Solvay (Formerly ACG) MTM45-1 7781 Glass Fabric Qualification Statistical Analysis Report

FAA Special Project Number: SP3505WI-Q

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1. Introduction

This report contains statistical analysis of ACG MTM45-1/GF0103-35%RW 7781 E glass fabric material property data published in "MTM45-1 GF0103 Data MH Cure Cycle Values Only 09-24-18.pdf" file. The lamina and laminate material property data have been generated with FAA oversight through FAA Special Project Number SP3505WI-Q, and retest material property data was generated with NCAMP oversight.

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 451/4. NMS 451/4 has additional requirements that are listed in its prepreg process control document (PCD), fiber specification, fiber PCD, and other raw material

Test Property	**Symbol**
Warp Compression Strength	F_1^{cu}

$_1^{cu}$

1.3 Basis Value Computational Process

The general form to compute engineering basis values is: basis value = $\bar{X} \quad kS$ where k is a factor based on the sample size and the distribution of the sample data. There are many different methods to determine the value of k in this equation, depending on the sample size and the distribution of the data. In addition, the computational formula used for the standard deviation, S may vary depending on the distribution of the data. The details of those different computations and when each should be used are in section 2.0.

1.4 Modified Coefficient of Variation (CV) Method

A common problem with new material qualifications is that the initial specimens produced and tested do not contain all of the variability that will be encountered when the material is being produced in larger amounts over a lengthy period of time. This can result in setting basis values that are unrealistically high. The variability as measured in the qualification program is often lower than the actual material variability because of several reasons. The materials used in the qualification programs are usually manufactured within a short period of time, typically 2-3 weeks only, which is not representative of the production material. Some raw ingredients that are used to manufacture the multi-batch qualification materials may actually be from the same production batches or manufactured within a short period of time so the qualification materials, although regarded as multiple batches, may not truly be multiple batches so they are not representative of the actual production material variability.

The modified Coefficient of Variation (CV) used in this report is in accordance with section 8.4.4 of CMH-17 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.

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 CMH-17 Rev G requirements for a single point analysis, estimates are created by a variety of methods depending on which is most appropriate for the dataset available. Specific procedures used are presented in the individual sections where the data is presented.

Where k refers to the number of batches and n_i refers to the number of specimens in the i^{th} sample

2.1.2.2 Pooled Coefficient of Variation

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

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

2.1.3 Basis Value Computations

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

Basis Values:

$$A\text{-}basis = \bar{X} - K_a S$$
$$B\text{-}basis = \bar{X} - K_b S$$

Equation 6

2.1.3.1 K-factor computations

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

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

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

Where

r = the number of environments being pooled together

n_j= number of data values for environment j

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

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

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

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

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

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

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 $S_i^* \quad CV^* \quad \bar{X}_i$ for each batch. Transform the data in each batch as follows:

$$X_{ij}c \quad C_i \quad X_{ij} \quad \bar{X}_i \quad \bar{X}_i$$

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

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

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

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

2.1.6 The k-Sample Anderson Darling Test for batch equivalency

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

The k-sample Anderson-Darling test statistic is:

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

Where

- n_i = the number of test specimens in each batch
- $n = n_1+n_2+\ldots+n_k$
- h_j = the number of values in the combined samples equal to $z_{(j)}$
- H_j = the number of values in the combined samples less than $z_{(j)}$ plus ½ the number of values in the combined samples equal to $z_{(j)}$
- F_{ij} = the number of values in the i^{th} group which are less than $z_{(j)}$ plus ½ the number of values in this group which are equal to $z_{(j)}$.

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

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

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

Where F_0

−10% Normal curve y-value: max($v_{(i)}$ − 0.1, −.1)

2.1.8.2 Normal Pearson's r

The Normal Pearson's r statistic is the correlation coefficient of the actual data values with the predicted values computed assuming a normal distribution with the same mean and standard deviation as the original data and using the probability of survival as the percentile of the normal distribution.

