ARL-TR-7728 ● July 2016

US Army Research Laboratory

Mechanical Properties of Polymers Used for Anatomical Components in the Warrior Injury Assessment Manikin (WIAMan) Technology Demonstrator

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NOTICES

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
July 2016	Final	August 2015–May 2016

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Mechanical Properties of Polymers Used for Anatomical Components in the Warrior Injury Assessment Manikin (WIAMan) Technology Demonstrator	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Dawn M Crawford, Mostafiz R Chowdhury, and Hollie A Pietsch	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army Research Laboratory ATTN: RDRL-DPW Aberdeen Proving Ground, MD 21005-5069	ARL-TR-7728
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Warrior Injury Assessment Manikin was developed to provide an instrumented anthropomorphic test device (ATD) specifically designed for underbody accelerative loading test environments. This first of its kind ATD was designed to exhibit human-like kinematic responses to underbody blasts. To achieve that goal, the ATD used numerous polymeric materials for component parts that simulate human tissue and enable compliance in the ATD. The polymeric materials' mechanical properties range from soft and flexible low-durometer polyurethanes to rigid high-modulus plastics. All materials are commercially available. This report presents tensile and compression properties for the 8 materials tested over a broad range of engineering strain rates. The mechanical tests at numerous strain rates provided an understanding of the strain rate sensitivity of the polymers and was used for material model validation.

15. SUBJECT TERMS

anthropomorphic test device, ATD, polymers, rubber, compliance, stress strain, loading rate, strain rate, underbody blast, mechanical testing, tension, compression

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dawn M Crawford
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)
Unclassified	Unclassified	Unclassified	UU	130	410-306-0708

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The authors would like to acknowledge the helpful discussions with Mr Greg Freeburn of Veryst Engineering LLC on the test apparatus and methods and observations of the materials' performance.

1. Introduction

Anthropomorphic test devices (ATDs) have been in use for automotive crash studies since the 1970s. Although automotive ATDs have evolved significantly since that time, they were designed primarily to address frontal and side impact conditions at automotive vehicle representative speeds and therefore do not address vertical loading rates of interest to the military to simulate underbody blasts (UBBs) generated from mines or improvised explosive devices. Information on early designs of ATDs for automotive uses can be found elsewhere.[1–3]

The Warrior Injury Assessment Manikin (WIAMan) project was commissioned in 2010 by the Department of Defense to provide an instrumented ATD specifically designed for UBB test environments. The WIAMan ATD must demonstrate biofidelity with respect to kinematics and kinetics, provide reproducible responses, and exhibit durability after numerous exposures in a vehicle subjected to severe UBB loading conditions. The WIAMan is the first ATD of this type, designed specifically for the UBB test condition.

To address the anthropometry and biofidelic response required for UBB conditions, the WIAMan ATD design concept includes numerous polymeric parts. The material compliance of the polymers will better simulate a human response to UBB than existing ATDs used for automotive crash test applications. The WIAMan project is not performing research and development of new polymeric materials but rather seeks to understand the properties of commercially available materials over a broad range of strain rates to enable the optimal selection of materials for this application.

This report discusses the mechanical properties of 8 commercial polymers that are used in key components in the WIAMan ATD Technology Demonstrator (TD). Components fabricated from these polymers are designed to align with the critical load path when the ATD is in a normal seated posture and exposed to underbody accelerative loading. The WIAMan TD is the first whole body iteration of the WIAMan design and thus represents a relatively early stage in a multiyear program, with final production planned in 2021.

This report will focus on the material properties. Fabrication and testing of the actual components and the modeling of the material or component responses is beyond the scope of this report. However, successful design, fabrication, and modeling are dependent on comprehensive material characterization. This report serves as a comprehensive material property guide for these 8 commercial polymers that have been tested in tension and compression over a large range of strain rates.

2. Experiments

Knowledge of the physical properties of materials is essential to the design, fabrication, modeling, and performance of products made from them. Polymers are a broad class of materials with diverse properties that can range from liquid-like gels to very-high-modulus plastics. Their physical properties are attributed to many factors including endless variations in the chemistry and molecular weight of the base polymer as well as formulating constituents. Their properties are also highly dependent on how the material was fabricated, how the test specimens were formed, test sample dimensions, ambient conditions such as temperature, and the strain rate used for testing.[4]

The tests discussed in this report were performed by Veryst Engineering LLC, Needham Heights, Massachusetts, which is a leading testing laboratory for characterization of materials that exhibit complex nonlinear viscoelastic behavior. Veryst also provides service in material modeling and nonlinear simulation. The test protocols were customized for the WIAMan program specifically for the development of material models for modeling and simulation work. The custom test methods were designed to capture the nonlinear strain-rate-dependent response of the materials characterized. The specific details of each customized test are described in the following sections.

2.1 Materials

Of the 8 materials discussed in this report, 6 are 2-part polyurethanes, one material is a thermoplastic acetyl resin with the tradename of Delrin (a registered trademark of DuPont), and the other is a custom-formulated vulcanized elastomer. The polyurethanes and the Delrin are commercially available. The custom-formulated rubber can be reproduced with the composition provided in Appendix A. The 8 materials are listed in Table 1.

Table 1 WIAMan technology demonstrator polymers

Commercial designation	Material supplier	Material type	Density (gm/cm^3)	Durometer	ATD component
Proflex 30	Mouldlife UK	2-part polyurethane elastomer	NA	29 Shore A	Pelvis flesh
XE 1031	Polymed Ltd UK	2-part polyurethane elastomer	NA	33 Shore A	Foot flesh
F-130 A/B	BJB Enterprises	2-part polyurethane elastomer	1.05	31 Shore A	Upper torso, leg, and arm flesh
Butyl rubber	SACO/RDAbbott rubber formulation ID no. XL-10216-E-1	Custom-compounded vulcanized elastomer	1.46	75 Shore A	Compliant elements in spine and tibia
FD-70	BJB Enterprises	2-part semi-rigid polyurethane elastomer	1.21	68 Shore D	Foot plate
Rencast 6425	Huntsman	2-part rigid polyurethane	1.18	67 Shore D	Coccyx
TC 892	BJB Enterprises	2-part rigid polyurethane	1.16	79 Shore D	Pelvic bone
Delrin	Stock material, numerous suppliers	Rigid thermoplastic (acetyl resin)	1.41	81 Shore D	Calcaneus cap

The materials in Table 1 are arranged by their durometer category (Shore A or Shore D). The 6 polyurethanes are all thermosets formed by mixing 2 liquid components (referred to as parts A and B) according to the manufacturer directions and pouring the mixture into a mold to shape and cure the polymers. Polyurethanes are very versatile polymers due to variations in their base chemistry, crosslinking agent, and ratio of their 2 components, making them amenable to properties that can range widely from very soft and flexible elastomers to rigid plastics. The WIAMan ATD design required such diversity in polymer properties to meet dynamic response properties of human tissue such as low-durometer flexible flesh and high-stiffness bone. Delrin is a highly crystalline engineering thermoplastic used for applications that require high stiffness and strength needed for applications to replace metal parts. The custom-formulated vulcanized elastomer is used for numerous compliant elements in the WIAMan to provide flexibility and damping in parts of the spine and legs. The anatomical parts for each material are shown in Table 1. Manufacturing data sheets for each commercial material can be found in Appendix B.

2.2 Test Methods

2.2.1 Durometer

Hardness of polymers is defined as a measure of resistance of the material to indentation without puncturing the material. The hardness value is dependent on several factors including the indenter geometry, degree of indentation, and time of indentation.[5] A CHECK-LINE Shore A durometer and Rex Durometer Shore D durometer were used for the measurements of the 8 polymers. Measurements were taken in accordance with ASTM D-2240-05 (Type A and Type D).[6] The durometers of the 8 materials are shown in Table 1.

2.2.2 Monotonic Tensile

Monotonic tensile tests were performed at 3 engineering strain rates ($0.01s^{-1}$, $0.10s^{-1}$, and $1.0s^{-1}$) on either an Admet 2608 electromechanical test machine or an Instron 8800 servo-hydraulic test machine depending on the load capacity required for each test. The tests were controlled using crosshead displacement. Strain was measured using digital image correlation (DIC) on the gauge section of the specimen. A Point Grey Gazelle Camera was used for image acquisition. Specimen geometry conformed to ASTM D638 Type IV[7] for engineering strain rates of 0.01 s^{-1} and 0.10 s^{-1} while Type V geometry was used for tests run at 1.0-s^{-1} engineering strain rate. Tensile specimens were stamped or waterjet cut from molded sheets. Sheet thickness was measured for each specimen and varied between 2.03 and 5.08 mm depending on the material. Cross-sectional area was calculated for each specimen tested.

2.2.3 Monotonic Compression

Monotonic compression tests were performed on the same test machines as used for the monotonic tensile tests. Specimens were strained to approximately 50% using crosshead-controlled displacement. An Epsilon Technology axial extensometer was used to measure strain. Cylindrical samples were used for compression testing. The low-durometer (Shore A) material compression specimens were prepared by stacking molded cylindrical compression “buttons” 2 high to reduce friction effects and improving the aspect ratio (height/diameter). Cylindrical specimens of the butyl rubber were cut from sheets and stacked 3 high. Compression samples for the high-durometer (Shore D) materials were prepared by cutting 10.16-mm-diameter rods to the desired cylinder height (H). For all test geometries, a lubricant such as 3-in-1 multipurpose oil or Krytox performance lubricant (GPL207) was used between the specimen and the plates to reduce friction. Compression sample dimensions varied for each material but were generally in the following ranges: soft polyurethanes diameter (D) = 8.1 mm, stacked height (SH) = 9.5 mm; butyl rubber D = 11.2 mm, SH = 7.3 mm; and rigid polyurethanes and Delrin D = 9 mm, H = 9 mm. Monotonic uniaxial compression tests were conducted at 0.01 s^{-1}, 0.10 s^{-1}, and 1.0 s^{-1} engineering strain rates.

2.2.4 Cyclic Tension

Cyclic tension tests were performed using the same test machines and sample geometries described in Section 2.2.2. Engineering strain rates used for the cyclic tension tests were 0.0033 s^{-1}, 0.033 s^{-1}, and 0.33 s^{-1}. Cyclic testing included a load/hold/unload condition. A 10-s hold segment was performed following each loading segment and a 5-s hold segment followed each unloading segment to measure stress relaxation. The sample was unloaded to a force of 0.5 N during each cycle.

2.2.5 Cyclic Compression

Cyclic compression tests were performed using the same test machines and sample geometries described in Section 2.2.3. The specimens were tested at 0.01 s^{-1}, 0.1 s^{-1}, and 1.0 s^{-1} engineering strain rates with the exception of TC 892, which was tested at 0.01 s^{-1}, 0.1 s^{-1}, and 0.5 s^{-1} engineering strain rates. Cyclic compression tests included load/hold/unload cycles that varied with each material depending on properties measured in the monotonic tests. A typical compression cycle involved compression of the specimen to approximately 10% strain, hold 10 s, unload to 0.5 N, compression to approximately 30% strain, hold 10 s, unload to 0.5 N, compression to approximately 40% strain, hold 10 s, unload to 0.5 N, compression to approximately 50% strain, hold 10 s, and unload to 0.5 N.

2.2.6 High-Rate-Tension Drop Tower

High-rate-tension tests were performed on the Veryst Engineering custom-built drop tower using custom tension fixtures. The details of the equipment and setup are proprietary and therefore are not discussed here. The test procedure involved coating the test specimen with speckled spray paint and loading the specimen into the tension grips. A weighted sled was raised to a height corresponding to the desired strain rate. The drop height was determined based on preliminary testing, equating drop height to strain rate for each material. The test commenced when the sled was released and allowed to fall, striking the test fixture, which loaded the specimen to large strains or to failure depending on the elastic or ductile nature of the material. The high-speed camera (Photron FastCam mini UX100) was focused on the speckle pattern, and the engineering strain was calculated using DIC. Sample geometry conformed to ASTM D638 Type V.[7] Tests were performed at 3 engineering strain rates per material that ranged between 30 s^{-1} and 400 s^{-1}. Each material strains differently based on its material stiffness. Therefore, the strain rates varied with each material, unlike the slower rate testing, which was controlled by crosshead displacement. The specific strain rates for each material and test are shown in Appendix C.

2.2.7 High-Rate-Compression Drop Tower

High-rate-compression tests were performed on the same equipment as for the high-rate-tension tests. The compression specimen was placed on the platens of the compression drop tower fixture. The crosshead was raised to a height corresponding to the desired strain rate. The test was initiated when the sled was released. The top platen came into contact with specimen, causing compression of the specimen, and the compressive force was measured using a load cell under the bottom platen. Strain was measured from the movement of fiducial markers on the platens using the Photron FastCam mini UX100 high-speed camera. Compression specimens and dimensions were prepared as described for the monotonic compression test specimens (Section 2.2.3) with the exception that the rigid (Shore D) material test specimens were cylinders with dimensions of D = 6 mm and H = 6 mm. Tests were performed at 2 engineering strain rates that varied per material (approximately 50 s^{-1} and 150 s^{-1}) as discussed in Section 2.2.6.

2.2.8 Split Hopkinson Pressure Bar (SHPB)

The high-rate-compression tests using SHPB were performed on a Veryst Engineering custom-designed and -built instrument. The test method used a gas gun that fired a striker bar into a 90-inch-long aluminum incident bar to induce a stress wave ("incident wave") that travels the length of the bar and transmits the stress wave into the test specimen placed between the incident bar and the transmitted bar. At the bar/sample interface, a portion of the energy is transmitted to the sample and the rest is reflected ("reflected wave"). The transmitted wave travels through the specimen, inducing deformation, and into the transmitted bar. The reflected wave travels back up the incident bar. Strain caused by the stress waves was measured by strain gauges placed on the bars. Stress and strain were calculated from the amplitudes of the incident, transmitted, and reflected waves. Using properties of the aluminum bars and other data recorded during the test, properties of the tested material was calculated at high strain rates. SHPB was used to measure compression properties of the 4 Shore D materials at 2 engineering strain rates of approximately 500 s^{-1} and 1000 s^{-1}. Cylindrical test specimens were used with dimensions of D = 6 mm and H = 6 mm.

2.2.9 Failure Tests

Specimen failure was characterized in tensile mode and used to specify a stress-, strain-, or energy-based failure condition. Failure tests were performed on the Admet 2608 electromechanical test machine at an engineering strain rate of 0.01 s^{-1}. The Shore A materials were tested using sample geometry in accordance with ASTM D624 Type C.[8] The Shore D materials were tested in tensile mode but using the sample geometry specified in ASTM D5379.[9] The force at failure and the crosshead displacement were recorded as well as full-field strain fields using DIC to observe local and global strain measurements.

3. Results and Discussion

The soft (Shore A)-durometer polyurethanes and the butyl rubber were tested in tension at 3 monotonic strain rates and 3 high strain rates. Due to the ductility of the soft materials, the ultimate tensile stress and strain at failure was only obtained for the monotonic strain rates. The stress strain curves tested at a strain rate of 0.1 s^{-1} for the 3 polyurethanes at similar durometer (~30 Shore A) are shown in Fig. 1. The stress strain curves show that these materials exhibit similar tensile behavior. Although the strain at failure was not recorded, it was noted by the test engineer that these materials exhibited high extensions, typically greater than 500%.

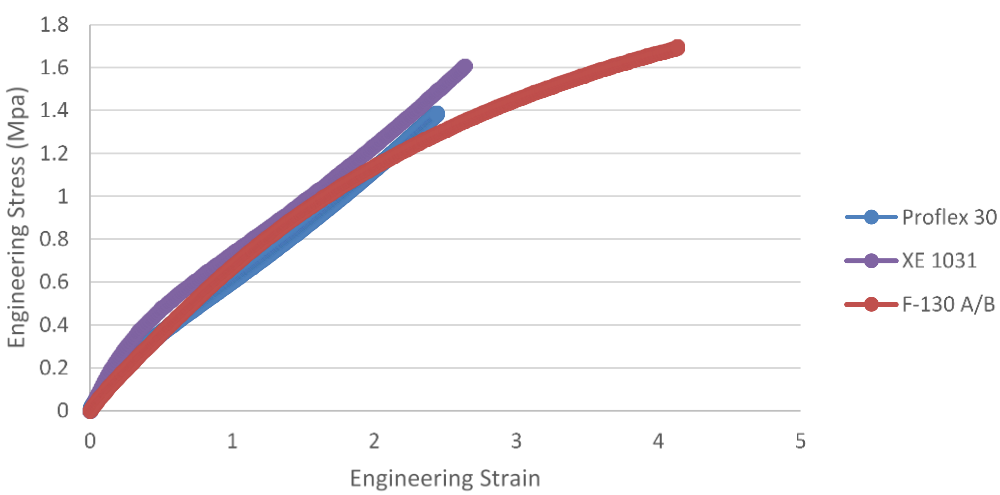

Fig. 1 Tensile properties of Shore A polyurethanes at 0.1 s^{-1} strain rate

The effect of increasing strain rate on the tensile properties for XE 1031 is shown in Fig. 2. The tensile response to strain rate for this material was very similar to the response measured for the other 2 soft polyurethane flesh materials. The low-durometer polyurethane material exhibited a slight but discernable strain rate dependence.

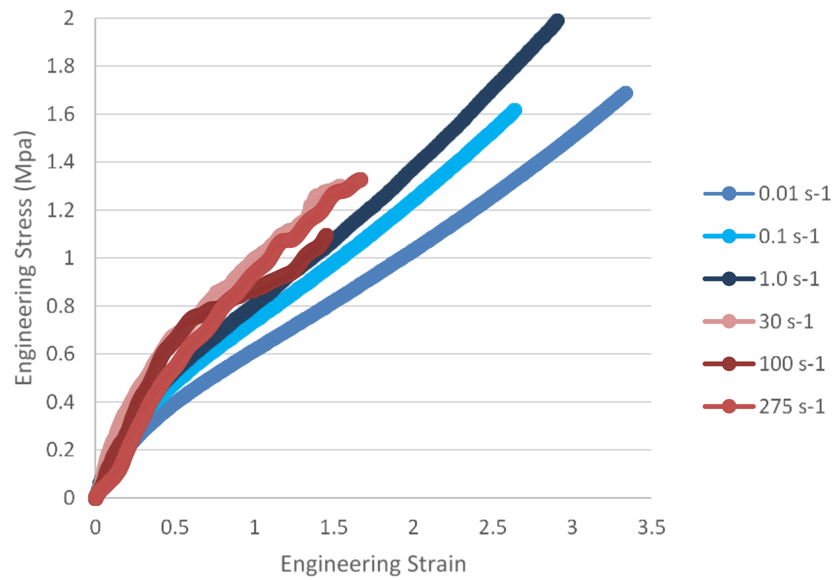

Fig. 2 Tensile properties of XE 1031 at quasi-static and high strain rates

Figure 3 shows the tensile properties of the 3 soft polyurethanes (Proflex 30, XE 1031, and F-130) at a low and high strain rates. Butyl rubber (75 Shore A) is also plotted to show the significant difference in the tensile properties of these 2 classes of elastomers. The butyl rubber exhibited much greater tensile strength and much higher strain rate dependence than the other Shore A polymers tested. The higher stiffness of the butyl rubber is required for the components where it is used in the WIAMan TD (spine- and leg-compliant elements) to enable the torso and head to stay in an upright posture when seated and provide damping properties in UBB test conditions.

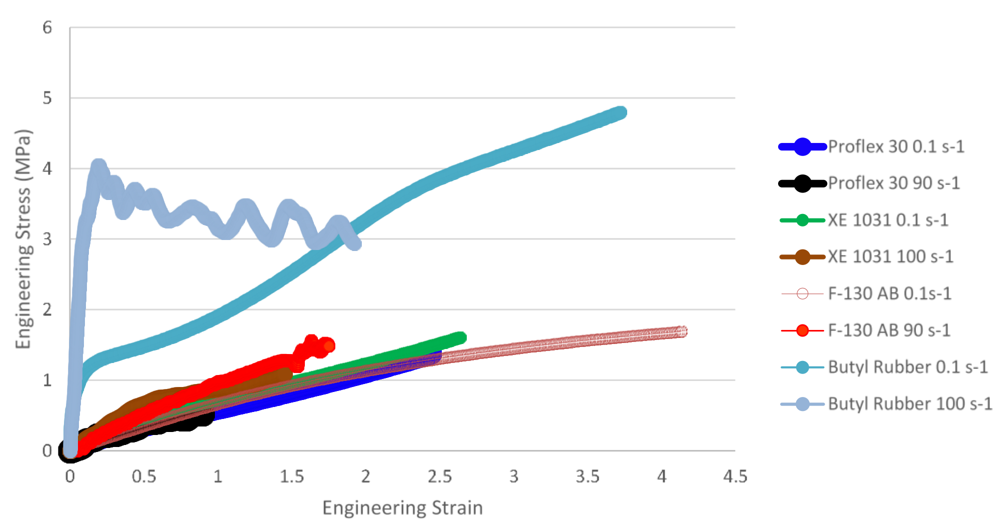

Fig. 3 Tensile properties of Shore A polyurethanes and butyl rubber at low and high strain rates

The tensile properties of the Shore D polyurethanes are shown in Fig. 4. The tests for the Shore D polymers were taken to failure and the plots show their distinct differences in failure stress and failure strain. While the ultimate tensile strength of the polymers are roughly grouped according to their durometer (Delrin and TC 892 have durometers of approximately 80 Shore D; Rencast 6425 and FD-70 have durometers of approximately 68 Shore D), all 4 polymers vary distinctly in failure strain, a measure of ductility. TC 892 (pelvic bone) had the lowest strain to failure of all the materials tested and exhibited brittle failure. FD-70 (used for the foot plate) showed very high ductility. Durometer is a useful measurement to rank hardness of various polymers but does not correlate well with specific properties and should not be used as a key metric for design or manufacturing as is demonstrated by the stress strain behavior of these polymers.[6]

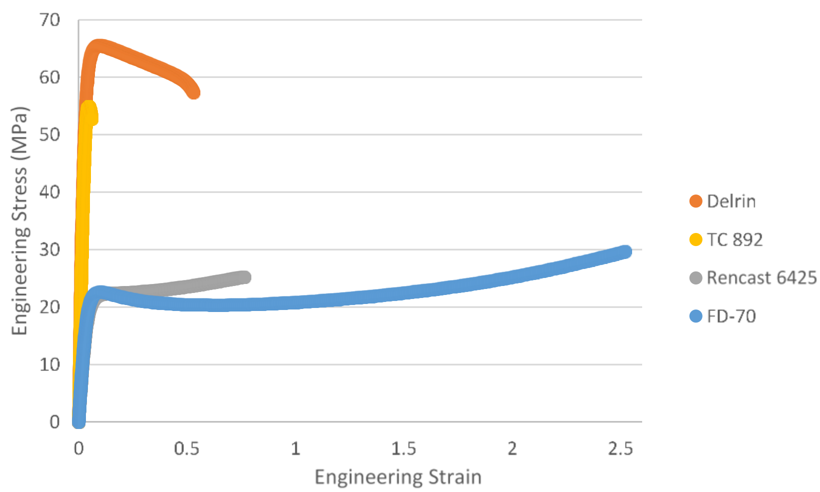

Fig. 4 Tensile properties of Shore D polymers at 0.1-s^{-1} strain rate

Compression properties of the Shore A and Shore D polymers at an engineering strain rate of 0.1 s^{-1} are shown in Figs. 5 and 6. Compression tests were performed to approximately 50% strain, and therefore differences in material ductility were not apparent as in the tensile data. However, the trends in compressive strength were similar to the trends in tensile strength. The significant difference in the compressive strength of the 80 Shore D durometer polymers compared with the 68 Shore D durometer polymers was readily seen in the data, and the high compressive strength of Delrin at 50% strain was noteworthy.

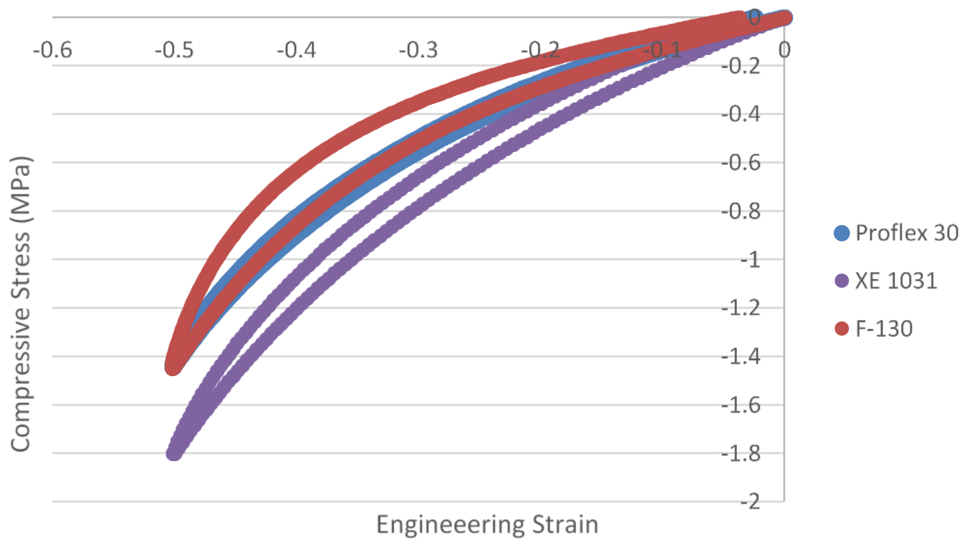

Fig. 5 Compression properties of Shore A polyurethanes at 0.1-s^{-1} strain rate

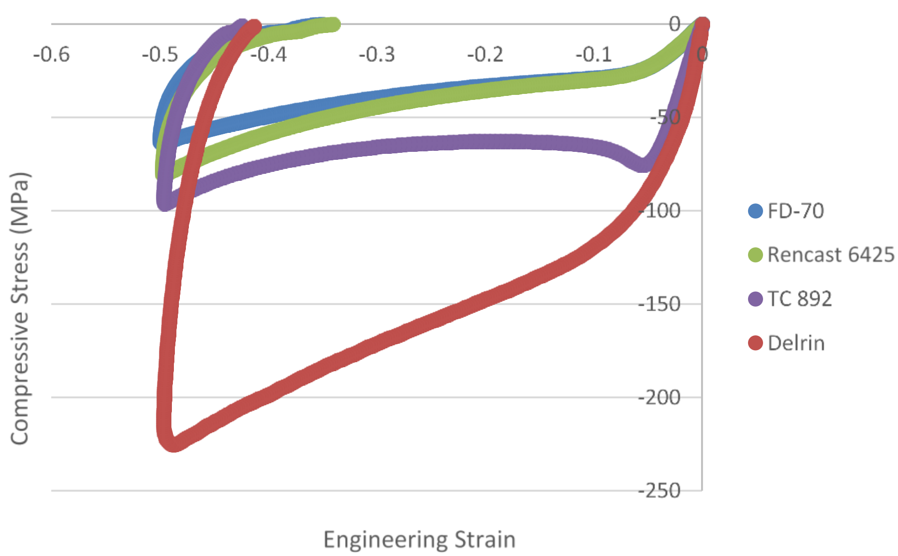

Fig. 6 Compression properties of Shore D polymers tested at 0.1-s^{-1} strain rate

Figures 7 and 8 show the effect of strain rate on the tensile and compression properties of Rencast 6425. The data indicate that this polymer was highly strain rate dependent. At the lower monotonic strain rates there was a slight but pronounced increase in strength with increasing strain rate; however, there was a significant jump in material response when the strain is increased from 1.0 s^{-1} to 50 s^{-1}. This relationship was seen in all of the Shore D polymers.

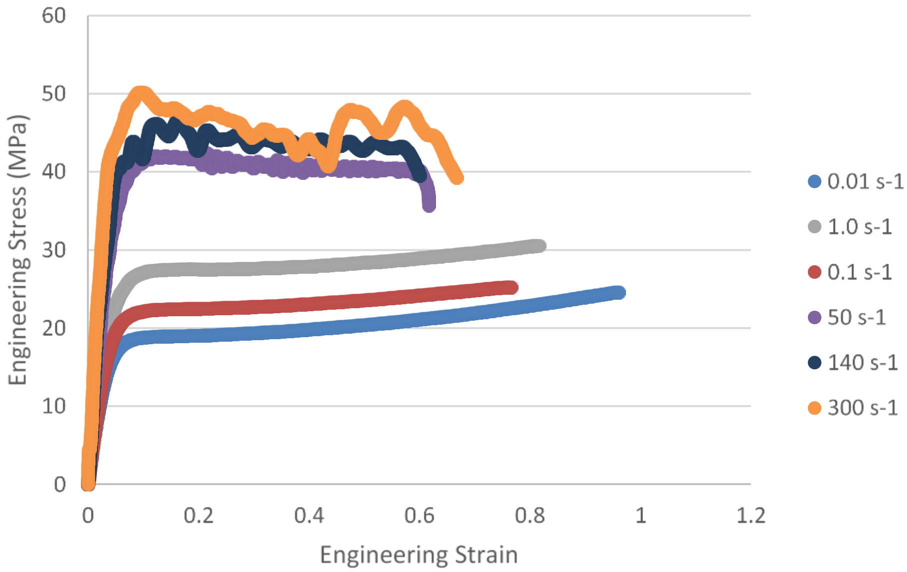

Fig. 7 Tensile properties of Rencast 6425 as a function of engineering strain rate

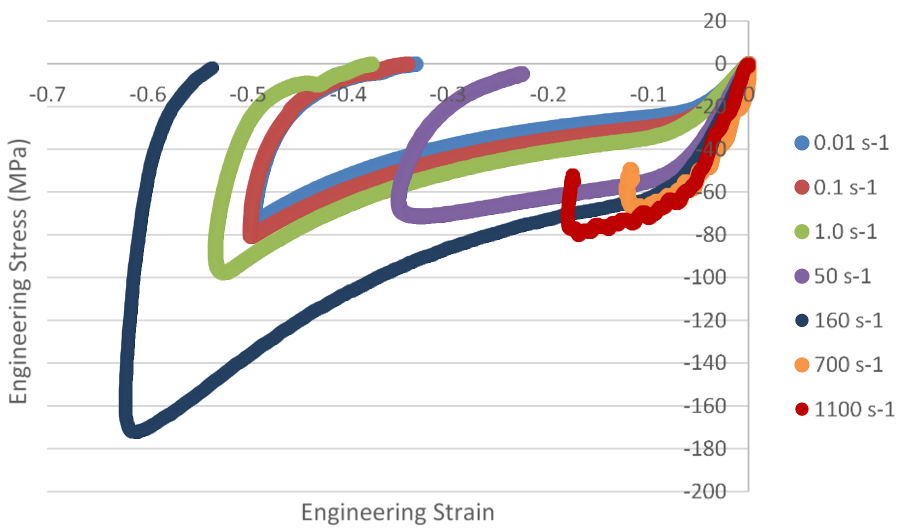

Fig. 8 Compression properties of Rencast 6425 as a function of engineering strain rate

Figure 9 shows the overall strain rate effects of all 8 polymers in tension and compression. Butyl 75A exhibited the greatest strain rate dependence of the Shore A polymers as seen in the increasing tensile and compressive response with respect to increasing strain rate. Similar conclusions were found in an earlier study of butyl rubber (unspecified formulation) used in the Hybrid III ATD neck component.[10] The Shore A polyurethanes showed a greater strain rate sensitivity in compression than in tension. The Shore D materials showed significant strain rate sensitivity, which is typical for rigid thermosets and thermoplastics of this type.

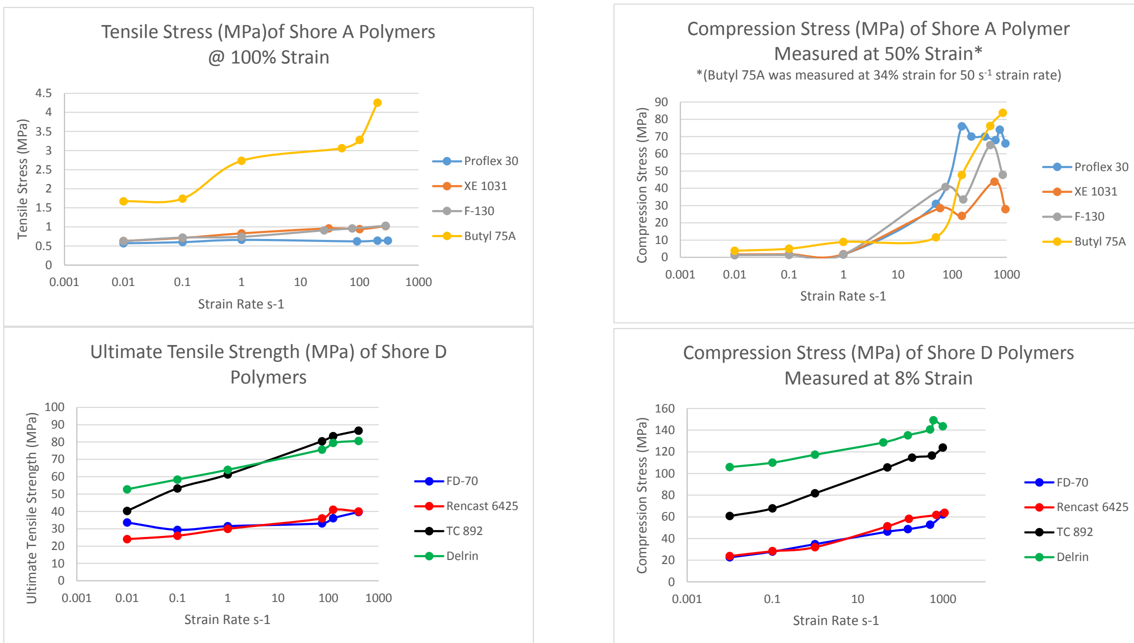

Fig. 9 Strain rate effects on Shore A and Shore D polymers in tension and compression

Cyclic tension and compression tests were performed on the 8 materials. Strains for the cyclic testing were selected from various regions of the stress strain curve, such as the linear region, close to the yield point, and after the yield point. The cyclic tests included a complete unloading cycle that provided information about hysteresis and permanent set of the 8 materials.[11] Figures 10 and 11 show the cyclic data in tension (0.33 s^{-1}) and compression (0.1 s^{-1}), respectively, for 2 Shore A materials and 2 Shore D materials representing all 8 durometers.

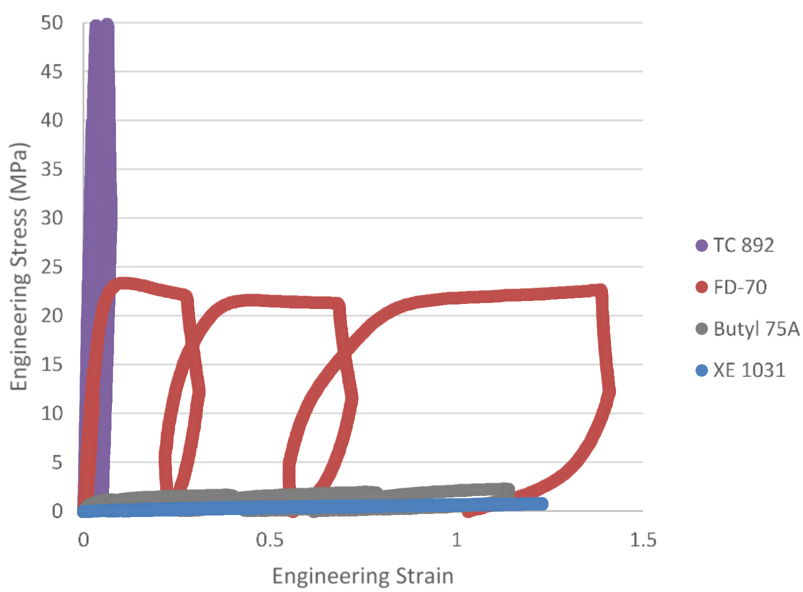

Fig. 10 Cyclic tension at 0.33-s^{-1} engineering strain rate

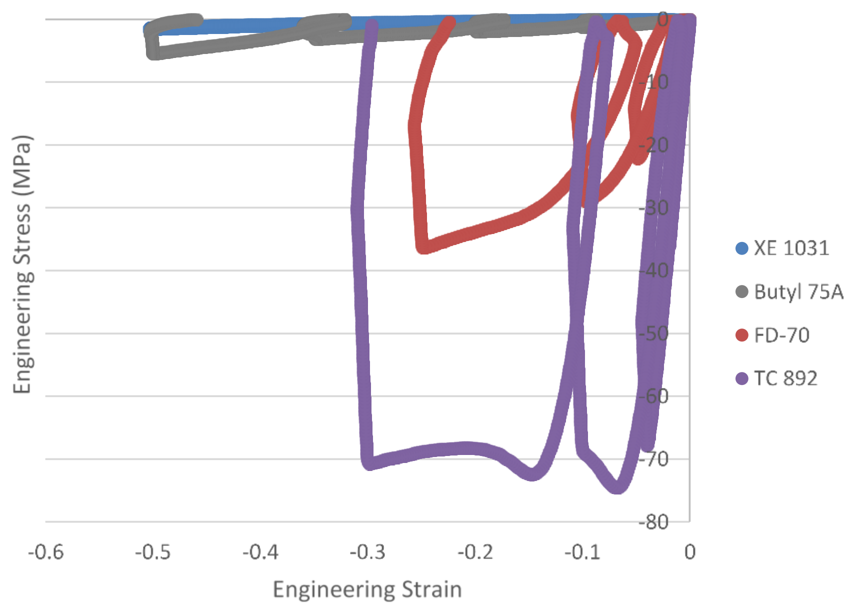

Fig. 11 Cyclic compression at 0.1 s^{-1} engineering strain rate

The material response of the 4 materials followed similar trends in both cyclic tension and cyclic compression. XE 1031, the softest polyurethane, exhibited low hysteresis and low permanent set, as expected, for an unfilled polyurethane elastomer in that durometer range (approximately 30 Shore A). All of the flesh materials (XE 10310, Proflex 30, and FD-130) behaved similarly; however, the 3 materials varied slightly in hysteresis.

Butyl 75A (a carbon-black-filled vulcanized rubber) showed greater hysteresis, as seen by the larger hysteresis loops resulting from the test cycles. This material response was typical for filled elastomers. Filler such as carbon black can significantly affect material stiffness and hysteresis, increasing both properties with increasing levels of filler.[12,13]

The Shore D polyurethanes FD-70 and TC-892 exhibited much higher strength than the low-durometer materials, as expected, based on the monotonic test results. FD-70 showed very high ductility in the monotonic testing, which was demonstrated in the cyclic testing by high hysteresis in both tension and compression. TC 892 exhibited high stiffness and low strain at failure in the monotonic tests, which correlated to low hysteresis as a result of cyclic tension because the cyclic tests had to be performed in the linear region of the stress strain curve to avoid fracture during the test. However, TC 892 did exhibit significant hysteresis in compression at strains beyond the linear range. Delrin (not shown) performed similarly to TC 892 but exhibited much higher stresses (approximately 30% higher in tension and 100% or higher in compression).

Tensile and compression properties at an engineering strain rate of 0.01 s^{-1} for all 8 materials are shown in Table 2, which compares the 8 materials at a quasi-static strain rate that better correlates to typical crosshead speeds of similar tests performed in accordance with standardized test methods. In this regard, the table serves as a general reference for comparison with other commercial material properties typically shown in manufacturer data sheets. General trends in compression and tensile strength were observed with respect to durometer. Strain to failure does not correlate well with durometer, as discussed earlier. The failure tests (tear test for Shore A polymers and tensile using v-notch shear specimen for Shore D polymers) are shown in the table as well as the crosshead displacement recorded at failure.

Table 2 Mechanical properties at 0.01-s^{-1} engineering strain rate

	Proflex 30	**XE 1031**	**F-130 A/B**	**Butyl 75A**	**FD-70**	**Rencast 6425**	**TC 892**	**Delrin**
Durometer	29 Shore A	33 Shore A	31 Shore A	70 Shore A	68 Shore D	67 Shore D	79 Shore D	81 Shore D
Density (g/cm^3)	NA	NA	1.05	1.46	1.21	1.18	1.16	1.41
Tensile strength at failure (MPa)	1.56	1.81	1.71	5.98	33.6	24	40.3	52.8
Strain at failure (%)	>500	200–600	400–950	300–500	258	96	9.1	64
Tensile stress at 100% modulus (MPa)	0.57	0.633	0.625	1.67	. . .	. . .	. . .	. . .
Tear strength (Die C) (N/mm)	5.3 (21.5 N)	6.1 (24.7 N)	10.1 (25.6 N)	34.57 (70.1 N)	. . .	. . .	. . .	. . .
Failure test using v-notch specimen (N)	. . .	. . .	. . .	. . .	1041	3400	1178	2220
Crosshead displacement at failure during tear and v-notch failure tests (mm)	43–44	36–46	90–105	90–135	13–14	7–9	4–5	2–3
Yield strength (MPa)	. . .	. . .	. . .	. . .	18	18	47	61
Young's modulus (MPa)	. . .	. . .	. . .	. . .	485	426	1850	2530
Compression strength (MPa) at 50% strain (%)	1.47	1.66	1.28	3.8 (47% strain)	53.7	73.9	102.2	245.4

High strain rate compression using SHPB was performed on the Shore D polymers.

Tests were performed at 2 strain rates for each material. The lower strain rate varied per material between 500 s^{-1} and 700 s^{-1}. The higher strain rate (1000 s^{-1}) was used for all 4 materials. SHPB data for the 4 polymers is shown in Fig. 12. These data indicate that FD-70 showed the greatest rate dependence in the SHPB tests, while the TC 892 response did not change as a result of the increased strain rate for this method.

Tensile and compression data for all 8 materials are presented in tabular format in Appendix C. Appendix D shows the stress strain curves in tension and compression for each material.

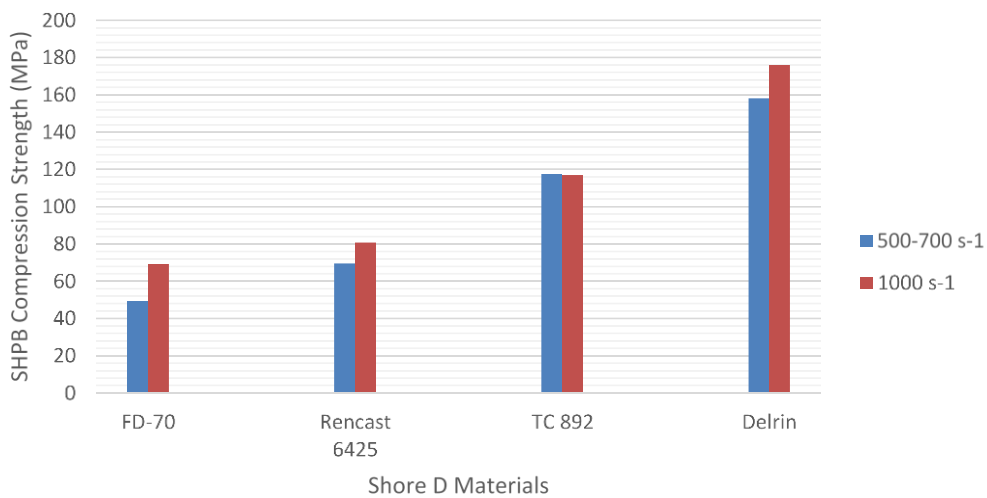

Fig. 12 SHPB compression strength for Shore D polymers

4. Summary and Conclusions

This reports details mechanical testing of 8 candidate polymers used in the WIAMan Technology Demonstrator. The purpose of this material investigation was to gain quantitative information of the commercial materials for their unique application in the first of its kind ATD designed for UBB test events and to inform the finite element analysis model development. The test results provide a comprehensive assessment of the material performance in tension and compression over a broad range of engineering strain rates. This report also serves as a reference for future material development and to aid selection of materials for similar components and applications.

The 3 Shore A polyurethanes performed similarly in the tensile tests, showing only a slight degree of strain rate dependence. They demonstrated behavior expected for soft elastomers such as low hysteresis during cyclic tests and generally low values in tensile strength with high elongations. The Shore A polyurethanes showed a greater degree of strain rate dependence in compression especially at strain rates greater than 1 s^{-1}. Butyl 75A rubber, which was very different in chemistry and composition than the polyurethanes, exhibited very high strain rate sensitivity in both tension and compression, which is primarily due to the level of carbon black used in the formulations (the polyurethanes discussed in this report are unfilled elastomers).

The Shore D polyurethanes exhibited significant differences in their material response to the loading conditions. TC 892 was stronger than the other 2 Shore D polyurethanes in both tension and compression and exhibited very low ultimate strain and brittle failure. Rencast 6425 and FD-70 showed similar strength in tension and compression, but FD-70 exhibited much greater elongation and highly ductile failure, demonstrating how materials of similar durometer can vary tremendously in performance. All of the Shore D polymers showed strain rate sensitivity and high hysteresis when deformed beyond their yield point. Delrin, an acetyl resin, showed the highest compressive strength at all engineering strain rates tested.

