# Stratasys Certified ULTEM™ 9085 Fortus 900mc Additively Manufactured Polymer Material Qualification Statistical Analysis Report

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## Elizabeth Clarkson, Ph.D.

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


## Testing Facility:

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

## Fabrication Facility:

RP+M
33490 Pin Oak Pkwy
Avon Lake, OH 44012

**Prepared by:** Dr. Elizabeth Clarkson

Digitally signed by Dr. Elizabeth Clarkson
DN: cn=Dr. Elizabeth Clarkson, o=Wichita State University, ou=NCAMP, email=bclarkson@niar.wichita.edu, c=US
Date: 2019.06.14 13:23:02 -05'00'

**Elizabeth Clarkson**

**Reviewed by:** Evelyn Lian

Digitally signed by Evelyn Lian
DN: cn=Evelyn Lian, o=NIAR/NCAMP, ou=NIAR/NCAMP, email=evelyn@niar.wichita.edu, c=US
Date: 2019.06.17 09:16:04 -05'00'

**Evelyn Lian**

Jonathan Tisack

Digitally signed by Jonathan Tisack
DN: cn=Jonathan Tisack, o=NIAR, ou=NCAMP, email=jtisack@niar.wichita.edu, c=US
Date: 2019.06.14 18:49:11 -05'00'

**Jonathan Tisack**

Michelle Man

Digitally signed by Michelle Man
DN: cn=Michelle Man, o=NIAR, ou=NCAMP, email=kxman@niar.wichita.edu, c=US
Date: 2019.06.20 09:16:21 -05'00'

**Michelle Man**

**Approved by:** Royal Lovingfoss

Digitally signed by Royal Lovingfoss
DN: cn=Royal Lovingfoss, o=NIAR, ou=NCAMP, email=rlovingfoss@niar.wichita.edu, c=US
Date: 2019.06.14 18:36:01 -05'00'

**Royal Lovingfoss**

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| A | Elizabeth Clarkson | 06/17/2019 | Royal Lovingfoss | OHC and FHC Basis values were removed due to inappropriate test method. Table 3-1 was updated. Clarification has been added to the affected sections in Section 4.7(OHC) and 4.8 (FHC). |
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Table of Contents

# List of Figures

# List of Tables

# 1. Introduction

This report contains statistical analysis of the Stratasys Certified ULTEM™ 9085 / Fortus 900mc material property data published in NCAMP Test Report CAM-RP-2018-013 Rev N/C. The material property data have been generated with NCAMP oversight in accordance with NCAMP Standard Operating Procedures NSP 100; the 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 orientation, 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 085/1 Rev IR dated April 12, 2019. The qualification test coupons were manufactured in accordance with NCAMP Process Specification NPS 89085 Rev C dated April 12, 2019. The NCAMP Test Plan NTP AM-P-001 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-HDBK-17 and are statistically valid regardless of the material type.

When appropriate, in addition to the traditional computational methods, values computed using the modified coefficient of variation method developed for carbon fiber composites are also provided. While this approach is included in CMH-17-1G, it has not yet been evaluated for use with additive manufacturing materials.

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, laminate architecture, and loading situations that individual projects need may require additional testing.

The use of NCAMP material and process specifications do not guarantee material or structural performance. Material users should be actively involved in evaluating material performance and quality including, but not limited to, performing regular purchaser quality control tests, performing periodic equivalency/additional testing, participating in material change management activities, conducting statistical process control, and conducting regular supplier audits.

The applicability and accuracy of NCAMP material property data, material allowables, and specifications must be evaluated on case-by-case basis by aircraft companies and certifying agencies. NCAMP assumes no liability whatsoever, expressed or implied, related to the use of the material property data, material allowables, and specifications.

Part fabricators that wish to utilize the material property data, allowables, and specifications may be able to do so by demonstrating the capability to reproduce the original material properties; a process known as equivalency. More information about this equivalency process including the test statistics and its limitations can be found in Section 6 of DOT/FAA/AR-03/19 and Section 8.4.1 of CMH-17-1G. 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 085/1. NMS 085/1 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 085/1. NMS 085/1 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.

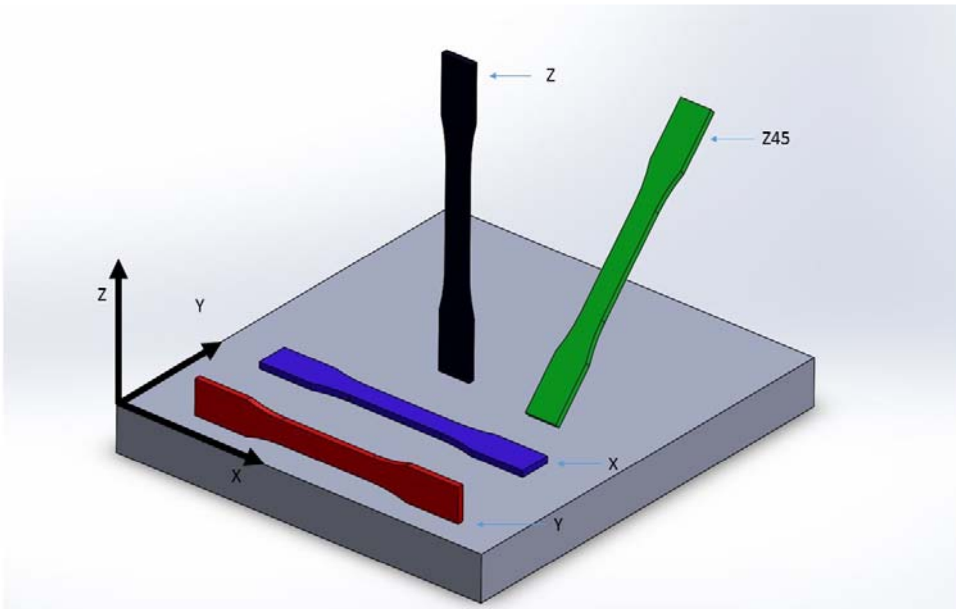



**Figure 1-1: Specimen Orientation Diagram**
(Note that: X=XY, Y=XZ, Z=ZX, Z45=ZX-45, in the two-letter nomenclature for AM)

- Batch
    - **Raw Resin Batch:** *Total quantity of a unique batch identifier as defined by original resin manufacturer.*
    - **Filament Lot:** *The quantity of consumables manufactured at one time to a single set of defined properties using a single raw resin batch.*
    - **Filament Extrusion Line:** *One dedicated manufacturing line that takes raw resin batches and extrudes them into filament lots through a controlled process. Multiple lines may be in use at one location, but they are independent of each other.*
- Machine: A single manufacturing device that prints the test coupons from the raw resin mixed with filament.

## 1.2 Symbols and Abbreviations

| | |
|---|---|
| XT: X Tension | XOHT: X Open Hole Tension |
| YT: Y Tension | YOHT: Y Open Hole Tension |
| ZT: Z Tension | ZOHT: Z Open Hole Tension |
| Z45T: Z (45) Tension | Z45OHT: Z (45) Open Hole Tension |
| XC: X Compression | XFHT: X Filled Hole Tension |
| YC: Y Compression | YFHT: Y Filled Hole Tension |
| ZC: Z Compression | ZFHT: Z Filled Hole Tension |
| Z45C: Z (45) Compression | Z45FHT: Z (45) Filled Hole Tension |
| XF: X Flex | XVIPS: X Vnotch IPS |
| YF: Y Flex | XOHC: X Open Hole Compression |
| ZF: Z Flex | YOHC: Y Open Hole Compression |
| Z45F: Z (45) Flex | ZOHC: Z Open Hole Compression |
| XFHC: X Filled Hole Compression | Z45OHC: Z (45) Open Hole Compression |
| YFHC: Y Filled Hole Compression | XSSB: X Single Shear Bearing |
| ZFHC: Z Filled Hole Compression | YSSB: Y Single Shear Bearing |
| Z45FHC: Z (45) Filled Hole Compression | ZSSB: Z Single Shear Bearing |
| | Z45SSB: Z (45) Single Shear Bearing |

X,Y,Z and Z45 indicate the build orientation used

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

| Environmental Condition | Abbreviation | Temperature |
|---|---|---|
| Cold Temperature Dry | CTD | −65˚F |
| Room Temperature Dry | RTD | 70˚F |
| Room Temperature Wet | RTW | 70˚F |
| Elevated Temperature Dry | ETD1 | 180˚F |
| Elevated Temperature Wet | ETW1 | 180˚F |

**Table 1-2: Environmental Conditions Abbreviations**

Detailed information about the test methods and conditions used is given in NCAMP Test Report CAM-RP-2018-013.

## 1.3 Pooling Across Environments

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

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

## 1.4 Basis Value Computational Process

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

## 1.5 Modified Coefficient of Variation (CV) Method

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

The modified Coefficient of Variation (CV) used in this report is in accordance with section 8.4.4 of CMH-17-1G. It is a method of adjusting the original basis values downward in anticipation of the expected additional variation. Composite materials are expected to have a CV of at least 6%. The modified coefficient of variation (CV) method increases the measured coefficient of variation when it is below 8% prior to computing basis values. A higher CV will result in lower or more conservative basis values and lower specification limits. The use of the modified CV method is intended for a temporary period of time when there is minimal data available. When a sufficient number of production batches (approximately 8 to 15) have been produced and tested, the as-measured CV may be used so that the basis values and specification limits may be adjusted higher.

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

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

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

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

# 2. Background

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

## 2.1 CMH17 STATS Statistical Formulas and Computations

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

### 2.1.1 Basic Descriptive Statistics

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

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

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

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

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

### 2.1.2 Statistics for Pooled Data

Prior to computing statistics for the pooled 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.:** $$S_p = \sqrt{\frac{\sum_{i=1}^{k} \left( n_i - 1 \right) S_i^2}{\sum_{i=1}^{k} \left( n_i - 1 \right)}}$$ **Equation 4**

Where $k$ refers to the number of batches, $S_i$ 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.

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

### 2.1.3 Basis Value Computations

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

**Basis Values:**

$$A-basis = \bar{X} - K_a S$$
$$B-basis = \bar{X} - K_b S \qquad \textbf{Equation 6}$$

#### 2.1.3.1 K-factor computations

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

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

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

Where

r = the number of environments being pooled together

$n_j$ = number of data values for environment j

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

$$f = N - r$$

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

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

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

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

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

### 2.1.4 Modified Coefficient of Variation

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

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

This is converted to percent by multiplying by 100%.

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

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

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

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

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

#### 2.1.4.1 Transformation of data based on Modified CV

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

To accomplish this requires a transformation in two steps:

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

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

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

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

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

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

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

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

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

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

### 2.1.5 Determination of Outliers

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

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

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

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

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

### 2.1.6 The k-Sample Anderson Darling Test for Batch Equivalency

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

The k-sample Anderson-Darling test statistic is:

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

Where

$n_i$ = the number of test specimens in each batch

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

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

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

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

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

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

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

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

With

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

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

### 2.1.7 The Anderson Darling Test for Normality

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

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

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

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

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

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

The Anderson Darling test statistic (AD) is:

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

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

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

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

### 2.1.8 Levene's Test for Equality of Coefficient of Variation

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

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

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

### 2.1.9 Distribution Tests

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

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

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

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

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

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

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

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

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

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

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

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

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

#### 2.1.9.3 Two-parameter Weibull Distribution

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

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

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

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

##### 2.1.9.3.1 Estimating Weibull Parameters

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

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

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

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

#### 2.1.9.3.2 Goodness-of-fit test for the Weibull distribution

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

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

The Anderson-Darling test statistic is

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

and the observed significance level is

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

where

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

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

#### 2.1.9.3.3 Basis value calculations for the Weibull distribution

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

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

where

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

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

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

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

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

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

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

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

**Table 2-1: Weibull Distribution Basis Value Factors**

### 2.1.9.4 Lognormal Distribution

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

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

#### 2.1.9.4.1 Goodness-of-fit test for the Lognormal distribution

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

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

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

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

#### 2.1.9.4.2 Basis value calculations for the Lognormal distribution

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

### 2.1.10 Non-parametric Basis Values

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

#### 2.1.10.1 Non-parametric Basis Values for large samples

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

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

For B-basis values:

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

For A-Basis values:

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

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

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

### 2.1.10.2 Non-parametric Basis Values for small samples

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

The Hanson-Koopmans B-basis value is:

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

The A-basis value is:

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

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

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

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

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

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

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

### 2.1.11 Analysis of Variance (ANOVA) Basis Values

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

#### 2.1.11.1 Calculation of basis values using ANOVA

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

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

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

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

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

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

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

Next, the mean sums of squares are computed:

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

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

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

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

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

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

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

Denote the ratio of mean squares by

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

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

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

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

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

## 2.2 Single Batch and Two Batch Estimates using Modified CV

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

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

# 3. Summary of Results

The B-basis values and estimates for all tests are summarized in the following tables. The summary tables given in each individual section provide a complete listing of all computed basis values and estimates of basis values. Modified CV basis values were not included in the summary tables because the modified CV method has not yet been approved for use with additive materials. The results for the CTD, RTD and ETW1 conditions are shown in Table 3-1. Data that does not meet the requirements of CMH-17-1G are shown in shaded boxes and labeled as estimates.

**Additively Manufactured Material:** Stratasys Certified ULTEM™ 9085 / Fortus 900mc
**Material Specification:** NMS 085/1
**Process Specification:** NPS 89085

**Stratasys Certified ULTEM™ 9085 / Fortus 900mc -45/45 Properties Summary**

**Tg(dry):** 353.51 °F **Tg(wet):** 349.41 °F **Tg METHOD:** ASTM D7028

**Date of raw material manufacture:** Aug 2015, Mar 2016, Sept 2016
**Date of filament manufacture:** Mar 2016, Dec 2016, Feb 2017
**Date of Coupon manufacture:** Mar 2017 - Aug 2018
**Date of testing:** Aug 2017 - Feb 2019
**Date of data submittal:** Feb 2019

| The lowest B-basis value for each property in each condition is bolded. Shaded gray indicates B-Estimate | | CTD | | | | RTD | | | | ETW1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X Direction | Y Direction | Z Direction | Z45 Direction | X Direction | Y Direction | Z Direction | Z45 Direction | X Direction | Y Direction | Z Direction | Z45 Direction |
| Dogbone Tension | 0.2% Offset Yield Mean [ksi] | 6.714 | 7.792 | 6.804 | 6.606 | 5.544 | 6.561 | 5.540 | 5.367 | 4.675 | 5.698 | 4.612 | 4.513 |
| | 0.2% Offset Yield B-Basis [ksi] | 5.398 | 6.868 | 6.066 | **5.149** | 4.865 | 5.648 | 5.283 | **4.823** | 4.145 | 4.995 | 4.144 | **3.917** |
| | Strength Mean [ksi] | 12.965 | 13.594 | 10.720 | 9.768 | 9.728 | 11.183 | 8.550 | 7.957 | 6.754 | 7.707 | 5.416 | 5.795 |
| | Strength B-Basis [ksi] | 11.733 | 11.879 | 9.374 | **8.648** | 8.827 | 9.977 | 8.214 | **6.802** | 5.865 | 7.242 | **4.784** | 5.188 |
| | Modulus Mean [Msi] | 0.388 | 0.433 | 0.394 | 0.387 | 0.337 | 0.377 | 0.347 | 0.341 | 0.302 | 0.339 | 0.307 | 0.311 |
| Dogbone Compression | 0.2% Offset Mean [ksi] | 10.022 | 11.827 | 11.357 | 11.035 | 8.048 | 11.343 | 9.183 | 8.935 | 8.721 | 9.884 | 9.582 | 8.168 |
| | 0.2% Offset B-Basis [ksi] | **7.038** | 9.580 | 10.388 | 9.172 | **6.871** | 9.097 | 8.214 | 7.072 | 6.678 | **5.705** | 5.997 | 4.493 |
| | 1.0% Offset Mean [ksi] | 15.472 | 18.647 | 17.862 | 16.611 | 12.253 | 16.695 | 13.515 | 13.015 | 11.816 | 12.925 | 11.989 | 11.010 |
| | 1.0% Offset B-Basis [ksi] | **12.750** | 16.405 | 16.709 | 15.397 | **10.400** | 14.452 | 12.843 | 11.802 | 9.265 | 7.805 | 9.001 | **6.128** |
| | Modulus Mean [Msi] | 0.398 | 0.443 | 0.421 | 0.392 | 0.385 | 0.430 | 0.377 | 0.364 | 0.426 | 0.418 | 0.380 | 0.373 |
| Flex | Strength Mean [ksi] | 21.693 | 24.300 | 15.695 | 14.321 | 16.725 | 18.943 | 13.133 | 12.452 | 12.955 | 14.575 | 9.545 | 9.951 |
| | Strength B-Basis [ksi] | 19.104 | 23.078 | **10.250** | 11.926 | 16.205 | 17.855 | **8.331** | 10.455 | 11.337 | 12.803 | **5.986** | 8.476 |
| | Modulus Mean [Msi] | 0.406 | 0.421 | 0.374 | 0.360 | 0.353 | 0.382 | 0.333 | 0.314 | 0.326 | 0.360 | 0.302 | 0.282 |
| V-Notch | 0.2% Offset Mean[ksi] | 4.710 | -- | -- | -- | 3.506 | -- | -- | -- | 2.841 | -- | -- | -- |
| | 0.2% Offset B-Basis [ksi] | **3.753** | | | | **3.208** | | | | **2.543** | | | |
| | Strength at 5% Strain Mean [ksi] | 6.693 | -- | -- | -- | 5.629 | -- | -- | -- | 4.743 | -- | -- | -- |
| | Strength at 5% Strain B-Basis [ksi] | **6.360** | | | | **5.143** | | | | **4.534** | | | |
| | Ultimate Strength Mean [ksi] | 5.679 | -- | -- | -- | 4.820 | -- | -- | -- | -- | -- | -- | -- |
| | Ultimate Strength B-Basis [ksi] | **4.797** | | | | **3.922** | | | | | | | |
| | Modulus Mean [Msi] | 0.152 | -- | -- | -- | 0.136 | -- | -- | -- | 0.126 | -- | -- | -- |
| OHT | Strength Mean [ksi] | 8.327 | 8.399 | 4.487 | 5.737 | 6.556 | 8.877 | 4.199 | 5.075 | 4.638 | 6.236 | 2.842 | 3.946 |
| | Strength B-Basis [ksi] | 7.901 | 5.952 | 3.744 | **3.344** | 5.777 | 8.098 | **3.209** | 4.482 | 4.259 | 5.729 | **1.887** | 3.280 |
| FHT | Strength Mean [ksi] | 10.075 | 13.179 | 8.772 | 8.194 | 7.413 | 10.052 | 7.298 | 6.629 | 5.277 | 6.818 | 4.595 | 5.054 |
| | Strength B-Basis [ksi] | 9.002 | 10.513 | **5.469** | 6.543 | 7.059 | 9.564 | 6.794 | **5.768** | 4.913 | 6.330 | **3.810** | 4.334 |
| SSB | 2% Offset Mean [ksi] | -- | -- | -- | -- | 14.562 | 14.770 | 12.629 | 15.467 | 11.914 | 12.397 | 12.398 | 12.395 |
| | 2% Offset B-Basis [ksi] | | | | | 11.835 | 7.618 | 8.504 | **6.394** | 9.187 | **7.667** | 10.415 | 8.960 |
| | Ultimate Strength Mean [ksi] | -- | -- | -- | -- | 29.491 | 28.505 | 22.451 | 27.079 | 22.235 | 21.991 | 18.874 | 21.421 |
| | Ultimate Strength B-Basis [ksi] | | | | | 26.937 | 25.488 | **19.252** | 24.032 | 20.045 | 19.155 | **14.762** | 18.980 |

**Table 3-1: Summary of Test Results for CTD, RTD and ETW1 Data**

The results for the RTW and ETD1 conditions do not meet the requirements of CMH-17-1G and are labeled B-estimates rather than B-basis. They are shown in Table 3-2. Means of all strength properties are graphed in Figure 3-1.

**Additively Manufactured Material:** Stratasys Certified ULTEM™ 9085 / Fortus 900mc
**Material Specification:** NMS 085/1
**Process Specification:** NPS 89085

**Stratasys Certified ULTEM™ 9085 / Fortus 900mc**
**-45/45**
**Properties Summary**

**Tg(dry):** 353.51 °F **Tg(wet):** 349.41 °F **Tg METHOD:** ASTM D7028

| | | | |
|---|---|---|---|
| **Date of raw material manufacture:** | Aug 2015, Mar 2016, Sept 2016 | **Date of testing:** | Aug 2017 - Feb 2019 |
| **Date of filament manufacture:** | Mar 2016, Dec 2016, Feb 2017 | **Date of data submittal:** | Feb 2019 |
| **Date of Coupon manufacture:** | Mar 2017 - Aug 2018 | | |

| The lowest B-basis value for each property in each condition is bolded. Shaded gray indicates B-Estimate | | RTW | | | | ETD1 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | X Direction | Y Direction | Z Direction | Z45 Direction | X Direction | Y Direction | Z Direction | Z45 Direction |
| Dogbone Tension | 0.2% Offset Yield Mean [ksi] | 5.461 | 6.739 | 6.270 | 5.692 | -- | -- | -- | -- |
| | 0.2% Offset Yield B-Basis [ksi] | **1.382** | 6.124 | 5.126 | 4.499 | | | | |
| | Strength Mean [ksi] | 9.406 | 10.937 | 7.876 | 8.307 | -- | -- | -- | -- |
| | Strength B-Basis [ksi] | **0.188** | 9.870 | 6.483 | 2.074 | | | | |
| | Modulus Mean [Msi] | 0.330 | 0.376 | 0.359 | 0.349 | -- | -- | -- | -- |
| Dogbone Compression | 0.2% Offset Mean [ksi] | 7.560 | 9.532 | 8.910 | 8.030 | 7.952 | 10.866 | 8.573 | 7.478 |
| | 0.2% Offset B-Basis [ksi] | 6.011 | **7.521** | 6.788 | 6.643 | 6.853 | 8.467 | 7.474 | **6.124** |
| | 1.0% Offset Mean [ksi] | 12.237 | 13.904 | 12.775 | 12.185 | 10.520 | 14.113 | 11.210 | 9.941 |
| | 1.0% Offset B-Basis [ksi] | 10.312 | 11.007 | 10.866 | **9.665** | 9.044 | 12.210 | 10.355 | **8.735** |
| | Modulus Mean [Msi] | 0.428 | 0.407 | 0.373 | 0.373 | 0.355 | 0.400 | 0.349 | 0.331 |
| V-Notch | 0.2% Offset Mean[ksi] | 2.994 | -- | -- | -- | -- | -- | -- | -- |
| | 0.2% Offset B-Basis [ksi] | **2.656** | | | | | | | |
| | Strength at 5% Strain Mean [ksi] | 5.485 | -- | -- | -- | -- | -- | -- | -- |
| | Strength at 5% Strain B-Basis [ksi] | **5.118** | | | | | | | |
| | Modulus Mean [Msi] | 0.140 | -- | -- | -- | -- | -- | -- | -- |

**Table 3-2: Summary of Test Results for RTW and ETD1 Data**

## Trends across directions, conditions, and test properties

- A plot of all tests by is shown in Figure 3-1.
- The Y-axis results had higher strength values than the other axes for nearly all tests and conditions. The exception is SSB tests, which show the Z-axis results lower than the other axes.
- Strength is inversely related to temperature for all tested properties.
- Dry compression strength is greater than wet compression strength for all axes at room temperature but only for the Y-axis at elevated temperatures. For the 0.2% Offset Strength, the elevated temperature wet results are stronger than the room temperature wet results while the opposite relationship holds for 1.0% Offset Strength.
- Variance was larger in the CTD condition than in other conditions.

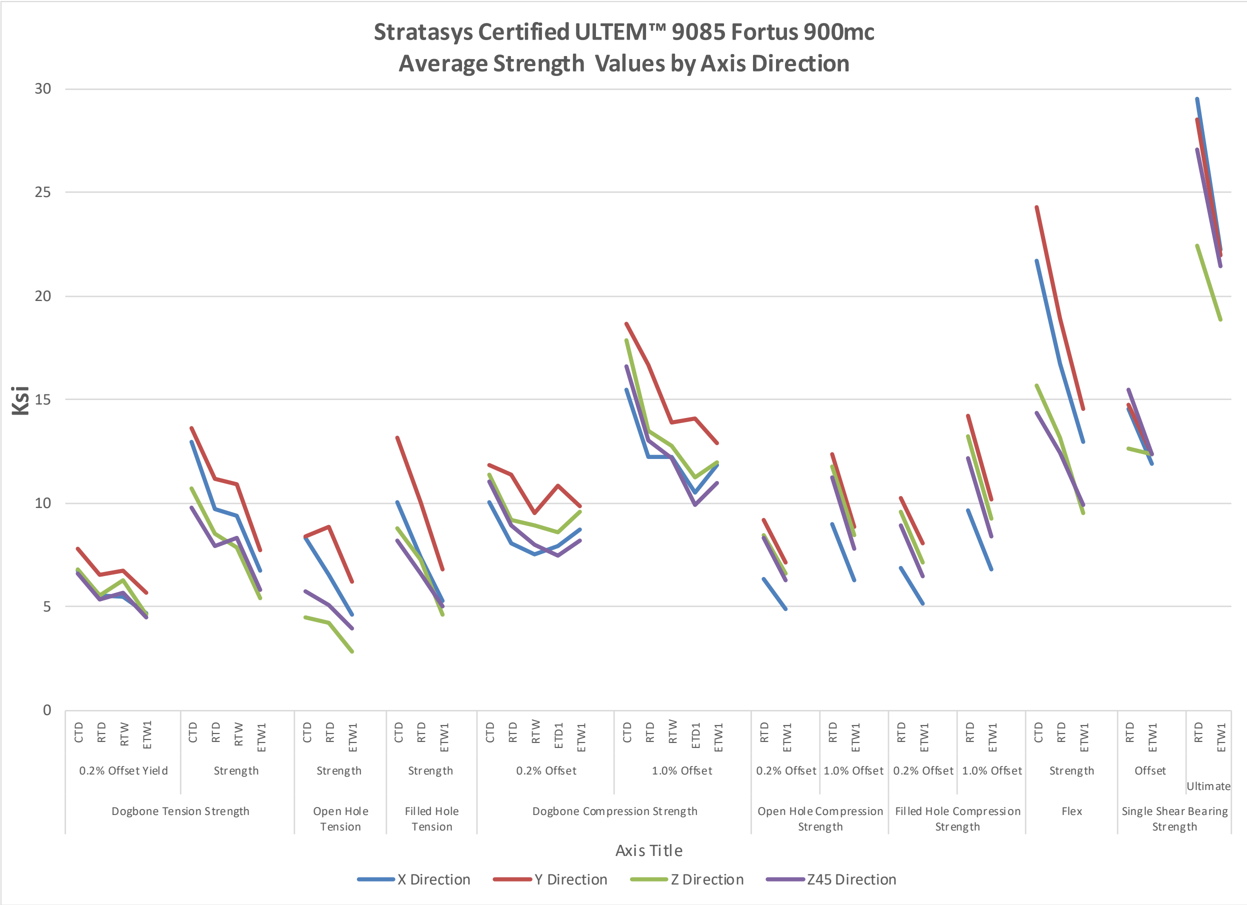



**Figure 3-1: Plot of all tested properties and conditions**

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

Test data for additively manufactured test properties were not normalized. The as-measured statistics were included in the tables, and the data values were graphed. Test failures, outliers and explanations regarding computational choices were noted in the accompanying text for each test. An ANOVA analysis was conducted to determine if the results for different axes were sufficiently similar to be combined. When appropriate, basis value results were provided for the combined axes in addition to each axis individually.

Individual specimen results were graphed for each test in a variety of ways, including by batch and axis with the recommended basis values for each environmental condition. When there are more than two properties reported for a test, scatter plots were constructed to indicate the degree of correlation between the properties.

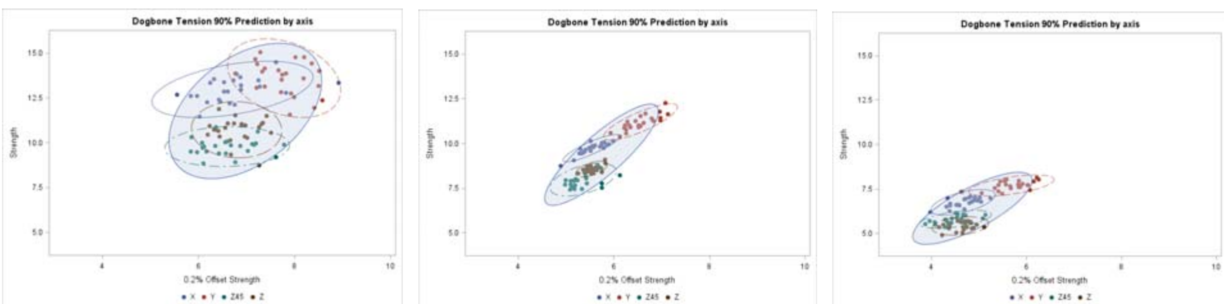
When a dataset fails the Anderson-Darling k-sample (ADK) test for batch-to-batch variation, an ANOVA analysis is required. In order for B-basis values to be computed for composite materials using the ANOVA method, CMH17 requires data from five batches. However, the definition of batches for composite materials as defined by CMH17 cannot be applied to the additive manufacturing ULTEM™ 9085 material. After examination of the data results for this report, the six combinations of two machines and three batches of raw materials were treated as six separate groups when using the ANOVA method to compute design values. Estimates of A-basis values are provided, but with the small datasets (24 specimens), these values should be considered estimates only.

The modified CV method as developed for composite materials was applied to these results but further research and investigation regarding the suitability of this approach to additive manufacturing is needed. The ADK test was performed again after a transformation of the data according to the assumptions of the modified CV method (see section 2.1.4 for details). If the dataset passes the ADK test and normality tests at this point basis values were also computed using the modified CV method.

## 4.1 Dogbone Tension (DT)

Dogbone Tension tests reported three properties: 0.2% Offset Yield Strength, Strength and Modulus. Tests were performed in four conditions: CTD, RTD, RTW and ETW1. The RTW condition tests were limited to eight specimens from batch three only, four from each of two machines. Only estimates of basis values are provided for the RTW condition due to the small sample size. The ETW1 test results show the lowest strength values and variation of all tested conditions.

Scatter plots of the test results for the two properties for the CTD, RTD and ETW1 conditions with 90% prediction ellipses for each axis are shown in Figure 4-1. The Strength and 0.2% Offset Yield Strength measurements were highly correlated. The correlations computed by specimen for each axis and condition tested are shown in Table 4-1. There were strong correlations. The correlations between 0.2% Offset Yield Strength and Strength were high in the X and Y directions for all four conditions tested, and weaker for the Z and Z45 directions. A box plot of the dogbone tension strength measurements by axis and condition is shown in Figure 4-2.




CTD RTD ETW1

**Figure 4-1: Scatter Plots of DT Strength Properties by Condition and Axis**

| Pearson Correlation Coefficients – 0.2% Offset Yield Strength with Strength | | | | | |
|---|---|---|---|---|---|
| | X | Y | Z | Z45 | All |
| CTD | 0.4458 | -0.3136 | -0.0417 | 0.0692 | 0.4401 |
| RTD | 0.8778 | 0.8234 | 0.5738 | 0.5084 | 0.8583 |
| RTW | 0.9713 | 0.6391 | 0.2499 | 0.6778 | 0.4579 |
| ETW1 | 0.5933 | 0.5628 | 0.2506 | 0.5108 | 0.7768 |
| ALL | 0.9066 | 0.8639 | 0.8875 | 0.8917 | 0.8614 |

**Table 4-1: Correlation Statistics for Dogbone Tension Strength Data**

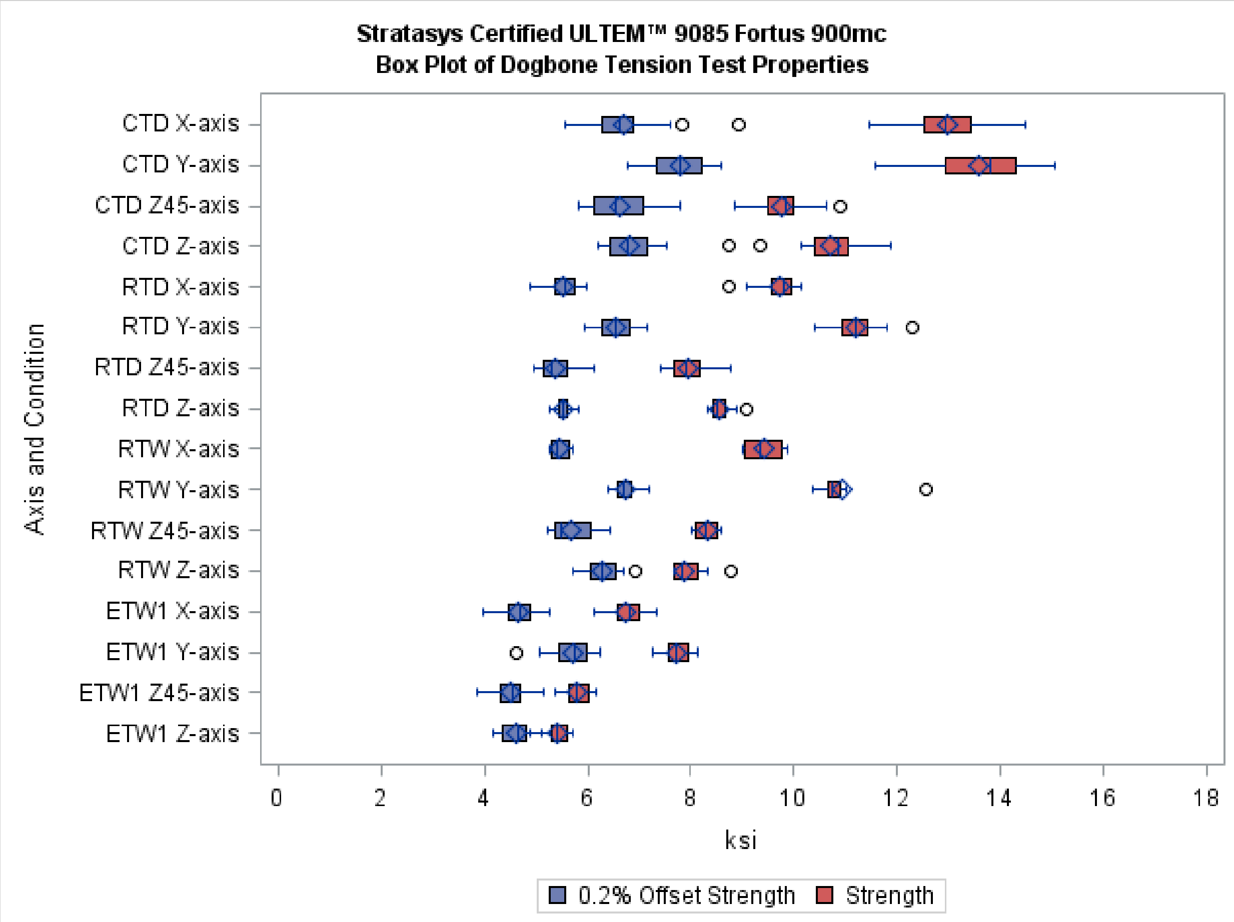



**Figure 4-2: Box Plots of Dogbone Tension Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. The strength measurements were all statistically significantly different with each axis requiring separate analyses in each condition. The Y-axis measurements for 0.2% Offset Yield Strength were significantly different from the other three axes in all conditions. For the 0.2% Offset Yield Strength measurement the X, Z45 and Z-axes measurements could be combined for the CTD and ETW1 conditions while the X could be combined with the Z-axis for the RTD condition.

Each batch and machine combination was considered a separate grouping for the purpose of computing basis values by the ANOVA method.

Pooling of all four conditions was acceptable for the Y-axis. Pooling was acceptable only for the 0.2% Offset Yield Strength property modified CV basis value computations. The other axes did not meet the CMH17 requirements for pooling across conditions.

Outlier status was checked for each specimen by condition, batch, machine and the combination of batch and machine. For all of these different groupings for the two strength properties, there was a total of 15 specimens identified as outliers for one or both of those properties. Details are given in the text for each condition and all outliers are listed in Table 4-44. All outliers were retained for this analysis.

### 4.1.1 Dogbone Tension CTD Condition

The X, Z and Z45-axes could be combined to compute basis values for the 0.2% Offset Yield Strength measurements. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six batch and machine combinations for the 0.2% Offset combined X, Z, and Z45- axes and for both strength properties from the Z45-axis, so the ANOVA method was required to compute those basis values and estimates. The 0.2% Offset measurements in the X-axis, Z45-axis and the combined X, Z and Z45-axes had a CV value above 8%, so modified CV basis values could not be computed for them. The Y-axis 0.2% Offset Yield Strength datasets were pooled across conditions for the modified CV basis value computations.

The X, Y, and Z-axes data for 0.2% Offset had an adequate fit to the normal distribution to compute basis values. For the strength measurements, both the X and Y-axes had an adequate fit to the normal distribution. The Z-axis fit the Weibull distribution.

Six outliers were identified in the data from the CTD condition: three for 0.2% Offset and three for Strength. Three were for the X-axis, one for the Z45-axis, and two for the Z-axis.

For the 0.2% Offset Yield Strength property, the largest value from the X-axis batch two machine one was an outlier for the CTD condition and for the machine batch combination for the combined X, Z45 and Z-axes. The largest value from the X-axis batch two machine two was an outlier for the machine batch combination for the X-axis, but not for the combined X, Z45 and Z-axes, batch two, machine two or the CTD condition. The largest value from the Z45-axis batch one machine one was an outlier for the machine batch combination for the Z45-axis but not for the combined X, Z45 and Z-axes, batch one, machine one or the CTD condition.

For the Strength property, the lowest value from the X-axis batch one machine one was an outlier for the machine batch combination, but not for batch one, machine one, or the CTD condition. The Z-axis had two outliers, the smallest strength values in batch one machine one and batch three machine two were outliers. The Z-axis batch one machine one outlier was an outlier for machine one but not for batch one, the machine batch combination or the CTD condition. The smallest strength value in batch three on machine two was an outlier for batch three, machine two, and the CTD condition, but not for the machine batch combination.

Statistics, estimates and basis values are given for the strength data in Table 4-2 and for the modulus data in Table 4-3. The data and B-basis values are shown graphically for Strength in Figure 4-3, for 0.2% Offset Yield Strength in Figure 4-4, and for both together in Figure 4-5.

