INL/MIS-19-56195-Revision-0

Baseline Characterization Database Verification Report IG-110 Billet 10X69

David T Rohrbaugh

December 2019

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ENGINEERING CALCULATIONS AND ANALYSIS INL/MIS-19-56195

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

SIGNATURES

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Performer:	David Rohrbaugh	D520	[signature]	11/14/2019
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1. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
2. Concurrence of method or approach. See definition, LWP-10106.
3. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
4. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.
5. Does the document contain CUI material please check either yes or no.

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1.	Does this ECAR involve a Safety SSC?	No	**Professional Engineer's Stamp** N/A See LWP-10010 for requirements.
2.	Safety SSC Determination Document ID	NA	
3.	Engineering Job (EJ) No.	NA	
4.	SSC ID	NA	
5.	Building	IRC	
6.	Site Area	REC	

7. Objective/Purpose:

The purpose of this engineering calculations and analysis report (ECAR) is to present the data being collected in the Baseline Graphite Characterization program. This program is directly tasked with supporting Idaho National Laboratory's (INL's) research and development efforts in the Advanced Reactor Technologies (ART) program. This program populates a comprehensive database that will reflect the baseline properties of nuclear-grade graphite with regard to individual grade, billet, and position within individual billets. The physical- and mechanical-property information being collected will be transferred to the Nuclear Data Management and Analysis System (NDMAS), and that database will help populate the handbook of property data available to member nations of the Generation-IV International Forum.

The transfer of these data from the applicable technical lead to the dissemination databases available to other end users requires a full review of test procedures and data-collection efforts through an analysis of the multiple summary spreadsheets and values being collected. This report represents that analysis for IG-110, Billet 10X69 and facilitates the release of the associated data to the NDMAS custodians.

8. If revision, please state the reason and list sections and/or pages being affected:

NA

9. Conclusions/Recommendations:

Based on a review of data spreadsheets compiled from physical- and mechanical-property measurements on nuclear-grade graphite Billet IG-110, 10X69, no notable errors or omissions were found that will preclude the transfer of these data to the NDMAS site for storage.

In addition to a full visual review of the data files to determine whether obvious errors, such as missing information, were made in the data collected, graphical representations were made of individual evaluations to provide a means to identify anomalies. The techniques employed are an adequate means of ensuring comprehensively that data collected reflect the intended values of interest. A review of the data indicates that the files, as submitted, are fully representative of the measured properties of the graphite billets being tested, as outlined in the applicable test procedures and program plans.

CONTENTS

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
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Checker[a]	W. David Swank	B612	All
Independent Reviewer[b]	NA		
CUI Reviewer[c]	NA		
Manager[d]	Robert Caliva	D520	
Requestor[e]	William Windes	B612	
Nuclear Safety[e]	NA		
Document Owner[e]	William Windes	B612	

Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.

b. Concurrence of method or approach. See definition, LWP-10106.

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NOTE: *Delete or mark "N/A" for project roles not engaged. Include ALL personnel and their roles listed above in the eCR system. The list of the roles above is not all inclusive. If needed, the list can be extended or reduced.*

SCOPE AND BRIEF DESCRIPTION

This ECAR is a validity evaluation of the physical- and mechanical-property databases collected on a billet of nuclear-grade graphite (i.e., IG-110 Billet 10X69) in support of the ART Baseline Graphite Characterization Program.[1,2] Millions of raw data points that have been collected during testing and quantification analyses for these billets, the summary scalar property values, and supplementary traceability data are collected into comprehensive spreadsheets. Data sets comprise single billets of graphite for any given grade, organized by mechanical test-specimen type, and further subdivided into individual spreadsheet tabs according to the specific test or evaluation performed.

This report is not a direct analysis of properties and will not provide information on the validity or performance characteristics of the graphite itself. Rather, it is intended as a verification of the completeness of actual data collected in accordance with PLN-3467,[3] "Baseline Graphite Characterization Plan: Electromechanical Testing," and its representation of the measurement and test results with sole regard to the graphite billets under evaluation.

DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

Mechanical- and physical-property testing is carried out in accordance with PLN-3348 [2], "Graphite Mechanical Testing," PLN-3467,[3] "Baseline Graphite Characterization Plan: Electromechanical Testing," and PLN-3267,[4] "AGC-2 Characterization Plan."

RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

None

ASSUMPTIONS

None

COMPUTER CODE VALIDATION

Data collection and storage is organized as reported in PLN-3467 [3] and INL/EXT-10-19910,[5] "Baseline Graphite Characterization: First Billet." Individual computers used run the Windows 7 operating systems and store data in Microsoft Office Excel 2007 spreadsheets.

Control of individual test equipment is carried out by proprietary Netzsch software (IRC C-20) or Instron's Bluehill (Version 2) software (load frames in IRC B-11). Both software suites are commercially available packages. Updates and data transfers and integration are handled outside of INL's network system on a dedicated local area network.

The comprehensive interface between data collection, evaluation, and storage computers is handled through the customized LabVIEW-based Graphite Mechanical Properties Data Acquisition Software (Version 4.0). The Baseline Graphite Characterization Program's version control and operability checks are documented and validated in a registered laboratory notebook, LAB 2143, "Baseline Graphite Characterization."" Validation of commercial packages is handled via integrated system checks specific to each new element or upgrade as appropriate.

DISCUSSION/ANALYSIS

Introduction

The ART Project Graphite Research and Development Program is generating the extensive quantitative data necessary for predicting the behavior and operating performance of available nuclear-graphite grades. To determine the in-service behavior of graphite for the latest proposed designs, two main programs are underway: The Advanced Graphite Creep (AGC) Program and the Baseline Graphite Characterization Program. The AGC Program provides a set of tests that are designed to evaluate the irradiated properties and behavior of nuclear-grade graphite over a large spectrum of conditions based on the operating environment of the very high-temperature reactor core.[1] Limited data can be generated on irradiated material because of the availability of space within the Advanced Test Reactor and the geometric constraints placed on the AGC specimens to be inserted. To supplement the AGC data set, the Baseline Graphite Characterization Program provides additional data that will characterize inherent property variability in nuclear-grade graphite without the testing constraints of the AGC Program.[2] This variability in properties is a natural artifact of graphite due to the geologic raw materials that are used in its production. This variability is being quantified, not only within a single billet of as-produced graphite, but also from billets within a single lot, billets from different lots of the same grade, and across different billets of the numerous grades of nuclear graphite that are presently available.

This particular report covers the release of physical- and mechanical-property data from a billet of IG-110 graphite. The graphite billet (IG-110-10X69) is a block of iso-molded graphite with a fine grain structure. The main baseline mechanical-properties database for this billet, plots of which are included throughout this report, comprise solely scalar results from each of the different evaluations (mechanical testing and physical properties) in summary form, and consists of tabbed spreadsheets occupied by over 70,000 cells of individual characteristic or property values and associated tagging information.

This report is intended as a validation review of the billet listed above. It is not an analysis of property characteristics or trends beyond the evaluation necessary to determine whether or not the data that has been collected is reflective of the properties of this particular graphite billet. It is an acceptance of test methods used and data calculations and conversions being carried out and a review of the values to determine whether they reflect anomalous behavior that must be further investigated.

Ultimately, this report is the justification for transfer of this data set into a storage and analysis system that is available for internal and external analysts and used to evaluate relevant characteristics and performance of nuclear-grade graphite.

Database Analysis

The many data sets generated for the Baseline Graphite Characterization Program consist of properties collected on standard American Society of Testing and Materials (ASTM) International-based mechanical test specimens, as shown in Figure 1. Details of specimen tracking, traceability, process flow, and the techniques being employed to facilitate those activities are provided in INL/EXT-10-19910.[5] An example of a sectioning diagram for IG-110 graphite, along with the applicable specimen-identification codes, is provided in Figure 2. This figure is representative of a single subblock of graphite from this billet. Detailed drawings of IG-110 graphite billet sectioning can be found in INL drawings 780930 and 780931.

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

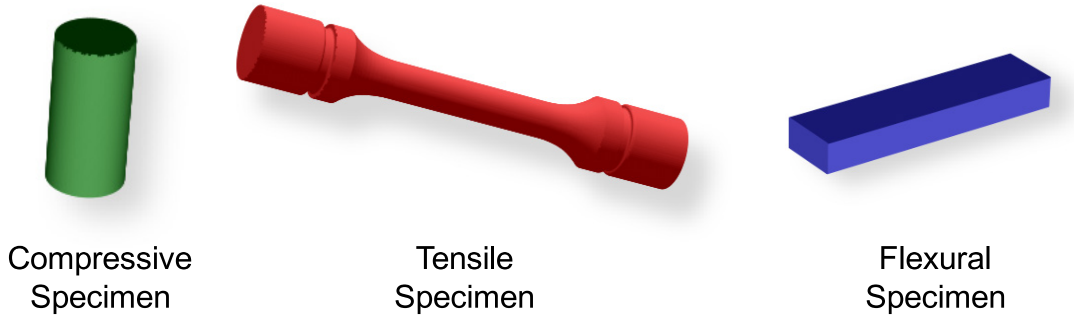

Figure 1. The three types of mechanical test specimens that will be machined from stock graphite and provide the basis for material property evaluations.

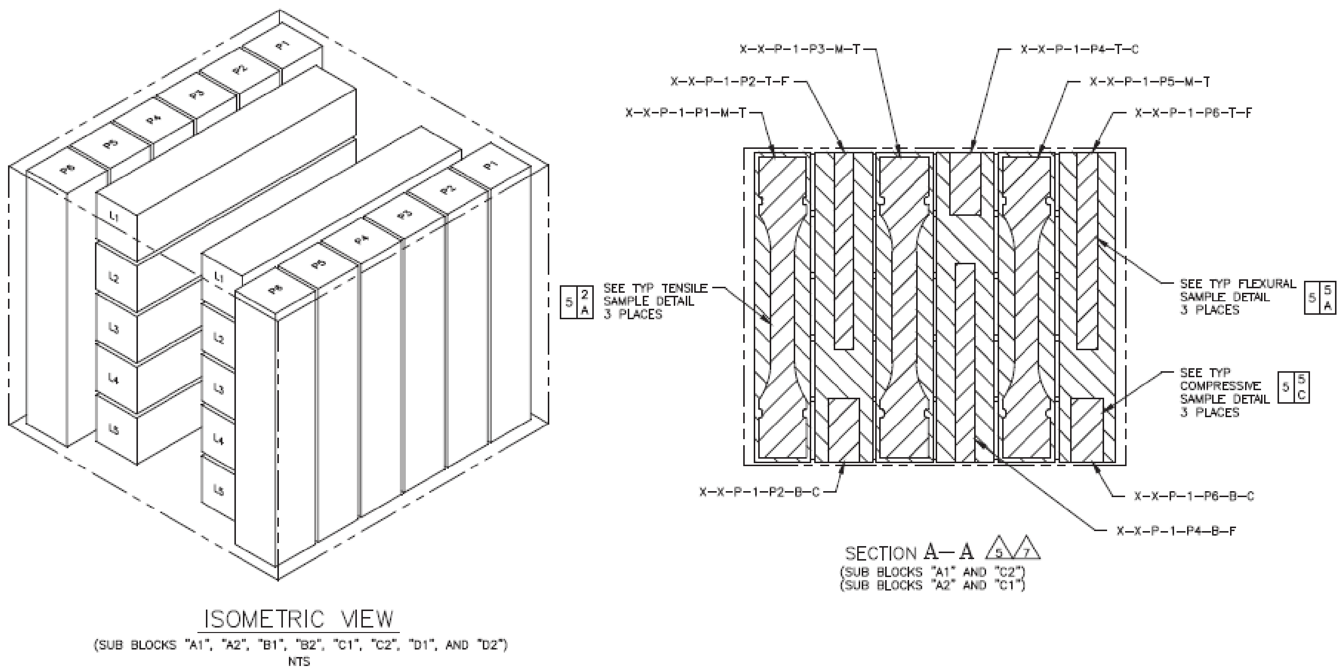

Figure 2. Extraction of individual specimens and identification for tracking purposes from IG-110-10X69.

Sections of this report, which are divided by mechanical test-specimen type (e.g., compressive, flexural, or tensile) cover each of the individual databases for this billet and are organized so they present data in graphical form. The graphic representations are not sorted in any way aside from the actual order in which they were tested, which was randomized for the express purpose of minimizing test anomalies based on actual test timeframes. Some expectation of variation in the property values exists, but individual data points that fall within a reasonable property-value range are considered acceptable. Comparisons of extreme values with other associated properties (i.e., a comparison of maximum tensile load values with measured strain to determine whether they are related by the expected elastic modulus) are carried out where applicable. Each of these comparisons and analyses may not be explicitly included in the text of this report, but the process-control charts with standard-deviation values and/or property-trend charts for the various characteristics being measured are included both in this section as well as the appendices (±1, 2, and 3 standard deviations are represented by the yellow, orange, and red dotted lines, and the mean is represented by the green line).

One of the clear goals of the Baseline Graphite Characterization Program is to identify and quantify interbillet variation. However, the focus of this analysis is to compare values from complete data sets to quickly identify outlying points. One example would be a “zero” value for a specific property—quickly identifiable on a test-result trend graph—providing an indication that the specific spreadsheet cell is improperly empty. Another example would be a large disparity between a limited number of points on that same test-result trend graph that results from missing values in other cells (i.e., dimensional measurements from which final properties are calculated). This verification will couple those observations with a comprehensive data scan of individual points to determine whether the data set can be considered complete and the scalar summary points provided to the NDMAS are appropriately representative of the billet under evaluation.

Compression Specimen Spreadsheet Database (IG-110-10X69C)

Compression Testing

Compression testing was performed per ASTM C695-91[6] and INL PLN-3467. Figure 3 shows the maximum load applied to each of the 233 compression specimens from Billet 10X69. Three specimens in this plot have load values that are less than three standard deviations from the mean. These data prompted a closer look at the consistency of the specimens’ other property measurements, such as dimensions, densities, and modulus values. When explored, these values were found to be consistent with the other 230 specimens’ measurements. Thus, their load data will be accepted.

The compressive-strength values (Figure 4) correlate directly with the recorded load values, confirming the stress calculations were performed correctly. An additional check of critical property values is the measured deflection (Figure 5) of the loading surface, or upper platen, as measured by a calibrated deflectometer. Within geometric variations, the deflection should reflect the calculated compressive strain, as shown in Figure 6.

