Markforged X7 System and Onyx FR-A w/ Carbon Fiber FR-A Material Qualification Material Allowables Statistical Analysis Report

NCAMP Project Number: NPN 032004

Report Number: NCP-RP-2023-007 Rev -

Report Date: November 10th, 2023

Jorge Chavez-Salas, M.Sc.

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

Testing Facility:

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

Fabrication Facility:

Markforged
85 School Street
Watertown, MA 02472

Prepared by: Jorge Chavez-Salas Digitally signed by Jorge Chavez-Salas DN: cn=Jorge Chavez-Salas, o=WSU, ou=NIAR, email=jchavezsalas@niar.wichita.edu, c=US Date: 2023.11.20 14:17:48 -06'00'

Jorge Chavez-Salas

Reviewed by: Elizabeth Clarkson Digitally signed by Elizabeth Clarkson Date: 2023.11.20 11:57:33 -06'00'

Elizabeth Clarkson

Evelyn Lian Digitally signed by Evelyn Lian Date: 2023.11.20 12:59:42 -06'00'

Evelyn Lian

Approved by: Royal Lovingfoss Digitally signed by Royal Lovingfoss Date: 2023.11.20 12:49:43 -06'00'

Royal Lovingfoss

REVISIONS:

Rev	By	Date	Pages Revised or Added
-	Jorge Chavez-Salas	11/10/23	Document Initial Release

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Introduction

This report contains statistical analysis of the Markforged Onyx FR-A and Carbon Fiber FR-A qualification material property data published in NCAMP Test Report CAM-RP-2023-008 Rev N/C. The material property data have been generated with NCAMP oversight in accordance with NSP 100 NCAMP Standard Operating Procedures; the test panels and test specimens have been inspected by NCAMP Authorized Inspection Representatives (AIR) and the testing has been witnessed by NCAMP Authorized Engineering Representatives (AER). However, the data may not fulfill all the needs of any specific company's program; specific properties, environments, build orientations, fiber placement, and loading situations may require additional testing.

B-Basis values, A-estimates, and B-estimates were calculated using a variety of techniques that are detailed in Section two. The qualification material was procured to NCAMP Material Specification NMS 754/1 Rev A dated August 9, 2023. The qualification test coupons were manufactured in accordance with NCAMP Process Specification NPS 86754 Rev B dated August 9, 2023. The NCAMP Test Plan NTP AM-6754Q1 Rev A was used for this qualification program. Newer revisions of the Material and Process Specification may contain more current information and process parameters but any variation from the Qualification program should be carefully considered.

Basis numbers are labeled as ‘values’ when the data meets all the requirements of CMH-17-1G. When those requirements are not met, they will be labeled as ‘estimates.’ When the data does not meet all requirements, the failure to meet these requirements is reported and the specific requirement(s) the data fails to meet is identified. The method used to compute the basis value is noted for each basis value provided. These methods were described in the original MIL-HDBK17 and are statistically valid regardless of the material type.

The material property data acquisition process is designed to generate basic material property data with sufficient pedigree for submission to Complete Documentation sections of the Composite Materials Handbook (CMH-17 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, build orientations, fiber placement, 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-17-1G. 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-17-1G are adequate for the given program.

Aircraft companies should not use the data published in this report without specifying NCAMP Material Specification NMS 754/1. NMS 754/1 may have additional requirements that are listed in its material process control document (PCD) and other raw material specifications and PCDs which impose essential quality controls on the raw materials and raw material manufacturing equipment and processes. Aircraft companies and certifying agencies should assume that the material property data published in this report is not applicable when the material is not procured to NMS 754/1. NMS 754/1 is a free, publicly available, non-proprietary aerospace industry material specification. The data in this report is intended for general distribution to the public, either freely or at a price that does not exceed the cost of reproduction (e.g. printing) and distribution (e.g. postage).

1.1 Definitions

Axes or Directions are defined by the orientation of the specimen during the build operation. The specimens are constructed such that the tested strength corresponds to the strength of the build orientation. See Figure 1-1.

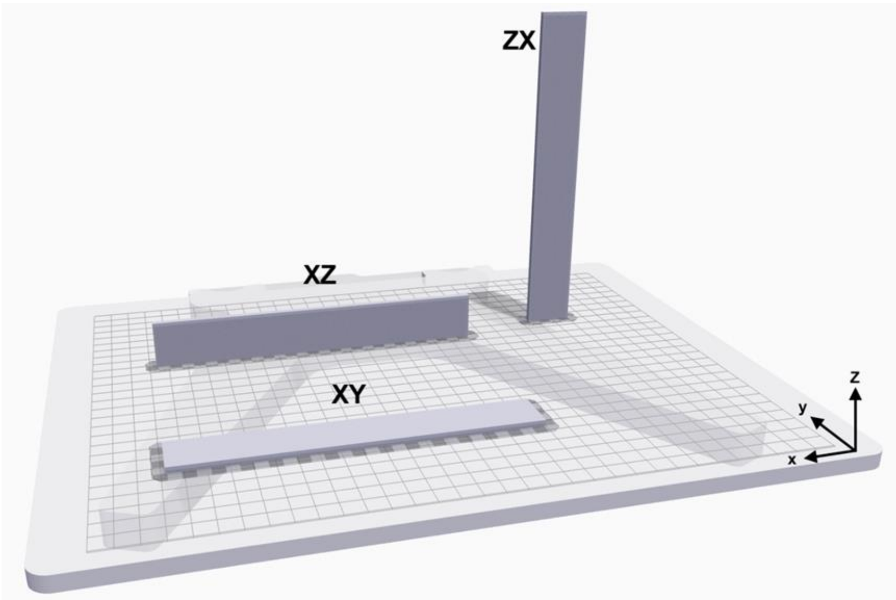

Figure 1-1. Specimen Build Orientation Diagram

- Batch

- **Raw Feedstock Lot:** *Total quantity of a unique lot identifier incoming to the Filament Lot Supplier as defined by the Raw Feedstock Supplier.*
- **Filament Lot:** *The quantity of Markforged Filament Spools manufactured at one time to a set of defined properties in compliance with this specification using a single Raw Feedstock Lot.*
- **Fiber Lot:** *The quantity of Markforged Fiber Spools manufactured at one time to a single set of defined properties in compliance with the material specification using a minimal set of Raw Feedstock Lots.*

- Machine: A single manufacturing device that prints the test coupons from the raw resin mixed with filament.

1.1.1 Fiber Volume

OFRA has the capability to include continuous carbon fiber within the material, this process is limited by specimen geometry. There is a minimum thickness requirement in order to include continuous carbon fiber as seen in Section 5.4 of the process specification. For the purposes of this qualification, three separate fiber volumes will be tested. These volumes are defined below with illustration of pre-processing captures from the Markforged Eiger software.

1.1.1.1 No Fiber (NF)

The NF fill configuration avoids the inclusion of any Carbon Fiber FR-A in the part. Test specimens identified with NF are solely composed of OFRA.

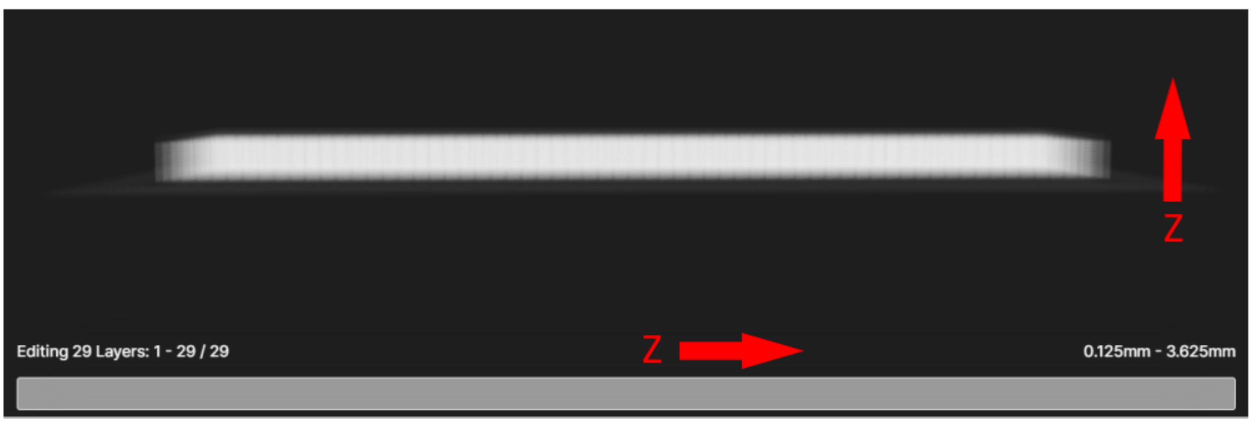

Figure 1-2. Pre-processing capture of an OFRA beam that does not have any CFRA reinforcement. Horizontal Z axis (bottom) represents the OFRA material through the thickness.

1.1.1.2 Full Fiber (FF)

The FF fill configuration fits as much continuous Carbon Fiber FR-A in the test specimen as possible, while maintaining the standard 2 shells, 4 roof layers, and 4 floor layers.

XY orientation test specimens identified with FF use Isotropic Fiber fill on all eligible layers (layers that are not roofs or floors), with zero concentric rings of continuous fiber. The fiber angle varies based on the test specimen and is specified in the test plan (NTP AM-6754Q1). Typically, test specimens use either:

- All 0° fiber
- ±45° fiber
- Quasi-isotropic stack
    - Quasi fiber orientation for FF Fiber Content specimens of XY orientation. Fiber orientation will follow in this manner from build plate to top of specimen, [45/0/-45/90____90/-45/0/45]. Quasi fiber orientation for PF Fiber Content specimens of XY orientation will follow the same pattern but will be limited by the number of layers containing fiber due to Partial Fill.

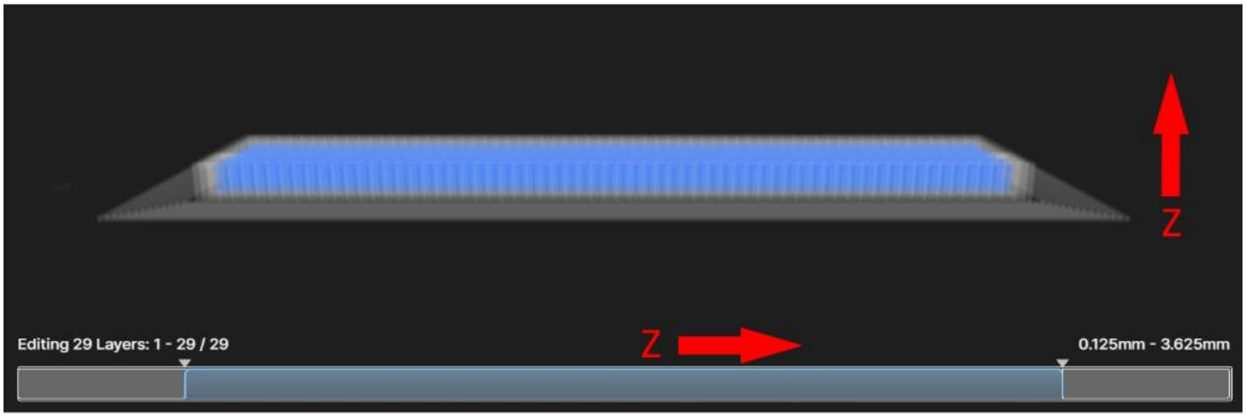

Figure 1-3. The blue areas throughout the part geometry in the figure show where CFRA reinforcement is planned for Full Fiber printing in XY orientation. Horizontal Z axis (bottom) represents the OFRA and CFRA material through the thickness.

XZ orientation test specimens with a wall thickness less than 5mm identified with FF use Concentric Fiber fill on all eligible layers (layers that are not roofs or floors). These test specimens may only contain 0° fiber. XZ orientation test specimens with a wall thickness greater than 5mm use a fill strategy similar to XY orientation test specimens.

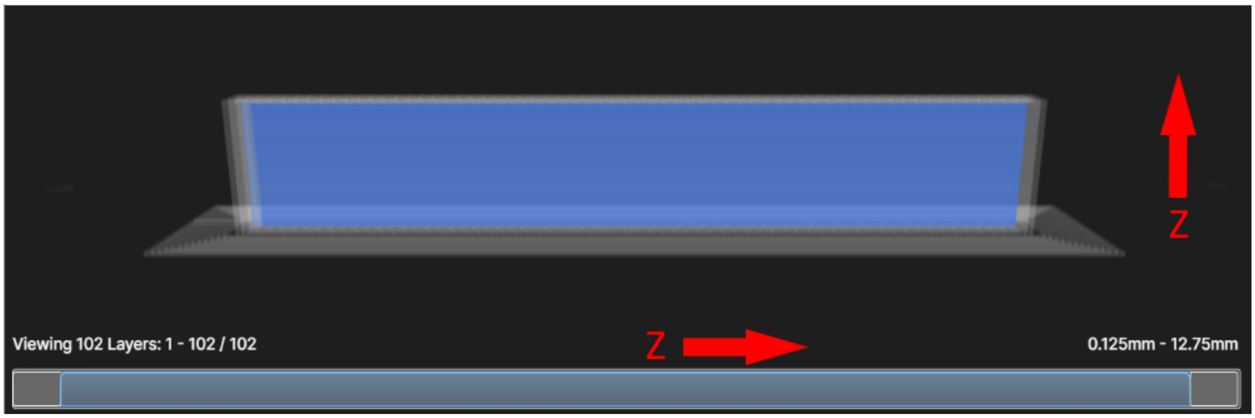

Figure 1-4. The blue areas throughout the part geometry in the figure show where CFRA reinforcement is planned for Full Fiber printing in XZ orientation. Horizontal Z axis (bottom) represents the OFRA and CFRA material through the thickness.

ZX orientation test specimens follow a fill strategy similar to XZ orientation test specimens. However, due to the change in print orientation, ZX orientation test specimens with a wall thickness less than 5mm can only contain 0° fiber. ZX orientation specimens after removal from build plate will look as is the fiber is in the 90° orientation due to the specimen being laid on a flat surface.

1.1.1.3 Partial Fiber (PF)

The PF fill configuration fits less than the maximum allowable amount of fiber within the test specimen as possible. Fill strategy is similar to that described in Section 1.1.1.2, however not all eligible layers feature fiber. XY orientation test specimens fit fiber in the four lowest and four highest eligible layers.

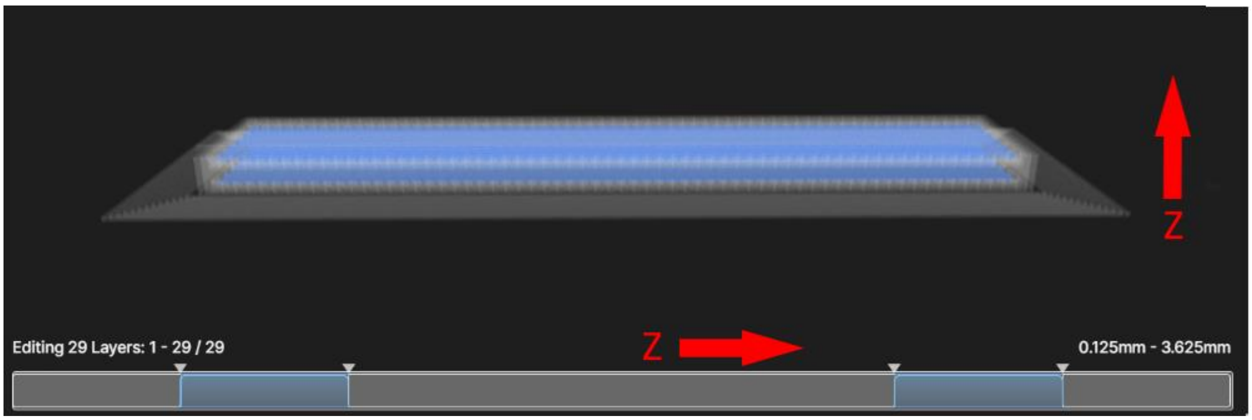

Figure 1-5. The blue areas in both the top and bottom of the figure show where CFRA reinforcement is planned for Partial Fiber printing in XY orientation. Horizontal Z axis (bottom) represents the OFRA and CFRA material through the thickness.

XZ orientation test specimens fit fiber in a number of layers that produces an equivalent Carbon Fiber FR-A volume to the corresponding XY orientation part. These layers are evenly distributed between the bottom-most and top-most eligible layers. Where an odd number of layers produces an equivalent Carbon Fiber FR-A volume, the closest even number is chosen instead.

Figure 1-6. The blue areas in both the top and bottom of the figure show where CFRA reinforcement is planned for Partial Fiber printing in XZ orientation. Horizontal Z axis (bottom) represents the OFRA and CFRA material through the thickness.

ZX orientation test specimens fit fiber in layers around the targeted break location. Notched test specimens feature fiber placed in the area the notch will be machined, plus an extra 10mm worth of layers above and below the notched region. Unnotched test specimens feature a 30mm thick band of fiber layers around the expected break region. If the expected break region cannot be determined, fiber is placed on all eligible layers.

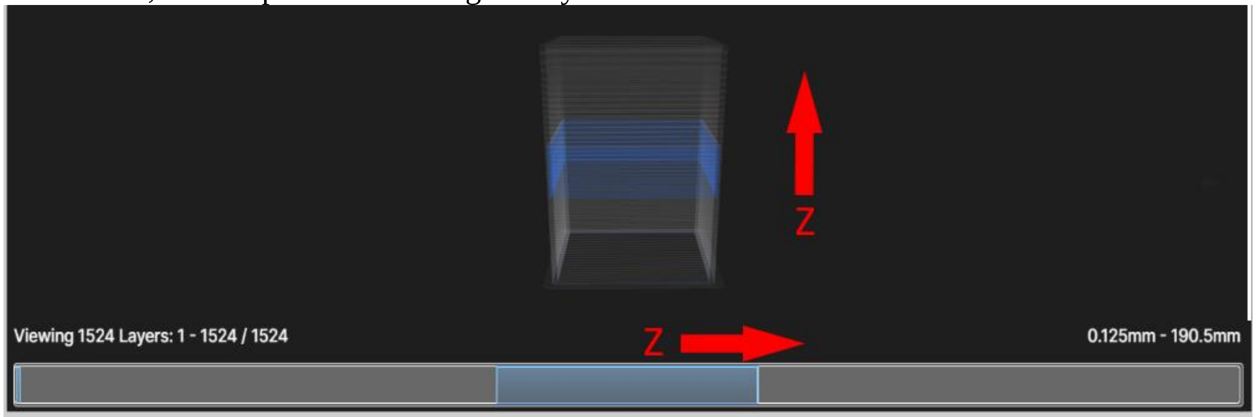

Figure 1-7. The blue area in the figure show where CFRA reinforcement is planned for Partial Fiber printing in ZX orientation.
Horizontal Z axis (bottom) represents the OFRA and CFRA material through the thickness.

1.2 Symbols and Abbreviations

Test Method	Abbreviation
ASTM D790: Flex	F
ASTM D2344: Short Beam Strength	SBS
ASTM D3039: Tension	T
ASTM D3518: In-Plane Shear	IPS
ASTM D5766: Open-Hole Tension	OHT
ASTM D5961: Single Shear Bearing	SSB
ASTM D6641: Combined Loading Compression	CLC
ASTM D6742: Filled Hole Tension	FHT

Table 1-1: Test Method Abbreviations

Fiber Portion	Abbreviation
Full Fiber	FF
Partial Fiber	PF
No Fiber	NF

Table 1-2: Fiber Abbreviations

Environmental Condition	Abbreviation	Temperature
Cold Temperature Dry	CTD	−65˚±5˚F
Room Temperature Dry	RTD	70˚±10˚F
Elevated Temperature Dry	ETD	130˚±5˚F
Elevated Temperature Wet	ETW	130˚±5˚F

Table 1-3: Environmental Conditions Abbreviations

In table 1-4 we introduce the abbreviation used for the combination of Batch and Machine in this report.

Batch and Machine Number	Abbreviation
Batch 1 Machine 1	Batch #1#1
Batch 1 Machine 2	Batch #1#2
Batch 2 Machine 1	Batch #2#1
Batch 2 Machine 2	Batch #2#2
Batch 3 Machine 1	Batch #3#1
Batch 3 Machine 2	Batch #3#2

Table 1-4: Batch and Machine Number abbreviation

Detailed information about the test methods and conditions used is given in NCAMP Material Property Data Report CAM-RP-2023-008 Rev N/C.

1.3 Pooling Across Environments

When pooling across environments was allowable, the pooled co-efficient of variation was used. CMH17 STATS (CMH17 Approved Statistical Analysis Program) was used to determine if pooling was allowable and to compute the pooled coefficient of variation for those tests.

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

1.4 Basis Value Computational Process

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

2. Background

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

2.1 CMH17 STATS Statistical Formulas and Computations

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

2.1.1 Basic Descriptive Statistics

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

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

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

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

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

2.1.2 Statistics for Pooled Data

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

2.1.2.1 Pooled Standard Deviation

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

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

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

2.1.2.2 Pooled Coefficient of Variation

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

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

2.1.3 Basis Value Computations

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

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

2.1.3.1 K-factor computations

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

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

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

Where

r = the number of environments being pooled together

n_j = number of data values for environment j

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

$$f = N - r$$

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

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

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

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

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

2.1.4 Determination of Outliers

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

$$MNR = \frac{\max\limits_{all\ i} \left| X_i - \bar{X} \right|}{S}, i = 1 \ldots n$$ **Equation 14**

$$C = \frac{n-1}{\sqrt{n}} \sqrt{\frac{t^2}{n - 2 + t^2}}$$ **Equation 15**

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

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

2.1.5 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:

$$ADK = \frac{n-1}{n^2(k-1)} \sum_{i=1}^{k} \left[\frac{1}{n_i} \sum_{j=1}^{L} h_j \frac{\left(nF_{ij} - n_i H_j\right)^2}{H_j\left(n - H_j\right) - \frac{nh_j}{4}} \right]$$ **Equation 16**

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:

$$ADC = 1 + \sigma_n \left[z_\alpha + \frac{0.678}{\sqrt{k-1}} - \frac{0.362}{k-1} \right]$$ **Equation 17**

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

$$\sigma_n^2 = VAR(ADK) = \frac{an^3 + bn^2 + cn + d}{(n-1)(n-2)(n-3)(k-1)^2}$$ **Equation 18**

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.

2.1.6 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:

$$F(x) = \int_a^b \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx \quad \textbf{Equation 19}$$

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

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

$$z_{(i)} = \frac{x_{(i)} - \bar{x}}{s}, \quad \text{for i = 1,\ldots,n} \quad \textbf{Equation 20}$$

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

The Anderson Darling test statistic (AD) is:

$$AD = \sum_{i=1}^{n} \frac{1-2i}{n} \left\{ \ln\left[F_0(z_{(i)})\right] + \ln\left[1 - F_0\left(z_{(n+1-i)}\right)\right] \right\} - n \quad \textbf{Equation 21}$$

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

$$OSL = \frac{1}{1 + e^{-0.48+0.78\ln(AD^*)+4.58AD^*}}, \quad AD^* = \left(1 + \frac{4}{n} - \frac{25}{n^2}\right) AD \quad \textbf{Equation 22}$$

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.

2.1.7 Levene's Test for Equality of Coefficient of Variation

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

$$F = \frac{\sum_{i=1}^{k} n_i \left(\bar{w}_i - \bar{w}\right)^2 / (k-1)}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} {}_i\left(w_{ij} - \bar{w}_i\right)^2 / (n-k)} \quad \textbf{Equation 23}$$

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

2.1.8 Distribution Tests

In addition to testing for normality using the Anderson-Darling test (see 2.1.6), CMH17 STATS also tests to see if the Weibull or Lognormal distribution is a good fit for the data.

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

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

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

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

2.1.8.1 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 24**

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

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

The exact computation of k_A values is $1/\sqrt{n}$ times the 0.95th quantile of the noncentral t-distribution with noncentrality parameter $2.326\sqrt{n}$ and n − 1 degrees of freedom (Reference

11). Since this is not a calculation that Excel can handle easily, the following approximation to the k_A values is used:

$$k_A \approx 2.326 + \exp\{1.34 - 0.522\ln(n) + 3.87/n\}$$ **Equation 25**

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

2.1.8.3 Two-parameter Weibull Distribution

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

$$e^{-\left(a/\alpha\right)^{\beta}} - e^{-\left(b/\alpha\right)^{\beta}}$$ **Equation 26**

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

In order to compute a check of the fit of a data set to the Weibull distribution and compute basis values assuming Weibull, it is first necessary to obtain estimates of the population shape and scale parameters (Section 2.1.8.3.1). Calculations specific to the goodness-of-fit test for the Weibull distribution are provided in section 2.1.8.3.2.

2.1.8.3.1 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 27**

$$\frac{n}{\hat{\beta}} - n\ln\hat{\alpha} + \sum_{i=1}^{n}\ln x_i - \sum_{i=1}^{n}\left[\frac{x_i}{\hat{\alpha}}\right]^{\hat{\beta}}\left(\ln x_i - \ln\hat{\alpha}\right) = 0$$ **Equation 28**

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

2.1.8.3.2 Goodness-of-fit test for the Weibull distribution

The two-parameter Weibull distribution is considered by comparing the cumulative Weibull distribution function that best fits the data with the cumulative distribution function of the data. Using the shape and scale parameter estimates from section 2.1.8.3.1, let

$$z_{(i)} = \left[x_{(i)}/\hat{\alpha}\right]^{\hat{\beta}}, \quad \text{for } i = 1, \ldots, n$$ **Equation 29**

The Anderson-Darling test statistic is

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

and the observed significance level is

$$OSL = 1/\left\{1 + \exp[-0.10 + 1.24\ln(AD^{*}) + 4.48AD^{*}]\right\}$$ **Equation 31**

where

$$AD^{*} = \left(1 + \frac{0.2}{\sqrt{n}}\right) AD$$ **Equation 32**

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.

2.1.8.3.3 Basis value calculations for the Weibull distribution

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

$$B = \hat{q} e^{\left(-V / \hat{\beta}\sqrt{n}\right)}$$ **Equation 33**

where

$$\hat{q} = \hat{\alpha}\left(0.10536\right)^{1/\hat{\beta}}$$ **Equation 34**

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

$$\hat{q} = \hat{\alpha}(0.01005)^{1/\beta}$$ **Equation 35**

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

$$V_B \approx 3.803 + \exp\left[1.79 - 0.516\ln(n) + \frac{5.1}{n-1}\right]$$ **Equation 36**

$$V_A \approx 6.649 + \exp\left[2.55 - 0.526\ln(n) + \frac{4.76}{n}\right]$$ **Equation 37**

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

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

Table 2-1: Weibull Distribution Basis Value Factors

2.1.8.4 Lognormal Distribution

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

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

2.1.8.4.1 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 2.1.6. Using the natural logarithm, replace Equation 29 above with Equation 47 below:

$$z_{(i)} = \frac{\ln\left(x_{(i)}\right) - \overline{x}_L}{s_L}, \quad \text{for } i = 1, \ldots, n$$ **Equation 38**

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

2.1.8.4.2 Basis value calculations for the Lognormal distribution

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

2.1.9 Non-parametric Basis Values

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

2.1.9.1 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:

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

Equation 39

For A-Basis values:

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

Equation 40

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

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

2.1.9.2 Non-parametric Basis Values for small samples

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

The Hanson-Koopmans B-basis value is:

$$B = x_{(r)} \left[\frac{x_{(1)}}{x_{(r)}} \right]^k$$ **Equation 41**

The A-basis value is:

$$A = x_{(n)} \left[\frac{x_{(1)}}{x_{(n)}} \right]^k$$ **Equation 42**

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

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

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

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

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

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

2.1.10 Analysis of Variance (ANOVA) Basis Values

ANOVA is used to compute basis values when the group to group variability of the data does not pass the ADK test. Since ANOVA makes the assumption that the different groups 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 2.1.7). If the dataset fails Levene's test, the basis values computed are likely to be conservative. Thus this method can still be used but the values produced will be listed as estimates.

2.1.10.1 Calculation of basis values using ANOVA

The following calculations address group to group variability. The datasets are grouped by both machine and raw material batch and the k-sample Anderson-Darling test (Section 2.1.5) indicates that the group to group variability is too large to pool the data. The method is based on the one-way analysis of variance random-effects model, and the procedure is documented in reference 10.

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

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

$$SSB = \sum_{i=1}^{k} n_i \overline{x}_I^2 - n\overline{x}^2 \qquad \text{Equation 43}$$

$$SST = \sum_{i=1}^{k} \sum_{j=1}^{n_i} x_{ij}^2 - n\overline{x}^2 \qquad \text{Equation 44}$$

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

$$SSE = SST - SSB \qquad \text{Equation 45}$$

Next, the mean sums of squares are computed:

$$MSB = \frac{SSB}{k-1} \qquad \text{Equation 46}$$

$$MSE = \frac{SSE}{n-k} \qquad \text{Equation 47}$$

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

$$n' = \frac{n - \frac{1}{n}\sum_{i=1}^{k} n_i^2}{k-1} \qquad \text{Equation 48}$$

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

$$S = \sqrt{\frac{MSB}{n'} + \left(\frac{n'-1}{n'}\right) MSE} \qquad \text{Equation 49}$$

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

Denote the ratio of mean squares by

$$u = \frac{MSB}{MSE} \qquad \textbf{Equation 50}$$

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

$$T = \frac{k_0 - \frac{k_1}{\sqrt{n'}} + \left(k_1 - k_0\right)\sqrt{\frac{u}{u + n' - 1}}}{1 - \frac{1}{\sqrt{n'}}} \qquad \textbf{Equation 51}$$

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.

3. Summary of Results

The basis values for all tests are summarized in the following tables. The NCAMP recommended B-basis values meet all requirements of CMH-17-1G. However, not all test data meets those requirements. The summary tables provide a complete listing of all computed basis values and estimates of basis values. Data that does not meet the requirements of CMH-17-1G are shown in shaded boxes and labeled as estimates.

3.1 NCAMP Recommended B-basis Values

The following rules are used in determining what B-basis value, if any, is included in Table 3-1 and Table 3-2 of recommended values.

1. Recommended values are NEVER estimates. Only B-basis values that meet all requirements of CMH-17-1G are recommended.
2. ANOVA B-basis values are not recommended since only three batches of material are available and CMH-17-1G recommends that no less than five batches be used when computing basis values with the ANOVA method.
3. Basis values of 90% or more of the mean value imply that the CV is unusually low and may not be conservative. Caution is recommended with B-Basis values calculated from CMH17 STATS when the B-basis value is 90% or more of the average value. Such values will be indicated.

If the data appear questionable (e.g. when the CTD-RTD-ETW trend of the basis values is not consistent with the CTD-RTD-ETW trend of the average values), then the B-basis values will not be recommended.