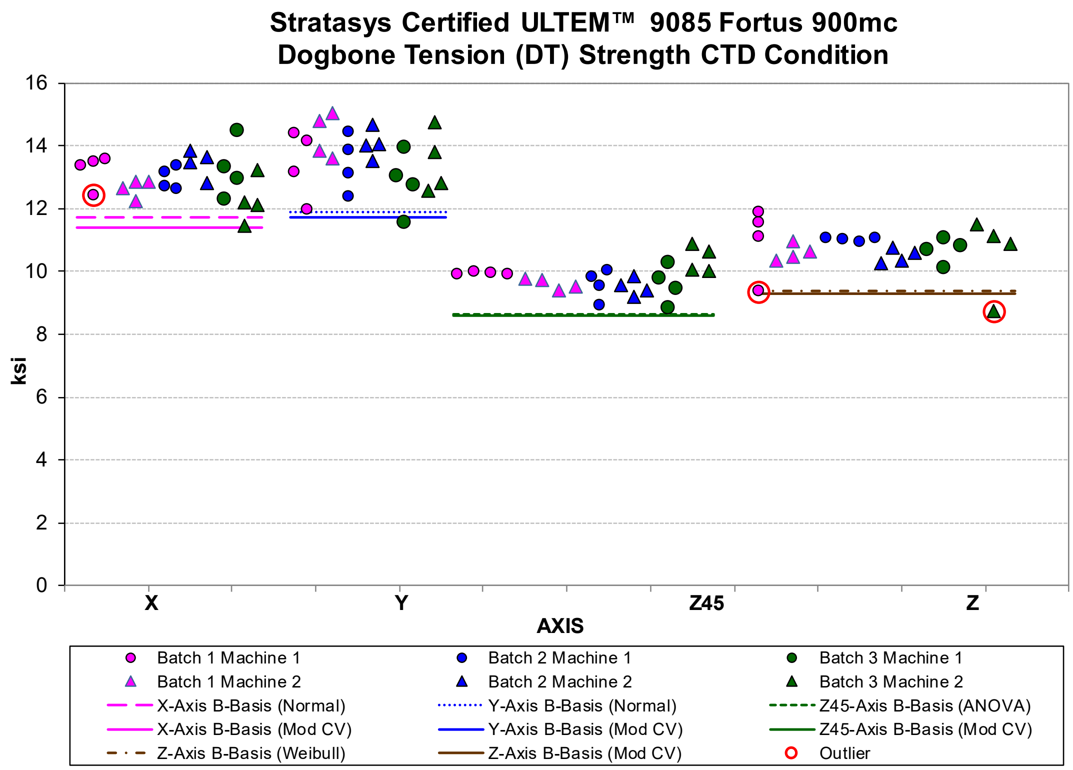



**Figure 4-3: Plot for Dogbone Tension Strength CTD Condition**

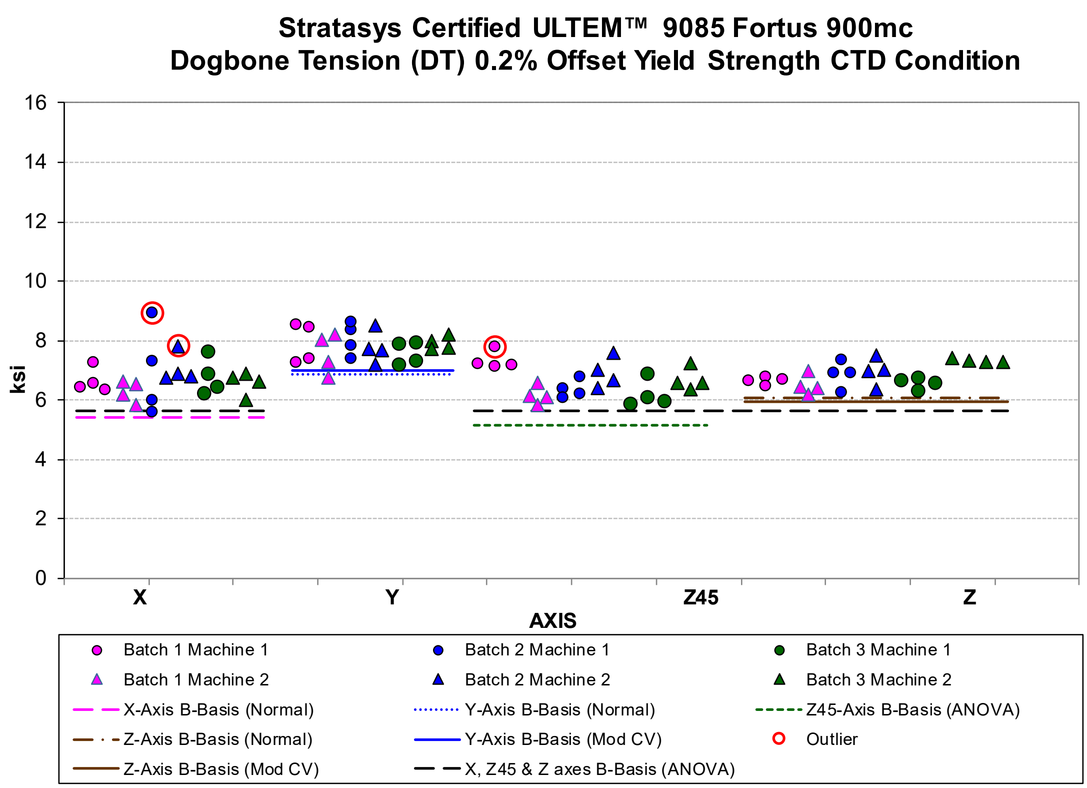



**Figure 4-4: Plot for Dogbone Tension 0.2% Offset Yield Strength CTD Condition**

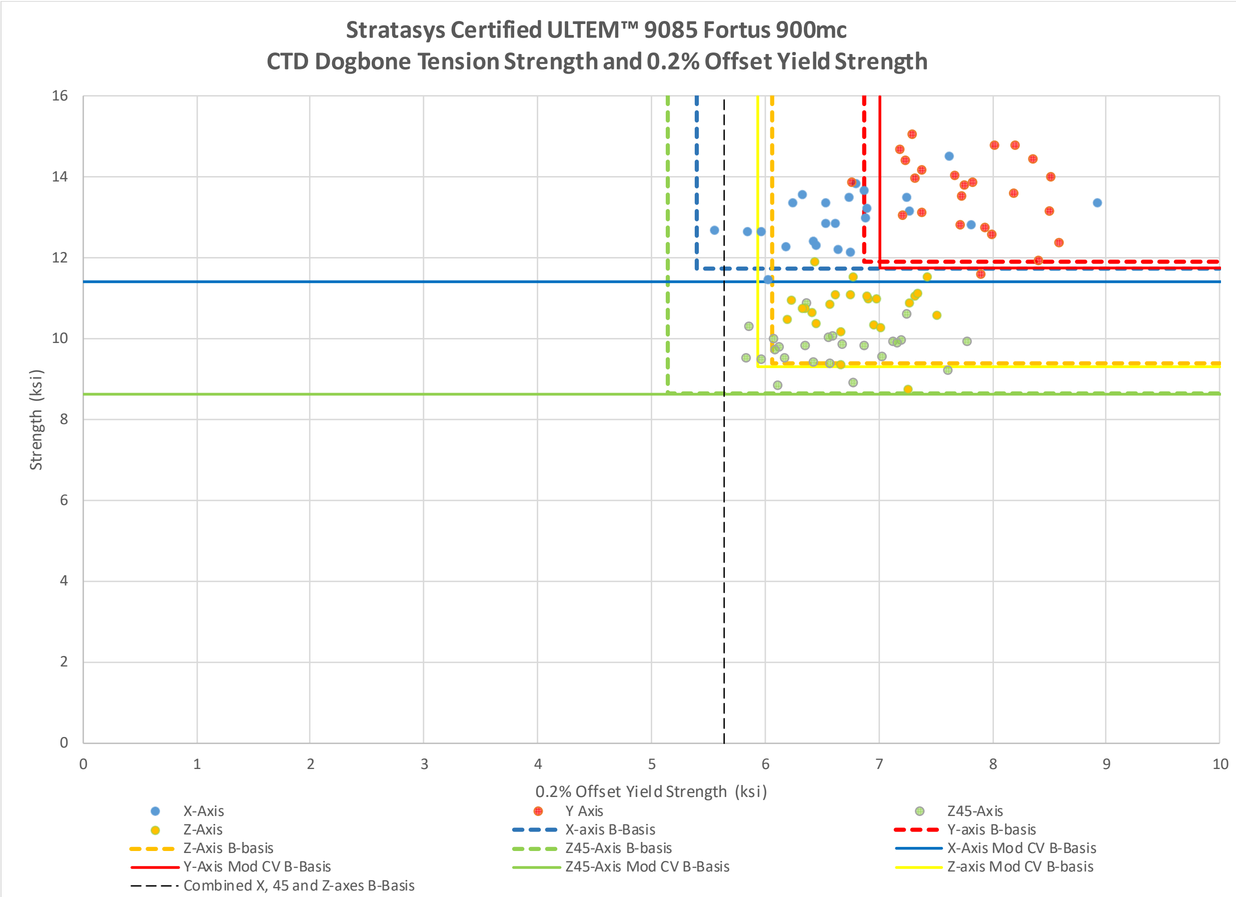



**Figure 4-5: Plot for Dogbone Tension Strength and 0.2% Offset Yield Strength CTD Condition**

| Dogbone Tension (DT) Basis Values and Statistics - CTD Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Yield Strength | | | | | Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X, Z45 & Z Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 6.714 | 7.792 | 6.606 | 6.804 | 6.708 | 12.965 | 13.594 | 9.768 | 10.720 |
| Stdev | 0.710 | 0.499 | 0.549 | 0.398 | 0.565 | 0.665 | 0.926 | 0.466 | 0.667 |
| CV | 10.582 | 6.407 | 8.314 | 5.855 | 8.424 | 5.131 | 6.814 | 4.773 | 6.225 |
| Mod CV | 10.582 | 7.204 | 8.314 | 6.927 | 8.424 | 6.565 | 7.407 | 6.386 | 7.112 |
| Min | 5.557 | 6.762 | 5.837 | 6.194 | 5.557 | 11.465 | 11.584 | 8.848 | 8.730 |
| Max | 8.917 | 8.582 | 7.780 | 7.512 | 8.917 | 14.501 | 15.050 | 10.877 | 11.880 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 72 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 5.398 | 6.868 | 5.149 | 6.066 | 5.642 | 11.733 | 11.879 | 8.648 | 9.374 |
| A-Estimate | 4.455 | 6.205 | 4.139 | 5.537 | 4.866 | 10.849 | 10.649 | 7.866 | 8.025 |
| Method | Normal | Normal | ANOVA | Normal | ANOVA | Normal | Normal | ANOVA | Weibull |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | NA | 7.003 | NA | 5.931 | NA | 11.387 | 11.728 | 8.612 | 9.307 |
| A-Estimate | | 6.467 | | 5.305 | | 10.257 | 10.391 | 7.784 | 8.294 |
| Method | | pooled | | Normal | | Normal | Normal | Normal | Normal |

**Table 4-2: Statistics and Basis values for CTD Strength Data**

| Dogbone Tension (DT) Modulus Statistics CTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.388 | 0.433 | 0.387 | 0.394 |
| Stdev | 0.018 | 0.010 | 0.019 | 0.011 |
| CV | 4.598 | 2.370 | 4.808 | 2.854 |
| Min | 0.357 | 0.410 | 0.348 | 0.377 |
| Max | 0.423 | 0.455 | 0.424 | 0.424 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-3: Statistics from CTD Modulus Data

### 4.1.2 Dogbone Tension RTD Condition

The X and Z-axes could be combined to compute basis values for the 0.2% Offset Yield Strength measurements. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six batch and machine combinations for the X and Y-axes for 0.2% Offset Yield Strength and for the X, Y and Z45-axes for Strength, which means that the ANOVA method was required to compute those basis values and estimates. The Z-axis, Z45-axis and the combined X and Z-axes for the 0.2% Offset Yield Strength and the Z-axis for Strength, all had an adequate fit to the normal distribution for computing basis values. The Y-axis dataset was pooled across conditions for the modified CV basis value computations.

Four outliers were identified in the data from the RTD condition: two for 0.2% Offset, one for Strength and one for both measurements. Two were for the X-axis and two for the Z-axis.

The largest value in batch two on machine two for 0.2% Offset on the X-axis was an outlier for the machine batch combination but not for batch two, machine two or the RTD condition.

The smallest value in batch one on machine two on the X-axis was an outlier for Strength for the RTD condition. It was not an outlier for batch one, machine two or the machine batch combination. The 0.2% Offset value was an outlier for the RTD condition for the combined X and Z-axes but not the X-axis alone while the strength value was an outlier for the RTD condition for the X-axis but not for the combined X and Z-axes.

The smallest 0.2% Offset value in batch three on machine one on the Z-axis was an outlier for the machine batch combination, but not for machine one, batch three, or the RTD condition. The largest Strength value in batch three on machine two on the Z-axis was an outlier for the RTD condition, but not for batch three, machine two, or the machine batch combination. Neither of the Z-axis outliers were outliers for the combined X and Z-axes.

Statistics, estimates and basis values are given for the strength data in Table 4-4 and for the modulus data in Table 4-5. The data and B-basis values are shown graphically for Strength in Figure 4-6, for 0.2% Offset Yield Strength in Figure 4-7, and for both together in Figure 4-8.

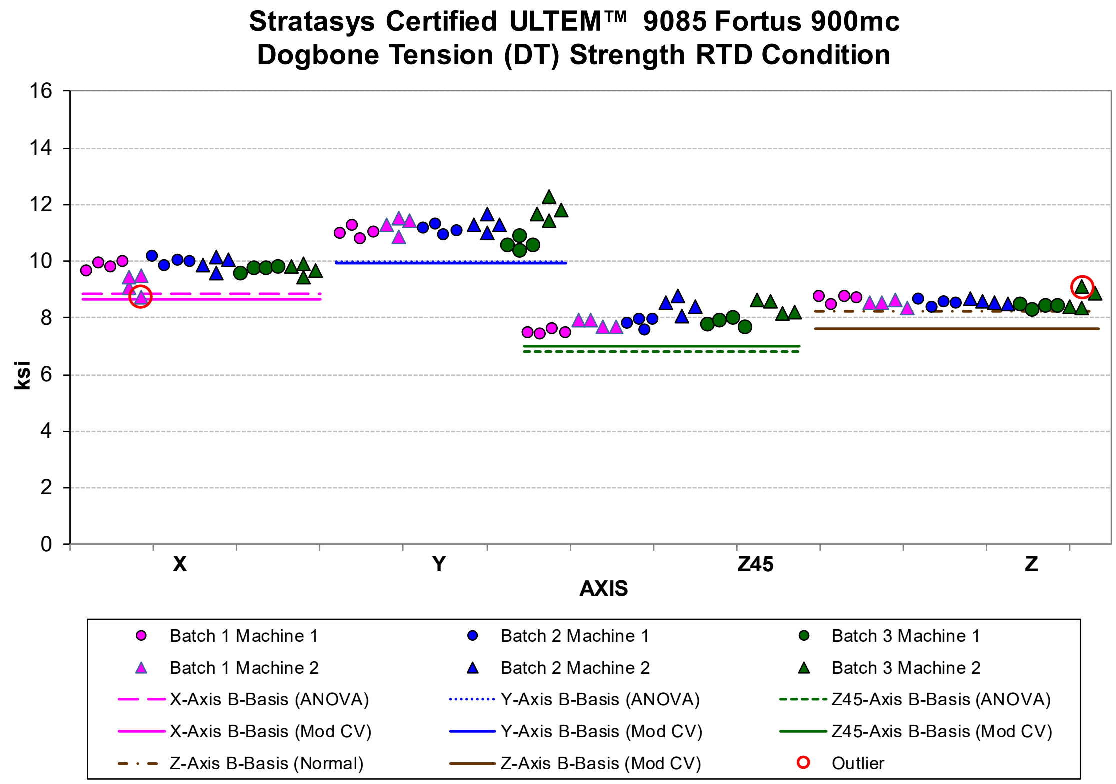



**Figure 4-6: Plot for Dogbone Tension Strength RTD Condition**

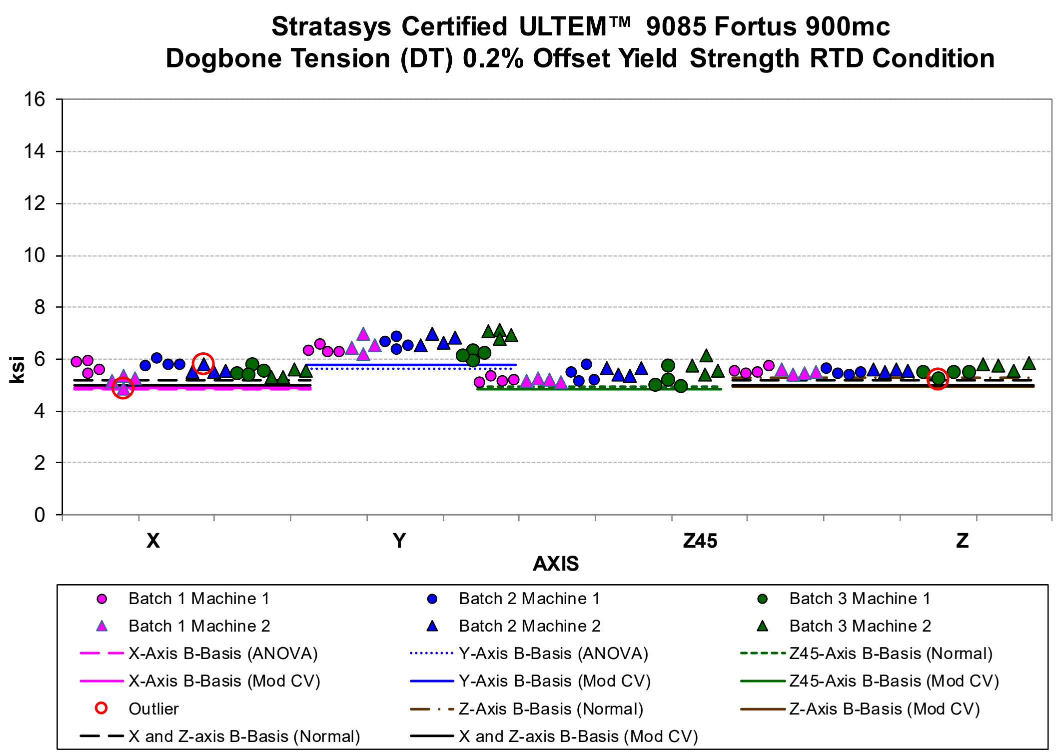



**Figure 4-7: Plot for Dogbone Tension 0.2% Offset Yield Strength RTD Condition**

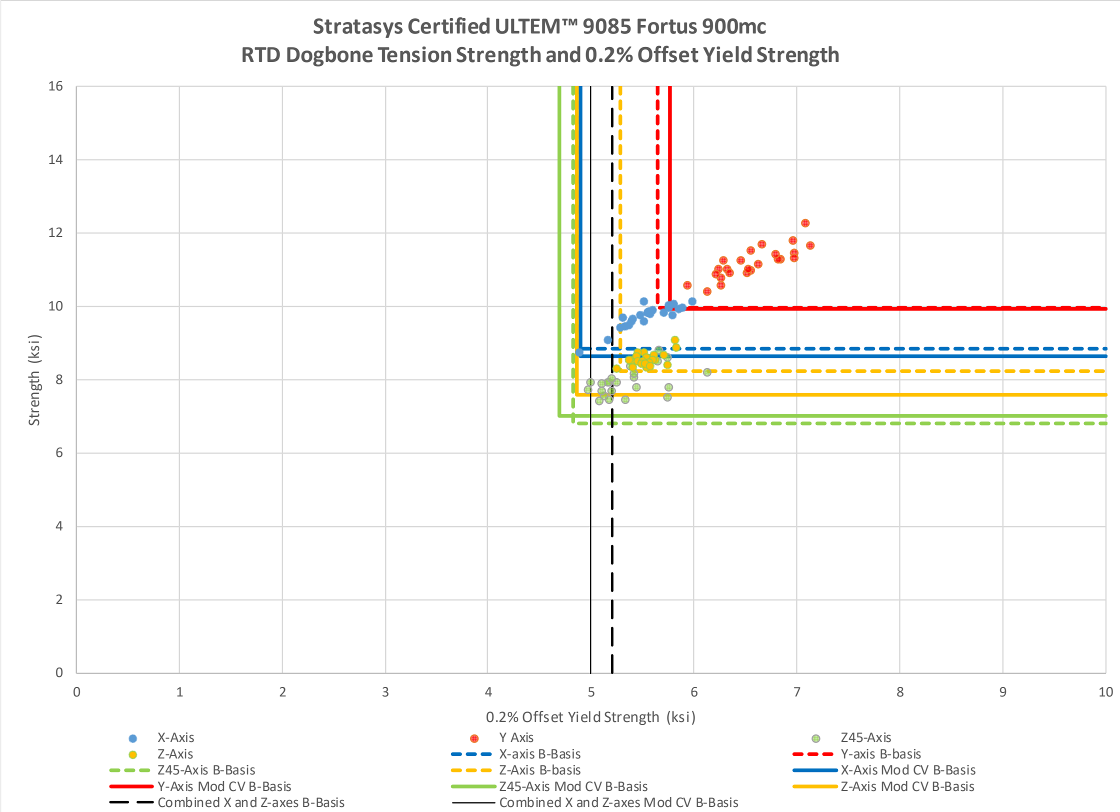



**Figure 4-8: Plot for Dogbone Tension Strength and 0.2% Offset Yield Strength RTD Condition**

| Dogbone Tension (DT) Basis Values and Statistics - RTD Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Yield Strength | | | | | Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X & Z Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 5.544 | 6.561 | 5.367 | 5.540 | 5.542 | 9.728 | 11.183 | 7.957 | 8.550 |
| Stdev | 0.252 | 0.329 | 0.294 | 0.139 | 0.201 | 0.328 | 0.427 | 0.391 | 0.182 |
| CV | 4.550 | 5.009 | 5.470 | 2.506 | 3.635 | 3.369 | 3.816 | 4.908 | 2.126 |
| Mod CV | 6.275 | 6.504 | 6.735 | 6.000 | 6.000 | 6.000 | 6.000 | 6.454 | 6.000 |
| Min | 4.890 | 5.934 | 4.976 | 5.255 | 4.890 | 8.743 | 10.391 | 7.415 | 8.313 |
| Max | 5.980 | 7.135 | 6.129 | 5.832 | 5.980 | 10.144 | 12.274 | 8.792 | 9.085 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 4.865 | 5.648 | 4.823 | 5.283 | 5.209 | 8.827 | 9.977 | 6.802 | 8.214 |
| A-Estimate | 4.396 | 5.018 | 4.434 | 5.098 | 4.963 | 8.205 | 9.145 | 6.009 | 7.972 |
| Method | ANOVA | ANOVA | Normal | Normal | Normal | ANOVA | ANOVA | ANOVA | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | 4.899 | 5.772 | 4.697 | 4.924 | 4.992 | 8.646 | 9.939 | 7.006 | 7.600 |
| A-Estimate | 4.437 | 5.236 | 4.217 | 4.482 | 4.586 | 7.871 | 9.048 | 6.324 | 6.918 |
| Method | Normal | pooled | Normal | Normal | Normal | Normal | Normal | Normal | Normal |

**Table 4-4: Statistics and Basis values for RTD Strength Data**

| Dogbone Tension (DT) Modulus Statistics RTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.337 | 0.377 | 0.341 | 0.347 |
| Stdev | 0.008 | 0.006 | 0.014 | 0.006 |
| CV | 2.513 | 1.520 | 3.973 | 1.842 |
| Min | 0.316 | 0.366 | 0.304 | 0.338 |
| Max | 0.358 | 0.389 | 0.356 | 0.358 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-5: Statistics from RTD Modulus Data

### 4.1.3 Dogbone Tension RTW Condition

For the RTW condition only a single batch of material was tested so only estimates of basis values are provided for this condition. The basis value estimates shown were computed separately for each axis.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the two machines for the X and Z-axes for 0.2% Offset Yield Strength and for the X and Z45-axes for Strength measurements which means the ANOVA method was required to compute those basis values and estimates. For 0.2% Offset Yield Strength, the basis values for the Z-axis computed using this method were negative, so only the modified CV basis values are provided. After the data was transformed according to the assumptions of the modified CV approach, they all passed the Anderson-Darling k-sample test so modified CV basis values could be provided. The Y and Z45-axes for the 0.2% Offset Yield Strength and the Z-axis for Strength all had an adequate fit to the normal distribution for computing basis values. The Y-axis data for Strength did not fit any of the tested distributions adequately, so the non-parametric method was used to compute basis value estimates. The 0.2% Offset Yield Strength for the Z45-axis had a CV value above 8%, so modified CV basis values could not be computed. The Y-axis dataset was pooled across conditions for the modified CV basis value computations.

Two outliers were identified in the data from the RTW condition. The largest value on machine one on the Y-axis was an outlier for both 0.2% Offset and Strength for machine one. It was also an outlier for the batch, but only for strength. The smallest Strength value on machine two on the Z-axis was an outlier for machine two only, not for the batch.

Statistics, estimates and basis values are given for the strength data in Table 4-6 and for the modulus data in Table 4-7. The data and B-estimates are shown graphically for Strength in Figure 4-9, for 0.2% Offset Yield Strength in Figure 4-10, and for both together in Figure 4-11.

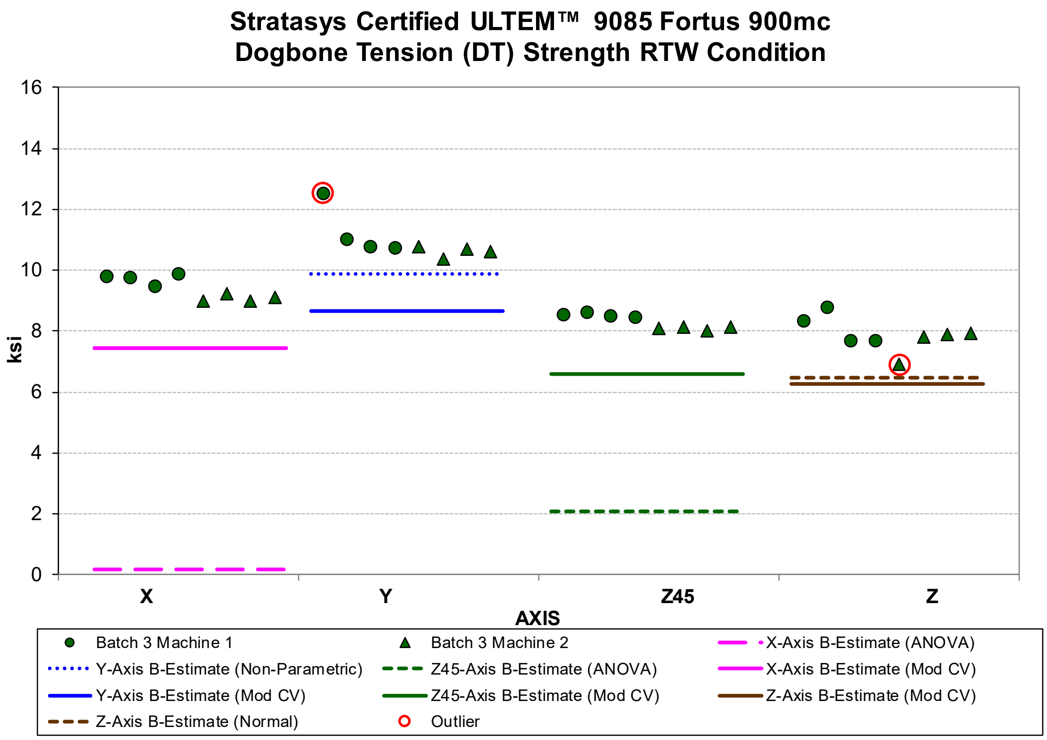



**Figure 4-9: Plot for Dogbone Tension Strength RTW Condition**

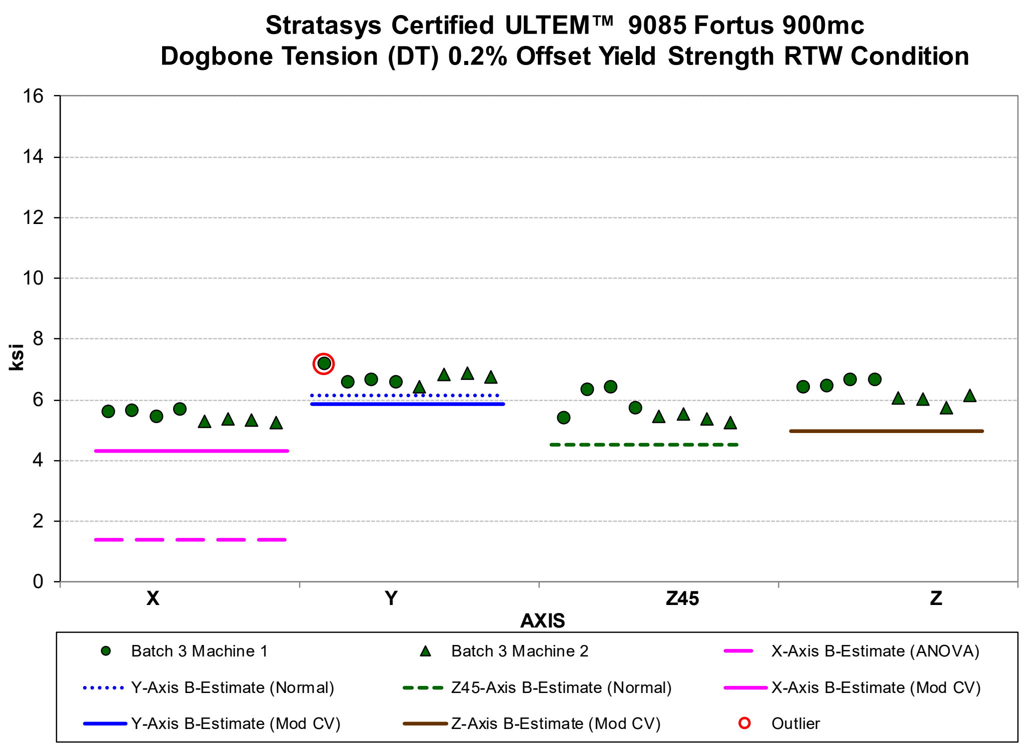



**Figure 4-10: Plot for Dogbone Tension 0.2% Offset Yield Strength RTW Condition**

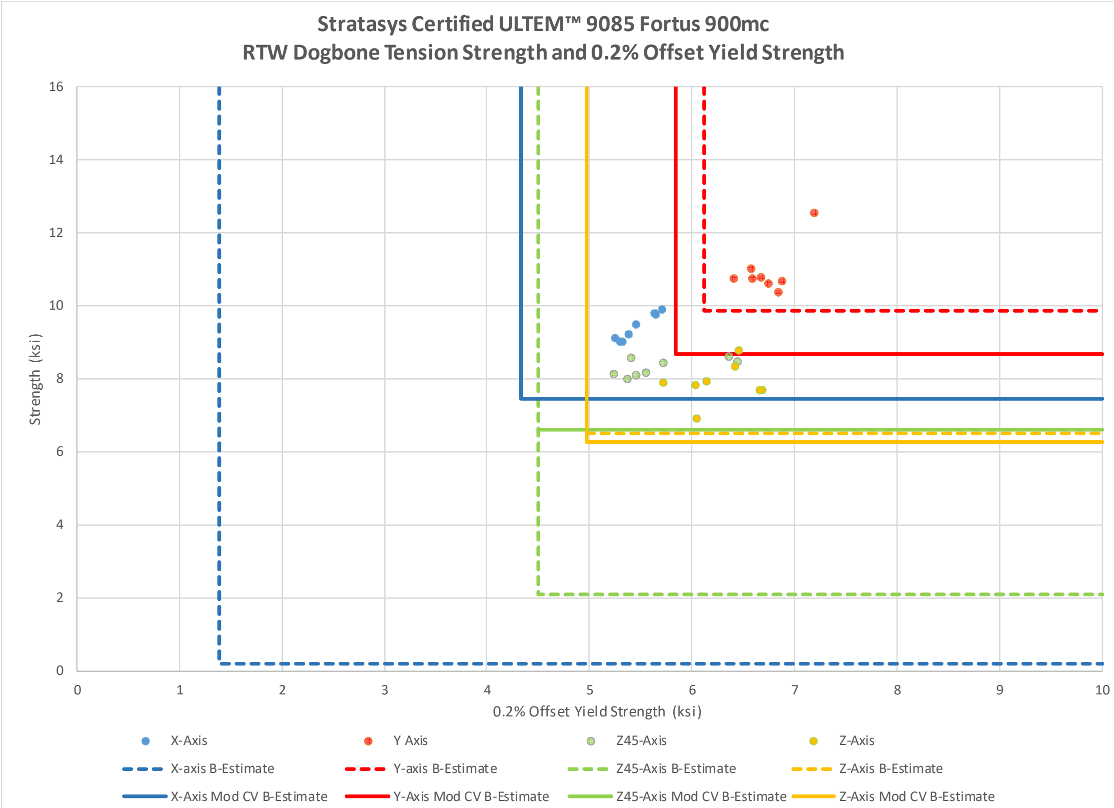



**Figure 4-11: Plot for Dogbone Tension Strength and 0.2% Offset Yield Strength RTW Condition**

| Dogbone Tension (DT) Basis Values and Statistics - RTW Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Yield Strength | | | | Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 5.461 | 6.739 | 5.692 | 6.270 | 9.406 | 10.937 | 8.307 | 7.876 |
| Stdev | 0.177 | 0.237 | 0.459 | 0.338 | 0.372 | 0.671 | 0.240 | 0.536 |
| CV | 3.239 | 3.514 | 8.067 | 5.388 | 3.957 | 6.136 | 2.886 | 6.805 |
| Mod CV | 8.000 | 8.000 | 8.067 | 8.000 | 8.000 | 8.000 | 8.000 | 8.000 |
| Min | 5.252 | 6.410 | 5.237 | 5.724 | 8.995 | 10.381 | 8.008 | 6.912 |
| Max | 5.705 | 7.187 | 6.443 | 6.687 | 9.885 | 12.541 | 8.606 | 8.776 |
| Batches | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Basis Value Estimates | | | | | | | | |
| B-Estimate | 1.382 | 6.124 | 4.499 | NA | 0.188 | 9.870 | 2.074 | 6.483 |
| A-Estimate | NA | 5.693 | 3.664 | | NA | 5.616 | NA | 5.508 |
| Method | ANOVA | Normal | Normal | | ANOVA | Non-Parametric | ANOVA | Normal |
| Modified CV Basis Value Estimates | | | | | | | | |
| B-Estimate | 4.332 | 5.841 | NA | 4.973 | 7.461 | 8.676 | 6.589 | 6.247 |
| A-Estimate | 3.557 | 5.318 | | 4.084 | 6.127 | 7.124 | 5.411 | 5.130 |
| Method | Normal | pooled | | Normal | Normal | Normal | Normal | Normal |

**Table 4-6: Statistics and Basis values for RTW Strength Data**

| Dogbone Tension (DT) Modulus Statistics RTW Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.330 | 0.376 | 0.349 | 0.359 |
| Stdev | 0.011 | 0.016 | 0.011 | 0.008 |
| CV | 3.372 | 4.182 | 3.132 | 2.365 |
| Min | 0.317 | 0.356 | 0.334 | 0.350 |
| Max | 0.347 | 0.407 | 0.363 | 0.372 |
| Batches | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 |

**Table 4-7: Statistics from RTW Modulus Data**

### 4.1.4 Dogbone Tension ETW1 Condition

The X, Z and Z45-axes could be combined to compute basis values for the 0.2% Offset Yield Strength measurements, but all four axes were statistically significantly different for the Strength measurement. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six different batch and machine combinations for strength measurements for the X, Z45 and Z-axes, so the ANOVA method was required to compute those basis values and estimates. All other datasets had an adequate fit to the normal distribution to compute basis values. The Y-axis dataset was pooled across conditions for the modified CV basis value computations.

Three outliers were identified in the data from the ETW1 condition: two for the 0.2% Offset and one for Strength. There was one outlier in each of the X, Z45 and Z-axes.

The largest 0.2% Offset value for batch three machine two from the Z45-axis was an outlier for batch three but not for machine two, the machine batch combination or the ETW1 condition. It was not an outlier for the X, Z and Z45-axes combined dataset.

The smallest 0.2% Offset value for batch three machine one from the Z-axis was an outlier for batch three but not for machine one, the machine batch combination or the ETW1 condition. It was not an outlier for the X, Z and Z45-axes combined dataset.

The largest Strength value for batch two machine one from the X-axis was an outlier for batch two but not for machine one, the machine batch combination or the ETW1 condition. It was not an outlier for the X, Z and Z45-axes combined dataset.

Statistics, estimates and basis values are given for the strength data in Table 4-8 and for the modulus data in Table 4-9. The data and B-basis values are shown graphically for Strength in Figure 4-12, for 0.2% Offset Yield Strength in Figure 4-13, and for both together in Figure 4-14.

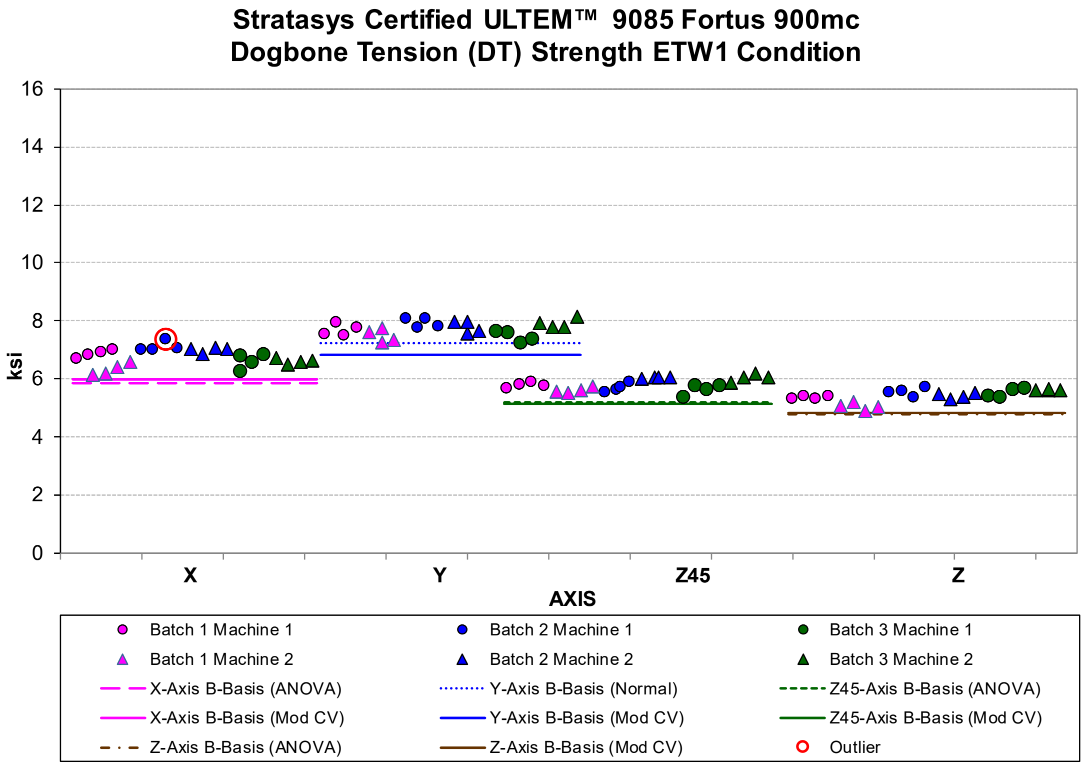



**Figure 4-12: Plot for Dogbone Tension Strength ETW1 Condition**

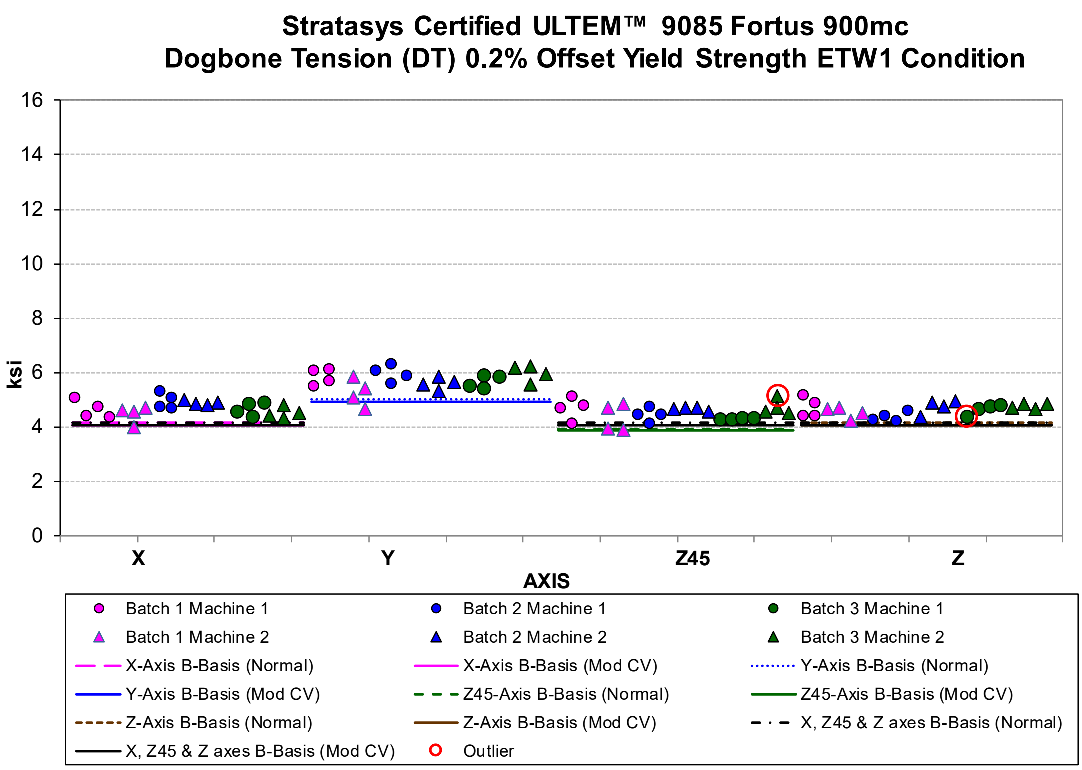



**Figure 4-13: Plot for Dogbone Tension 0.2% Offset Yield Strength ETW1 Condition**

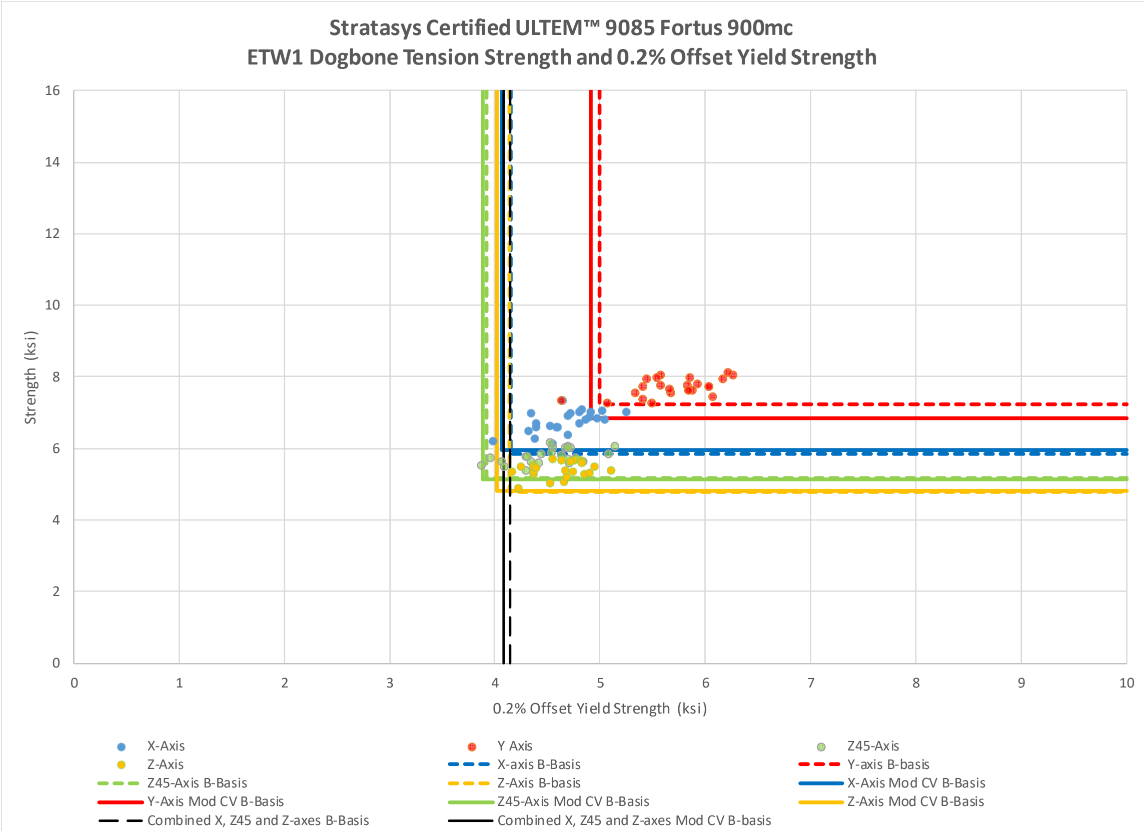



**Figure 4-14: Plot for Dogbone Tension Strength and 0.2% Offset Yield Strength ETW1 Condition**

| Dogbone Tension (DT) Basis Values and Statistics - ETW1 Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Yield Strength | | | | | Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X, Z45 & Z Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 4.675 | 5.698 | 4.513 | 4.612 | 4.600 | 6.754 | 7.707 | 5.795 | 5.416 |
| Stdev | 0.286 | 0.379 | 0.321 | 0.253 | 0.292 | 0.308 | 0.251 | 0.211 | 0.215 |
| CV | 6.116 | 6.656 | 7.124 | 5.485 | 6.346 | 4.566 | 3.261 | 3.646 | 3.966 |
| Mod CV | 7.058 | 7.328 | 7.562 | 6.742 | 7.173 | 6.283 | 6.000 | 6.000 | 6.000 |
| Min | 3.982 | 4.636 | 3.871 | 4.162 | 3.871 | 6.129 | 7.264 | 5.383 | 4.902 |
| Max | 5.249 | 6.260 | 5.135 | 5.108 | 5.249 | 7.356 | 8.140 | 6.172 | 5.719 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 72 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 4.145 | 4.995 | 3.917 | 4.144 | 4.140 | 5.865 | 7.242 | 5.188 | 4.784 |
| A-Estimate | 3.766 | 4.492 | 3.490 | 3.808 | 3.795 | 5.253 | 6.908 | 4.770 | 4.350 |
| Method | Normal | Normal | Normal | Normal | Normal | ANOVA | Normal | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | 4.063 | 4.909 | 3.880 | 4.036 | 4.080 | 5.967 | 6.850 | 5.150 | 4.814 |
| A-Estimate | 3.625 | 4.372 | 3.427 | 3.623 | 3.690 | 5.404 | 6.236 | 4.689 | 4.382 |
| Method | Normal | pooled | Normal | Normal | Normal | Normal | Normal | Normal | Normal |

**Table 4-8: Statistics and Basis values for ETW1 Strength Data**

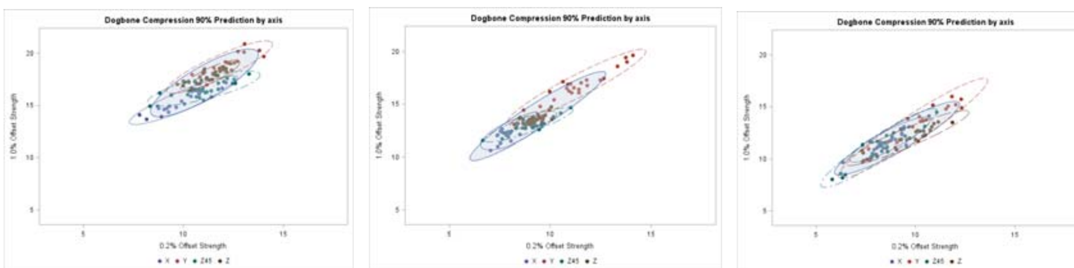
| Dogbone Tension (DT) Modulus Statistics ETW1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.302 | 0.339 | 0.311 | 0.307 |
| Stdev | 0.016 | 0.011 | 0.014 | 0.012 |
| CV | 5.172 | 3.312 | 4.398 | 3.789 |
| Min | 0.276 | 0.322 | 0.290 | 0.290 |
| Max | 0.343 | 0.365 | 0.338 | 0.331 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-9: Statistics from ETW1 Modulus Data

## 4.2 Dogbone Compression (DC)

Dogbone Compression tests reported three properties: 0.2% Offset Strength, 1% Offset Strength and Modulus. Tests were performed in five conditions: CTD, RTD, RTW, ETD1 and ETW1. The RTW and ETD1 condition tests were limited to eight specimens from only one batch, four from each of two machines. Only estimates of basis values can be provided for the RTW and ETD1 conditions due to having only one batch tested.