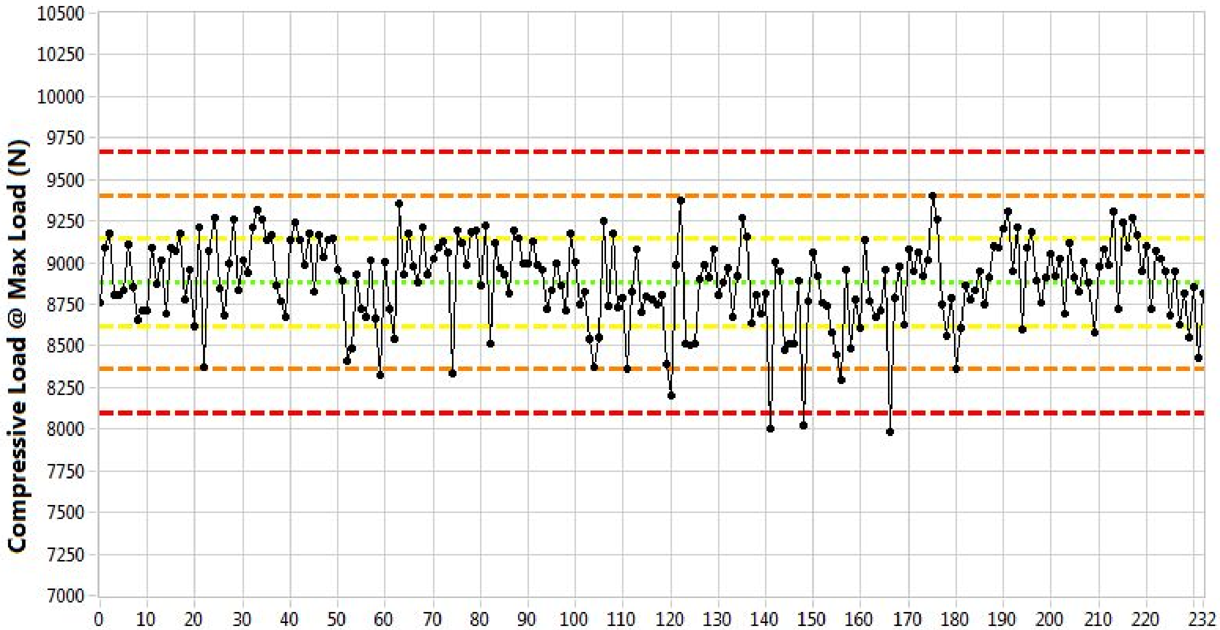

Figure 3. Compressive load at max load (N), mean = 8883, standard deviation = 262.

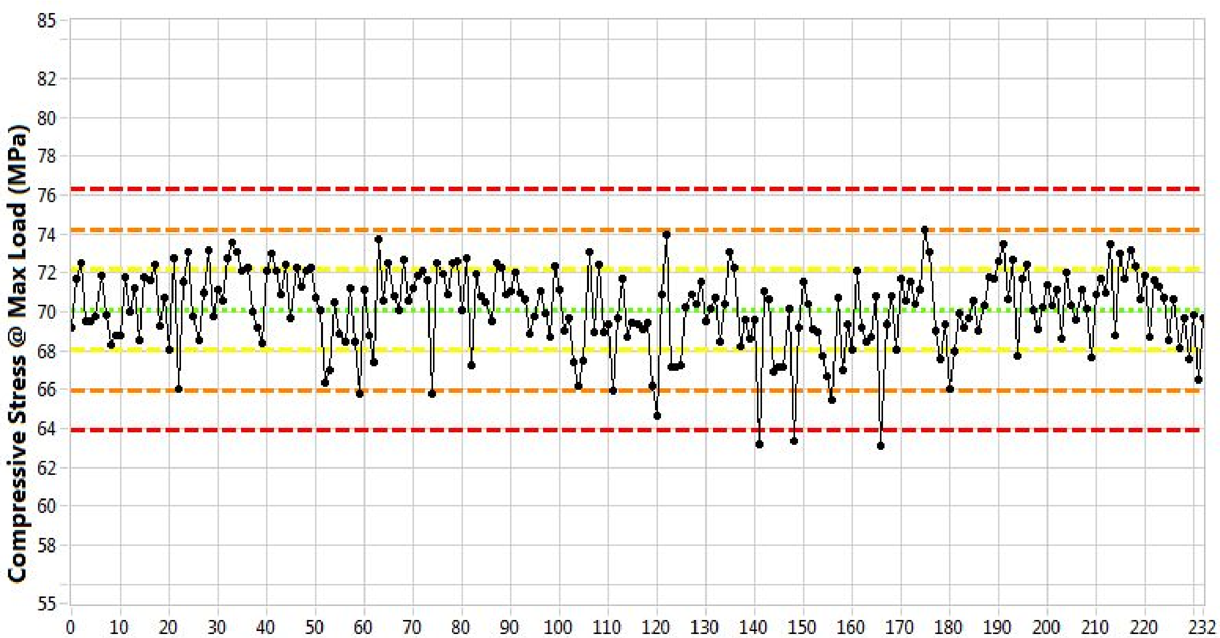

Figure 4. Compressive stress at max load (MPa), mean = 70.1, standard deviation = 2.1.

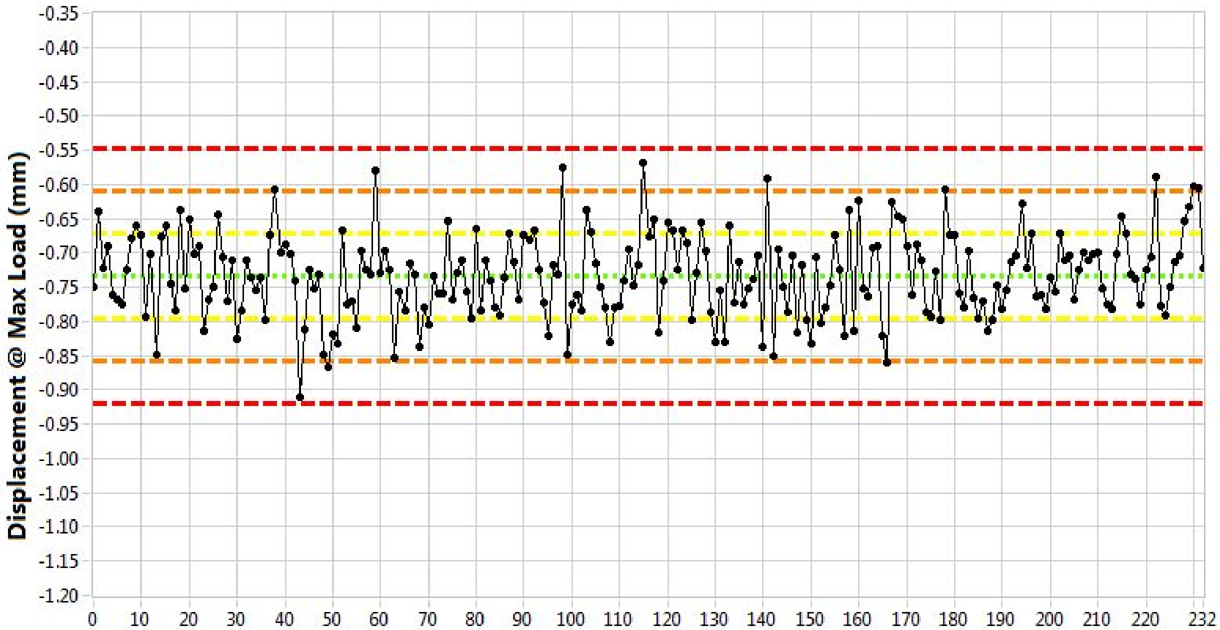

Figure 5. Displacement at max load (mm), mean = -0.7329, standard deviation = 0.0621.

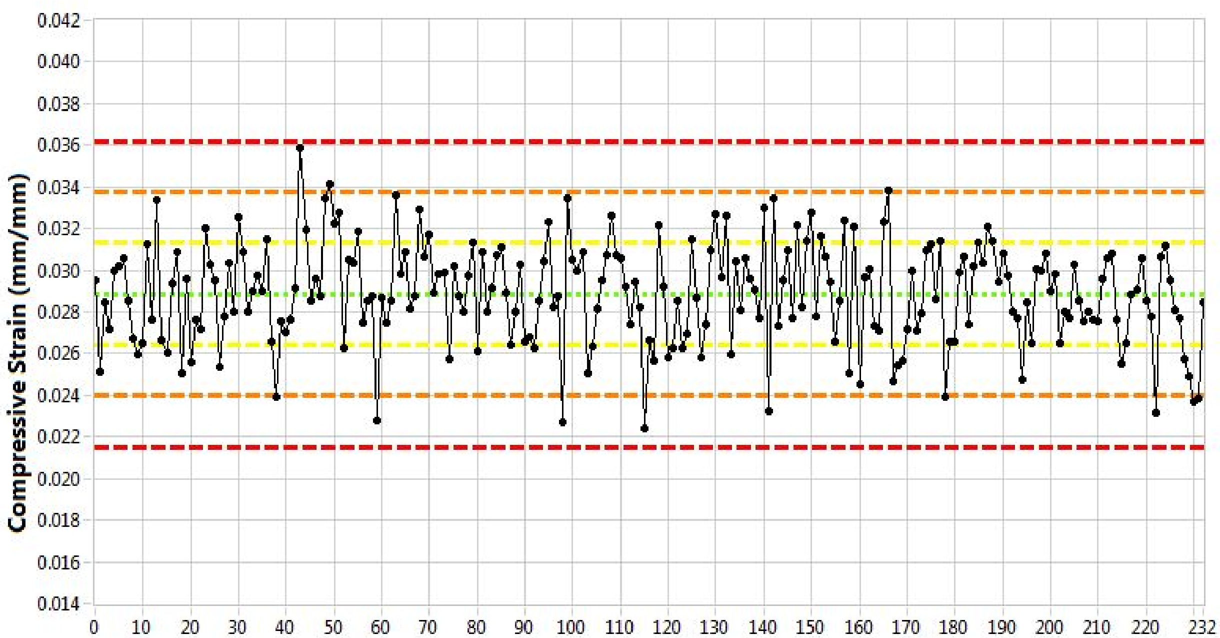

Figure 6. Compressive strain (mm/mm), mean = 0.0289, standard deviation = 0.0024.

Fracture-surface Categorization

The resulting fracture surfaces from compressive specimens offer an additional opportunity to collect scalar data that can be sorted with respect to graphite type and position. To allow for consistency in what is essentially a qualitative attribute, a description of each of the fracture types is provided to the user of the Graphite Mechanical Properties Data Acquisition Software. A screen shot of this categorization, along with the distribution of recorded fracture categories for each of the 233 compressive specimens from IG-110 10X69 (with no anomalous values indicative of an unallowable characterization) is provided in Figure 7.

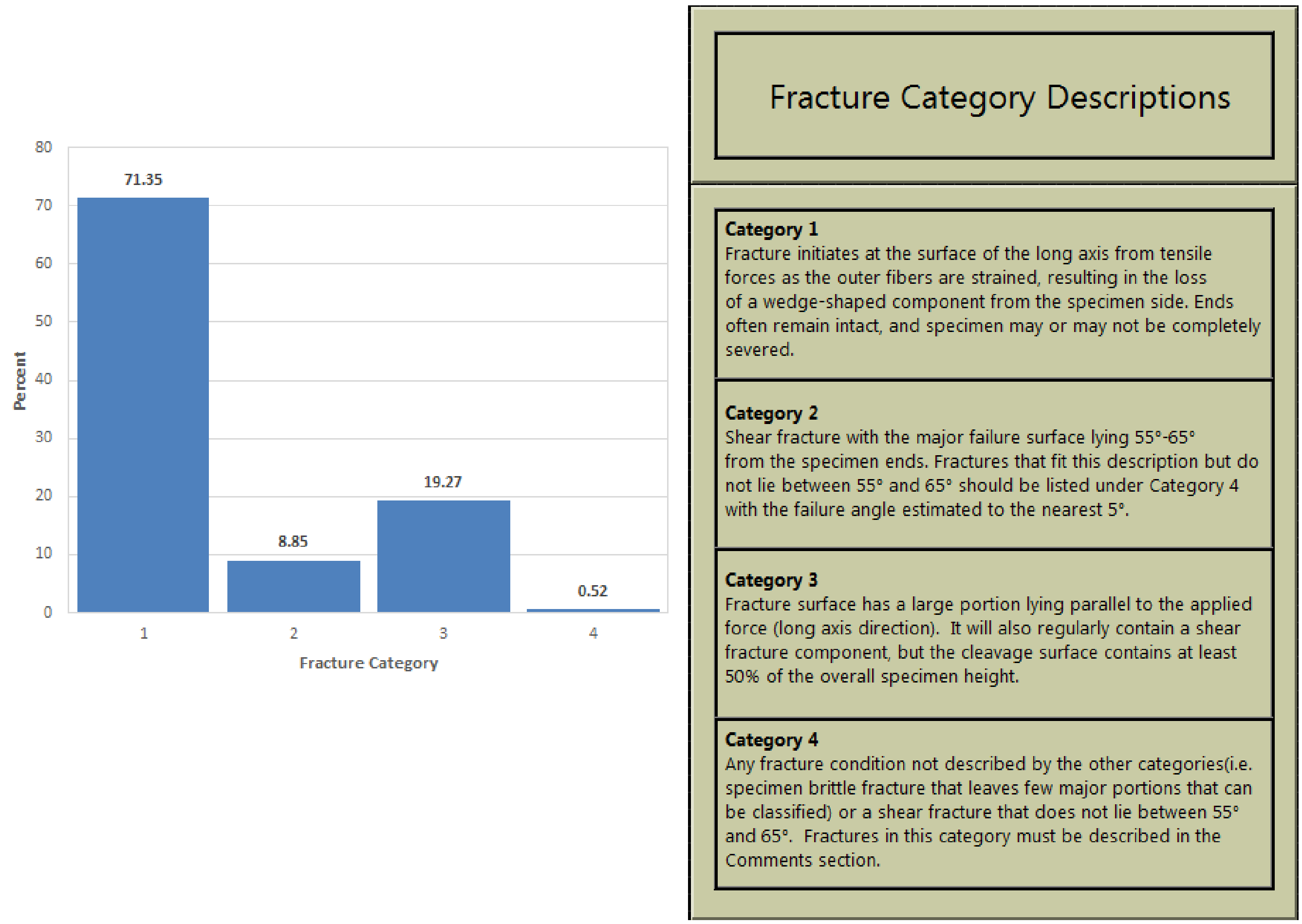

Figure 7. Fracture categorization results and description.

Density Values

The relatively simple geometric shape of the compressive specimens provides an opportunity to collect density data (per ASTM C559-90[7]) for a large portion of the specimens extracted from each billet. While not a true performance property, density measurements are relatively straightforward to collect and are often reflective of other properties, such as modulus and strength. The density values recorded for the compression specimens (Figure 8) don't show any anomalies and they had a very low coefficient of variation: 0.35%.

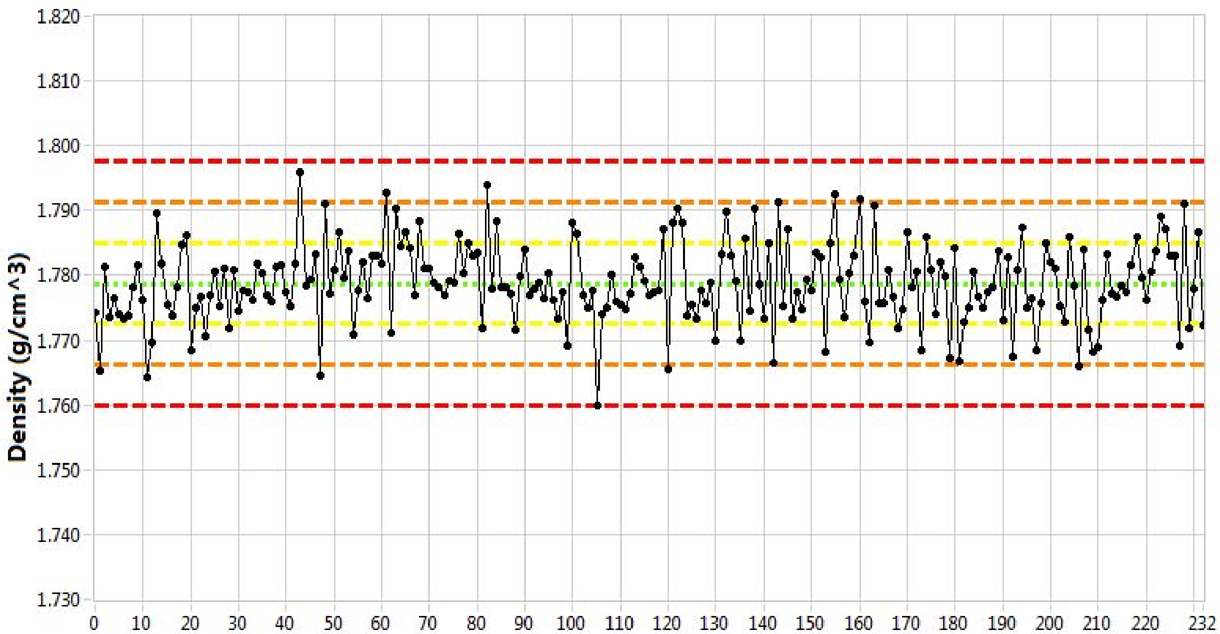

Figure 8. Density (g/cm^3), mean = 1.7788, standard deviation = 0.0063.