NCAMP Recommended B-basis Values for
Markforged Onyx FR-A™ - Carbon Fiber FR-A™ / Markforged X7
All B-basis values in this table meet the standards for publication in CMH-17-1G Handbook

Test Condition				CTD (–65° F)		RTD (70° F)		ETD (130° F)		ETW (130° F)	
Test Method	Orientation	Fiber Fill	Property	B-Basis	Mean	B-Basis	Mean	B-Basis	Mean	B-Basis	Mean
Tension	ZX	No	Strength [ksi]	3.996	4.726	2.408	2.823	1.527	1.782	1.051	1.241
	XY	Partial	Strength [ksi]	41.64	46.32	33.48	38.18	28.20	32.93	24.24	30.85
	XZ	Partial	Strength [ksi]	37.87	41.55	31.63	35.37	28.02	31.76	16.06	19.76
IPS	XY	Partial	0.2% Offset Strength [ksi]	3.444	3.911	1.538	1.697	1.104	1.264	0.2677	0.5711
	XY	Partial	5% Offset Strength [ksi]			2.756	3.120	2.043	2.293	0.6083	1.078
	XY	Partial	Maximum Strength [ksi]	5.611	6.355	3.260	3.997	2.623	3.368	1.380	1.779
SSB Proc. C	ZX	No	2% Offset Strength [ksi]	NA	18.31	7.161	10.13			2.078	2.690
	ZX	No	Ultimate Strength [ksi]	15.29	19.03	10.40	12.72			4.048	4.776
	XY	Partial	2% Offset Strength [ksi]	37.48	44.36	22.06	29.73			NA	13.69
	XY	Partial	Ultimate Strength [ksi]	42.43	47.86	27.94	33.37			9.252	14.66
	XZ	Partial	2% Offset Strength [ksi]			NA	10.75			3.283	5.008
	XZ	Partial	Ultimate Strength [ksi]	17.90	21.95	8.679	12.76			5.287	6.046
CLC	ZX	No	0.2% Offset Strength [ksi]	7.528	10.68	1.863	3.068	1.364	1.734	0.8212	1.014
	XY	Partial	Strength [ksi]	24.27	28.95	13.80	18.47	10.30	15.06	3.802	8.277
	XZ	Partial	Strength [ksi]	19.79	24.14	13.33	16.00	9.850	11.94	3.197	5.548
FHT	ZX	No	Strength [ksi]	2.751	3.562	2.012	2.574	1.397	1.529	0.8044	0.9386
	XY	Partial	Strength [ksi]	12.67	13.65	9.525	10.49	7.835	8.817	5.758	6.735
	XZ	Partial	Strength [ksi]	31.89	37.13	25.37	36.54	28.91	33.74	15.03	25.43
OHT	ZX	No	Strength [ksi]	2.709	3.327	1.883	2.502	1.099	1.407	0.6364	0.8699
	XY	Partial	Strength [ksi]	9.606	11.89	8.690	9.517	7.312	8.139	5.382	6.659
SBS	XY	Partial	Strength [ksi]	3.118	4.237	1.528	2.291	1.514	1.841	0.5464	0.8776
FLEX Proc. A	ZX	No	Strength [ksi]	7.261	10.97	5.493	6.937	2.964	3.640	1.426	1.856
	ZX	No	2% Offset Strength [ksi]	NA	12.02	3.975	4.771	1.896	2.236	0.5451	0.7953
	XY	Partial	Strength [ksi]	48.32	59.89	NA	38.07	22.97	26.87	0.7490	12.05
	XZ	Partial	Strength [ksi]	41.20	45.42	20.82	26.48	15.02	16.41	NA	7.679
	XZ	Partial	2% Offset Strength [ksi]	NA	34.77	11.65	18.91	13.01	14.25	NA	5.934

Table 3-1 : NCAMP Recommended B-basis values

3.2 Complete Summary Tables

NCAMP Properties Summary

Markforged Onyx FR-A™ - Carbon Fiber FR-A™ / Markforged X7

Values shown in shaded boxes do not meet CMH-17-1G requirements and are estimates only
These values may not be used for certification unless specifically allowed by the certifying agency

Test Condition				CTD (–65° F)		RTD (70° F)		ETD (130° F)		ETW (130° F)	
Test Method	Orientation	Fiber Fill	Property	B-Basis	Mean	B-Basis	Mean	B-Basis	Mean	B-Basis	Mean
Tension	ZX	No	Strength [ksi]	3.996	4.726	2.408	2.823	1.527	1.782	1.051	1.241
	ZX	No	Modulus [Msi]		0.5640		0.2473		0.1200		0.05809
	XY	Partial	Strength [ksi]	41.64	46.32	33.48	38.18	28.20	32.93	24.24	30.85
	XY	Partial	Modulus [Msi]		3.030		2.810		2.710		2.544
	XZ	Partial	Strength [ksi]	37.87	41.55	31.63	35.37	28.02	31.76	16.06	19.76
	XZ	Partial	Modulus [Msi]		3.260		2.831		2.606		2.032
IPS	XY	Full	0.2% Offset Strength [ksi]			2.561	3.103				
	XY	Full	5% Offset Strength [ksi]			4.502	5.700				
	XY	Full	Maximum Strength [ksi]			4.504	6.746				
	XY	Full	Modulus [Msi]				0.2507				
	XY	Partial	0.2% Offset Strength [ksi]	3.444	3.911	1.538	1.697	1.104	1.264	0.2677	0.5711
	XY	Partial	5% Offset Strength [ksi]			2.756	3.120	2.043	2.293	0.6083	1.078
	XY	Partial	Maximum Strength [ksi]	5.611	6.355	3.260	3.997	2.623	3.368	1.380	1.779
	XY	Partial	Modulus [Msi]		0.2482		0.1341		0.1029		0.04767
SSB Proc. C	ZX	No	2% Offset Strength [ksi]	15.11	18.31	7.161	10.13			2.078	2.690
	ZX	No	Ultimate Strength [ksi]	15.29	19.03	10.40	12.72			4.048	4.776
	ZX	No	Bearing Stiffness [Msi]		0.2259		0.1115				0.02442
	XY	Partial	2% Offset Strength [ksi]	37.48	44.36	22.06	29.73			8.983	13.69
	XY	Partial	Ultimate Strength [ksi]	42.43	47.86	27.94	33.37			9.252	14.66
	XY	Partial	Bearing Stiffness [Msi]		0.4210		0.3648				0.2335
	XZ	Partial	2% Offset Strength [ksi]			5.081	10.75			3.283	5.008
	XZ	Partial	Ultimate Strength [ksi]	17.90	21.95	8.679	12.76			5.287	6.046
	XZ	Partial	Bearing Stiffness [Msi]		0.3585		0.1860				0.06171
CLC	ZX	No	0.2% Offset Strength [ksi]	7.528	10.68	1.863	3.068	1.364	1.734	0.8212	1.014
	ZX	No	Avg. Modulus [Msi]		0.3234		0.6248		0.1891		0.1248
	XY	Partial	Strength [ksi]	24.27	28.95	13.80	18.47	10.30	15.06	3.802	8.277
	XY	Partial	Avg. Modulus [Msi]		2.835		2.674		2.795		2.838
	XZ	Partial	Strength [ksi]	19.79	24.14	13.33	16.00	9.850	11.94	3.197	5.548
	XZ	Partial	Avg. Modulus [Msi]		2.630		2.097		1.620		1.000
FHT	ZX	No	Strength [ksi]	2.751	3.562	2.012	2.574	1.397	1.529	0.8044	0.9386
	XY	Partial	Strength [ksi]	12.67	13.65	9.525	10.49	7.835	8.817	5.758	6.735
	XZ	Partial	Strength [ksi]	31.89	37.13	25.37	36.54	28.91	33.74	15.03	25.43
OHT	XY	Full	Strength [ksi]			17.51	20.61				
	XZ	Full	Strength [ksi]			45.60	52.39				
	ZX	No	Strength [ksi]	2.709	3.327	1.883	2.502	1.099	1.407	0.6364	0.8699
	XY	Partial	Strength [ksi]	9.606	11.89	8.690	9.517	7.312	8.139	5.382	6.659
	XZ	Partial	Strength [ksi]	19.06	28.53	18.90	34.84	29.98	32.96	16.90	24.28
	ZX	Partial	Strength [ksi]	0.4210	1.106	NA	1.030				
SBS	XY	Full	Strength [ksi]			2.601	3.306				
	XY	Partial	Strength [ksi]	3.118	4.237	1.528	2.291	1.514	1.841	0.5464	0.8776
FLEX Proc. A	ZX	No	Strength [ksi]	7.261	10.97	5.493	6.937	2.964	3.640	1.426	1.856
	ZX	No	2% Offset Strength [ksi]	9.415	12.02	3.975	4.771	1.896	2.236	0.5451	0.7953
	ZX	No	Modulus [Msi]		0.5612		0.3101		0.1209		0.05660
	XY	Partial	Strength [ksi]	48.32	59.89	29.86	38.07	22.97	26.87	0.7490	12.05
	XY	Partial	2% Offset Strength [ksi]	NA	68.05	NA	35.13	6.777	23.91	NA	10.00
	XY	Partial	Modulus [Msi]		2.715		2.126		1.831		1.172
	XZ	Partial	Strength [ksi]	41.20	45.42	20.82	26.48	15.02	16.41	NA	7.679
	XZ	Partial	2% Offset Strength [ksi]	31.50	34.77	11.65	18.91	13.01	14.25	NA	5.934
	XZ	Partial	Modulus [Msi]		1.898		1.343		0.9640		0.5093

Table 3-2: Summary of basis values

NCAMP Properties Summary - Information Purposes Only
Markforged Onyx FR-A™ - Carbon Fiber FR-A™ / Markforged X7

Test Condition				CTD (–65° F)		RTD (70° F)		ETD (130° F)	
Test Method	Orientation	Fiber Fill	Property	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Tension	XY	Full	Strength [ksi]			85.80	4.161		
	XY	Full	Modulus [Msi]			7.038	0.06328		
	XZ	Full	Strength [ksi]			63.27	4.297		
	XZ	Full	Modulus [Msi]			5.242	0.1681		
	ZX	Partial	Strength [ksi]			1.309	0.2766		
	ZX	Partial	Modulus [Msi]			0.2581	0.04932		
SSB Proc. C	ZX	Partial	2% Offset Strength [ksi]			4.572	0.5884		
	ZX	Partial	Ultimate Strength [ksi]			6.703	0.5577		
	ZX	Partial	Bearing Stiffness [Msi]			0.1246	0.01756		
	XY	Full	2% Offset Strength [ksi]			50.35	3.053		
	XY	Full	Ultimate Strength [ksi]			58.00	5.729		
	XY	Full	Bearing Stiffness [Msi]			0.6860	0.02303		
	XZ	Full	2% Offset Strength [ksi]			11.23	1.452		
	XZ	Full	Ultimate Strength [ksi]			12.19	0.7047		
	XZ	Full	Bearing Stiffness [Msi]			0.2080	0.07281		
CLC	ZX	Partial	Strength [ksi]	20.00	2.567	11.83	2.212	9.212	0.3366
	ZX	Partial	Avg. Modulus [Msi]	0.4401	0.06244	0.2962	0.05165	0.2172	0.01661
	XY	Full	Strength [ksi]			39.12	3.156		
	XY	Full	Avg. Modulus [Msi]			6.589	0.2089		
	XZ	Full	Strength [ksi]			23.48	1.688		
	XZ	Full	Avg. Modulus [Msi]			5.174	0.1922		
FHT	ZX	Partial	Strength [ksi]			1.005	0.1357		
	XY	Full	Strength [ksi]			22.53	1.361		
	XZ	Full	Strength [ksi]			53.36	3.264		
FLEX Proc. A	ZX	Partial	Strength [ksi]	4.450	1.329	4.097	0.6673		
	ZX	Partial	2% Offset Strength [ksi]			3.699	0.9343		
	ZX	Partial	Modulus [Msi]	0.4584	0.02355	0.3564	0.04161		
	XY	Full	Strength [ksi]			51.78	4.289		
	XY	Full	Modulus [Msi]			2.979	0.09090		
	XZ	Full	Strength [ksi]			36.57	2.680		
	XZ	Full	2% Offset Strength [ksi]			33.98	1.818		
	XZ	Full	Modulus [Msi]			1.851	0.1461		

Table 3-3: Summary of Basic Statistics - Informational Purposes Only

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

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

When a dataset fails the Anderson-Darling k-sample (ADK) test for batch-to-batch variation, an ANOVA analysis is required. In order for B-basis values to be computed using the ANOVA method, data from five batches are required. Since this qualification dataset has only three batches, the basis values computed using ANOVA are considered estimates only. However, the basis values resulting from the ANOVA method using only three batches may be overly conservative.

In the data reported, we detected more variability between machines than between batches. This means, if we adopt batches as our statistical unit of analysis, we would have allowables, computed using ANOVA method, that are too low. Therefore, we adopted batch – machine combination as our statistical unit of analysis. In all the tables in the sections below, we report the number of statistical units of analysis because the computations use these. For each section below there is usually 3 batches and 2 machines for each batch, which makes 6 batch - machine combinations, in some cases there are 1 batch and 2 machines, which makes 2 batch-machines combinations or 1 batch and 1 machine which makes 1 batch-machine combination.

4.1 Tension (T) XY Orientation Full Fiber (FF) Fill (Informational purposes)

In this case, only RTD environment data are provided for tensile strength and modulus properties. Since this data are only for informational purposes, only basic statistics are provided and no allowables.

There were no statistical outliers.

Statistics are given for the tensile strength data in Table 4-1. For modulus data in Table 4-2. The data are shown graphically in Fig 4-1.

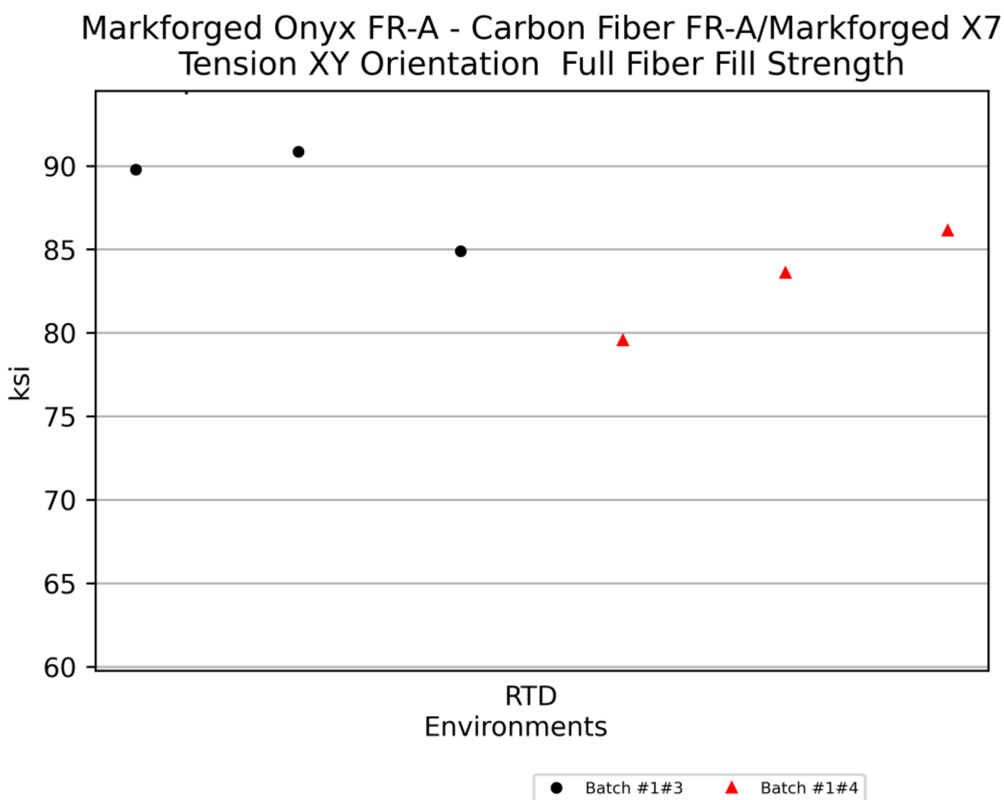

Figure 4-1: Batch plot for XY Orientation FF Tensile Strength

Tension XY Orientation Full Fiber Fill Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	85.80
Stdev	4.161
CV	4.850
Min	79.54
Max	90.86
No. Batches/Machines	2
No. Spec.	6

Table 4-1: Statistics for XY Orientation FF Tensile Strength

Tension XY Orientation Full Fiber Fill Statistics	
	Modulus [Msi]
Env	RTD(70°F)
Mean	7.038
Stdev	0.06328
CV	0.8991
Min	6.958
Max	7.114
No. Batches/Machines	2
No. Spec.	6

Table 4-2: Statistics for XY Orientation FF Modulus

4.2 Tension (T) XZ Orientation Full Fiber (FF) Fill (Informational purposes)

In this case, only RTD environment data are provided for tensile strength and modulus properties. Since this data are only for informational purposes, only basic statistics are provided and no allowables.

There were no statistical outliers.

Statistics are given for the tensile strength data in Table 4-3. For modulus data in Table 4-4. The strength data are shown graphically in Fig 4-2.

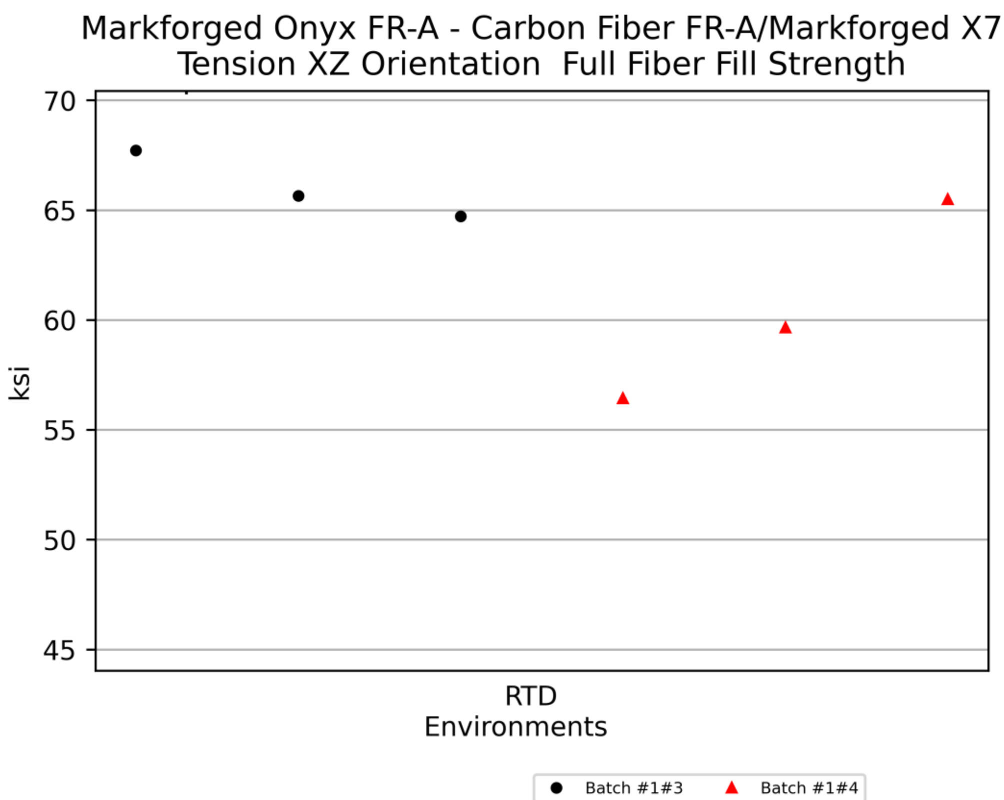

Figure 4-2: Batch Plot for XZ Orientation FF Tensile Strength

Tension XZ Orientation Full Fiber Fill Statistics	
	Strength [ksi]
Env	RTD (70°F)
Mean	63.27
Stdev	4.297
CV	6.790
Min	56.43
Max	67.72
No. Batches/Machines	2
No. Spec.	6

Table 4-3: Statistics and Basis Values for XZ Orientation FF Tensile Strength

Tension XZ Orientation Full Fiber Fill Statistics	
	Modulus [Msi]
Env	RTD(70˚F)
Mean	5.242
Stdev	0.1681
CV	3.207
Min	4.927
Max	5.373
No. Batches/Machines	2
No. Spec.	6

Table 4-4: Statistics for XZ Orientation FF Modulus

4.3 Tension (T) ZX Orientation No Fiber (NF) Fill

In this case, all four environments CTD, RTD, ETD, and ETW data are provided for tensile strength and modulus properties. The CTD and RTD environments pass ADK and normality test, so the normal method was used to compute basis values for both environments. However, ETD and ETW fail ADK test, so ANOVA method was used for these. Since each environment has more than five batch/machine combinations, ANOVA method provides B-basis values and not estimates.

One outlier was detected. A lower batch-machine outlier in condition RTD, Batch #2 Machine #2. The outlier was retained for statistical analysis purposes as no assignable cause was found after further investigation.

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

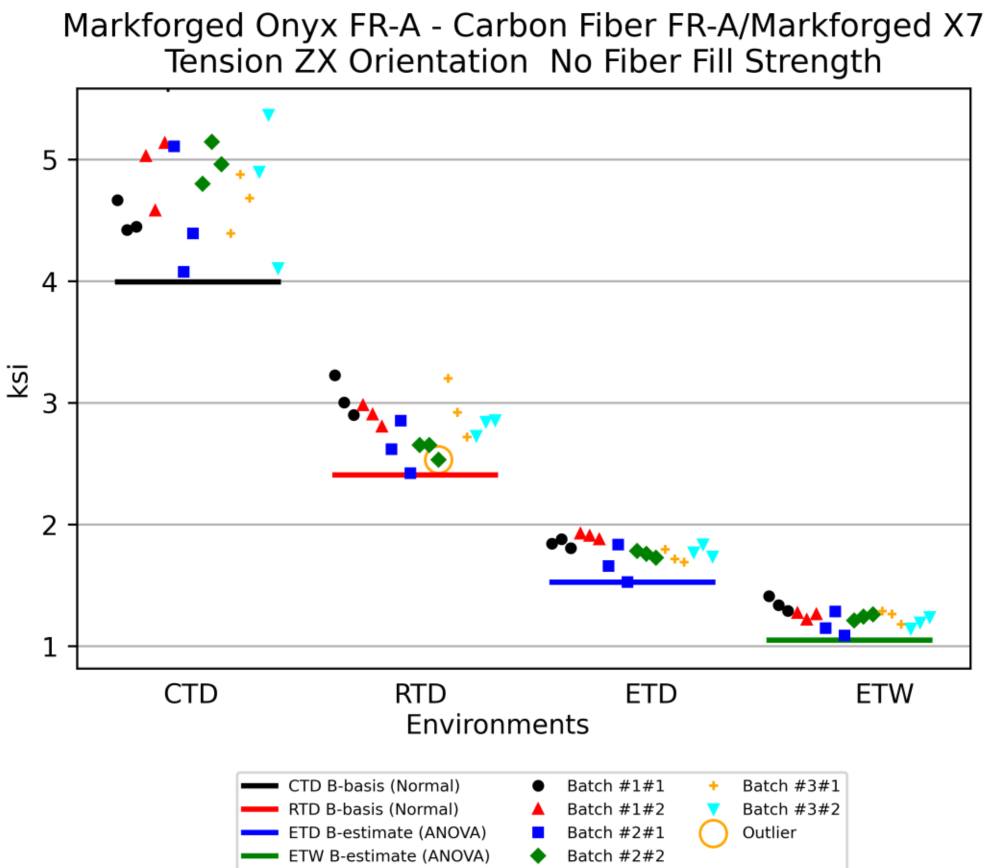

Figure 4-3: Batch Plot for ZX Orientation NF Tensile Strength

Tension ZX Orientation No Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65˚F)	RTD(70˚F)	ETD(130˚F)	ETW(130˚F)
Mean	4.726	2.823	1.782	1.241
Stdev	0.3700	0.2105	0.09791	0.07514
CV	7.829	7.455	5.495	6.053
Min	4.076	2.421	1.527	1.089
Max	5.369	3.226	1.926	1.412
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	3.996	2.408	1.527	1.051
A-Estimate	3.478	2.113	1.350	0.9190
Method	Normal	Normal	ANOVA	ANOVA

Table 4-5: Statistics and Basis Values for ZX Orientation NF Tensile Strength

Tension ZX Orientation No Fiber Fill Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	0.5640	0.2473	0.1200	0.05809
Stdev	0.02506	0.02981	0.01001	0.008433
CV	4.442	12.05	8.337	14.52
Min	0.5151	0.1986	0.1010	0.04304
Max	0.6011	0.2966	0.1345	0.07182
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18

Table 4-6: Statistics for ZX Orientation NF Modulus

4.4 Tension (T) XY Orientation Partial Fiber (PF) Fill

In this case, all four environments CTD, RTD, ETD, and ETW data are provided for tensile strength and modulus properties. The CTD, RTD, and ETD environments pass the pooling test, so pooling method was used to compute basis values for these three environments. However, ETW failed ADK test, so ANOVA method was used for this. Since each environment has more than five batch/machine combinations, ANOVA method provides B-basis values and not estimates.

One statistical outlier was detected in condition ETD using Maximum Normed Residual statistical method. A higher batch-machine outlier in batch #1 machine #2 condition ETD. It was retained for this analysis. Another outlier was detected visually in condition ETW. A lower condition outlier in batch #3 machine #2 condition ETW. Note: The latter had a LAT (Lateral at Grip-Top) failure mode which aligned with other specimens within this batch. The lower performance is due to the hygroscopic nature of the OFRA material and the elevated test environment that caused the material to act erratically. This outlier was retained for performing the computations.

Statistics, basis values, and estimates are given for the XY orientation PF tensile strength data in Table 4-7 and the XY orientation PF modulus data in Table 4-8. The strength data, B-estimates, and B-basis values are shown graphically in Fig. 4-4.

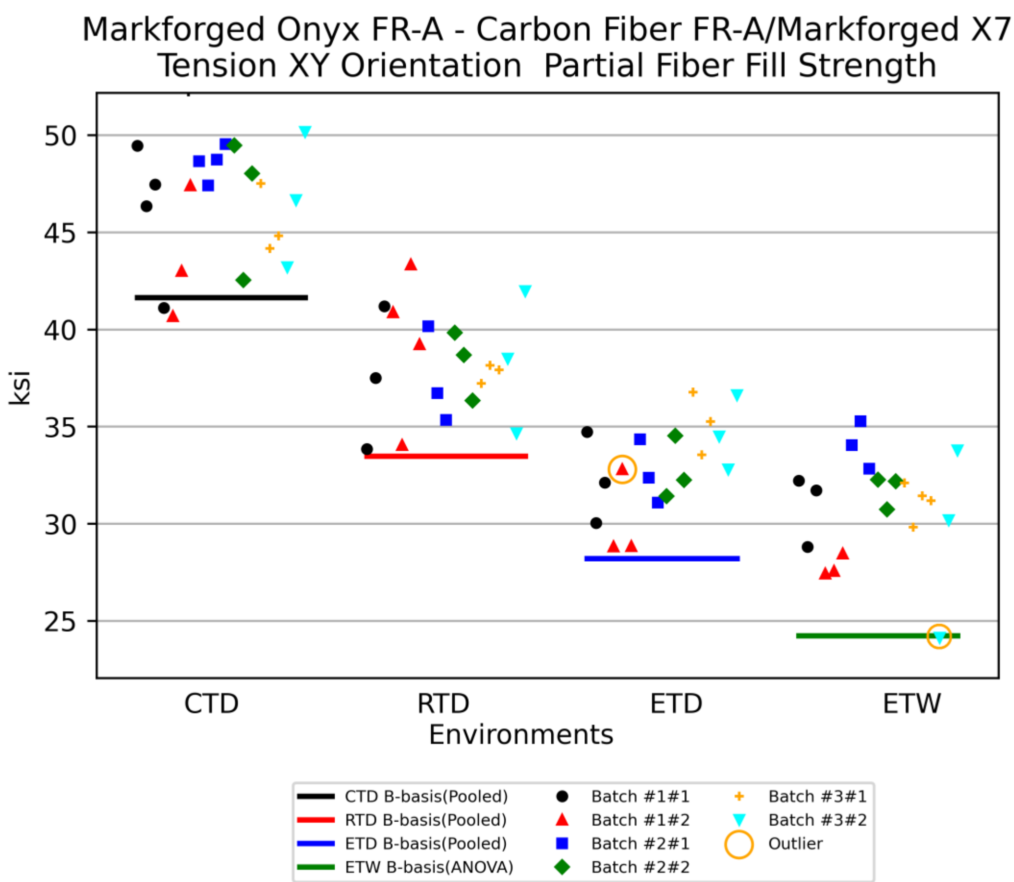

Figure 4-4: Batch Plot for XY Orientation PF Tensile Strength

Tension XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	46.32	38.18	32.93	30.85
Stdev	2.950	2.675	2.346	2.682
CV	6.369	7.005	7.123	8.695
Min	40.68	33.85	28.82	24.14
Max	50.17	43.33	36.77	35.28
No. Batches/Machines	6	6	6	6
No. Spec.	20	19	18	19
Basis Values and Estimates				
B-Basis	41.64	33.48	28.20	24.24
A-Estimate	38.48	30.33	25.06	19.64
Method	Pooled	Pooled	Pooled	ANOVA

Table 4-7: Statistics and Basis Values for XY Orientation PF Tensile Strength

Tension XY Orientation Partial Fiber Fill Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	3.030	2.810	2.710	2.544
Stdev	0.07836	0.07316	0.07723	0.1009
CV	2.587	2.603	2.850	3.966
Min	2.884	2.690	2.521	2.257
Max	3.174	2.942	2.827	2.707
No. Batches/Machines	6	6	6	6
No. Spec.	19	19	18	19

Table 4-8: Statistics for XY Orientation PF Modulus

4.5 Tension (T) ZX Orientation Partial Fiber (PF) Fill (Informational purposes)

In this case, only RTD condition data is available for strength and modulus properties. Data is provided for informational purposes only, so no allowables were calculated.

No outliers were detected.

Statistics are given for the strength data in Table 4-9 and modulus data in Table 4-10. The strength data are shown graphically in **Error! Reference source not found.**5.

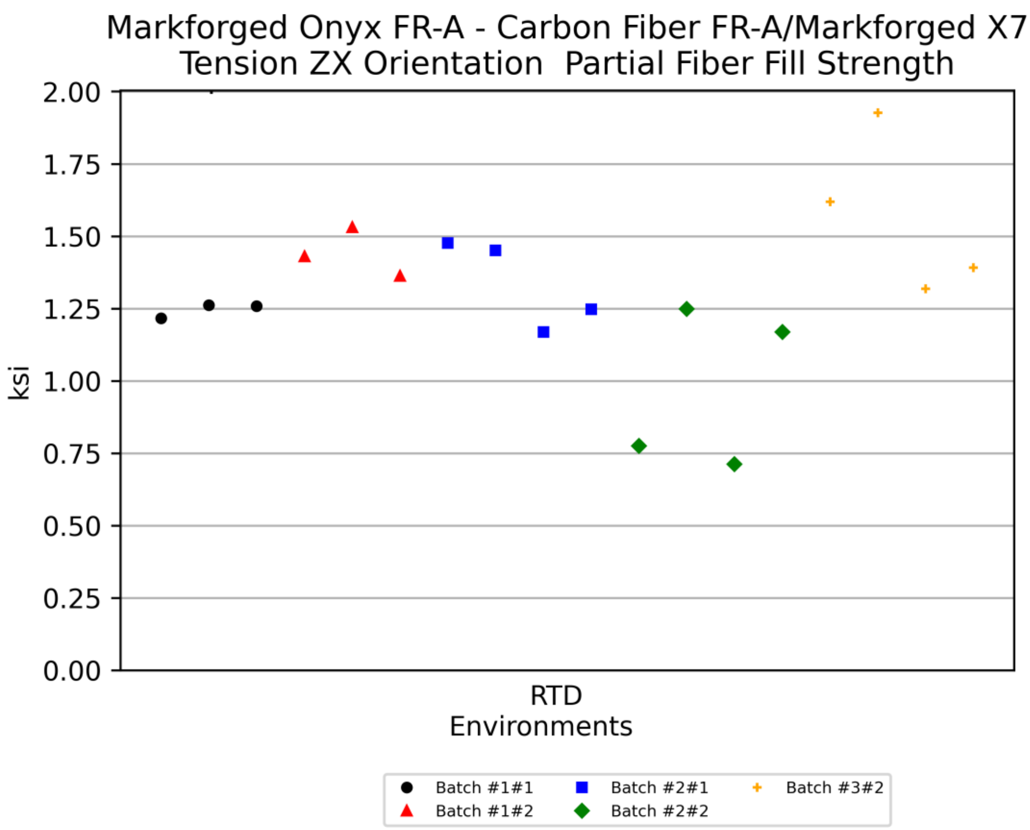

Figure 4-5: Batch plot for ZX Orientation PF Tensile Strength

Tension ZX Orientation Partial Fiber Fill Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	1.309
Stdev	0.2766
CV	21.13
Min	0.7123
Max	1.927
No. Batches/Machines	5
No. Spec.	18

Table 4-9: Statistics and Basis Values for ZX Orientation PF Tensile Strength

Tension ZX Orientation Partial Fiber Fill Statistics	
	Modulus [Msi]
Env	RTD(70˚ F)
Mean	0.2581
Stdev	0.04932
CV	19.11
Min	0.2074
Max	0.3855
No. Batches/Machines	5
No. Spec.	18

Table 4-10: Statistics and Basis Values for ZX Orientation PF Modulus

4.6 In-Plane Shear (IPS) XY Orientation Full Fiber (FF) Fill

In this case, only RTD condition and three test properties (0.2% offset strength, 5% offset strength, and maximum strength) are available. All three properties passed normality test, so normal method was used for computing allowables.

One lower batch-machine outlier was detected for 0.2% offset strength data in batch#1 machine#4 in condition RTD. It was retained for this analysis.

Statistics, basis values, and estimates are given for the three strength properties data in Table 4-11 and modulus data in Table 4-12. The three strength properties data and B-basis values are shown graphically in **Error! Reference source not found.**6, 4-7 and 4-8.