Scatter plots of the test results for the two properties for the CTD, RTD and ETW1 conditions with 90% prediction ellipses for each axis is shown in Figure 4-15. The 1% Offset and 0.2% Offset Strength measurements were highly correlated as shown in the scatter plots of Figure 4-15. The correlations computed by specimen for each direction and condition tested are shown in Table 4-10. A box plot of the dogbone compression strength measurements by axis and condition is shown in Figure 4-16.



CTD RTD ETW1

**Figure 4-15: Scatter Plots of DC Strength Properties by Condition and Axis**

| Pearson Correlation Coefficients – 0.2% Offset Strength with 1% Offset Strength | | | | | |
|---|---|---|---|---|---|
| | X | Y | Z | Z45 | All |
| CTD | 0.9057 | 0.8777 | 0.8513 | 0.7693 | 0.8369 |
| RTD | 0.7056 | 0.9407 | 0.5908 | 0.8786 | 0.9457 |
| RTW | 0.6044 | 0.9260 | 0.9623 | -0.1472 | 0.8010 |
| ETD1 | 0.9184 | 0.9727 | 0.1265 | 0.8567 | 0.9740 |
| ETW1 | 0.8808 | 0.9525 | 0.9268 | 0.9334 | 0.9213 |
| ALL | 0.8206 | 0.8546 | 0.8368 | 0.9029 | 0.8805 |

**Table 4-10: Correlation Statistics for Dogbone Compression Strength Data**

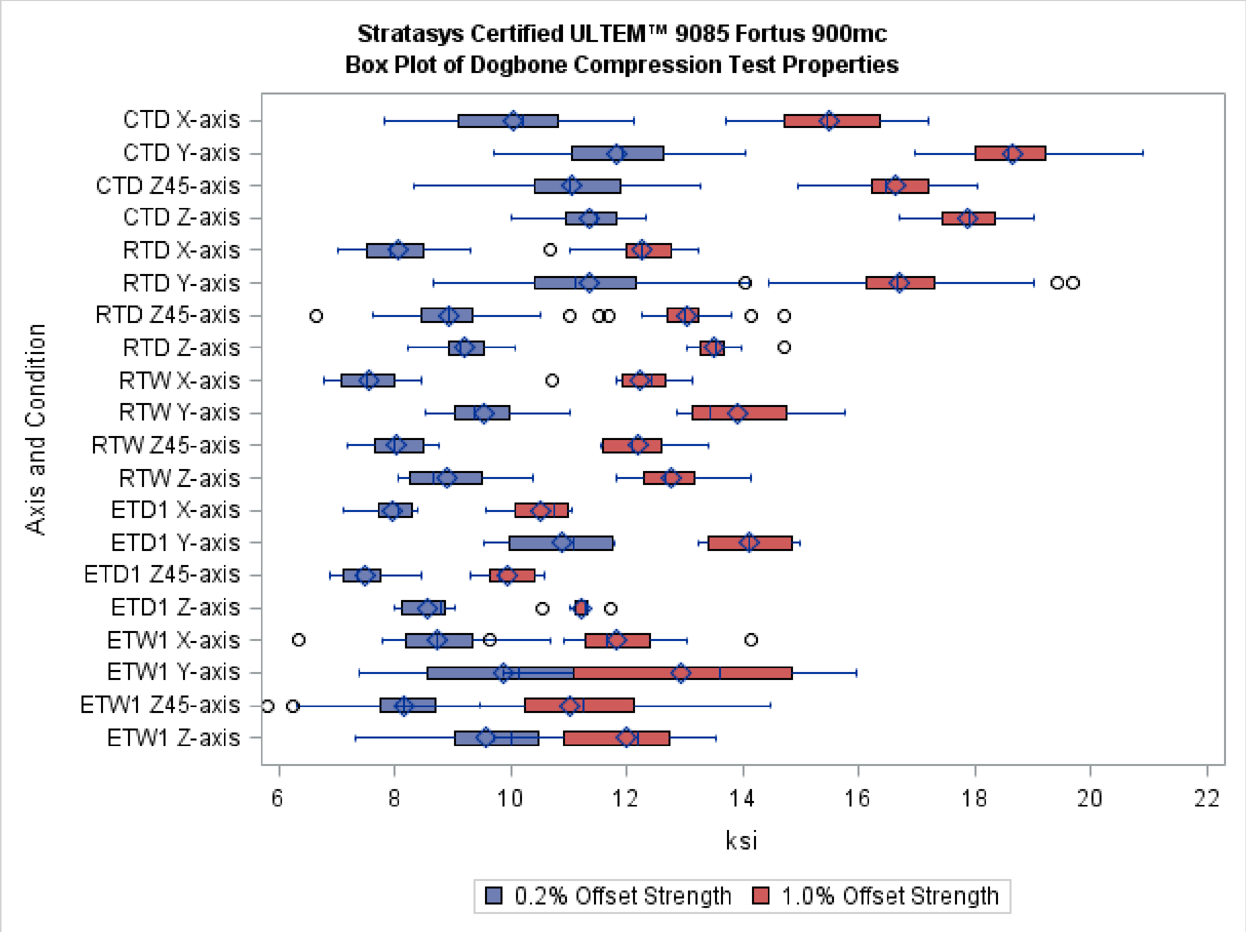



**Figure 4-16: Box Plots of Dogbone Compression Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. The Z and Z45-axes can be combined for the CTD and RTD conditions for the 0.2% Offset Strength property, the combined axes datasets could also be pooled across the two conditions. However, all four axes were statistically significantly different for the 1% Offset Strength property in the CTD and RTD conditions.

The X and Z45-axes can be combined for the RTW and ETD1 conditions for the 0.2% Offset Strength property. The RTW condition has sufficient similarity between the X, Z, and Z45-axes to be combined for the 1.0% Offset Strength. In the ETW1 condition, the Y and Z-axes as well as the X and Z45-axes can be combined for the 0.2% Offset Strength data.

Pooling of the CTD and RTD conditions was acceptable for the Y-axis (original CV only), X and Z-axes (modified CV only) and Z45-axis (both) for 1% Offset Strength and for the Y, Z45, and Z-axes (original CV only) for 0.2% Offset Strength. The other axes did not meet the CMH17 requirements for pooling across conditions.

Outlier status was checked for each specimen by condition, batch, machine and the combination of batch and machine. For all of these different groupings for the two strength properties, there were a total of 19 specimens identified as outliers. Details are given in the text for each condition and all outliers are listed in Table 4-44. All outliers were retained for this analysis.

### 4.2.1 Dogbone Compression CTD Condition

The Z and Z45-axes could be combined to compute basis values for the 0.2% Offset Strength property. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six batch and machine combinations for both strength properties for the X-axis so the ANOVA method was required to compute those basis values and estimates. All other datasets had an adequate fit to the normal distribution to compute basis values. The 0.2% Offset Strength property Y, Z, and Z45-axes could each be pooled across the CTD and RTD conditions. No modified CV basis values could be computed for the 0.2% Offset Strength data due to the CV being above 8%. The 1% Offset Strength data could be pooled across the CTD and RTD conditions for the X and Z-axes (Mod CV only), Y-axis (original data only because CV greater than 8% for RTD condition) and the Z45-axis (both original data and Mod CV).

There were two outliers. The lowest strength value in the batch one machine one 0.2% Offset dataset for the X-axis was an outlier for the machine batch combination, but not for batch one, machine one, or the CTD condition. The largest strength value in the batch one machine one 1% Offset dataset for the Z45-axis was an outlier for the machine batch combination, but not for batch one, machine one, or the CTD condition. Both outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-11 and for the modulus data in Table 4-12. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-17, for 1% Offset Strength in Figure 4-18, and for both together in Figure 4-19.

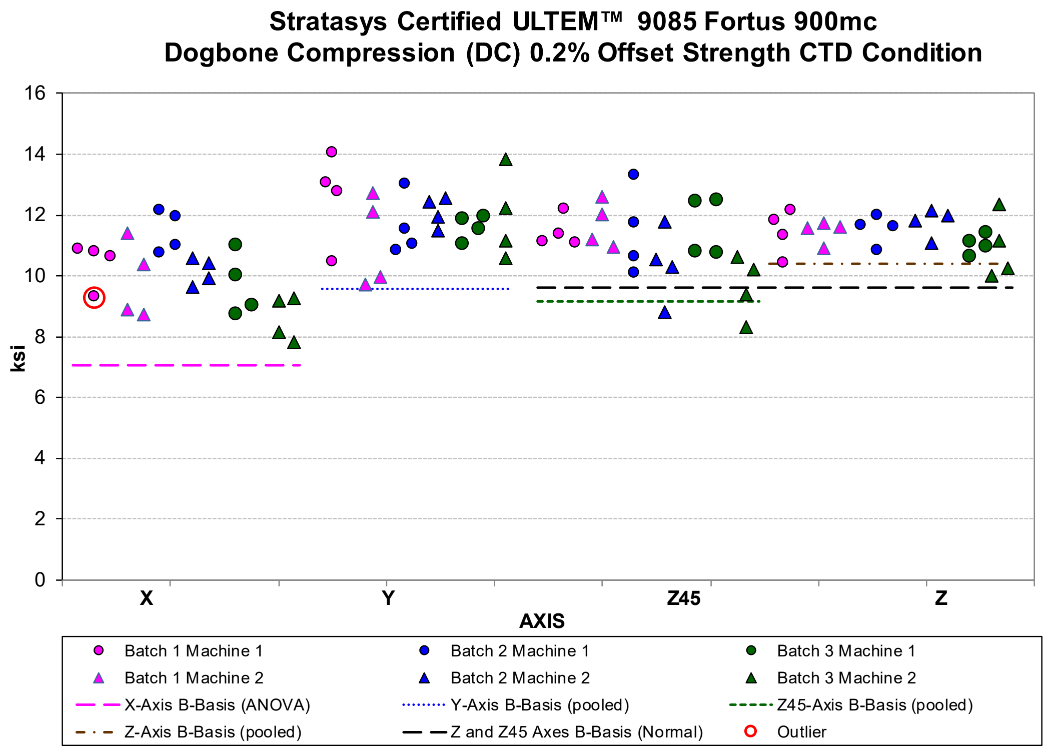



Figure 4-17: Plot for Dogbone Compression 0.2% Offset Strength CTD Condition

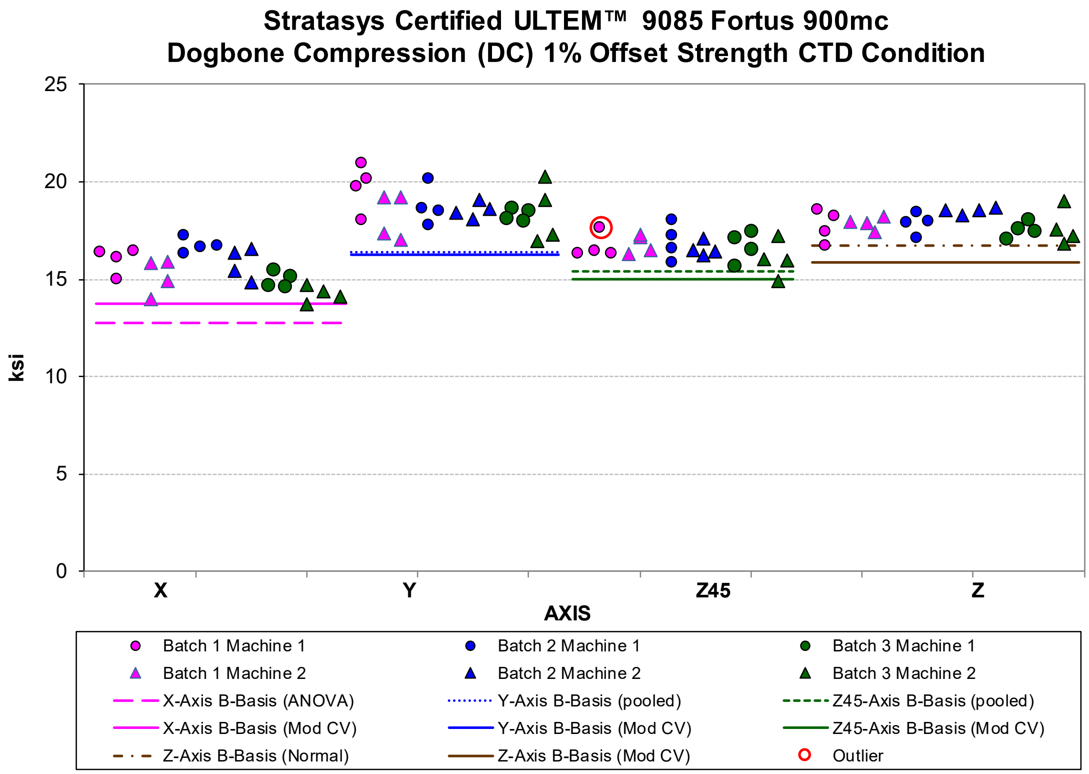



Figure 4-18: Plot for Dogbone Compression 1% Offset Strength CTD Condition

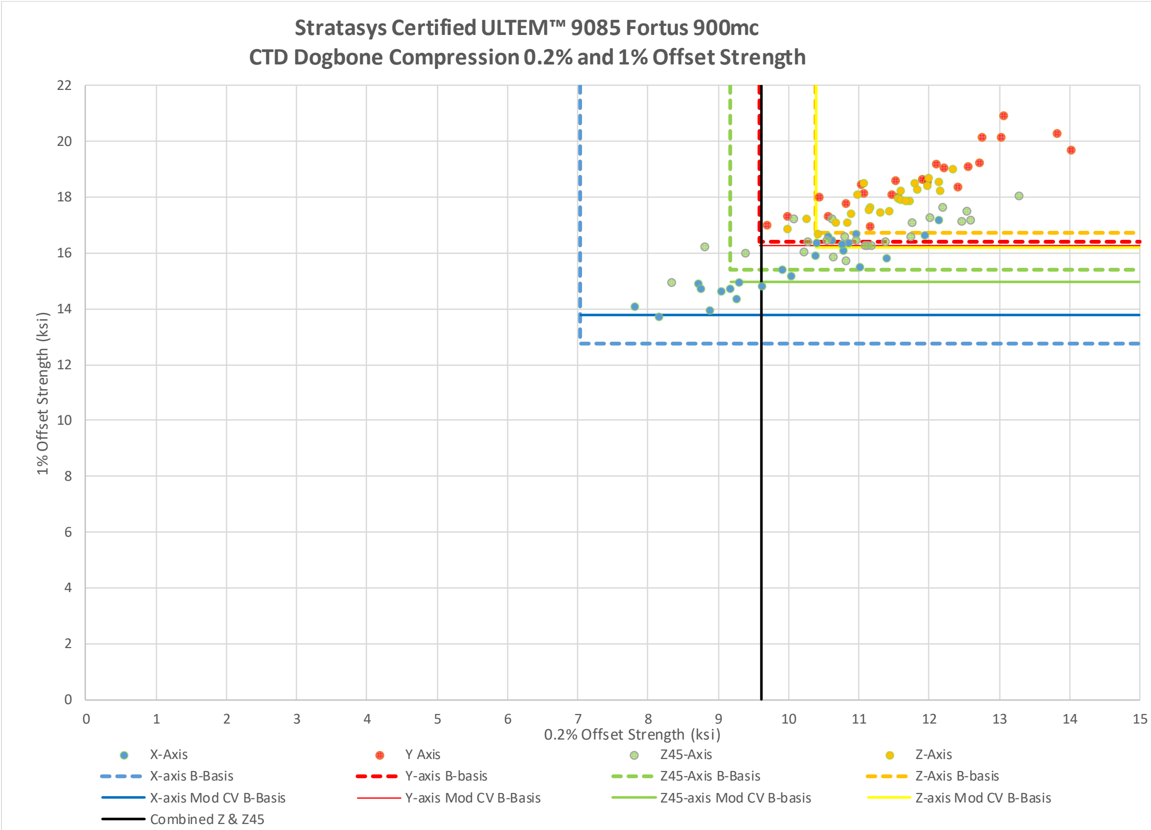



Figure 4-19: Plot for Dogbone Compression 0.2% and 1% Offset Strength CTD Condition

| Dogbone Compression (DC) Basis Values and Statistics - CTD Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | Z45 & Z Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 10.022 | 11.827 | 11.035 | 11.357 | 11.196 | 15.472 | 18.647 | 16.611 | 17.862 |
| Stdev | 1.154 | 1.122 | 1.198 | 0.627 | 0.960 | 0.987 | 1.057 | 0.706 | 0.622 |
| CV | 11.518 | 9.483 | 10.854 | 5.520 | 8.571 | 6.382 | 5.671 | 4.248 | 3.484 |
| Mod CV | 11.518 | 9.483 | 10.854 | 6.760 | 8.571 | 7.191 | 6.835 | 6.124 | 6.000 |
| Min | 7.811 | 9.703 | 8.334 | 9.989 | 8.334 | 13.699 | 16.960 | 14.928 | 16.677 |
| Max | 12.136 | 14.021 | 13.278 | 12.340 | 13.278 | 17.188 | 20.906 | 18.033 | 19.019 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 7.038 | 9.580 | 9.172 | 10.388 | 9.609 | 12.750 | 16.405 | 15.397 | 16.709 |
| A-Estimate | 4.966 | 8.023 | 7.880 | 9.715 | 8.437 | 10.870 | 14.850 | 14.556 | 15.883 |
| Method | ANOVA | pooled | pooled | pooled | Normal | ANOVA | pooled | pooled | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | NA | NA | NA | NA | NA | 13.763 | 16.285 | 14.970 | 16.212 |
| A-Estimate | | | | | | 12.577 | 14.592 | 13.833 | 15.068 |
| Method | | | | | | pooled | Normal | pooled | pooled |

Table 4-11: Statistics and Basis Values for CTD Condition Data

| Dogbone Compression (DC) Modulus Statistics CTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.398 | 0.443 | 0.392 | 0.421 |
| Stdev | 0.018 | 0.015 | 0.019 | 0.012 |
| CV | 4.578 | 3.347 | 4.945 | 2.836 |
| Min | 0.366 | 0.419 | 0.367 | 0.405 |
| Max | 0.430 | 0.471 | 0.438 | 0.450 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-12: Statistics from CTD Modulus Data

### 4.2.2 Dogbone Compression RTD Condition

The Z and Z45-axes could be combined to compute basis values for the 0.2% Offset Strength property. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six batch and machine combinations for strength measurements for the X-axis 1% Offset Strength. The ANOVA method was required to compute those basis values and estimates. All other datasets had an adequate fit to the normal distribution to compute basis values. The 0.2% Offset Strength property for the Y, Z, and Z45-axes could each be pooled across the CTD and RTD conditions. The 1% Offset Strength data could be pooled across the CTD and RTD conditions for the X and Z-axes (Mod CV only), Y-axis (original data only) and the Z45-axis (both original data and Mod CV). No modified CV basis values could be computed for the 0.2% Offset Strength data in the Y-axis, Z45-axis and combined Z and Z45-axes or for the 1% Offset Strength data in the Y-axis due to the CV being above 8%.

There were eight outliers in the RTD condition, one in the X-axis data (0.2% Offset only), two in the Y-axis data (one in 1% Offset only, one in both 0.2% and 1% Offset), one in the Z45-axis data (outlier in both 0.2% and 1% Offset) and four in the Z-axis data (three in the 0.2% Offset and one in the 1% Offset). All eight outliers were retained for this analysis.

The largest strength value in the X-axis batch one machine one 0.2% Offset dataset was an outlier for the batch machine combination and for batch one, but not for machine one or the RTD condition.

The lowest value in the Y-axis batch two machine one dataset was an outlier for the batch machine combination for both 0.2% and 1% Offset Strength measurements, but it was not an outlier for batch two, machine one, or the RTD condition. The lowest value in the Y-axis batch three machine one dataset was an outlier for the 1% Offset Strength measurements of batch three, but it was not an outlier for machine one, the batch machine combination or the RTD condition.

The lowest value in the Z45-axis batch one machine two dataset was an outlier for machine two for both 0.2% and 1% Offset Strength measurements, but it was not an outlier for batch one, the machine batch combination, or the Z45-axis RTD condition. The 0.2% Offset Strength value was an outlier for the RTD condition of the combined Z and Z45-axes dataset, but the 1% Offset Strength measurement was not.

The Z-axis had four outliers, three for the 0.2% Offset Strength data and one for the 1% Offset Strength data. The largest value in the 1% Offset Strength data for batch one machine one was an outlier for every group tested, i.e. batch one, machine one, and the RTD condition but not for the machine batch combination or the combined axes dataset. The largest value in the 0.2% Offset Strength data for batch two machine two was an outlier for the machine batch combination of the combined Z and Z45-axes dataset. It was not an outlier for batch two, machine two, the RTD condition or the machine batch combination for the Z-axis only. The lowest value in the 0.2% Offset Strength data for batch two machine one was an outlier for the machine batch combination of the Z-axis dataset but not for batch two, machine one or the RTD condition. The lowest value in the 0.2% Offset Strength data for batch three machine one was an outlier for batch three but not for the machine batch combination, machine one, or the RTD condition.

Statistics, basis values and estimates are given for the strength data in Table 4-13 and for the modulus data in Table 4-14. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-20, for 1% Offset Strength in Figure 4-21, and for both together in Figure 4-22.

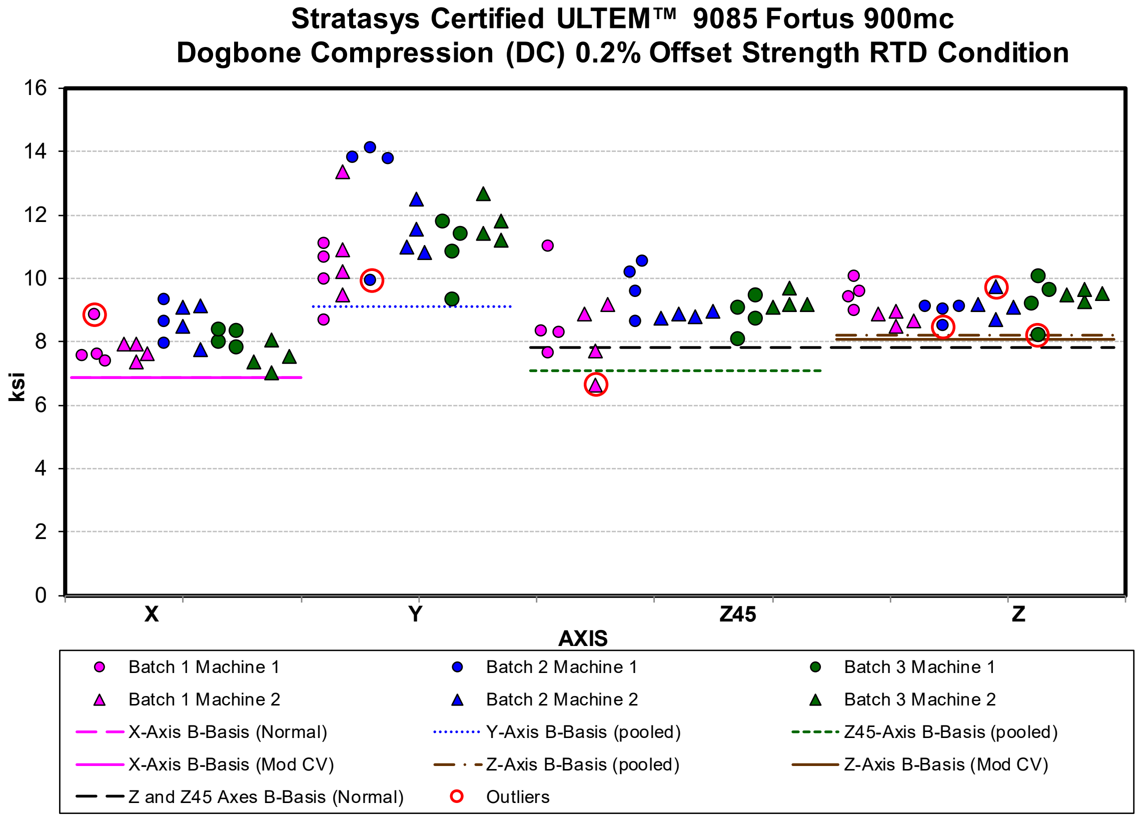



**Figure 4-20: Plot for Dogbone Compression 0.2% Offset Strength RTD Condition**

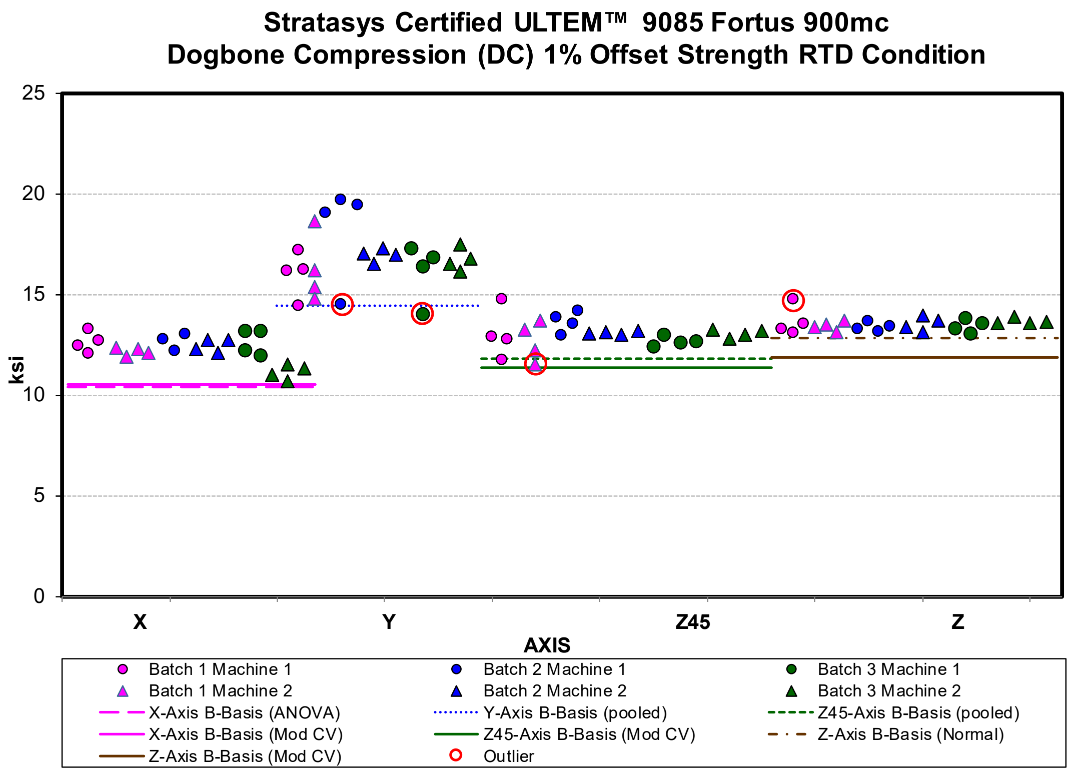



**Figure 4-21: Plot for Dogbone Compression 1% Offset Strength RTD Condition**

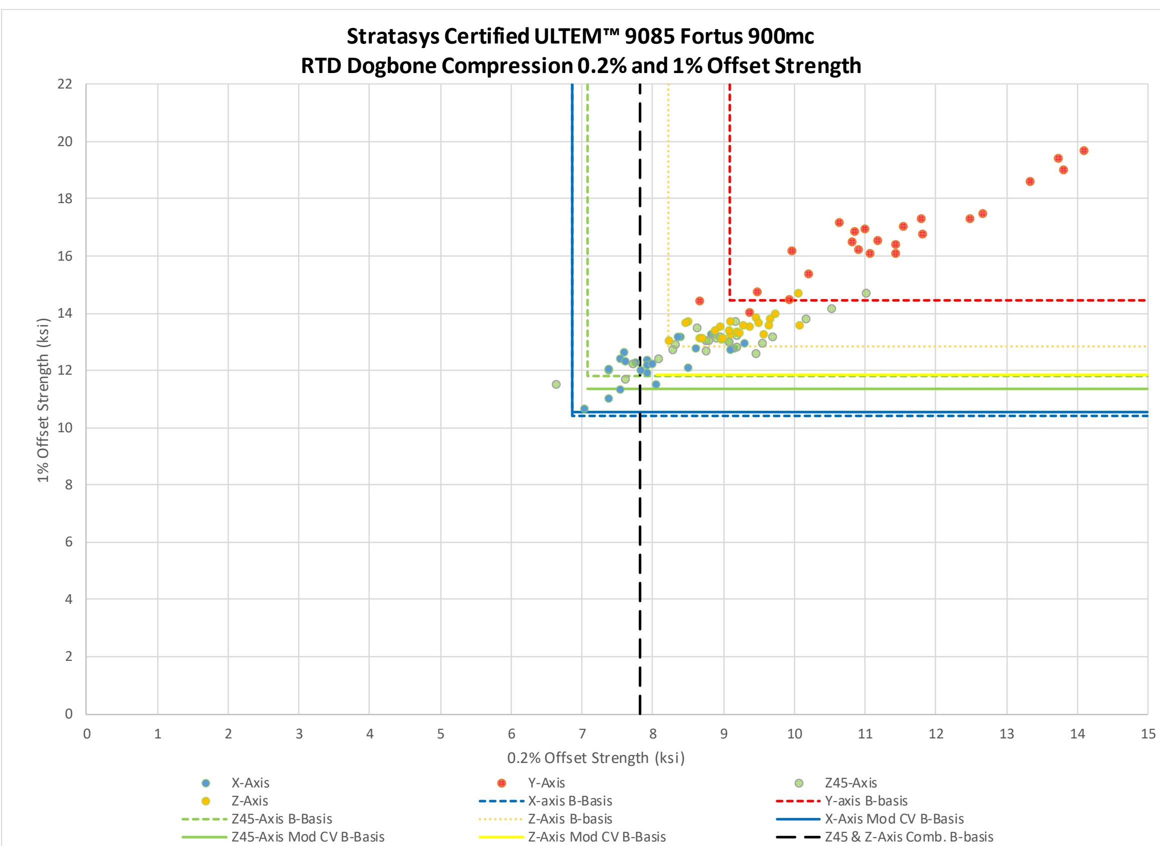



**Figure 4-22: Plot for Dogbone Compression 0.2% and 1% Offset Strength RTD Condition**

| Dogbone Compression (DC) Basis Values and Statistics - RTD Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | Z45 & Z Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 8.048 | 11.343 | 8.935 | 9.183 | 9.059 | 12.253 | 16.695 | 13.015 | 13.515 |
| Stdev | 0.630 | 1.446 | 0.931 | 0.480 | 0.744 | 0.671 | 1.489 | 0.692 | 0.363 |
| CV | 7.822 | 12.746 | 10.423 | 5.229 | 8.209 | 5.474 | 8.918 | 5.318 | 2.684 |
| Mod CV | 7.911 | 12.746 | 10.423 | 6.614 | 8.209 | 6.737 | 8.918 | 6.659 | 6.000 |
| Min | 7.027 | 8.670 | 6.644 | 8.221 | 6.644 | 10.673 | 14.037 | 11.529 | 13.045 |
| Max | 9.300 | 14.104 | 11.009 | 10.073 | 11.009 | 13.245 | 19.667 | 14.697 | 14.702 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 23 | 24 | 24 | 24 | 48 | 23 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 6.871 | 9.097 | 7.072 | 8.214 | 7.829 | 10.400 | 14.452 | 11.802 | 12.843 |
| A-Estimate | 6.030 | 7.539 | 5.781 | 7.541 | 6.921 | 9.121 | 12.898 | 10.960 | 12.362 |
| Method | Normal | pooled | pooled | pooled | Normal | ANOVA | pooled | pooled | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | 6.858 | | | 8.058 | | 10.538 | | 11.374 | 11.865 |
| A-Estimate | 6.006 | NA | NA | 7.251 | NA | 9.354 | NA | 10.237 | 10.721 |
| Method | Normal | | | Normal | | pooled | | pooled | pooled |

Table 4-13: Statistics and Basis Values for RTD Condition Data

| Dogbone Compression (DC) Modulus Statistics RTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.385 | 0.430 | 0.364 | 0.377 |
| Stdev | 0.018 | 0.018 | 0.011 | 0.013 |
| CV | 4.602 | 4.122 | 2.970 | 3.359 |
| Min | 0.352 | 0.398 | 0.344 | 0.355 |
| Max | 0.416 | 0.458 | 0.383 | 0.405 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 23 | 24 | 24 | 24 |

Table 4-14: Statistics from RTD Modulus Data

### 4.2.3 Dogbone Compression RTW Condition

The RTW condition tested only one batch of material, so the dataset lacked sufficient specimens to meet CMH-17 guidelines and only estimates are provided. The data from the X and Z45-axes were sufficiently similar to be combined to compute basis value estimates for the 0.2% Offset Strength. The data from the X, Z, and Z45-axes could be combined to compute basis value estimates for the 1% Offset Strength data.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the two machines for strength measurements for the Y-axis (0.2% Offset) and the Z45-axis (1% Offset), so the ANOVA method was required to compute those basis value estimates. With only two groups, this method resulted in negative basis values. Estimates of basis values were provided for the Y-axis 0.2% Offset Strength dataset by overriding the ADK test result and using the normal distribution. The Z45-axis passed the ADK test with the use of the modified CV method, so estimates of basis values for this dataset were provided using the mod CV approach.

There was one outlier in the RTW dataset. The largest value in the Z-axis machine one 0.2% Offset Strength dataset was an outlier for machine one but not for the Z-axis.

The 1% Offset Strength data shows a distinct difference for the two machines with machine one showing significantly higher values than the results from machine two. This difference did not show up in the 0.2% Offset Strength data.

Statistics and basis value estimates are given for the strength data in Table 4-15 and for the modulus data in Table 4-16. The data and B-estimates are shown graphically for 0.2% Offset Strength in Figure 4-23, for 1% Offset Strength in Figure 4-24, and for both together in Figure 4-25.

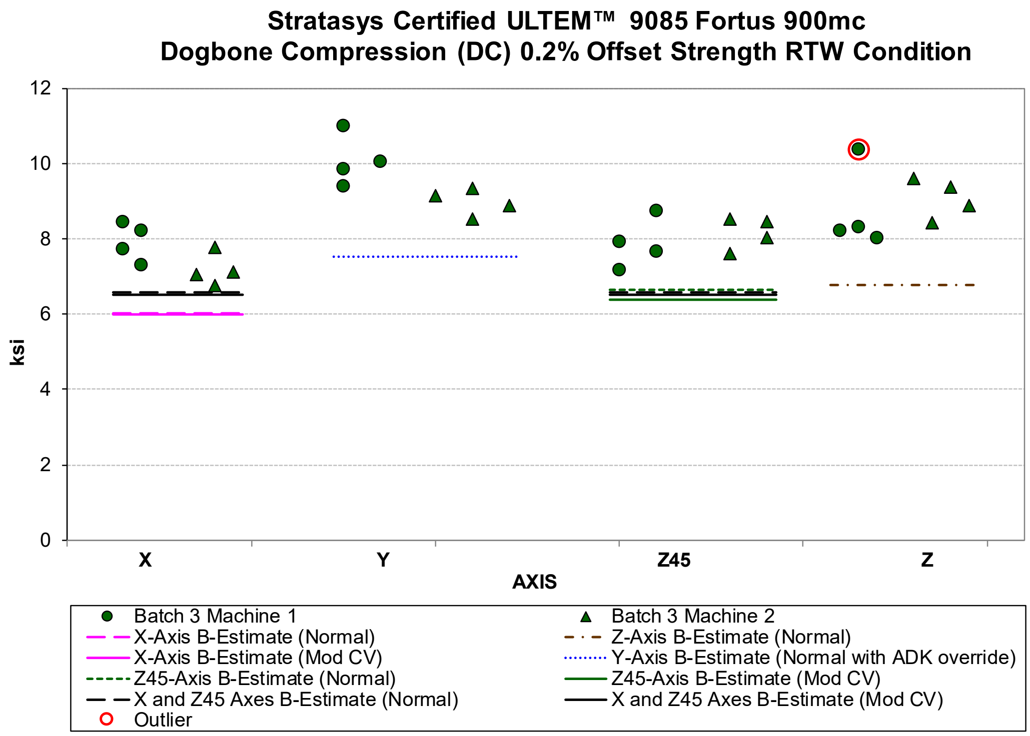



**Figure 4-23: Plot for Dogbone Compression 0.2% Offset Strength RTW Condition**

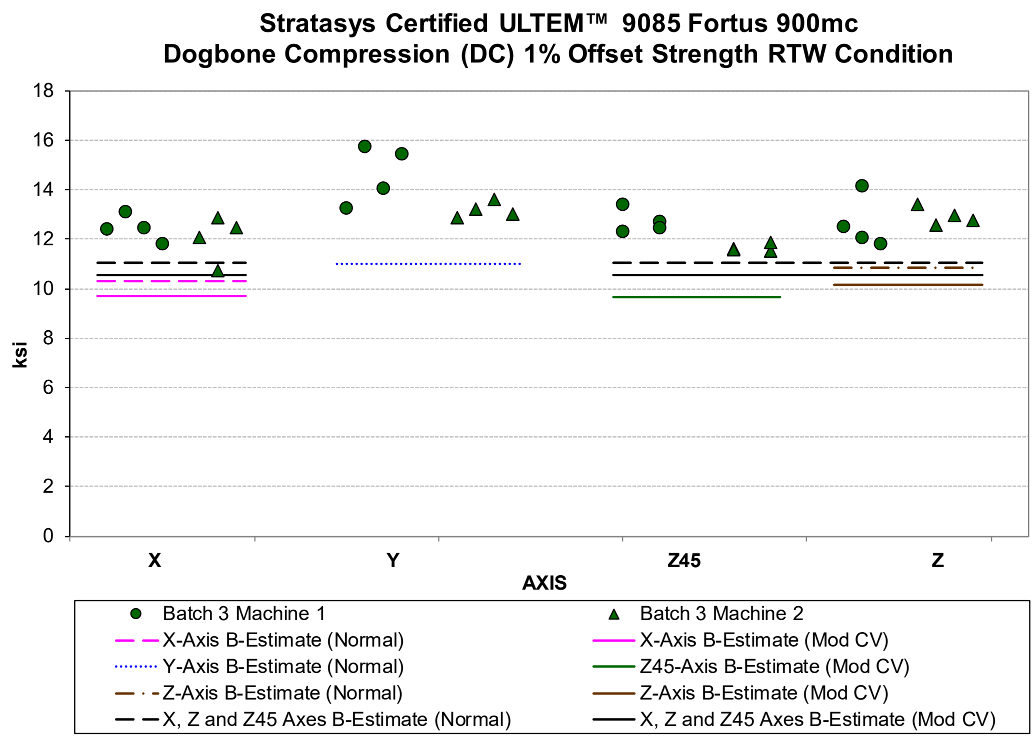



**Figure 4-24: Plot for Dogbone Compression 1% Offset Strength RTW Condition**

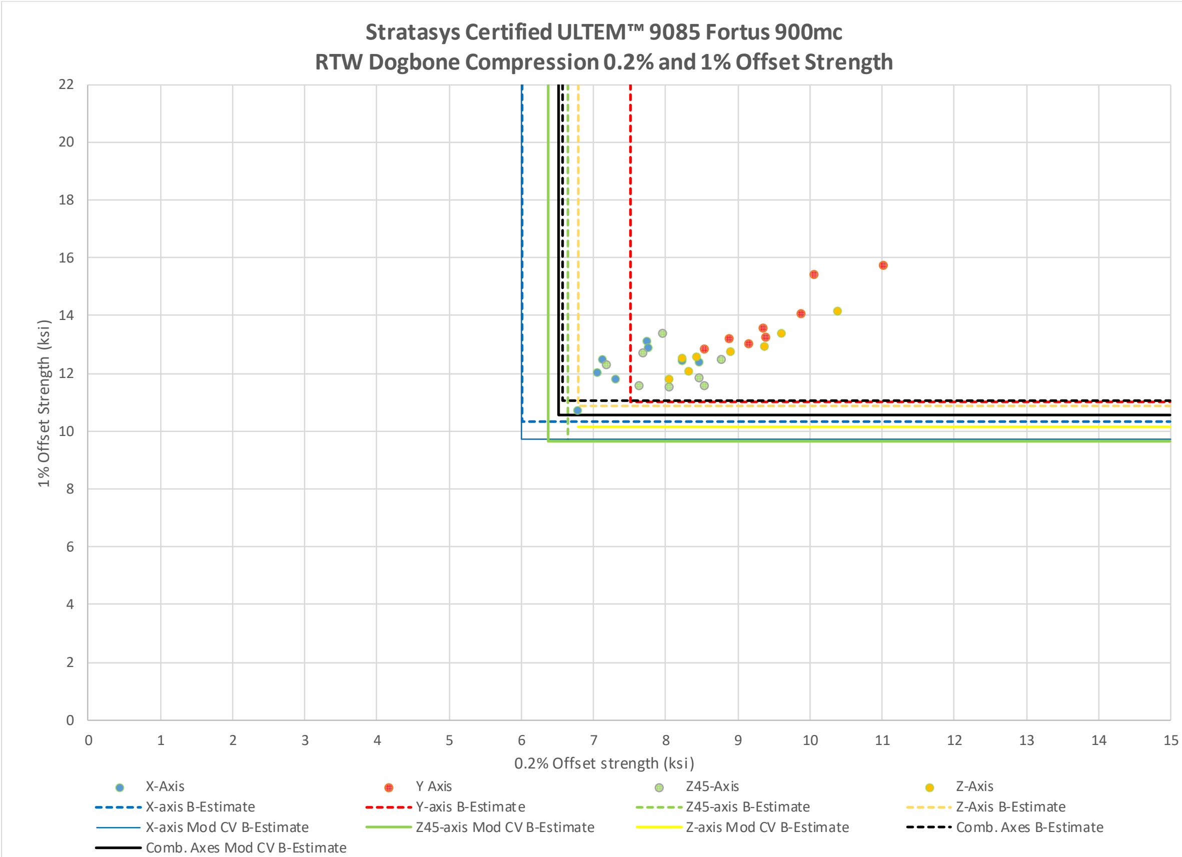



**Figure 4-25: Plot for Dogbone Compression 0.2% and 1% Offset Strength RTW Condition**

| | 0.2% Offset Strength | | | | | 1% Offset Strength | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X and Z45-Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X, Z, and Z45-Axes |
| Mean | 7.560 | 9.532 | 8.030 | 8.910 | 7.795 | 12.237 | 13.904 | 12.185 | 12.775 | 12.399 |
| Stdev | 0.596 | 0.774 | 0.534 | 0.816 | 0.598 | 0.741 | 1.115 | 0.667 | 0.734 | 0.735 |
| CV | 7.886 | 8.119 | 6.648 | 9.162 | 7.673 | 6.052 | 8.017 | 5.473 | 5.748 | 5.930 |
| Mod CV | 8.000 | 8.119 | 8.000 | 9.162 | 8.000 | 8.000 | 8.017 | 8.000 | 8.000 | 8.000 |
| Min | 6.775 | 8.540 | 7.181 | 8.042 | 6.775 | 10.720 | 12.854 | 11.538 | 11.815 | 10.720 |
| Max | 8.472 | 11.010 | 8.770 | 10.377 | 8.770 | 13.133 | 15.761 | 13.411 | 14.139 | 14.139 |
| Batches | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 | 16 | 8 | 8 | 8 | 8 | 24 |
| Basis Value Estimates | | | | | | | | | | |
| B-Estimate | 6.011 | 7.521 | 6.643 | 6.788 | 6.578 | 10.312 | 11.007 | NA | 10.866 | 11.037 |
| A-Estimate | 4.926 | 6.113 | 5.671 | 5.303 | 5.720 | 8.965 | 8.979 | | 9.530 | 10.061 |
| Method | Normal | Normal with ADK Override | Normal | Normal | Normal | Normal | Normal | | Normal | Normal |
| Modified CV Basis Value Estimates | | | | | | | | | | |
| B-Estimate | 5.997 | NA | 6.370 | NA | 6.527 | 9.707 | NA | 9.665 | 10.134 | 10.561 |
| A-Estimate | 4.924 | | 5.230 | | 5.635 | 7.971 | | 7.936 | 8.321 | 9.244 |
| Method | Normal | | Normal | | Normal | Normal | | Normal | Normal | Normal |

**Table 4-15: Statistics and Basis Values for RTW Condition Data**

| Dogbone Compression (DC) Modulus Statistics RTW Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.428 | 0.407 | 0.373 | 0.373 |
| Stdev | 0.043 | 0.018 | 0.023 | 0.013 |
| CV | 10.012 | 4.523 | 6.295 | 3.498 |
| Min | 0.383 | 0.392 | 0.342 | 0.362 |
| Max | 0.497 | 0.451 | 0.404 | 0.402 |
| Batches | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 |

Table 4-16: Statistics from RTW Modulus Data

### 4.2.4 Dogbone Compression ETD1 Condition

The ETD1 condition tested only one batch of material, so the dataset lacked sufficient specimens to meet CMH-17 guidelines and only estimates are provided. The data from the X and Z45-axes were sufficiently similar to be combined to compute basis value estimates for the 0.2% Offset Strength, but no two axes were similar enough to combine for the 1% Offset Strength data. All datasets had an adequate fit to the normal distribution to compute estimates of basis values. The Y-axis 0.2% Offset dataset had a CV over 8%, so modified CV basis values were not computed for that dataset.