Electrical Resistivity, Modulus, Coefficient of Thermal Expansion

Electrical resistivity, Young's and shear modulus by sonic velocity, Young's modulus by sonic resonance, and coefficient of thermal expansion (CTE) tests were performed on 60 of the compression specimens before they were broken. These tests were carried out via the appropriate ASTM standards.[13, 14, 9, 10, 15] Charts of those data are shown as Figure 9 through Figure 13.

Elastic modulus data are shown in Figure 10. These data were obtained through the sonic-velocity method. This plot shows one specimen that is greater than three standard deviations above the mean, namely Specimen 14. Further investigation showed that this specimen's elastic modulus by the sonic-resonance method was also high (Figure 12, Specimen 8). This indicates that elastic-modulus data for this specimen are consistent and, therefore, will be kept.

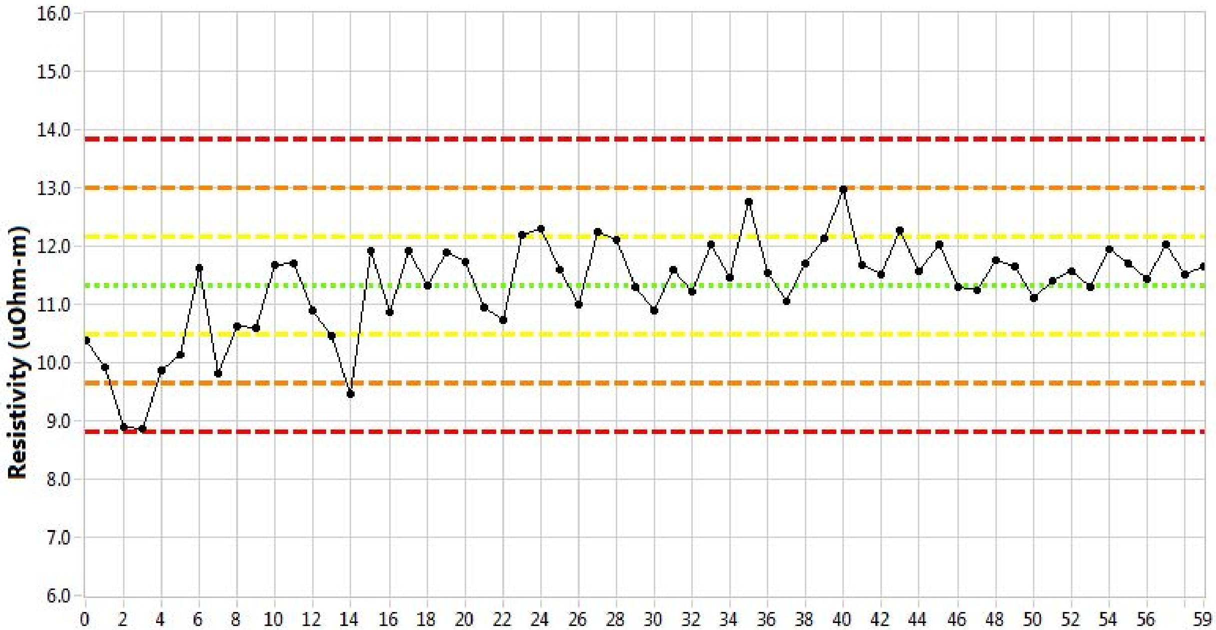

Figure 9. Resistivity (μΩ–m), mean = 11.3, standard deviation = 0.84.

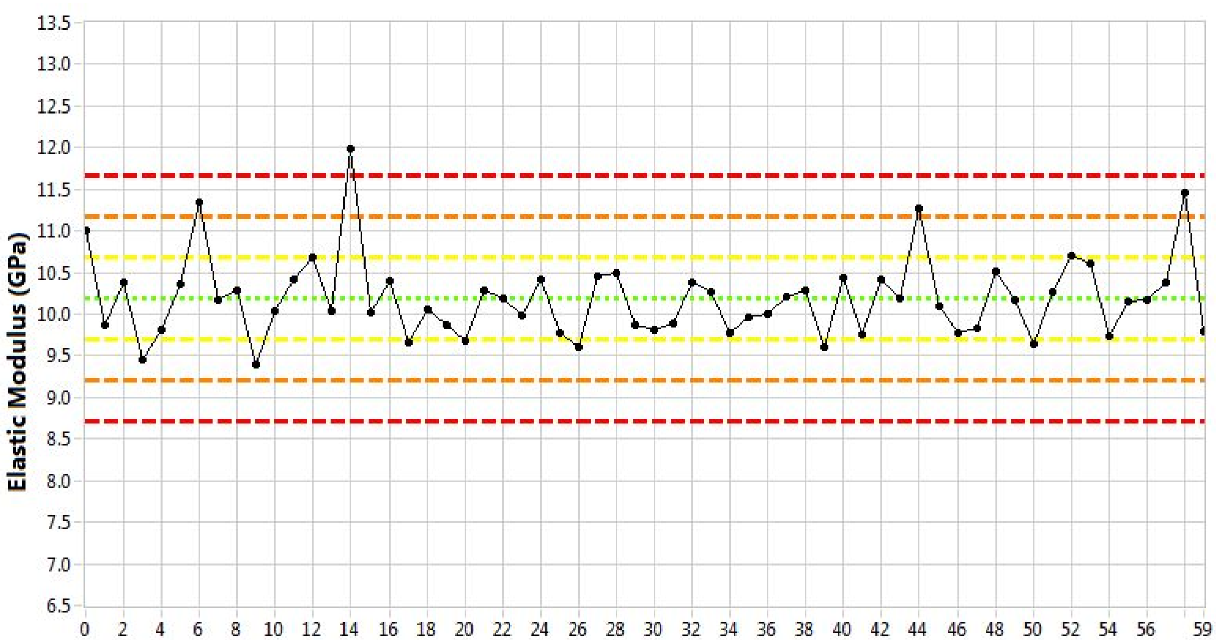

Figure 10. Elastic modulus by sonic-velocity method (GPa), mean = 10.2, standard deviation = 0.49.

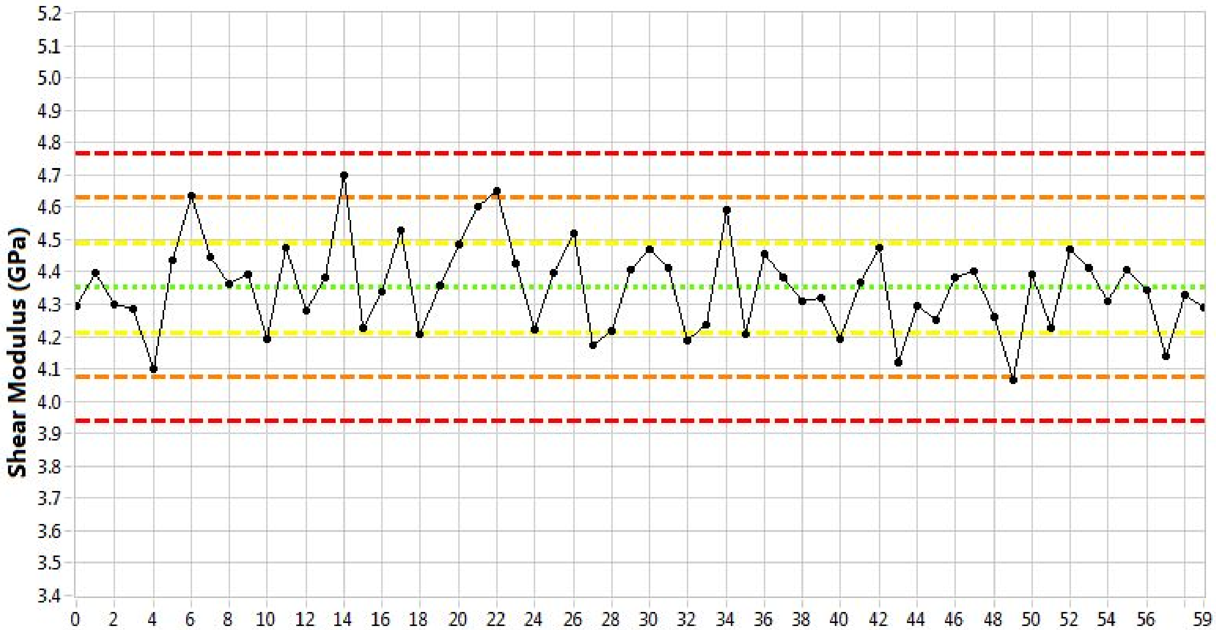

Figure 11. Shear modulus by sonic-velocity method (GPa), mean = 4.4, standard deviation = 0.14.

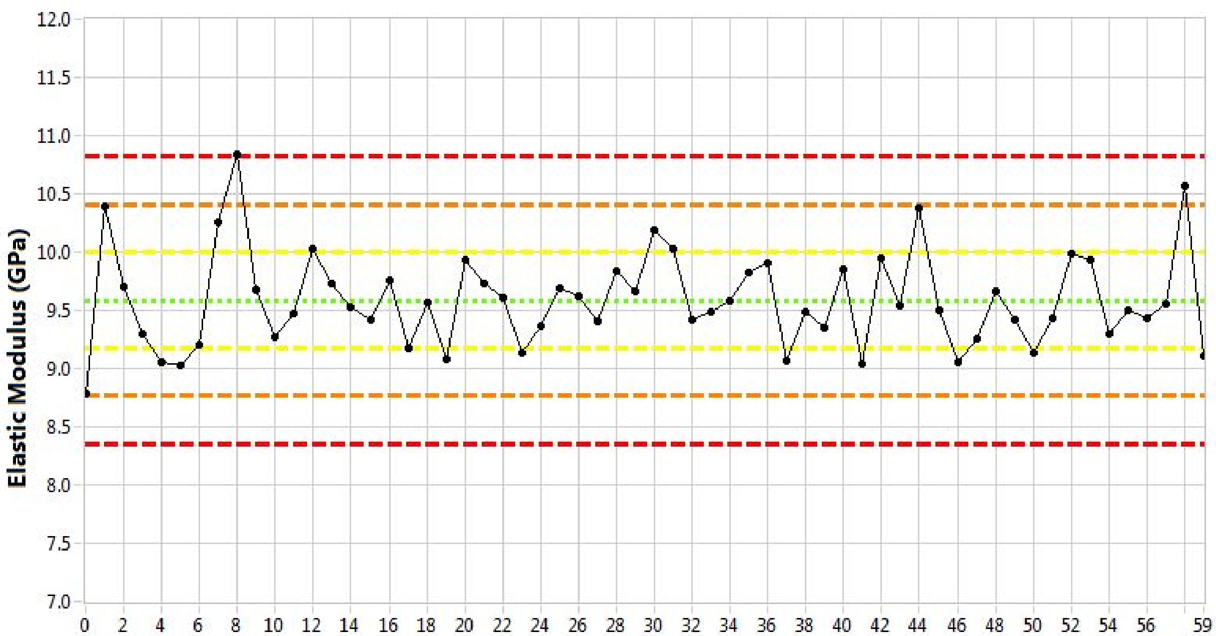

Figure 12. Elastic modulus by sonic-resonance method (GPa), mean = 9.6, standard deviation = 0.41.

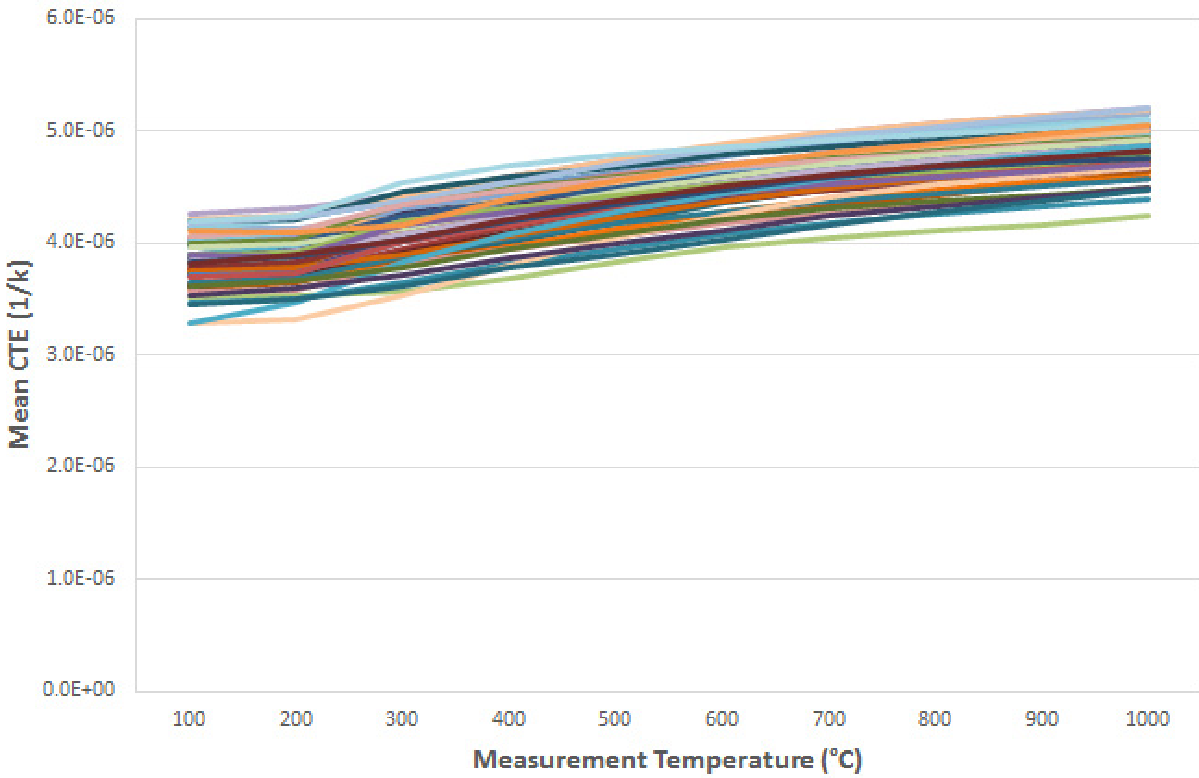

Figure 13. Mean CTE (1/K).