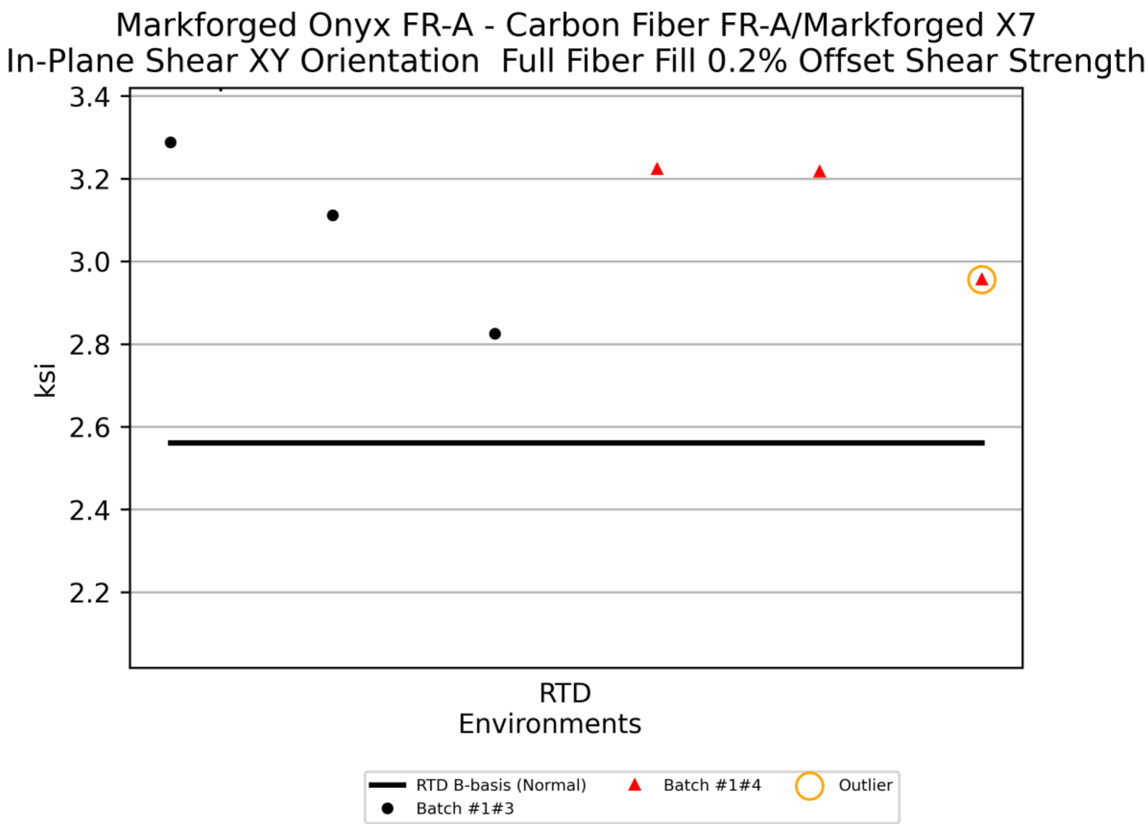

Figure 4-6: Batch plot for IPS XY Orientation FF 0.2% Offset Strength

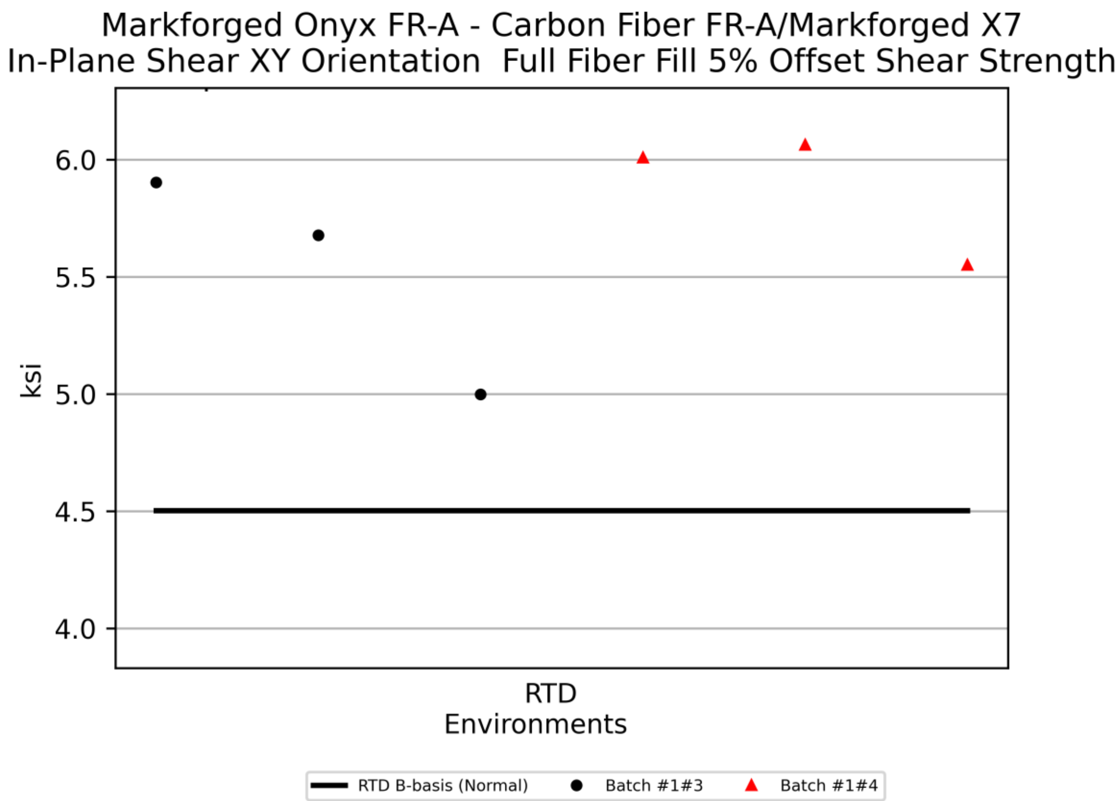

Figure 4-7: Batch plot for IPS XY Orientation FF 5% Offset Strength

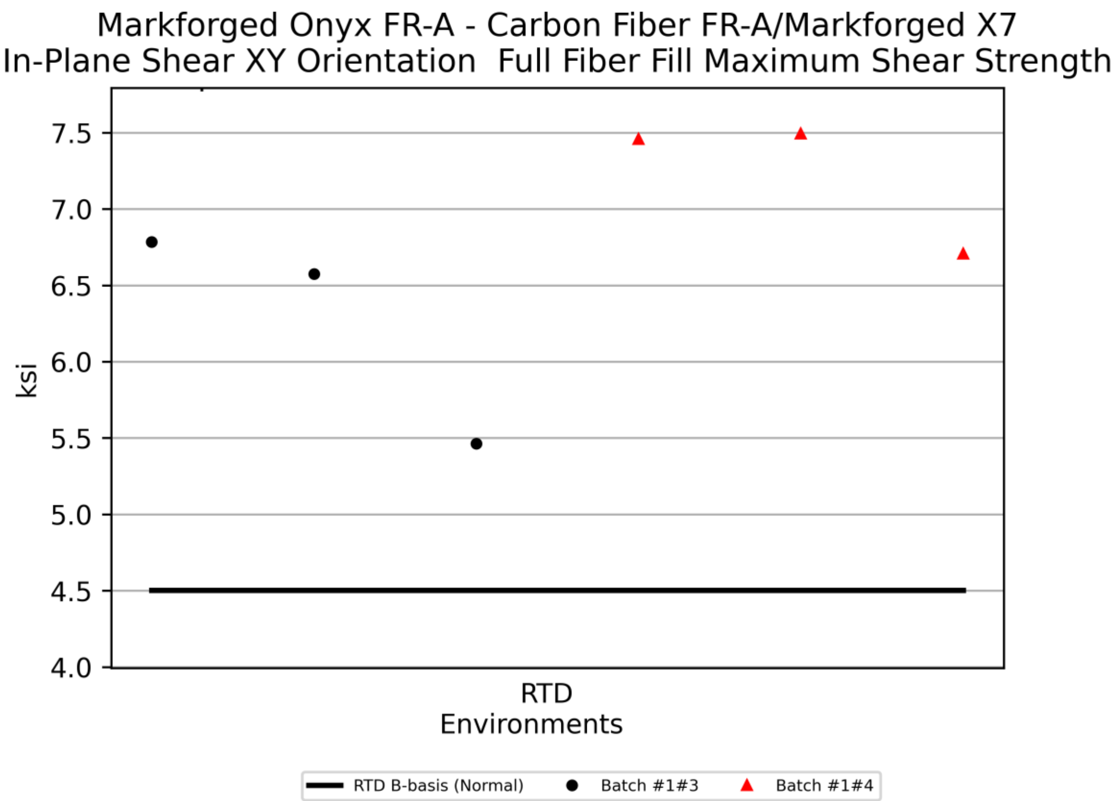

Figure 4-8: Batch plot for IPS XY Orientation FF Maximum Strength

In-Plane Shear XY Orientation Full Fiber Fill Basis Values and Statistics			
	0.2% Offset Strength [ksi]	5% Offset Strength [ksi]	Maximum Strength [ksi]
Env	RTD(70°F)	RTD(70°F)	RTD(70°F)
Mean	3.103	5.700	6.746
Stdev	0.1791	0.3955	0.7403
CV	5.771	6.939	10.97
Min	2.826	4.999	5.464
Max	3.288	6.063	7.493
No. Batches/Machines	2	2	2
No. Spec.	6	6	6
Basis Values and Estimates			
B-Estimate	2.561	4.502	4.504
A-Estimate	2.175	3.650	2.909
Method	Normal	Normal	Normal

Table 4-11: Statistics and Basis Values for IPS XY Orientation FF

In-Plane Shear XY Orientation Full Fiber Fill Statistics	
	Modulus [Msi]
Env	RTD(70°F)
Mean	0.2507
Stdev	0.01412
CV	5.630
Min	0.2338
Max	0.2687
No. Batches/Machines	2
No. Spec.	6

Table 4-12: Statistics for In-Plane Shear Modulus Data

4.7 In-Plane Shear (IPS) XY Orientation Partial Fiber (PF) Fill

In this case, four conditions (CTD, RTD, ETD, and ETW) and three properties (0.2% offset strength, 5% offset strength, and maximum strength) are available. For 0.2% offset strength, RTD and ETD passed pooling tests, so pooling method was used for these two conditions. CTD passed normality test, so normal method was used for this condition. ETW condition failed normality test and ADK test, so ANOVA method was used. Since there are more than five batch machine combinations, the results are B-basis values and not estimates. For 5% offset strength, CTD data is not available due to failure occurring before 50,000 microstrain so only RTD, ETD, and ETW conditions are reported. RTD and ETD passed normality test, so normal method was used for these two conditions. ETW condition failed normality test and ADK test, so ANOVA method was used. Since there are more than five batch machine combinations, the results are B-basis values and not estimates. For maximum strength, CTD, RTD, and ETD passed pooling tests, so pooling method was used for these three conditions. ETW passed normality test, so normal method was used for this condition.

Six outliers were detected. The lowest value in batch one machine two of the ETW condition was an outlier for both 0.2% offset and 5% offset. The lowest value in batch three, machine two of the ETW condition was an outlier for the 0.2% Offset. The lowest value in batch one machine one of the ETW condition was an outlier for 5% Offset. The lowest value in batch two machine two for the CTD condition was an outlier for maximum strength. The largest value in batch one machine two of the ETD condition was an outlier for maximum strength. The lowest value in batch three machine one in the ETD condition was an outlier for maximum strength. All outliers were retained for this analysis.

Statistics, basis values, and estimates are given for the three strength properties data in Tables 4-13, 4-14, 4-15 and modulus data in Table 4-16. The three strength properties data and B-basis values are shown graphically in **Error! Reference source not found.**9, 4-10, and 4-11.

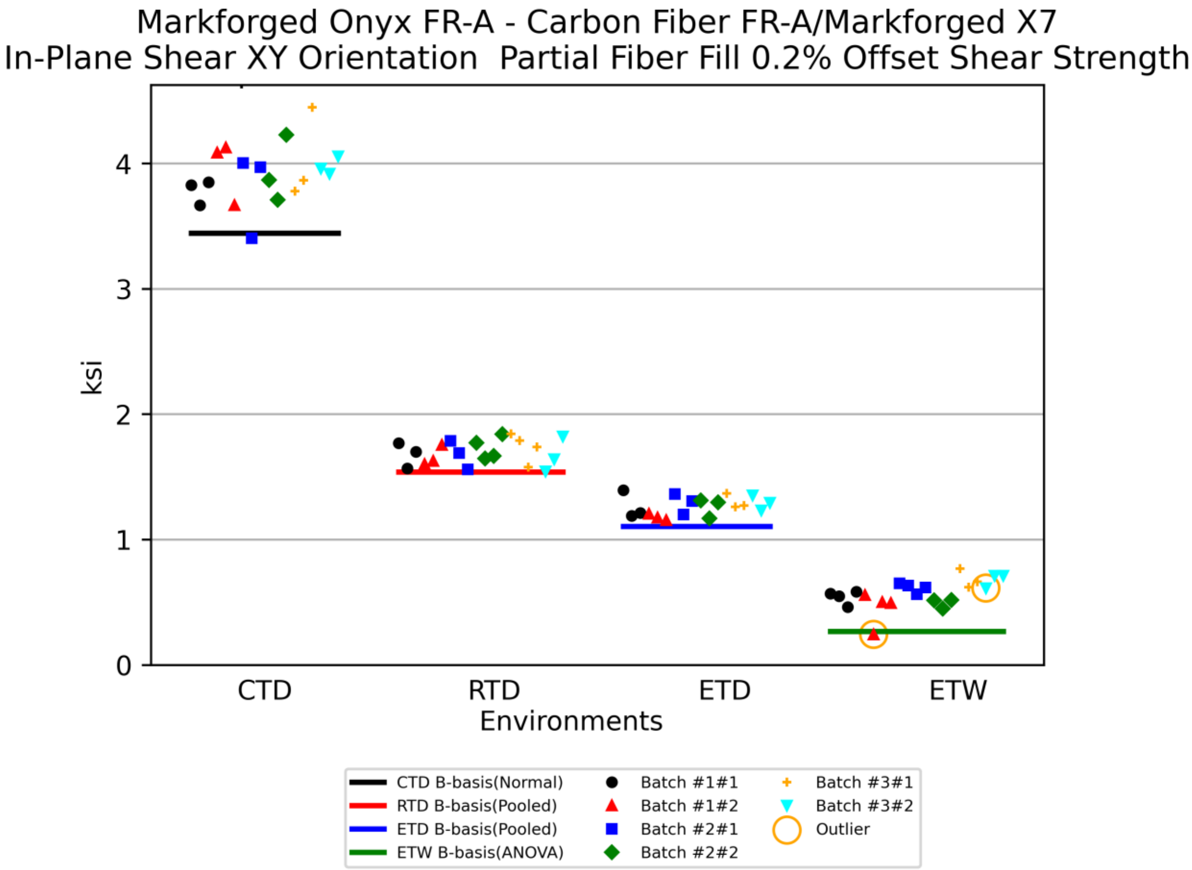

Figure 4-9: Batch plot for In-Plain Shear XY Orientation PF 0.2% Offset Strength

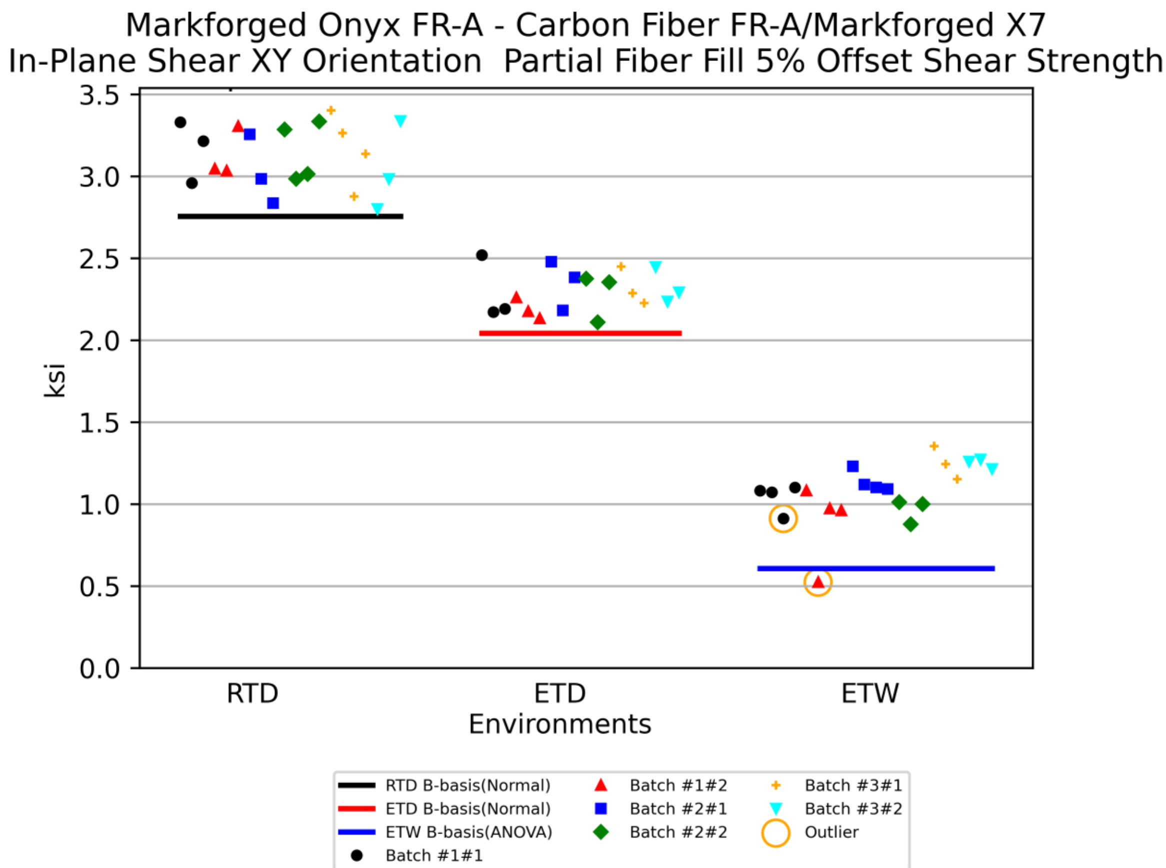

Figure 4-10: Batch plot for In-Plain Shear XY Orientation PF 5% Offset Strength

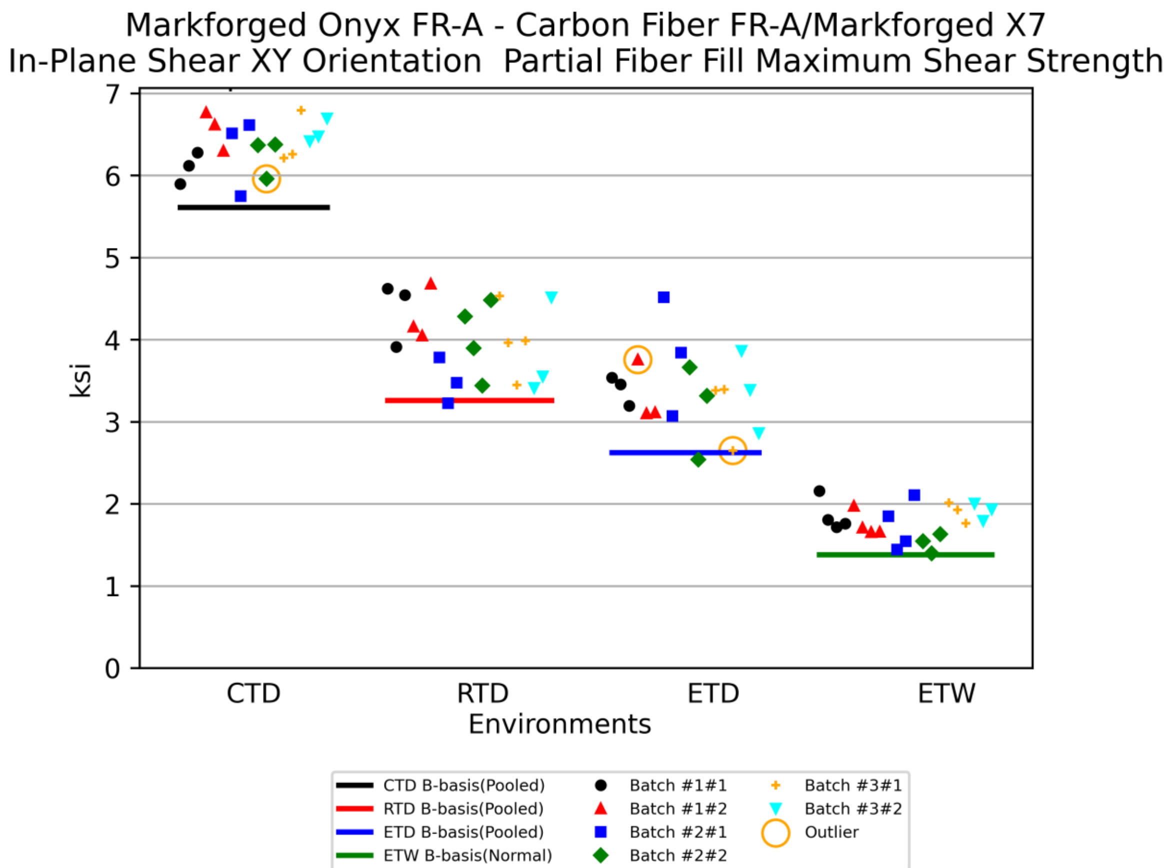

Figure 4-11: Batch plot for In-Plain Shear XY Orientation PF Maximum Strength

In-Plane Shear XY Orientation Partial Fiber Fill Basis Values and Statistics				
	0.2% Offset Shear Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	3.911	1.697	1.264	0.5711
Stdev	0.2366	0.09841	0.07574	0.1129
CV	6.050	5.800	5.991	19.76
Min	3.401	1.544	1.154	0.2437
Max	4.447	1.842	1.393	0.7673
No. Batches/Machines	6	6	6	6
No. Spec.	18	20	18	21
Basis Values and Estimates				
B-Basis	3.444	1.538	1.104	0.2677
A-Estimate	3.113	1.429	0.9952	0.05786
Method	Normal	Pooled	Pooled	ANOVA

Table 4-13: Statistics and Basis Values for In-Plain Shear XY Orientation PF 0.2% Offset Strength

In-Plane Shear XY Orientation Partial Fiber Fill Basis Values and Statistics			
	5% Offset Shear Strength		
Env	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	3.120	2.293	1.078
Stdev	0.1886	0.1264	0.1784
CV	6.047	5.512	16.55
Min	2.801	2.109	0.5229
Max	3.403	2.519	1.353
No. Batches/Machines	6	6	6
No. Spec.	20	18	21
Basis Values and Estimates			
B-Basis	2.756	2.043	0.6083
A-Estimate	2.498	1.867	0.2830
Method	Normal	Normal	ANOVA

Table 4-14: Statistics and Basis Values for In-Plain Shear XY Orientation PF 5% Offset Strength

In-Plane Shear XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Maximum Shear Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	6.355	3.997	3.368	1.779
Stdev	0.2964	0.4665	0.4720	0.2096
CV	4.664	11.67	14.01	11.78
Min	5.747	3.224	2.538	1.394
Max	6.794	4.678	4.517	2.158
No. Batches/Machines	6	6	6	6
No. Spec.	18	20	18	21
Basis Values and Estimates				
B-Basis	5.611	3.260	2.623	1.380
A-Estimate	5.115	2.762	2.127	1.095
Method	Pooled	Pooled	Pooled	Normal

Table 4-15: Statistics and Basis Values for In-Plain Shear XY Orientation PF Maximum Strength

In-Plane Shear XY Orientation Partial Fiber Fill Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	0.2482	0.1341	0.1029	0.04767
Stdev	0.01071	0.006885	0.005230	0.008880
CV	4.316	5.133	5.083	18.63
Min	0.2190	0.1228	0.09519	0.01905
Max	0.2692	0.1431	0.1138	0.05914
No. Batches/Machines	6	6	6	6
No. Spec.	18	20	18	21

Table 4-16: Statistics for In-Plain Shear XY Orientation PF Modulus

4.8 Single-Shear Bearing (SSB) XY Orientation Full Fiber (FF) Fill (Informational)

In this case, four conditions (CTD, RTD, ETD, and ETW) and three properties (2% offset strength, ultimate strength, and bearing stiffness) are available. Only the basic statistics are reported for these properties, since this data are reported for informational purposes only.

One lower batch-machine outlier was detected for 2% offset strength data in batch#1 machine#4 in condition RTD.

Statistics are given for the strength properties and stiffness data in Table 4-17. The 2% offset strength data are shown graphically in **Error! Reference source not found.**12 and ultimate strength in Figure 4-13.

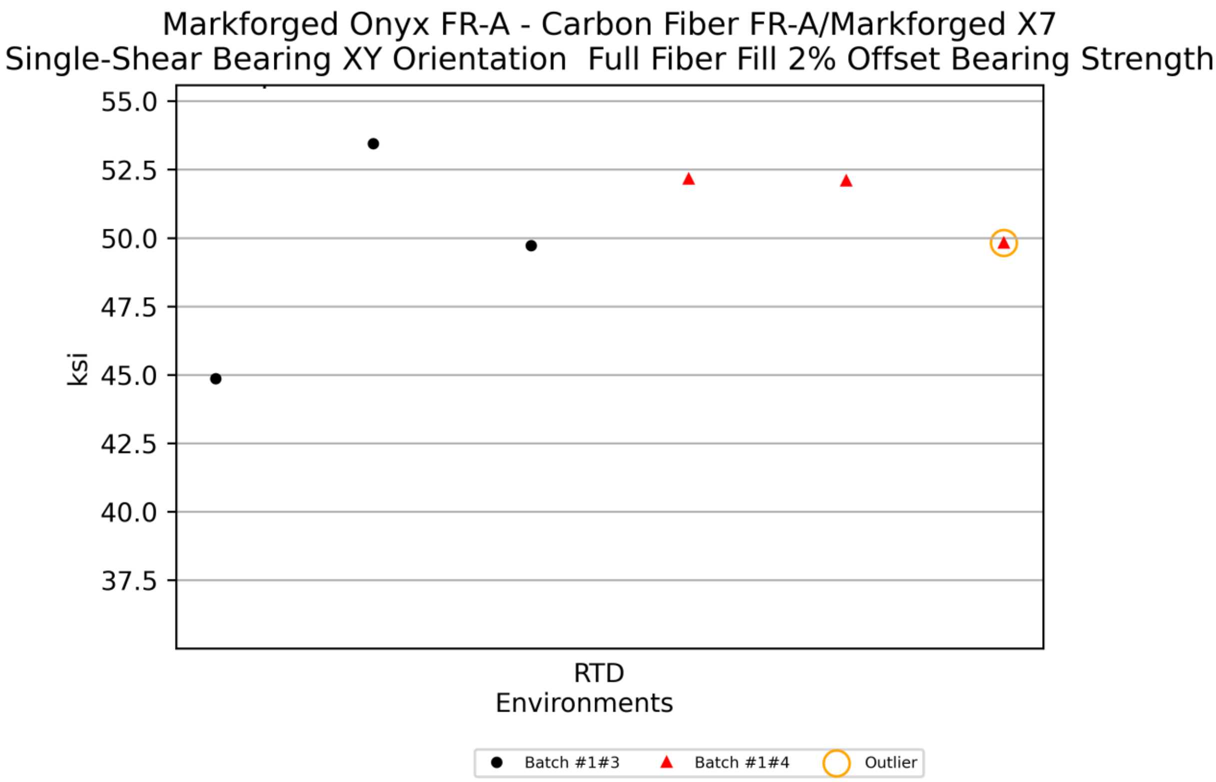

Figure 4-12: Batch plot for Single Shear Bearing XY Orientation FF 2% Offset Strength

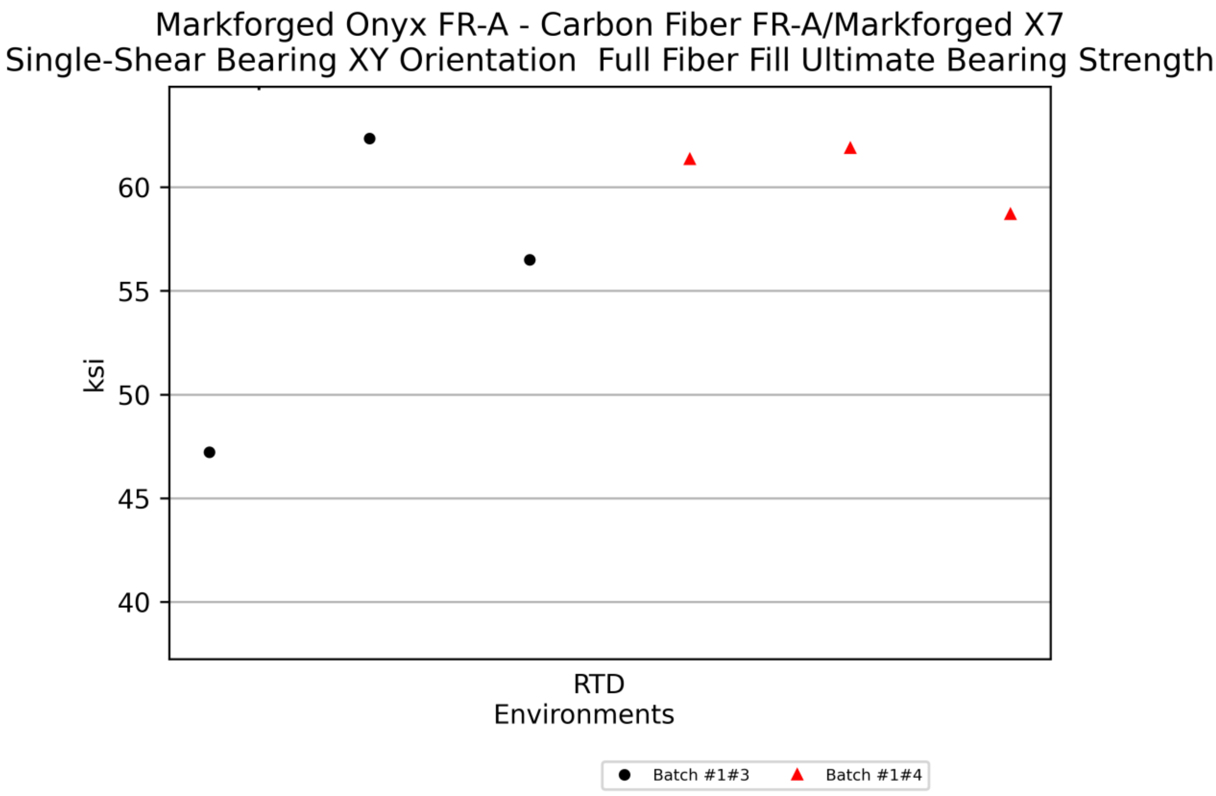

Figure 4-13: Batch plot for Single Shear Bearing XY Orientation FF Ultimate Strength

Single-Shear Bearing XY Orientation Full Fiber Fill Statistics			
	2% Offset Strength [ksi]	Ultimate Strength [ksi]	Bearing Stiffness [ksi]
Env	RTD(70°F)	RTD(70°F)	RTD(70°F)
Mean	50.35	58.00	0.6860
Stdev	3.053	5.729	0.02303
CV	6.064	9.877	3.357
Min	44.86	47.22	0.6480
Max	53.44	62.35	0.7086
No. Batches/Machines	2	2	2
No. Spec.	6	6	6

Table 4-17: Statistics for Single Shear Bearing XY Orientation FF

4.9 Single-Shear Bearing (SSB) XZ Orientation Full Fiber (FF) Fill (Informational)

In this test method, only RTD condition along with three properties (2% offset strength, ultimate strength, and bearing stiffness) are available. Only the basic statistics are reported for these properties since these data are reported for informational purposes only.

No outliers were detected for this test method.

Statistics are given for the strength properties data and for bearing stiffness data in Table 4-18. The 2% offset strength data are shown graphically in **Error! Reference source not found.**14 and ultimate strength in Figure 4-15.

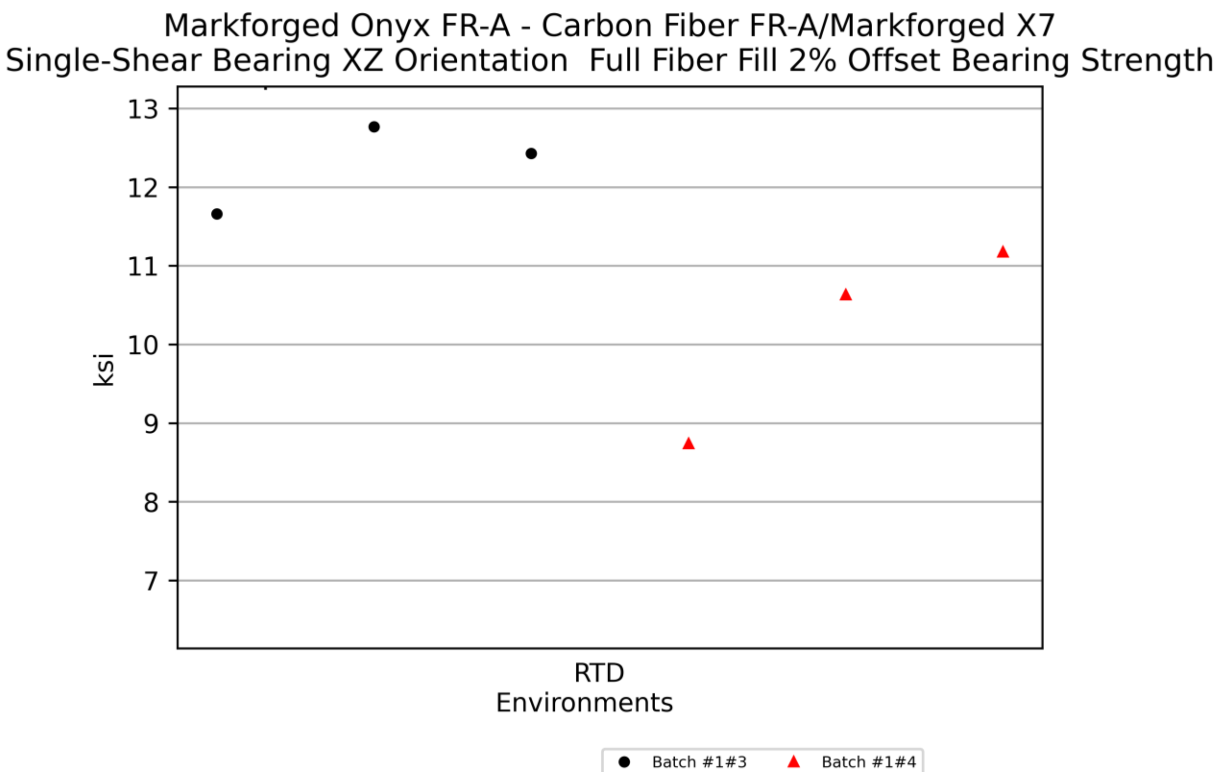

Figure 4-14: Batch plot for Single Shear Bearing XZ Orientation FF 2% Offset Bearing Strength

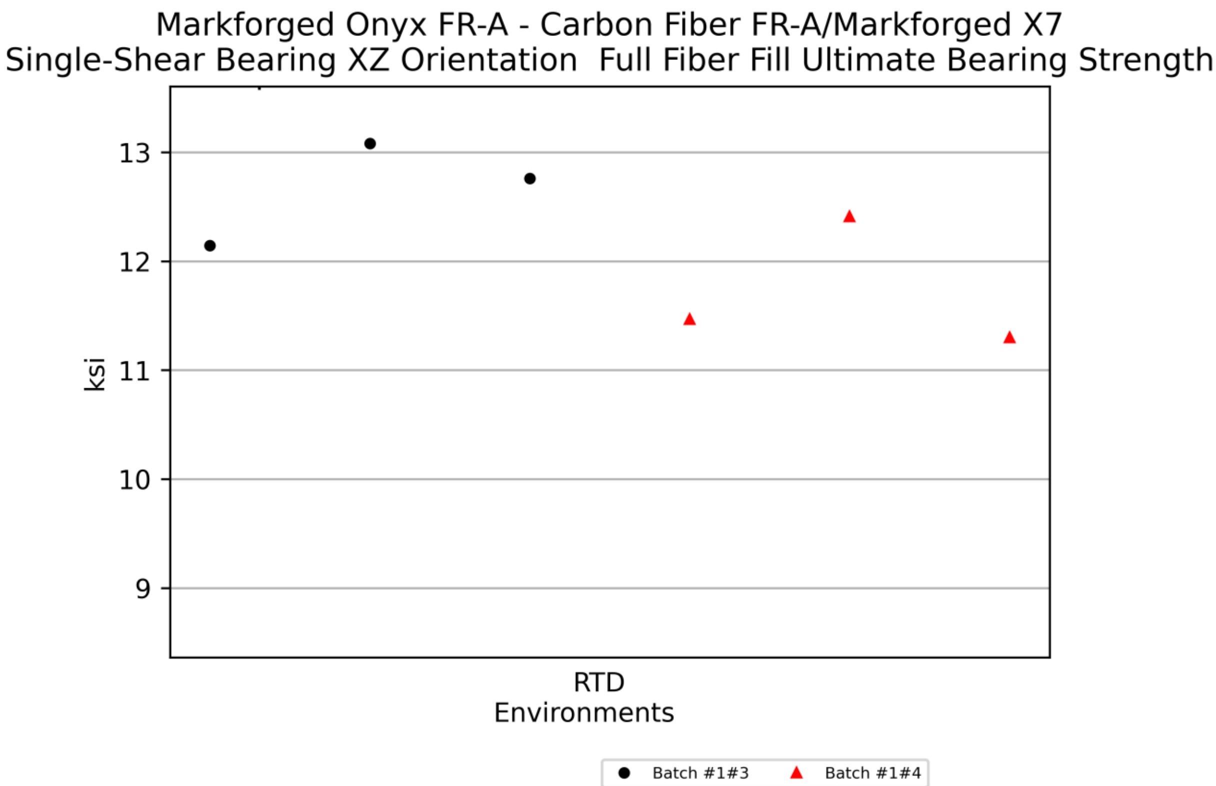

Figure 4-15: Batch plot for Single Shear Bearing XZ Orientation FF Ultimate Bearing Strength

Single-Shear Bearing XZ Orientation Full Fiber Fill Statistics			
	2% Offset Strength [ksi]	Ultimate Strength [ksi]	Bearing Stiffness [ksi]
Env	RTD(70°F)	RTD(70°F)	RTD(70°F)
Mean	11.23	12.19	0.2080
Stdev	1.452	0.7047	0.07281
CV	12.93	5.779	35.00
Min	8.740	11.30	0.08701
Max	12.77	13.08	0.2829
No. Batches	2	2	2
No. Spec.	6	6	6

Table 4-18: Statistics for Single Shear Bearing XZ Orientation FF

4.10 Single-Shear Bearing (SSB) ZX Orientation No Fiber (NF) Fill

This SSB test method was performed for three properties, 2% offset strength, ultimate strength, and bearing stiffness. For 2% offset strength, CTD and RTD passed normality test, so normal distribution method was used for computing allowables. ETW passed lognormal test, so the correspondent method was used. For ultimate strength, all conditions passed normality test, so normal method was used for these.

