | 6.280 | 5.055 |
| Mod CV | 7.169 | 7.245 | 6.779 | 7.140 | 6.528 |
| Min | 11.303 | 8.932 | 7.256 | 6.128 | 4.675 |
| Max | 13.504 | 10.815 | 8.623 | 7.385 | 5.504 |
| No. Batches | 3 | 3 | 3 | 3 | 3 |
| No. Spec. | 20 | 19 | 19 | 19 | 19 |
| Basis Values and/or Estimates | | | | | |
| B-basis Value | 10.925 | 8.791 | 7.023 | 6.064 | |
| B-estimate | | | | | 4.151 |
| A-estimate | 8.863 | 6.797 | 6.418 | 4.695 | 3.446 |
| Method | Non-Parametric | Non-Parametric | Normal | Non-Parametric | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | |
| B-basis Value | NA | NA | 6.836 | NA | 4.486 |
| A-estimate | NA | NA | 6.098 | NA | 4.022 |
| Method | NA | NA | Normal | NA | Normal |

**Table 4-11: Statistics, Basis Values and/or Estimates for SBS Strength data as measured**

# 5. Laminate Test Results, Statistics, Basis Values and Graphs

Many of the laminate tests were performed with one batch only. In those cases, there was insufficient data to produce basis values meeting the requirements of CMH-17 Rev G, so only estimates are provided. When possible, estimates were prepared in the following ways and multiple estimates are provided.

1. Using the ASAP program to pool across the available environments. The modified CV values from this program are provided.
2. The Lamina Variability method detailed in section 2.4. For properties that use the CV of the WC ETW2 or FC ETD datasets, modified CV values are not available due to the large CV (over 8%) of those datasets.

## 5.1 Quasi Isotropic Unnotched Tension Properties (UNT1)

The pooled dataset failed the Anderson Darling normality test so pooling across the environments is not appropriate for the normalized data. The RTD data did not fit the normal, Weibull or lognormal distribution, so the non-parametric method of computing basis values was employed. Due to the non-normality of the data, modified CV values were not provided.

The as measured RTD data did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means that dataset requires the ANOVA method to compute basis values which may result in overly conservative basis values. However, the as measured RTD data does pass the normality test, and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset. Pooling across environments is acceptable for the as measured values using the modified CV method.

There were two outliers. One in the CTD environment, batch 3 on the low side. This was an outlier before, but not after, pooling batches and was an outlier for the as measured data only. The other outlier was in the ETW2 data. It was an outlier in both the normalized and the as measured data.

Statistics, estimates and basis values are given for the UNT1 strength data in Table 5-1. Statistics for the modulus data are given in Table 5-2. The normalized data, B-estimates and B-basis values are shown in Figure 5-1.

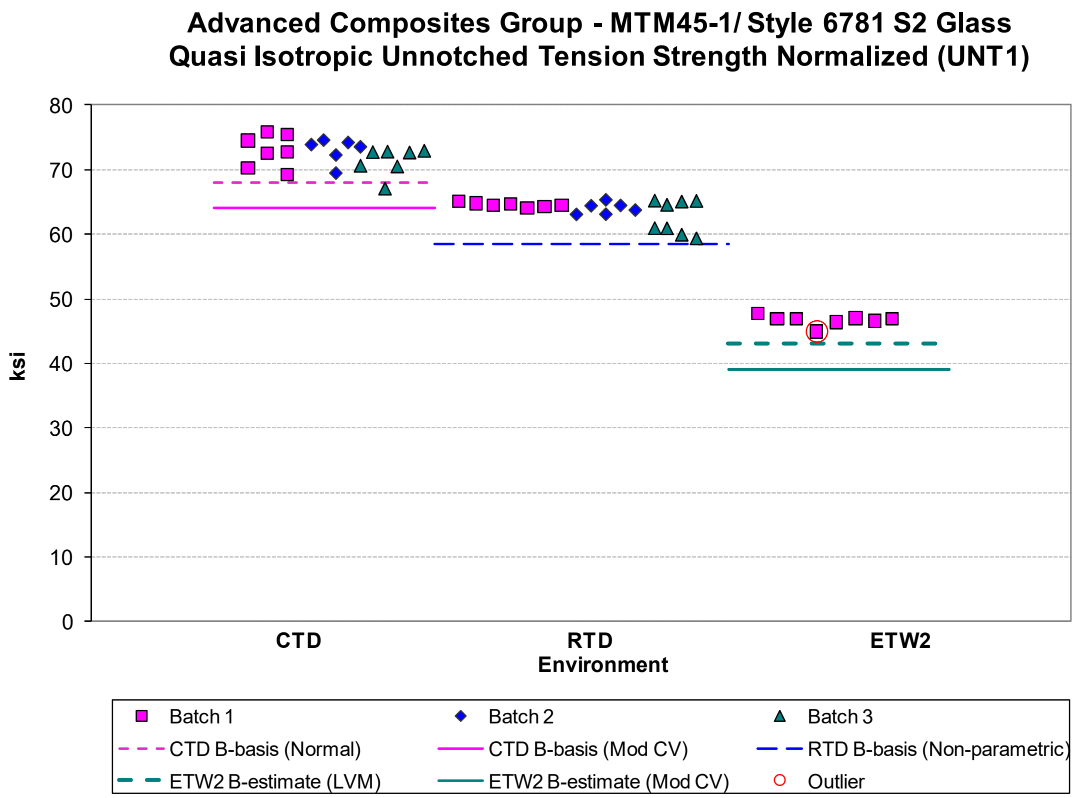


**Figure 5-1: Batch plot for UNT1 Strength normalized**

| Unnotched Tension (UNT1) Strength Basis Values and Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | CTD | RTD | ETW2 | CTD | RTD | ETW2 |
| Mean | 72.416 | 63.704 | 46.686 | 70.316 | 61.790 | 46.224 |
| Stdev | 2.249 | 1.798 | 0.794 | 2.474 | 2.467 | 0.976 |
| CV | 3.105 | 2.822 | 1.701 | 3.518 | 3.993 | 2.111 |
| Modified CV | 6.000 | 6.000 | 8.000 | 6.000 | 6.000 | 6.000 |
| Min | 67.107 | 59.425 | 44.979 | 65.084 | 57.206 | 44.142 |
| Max | 75.903 | 65.367 | 47.757 | 75.169 | 65.095 | 47.639 |
| No. Batches | 3 | 3 | 1 | 3 | 3 | 1 |
| No. Spec. | 20 | 21 | 8 | 20 | 21 | 8 |
| Basis Values and/or Estimates | | | | | | |
| B-basis Value | 68.086 | 58.383 | | 65.552 | | |
| B-estimate | | | 43.101 | | 48.810 | 42.241 |
| A-estimate | 65.004 | 52.445 | NA | 62.162 | 39.544 | NA |
| Method | Normal | Non-Parametric | LVM | Normal | ANOVA | LVM |
| Modified CV Basis Values and/or Estimates | | | | | | |
| B-basis Value | 64.047 | NA | | 63.601 | 55.104 | |
| B-estimate | | | 39.041 | | | 38.756 |
| A-estimate | 58.098 | NA | NA | 59.038 | 50.535 | 34.311 |
| Method | Normal | NA | LVM | pooled | pooled | pooled |

Table 5-1: Statistics, Basis Values and/or Estimates for UNT1 Strength data

| Unnotched Tension (UNT1) Modulus Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | CTD | RTD | ETW2 | CTD | RTD | ETW2 |
| Mean | 3.422 | 3.129 | 2.778 | 3.323 | 3.034 | 2.751 |
| Stdev | 0.056 | 0.043 | 0.062 | 0.081 | 0.080 | 0.077 |
| CV | 1.638 | 1.381 | 2.240 | 2.424 | 2.621 | 2.813 |
| Modified CV | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 |
| Min | 3.333 | 3.068 | 2.669 | 3.199 | 2.932 | 2.619 |
| Max | 3.544 | 3.240 | 2.854 | 3.510 | 3.174 | 2.843 |
| No. Batches | 3 | 3 | 1 | 3 | 3 | 1 |
| No. Spec. | 20 | 21 | 8 | 20 | 21 | 8 |

Table 5-2: Statistics from UNT1 Modulus Data

## 5.2 Quasi Isotropic Unnotched Compression Properties (UNC1)

The as measured data for both the RTD and ETW2 environments did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means those datasets require the ANOVA method to compute basis values which may result in overly conservative basis values. However, the as measured RTD data does pass the normality test, and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset.

The normalized ETW2 fails ADK test before and after the modified CV transform, so ANOVA values are provided for that dataset. The ETW2 data did pass the normality test, so estimates based on the normal distribution and using the modified CV method are provided.

There were three outliers, all in the ETW2 environment: batch 1 on the high side for both normalized and as measured datasets, batch 2 on the high side for the normalized data only, and batch 3 on the high side for both normalized and as measured datasets. All three were outliers before but not after pooling the three batches.

Statistics, estimates and basis values are given for the UNC1 strength data in Table 5-3. Modulus statistics are given in Table 5-4. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-2.