There was one outlier. The lowest value from batch one machine two in the Y-axis 0.2% Offset Strength dataset was an outlier for machine two and the machine batch combination but not batch one or the ETD1 condition. It was retained for this analysis.

Statistics and basis value estimates are given for the strength data in Table 4-17 and for the modulus data in Table 4-18. The data and B-estimates are shown graphically for 0.2% Offset Strength in Figure 4-26, for 1% Offset Strength in Figure 4-27, and for both together in Figure 4-28.

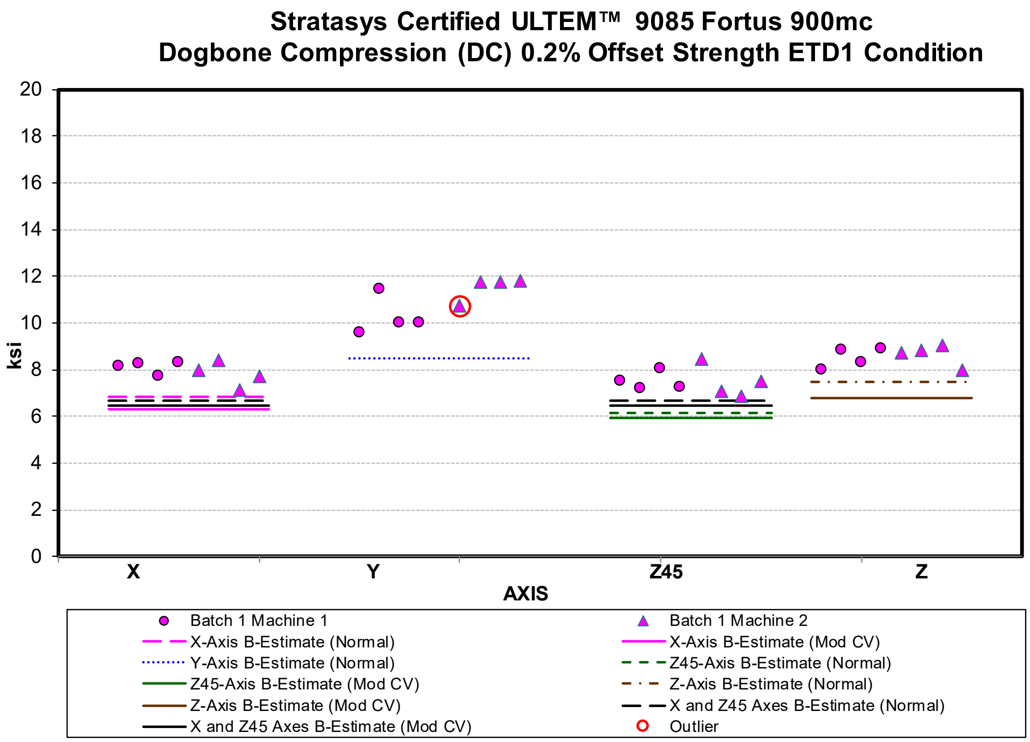



**Figure 4-26: Plot for Dogbone Compression 0.2% Offset Strength ETD1 Condition**

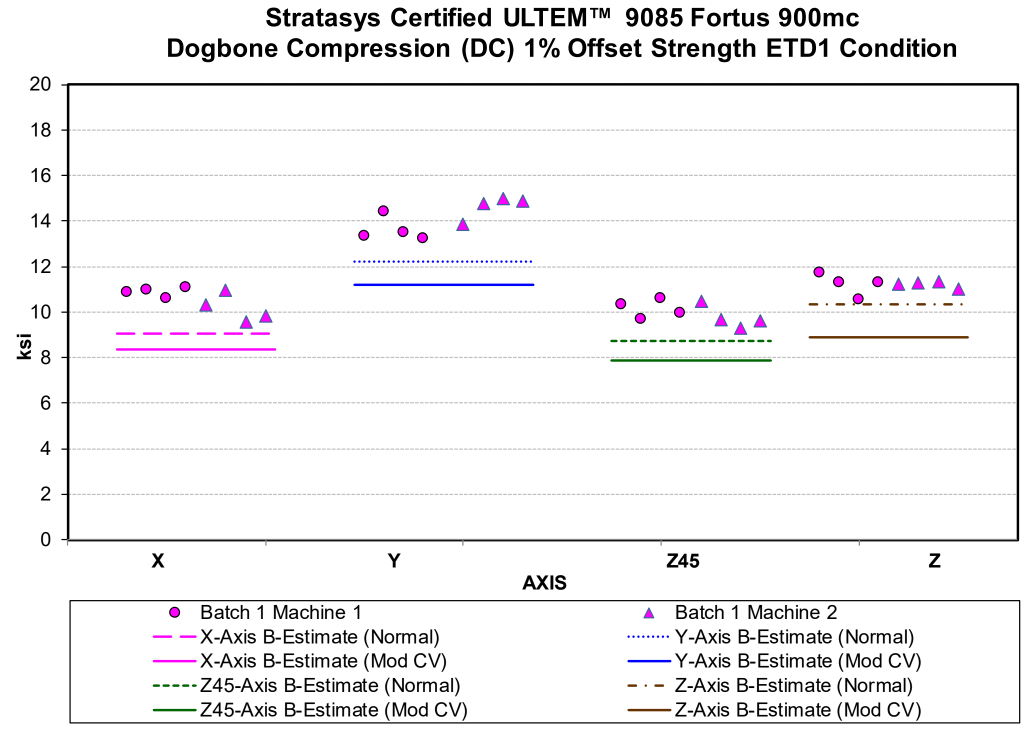



**Figure 4-27: Plot for Dogbone Compression 1% Offset Strength ETD1 Condition**

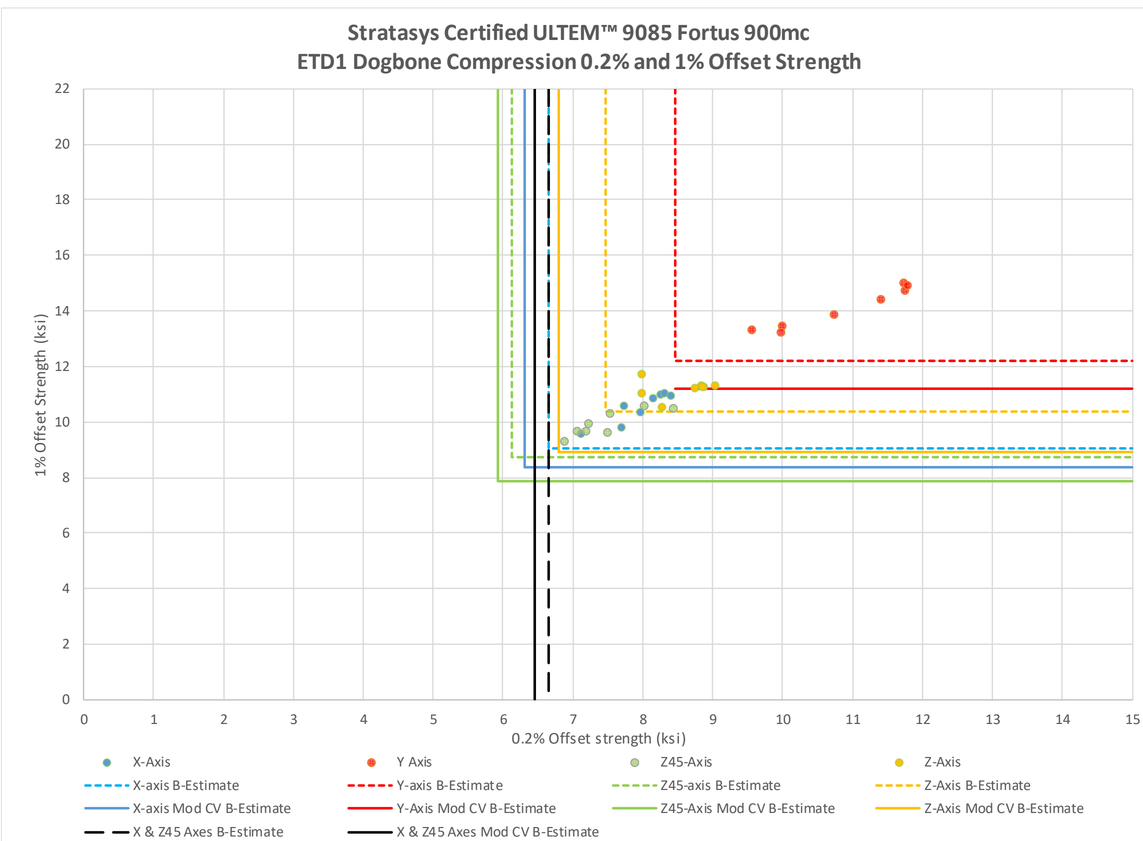



**Figure 4-28: Plot for Dogbone Compression 0.2% and 1% Offset Strength ETD1 Condition**

| Dogbone Compression (DC) Basis Values and Statistics - ETD1 Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X & Z45 Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 7.952 | 10.866 | 7.478 | 8.573 | 7.715 | 10.520 | 14.113 | 9.941 | 11.210 |
| Stdev | 0.423 | 0.923 | 0.521 | 0.423 | 0.520 | 0.568 | 0.732 | 0.464 | 0.329 |
| CV | 5.318 | 8.494 | 6.967 | 4.933 | 6.734 | 5.396 | 5.189 | 4.668 | 2.935 |
| Mod CV | 8.000 | 8.494 | 8.000 | 8.000 | 8.000 | 8.000 | 8.000 | 8.000 | 8.000 |
| Min | 7.122 | 9.548 | 6.879 | 7.985 | 6.879 | 9.554 | 13.216 | 9.289 | 10.555 |
| Max | 8.395 | 11.780 | 8.443 | 9.028 | 8.443 | 11.048 | 14.983 | 10.564 | 11.721 |
| Batches | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 | 16 | 8 | 8 | 8 | 8 |
| Basis Values and Estimates | | | | | | | | | |
| B-Estimate | 6.853 | 8.467 | 6.124 | 7.474 | 6.658 | 9.044 | 12.210 | 8.735 | 10.355 |
| A-Estimate | 6.083 | 6.788 | 5.176 | 6.704 | 5.912 | 8.012 | 10.878 | 7.891 | 9.756 |
| Method | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Estimate | 6.308 | NA | 5.932 | 6.800 | 6.460 | 8.345 | 11.195 | 7.886 | 8.892 |
| A-Estimate | 5.179 | | 4.871 | 5.584 | 5.577 | 6.852 | 9.192 | 6.475 | 7.302 |
| Method | Normal | | Normal | Normal | Normal | Normal | Normal | Normal | Normal |

**Table 4-17: Statistics and Basis Values for ETD1 Condition Data**

| Dogbone Compression (DC) Modulus Statistics ETD1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.355 | 0.400 | 0.331 | 0.349 |
| Stdev | 0.018 | 0.011 | 0.008 | 0.021 |
| CV | 5.001 | 2.643 | 2.451 | 6.106 |
| Min | 0.325 | 0.383 | 0.317 | 0.329 |
| Max | 0.373 | 0.415 | 0.343 | 0.397 |
| Batches | 1 | 1 | 1 | 1 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 8 | 8 | 8 | 8 |

**Table 4-18: Statistics from ETD1 Modulus Data**

### 4.2.5 Dogbone Compression ETW1 Condition

Data from the X and Z45-axes could be combined and data from the Y and Z-axes could be combined to compute basis values for the 0.2% Offset Strength measurements. No axes were sufficiently similar to be combined for the 1% Offset Strength measurements.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six machine batch combinations for strength measurements for all datasets. The ANOVA method was required to compute those basis values and estimates. Modified CV basis values could not be computed for any dataset in the ETW1 condition due to failure to pass the ADK test and/or having a CV greater than 8%.

The Z45-axis dataset for batch one machine one had unusually low values for both the 1% Offset and the 0.2% Offset in ETW1 condition. No specific reason was found for this difference, so this data is included in the analysis.

There were seven outliers in the ETW1 condition. The lowest value in the X-axis batch one machine one 0.2% Offset dataset was an outlier for batch one, but not for machine one, the ETW1 condition, or the machine batch combination. The largest value in the X-axis batch two machine one dataset was an outlier for batch two in the 0.2% Offset Strength dataset and an outlier for the machine batch combination in the 1% Offset Strength dataset. It was not an outlier for the machine or machine batch combination in the 0.2% Offset Strength dataset, or for the batch or machine in the 1% Offset Strength dataset, or for the ETW1 condition in either dataset.

The lowest strength value in Y-axis batch one machine two was an outlier for machine batch combination in both the 0.2% Offset (combined axes only) and the 1% Offset, but not for batch one or machine two or for the ETW1 condition.

The largest strength value in Z45-axis batch two machine two was an outlier for the machine batch combination in the 0.2% Offset but not for 1% Offset and not for batch two or machine two or for the ETW1 condition.

The Z-axis had three outliers. The lowest strength value in batch one machine two 0.2% Offset was an outlier for the batch one machine two combination but not for batch one or machine two or the ETW1 condition. The lowest strength value in batch three machine two was an outlier for both the 0.2% Offset and 1% Offset datasets for machine two and the 1% Offset value was also an outlier for batch three. It was not an outlier for the machine batch combination or for the ETW1 condition. The lowest value in the batch one machine two 1% Offset dataset was an outlier for the machine batch combination, but not for batch one or machine two or the ETW1 condition. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-19 and for the modulus data in Table 4-20. The data, B-estimates and B-basis values are shown graphically for

0.2% Offset Strength in Figure 4-29, for 1% Offset Strength in Figure 4-30, and for both together in Figure 4-31.

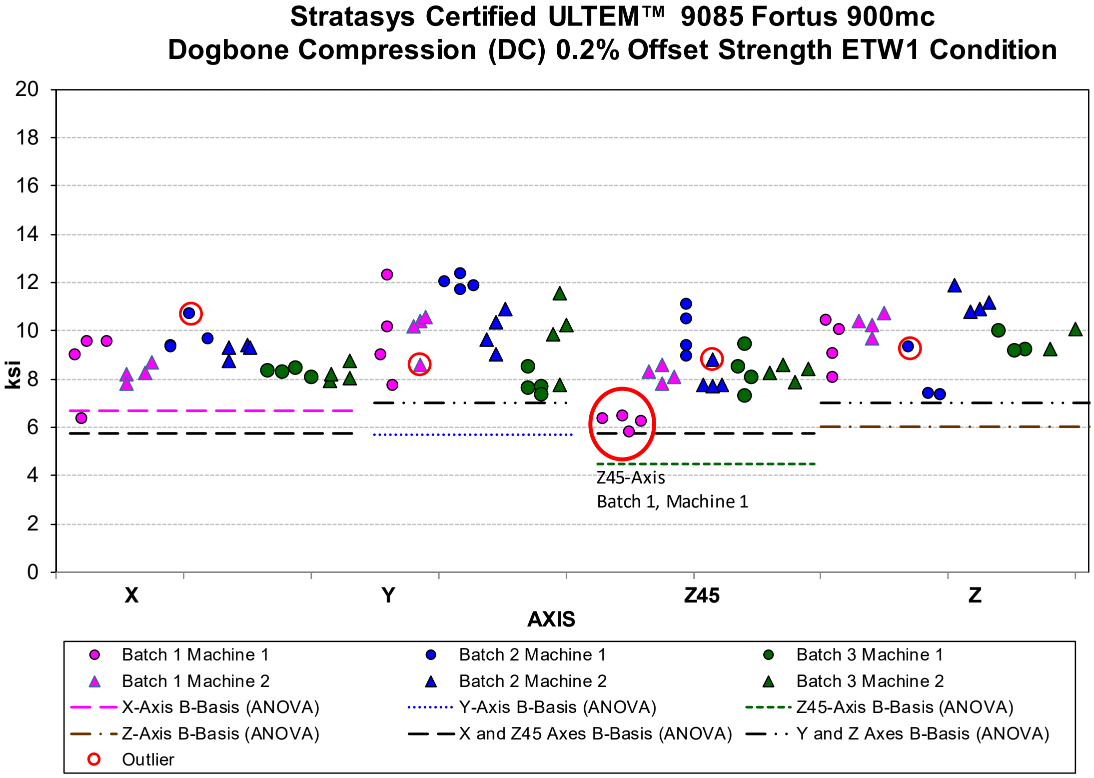



**Figure 4-29: Plot for Dogbone Compression 0.2% Offset Strength ETW1 Condition**

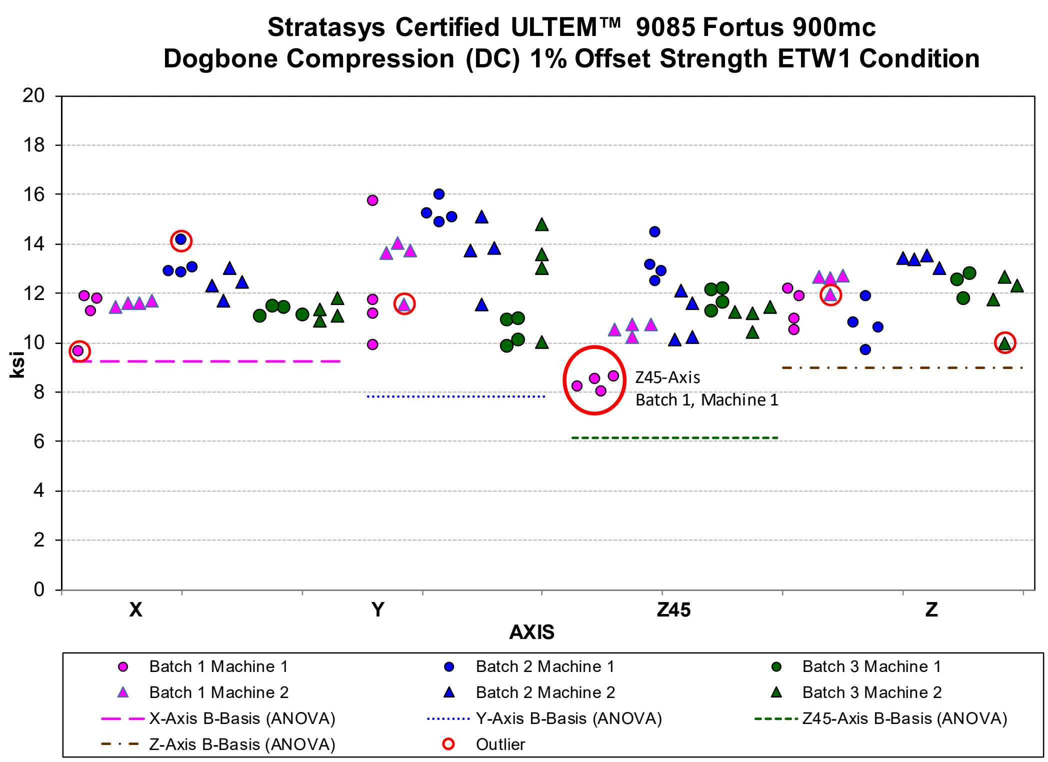


**Figure 4-30: Plot for Dogbone Compression 1% Offset Strength ETW1 Condition**

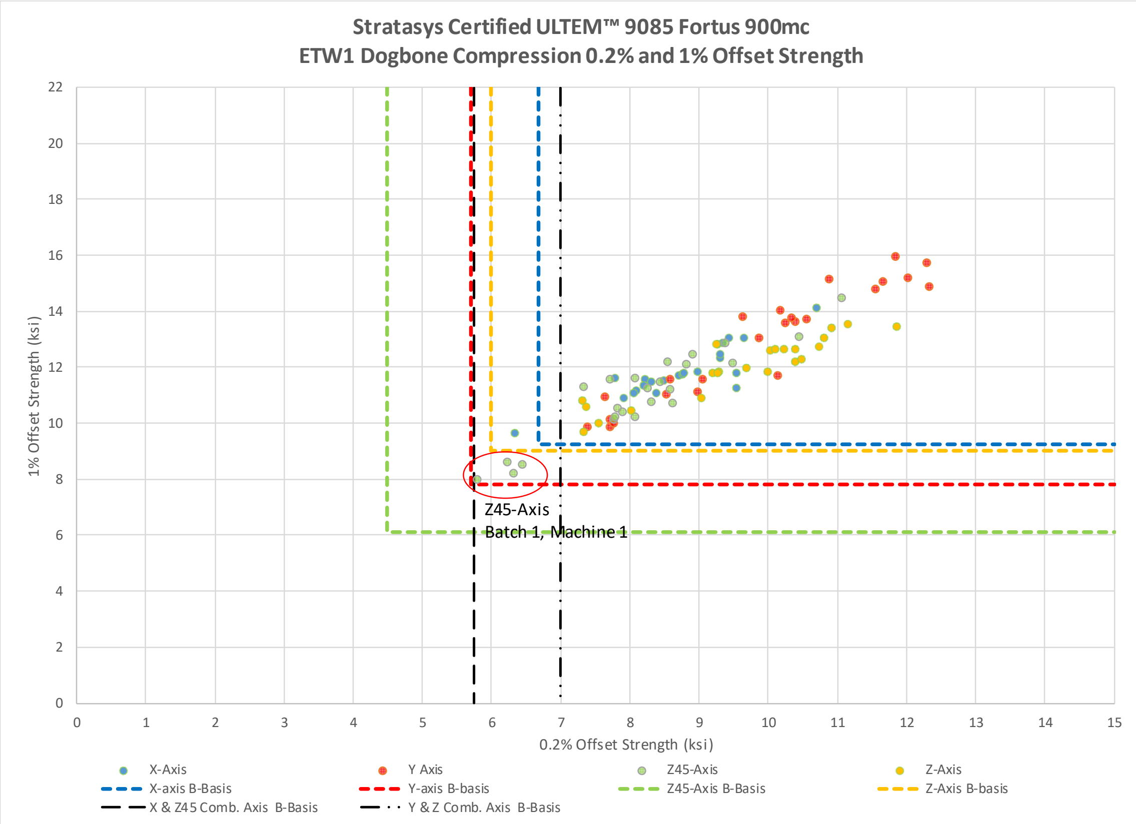



**Figure 4-31: Plot for Dogbone Compression 0.2% and 1% Offset Strength ETW1 Condition**

| Dogbone Compression (DC) Basis Values and Statistics - ETW1 Condition | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X- & Z45-Axes | Y- & Z-Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 8.721 | 9.884 | 8.168 | 9.582 | 8.444 | 9.736 | 11.816 | 12.925 | 11.010 | 11.989 |
| Stdev | 0.864 | 1.596 | 1.244 | 1.312 | 1.096 | 1.456 | 0.912 | 2.023 | 1.591 | 1.104 |
| CV | 9.904 | 16.143 | 15.229 | 13.697 | 12.974 | 14.955 | 7.720 | 15.656 | 14.447 | 9.209 |
| Mod CV | 9.904 | 16.143 | 15.229 | 13.697 | 12.974 | 14.955 | 7.860 | 15.656 | 14.447 | 9.209 |
| Min | 6.337 | 7.378 | 5.793 | 7.303 | 5.793 | 7.303 | 9.632 | 9.876 | 8.012 | 9.687 |
| Max | 10.689 | 12.319 | 11.058 | 11.863 | 11.058 | 12.319 | 14.122 | 15.965 | 14.470 | 13.525 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 23 | 48 | 47 | 24 | 24 | 24 | 23 |
| Basis Values and Estimates | | | | | | | | | | |
| B-Basis | 6.678 | 5.705 | 4.493 | 5.997 | 5.741 | 7.005 | 9.265 | 7.805 | 6.128 | 9.001 |
| A-Estimate | 5.248 | 2.807 | 1.968 | 3.519 | 3.846 | 5.027 | 7.505 | 4.245 | 2.780 | 6.935 |
| Method | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA |

**Table 4-19: Statistics and Basis Values for ETW1 Condition Data**

| Dogbone Compression (DC) Modulus Statistics ETW1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.426 | 0.418 | 0.373 | 0.380 |
| Stdev | 0.039 | 0.050 | 0.032 | 0.022 |
| CV | 9.076 | 11.857 | 8.707 | 5.817 |
| Min | 0.353 | 0.333 | 0.323 | 0.333 |
| Max | 0.483 | 0.497 | 0.425 | 0.433 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-20: Statistics from ETW1 Modulus Data

## 4.3 Flex (F)

Flex reported two properties: strength and modulus. Tests were performed in three conditions: CTD, RTD, and ETW1. A box plot of the Flex strength measurements by axis and condition is shown in Figure 4-32.

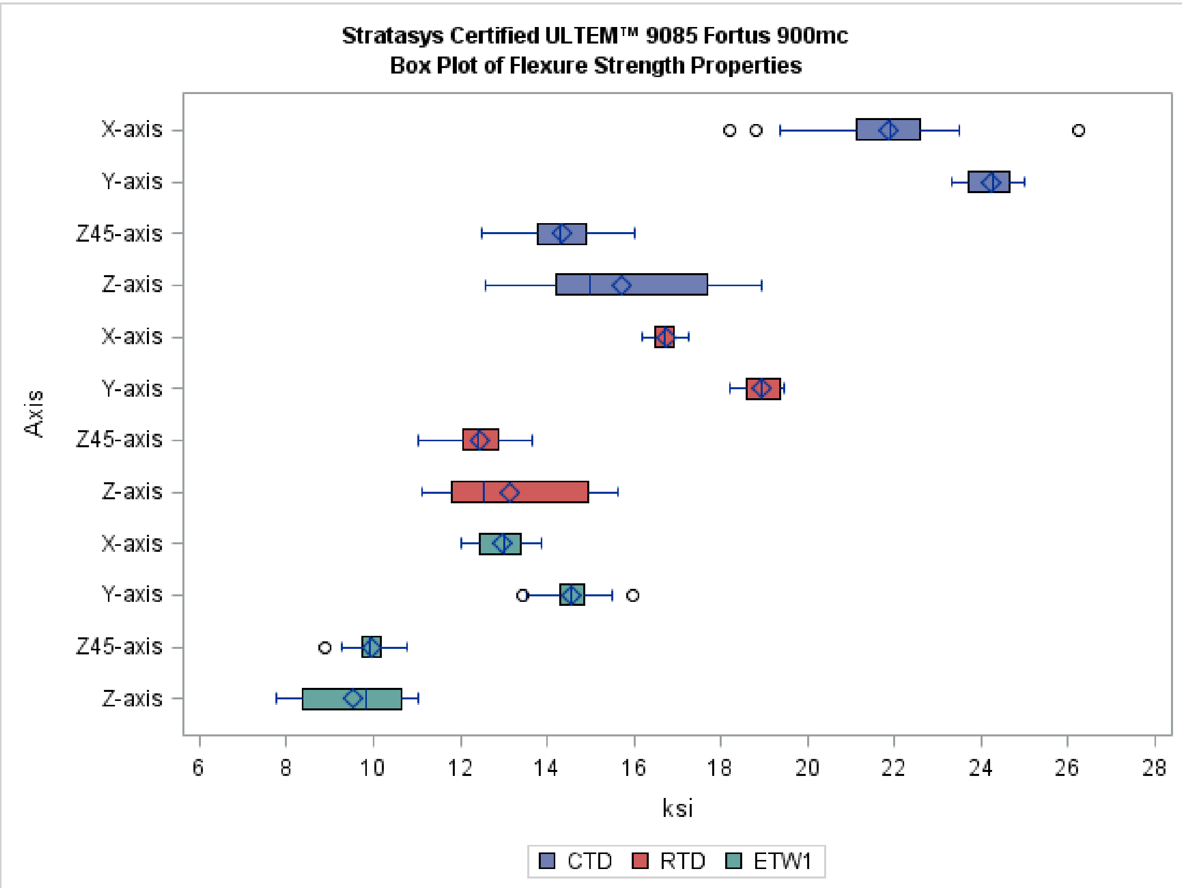



**Figure 4-32: Box Plot for Flex Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. With only one exception (the Z and Z45-axes for the ETW1 condition) all conditions and axes showed statistically significant differences. Basis values were computed for the Z and Z45-axes combined dataset of multiple axes for the ETW1 condition, but basis values were computed individually for all other axes and conditions. The Y-axis strength values were consistently higher across all three conditions.

Modified CV basis values are provided when applicable, but could not be applied to the Z-axis due to the CV being above 8%. There were a total of ten statistical outliers identified in the Flex datasets. All outliers were retained for this analysis.

### 4.3.1 Flex CTD Condition

The X-axis failed the normality test, but the Weibull distribution showed an adequate fit, so it was used to compute basis values. After applying the transformation for the modified CV approach, it had an adequate fit to the normal distribution so modified CV basis values are provided for that axis.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six machine batch combinations for Strength measurements for the Z45 and Z-axes CTD datasets. The ANOVA method was required to compute those basis values and estimates. Modified CV basis values could not be computed for the Z-axis because it had a CV greater than 8%. Modified CV basis values were computed for the Z45-axis by pooling the CTD and RTD conditions.

There were six outliers in the CTD condition, one for the X-axis, two for the Y-axis and three for the Z-axis. All outliers were retained for this analysis. The lowest strength value in the batch two machine two dataset for the X-axis data is an outlier for batch two and for machine two, but not for the CTD condition or the machine batch combination. The largest strength value in batch one machine one for the Y-axis data is an outlier for machine one, but not for batch one, the machine batch combination or the CTD condition. The lowest strength value in the batch three machine one dataset for the Y-axis data is an outlier for batch three but not for machine one, the machine batch combination or the Y-axis. The largest strength value in batch one machine one for the Z-axis data is an outlier for batch one and the batch one machine one combination, but not for machine one or the CTD condition. The highest strength value in batch two machine one for the Z-axis data is an outlier for the batch machine combination, but not for batch two, machine one or the CTD condition. The lowest strength value in batch three machine one for the Z-axis data is an outlier for the batch machine combination, but not for batch three, machine one or the CTD condition.

Statistics, basis values and estimates are given for the strength data in Table 4-21 and for the modulus data in Table 4-22. The data and B-basis values are shown graphically in Figure 4-33.

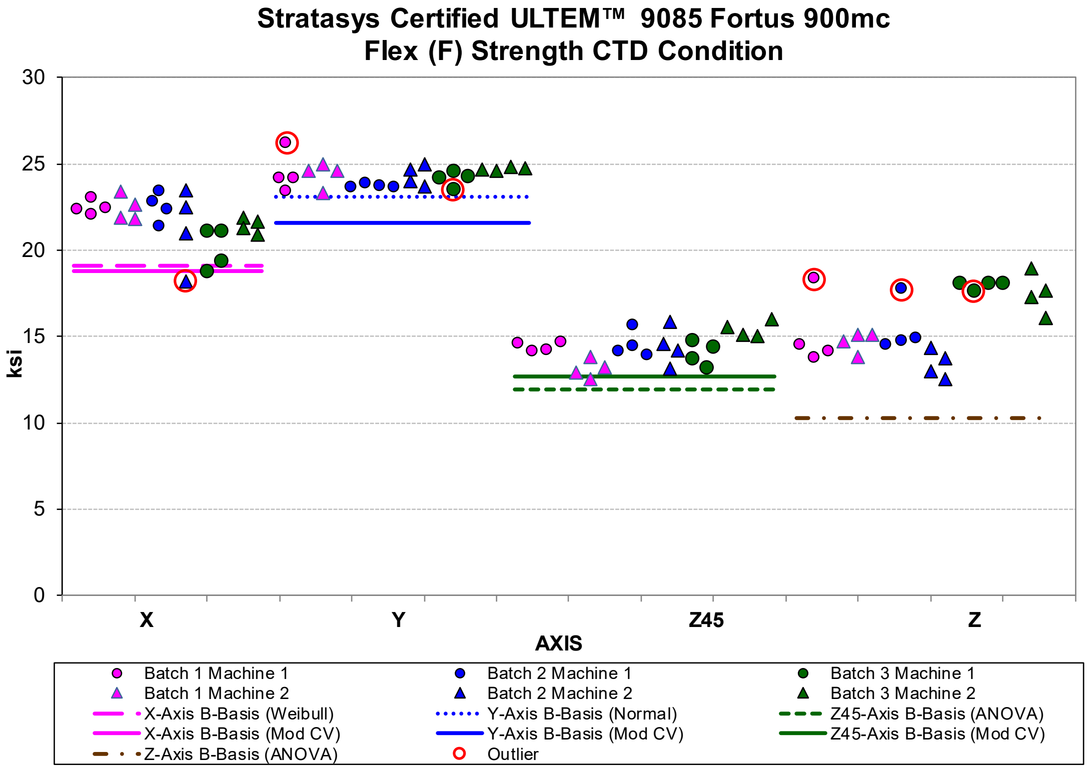



Figure 4-33: Plot for Flex CTD Strength

| Flex Strength (ksi) Basis Values and Statistics CTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 21.693 | 24.300 | 14.321 | 15.695 |
| Stdev | 1.363 | 0.660 | 0.936 | 1.961 |
| CV | 6.283 | 2.716 | 6.535 | 12.492 |
| Mod CV | 7.142 | 6.000 | 7.267 | 12.492 |
| Min | 18.211 | 23.337 | 12.514 | 12.560 |
| Max | 23.471 | 26.220 | 16.019 | 18.950 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | |
| B-Basis | 19.104 | 23.078 | 11.926 | 10.250 |
| A-Estimate | 16.461 | 22.201 | 10.263 | 6.491 |
| Method | Weibull | Normal | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | |
| B-Basis | 18.822 | 21.599 | 12.673 | NA |
| A-Estimate | 16.764 | 19.662 | 11.530 | |
| Method | Normal | Normal | pooled | |

Table 4-21: Statistics and Basis Values for Flex CTD Strength Data

| Flex (F) Modulus Statistics CTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.406 | 0.421 | 0.360 | 0.374 |
| Stdev | 0.011 | 0.021 | 0.012 | 0.017 |
| CV | 2.748 | 4.969 | 3.307 | 4.678 |
| Min | 0.390 | 0.393 | 0.344 | 0.348 |
| Max | 0.431 | 0.457 | 0.384 | 0.405 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-22: Statistics from Flex CTD Modulus Data

### 4.3.2 Flex RTD Condition

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six machine batch combinations for Strength measurements for the Y, Z and Z45-axes RTD datasets. The ANOVA method was required to compute those basis values and estimates. No modified CV basis values could be computed for the Z-axis data because it had a CV greater than 8% or for the X and Y-axes data because those datasets failed the normality test after applying the modified CV transformation to the dataset.

There was one outlier in the RTD condition. The lowest strength value in batch one machine two for the Z-axis data was an outlier for batch one but not for machine two, the batch machine combination, or the RTD condition. It was retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-23 and for the modulus data in Table 4-24. The data and B-basis values are shown graphically in Figure 4-34.

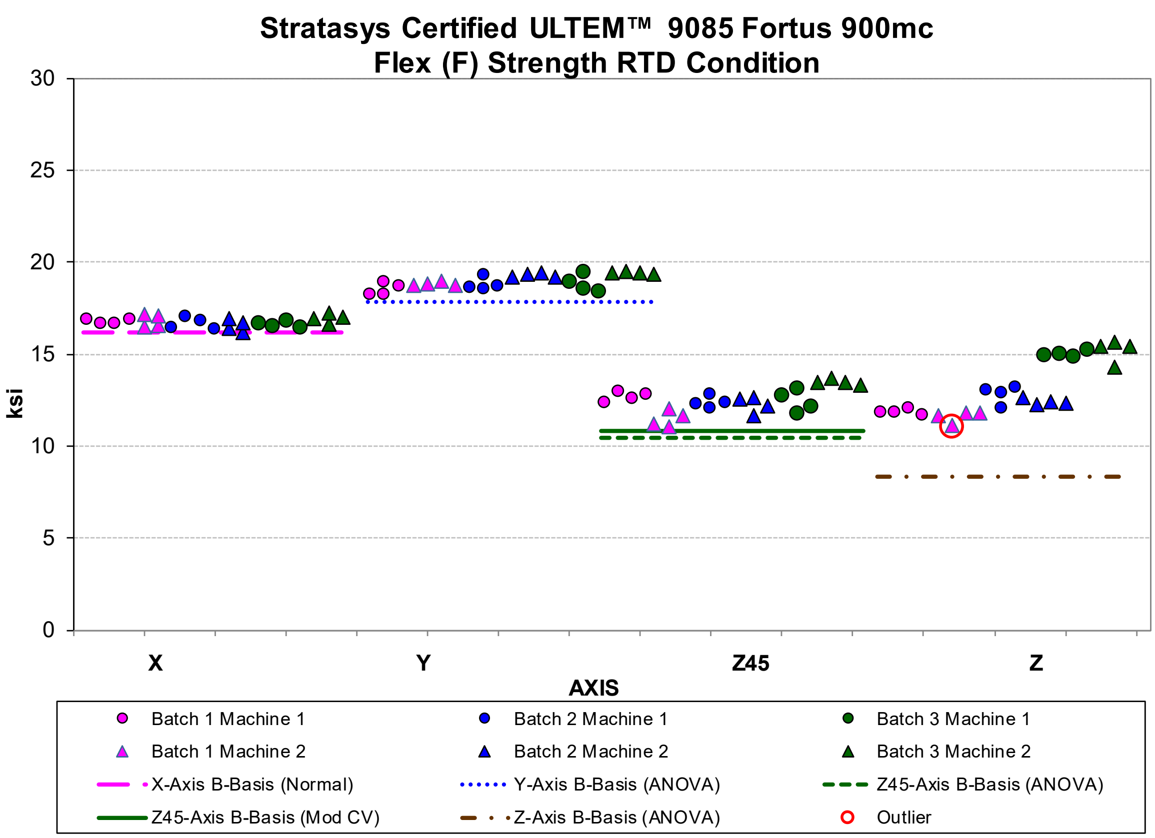



Figure 4-34: Plot for Flex RTD Strength

| Flex Strength (ksi) Basis Values and Statistics RTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 16.725 | 18.943 | 12.452 | 13.133 |
| Stdev | 0.281 | 0.408 | 0.699 | 1.517 |
| CV | 1.677 | 2.154 | 5.613 | 11.550 |
| Mod CV | 6.000 | 6.000 | 6.807 | 11.550 |
| Min | 16.177 | 18.220 | 11.035 | 11.103 |
| Max | 17.256 | 19.467 | 13.661 | 15.627 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | |
| B-Basis | 16.205 | 17.855 | 10.455 | 8.331 |
| A-Estimate | 15.833 | 17.101 | 9.079 | 5.046 |
| Method | Normal | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | |
| B-Basis | NA | NA | 10.804 | NA |
| A-Estimate | | | 9.662 | |
| Method | | | pooled | |

Table 4-23: Statistics and Basis Values for Flex RTD Strength Data

| Flex(F) Modulus Statistics RTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.353 | 0.382 | 0.314 | 0.333 |
| Stdev | 0.007 | 0.007 | 0.010 | 0.008 |
| CV | 2.107 | 1.928 | 3.290 | 2.265 |
| Min | 0.341 | 0.369 | 0.298 | 0.321 |
| Max | 0.367 | 0.394 | 0.335 | 0.347 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-24: Statistics from Flex RTD Modulus Data

### 4.3.3 Flex ETW1 Condition

Data from the Z and Z45-axes were sufficiently similar to be combined for the purpose of computing basis values. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six machine batch combinations for strength measurements for all of the Flex ETW1 datasets. The ANOVA method was required to compute those basis values and estimates. The X and Y-axes passed the ADK test after the modified CV transformation, so modified CV basis values could be provided. No modified CV basis values could be computed for the strength data in the Z-axis and combined Z and Z45-axes dataset because it had a CV greater than 8%.