Six outliers were detected for this test method. For 2% offset strength, the largest value in batch three machine two for the ETW condition was an outlier for that machine batch combination but not for the ETW condition. There were three outliers for the ultimate strength property in the ETW condition. The largest value in batch one machine one was an outlier for the batch machine combination but not for the ETW condition. The lowest value in batch one machine two was an outlier for the machine batch combination but not the ETW condition. The lowest value in batch two machine one was an outlier for the ETW condition but not for the batch machine combination. There were two outliers for the bearing stiffness property. The largest value in batch two machine one for the RTD condition was an outlier for the machine batch combination but not for the RTD condition. The lowest value in batch three machine one was an outlier for the machine batch combination but not for the ETW condition. All outliers were retained for this analysis.

Statistics, basis values, and estimates are given for 2% offset strength property data in Table 4-19, for ultimate strength in Table 4-20 and statistics for bearing stiffness data in Table 4-21. The data and B-estimates values are shown graphically for 2% offset strength in **Error! Reference source not found.**16 and for ultimate strength in Figure 4-17.

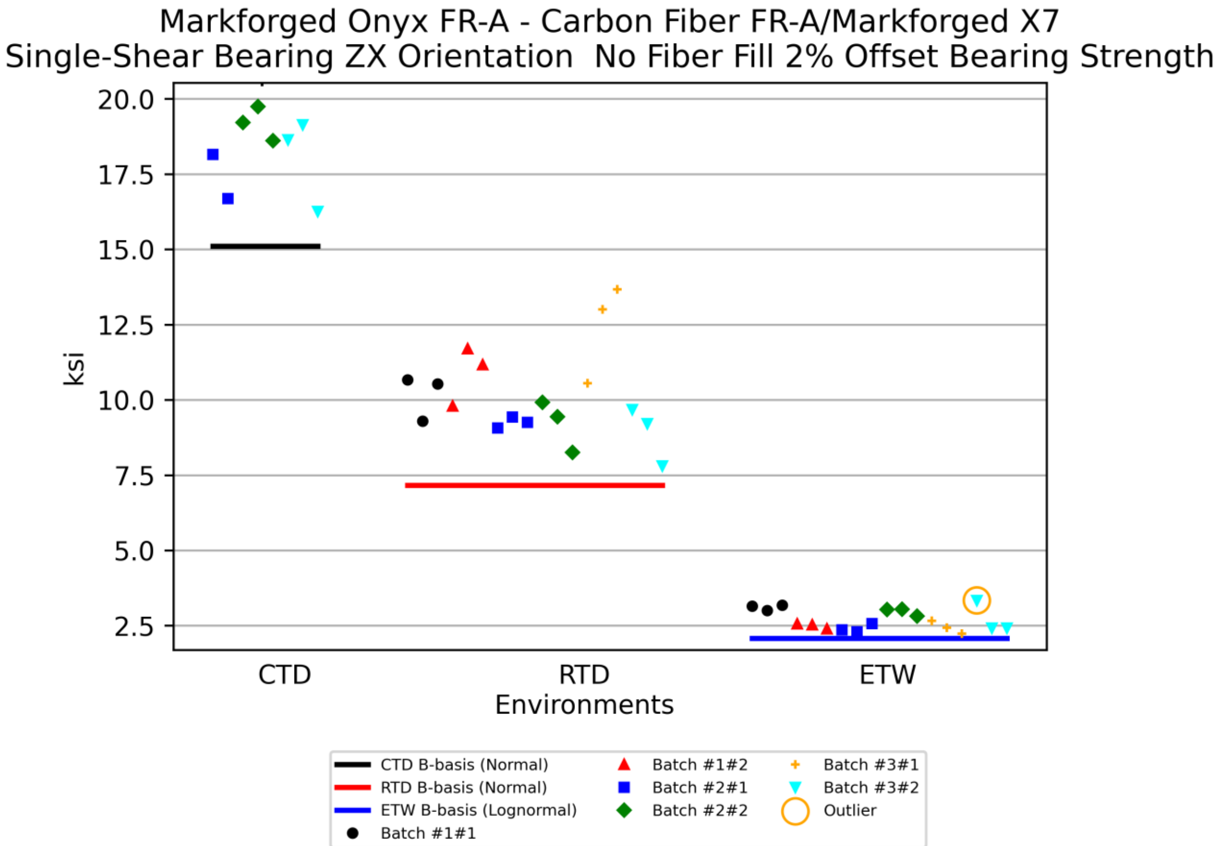

Figure 4-16: Plot for Single-Shear Bearing ZX Orientation NF 2% Offset Strength

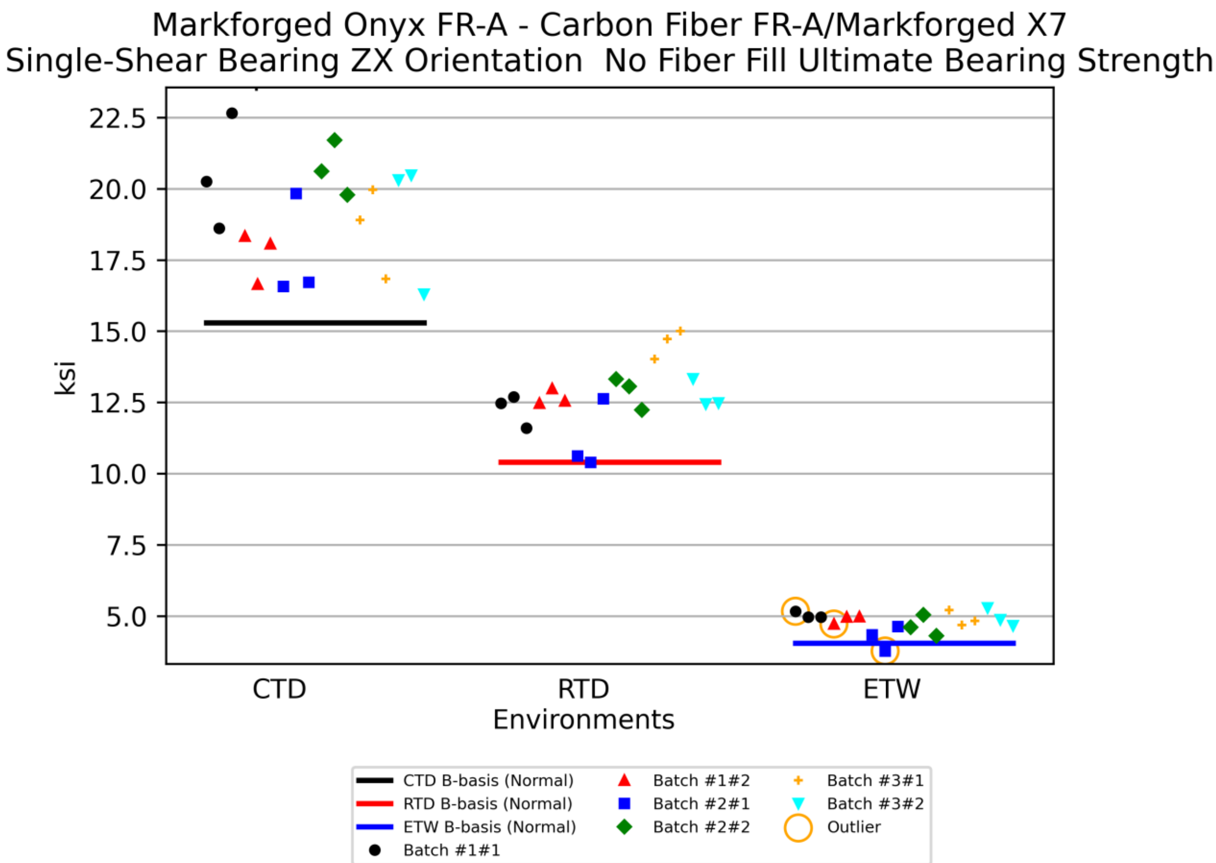

Figure 4-17: Plot for Single-Shear Bearing ZX Orientation NF Ultimate Strength

Single-Shear Bearing ZX Orientation No Fiber Fill Basis Values and Statistics			
	2% Offset Bearing Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	18.31	10.13	2.690
Stdev	1.230	1.506	0.3482
CV	6.721	14.86	12.94
Min	16.26	7.812	2.238
Max	19.74	13.67	3.336
No. Batches/Machines	3	6	6
No. Spec.	8	18	18
Basis Values and Estimates			
B-Basis		7.161	2.078
B-Estimate	15.11		
A-Estimate	12.87	5.054	1.739
Method	Normal	Normal	Lognormal

Table 4-19: Statistics and Basis Values for SSB ZX Orientation NF 2% Offset Strength

Single-Shear Bearing ZX Orientation No Fiber Fill Basis Values and Statistics			
	Ultimate Bearing Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	19.03	12.72	4.776
Stdev	1.895	1.176	0.3688
CV	9.955	9.247	7.721
Min	16.30	10.39	3.772
Max	22.65	15.00	5.283
No. Batches/Machines	6	6	6
No. Spec.	18	18	18
Basis Values and Estimates			
B-Basis	15.29	10.40	4.048
A-Estimate	12.64	8.753	3.532
Method	Normal	Normal	Normal

Table 4-20: Statistics and Basis Values for SSB ZX Orientation NF Ultimate Strength

Single-Shear Bearing ZX Orientation No Fiber Fill Statistics			
	Bearing Stiffness [Msi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	0.2259	0.1115	0.02442
Stdev	0.03643	0.02943	0.004377
CV	16.13	26.40	17.92
Min	0.1811	0.06979	0.01491
Max	0.2910	0.1661	0.03235
No. Batches/Machines	6	6	6
No. Spec.	18	18	18

Table 4-21: Statistics for SSB ZX Orientation NF Bearing Stiffness

4.11 Single Shear Bearing (SSB) XY Orientation Partial Fiber (PF) Fill

This SSB test method was performed for three properties, 2% offset strength, ultimate strength, and bearing stiffness. For each of the three properties, CTD, RTD, and ETW conditions are available.

For 2% offset strength property, CTD and ETW condition passed normality test, so normal distribution method was used to compute basis values and RTD failed normality and ADK test, so ANOVA method was used. ANOVA was used with 6 groups and 18 specimens, so B-basis values were produced and no estimates. For ultimate strength property, CTD and ETW condition passed normality test, so normal distribution method was used to compute basis values and RTD failed normality and ADK test, so ANOVA method was used. ANOVA was used with 6 groups and 18 specimens, so B-basis values were produced and no estimates.

Four outliers were detected for this test method. A higher batch-machine outlier in CTD condition batch#1 machine#2 for ultimate bearing strength property. A lower batch-machine outlier in RTD condition batch#2 machine#2 for ultimate bearing strength property. A higher batch-machine outlier in CTD condition for bearing stiffness property. A higher batch-machine outlier in RTD condition for bearing stiffness property. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength properties data in Table 4-22 and 4-23 and statistics for bearing stiffness data in Table 4-24. The data and B-estimates values are shown graphically in **Error! Reference source not found.**18 and 4-19.

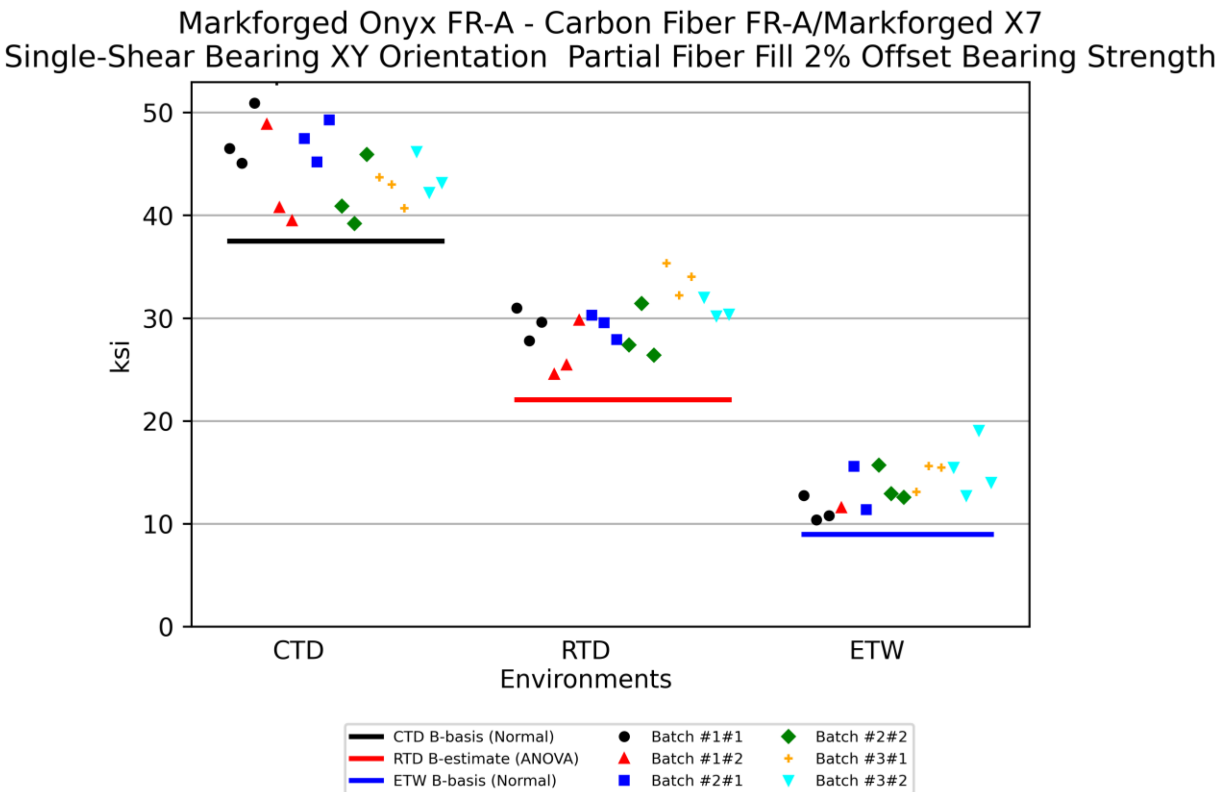

Figure 4-18: Plot for SSB XY Orientation PF 2% Offset Bearing Strength

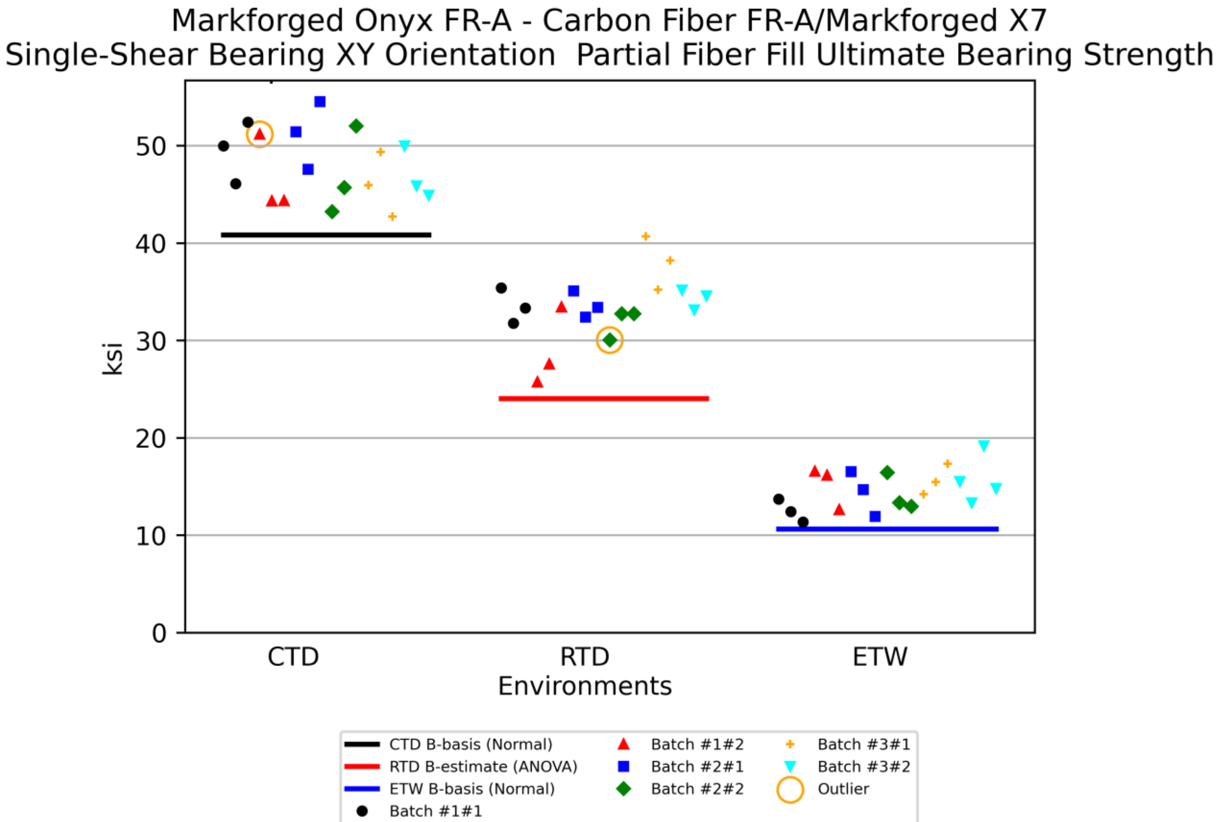

Figure 4-19: Plot for SSB XY Orientation PF Ultimate Bearing Strength

Single-Shear Bearing XY Orientation Partial Fiber Basis Values and Statistics			
	2% Offset Bearing Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	44.36	29.73	13.69
Stdev	3.482	2.829	2.313
CV	7.849	9.515	16.90
Min	39.19	24.53	10.37
Max	50.92	35.34	19.09
No. Batches/Machines	6	6	6
No. Spec.	18	18	16
Basis Values and Estimates			
B-Basis	37.48	22.06	
B-Estimate			8.983
A-Estimate	32.61	16.77	5.662
Method	Normal	ANOVA	Normal

Table 4-22: Statistics for SSB XY Orientation PF 2% Offset Bearing Strength

Single-Shear Bearing XY Orientation Partial Fiber Fill Basis Values and Statistics			
	Ultimate Bearing Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	47.86	33.37	14.66
Stdev	3.554	3.426	2.059
CV	7.426	10.27	14.05
Min	42.71	25.73	11.37
Max	54.52	40.68	19.18
No. Batches/Machines	6	6	6
No. Spec.	18	18	19
Basis Values and Estimates			
B-Basis	42.43	27.94	9.252
A-Estimate	38.81	24.31	5.625
Method	Pooled	Pooled	Pooled

Table 4-23: Statistics for SSB XY Orientation PF Ultimate Bearing Strength

Single-Shear Bearing XY Orientation Partial Fiber Statistics			
	Bearing Stiffness [Msi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	0.4210	0.3648	0.2335
Stdev	0.04625	0.04850	0.04419
CV	10.99	13.29	18.92
Min	0.3476	0.2942	0.1564
Max	0.4852	0.4460	0.3104
No. Batches/Machines	6	6	6
No. Spec.	18	18	19

Table 4-24: Statistics for SSB XY Orientation PF Bearing Stiffness

4.12 Single Shear Bearing (SSB) XZ Orientation Partial Fiber (PF) Fill

This SSB test method was performed for three properties, 2% offset strength, ultimate strength, and bearing stiffness. For the Ultimate strength and Bearing Stiffness, each of the three CTD, RTD, and ETW conditions are available. For the 2% Offset Strength, only the RTD and ETW conditions have data available and the RTD condition has insufficient specimens to meet CMH17 requirements so only estimates are available for that property and condition.

For 2% offset strength property, RTD and ETW conditions failed normality and ADK tests, so ANOVA method was used. For ultimate strength property, CTD and ETW conditions passed normality test, so normal method was used. For RTD condition, ANOVA method was used, since it fails normality and ADK test.

Seven outliers were detected for this test method. A higher batch-machine outlier in ETW condition batch#3 machine#1 for 2% offset strength property. A higher condition outlier in CTD condition batch#2 machine#2 for bearing stiffness property. A higher batch-machine outlier in CTD condition batch#2 machine#1 for bearing stiffness property. A lower batch-machine outlier in CTD condition batch#3 machine#1 for bearing stiffness property. A higher batch-machine outlier in RTD condition batch#2 machine#2 for bearing stiffness property. A lower batch-machine outlier in ETW condition batch#1 machine#2 for bearing stiffness property. A lower batch-machine outlier in ETW condition batch#3 machine#1 for bearing stiffness property. All outliers were retained for this analysis.

Statistics, basis values, and estimates are given for the strength properties data in Table 4-25 and 4-26 and statistics for bearing stiffness data in Table 4-27. The data and B-estimates values are shown graphically in **Error! Reference source not found.**20 and 4-21.

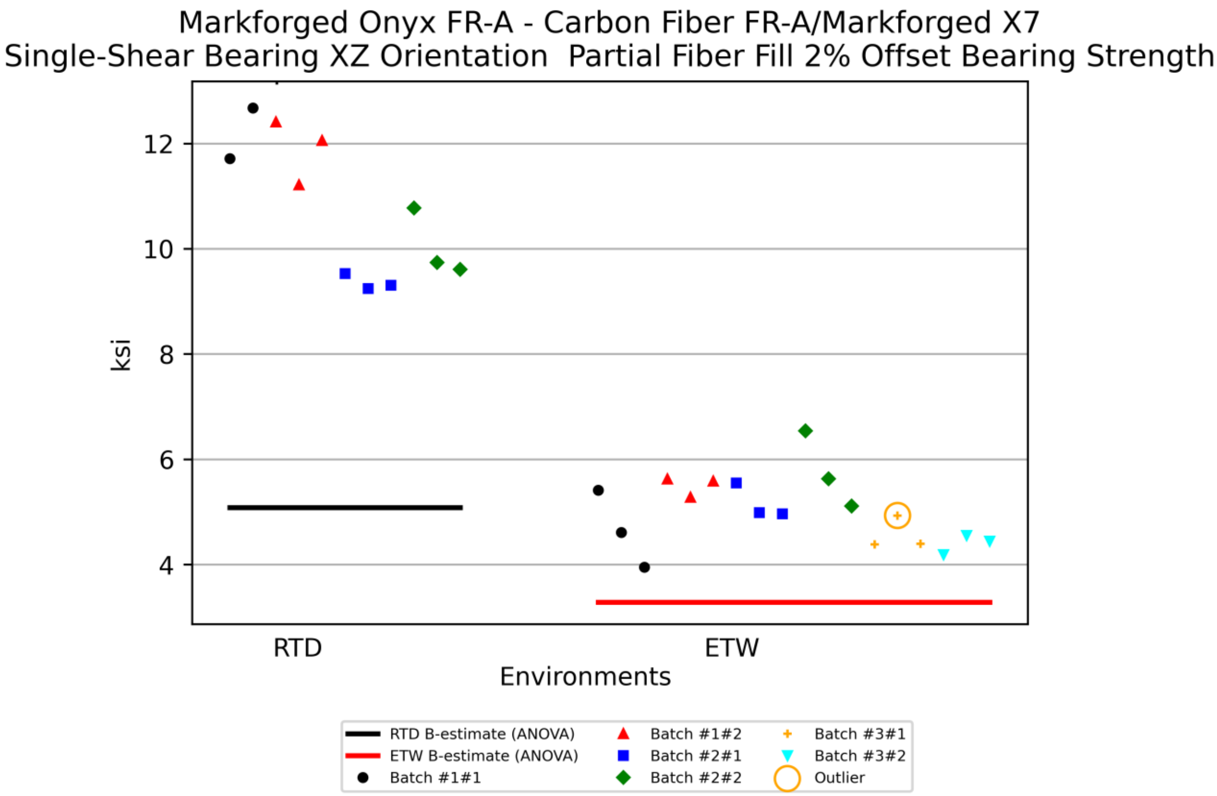

Figure 4-20: Plot for SSB XZ Orientation PF 2% Offset Bearing Strength

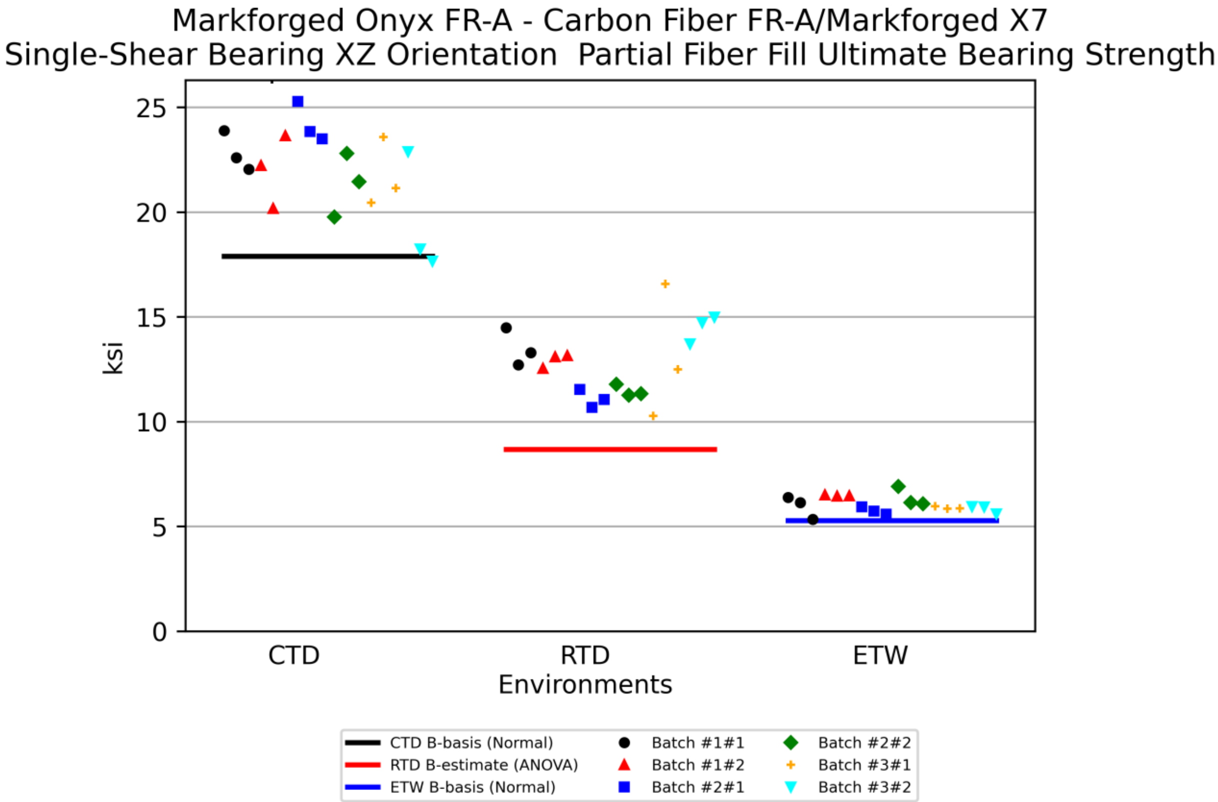

Figure 4-21: Plot for SSB XZ Orientation PF Ultimate Bearing Strength

Single-Shear Bearing XZ Orientation Partial Fiber Basis Values and Statistics		
2% Offset Bearing Strength [ksi]		
Env	RTD(70°F)	ETW(130°F)
Mean	10.75	5.008
Stdev	1.322	0.6521
CV	12.29	13.02
Min	9.246	3.950
Max	12.67	6.538
No. Batches/Machines	4	6
No. Spec.	11	18
Basis Values and Estimates		
B-Basis		3.283
B-Estimate	5.081	
A-Estimate	1.160	2.089
Method	ANOVA	ANOVA

Table 4-25: Statistics for SSB XZ Orientation PF 2% Offset Bearing Strength

Single-Shear Bearing XZ Orientation Partial Fiber Basis Values and Statistics			
	Ultimate Bearing Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	21.95	12.76	6.046
Stdev	2.054	1.682	0.3846
CV	9.354	13.18	6.362
Min	17.66	10.27	5.347
Max	25.29	16.57	6.908
No. Batches/Machines	6	6	6
No. Spec.	18	18	18
Basis Values and Estimates			
B-Basis	17.90	8.679	5.287
A-Estimate	15.03	5.836	4.748
Method	Normal	ANOVA	Normal

Table 4-26: Statistics for SSB XZ Orientation PF Ultimate Bearing Strength

Single-Shear Bearing XZ Orientation Partial Fiber Statistics			
	Bearing Stiffness [Msi]		
Env	CTD(-65°F)	RTD(70°F)	ETW(130°F)
Mean	0.3585	0.1860	0.06171
Stdev	0.04469	0.06844	0.02517
CV	12.47	36.80	40.79
Min	0.2982	0.09467	0.02940
Max	0.4818	0.3188	0.1019
No. Batches/Machines	6	6	6
No. Spec.	18	18	18

Table 4-27: Statistics for SSB XZ Orientation PF Bearing Stiffness

4.13 Single Shear Bearing (SSB) ZX Orientation Partial Fiber (PF) Fill (Informational)

This SSB test method was performed for three properties, 2% offset strength, ultimate strength, and bearing stiffness. Only RTD condition was tested. Since this is informational data only, general statistics are provided but no basis values/estimates were computed.

No outliers were detected for this test method.

Statistics are given for the three properties in Table 4-28. The data for ultimate strength are shown graphically in **Error! Reference source not found.**22. The data for 2% offset strength are shown graphically in **Error! Reference source not found.**23.

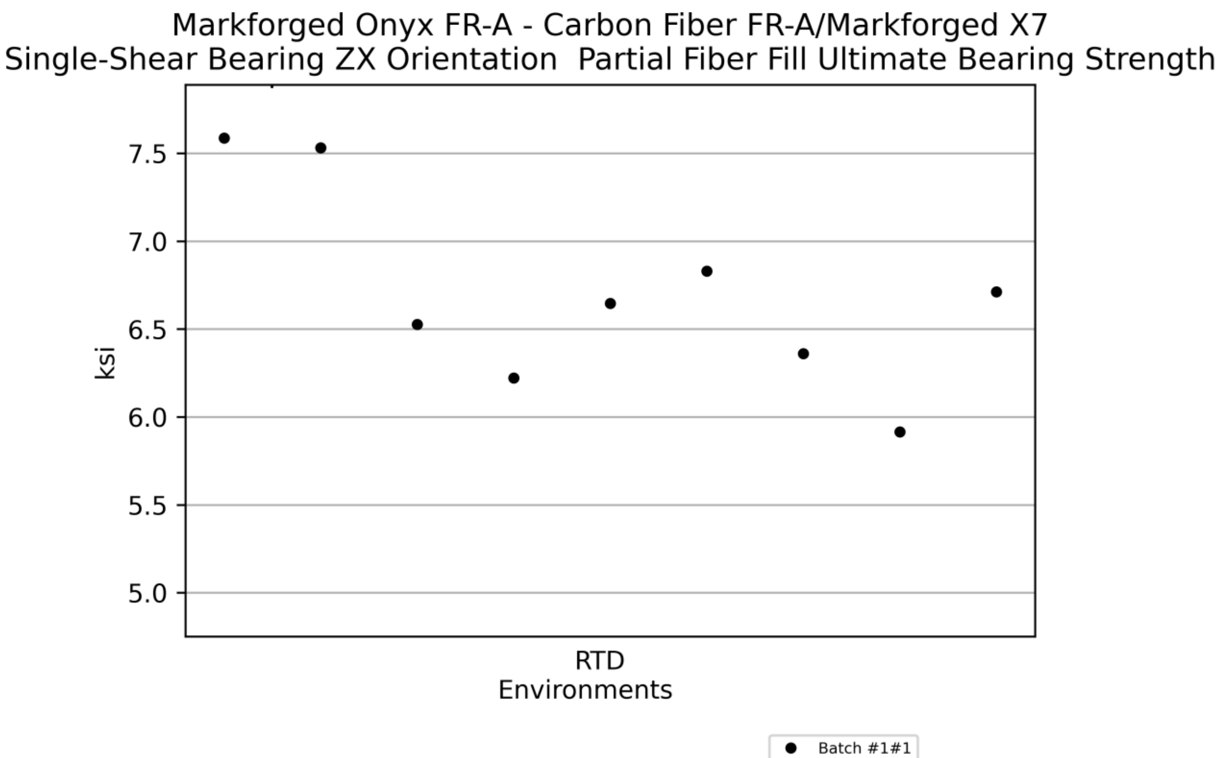

Figure 4-22: Plot for SSB ZX Orientation PF Ultimate Bearing Strength

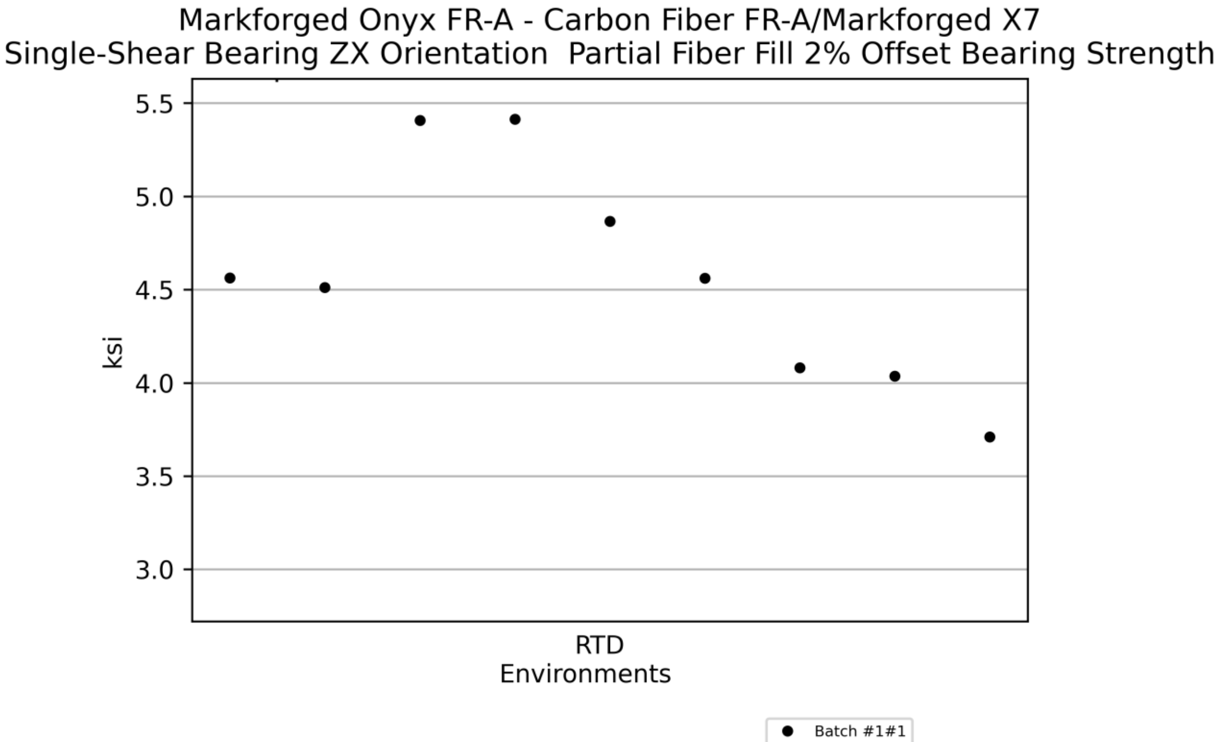

Figure 4-23: Plot for SSB ZX Orientation PF 2% Offset Bearing Strength

Single-Shear Bearing ZX Orientation Partial Fiber Statistics			
	Ultimate Strength [ksi]	2% Offset Strength [ksi]	Bearing Stiffness [Msi]
Env	RTD(70°F)	RTD(70°F)	RTD(70°F)
Mean	6.703	4.572	0.1246
Stdev	0.5577	0.5884	0.01756
CV	8.320	12.87	14.09
Min	5.914	3.710	0.1033
Max	7.587	5.414	0.1525
No. Batches/Machines	1	1	1
No. Spec.	9	9	9

Table 4-28: Statistics for SSB ZX Orientation Partial Fiber

4.14 Combined Loading Compression (CLC) XY Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for two properties: compressive strength and average compressive modulus. Since this is informational purposes data, only general statistics are provided.