Correlation Formula: $$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{s_x}\right)\left(\frac{y_i-\bar{y}}{s_y}\right)$$ **Equation 34**

2.1.9 Levene's test for Equality of Coefficient of Variation

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

$$F = \frac{\sum_{i=1}^{k} n_i\left(\bar{w}_i - \bar{w}\right)^2/(k-1)}{\sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(w_{ij} - \bar{w}_i\right)^2/(n-k)}$$ **Equation 35**

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); Stat-17 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 te

2.2.2.1 One-sided B-basis tolerance factors, k

Stat-17 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

$$z_i = \left[x_i / \hat{\alpha}\right]^{\hat{\beta}}, \text{ for } i = 1, \ldots, n \qquad \textbf{Equation 41}$$

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.

$$V_B \approx 3.803 \times \exp\left(1.79 - 0.516\ln(n) + \frac{5.1}{n-1}\right) \quad \textbf{Equation 48}$$

$$V_A \approx 6.649 \times \exp\left(2.55 - 0.526\ln(n) + \frac{4.76}{n}\right) \quad \textbf{Equation 49}$$

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

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

Table 2-2: Weibull Distribution Basis Value Factors

2.2.2.4 Lognormal Distribution

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

$$z_i = \frac{\ln(x_i) - \bar{x}_L}{s_L}, \quad \text{for } i = 1, \ldots, n \qquad \text{Equation 50}$$

where x

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.

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				

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 $n_i, \bar{x}_i, s_i^2$ 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

Denote the ratio of mean squares by

$$u = \frac{MSB}{MSE} \qquad \textbf{Equation 62}$$

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

$$T = \frac{k_0 - \frac{k_1}{\sqrt{n'}} + (k_1 - k_0)\sqrt{\frac{u}{u + n' - 1}}}{1 - \frac{1}{\sqrt{n'}}} \qquad \textbf{Equation 63}$$

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.

$$\textbf{Estimated B-Basis} = \bar{X} - k_b S_{adj} = \bar{X} - k_b\left(0.08 \cdot \bar{X}\right) \qquad \textbf{Equation 64}$$

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.

3. Summary of Results

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 basis values

Lamina Strength Tests

						0.2% Offset	5% Strain
B-basis	NA:A	94.48	61.18	80.68	10.82	6.12	NA:I
Mean	80.89	104.11	68.69	91.85	12.29	6.93	13.00
CV	7.07%	7.21%	6.06%	6.16%	6.06%	9.47%	3.30%
B-basis	62.25	71.50	53.01	NA:A	9.89**	4.56	NA:I
Mean	68.15	81.13	60.53	70.19	10.44	5.39	9.80
CV	6.09%	6.94%	6.75%	6.61%	2.63%	9.35%	4.95%
B-basis				53.34	8.19**		
Mean				62.66	8.39		
CV				7.54%	1.87%		
B-basis	38.54	35.27	34.17	NA:A	4.57**	2.12	4.62
Mean	44.46	44.90	38.76	45.74	4.86	2.94	5.30
CV	6.37%	8.69%	6.00%	6.80%	6.89%	10.65%	6.53%
B-basis	35.74	30.79	32.37	NA:A	3.59**	1.84	NA:I
Mean	41.67	40.42	36.80	40.73	3.86	2.67	4.70
CV	6.83%	10.65%	6.18%	5.79%	6.00%	7.82%	8.81%

[redacted]

3.2 Lamina and Laminate Summary Tables

Material:	MTM45-1/GF0103-35%RW		
Material Specificaton:	ACGM1001-04 or NCAMP NMS 451/4.		
Prepreg:	MTM45-1/GF0103-35%RW		
Fiber:	BGF E-Glass ACDE75 1/0 Yarn	**Resin:**	MTM45-1

Tg(dry): 356°F **Tg(wet)** 320°F **Tg METHOD: SACMA SRM18R-94**

PROCESSING: ACGP 1001-02 Process Specification "MH" Cure Cycle

Date of fiber manufacture	10/21/2004; 3/31/2006; 1/14/2016	**Date of testing**	8/2/2005 - 4/13/2006
Date of resin manufacture	11/19/2004, 12/16/2004	**Date of Retests**	1/3/2017 - 3/31/2017
	02/04/2006, 09/22/2006	**Date of data submittal**	6/13/2006 - 8/13/2006; 5/15/2017
	08/09/2016, 08/10/2016; 8/23/2016	**Date of analysis**	Sept 2008 - August 2009, May 2018
Date of prepreg manufacture	11/19/2004, 12/16/2004, 2/4/2005, 09/22/2006; 8/10/2016; 8/24/2016		
Date of composite manufacture	8/2/2005 - 4/13/2006; 11/1/2016 - 11/4/2016		

B-Basis	Modified CV B-basis	Mean	B-Basis	Modified CV B-basis	Mean	B-Basis	Modified CV B-basis	Mean	B-Basis