The mechanical behavior of the 8 commercial materials demonstrate the diversity of properties needed to meet the requirements of the novel WIAMan ATD.

5. Future Work

Further development and testing of the WIAMan ATD may result in changes to the materials used for specific anatomical components. System-level ATD tests may reveal a need to modify materials to achieve a specific modulus, ultimate strain, or other factors to meet durability requirements or performance corridors. New materials will undergo similar testing as described in this report. Materials selected for the final WIAMan ATD will undergo a series of ASTM tests to define all material properties necessary to define material requirements and will become part of the WIAMan technical data package.

6. References

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Appendix A. Butyl Formulations and Test Report

This appendix appears in its original form, without editorial change.

Butyl Rubber Compound Formulation, SACO Research/R.D. Abbott

Formulation ID	XL-10216-E-1	XL-10216-E-2	XL-10216-E-3
Test Date	7/31/15	7/31/15	7/31/15
Cure	15min@330F	15min@330F	15min@330F
Test Results			
Tensile Strength (psi)	840	933	829
Elongation %	542	596	456
Durometer, Shore A	75	70	79
Modulus @ 25%	195	175	234
Modulus @ 50%	228	206	274
Modulus @ 100%	313	278	367

Formulation Ingredients			
Butyl 101-3 (Base)	100.00	100.00	100.00
Calcium Carbonate (Non-reinforcing Filler)	100.00	100.00	100.00
Carbon Black N550 (Reinforcing Filler)	78.00	66.00	92.00
Carbon Black N990 (Reinforcing Filler)	25.00	25.00	25.00
Zinc (Activator)	4.00	4.00	4.00
Stearic Acid (Processing Aid)	1.00	1.00	1.00
MBTS (Accelerant)	2.00	2.00	2.00
TMTD (Accelerant)	1.00	1.00	1.00
Sulfur (Curative)	0.50	0.50	0.50
Aflux 12 (Processing Aid)	1.00	1.00	1.00
Rhenofit OCD (Antioxidant)	1.00	1.00	1.00

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Result & Graph

Selection Parameters:

Compound = XL-10216-E-1
Order = 1
Batch = 245281a-001
Test = SACO

Compound: XL-10216-E-1 **Order:** 1

Test: SACO --- 0 - Ready00

Batch	Specification	Date/Time	Status
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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Ready Temp	330.0	F					Setpoint
Sample Preheat Time	0.0	s					Setpoint
Ready Temp Range	0.5	F					Setpoint
Ready Time	30.0	s					Setpoint

Compound: XL-10216-E-1 **Order:** 1

Test: SACO --- 1 - Cure01

Batch	Specification	Date/Time	Status
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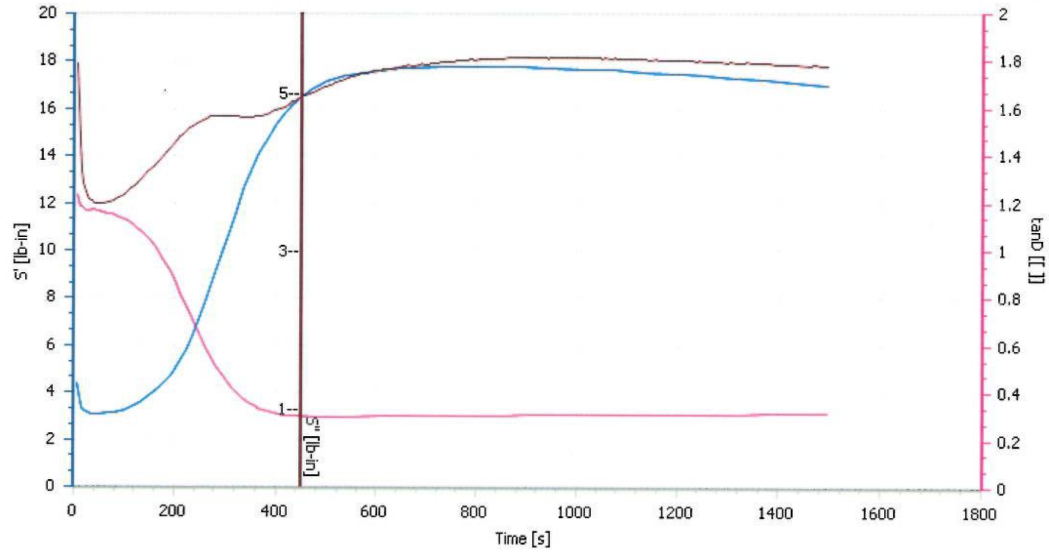
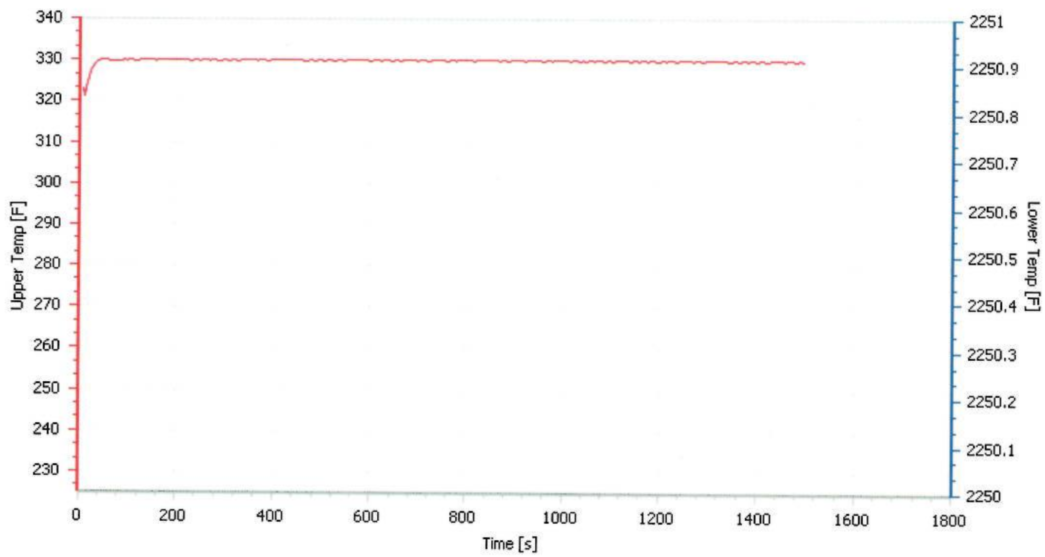
Variable	Result	Unit	LSL	LWL	UWL	USL	Status
AEOC Min Time	36000.0	s					Setpoint
AEOC tanD Limit	0.002	[ ]					Setpoint
AEOC S' Rate Limit	0.060	lb-in/s					Setpoint
AEOC Enabled	1.000	[ ]					Setpoint
AEOC Addl Time	60.0	s					Setpoint
Smoothing	9.000	[ ]					Setpoint
I-Filter	0.0	s					Setpoint
Stop at Scorch	100.000	lb-in					Setpoint
Interpolate	0.000	[ ]					Setpoint
Rate Window	11.000	[ ]					Setpoint
Time	1500.0	s					Setpoint
Temp	330.0	F					Setpoint
Freq	1.00	Hz					Setpoint
Angle	1.00	Deg					Setpoint
Min S' (ML)	3.076	lb-in					Tested
Max S' (MH)	17.799	lb-in					Tested
tc2	202.4	s					Tested
tc90	438.6	s					Tested





Compound: XL-10216-E-1 **Order:** 1

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Number of Readings	5.000	[ ]					Setpoint

Temp@330.0 F	330.0	F					Setpoint
Temp@300.0 F	300.0	F					Setpoint
Temp@250.0 F	250.0	F					Setpoint
Temp@200.0 F	200.0	F					Setpoint
Temp@150.0 F	150.0	F					Setpoint
Temp@100.0 F	100.0	F					Setpoint
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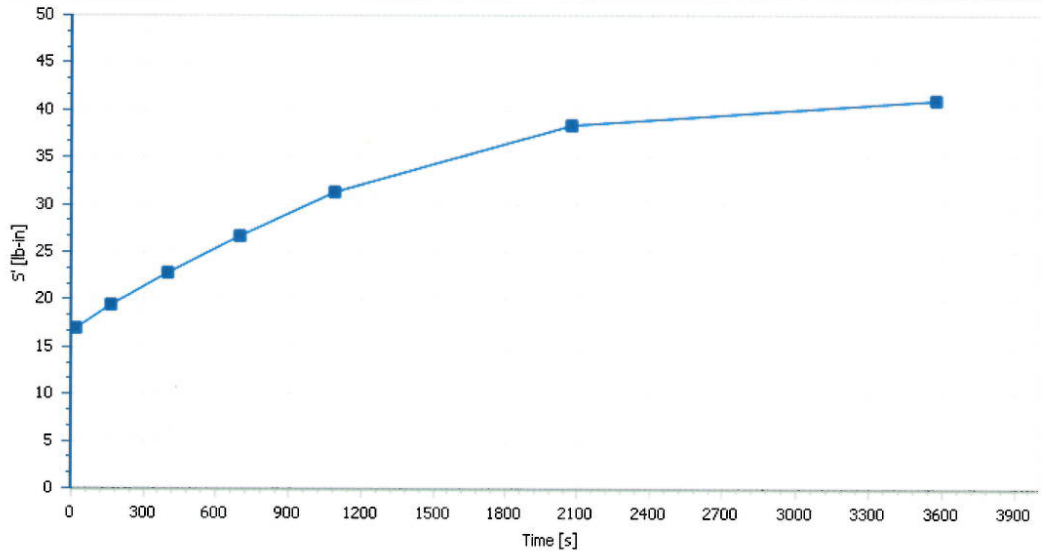
Angle	1.00	Deg					Setpoint



Compound: XL-10216-E-1 **Order:** 1

Test: SACO --- 3 - Freq03

Batch	Specification	Date/Time	Status
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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Sweep Length	11.000	[ ]					Setpoint
Number of Readings	1.000	[ ]					Setpoint
Temperature	86.0	F					Setpoint
Freq@1.00 Hz	1.00	Hz					Setpoint
Freq@1.55 Hz	1.55	Hz					Setpoint
Freq@2.10 Hz	2.10	Hz					Setpoint
Freq@2.65 Hz	2.65	Hz					Setpoint
Freq@3.20 Hz	3.20	Hz					Setpoint
Freq@3.75 Hz	3.75	Hz					Setpoint
Freq@4.30 Hz	4.30	Hz					Setpoint
Freq@4.85 Hz	4.85	Hz					Setpoint
Freq@5.40 Hz	5.40	Hz					Setpoint
Freq@5.95 Hz	5.95	Hz					Setpoint
Freq@6.50 Hz	6.50	Hz					Setpoint
Angle	7.20	Deg					Setpoint

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8/4/2015 8:36:08 AM **Result & Graph**

G'@1.00 Hz	83.27	psi					Tested
G'@1.55 Hz	81.48	psi					Tested
G'@2.10 Hz	80.68	psi					Tested
G'@2.65 Hz	79.97	psi					Tested
G'@3.20 Hz	79.27	psi					Tested
G'@3.75 Hz	78.44	psi					Tested
G'@4.30 Hz	77.62	psi					Tested
G'@4.85 Hz	76.63	psi					Tested
G'@5.40 Hz	75.75	psi					Tested
G'@5.95 Hz	74.86	psi					Tested
G'@6.50 Hz	74.10	psi					Tested
G"@1.00 Hz	43.80	psi					Tested
G"@1.55 Hz	44.10	psi					Tested
G"@2.10 Hz	44.65	psi					Tested
G"@2.65 Hz	45.09	psi					Tested
G"@3.20 Hz	45.41	psi					Tested
G"@3.75 Hz	45.57	psi					Tested
G"@4.30 Hz	45.72	psi					Tested
G"@4.85 Hz	45.73	psi					Tested
G"@5.40 Hz	45.62	psi					Tested
G"@5.95 Hz	45.55	psi					Tested
G"@6.50 Hz	45.42	psi					Tested
G*@1.00 Hz	94.09	psi					Tested
G*@1.55 Hz	92.65	psi					Tested
G*@2.10 Hz	92.21	psi					Tested
G*@2.65 Hz	91.80	psi					Tested
G*@3.20 Hz	91.35	psi					Tested
G*@3.75 Hz	90.72	psi					Tested
G*@4.30 Hz	90.08	psi					Tested
G*@4.85 Hz	89.24	psi					Tested
G*@5.40 Hz	88.43	psi					Tested
G*@5.95 Hz	87.63	psi					Tested
G*@6.50 Hz	86.91	psi					Tested
tanD@1.00 Hz	0.526	[]					Tested
tanD@1.55 Hz	0.541	[]					Tested
tanD@2.10 Hz	0.553	[]					Tested
tanD@2.65 Hz	0.564	[]					Tested
tanD@3.20 Hz	0.573	[]					Tested
tanD@3.75 Hz	0.581	[]					Tested
tanD@4.30 Hz	0.589	[]					Tested
tanD@4.85 Hz	0.597	[]					Tested
tanD@5.40 Hz	0.602	[]					Tested
tanD@5.95 Hz	0.608	[]					Tested
tanD@6.50 Hz	0.613	[]					Tested

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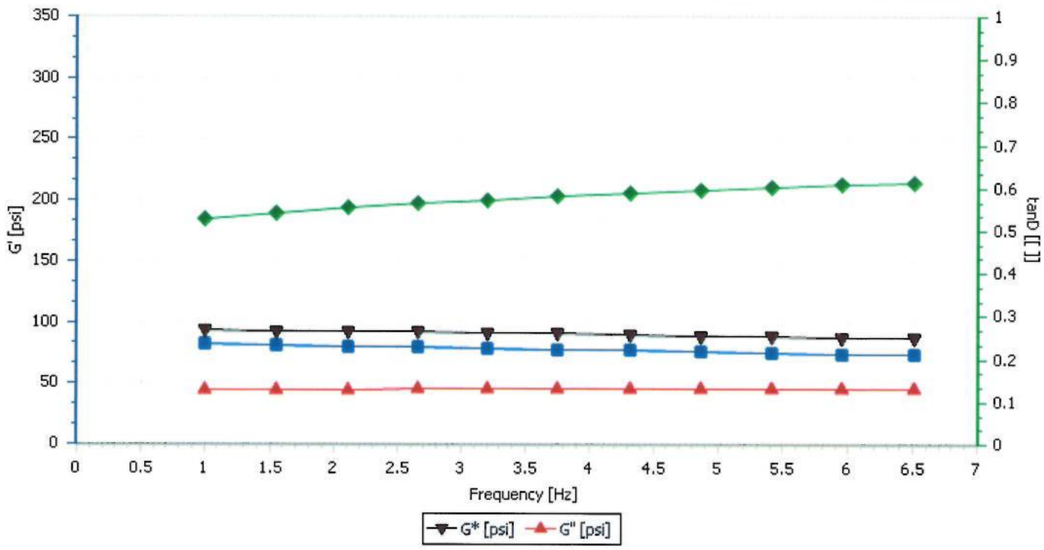
Result & Graph



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Result & Graph

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Ready Temp Range	0.5	F					Setpoint
Ready Time	30.0	s					Setpoint

Compound: XL-10216-E-2 **Order:** 1

Test: SACO --- 1 - Cure01

Batch	Specification	Date/Time	Status
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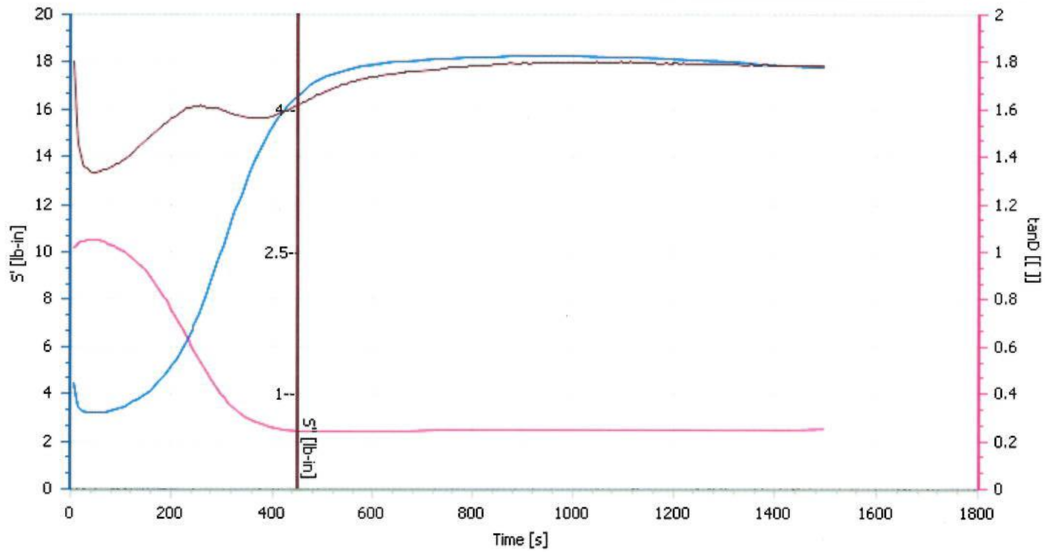
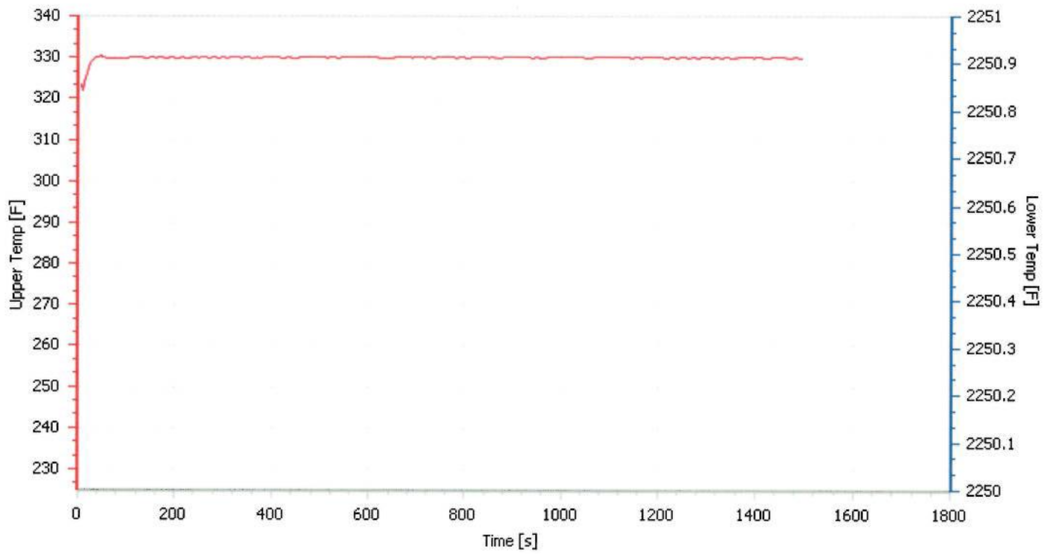
Variable	Result	Unit	LSL	LWL	UWL	USL	Status
AEOC Min Time	36000.0	s					Setpoint
AEOC tanD Limit	0.002	[ ]					Setpoint
AEOC S' Rate Limit	0.060	lb-in/s					Setpoint
AEOC Addl Time	60.0	s					Setpoint
AEOC Enabled	1.000	[ ]					Setpoint
Smoothing	9.000	[ ]					Setpoint
I-Filter	0.0	s					Setpoint
Stop at Scorch	100.000	lb-in					Setpoint
Interpolate	0.000	[ ]					Setpoint
Rate Window	11.000	[ ]					Setpoint
Time	1500.0	s					Setpoint
Temp	330.0	F					Setpoint
Freq	1.00	Hz					Setpoint
Angle	1.00	Deg					Setpoint
Min S' (ML)	3.181	lb-in					Tested
Max S' (MH)	18.270	lb-in					Tested
tc2	202.0	s					Tested
tc90	458.2	s					Tested

Result & Graph





Compound: XL-10216-E-2 **Order:** 1

Test: SACO --- 2 - Temp02

Batch	Specification	Date/Time	Status
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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Sweep Length	7.000	[ ]					Setpoint
Number of Readings	5.000	[ ]					Setpoint

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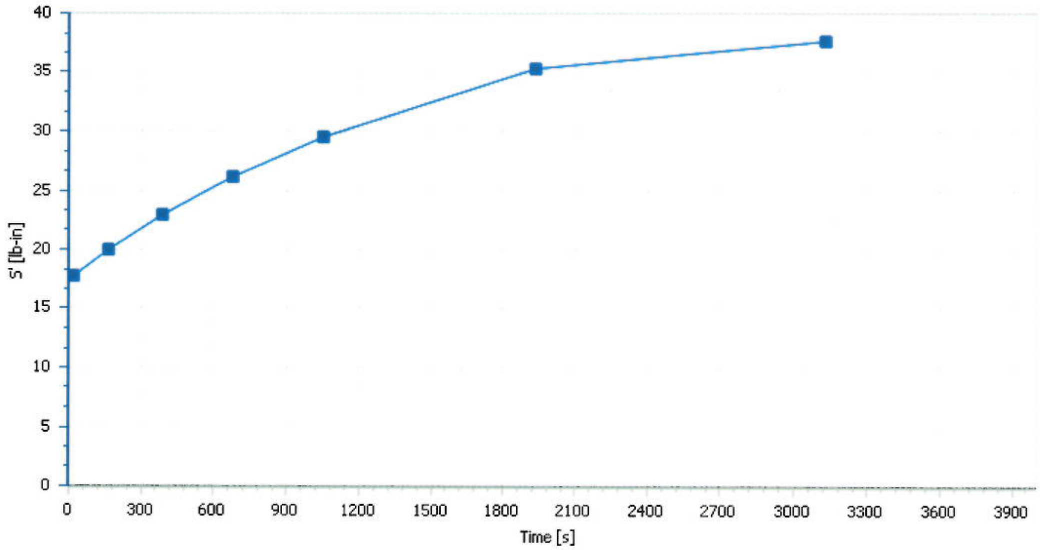
Result & Graph

Temp@330.0 F	330.0	F					Setpoint
Temp@300.0 F	300.0	F					Setpoint
Temp@250.0 F	250.0	F					Setpoint
Temp@200.0 F	200.0	F					Setpoint
Temp@150.0 F	150.0	F					Setpoint
Temp@100.0 F	100.0	F					Setpoint
Temp@86.0 F	86.0	F					Setpoint
Freq	1.00	Hz					Setpoint
Angle	1.00	Deg					Setpoint



Compound: XL-10216-E-2 **Order:** 1

Test: SACO --- 3 - Freq03

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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Sweep Length	11.000	[ ]					Setpoint
Number of Readings	1.000	[ ]					Setpoint
Temperature	86.0	F					Setpoint
Freq@1.00 Hz	1.00	Hz					Setpoint
Freq@1.55 Hz	1.55	Hz					Setpoint
Freq@2.10 Hz	2.10	Hz					Setpoint
Freq@2.65 Hz	2.65	Hz					Setpoint
Freq@3.20 Hz	3.20	Hz					Setpoint
Freq@3.75 Hz	3.75	Hz					Setpoint
Freq@4.30 Hz	4.30	Hz					Setpoint
Freq@4.85 Hz	4.85	Hz					Setpoint
Freq@5.40 Hz	5.40	Hz					Setpoint
Freq@5.95 Hz	5.95	Hz					Setpoint
Freq@6.50 Hz	6.50	Hz					Setpoint
Angle	7.20	Deg					Setpoint

G'@1.00 Hz	82.63	psi						Tested
G'@1.55 Hz	81.62	psi						Tested
G'@2.10 Hz	81.31	psi						Tested
G'@2.65 Hz	80.96	psi						Tested
G'@3.20 Hz	80.60	psi						Tested
G'@3.75 Hz	80.22	psi						Tested
G'@4.30 Hz	79.54	psi						Tested
G'@4.85 Hz	78.90	psi						Tested
G'@5.40 Hz	78.25	psi						Tested
G'@5.95 Hz	77.44	psi						Tested
G'@6.50 Hz	76.70	psi						Tested
G"@1.00 Hz	37.87	psi						Tested
G"@1.55 Hz	38.96	psi						Tested
G"@2.10 Hz	40.06	psi						Tested
G"@2.65 Hz	40.81	psi						Tested
G"@3.20 Hz	41.40	psi						Tested
G"@3.75 Hz	41.79	psi						Tested
G"@4.30 Hz	42.10	psi						Tested
G"@4.85 Hz	42.24	psi						Tested
G"@5.40 Hz	42.22	psi						Tested
G"@5.95 Hz	42.25	psi						Tested
G"@6.50 Hz	42.20	psi						Tested
G*@1.00 Hz	90.90	psi						Tested
G*@1.55 Hz	90.44	psi						Tested
G*@2.10 Hz	90.64	psi						Tested
G*@2.65 Hz	90.66	psi						Tested
G*@3.20 Hz	90.61	psi						Tested
G*@3.75 Hz	90.45	psi						Tested
G*@4.30 Hz	89.99	psi						Tested
G*@4.85 Hz	89.50	psi						Tested
G*@5.40 Hz	88.91	psi						Tested
G*@5.95 Hz	88.22	psi						Tested
G*@6.50 Hz	87.55	psi						Tested
tanD@1.00 Hz	0.458	[]						Tested
tanD@1.55 Hz	0.477	[]						Tested
tanD@2.10 Hz	0.493	[]						Tested
tanD@2.65 Hz	0.504	[]						Tested
tanD@3.20 Hz	0.514	[]						Tested
tanD@3.75 Hz	0.521	[]						Tested
tanD@4.30 Hz	0.529	[]						Tested
tanD@4.85 Hz	0.535	[]						Tested
tanD@5.40 Hz	0.540	[]						Tested
tanD@5.95 Hz	0.546	[]						Tested
tanD@6.50 Hz	0.550	[]						Tested

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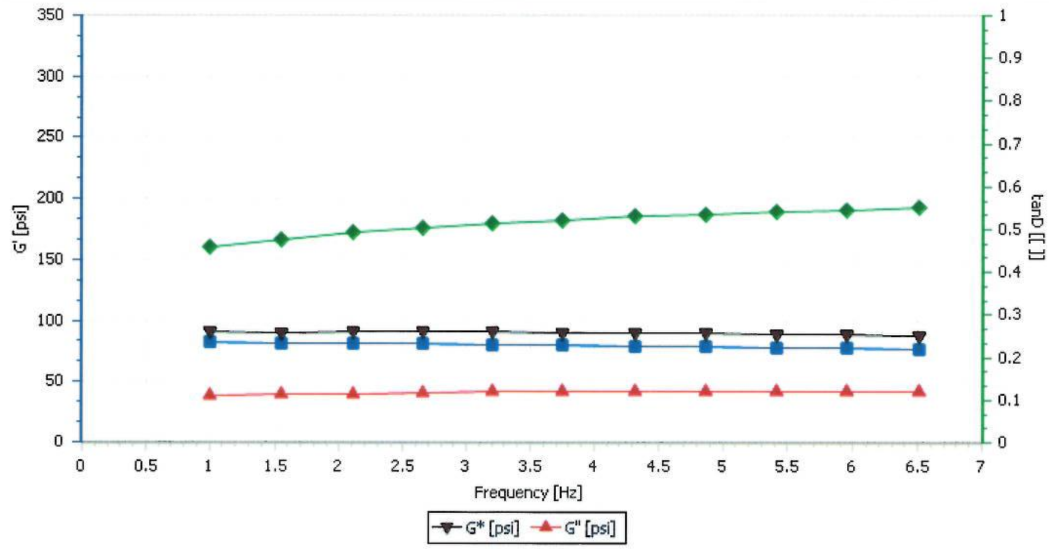
Result & Graph

Page 5 of 5



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Result & Graph

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Batch = 245283A-001 Test = SACO

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Sample Preheat Time	0.0	s					Setpoint
Ready Temp Range	0.5	F					Setpoint
Ready Time	30.0	s					Setpoint

Compound: XL-10216-E-3 **Order:** 1

Test: SACO --- 1 - Cure01

Batch	Specification	Date/Time	Status
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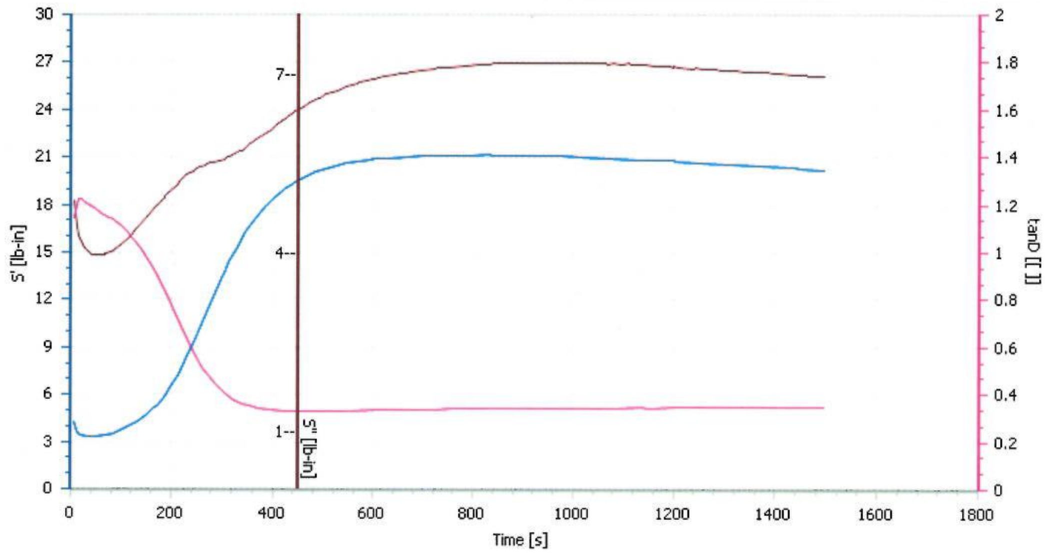
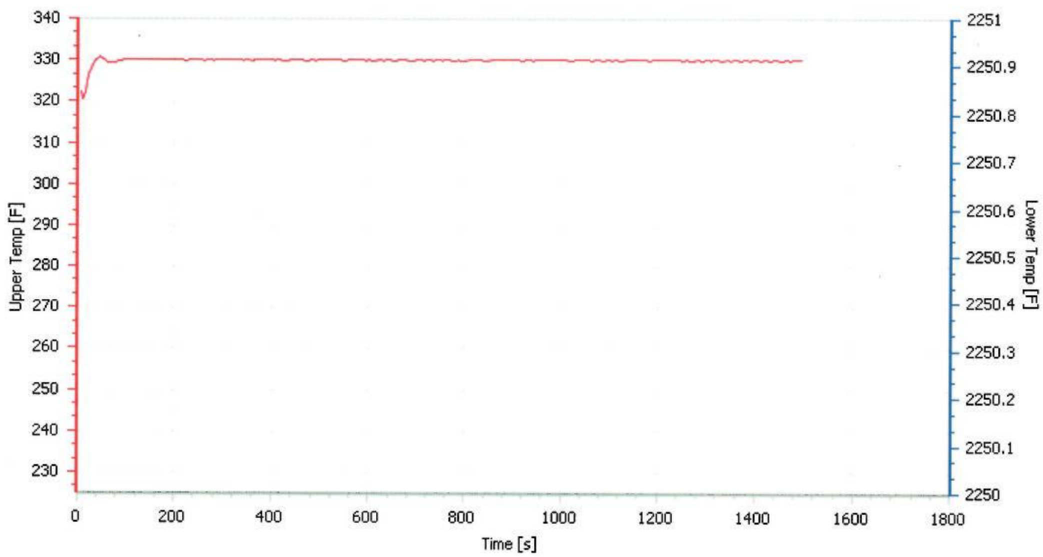
Variable	Result	Unit	LSL	LWL	UWL	USL	Status
AEOC Min Time	36000.0	s					Setpoint
AEOC tanD Limit	0.002	[ ]					Setpoint
AEOC S' Rate Limit	0.060	lb-in/s					Setpoint
AEOC Addl Time	60.0	s					Setpoint
AEOC Enabled	1.000	[ ]					Setpoint
Smoothing	9.000	[ ]					Setpoint
I-Filter	0.0	s					Setpoint
Stop at Scorch	100.000	lb-in					Setpoint
Interpolate	0.000	[ ]					Setpoint
Rate Window	11.000	[ ]					Setpoint
Time	1500.0	s					Setpoint
Temp	330.0	F					Setpoint
Freq	1.00	Hz					Setpoint
Angle	1.00	Deg					Setpoint
Min S' (ML)	3.322	lb-in					Tested
Max S' (MH)	21.159	lb-in					Tested
tc2	171.2	s					Tested
tc90	438.0	s					Tested

Result & Graph





Compound: XL-10216-E-3 **Order:** 1

Test: SACO --- 2 - Temp02

Batch	Specification	Date/Time	Status
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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Sweep Length	7.000	[ ]					Setpoint
Number of Readings	5.000	[ ]					Setpoint

Temp@330.0 F	330.0	F					Setpoint
Temp@300.0 F	300.0	F					Setpoint
Temp@250.0 F	250.0	F					Setpoint
Temp@200.0 F	200.0	F					Setpoint
Temp@150.0 F	150.0	F					Setpoint
Temp@100.0 F	100.0	F					Setpoint
Temp@86.0 F	86.0	F					Setpoint
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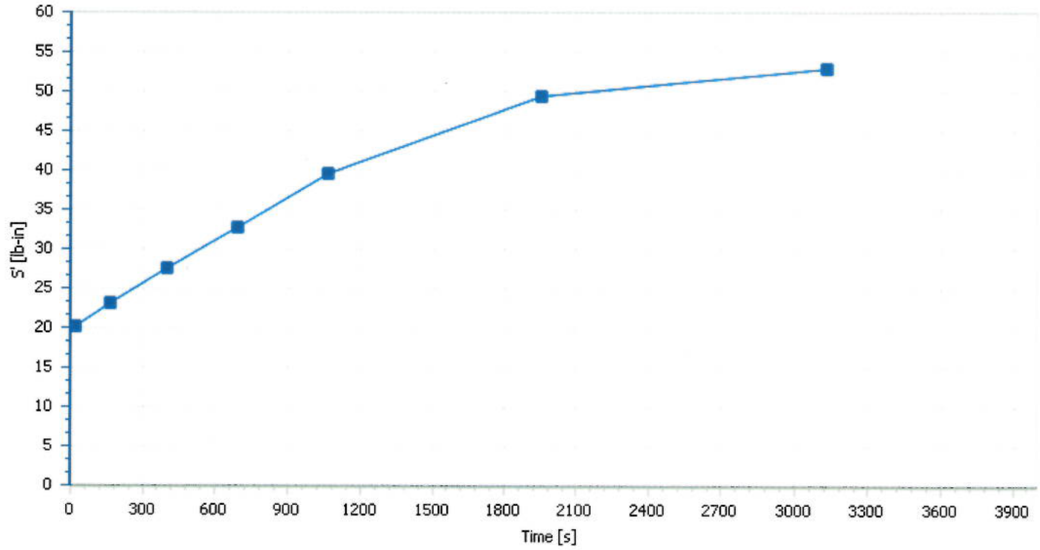
Angle	1.00	Deg					Setpoint



Compound: XL-10216-E-3 **Order:** 1

Test: SACO --- 3 - Freq03

Batch	Specification	Date/Time	Status
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Variable	Result	Unit	LSL	LWL	UWL	USL	Status
Sweep Length	11.000	[ ]					Setpoint
Number of Readings	1.000	[ ]					Setpoint
Temperature	86.0	F					Setpoint
Freq@1.00 Hz	1.00	Hz					Setpoint
Freq@1.55 Hz	1.55	Hz					Setpoint
Freq@2.10 Hz	2.10	Hz					Setpoint
Freq@2.65 Hz	2.65	Hz					Setpoint
Freq@3.20 Hz	3.20	Hz					Setpoint
Freq@3.75 Hz	3.75	Hz					Setpoint
Freq@4.30 Hz	4.30	Hz					Setpoint
Freq@4.85 Hz	4.85	Hz					Setpoint
Freq@5.40 Hz	5.40	Hz					Setpoint
Freq@5.95 Hz	5.95	Hz					Setpoint
Freq@6.50 Hz	6.50	Hz					Setpoint
Angle	7.20	Deg					Setpoint

Result & Graph

G'@1.00 Hz	106.72	psi						Tested
G'@1.55 Hz	104.04	psi						Tested
G'@2.10 Hz	102.91	psi						Tested
G'@2.65 Hz	102.33	psi						Tested
G'@3.20 Hz	101.85	psi						Tested
G'@3.75 Hz	101.55	psi						Tested
G'@4.30 Hz	101.13	psi						Tested
G'@4.85 Hz	100.94	psi						Tested
G'@5.40 Hz	100.80	psi						Tested
G'@5.95 Hz	100.45	psi						Tested
G'@6.50 Hz	100.29	psi						Tested
G"@1.00 Hz	63.14	psi						Tested
G"@1.55 Hz	64.34	psi						Tested
G"@2.10 Hz	65.81	psi						Tested
G"@2.65 Hz	66.82	psi						Tested
G"@3.20 Hz	67.53	psi						Tested
G"@3.75 Hz	68.01	psi						Tested
G"@4.30 Hz	68.16	psi						Tested
G"@4.85 Hz	68.27	psi						Tested
G"@5.40 Hz	68.07	psi						Tested
G"@5.95 Hz	67.56	psi						Tested
G"@6.50 Hz	66.91	psi						Tested
G*@1.00 Hz	124.00	psi						Tested
G*@1.55 Hz	122.33	psi						Tested
G*@2.10 Hz	122.15	psi						Tested
G*@2.65 Hz	122.21	psi						Tested
G*@3.20 Hz	122.21	psi						Tested
G*@3.75 Hz	122.22	psi						Tested
G*@4.30 Hz	121.96	psi						Tested
G*@4.85 Hz	121.86	psi						Tested
G*@5.40 Hz	121.63	psi						Tested
G*@5.95 Hz	121.05	psi						Tested
G*@6.50 Hz	120.56	psi						Tested
tanD@1.00 Hz	0.592	[]						Tested
tanD@1.55 Hz	0.618	[]						Tested
tanD@2.10 Hz	0.639	[]						Tested
tanD@2.65 Hz	0.653	[]						Tested
tanD@3.20 Hz	0.663	[]						Tested
tanD@3.75 Hz	0.670	[]						Tested
tanD@4.30 Hz	0.674	[]						Tested
tanD@4.85 Hz	0.676	[]						Tested
tanD@5.40 Hz	0.675	[]						Tested
tanD@5.95 Hz	0.673	[]						Tested
tanD@6.50 Hz	0.667	[]						Tested

RD Abbott

ALPHATECHNOLOGIES

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Result & Graph

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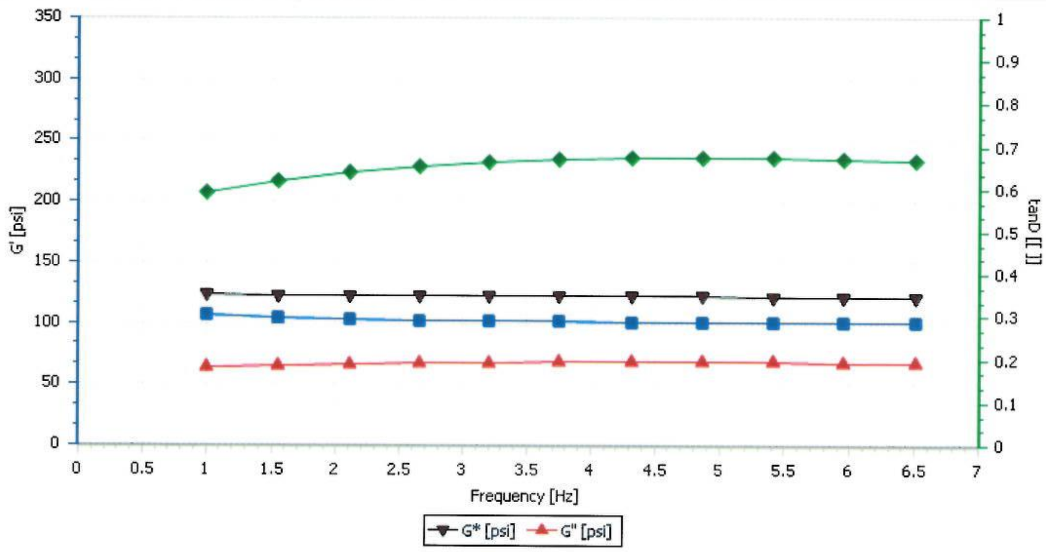

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Appendix B. Manufacturer Data Sheets

This appendix appears in its original form, without editorial change.

Mouldlife Material innovation PRO CAST RANGE

PRO FLEX 30

30K

DESCRIPTION:

Pro Flex 30 Liquid Rubber is a flexible 30 shore A, fast-curing rubber, which has been developed specifically for prototyping and model making applications. It is excellent for casting decorative objects, production parts, tools, models, patterns, duplicate masters and more. With the addition of Poly Colour Dyes, **Pro Flex 30** can be used to cast parts of any colour.

PRODUCT HIGHLIGHTS:

- **Very easy to use**
- **Quick de-mould time**
- **Good tear strength**
- **Easley pigment-able**
- **Can be vacuum cast or hand poured**

PHYSICAL PROPERTIES:

Property		Typical Value	Units
Colour	Part A	Clear Yellow	-
	Part B	Clear Yellow/Amber	-
Mix Ratio	By Weight	100A:94B	-
	(By Volume)	1A:1B	-
Specific Gravity	Mixed	1.04	-
Mix Viscosity		1300	cP
Pot Life	(100g @25oC)	15	Minutes
De-mould time	(100g @25oC)	2-3	Hours
Linear Shrinkage		0.0004	
Tensile Strength		675(4.20)	psi (MPa)
Elastic Modulus		N/A	psi (MPa)
Shore Hardness		A30	
Die C Tear Strength		484 (85)	pli (kN/m)
Elongation		950	%

Key Data

Mix Ratio
100 Part A
to
94 Part B

Gel Time
(100g @ 25°C)
15Min

De-mould Time
(100g @ 25°C)
2-3 Hours

Hardness
(Shore A)
30

Colour
Translucent Amber

Mouldlife, Tollgate Workshop, Bury Road, Kentford, Suffolk CB8 7PY
t. +44(0) 1638 750679 f. +44(0) 1638 751779

MOLD PREPARATION:

Pro Flex 30 reproduce minute details from moulds or patterns, but may stick or foam when poured on improperly prepared surfaces. To avoid damaging a valuable mould, perform a trial casting on a similar surface. Polyethylene and platinum silicone rubber (i.e., Platsil®) moulds do not require release agents. Latex, polyurethane rubber or metal moulds must be dry and coated with a suitable release agent, such as Spray Wax or Release Extra

MIXING: Prior to mixing, be sure that all moulds, equipment and Pro Flex liquids are ready at room temperature (i.e., >23°C).

Shake or stir Parts A and B if directed by product label. Over time, sediment may accumulate on the container bottom of **Pro Flex 30**

Part B. Normally, gentle mixing is all that is required to disperse the sediment. Use metal or plastic mixing vessels and spatulas to avoid introducing moisture (i.e., with paper or wood tools). Measure or weigh Parts A and B into a mixing container, such as a polyethylene pail. Mix immediately, thoroughly scraping sides and bottom for one minute. Pour mix into cavity as quickly as possible. Once the containers of Parts A and B are opened, they should be used or resealed tightly since atmospheric moisture contamination may cause foaming. Poly Purge™, a dry-gas product, can be sprayed into opened containers to displace moist air before resealing containers to extend shelf life.

SAFETY PRECAUTIONS:

Use in a well-ventilated area. Avoid contact with skin. Repeated or prolonged contact may cause an allergic reaction.

Eye protection is very important. Always use approved safety glasses or goggles when handling this product

PACKAGING:

1.94kg (1kg A + 940g B, 9.7kg (5kg A + 4.7kg B)

Suitability for Use:

The information in this data sheet is given to the best of our knowledge and belief but without warranty or liability. The user must establish the suitability of the material for the intended application by carrying out any appropriate tests. No liability will be accepted for direct or consequential losses arising from the use of this material.

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Polymed Limited
1 & 2 Clos Menter
Western Avenue Cardiff CF14 3AY
Tel 029 2052 1234 Fax 029 2052 1221

Polymed XE1031 Polyurethane Elastomer

1 INTRODUCTION

Polymed XE1031 is a polyether compound which reacts with Polymed I1000 isocyanate to form a polyurethane elastomer with good resistance to hydrolysis and good overall mechanical properties.

This material is one of a series of products ranging in hardness from 35 Shore A to 95 Shore A.

The range of polyols use a common isocyanate and the required grade of polyol should be selected to produce the required hardness.