Flexural-specimen Database (IG-110-10X69F)

Flexural Testing

Flexural testing was performed per ASTM C651-91,[8] with clarifications to ambiguities in the standard identified in PLN-3467.[3] As with the presentation of the compression-specimen results, test validation lies not only in documented adherence to applicable test plans and standards, but also in the noted correlations between recorded test properties and analyses for extreme or anomalous values.

Figure 14 and Figure 15 show the relationship between flexural load and recorded flexural stress for the 233 specimens tested in flexure from IG-110 10X69. Further comparisons and verification can be made with measured deflection, as shown in Figure 16, which will reflect an additional correlation with stress values through material elastic constants.

It was noted for one of the flexural specimens in the data file that, during one of the bending tests, the extensometer was not touching the specimen. This resulted in a measured deflection for that specimen of zero. This data point is the extreme outlier shown in Figure 16.

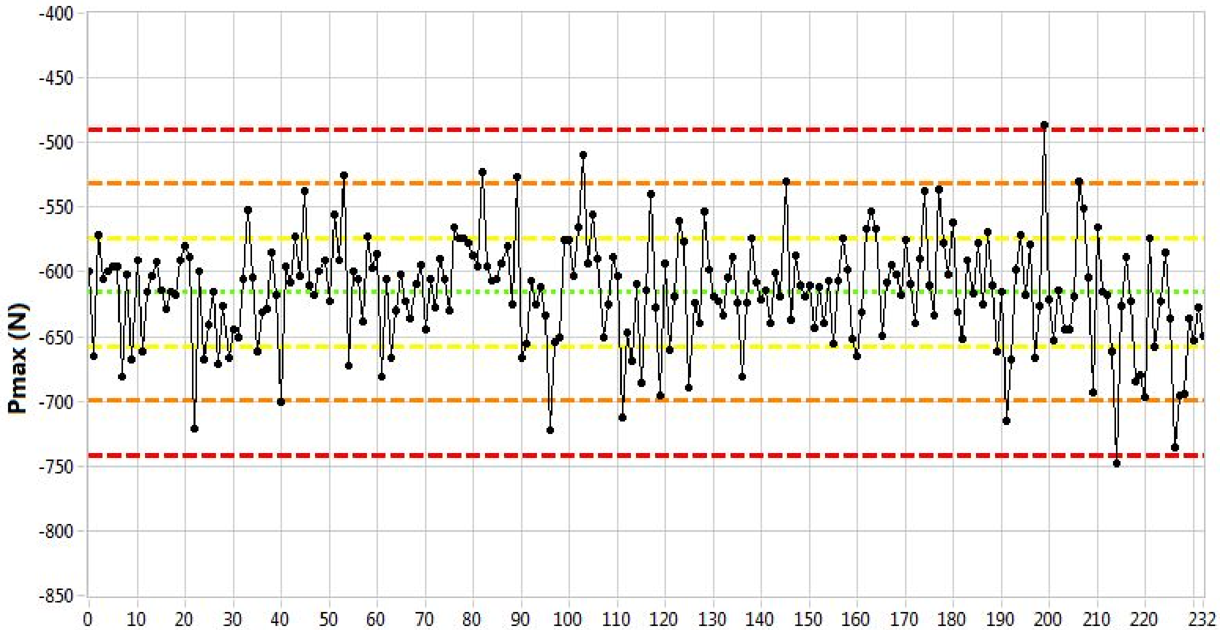

Figure 14. Max load (N), mean = -615.6, standard deviation = 42.0.

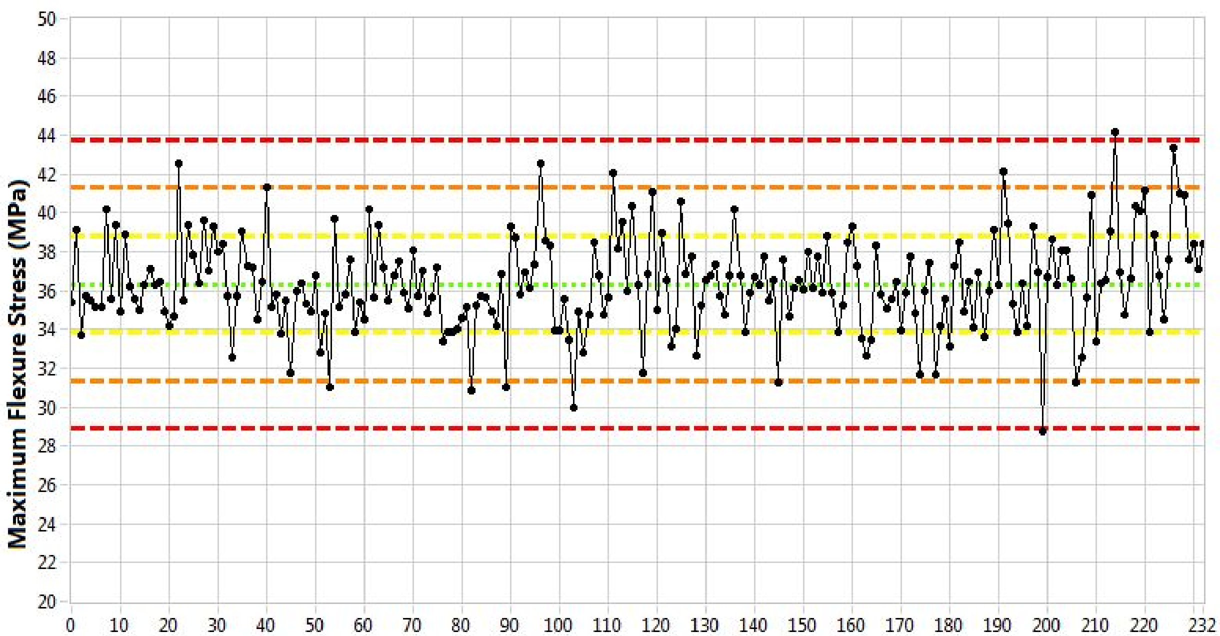

Figure 15. Maximum flexure stress (MPa), mean = 36.3, standard deviation = 2.5.

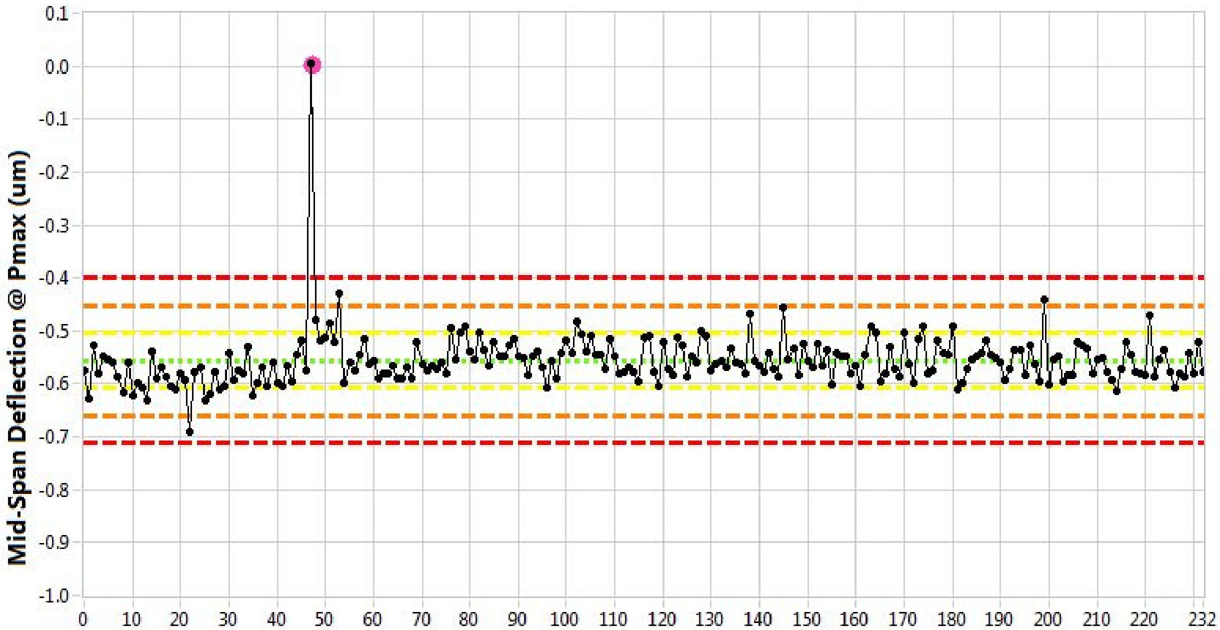

Figure 16. Mid-span deflection at max load (um), mean = -0.5564, standard deviation = 0.0518.

Density Values

As with the compression specimens, the flexural specimens' geometry facilitated an opportunity to make density measurements. Figure 17 shows density from the flexural specimens. All of the flexural specimens' data and associated deviations compare well with the compression specimens' density data.

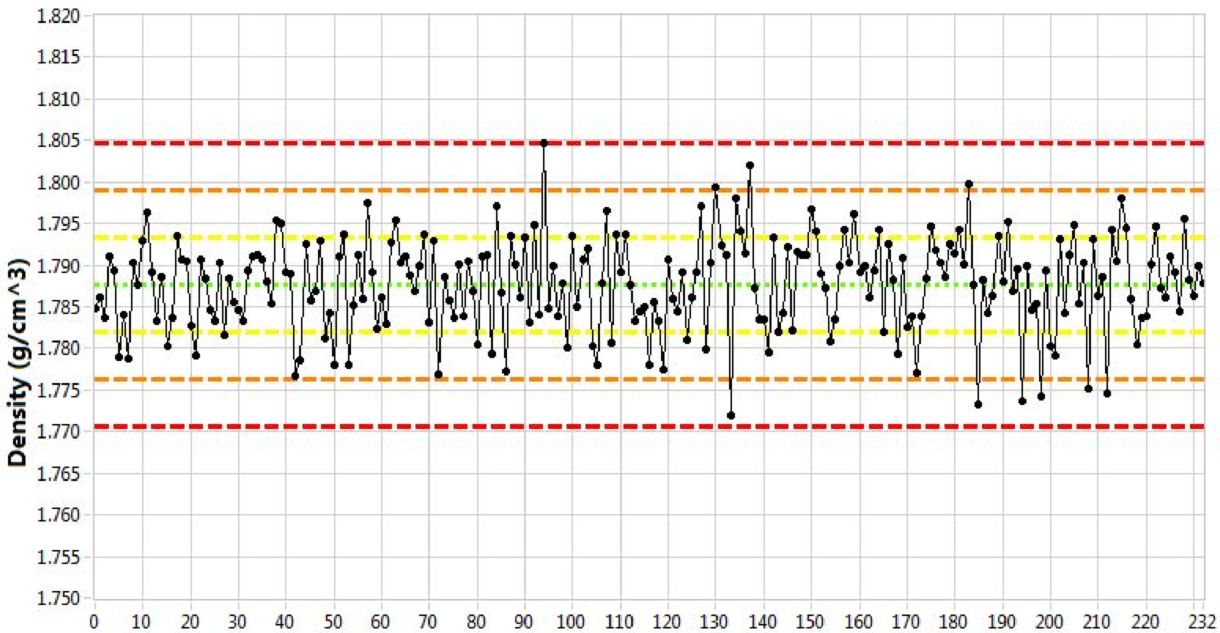

Figure 17. Density (g/cm^3), mean = 1.7877, standard deviation = 0.0057.

Fundamental Frequency

The precisely parallelepiped geometry of flexural specimens renders them particularly valuable for accurate measurements of fundamental frequency to collect elastic constants, both for dynamic Young's modulus and shear modulus (ASTM C747-93[9]). Values for fundamental-frequency-based moduli, both in flexural and in torsional modes (shown in Figure 18 and Figure 19), are calculated from the equations provided in ASTM C1259-08.[10] All of the flexural mode data fall within ±3 standard deviations from the mean. There are two torsional-mode data points outside of the three standard deviation limits. Investigation of these specimens' other property measurements did not reveal any further inconsistencies. It is thought that the differences in the shear modulus are a result of variation in the specimens' densities. Therefore, these data will be included in the NDMAS database.

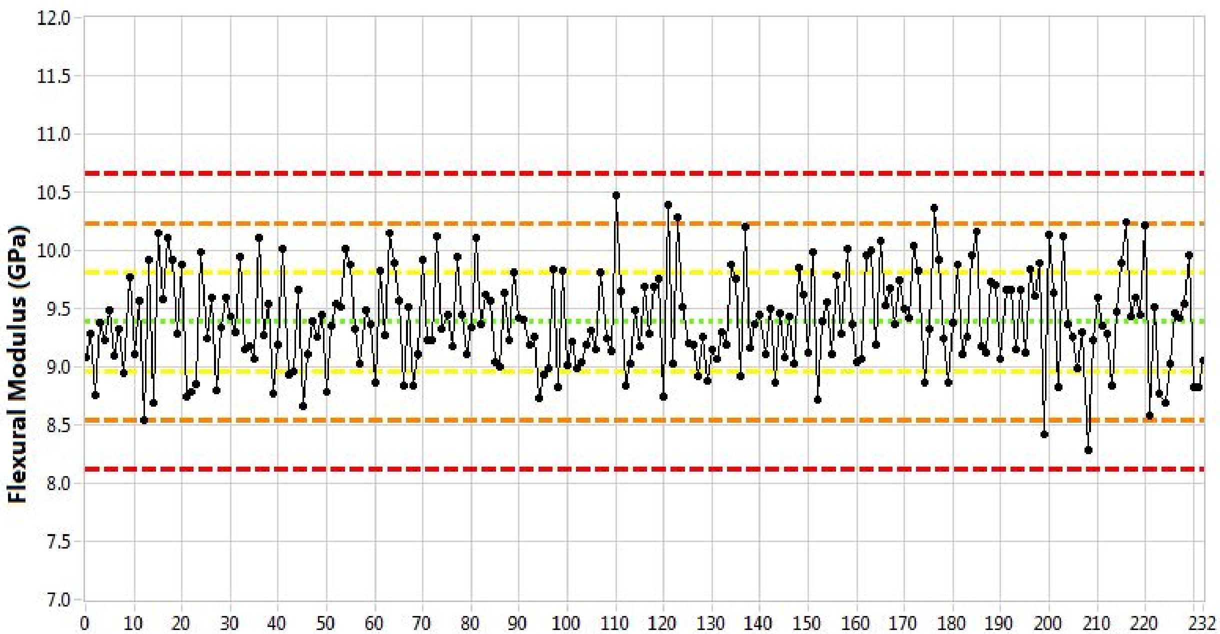

Figure 18. Flexural vibration mode modulus (GPa), mean = 9.39, standard deviation = 0.42.