Material:	MTM45-1/GF0103-35%RW		
Material Specificaton:	ACGM1001-04 or NCAMP NMS 451/4.		
Prepreg:	MTM45-1/GF0103-35%RW		
Fiber:	BGF E-Glass ACDE75 1/0 Yarn	**Resin:**	MTM45-1

Tg(dry) 356°F **Tg(wet)** 320°F **Tg METHOD: SACMA SRM18R-94**

PROCESSING: ACGP 1001-02 Process Specification "MH" Cure Cycle

Date of fiber manufacture	10/21/2004; 3/31/2006	**Date of testing**	8/2/2005 - 4/13/2006
Date of resin manufacture	11/19/2004, 12/16/2004	**Date of data submittal**	6/13/2006 - 8/13/2006
	02/04/2006, 09/22/2006	**Date of analysis**	Sept 2008 - August 2009
Date of prepreg manufacture	11/19/2004, 12/16/2004, 02/04/2005, 09/22/2006		
Date of composite manufacture	8/2/2005 - 4/13/2006		

Test Condition	Unit	B-value	Mod. CV B-value

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 horizontal axis values will vary depending on the data and how much overlapping there was of the data within and between batches. When there was little variation, the batches were graphed from left to right and the environmental conditions were identified by the shape and color of the symbol used to plot the data. Otherwise, the environmental conditions were graphed from left to right and the batches were identified by the shape and color of the symbol.

When a dataset fails the Anderson-Darling k-sample (ADK) test for batch-to-batch variation an ANOVA analysis is required. In order for B-basis values 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 transformati

4.1 Warp (0º) Tension Properties (WT)

The RTD (both as measured and normalized) and the ETW2 (as measured only) datasets passed the Anderson-Darling k-sample test (ADK test) for batch-to-batch variation. The remaining datasets required the ANOVA method to compute basis values, which may result in overly conservative estimates of the basis values.

The normalized ETW and ETW2 data passes the ADK test with the modified CV transformation,

4.2 Fill (90º) Tension Properties (FT)

For the normalized data, all environments pass both the normality test and the ADK test, but the pooled dataset did not pass the normality test, so pooling all four environments was not appropriate. Only the CTD and RTD environments could be pooled together.

For the as measured data, the ETW environment did not pass the Anderson-Darling k-sample test for batch-to-batch variation. That dataset required the ANOVA method to compute basis values, which may result in overly conservative estimates of the basis values. Only the CTD and RTD environments could be pooled. The ETW data passed the ADK test with the modified CV transformation, so all four environments could be pooled for the modified CV basis values.

There were a total of four outliers in the normalized data. There were two outliers before pooling batches, RTD batch 3 and ETW2 batch 2, both on the low side. There were another two outliers after pooling batches, one each in ETW and ETW2, both in batch one and both on the low side. All outliers were retained for this analysis. There were no outliers in the as measured data.

Statistics, estimates and basis values are given

Fill Tension Strength (ksi) Basis Values and Statistics

	Normalized				As Measured			
Env	CTD	RTD	ETW	ETW2	CTD	RTD	ETW	ETW2
Mean	68.69	60.53	38.76	36.80	69.96	61.58	39.17	37.34
Stdev	2.83	3.33	1.20	1.61	3.46	3.02	1.34	1.81
CV	4.13	5.50	3.08	4.36	4.95	4.91	3.41	4.86
Mod CV	6.06	6.75	6.00	6.18	6.47	6.45	6.00	6.43
Min	63.62	53.40	35.42	32.45	63.09	55.24	36.02	33.00
Max	73.85	66.44	40.69	39.84	74.84	67.00	40.91	41.21
No. Batches	3	3	3	3	3	3	3	3
No. Spec.	18	18	18	19	18	18	18	19
Basis Values and/or Estimates								
B-basis Value	63.06	54.90	36.40	33.67	64.04	55.66		33.81
B-estimate							33.76	
A-estimate	59.23	51.07	34.73	31.45	60.01	51.63	29.91	31.30
Method	pooled	pooled	Normal	Normal	pooled	pooled	ANOVA	Normal
Modified CV Basis Values and/or Estimates								
B-basis Value	61.18	53.01	34.17	32.37	63.97	55.58	33.18	31.38
A-estimate	56.06	47.90	30.92	29.23	60.02	51.63	29.23	27.43
Method	pooled	pooled	normal	normal	pooled	pooled	pooled	pooled