No outliers were detected for this test method.

Statistics are given for the strength property data in Table 4-29 and for modulus data in Table 4-30. The strength data are shown graphically in **Error! Reference source not found.**24.

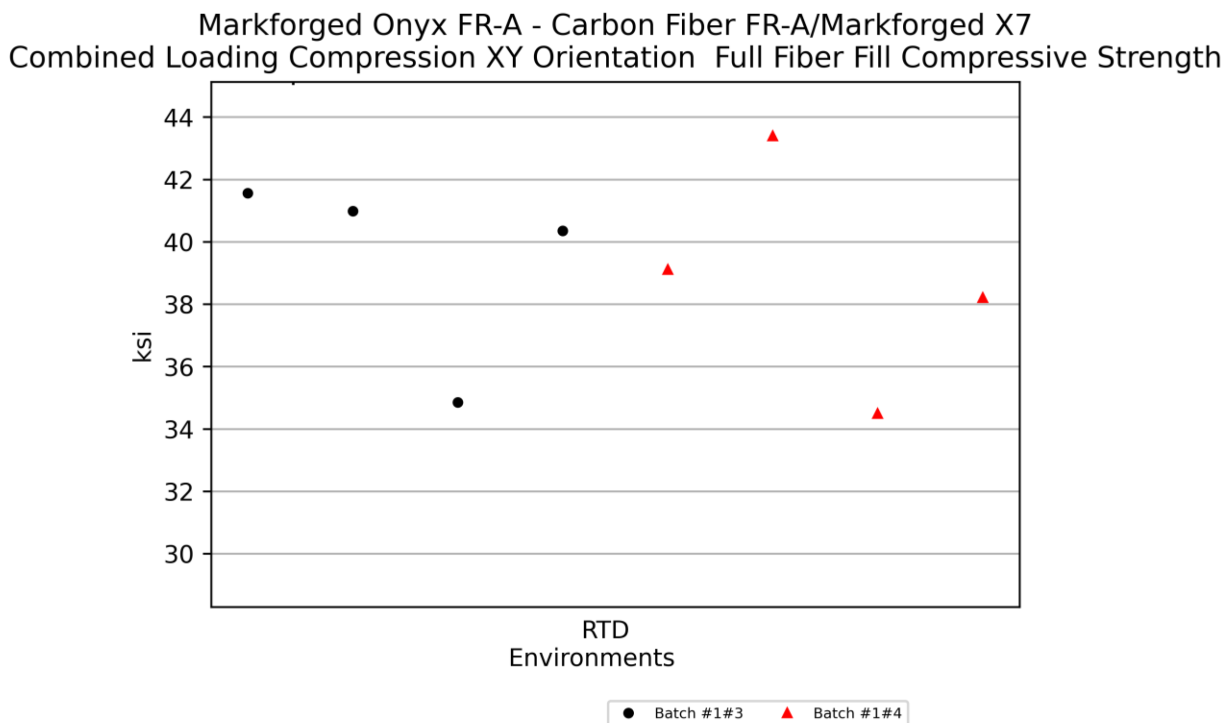

Figure 4-24: Plot for CLC XY Orientation Full Fiber Compressive Strength

Combined Loading Compression XY Orientation Full Fiber Fill Statistics	
Compressive Strength [ksi]	
Env	RTD(70°F)
Mean	39.12
Stdev	3.156
CV	8.067
Min	34.49
Max	43.39
No. Batches/Machines	2
No. Spec.	8

Table 4-29: Statistics for CLC XY Orientation Full Fiber Compressive Strength

Combined Loading Compression XY Orientation Full Fiber Fill Statistics	
Avg. Compressive Modulus [Msi]	
Env	RTD(70°F)
Mean	6.589
Stdev	0.2089
CV	3.171
Min	6.307
Max	6.884
No. Batches/Machines	2
No. Spec.	8

Table 4-30: Statistics for CLC XY Orientation Full Fiber Avg. Compressive Modulus

4.15 Combined Loading Compression (CLC) XZ Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for two properties: compressive strength and average compressive modulus. Since this is informational data, only general statistics are provided.

No outliers were detected for this test method.

Statistics are given for the strength property data in Table 4-31 and for modulus data in Table 4-32. The strength data are shown graphically in **Error! Reference source not found.**25.

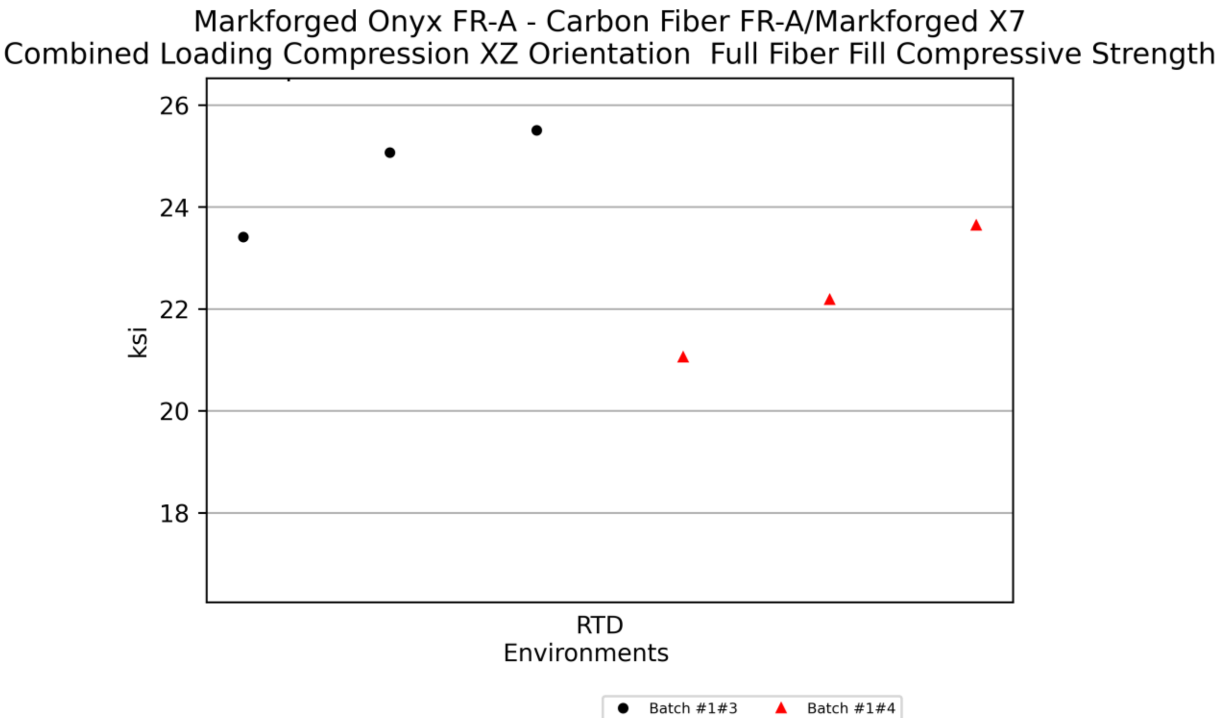

Figure 4-25: Plot for CLC XZ Orientation Full Fiber Compressive Strength

Combined Loading Compression XZ Orientation Full Fiber Fill Statistics	
Compressive Strength [ksi]	
Env	RTD(70°F)
Mean	23.48
Stdev	1.688
CV	7.192
Min	21.05
Max	25.51
No. Batches/Machines	2
No. Spec.	6

Table 4-31: Statistics for CLC XZ Orientation Full Fiber Compressive Strength

Combined Loading Compression XZ Orientation Full Fiber Fill Statistics	
Avg. Compressive Modulus [Msi]	
Env	RTD(70°F)
Mean	5.174
Stdev	0.1922
CV	3.716
Min	4.952
Max	5.501
No. Batches/Machines	2
No. Spec.	6

Table 4-32: Statistics for CLC XZ Orientation Full Fiber Avg. Compressive Modulus

4.16 Combined Loading Compression (CLC) ZX Orientation No Fiber (NF) Fill

This test method was performed for two properties: 0.2% offset strength and average compressive modulus. For 0.2% offset strength, CTD condition passed ADK test and normality test, so normal method was used for computing basis values. However, conditions RTD, ETD and ETW failed ADK test so ANOVA method was used. Since six batch machine combination groups are available, ANOVA produced B-basis values (rather than estimates).

There was one outlier for 0.2% offset strength. The largest value in batch#2 machine#2 for the ETD condition was an outlier for that batch machine combination but not for the ETD condition. It was retained for this analysis.

Statistics and allowables are given for the 0.2% offset strength property data in Table 4-33 and for modulus data in Tables 4-34. The data and B-estimates for strength data are shown graphically in **Error! Reference source not found.**26.

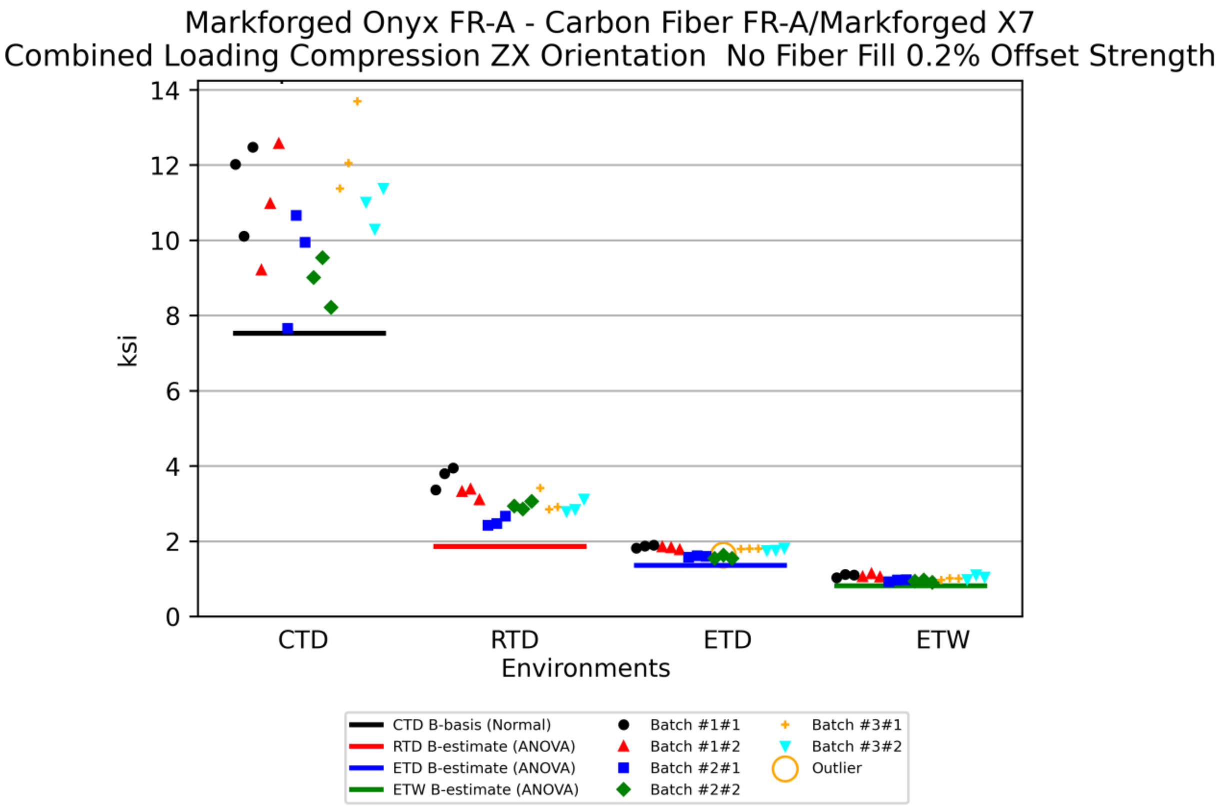

Figure 4-26: Plot for CLC ZX Orientation No Fiber 0.2% Offset Strength

Combined Loading Compression ZX Orientation No Fiber Basis Values and Statistics				
	0.2% Offset Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	10.68	3.068	1.734	1.014
Stdev	1.595	0.4107	0.1188	0.06829
CV	14.94	13.39	6.848	6.737
Min	7.656	2.419	1.538	0.9005
Max	13.70	3.948	1.895	1.129
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	7.528	1.863	1.364	0.8212
A-Estimate	5.297	1.035	1.110	0.6886
Method	Normal	ANOVA	ANOVA	ANOVA

Table 4-33: Statistics for CLC ZX Orientation No Fiber 0.2% Offset Strength

Combined Loading Compression ZX Orientation No Fiber Fill Statistics				
	Avg. Compressive Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	0.6248	0.3234	0.1891	0.1248
Stdev	0.03017	0.03364	0.01135	0.005936
CV	4.829	10.40	6.001	4.757
Min	0.5756	0.2591	0.1687	0.1141
Max	0.6947	0.3869	0.2019	0.1373
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18

Table 4-34: Statistics for CLC ZX Orientation No Fiber Avg. Compressive Modulus

4.17 Combined Loading Compression (CLC) XY Orientation Partial Fiber (PF) Fill

This test method was performed for two properties: compressive strength and average compressive modulus. For compressive strength, conditions CTD, RTD, and ETD passed pooling tests so pooling method was used for computing basis values, while ETW condition failed ADK test, so ANOVA method was used. Since 6 groups are available, ANOVA produced B-basis values (rather than just estimates).

An outlier was detected in ETW condition using the Maximum Normed Residual method. The largest value in batch #1 machine #2 of the ETW condition is an outlier for that batch-machine combination but not for the ETW condition. The outlier was retained for performing the computations. Another outlier was detected in CTD condition visually. The lowest value in batch #2 machine #1 of the CTD condition is an outlier for that batch-machine combination and for the CTD condition. Note: The outlier had a DGM (Delamination at Gage-Middle) failure mode that aligns with other specimens within this batch. However, the lower performance was attributed to an improper test setup by the testing operator, therefore it was removed for purposes of the computations. No replacement coupon was needed due to sufficient data available within this batch-machine combination.

Statistics and allowables are given for the compressive strength property data in Table 4-35 and for modulus data in Tables 4-36. The data and B-basis for strength data are shown graphically in **Error! Reference source not found.**27.

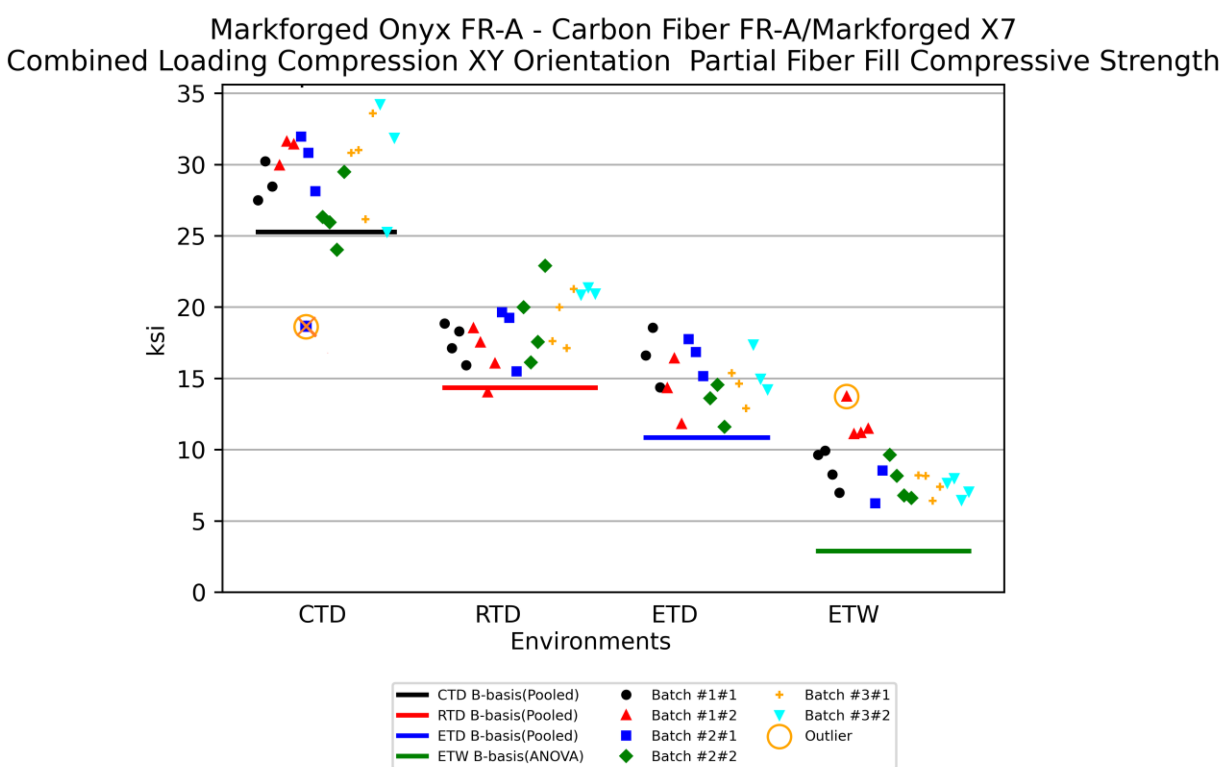

Figure 4-27: Plot for CLC XY Orientation Partial Fiber Compressive Strength

Combined Loading Compression XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Compressive Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	29.44	18.47	15.06	8.524
Stdev	2.851	2.262	1.938	1.970
CV	9.686	12.25	12.87	23.11
Min	24.02	14.01	11.60	6.225
Max	34.24	22.90	18.56	13.72
No. Batches	6	6	6	6
No. Spec.	20	22	18	22
Basis Values and Estimates				
B-Basis	25.27	14.34	10.85	2.894
A-Estimate	22.47	11.53	8.054	0.000
Method	Pooled	Pooled	Pooled	ANOVA

Table 4-35: Statistics for CLC XY Orientation Partial Fiber Compressive Strength

Combined Loading Compression XY Orientation Partial Fiber Statistics				
	Avg. Compressive Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	2.853	2.674	2.795	2.838
Stdev	0.08510	0.1012	0.07639	0.1961
CV	2.983	3.783	2.733	6.911
Min	2.718	2.514	2.703	2.542
Max	3.004	2.883	2.979	3.228
No. Batches/Machines	6	6	6	6
No. Spec.	21	22	18	24

Table 4-36: Statistics for CLC XY Orientation Partial Fiber Avg. Compressive Modulus

4.18 Combined Loading Compression (CLC) XZ Orientation Partial Fiber (PF) Fill

This test method was performed for two properties: compressive strength and average compressive modulus. For compressive strength, conditions CTD and ETD passed ADK test and normality test, so normal method was used for computing basis values. Condition RTD passed ADK test but failed all distribution tests, so non-parametric method was used. Condition ETW failed normality test but passed lognormal test, so lognormal method was used.

Five outliers were detected for compressive strength. A higher batch-machine outlier in condition CTD batch#1 machine#2. A higher batch-machine outlier in condition CTD batch#3 machine#1. A higher batch-machine outlier in condition RTD batch#1 machine#2. A higher batch-machine outlier in condition RTD batch#2 machine#1. A higher batch-machine outlier in condition RTD batch#3 machine#1. All outliers were retained for this analysis.

Statistics and allowables for the compressive strength property data are given in Table 4-37 and for modulus data in Tables 4-38. The data and B-values for compressive strength data are shown graphically in **Error! Reference source not found.**28.

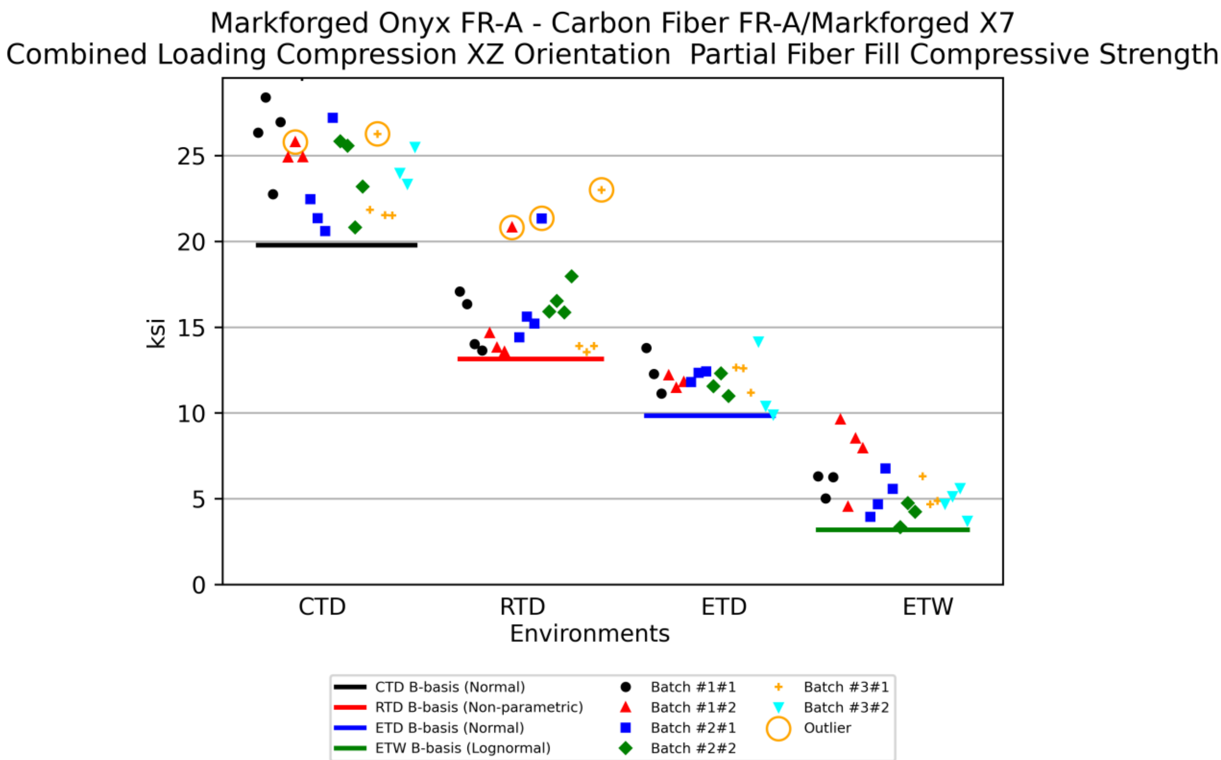

Figure 4-28: Plot for CLC XZ Orientation Partial Fiber Compressive Strength

Combined Loading Compression XZ Orientation Partial Fiber Basis Values and Statistics				
	Compressive Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	24.14	16.00	11.94	5.548
Stdev	2.309	2.604	1.060	1.604
CV	9.564	16.28	8.876	28.91
Min	20.60	13.55	9.905	3.338
Max	28.40	23.00	14.17	9.621
No. Batches/Machines	6	6	6	6
No. Spec.	22	23	18	21
Basis Values and Estimates				
B-Basis	19.79	13.33	9.850	3.197
A-Estimate	16.68	7.128	8.367	2.214
Method	Normal	Non-parametric	Normal	Lognormal

Table 4-37: Statistics for CLC XZ Orientation Partial Fiber Compressive Strength

Combined Loading Compression XZ Orientation Partial Fiber Statistics				
	Avg. Compressive Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	2.630	2.097	1.620	1.000
Stdev	0.1567	0.3050	0.1511	0.1764
CV	5.959	14.55	9.326	17.64
Min	2.353	1.595	1.425	0.8236
Max	2.895	2.693	1.994	1.539
No. Batches/Machines	6	6	6	6
No. Spec.	22	23	18	23

Table 4-38: Statistics for CLC XZ Orientation Partial Fiber Avg. Compressive Modulus

4.19 Combined Loading Compression (CLC) ZX Orientation Partial Fiber (PF) Fill (Informational purposes)

This test method was performed for three properties: compressive strength, compressive modulus 1 and compressive modulus 2. Since this is informational purposes data, only general statistics are provided.

One outlier was detected for compressive strength. The largest value in the ETD condition which had only three specimens from a single batch machine combination was a statistical outlier.

Statistics are given for the compressive strength property data in Table 4-39 and for modulus data in Table 4-40. The data for compressive strength are shown graphically in **Error! Reference source not found.**29.

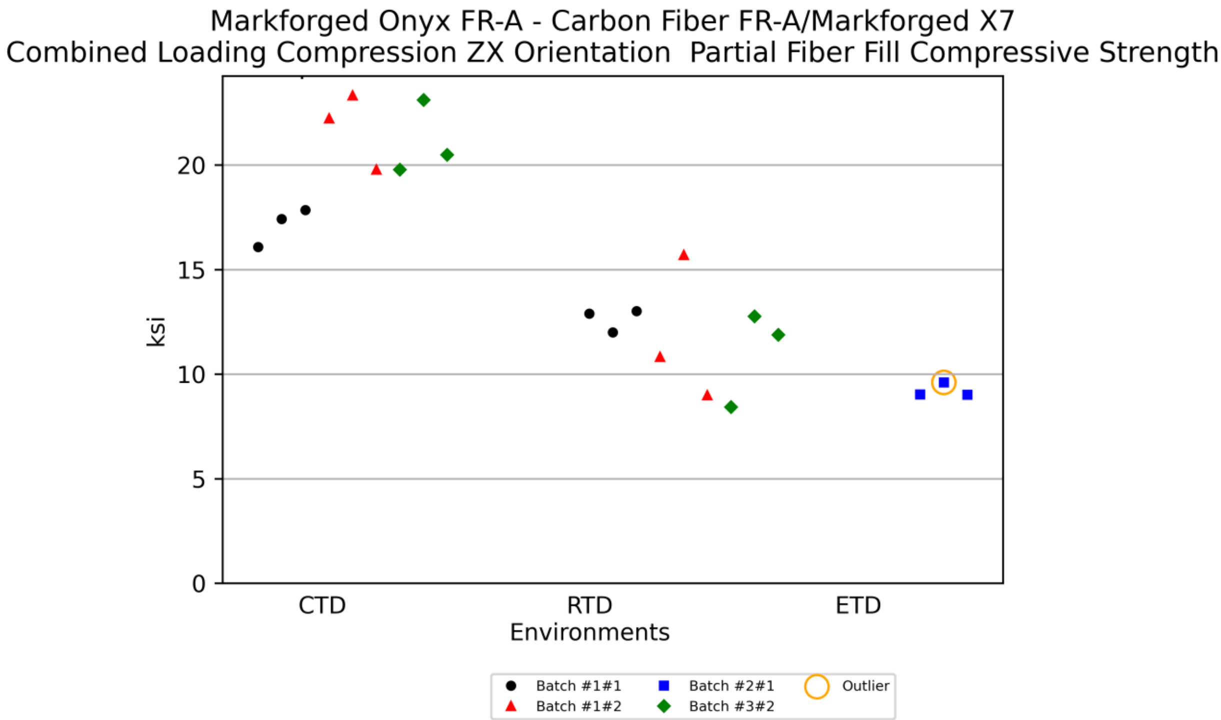

Figure 4-29: Plot for CLC ZX Orientation Partial Fiber Compressive Strength

Combined Loading Compression ZX Orientation Partial Fiber Fill Statistics			
	Compressive Strength [ksi]		
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)
Mean	20.00	11.83	9.212
Stdev	2.567	2.212	0.3366
CV	12.83	18.70	3.654
Min	16.07	8.420	9.016
Max	23.33	15.69	9.601
No. Batches/Machines	3	3	1
No. Spec.	9	9	3

Table 4-39: Statistics for CLC ZX Orientation Partial Fiber Compressive Strength

Combined Loading Compression ZX Orientation Partial Fiber Fill Statistics			
	Avg. Compressive Modulus [Msi]		
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)
Mean	0.4401	0.2962	0.2172
Stdev	0.06244	0.05165	0.01661
CV	14.19	17.44	7.645
Min	0.3657	0.2345	0.2032
Max	0.5492	0.3572	0.2356
No. Batches	3	3	1
No. Spec.	9	9	3

Table 4-40: Statistics for CLC ZX Orientation Partial Fiber Avg. Compressive Modulus

4.20 Filled Hole Tension (FHT) XY Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for one property, tensile strength, and one condition RTD. Since this is informational purposes data, only general statistics are provided. No outlier was detected for this test method.

Statistics are given for the tensile strength property data Table 4-41. The data for tensile strength are shown graphically in **Error! Reference source not found.**30.

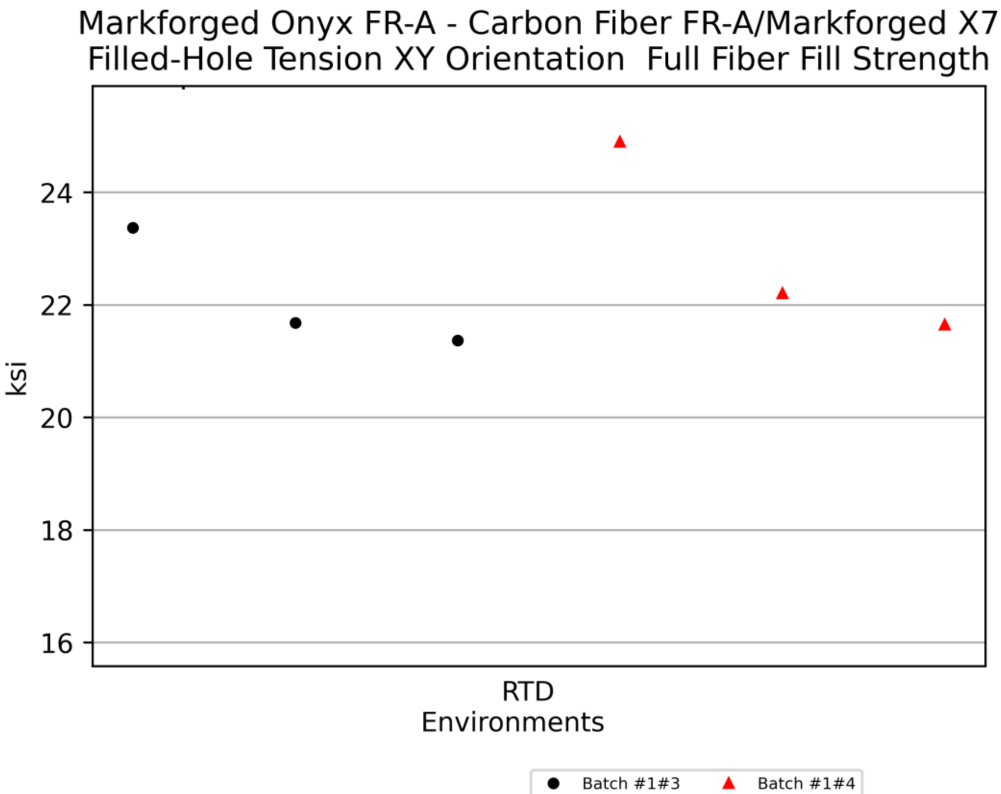

Figure 4-30: Plot for FHT XY Orientation Full Fiber Strength

Filled-Hole Tension XY Orientation Full Fiber Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	22.53
Stdev	1.361
CV	6.043
Min	21.37
Max	24.90
No. Batches/Machines	2
No. Spec.	6

Table 4-41: Statistics for FHT XY Orientation Full Fiber Strength

4.21 Filled Hole Tension (FHT) XZ Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for one property, tensile strength, and one condition RTD. Since this is informational data, only general statistics are provided. No outlier was detected for this test method.

Statistics are given for the tensile strength property data in Table 4-42. The data for tensile strength are shown graphically in **Error! Reference source not found.**31.