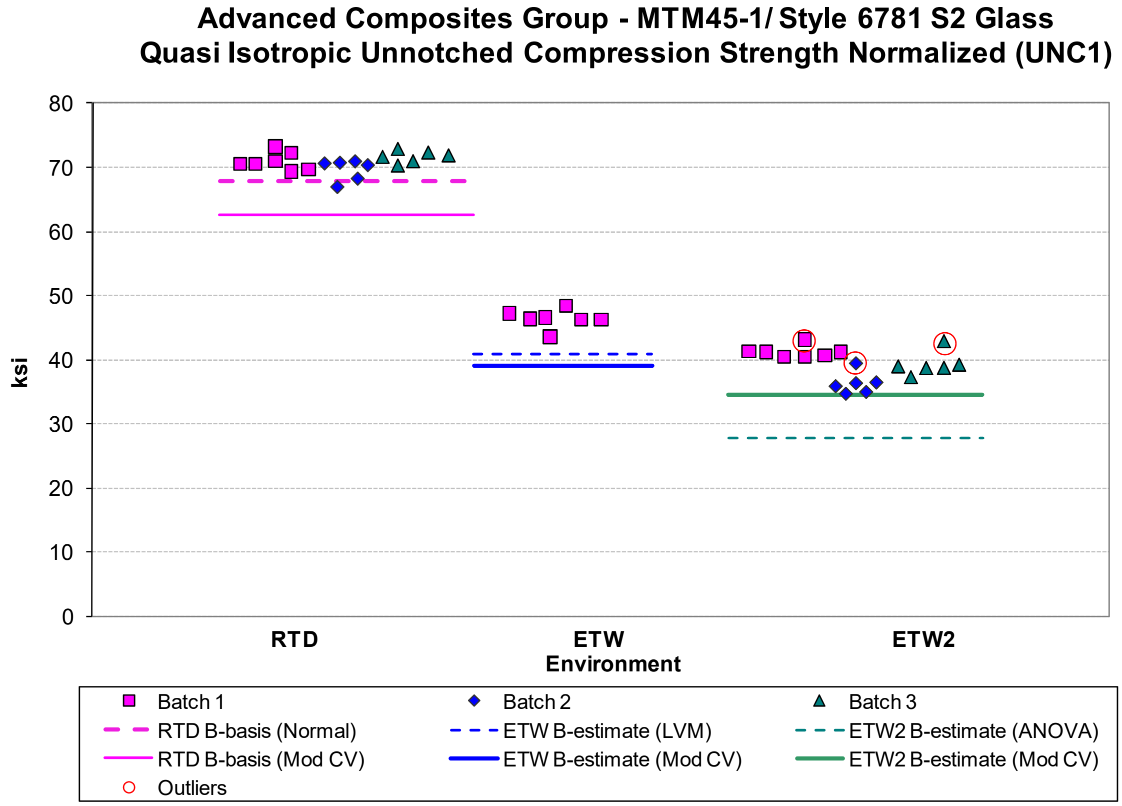


**Figure 5-2: Batch plot for UNC1 Strength normalized**

| Unnotched Compression (UNC1) Strength Basis Values and Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | RTD | ETW | ETW2 | RTD | ETW | ETW2 |
| Mean | 70.765 | 46.794 | 39.732 | 69.882 | 46.387 | 39.068 |
| Stdev | 1.502 | 1.447 | 2.229 | 1.919 | 1.458 | 2.502 |
| CV | 2.122 | 3.093 | 5.611 | 2.746 | 3.142 | 6.405 |
| Modified CV | 6.000 | 8.000 | 6.806 | 6.000 | 8.000 | 7.202 |
| Min | 67.016 | 43.912 | 36.149 | 64.884 | 43.547 | 34.795 |
| Max | 73.207 | 48.652 | 43.562 | 73.017 | 48.366 | 43.162 |
| No. Batches | 3 | 1 | 3 | 3 | 1 | 3 |
| No. Spec. | 19 | 7 | 19 | 19 | 7 | 19 |
| Basis Values and/or Estimates | | | | | | |
| B-basis Value | 67.838 | | | | | |
| B-estimate | | 40.864 | 27.817 | 60.226 | 40.438 | 24.345 |
| A-estimate | 65.759 | NA | 19.316 | 53.338 | NA | 13.838 |
| Method | Normal | LVM | ANOVA | ANOVA | LVM | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | | |
| B-basis Value | 62.489 | | | 61.710 | | |
| B-estimate | | 38.963 | 34.462 | | 38.623 | 33.584 |
| A-estimate | 56.621 | NA | 30.725 | 55.915 | NA | 29.695 |
| Method | Normal | LVM | Normal | Normal | LVM | Normal |

Table 5-3: Statistics, Basis Values and/or Estimates for UNC1 Strength data

| Unnotched Compression (UNC1) Modulus Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | RTD | ETW | ETW2 | RTD | ETW | ETW2 |
| Mean | 3.299 | 3.092 | 3.285 | 3.258 | 3.065 | 3.228 |
| Stdev | 0.101 | 0.082 | 0.208 | 0.107 | 0.087 | 0.199 |
| CV | 3.049 | 2.636 | 6.340 | 3.297 | 2.837 | 6.179 |
| Modified CV | 6.000 | 6.000 | 7.170 | 6.000 | 6.000 | 7.089 |
| Min | 3.079 | 2.966 | 2.752 | 3.057 | 2.934 | 2.702 |
| Max | 3.443 | 3.231 | 3.614 | 3.411 | 3.212 | 3.578 |
| No. Batches | 3 | 1 | 3 | 3 | 1 | 3 |
| No. Spec. | 19 | 7 | 19 | 19 | 7 | 19 |

Table 5-4: Statistics from UNC1 Modulus data

## 5.3 Laminate Short Beam Strength Properties (LSBS)

The RTD data and the ETW2 data both fail the Anderson Darling normality test so pooling across the environments is not appropriate. The RTD data did not fit the Weibull or lognormal distribution well enough to use either of them, so the non-parametric method of computing basis values was employed. The Weibull distribution provided an acceptable fit to the ETW2 data. Modified CV values are not provided due to the non-normality of the data. There was one outlier in the ETW data on the high side.

Statistics, estimates and basis values are given for the LSBS strength data in Table 5-5. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-3.

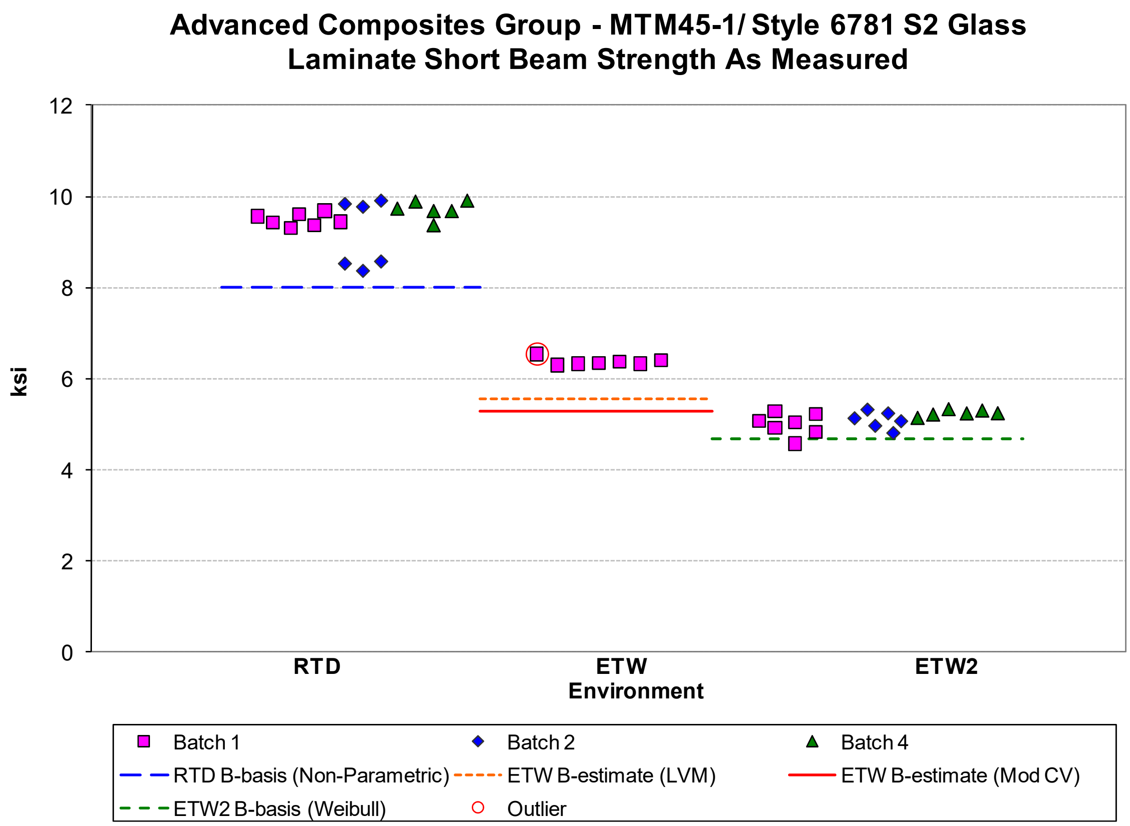


**Figure 5-3: Batch plot for LSBS Strength as measured**

| Laminate Short Beam Strength (LSBS) as measured (ksi) | | | |
|---|---|---|---|
| Env | RTD | ETW | ETW2 |
| Mean | 9.456 | 6.380 | 5.107 |
| Stdev | 0.469 | 0.080 | 0.205 |
| CV | 4.960 | 1.257 | 4.018 |
| Modified CV | 6.480 | 8.000 | 6.009 |
| Min | 8.368 | 6.305 | 4.578 |
| Max | 9.908 | 6.545 | 5.334 |
| No. Batches | 3 | 1 | 3 |
| No. Spec. | 19 | 7 | 19 |
| **Basis Values and/or Estimates** | | | |
| B-basis Value | 8.027 | | 4.708 |
| B-estimate | | 5.561 | |
| A-estimate | 6.575 | NA | 4.283 |
| Method | Non-Parametric | LVM | Weibull |
| **Modified CV Basis Values and/or Estimates** | | | |
| B-estimate | NA | 5.312 | NA |
| A-estimate | NA | NA | NA |
| Method | NA | LVM | NA |

**Table 5-5: Statistics, Basis Values and/or Estimates for LSBS Strength data**

## 5.4 Open Hole Tension Properties (OHT1, OHT2, OHT3)

### 5.4.1 Quasi Isotropic Open Hole Tension (OHT1)

The normalized ETW2 data did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means the ETW2 dataset requires the ANOVA method to compute basis values which may result in overly conservative basis values. However, the data does pass the normality test and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset. Pooling across environments was acceptable for the normalized CTD and RTD environments.