Env	CTD	RTD	ETW	ETW2	CTD	RTD	ETW	ETW2
Mean	104.11	81.13	44.90	40.42	106.42	82.76	46.19	41.09
Stdev	6.69	4.77	3.90	4.31	7.00	3.83	3.60	4.04
CV	6.42	5.88	8.69	10.65	6.58	4.63	7.80	9.83

4.4

Fill Compression Strength (ksi) Basis Values and Statistics										
	Normalized					As Measured				
Env	CTD	RTD	ETD	ETW	ETW2	CTD	RTD	ETD	ETW	ETW2
Mean	91.845	70.194	62.659	45.741	40.726	89.573	68.964	61.095	44.588	39.509
Stdev	3.968	4.642	4.432	3.113	2.359	3.130	3.648	3.462	2.479	1.774
CV	4.320	6.613	7.073	6.805	5.792	3.495	5.289	5.666	5.561	4.489
Mod CV	6.160	7.307	7.536	7.402	6.896	6.000	6.645	6.833	6.780	6.245
Min	84.900	62.759	54.317	41.313	36.966	84.770	62.908	54.166	40.497	36.439
Max	97.094	78.659	73.399	52.436	47.002	95.898	74.479	68.946	49.716	44.359
No. Batches	3	3	3	3	3	3	3	3	3	3
No. Spec.	18	18	18	26	19	18	18	18	26	19
Basis Values and/or Estimates										
B-basis Value	84.011					83.392		54.260	40.067	
B-estimate		43.861	41.726	28.549	26.549		51.022			30.823
A-estimate	78.460	25.074	26.801	16.264	16.431	79.013	38.229	49.417	36.815	24.627
Method	Normal	ANOVA	ANOVA	ANOVA	ANOVA	Normal	ANOVA	Normal	Normal	ANOVA
Modified CV Basis Values and/or Estimates										
B-basis Value	80.676	NA	53.336	NA	NA	78.963	59.917	52.853	39.075	34.700
A-estimate	72.774	NA	46.742	NA	NA	71.457	53.518	47.023	35.110	31.291
Method	Normal	NA	Normal	NA	NA	Normal	Normal	Normal	Normal	Normal

4.5 In-Plane Shear Properties (IPS)

In the 5% strain strength data, there were insufficient specimens in the CTD, RTD, and ETW2 environments to produce B-basis values that meet all CMH-17 Rev G requirements for publication, so only estimates of the basis values are available. The ETW data failed the ADK initially, but passes with the modified CV transform, so modified CV basis values are provided

In-Plane Shear Modulus (Msi) Statistics				
Env	CTD	RTD	ETW	ETW2
Mean	0.64	0.54	0.34	0.33
Stdev	0.04	0.06	0.03	0.03
CV	6.01	10.25	7.49	7.89
Mod CV	7.00	10.25	7.75	7.95
Min	0.56	0.49	0.30	0.28
Max	0.72	0.74	0.41	0.38
No. Batches	3	3	3	3
No. Spec.	23	17	18	17

Table 4-10 : Statistics for IPS Modulus data

Short Beam Strength (ksi) Basis Values and Statistics					
Env	CTD	RTD	ETD	ETW	ETW2
Mean	12.29	10.44	8.39	4.86	3.86
Stdev	0.51	0.27	0.16	0.34	0.23
CV	4.11	2.63	1.87	6.89	6.00
Mod CV	6.06	6.00	6.00	7.44	7.00
Min	11.32	9.88	8.23	4.59	3.63
Max	12.85	10.77	8.73	5.53	4.38
No. Batches	3	3	3	3	3
No. Spec.	18	18	18	18	18
Basis Values and/or Estimates					
B-basis Value	11.29	9.89	8.19	4.57	3.59
A-estimate	10.58	9.28	7.53	3.48	2.74
Method	Normal	Weibull	Non Para	Non Para	Non Para
Modified CV Basis Values and/or Estimates					
B-basis Value	10.82	NA	NA	NA	NA
A-estimate	9.78	NA	NA	NA	NA
Method	normal	NA	NA	NA	NA