This material complies with the following legislation:-
1. End of Life Vehicles Regulations(SI2003/2635) ELVs Regulations
2. EC Directive 2000/53/EC ELVs Directive

3. The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations (SI2012/3032) RoHS Regulations.
4. EC Directive 2011/65/EU (and amendments) RoHS Directive.

PLEASE NOTE:

These notes are for guidance only. This material is a development product and the formulation has not been proved in all circumstances. Therefore customers are strongly advised to satisfy themselves as to the suitability of the material for use in their process and for their application. No liability will be accepted for direct or consequential losses arising from using this material.

Notwithstanding the above any comments or suggestions customers may have with a view to improving the characteristics or processing of the material will be favourably received.

2 APPLICATIONS

XE1031 has been formulated for applications requiring a 35 Shore A polyurethane elastomer with good mechanical properties and good resistance to hydrolysis. These properties are obtained using moderate moulding and postcure temperatures.

Typical applications include: the manufacture of dunnage equipment; the encapsulation of sonar transducers and arrays; cable termination and sheath reinstatement; the manufacture of tough flexible moulds; general moulding of tough flexible components.

3 SPECIFICATION

Specification	Units	Min	Max
Gel Time 100g at 25C	minutes	6.00	10.00
Hardness	Shore A	30.00	40.00
Appearance	Smooth off white/pale straw hazy liquid		

This is a PROVISIONAL Test Specification as the material is UNVERIFIED

4 MIX RATIOS

Mix Ratios with I1000 Isocyanate.

By weight 5.70 : 1.00 Parts polyol to parts isocyanate

The quantity of each component should be measured to an accuracy of within 2%. Measurement by volume is usually highly inaccurate unless carried out using specialist measuring equipment and we do not recommend it. Measurement should be by weight using a balance of suitable capacity and accuracy.

5 TYPICAL PROPERTIES

Pot Life @	25C	100g	4-5 minutes
		1kg	Not measured
Gel Time @	25C	100g	7-9 minutes
		1kg	Not measured
Demould Time @	25C	100g	15-20 minutes
		1kg	Not measured

Hardness	35	Shore A
Elongation At Break	945.1	%
Tensile Strength	2.95	MN/m2
Tear Strength	7.24	N/mm

6 PREPARATION OF COMPONENTS

The polyol component should be warmed to 20-30C and thoroughly mixed before any material is removed from the container. The recommended method of mixing is by means of a mechanical drum roller.
The material should then be checked to ensure that it is free from lumps or sediment or from separated pigment before use.

The isocyanate component does not require any mixing prior to use. However it should be warmed to 20-30C and checked to ensure that it is free fom crystals lumps or cloudiness.

Both components should be prewarmed to 20-30C before using. Refer to the PREPARATION OF MOULDS section for details of any elevated mould temperatures which may be required and to the METHOD OF USE section for any postcure requirements.

7 PREPARATION OF MOULDS

Moulds should be clean and dry and unless made of silicone rubber should be sprayed lightly with a good quality release agent such as MACSIL or MACWAX. Allow sufficient time for release agents to dry fully before moulding. This is particularly important when water based release agents are used.

Moulds should be warmed to 60-80C prior to moulding. If this is not done the mould will slow the cure of the material in contact with the mould surface. This results in an increased demould time and may also cause differential shrinkage rates between the edges and the bulk of the material. In addition the material may not cure correctly.

8 METHOD OF USE

WEIGHING
The two components should be weighed on an accurate balance to an accuracy of 1-2% for each component. The polyol should be weighed into a clean dry vessel large enough to allow isocyanate to be added thoroughly mixed and degassed. Wherever possible use a vessel two to three times the volume of the mixed materials.

Weigh the isocyanate directly into the polyol. Do not weigh the isocyanate into a separate container and decant into the polyol as this will lead to insufficient isocyanate being added. This will result in poor cure and low hardness in the finished material.

MIXING
Mix the materials thoroughly either by hand using a flat blade such as a palette knife or by drill using a Jiffy type mixer. Care should be taken to avoid trapping air during mixing and to ensure that the sides and bottom of the vessel are scraped to remove polyol which should then be mixed in.

To be sure of avoiding patches of unmixed polyol in the cured material the mix may be poured into a second mixing vessel and mixed thoroughly again before degassing or pouring into the mould. However this can only be done if the gel time is sufficiently long and trials should be carried out to establish the viability of this second mixing stage.

DEGASSING
For best results and void free casting we recommend degassing immediately after mixing. Please discuss the need for degassing with your supplier. The degassing chamber must be large enough to accomodate the mixing vessel and the vacuum pump should be able to evacuate the chamber and start degassing within one minute.

Degassing should continue until the violent bubbling ceases. Further degassing removes only a tiny proportion of air and is not usually necessary. The vacuum should be released and the material poured into the mould as soon as possible to maximise the working time before the material gels.

Increasing the amount of material or the processing temperature will reduce the gel time. Trials should therefore be carried out using production quantities and conditions to ensure that there is sufficient time to degass and pour into the mould before the material gels.

POURING
The material should be poured carefully into the prepared mould to avoid entrapment of air. The material should flow slowly over the mould surface to allow reproduction of fine detail and to fill narrow channels and cavities. Pouring the material quickly may trap air causing voids and bubbles in the finished moulding.

Do not scrape the sides of the mixing container in order to use the last of the material. This frequently introduces poorly mixed material giving defects in the finished product. The amount of material weighed and mixed should include a small excess to allow for that left behind in the mixing container.

POSTCURE
This material will postcure at ambient temperature. However to obtain maximum physical properties and especially where sections below 5mm are moulded the material should be postcured at 70-80C for 1-2 hours.

9 HANDLING & STORAGE

Refer to the section HEALTH AND SAFETY below and also to the relevant Safety Data Sheets for details regarding the safe handling of this material.

Good housekeeping is important when using this material. Spillages and drips should be cleaned up immediately and the drums wiped clean after use. Isocyanate spillages are especially hazardous and the procedures given in the Safety Data Sheet should be followed as soon as a spillage occurs.

Both components are sensitive to atmospheric moisture and should be handled in such a way as to minimise exposure to the atmosphere. The containers should not be left open and must be resealed as soon as possible after use. Purging the airspace above the material with dry nitrogen prior to resealing the container is recommended.

The polyol component should be stored in the original container and in a dry environment at a MINIMUM of 15C. Note however that storage at temperatures below 20C may result in some solidification of the material. If this occurs the material should be raised to the processing temperature and mixed well before use.

The isocyanate component should be stored in tightly sealed containers in a dry environment at a temperature of 25 - 35C.
Storage below the recommended minimum temperature may result in freezing of the isocyanate. Contact Polymed for advice on re-melting. Avoid contact with moisture.

The polyol has a shelf life of 12 months from the original date of manufacture when stored as described above in the original unopened container. The expiry date is shown on the product label.

The isocyanate has a shelf life of 6 months from the original date of manufacture when stored as described above in the original unopened container. The expiry date is shown on the product label.

10 HEALTH & SAFETY

The Safety Data Sheet provides details of the Health and Safety aspects of this product. This should be read carefully before the containers are opened and before storage or use. Please contact us immediately if you are not in possession of a Safety Data Sheet for this product.

The polyol component is not classified as hazardous under current classification legislation. However gloves goggles and overalls should be worn to minimise unnecessary contact with the material. In addition the polyol should not be swallowed. Refer to the Safety Data Sheet for details. If in doubt please contact your supplier.

Isocyanates are classified as hazardous by inhalation and contact with the skin. They are also sensitising. Adequate ventilation must be provided wherever isocyanates are handled and used. Refer to the Safety Data Sheet for details. If in doubt please contact your supplier.

11 ADDITIONAL INFORMATION

This product is available in 5kg 25kg and 250kg packs. Other pack sizes are available including 1kg Pre-Weighed Kits.

12 SUITABILITY FOR USE

Information is given to the best of our knowledge and belief but without warranty or liability. Materials must be tested for suitability of application by the user. Finished products produced from any batch of our materials must be subjected to comprehensive standards of quality control by the user.

BJB ENTERPRISES

SHORE A POLYURETHANES

"Dedicated to QUALITY, SERVICE, SAFETY, and INNOVATION"

F-130 A/B

30 SHORE A POLYURETHANE ELASTOMER

RoHS

BJB's "F-1 Series", with its 3 to 10 minutes of work time, addresses the need for shorter processing times and higher part production. These 5-95 Shore A products exhibit excellent physical properties and easily process at room temperature. You'll also find the easy mix ratio to be extremely convenient and cartridge dispense friendly. For longer work times consider our M Series or L Series of elastomers.

- RoHS/REACH Compliant
- Special Effects & Props
- Popular for Parts & Molds
- Over Molding
- High Tensile & Tear Strength
- Easy to Pigment

PHYSICAL PROPERTIES	TEST METHOD	7 DAY AMBIENT CURE	21 DAY AMBIENT CURE	ELEVATED TEMPERATURE CURE*
Hardness, Shore A	ASTM D2240-04e1	30 ± 5	30 ± 5	30 ± 5
Density (g/cc)	ASTM D792-00	1.029	1.029	1.029
Cubic Inches per Pound	N/A	26.98	26.98	26.98
Color/Appearance	Visual	Translucent Amber	Translucent Amber	Translucent Amber
Tensile Strength (psi)	ASTM D412-98a(2002)e1	810	795	935
Tensile Modulus (psi)	ASTM D412-98a(2002)e1	165	145	210
Elongation (%)	ASTM D412-98a(2002)e1	970	1,170	1,230
Tear Strength (pli)	ASTM D624-00e1	80	80	92
Shrinkage (in/in) linear	ASTM D2566 @ 1" depth	0.0030†	TBD	TBD
Dielectric Constant, 1 MHz	ASTM D150-87	5.769	5.769	5.769
Dissipation Factor, 1 MHz	ASTM D150-87	0.058	0.058	0.058

***Note:** Reported physical properties are based on test specimens cured 1-3 hours at room temperature then 16 hours at 160°F (71°C).
†Shrink test specimens are cured for 24 hours at room temperature and then 16 hours at 160°F (71°C).

HANDLING PROPERTIES	Part A	Part B
Mix Ratio by weight	100	100
Mix Ratio by volume (cartridge dispense friendly)	100	100
Specific Gravity @ 77°F (25°C)	1.030	1.026
Color	Pale Yellow	Amber
Viscosity (cps) @ 77°F (25°C) Brookfield	780	1,075
Mixed Viscosity (cps) @77°F (25°C) Brookfield	1,500	
Work Time, 100g mass @ 77°F (25°C)	8 – 9 minutes	
Gel Time	12 – 13 minutes	
Demold Time @ 77°F (25°C)	2 – 3 hours	

Properties above are typical and not for specifications.

Quality Management System Registered to ISO 9001:2008

For more information call BJB Enterprises, Inc. (714) 734-8450 Fax (714) 734-8929
www.bjbenterprises.com

Date: 08/21/2014

CURE SCHEDULE/HEAT CURING:
Most of the physical properties can be achieved in 5-7 days at 77°F (25°C). You may use your own post-cure schedule but the physical properties may vary from BJB's cure schedule of 1-3 hours at 77°F (25°C) followed by 16 hours at 160°F (71°C). Do not exceed curing temperature of 200°F (93°C).

ACCESSORIES:
BJB offers silicone RTV mold making materials along with a wide range of accessory items. These include de-airing agents, pigments, mold releases, and Jiffy® Mixers. Visit BJB's website at www.bjbenterprises.com or consult a BJB representative for more information.

COLOR VARIATIONS:
The color of the base material may vary slightly from batch to batch due to raw ingredients. Color variations will not affect the cured physical properties. Exposing the material to various conditions such as heat and UV light will alter the color of the cured system. Color stability is not guaranteed. This product can be pigmented, but you may see more color shift when using lighter pigments.

UV RESISTANCE:
This product is not classified as UV resistant. BJB offers an additive called UV-100, a UV inhibitor and anti-oxidant blend that will help slow down the effects of UV degradation and color change. The level of effectiveness varies from product to product.

STORAGE:
Store at ambient temperatures, 65-80°F (18-27°C). Unopened containers will have a shelf life of 6 months from date of shipment when properly stored at recommended temperatures. Purge opened containers with dry nitrogen before re-sealing.

PACKAGING	Part A	Part B	Cubic Inches Per Kit
Gallon Kits	8 lbs.	8 lbs.	431.7
5-Gallon Kits	40 lbs.	40 lbs.	2,158.4
55-Gallon Drum Kits	440 lbs.	440 lbs.	23,742.4

SAFETY PRECAUTIONS:
Use in a well-ventilated area. Avoid contact with skin using protective gloves and protective clothing. Repeat or prolonged contact on the skin may cause an allergic reaction. Eye protection is extremely important. Always use approved safety glasses or goggles when handling this product.

IF CONTACT OCCURS:

Skin: Immediately wash with soap and water. Remove contaminated clothing and launder before reuse. It is *not* recommended to remove resin from skin with solvents. Solvents only increase contact and dry skin. Seek qualified medical attention if allergic reactions occur.

Eyes: Immediately flush with water for at least 15 minutes. Call a physician.

Ingestion: If swallowed, call a physician immediately. Remove stomach contents by gastric suction or induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person.

Refer to the Material Safety Data Sheet before using this product.

Handling Guide

F-130 Part A SDS

F-130 Part B SDS

BJB ENTERPRISES

SHORE D SEMI-RIGID URETHANES

"Dedicated to QUALITY, SERVICE, SAFETY, and INNOVATION"

FD-70 A/B

70 SHORE D POLYURETHANE ELASTOMER

RoHS

BJB's FD Series of semi rigid, fast reacting urethane elastomers exhibit great flexibility and excellent durability. These tough, abrasion resistant systems easily process at room temperature and range in hardness from 45 Shore D to 70 Shore D. The FD Series offers superior performance in many applications such as rollers, foundry tooling and high impact semi rigid parts. For longer work times consider BJB's MD Series of elastomers.

- RoHS/REACH compliant
- High tear and tensile strength
- Production oriented
- Exceptional abrasion resistance
- Used for molds and cast parts
- Easy processing

PHYSICAL PROPERTIES	TEST METHOD	7 DAY AMBIENT CURE	21 DAY AMBIENT CURE	ELEVATED TEMPERATURE CURE*
Hardness, Shore D	ASTM D2240-04e1	70 ± 5	70 ± 5	70 ± 5
Density (g/cc)	ASTM D792-00	1.17	1.17	1.17
Cubic Inches per Pound	N/A	24.55	24.55	24.55
Color/Appearance	Visual	Clear Amber	Clear Amber	Clear Amber
Tensile Strength (psi)	ASTM D412-98a(2002)e1	4,631	5,176	6,205
Tensile Modulus (psi)	ASTM D412-98a(2002)e1	121,700	140,054	86,375
Elongation (%)	ASTM D412-98a(2002)e1	310	325	357
Tear Strength (pli)	ASTM D624-00e1	748	759	715
Flexural Strength (psi)	ASTM D790-03	3,111	2,766	3,148
Flexural Modulus (psi)	ASTM D790-03	76,243	69,653	76,460
Shrinkage (in/in) linear	ASTM D2566 @ 1" depth	0.0076†	TBD	TBD
Izod Impact (ft-lb/in) notched	ASTM D256-05	>16.5	>16.5	>16.5
Heat Deflection Temperature (66 psi)	ASTM D648-04	117°F (47°C)	122°F (50°C)	161°F (72°C)
Dielectric Constant, 1 MHz	ASTM D150-87	4.1	4.1	4.1
Dissipation Factor, 1 MHz	ASTM D150-87	0.0383	0.0383	0.0383

***Note:** Reported physical properties are based on test specimens cured 1-3 hours at room temperature then 16 hours at 160°F (71°C).
†Shrink test specimens are cured for 24 hours at room temperature and then 16 hours at 160°F (71°C).

HANDLING PROPERTIES	Part A	Part B
Mix Ratio (by weight)	100	40
Mix Ratio (by volume)	100	38
Specific Gravity @ 77°F (25°C)	1.111	1.175
Color	Pale Yellow	Amber
Viscosity (cps) @77°F (25°C) Brookfield	3,460	385
Mixed Viscosity (cps) @77°F (25°C) Brookfield	2,150	
Work Time, 100g mass @ 77°F (25°C)	7 - 8 minutes	
Gel Time	9 - 10 minutes	
Demold Time @ 77°F (25°C)	1 - 2 hours	

Properties above are typical and not for specifications.

Quality Management System Registered to ISO 9001:2008

CURE SCHEDULE/HEAT CURING:

Most of the physical properties can be achieved in 5-7 days at 77°F (25°C). You may use your own post-cure schedule but the physical properties may vary from BJB's cure schedule of 1-3 hours at 77°F (25°C) followed by 16 hours at 160°F (71°C). Do not exceed curing temperature of 200°F (93°C).

PREPARATION AND RELEASING:

When FD-70 A/B is used to produce molds or parts from plaster, wood or other porous substrates, we would first recommend that they be sealed. Release agents may then be applied over the sealed surface.

NOTE:

Prolonged direct exposure to sunlight can affect the surface of this product. Cover molds or other products when storing outdoors.

ACCESSORIES:

BJB offers silicone RTV mold making materials along with a wide range of accessory items. These include de-airing agents, pigments, mold releases, and Jiffy® Mixers. Visit BJB's website at www.bjbenterprises.com or consult a BJB representative for more information.

STORAGE:

Store ambient temperatures, 65-80°F (18-27°C). Unopened containers will have a shelf life of 6 months from date of shipment when properly stored at recommended temperatures. Purge opened containers with dry nitrogen before re-sealing.

PACKAGING	Part A	Part B	Cubic Inches Per Kit
Gallon Kits	8 lbs.	3.2 lbs.	274.96
5-Gallon Kits	40 lbs.	16 lbs.	1,374.8
55-Gallon Drum Kits	440 lbs.	176 lbs.	15,122.8

SAFETY PRECAUTIONS:

Use in a well-ventilated area. Avoid contact with skin using protective gloves and protective clothing. Repeated or prolonged contact on the skin may cause an allergic reaction. Eye protection is extremely important. Always use approved safety glasses or goggles when handling this product.

IF CONTACT OCCURS:

Skin: Immediately wash with soap and water. Remove contaminated clothing and launder before reuse. It is *not* recommended to remove resin from skin with solvents. Solvents only increase contact and dry skin. Seek qualified medical attention if allergic reactions occur.

Eyes: Immediately flush with water for at least 15 minutes. Call a physician.

Ingestion: If swallowed, call a physician immediately. Remove stomach contents by gastric suction or induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person.

Refer to the Material Safety Data Sheet before using this product.

Handling Guide

FD-70 Part A SDS

FD-70 Part B SDS

Quality Management
System Registered
to ISO 9001:2008

Date: 07/11/2014

For more information call BJB Enterprises, Inc. (714) 734-8450 Fax (714) 734-8929 www.bjbenterprises.com

HUNTSMAN

Enriching lives through innovation

Advanced Materials

RenCast 6425 A / RenCast 5425 B

FOR THE PRODUCTION OF CASTINGS AND IN APPLICATIONS REQUIRING HIGH LEVELS OF TOUGHNESS AND DURABILITY

KEY PROPERTIES

- Withstand moisture well, thus also suitable for thin layers
- High tear strength and elongation
- High abrasion resistance

APPLICATIONS

- Foundry Patterns
- Core boxes
- Abrasion and impact-resistant parts
- Percussion tools
- Impact protection
- Conveyor rollers
- Machinery Parts
- Assembly jigs

PRODUCT DATA

Property	Unit	RenCast 6425 A	RenCast 5425 B
Appearance Colour	visual	Liquid brown	Liquid pale yellow
Viscosity at 25°C	mPas	1800 - 3200	250 - 550
Density at 23°C	g/cm^3	1.11	1.13

PROCESSING

Mix ratio	Parts by weight
RenCast 6425 A	100
RenCast 5425 B	24

Mix the two components thoroughly in the ratio indicated.
Evacuated materiel will improve properties. Post-curing will improve final properties.

PROPERTIES

Resin/Hardener mix:	Volume	Unit	RenCast 6425 A RenCast 5425 B
Appearance			brown
Mix viscosity 25°C		mPa s	1900 - 2100
Pot life at 25°C	1000 ml	min	15 - 20
Max. layer thickness		mm	10 - 12
Demoulding time* at 23°C		hours	20 - 24

Density	ISO 1183	g/cm^3	1.20
Hardness	ISO 868	Shore D	60 - 65
Tear propagation resistance	DIN 53356	kN/m	28 - 30
Tensile strength	ISO 527-2	MPas	30 - 35
Elongation at break	ISO 527-2	%	130 - 170
Linear shrinkage**		mm/m	1.8
Abrasion***	Taber	mg	1600

* For parts with uniform face-cast layers of 8-12 mm, allow 20 - 24 hours of final cure time prior to demoulding. To avoid creep, always store parts on a flat surface without stressing. Follow recommendation for curing before subjecting the parts to loading.
**Shrinkage measurement using test specimen size 500 x 50 x 10mm
*** Lost weight by 4000 cycles, 60 rpm, 1kg load, S 60 sandpaper strips

STORAGE

The resin and hardeners described in this instruction sheet have the shelf lives shown provided they are stored at 6 - 28°C in a dry place and sealed containers, preferably those in which they are supplied.

WORKING CONDITIONS

The product should be used when in the temperature range 18-25°C

PACKAGING

System	RenCast 6425 A	RenCast 5425 B
Quantity and Weight	4 x 5 kg	4.8 kg
Quantity and Weight		

HUNTSMAN

Enriching lives through innovation

HANDLING PRECAUTIONS

Caution

Our products are generally quite harmless to handle provided that certain precautions normally taken when handling chemicals are observed. The uncured materials must not, for instance, be allowed to come into contact with foodstuffs or food utensils, and measures should be taken to prevent the uncured materials from coming in contact with the skin, since people with particularly sensitive skin may be affected. The wearing of impervious rubber or plastic gloves will normally be necessary; likewise the use of eye protection. The skin should be thoroughly cleansed at the end of each working period by washing with soap and warm water. The use of solvents is to be avoided. Disposable paper - not cloth towels - should be used to dry the skin. Adequate ventilation of the working area is recommended. These precautions are described in greater detail in the Material Safety Data sheets for the individual products and should be referred to for fuller information

Main Office :
Huntsman Advanced Materials (Switzerland) GmbH
Klybeckstrasse 200
CH-4057 BASEL
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TC-892 A/B

RIGID 80 SHORE D URETHANE CASTING SYSTEM

RoHS

PRODUCT DESCRIPTION:

TC-892 A/B incorporates a non-mercury based catalyst system that produces a tough 80 shore D material with a 20-minute work time. This system can be used to hand pour large electronic housing, models of all kinds, and point of purchase items. This system is also available in a 5-minute work time (TC-890), and a 12-minute work time (TC-891).

PRODUCT HIGHLIGHTS:

- ✓ Non-mercury
- ✓ RoHS compliant
- ✓ Convenient mixing ratio: 1 to 1 parts by weight
- ✓ Long working time: 20 minutes
- ✓ Low viscosity, flows easily
- ✓ Demold time: 5-6 hours at ambient temperature in a silicone rubber mold (1/8" thick section)

PHYSICAL PROPERTIES:

Hardness, Shore D ASTM D2240	80 ± 2
Density, (g/cc) ASTM D792	1.14
Cubic Inches per Pound	25
Color/Appearance	White/Opaque
Tensile Strength, (psi) ASTM D638	7,600
Tensile Modulus, (psi) ASTM D-638	2.4×10^5
Elongation, (%) ASTM D638	10
Flexural Strength, (psi) ASTM D790	10,000
Flexural Modulus, (psi) ASTM D790	2.5×10^5
Shrinkage, (in/in) linear 12" x ½" x ½"	0.005
Izod Impact, notched (ft-lb/in) ASTM D256	0.7
Heat Deflection Temperature, ASTM D648:	
66 psi	195°F (91°C)
264 psi	177°F (81°C)

Note: Reported physical properties are based on test specimens cured at an elevated temperature, 180°F (82°C).

HANDLING PROPERTIES:

Mix Ratio (by weight):	
Part A	100 parts by weight
Part B	100 parts by weight
Mix Ratio (by volume):	
Part A	88 parts by volume
Part B	100 parts by volume
Specific Gravity @ 77°F (25°C):	
Part A	1.18
Part B	1.04

HANDLING PROPERTIES (continued):

Viscosity, (cps) @ 77°F (25°C) Brookfield:	
Part A	325
Part B	830
Mixed	725
Color:	
Part A	Yellow
Part B	White
Work Time, 100g mass @ 77°F (25°C)	20 minutes
Gel Time	25 minutes
Demold Time @ 77°F (25°C)	5-6 hours

CURE SCHEDULE/HEAT CURING:

Most of the physical properties can be achieved in 5-7 days at ambient temperature, 77°F (25°C). In order to achieve maximum physical properties, a post cure with heat is required. BJB recommends 24 hours at ambient temperature, 77°F (25°C), followed by 16 hours at 150-180°F (66-82°C). Support of the part may be required to prevent part deformation during heat cure.

NOTE:

It is advisable whenever possible to evacuate entrapped air prior to casting this system. The use of a de-airing agent can speed up the process. BJB's AF-7 antifoam works best as the de-airing agent. In conjunction with these support products BJB offers pigments in a wide variety of colors and stainless steel mixers called "Jiffy Mixers." If help is required call BJB for assistance. For additional information on the use of this product, refer to BJB Guidelines for Handling Polyurethane Products.

STORAGE:

Store in a cool dry place. Unopened containers will have a shelf life of 6 months from date of shipment when properly stored at room temperatures. Purge opened containers with dry nitrogen before re-sealing.

PACKAGING:

Gallon Kits	8 lbs. A, 8 lbs. B
5-Gallon Kits	40 lbs. A, 40 lbs. B
55-Gallon Drum Kits	400 lbs. A, 400 lbs. B

SAFETY PRECAUTIONS:

Use in a well-ventilated area. Avoid contact with skin using protective gloves and protective clothing. Repeated or prolonged contact on the skin may cause an allergic reaction. Eye protection is extremely important. Always use approved safety glasses or goggles when handling this product.

IF CONTACT OCCURS:

Skin: Immediately wash with soap and water. Remove contaminated clothing and launder before reuse. It is *not* recommended to remove resin from skin with solvents. Solvents only increase contact and dry skin. Seek qualified medical attention if allergic reactions occur.

Eyes: Immediately flush with water for at least 15 minutes. Call a physician.

Ingestion: If swallowed, call a physician immediately. Remove stomach contents by gastric suction or induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person.

Refer to the Material Safety Data Sheet before using this product.

Acetal (POM-C and POM-H) DATA SHEET

A VERSATILE ENGINEERING PLASTIC FOR MANY APPLICATIONS

TYPICAL APPLICATIONS

Mechanical engineering, automotive, textile and foodstuff industries-
E.g. gears, meter components, valve discs, impellers, seals, bearings, sliding & spring elements, valve bodies, snap-on connections, pump components, bearing cages, clutch and gearbox parts, sorting & feeding devices.
Electrical & electronic industry-
E.g. coil bodies, insulators, relay and transformer housings.
Medical technology-
E.g. instrument handles, adapters.

PRODUCT DESCRIPTION

A high-quality general purpose engineering plastic material; the chemical name is polyoxymethylene. It's available in a range of grades and forms to suit many applications.

TECHNICAL DESCRIPTION

Smiths' range of extruded Acetal includes the following grade options –

Grade	Modification	Purpose
Acetal co-polymer (POM-C)	Colours, natural black, blue, others on application.	Component identification
Acetal co-polymer +25% glass (POM-C GF25)	Reinforced with 25% glass fibre	Increased strength and stiffness
Acetal co-polymer (ESD60 & ESD90)	Additives to provide electrical conductivity or electro-static dissipation.	To prevent uncontrolled static discharge in sensitive electronic environments or in explosive atmospheres.
Acetal co-polymer - Medical grade	Special production and testing. Colour coded for component identification.	Certified biocompatibility to USP Class VI and cytotoxicity to DIN EN ISO 10993-5
Acetal co-polymer – GLD160	Tribological modification.	Improved bearing & wear properties.
Acetal homo-polymer (POM-H)	Colours, natural and black.	Component identification

MACHINABILITY

The machinability of un-modified acetal is excellent. Good chip forming leads to fine surface finishes.
As with all plastic materials, experience has shown that extra care must be taken with larger diameters, especially in the colder months when plastic materials lose some of their toughness and so have less resistance to machining stresses. It's therefore important that these materials are not machined while in a chilled condition.
Full machining instructions may be supplied on request.

PRODUCT ATTRIBUTES	CUSTOMER BENEFITS
Range of grades available.	Correct grade selection for application is optimised.
High mechanical strength & stiffness. Able to resist very high impact loads. High surface hardness. Good chemical resistance. Natural product may be used in contact with foodstuffs (subject to appropriate limits).	Very good all-round product for diverse engineering applications.
Very good dimensional stability. Good resistance to creep. Minimal absorption of moisture.	Stability when dimensional accuracy is important.
Good sliding properties. High wear resistance.	Good wear life in many industrial bearing and gear applications.
Product sourced from long-standing manufacturer with ISO accreditation.	Consistent quality ensures uniform characteristics in machining and performance.

PRODUCT AVAILABILITY*

Extruded round bar	Natural colour made up to 500mm dia, black to 350mm. Modified grades – please call for a quotation
Extruded sheet/plate	Natural and black colours made to 200mm thk and in a range of area formats. Modified grades – please call for a quotation.
Tubular bar	Natural up to 450mm o/d.
Strip	Natural from 0.30mm thk.

* *Sizes not stocked are available on relatively short delivery time. 1, 2 or 3m lengths supplied or cut to customer requirements.*

CHEMICAL RESISTANCE

Acetal co-polymer has chemical resistance similar to nylon 66, but is slightly more prone to attack – having good resistance to many common solvents, lubricant, esters, ketones and aqueous solutions of acids and alkalis between ph5 and ph11. The co-polymer is not resistant to phenols, cresols, formic acid, concentrated mineral acids and alkalis, and strong oxidising agents including halogens.
The homo-polymer has slightly reduced resistance to alkalis and hot water compared with co-polymer.

POM-C iss3-0512

TYPICAL PROPERTIES	Natural or Black un-modified	Acetal-C +25% Glass	Acetal-C + PTFE	Acetal-C ESD60, conductive	Acetal-C ESD90, dissipative	
MECHANICAL						
Density at 20°C	1.41	1.58	1.52	1.40	1.34	g/cm³
Tensile strength @ yield	67	65	50	40	42	MPa
Elongation @ break	30	3.0	16	30	20	%
Tensile modulus of elasticity	2,800	4,500	2,500	1,900	1,800	MPa
Notched impact strength (Charpy)	6	4	4	5	5	kJ/m²
Ball indentation hardness	150	195	120	100	90	N/mm²
Hardness (Shore D)	81	85	80	-	76	Scale D

ELECTRICAL						
Volume resistivity	10^{13}	-	-	10^{3}	$10^{9} – 10^{12}$	Ohm cm
Surface resistivity	10^{13}	-	-	10^{3}	$10^{9} – 10^{11}$	Ohm
Dielectric constant, 50 Hz	3.8	-	3.7	-	-	-
Dielectric dissipation factor, 50 Hz	0.002	-	0.002	-	-	-
Dielectric strength	40	-	33	-	-	Kv/mm
Comparative tracking index (CTI) – solution A	600	-	600	-	-	-

THERMAL						
Melting temperature	165	165	165	165	165	°C
Heat deflection temperature - method A, 1.8 MPa	110	160	98	89		°C
Coefficient of thermal expansion (Ave. between 20 - 60 °C)	110	30	120	130	170	$10^{-6}.K^{-1}$
Specific thermal capacity at 100°C	1.50	-	-	-	-	kJ/(kg · K)
Thermal conductivity at 20°C	0.31	-	-	0.31		W/(m · K)
Service temperature – long term – short term (max)	-50 to +100 +140	-20 to +100 +140	-50 to +100 +140	-20 to +100 +140	-50 to +85 +140	°C

OTHER PHYSICAL PROPERTIES						
Moisture absorption Saturation in air @ 23°C and 50% RH	0.20	0.15	0.65	0.25	0.20	%
Friction coefficient – min. dynamic	0.42	-	0.28	-	-	ISO 7148
Flammability according to UL94 (3mm/6mm thick)			HB / HB			-

CHEMICAL RESISTANCE						
Acid resistance	+	+ / 0		+ / 0	+	
Alkali resistance	+	+		+	+	
Hydrocarbon resistance	+	+		+	+	
Chlorinated hydrocarbon resistance	0	0		0	0	
Aromatic resistance	+	+		+	+	
Ketone resistance	+	+		+	+	
Resistance to hot water	+	+		+	+	

Key: + yes 0 limited - no

TECHNICAL SALES ASSISTANCE

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POM-C iss3-0512

Appendix C. Tensile and Compression Properties

This appendix appears in its original form, without editorial change.

Tensile Properties: Proflex 30, Polyurethane Elastomer, Pelvis Flesh (Mouldlife, UK)							
Tensile Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	90 s^{-1}	200 s^{-1}	300 s^{-1}	
Failure Stress (MPa) ASTM D 638	1.56 ± 0.18 ASTM D 638 Type IV	2.06 ± 0.31 ASTM D 638 Type IV	2.15 ± 0.19 ASTM D 638 Type V	Failure stress and strain was not recorded due to the high ductility of the material.			4.2
Failure Strain (%) ASTM D 638	>500 *	>500*	>500*				950
* Samples stretched beyond digital camera range thus ultimate strain at break was not recorded							
Tensile Stress @ 100% Strain (MPa)	0.57	0.60	0.66	0.62	0.64	0.64	
				ASTM D 638 Type V using custom built drop tower			
Tensile Stress @ 200% Strain (MPa)	1.02	1.13	1.29	Not recorded			
Tear Strength ASTMD 624 (Die C) (N/mm)	5.3						85 This is likely a typo n the data sheet, 8.5 N/mm is more realistic for this material.
Durometer (Shore A)	29 measured						30 data sheet
Some voids were noticed in the die cut specimen cross-sections. Samples with voids were not used. High strain rate data exhibited high scatter due to the softness of the material. This material exhibits a weak strain rate dependence.							

Tensile Properties: XE 1031, Polyurethane Elastomer, Foot Flesh (Polymed LTD, UK)							
Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	30 s^{-1}	100 s^{-1}	275 s^{-1}	
Failure Stress (MPa) ASTM D 638	1.81 $\pm$ 0.15 ASTM D 638 Type IV	2.11 $\pm$ 0.30 ASTM D 638 Type IV	3.52 $\pm$ 0.49 ASTM D 638 Type V	Failure stress and strain was not recorded due to the high ductility of the material.			2.95
Failure Strain (%) ASTM D 638	200-600*	200-600*	200-600*				945
* Samples stretched beyond digital camera range thus ultimate strain at break was not recorded							
Tensile Stress @ 100% Strain (MPa)	0.633	0.716	0.838	0.963	0.946	1.02	
				ASTM D 638 Type V using custom built drop tower			
Tensile Stress @ 200% Strain (MPa)	1.05	1.19	1.38	Not recorded			
Tear Strength ASTMD 624 (Die C) (N/mm)	6.1						7.24
Durometer (Shore A)	33 measured						35 data sheet
Some voids were noticed in the die cut specimen cross-sections. Samples with voids were not used. High strain rate data exhibited high scatter due to the softness of the material. The noise is caused by the low force in the soft specimens. This material exhibits a weak strain rate dependence, but a slightly greater strain rate dependence compared to Proflex30.							

Tensile Properties: FD70, Hard Polyurethane Elastomer, Foot Plate (BJB Enterprises)							
Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	75 s^{-1}	125 s^{-1}	400 s^{-1}	
Young's Modulus (MPa)	485	525	598	551	491	450	839 ASTMD 412
Failure Stress (MPa) ASTM D 638	33.6 ASTM D 638 Type IV	29.4 ASTM D 638 Type IV	31.5 ASTM D 638 Type V	33.1	36.1	39.7	31.9 ASTMD 412
				ASTM D 638 Type V using custom built drop tower			
Failure Strain (%) ASTM D 638	258	251	264	194	199	198	300 ASTMD 412
Tensile Strength @ Yield (MPa)	18	23	26	35.2	37.5	42.5	
Failure Test (tensile test to failure using V-notch specimen (N)	1041* Highly ductile failure						
Tear Strength	Not tested						130.9 ASTMD 624
Durometer (Shore D)	68 Measured						70±5 data sheets
Some voids were noticed in the die cut specimen cross-sections. Samples with voids were not used. Yield stress increases with strain rate. Strongly strain rate dependent. E' trends decrease with strain rate unlike slower strain rates. This may be due to test instrumentation differences (i.e. drop tower vs. MTS/crosshead displacement method).							

Tensile Properties: Delrin, Rigid Thermoplastic (Acetyl Resin), Calcaneus Cap							
Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	50 s^{-1}	100 s^{-1}	200 s^{-1}	
Young's Modulus (GPa)	2.53	2.56	2.69	2.30	2.83	2.97	2.80
Failure Stress (MPa) ASTM D 638	52.8 ASTM D 638 Type IV	58.4 ASTM D 638 Type IV	64 ASTM D 638 Type V	75.7 ASTM D 638 Type V Using custom drop tower	79.5	80.7	
Failure Strain (%) ASTM D 638	64	49	36	13	11	11	30
Tensile Strength @ Yield (MPa)	61	65	67	75.6	77.6	83.0	67
Failure Test (tensile test to failure using V-notch specimen (N)	3400 Brittle Failure						
Tear Strength	Not tested						
Durometer (Shore D)	81 measured						81 data sheet
Strongly strain rate dependant.							

<table>
<tr><td colspan="8">Tensile Properties: F-130 A/B, Polyurethane Elastomer, Flesh (BJB Enterprises)</td></tr>
<tr><td>Property</td><td colspan="6">Strain Rate</td><td>Per Product/Mfg Data Sheet</td></tr>
<tr><td></td><td>0.01 s^{-1}</td><td>0.10 s^{-1}</td><td>1.0 s^{-1}</td><td>25 s^{-1}</td><td>75 s^{-1}</td><td>225 s^{-1}</td><td></td></tr>
<tr><td>Failure Stress (MPa) ASTM D 638</td><td>1.71 ± 0.13

ASTM D 638 Type IV</td><td>2.13 ± 0.07

ASTM D 638 Type IV</td><td>2.30 ± 0.06

ASTM D 638 Type V</td><td colspan="3" rowspan="2">Failure stress and strain was not recorded due to the high ductility of the material.</td><td>2.75</td></tr>
<tr><td>Failure Strain (%) ASTM D 638</td><td colspan="3">400-950 *
*Samples stretched beyond digital camera range thus ultimate strain at break was not recorded</td><td>800</td></tr>
<tr><td>Tensile Stress @ 100% Strain (MPa)</td><td>0.625</td><td>0.724</td><td>0.746</td><td>0.910</td><td>0.962</td><td>1.03</td><td></td></tr>
<tr><td colspan="4"></td><td colspan="3">ASTM D 638 Type IV
(type V specimens too soft for these tests)
used custom built drop tower</td><td></td></tr>
<tr><td>Tensile Stress @ 200% Strain (MPa)</td><td>1.03</td><td>1.19</td><td>1.27</td><td colspan="3">Not recorded</td><td></td></tr>
<tr><td>Tear Strength ASTMD 624 (Die C) (N/mm)</td><td>10.1</td><td></td><td></td><td colspan="3"></td><td>11.2</td></tr>
<tr><td>Durometer (Shore A)</td><td colspan="6">31 measured</td><td>30 data sheet</td></tr>
<tr><td colspan="8">No voids were noticed in the samples. High rate tests exhibit oscillations due to material softness that causes elastic waves to reflect within the material. Weak strain rate dependence similar to XE 1031.</td></tr>
</table>

<table>
<tr><td colspan="8">Tensile Properties: Butyl Rubber Custom Compound,
Compliant Elements in Spine and Legs (SACO Research/ RD Abbott)</td></tr>
<tr><td>Property</td><td colspan="6">Strain Rate</td><td>Per Product/Mfg Data Sheet</td></tr>
<tr><td></td><td>0.01 s^{-1}</td><td>0.10 s^{-1}</td><td>1.0 s^{-1}</td><td>50 s^{-1}</td><td>100 s^{-1}</td><td>200 s^{-1}</td><td></td></tr>
<tr><td>Failure Stress (MPa)
ASTM D 638</td><td>5.98± 0.03

ASTM D 638 Type IV</td><td>6.34± 0.1

ASTM D 638 Type IV</td><td>5.98± 0.01

ASTM D 638 Type V</td><td colspan="3" rowspan="2">Failure stress and strain was not recorded due to the high ductility of the material.</td><td>5.79</td></tr>
<tr><td>Failure Strain (%)
ASTM D 638</td><td colspan="3">350-500 *
*Samples stretched beyond digital camera range thus ultimate strain at break was not recorded</td><td>542</td></tr>
<tr><td>Tensile Stress @ 100% Strain (MPa)</td><td>1.67</td><td>1.74</td><td>2.73</td><td>3.06</td><td>3.28</td><td>4.25</td><td>2.15</td></tr>
<tr><td>Tensile Stress @ 200% Strain (MPa)</td><td>3.05</td><td>3.37</td><td>4.04</td><td colspan="3">Not Recorded</td><td></td></tr>
<tr><td>Yield Stress (MPa)</td><td>0.992</td><td>1.26</td><td>1.86</td><td>3.83</td><td>4.25</td><td>6.49</td><td></td></tr>
<tr><td>Tear Strength ASTMD 624 (Die C) (N/mm)</td><td>34.57</td><td></td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>Durometer (Shore A)</td><td colspan="6">70 measured</td><td>75 data sheet
70 measured</td></tr>
<tr><td colspan="8">No voids were noticed in the samples. High rate data exhibits oscillations due to softness similar to other soft materials. Yield stress is strongly rate dependent. Material exhibits softening after yield point in high rate tests that may be the result of increased temperature due to energy dissipation.</td></tr>
</table>

Tensile Properties: Rencast 6425, Hard Polyurethane, Tail Bone (Huntsman)							
Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	50 s^{-1}	140 s^{-1}	300 s^{-1}	
Young's Modulus (MPa)	426	485	535	777	934	1137	
Failure Stress (MPa) ASTM D 638	24 ASTM D 638 Type IV	26 ASTM D 638 Type IV	30 ASTM D 638 Type V	36 ASTM D 638 Type V Using custom built drop tower	41	40	30-35 ISO 527-2
Failure Strain (%) ASTM D 638	96	87	80	67	62	63	130-170 ISO 527-2
Tensile Strength @ Yield (MPa)	18	21	26	40	43	49	
Failure Test (tensile test to failure using V-notch specimen (N)	1178						
Tear Strength	Not tested						
Durometer (Shore D)	67 measured						60-65
Some voids were noticed in the die cut specimen cross-sections. Samples with voids were not used.							

Tensile Properties: TC 892, Rigid Polyurethane, Pelvic Bone (BJB Enterprises)							
Property	Strain Rate						Per Product/Mfg Data Sheet
	0.01 s^{-1}	0.10 s^{-1}	1.0 s^{-1}	30 s^{-1}	80 s^{-1}	150 s^{-1}	
Young's Modulus (GPa)	1.85	1.96	1.98	2.08	2.54	2.70	1.6 ASTM D 638
Failure Stress (MPa) ASTM D 638	40.3 ASTM D 638 Type IV	53.3 ASTM D 638 Type IV	61.3 ASTM D 638 Type V	80.5	83.4	86.8	52.4 ASTM D 638
				ASTM D 638 Type V using custom built drop tower			
Failure Strain (%) ASTM D 638	9.1	5.5	4.1	5.0	4.9	4.9	10 ASTM D 638
Tensile Strength @ Yield (MPa)	47.8	54.5	59.0	n/a	n/a	n/a	
Failure Test (tensile test to failure using V-notch specimen (N)	2220 Very Brittle Failure						
Tear Strength	Not tested						
Durometer (Shore D)	79 measured						80 $\pm$ 2
No voids were noticed in the specimens. Due to acceleration limits of the material and low strain to failure, a maximum strain rate of 150 s^{-1} was the highest strain rate tested.							