There were three outliers in the ETW1 condition, one each in the X, Z and Z45-axes. The lowest strength value in batch one machine two of the X-axis dataset was an outlier for the machine batch combination, but not for batch one, machine two, or the ETW1 condition. The lowest strength value in batch three machine one of the Z45-axis dataset was an outlier for the machine batch combination, but not for batch three, machine one, or the ETW1 condition. The lowest strength value in batch two machine one of the Z-axis dataset was an outlier for batch two, but not for machine one, the machine batch combination, or the ETW1 condition. All three outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-25 and for the modulus data in Table 4-26. The data and B-basis values are shown graphically in Figure 4-35.

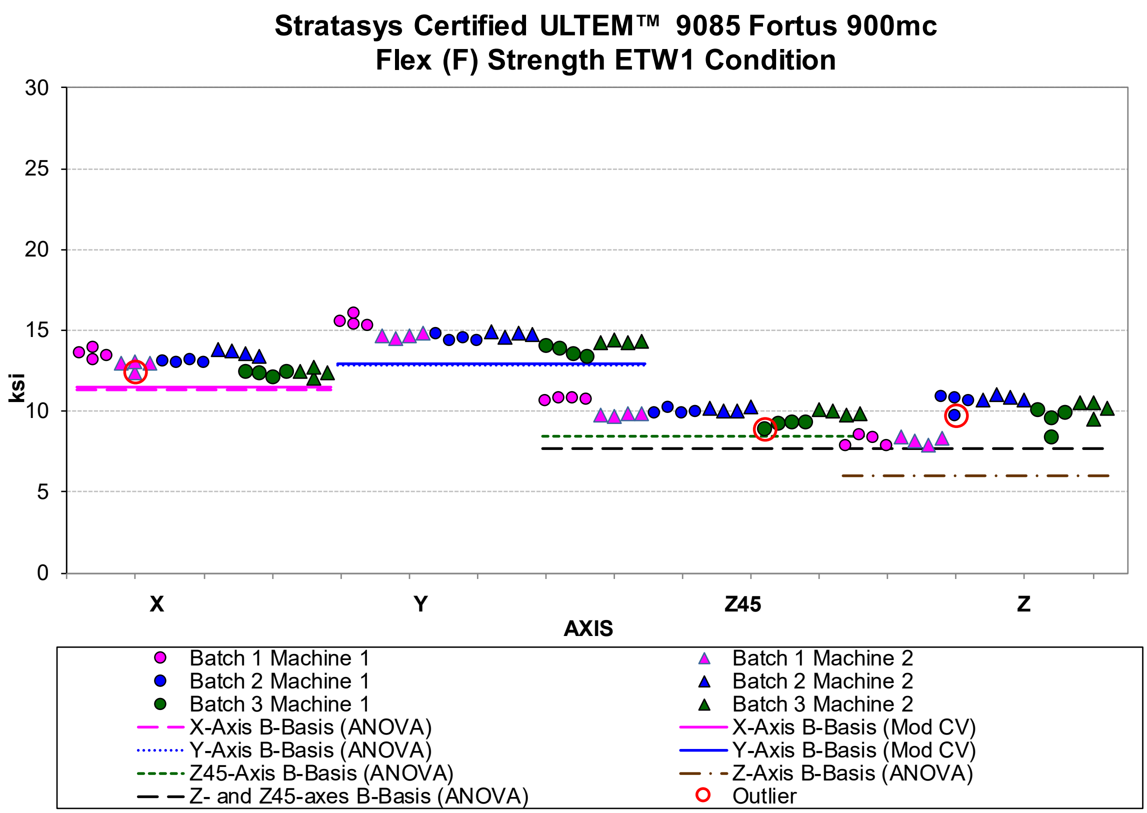



**Figure 4-35: Plot for Flex ETW1 Strength**

| Flex Strength (ksi) Basis Values and Statistics ETW1 Condition | | | | | |
|---|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | Z- & Z45-Axes |
| Mean | 12.955 | 14.575 | 9.951 | 9.545 | 9.748 |
| Stdev | 0.535 | 0.576 | 0.471 | 1.165 | 0.903 |
| CV | 4.131 | 3.955 | 4.736 | 12.207 | 9.262 |
| Mod CV | 6.065 | 6.000 | 6.368 | 12.207 | 9.262 |
| Min | 12.009 | 13.418 | 8.892 | 7.780 | 7.780 |
| Max | 13.867 | 15.970 | 10.787 | 11.035 | 11.035 |
| Batches | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 |
| Basis Values and Estimates | | | | | |
| B-Basis | 11.337 | 12.803 | 8.476 | 5.986 | 7.679 |
| A-Estimate | 10.228 | 11.588 | 7.466 | 3.545 | 6.218 |
| Method | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | |
| B-Basis | 11.498 | 12.955 | NA | NA | NA |
| A-Estimate | 10.455 | 11.793 | | | |
| Method | Normal | Normal | | | |

Table 4-25: Statistics and Basis Values for Flex ETW1 Strength Data

| Flex (F) Modulus Statistics ETW1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 0.326 | 0.360 | 0.282 | 0.302 |
| Stdev | 0.014 | 0.015 | 0.007 | 0.009 |
| CV | 4.172 | 4.053 | 2.635 | 2.946 |
| Min | 0.302 | 0.335 | 0.270 | 0.286 |
| Max | 0.346 | 0.380 | 0.295 | 0.318 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |

Table 4-26: Statistics from Flex ETW1 Modulus Data

## 4.4 V-Notch In-Plane Shear (VIPS)

Testing was done only on X-axis specimens for V-notch In-Plane Shear. Measurements were taken for 0.2% Offset Strength and Strength at 5% Strain in four conditions: CTD, RTD, RTW and ETW1. Ultimate Strength values were only available for the CTD and RTD conditions and only for a few of the specimens, so only estimates are provided for Ultimate Strength and only for those two conditions. A box plot of the VIPS strength measurements by axis and condition is shown in Figure 4-36.

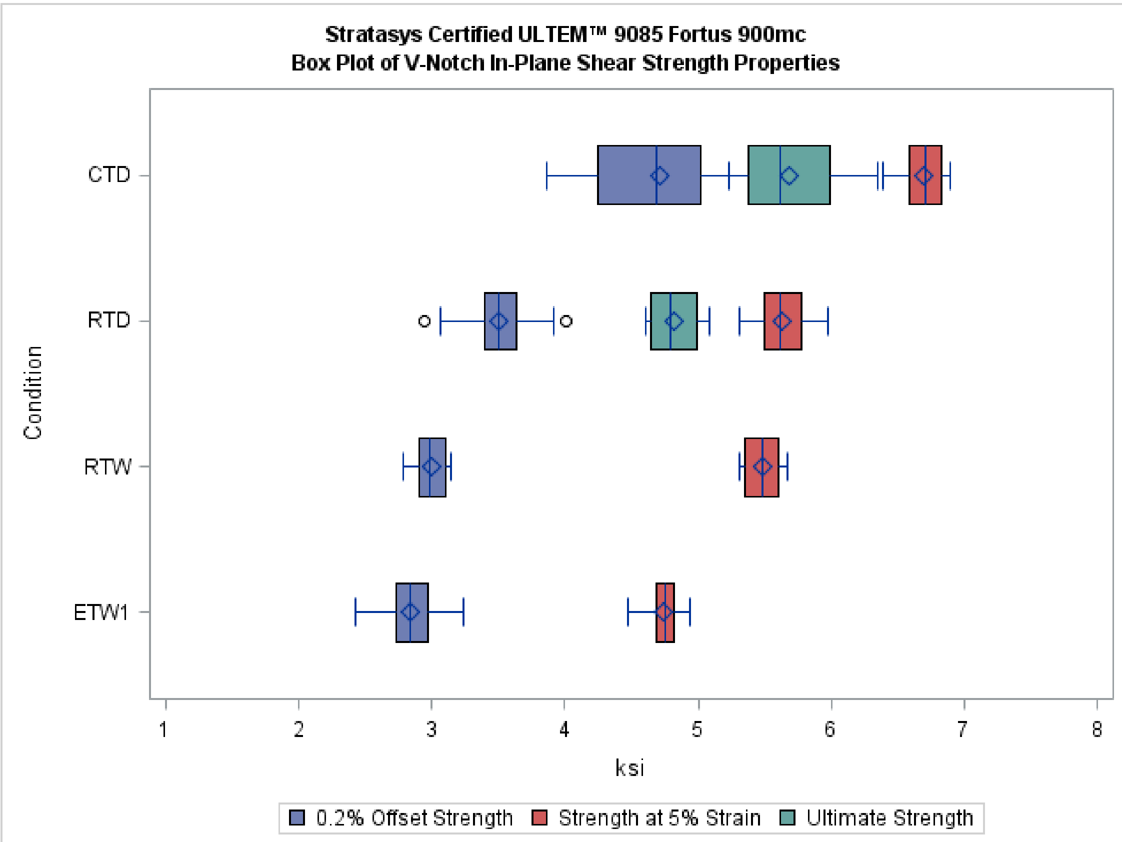



**Figure 4-36: Box Plot for X-Axis V-Notch In-Plane Shear Strength**

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six batch and machine combinations in the Strength at 5% Strain RTD condition so the ANOVA method was required to compute the basis values and estimates. The 0.2% Offset Strength data could be pooled across the RTD, RTW and ETW1 conditions. The CTD condition could not be included due to a failure of Levene's test.

Modified CV basis values are provided when applicable. The Modified CV approach could not be applied to the 0.2% Offset Strength dataset for the CTD condition due to the CV being above 8%.

There were a total of four statistical outliers identified in the VIPS datasets. Two outliers for the 0.2% Offset Strength and two outliers for the Strength at 5% Strain.

The lowest 0.2% Offset Strength value in batch one machine one for the CTD was an outlier for the batch machine combination but not for batch one, machine one, or the CTD condition. The lowest 0.2% Offset Strength value in batch one machine one for the RTD condition was an outlier for batch one but not for machine one, the machine batch combination or for the RTD condition.

The largest Strength at 5% Strain value for batch three machine two for the RTD condition was an outlier only for batch three, not machine two, the batch machine combination or the RTD condition. The largest Strength at 5% Strain value for batch two machine two for the ETW1 condition was an outlier only for the batch two machine two combination, not machine two, batch two or the RTD condition. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-27 and for the modulus data in Table 4-28. The data, B-basis values and B-estimates are shown graphically for 0.2% Offset Strength in Figure 4-37, for Strength at 5% Strain in Figure 4-38, and for Ultimate Strength in Figure 4-39.

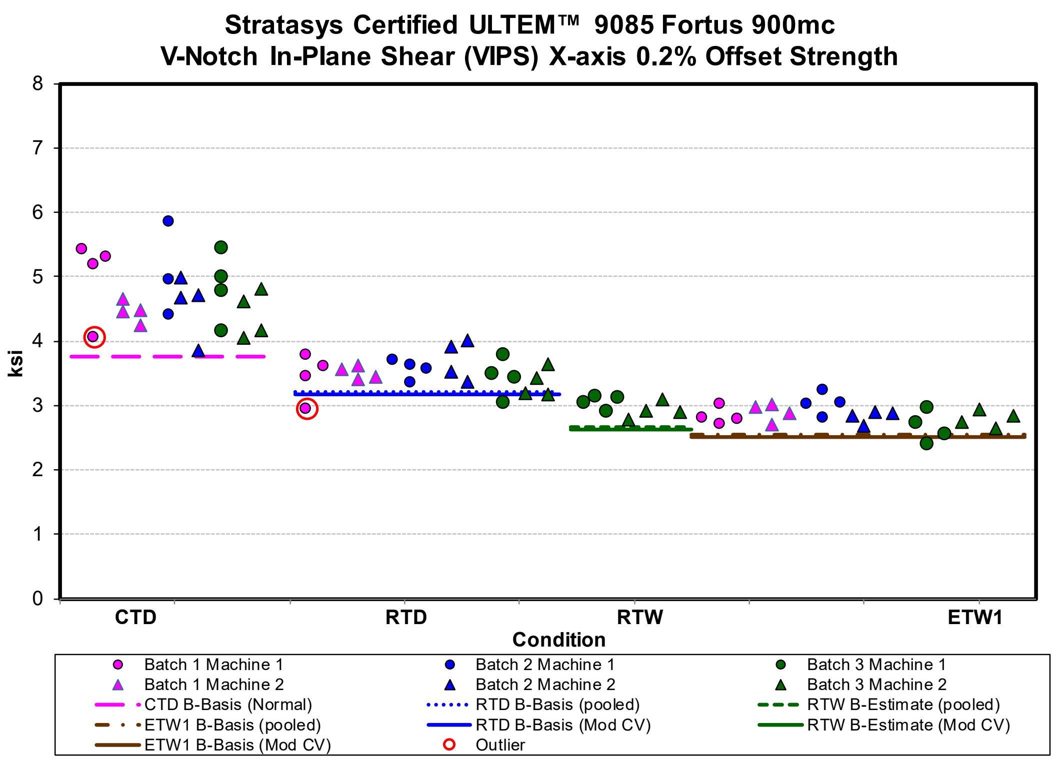


**Figure 4-37: Plot for X-Axis VIPS 0.2% Offset Strength**

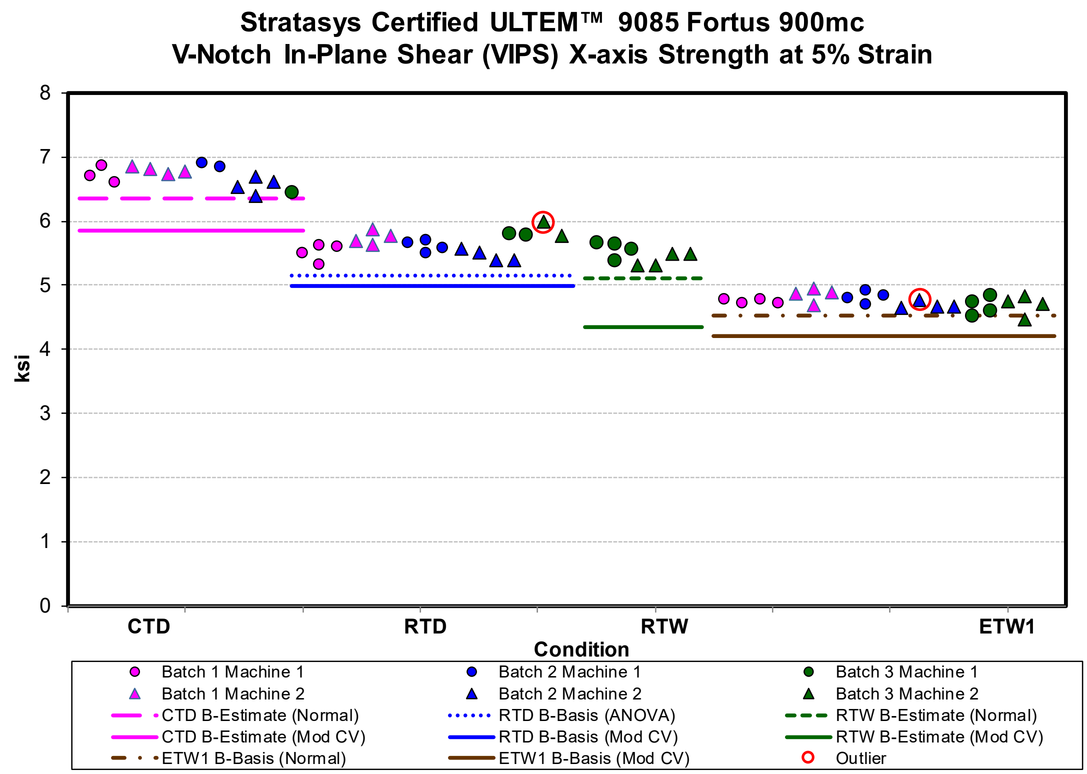


**Figure 4-38: Plot for X-Axis VIPS Strength at 5% Strain**

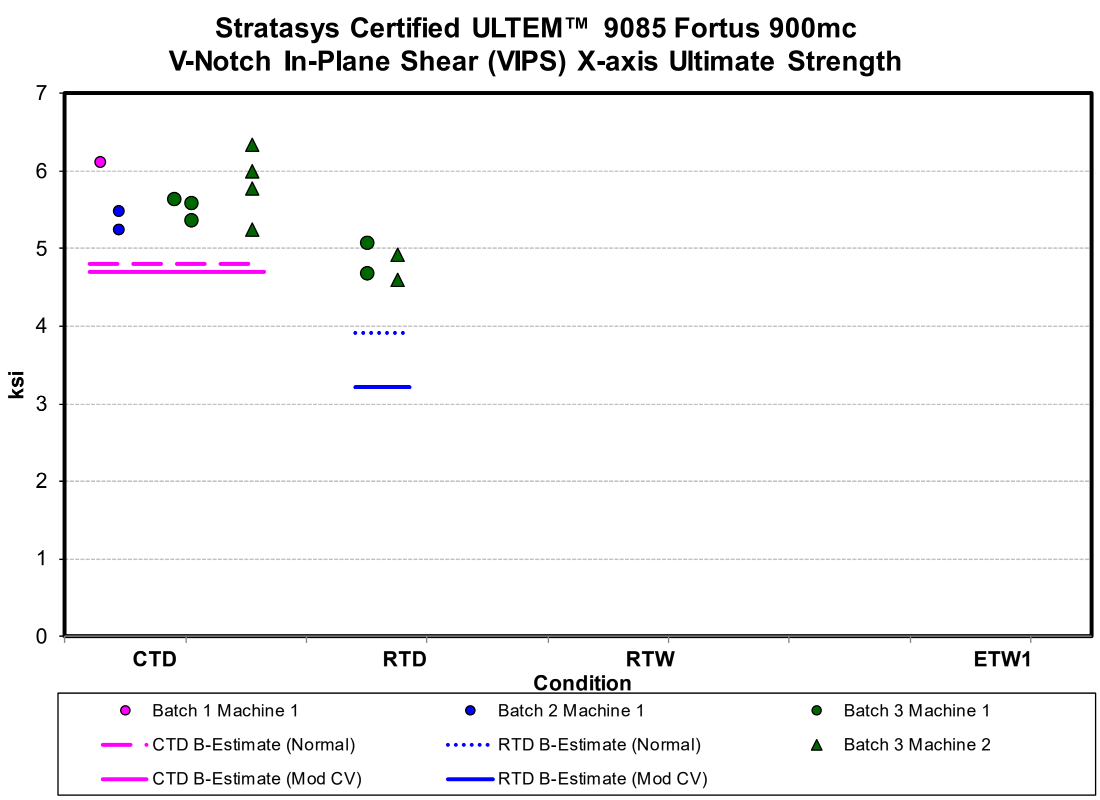


**Figure 4-39: Plot for X-Axis VIPS Ultimate Strength**

| V-Notch In-Plane Shear (VIPS) Basis Values and Statistics X-axis | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | Strength at 5% Strain | | | | Ultimate Shear Str. | |
| Condition | CTD | RTD | RTW | ETW1 | CTD | RTD | RTW | ETW1 | CTD | RTD |
| Mean | 4.710 | 3.506 | 2.994 | 2.841 | 6.693 | 5.629 | 5.485 | 4.743 | 5.679 | 4.820 |
| Stdev | 0.512 | 0.253 | 0.128 | 0.175 | 0.158 | 0.172 | 0.141 | 0.113 | 0.373 | 0.219 |
| CV | 10.877 | 7.225 | 4.285 | 6.149 | 2.355 | 3.051 | 2.568 | 2.373 | 6.566 | 4.552 |
| Mod CV | 10.877 | 7.613 | 8.000 | 7.075 | 6.000 | 6.000 | 8.000 | 6.000 | 7.283 | 8.000 |
| Min | 3.856 | 2.939 | 2.789 | 2.420 | 6.387 | 5.312 | 5.311 | 4.476 | 5.234 | 4.602 |
| Max | 5.848 | 4.013 | 3.149 | 3.231 | 6.895 | 5.982 | 5.678 | 4.943 | 6.348 | 5.080 |
| Batches | 3 | 3 | 1 | 3 | 3 | 3 | 1 | 3 | 3 | 1 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 23 | 24 | 8 | 24 | 14 | 20 | 8 | 24 | 10 | 4 |
| Basis Values and Estimates | | | | | | | | | | |
| B-Basis | 3.753 | 3.208 | | 2.543 | | 5.143 | | 4.534 | | |
| B-Estimates | | | 2.656 | | 6.360 | | 5.118 | | 4.797 | 3.922 |
| A-Estimate | 3.068 | 3.002 | 2.457 | 2.337 | 6.126 | 4.808 | 4.862 | 4.385 | 4.181 | 3.241 |
| Method | Normal | pooled | pooled | pooled | Normal | ANOVA | Normal | Normal | Normal | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | | |
| B-Basis | NA | 3.182 | | 2.517 | | 4.979 | | 4.216 | | |
| B-Estimates | | | 2.627 | | 5.845 | | 4.351 | | 4.704 | 3.215 |
| A-Estimate | | 2.959 | 2.411 | 2.294 | 5.253 | 4.516 | 3.572 | 3.838 | 4.031 | 2.105 |
| Method | | pooled | pooled | pooled | Normal | Normal | Normal | Normal | Normal | Normal |

**Table 4-27: Statistics and Basis Values for X-Axis VIPS Strength Data**

| V-Notch In-Plane Shear (VIPS) Modulus Statistics X-axis | | | | |
|---|---|---|---|---|
| Condition | CTD | RTD | RTW | ETW1 |
| Mean | 0.152 | 0.136 | 0.140 | 0.126 |
| Stdev | 0.005 | 0.008 | 0.005 | 0.003 |
| CV | 3.342 | 6.142 | 3.806 | 2.070 |
| Min | 0.141 | 0.123 | 0.134 | 0.119 |
| Max | 0.161 | 0.152 | 0.149 | 0.131 |
| Batches | 3 | 3 | 1 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 8 | 24 |

**Table 4-28: Statistics and Basis Values for X-Axis VIPS Modulus Data**

## 4.5 Open-Hole Tension (OHT)

Open-Hole Tension reported one property: Strength. Tests were performed in three conditions: CTD, RTD, and ETW1. An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. With only one exception (the X and Y-axes for the CTD condition) all conditions and axes showed statistically significant differences. Basis values were computed for the X and Y-axes combined dataset of multiple axes for the CTD condition, but basis values were computed individually for all other axes and conditions. The Y-axis data showed the greatest strength values followed by the X-axis, Z45-axis and the Z-axis in that order.

A box plot of the OHT strength measurements by axis and condition is shown in Figure 4-40.

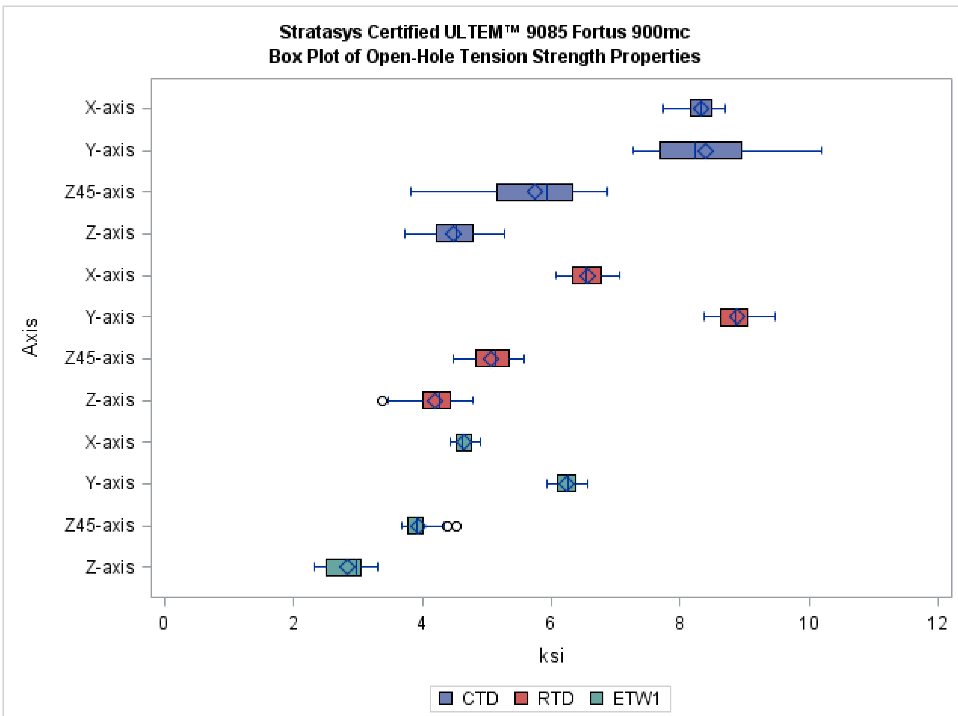



**Figure 4-40: Box Plot for OHT Strength Properties**

Modified CV basis values are provided when applicable. The Modified CV approach could not be applied to the CTD dataset combining X and Y axes because the dataset failed the Anderson-Darling k-sample test even after the modified CV transformation. The Modified CV approach could not be used with the Y-axis and Z45-axis datasets in the CTD condition and the Z-axis datasets in any condition due to the CV being above 8%.

There were a total of eight statistical outliers identified in the OHT datasets. Three in the CTD condition, three in the RTD condition and two in the ETW1 condition. All outliers were retained for this analysis.

### 4.5.1 Open-Hole Tension CTD Condition

Basis values were computed for the combined X and Y-axes dataset of multiple axes for the CTD condition. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the Y-axis and Z45-axis datasets and the combined X and Y-axes dataset so the ANOVA method was required to compute those basis values and estimates. The Modified CV approach could not be applied to the CTD dataset combining X and Y-axes because the dataset failed the Anderson-Darling k-sample test even after the modified CV transformation.

There were three outliers in the CTD datasets. The lowest Y-axis value in the batch three machine two dataset was an outlier for the combined X and Y-axes dataset for the batch three machine two combination, but not for batch three, machine two or the CTD condition. The lowest value in the batch three machine one dataset of the Z45-axis was an outlier for the batch three machine one combination but not for batch three, machine one or the CTD condition. The largest Z-axis value in the batch two machine two CTD condition dataset was an outlier for that machine batch combination, but not for batch two, machine two or the CTD condition. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-29. The data, B-basis values and B-estimates are shown graphically in Figure 4-41.

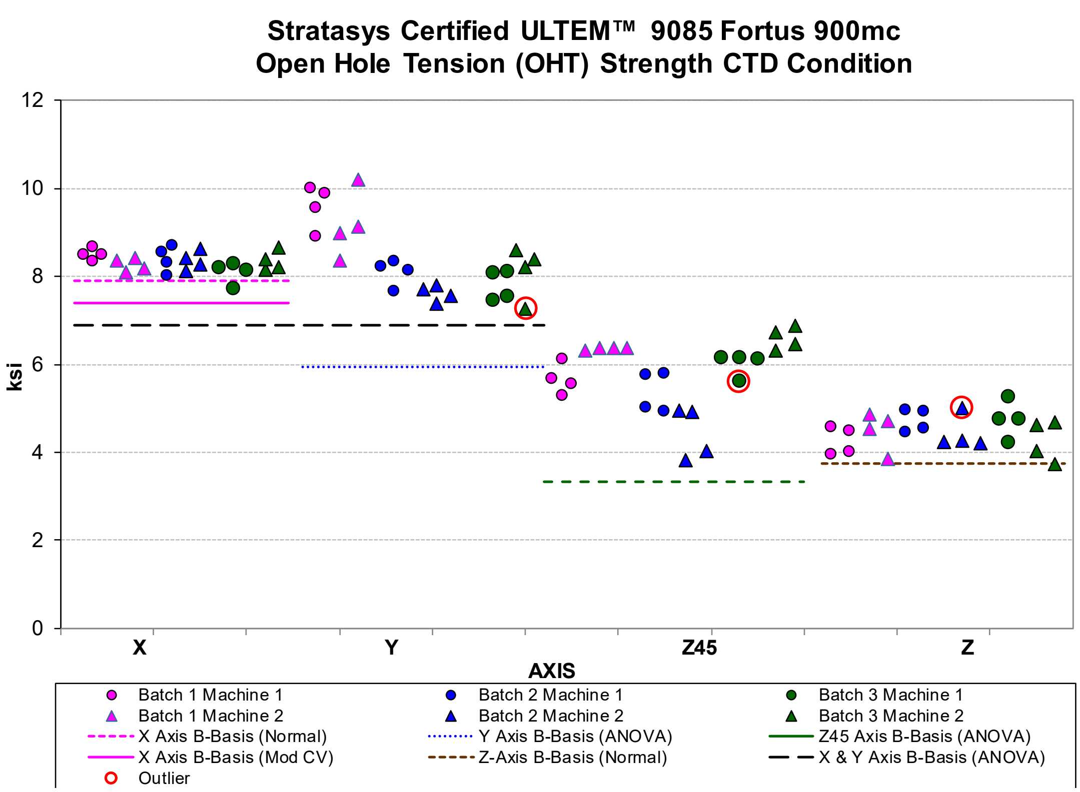



**Figure 4-41: Plot for OHT CTD Strength**

| Open Hole Tension (OHT) Strength Basis Values and Statistics CTD Condition | | | | | |
|---|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X- & Y-Axes |
| Mean | 8.327 | 8.399 | 5.737 | 4.487 | 8.363 |
| Stdev | 0.230 | 0.851 | 0.798 | 0.401 | 0.618 |
| CV | 2.762 | 10.135 | 13.911 | 8.945 | 7.389 |
| Mod CV | 6.000 | 10.135 | 13.911 | 8.945 | 7.695 |
| Min | 7.743 | 7.269 | 3.813 | 3.728 | 7.269 |
| Max | 8.689 | 10.189 | 6.872 | 5.283 | 10.189 |
| Batches | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 |
| Basis Values and Estimates | | | | | |
| B-Basis | 7.901 | 5.952 | 3.344 | 3.744 | 6.888 |
| A-Estimate | 7.595 | 4.266 | 1.701 | 3.211 | 5.850 |
| Method | Normal | ANOVA | ANOVA | Normal | ANOVA |
| Modified CV Basis Values and Estimates | | | | | |
| B-Basis | 7.401 | NA | NA | NA | NA |
| A-Estimate | 6.737 | | | | |
| Method | Normal | | | | |

Table 4-29: Statistics and Basis Values for OHT CTD Strength Data

### 4.5.2 Open-Hole Tension RTD Condition

Basis values were computed individually for each axis in the RTD condition. The Y-axis data showed the greatest strength values followed by the X-axis, Z45-axis and the Z-axis in that order.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X, Y, and Z-axes, so the ANOVA method was required to compute those basis values and estimates.

There were three statistical outliers in the RTD datasets. The largest value in batch three machine one from the X-axis dataset in the RTD condition was an outlier for batch three, but not the RTD condition and not for machine one or the machine batch combination. The largest value in batch two machine one from the Z45-axis dataset in the RTD condition was an outlier for the combination of batch two machine one, but not batch two, machine one, or the RTD condition. The smallest value in batch three machine two from the Z-axis dataset in the RTD condition was an outlier for that machine batch combination, but not for batch three, machine two or the RTD condition. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-30. The data, B-basis values and B-estimates are shown graphically in Figure 4-42.

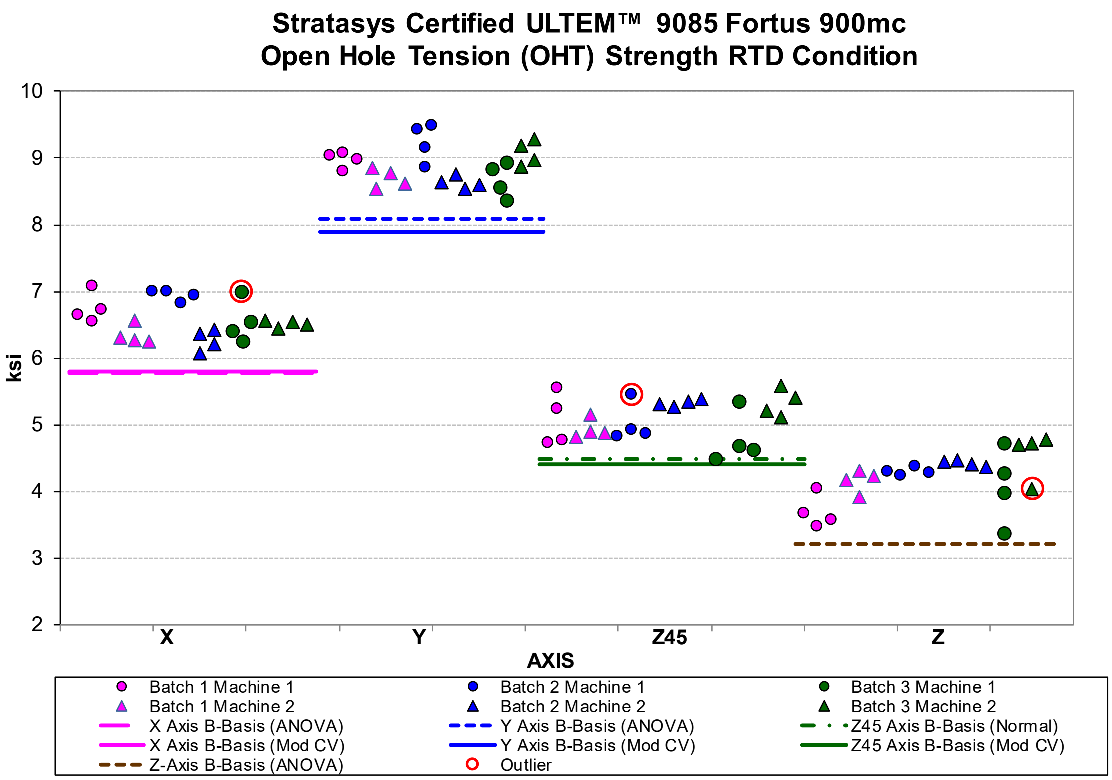



**Figure 4-42: Plot for OHT RTD Strength**

| Open Hole Tension (OHT) Strength Basis Values and Statistics RTD Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 6.556 | 8.877 | 5.075 | 4.199 |
| Stdev | 0.284 | 0.287 | 0.320 | 0.390 |
| CV | 4.339 | 3.234 | 6.305 | 9.291 |
| Mod CV | 6.170 | 6.000 | 7.153 | 9.291 |
| Min | 6.071 | 8.365 | 4.478 | 3.369 |
| Max | 7.067 | 9.473 | 5.589 | 4.786 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | |
| B-Basis | 5.777 | 8.098 | 4.482 | 3.209 |
| A-Estimate | 5.239 | 7.559 | 4.057 | 2.521 |
| Method | ANOVA | ANOVA | Normal | ANOVA |
| Modified CV Basis Values and Estimates | | | | |
| B-Basis | 5.806 | 7.890 | 4.402 | NA |
| A-Estimate | 5.269 | 7.183 | 3.920 | |
| Method | Normal | Normal | Normal | |

Table 4-30: Statistics and Basis Values for OHT RTD Strength Data

### 4.5.3 Open-Hole Tension ETW1 Condition

Basis values were computed individually for each axis in the ETW1 condition. Similar to the RTD condition, the Y-axis data showed the greatest strength values followed by the X-axis, Z45-axis and the Z-axis in that order.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for all four axes, so the ANOVA method was required to compute those basis values and estimates.

There were two statistical outliers in the ETW1 datasets. The smallest value in the batch three machine one combination dataset from the Z-axis dataset for the ETW1 condition was an outlier for the batch three machine one combination dataset but not for batch three, machine one or the ETW1 condition. The largest value in the batch three machine two combination dataset from the Z45-axis dataset for the ETW1 condition was an outlier for the batch three machine two combination dataset, but not for batch three, machine two or the ETW1 condition. Both outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-31. The data, B-basis values and B-estimates are shown graphically in Figure 4-43.

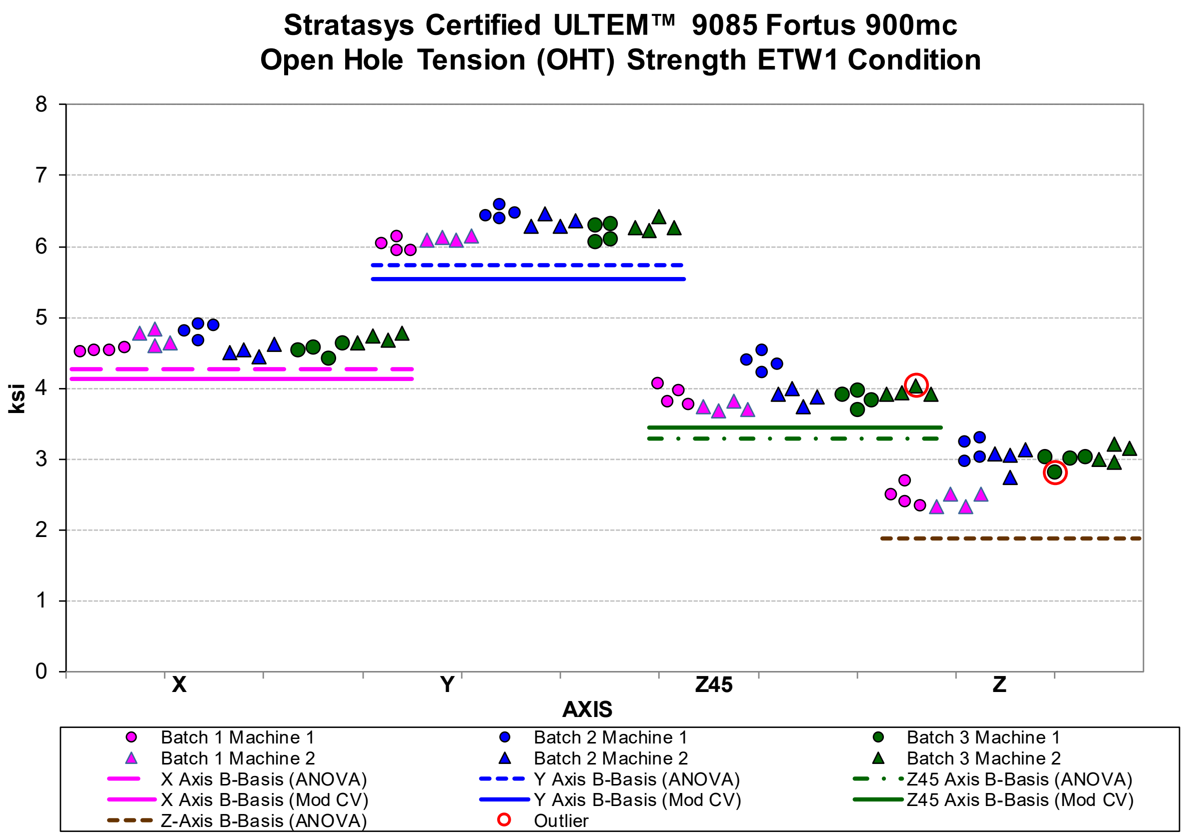



**Figure 4-43: Plot for OHT ETW1 Strength**

| Open Hole Tension (OHT) Strength Basis Values and Statistics ETW1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 4.638 | 6.236 | 3.946 | 2.842 |
| Stdev | 0.135 | 0.173 | 0.223 | 0.312 |
| CV | 2.906 | 2.767 | 5.658 | 10.978 |
| Mod CV | 6.000 | 6.000 | 6.829 | 10.978 |
| Min | 4.433 | 5.931 | 3.682 | 2.370 |
| Max | 4.900 | 6.573 | 4.526 | 3.297 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | |
| B-Basis | 4.259 | 5.729 | 3.280 | 1.887 |
| A-Estimate | 3.998 | 5.380 | 2.823 | 1.233 |
| Method | ANOVA | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | |
| B-Basis | 4.122 | 5.543 | 3.447 | NA |
| A-Estimate | 3.753 | 5.046 | 3.089 | |
| Method | Normal | Normal | Normal | |

Table 4-31: Statistics and Basis Values for OHT ETW1 Strength Data

## 4.6 Filled-Hole Tension (FHT)

Filled-Hole Tension reported one property: Strength. Tests were performed in three conditions: CTD, RTD, and ETW1. An ANOVA analysis was done on the strength results for each condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. The X and Z-axes could be combined for the RTD Condition. The Z and Z45-axes could be combined for the CTD condition. The Y-axis data showed the greatest strength values.

A box plot of the FHT strength measurements by axis and condition is shown in Figure 4-44.