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

5. Laminate Test Results, Statistics and Basis Values

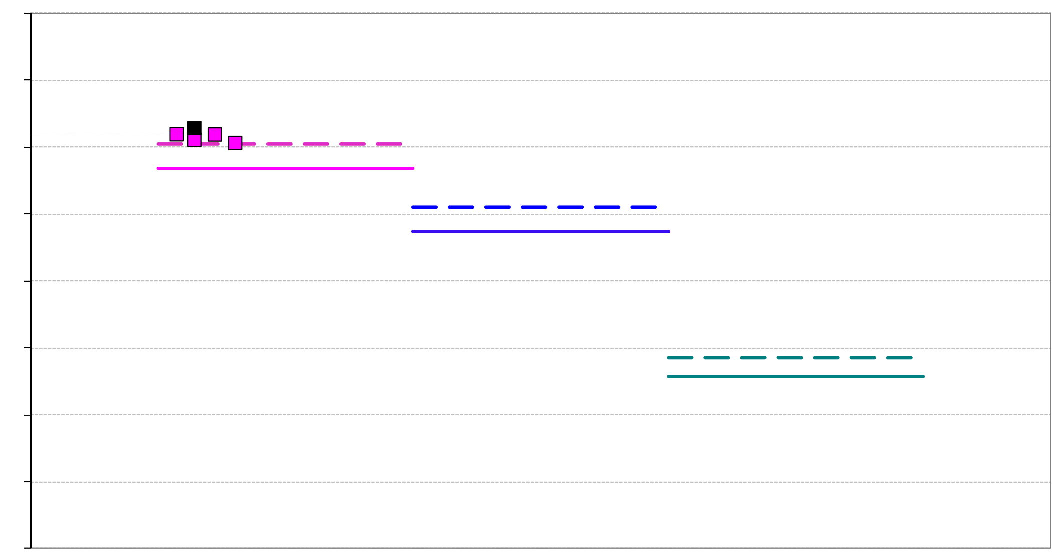
Some laminate tests were performed with one batch only. This is insufficient data to produce basis values that meet the requirements of CMH-17 Rev G, so only estimates are provided. Estimates were prepared using the lamina variability method documented in section 2.4 or by pooling with the other environments when appropriate. The more conservative of the LVM or pooled estimate was provided.

5.1 Quasi Isotropic Unnotched Tension (UNT1) Properties

The UNT1 data was pooled across the three environments. The ETW2 environment has only seven specimens available, so estimates only are provided. The ETW2 data was included in the pooled dataset, but because the LVM estimate was more conservative, the LVM estimate is provided. For the modified CV approach, the pooled estimate was more conservative than the LVM estimate, to the pooled estimate is provided as the ETW2 Mod CV estimate.

There was one outlier. It was on the high side of batch three in the CTD environment for the as measured data only. It was an outlier both before and after pooling. It was retained for this analysis.

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 graphically in Figure 8.



Quasi Isotropic Unnotched Tension Strength (ksi) Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW2	CTD	RTD	ETW2
Mean	62.67	53.29	32.42	63.64	54.14	33.31
Stdev	1.12	1.44	0.86	1.60	1.99	1.19
CV	1.78	2.71	2.64	2.51	3.67	3.56
Modified CV	6.00	6.00	6.00	6.00	6.00	6.00
Min	60.70	50.47	31.07	61.21	50.90	32.14
Max	64.36	55.50	33.37	68.58	58.42	35.28
No. Batches	3	3	1	3	3	1
No. Spec.	18	18	7	18	18	7
Basis Values and/or Estimates						
B-basis Value	60.45	51.07		60.53	51.04	
B-estimate			28.56			29.83
A-estimate	58.95	49.57	NA	58.44	48.94	27.80
Method	pooled	pooled	LVM	pooled	pooled	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	56.73	47.35		57.60	48.10	
B-estimate			25.76			26.54
A-estimate	52.72	43.33	21.86	53.52	44.02	22.58
Method	pooled	pooled	pooled	pooled	pooled	pooled