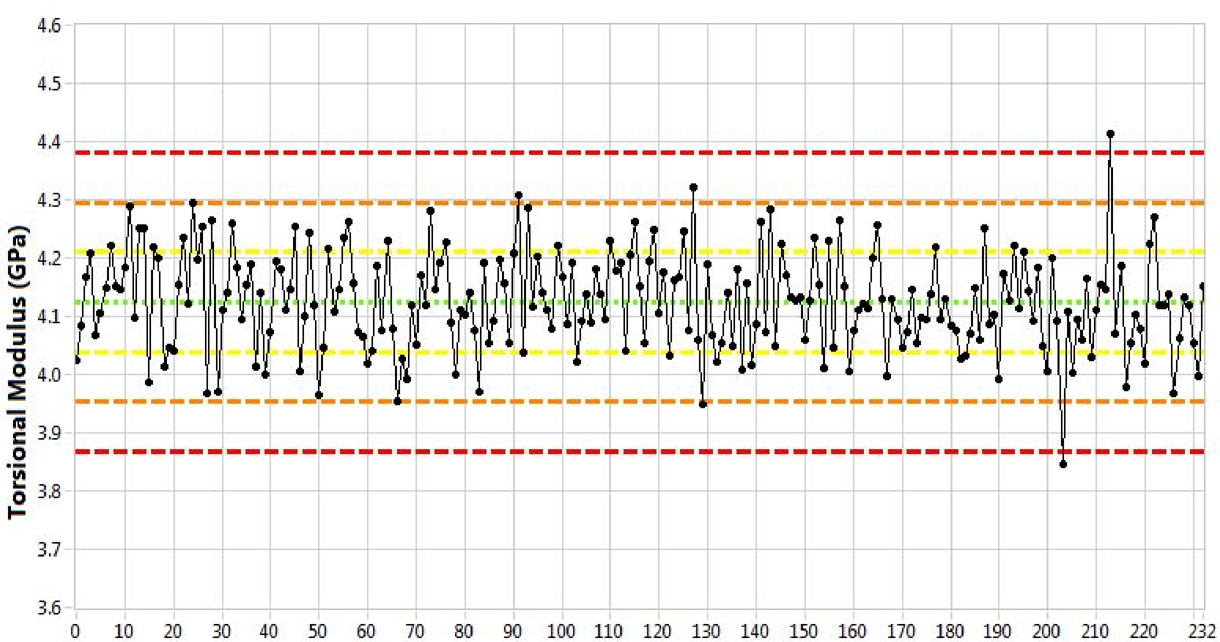

Figure 19. Torsional vibration mode modulus (GPa), mean = 4.12, standard deviation = 0.09. Tensile Specimen Database (IG-110-10X69T)

Tensile Testing

Tensile testing was performed per ASTM C749-08.[11] Data verification follows the principles discussed in previous sections. As with the other specimen types, data verification lies not only in documented adherence to applicable test plans and standards, but in the noted correlations between recorded test properties and analyses for outlying values. Additional verification of test conditions can be carried out through an analysis of ancillary physical characteristics. Figure 20 shows the gauge diameter measurements for the 242 tensile specimens. Figure 21 and Figure 22 show the relationship between tensile load and recorded tensile stress for the IG-110 10X69 specimens tested in uniaxial tension.

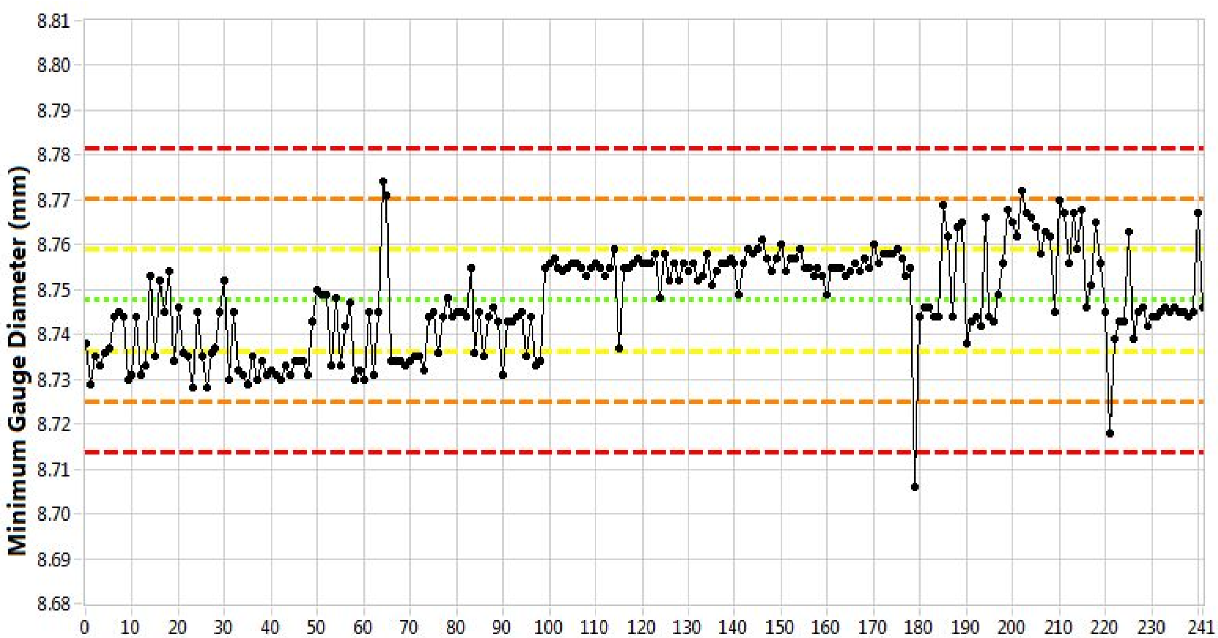

Figure 20. Minimum gauge diameter (mm), mean = 8.748, standard deviation = 0.011.

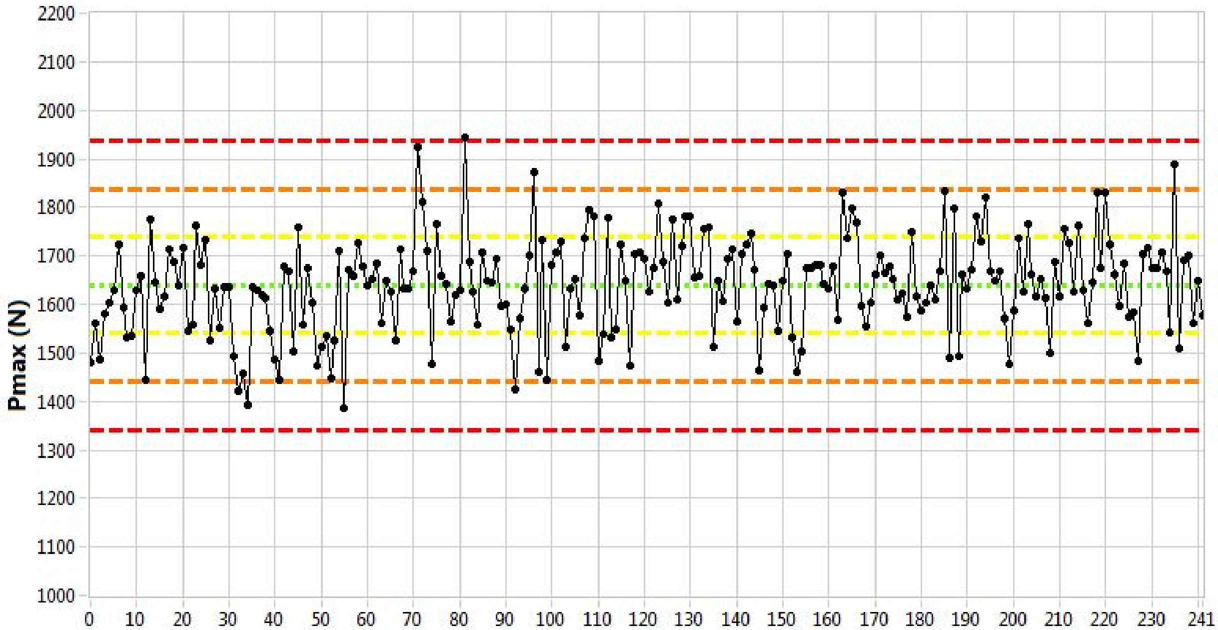

Figure 21. Max load (N), mean = 1639.3, standard deviation = 99.2.

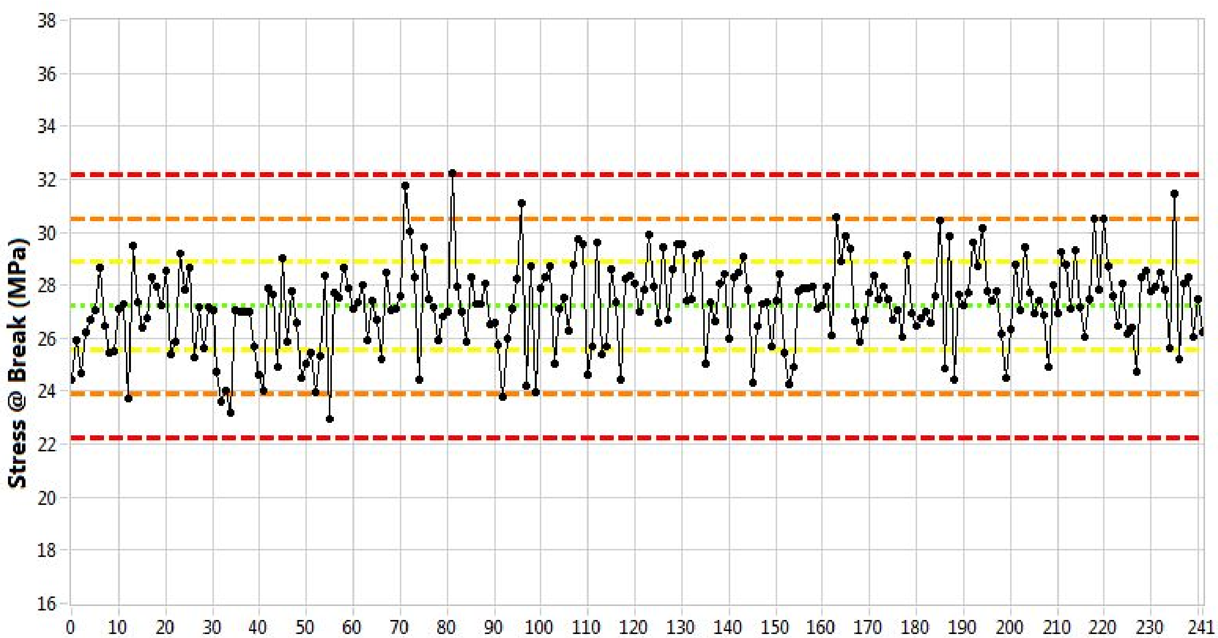

Figure 22. Stress at break (MPa), mean = 27.2, standard deviation = 1.7.

Further comparisons and verification can be made with extensometer-based measured deflection (shown in Figure 23), which will reflect an additional correlation with stress values through material elastic constants. There is one extreme outlier shown in Figure 23 (point 4). The stress and load values for this specimen were both within ±1 standard deviation of the mean. Because of this, the low strain value is believed to be the result of an issue with the extensometer. Consequently, the data for this specimen is not included in the database.

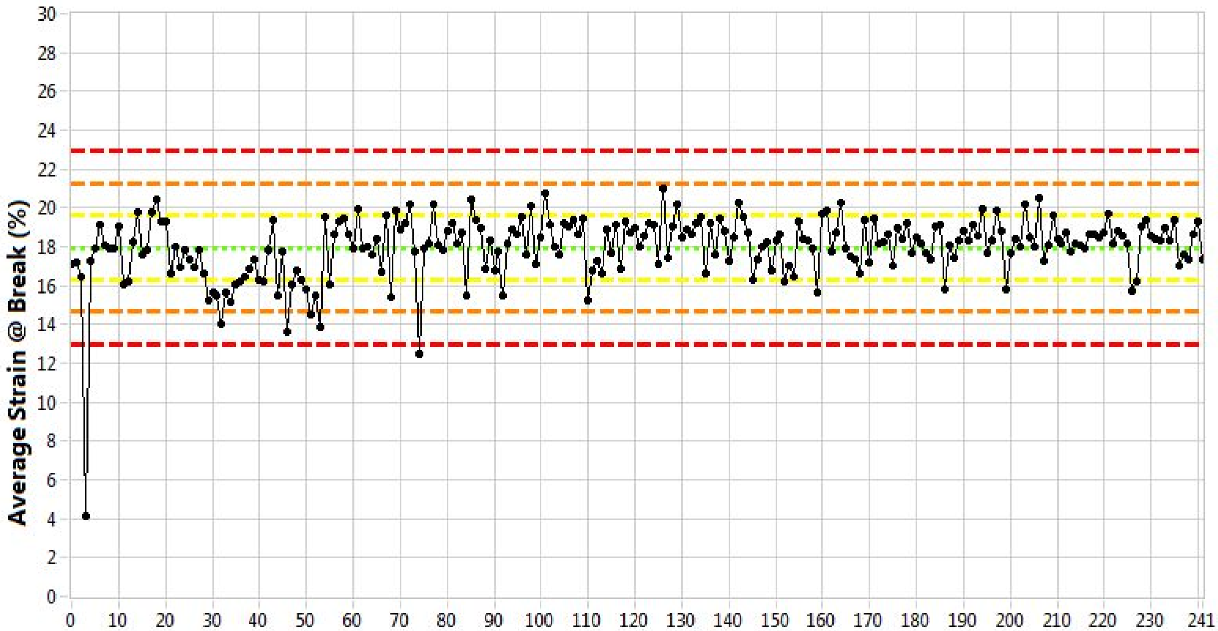

Figure 23. Average strain at break (%), mean = 18.0, standard deviation = 1.65.

Remachined Specimen Properties

Two key components of direct comparisons between baseline and AGC data are (1) the analyses of specimens with similar geometries and (2) employment of similar test techniques for comprehensive validation. The geometry of tensile specimens provides the opportunity to “remachine” the unstressed sections of the specimen ends (shown in Figure 24) to the same dimensions as AGC piggyback specimens. A random cross-section of tensile specimens was remachined to repeat tests on AGC-sized specimens (i.e., diffusivity and split-disc testing). Using actual test specimens for remachining enables continued employment of the specimen-identification and tracking-code system because specimens are machined from tracked locations and can reuse the identification code.

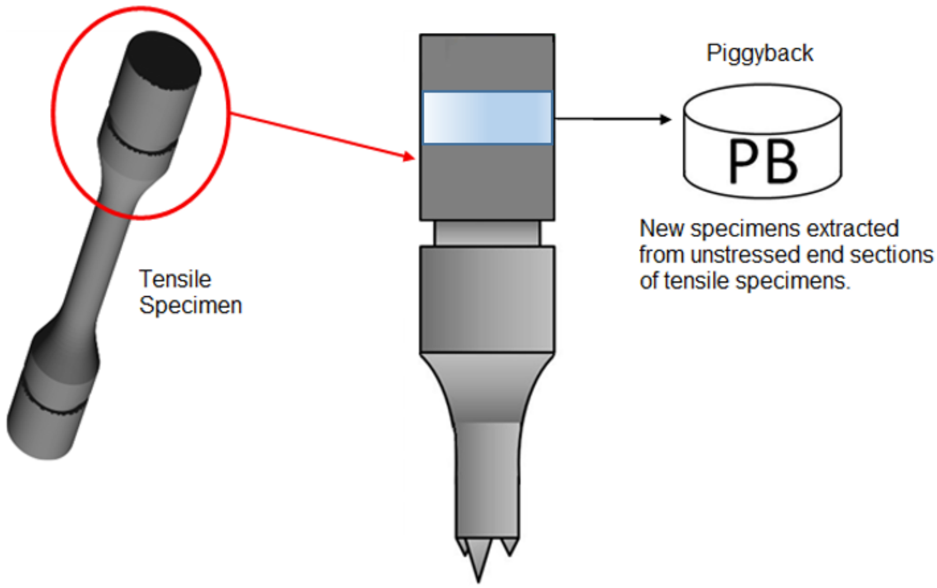

Figure 24. Unstressed specimen remnants from tensile specimens are remachined into AGC geometries.