Compression Properties: Proflex 30, Polyurethane Elastomer, Pelvis Flesh (Mouldlife, UK)										
Property	Strain Rate (s^{-1})									
	0.01	0.10	1.0	50	150	225	400	625	750	950
Compression Strength @ 50% Strain (MPa)	1.47	1.46	1.61	1.52	1.63	1.75	1.94	2.00	2.03	2.32
MAX strain of test (%)	50	50	50	82	91	90	87	87	86	85
Compression Strength @ Max Strain of Test	1.47	1.46	1.61	31	76	70	70	68	74	66
Modulus at initial part of curve (MPa)	1.38	1.47	1.56	1.72	1.91	1.92	2.33	2.21	n/a	2.66
Durometer (Shore A)	29									

Compression Properties: XE 1031, Polyurethane Elastomer, Foot Flesh (Polymed LTD, UK)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	60	150	600	950
Compression Strength @ 50% Strain (MPa)	1.66	1.77	1.80	2.94	3.40	4.05	4.29
MAX strain of test (%)	50	50	50	83	80	82	77
Compression Strength @ Max Strain of Test	1.66	1.77	1.80	28.5	24	43.8	27.9
Modulus at initial part of curve (MPa)	1.79	2.07	2.27	n/a	n/a	4.42	4.95
Durometer (Shore A)	33						

Compression Properties: FD70, Hard Polyurethane Elastomer, Foot Plate (BJB Enterprises)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	50	150	500	1000
Compression Strength @ 50% Strain (MPa)	53.7	62.4	76.8	n/a	105.8	n/a	n/a
MAX strain of test (%)	50	50	50	38	67	8.2	16
Compression Strength @ Max Strain of Test	53.7	62.4	76.8	69.0	163.9	49.4	69.4
Modulus at initial part of curve (MPa)	432.3	520.0	591.1	743.3	749.5	n/a	n/a
Durometer (Shore D)	68						
50 s^{-1} and 150 s^{-1} tests performed on custom drop tower. 500 s^{-1} and 1000 s^{-1} performed using Split Hopkinson Pressure Bar (SHPB).							

Compression Properties: Delrin, Rigid Thermoplastic (Acetyl Resin), Calcaneus Cap								
Property	Strain Rate (s^{-1})							
	0.01	0.10	1.0	40	150	500	600	1000
Compression Strength @ 50% Strain (MPa)	245.4	230.1	n/a	n/a	238.1	256.3	n/a	n/a
MAX strain of test (%)	50	50	45	15	66	82	10	15
Compression Strength @ Max Strain of Test	245.4	230.1	219.6	151.0	286.2	497.5	158.0	176.1
Modulus at initial part of curve (MPa)	2941	2737	2741	2686	2820	n/a	> 10K	> 10K
Durometer (Shore D)	81							
40 s^{-1} and 150 s^{-1} tests performed on custom drop tower. 600 s^{-1} and 1000 s^{-1} performed using Split Hopkinson Pressure Bar (SHPB)								

Compression Properties: F-130 A/B, Polyurethane Elastomer, Flesh (BJB Enterprises)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	75	160	500	850
Compression Strength @ 50% Strain (MPa)	1.28	1.39	1.62	2.26	2.55	3.36	3.43
MAX strain of test (%)	50	50	52	86	84	88	83
Compression Strength @ Max Strain of Test	1.28	1.39	1.83	40.8	33.6	65.1	47.85
Modulus at initial part of curve (MPa)	1.22	1.28	1.38	n/a	n/a	13.1	31.2
Durometer (Shore A)	31						
75 s^{-1}, 160 s^{-}, 500 s^{-1} and 850 s^{-1} tests performed on custom drop tower. Weak strain rate dependence at lower strain rates. Strong strain dependence at high strain rates (>75 s^{-1}).							

Compression Properties: Butyl Rubber Custom Compound, Compliant Elements in Spine and Legs (Abbott Rubber)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	50	150	500	850
Compression Strength @ 50% Strain (MPa)	n/a	n/a	7.8	n/a	46.4	76.2	84.1
MAX strain of test (%)	47	47	53	31	63	65	64
Compression Strength @ Max Strain of Test	3.8	5.0	8.9	13.5	49.1	110.7	127.0
Modulus at initial part of curve (MPa)	14.9	16.4	15.2	123.3	185.8	337.3	n/a
Durometer (Shore A)	70						
Strain rates > 50 s^{-1} were performed on custom drop tower. Weak strain rate dependence at slower strain rates. Strong strain dependence at high strain rates (>50 s^{-1}).							

Compression Properties: Rencast 6425, Hard Polyurethane, Tail Bone (Huntsman)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	50	160	700	1100
Compression Strength @ 50% Strain (MPa)	73.9	80.2	91.2	n/a	134.7	n/a	n/a
MAX strain of test (%)	50	50	50	33	61	10	17
Compression Strength @ Max Strain of Test	73.9	80.2	91.2	73.7	171.7	69.5	80.8
Modulus at initial part of curve (MPa)	445.7	502.1	509.8	802.2	859.5	>6000	>11000
Durometer (Shore D)	67						
Strain rates of 50 s^{-1} and 160 s^{-1} were performed on custom drop tower. Strain rates of 700 s^{-1} and 1100 s^{-1} were performed using a Split Hopkinson Pressure Bar (SHPB). Rencast 6425 exhibits strong strain dependence at high strain rates (>50 s^{-1}).							

Compression Properties: TC 892, Rigid Polyurethane, Pelvic Bone (BJB Enterprises)							
Property	Strain Rate (s^{-1})						
	0.01	0.10	1.0	50	190	550	1000
Compression Strength @ 50% Strain (MPa)	102.2	98.2	120.0	n/a	163.5	n/a	n/a
MAX strain of test (%)	50	50	51	23	52	8.0	14
Compression Strength @ Max Strain of Test	102.2	98.2	117.0	87.0	173.5	117.5	116.9
Modulus at initial part of curve (MPa)	1950.1	1847.2	1887.5	2283.7	2317.4	>5000	>4000
Durometer (Shore D)	79						
Strain rates of 50 s^{-1} and 190 $^{s-}1$ were performed on custom drop tower. Strain rates of 550 s^{-1} and 1000 s^{-1} were performed using a Split Hopkinson Pressure Bar (SHPB). TC 892 exhibits strong strain dependence at high strain rates (>50 s^{-1}).							

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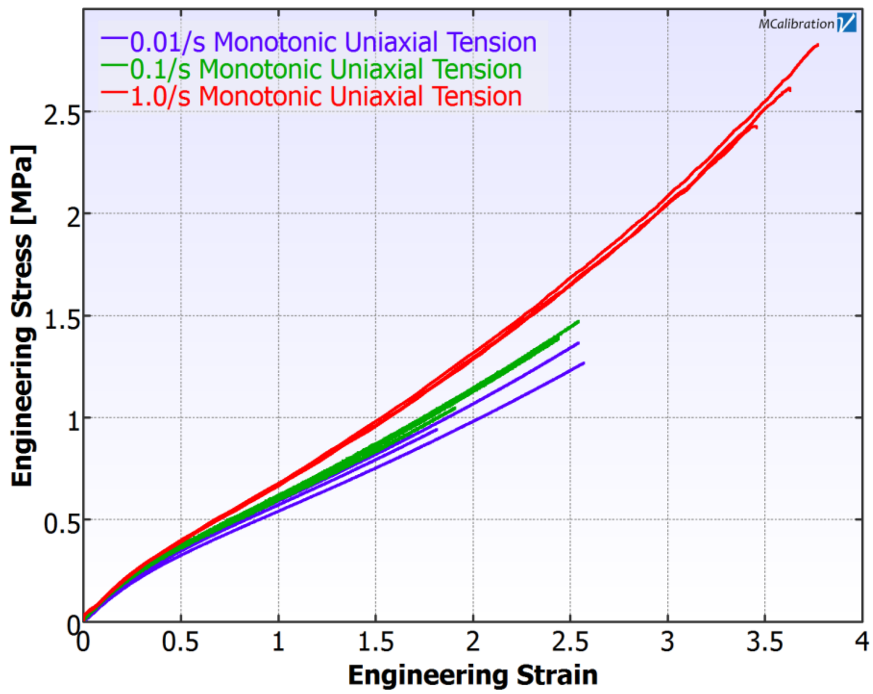
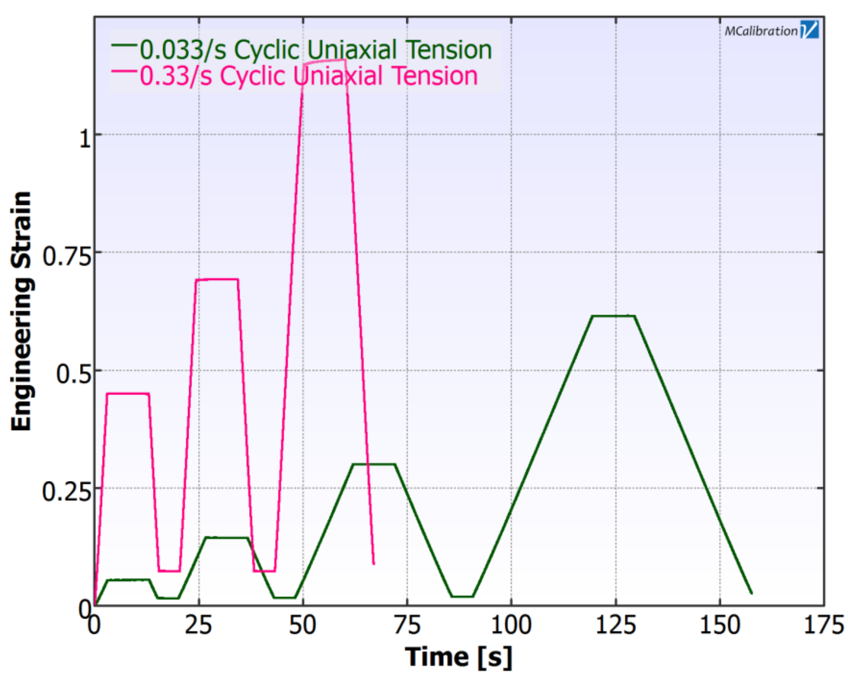
Appendix D. Experiment Data