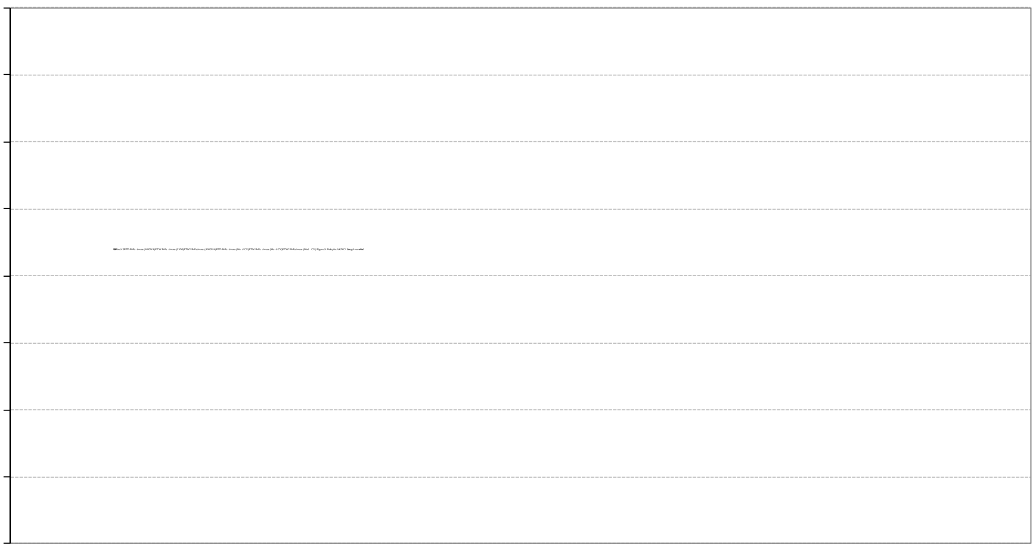
Table 5-1 : Statistics, Basis Values and/or Estimates for UNT1 Strength data

Env	CTD	RTD	ETW2	CTD	RTD	ETW2
Mean	2.98	2.86	2.70	3.02	2.92	2.77
Stdev	0.08	0.18	0.24	0.09	0.21	0.24
CV	2.77	6.41	8.90	3.13	7.19	8.74
Modified CV	6.00	7.20	8.90	6.00	7.59	8.74

5.2 Quasi Isotropic Un-notched Compression (UNC1) Properties

The RTD and ETW2 datasets did not pass the ADK test even with the modified CV transform. They required the ANOVA method to compute basis values which may result in overly conservative estimates of the basis values. Estimates were computed using the modified CV method. These are termed estimates due to the failure of the ADK test after the transformation for the modified CV method. Pooling was used to compute the Mod CV estimates.

There were no outliers. Statistics, A- and B-estimates are given for the UNC1 normalized strength data in Table 5-3. Statistics for the modulus data are given in Table 5-4. The normalized data and B-estimates are shown graphically in Figure 9.



Quasi Isotropic Unnotched Compression Strength (ksi) Basis Values and Statistics						
	Normalized			As Measured		
Env	RTD	ETW	ETW2	RTD	ETW	ETW2
Mean	65.78	35.51	32.77	67.83	36.63	34.03
Stdev	3.75	2.91	3.44	3.62	2.91	3.18
CV	5.70	8.21	10.49	5.33	7.95	9.33
Modified CV	6.85	8.21	10.49	6.67	7.98	9.33
Min	59.74	32.41	26.50	61.80	33.54	28.14
Max	71.68	39.48	38.49	74.01	41.20	38.94
No. Batches	3	1	3	3	1	3
No. Spec.	19	6	18	19	6	18
Basis Values and/or Estimates						
B-estimate	43.57	28.86	12.13	45.09	30.35	14.95
A-estimate	27.71	NA	NA	28.86	NA	1.34
Method	ANOVA	LVM	ANOVA	ANOVA	LVM	ANOVA
Modified CV Basis Values and/or Estimates						
B-estimate	58.80	27.47	25.75	61.00	28.76	27.17
A-estimate	54.06	22.88	21.02	56.36	24.28	22.54
Method	pooled	pooled	pooled	pooled	pooled	pooled

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

Env	RTD	ETW	ETW2	RTD	ETW	ETW2
Mean	3.07	2.97	4.04	3.17	3.07	4.21
Stdev	0.26	0.25	0.28	0.27	0.30	0.30
CV	8.47	8.31	6.84	8.53	9.86	7.06
Modified CV	8.47	8.31	7.42	8.53	9.86	7.53

5.3 Laminate Short Beam Strength (LSBS)

The RTD and ETW2 data failed the ADK initially, so they required the ANOVA method to

Env	RTD	ETW	ETW2
Mean	9.58	5.83	4.61
Stdev	0.41	0.42	0.24
CV	4.31	7.26	5.22
Modified CV	6.15	8.00	6.61
Min	9.16	5.36	4.33
Max	10.50	6.33	5.10
No. Batches	3	1	3
No. Spec.	18	6	18
B-estimate	7.27	4.85	3.75
A-estimate	5.63	NA	3.14
Method	ANOVA	LVM	ANOVA
B-basis Value	8.74		3.77
B-estimate		4.83	

5.4

Ter on (OHT2)

T2 C D data. It was on the high side of batch two. It was an ee b ches. It was retained for this analysis.

alues e given for the OHT2 strength data in Table 5-7. The m nd B-basis values are shown graphically in Figure 12.