Remachined Split Disc Testing

Split disc tensile-strength testing was performed in accordance with PLN-3348 [2], Revision 4, Section 6.1.1.5. This allows for a direct comparison of tensile data to data that were acquired through strict application of ASTM C749-08.[11] Figure 25 **Error! Reference source not found.**and Figure 26 show strength and load data from the split disc testing. While the mean strength value calculated from the split disc testing was 20% lower than that from the traditional tensile testing (Figure C-1), there was less spread in the data.

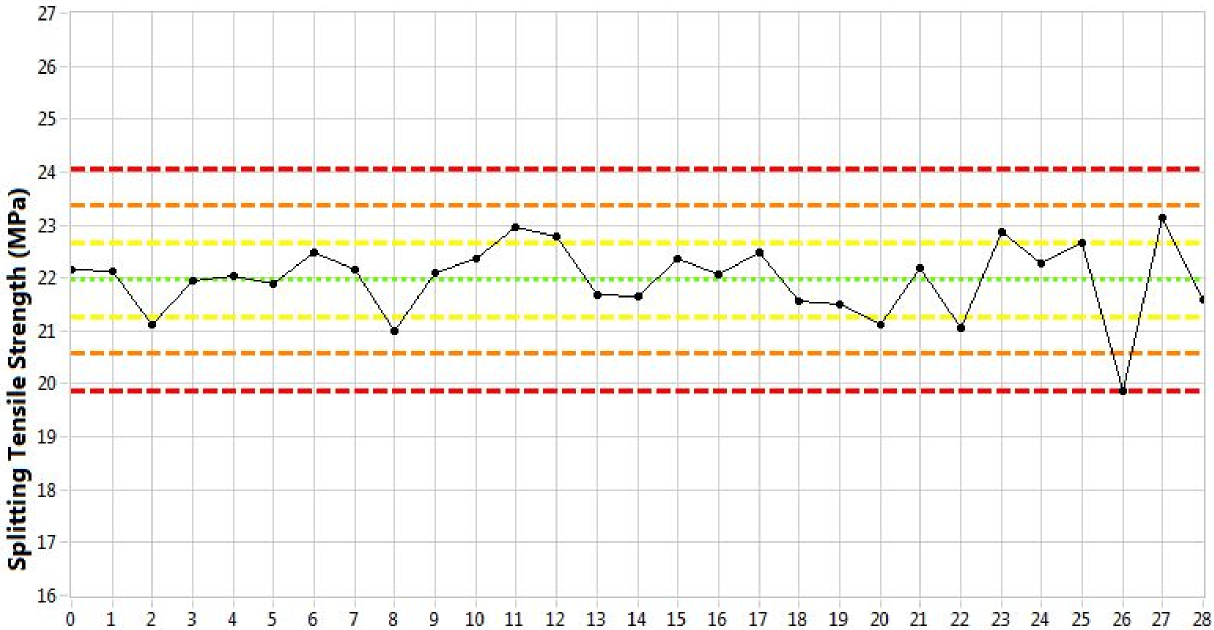

Figure 25. Split disc tensile strength (MPa), mean = 21.97, standard deviation = 0.70.

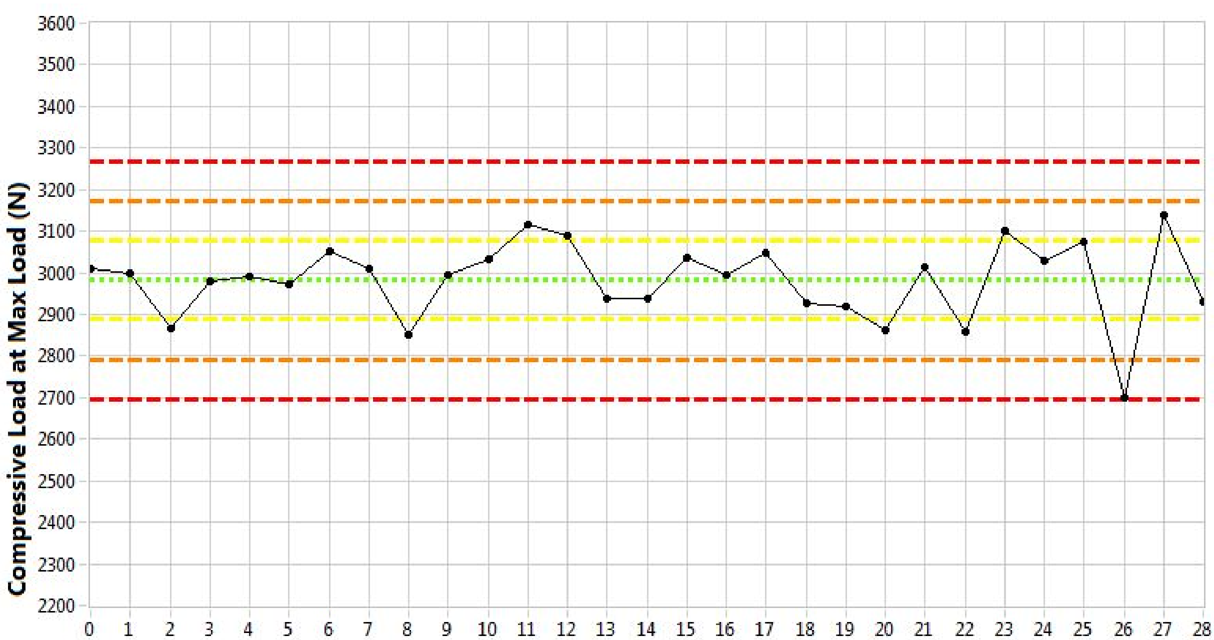

Figure 26. Split disc compressive load at max load (N), mean = 2982.03, standard deviation = 95.01.

Remachined Specimen Diffusivity

Thermal diffusivity values are collected from the remachined tensile specimens per ASTM E1461-07.[12] Diffusion of heat through the specimen following application of thermal energy via a laser source demonstrates heat-transfer characteristics and can be used to calculate thermal conductivity for design purposes. The resulting group of diffusivity values, revealing a tight grouping of thermal transfer characteristics, is shown in Figure 27.

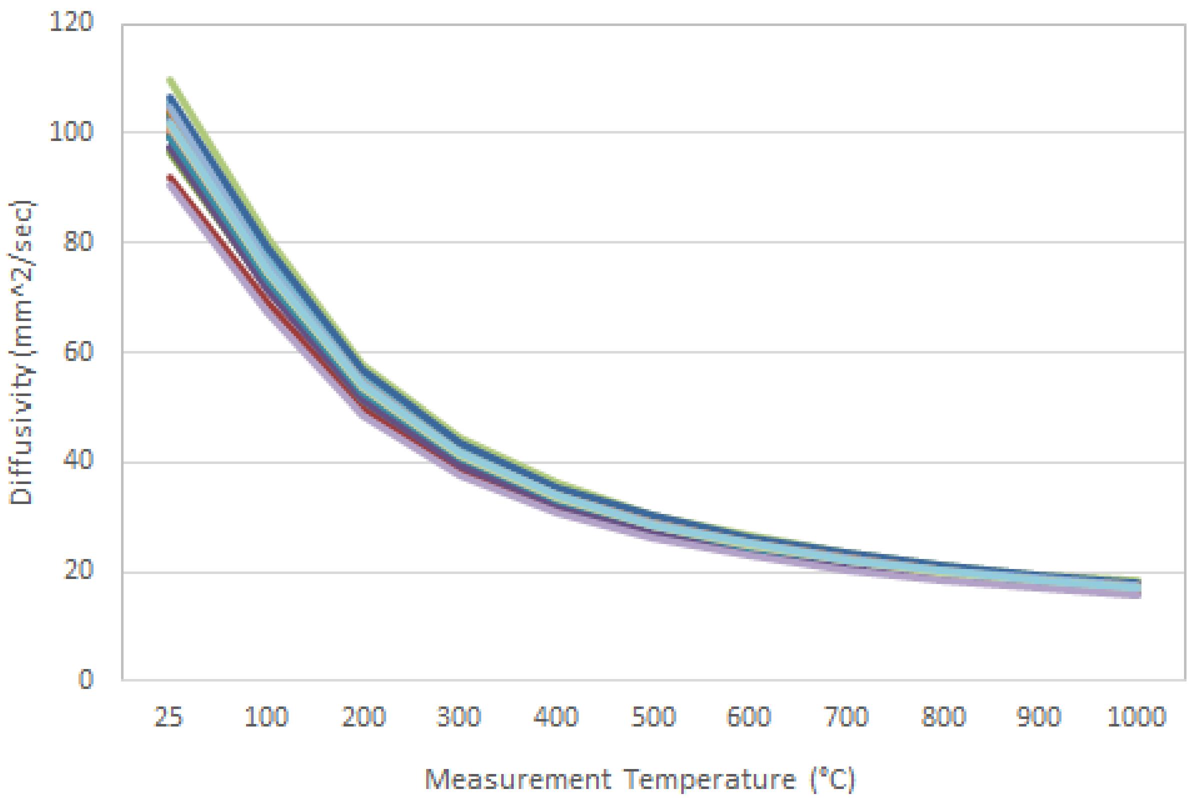

Figure 27. Diffusivity (mm^2/sec).

SUMMARY

The comprehensive data sets for the IG-110 billet 10X69 have been compiled into summary files of property scalar values. The data spreadsheet files are divided by mechanical test-specimen type into three main sets: compressive, flexural, and tensile. The multitude of tests and evaluations performed on each specimen type are individually tabbed in the main data set files.

In addition to a full visual review of the data files to determine whether obvious errors were made with the data collected, such as missing information or otherwise blank cells, graphical representations were made of individual evaluations to provide a means to spot anomalies. A review of the data indicates that the files, as submitted, are fully representative of the measured properties of the graphite billets being tested, as outlined in the applicable test procedures and program plans.

REFERENCES

1. PLN-2497, "Graphite Technology Development Plan," Rev. 1, October 2010.

2. PLN-3348, "Graphite Mechanical Testing," Rev. 2, April 2011.

3. PLN-3467, "Baseline Graphite Characterization Plan: Electromechanical Testing," Rev. 1, August 2011.

4. PLN-3267, "AGC-2 Characterization Plan," Rev. 0, March 2010.

5. Mark Carroll, Joe Lord, and David Rohrbaugh, 2010, *Baseline Graphite Characterization: First Billet*, INL/EXT-10-19910, September 2010.

6. ASTM Standard C695-91 (Reapproved 2010), "Standard Test Method for Compressive Strength of Carbon and Graphite," ASTM International, 2010.

7. ASTM Standard C559-90 (Reapproved 2005), "Standard Test Method for Bulk Density by Physical Measurements of Manufactured Carbon and Graphite Articles," ASTM International, 2005.

8. ASTM Standard C651-91 (Reapproved 2005), "Standard Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four-Point Loading at Room Temperature," ASTM International, 2005.

9. ASTM Standard C747-93 (Reapproved 2005), "Standard Test Method for Moduli of Elasticity and Fundamental Frequencies of Carbon and Graphite Materials by Sonic Resonance," ASTM International, 2005.

10. ASTM Standard C1259-08, "Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration," ASTM International, 2008.

11. ASTM Standard C749-08, "Standard Test Method for Tensile Stress-Strain of Carbon and Graphite," ASTM International, 2008.

12. ASTM Standard E1461-07, "Standard Test Method for Thermal Diffusivity by the Flash Method," ASTM International, 2007.

13. ASTM Standard C611-05, 2005, "Standard Test Method for Electrical Resistivity of Manufactured Carbon and Graphite Articles at Room Temperature," ASTM International.

14. ASTM Standard C769-09, 2009, "Standard Test Method for Sonic Velocity in Manufactured Carbon and Graphite Material for Use in Obtaining an Approximate Young's Modulus," ASTM International.

15. ASTM Standard E228-06, 2006, "Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push Rod Dilatometer," ASTM International.

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

Appendix A

Additional Compression Specimen Database Plots (IG-110 10X69C)

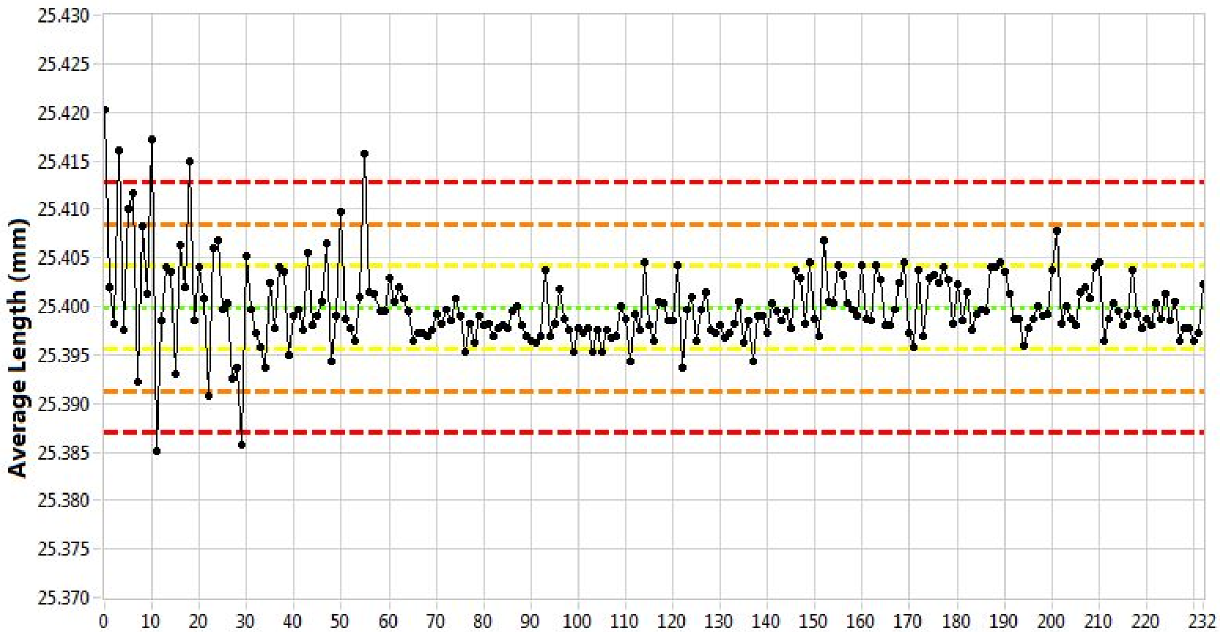

Figure A-1. Average length (mm), mean = 25.3999, standard deviation = 0.0043.