The as measured CTD and ETW2 environments failed ADK test but passed with the modified CV transform, so the modified CV values are provided in addition to the basis values computed using the ANOVA method. Pooling was not acceptable as the pooled transformed data failed both the normality test and Levene's test for equality of variance.

The ETW environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There were two outliers, both in the RTD environment. One was on the low side of batch two. This was an outlier in the as measured data but not the normalized data. The other was on the low side of batch three. This was an outlier in both the normalized and the as measured datasets. Both were outliers before but not after pooling the three batches.

Statistics, estimates and basis values are given for the OHT1strength data in Table 5-6. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-4.

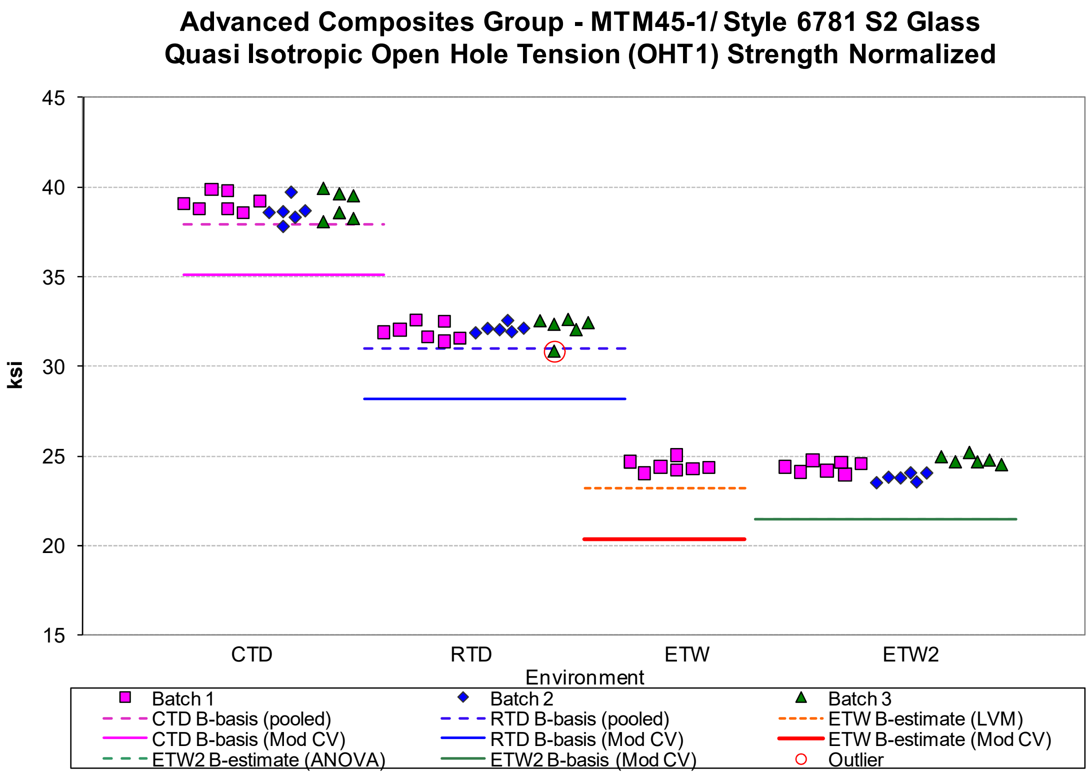


**Figure 5-4: Batch plot for OHT1 Strength normalized**

| Open Hole Tension (OHT1) Strength Basis Values and Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Normalized | | | | As Measured | | | |
| Env | CTD | RTD | ETW | ETW2 | CTD | RTD | ETW | ETW2 |
| Mean | 38.931 | 32.064 | 24.430 | 24.336 | 37.812 | 31.078 | 24.258 | 23.638 |
| Stdev | 0.651 | 0.465 | 0.330 | 0.472 | 0.851 | 0.523 | 0.318 | 0.532 |
| CV | 1.673 | 1.451 | 1.351 | 1.941 | 2.251 | 1.684 | 1.312 | 2.250 |
| Modified CV | 6.000 | 6.000 | 8.000 | 6.000 | 6.000 | 6.000 | 8.000 | 6.000 |
| Min | 37.789 | 30.851 | 24.045 | 23.538 | 36.494 | 29.692 | 23.809 | 22.555 |
| Max | 39.935 | 32.618 | 25.034 | 25.198 | 39.819 | 32.029 | 24.826 | 24.658 |
| No. Batches | 3 | 3 | 1 | 3 | 3 | 3 | 1 | 3 |
| No. Spec. | 19 | 19 | 7 | 19 | 19 | 19 | 7 | 19 |
| Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 37.910 | 31.040 | | | | 29.262 | | |
| B-estimate | | | 23.224 | 21.442 | 33.436 | | 23.015 | 20.627 |
| A-estimate | 37.210 | 30.350 | NA | 19.377 | 30.314 | 26.646 | NA | 18.478 |
| Method | pooled | pooled | LVM | ANOVA | ANOVA | Non-Parametric | LVM | ANOVA |
| Modified CV Basis Values and/or Estimates | | | | | | | | |
| B-basis Value | 35.070 | 28.200 | | 21.490 | 33.390 | NA | | 20.874 |
| B-estimate | | | 20.341 | | | | 20.198 | |
| A-estimate | 32.440 | 25.570 | NA | 19.472 | 30.254 | NA | NA | 18.914 |
| Method | pooled | pooled | LVM | Normal | Normal | NA | LVM | Normal |

**Table 5-6: Statistics, Basis Values and/or Estimates for OHT1 Strength data**

### 5.4.2 "Soft" Open Hole Tension 2 (OHT2)

The as measured CTD data did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means the as measured CTD dataset requires the ANOVA method to compute basis values which may result in overly conservative basis values. However, the data does pass the normality test and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset. There were no outliers.

The RTD and ETW2 environments had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

Statistics, estimates and basis values are given for the OHT2 strength data in Table 5-7. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-5.