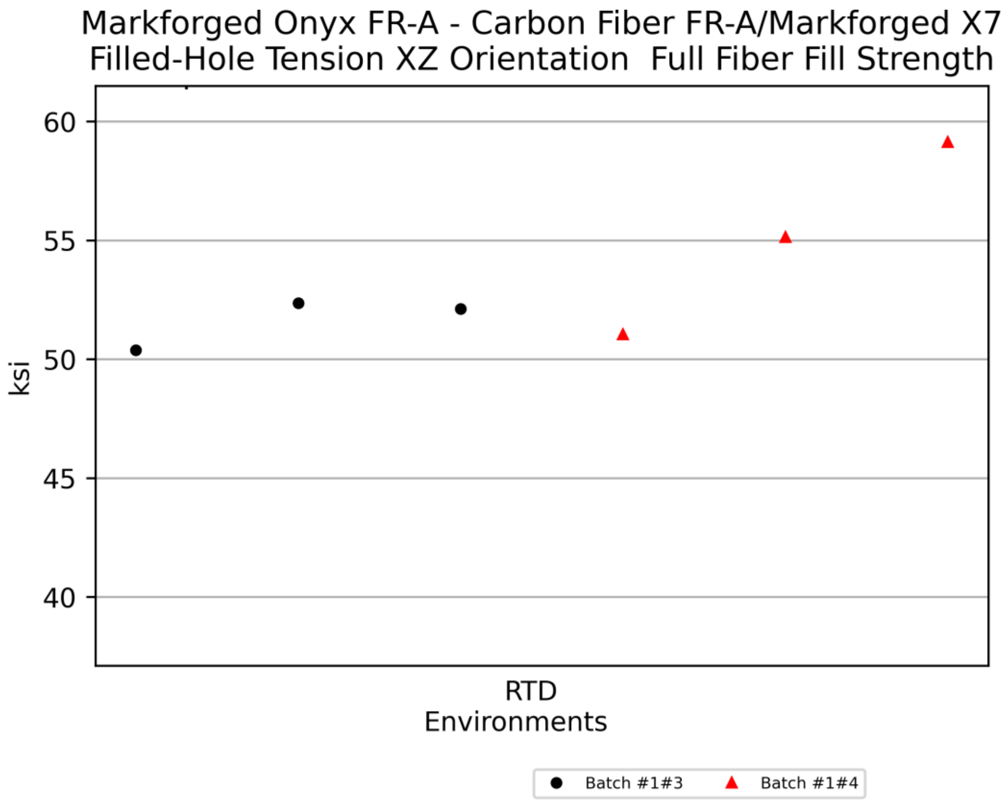

Figure 4-31: Plot for FHT XZ Orientation Full Fiber Strength

Filled-Hole Tension XZ Orientation Full Fiber Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	53.36
Stdev	3.264
CV	6.117
Min	50.38
Max	59.13
No. Batches/Machines	2
No. Spec.	6

Table 4-42: Statistics for FHT XZ Orientation Full Fiber Strength

4.22 Filled Hole Tension (FHT) ZX Orientation No Fiber (NF) Fill

This test method was performed for strength property and four conditions CTD, RTD, ETD, and ETW. For conditions CTD, ETD, and ETW data passed ADK test and normality test, so normal method was used for computing basis values, while RTD condition failed ADK test, so ANOVA method was used. Since RTD has more than 5 groups, ANOVA provides a B-basis rather than an estimate.

Two outliers were detected for strength. For the ETW condition, the lowest values in both batch#1 machine#1 and batch#3 machine#2 groups were outliers for the machine batch combination but not for the ETW condition. Both outliers were retained for this analysis.

Statistics and allowables are given for the strength property data in Table 4-43. The data and B-estimates are shown graphically for compressive strength data in **Error! Reference source not found.**32.

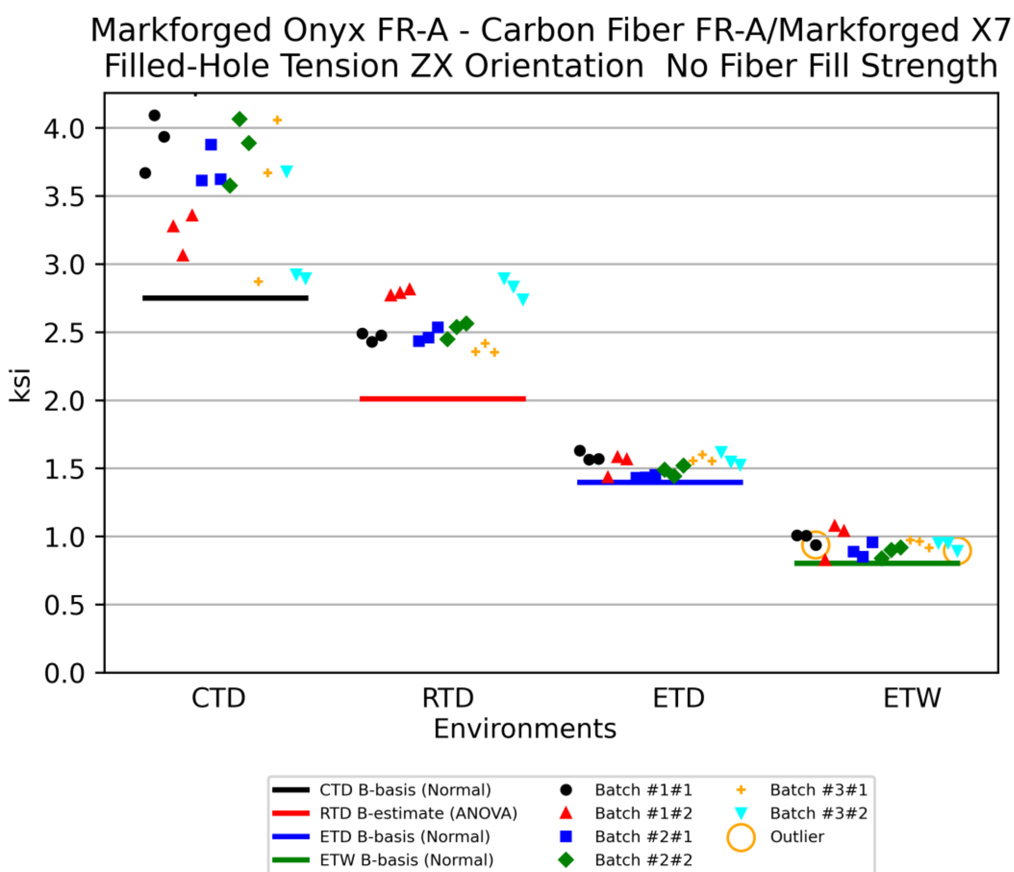

Figure 4-32: Plot for FHT ZX Orientation No Fiber Strength

Filled-Hole Tension ZX Orientation No Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	3.562	2.574	1.529	0.9386
Stdev	0.4110	0.1800	0.06653	0.06795
CV	11.54	6.992	4.352	7.240
Min	2.870	2.352	1.430	0.8234
Max	4.093	2.896	1.631	1.075
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	2.751	2.012	1.397	0.8044
A-Estimate	2.176	1.627	1.304	0.7093
Method	Normal	ANOVA	Normal	Normal

Table 4-43: Statistics for FHT ZX Orientation No Fiber Strength

4.23 Filled Hole Tension (FHT) XY Orientation Partial Fiber (PF) Fill

This test method was performed for strength property and four conditions CTD, RTD, ETD, and ETW. All four conditions passed pooling test, so pooling method was used for computing basis values.

There was one outlier. The lowest value for the CTD condition for batch#2 machine#2 was an outlier for that batch machine combinations but not for the CTD condition. It was retained for this analysis.

Statistics and allowables are given for the strength property data in Table 4-44. The data and B-estimates are shown graphically for compressive strength data in **Error! Reference source not found.**33.

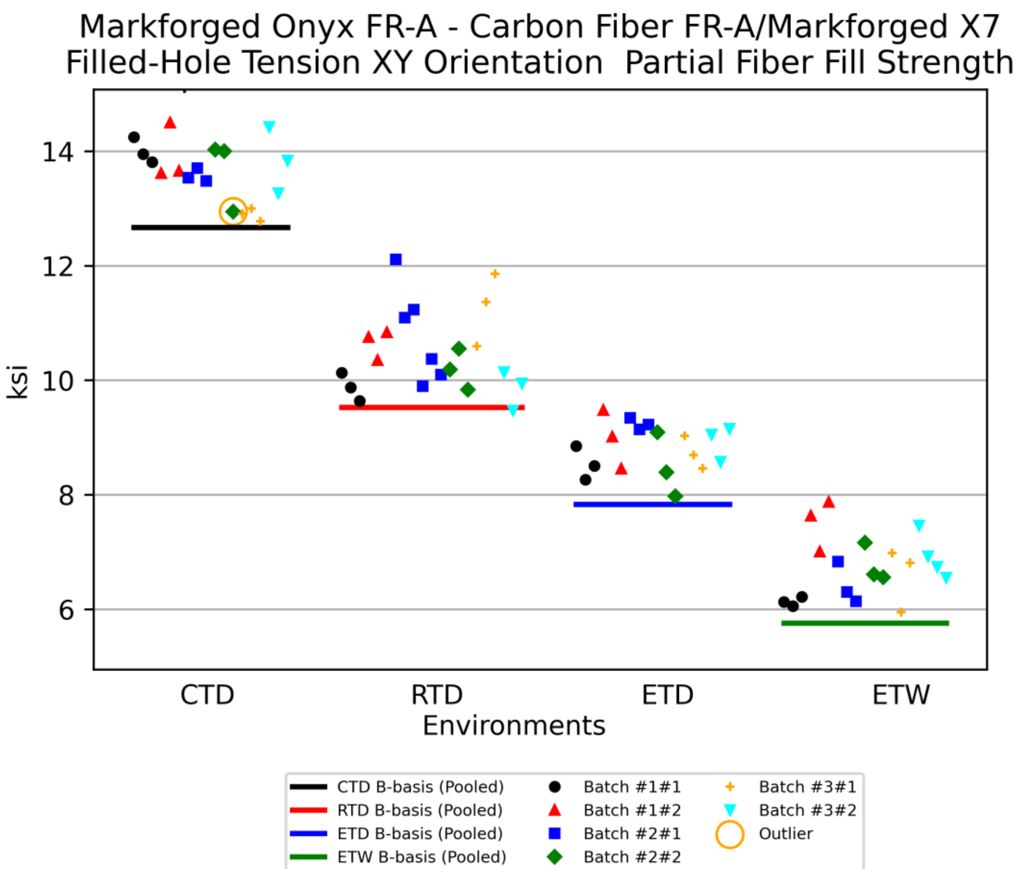

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Figure 4-33: Plot for FHT XY Orientation Partial Fiber Strength

Filled-Hole Tension XY Orientation Partial Fiber Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	13.65	10.49	8.817	6.735
Stdev	0.5156	0.7114	0.4151	0.5445
CV	3.778	6.780	4.708	8.085
Min	12.77	9.474	7.976	5.948
Max	14.50	12.11	9.480	7.876
No. Batches/Machines	6	6	6	6
No. Spec.	18	21	18	19
Basis Values and Estimates				
B-Basis	12.67	9.525	7.835	5.758
A-Estimate	12.02	8.876	7.189	5.112
Method	Pooled	Pooled	Pooled	Pooled

Table 4-44: Statistics for FHT XY Orientation Partial Fiber Strength

4.24 Filled Hole Tension (FHT) XZ Orientation Partial Fiber (PF) Fill

This test method was performed for strength property and four conditions CTD, RTD, ETD, and ETW. CTD condition passed normality test, so normal method was used for computing basis values. RTD condition failed all distribution tests, so non-parametric method was used for computing basis values. ETD and ETW conditions failed ADK test, so ANOVA method was used for computing basis values. Since there were six batch/machine combinations, ANOVA method produces B-basis values (rather than estimates).

Three outliers were detected. For the CTD condition, the largest value in batch #3 machine #1 was an outlier for that batch machine combination but not for the CTD condition. For the RTD condition, the lowest value in batch #2 machine #2 was an outlier for that batch machine combination but not for the RTD condition and the lowest value in batch #3 machine #1 was an outlier for the RTD condition but not for that batch machine combination. All three outliers were retained for this analysis. Note: The failure modes for batch #3 in condition RTD were consistent. After carrying out further investigations for the two lower data points in batch #3 machine #1, no assignable cause was found. The difference in strength values were attributed to inherent material properties.

Statistics and allowables are given for the strength property data in Table 4-45. The data and B-estimates are shown graphically for compressive strength data in **Error! Reference source not found.**34.

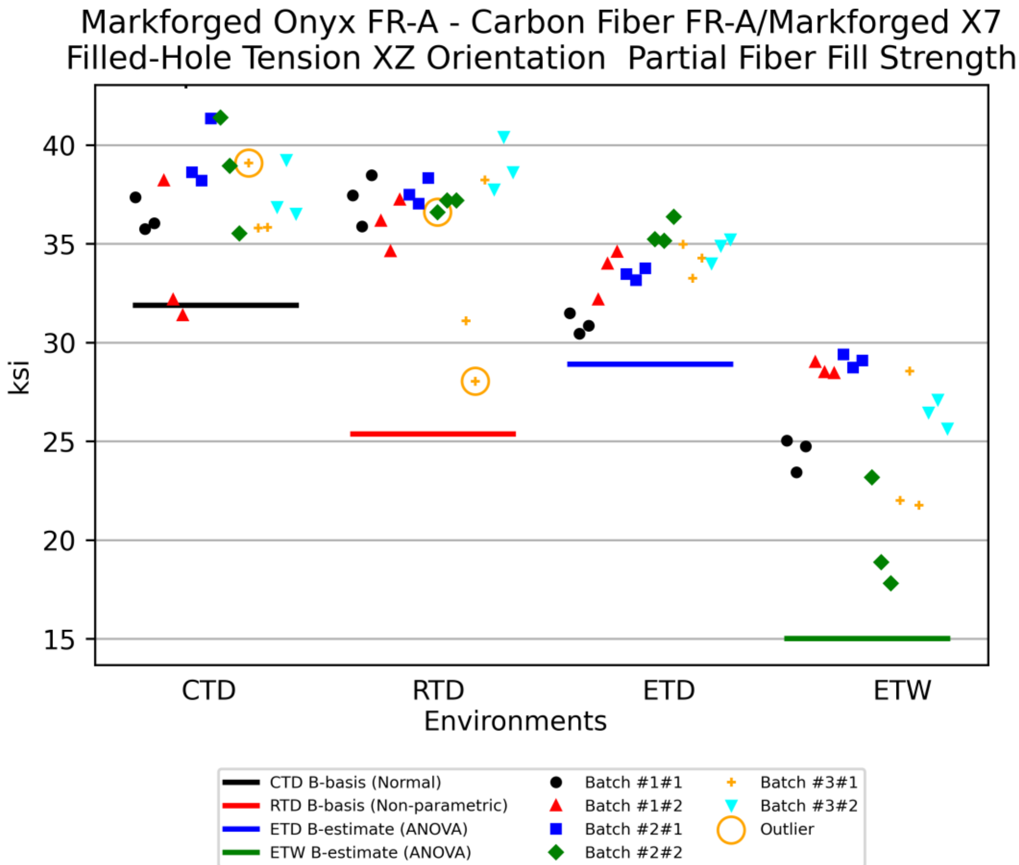

Figure 4-34: Plot for FHT XZ Orientation Partial Fiber Strength

Filled-Hole Tension XZ Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	37.13	36.54	33.74	25.43
Stdev	2.650	2.870	1.622	3.606
CV	7.137	7.853	4.806	14.18
Min	31.37	28.04	30.45	17.81
Max	41.39	40.42	36.36	29.40
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	31.89	25.37	28.91	15.03
A-Estimate	28.19	16.22	25.60	7.877
Method	Normal	Non-parametric	ANOVA	ANOVA

Table 4-45: Statistics for FHT XZ Orientation Partial Fiber Strength

4.25 Filled Hole Tension (FHT) ZX Orientation Partial Fiber (PF) Fill (Informational purposes)

This test method was performed for strength property and RTD condition. Data is provided for informational purposes only, so allowables were not computed. No outliers were detected.

Statistics are given for the strength property data in Table 4-46. The data for compressive strength data are shown graphically in **Error! Reference source not found.**35.

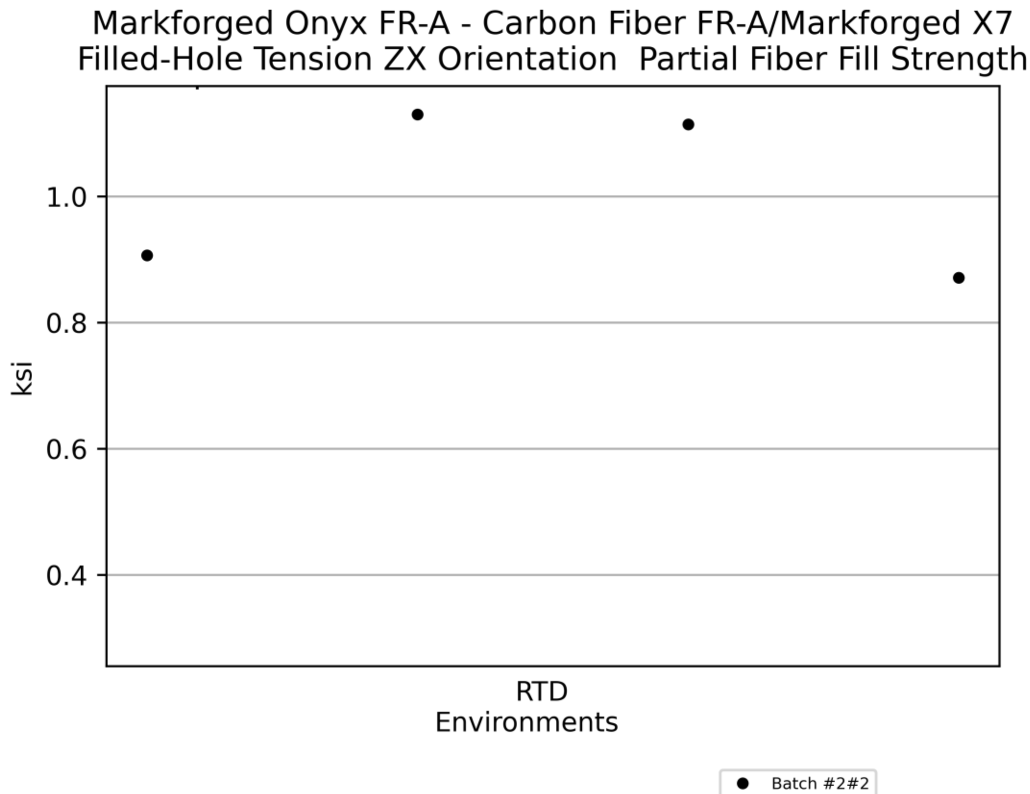

Figure 4-35: Plot for FHT ZX Orientation Partial Fiber Strength

Filled-Hole Tension ZX Orientation Partial Fiber Fill Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	1.005
Stdev	0.1357
CV	13.50
Min	0.8710
Max	1.130
No. Batches/Machines	1
No. Spec.	4

Table 4-46: Statistics for FHT ZX Orientation Partial Fiber Strength

4.26 Open Hole Tension (OHT) XY Orientation Full Fiber (FF) Fill

This test method was performed for tensile strength property and RTD condition. The data passed normality test, so normal method was used for computing basis values for RTD. There were insufficient specimens, so only estimates of basis values could be provided.

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-47. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**36.

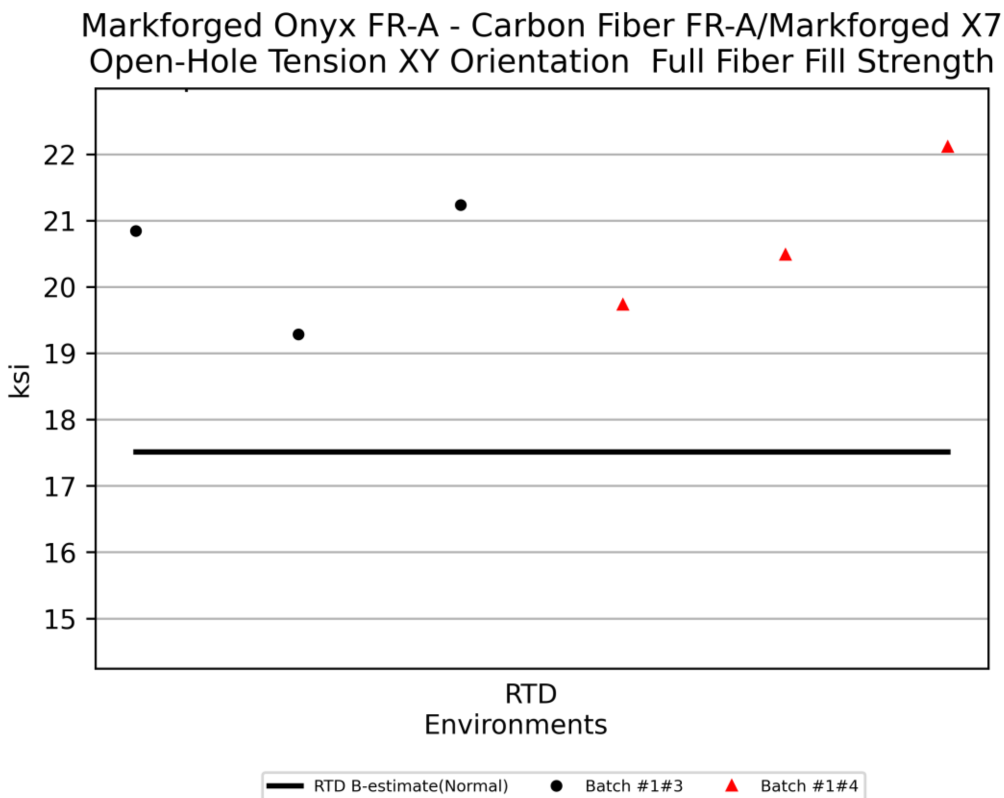

Figure 4-36: Plot for OHT XY Orientation Full Fiber Strength

Open-Hole Tension XY Orientation Full Fiber Fill Basis Values and Statistics	
	Strength[ksi]
Env	RTD(70°F)
Mean	20.61
Stdev	1.023
CV	4.964
Min	19.29
Max	22.11
No. Batches/Machines	2
No. Spec.	6
Basis Values and Estimates	
B-Estimate	17.51
A-Estimate	15.31
Method	Normal

Table 4-47: Statistics for OHT XY Orientation Full Fiber Strength

4.27 Open Hole Tension (OHT) XZ Orientation Full Fiber (FF) Fill

This test method was performed for tensile strength property and RTD condition. Data passed normality test, so normal method was used for computing basis values for RTD. There were insufficient specimens, so only estimates of basis values could be provided.

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-48. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**37.

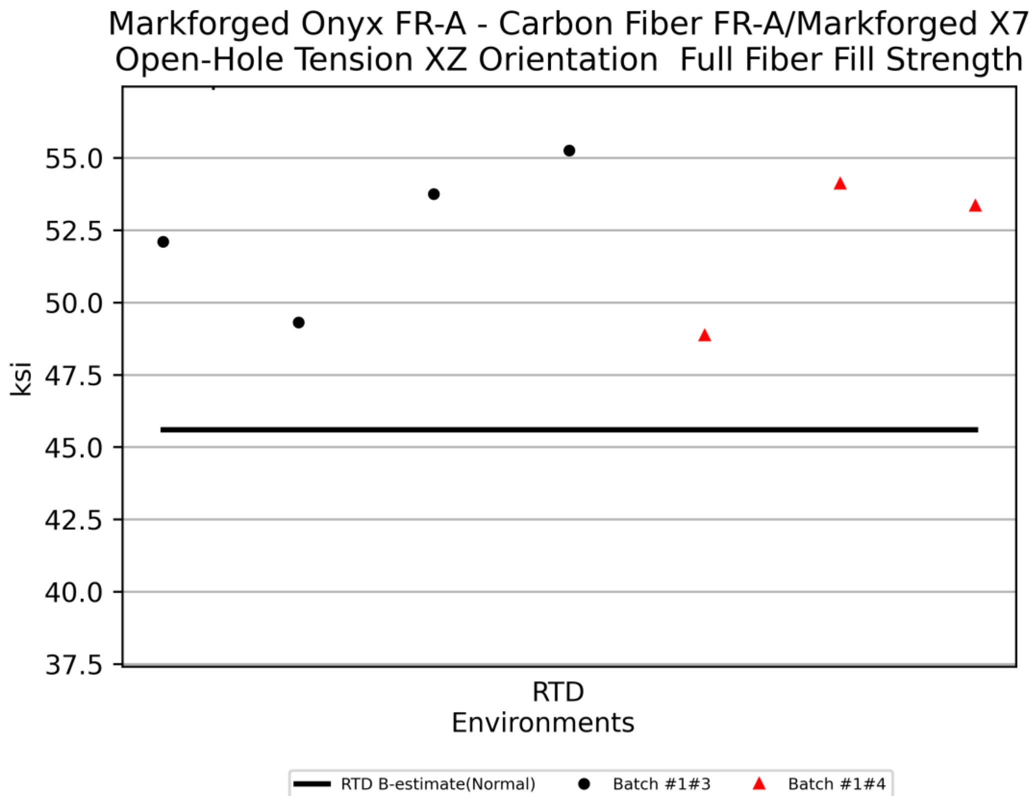

Figure 4-37: Plot for OHT XZ Orientation Full Fiber Strength

Open-Hole Tension XZ Orientation Full Fiber Fill Basis Values and Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	52.39
Stdev	2.447
CV	4.670
Min	48.86
Max	55.26
No. Batches/Machines	2
No. Spec.	7
Basis Values and Estimates	
B-Estimate	45.60
A-Estimate	40.82
Method	Normal

Table 4-48: Statistics for OHT XZ Orientation Full Fiber Strength

4.28 Open Hole Tension (OHT) ZX Orientation No Fiber (NF) Fill

This test method was performed for tensile strength property and conditions CTD, RTD, ETD, and ETW. Data for CTD and RTD passed pooling tests, so pooling method was used for computing basis values. For conditions ETD and ETW, data fails ADK test, so ANOVA method was used. Since there were six batch/machine combinations, ANOVA method produces B-basis values rather than estimates.

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-49. The data and B-basis for strength property are shown graphically in **Error! Reference source not found.**38.

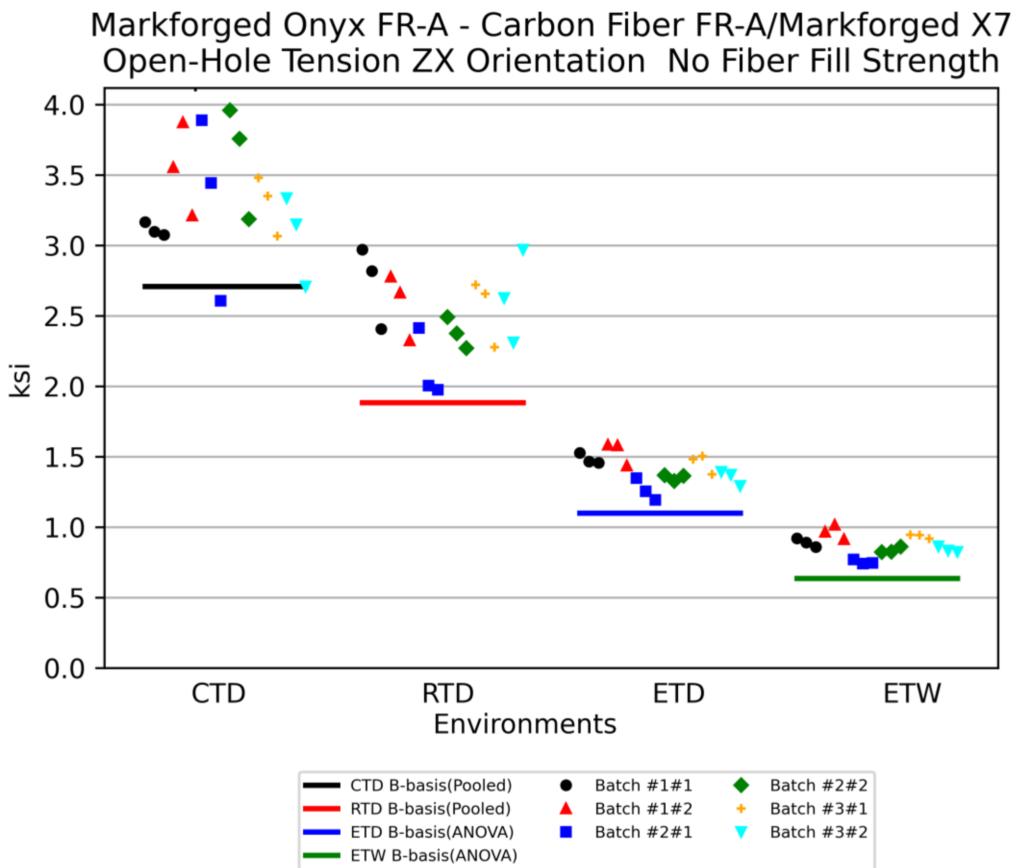

Figure 4-38: Plot for OHT ZX Orientation No Fiber Strength

Open-Hole Tension ZX Orientation No Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	3.327	2.502	1.407	0.8699
Stdev	0.3808	0.2930	0.1071	0.07626
CV	11.44	11.71	7.613	8.766
Min	2.605	1.974	1.192	0.7405
Max	3.959	2.970	1.584	1.016
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	2.709	1.883	1.099	0.6364
A-Estimate	2.288	1.462	0.8882	0.4764
Method	Pooled	Pooled	ANOVA	ANOVA

Table 4-49: Statistics for OHT ZX Orientation No Fiber Strength

4.29 Open Hole Tension (OHT) XY Orientation Partial Fiber (PF) Fill

This test method was performed for tensile strength property and conditions CTD, RTD, ETD, and ETW. For conditions RTD and ETD, data passes pooling tests, so pooling method was used for computing basis values. For conditions CTD and ETW, data passed normality test, so normal method was used.

There was one statistical outlier. In the CTD condition, the lowest value in batch#1 machine#1 was an outlier for that batch machine combination but not for the CTD condition. It was retained for this analysis.

Statistics and allowables are given for the strength property data in Table 4-50. The data and B-basis for strength properties are shown graphically in **Error! Reference source not found.**39.

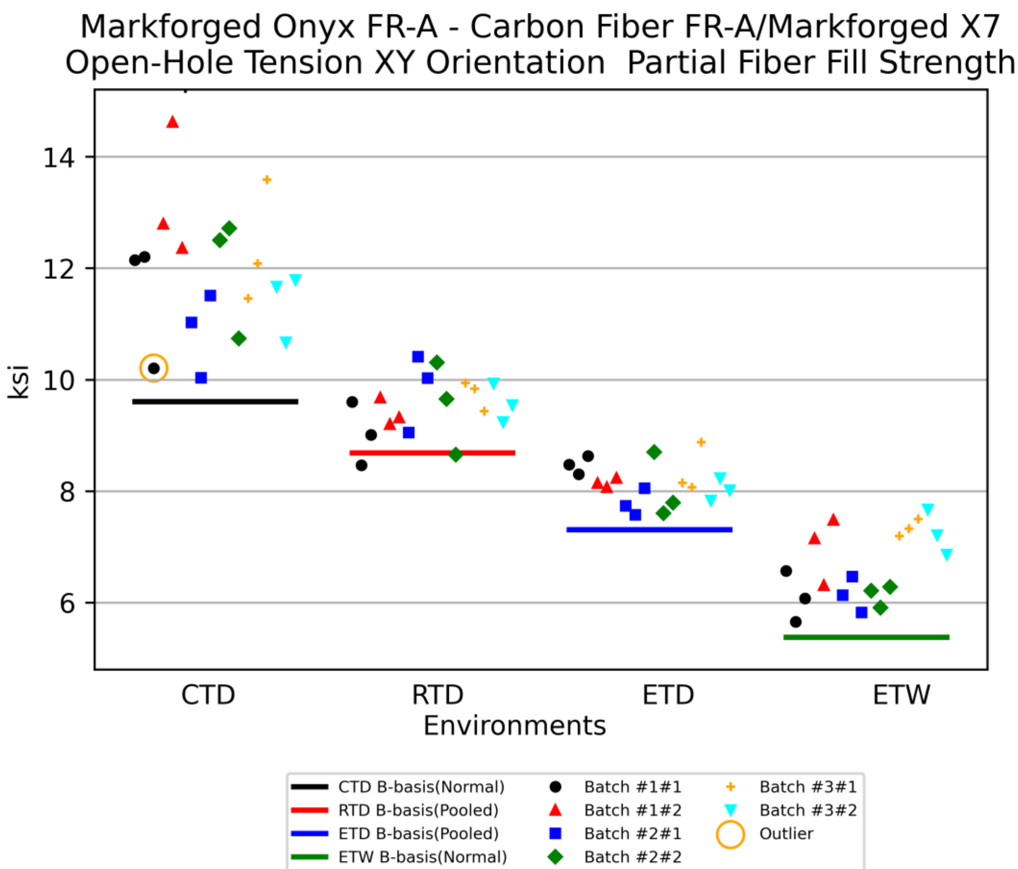

Figure 4-39: Plot for OHT XY Orientation Partial Fiber Strength

Open-Hole Tension XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	11.89	9.517	8.139	6.659
Stdev	1.159	0.5281	0.3659	0.6471
CV	9.747	5.549	4.496	9.717
Min	10.04	8.467	7.575	5.658
Max	14.62	10.41	8.880	7.675
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	9.606	8.690	7.312	5.382
A-Estimate	7.984	8.127	6.749	4.476
Method	Normal	Pooled	Pooled	Normal

Table 4-50: Statistics for OHT XY Orientation Partial Fiber Strength

4.30 Open Hole Tension (OHT) XZ Orientation Partial Fiber (PF) Fill

This test method was performed for tensile strength property and conditions CTD, RTD, ETD, and ETW. For condition CTD, data pass ADK but fails the standard distribution tests, so a non-parametric method was used for computing basis values. For condition RTD, data failed ADK, so ANOVA method was used. Since there are six batch machine combinations, ANOVA produce B-basis values rather than estimates. For ETD and ETW conditions, data passes normality test, so normal method was used.

Three outliers were detected. For the RTD condition, the lowest value in batch#2 machine#2 as an outlier for the RTD condition but not for that batch machine combination. For the ETW condition, the lowest values in batch#2 machine#2 and in batch#3 machine#2 were outliers for their respective batch machine combinations but not for the ETW condition. All three outliers were retained for this analysis.

Note: Due to the manufacturing operations of the machine the fiber reinforcement is not fully integrated throughout the entire coupon, leaving the hole area un-reinforced. This causes the failure mode of the material to act erratically, causing both hole and long splitting failures. This test data is being provided as informational and should be used with caution keeping the design in mind and how fiber reinforcement will be used. Therefore, we consider the computed allowables as estimates only.

Statistics and allowables are given for the strength property in Table 4-51. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**40.