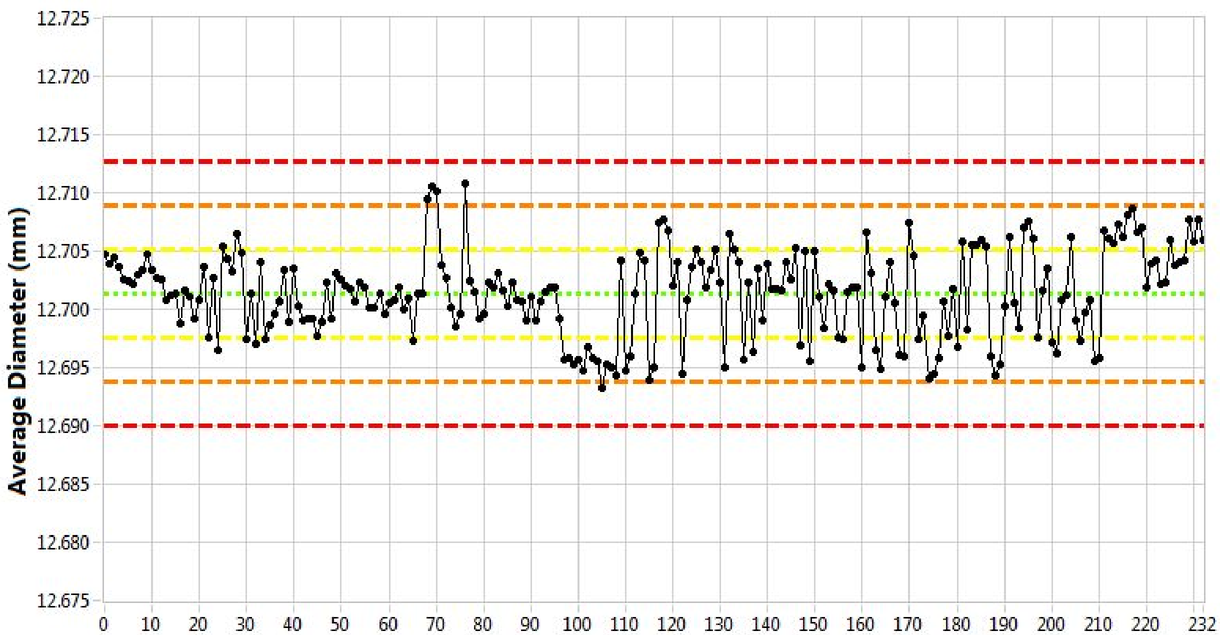

Figure A-2. Average diameter (mm), mean = 12.7013, standard deviation = 0.0038.

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

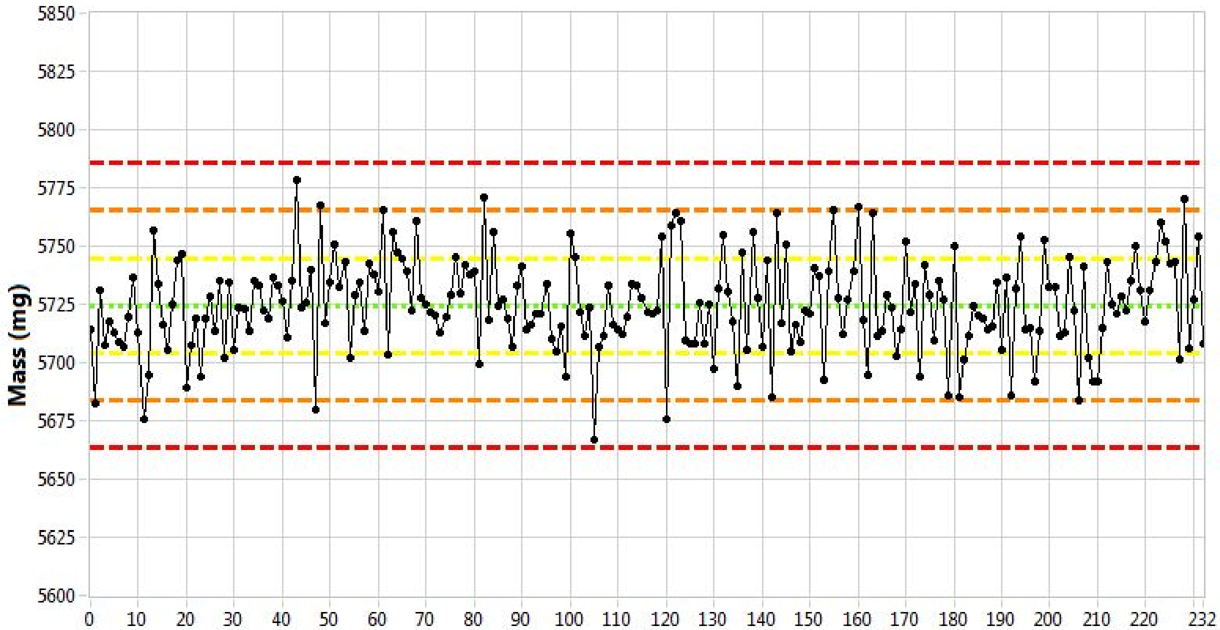

Figure A-3. Mass (mg), mean = 5724.5, standard deviation = 20.4.

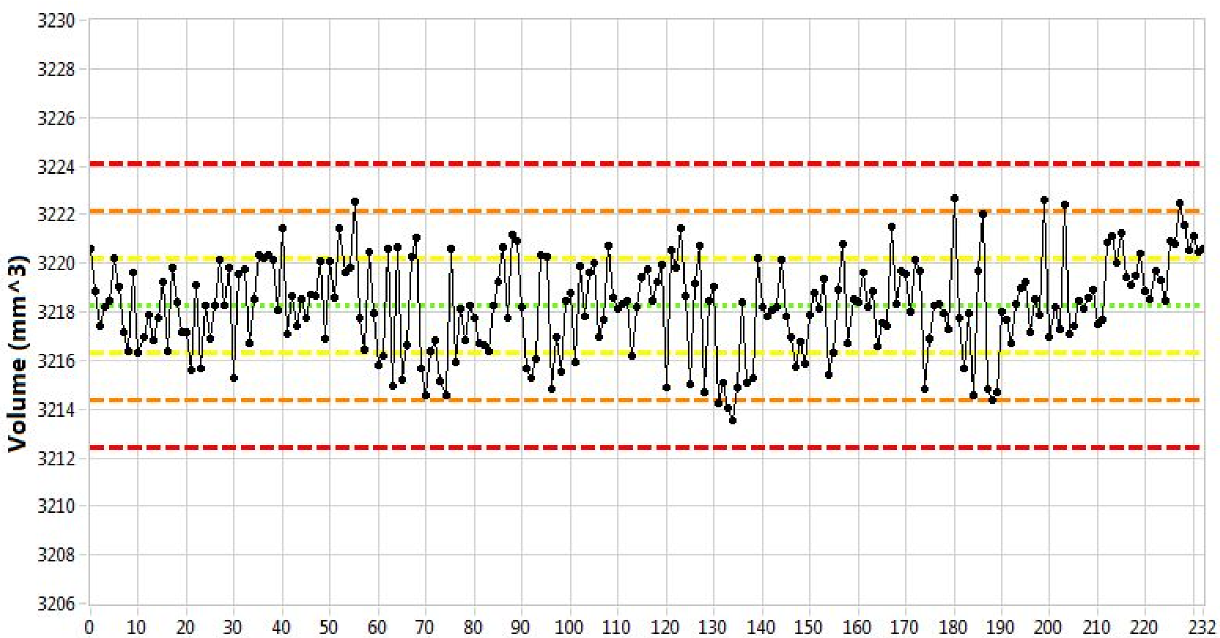

Figure A-4. Volume (mm^3), mean = 3218.3, standard deviation = 1.9.

Appendix B

Additional Flexural Specimen Database Plots (IG-110 10X69)

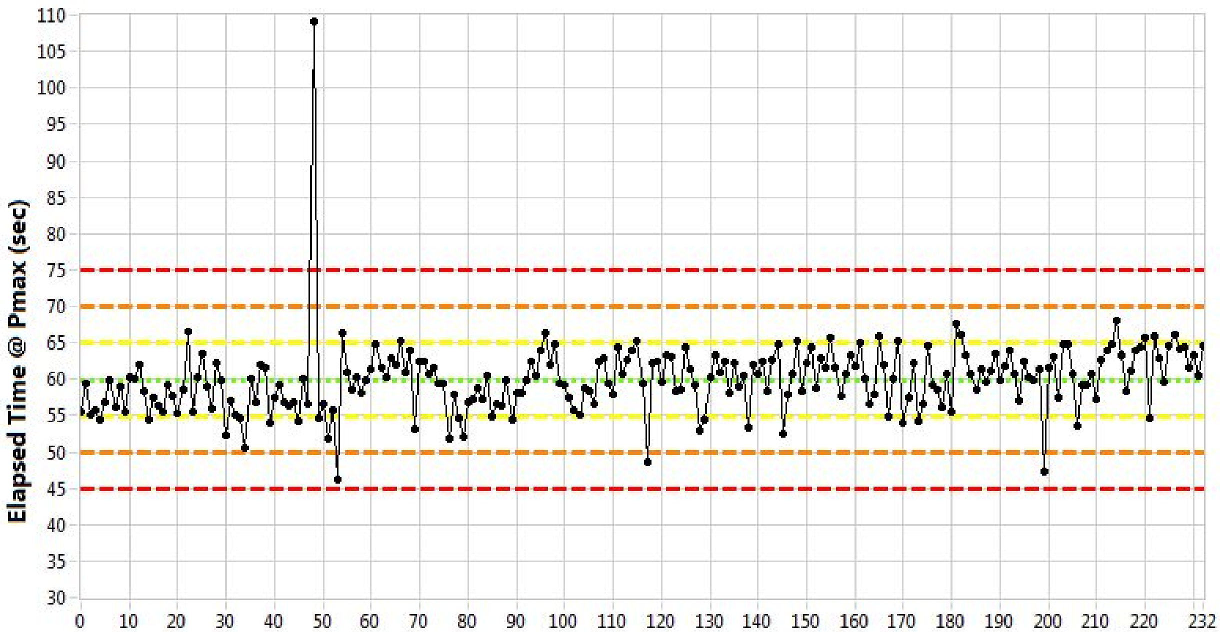

Figure B-1. Elapsed time at max load (sec), mean = 59.92, standard deviation = 5.01.

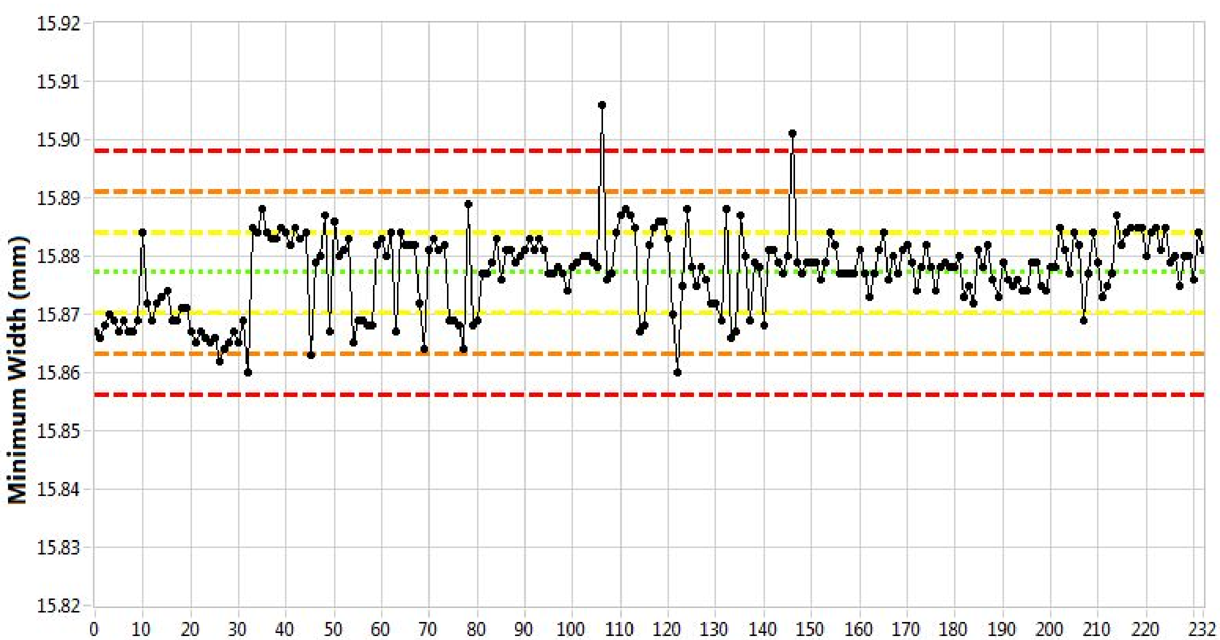

Figure B-2. Minimum Width (mm), mean = 15.88, standard deviation = 0.01.

Title: Baseline Characterization Database Verification Report – IG-110 Billet 10X69

ECAR No.: 4182 Rev. No.: 0 Project No.: 32138 Date: 12/03/2019

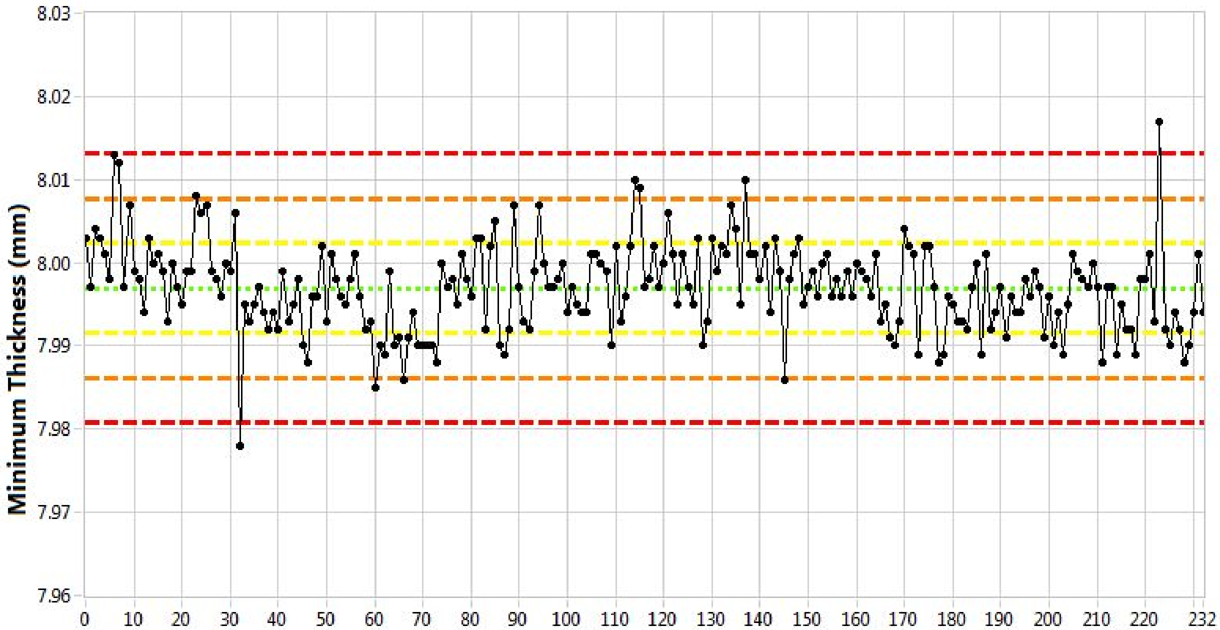

Figure B-3. Minimum thickness (mm), mean = 8.00, standard deviation = 0.01.