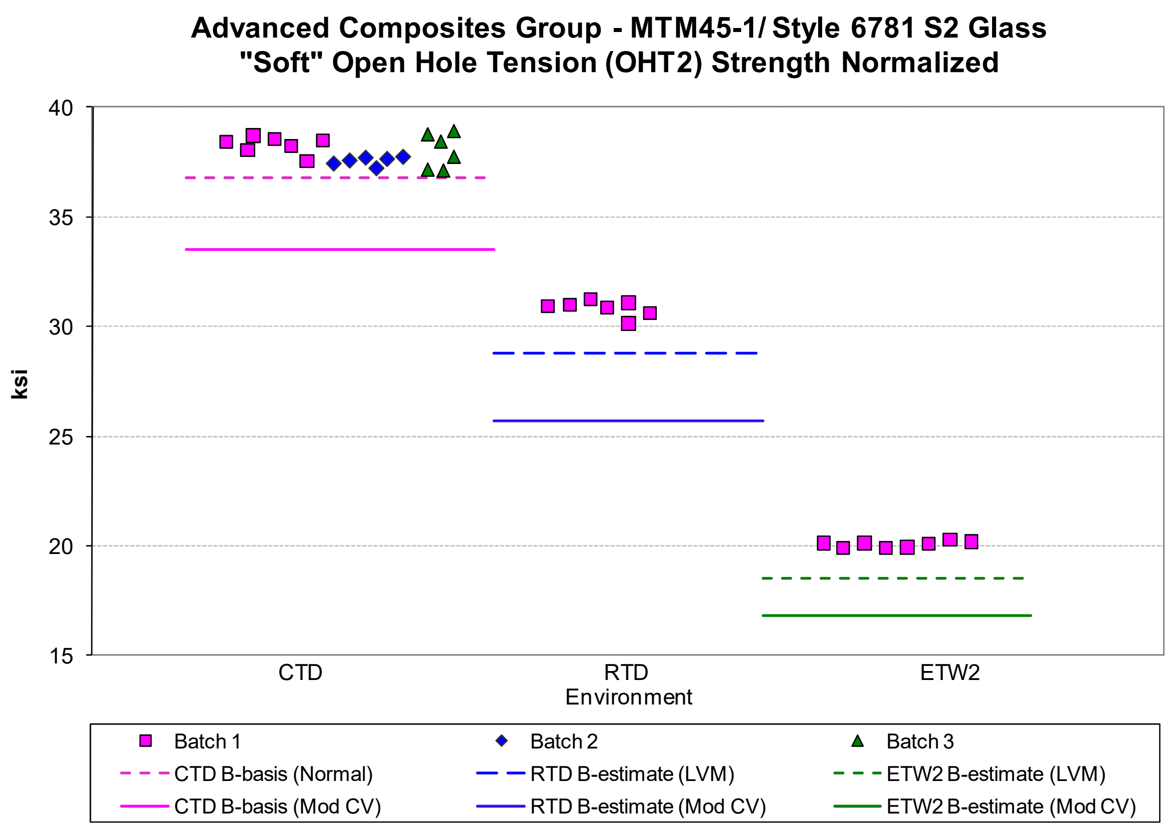


**Figure 5-5: Batch plot for OHT2 Strength normalized**

| Open Hole Tension (OHT2) Strength Basis Values and Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | CTD | RTD | ETW2 | CTD | RTD | ETW2 |
| Mean | 37.967 | 30.844 | 20.076 | 36.871 | 30.397 | 19.602 |
| Stdev | 0.583 | 0.364 | 0.136 | 0.695 | 0.258 | 0.206 |
| CV | 1.534 | 1.179 | 0.678 | 1.884 | 0.849 | 1.051 |
| Modified CV | 6.000 | 8.000 | 8.000 | 6.000 | 8.000 | 8.000 |
| Min | 37.144 | 30.150 | 19.920 | 35.657 | 29.946 | 19.284 |
| Max | 38.927 | 31.238 | 20.283 | 38.006 | 30.801 | 19.911 |
| No. Batches | 3 | 1 | 1 | 3 | 1 | 1 |
| No. Spec. | 19 | 7 | 8 | 19 | 7 | 8 |
| Basis Values and/or Estimates | | | | | | |
| B-basis Value | 36.832 | | | | | |
| B-estimate | | 28.826 | 18.535 | 33.502 | 28.389 | 17.913 |
| A-estimate | 36.026 | NA | NA | 31.099 | NA | NA |
| Method | Normal | LVM | LVM | ANOVA | LVM | LVM |
| Modified CV Basis Values and/or Estimates | | | | | | |
| B-basis Value | 33.527 | | | 32.559 | | |
| B-estimate | | 25.682 | 16.789 | | 25.309 | 16.392 |
| A-estimate | 30.379 | NA | NA | 29.502 | NA | NA |
| Method | Normal | LVM | LVM | Normal | LVM | LVM |

Table 5-7: Statistics, Basis Values and/or Estimates for OHT2 Strength data

### 5.4.3 "Hard" Open Hole Tension 3 (OHT3)

The normalized and the as measured CTD data did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means the CTD data requires the ANOVA method to compute basis values, but with data from only three batches, these values are considered estimates and may result in overly conservative basis values. Both the normalized and as measured CTD data passes the ADK test and the normality test under the modified CV transformation, so modified CV basis values are provided. The RTD and ETW2 environments had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There were no outliers. Statistics, estimates and basis values are given for the OHT3 strength data in Table 5-8. The normalized data and B-estimates values are shown graphically in Figure 5-6.

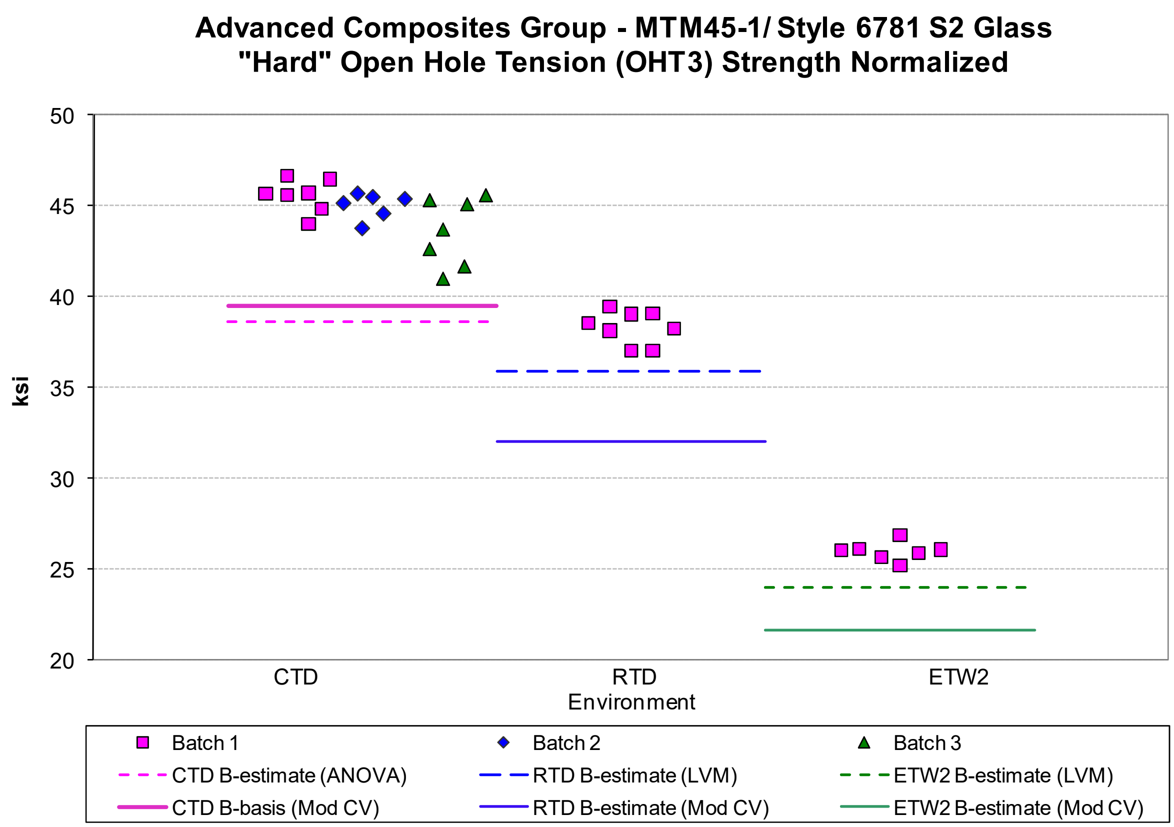


**Figure 5-6: Batch plot for OHT3 Strength normalized**

| Open Hole Tension (OHT3) Strength (ksi) Basis Values and Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | CTD | RTD | ETW2 | CTD | RTD | ETW2 |
| Mean | 44.694 | 38.334 | 25.999 | 43.495 | 37.715 | 25.776 |
| Stdev | 1.502 | 0.908 | 0.500 | 1.731 | 0.971 | 0.693 |
| CV | 3.360 | 2.367 | 1.923 | 3.981 | 2.574 | 2.689 |
| Modified CV | 6.000 | 8.000 | 8.000 | 6.000 | 8.000 | 8.000 |
| Min | 40.991 | 37.039 | 25.220 | 39.576 | 36.230 | 24.741 |
| Max | 46.649 | 39.461 | 26.871 | 46.197 | 38.804 | 26.757 |
| No. Batches | 3 | 1 | 1 | 3 | 1 | 1 |
| No. Spec. | 20 | 8 | 7 | 20 | 8 | 7 |
| Basis Value Estimates | | | | | | |
| B-estimate | 38.608 | 35.880 | 23.959 | 33.701 | 35.278 | 23.506 |
| A-estimate | 34.267 | NA | NA | 26.711 | NA | NA |
| Method | ANOVA | LVM | LVM | ANOVA | LVM | LVM |
| Modified CV Basis Values and/or Estimates | | | | | | |
| B-basis Value | 39.528 | | | 38.467 | | |
| B-estimate | | 32.056 | 21.648 | | 31.539 | 21.462 |
| A-estimate | 35.857 | NA | NA | 34.895 | NA | NA |
| Method | Normal | LVM | LVM | Normal | LVM | LVM |

**Table 5-8: Statistics, Basis Values and/or Estimates for OHT3 Strength data normalized**

## 5.5 Open Hole Compression Properties (OHC1, OHC2, OHC3)

### 5.5.1 Quasi Isotropic Open Hole Compression 1 (OHC1)

The RTD data (both as measured and normalized) did not pass the Anderson-Darling k-sample test for batch-to-batch variation. This means the RTD dataset requires the ANOVA method to compute basis values which may result in overly conservative basis values. However, the data (both as measured and normalized) does pass the normality test and passes the ADK test under the modified CV transformation, so the modified CV values are provided for that dataset.

The pooled dataset (both as measured and normalized) did not pass Levene's test for equality of variances under the modified CV transformation, so the modified CV basis values are provided on a single point basis.

The ETW environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There was one outlier. It was in the normalized RTD dataset, batch 4, and was an outlier on the high side. It was an outlier before, but not after, pooling the three batches.

Statistics, estimates and basis values are given for the OHC1 strength data in Table 5-9. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-7.