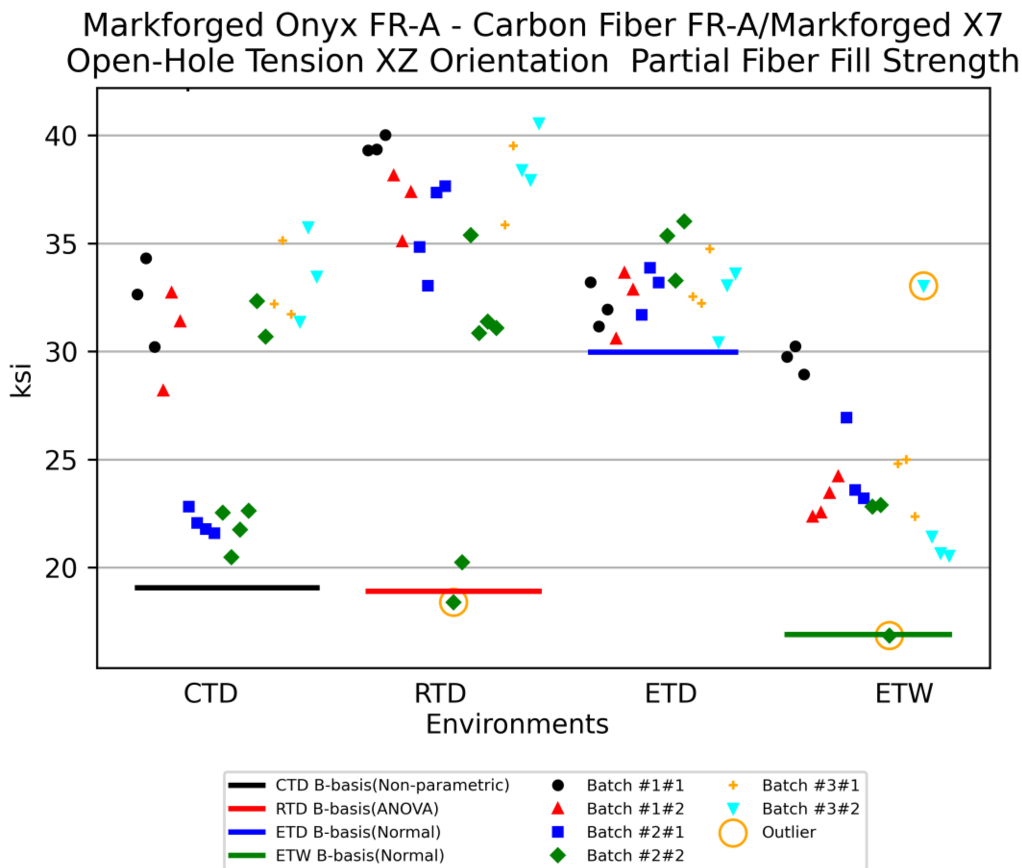

Figure 4-40: Plot for OHT XZ Orientation Partial Fiber Strength

Open-Hole Tension XZ Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	28.53	34.84	32.96	24.28
Stdev	5.344	5.942	1.514	3.832
CV	18.73	17.05	4.592	15.78
Min	20.48	18.38	30.43	16.84
Max	35.75	40.57	36.02	33.03
No. Batches/Machines	6	6	6	6
No. Spec.	22	21	18	20
Basis Values and Estimates				
B-Estimate	19.06	18.90	29.98	16.90
A-Estimate	10.14	7.869	27.86	11.65
Method	Non-parametric	ANOVA	Normal	Normal

Table 4-51: Statistics for OHT XZ Orientation Partial Fiber Strength

4.31 Open Hole Tension (OHT) ZX Orientation Partial Fiber (PF) Fill

This test method was performed for tensile strength property and conditions CTD and RTD. The number of specimens for both conditions was insufficient, so only estimates are provided. For condition CTD, data passed normality test, so normal method was used for computing allowables, however these are estimates due to the low number of specimens. For condition RTD, data failed ADK test, so ANOVA method was used, however the results are null, so we consider the allowables for RTD not available (NA).

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-52. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**41.

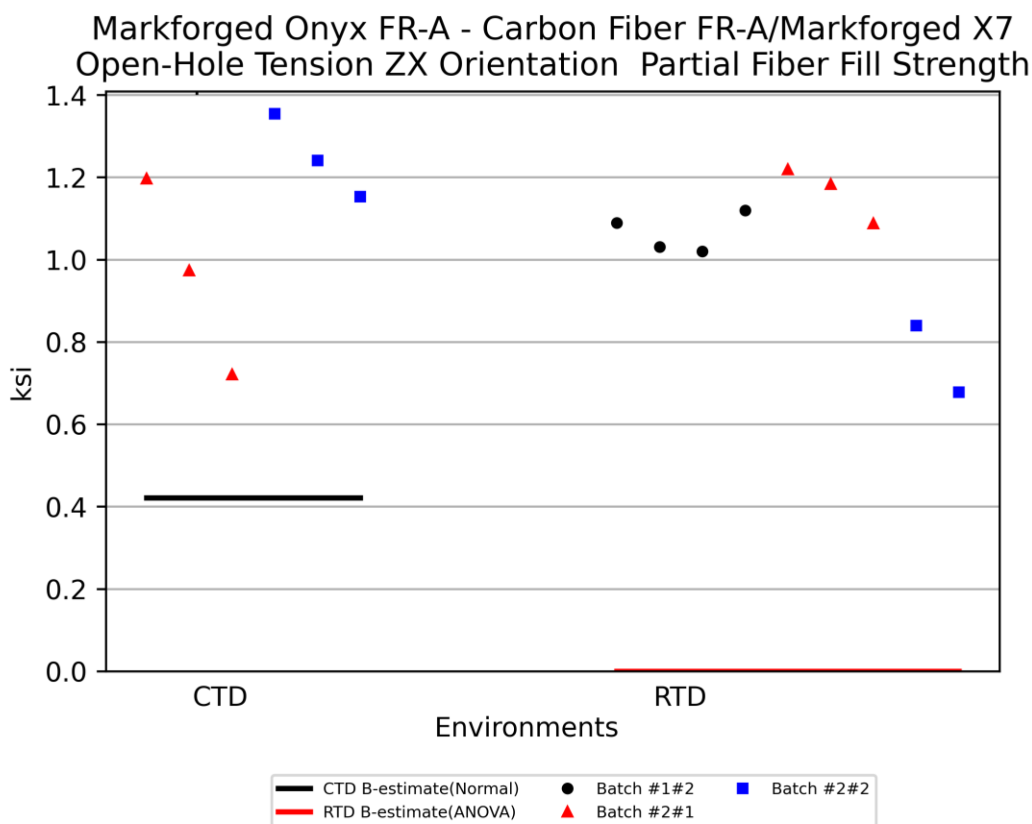

Figure 4-41: Plot for OHT ZX Orientation Partial Fiber Strength

Open-Hole Tension ZX Orientation Partial Fiber Fill Basis Values and Statistics		
	Strength [ksi]	
Env	CTD(-65°F)	RTD(70°F)
Mean	1.106	1.030
Stdev	0.2262	0.1712
CV	20.45	16.63
Min	0.7210	0.6779
Max	1.354	1.219
No. Batches/Machines	2	3
No. Spec.	6	9
Basis Values and Estimates		
B-Estimate	0.4210	NA
A-Estimate	NA	
Method	Normal	

Table 4-52: Statistics for OHT ZX Orientation Partial Fiber Strength

4.32 Short Beam Strength (SBS) XY Orientation Full Fiber (FF) Fill

This test method was performed for strength property and condition RTD. Data passed normality test, so normal method was used for computing allowables, however due to the low number of specimens these are considered estimates.

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-53. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**42.

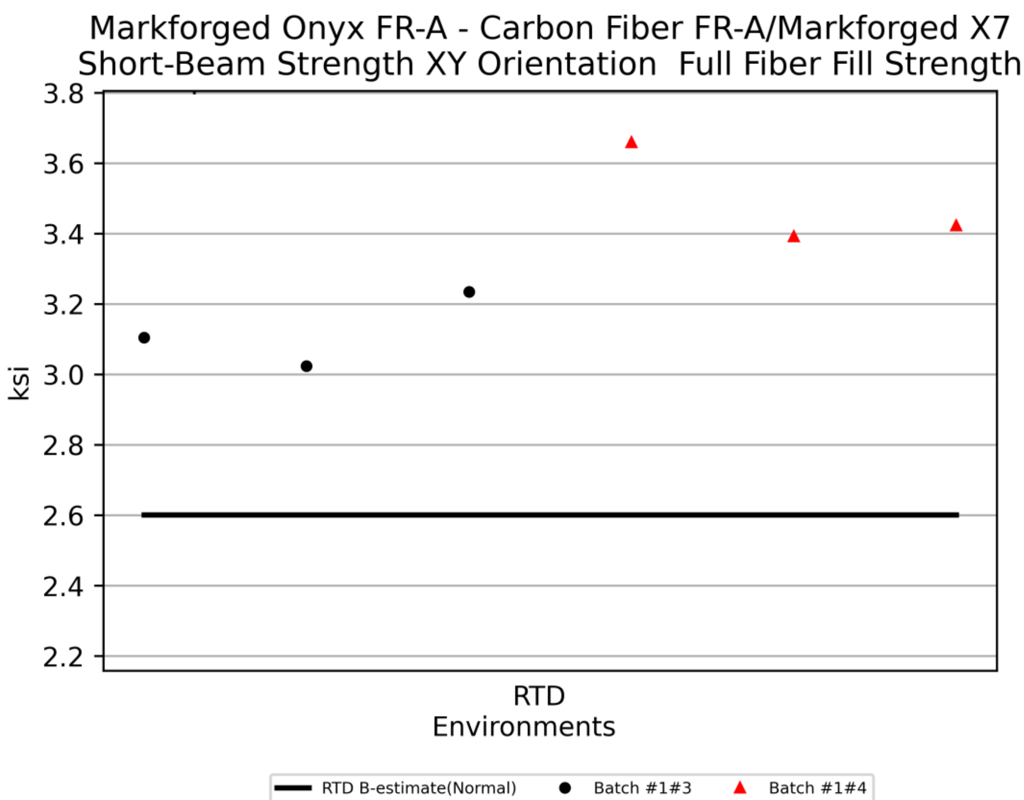

Figure 4-42: Plot for SBS XY Orientation Full Fiber Strength

Short-Beam Strength XY Orientation Full Fiber Fill Basis Values and Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	3.306
Stdev	0.2327
CV	7.038
Min	3.024
Max	3.659
No. Batches/Machines	2
No. Spec.	6
Basis Values and Estimates	
B-Estimate	2.601
A-Estimate	2.100
Method	Normal

Table 4-53: Statistics for SBS XY Orientation Full Fiber Strength

4.33 Short Beam Strength (SBS) XY Orientation Partial Fiber (PF) Fill

This test method was performed for strength property and conditions CTD, RTD, ETD, and ETW. For all conditions, except RTD, data passed normality test, so normal method was used for computing basis values. For condition RTD, data failed ADK test, so ANOVA method was used. Since there are six batch machine combinations for RTD, the result is B-basis value rather than an estimate.

No outliers were detected.

Statistics and allowables are given for the strength property data in Table 4-54. The data and B-basis for strength are shown graphically in **Error! Reference source not found.**43.

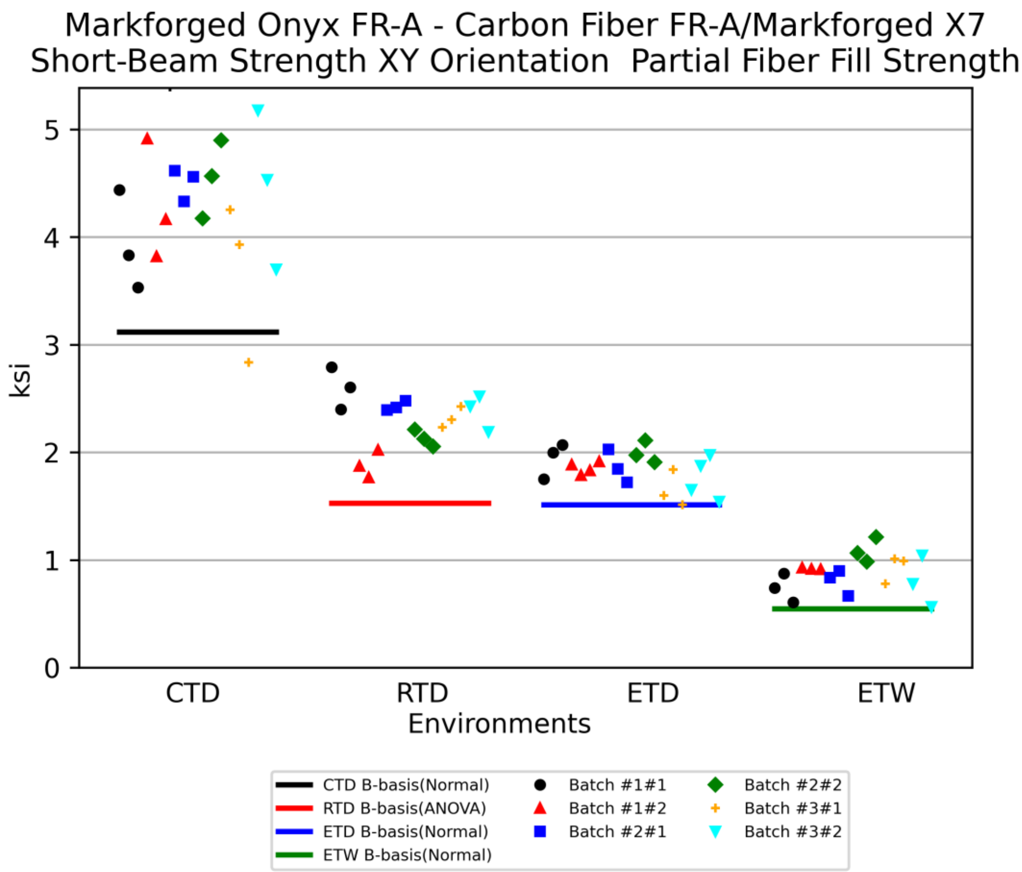

Figure 4-43: Plot for SBS XY Orientation Partial Fiber Strength

Short-Beam Strength XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	4.237	2.291	1.841	0.8776
Stdev	0.5671	0.2587	0.1699	0.1677
CV	13.38	11.29	9.231	19.11
Min	2.837	1.766	1.514	0.5634
Max	5.179	2.790	2.111	1.214
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	20	18
Basis Values and Estimates				
B-Basis	3.118	1.528	1.514	0.5464
A-Estimate	2.324	1.004	1.281	0.3117
Method	Normal	ANOVA	Normal	Normal

Table 4-54: Statistics for SBS XY Orientation Partial Fiber Strength

4.34 Flexural (F) Properties XY Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for strength and modulus properties and RTD condition. This data is presented for informational purposes only, so no allowables were calculated.

No outliers were detected.

Statistics are given for the strength property data in Table 4-55 and for modulus data in Table 4-56. The data for strength property are shown graphically in **Error! Reference source not found.**44.

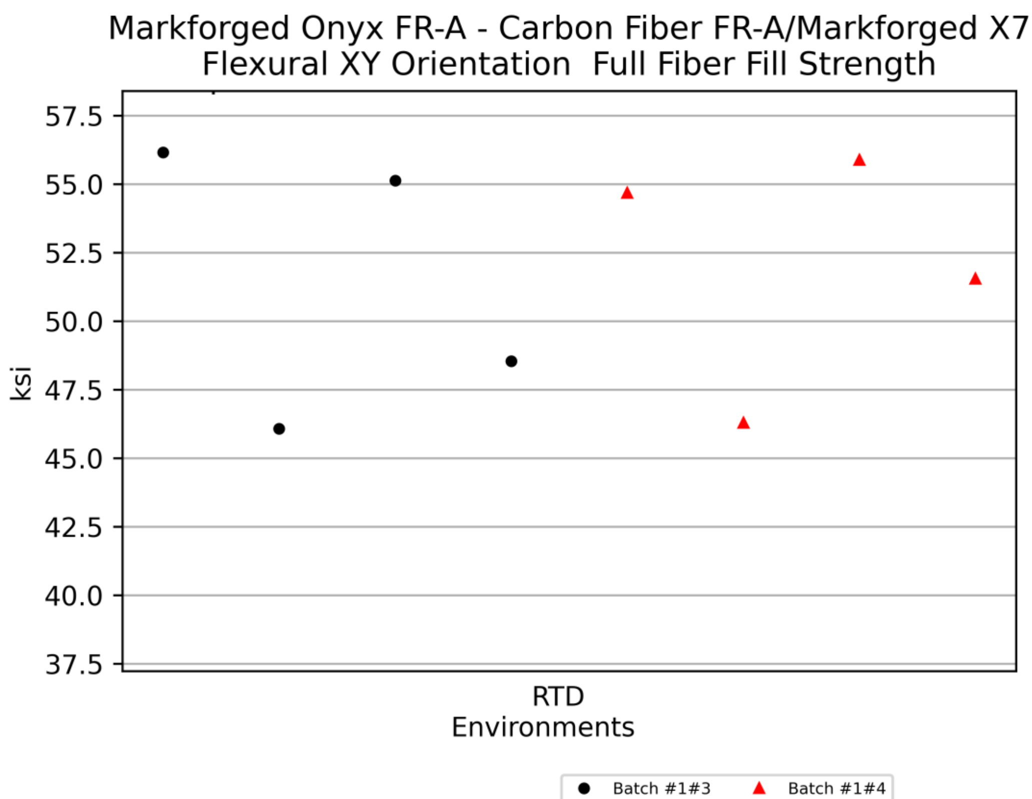

Figure 4-44: Plot for (F) XY Orientation Full Fiber Strength

Flexural XY Orientation Full Fiber Statistics	
	Strength [ksi]
Env	RTD(70°F)
Mean	51.78
Stdev	4.289
CV	8.283
Min	46.07
Max	56.15
No. Batches/Machines	2
No. Spec.	8

Table 4-55: Statistics for (F) XY Orientation Full Fiber Strength

Flexural XY Orientation Full Fiber Statistics	
	Modulus [Msi]
Env	RTD(70°F)
Mean	2.979
Stdev	0.09090
CV	3.051
Min	2.863
Max	3.100
No. Batches/Machines	2
No. Spec.	8

Table 4-56: Statistics for (F) XY Orientation Full Fiber Modulus

4.35 Flexural (F) Properties XZ Orientation Full Fiber (FF) Fill (Informational purposes)

This test method was performed for strength, 2% offset yield strength, and modulus properties and RTD condition. This data is presented for informational purposes only, so no allowables were calculated.

No outliers were detected.

Statistics are given for the strength properties data in Table 4-57 and for modulus property in Table 4-58. The data for strength property are shown graphically in **Error! Reference source not found.**45 and for 2% offset yield strength property in **Error! Reference source not found.**46.

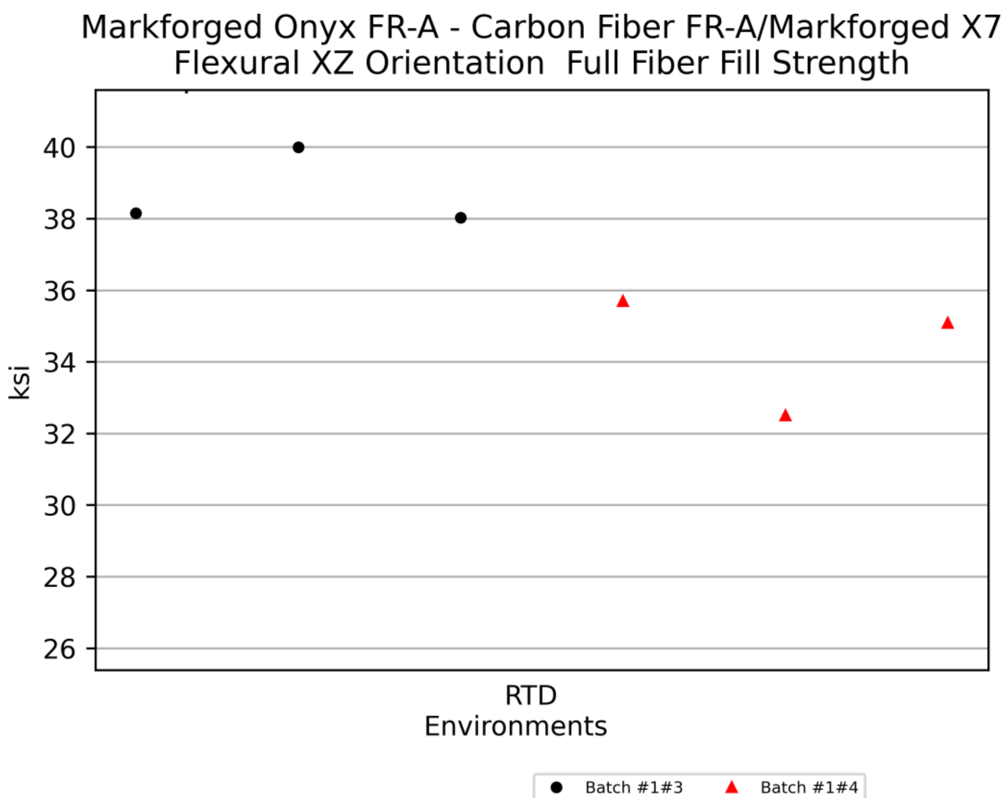

Figure 4-45: Plot for (F) XZ Orientation Full Fiber Strength

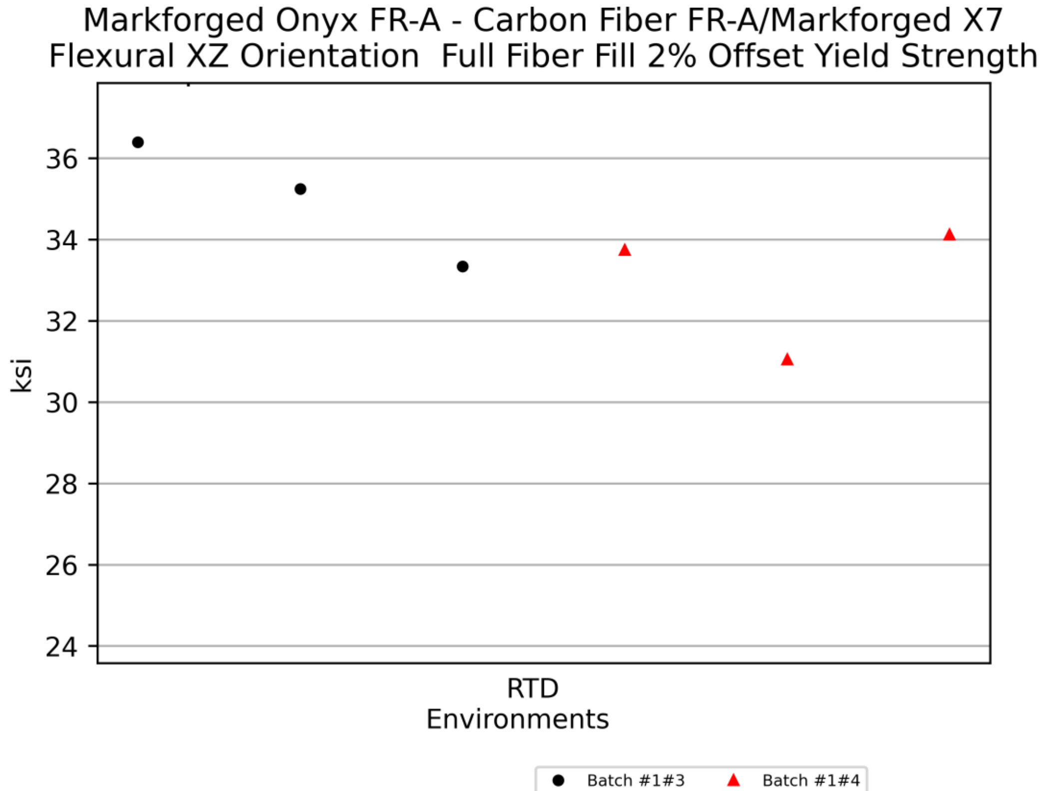

Figure 4-46: Plot for (F) XZ Orientation Full Fiber 2% Offset Yield Strength

Flexural XZ Orientation Full Fiber Fill Statistics		
	Strength [ksi]	2% Offset Yield Strength [ksi]
Env	RTD(70°F)	RTD(70°F)
Mean	36.57	33.98
Stdev	2.680	1.818
CV	7.328	5.351
Min	32.50	31.05
Max	40.00	36.40
No. Batches/Machines	2	2
No. Spec.	6	6

Table 4-57: Statistics for (F) XZ Orientation Full Fiber Strength & 2% Offset Strength

Flexural XZ Orientation Full Fiber Statistics	
	Modulus [Msi]
Env	RTD(70°F)
Mean	1.851
Stdev	0.1461
CV	7.892
Min	1.707
Max	2.047
No. Batches/Machines	2
No. Spec.	6

Table 4-58: Statistics for (F) XZ Orientation Full Fiber Modulus

4.36 Flexural (F) Properties ZX Orientation Partial Fiber (PF) Fill (Informational purposes)

This test method was performed for strength, 2% offset yield strength, and modulus properties and CTD, RTD conditions. This data is presented for informational purposes only, so no allowables were calculated.

No outliers were detected.

Statistics are given for the strength properties in Table 4-59 and for modulus in Table 4-60. The data for strength property are shown graphically in **Error! Reference source not found.**47 and for 2% offset yield strength in Figure 4-48.

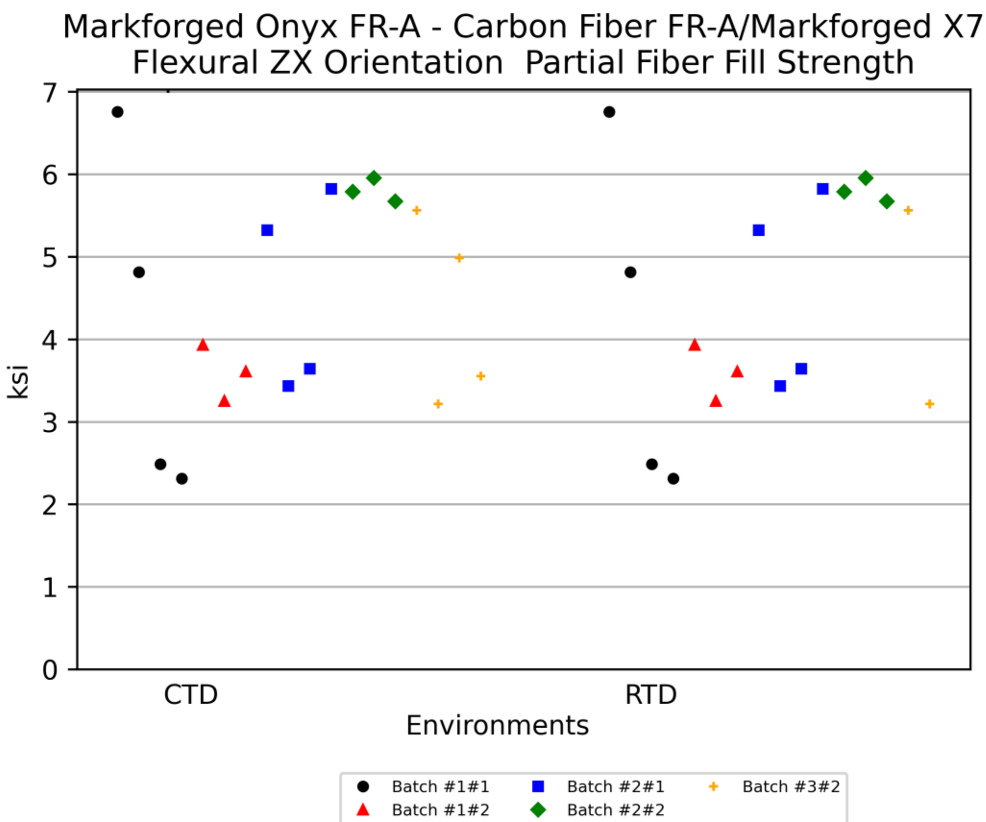

Figure 4-47: Plot for (F) ZX Orientation Partial Fiber Strength

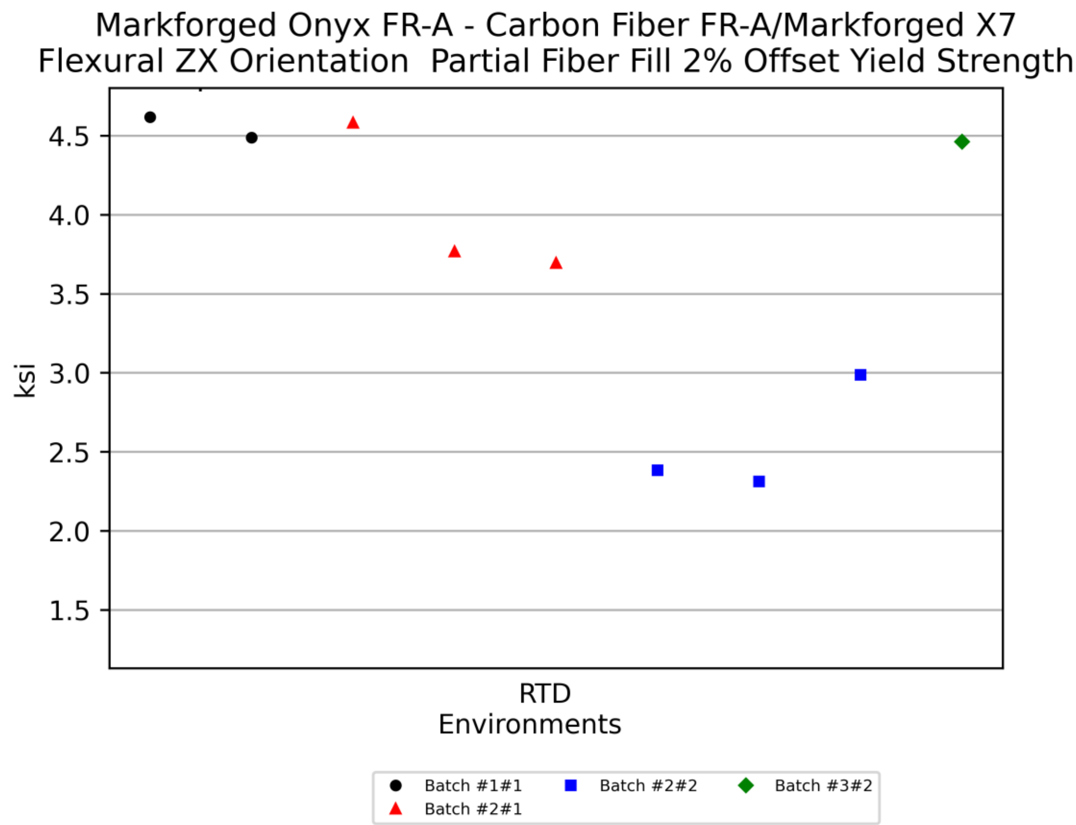

Figure 4-48: Plot for (F) ZX Orientation Partial Fiber 2% Offset Yield Strength

Flexural ZX Orientation Partial Fiber Fill Statistics			
	Strength [ksi]		2% Offset Yield Strength [ksi]
Env	CTD(-65°F)	RTD(70°F)	RTD(70°F)
Mean	4.450	4.097	3.699
Stdev	1.329	0.6673	0.9343
CV	29.87	16.29	25.26
Min	2.312	3.013	2.313
Max	6.758	4.906	4.616
No. Batches/Machines	5	5	4
No. Spec.	18	18	9

Table 4-59: Statistics for (F) ZX Orientation Partial Fiber Strength & 2% Offset Strength

Flexural ZX Orientation Partial Fiber Fill Statistics		
	Modulus [Msi]	
Env	CTD(-65°F)	RTD(70°F)
Mean	0.4584	0.3564
Stdev	0.02355	0.04161
CV	5.138	11.67
Min	0.4135	0.2470
Max	0.5012	0.4090
No. Batches/Machines	5	5
No. Spec.	20	18

Table 4-60: Statistics for (F) ZX Orientation Partial Fiber Modulus

4.37 Flexural (F) Properties ZX Orientation No Fiber (NF) Fill

This test method was performed for strength, 2% offset yield strength, and modulus properties at CTD, RTD, ETD, and ETW conditions. CTD and RTD passed normality test, so normal method was used to compute allowables. ETD and ETW failed ADK test, so ANOVA method was used. Since the data has six batch machine combinations, the results are B-basis values rather than estimates. The 2% offset yield strength in the CTD condition has insufficient data to compute B-basis values, only B-estimates are available.

Two outliers were detected, both in the ETW condition for the 2% offset yield strength property. The lowest values in batch#1 machine#2 and batch#2 machine#2 were outliers for their respective batch machine combinations but not for the ETW condition. Both outliers were retained for this analysis.

Statistics and allowables are given for the strength property data in Table 4-61, for 2% offset yield strength in Table 4-62, and for modulus data in Table 4-63. The data and B-basis for strength data are shown graphically in **Error! Reference source not found.**49 and for 2% offset yield strength in Figure 4-50.