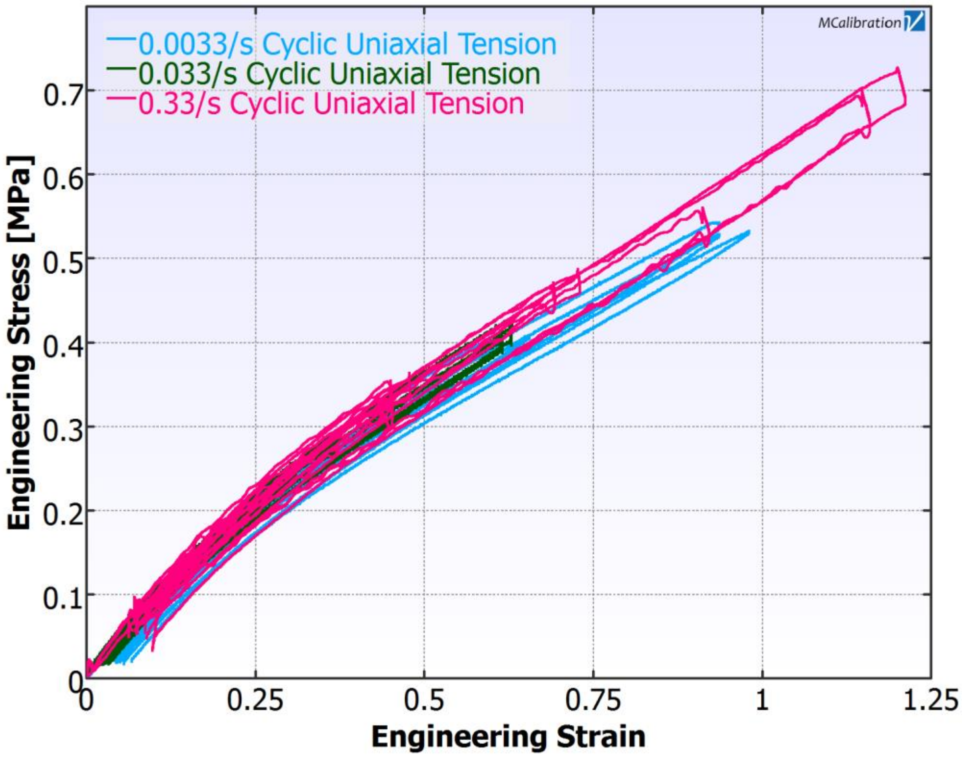
Proflex 30 Tension

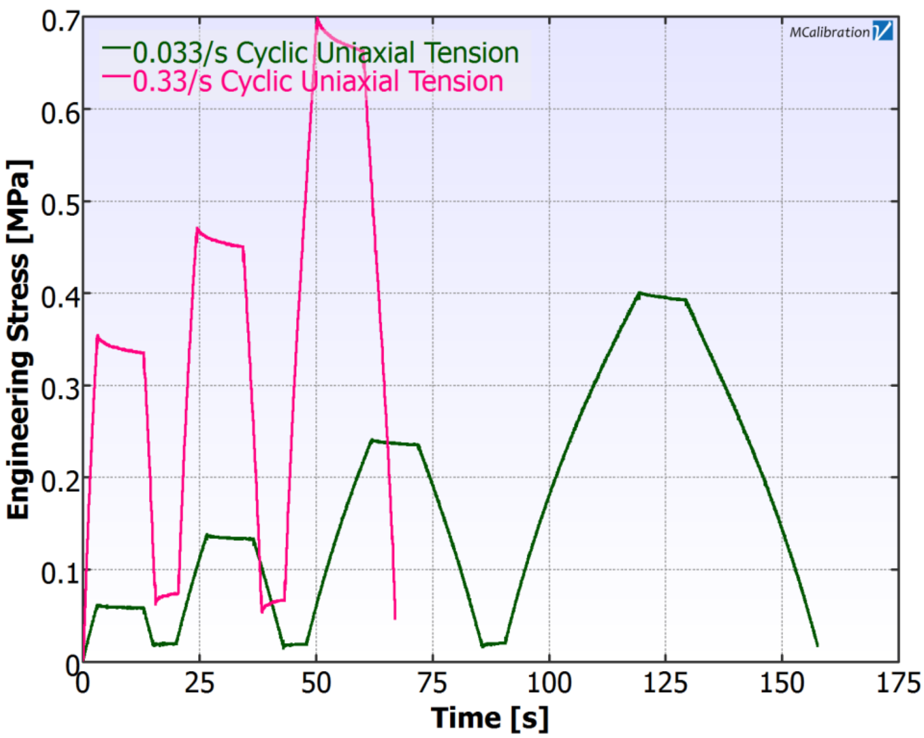


Cyclic Tension Strain History

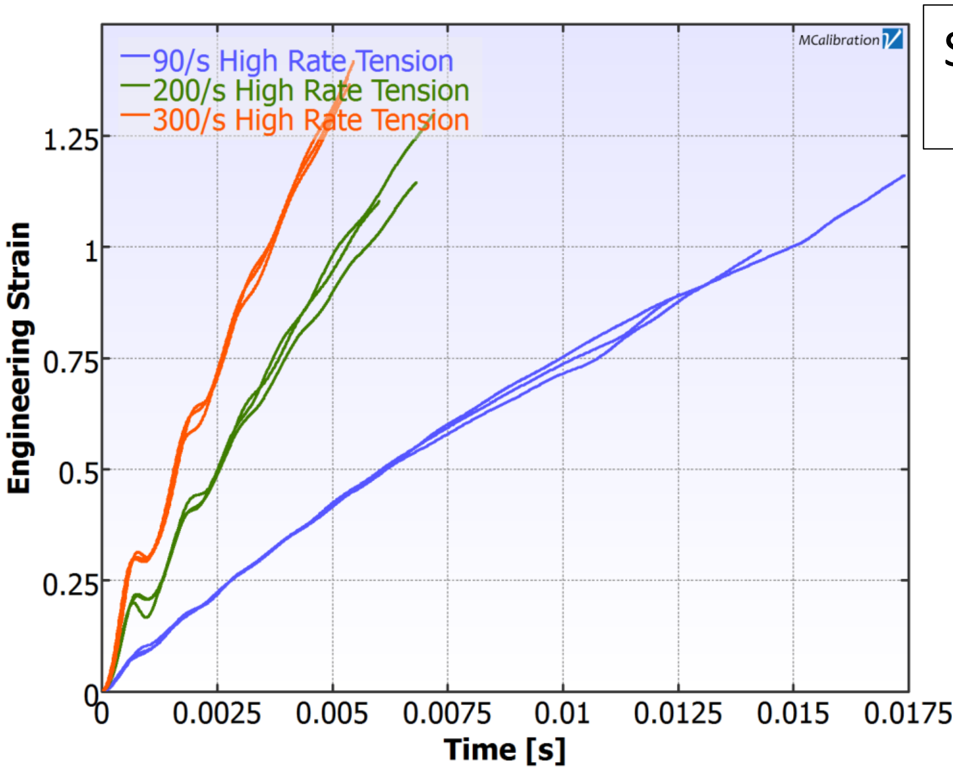


Proflex 30 Cyclic Tension

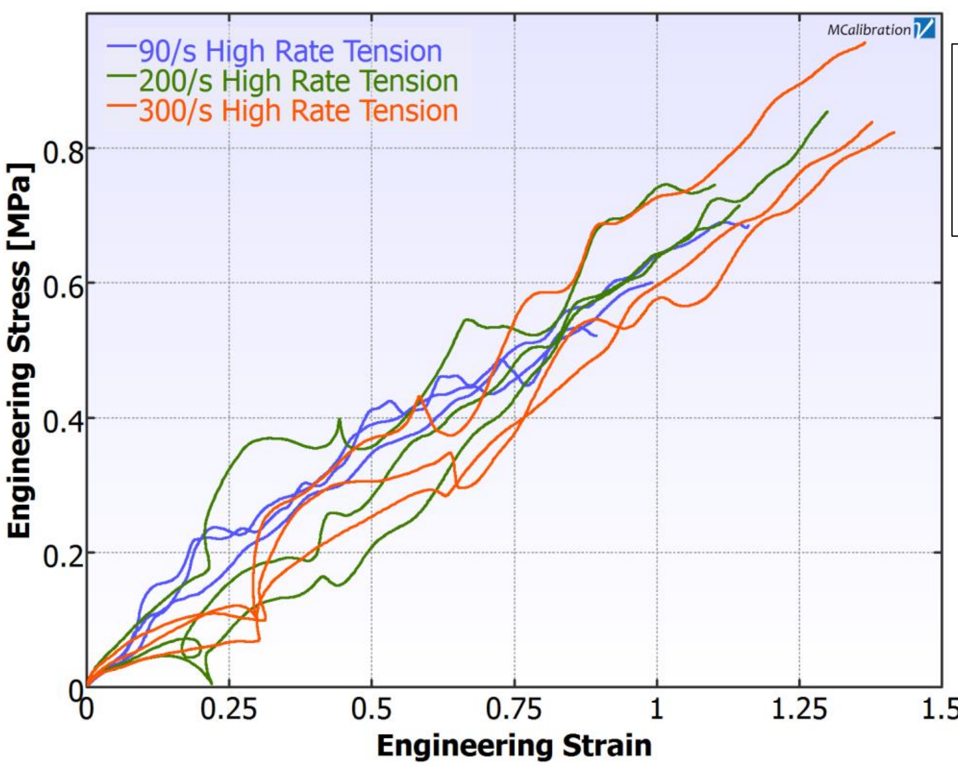




Proflex 30 High Rate Tension

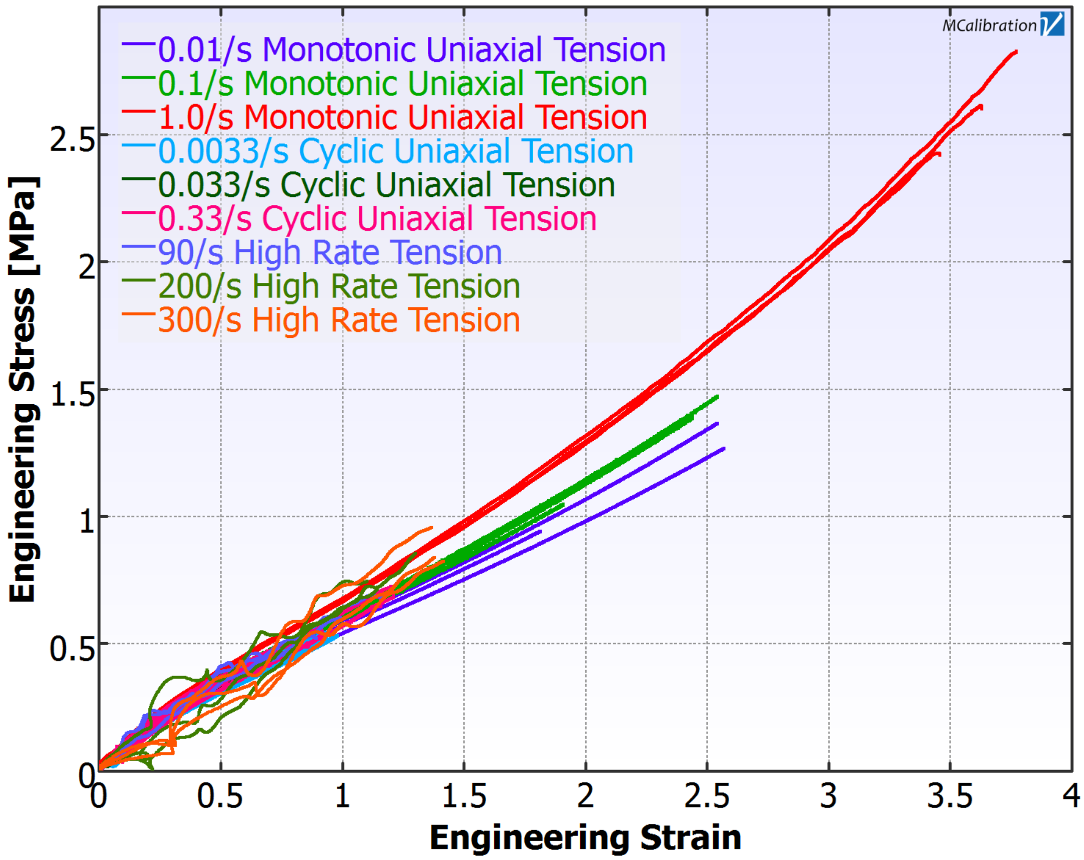


Strain History

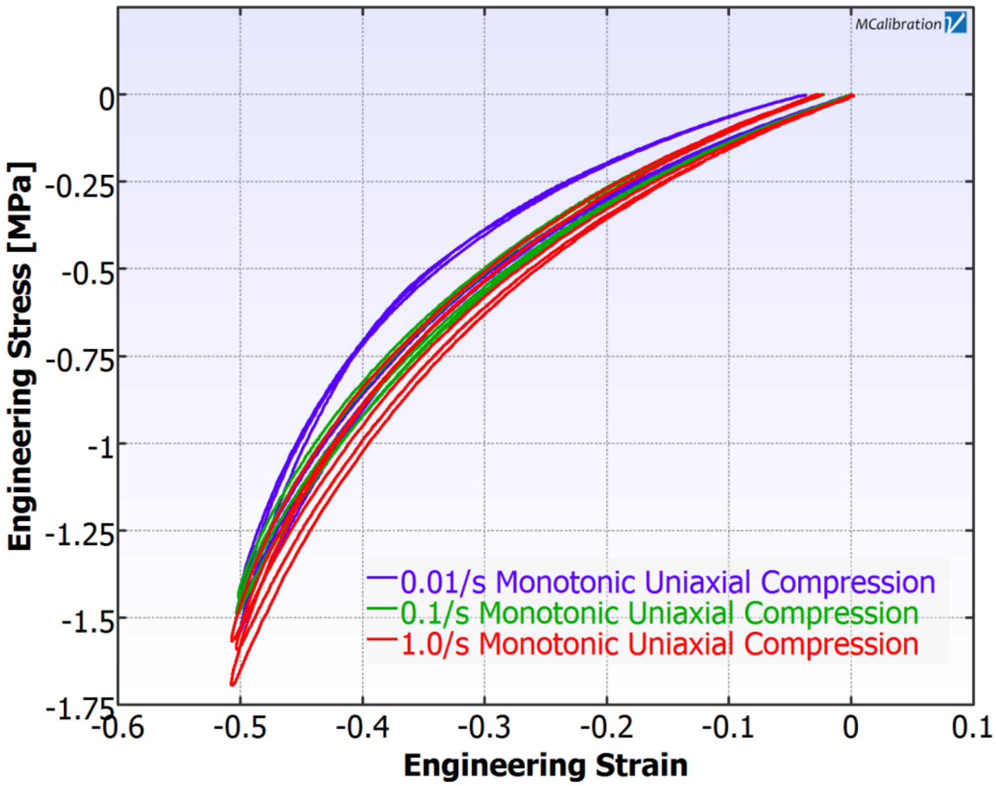


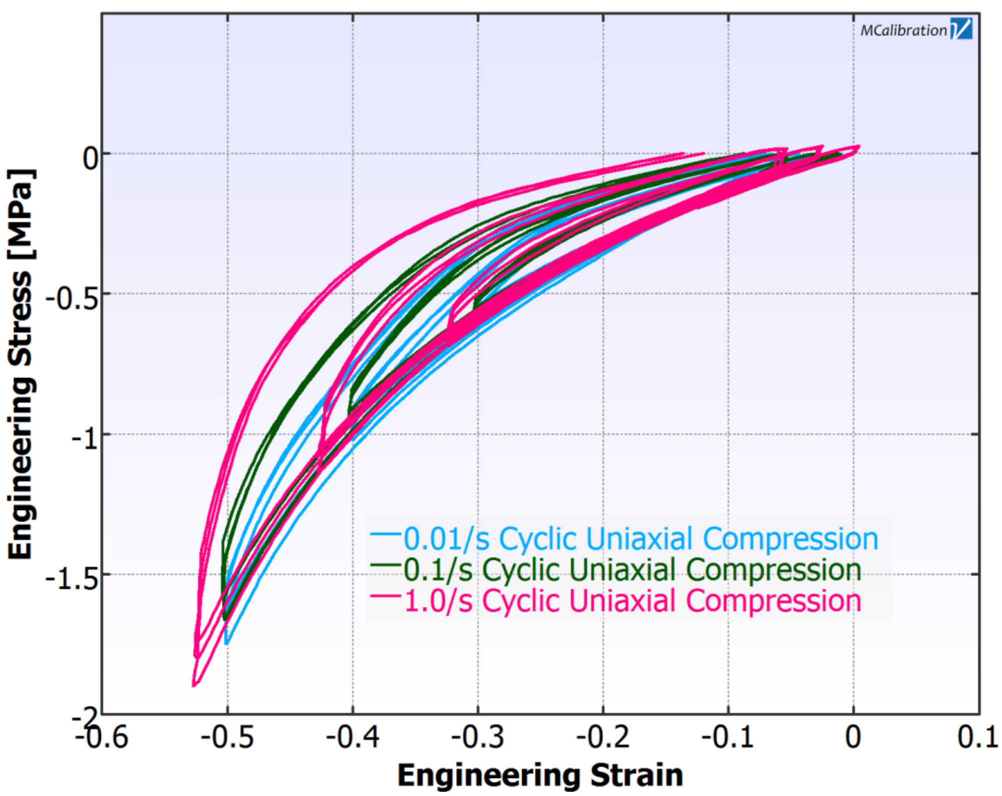
High Rate Tension

Proflex 30 All Tension Data



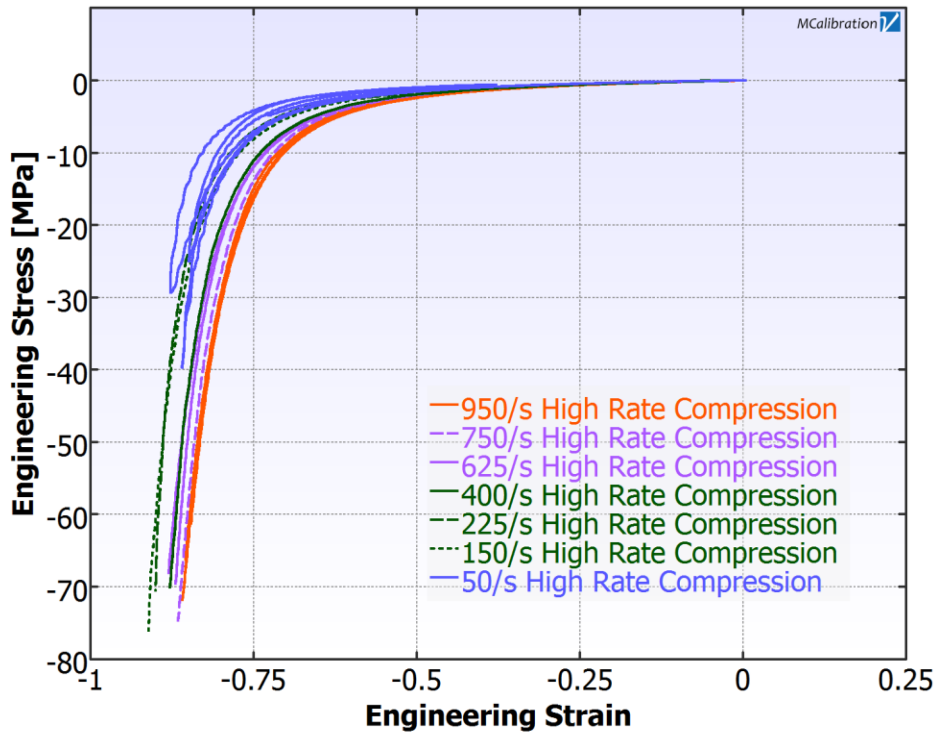
Proflex 30 Compression



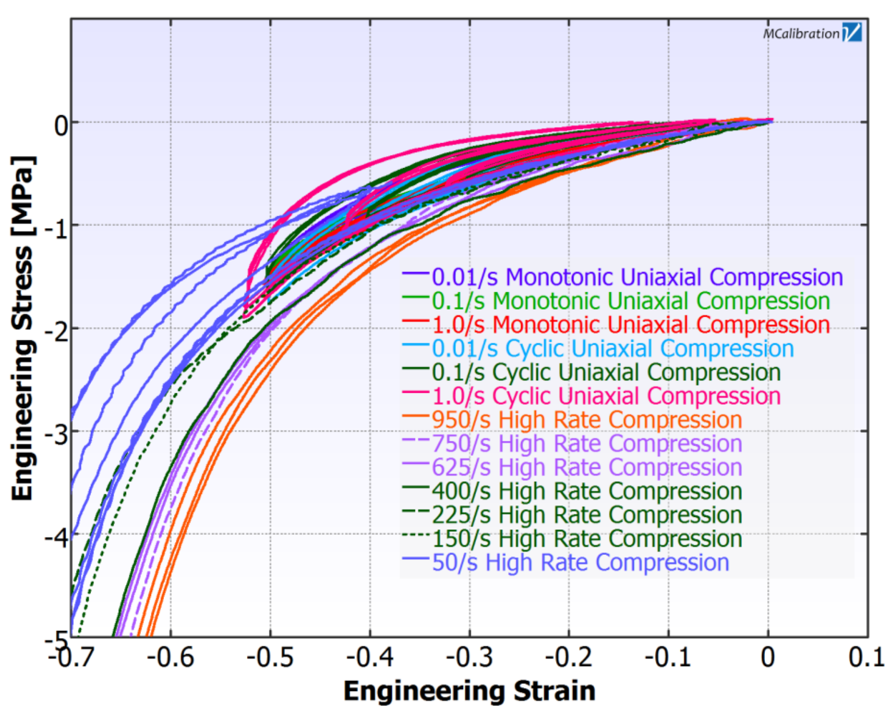


Cyclic Compression

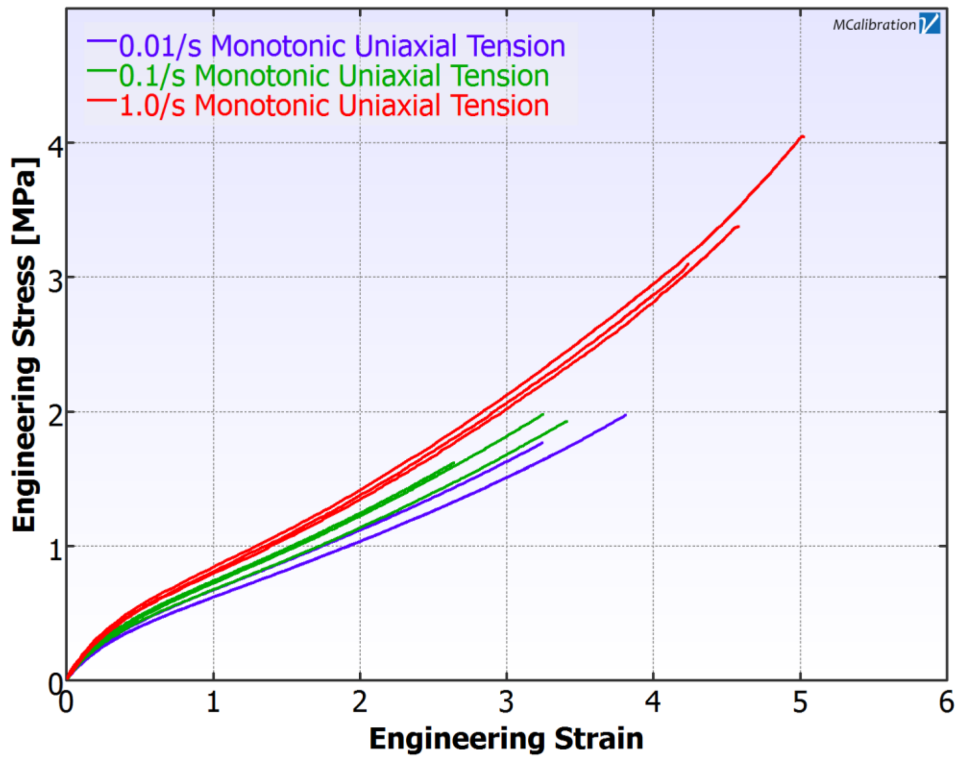
Proflex 30 High Rate Compression

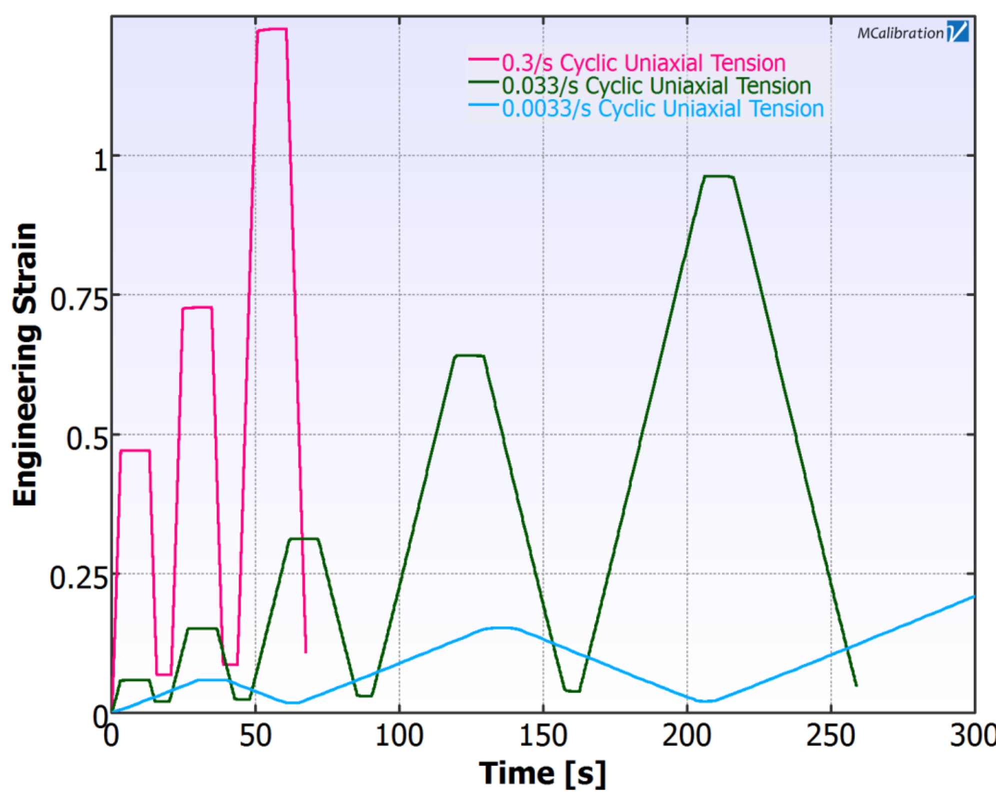


All Compression Data



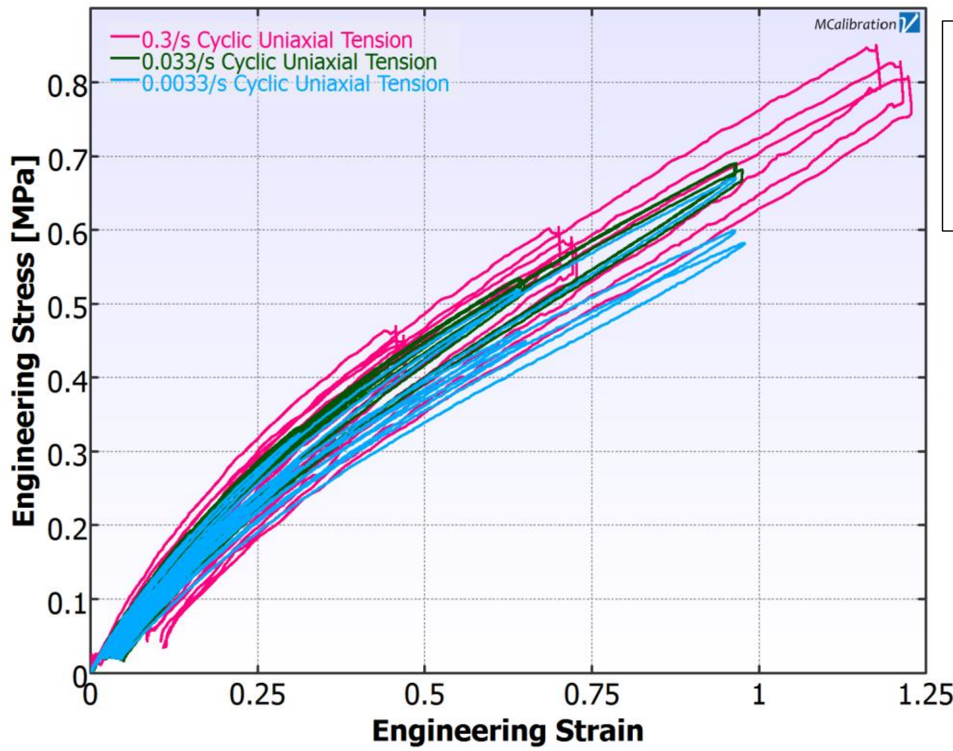
XE 1031 Tension





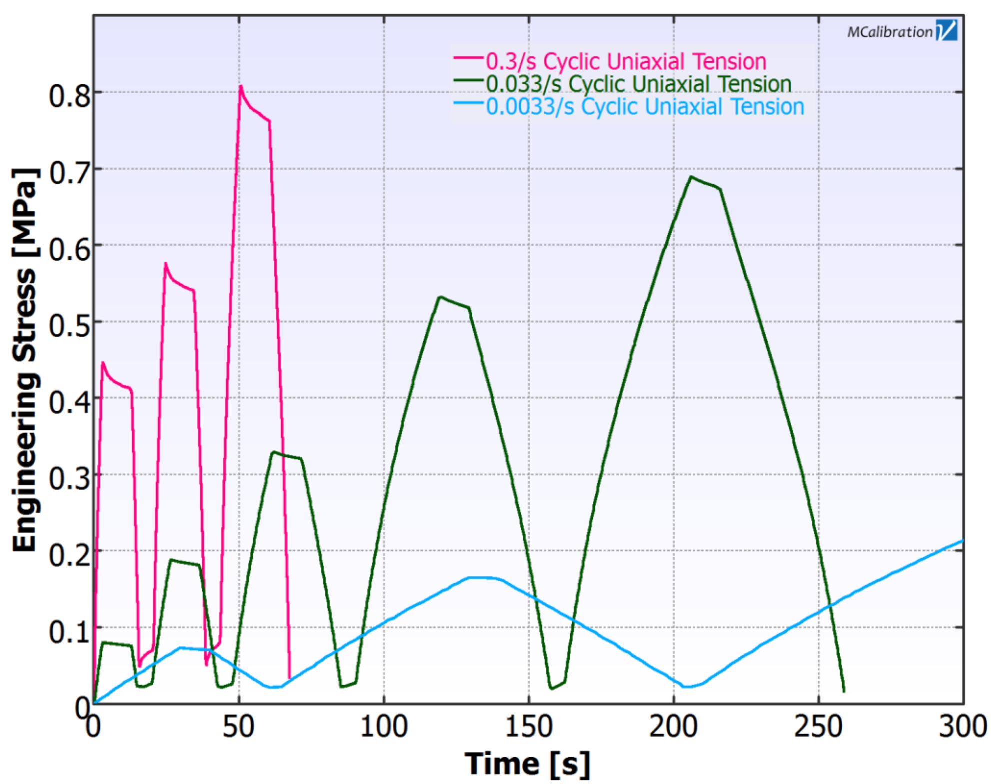
Cyclic Tension Strain History

XE 1031

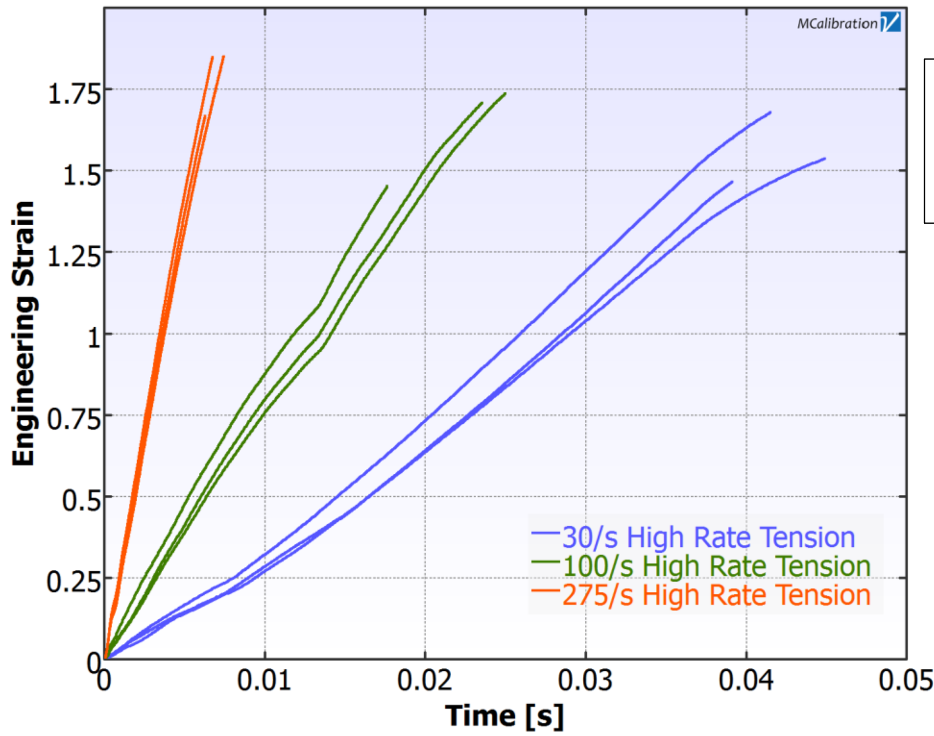


Cyclic Tension

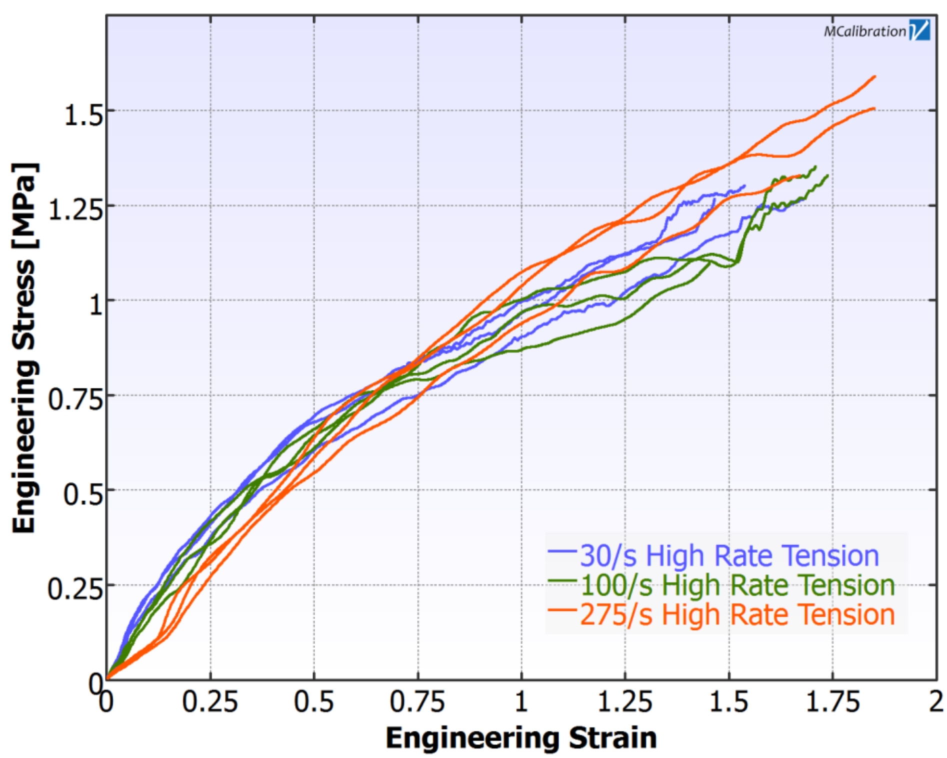
Results



XE 1031 High Rate Tension

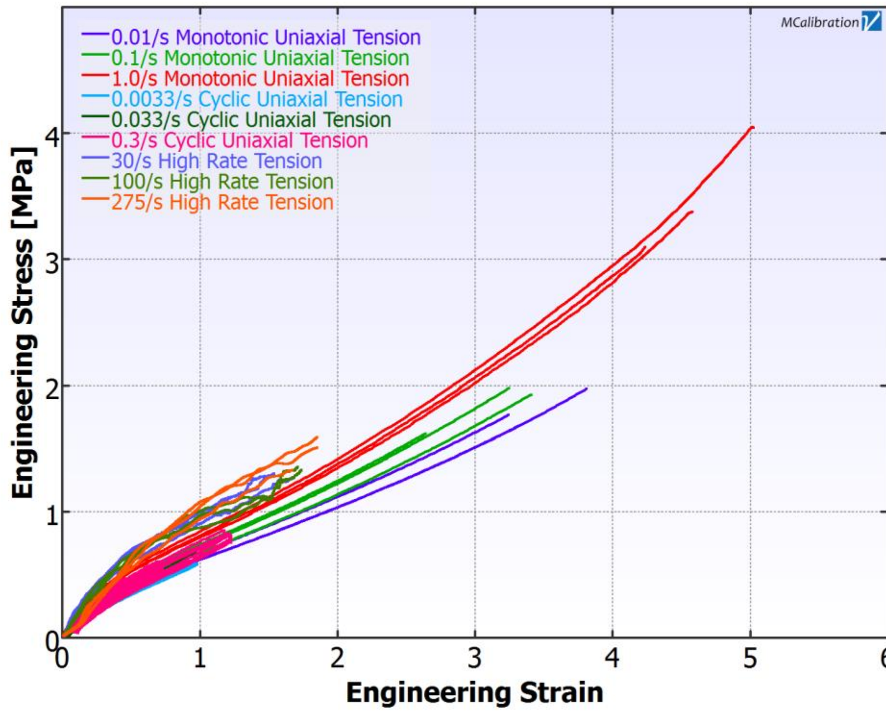


Strain History



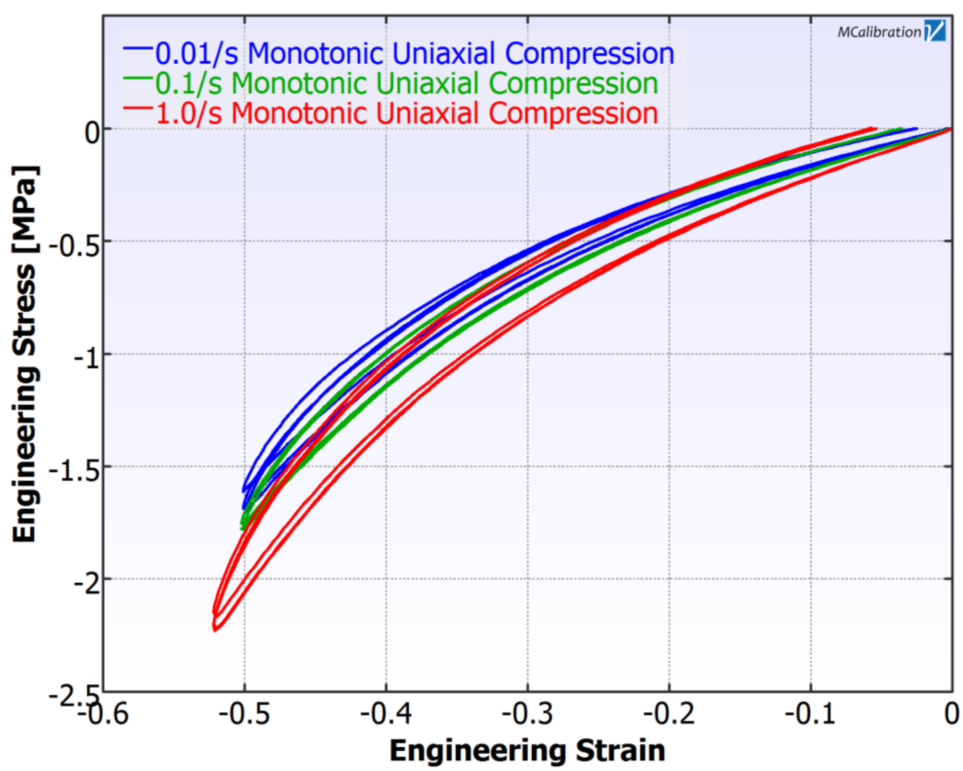
Results

XE 1031



All Tension Data

Compression



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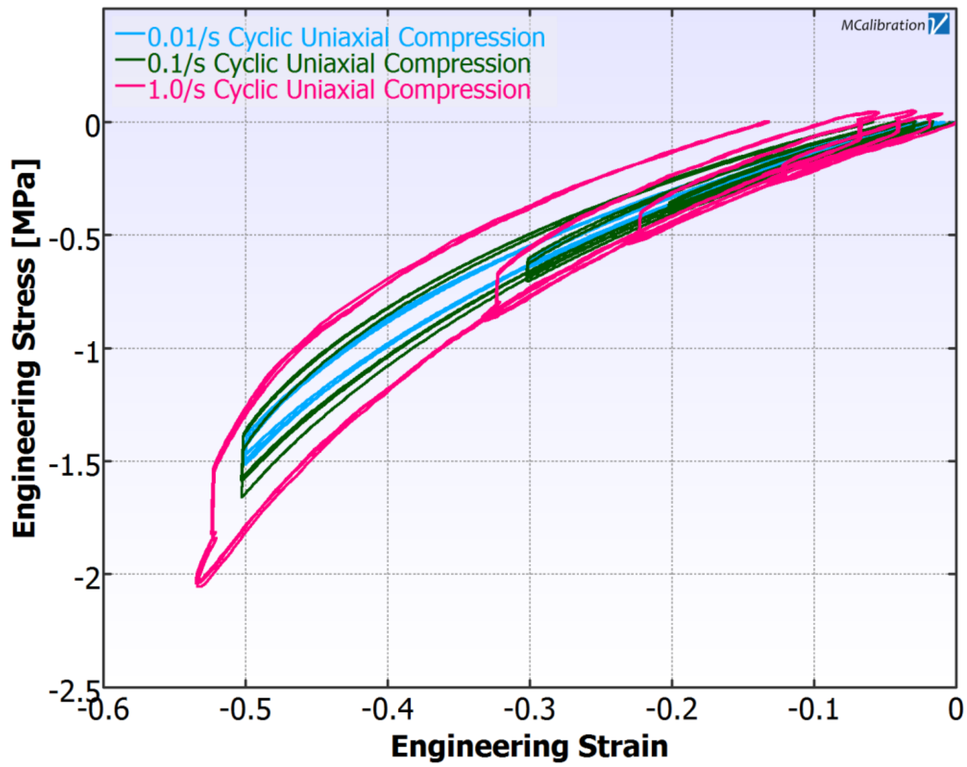

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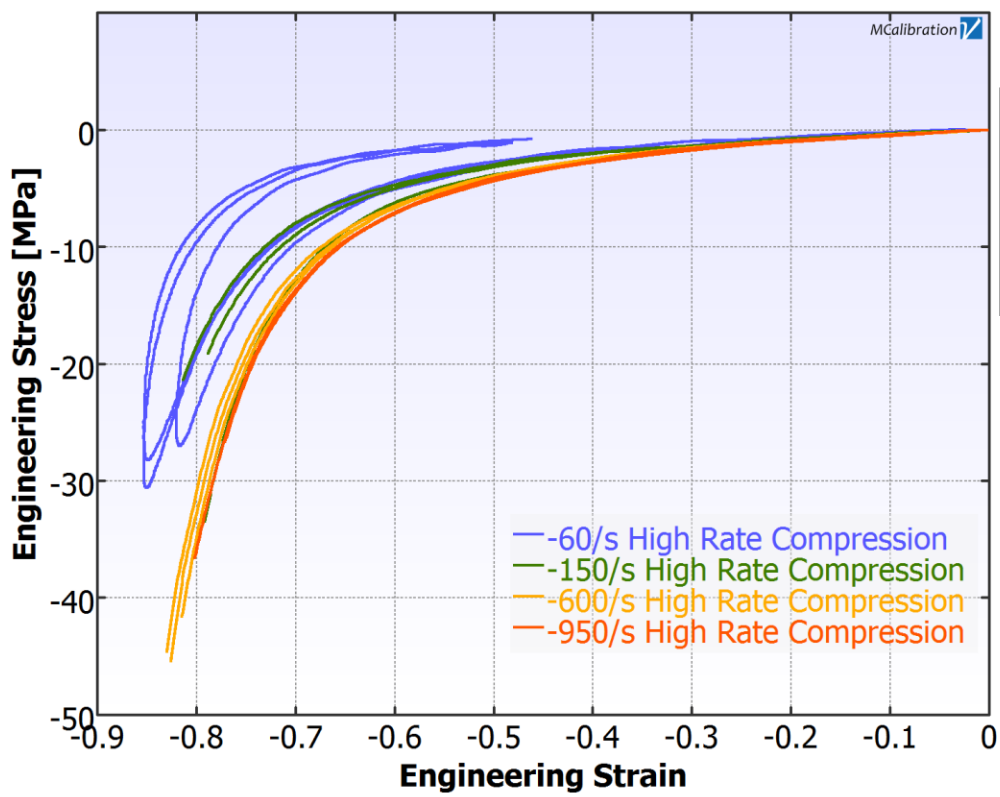
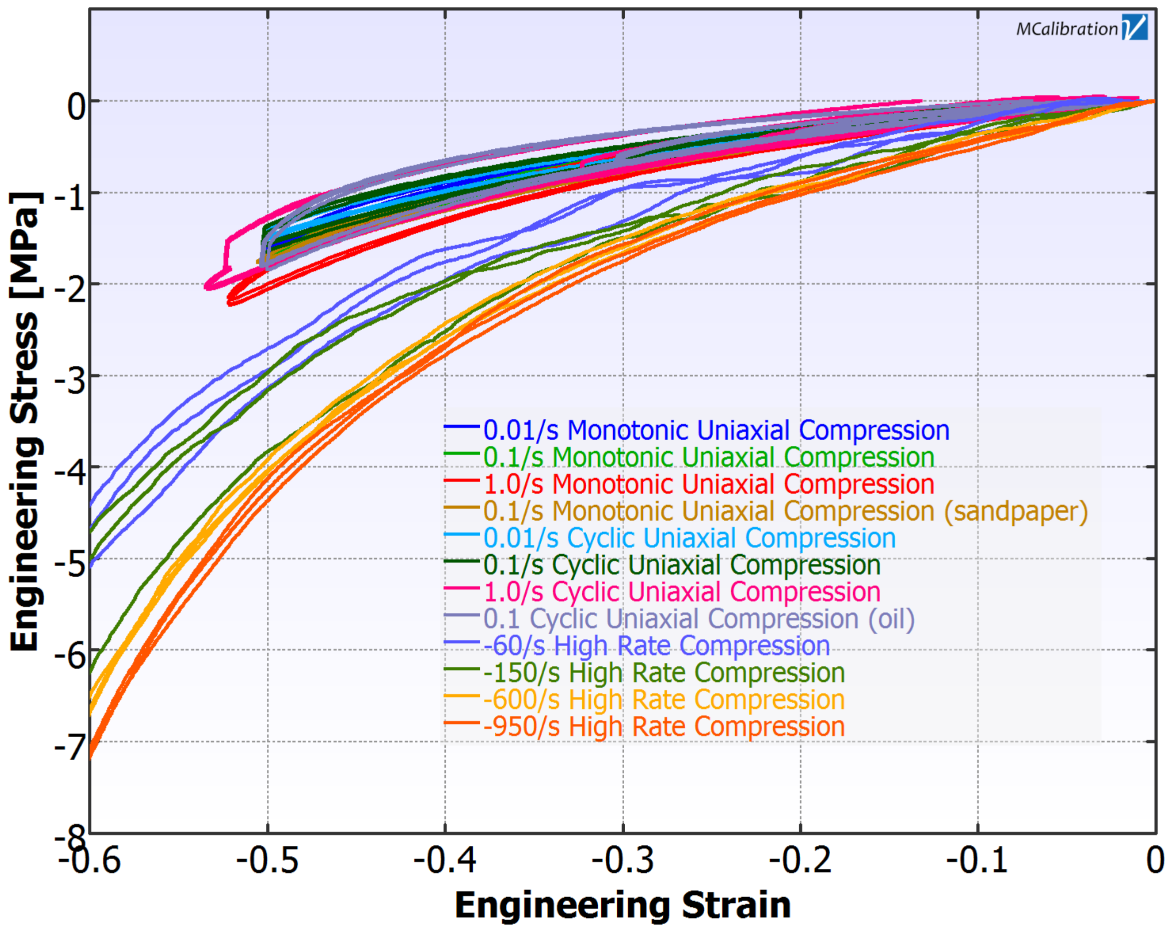


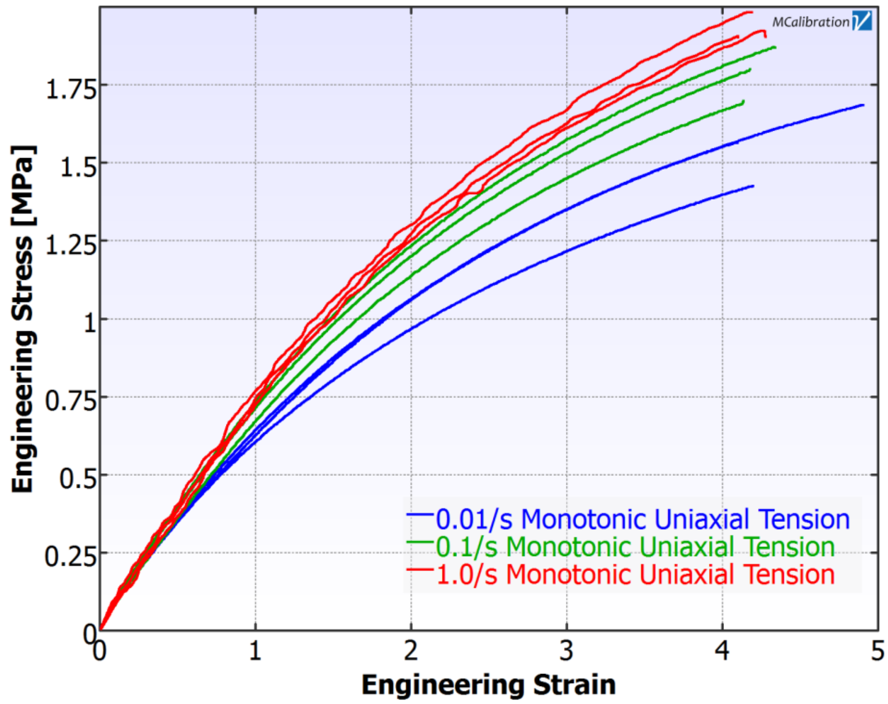
High Rate Compression

XE 1031

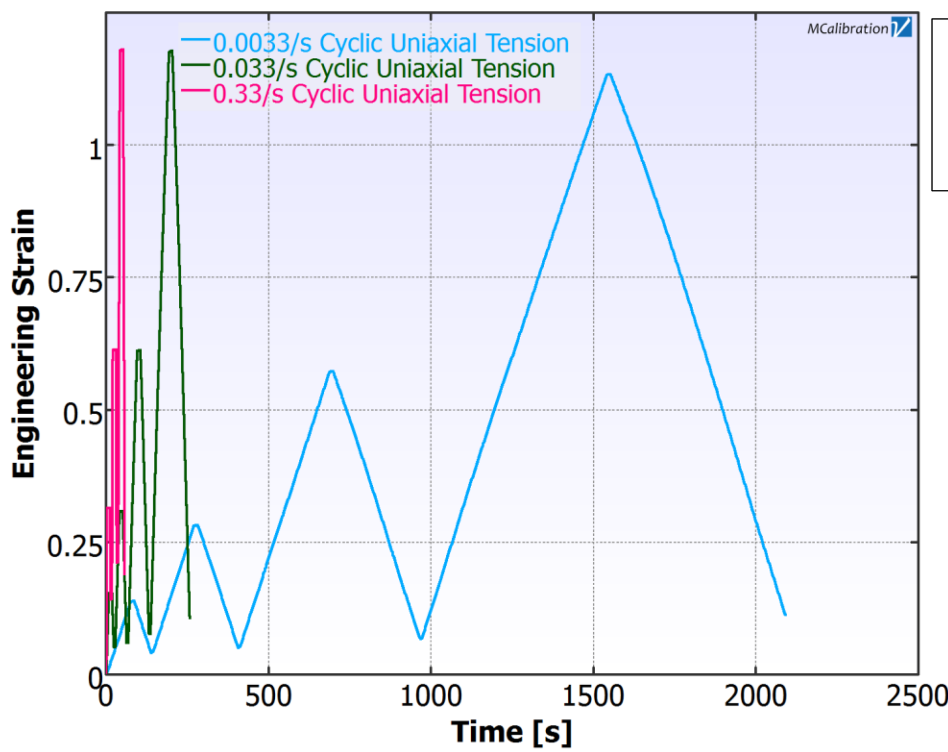
All Compression Data



F-130

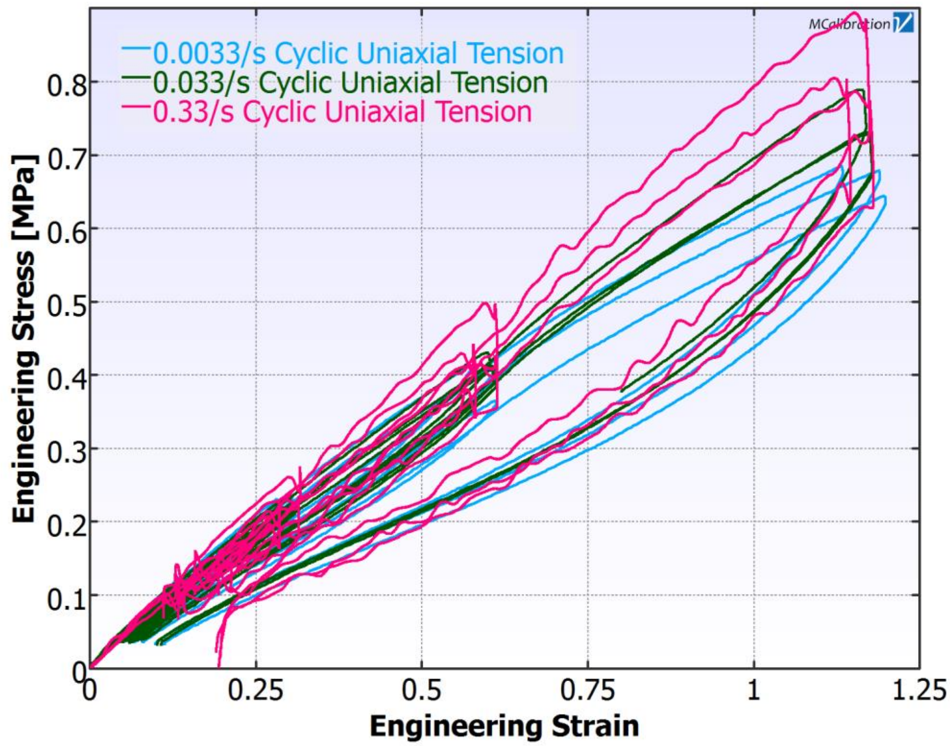


Tension

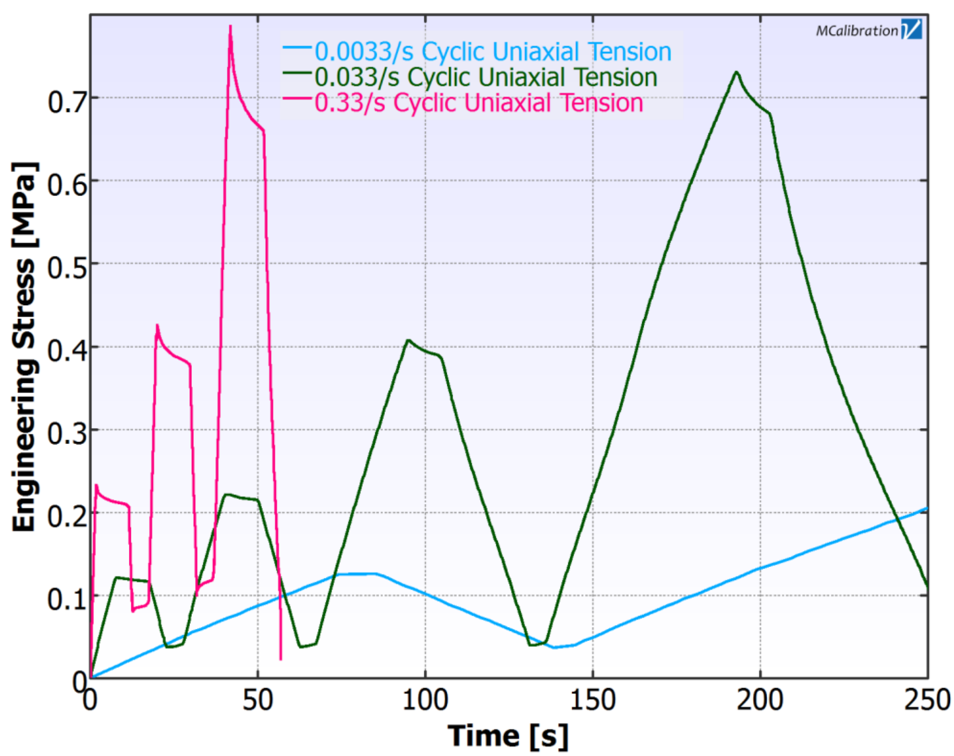


Cyclic Tension Strain History

F-130



Cyclic Tension Results



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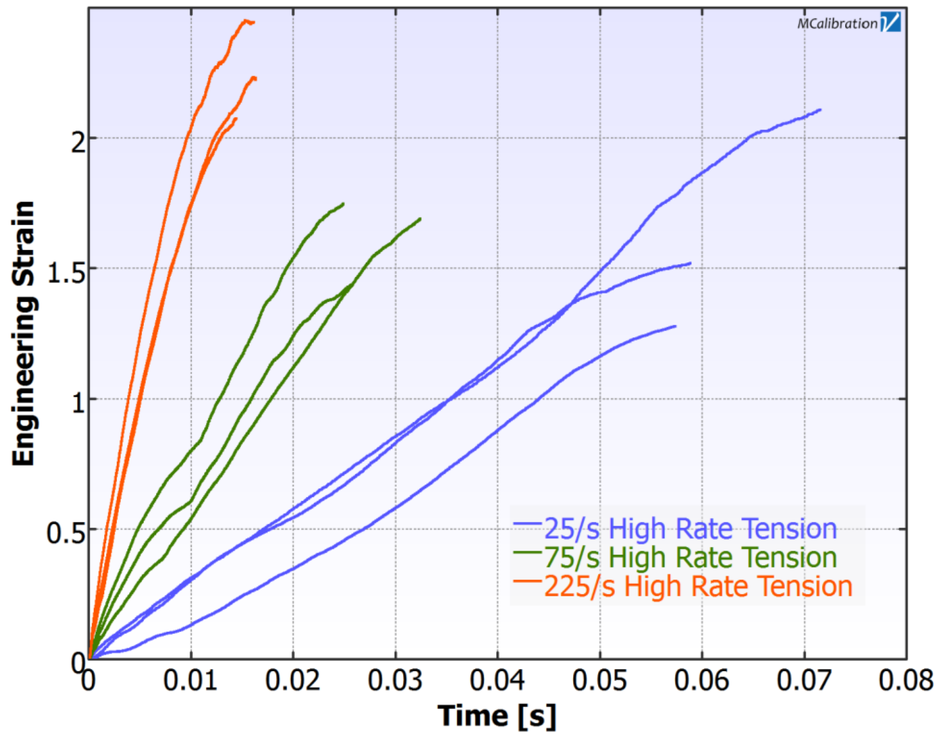
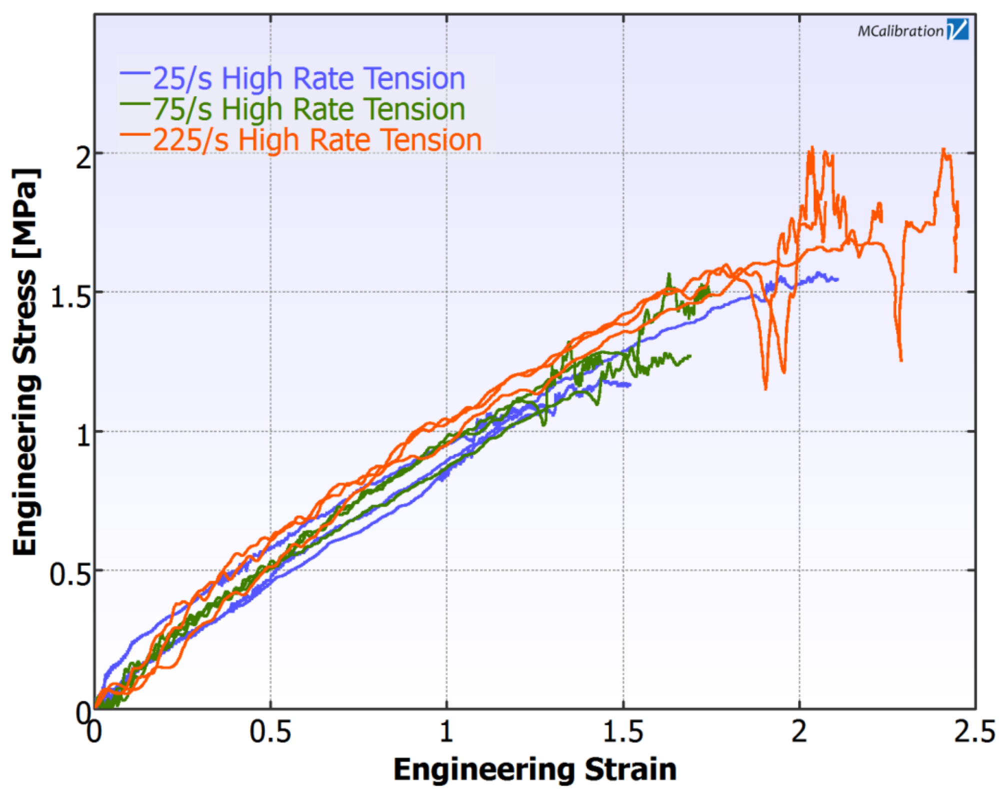