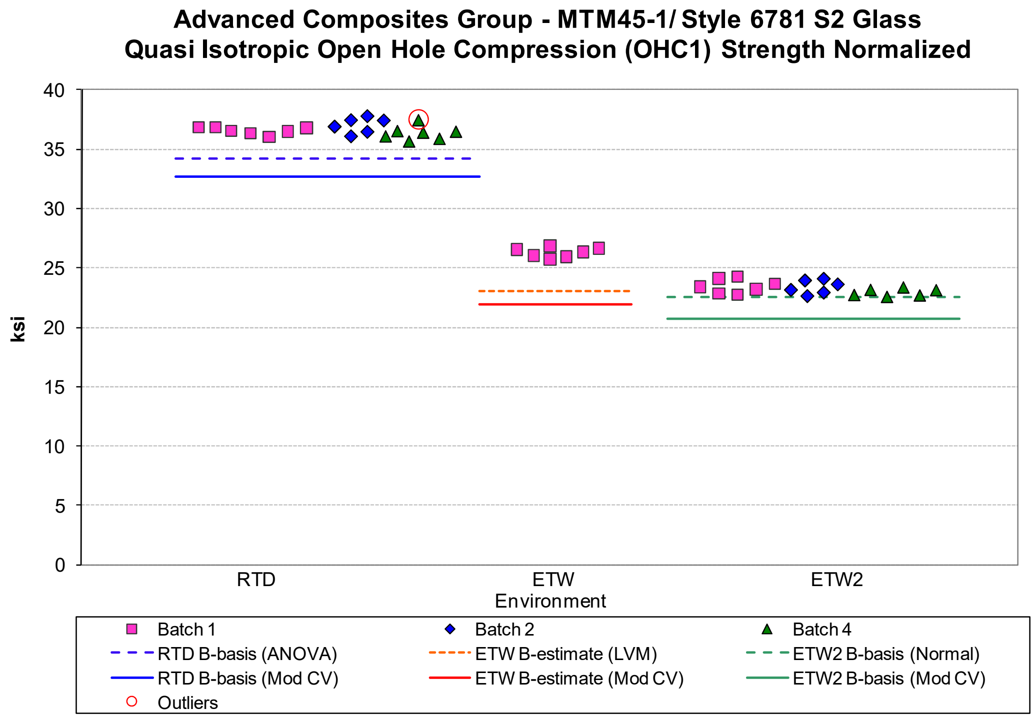


**Figure 5-7: Batch plot for OHC1 Strength normalized**

| Open Hole Compression (OHC1) Strength Basis Values and Statistics | | | | | | |
|---|---|---|---|---|---|---|
| | Normalized | | | As Measured | | |
| Env | RTD | ETW | ETW2 | RTD | ETW | ETW2 |
| Mean | 37.020 | 26.299 | 23.478 | 36.374 | 26.261 | 23.046 |
| Stdev | 0.585 | 0.408 | 0.492 | 0.623 | 0.453 | 0.608 |
| CV | 1.581 | 1.552 | 2.095 | 1.712 | 1.727 | 2.639 |
| Modified CV | 6.000 | 8.000 | 6.000 | 6.000 | 8.000 | 6.000 |
| Min | 36.062 | 25.748 | 22.608 | 35.159 | 25.492 | 21.988 |
| Max | 38.257 | 26.864 | 24.284 | 37.433 | 26.809 | 24.384 |
| No. Batches | 3 | 1 | 3 | 3 | 1 | 3 |
| No. Spec. | 20 | 7 | 19 | 20 | 7 | 19 |
| Basis Values and/or Estimates | | | | | | |
| B-basis Value | | | 22.519 | | | 21.861 |
| B-estimate | 34.227 | 22.966 | | 33.829 | 22.894 | |
| A-estimate | 32.234 | NA | 21.839 | 32.013 | NA | 21.019 |
| Method | ANOVA | LVM | Normal | ANOVA | LVM | Normal |
| Modified CV Basis Values and/or Estimates | | | | | | |
| B-basis Value | 32.741 | | 20.732 | 32.170 | | 20.351 |
| B-estimate | | 21.898 | | | 21.866 | |
| A-estimate | 29.700 | NA | 18.785 | 29.182 | NA | 18.440 |
| Method | Normal | LVM | Normal | Normal | LVM | Normal |

**Table 5-9: Statistics, Basis Values and/or Estimates for OHC1 Strength data**

### 5.5.2 "Soft" Open Hole Compression 2 (OHC2)

The RTD environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There were no outliers in this data. Statistics, estimates and basis values are given for the OHC2 strength data in Table 5-10 . The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-8.

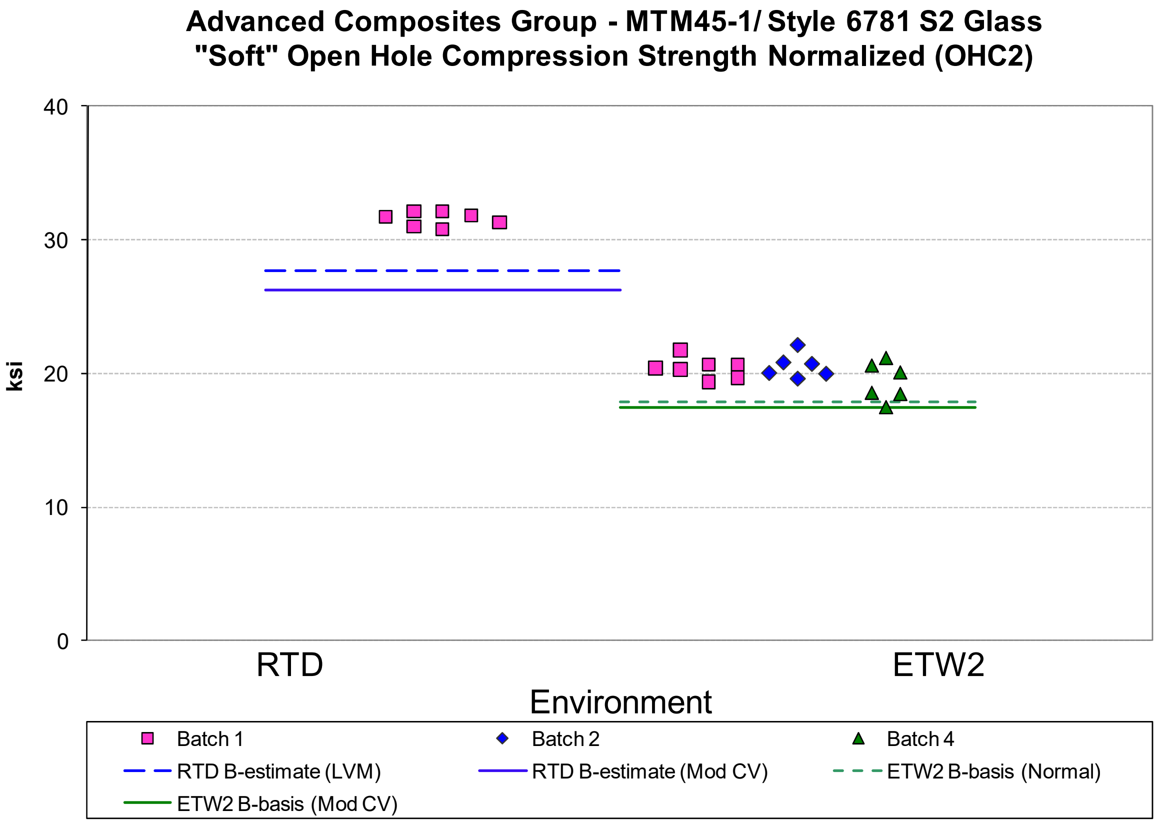


**Figure 5-8: Batch plot for OHC2 Strength normalized**

| Open-Hole Compression (OHC2) Strength Basis Values and Statistics | | | | |
|---|---|---|---|---|
| | Normalized | | As Measured | |
| Env | RTD | ETW2 | RTD | ETW2 |
| Mean | 31.557 | 20.142 | 31.439 | 19.726 |
| Stdev | 0.541 | 1.137 | 0.311 | 1.266 |
| CV | 1.713 | 5.643 | 0.990 | 6.417 |
| Modified CV | 8.000 | 6.822 | 8.000 | 7.208 |
| Min | 30.770 | 17.465 | 30.889 | 16.820 |
| Max | 32.140 | 22.185 | 31.845 | 21.827 |
| No. Batches | 1 | 3 | 1 | 3 |
| No. Spec. | 7 | 19 | 7 | 19 |
| Basis Values and/or Estimates | | | | |
| B-basis Value | | 17.927 | | 17.259 |
| B-estimate | 27.748 | | 27.385 | |
| A-estimate | NA | 16.354 | NA | 15.508 |
| Method | LVM | Normal | LVM | Normal |
| Modified CV Basis Values and/or Estimates | | | | |
| B-basis Value | | 17.464 | | 16.955 |
| B-estimate | 26.275 | | 26.177 | |
| A-estimate | NA | 15.565 | NA | 14.990 |
| Method | LVM | Normal | LVM | Normal |

Table 5-10: Statistics, Basis Values and/or Estimates for OHC2 Strength data

### 5.5.3 "Hard" Open Hole Compression 3 (OHC3)

The RTD environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There were no outliers in this data. Statistics, estimates and basis values are given for the OHC3 strength data in Table 5-11. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-9.