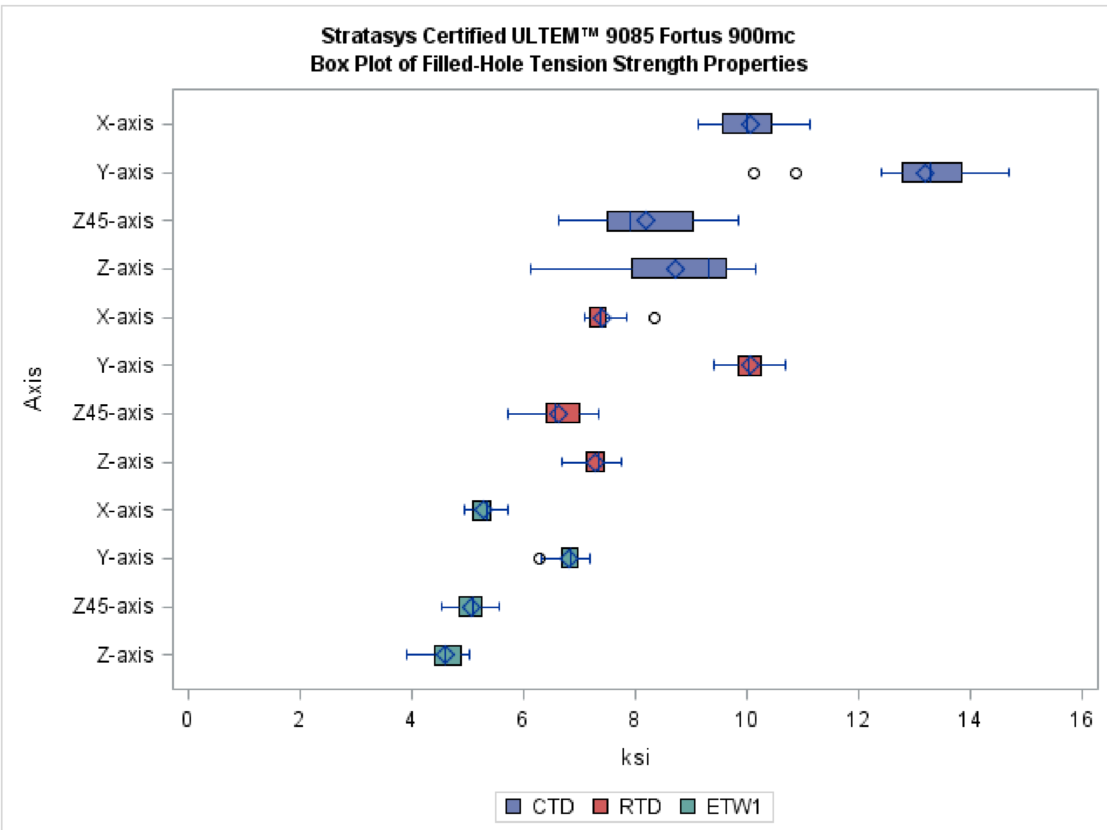



**Figure 4-44: Box Plot for FHT Strength Properties**

Modified CV basis values are provided when applicable. The Modified CV approach could not be applied to the CTD Z-axis, Z45-axis and the combined Z and Z45-axes datasets due to the CV being above 8%.

There were a total of ten statistical outliers identified in the FHT datasets. Three in the CTD condition, three in the RTD condition and four in the ETW1 condition. All outliers were retained for this analysis.

### 4.6.1 Filled-Hole Tension CTD Condition

Basis values were computed for the Z and Z45-axes combined dataset of multiple axes for the CTD condition. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the Y-axis, Z-axis, and the Z and Z45-axes combined dataset, so the ANOVA method was required to compute those basis values and estimates.

There were three statistical outliers in the CTD datasets. The smallest value in batch two machine one from the Y-axis dataset was an outlier for the CTD condition, but not for batch two, machine one, or the batch machine combination. The largest value in batch one machine two from the Z45-axis dataset was an outlier for the machine batch combination dataset, but not for batch one, machine two or the CTD condition. The largest value in batch two machine one from the Z-axis dataset was an outlier for the machine batch combination, but not for batch two, machine one, or the CTD condition. All three outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-32. The data, B-basis values and B-estimates are shown graphically in Figure 4-45.

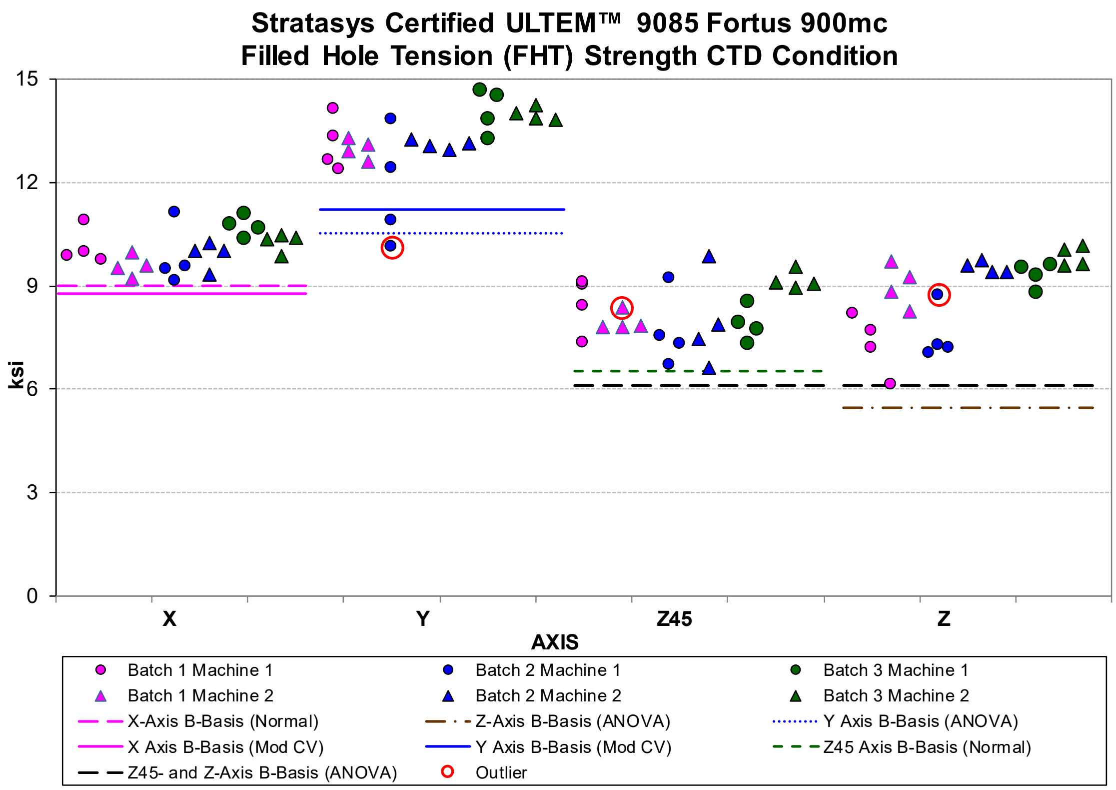



Figure 4-45: Plot for FHT CTD Strength

| Filled Hole Tension (FHT) Strength Basis Values and Statistics CTD Condition | | | | | |
|---|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | Z- & Z45-Axes |
| Mean | 10.075 | 13.179 | 8.194 | 8.772 | 8.483 |
| Stdev | 0.579 | 1.048 | 0.891 | 1.123 | 1.044 |
| CV | 5.747 | 7.948 | 10.877 | 12.797 | 12.311 |
| Mod CV | 6.874 | 7.974 | 10.877 | 12.797 | 12.311 |
| Min | 9.138 | 10.120 | 6.619 | 6.141 | 6.141 |
| Max | 11.127 | 14.697 | 9.849 | 10.157 | 10.157 |
| Batches | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 |
| Basis Values and Estimates | | | | | |
| B-Basis | 9.002 | 10.513 | 6.543 | 5.469 | 6.106 |
| A-Estimate | 8.233 | 8.659 | 5.360 | 3.199 | 4.425 |
| Method | Normal | ANOVA | Normal | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | |
| B-Basis | 8.791 | 11.231 | NA | NA | NA |
| A-Estimate | 7.872 | 9.836 | | | |
| Method | Normal | Normal | | | |

Table 4-32: Statistics and Basis Values for FHT CTD Strength Data

### 4.6.2 Filled-Hole Tension RTD Condition

Basis values were computed for the X and Z-axes combined dataset of multiple axes for the RTD condition. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X and Z-axes combined dataset, so the ANOVA method was required to compute those basis values and estimates. The X-axis data did not fit any of the tested distributions, so the non-parametric method was used to compute basis values. The RTD and ETW1 conditions could be pooled for the Y-axis, but only for the original CV data because after the Mod CV transformation, the pooled data failed Levene's test for equality of variance.

There were three statistical outliers in the RTD datasets, all for the X-axis. The largest value in batch one machine one was an outlier for the batch one machine one combination dataset only, not for batch one, machine one or the RTD condition. The largest value in batch two machine one was an outlier for the RTD condition, but not for batch two, machine one, or the batch machine combination. The largest value in batch three machine one was an outlier for the batch three machine one combination dataset only, not for batch three, machine one or the RTD condition. All three outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-33. The data, B-basis values and B-estimates are shown graphically in Figure 4-46.

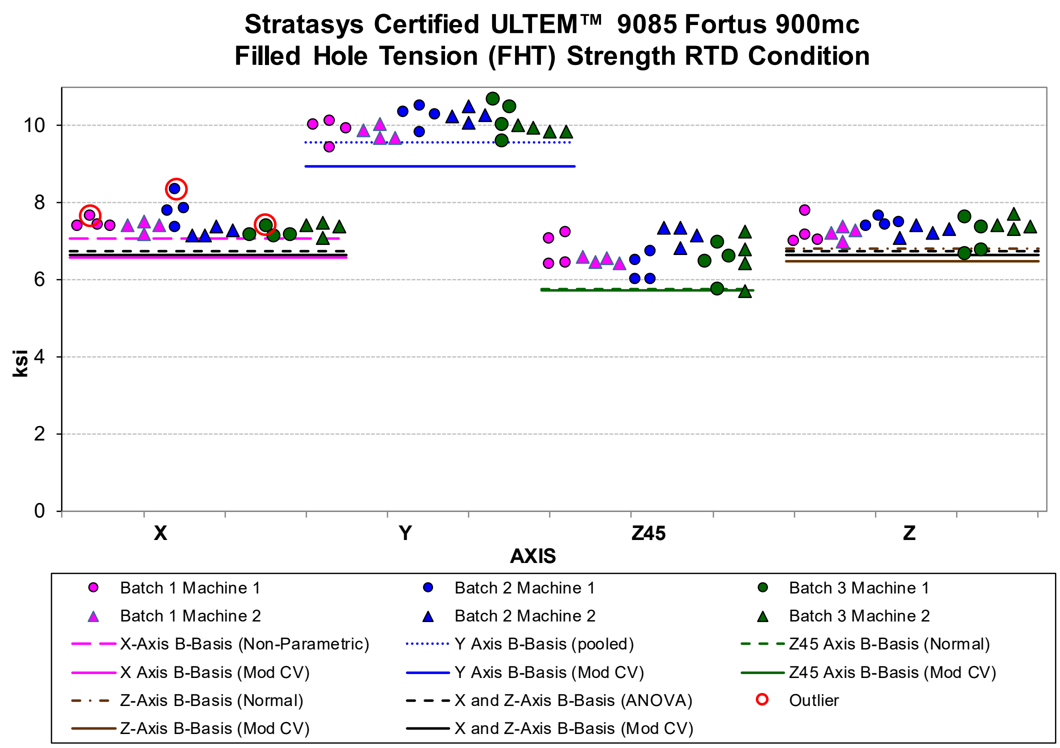



**Figure 4-46: Plot for FHT RTD Strength**

| Filled Hole Tension (FHT) Strength Basis Values and Statistics RTD Condition | | | | | |
|---|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X- & Z-Axes |
| Mean | 7.413 | 10.052 | 6.629 | 7.298 | 7.356 |
| Stdev | 0.277 | 0.317 | 0.465 | 0.272 | 0.278 |
| CV | 3.742 | 3.150 | 7.018 | 3.729 | 3.779 |
| Mod CV | 6.000 | 6.000 | 7.509 | 6.000 | 6.000 |
| Min | 7.092 | 9.417 | 5.719 | 6.703 | 6.703 |
| Max | 8.341 | 10.698 | 7.360 | 7.762 | 8.341 |
| Batches | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 48 |
| Basis Values and Estimates | | | | | |
| B-Basis | 7.059 | 9.564 | 5.768 | 6.794 | 6.749 |
| A-Estimate | 5.866 | 9.226 | 5.150 | 6.433 | 6.318 |
| Method | Non-Parametric | pooled | Normal | Normal | ANOVA |
| Modified CV Basis Values and Estimates | | | | | |
| B-Basis | 6.589 | 8.935 | 5.707 | 6.487 | 6.626 |
| A-Estimate | 5.998 | 8.134 | 5.046 | 5.905 | 6.087 |
| Method | Normal | Normal | Normal | Normal | Normal |

**Table 4-33: Statistics and Basis Values for FHT RTD Strength Data**

### 4.6.3 Filled-Hole Tension ETW1 Condition

Basis values were computed individually for the four axes. Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the Z and Z45-axes datasets, so the ANOVA method was required to compute those basis values and estimates. The RTD and ETW1 conditions could be pooled for the Y-axis, but only for the original CV data because after the Mod CV transformation, the pooled data failed Levene's test for equality of variance.

There were four statistical outliers in the ETW1 datasets. The smallest value in the batch one machine two combination dataset for the X-axis was an outlier for batch one and the batch one machine two combination dataset, but not for machine two or the ETW1 condition. The smallest value in the batch three machine one combination dataset for the Y-axis was an outlier for batch three, but not for machine one, the ETW1 condition or the batch three machine one combination. The smallest value in the batch three machine one combination dataset for the Z-axis was an outlier for the batch three machine one combination only, not for batch three, machine one or the ETW1 condition. The smallest value in the batch one machine two combination dataset for the Z45-axis was an outlier for machine two only, not for batch one, the ETW1 condition or the batch one machine two combination. All four outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-34. The data, B-basis values and B-estimates are shown graphically in Figure 4-47.

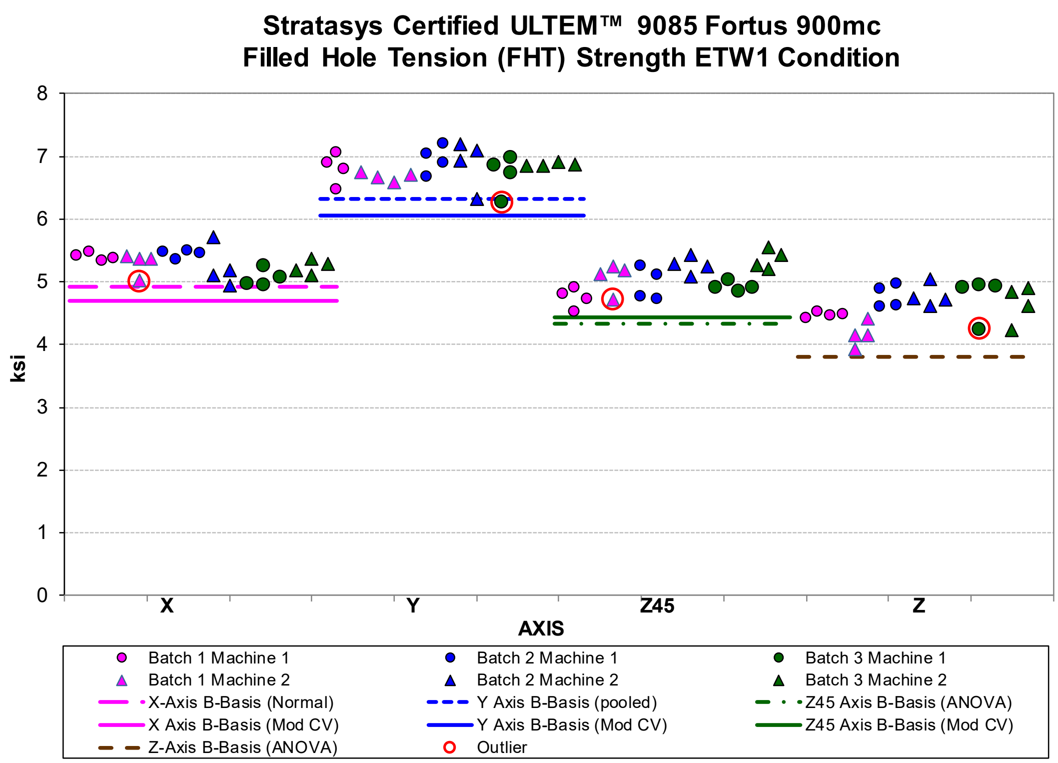



**Figure 4-47: Plot for FHT ETW1 Strength**

| Filled Hole Tension (FHT) Strength Basis Values and Statistics ETW1 Condition | | | | |
|---|---|---|---|---|
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 5.277 | 6.818 | 5.054 | 4.595 |
| Stdev | 0.197 | 0.240 | 0.267 | 0.306 |
| CV | 3.724 | 3.518 | 5.275 | 6.658 |
| Mod CV | 6.000 | 6.000 | 6.638 | 7.329 |
| Min | 4.945 | 6.275 | 4.521 | 3.924 |
| Max | 5.708 | 7.203 | 5.555 | 5.034 |
| Batches | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | |
| B-Basis | 4.913 | 6.330 | 4.334 | 3.810 |
| A-Estimate | 4.652 | 5.992 | 3.836 | 3.264 |
| Method | Normal | pooled | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | |
| B-Basis | 4.690 | 6.060 | 4.432 | NA |
| A-Estimate | 4.270 | 5.517 | 3.987 | |
| Method | Normal | Normal | Normal | |

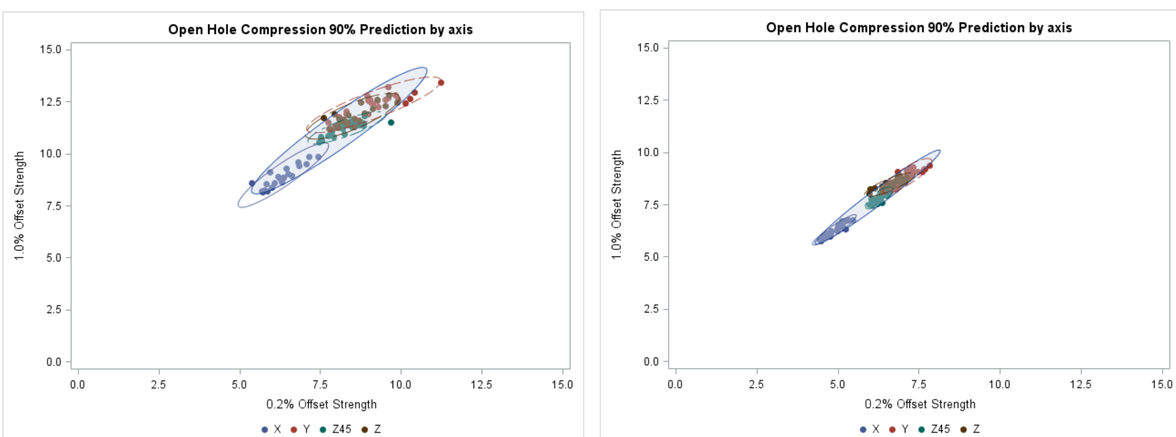
Table 4-34: Statistics and Basis Values for FHT ETW1 Strength Data

## 4.7 Open-Hole Compression (OHC)

Continued review of the data has shown that ASTM D6484 (Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates) is an inappropriate test method for the ULTEM 9085 material and FDM process. Modifications to the fixture and strain collection method/device introduced additional variables to the OHC and FHC properties making it difficult to reproduce accurate and precise data necessary for a robust qualification and equivalency program. While test results are reported, basis values are not.

Open-Hole Compression tests reported two properties: 0.2% Offset Strength and 1% Offset Strength. Tests were performed in two conditions: RTD and ETW1. There are strong correlations between the two properties. The correlations computed by specimen for each direction and condition tested are shown in Table 4-35.

Scatter plots of the test results for the two measurements for each condition and axis with 90% prediction ellipses are shown in Figure 4-48. A box plot of the two different measurements by axis and condition is shown in Figure 4-49. The graphs show that the X-axis has the lowest strength values for both conditions and properties.




RTD ETW1

**Figure 4-48: Scatter Plots of OHC Strength Properties by Condition and Axis**

| Pearson Correlation Coefficients – 0.2% Offset Strength with 1% Offset Strength | | | | | |
|---|---|---|---|---|---|
| | X | Y | Z | Z45 | All |
| RTD | 0.9135 | 0.8626 | 0.8056 | 0.8269 | 0.9487 |
| ETW1 | 0.9322 | 0.8241 | 0.8349 | 0.7532 | 0.9800 |
| ALL | 0.9644 | 0.9300 | 0.9487 | 0.9695 | 0.9591 |

**Table 4-35: Correlation Statistics for Open-Hole Compression Strength Data**

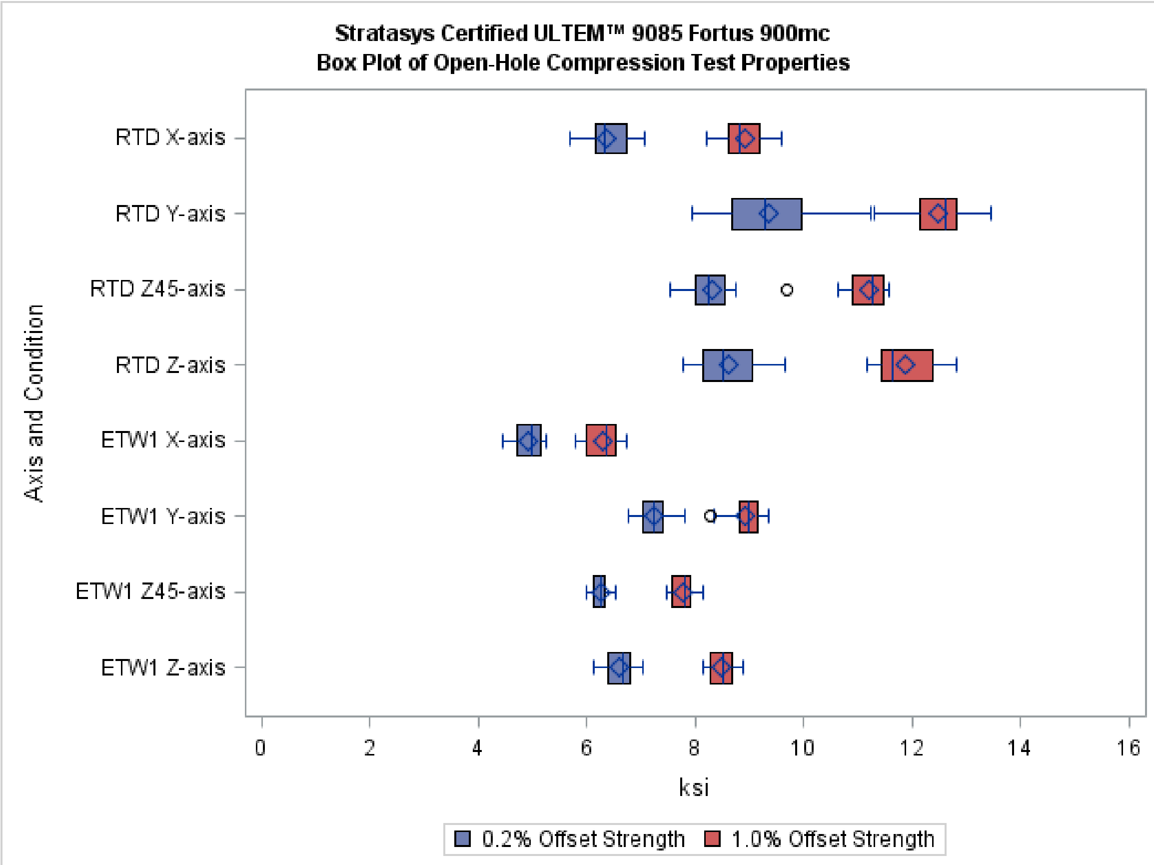



**Figure 4-49: Box Plot of Open-Hole Compression Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. The Z45 and Z-axes datasets were sufficiently similar that they could be combined for both the 0.2% Offset Strength and 1% Offset Strength, but the results of doing so were not advantageous to the basis value final results, so those results were not included in this report. No other axis datasets were sufficiently similar to be combined.

Outlier status was checked for each specimen by condition, batch, machine and the combination of batch and machine. For all of these different groupings for the two strength properties, there was a total of five specimens identified as outliers for one or more measurements. Details are given in the text for each condition and all outliers are listed in Table 4-44. All outliers were retained for this analysis.

### 4.7.1 Open-Hole Compression RTD Condition

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for all axes and properties except the Z-axis for 0.2% Offset Strength. The ANOVA method was required to compute those basis values and estimates. The X and Y-axis 0.2% Offset Strength datasets had CV values above 8% and the X-axis 1% Offset Strength failed the Anderson-Darling k-sample test after the modified CV transformation, so modified CV basis values could not be computed for those datasets. The 0.2% Offset Strength data for the Z-axis and the 1% Offset Strength data for the Y and Z45-axes could be pooled across the RTD and ETW1 conditions for the Modified CV basis value computations.

There were four statistical outliers in the RTD datasets, three for the X-axis and one for the Z45-axis. The highest value in the batch one machine one dataset from the X-axis 0.2% Offset Strength dataset was an outlier for batch machine combination, but it was not an outlier for batch one or machine one or the RTD condition. The highest value in the batch one machine one dataset from the Z45-axis 0.2% Offset Strength dataset was an outlier for batch machine combination, but it was not an outlier for batch one or machine one or the RTD condition.

There were two outliers in the X-axis 1% Offset Strength dataset. The largest value in the batch two machine two dataset was an outlier for batch two, machine two, and the RTD condition but not for the batch machine combination. The largest value in the batch three machine two combination dataset was an outlier for the batch three machine two combination, but not for machine two, batch three, or the RTD condition. All four outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-36. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-50 and for 1% Offset Strength in Figure 4-51 and together in Figure 4-52.

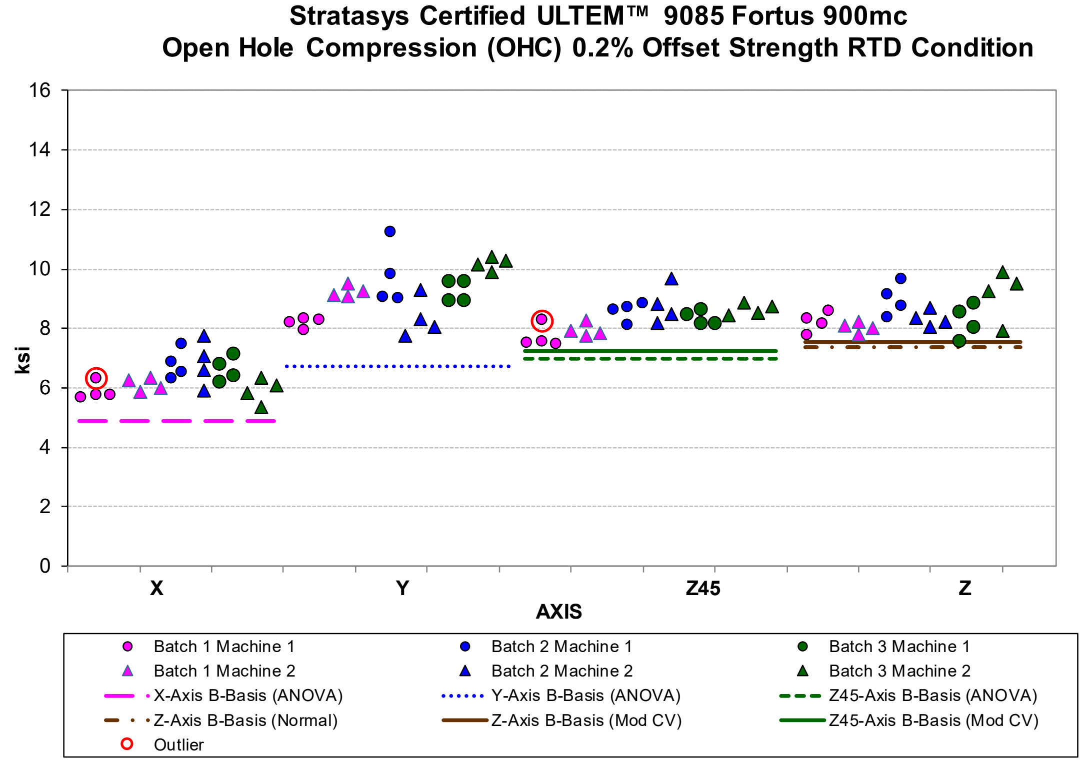



**Figure 4-50: Plot for RTD OHC 0.2% Offset Strength**

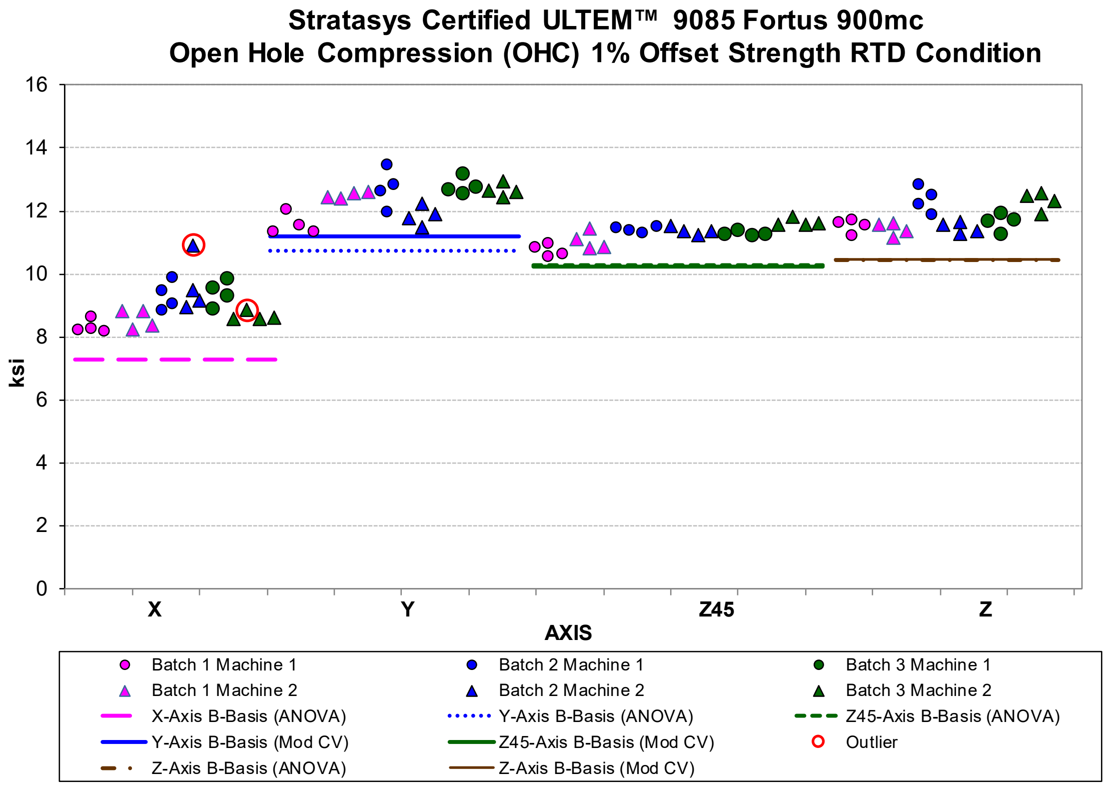



**Figure 4-51: Plot for RTD OHC 1% Offset Strength**

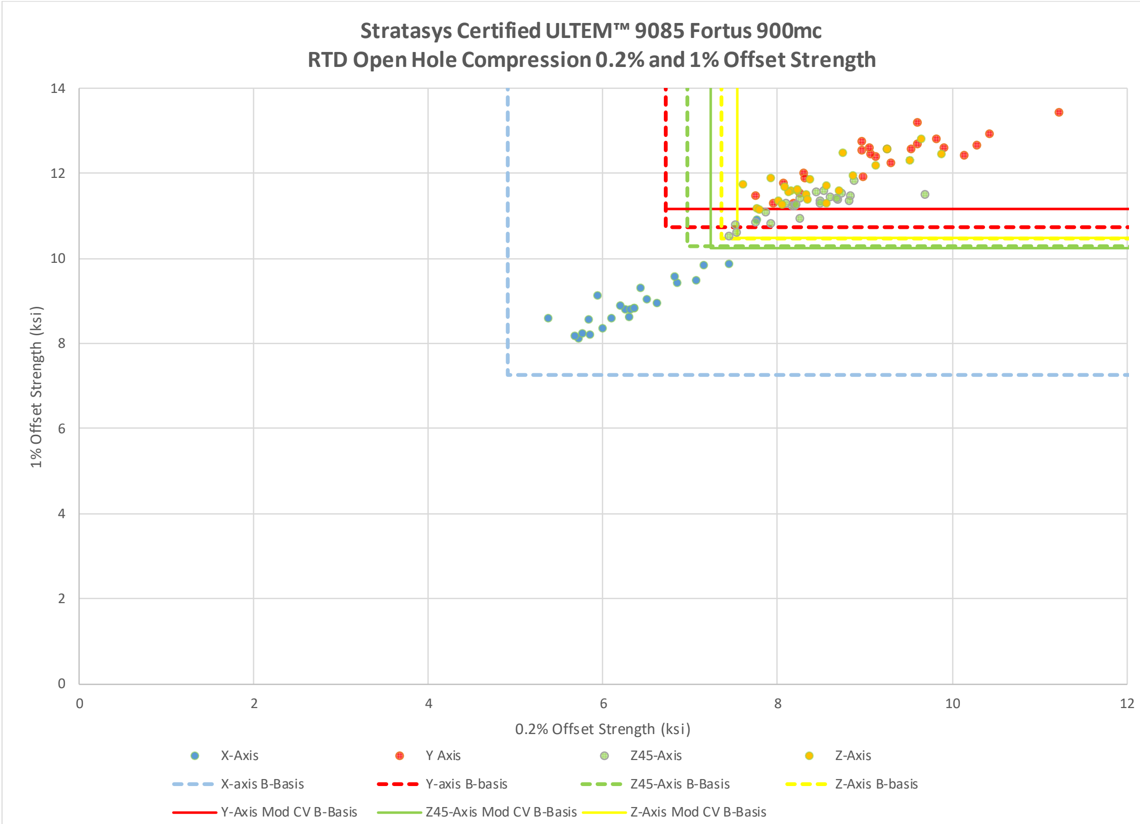



Figure 4-52: Plot for OHC 0.2% Offset Strength and 1% Offset Strength RTD Condition

| Open Hole Compression (OHC) Basis Values and Statistics RTD Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 6.362 | 9.167 | 8.336 | 8.491 | 8.971 | 12.339 | 11.244 | 11.781 |
| Stdev | 0.589 | 0.876 | 0.515 | 0.615 | 0.652 | 0.573 | 0.326 | 0.466 |
| CV | 9.263 | 9.559 | 6.182 | 7.248 | 7.270 | 4.648 | 2.898 | 3.960 |
| Mod CV | 9.263 | 9.559 | 7.091 | 7.624 | 7.635 | 6.324 | 6.000 | 6.000 |
| Min | 5.366 | 7.751 | 7.449 | 7.597 | 8.136 | 11.295 | 10.533 | 11.162 |
| Max | 7.769 | 11.226 | 9.682 | 9.877 | 10.913 | 13.437 | 11.827 | 12.821 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | |
| B-Basis | 4.909 | 6.718 | 6.971 | 7.351 | 7.261 | 10.725 | 10.277 | 10.453 |
| A-Estimate | 3.895 | 5.027 | 6.026 | 6.534 | 6.076 | 9.613 | 9.612 | 9.539 |
| Method | ANOVA | ANOVA | ANOVA | Normal | ANOVA | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | | | | |
| B-Basis | NA | NA | 7.240 | 7.539 | NA | 11.179 | 10.235 | 10.471 |
| A-Estimate | | | 6.455 | 6.879 | | 10.375 | 9.536 | 9.532 |
| Method | | | Normal | pooled | | pooled | pooled | Normal |

Table 4-36: Statistics and Basis Values for RTD OHC Strength Data

### 4.7.2 Open-Hole Compression ETW1 Condition

Basis values were computed individually for all four axes for both the 0.2% Offset Strength and 1% Offset Strength measurements. No axes were sufficiently similar to be combined when computing basis values. The Z-axis 1% Offset Strength dataset failed normality after the modified CV data transformation, so no modified CV basis values are provided for that dataset. The 0.2% Offset Strength data for the Z-axis and the 1% Offset Strength data for the Y and Z45-axes could be pooled across the RTD and ETW1 conditions for the Modified CV basis value computations.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X and Y-axes in both the 0.2% Offset Strength and 1% Offset Strength datasets, so the ANOVA method was required to compute those basis values and estimates.

There was one statistical outlier in the ETW1 dataset. The lowest value in the batch one machine two combination from the Y-axis 1% Offset Strength dataset was an outlier for batch one, but not for the batch one machine two combination, for machine two or for the RTD condition. It was retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-37. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-53 and for 1% Offset Strength in Figure 4-54 and together in Figure 4-55.