High Rate Tension

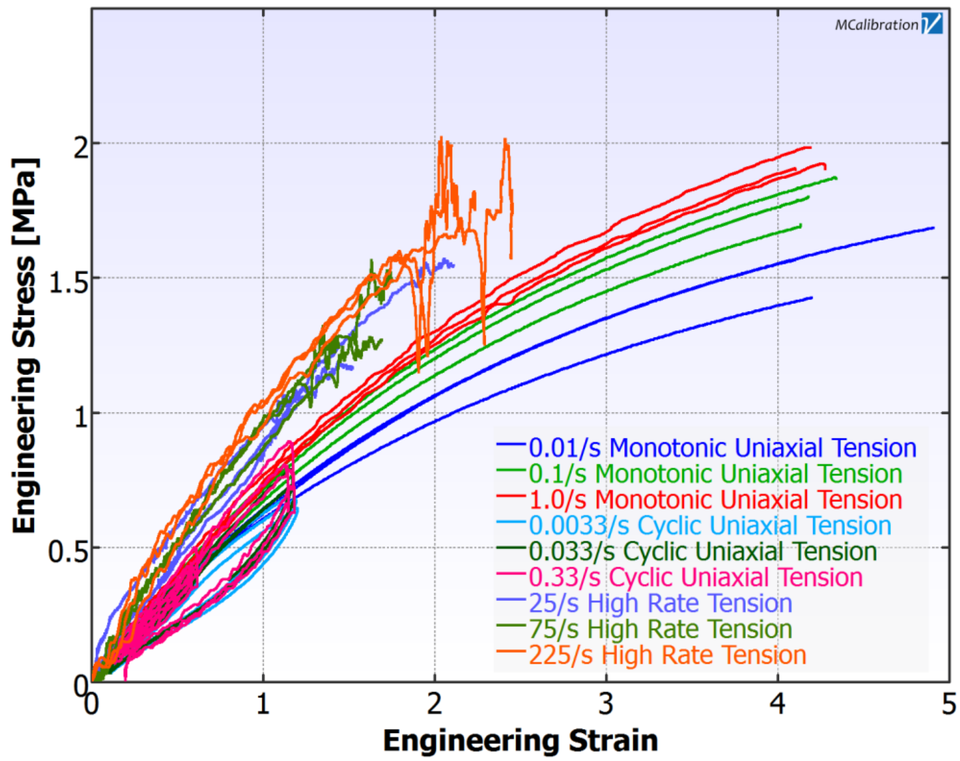
Strain History



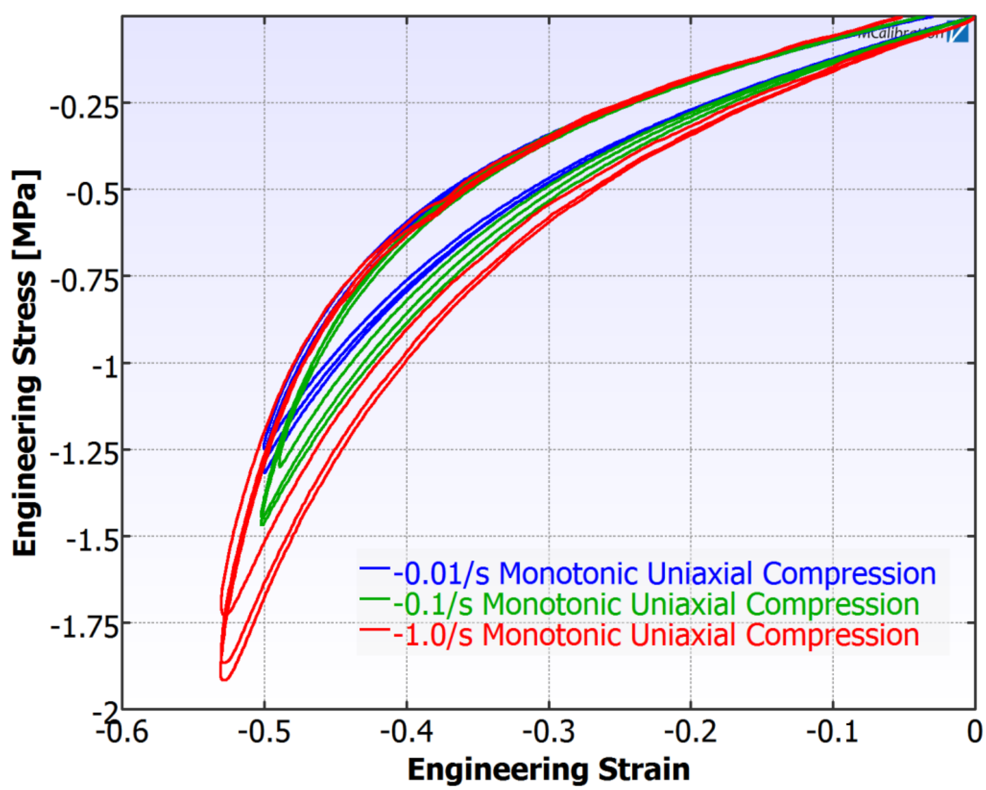
High Rate Tension

Results

F-130

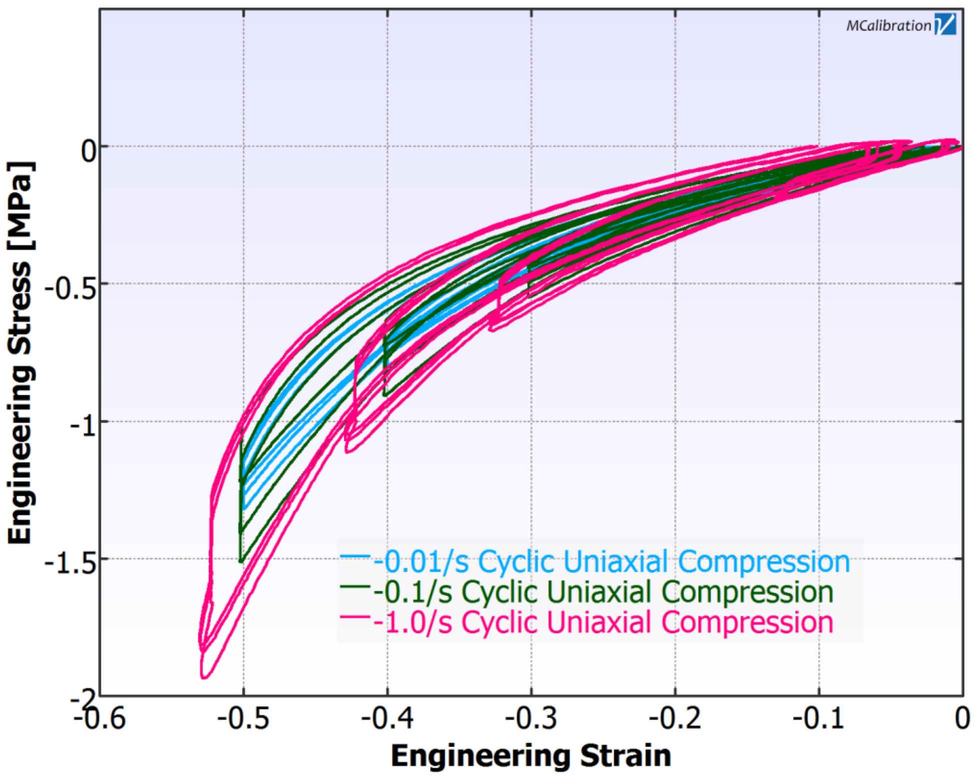


All Tension Data

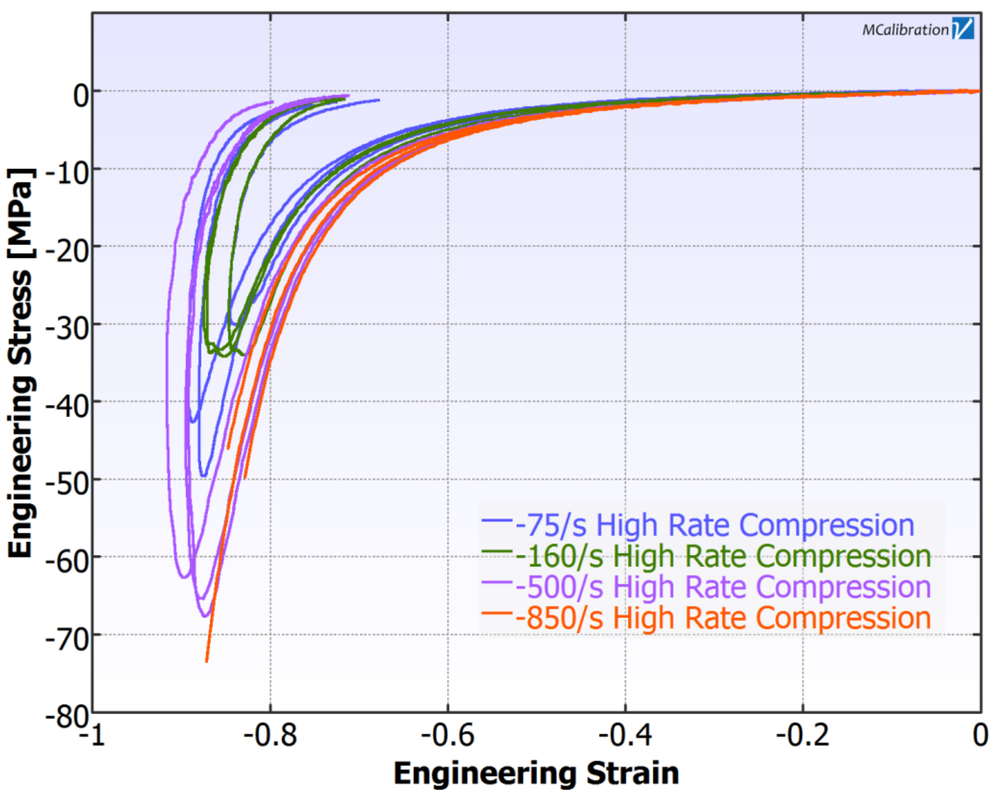


Compression

F-130

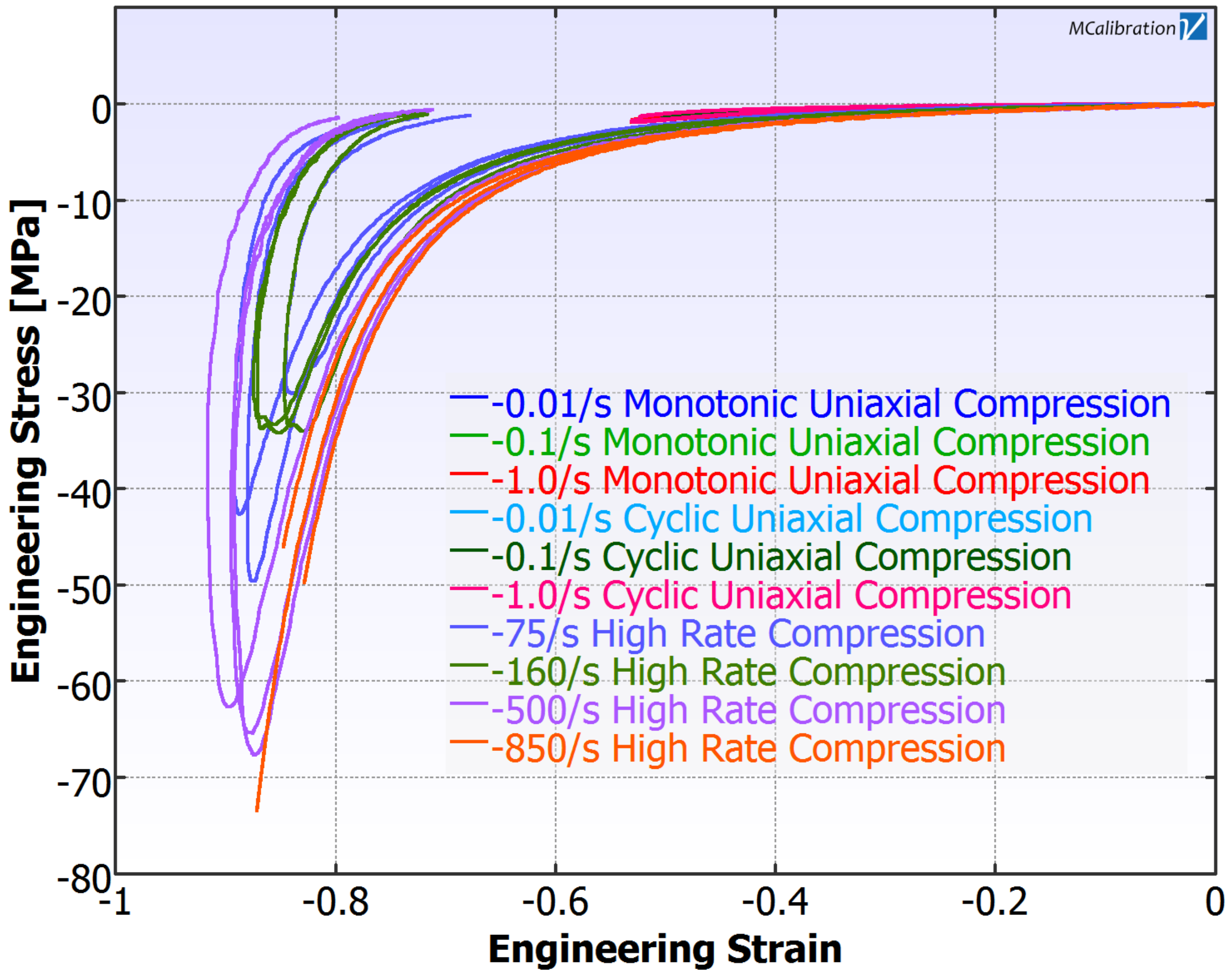


Cyclic Compression

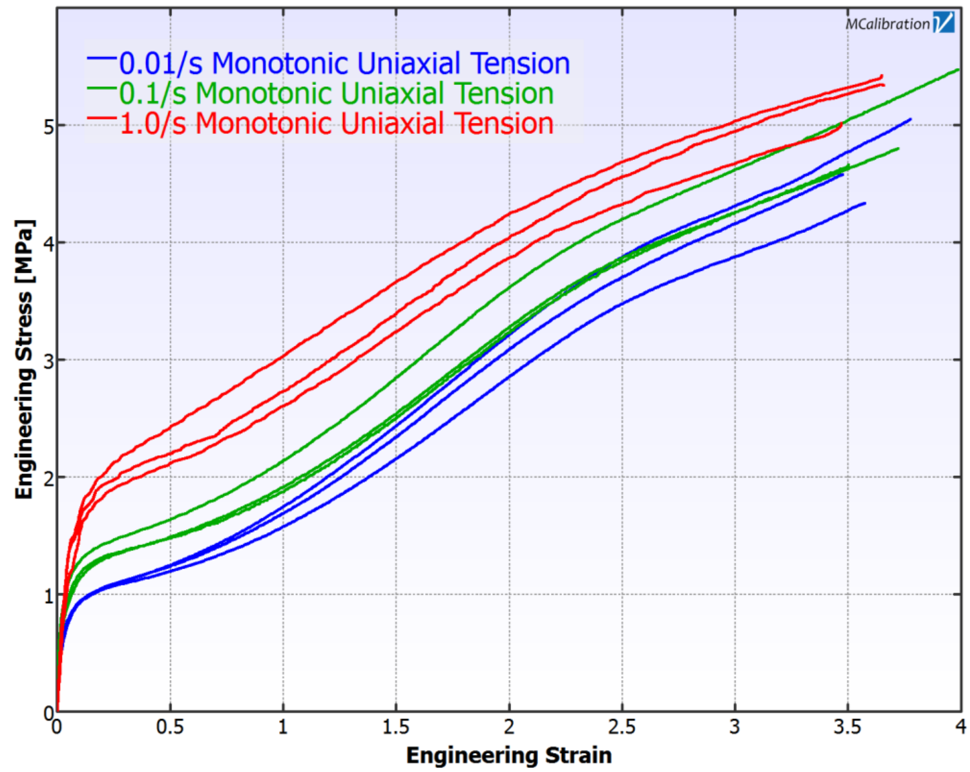


High Rate Compression

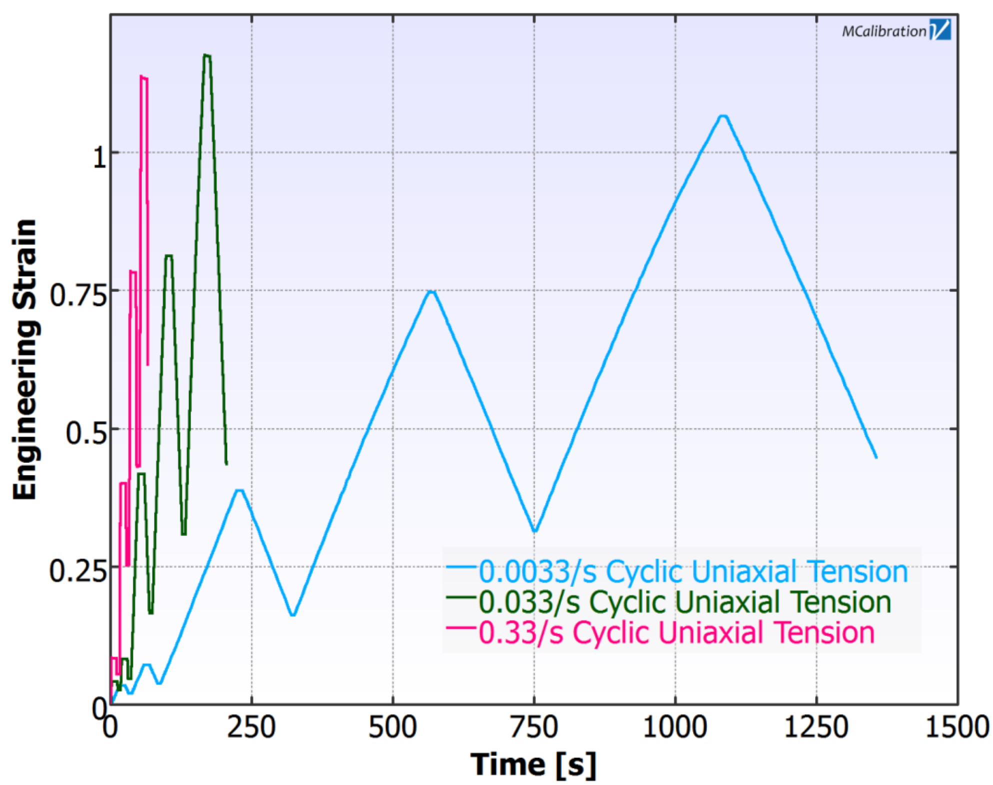
F-130- All Compression Data



Butyl 75A



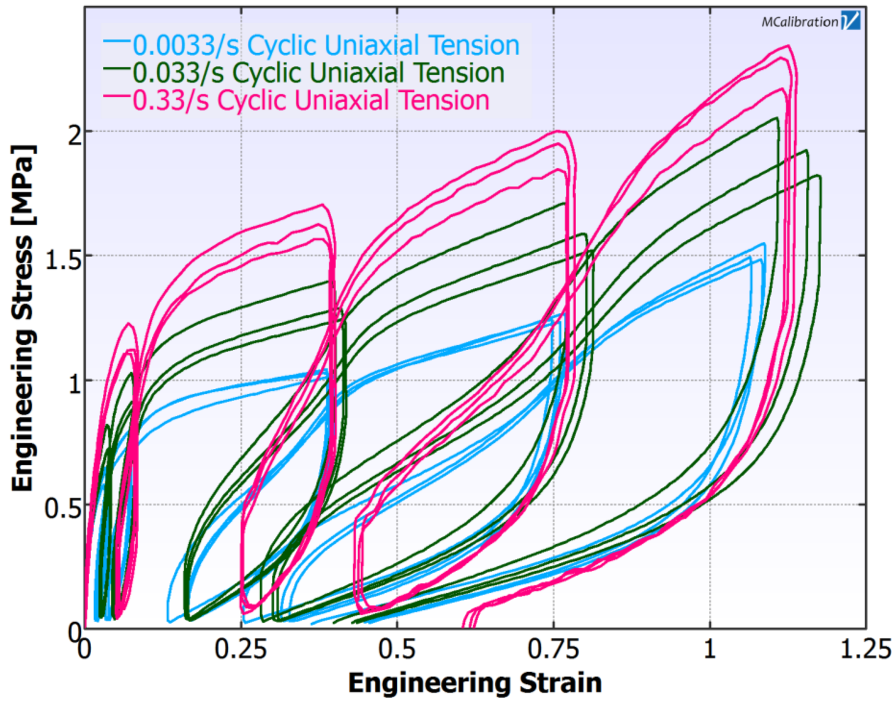
Tension



Cyclic Tension

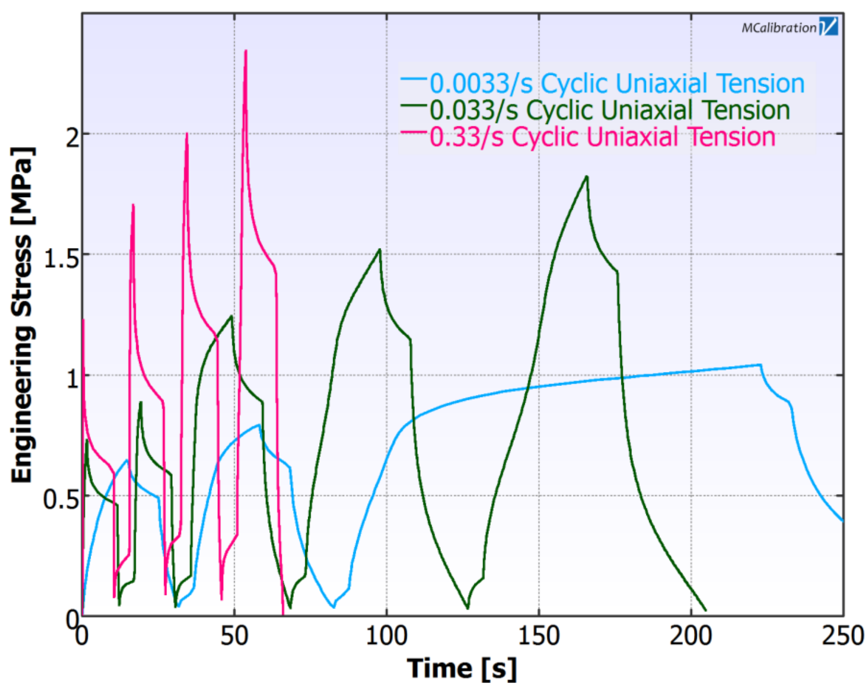
Strain History

Butyl 75A



Cyclic Tension

Results



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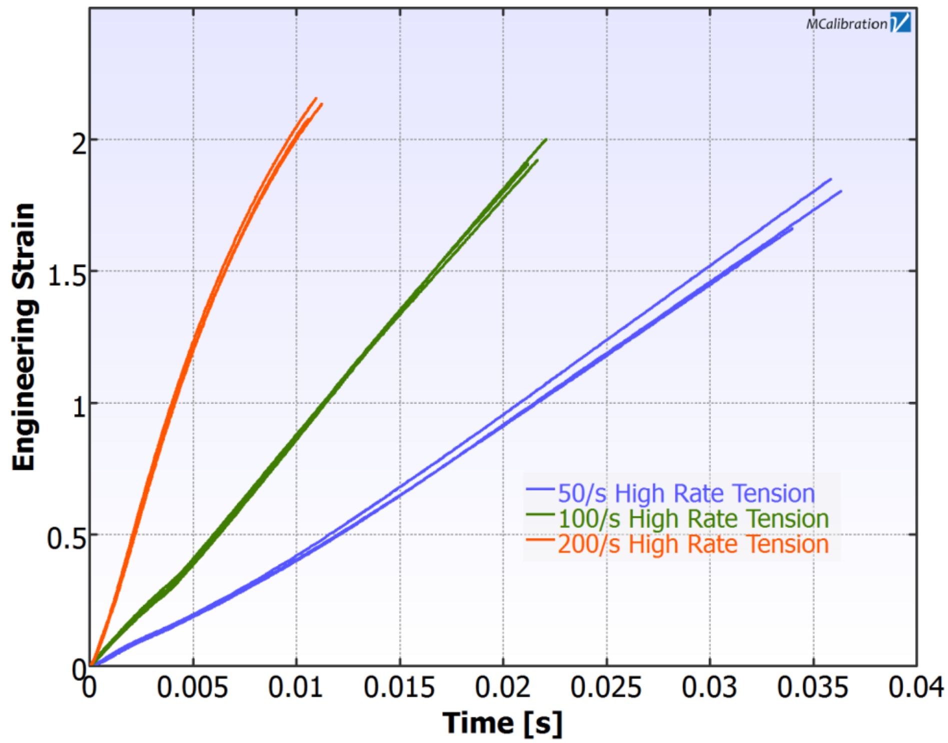
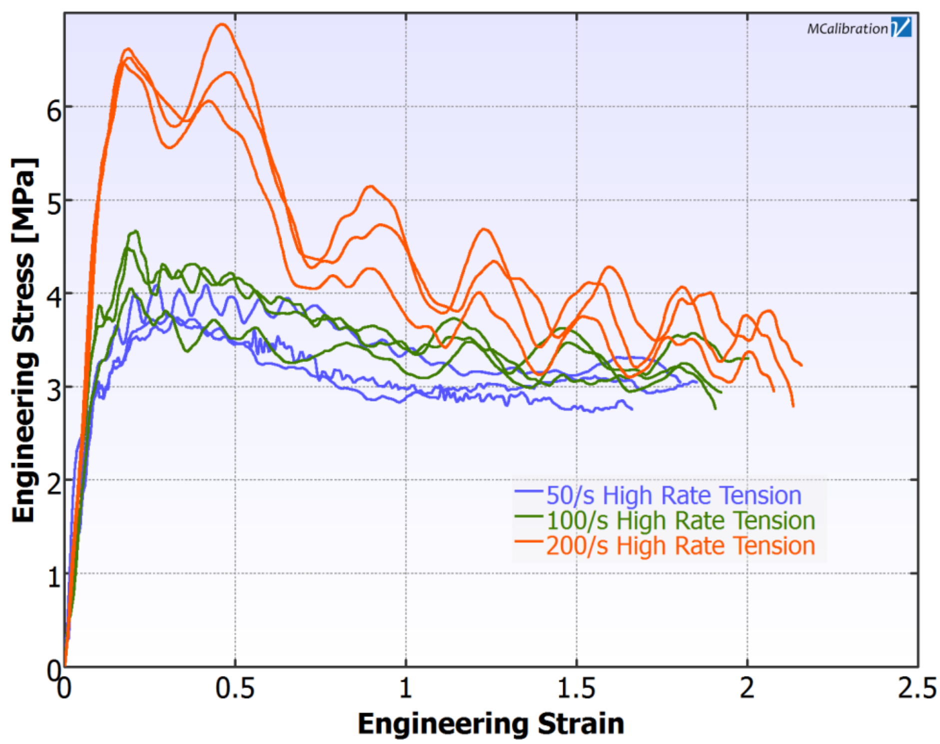