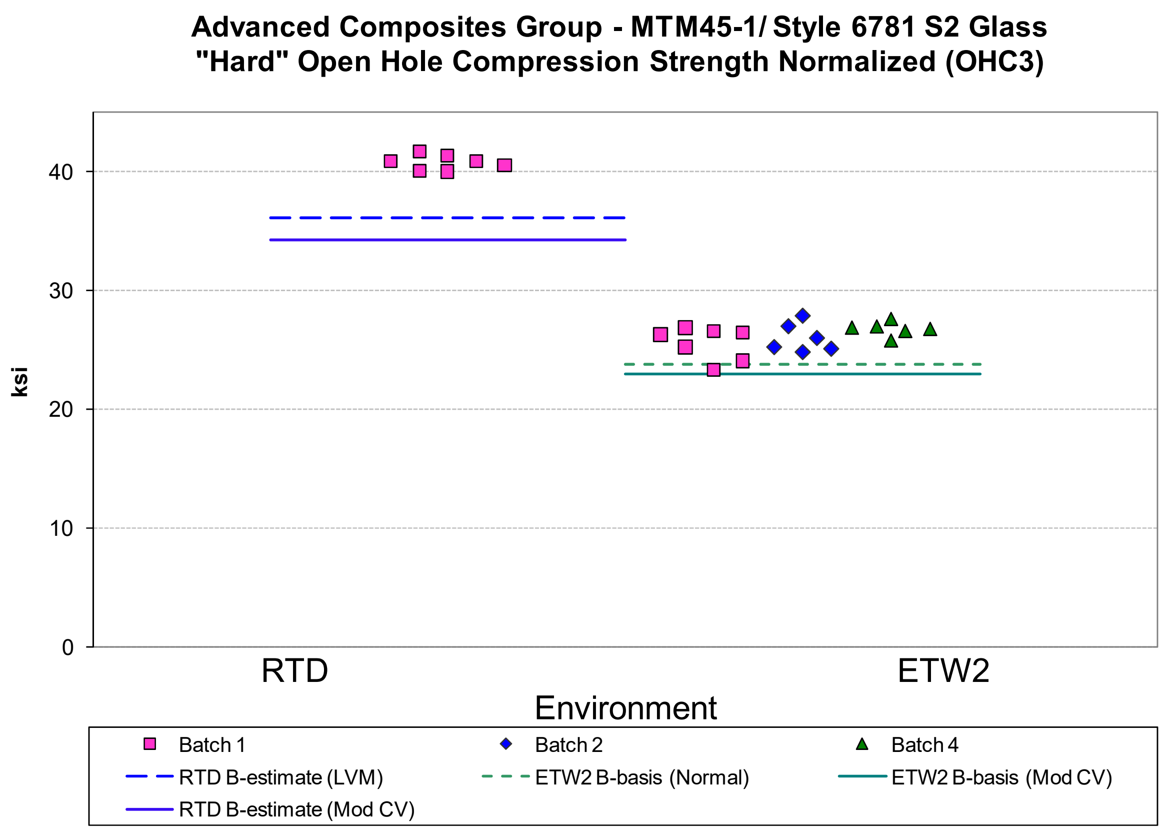


**Figure 5-9: Batch plot for OHC3 Strength normalized**

| Open-Hole Compression (OHC3) Strength Basis Values and Statistics | | | | |
|---|---|---|---|---|
| | Normalized | | As Measured | |
| Env | RTD | ETW2 | RTD | ETW2 |
| Mean | 41.079 | 26.053 | 40.726 | 25.615 |
| Stdev | 0.525 | 1.186 | 0.630 | 1.235 |
| CV | 1.278 | 4.552 | 1.548 | 4.823 |
| Modified CV | 8.000 | 6.276 | 8.000 | 6.411 |
| Min | 40.532 | 23.329 | 39.972 | 23.057 |
| Max | 41.890 | 27.804 | 41.633 | 27.352 |
| No. Batches | 1 | 3 | 1 | 3 |
| No. Spec. | 7 | 19 | 7 | 19 |
| Basis Values and/or Estimates | | | | |
| B-basis Value | | 23.742 | | 23.208 |
| B-estimate | 36.121 | | 35.475 | |
| A-estimate | NA | 22.101 | NA | 21.498 |
| Method | LVM | Normal | LVM | Normal |
| Modified CV Basis Values and/or Estimates | | | | |
| B-basis Value | | 22.866 | 33.910 | 22.414 |
| B-estimate | 34.204 | | | |
| A-estimate | NA | 20.607 | NA | 20.144 |
| Method | LVM | Normal | LVM | Normal |

Table 5-11: Statistics, Basis Values and/or Estimates for OHC3 Strength data

## 5.6 Quasi Isotropic Filled Hole Tension Properties (FHT1)

The RTD environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There was one outlier. The outlier was in the normalized data from the CTD environment. It was on the low side of batch four and it was an outlier only before pooling the three batches together. Statistics, estimates and basis values are given for the FHT1 strength data in Table 5-12. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-10.

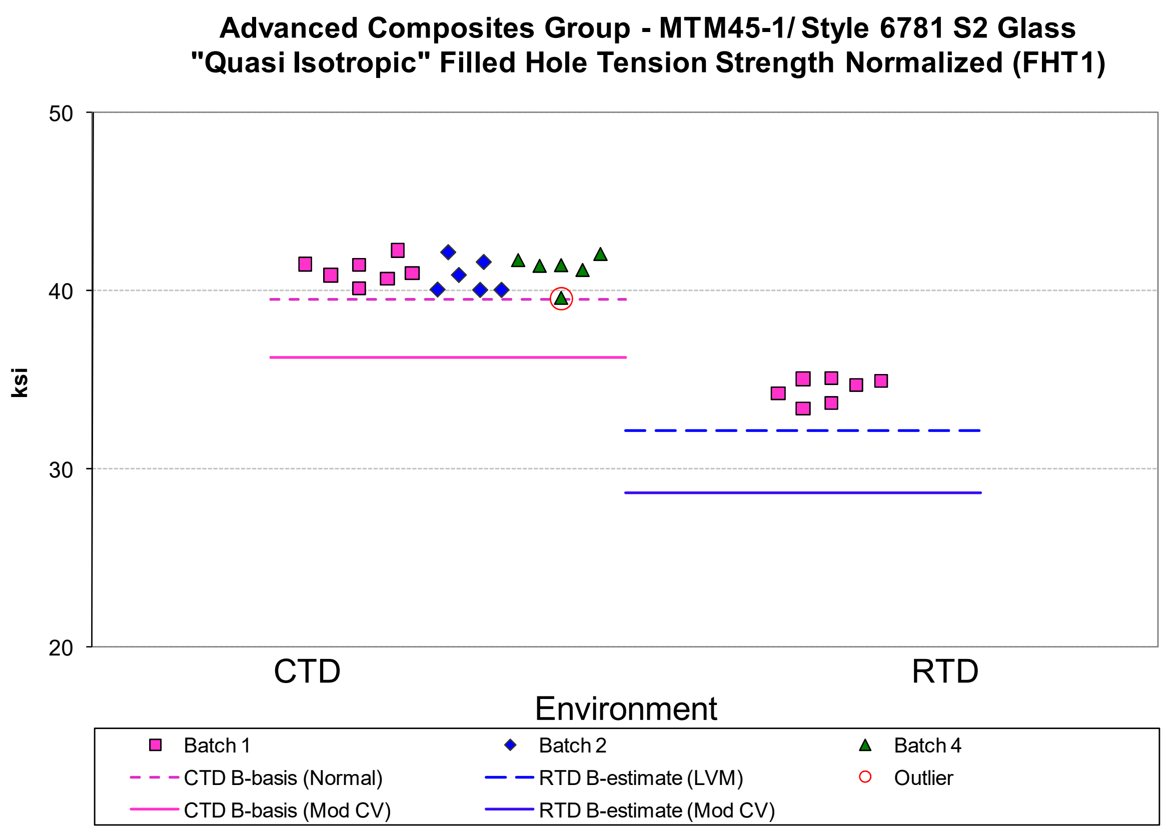


**Figure 5-10: Batch plot for FHT1 Strength normalized**

| Filled-Hole Compression (FHC1) Strength Basis Values and Statistics | | | | |
|---|---|---|---|---|
| | Normalized | | As Measured | |
| Env | RTD | ETW2 | RTD | ETW2 |
| Mean | 56.053 | 35.208 | 55.577 | 34.429 |
| Stdev | 1.265 | 2.454 | 1.387 | 2.444 |
| CV | 2.256 | 6.969 | 2.495 | 7.099 |
| Modified CV | 8.000 | 7.485 | 8.000 | 7.549 |
| Min | 54.593 | 31.636 | 53.926 | 31.266 |
| Max | 58.345 | 40.914 | 57.859 | 39.750 |
| No. Batches | 1 | 3 | 1 | 3 |
| No. Spec. | 7 | 20 | 7 | 20 |
| Basis Values and/or Estimates | | | | |
| B-basis Value | | 30.483 | | 30.811 |
| B-estimate | 49.287 | | 48.411 | |
| A-estimate | NA | 27.120 | NA | 22.520 |
| Method | LVM | Normal | LVM | Non-Parametric |
| Modified CV Basis Values and/or Estimates | | | | |
| B-basis Value | | 30.132 | | NA |
| B-estimate | 46.672 | | 46.276 | |
| A-estimate | NA | 26.524 | NA | NA |
| Method | LVM | Normal | LVM | NA |

Table 5-12: Statistics, Basis Values and/or Estimates for FHT1 Strength data

## 5.7 Quasi Isotropic Filled Hole Compression Properties (FHC1)

The RTD environment had insufficient data to meet the requirements of CMH-17 Rev G, so only estimates are provided.

There were no outliers in this data. Statistics, estimates and basis values are given for the FHC1 strength data in Table 5-13. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-11.