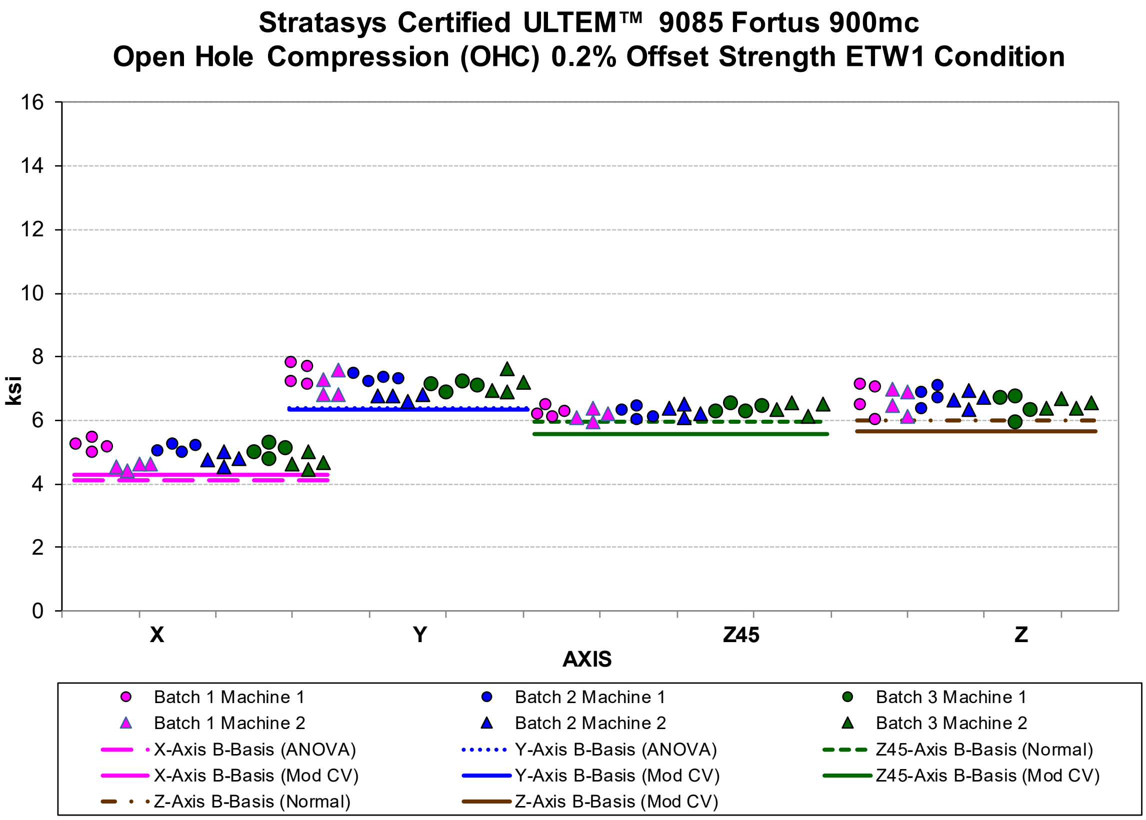



Figure 4-53: Plot for ETW1 OHC 0.2% Offset Strength

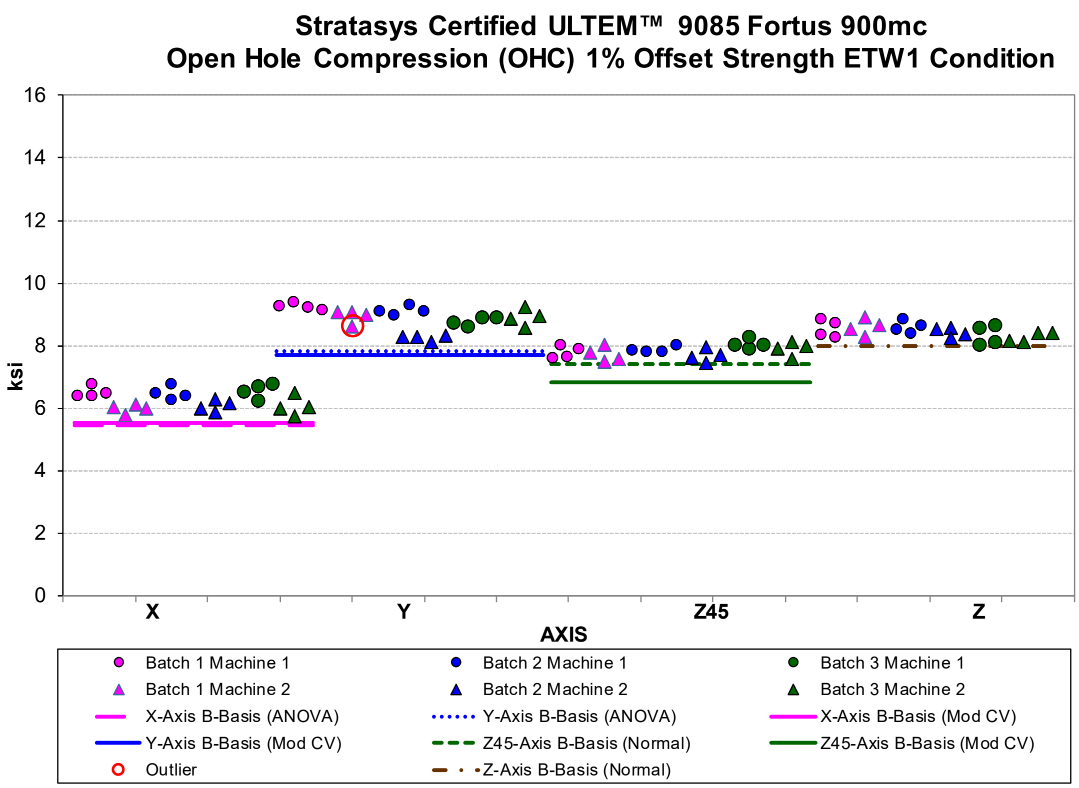



Figure 4-54: Plot for ETW1 OHC 1% Offset Strength

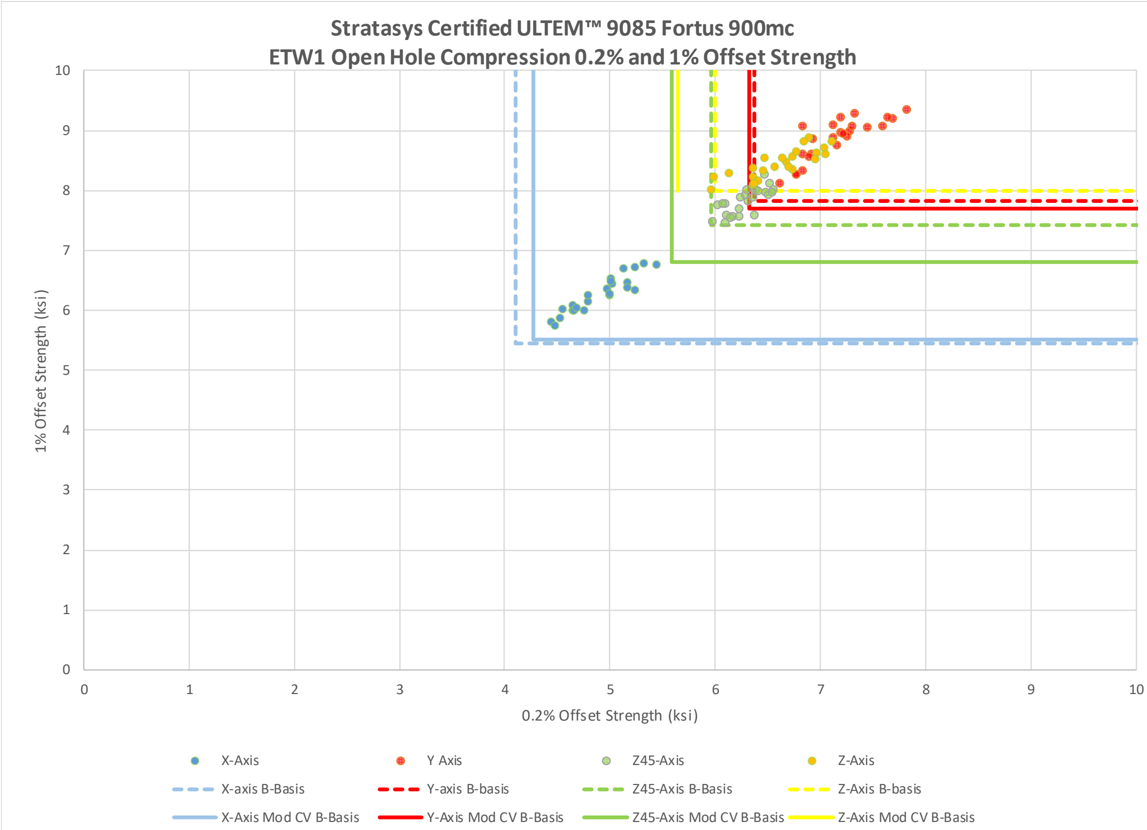



**Figure 4-55: Plot for OHC 0.2% Offset Strength and 1% Offset Strength ETW1 Condition**

| Open Hole Compression (OHC) Basis Values and Statistics ETW1 Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 4.902 | 7.155 | 6.284 | 6.605 | 6.268 | 8.865 | 7.818 | 8.449 |
| Stdev | 0.287 | 0.324 | 0.177 | 0.325 | 0.306 | 0.351 | 0.216 | 0.241 |
| CV | 5.855 | 4.527 | 2.809 | 4.922 | 4.884 | 3.954 | 2.766 | 2.851 |
| Mod CV | 6.928 | 6.264 | 6.000 | 6.461 | 6.442 | 6.000 | 6.000 | 6.000 |
| Min | 4.435 | 6.609 | 5.979 | 5.964 | 5.741 | 8.120 | 7.459 | 8.009 |
| Max | 5.448 | 7.816 | 6.556 | 7.111 | 6.775 | 9.355 | 8.259 | 8.886 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | |
| B-Basis | 4.103 | 6.369 | 5.957 | 6.003 | 5.451 | 7.826 | 7.418 | 8.003 |
| A-Estimate | 3.552 | 5.821 | 5.723 | 5.571 | 4.886 | 7.112 | 7.131 | 7.684 |
| Method | ANOVA | ANOVA | Normal | Normal | ANOVA | ANOVA | Normal | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | |
| B-Basis | 4.273 | 6.324 | 5.585 | 5.653 | 5.520 | 7.705 | 6.810 | NA |
| A-Estimate | 3.822 | 5.729 | 5.085 | 4.993 | 4.984 | 6.901 | 6.110 | |
| Method | Normal | Normal | Normal | pooled | Normal | pooled | pooled | |

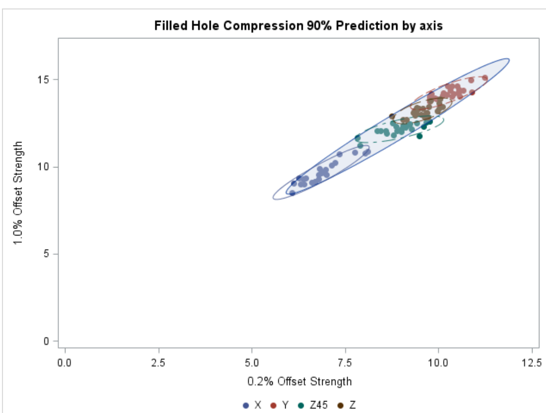
**Table 4-37: Statistics and Basis Values for ETW1 OHC Strength Data**

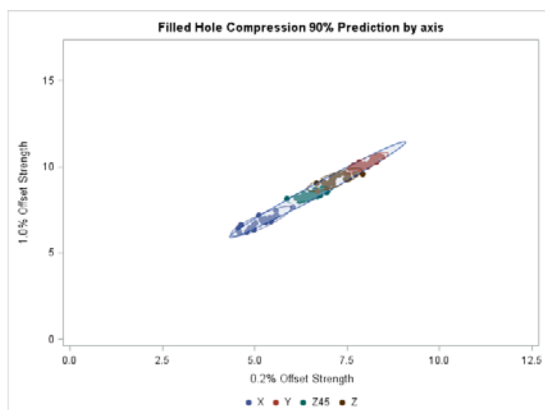
## 4.8 Filled-Hole Compression (FHC)

Continued review of the data has shown that ASTM D6742 (Standard Test Method for Filled-Hole Compressive Strength of Polymer Matrix Composite Laminates) is an inappropriate test method for the ULTEM 9085 material and FDM process. Modifications to the fixture and strain collection method/device introduced additional variables to the OHC and FHC properties making it difficult to reproduce accurate and precise data necessary for a robust qualification and equivalency program. While test results are reported, basis values are not.

Filled-Hole Compression tests reported two properties: 0.2% Offset Strength and 1% Offset Strength. Tests were performed in two conditions: RTD and ETW1. The correlations computed by specimen for each direction and condition tested are shown in Table 4-38. There are strong correlations between the two properties.

Scatter plots of the test results for the two properties for each condition and axis with 90% prediction ellipses are shown in Figure 4-56. A box plot of the two different measurements by axis and condition is shown in Figure 4-57. The graphs show that the X-axis has the lowest strength values for both conditions and properties while the Y-axis has the strongest strength values.




RTD ETW1

**Figure 4-56: Scatter Plots of FHC Strength Properties by Condition and Axis**

| Pearson Correlation Coefficients 0.2% Offset Strength with 1% Offset Strength | | | | | |
|---|---|---|---|---|---|
| | X | Y | Z | Z45 | All |
| RTD | 0.9288 | 0.8185 | 0.6513 | 0.7147 | 0.9773 |
| ETW1 | 0.8835 | 0.8660 | 0.7932 | 0.7440 | 0.9885 |
| ALL | 0.9769 | 0.9823 | 0.9834 | 0.9743 | 0.9809 |

**Table 4-38: Correlation Statistics for Filled-Hole Compression Strength Data**

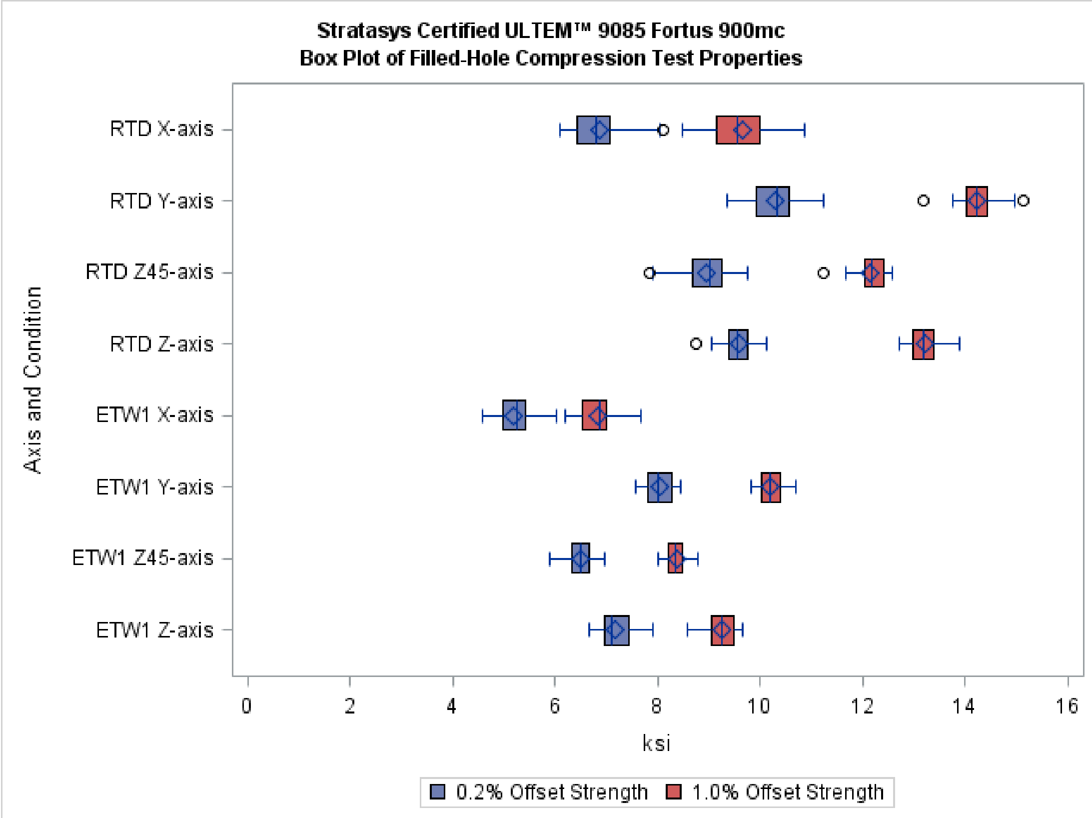



**Figure 4-57: Box Plot of Filled-Hole Compression Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. No axes datasets were sufficiently similar to be combined.

The 0.2% Offset Strength values could be pooled across the RTD and ETW1 conditions for the Y-axis data (original CV only). The Z-axis data could be pooled across the two conditions for the 0.2% Offset Strength (both original and Mod CV) and the 1% Offset Strength (Mod CV only).

Outlier status was checked for each specimen by condition, batch, machine and machine batch combination. For all of these different groupings for the two strength properties, there were a total of nine specimens identified as outliers for one or more measurements. Details are given in the text for each condition and all outliers are listed in Table 4-44. All outliers were retained for this analysis.

### 4.8.1 Filled-Hole Compression RTD Condition

Basis values were computed individually for all four axes for both the 0.2% Offset Strength and 1% Offset Strength measurements. No axes were sufficiently similar to be combined when computing basis values.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X-axis for both strength properties and the Y-axis 1% Offset Strength dataset, so the ANOVA method was required to compute those basis values and estimates.

There were six statistical outliers in the RTD dataset, with one specimen being an outlier for both properties. All outliers were retained for this analysis.

The largest value in batch two machine one of the X-axis 1% Offset Strength dataset was an outlier for the machine batch combination but not for batch two, machine one or the RTD condition. The largest value in batch two machine two of the X-axis 0.2% Offset Strength dataset was an outlier for batch two but not for machine two, the machine batch combination, or the RTD condition.

The lowest value in batch two machine one of the Y-axis 0.2% Offset Strength dataset was an outlier for the batch two machine one combination but not for batch two, machine one or the RTD condition. The lowest value in batch one machine one of the Y-axis 1% Offset Strength dataset was an outlier for batch one but not for machine one, the machine batch combination or the RTD condition.

The lowest value in batch two machine two of the Z45-axis was an outlier for both the 1% Offset Strength and the 0.2% Offset Strength datasets. The 1% Offset Strength measurement was an outlier for batch two and the RTD condition but not for the batch two machine two combination or machine two while the 0.2% Offset Strength measurement was an outlier for machine two but not batch two, the batch two machine two combination, or the RTD condition.

The largest value in batch two machine two of the Z-axis 0.2% Offset Strength dataset was an outlier for the batch two machine two combination but not for batch two, machine two or the RTD condition.

Statistics, basis values and estimates are given for the strength data in Table 4-39. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-58 and for 1% Offset Strength in Figure 4-59 and together in Figure 4-60.

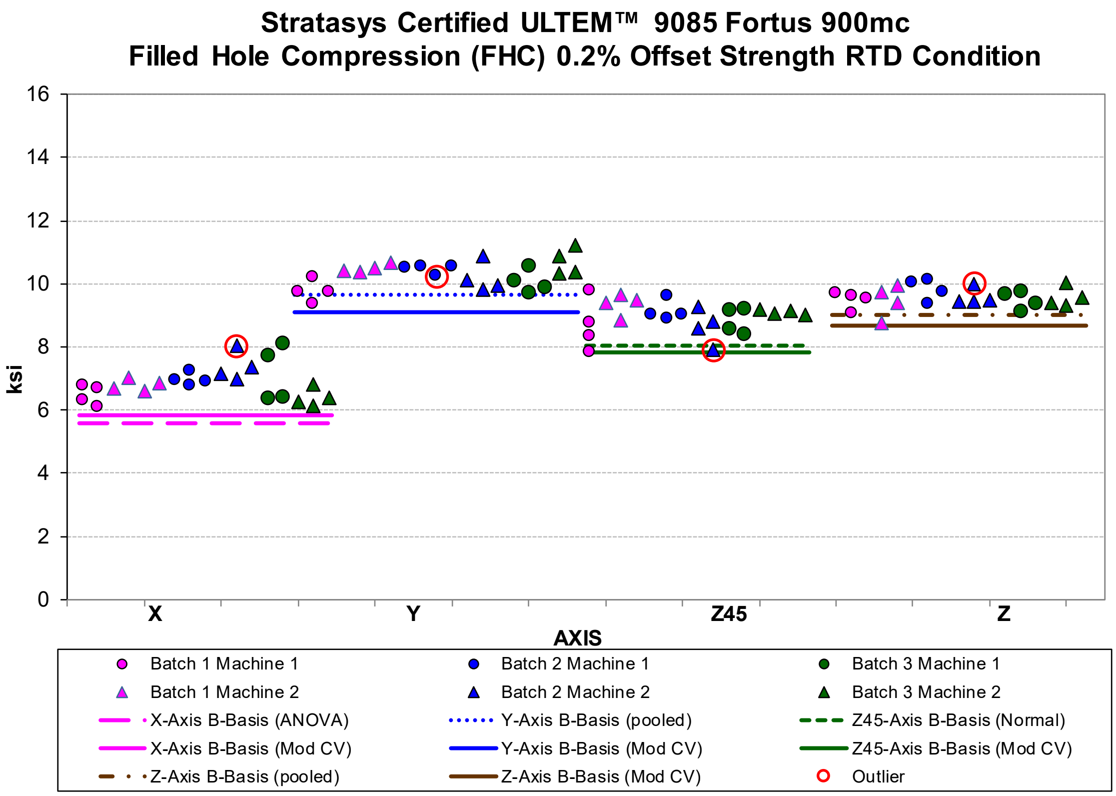



**Figure 4-58: Plot for RTD FHC 0.2% Offset Strength**

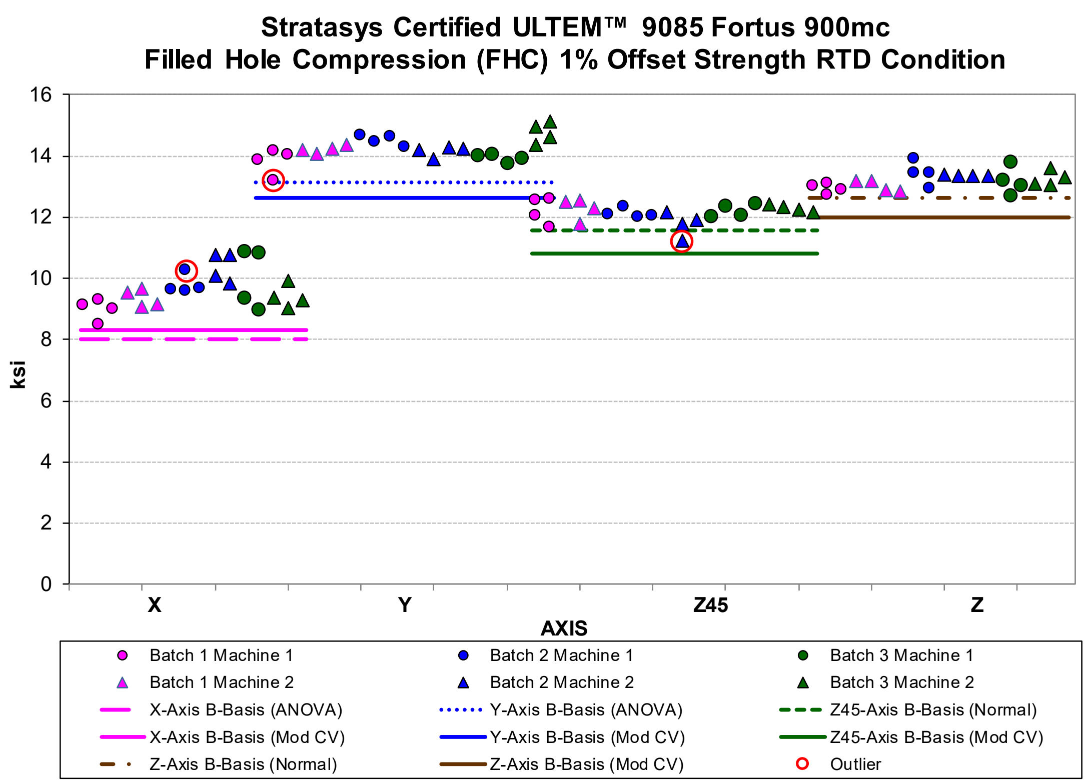



**Figure 4-59: Plot for RTD FHC 1% Offset Strength**

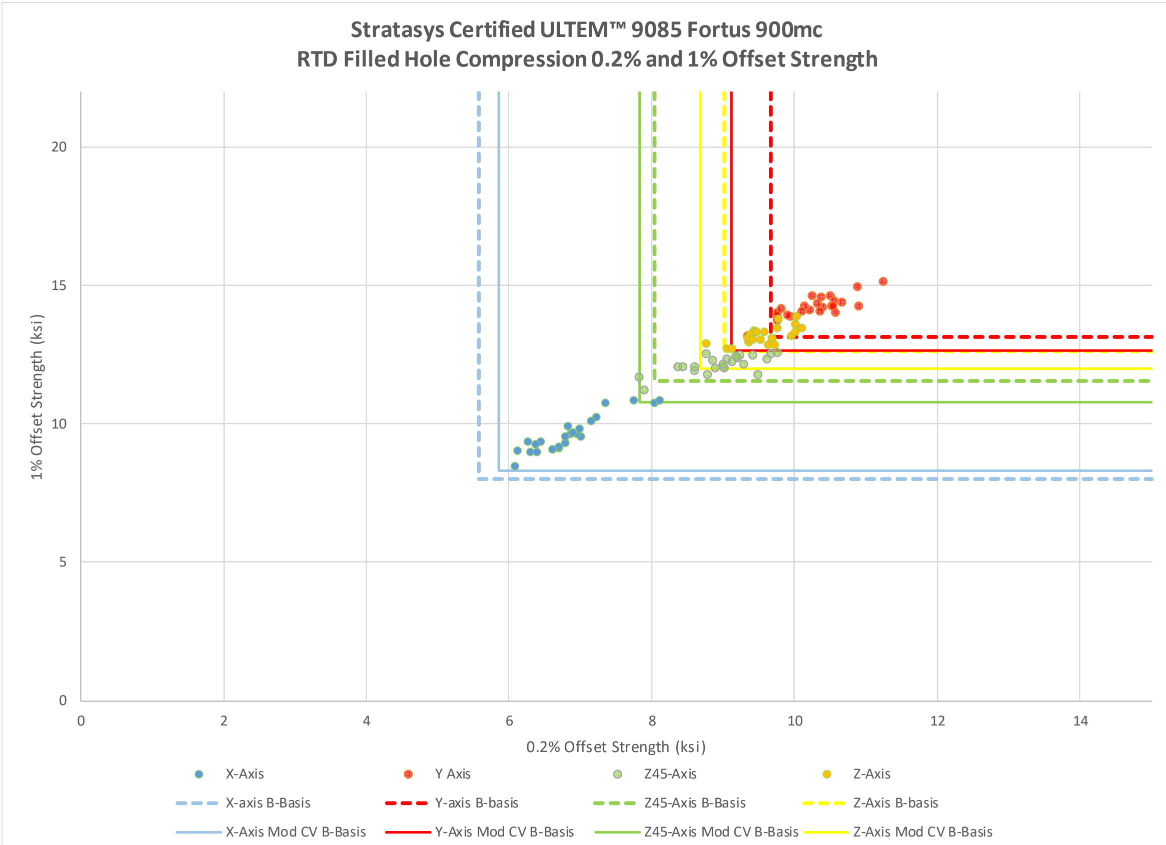



**Figure 4-60: Plot for FHC 0.2% Offset Strength and 1% Offset Strength RTD Condition**

| Filled Hole Compression (FHC) Basis Values and Statistics RTD Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 6.861 | 10.279 | 8.958 | 9.568 | 9.647 | 14.229 | 12.152 | 13.200 |
| Stdev | 0.544 | 0.437 | 0.501 | 0.332 | 0.657 | 0.398 | 0.323 | 0.308 |
| CV | 7.931 | 4.248 | 5.587 | 3.465 | 6.812 | 2.799 | 2.659 | 2.337 |
| Mod CV | 7.966 | 6.124 | 6.794 | 6.000 | 7.406 | 6.000 | 6.000 | 6.000 |
| Min | 6.088 | 9.340 | 7.824 | 8.759 | 8.483 | 13.194 | 11.227 | 12.709 |
| Max | 8.115 | 11.235 | 9.763 | 10.109 | 10.872 | 15.124 | 12.581 | 13.888 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | |
| B-Basis | 5.576 | 9.657 | 8.031 | 9.009 | 8.012 | 13.125 | 11.553 | 12.629 |
| A-Estimate | 4.677 | 9.227 | 7.366 | 8.622 | 6.874 | 12.363 | 11.124 | 12.219 |
| Method | ANOVA | pooled | Normal | pooled | ANOVA | ANOVA | Normal | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | |
| B-Basis | 5.848 | 9.112 | 7.830 | 8.678 | 8.323 | 12.647 | 10.801 | 12.013 |
| A-Estimate | 5.123 | 8.276 | 7.022 | 8.061 | 7.374 | 11.513 | 9.833 | 11.191 |
| Method | Normal | Normal | Normal | pooled | Normal | Normal | Normal | pooled |

**Table 4-39: Statistics and Basis Values for RTD FHC Strength Data**

### 4.8.2 Filled-Hole Compression ETW1 Condition

Basis values were computed individually for all four axes for both the 0.2% Offset Strength and 1% Offset Strength measurements. No axes were sufficiently similar to be combined when computing basis values.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X-axis in the 0.2% Offset Strength dataset and for all four axes in the 1% Offset Strength datasets, so the ANOVA method was required to compute those basis values and estimates. Modified CV basis values could not be computed for the X-axis for both the 0.2% and 1% Offset Strength because they did not pass the ADK test even after applying the modified CV transformation to the datasets. Modified CV basis values could not be computed for the Y-axis 1% Offset Strength because the dataset did not pass the normality test after applying the modified CV transformation.

There were three statistical outliers in the ETW1 dataset. The lowest value in batch one machine one from the Z45-axis 0.2% Offset Strength dataset was an outlier for batch one, but not for the batch one machine one combination, machine one or the ETW1 condition. The largest value in batch one machine two from the Z45-axis 0.2% Offset Strength dataset was an outlier for the batch one machine two combination, but not for batch one, machine two or the ETW1 condition. The largest value in batch one machine two from the Y-axis 1% Offset Strength dataset was an outlier for the batch one machine two combination but not for batch one, machine two or the ETW1 condition. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the strength data in Table 4-40. The data, B-estimates and B-basis values are shown graphically for 0.2% Offset Strength in Figure 4-61 and for 1% Offset Strength in Figure 4-62 and together in Figure 4-63.

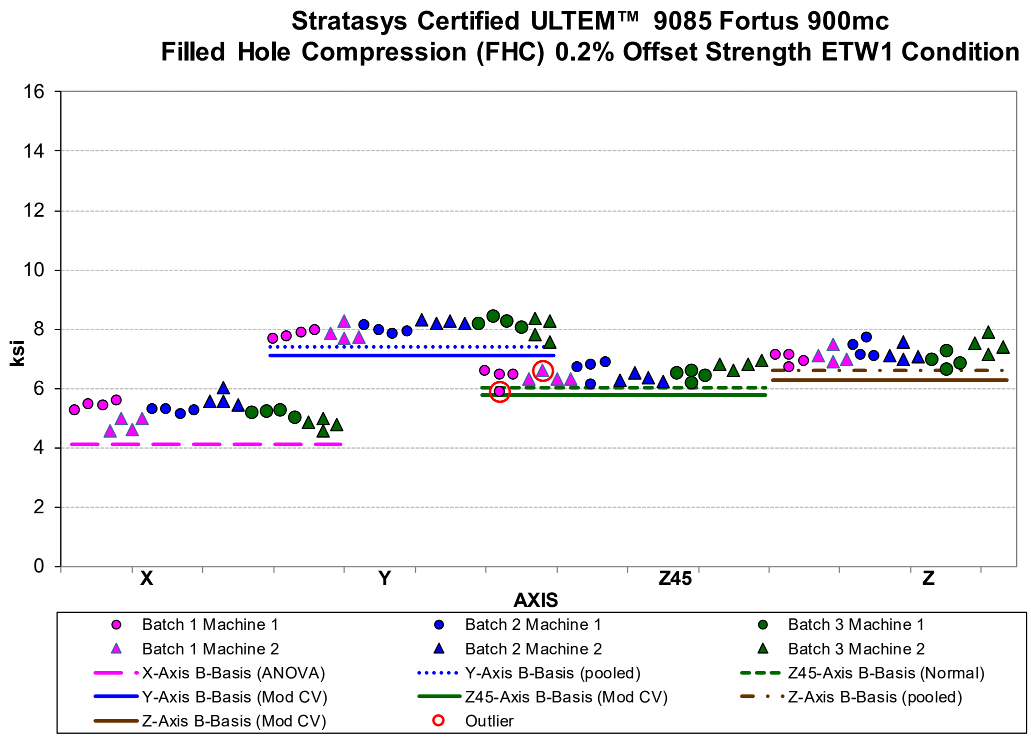



**Figure 4-61: Plot for ETW1 FHC 0.2% Offset Strength**

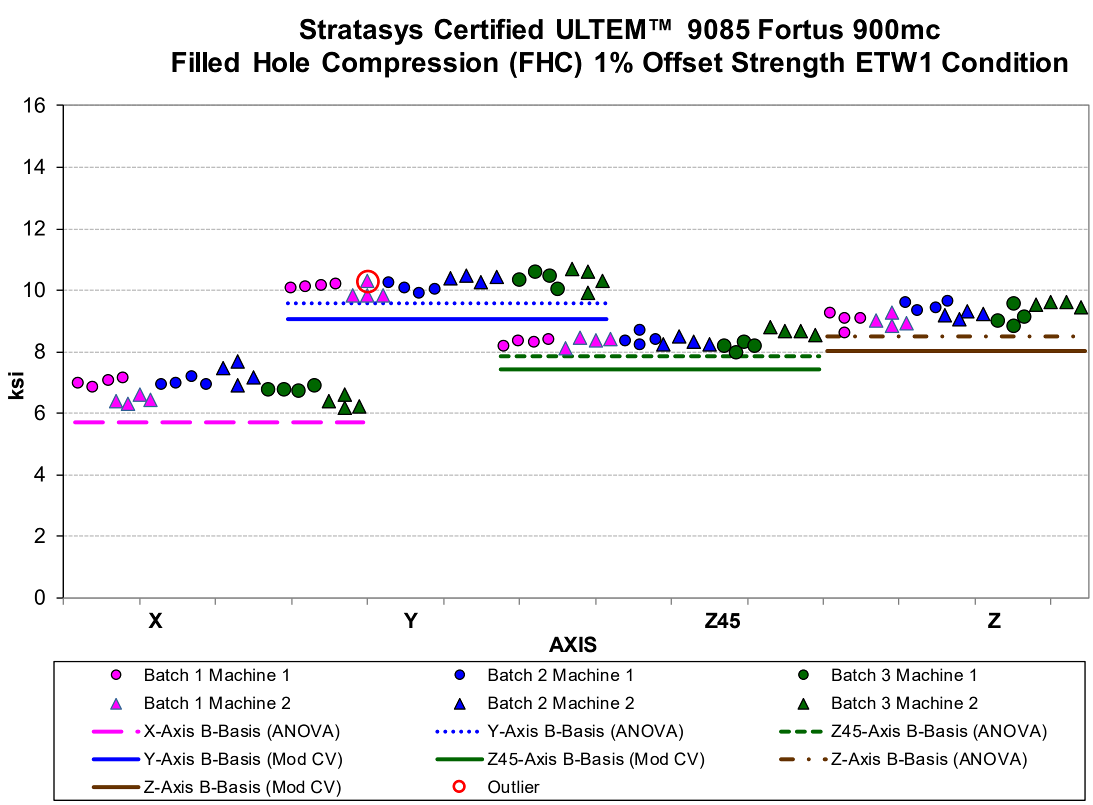



**Figure 4-62: Plot for ETW1 FHC 1% Offset Strength**

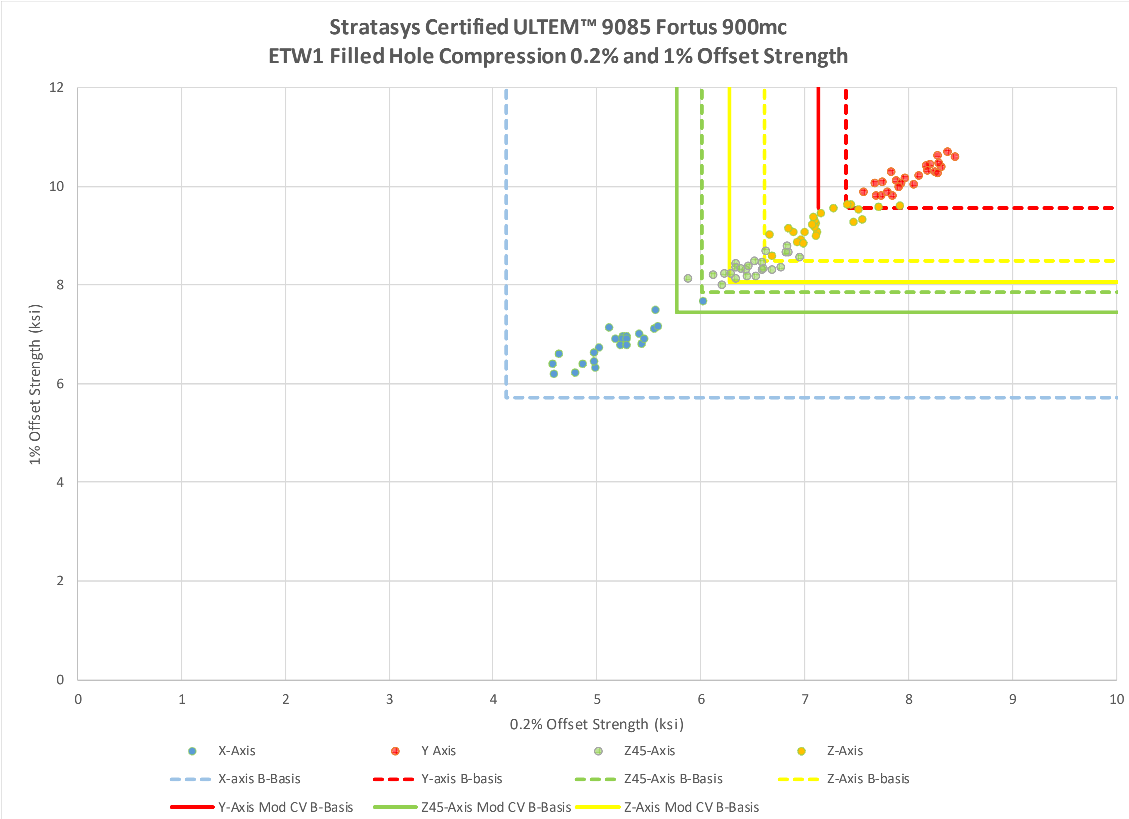



**Figure 4-63: Plot for FHC 0.2% Offset Strength and 1% Offset Strength ETW1 Condition**

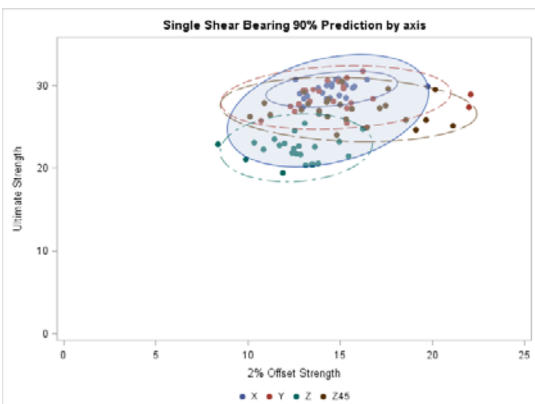
| Filled Hole Compression (FHC) Basis Values and Statistics ETW1 Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.2% Offset Strength | | | | 1% Offset Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 5.178 | 8.021 | 6.490 | 7.171 | 6.815 | 10.202 | 8.367 | 9.231 |
| Stdev | 0.351 | 0.256 | 0.259 | 0.311 | 0.371 | 0.264 | 0.199 | 0.282 |
| CV | 6.786 | 3.189 | 3.986 | 4.338 | 5.436 | 2.584 | 2.376 | 3.055 |
| Mod CV | 7.393 | 6.000 | 6.000 | 6.169 | 6.718 | 6.000 | 6.000 | 6.000 |
| Min | 4.569 | 7.565 | 5.873 | 6.666 | 6.193 | 9.811 | 8.001 | 8.589 |
| Max | 6.027 | 8.449 | 6.947 | 7.916 | 7.674 | 10.691 | 8.783 | 9.638 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | |
| B-Basis | 4.132 | 7.400 | 6.011 | 6.613 | 5.718 | 9.560 | 7.840 | 8.488 |
| A-Estimate | 3.414 | 6.969 | 5.667 | 6.226 | 4.964 | 9.112 | 7.475 | 7.973 |
| Method | ANOVA | pooled | Normal | pooled | ANOVA | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | | | | |
| B-Basis | NA | 7.129 | 5.768 | 6.281 | NA | NA | 7.437 | 8.044 |
| A-Estimate | | 6.490 | 5.251 | 5.664 | | | 6.770 | 7.222 |
| Method | | Normal | Normal | pooled | | | Normal | pooled |

**Table 4-40: Statistics and Basis Values for ETW1 FHC Strength Data**

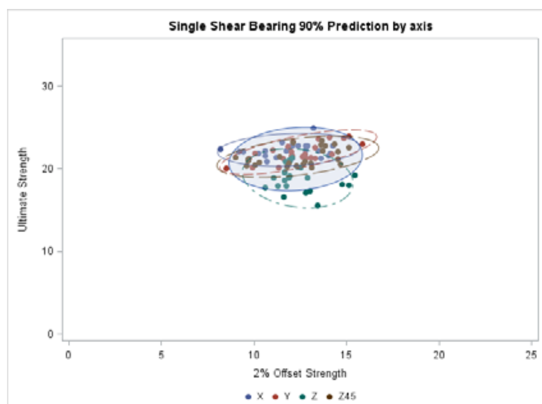
## 4.9 Single-Shear Bearing (SSB)

There were observed failure modes in the SSB tests that were considered inappropriate; a cleavage and lateral tension failure, per the ASTM D5961-17. In this case where a non-reinforced polymer material was tested, these failure modes and results should not be disregarded. The observed failures were predominantly in the Y, Z, and Z45 print directions and appear to be closely associated to the print direction and raster pattern combination for the coupons and may be the inherent behavior of Additively Manufactured Ultem 9085. Please reference Section 4 of NCAMP Test Report CAM-RP-2018-013 for clarification.

Single Shear Bearing tests reported two properties: 2% Offset Strength and Ultimate Strength. Tests were performed in two conditions: RTD and ETW1. The correlations computed by specimen for each direction and condition tested are shown in Table 4-41. The correlations between the two properties are not particularly strong. Scatter plots of the test results for the two measurements for each condition and axis with 90% prediction ellipses are shown in Figure 4-64. A box plot of the two different measurements by axis and condition is shown in Figure 4-65. The graphs show that the X, Y and Z45-axes have similar test results for SSB with large variability and little correlation between the two strength properties, and the Z-axis has the lowest measurements. The RTD condition has higher values for ultimate strength but there is little difference between the conditions for 2% Offset Strength.




RTD




ETW1

**Figure 4-64: Scatter Plots of SSB Strength Properties by Condition and Axis**

| Pearson Correlation Coefficients 2% Offset Strength with Ultimate Strength | | | | | |
|---|---|---|---|---|---|
| | X | Y | Z | Z45 | All |
| RTD | 0.3408 | 0.1582 | 0.1135 | -0.1426 | 0.3229 |
| ETW1 | 0.1760 | 0.6889 | -0.1841 | 0.4384 | 0.1376 |
| ALL | 0.6801 | 0.5482 | 0.0589 | 0.4938 | 0.4949 |

**Table 4-41: Correlation Statistics for Single Shear Bearing Strength Data**

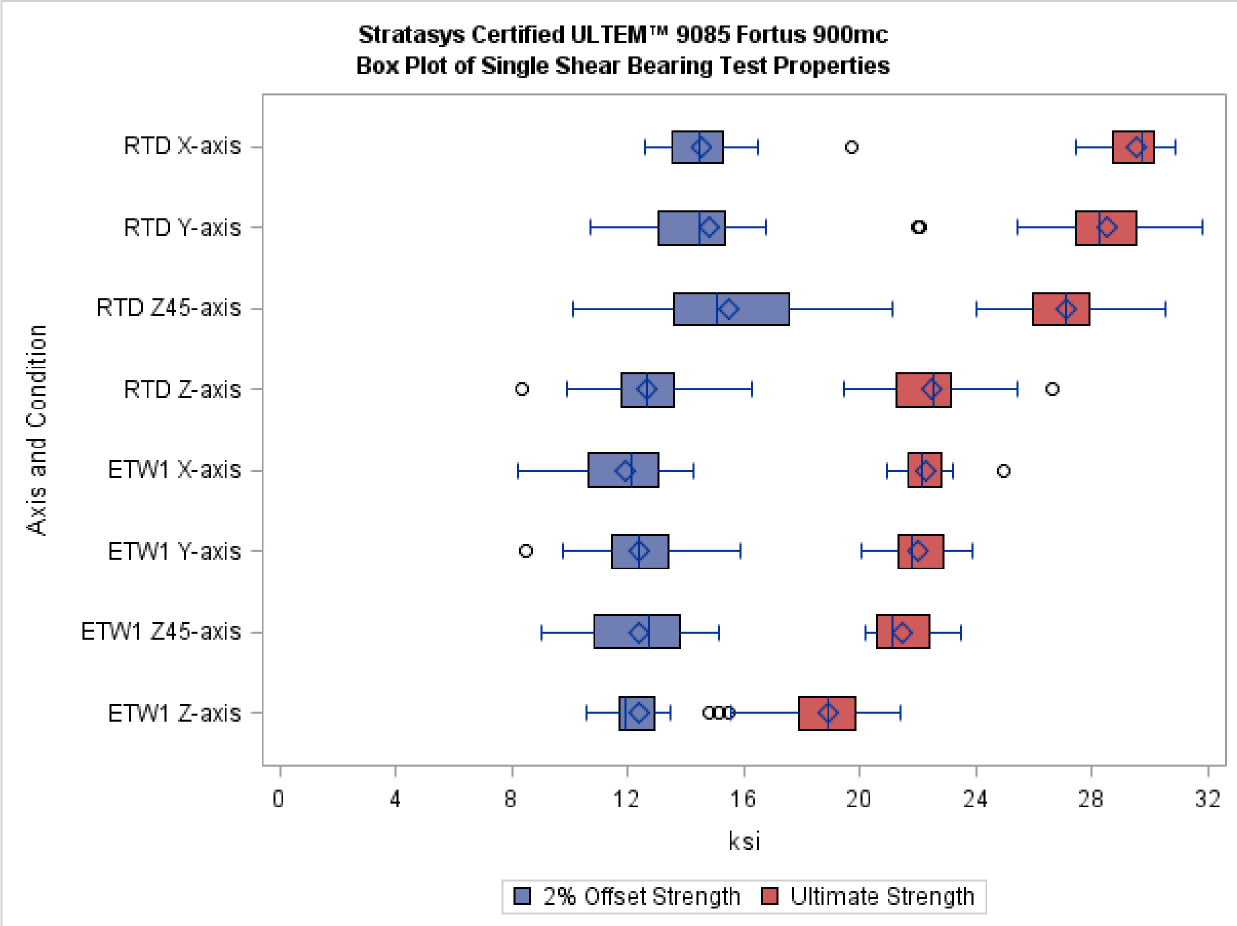



**Figure 4-65: Box Plot for SSB Strength Properties**

An ANOVA analysis was done on each strength property and condition to determine if data from different axes were sufficiently similar to be combined in setting basis values. If so, this was done in addition to computing basis values for each individual axis. There were no statistically significant differences between the X, Y and Z45-axes for 2% Offset Strength in the RTD condition. There were no statistically significant differences between any axes for 2% Offset Strength in the ETW1 condition. The X and Y-axes could be combined for Ultimate Strength in the ETW1 condition. Pooling across the two conditions was acceptable for the X-axis 2% Offset Strength (original CV only) and the X, Y and Z45-axes Ultimate Strength (Mod CV only).