High Rate Tension

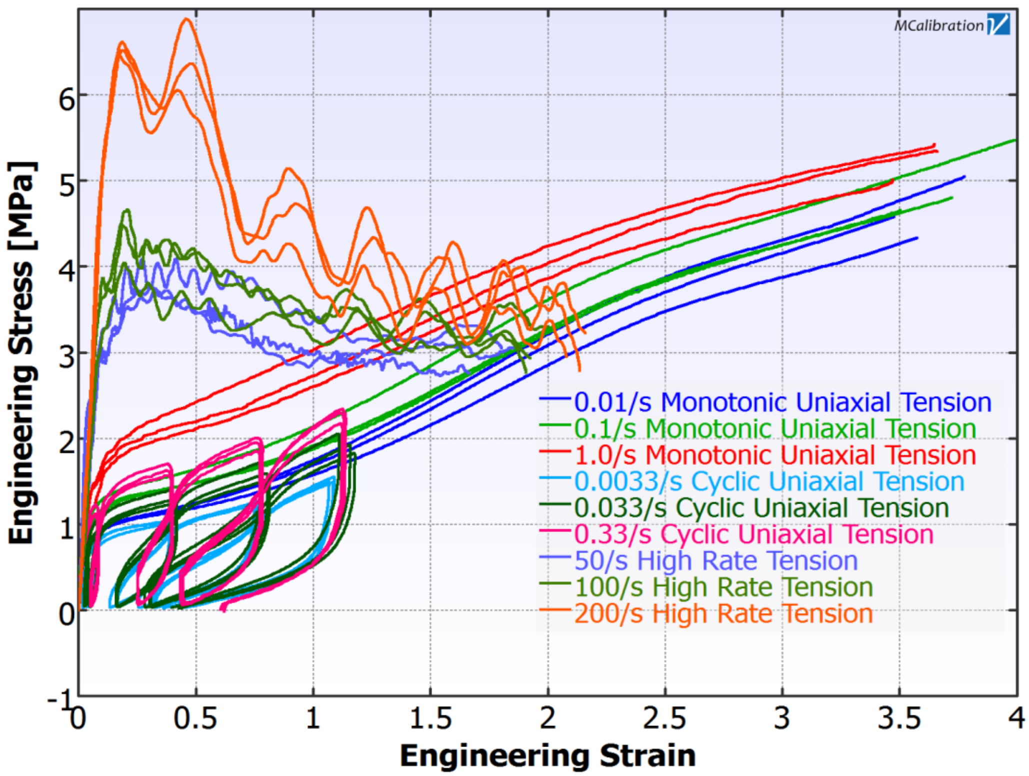
Strain History



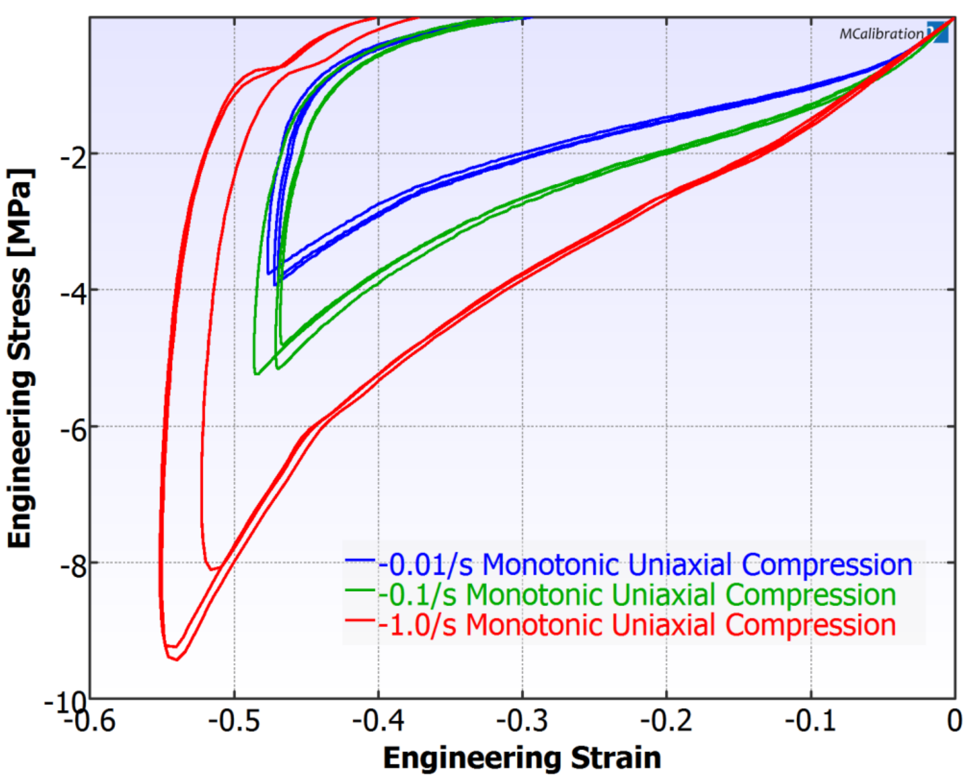
High Rate Tension

Results

Butyl 75A

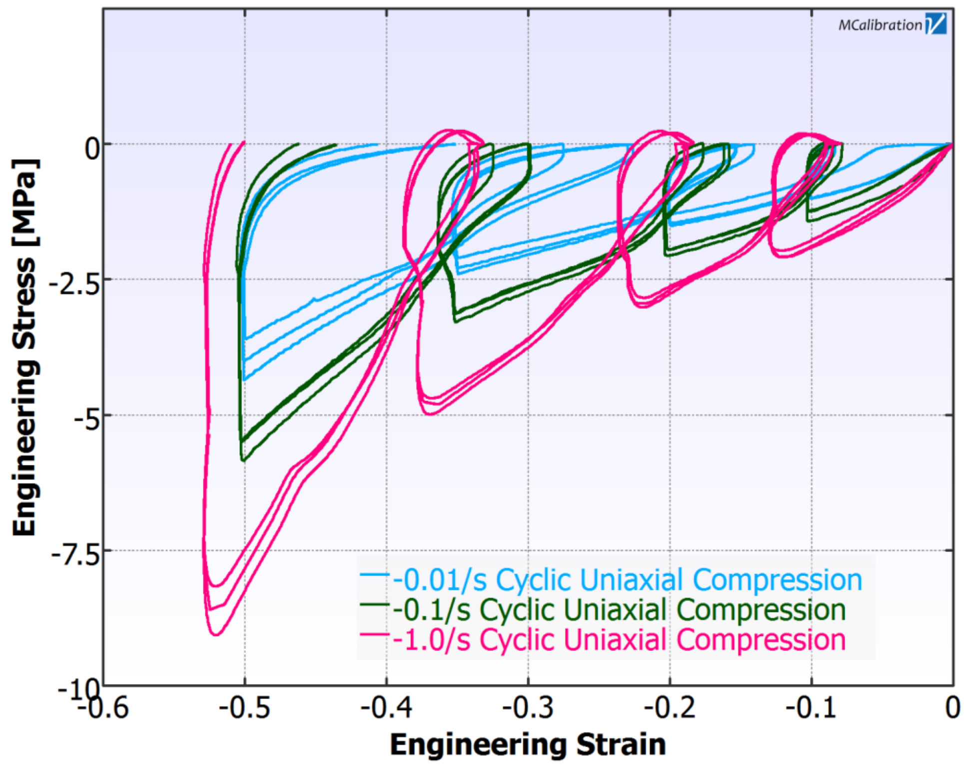


All Tension Data

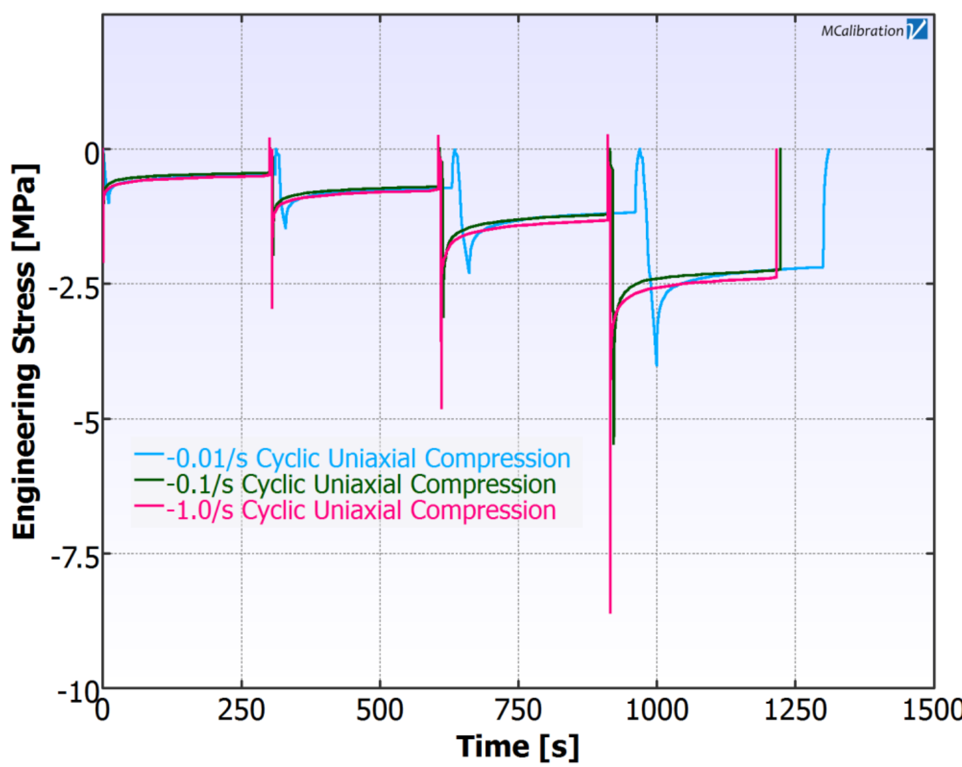


Slow Rate Compression

Butyl 75A



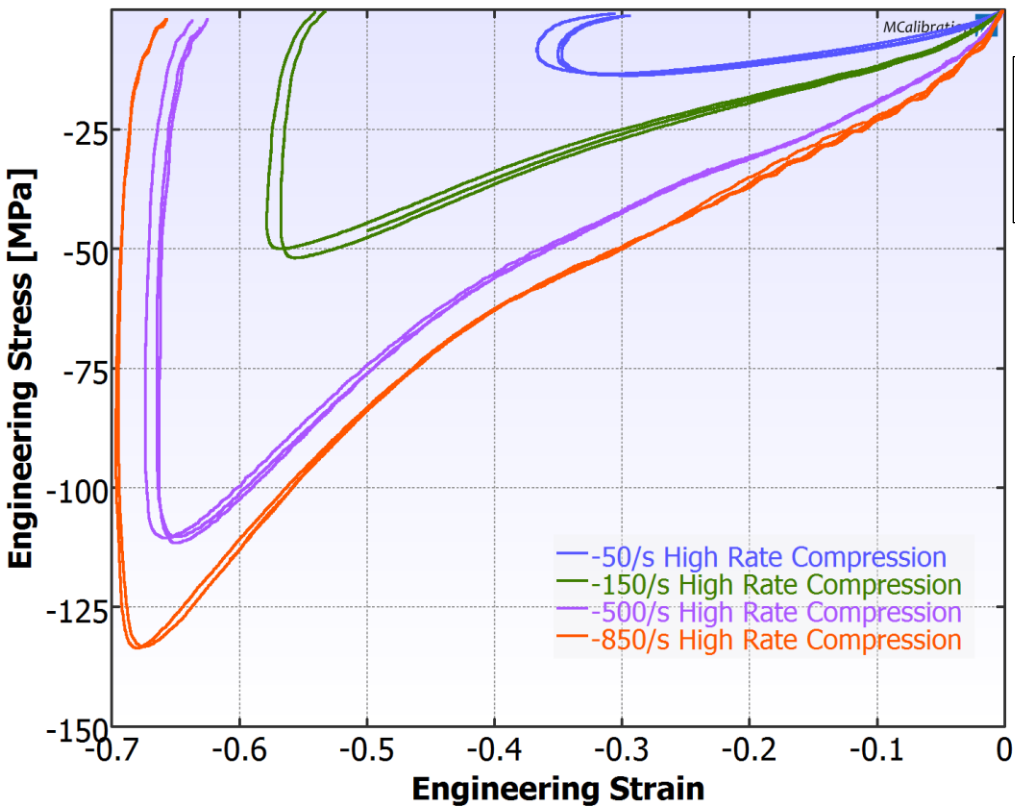
Cyclic Compression



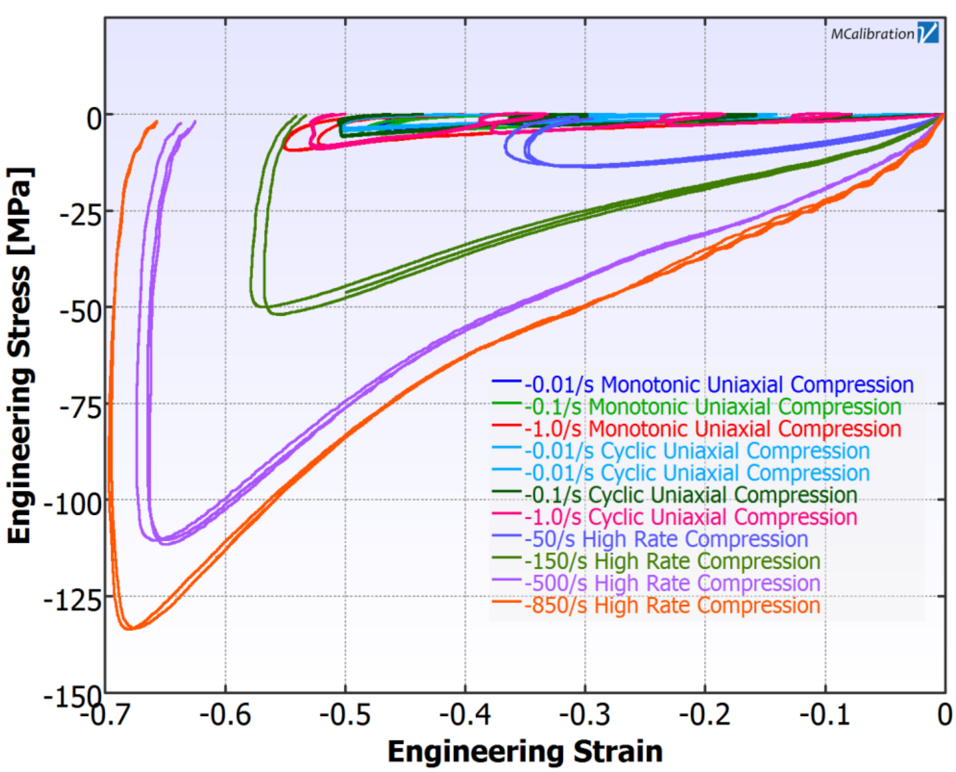
Cyclic Compression

5 minute hold segments

Butyl 75A

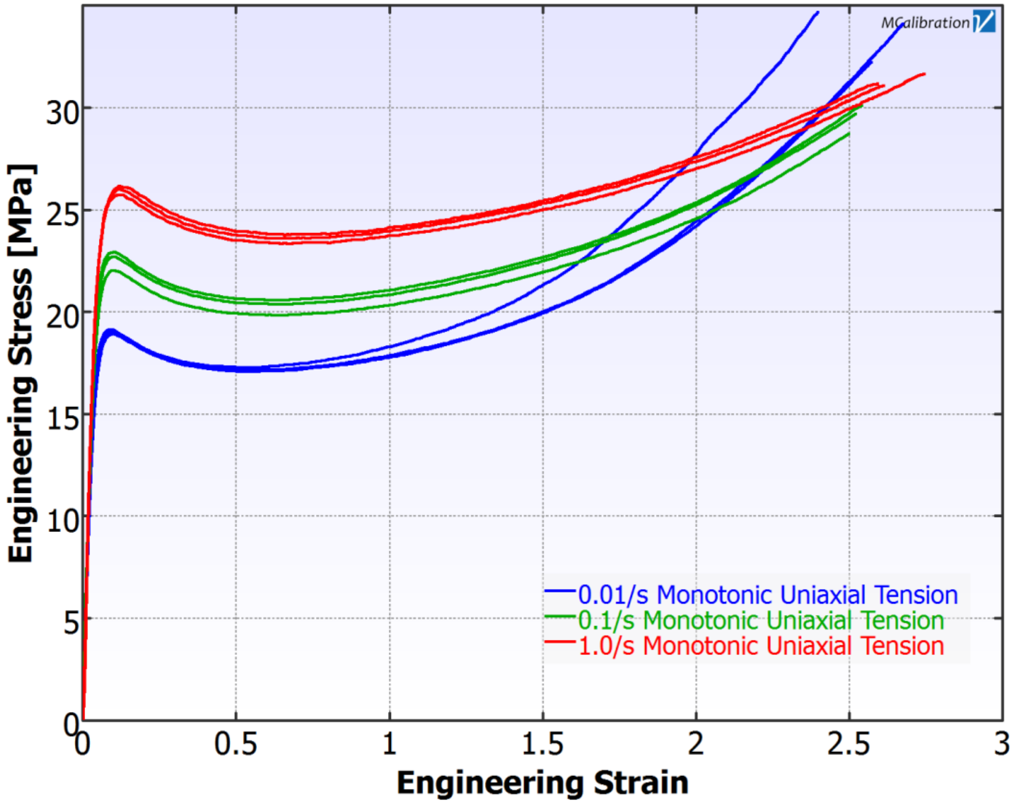


High Rate Compression

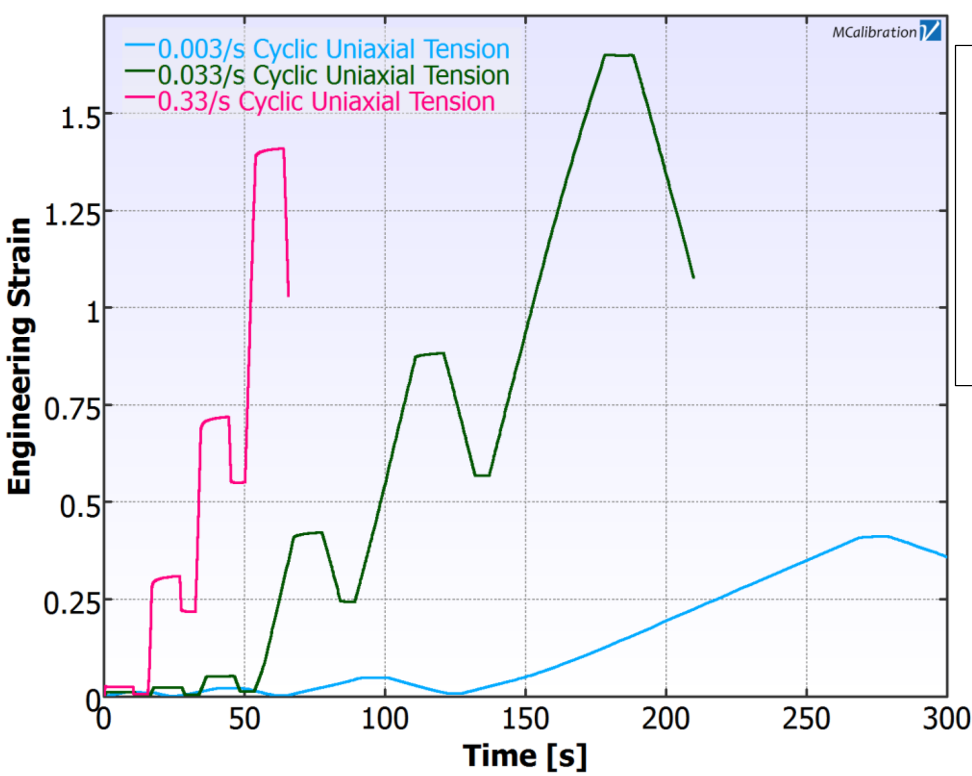


All Compression Data

FD-70

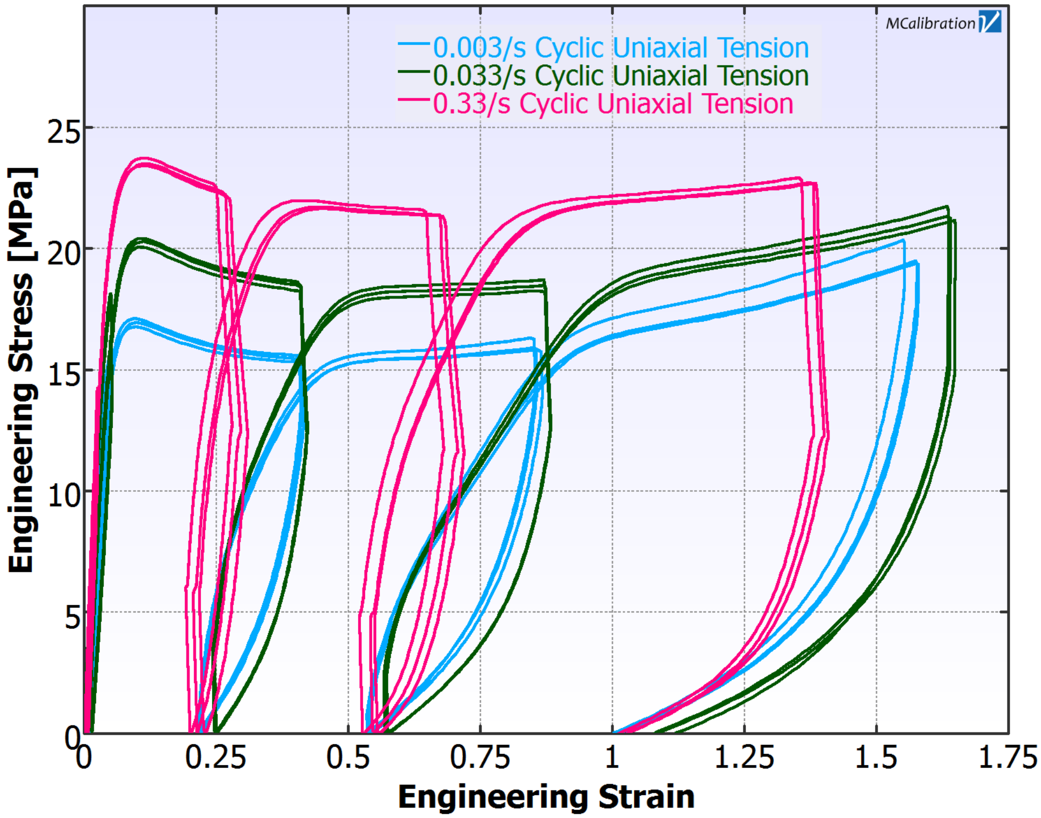


Tension

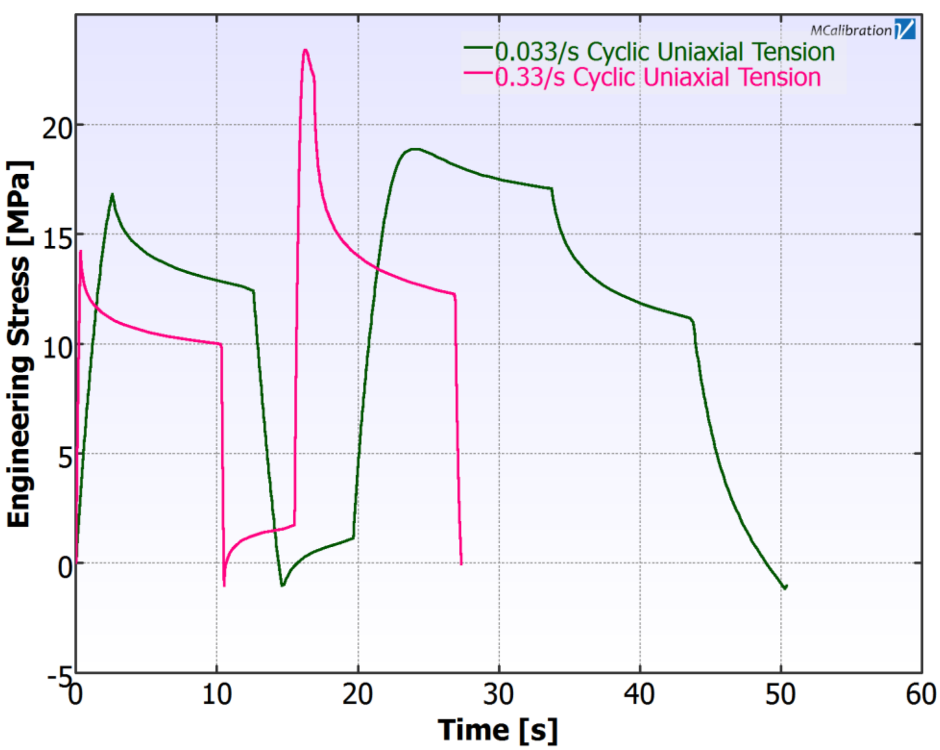


Cyclic Tension Strain History

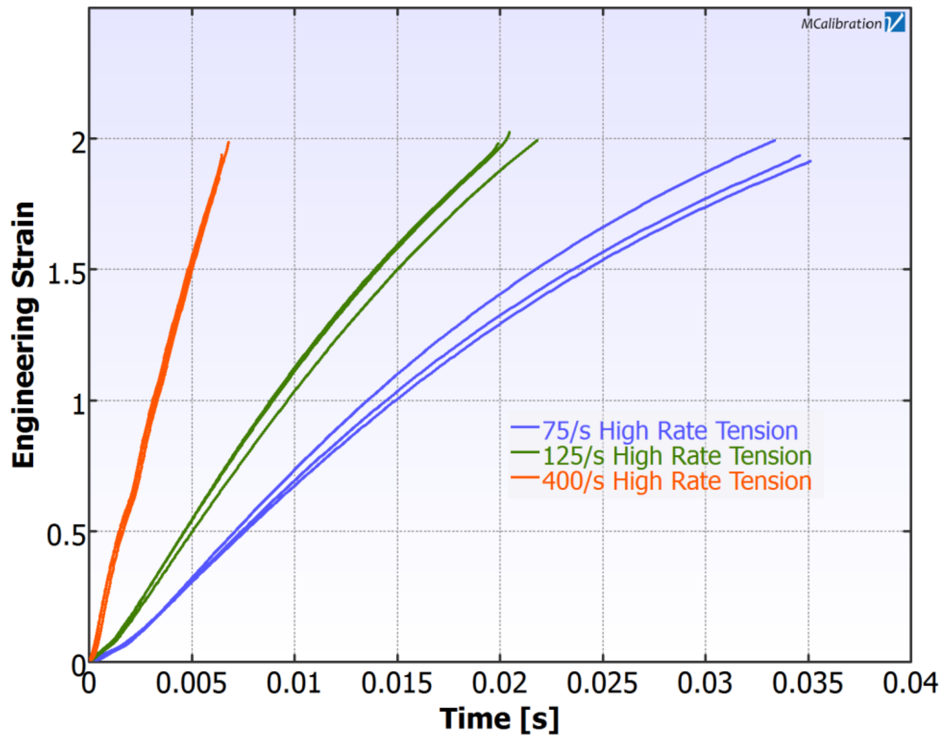
FD-70



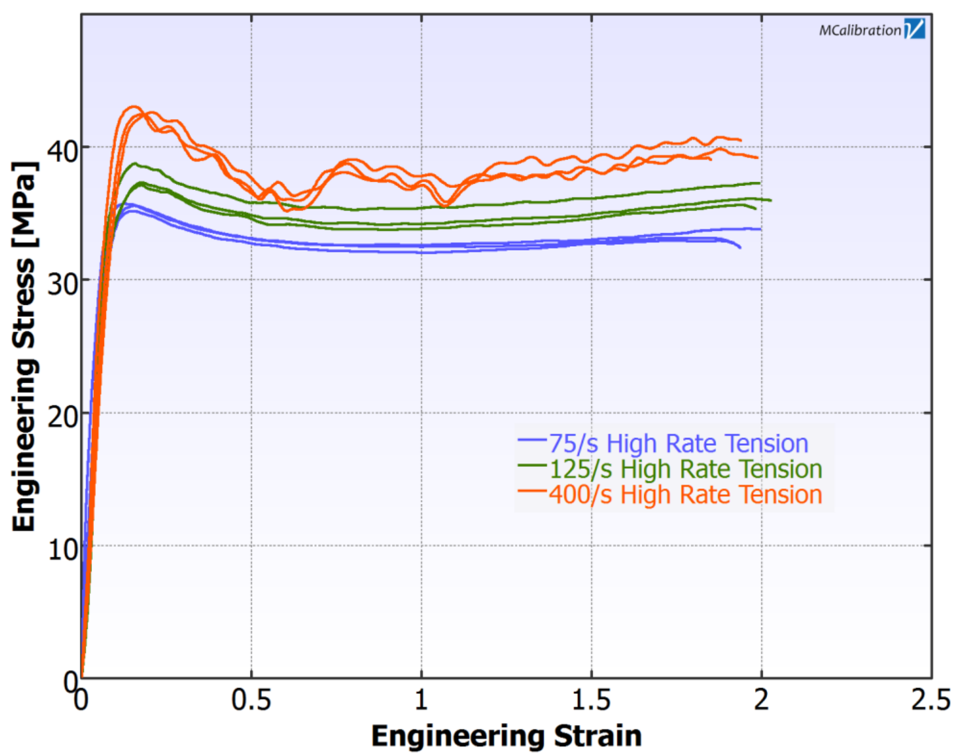
Cyclic Tension Results



FD-70

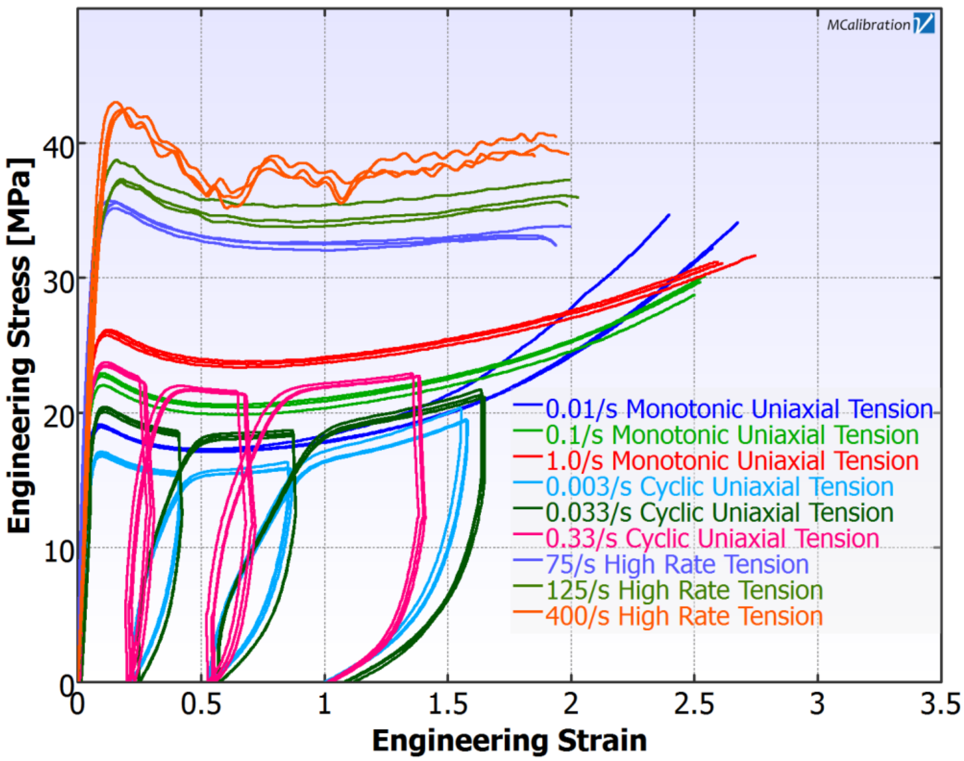


High Rate Tension Strain History



High Rate Tension Results

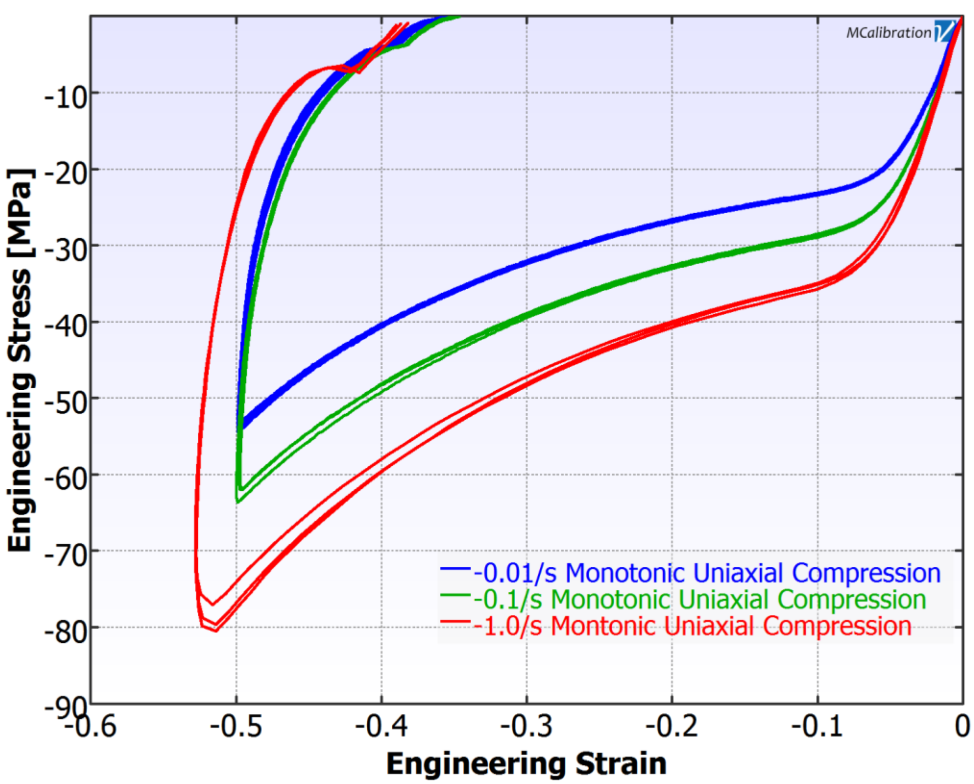
FD-70



All

Tension

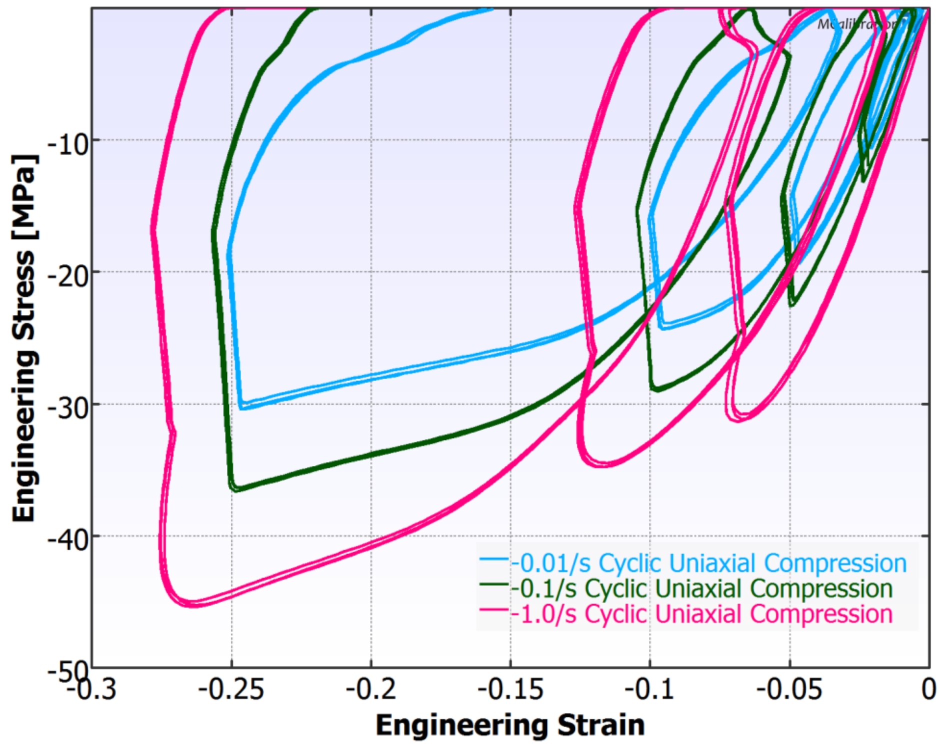
Data



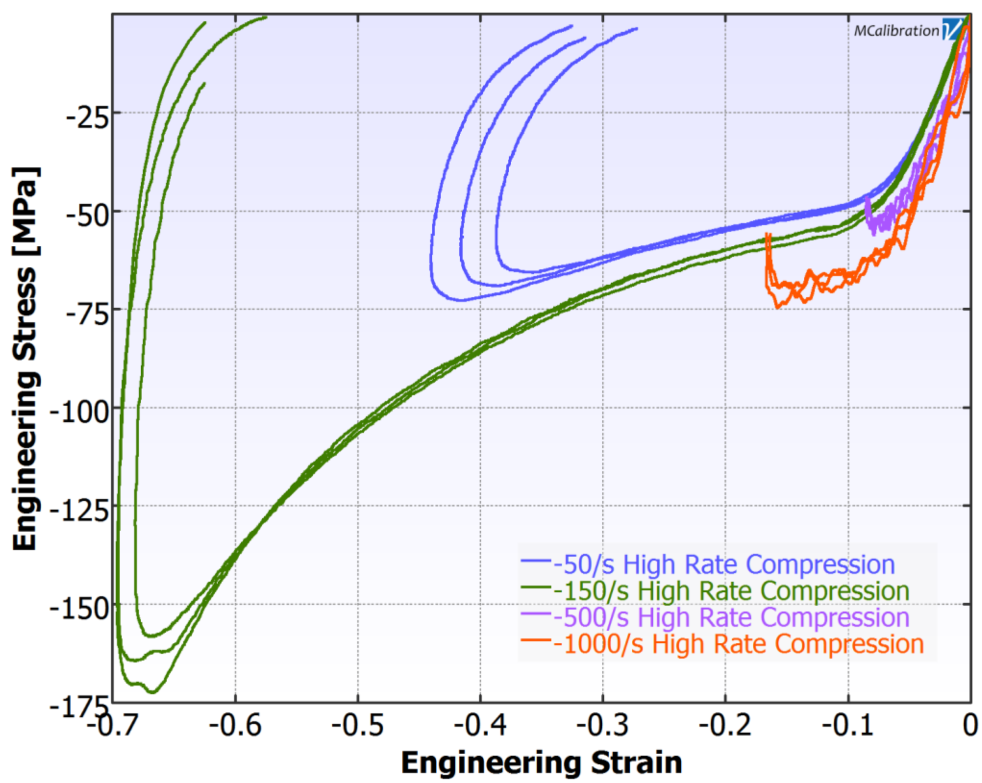
Slow Rate

Compression

FD-70



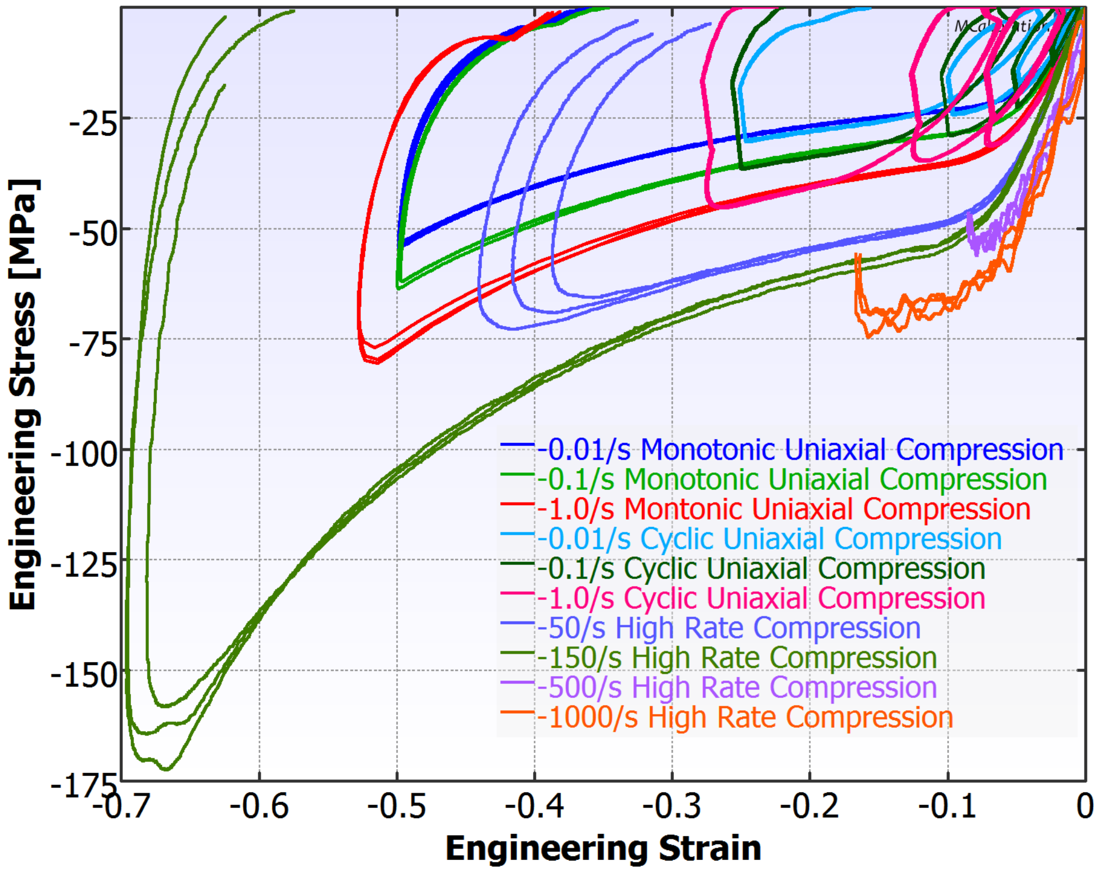
Cyclic Compression



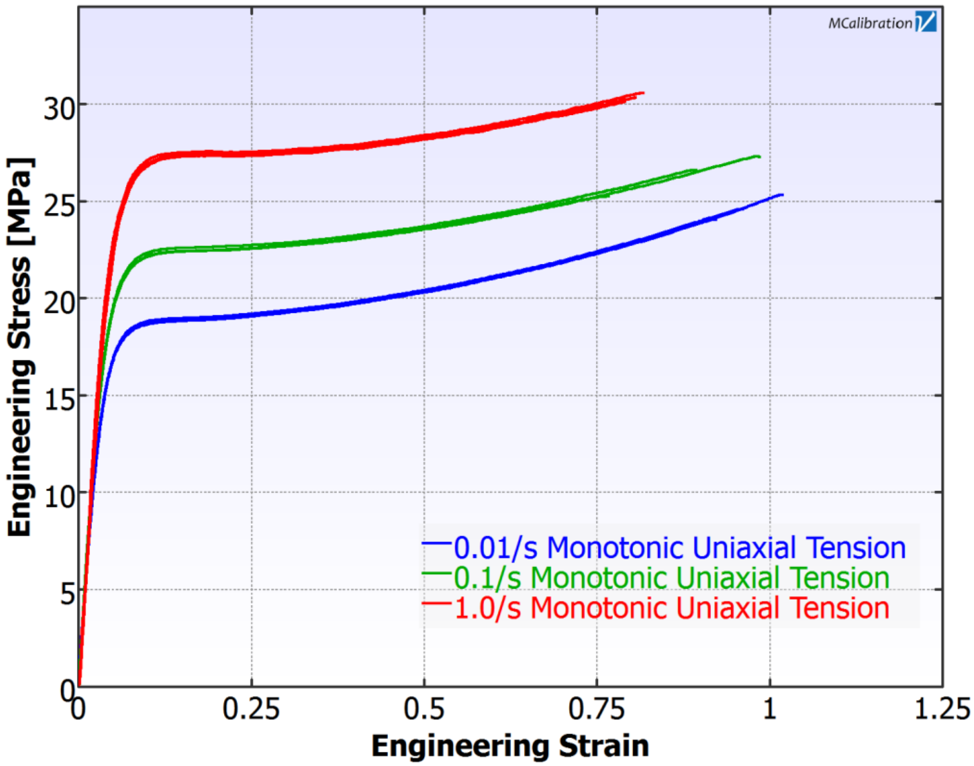
High Rate Compression

FD-70

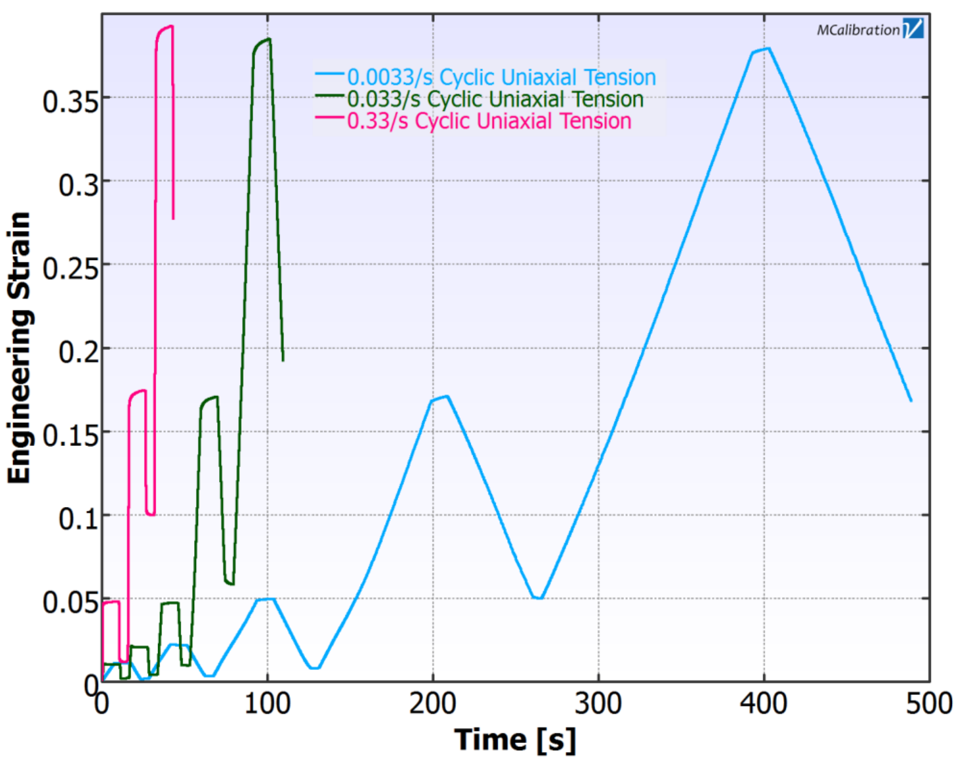
All Compression Data



Rencast 6425

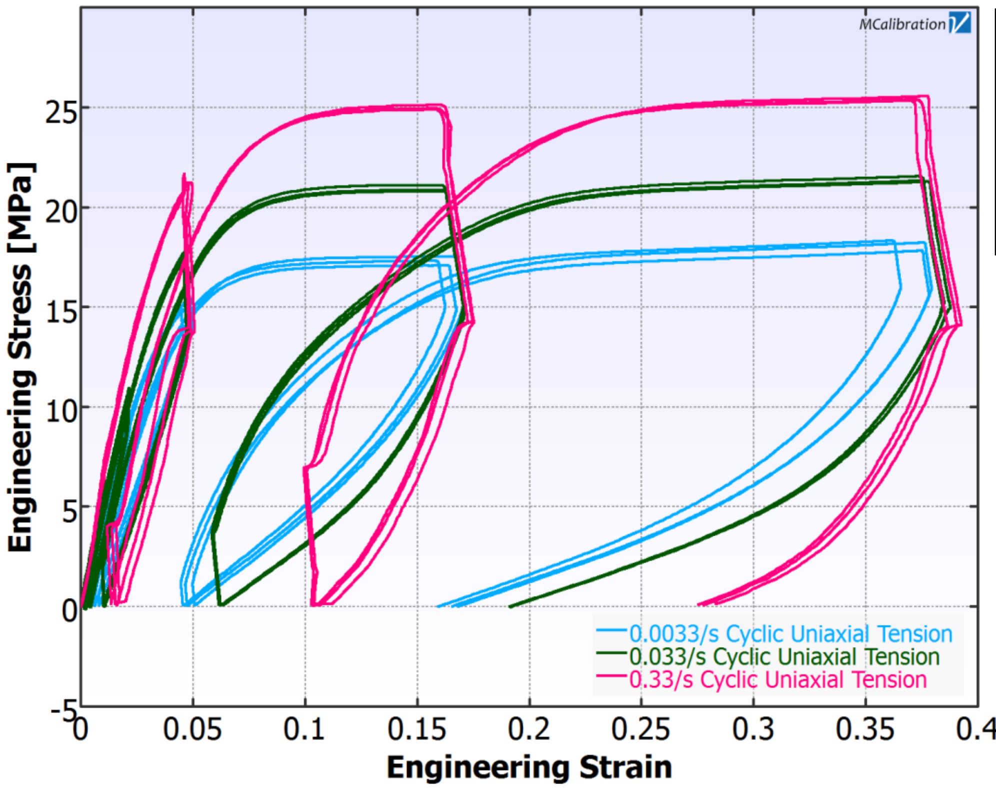


Slow Rate Tension

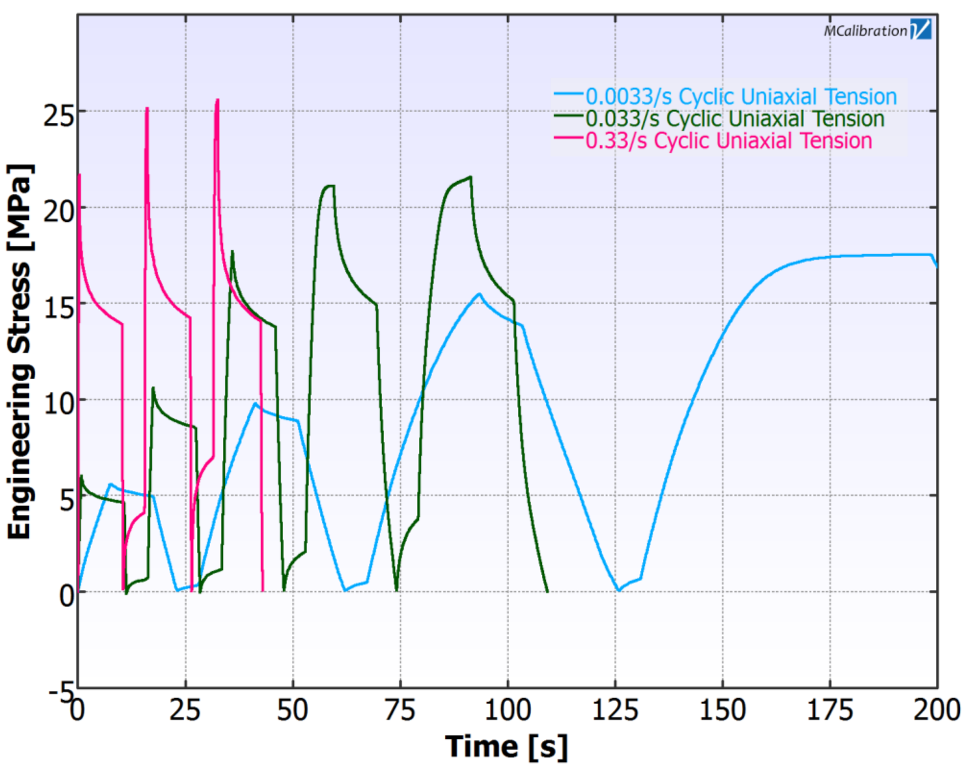


Cyclic Tension Strain History

Rencast 6425



Cyclic Tension Results



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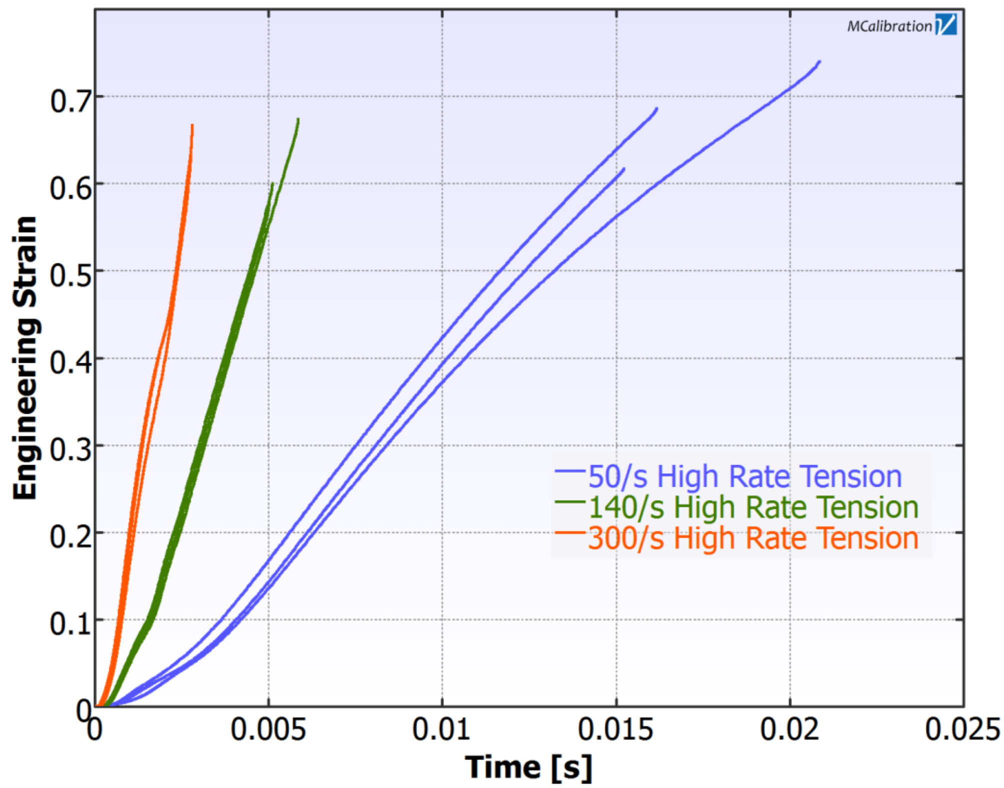
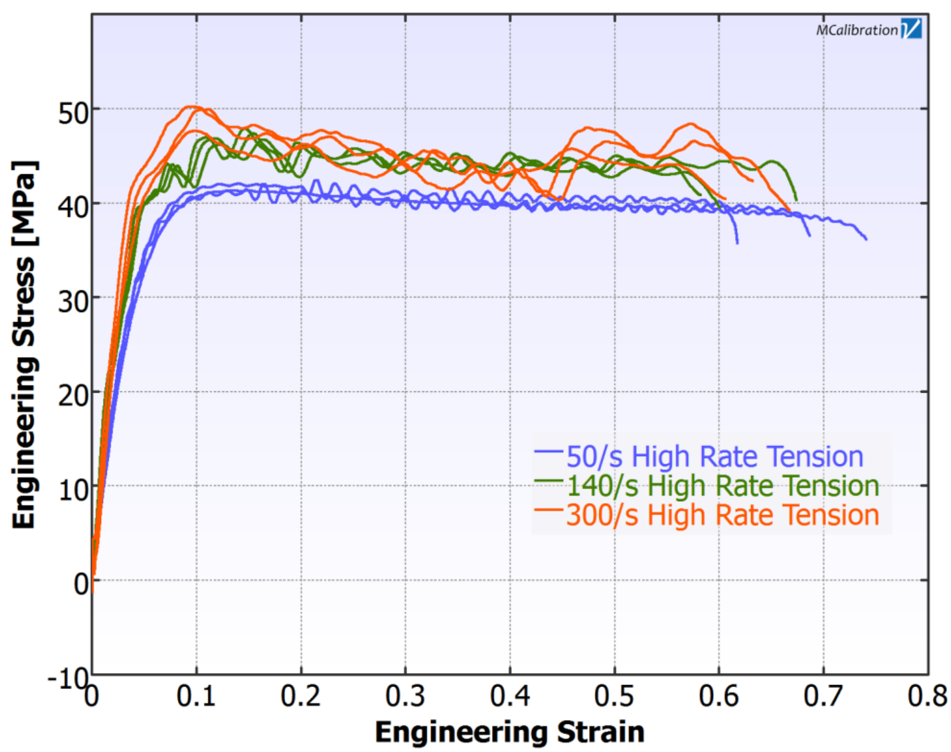


High Rate Tension Strain History



High Rate Tension Results

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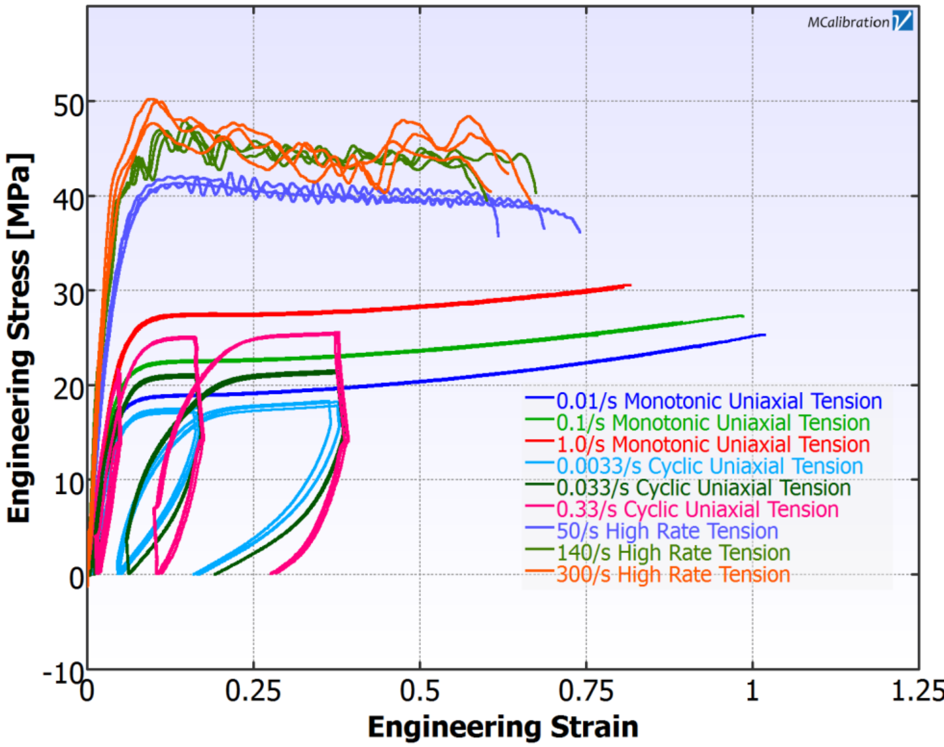
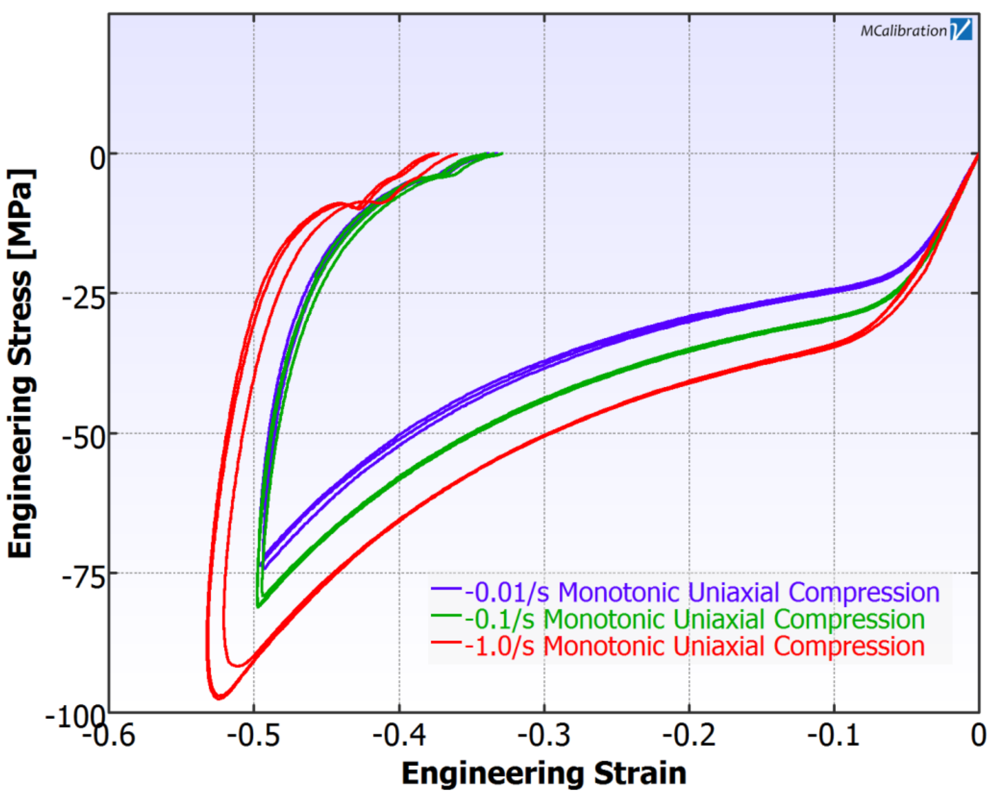


All

Tension

Data



Slow Rate Compression

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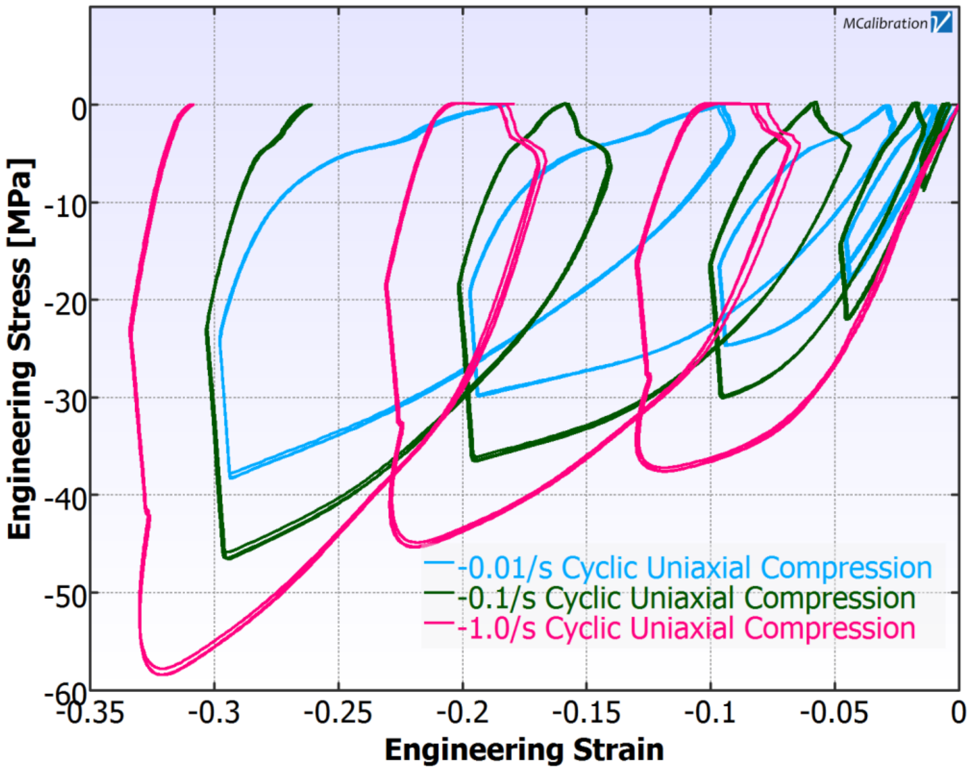

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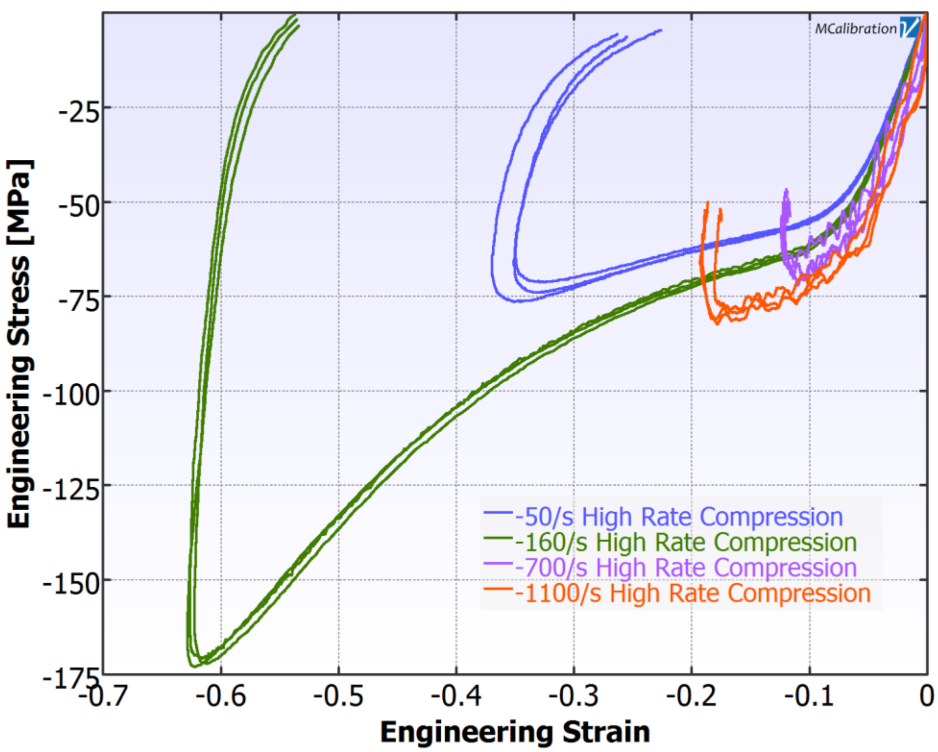

High Rate Compression

Rencast 6425

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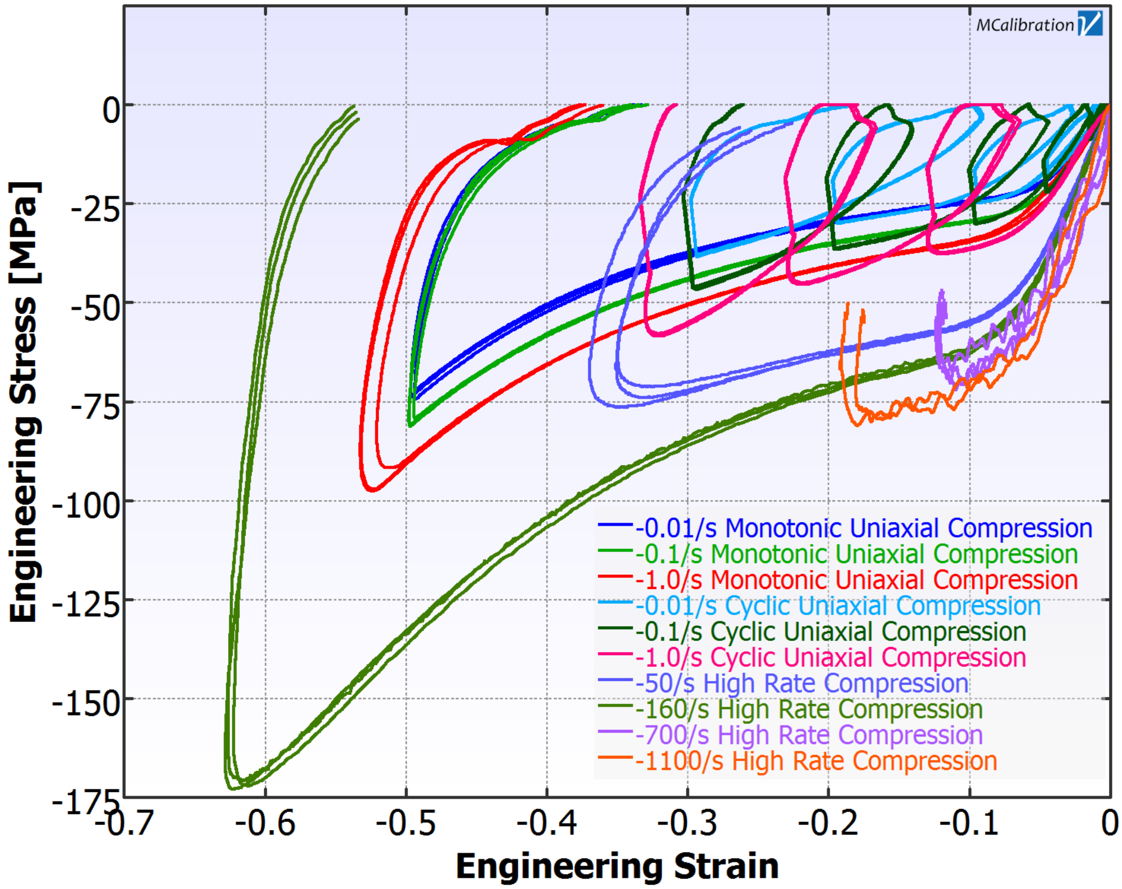

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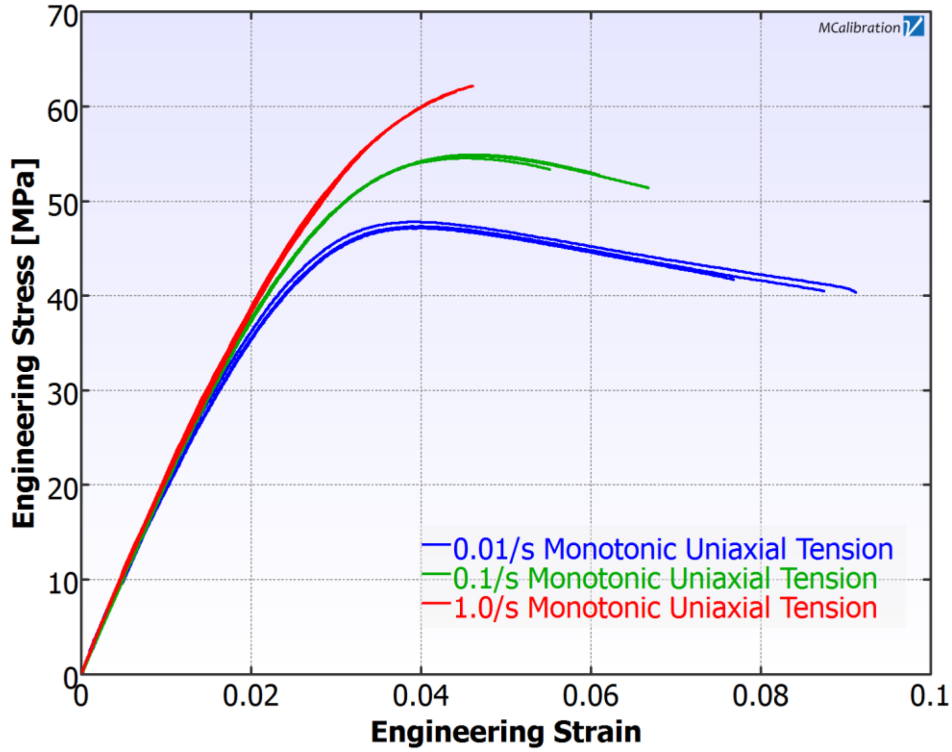

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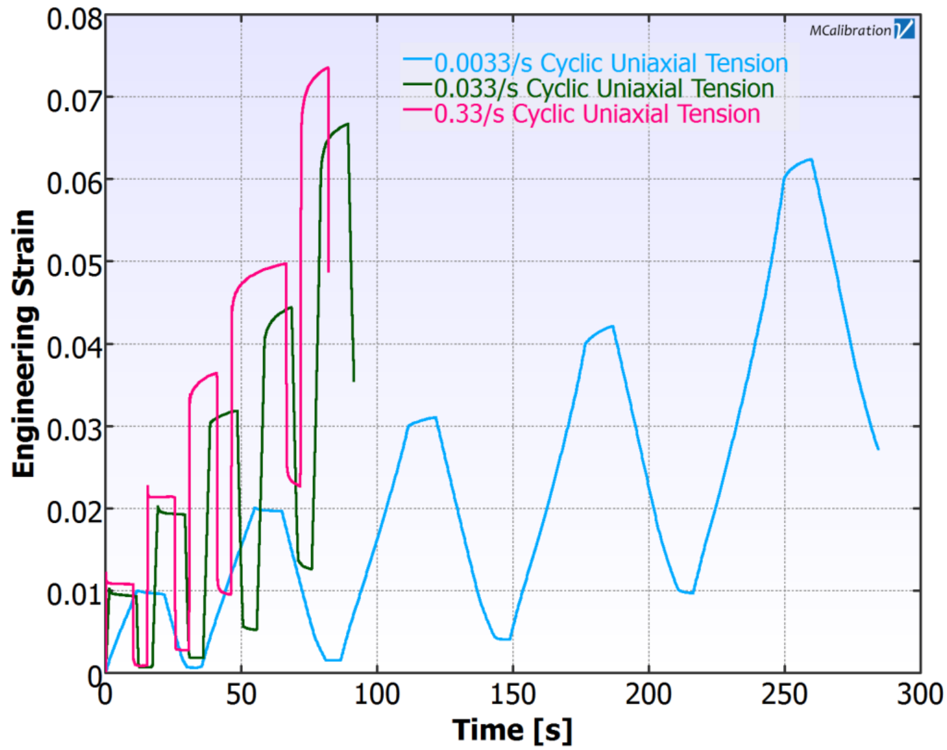

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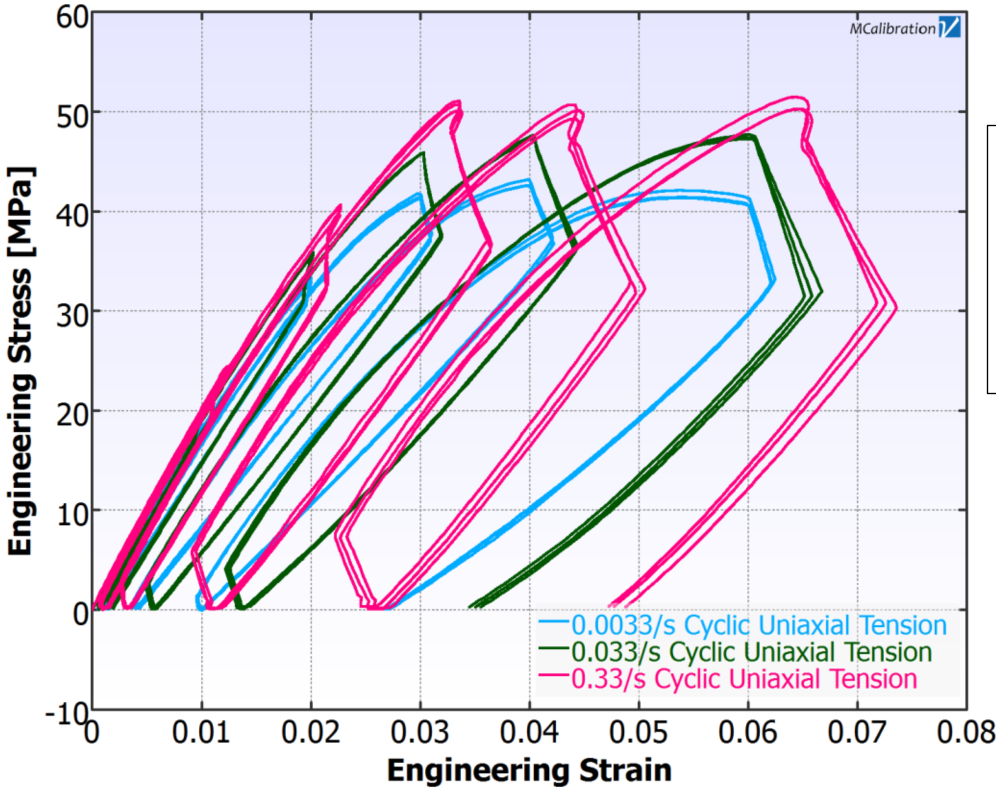

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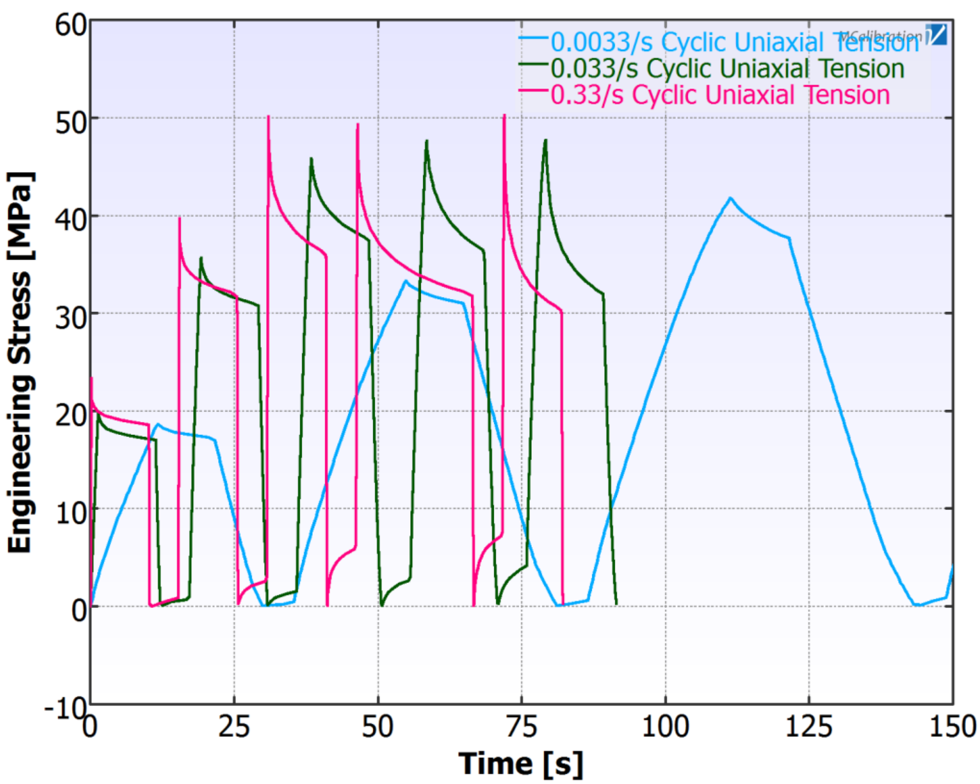

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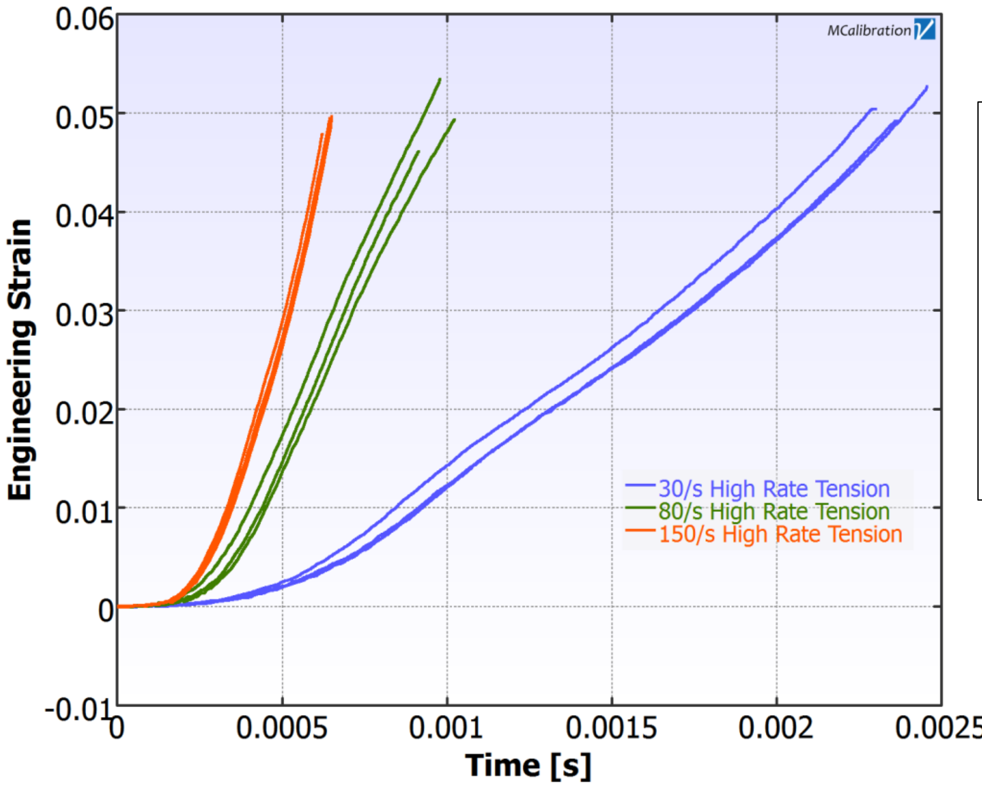