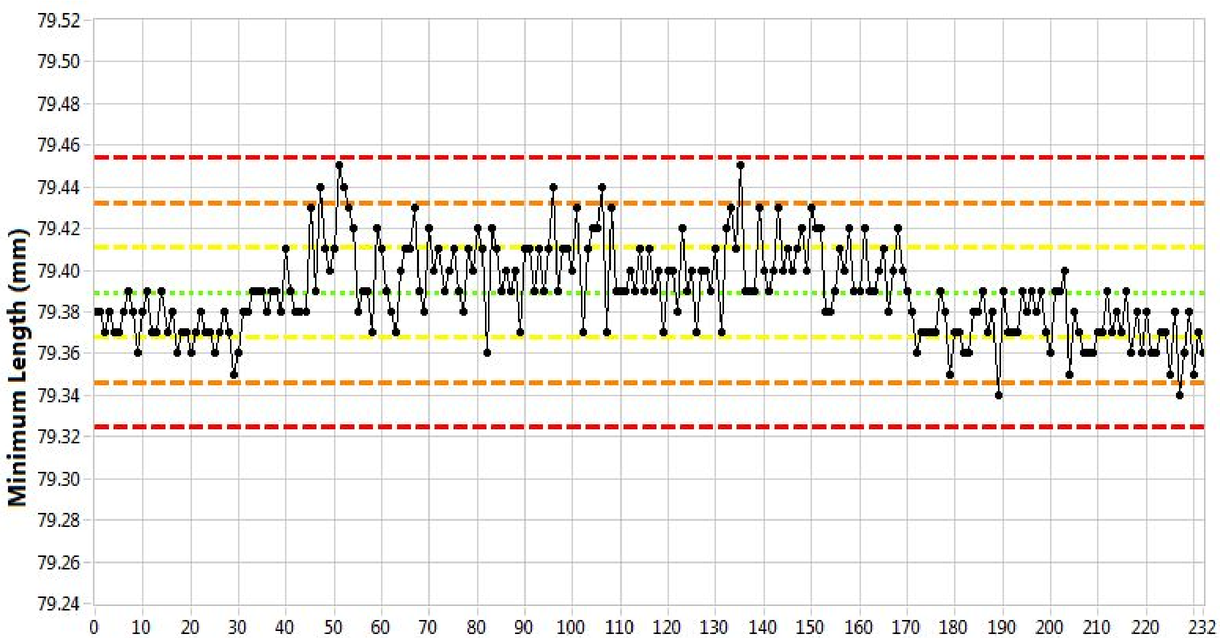

Figure B-4. Minimum length (mm), mean = 79.39, standard deviation = 0.02.

Appendix C

Additional Tensile Specimen Database Plots (IG-110 10X69)

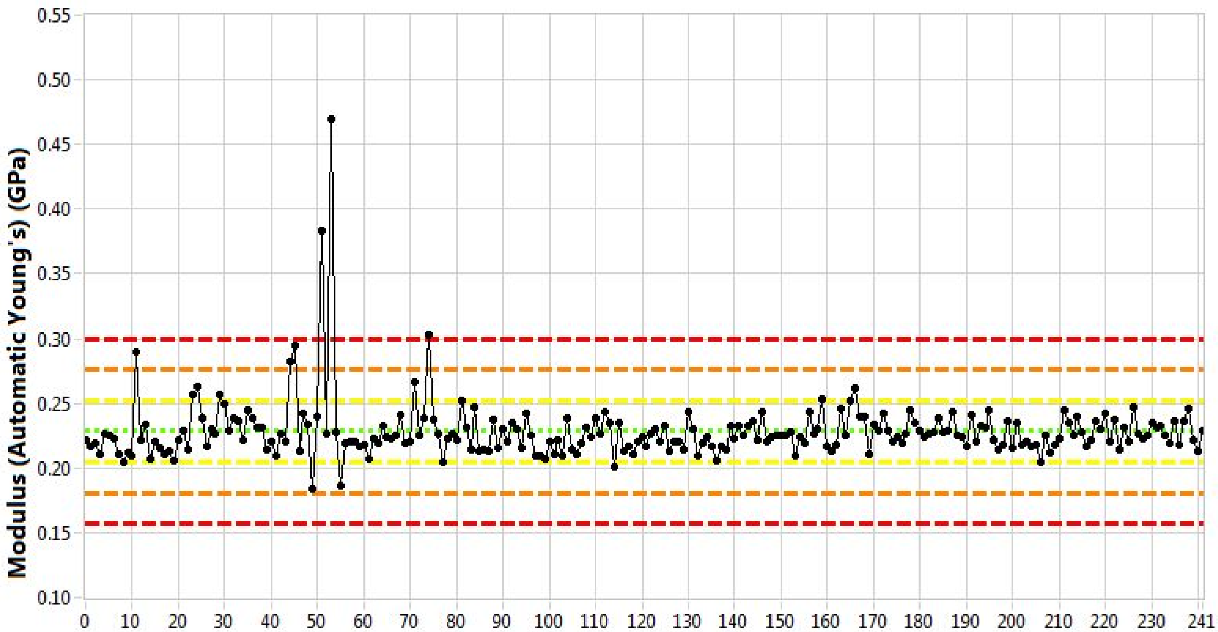

Figure C-2. Modulus (automatic Young's) (GPa), mean = 0.23, standard deviation = 0.02.

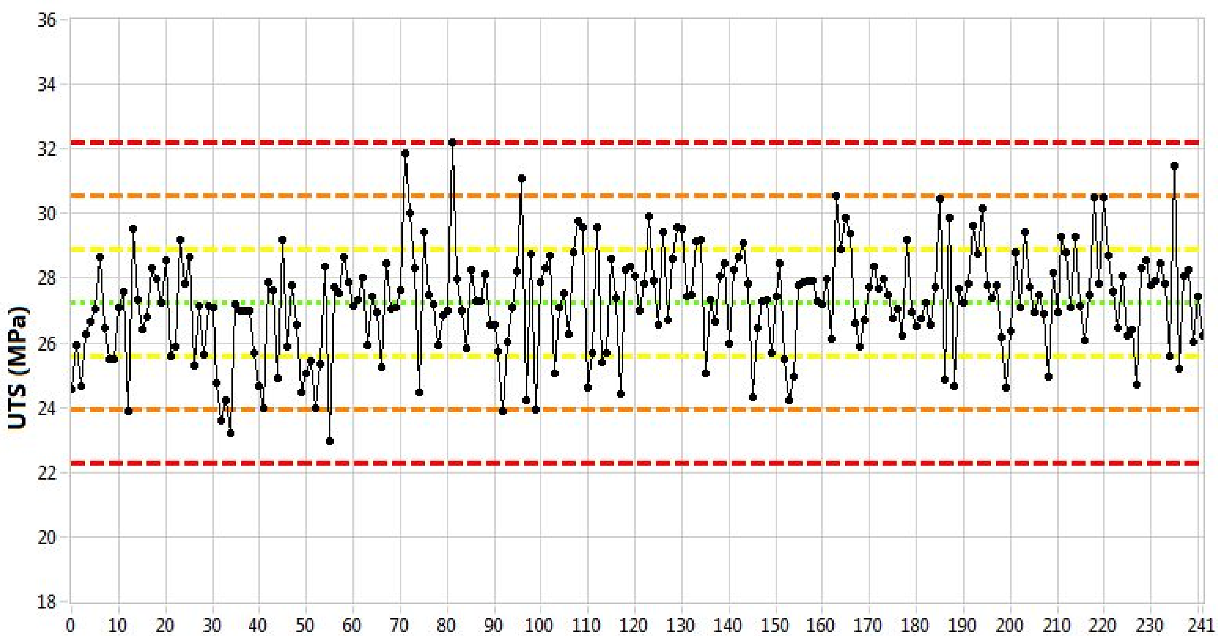

Figure C-3. Ultimate tensile strength (MPa), mean = 27.24, standard deviation = 1.65.

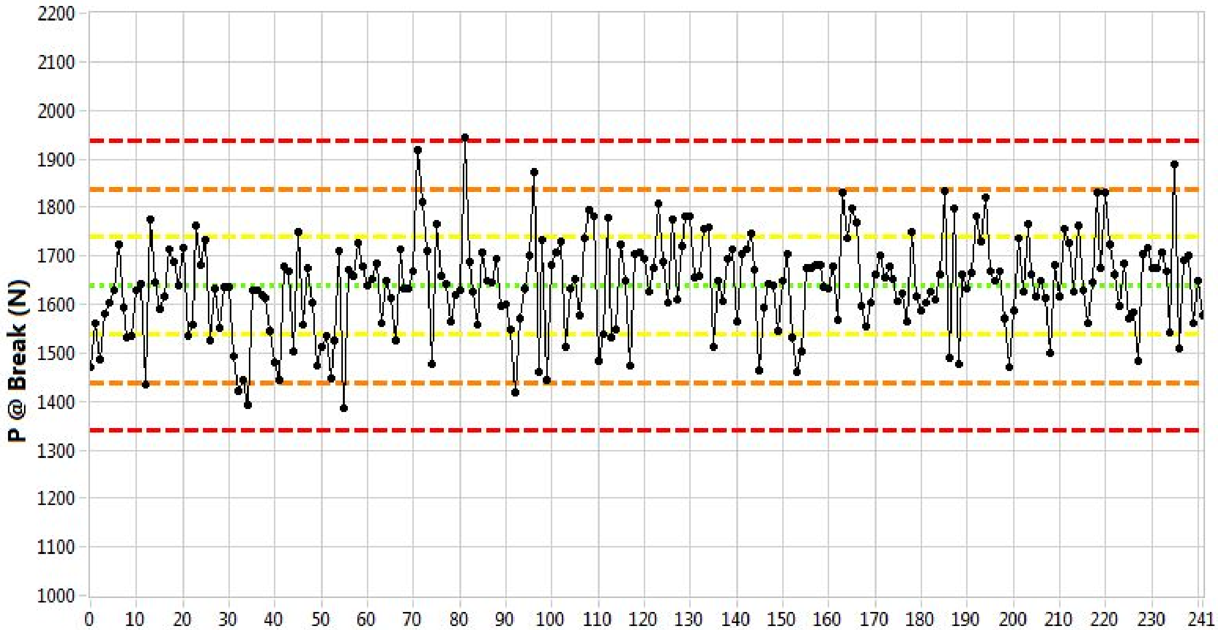

Figure C-4. Load at break (N), mean = 1638.45, standard deviation = 99.63.

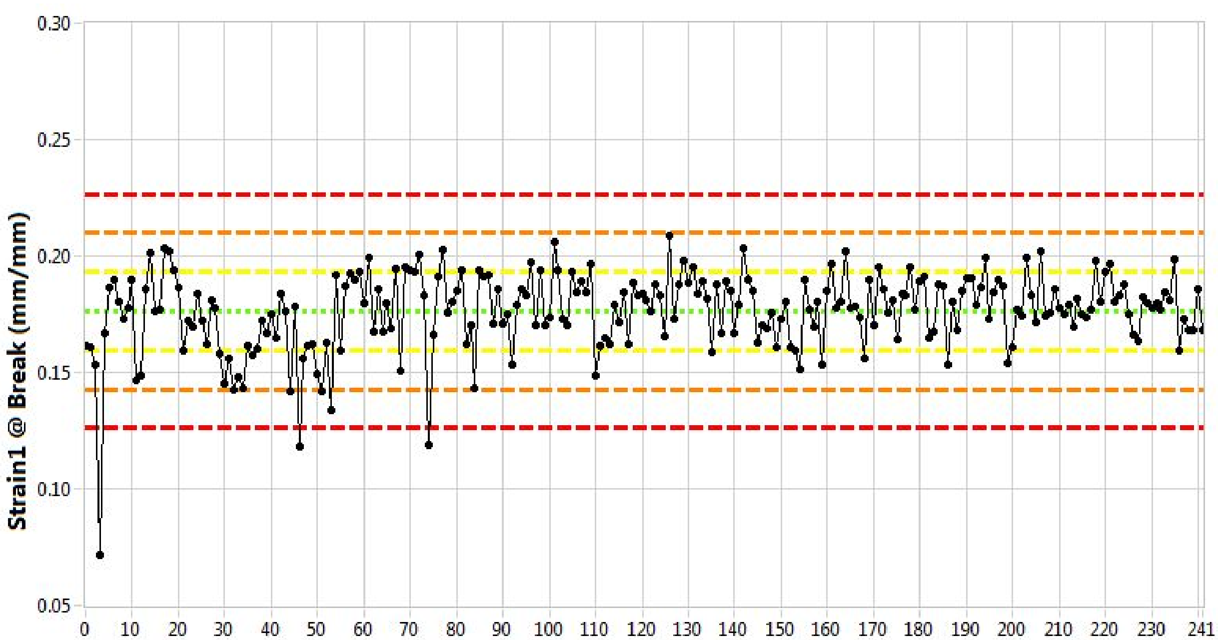

Figure C-5. Strain 1 at break (mm/mm), mean = 0.1763, standard deviation = 0.0168.

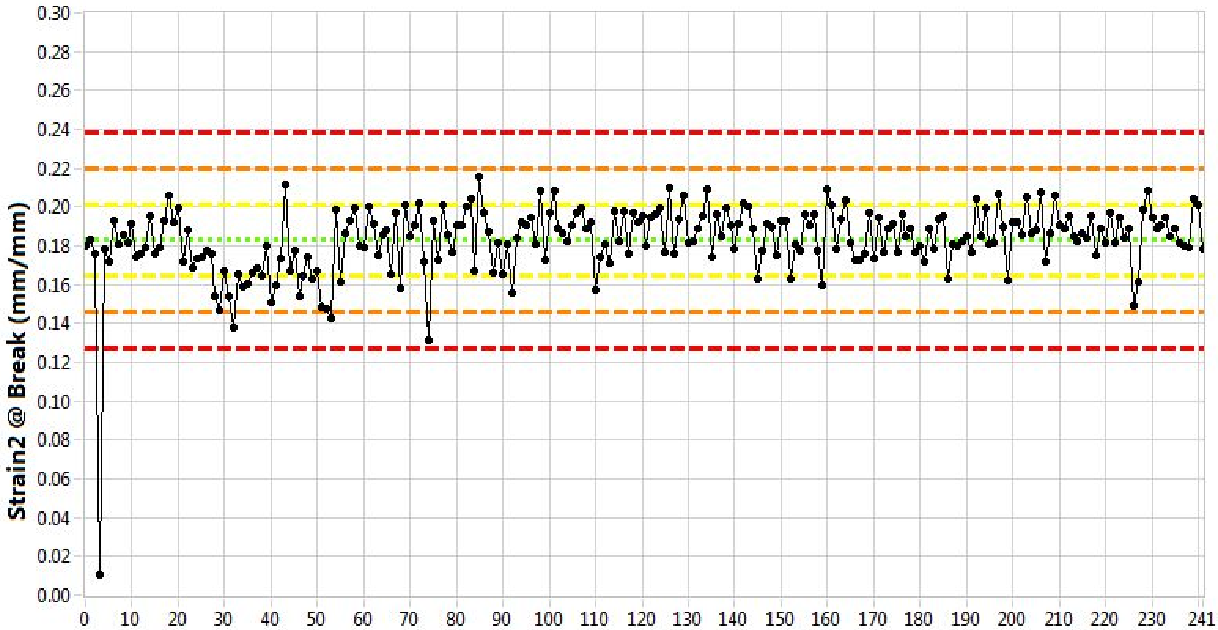

Figure C-6. Strain 2 at break (mm/mm), mean = 0.1829, standard deviation = 0.0184.