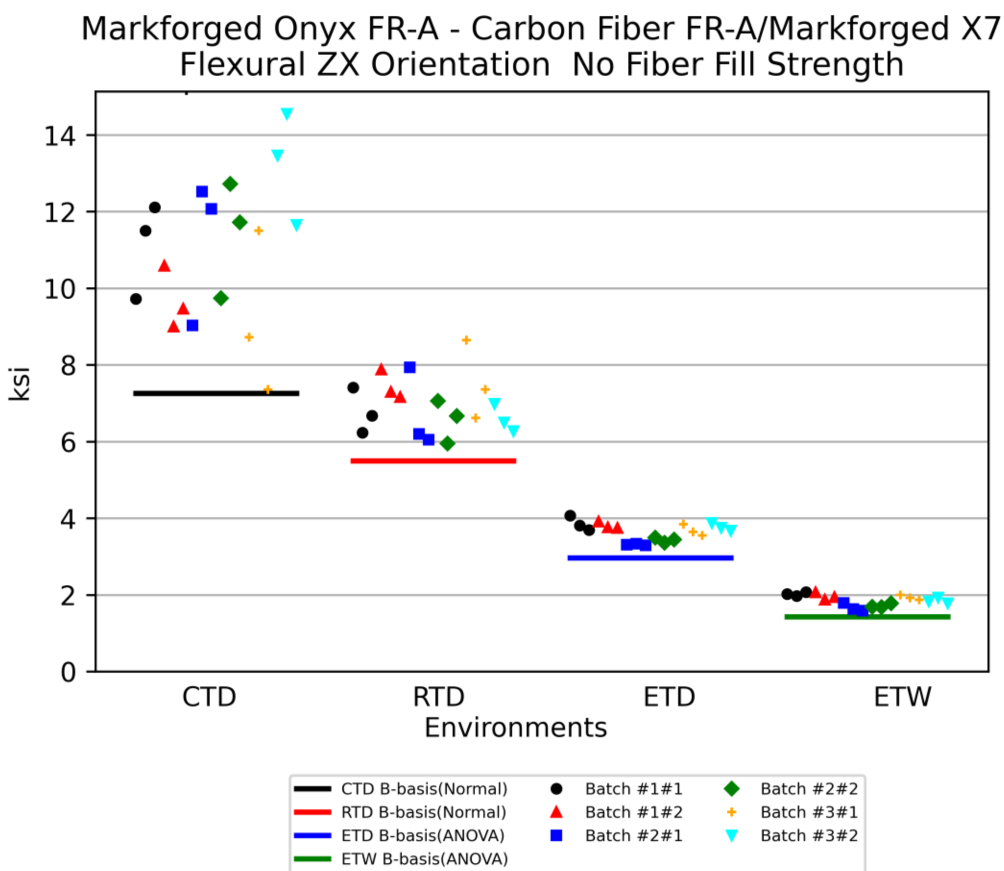

Figure 4-49: Plot for (F) ZX Orientation No Fiber Strength

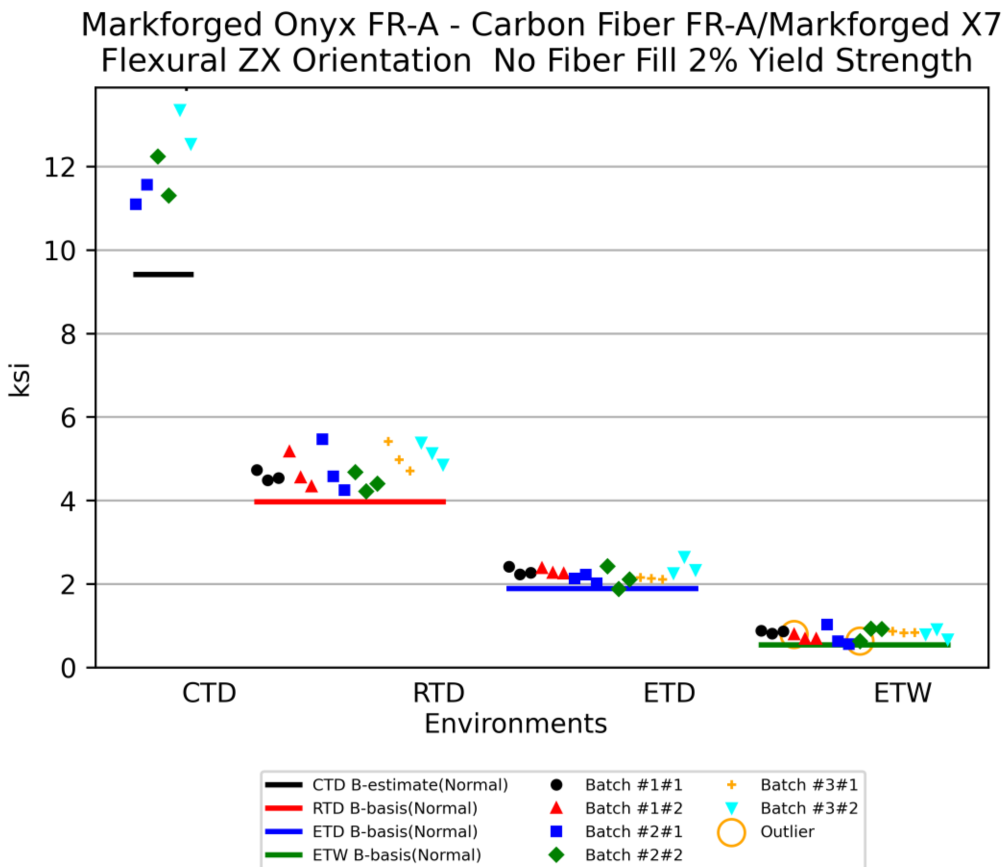

Figure 4-50: Plot for (F) ZX Orientation No Fiber 2% Offset Yield Strength

Flexural ZX Orientation No Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	10.97	6.937	3.640	1.856
Stdev	1.877	0.7316	0.2303	0.1472
CV	17.12	10.55	6.327	7.931
Min	7.355	5.951	3.290	1.585
Max	14.55	8.647	4.069	2.074
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18
Basis Values and Estimates				
B-Basis	7.261	5.493	2.964	1.426
A-Estimate	4.635	4.470	2.500	1.130
Method	Normal	Normal	ANOVA	ANOVA

Table 4-61: Statistics for (F) ZX Orientation No Fiber Strength

Flexural ZX Orientation No Fiber Fill Basis Values and Statistics				
	2% Yield Strength [ksi]			
Env	CTD(-65°F)	RTD(77°F)	ETD(130°F)	ETW(130°F)
Mean	12.02	4.771	2.236	0.7953
Stdev	0.8589	0.4033	0.1723	0.1268
CV	7.147	8.453	7.706	15.94
Min	11.10	4.217	1.880	0.5563
Max	13.36	5.465	2.650	1.027
No. Batches/Machines	3	6	6	6
No. Spec.	6	18	18	18
Basis Values and Estimates				
B-Basis		3.975	1.896	0.5451
B-Estimate	9.415			
A-Estimate	7.565	3.410	1.655	0.3677
Method	Normal	Normal	Normal	Normal

Table 4-62: Statistics for (F) ZX Orientation No Fiber 2% Offset Strength

Flexural ZX Orientation No Fiber Fill Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	0.5612	0.3101	0.1209	0.05660
Stdev	0.03481	0.02626	0.008430	0.003861
CV	6.202	8.470	6.971	6.822
Min	0.5187	0.2752	0.1049	0.04718
Max	0.6359	0.3607	0.1307	0.06208
No. Batches/Machines	6	6	6	6
No. Spec.	18	18	18	18

Table 4-63: Statistics for (F) ZX Orientation No Fiber Modulus

4.38 Flexural (F) Properties XY Orientation Partial Fiber (PF) Fill

This test method was performed for strength, 2% offset yield strength, and modulus properties at CTD, RTD, ETD, and ETW conditions. For strength property, conditions CTD, RTD, and ETD passed normality test, so normal method was used for computing allowables. ETW condition failed ADK test, so ANOVA method was used. Since the data has six batch machine combinations, the result is a B-basis value rather than an estimate. The RTD strength dataset and the 2% offset yield strength dataset for the ETD conditions have insufficient data to compute B-basis values, only B-estimates are available. The 2% offset yield strength datasets for the CTD and RTD conditions do not have sufficient data to compute estimates. ETD passed ADK test, but failed the standard distributions tests, so non-parametric method was used. ETW failed ADK test, so ANOVA method was used, however this method yielded negative values, so we consider these as not available (NA).

Two outliers were detected. For the ETD condition, the lowest value in batch#2 machine#1 was an outlier for both strength and 2% offset yield strength. For strength, it was an outlier for the machine batch combination only, but for the 2% offset yield strength it was an outlier for both the machine batch combination and the ETD condition. For the ETW condition, the lowest value in batch#1 machine#1 was an outlier for that machine batch combination but not for the ETW condition. Both outliers were retained for this analysis.

Statistics and allowables, for the strength property data, are given in Table 4-64, for 2% offset yield strength data in Table 4-65 and for modulus data in Table 4-66. The data and B-estimates for strength property are shown graphically in **Error! Reference source not found.**51 and for 2% offset yield strength property in Figure 4-52.

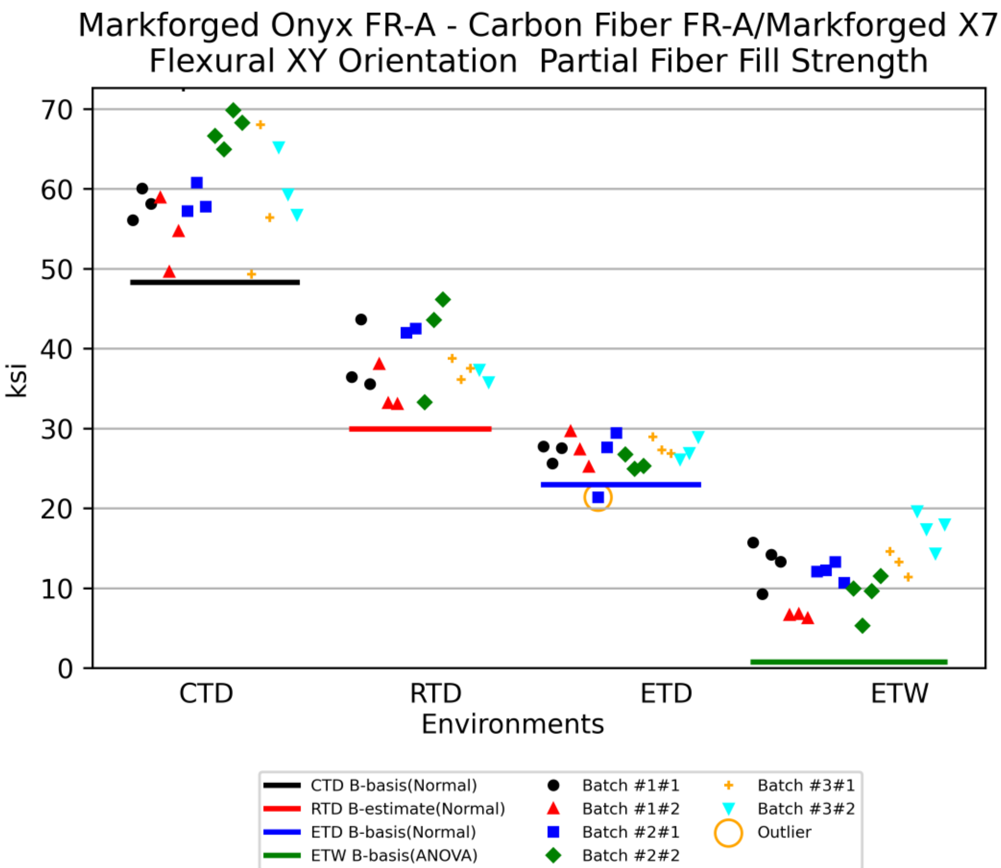

Figure 4-51: Plot for (F) XY Orientation Partial Fiber Strength

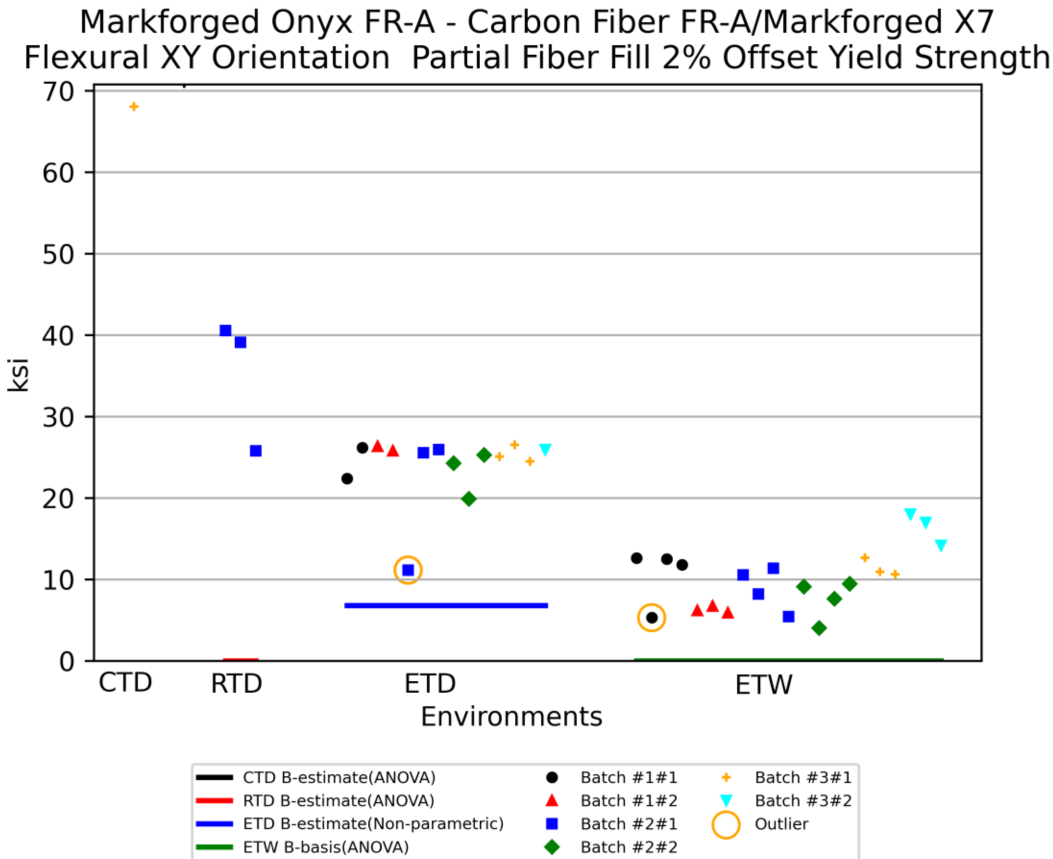

Figure 4-52: Plot for (F) XY Orientation Partial Fiber 2% Offset Yield Strength

Flexural XY Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	59.89	38.30	26.87	12.05
Stdev	5.936	4.104	1.973	3.867
CV	9.911	10.72	7.344	32.08
Min	49.32	33.02	21.37	5.299
Max	69.85	46.16	29.62	19.63
No. Batches/Machines	6	6	6	6
No. Spec.	19	16	18	22
Basis Values and Estimates				
B-Basis	48.32		22.97	0.7490
B-Estimate		29.95		
A-Estimate	40.11	24.06	20.21	0.0000
Method	Normal	Normal	Normal	ANOVA

Table 4-64: Statistics for (F) XY Orientation Partial Fiber Strength

Flexural XY Orientation Partial Fiber Fill Basis Values and Statistics				
	2% Offset Yield Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	68.05	35.13	23.91	10.00
Stdev	NA	8.124	4.090	3.797
CV	NA	23.12	17.11	37.96
Min	68.05	25.79	11.14	4.008
Max	68.05	40.53	26.52	18.01
No. Batches/Machines	1	1	6	6
No. Spec.	1	3	14	21
Basis Values and Estimates				
B-Estimate	NA	NA	6.777	NA
A-Estimate			2.201	
Method			Non-parametric	

Table 4-65: Statistics for (F) XY Orientation Partial Fiber 2% Offset Strength

Flexural Properties XY Orientation Partial Fiber Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	2.715	2.126	1.831	1.172
Stdev	0.1308	0.1317	0.07432	0.3047
CV	4.818	6.192	4.059	25.99
Min	2.462	1.954	1.590	0.4588
Max	2.991	2.508	1.914	1.565
No. Batches/Machines	6	6	6	6
No. Spec.	19	19	18	22

Table 4-66: Statistics for (F) XY Orientation Partial Fiber Modulus

4.39 Flexural (F) Properties XZ Orientation Partial Fiber (PF) Fill

This test method was performed for strength, 2% offset yield strength, and modulus properties at CTD, RTD, ETD, and ETW conditions. For strength property, CTD and ETW conditions passed normality test, so normal method was used for computing allowables. RTD and ETD passed pooling test, so pooling method was used. For 2% offset yield strength property, CTD and ETD conditions passed normality test, so normal method was used for computing allowables. However, CTD data has less than 18 specimens, so we consider the result as B-estimate rather than B-basis. RTD and ETW failed ADK test, so ANOVA method was used. For RTD the number of batch-machines is greater than 5, so the result is B-basis rather then an estimate. For ETW the results are null, so we consider them not available (NA).

Two outliers were detected. One higher condition outlier was detected for 2% offset yield strength property in CTD condition, batch#2 machine#2. One lower batch outlier was detected for strength in the RTD condition, batch#2 machine#1.

Statistics and allowables, for the strength property data in Table 4-67, are given, for 2% offset yield strength data in Table 4-68 and for modulus data in Table 4-69. The data and B-basis values for strength data are shown graphically in **Error! Reference source not found.**53 and for 2% offset yield strength data in Figure 4-54.

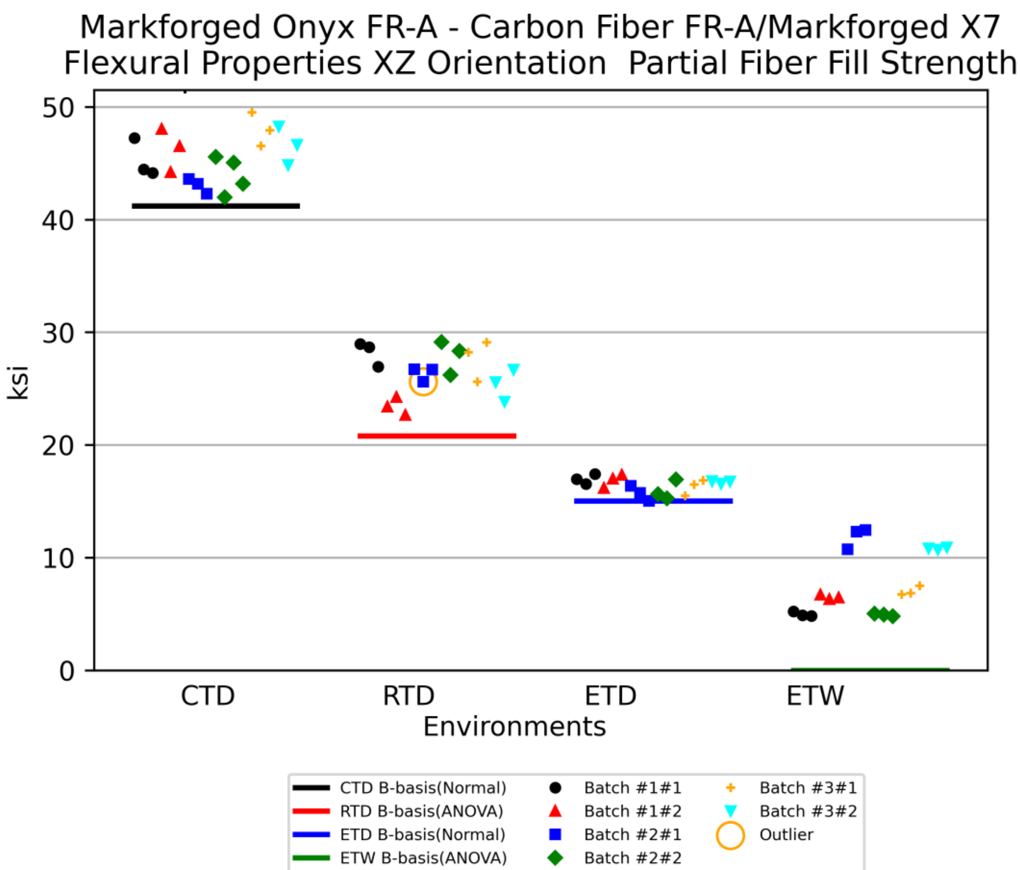

Figure 4-53: Plot for (F) XZ Orientation Partial Fiber Strength

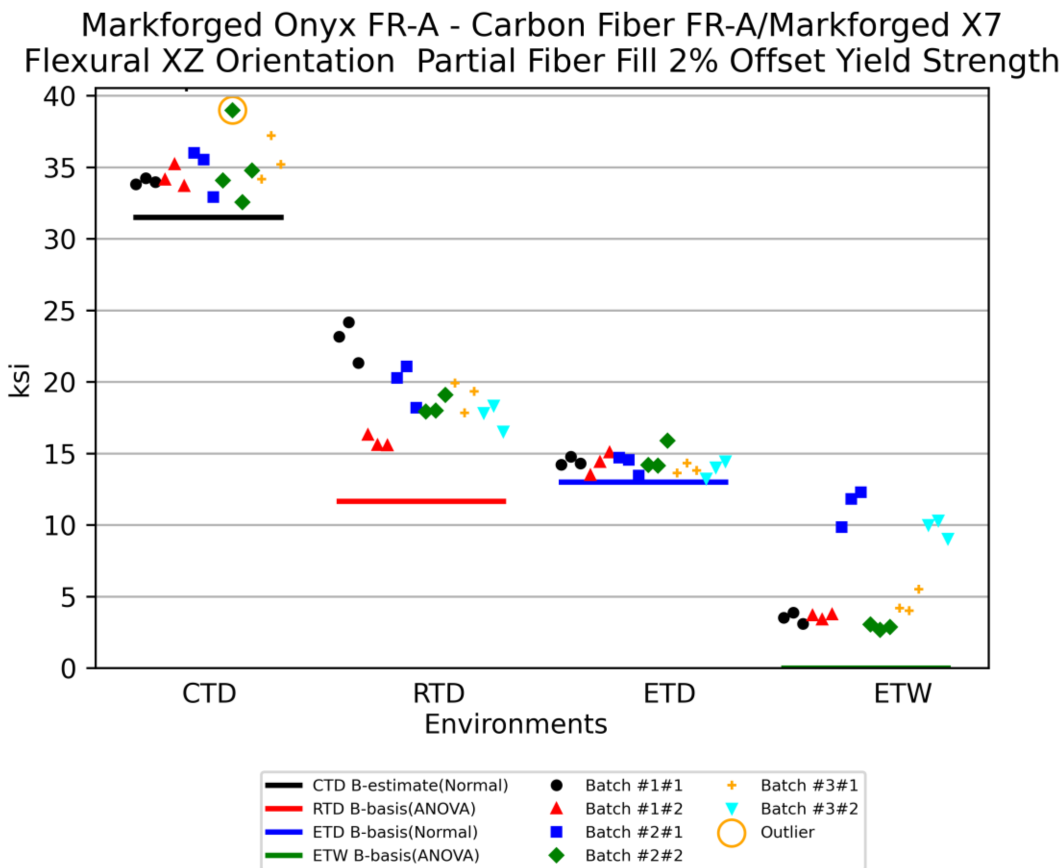

Figure 4-54: Plot for (F) XZ Orientation Partial Fiber 2% Offset Yield Strength

Flexural Properties XZ Orientation Partial Fiber Fill Basis Values and Statistics				
	Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	45.42	26.48	16.41	7.679
Stdev	2.169	2.030	0.7036	2.803
CV	4.775	7.667	4.287	36.51
Min	41.98	22.66	15.03	4.796
Max	49.52	29.12	17.42	12.44
No. Batches/Machines	6	6	6	6
No. Spec.	19	18	18	18
Basis Values and Estimates				
B-Basis	41.20	20.82	15.02	NA
A-Estimate	38.20	16.91	14.04	
Method	Normal	ANOVA	Normal	

Table 4-67: Statistics for (F) XZ Orientation Partial Fiber Strength

Flexural XZ Orientation Partial Fiber Fill Basis Values and Statistics				
	2% Offset Yield Strength [ksi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	34.77	18.91	14.25	5.934
Stdev	1.607	2.414	0.6313	3.477
CV	4.623	12.77	4.430	58.59
Min	32.56	15.54	13.26	2.662
Max	38.98	24.15	15.87	12.27
No. Batches/Machines	5	6	6	6
No. Spec.	16	18	18	18
Basis Values and Estimates				
B-Basis		11.65	13.01	NA
B-Estimate	31.50			
A-Estimate	29.20	6.672	12.12	
Method	Normal	ANOVA	Normal	

Table 4-68: Statistics for (F) XZ Orientation Partial Fiber 2% Offset Strength

Flexural XZ Orientation Partial Fiber Fill Statistics				
	Modulus [Msi]			
Env	CTD(-65°F)	RTD(70°F)	ETD(130°F)	ETW(130°F)
Mean	1.898	1.343	0.9640	0.5093
Stdev	0.1245	0.1154	0.07215	0.2157
CV	6.560	8.594	7.484	42.36
Min	1.670	1.144	0.7939	0.2312
Max	2.128	1.493	1.052	0.7929
No. Batches/Machines	6	6	6	6
No. Spec.	19	18	18	18

Table 4-69: Statistics for (F) XZ Orientation Partial Fiber Modulus

5. Outliers

Outliers were identified according to the standards documented in section 2.1.4, which are in accordance with the guidelines developed in section 8.3.3 of CMH-17-1G. A specimen may be an outlier for the batch-machine only (before pooling the batches within a condition together) or for the condition (after pooling the batch-machine units 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 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 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-2019-007 Rev N/C.

Statistical outliers are listed in Table 5-1. These outliers were included in the analysis for their respective test properties, except the outlier in shaded row, which was removed for the statistical analysis.

N	Test Method	Orienta-tion	Fiber	Condition	Batch	Machine	Specimen Number	Test Property	Strength value	High/ Low	Batch-Machine Outlier	Condition Outlier
1	FHT	ZX	NF	ETW	1	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M1-P60727-ZX-FHT-13-ETW-NF-3	Strength	0.9368	Low	Yes	No
2				ETW	3	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M2-P64990-ZX-FHT-13-ETW-NF-3	Strength	0.8948	Low	Yes	No
3		XY	PF	CTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P46559-XY-FHT-13-CTD-PF-3	Strength	12.94	Low	Yes	No
4		XZ	PF	CTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P52000-XZ-FHT-11-CTD-PF-1	Strength	39.08	High	Yes	No
5				RTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P35392-XZ-FHT-13-RTD-PF-SP	Strength	28.04	Low	No	Yes
6				RTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P39984-XZ-FHT-11-RTD-PF-1	Strength	36.60	Low	Yes	No
7	CLC	XY	PF	CTD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P58774-XY-CLC-12-CTD-PF-2	Strength	19.25	Low	Yes	Yes
8				ETW	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P31697-XY-CLC-11-ETW-PF-1	Compressive Strength	13.72	High	Yes	No
9		XZ	PF	CTD	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P31428-XZ-CLC-12-CTD-PF-2	Compressive Strength	25.79	High	Yes	No
10				CTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P36133-XZ-CLC-12-CTD-PF-2	Compressive Strength	26.27	High	Yes	No
11				RTD	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P31785-XZ-CLC-13-RTD-PF-SP	Compressive Strength	20.81	High	Yes	No
12				RTD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P33155-XZ-CLC-13-RTD-PF-1	Compressive Strength	21.34	High	Yes	No
13				RTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P35266-XZ-CLC-13-RTD-PF-SP	Compressive Strength	23.00	High	Yes	No
14		ZX	PF	ETD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P40434-ZX-CLC-12-ETD-PF-2	Compressive Strength	9.601	High	Yes	Yes
15			NF	ETD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P59497-ZX-CLC-12-ETD-NF-2	0.2% Offset Strength	1.625	High	Yes	No
16	Tension	ZX	NF	RTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P63506-ZX-T-13-RTD-NF-3	Tensile Strength	2.532	Low	Yes	No
17		XY	PF	ETW	3	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M2-P35422-XY-T-11-ETW-PF-1	Tensile Strength	24.140	Low	No	Yes
18				ETD	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P46114-XY-T-12-ETD-PF-2	Tensile Strength	32.79	High	Yes	No
19		XZ	PF	ETD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P41419-XZ-T-11-ETD-PF-1	Tensile Strength	34.37	High	Yes	No
20				ETW	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P41450-XZ-T-11-ETW-PF-1	Tensile Strength	23.10	High	Yes	No
21	Flex	ZX	NF	ETW	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P61255-ZX-F-11-ETW-NF-1	2% Offset Yield Strength	0.7894	High	Yes	No
22				ETW	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P63352-ZX-F-11-ETW-NF-1	2% Offset Yield Strength	0.6309	Low	Yes	No
23		XY	PF	ETD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P58774-XY-F-11-ETD-PF-1	Strength	21.37	Low	No	Yes
24				ETD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P58774-XY-F-11-ETD-PF-1	2% Offset Yield Strength	11.14	Low	Yes	Yes
25				ETW	1	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M1-P31153-XY-F-12-ETW-PF-2	2% Offset Yield Strength	5.296	Low	Yes	No
26		XZ	PF	CTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P58165-XZ-F-12-CTD-PF-2	2% Offset Yield Strength	38.98	High	No	Yes
27				RTD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P33716-XZ-F-12-RTD-PF-2	Strength	25.60	Low	Yes	No
28	SSB	ZX	NF	ETW	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P62411-ZX-SSB-12-ETW-NF-2	Ultimate Bearing Strength	3.772	Low	No	Yes
29				ETW	1	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M1-P61817-ZX-SSB-11-ETW-NF-1	Ultimate Bearing Strength	5.166	High	Yes	No
30				ETW	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P61818-ZX-SSB-11-ETW-NF-1	Ultimate Bearing Strength	4.718	Low	Yes	No
31				ETW	3	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M2-P65831-ZX-SSB-11-ETW-NF-1	2% Offset Bearing Strength	3.336	High	Yes	No
32				RTD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P66639-ZX-SSB-13-RTD-NF-3	Bearing Stiffness	0.1061	High	Yes	No
33				ETW	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P65365-ZX-SSB-11-ETW-NF-1	Bearing Stiffness	0.02463	Low	Yes	No
34		XY	PF	CTD	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P46125-XY-SSB-11-CTD-PF-1	Ultimate Bearing Strength	51.16	High	Yes	No
35				RTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P41201-XY-SSB-11-RTD-PF-1	Ultimate Bearing Strength	30.03	Low	Yes	No
36				CTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P41201-XY-SSB-12-CTD-PF-2	Bearing Stiffness	0.3761	High	Yes	No
37				RTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P48475-XY-SSB-13-RTD-PF-3	Bearing Stiffness	0.4460	High	Yes	No
38			FF	RTD	1	4	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M4-P41915-XY-SSB-13-RTD-FF-3	2% Offset Bearing Strength	49.81	Low	Yes	No
39		XZ	PF	ETW	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P48475-XZ-SSB-12-ETW-PF-2	2% Offset Bearing Strength	4.932	High	Yes	No
40				CTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P39984-XZ-SSB-13-CTD-PF-3	Bearing Stiffness	0.4818	High	No	Yes
41				CTD	2	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M1-P41167-XZ-SSB-11-CTD-PF-1	Bearing Stiffness	0.4331	High	Yes	No
42				CTD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P56877-XZ-SSB-13-CTD-PF-3	Bearing Stiffness	0.3404	Low	Yes	No
43				RTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P39984-XZ-SSB-12-RTD-PF-2	Bearing Stiffness	0.1678	High	Yes	No
44				ETW	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P42570-XZ-SSB-13-ETW-PF-3	Bearing Stiffness	0.03355	Low	Yes	No
45				ETW	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P56877-XZ-SSB-11-ETW-PF-1	Bearing Stiffness	0.08427	Low	Yes	No
46	IPS	XY	FF	RTD	1	4	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M4-P42161-XY-IPS-13-RTD-FF-3	0.2% Offset Shear Strength	2.956	Low	Yes	No
47			PF	ETW	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P30351-XY-IPS-12-ETW-PF-2	5% Offset Shear Strength	0.5229	Low	No	Yes
48								0.2% Offset Shear Strength	0.2437	Low	No	Yes
49				ETW	3	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M2-P35359-XY-IPS-11-ETW-PF-1	0.2% Offset Shear Strength	0.6131	Low	Yes	No
50				ETW	1	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M1-P30602-XY-IPS-13-ETW-PF-3	5% Offset Shear Strength	0.9121	Low	Yes	No
51				CTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P32235-XY-IPS-12-CTD-PF-2	Maximum Shear Strength	5.958	Low	Yes	No
52				ETD	1	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M2-P42916-XY-IPS-11-ETD-PF-1	Maximum Shear Strength	3.755	High	Yes	No
53				ETD	3	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M1-P48076-XY-IPS-13-ETD-PF-3	Maximum Shear Strength	2.648	Low	Yes	No
54	OHT	XY	PF	CTD	1	1	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-A-M1-P30189-XY-OHT-13-CTD-PF-3	Strength	10.21	Low	Yes	No
55		XZ	PF	RTD	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P33809-XZ-OHT-11-RTD-PF-1	Strength	18.38	Low	No	Yes
56				ETW	2	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-B-M2-P56729-XZ-OHT-13-ETW-PF-3	Strength	16.84	Low	Yes	No
57				ETW	3	2	NTPAM6754Q1-MFD-OFRA-CFRA-MFD-C-M2-P50838-XZ-OHT-11-ETW-PF-1	Strength	33.03	High	Yes	No

Table 5-1: List of Outliers

6. References

1. Snedecor, G.W. and Cochran, W.G., *Statistical Methods*, 7th ed., The Iowa State University Press, 1980, pp. 252-253.
2. Stefansky, W., "Rejecting Outliers in Factorial Designs," *Technometrics*, Vol. 14, 1972, pp. 469-479.
3. Scholz, F.W. and Stephens, M.A., "K-Sample Anderson-Darling Tests of Fit," *Journal of the American Statistical Association*, Vol. 82, 1987, pp. 918-924.
4. Lehmann, E.L., *Testing Statistical Hypotheses*, John Wiley & Sons, 1959, pp. 274-275.
5. Levene, H., "Robust Tests for Equality of Variances," in *Contributions to Probability and Statistics*, ed. I. Olkin, Palo, Alto, CA: Stanford University Press, 1960.
6. Lawless, J.F., *Statistical Models and Methods for Lifetime Data*, John Wiley & Sons, 1982, pp. 150, 452-460.
7. *Metallic Materials and Elements for Aerospace Vehicle Structures*, MIL-HDBK-5E, Naval Publications and Forms Center, Philadelphia, Pennsylvania, 1 June 1987, pp. 9-166,9-167.
8. Hanson, D.L. and Koopmans, L.H., "Tolerance Limits for the Class of Distribution with Increasing Hazard Rates," *Annals of Math. Stat.*, Vol 35, 1964, pp. 1561-1570.
9. Vangel, M.G., "One-Sided Nonparametric Tolerance Limits," *Communications in Statistics: Simulation and Computation*, Vol. 23, 1994, p. 1137.
10. Vangel, M.G., "New Methods for One-Sided Tolerance Limits for a One-Way Balanced Random Effects ANOVA Model," *Technometrics*, Vol 34, 1992, pp. 176-185.
11. Odeh, R.E. and Owen, D.B., *Tables of Normal Tolerance Limits, Sampling Plans and Screening*, Marcel Dekker, 1980.
12. Tomblin, John and Seneviratne, Waruna, *Laminate Statistical Allowable Generation for Fiber-Reinforced Composites Material: Lamina Variability Method*, U.S. Department of Transportation, Federal Aviation Administration, May 2006.
13. Tomblin, John, Ng, Yeow and Raju, K. Suresh, *Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure*, U.S. Department of Transportation, Federal Aviation Administration, September 2003.
14. CMH-17 Rev G, Volume 1, 2012. SAE International, 400 Commonwealth Drive, Warrendale, PA 15096