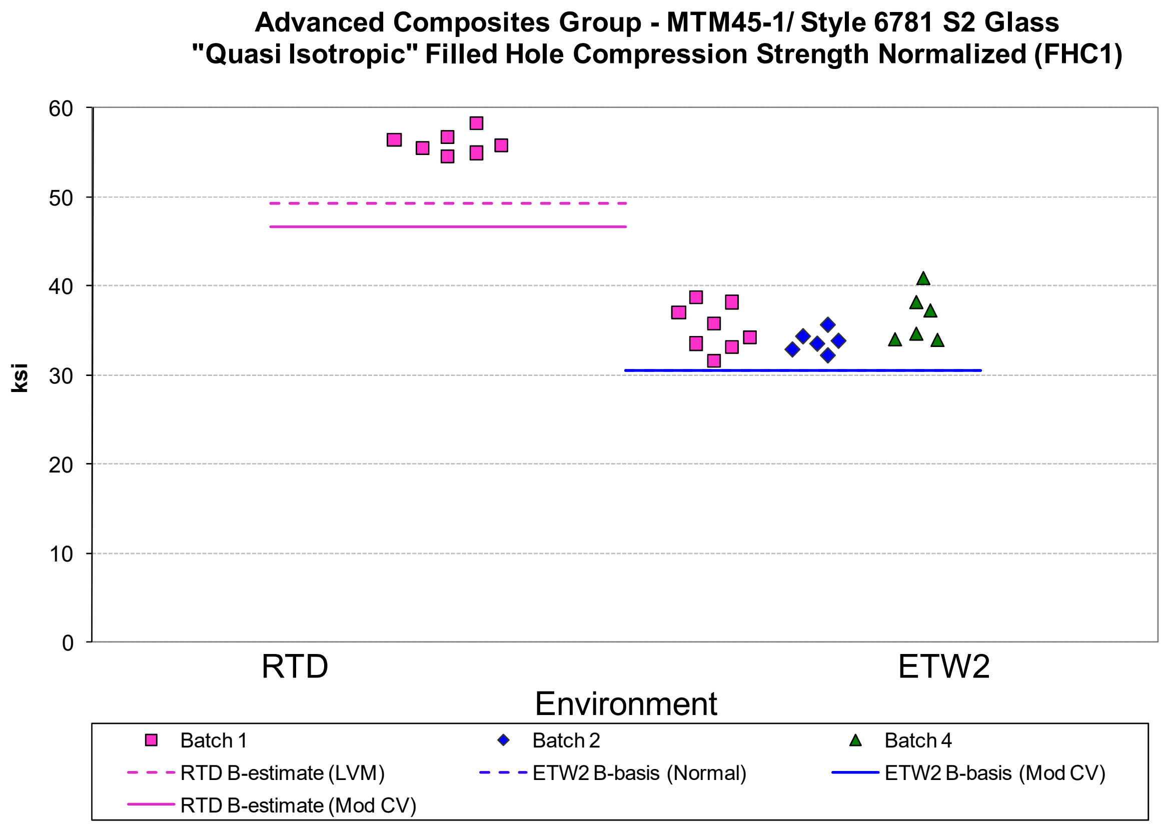


**Figure 5-11: Batch plot for FHC1 Strength normalized**

| Filled-Hole Tension (FHT1) Strength Basis Values and Statistics | | | | |
|---|---|---|---|---|
| | Normalized | | As Measured | |
| Env | CTD | RTD | CTD | RTD |
| Mean | 41.071 | 34.467 | 40.304 | 34.127 |
| Stdev | 0.801 | 0.679 | 0.842 | 0.713 |
| CV | 1.950 | 1.969 | 2.089 | 2.090 |
| Modified CV | 6.000 | 8.000 | 6.000 | 8.000 |
| Min | 39.606 | 33.422 | 38.654 | 33.031 |
| Max | 42.296 | 35.100 | 41.638 | 34.897 |
| No. Batches | 3 | 1 | 3 | 1 |
| No. Spec. | 19 | 7 | 19 | 7 |
| Basis Values and/or Estimates | | | | |
| B-basis Value | 39.511 | | 38.664 | |
| B-estimate | | 32.212 | | 31.873 |
| A-estimate | 38.402 | NA | 37.499 | NA |
| Method | Normal | LVM | Normal | LVM |
| Modified CV Basis Values and/or Estimates | | | | |
| B-basis Value | 36.268 | | 35.591 | |
| B-estimate | | 28.699 | | 28.416 |
| A-estimate | 32.863 | NA | 32.249 | NA |
| Method | Normal | LVM | Normal | LVM |

Table 5-13: Statistics, Basis Values and/or Estimates for FHC1 Strength data

## 5.8 Quasi Isotropic Pin Bearing Properties (PB1)

There was one outlier. It was in the as measured RTD 2% offset data in batch one. The outlier was on the high side and was identified as an outlier only after pooling the three batches. Pooling was acceptable across the two environments.

Statistics, estimates and basis values are given for the PB1 strength data in Table 5-14. The normalized data, B-estimates and B-basis values are shown graphically in Figure 5-12.

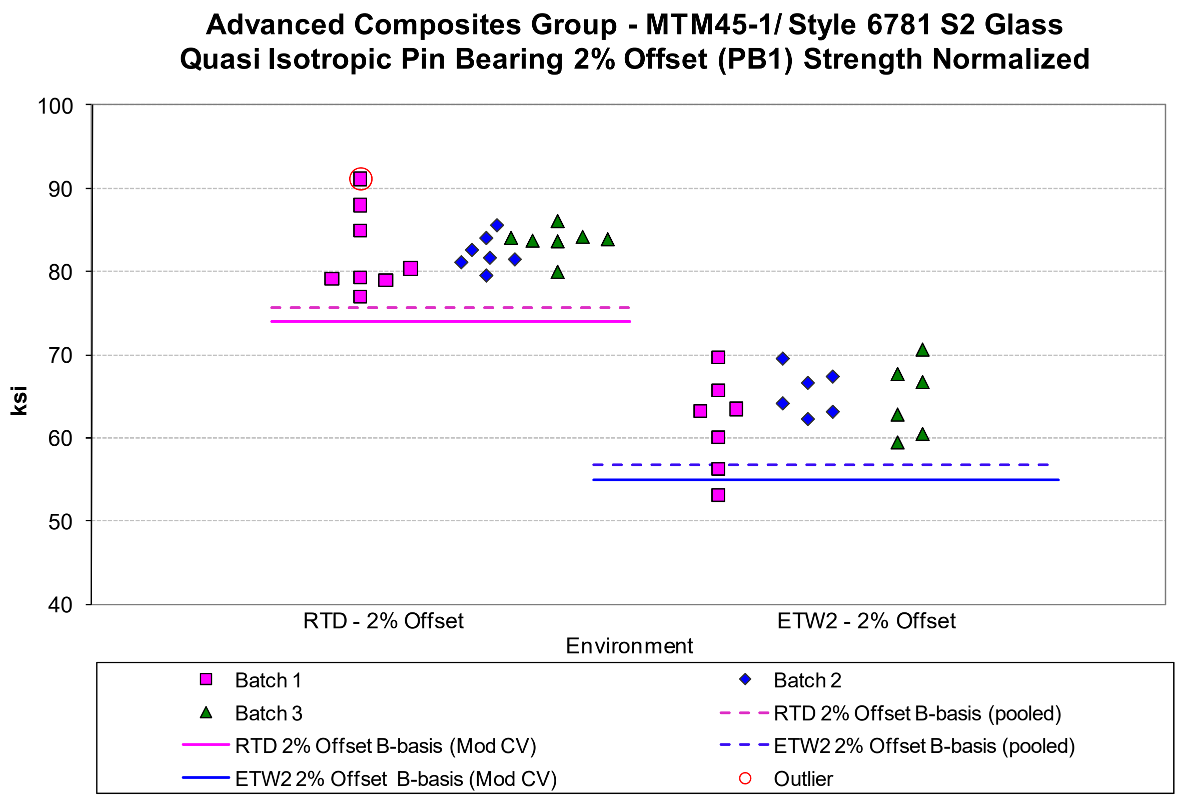


**Figure 5-12: Batch plot for PB1 Strength normalized**

| Pin Bearing (PB1) Strength Basis Values and Statistics | | | | |
|---|---|---|---|---|
| | Normalized | | As measured | |
| Env | RTD | ETW2 | RTD | ETW2 |
| Mean | 82.726 | 63.819 | 80.852 | 62.562 |
| Stdev | 3.317 | 4.610 | 3.293 | 4.275 |
| CV | 4.009 | 7.224 | 4.073 | 6.833 |
| Modified CV | 6.005 | 7.612 | 6.037 | 7.417 |
| Min | 77.004 | 53.103 | 76.406 | 52.798 |
| Max | 91.124 | 70.585 | 90.010 | 68.854 |
| No. Batches | 3 | 3 | 3 | 3 |
| No. Spec. | 22 | 19 | 22 | 19 |
| Basis Values and/or Estimates | | | | |
| B-basis Value | 75.707 | 56.709 | 74.166 | 55.789 |
| A-estimate | 70.848 | 51.870 | 69.537 | 51.180 |
| Method | pooled | pooled | pooled | pooled |
| Modified CV Basis Values and/or Estimates | | | | |
| B-basis Value | 74.025 | 55.005 | 72.409 | 54.009 |
| A-estimate | 68.001 | 49.007 | 66.564 | 48.189 |
| Method | pooled | pooled | pooled | pooled |

**Table 5-14: Statistics, Basis Values and/or Estimates for PB1 2% Offset Strength data**

## 5.9 Compression After Impact (CAI)

Basis values are not computed for the compression after impact data. Testing is done only for the RTD condition. Summary statistics are presented in Table 5-15 and the data are displayed graphically in Figure 5-13. There were no outliers. Only one batch of material was tested.