Outlier status was checked for each specimen by condition, batch, machine and the combination of batch and machine. Nine statistical outliers were identified in the SSB data: four in the RTD condition and five in the ETW1 condition. Of the RTD outliers, three were for 2% Offset Strength and one was for Ultimate Strength. Of the ETW1 outliers, one was for 2% offset strength and four were for ultimate strength. No specimen was an outlier for both properties. All outliers were retained for this analysis. Details are given in the text for each condition and all outliers are listed in Table 4-44.

Modified CV basis values are provided when applicable. The Modified CV approach could not be applied to the 2% Offset Strength data (all axes and conditions) due to the CV being above

8%. The Modified CV approach could not be applied to the Ultimate Strength dataset for the Z-axis ETW1 condition due to failure of the ADK test even after the modified CV data transformation.

### 4.9.1 Single Shear Bearing RTD Condition

The Z-axis results were statistically significantly different for both 2% Offset Strength and Ultimate Strength in the RTD condition and could not be combined. Basis values were computed for the X, Y, and Z45-axes combined for 2% Offset Strength measurements in the RTD condition.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for the X-axis Ultimate Strength dataset and the Y, Z45, and Z-axes 2% Offset Strength datasets, so the ANOVA method was required to compute those basis values and estimates.

There were four outliers in the RTD datasets. The highest value in batch two machine one from the X-axis 2% Offset Strength RTD dataset was an outlier for batch two, machine one, and the RTD condition, but not for its batch machine combination. The highest value in batch three machine one from the X-axis 2% Offset Strength RTD dataset was an outlier for its batch machine combination, but not for batch three, machine one, or the RTD condition. The lowest value in batch one machine two from the Y-axis 2% Offset Strength RTD dataset was an outlier for its batch machine combination, but not for batch one, machine two, or the RTD condition. The highest value in batch two machine two from the Z45-axis Ultimate Strength RTD dataset was an outlier for batch two, but not for machine two, the batch machine combination, or the RTD condition.

In the 2% Offset Strength RTD condition there are some Machine/Batch combinations with data clustered yet separate from remaining data. They are circled and identified in Figure 4-66. These data clusters were not sufficient to create statistically significant differences between the X, Y and Z45-axes, but they do illustrate the size of the differences that can be expected to occur between different batches and machines. They also show that those differences are not consistent from one axis to another or with the ultimate strength measurement.

Statistics, basis values and estimates are given for the RTD strength data in Table 4-42. The data, B-estimates and B-basis values are shown graphically for the 2% Offset Strength RTD condition in Figure 4-66, the Ultimate Strength RTD condition in Figure 4-67 and for both together in Figure 4-68.

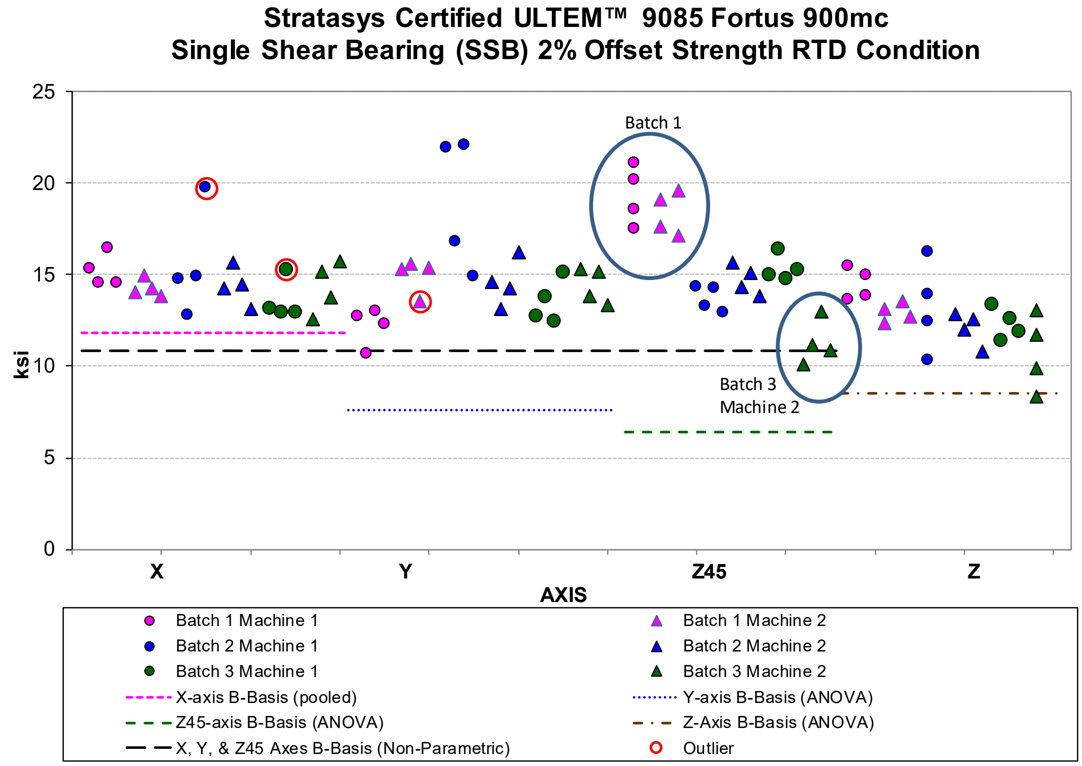



**Figure 4-66: Plot for SSB 2% Offset Strength RTD Condition**

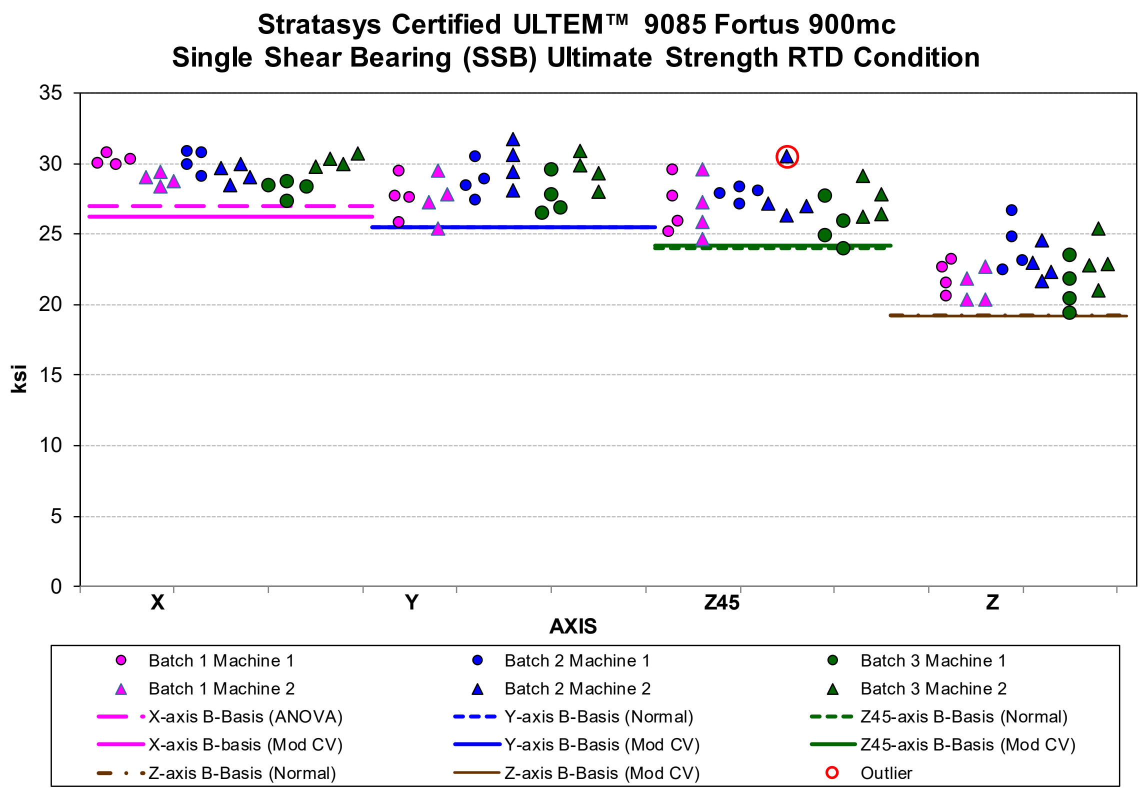



**Figure 4-67: Plot for SSB Ultimate Strength RTD Condition**

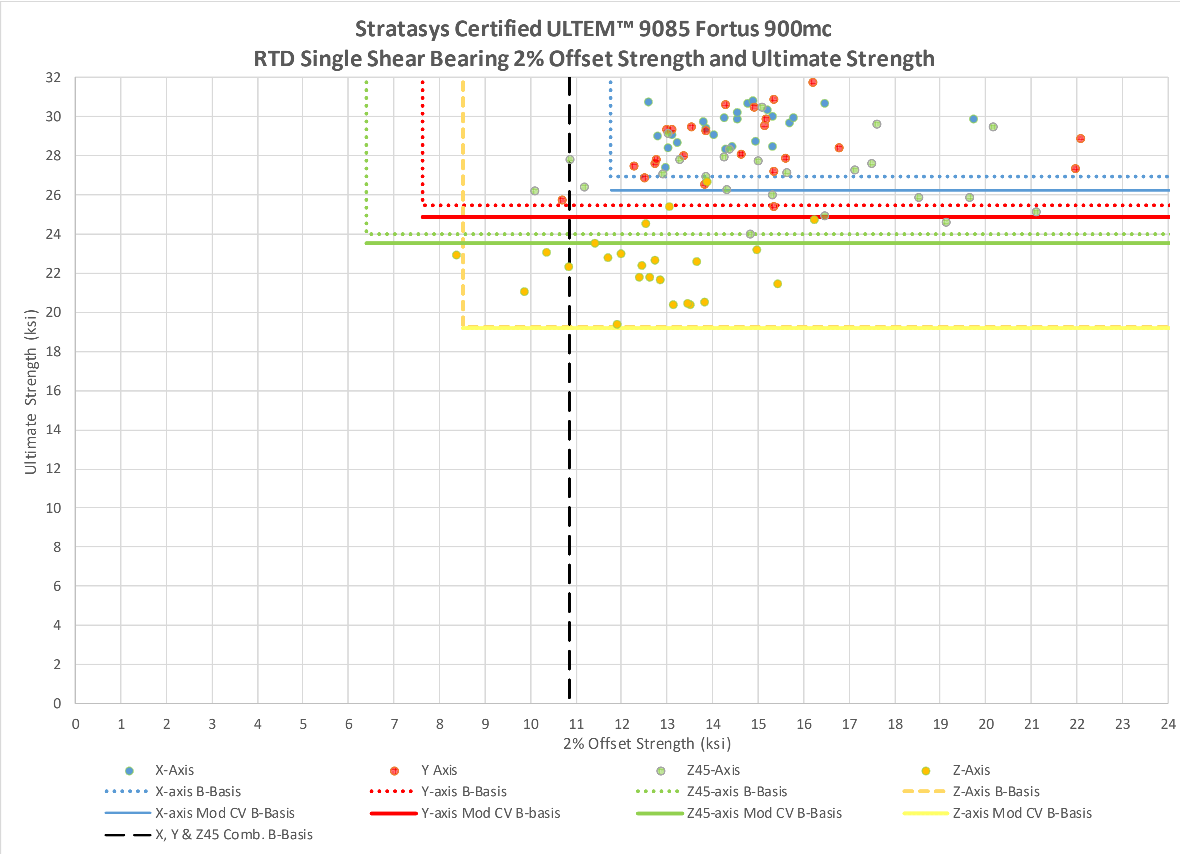



**Figure 4-68: Plot for Single Shear Bearing 2% Offset Strength and Ultimate Strength RTD Condition**

| Single Shear Bearing (SSB) Basis Values and Statistics RTD Condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2% Offset Strength | | | | | Ultimate Strength | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X, Y, Z45 Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis |
| Mean | 14.562 | 14.770 | 15.467 | 12.629 | 14.933 | 29.491 | 28.505 | 27.079 | 22.451 |
| Stdev | 1.508 | 2.644 | 2.948 | 1.744 | 2.443 | 0.920 | 1.629 | 1.645 | 1.727 |
| CV | 10.356 | 17.902 | 19.057 | 13.812 | 16.359 | 3.119 | 5.714 | 6.075 | 7.693 |
| Mod CV | 10.356 | 17.902 | 19.057 | 13.812 | 16.359 | 6.000 | 6.857 | 7.037 | 7.847 |
| Min | 12.584 | 10.689 | 10.095 | 8.363 | 10.095 | 27.396 | 25.409 | 24.002 | 19.410 |
| Max | 19.731 | 22.087 | 21.100 | 16.247 | 22.087 | 30.842 | 31.777 | 30.511 | 26.651 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 24 | 72 | 24 | 24 | 24 | 24 |
| Basis Values and Estimates | | | | | | | | | |
| B-Basis | 11.835 | 7.618 | 6.394 | 8.504 | 10.859 | 26.937 | 25.488 | 24.032 | 19.252 |
| A-Estimate | 9.945 | 2.670 | 0.175 | 5.619 | 7.148 | 25.173 | 23.326 | 21.848 | 16.958 |
| Method | pooled | ANOVA | ANOVA | ANOVA | Non-Parametric | ANOVA | Normal | Normal | Normal |
| Modified CV Basis Values and Estimates | | | | | | | | | |
| B-Basis | NA | NA | NA | NA | NA | 26.770 | 25.518 | 24.184 | 19.186 |
| A-Estimate | | | | | | 24.884 | 23.448 | 22.178 | 16.847 |
| Method | | | | | | pooled | pooled | pooled | Normal |

**Table 4-42: Statistics and Basis Values for RTD SSB Strength Data**

### 4.9.2 Single Shear Bearing ETW1 Condition

There were no statistically significant differences between any of the four axes for the 2% Offset Strength measurements for the ETW1 condition. All four axes could be combined. The Z and Z45-axes were statistically significantly different from each other and the X and Y-axes results but the X and Y-axes datasets could be combined for Ultimate Strength in the ETW1 condition.

Using the Anderson-Darling k-sample test, there were statistically significant differences between the six combinations of batch and machine for all Ultimate Strength datasets, and also for the Y-axis and the combined axes dataset for the 2% Offset Strength property. The ANOVA method was required to compute those basis values and estimates. The Z-axis 2% Offset Strength dataset did not fit the normal, lognormal or Weibull distributions, so the non-parametric method was used for that data. Modified CV basis values could not be computed for the Z-axis Ultimate Strength dataset because it failed the ADK test after applying the modified CV transformation. Every 2% Offset Strength dataset had a CV too high for use of the modified CV method.

There were five outliers. The lowest value in batch one machine two from the X-axis 2% Offset Strength ETW1 dataset was an outlier for batch one, but not for machine two, the batch machine combination, or the ETW1 condition. The highest value in batch two machine one from the X-axis Ultimate Strength ETW1 dataset was an outlier for batch two and the ETW1 condition, but not for machine one or the machine batch combination. The lowest value in batch two machine two from the X-axis Ultimate Strength ETW1 dataset was an outlier for its batch machine combination, but not for batch two, machine two, or the ETW1 condition. The lowest value in batch three machine one from the X-axis Ultimate Strength ETW1 dataset was an outlier for its batch machine combination, but not for batch three, machine one, or the ETW1 dataset. The lowest value in batch three machine two from the Y-axis Ultimate Strength ETW1 dataset was an outlier for its batch machine combination, but not for batch three, machine two, or the ETW1 dataset. All outliers were retained for this analysis.

Statistics, basis values and estimates are given for the ETW1 strength data in Table 4-43. The data, B-estimates and B-basis values are shown graphically for the 2% Offset Strength ETW1 condition in Figure 4-69, the Ultimate Strength ETW1 condition in Figure 4-70, and for both together in Figure 4-71.

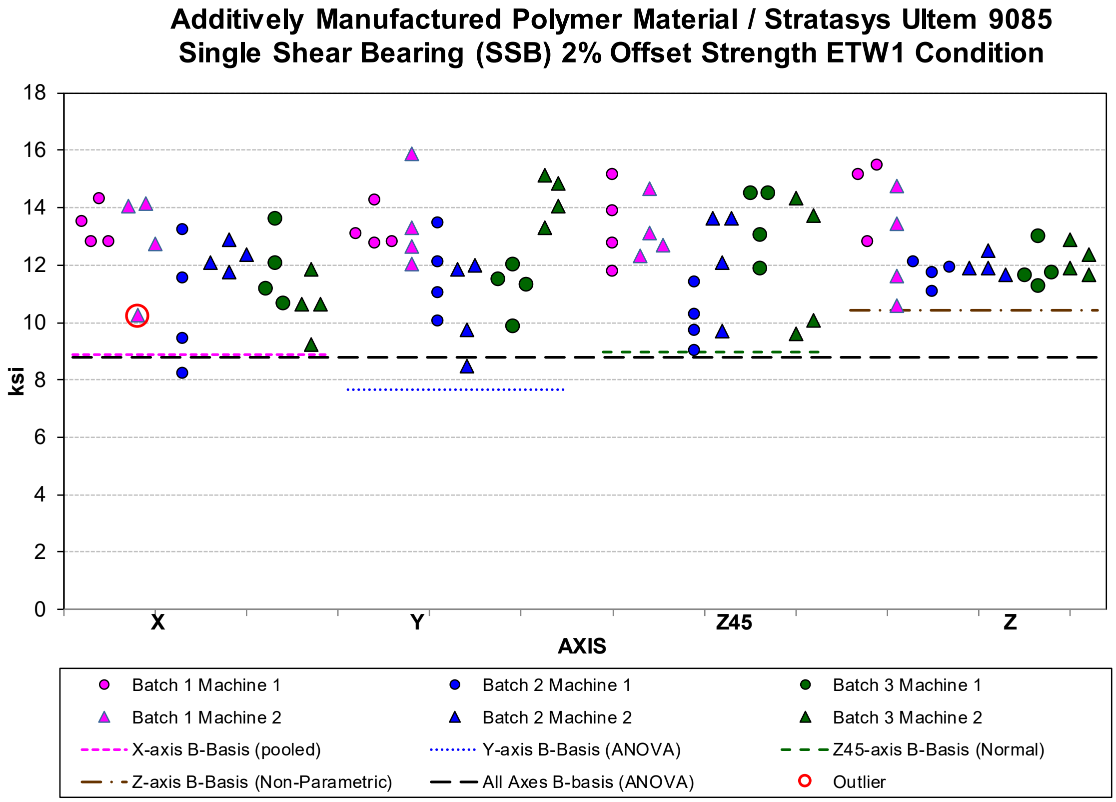



Figure 4-69: Plot for SSB 2% Offset Strength ETW1 Condition

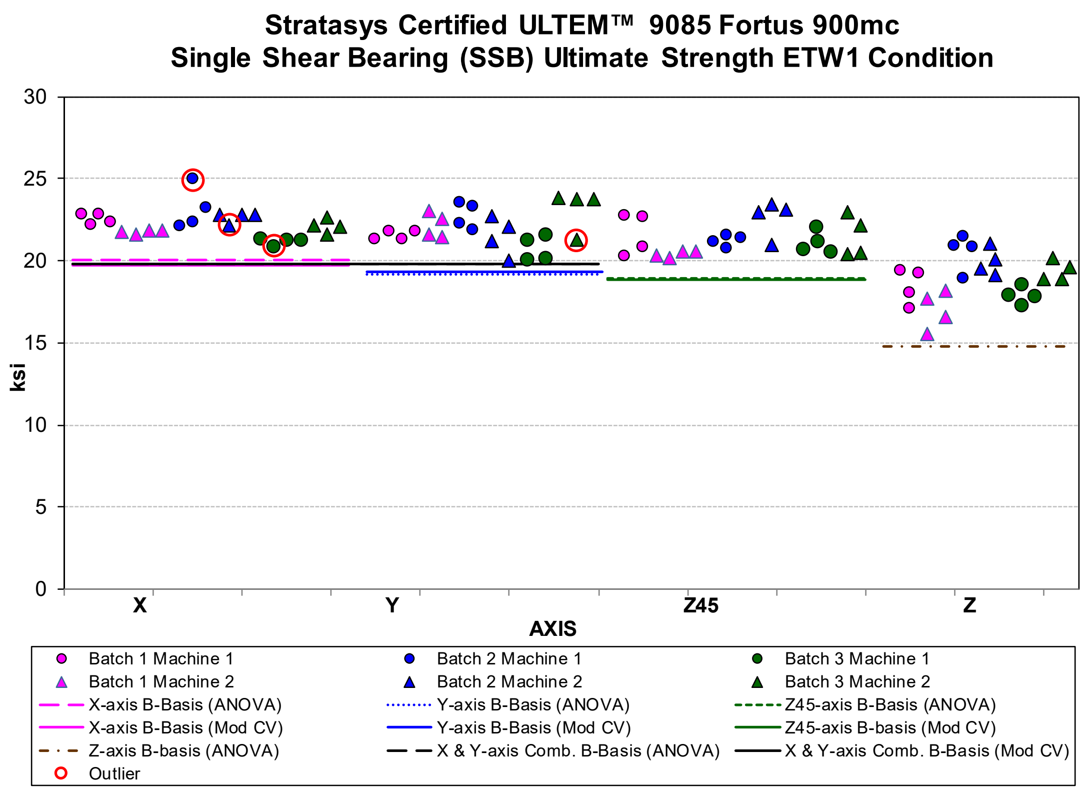



Figure 4-70: Plot for SSB Ultimate Strength ETW1 Condition

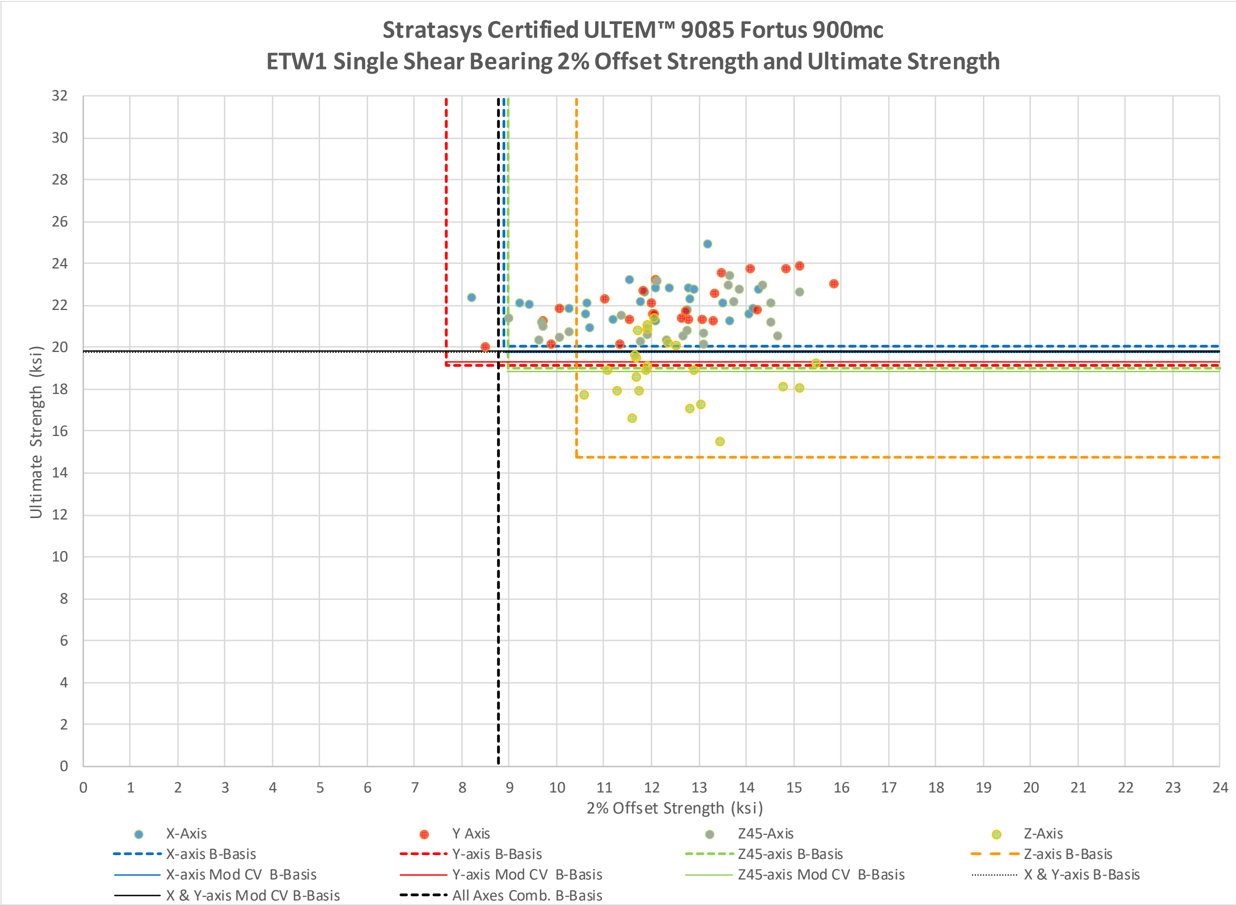



**Figure 4-71: Plot for Single Shear Bearing 2% Offset Strength and Ultimate Strength ETW1 Condition**

| Single Shear Bearing (SSB) Basis Values and Statistics ETW1 Condition | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Env | 2% Offset Strength | | | | | Ultimate Strength | | | | |
| Axis | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X, Y, Z, Z45 Axes | X-Axis | Y-Axis | Z45-Axis | Z-Axis | X & Y Axes |
| Mean | 11.914 | 12.397 | 12.395 | 12.398 | 12.275 | 22.235 | 21.991 | 21.421 | 18.874 | 22.113 |
| Stdev | 1.630 | 1.793 | 1.854 | 1.259 | 1.641 | 0.831 | 1.137 | 1.062 | 1.475 | 0.993 |
| CV | 13.683 | 14.461 | 14.960 | 10.156 | 13.370 | 3.736 | 5.170 | 4.957 | 7.817 | 4.489 |
| Mod CV | 13.683 | 14.461 | 14.960 | 10.156 | 13.370 | 6.000 | 6.585 | 6.478 | 7.908 | 6.245 |
| Min | 8.205 | 8.488 | 8.994 | 10.592 | 8.205 | 20.907 | 20.039 | 20.161 | 15.529 | 20.039 |
| Max | 14.272 | 15.859 | 15.125 | 15.468 | 15.859 | 24.925 | 23.879 | 23.445 | 21.413 | 24.925 |
| Batches | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Machines | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| No. Spec. | 24 | 24 | 24 | 23 | 95 | 24 | 24 | 24 | 24 | 48 |
| Basis Values and Estimates | | | | | | | | | | |
| B-Basis | 9.187 | 7.667 | 8.960 | 10.415 | 8.783 | 20.045 | 19.155 | 18.980 | 14.762 | 19.780 |
| A-Estimate | 7.297 | 4.388 | 6.498 | 6.689 | 6.279 | 18.526 | 17.180 | 17.268 | 11.924 | 18.137 |
| Method | pooled | ANOVA | Normal | Non-Parametric | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA | ANOVA |
| Modified CV Basis Values and Estimates | | | | | | | | | | |
| B-Basis | | | | | | 19.514 | 19.004 | 18.527 | | 19.829 |
| A-Estimate | NA | NA | NA | NA | NA | 17.628 | 16.933 | 16.520 | NA | 18.143 |
| Method | | | | | | pooled | pooled | pooled | | Normal |

**Table 4-43: Statistics and Basis Values for ETW1 SSB Strength Data**

## 4.10 Outliers

Outliers were identified according to the standards documented in section 2.1.5, 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 only (before pooling the three batches within a condition together), for the machine only, for the batch machine combination, and/or for the condition (after pooling the three batches within a condition together). When multiple axes can be combined together, an outlier might be identified in the combined axes dataset. All outliers are identified in the individual specimen graphs for each test type, property and condition.

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. All outliers were investigated to determine if a cause could be found. Outliers with identifiable causes were removed from the dataset, retests were done when appropriate and the retests and remaining specimens were analyzed for this report. Information about specimens that were removed from the dataset along with the cause for removal is documented in the material property data report, NCAMP Test Report CAM-RP-2018-013.

Outliers for which no causes could be identified are listed in Table 4-44. These outliers were included in the analysis for their respective test properties. Outliers identified at the condition level have been bolded.

| Test | Property | Condition | Axis | Batch | Machine | Specimen Number | Strength As-measured | High/ Low | Batch Outlier | Machine Outlier | Machine Batch Combination | Condition Outlier |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DC | 0.2% Offset | CTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XC-13-CTD-1 | 9.300 | Low | No | No | Yes | No |
| DC | 1.0% Offset | CTD | Z45-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-Z45C-11-CTD-4 | 17.630 | High | No | No | Yes | No |
| DC | 0.2% Offset | ETD1 | Y-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-YC-13-ETD1-1 | 10.739 | Low | No | Yes | Yes | No |
| DC | 1.0% Offset | ETW1 | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XC-13-ETW1-1 (R) | 9.632 | Low | Yes | No | No | No |
| DC | 0.2% Offset | ETW1 | X-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-XC-12-ETW1-3 | 10.689 | High | Yes | No | No | No |
| | 1.0% Offset | | | | | | 14.122 | | No | | Yes | |
| DC | 0.2% Offset | ETW1 | Y-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-YC-12-ETW1-3 (R) | 8.586 | Low | No | No | Combined Axes | No |
| | 1.0% Offset | | | | | | 11.570 | | | | Yes | |
| DC | 0.2% Offset | ETW1 | Z45-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-Z45C-13-ETW1-1 | 8.814 | High | No | No | Yes | No |
| DC | 1.0% Offset | ETW1 | Z-Axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-ZC-13-ETW1-1 | 11.960 | Low | No | No | Yes | No |
| DC | 0.2% Offset | ETW1 | Z-Axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-ZC-13-ETW1-1 | 9.288 | High | No | No | Yes | No |
| DC | 0.2% Offset | ETW1 | Z-Axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-ZC-14-ETW1-3 (R) | 7.548 | Low | No | Yes | No | No |
| | 1.0% Offset | | | | | | 9.992 | | Yes | | | |
| DC | 0.2% Offset | RTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XC-11-RTD-4 | 8.833 | High | Yes | No | Yes | No |
| DC | 0.2% Offset | RTD | Y-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-YC-13-RTD-1 (R) | 9.930 | Low | No | No | Yes | No |
| | 1.0% Offset | | | | | | 14.473 | | | | | |
| DC | 1.0% Offset | RTD | Y-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-YC-11-RTD-4 (R) | 14.037 | Low | Yes | No | No | No |
| DC | 0.2% Offset | RTD | Z45-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-Z45C-15-RTD-2 | 6.644 | Low | No | Yes | No | Combined Axes |
| | 1.0% Offset | | | | | | 11.529 | | | | | No |
| DC | 1.0% Offset | RTD | Z-Axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-ZC-13-RTD-1 (R) | 14.702 | High | Yes | Yes | No | Yes |
| DC | 0.2% Offset | RTD | Z-Axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-ZC-13-RTD-1 (R) | 8.466 | Low | No | No | Yes | No |
| DC | 0.2% Offset | RTD | Z-Axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-ZC-11-RTD-4 | 9.734 | High | No | No | Combined Axes | No |
| DC | 0.2% Offset | RTD | Z-Axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZC-12-RTD-3 | 8.221 | Low | Yes | No | No | No |
| DC | 0.2% Offset | RTW | Z-Axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZC-15-RTW-2 | 10.377 | High | No | Yes | Yes | NA (1 - Batch) |
| DT | Strength | CTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XT-13-CTD-1 | 12.407 | Low | No | No | Yes | No |
| DT | 0.2% Offset | CTD | X-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-XT-11-CTD-3 | 8.917 | High | No | No | Combined Axes | Yes |
| DT | 0.2% Offset | CTD | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XT-14-CTD-4 | 7.817 | High | No | No | Yes | No |
| DT | 0.2% Offset | CTD | Z45-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-Z45T-14-CTD-3 | 7.780 | High | No | No | Yes | No |
| DT | Strength | CTD | Z-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-ZT-15-CTD-2 | 9.341 | Low | No | Yes | No | No |
| DT | Strength | CTD | Z-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-ZT-15-CTD-2 | 8.730 | Low | Yes | Yes | No | Yes |
| DT | Strength | ETW1 | X-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-XT-11-ETW1-3 | 7.356 | High | Yes | No | No | No |
| DT | 0.2% Offset | ETW1 | Z45-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-Z45T-15-ETW1-2 | 5.135 | High | Yes | No | No | No |
| DT | 0.2% Offset | ETW1 | Z-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZT-13-ETW1-1 | 4.388 | Low | Yes | No | No | No |
| DT | Strength | RTD | X-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-XT-15-RTD-2 | 8.743 | Low | No | No | No | Yes |
| DT | 0.2% Offset | RTD | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XT-11-RTD-3 | 5.805 | High | No | No | Yes | No |
| DT | 0.2% Offset | RTD | Z-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZT-15-RTD-2 | 5.255 | Low | No | No | Yes | No |
| DT | Strength | RTD | Z-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-ZT-13-RTD-1 | 9.085 | High | No | No | No | Yes |
| DT | 0.2% Offset | RTW | Y-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-YT-13-RTW-1 | 7.187 | High | No | Yes | Yes | NA (1 - Batch) |
| | Strength | | | | | | 12.541 | | Yes | Yes | Yes | |
| DT | Strength | RTW | Z-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-ZT-13-RTW-1 | 6.912 | Low | No | Yes | Yes | NA (1 - Batch) |
| FHC | 1.0% Offset | ETW1 | Y-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-YFHC-12-ETW1-3 | 10.302 | High | No | No | Yes | No |
| FHC | 0.2% Offset | ETW1 | Z45-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-Z45FHC-13-ETW1-1 | 5.873 | Low | Yes | No | No | No |
| FHC | 0.2% Offset | ETW1 | Z45-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-Z45FHC-15-ETW1-2 | 6.593 | High | No | No | Yes | No |
| FHC | 1.0% Offset | RTD | X-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-XFHC-15-RTD-2 | 10.250 | High | No | No | Yes | No |
| FHC | 0.2% Offset | RTD | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XFHC-15-RTD-2 | 8.033 | High | Yes | No | No | No |
| FHC | 1.0% Offset | RTD | Y-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-YFHC-15-RTD-4 (R) | 13.194 | Low | Yes | No | No | No |
| FHC | 0.2% Offset | RTD | Y-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-YFHC-14-RTD-3 | 10.242 | Low | No | No | Yes | No |
| FHC | 0.2% Offset | RTD | Z45-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-Z45FHC-13-RTD-1 | 7.894 | Low | No | Yes | No | No |
| | 1.0% Offset | | | | | | 11.227 | | Yes | No | | Yes |
| FHC | 0.2% Offset | RTD | Z-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-ZFHC-14-RTD-3 | 10.009 | High | No | No | Yes | No |
| **FHT** | **Strength** | **CTD** | **Y-axis** | **2** | **1** | **NTPAMP001-SY-UM9085-RPM-B-M1-YFHT-11-CTD-4** | **10.120** | **Low** | **No** | **No** | **No** | **Yes** |
| FHT | Strength | CTD | Z45-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-Z45FHT-11-CTD-4 | 8.368 | High | No | No | Yes | No |
| FHT | Strength | CTD | Z-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-ZFHT-13-CTD-1 | 8.729 | High | No | No | Yes | No |
| FHT | Strength | ETW1 | X-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-XFHT-13-ETW1-1 | 5.016 | Low | Yes | No | Yes | No |
| FHT | Strength | ETW1 | Y-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-YFHT-13-ETW1-1 | 6.275 | Low | Yes | No | No | No |
| FHT | Strength | ETW1 | Z45-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-Z45FHT-13-ETW1-1 | 4.726 | Low | No | Yes | No | No |
| FHT | Strength | ETW1 | Z-Axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZFHT-13-ETW1-1 | 4.258 | Low | No | No | Yes | No |
| FHT | Strength | RTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XFHT-15-RTD-2 | 7.646 | High | No | No | Yes | No |
| **FHT** | **Strength** | **RTD** | **X-axis** | **2** | **1** | **NTPAMP001-SY-UM9085-RPM-B-M1-XFHT-13-RTD-1** | **8.341** | **High** | **No** | **No** | **No** | **Yes** |
| FHT | Strength | RTD | X-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-XFHT-15-RTD-2 | 7.425 | High | No | No | Yes | No |
| FLEX | Strength | CTD | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XF-15-CTD-2 | 18.211 | Low | Yes | Yes | No | No |
| **FLEX** | **Strength** | **CTD** | **Y-axis** | **1** | **1** | **NTPAMP001-SY-UM9085-RPM-A-M1-YF-13-CTD-1** | **26.220** | **High** | **No** | **Yes** | **No** | **Yes** |
| FLEX | Strength | CTD | Y-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-YF-15-CTD-2 | 23.521 | Low | Yes | No | No | No |
| FLEX | Strength | CTD | Z-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-ZF-12-CTD-4 | 18.330 | High | Yes | No | Yes | No |
| FLEX | Strength | CTD | Z-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-ZF-12-CTD-4 | 17.725 | High | No | No | Yes | No |
| FLEX | Strength | CTD | Z-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZF-11-CTD-3 | 17.651 | Low | No | No | Yes | No |
| FLEX | Strength | ETW1 | X-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-XF-13-ETW1-1 | 12.405 | Low | No | No | Yes | No |
| FLEX | Strength | ETW1 | Z45-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-Z45F-13-ETW1-1 | 8.892 | Low | No | No | Yes | No |
| FLEX | Strength | ETW1 | Z-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-ZF-11-ETW1-3 | 9.680 | Low | Yes | No | No | No |
| FLEX | Strength | RTD | Z45-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-Z45F-12-RTD-3 | 11.635 | Low | No | No | Combined Axes | No |
| FLEX | Strength | RTD | Z-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-ZF-15-RTD-2 | 11.103 | Low | Yes | No | No | No |
| OHC | 1.0% Offset | ETW1 | Y-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-YOHC-15-ETW1-2 | 8.616 | Low | Yes | No | No | No |
| OHC | 0.2% Offset | RTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XOHC-13-RTD-1 (R) | 6.306 | High | No | No | Yes | No |
| **OHC** | **1.0% Offset** | **RTD** | **X-axis** | **2** | **2** | **NTPAMP001-SY-UM9085-RPM-B-M2-XOHC-15-RTD-2** | **10.913** | **High** | **Yes** | **Yes** | **No** | **Yes** |
| OHC | 1.0% Offset | RTD | X-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-XOHC-15-RTD-2 | 8.847 | High | No | No | Yes | No |
| OHC | 0.2% Offset | RTD | Z45-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-Z45OHC-13-RTD-1 (R) | 8.255 | High | No | No | Yes | No |
| OHT | Strength | CTD | Y-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-YOHT-11-CTD-4 | 7.269 | Low | No | No | Combined Axes | No |
| OHT | Strength | CTD | Z45-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-Z45OHT-13-CTD-1 | 5.622 | Low | No | No | Yes | No |
| OHT | Strength | CTD | Z-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-ZOHT-11-CTD-4 | 5.021 | High | No | No | Yes | No |
| OHT | Strength | ETW1 | Z45-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-Z45OHT-13-ETW1-1 | 4.039 | High | No | No | Yes | No |
| OHT | Strength | ETW1 | Z-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-ZOHT-13-ETW1-1 | 2.813 | Low | No | No | Yes | No |
| OHT | Strength | RTD | X-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-XOHT-15-RTD-2 | 6.995 | High | Yes | No | No | No |
| OHT | Strength | RTD | Z45-axis | 2 | 1 | NTPAMP001-SY-UM9085-RPM-B-M1-Z45OHT-13-RTD-1 | 5.451 | High | No | No | Yes | No |
| OHT | Strength | RTD | Z-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-ZOHT-11-RTD-4 | 4.036 | Low | No | No | Yes | No |
| SSB | 2% Offset | ETW1 | X-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-XSSB-15-ETW1-2 | 10.253 | Low | Yes | No | No | No |
| **SSB** | **Ultimate** | **ETW1** | **X-axis** | **2** | **1** | **NTPAMP001-SY-UM9085-RPM-B-M1-XSSB-14-ETW1-3** | **24.925** | **High** | **Yes** | **No** | **No** | **Yes** |
| SSB | Ultimate | ETW1 | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XSSB-12-ETW1-3 | 22.174 | Low | No | No | Yes | No |
| SSB | Ultimate | ETW1 | X-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-XSSB-11-ETW1-4 | 20.907 | Low | No | No | Yes | No |
| SSB | Ultimate | ETW1 | Y-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-YSSB-12-ETW1-3 | 21.272 | Low | No | No | Yes | No |
| **SSB** | **2% Offset** | **RTD** | **X-axis** | **2** | **1** | **NTPAMP001-SY-UM9085-RPM-B-M1-XSSB-11-RTD-4** | **19.731** | **High** | **Yes** | **Yes** | **No** | **Yes** |
| SSB | 2% Offset | RTD | X-axis | 3 | 1 | NTPAMP001-SY-UM9085-RPM-C-M1-XSSB-13-RTD-1 | 15.309 | High | No | No | Yes | No |
| SSB | 2% Offset | RTD | Y-axis | 1 | 2 | NTPAMP001-SY-UM9085-RPM-A-M2-YSSB-11-RTD-4 | 13.550 | Low | No | No | Yes | No |
| SSB | Ultimate | RTD | Z45-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-Z45SSB-11-RTD-4 | 30.511 | High | Yes | No | No | No |
| VIPS | 0.2% Offset | CTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XVIPS-11-CTD-4 | 4.059 | Low | No | No | Yes | No |
| VIPS | 0.5% Strain | ETW1 | X-axis | 2 | 2 | NTPAMP001-SY-UM9085-RPM-B-M2-XVIPS-13-ETW1-1 | 4.776 | High | No | No | Yes | No |
| VIPS | 0.2% Offset | RTD | X-axis | 1 | 1 | NTPAMP001-SY-UM9085-RPM-A-M1-XVIPS-15-RTD-2 | 2.939 | Low | Yes | No | No | No |
| VIPS | 0.5% Strain | RTD | X-axis | 3 | 2 | NTPAMP001-SY-UM9085-RPM-C-M2-XVIPS-11-RTD-4 | 5.982 | High | Yes | No | No | No |

**Table 4-44: List of Outliers**

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