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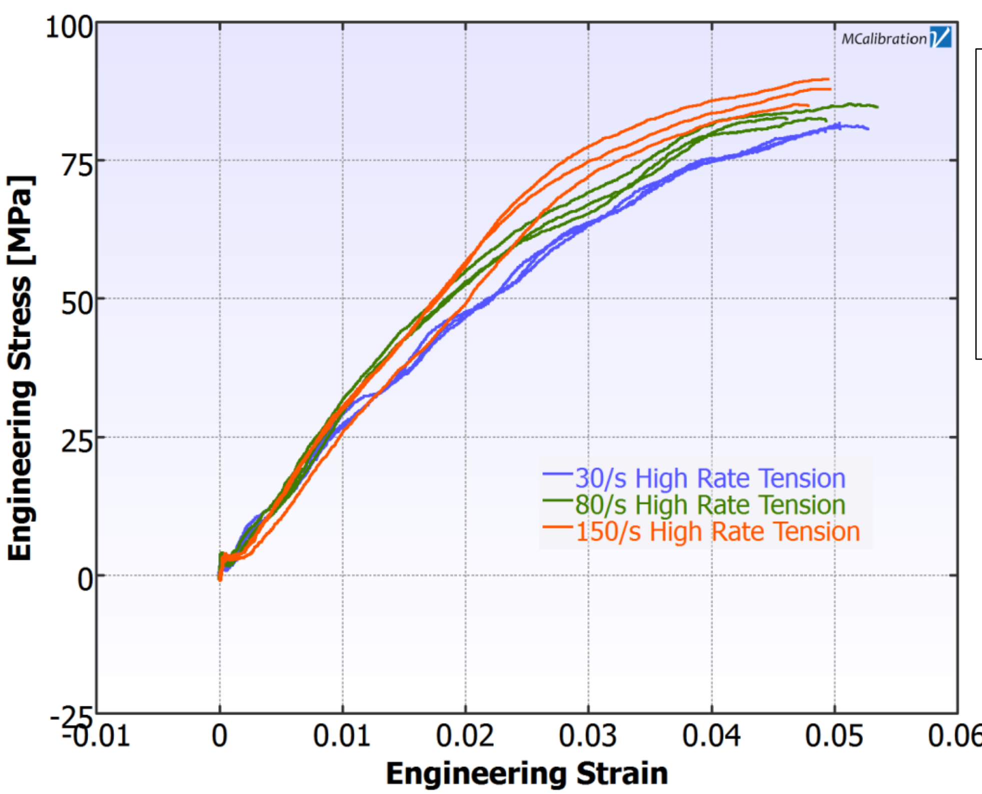

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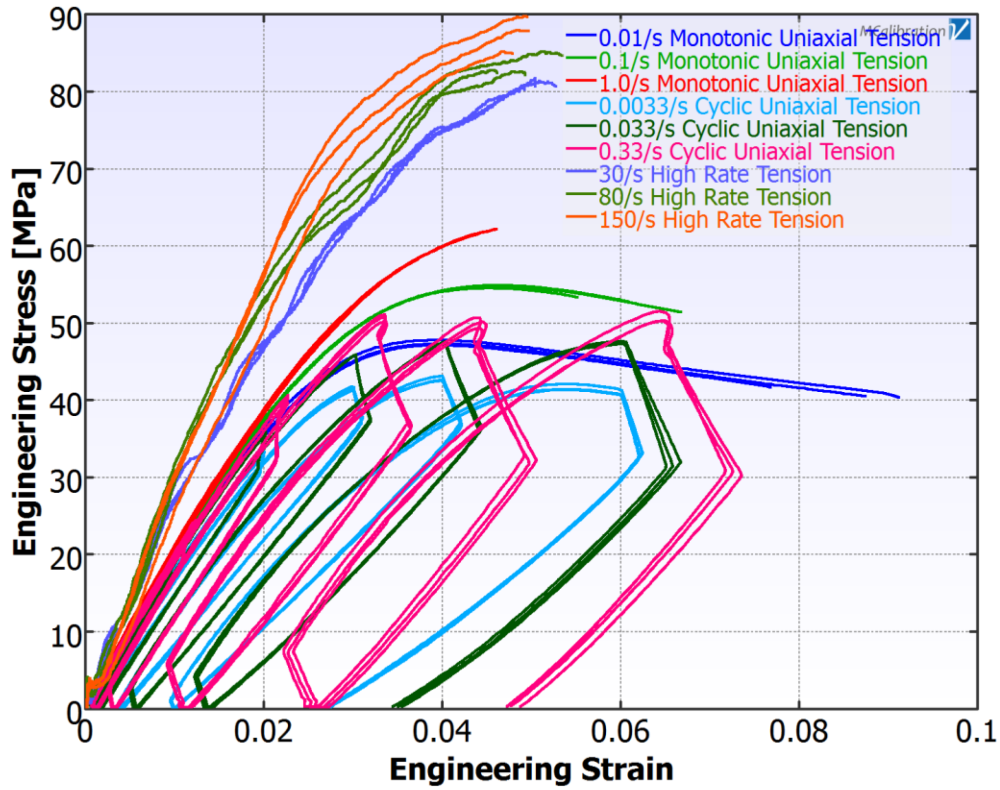

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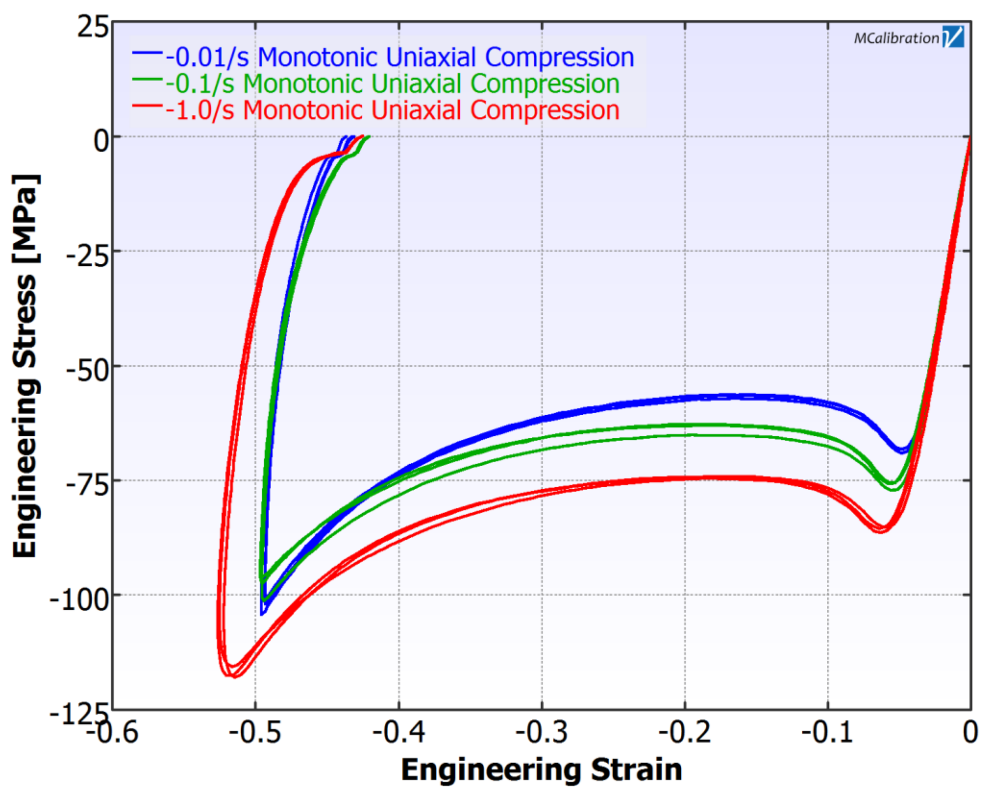

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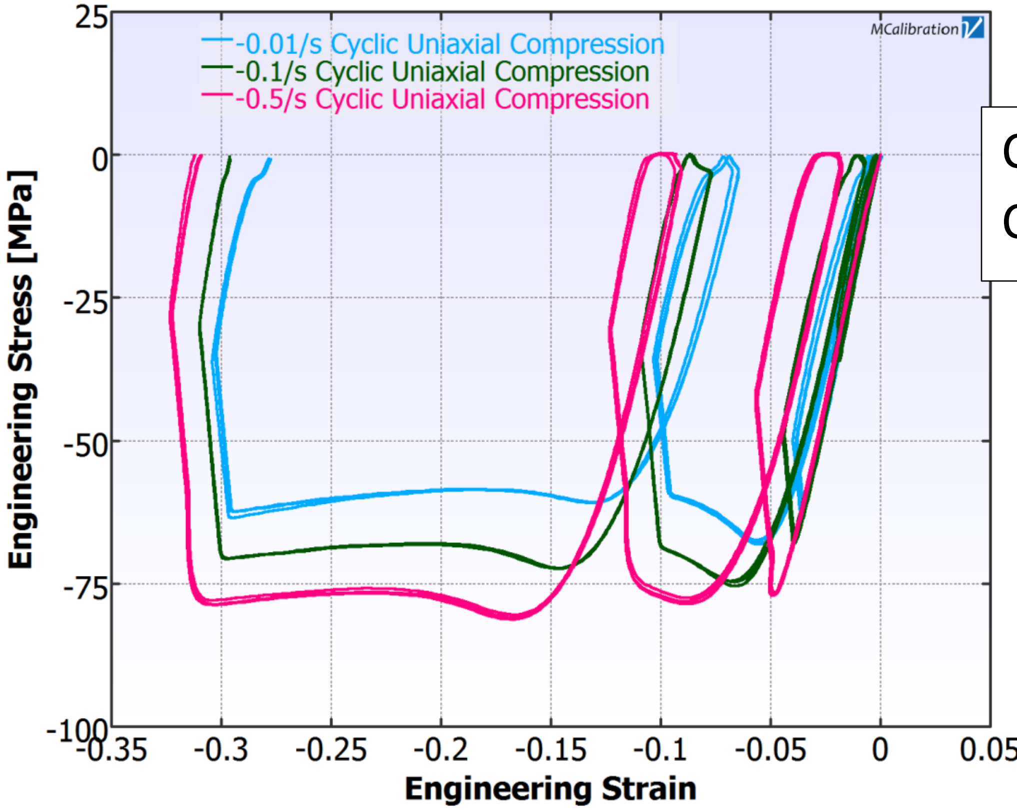

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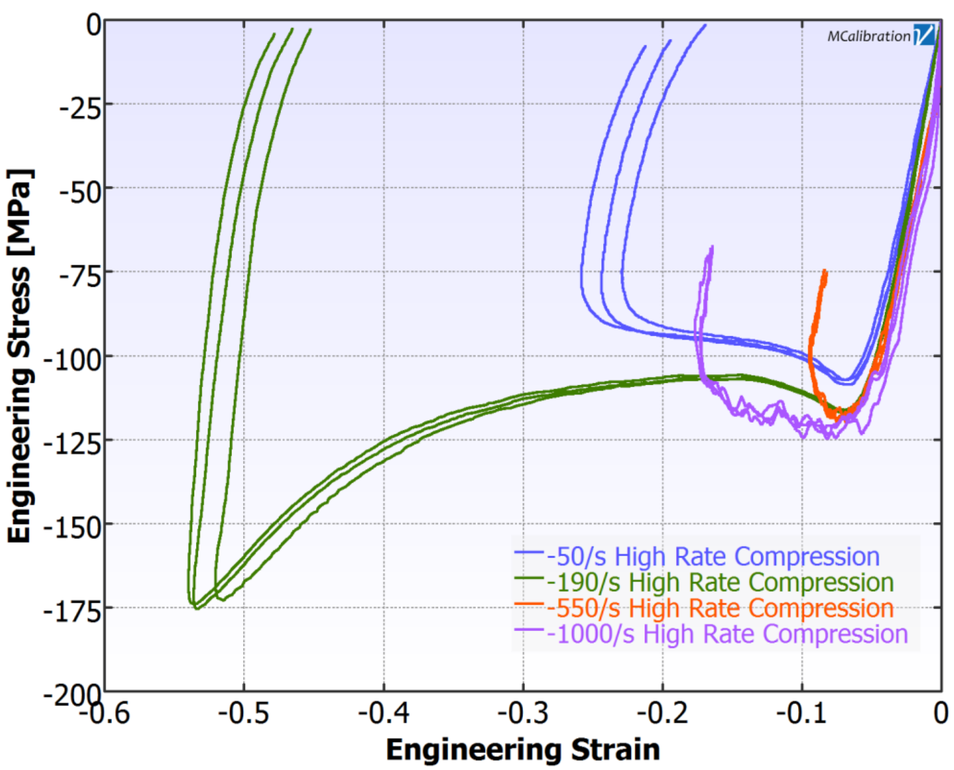

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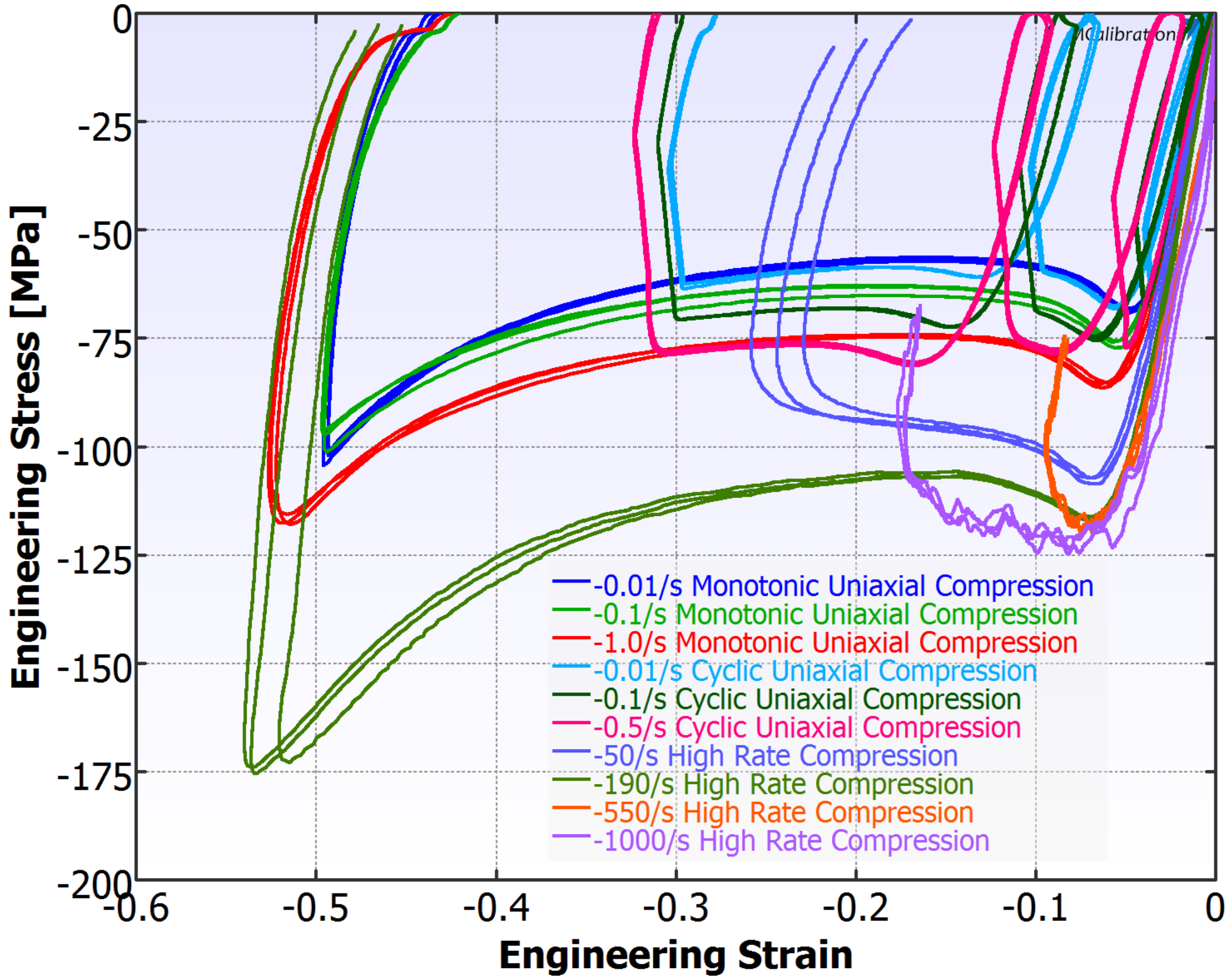

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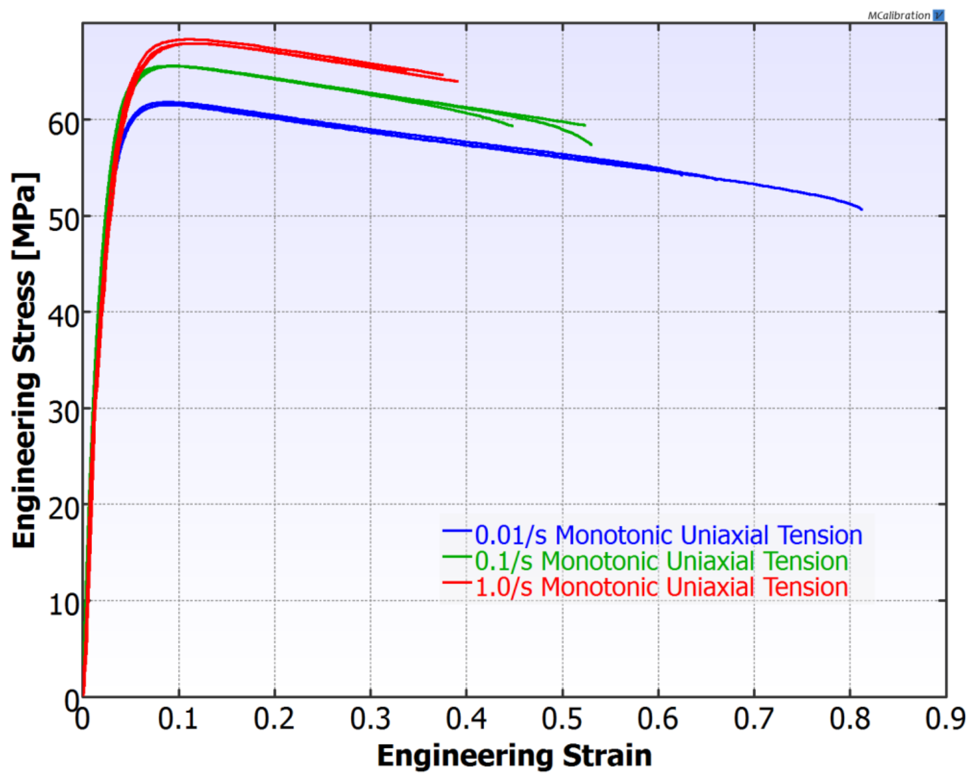

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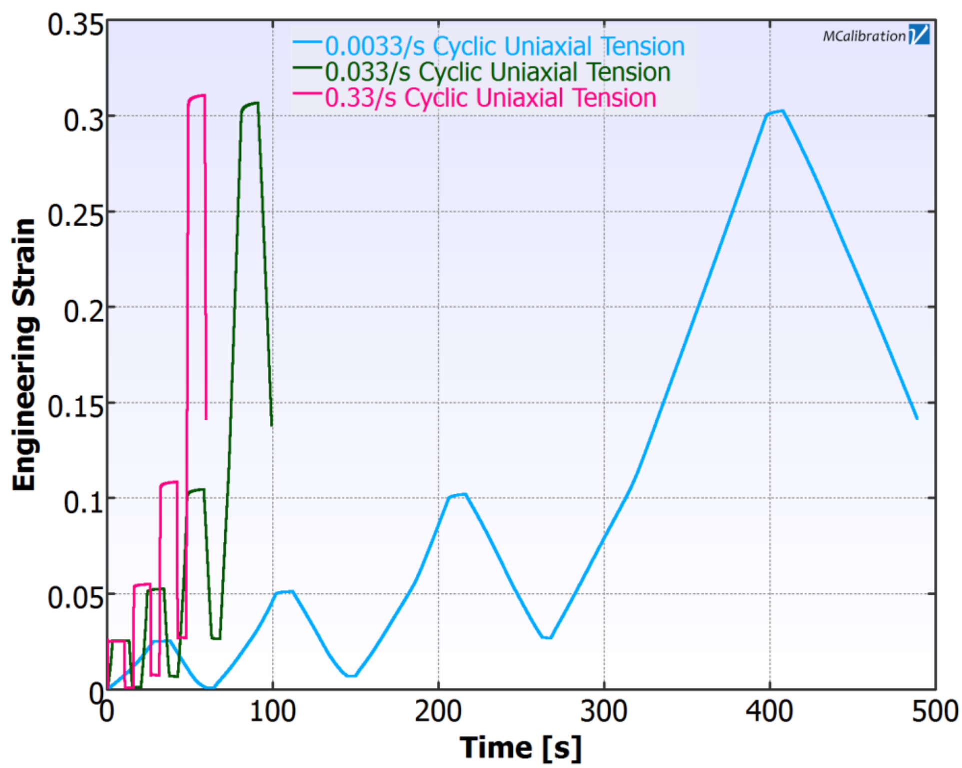

Cyclic Tension Strain History

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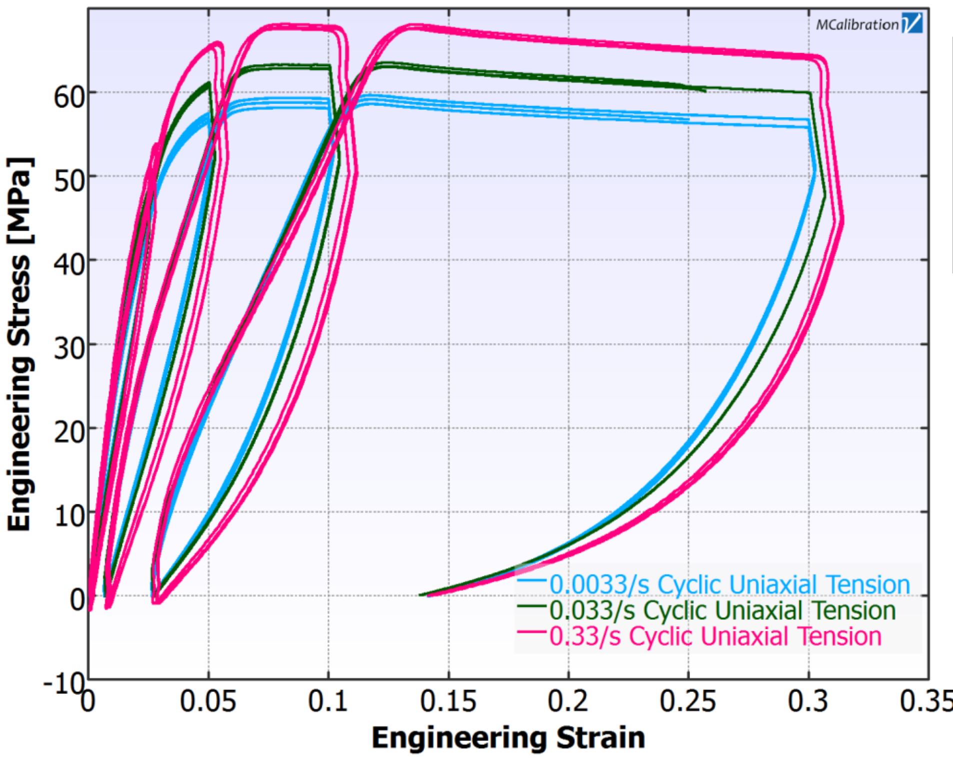

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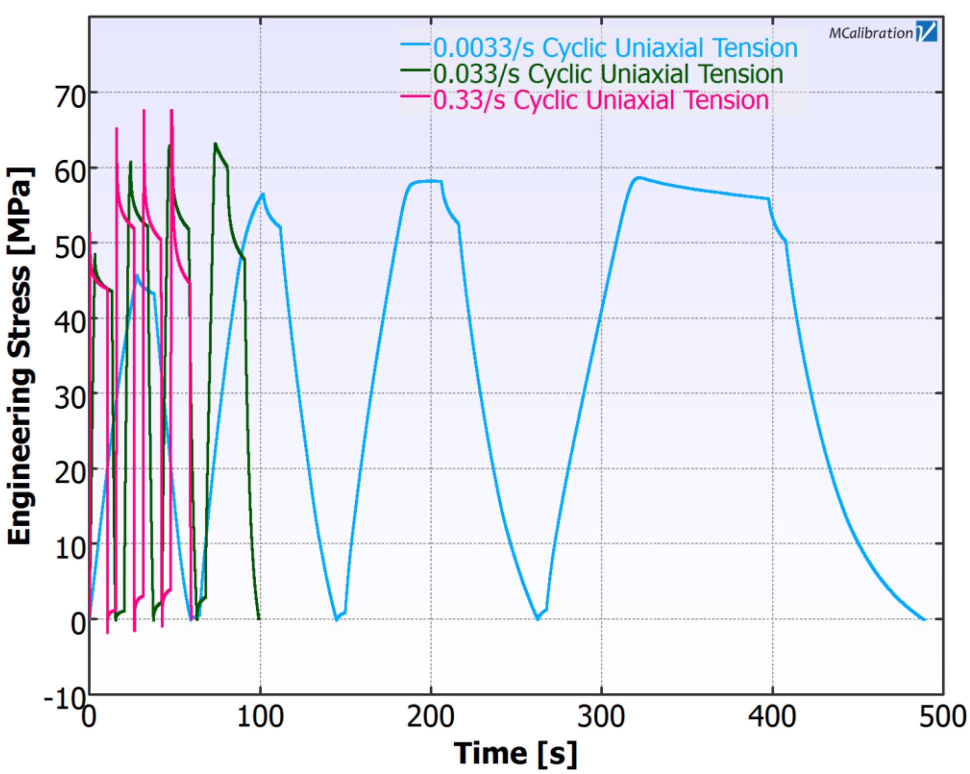

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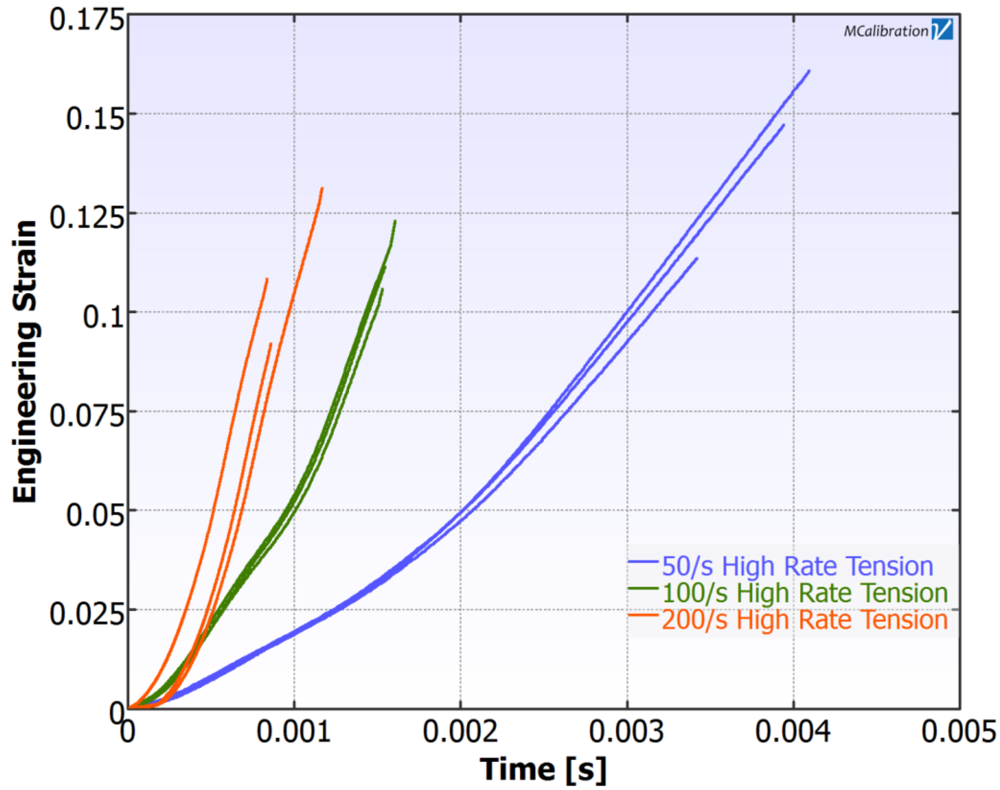

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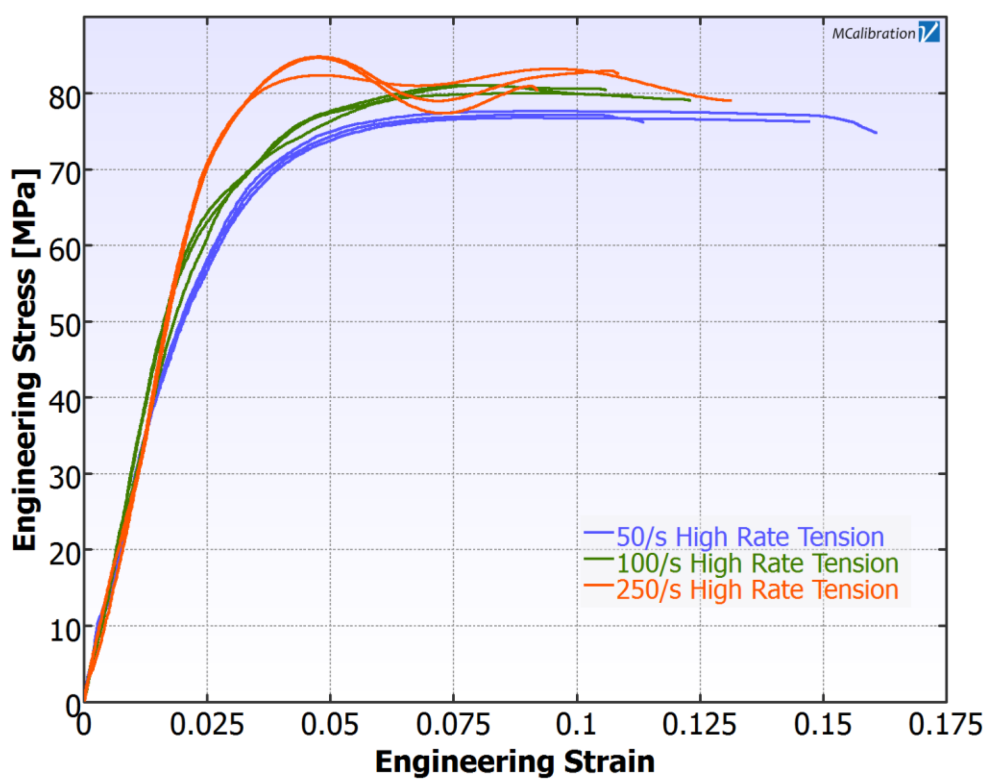
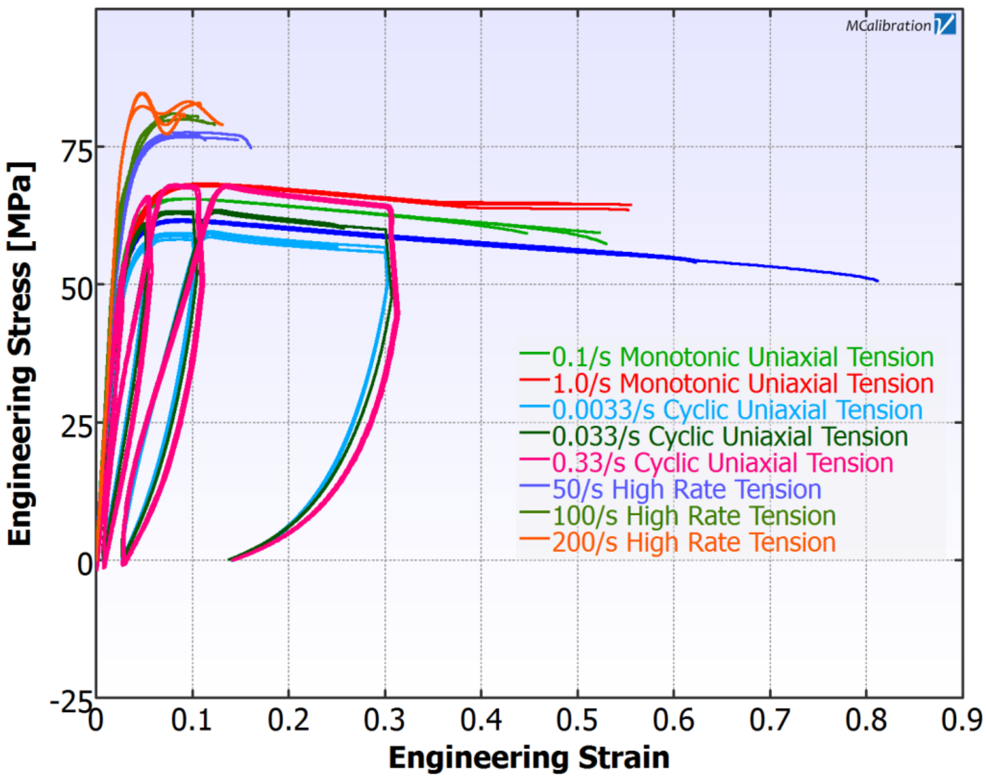


High Rate Tension Results

Delrin



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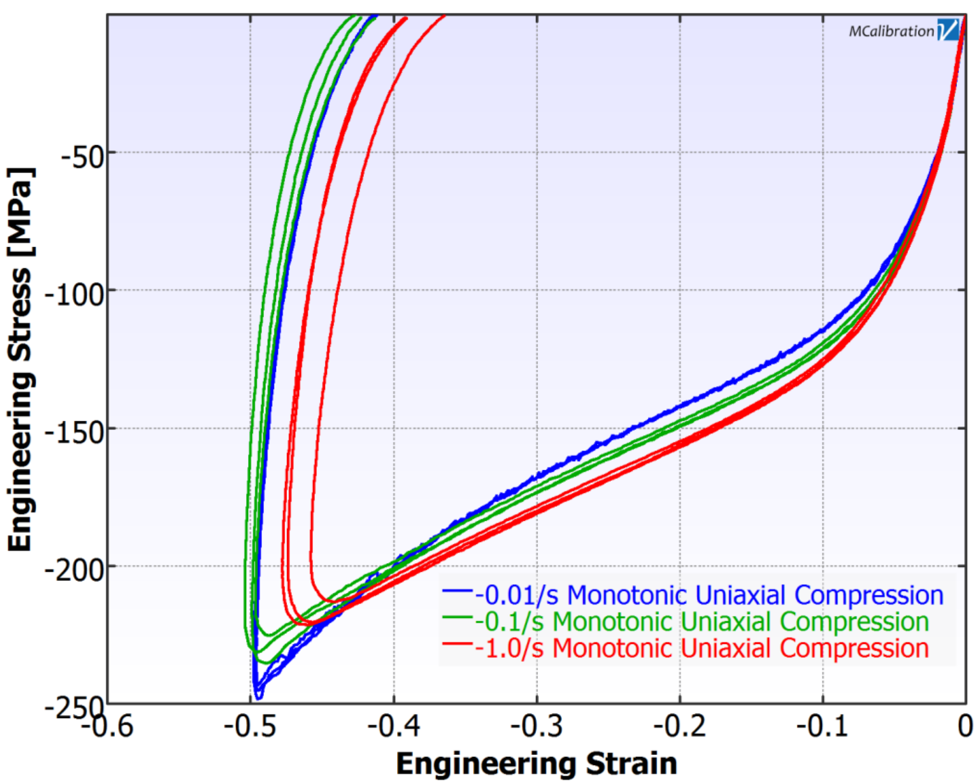

Slow Rate Compression

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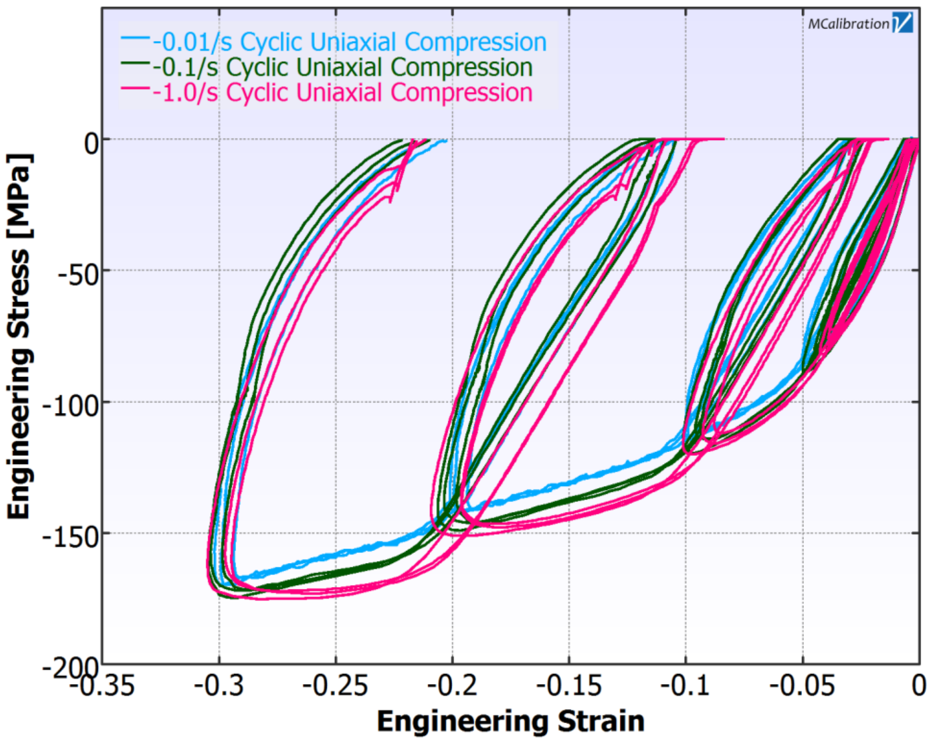
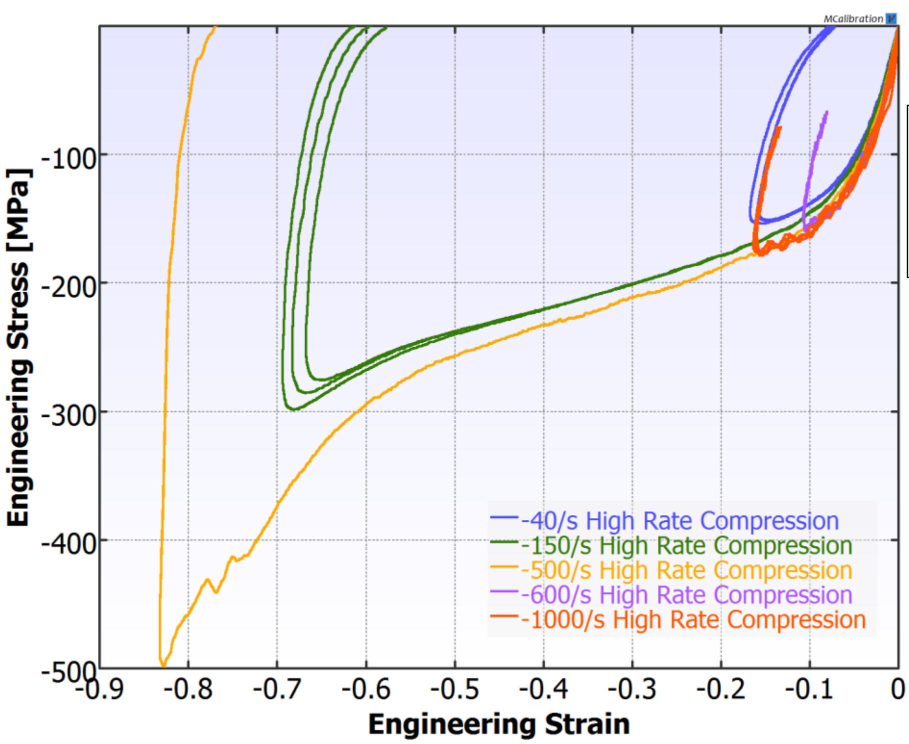


Cyclic Compression Results



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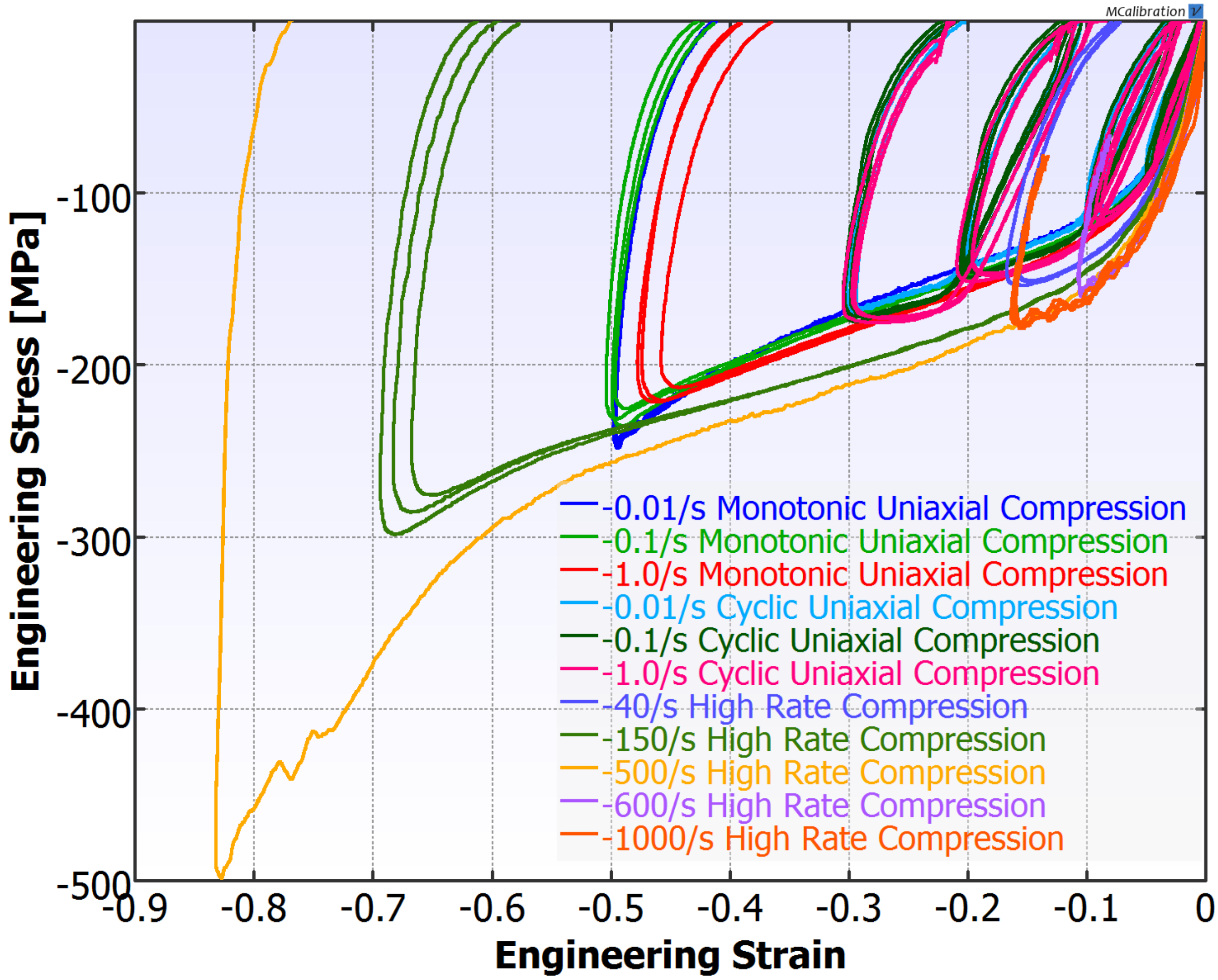

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List of Symbols, Abbreviations, and Acronyms

ATD	anthropomorphic test device
D	diameter
DIC	digital image correlation
H	height
SH	stacked height
SHPB	Split Hopkinson Pressure Bar
TD	Technology Demonstrator
UBB	underbody blast
WIAMan	Warrior Injury Assessment Manikin

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