ETW2 Environment Advanced Composites Group -Mp TM 45-1 7

	Normalized		As Measured	
Env	CTD	ETW2	CTD	ETW2
Mean	32.72	14.23	33.40	14.43
Stdev	0.78	0.54	1.20	0.48
CV	2.38	3.80	3.59	3.34
Modified CV	6.00	8.00	6.00	8.00
Min	31.56	13.42	31.56	13.70
Max	34.93	15.03	36.39	15.13
No. Batches	3	1	3	1
No. Spec.	18	7	18	7
B-basis Value	31.18		31.04	
B-estimate		12.54		13.39
A-estimate	30.09	NA	29.36	NA
Method	Normal	LVM	Normal	LVM
B-basis Value	28.84		29.45	
B-estimate		11.84		12.01
A-estimate	26.10	NA	26.65	NA
Method	Normal	LVM	Normal	LVM

"Hard" Open Hole Tension Strength (ksi) Basis Values and Statistics						
	Normalized			As Measured		
Env	CTD	RTD	ETW2	CTD	RTD	ETW2
Mean	38.30	30.30	19.97	38.59	29.29	19.53
Stdev	1.64	1.18	0.66	1.70	0.87	0.33
CV	4.27	3.88	3.31	4.41	2.99	1.69
Modified CV	6.14	8.00	8.00	6.21	8.00	8.00
Min	36.19	28.74	19.10	35.71	28.09	18.97
Max	42.06	31.92	20.77	42.92	30.23	19.85
No. Batches	3	1	1	3	1	1
No. Spec.	18	6	6	18	6	6
Basis Values and/or Estimates						
B-basis Value	35.07			35.23		
B-estimate		27.58	17.53		26.64	18.09
A-estimate	32.78	NA	NA	32.85	NA	NA
Method	Normal	LVM	LVM	Normal	LVM	LVM
Modified CV Basis Values and/or Estimates						
B-basis Value	33.66			33.86		
B-estimate		25.10	16.52		24.26	16.16
A-estimate	30.38	NA	NA	30.52	NA	NA
Method	Normal	LVM	LVM	Normal	LVM	LVM

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

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

5.5.1 Quasi Isotropic Open Hole Compression 1 (OHC1)

The OHC1 data could be pooled across the three environments. The ETW environment has only six specimens available, so estimates only are pr

Quasi Isotropic Open Hole Compression Strength (ksi) Basis Values and Statistics						
	Normalized			As Measured		
Env	RTD	ETW	ETW2	RTD	ETW	ETW2
Mean	34.22	22.41	20.63	34.70	22.96	20.89
Stdev	0.84	0.31	0.76	0.93	0.53	0.69
CV	2.47	1.39	3.70	2.67	2.32	3.30
Modified CV	6.00	8.00	6.00	6.00	8.00	6.00
Min	32.47	21.91	19.35	32.79	22.36	19.78
Max	35.61	22.77	22.37	36.43	23.76	22.37
No. Batches	3	1	3	3	1	3
No. Spec.	18	6	18	18	6	18
Basis Values and/or Estimates						
B-basis Value	32.85		19.26	33.29		19.47
B-estimate		18.21			19.09	
A-estimate	31.92	NA	18.33	32.33	NA	18.52
Method	pooled	LVM	pooled	pooled	LVM	pooled
Modified CV Basis Values and/or Estimates						
B-basis Value	31.24		17.65	31.68		17.86
B-estimate		NA			18.99	
A-estimate	29.22	NA	15.63	29.64	NA	15.82
Method	pooled	NA	pooled	pooled	LVM	pooled

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

5.5.2 "Soft" Open Hole Compression (OHC2)

The OHC2 ETW2 data failed the ADK initially, but passes with the modified CV transform, so modified CV basis values are provided for that environment. There were no outliers. Statistics, estimates and basis values are given for the OHC2 strength data in Table 5-10. The normalized data, B-estimates and the B-basis values are shown graphically in Figure 15.