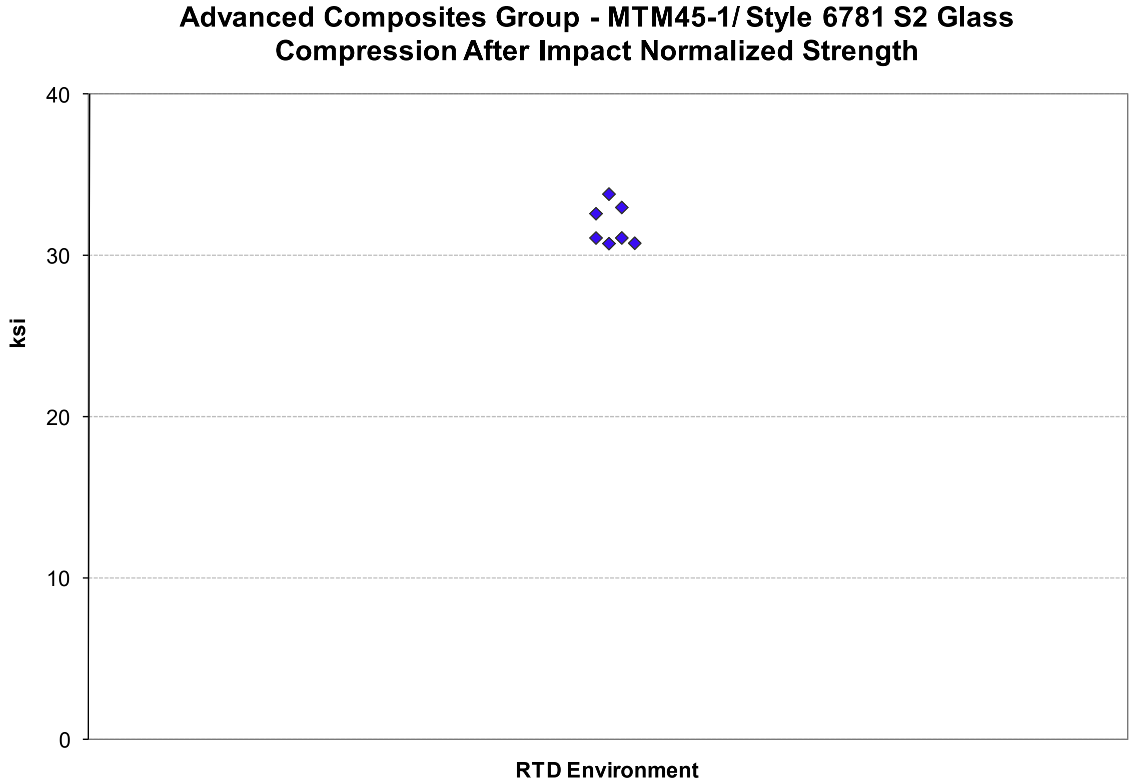


Figure 5-13: Plot for Compression After Impact normalized strength

| Compression After Impact Strength (ksi) | | |
|---|---|---|
| | Normalized | As Measured |
| Env | RTD | RTD |
| Mean | 31.866 | 31.529 |
| Stdev | 1.255 | 1.260 |
| CV | 3.940 | 3.997 |
| Modified CV | 6.000 | 6.000 |
| Min | 30.727 | 30.342 |
| Max | 33.830 | 33.372 |
| No. Batches | 1 | 1 |
| No. Spec. | 7 | 7 |

Table 5-15: Statistics for CAI Strength data

## 5.10 Interlaminar Tension (ILT) and Curved Beam Strength (CBS)

The ILT and CBS data is not normalized. Basis values are not computed for these properties. However the summary statistics are presented in Table 5-16 and the data are displayed graphically in Figure 5-14 .

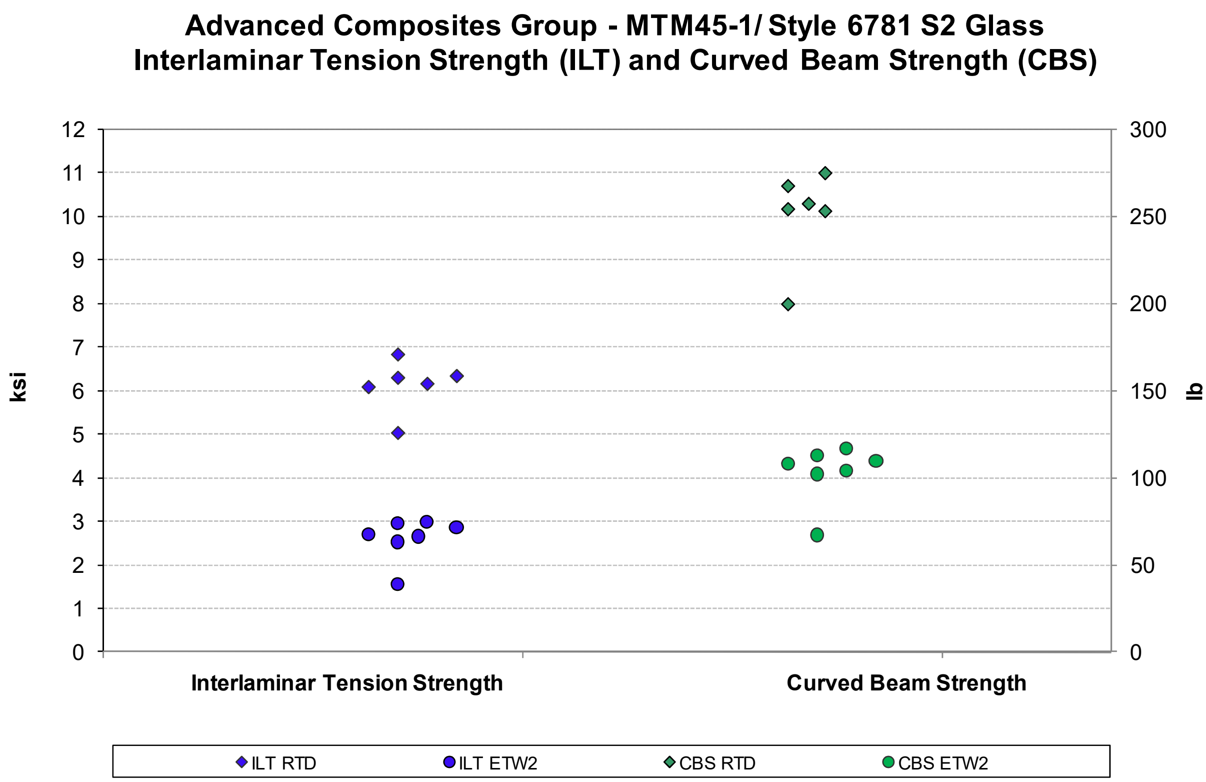


**Figure 5-14: Plot for Interlaminar Tension and Curved Beam Strength**

| Property | ILT (ksi) | | CBS (lb) | |
|---|---|---|---|---|
| Env | RTD | ETW2 | RTD | ETW2 |
| Mean | 6.130 | 2.601 | 251.245 | 102.965 |
| Stdev | 0.597 | 0.492 | 26.627 | 16.571 |
| CV | 9.740 | 18.910 | 10.598 | 16.094 |
| Mod CV | 9.740 | 18.910 | 10.598 | 16.094 |
| Min | 5.035 | 1.548 | 199.713 | 67.167 |
| Max | 6.841 | 2.978 | 275.080 | 116.929 |
| No. Batches | 1 | 1 | 1 | 1 |
| No. Spec. | 6 | 7 | 6 | 7 |

**Table 5-16: Statistics for ILT and CBS Strength data**

# 6. 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 section 8.3.3. 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 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-2009-001 Rev C.

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 | Normalized Strength | Strength As Measured | High/ Low | Batch Outlier | Condition Outlier |
|---|---|---|---|---|---|---|---|---|
| WT | RTD | 1 | ABJJA111A | Not an Outlier | 79.314 | Low | Yes | No |
| FT | CTD | 2 | ABJUB115B | 95.810 | 92.947 | High | Yes | No |
| FT | ETW2 | 2 | ABJUB119D | 59.615 | Not an Outlier | High | Yes | No |
| FC | ETD | 1 | ABJZA11IC | 63.991 | 63.355 | High | Yes | No |
| IPS - 0.2% Offset | CTD | 1 | ABJNA217B | NA | 7.072 | Low | Yes | No |
| IPS - 0.2% Offset | ETW2 | 2 | ABJNB119D | NA | 2.418 | Low | Yes | Yes |
| IPS - 5% Strain | ETW | 1 | ABJNA11GN | NA | 5.936 | High | Yes | No |
| IPS - 5% Strain | ETW2 | 3 | ABJNC219D | NA | 5.072 | High | Yes | Yes |
| UNT1 | CTD | 3 | ABJAC112B | Not an Outlier | 65.084 | Low | Yes | No |
| UNT1 | ETW2 | 1 | ABJAA21CD | 44.979 | 44.142 | Low | Yes | No |
| UNC1 | ETW2 | 1 | ABJWA21HD | 43.198 | 43.162 | High | Yes | No |
| UNC1 | ETW2 | 2 | ABJWB11BD | 41.021 | Not an Outlier | High | Yes | No |
| UNC1 | ETW2 | 3 | ABJWC116D | 43.562 | 42.831 | High | Yes | No |
| LSBS | ETW | 1 | ABJqA247N | NA | 6.545 | High | Yes | No |
| OHT1 | RTD | 2 | ABJDB113A | Not an Outlier | 30.240 | Low | Yes | No |
| OHT1 | RTD | 3 | ABJDC112A | 30.851 | 29.692 | Low | Yes | No |
| OHC1 | RTD | 4 | ABJGD212A | 38.257 | Not an Outlier | High | Yes | No |
| FHT1 | CTD | 4 | ABJ4D216B | 39.606 | Not an Outlier | Low | Yes | No |
| PB1 - 2% Offset | RTD | 1 | ABJ1A112A | Not an Outlier | 90.010 | High | No | Yes |

**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. CMH-17 Rev G, Volume 1, 2012. SAE International, 400 Commonwealth Drive, Warrendale, PA 15096