"Soft" Open Hole Compression Properties (OHC2) Strength (ksi) Basis Values and Statistics				
	Normalized		As Measured	
Env	RTD	ETW2	RTD	ETW2
Mean	30.97	18.94	31.80	19.31
Stdev	0.81	0.85	0.77	0.70
CV	2.62	4.47	2.41	3.64
Modified CV	8.00	6.24	8.00	6.00
Min	29.50	17.76	30.75	18.12
Max	32.38	20.77	33.10	20.64
No. Batches	1	3	1	3
No. Spec.	8	18	8	18
Basis Values and/or Estimates				
B-basis Value				17.92
B-estimate	27.23	14.57	28.77	
A-estimate	NA	11.45	NA	16.94
Method	LVM	ANOVA	LVM	Normal
Modified CV Basis Values and/or Estimates				
B-basis Value		16.61		17.02
B-estimate	25.88		26.57	
A-estimate	NA	14.96	NA	15.40
Method	LVM	Normal	LVM	Normal

Table 5-10 : Statistics, Ba

5.5.3

Env	RTD	ETW2	RTD	ETW2
Mean	37.10	23.47	38.14	23.57
Stdev	0.74	0.65	1.08	0.84
CV	1.99	2.77	2.83	3.57
Modified CV	8.00	6.00	8.00	6.00
Min	36.40	22.27	37.04	22.28
Max	37.94	24.72	39.68	25.57
No. Batches	1	3	1	3
No. Spec.	6	18	6	18
B-basis Value				21.91
B-estimate	32.40	20.73	34.33	
A-estimate	NA	18.77	NA	20.74
Method	LVM	ANOVA	LVM	Normal
B-basis Value		20.69		20.78
B-estimate	30.70		31.55	
A-estimate	NA	18.73	NA	18.80
Method	LVM	Normal	LVM	Normal

5.6 Quasi Isotropic Filled Hole Tension (FHT1) Properties

The FHT1 data had no outliers or test failures. 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 17.

Quasi Isotropic Filled-Hole Tension Strength (ksi) Basis Values and Statistics				
	Normalized		As Measured	
Env	CTD	RTD	CTD	RTD
Mean	35.54	28.83	36.37	29.62
Stdev	1.23	0.47	1.69	0.39
CV	3.46	1.64	4.65	1.32
Modified CV	6.00	8.00	6.33	8.00
Min	32.96	28.05	34.41	29.21
Max	37.36	29.35	40.41	30.06
No. Batches	3	1	3	1
No. Spec.	21	6	21	6
Basis Values and/or Estimates				
B-basis Value	33.19		33.15	
B-estimate		26.24		26.94
A-estimate	31.52	NA	30.85	NA
Method	Normal	LVM	Normal	LVM
Modified CV Basis Values and/or Estimates				
B-basis Value	31.47		31.99	
B-estimate		23.87		24.53
A-estimate	28.58	NA	28.86	NA
Method	Normal	LVM	Normal	LVM

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

5.7 Quasi Isotropic Filled Hole Compression (FHC1) Properties

There was insufficient data to produce any basis values that would not be considered estimates. The FHC1 ETW2 data did not pass the normality test. The lognormal distribution was the best fit. There were no outliers. Statistics and A- and B-estimates are given for the FHC1 strength data in Table 5-13. The normalized data and B-estimates are shown graphically in Figure 18.

Quasi isotropic Filled-Hole Compression Strength (ksi) Basis Values and Statistics				
	Normalized		As Measured	
Env	RTD	ETW2	RTD	ETW2
Mean	54.69	36.24	56.88	37.14
Stdev	2.09	2.87	2.35	2.66
CV	3.83	7.91	4.14	7.16
Modified CV	8.00	7.96	8.00	7.58
Min	53.06	33.00	54.99	34.14
Max	57.63	43.20	59.98	43.20
No. Batches	1	3	1	3
No. Spec.	4	15	4	15
Basis Values and/or Estimates				
B-estimate	47.23	30.88	50.77	31.64
A-estimate	NA	27.65	NA	27.78
Method	LVM	Lognormal	LVM	Normal
Modified CV Basis Values and/or Estimates				
B-estimate	44.53	NA	46.31	31.32
A-estimate	NA	NA	NA	27.23
Method	LVM	NA	LVM	Normal

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 iden

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