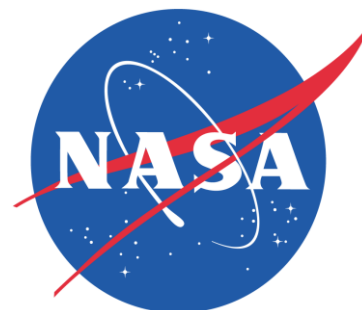
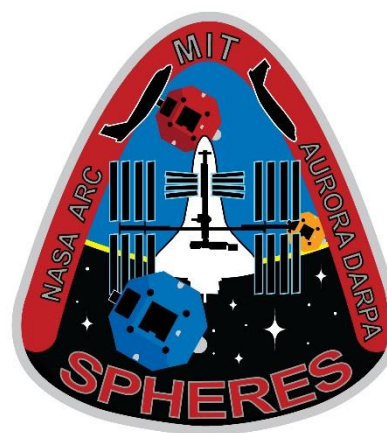


SPH-04-XS-100

3-D Printed Ultem 9085 Testing and Analysis



June 17, 2015



National Aeronautics and Space Administration
Ames Research Center
Moffett Field, CA



SPHERES



Written by:

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Abstract

The purpose of this document is to analyze the mechanical properties of 3-D printed Ultem 9085. This document will focus on the capabilities, limitations, and complexities of 3D printing in general, and explain the methods by which this material is tested. Because 3-D printing is a relatively new process that offers an innovative means to produce hardware, it is important that the aerospace community understands its current advantages and limitations, so that future endeavors involving 3-D printing may be completely safe. This document encompasses three main sections: a Slosh damage assessment, a destructive test of 3-D printed Ultem 9085 samples, and a test to verify simulation for the 3-D printed SDP (SPHERES Docking Port). Described below, ‘Slosh’ and ‘SDP’ refer to two experiments that are built using Ultem 9085 for use with the SPHERES (Synchronized Position Hold, Engage, Reorient, Experimental Satellites) program onboard the International Space Station (ISS) [16]. The SPHERES Facility is managed out of the National Aeronautics and Space Administration (NASA) Ames Research Center in California.

1.0 Background

3-D printing of thermoplastics has recently become of great interest. Made from polymer resins, a thermoplastic is a type of plastic that becomes a homogenized liquid when heated, hardens when cooled, and becomes brittle and subject to fracture when frozen. These characteristics are reversible, which lends the material its name. 3-D printing hardware and software have grown in resolution and stability. This, along with a reduction in manufacturing costs, allows for a more mainline implementation over many fields of use. Currently, NASA allows Ultem 9085, a polyetherimide (PEI) based thermoplastic, and onboard the International Space Station (ISS) as an approved 3-D printed material [13]. Ultem 9085 is one of the few 3-D printed materials approved for use inside the ISS. Ultem has desirable properties such as decreased outgassing and flammability as seen in table one below. Many of the other common 3-D printable thermoplastics are too hazardous to be safely implemented inside the ISS due to risk to science, facility, and crew member safety.



Table 1: Material Outgassing [13]

Material	% TML	% CVCM	% WVR	Data Ref	Application	MFR Code
ABS Plastic	0.94	0.04	0.25	GSC35076	3-D Printing	CIM
ABS Plus	0.63	0.08	0.25	GSC33928	3-D Printing	XXX
Ultem 9085, Injection molded	0.4	0	0.32	GSC32863	Molding Compound	SBC
Ultem 9085	0.41	0.1	0.37	N/A	3-D Printing	SYS
PET Plastic (Makergeeks.com)	0.61	0.05	0.24	GSC35079	3-D Printing	XXX
PLA Plastic (Makerbot)	0.56	0.01	0.33	GSC35082	3-D Printing	XXX
P430 ABS Plus	0.37	0	0.25	GSC33853	3-D Printing	SYS

SPHERES is a NASA project currently in use onboard the ISS. SPHERES consists of three free flying vehicles identifiable by their shell colors of Red, Blue, and Orange. Initially, the SPHERES were designed for testing of control theory algorithms. The Satellites are about the size and mass of an eight pound bowling ball and use cold gas (CO₂) thrusters to propel themselves around a fixed experimental volume. The SPHERES program currently operates out of the Japanese Experiment Module (JEM) inside the ISS. SPHERES uses ultrasound beacons and infrared radiation (IR) as a metrology system to identify their position in conjunction with accelerometers and gyroscopes. SPHERES has had continual success through the years due to an expansion port built into the vehicle allowing guest scientists to utilize some or all of the SPHERES core features. SPHERES is one of the most popular projects on board the ISS. [16]

In the spring of 2013, a crew member found a slightly damaged component on the SPHERES payload known as Slosch during the unpacking inspection aboard the ISS. Several components of the Slosch experiment are made of 3-D printed Ultem 9085 which were printed by a company called RedEye, a subsidiary of Stratasys. Stratasys is the manufacturer of the 3-D printers which utilize Ultem 9085 [19]. The SPHERES engineering team undertook the task to assess what the probable causes of the Slosch avionics box fracture were.

The component that fractured was not under high loads or crucial to structural integrity. No harm to the crew members or science resulted from this incident. Nevertheless, this incident provides an opportunity to develop and improve the current understanding of 3-D printed parts in order to prevent further incidents from occurring. All tests were conducted at NASA Ames Research Center by the authors of this document along with other members of the SPHERES engineering team. When the incident first occurred, the time and location of the break was unknown. As a result, the initial goal was to improve the strength and deflection properties of Ultem 9085 samples by post processing. However, the break was later found to have occurred on the



ground before flight, and so the team decided to look closer at the torque specifications and design choices for future payloads that will use Ultem 9085.

1.1 The 3-D Print Process

3-D printing is categorized as additive manufacturing, also technically known as fused deposition modeling (FDM). Essentially, the product is created by a hot extrusion process that is computer numerically controlled (CNC) to ensure extreme accuracy and tolerances. This is quantifiable as a welding process as the printed Ultem 9085 thermoplastic has numerous welded contact points. As a visual, think of a hot glue gun creating overlapping extrusions in a grid pattern on a microscopic scale. During the fabrication of a 3-D printed component, there are four phases of development that have an effect on the quality of the final product. These phases are: the principal investigators' design, computer aided drawing (CAD) to a computer aided machining (CAM) conversion, manufacturing operations, and post processing.

1.1.1 The first phase is the principal investigators' (PI) design. The design of a product is often driven by the intended purpose, as well as machinability and assembly. One of the attractive features of 3-D printing is the capability to produce geometries that conventional machining would never allow. That being said, it is critical that the designer keeps this in mind to fully utilize the benefits of the technology. This encompasses the choice of including additional ribs, fillets, and other geometries that encourage strength and reduced mass which are often desirable traits for aerospace applications. There is no set of established rules; however one can state that the designer must view the product in a new light, as the limitations of conventional machining are no longer a restriction.

1.1.2 The second phase is the implementation of a solid model into a real product. In order to convey the computer code language the machine operates from, a software process must convert the solid model into a compatible format. The software to convert CAD to CAM code is a proprietary software used by the manufacturing company. The software, called Insight, has the authority to produce a CAM code using a simplistic algorithm without human oversight. This is often used to expedite the process and reduce cost to quickly produce a product not intended for maximum strength qualities. The alternative to the default quick print option is to have a skilled engineer/operator introduce modifications to the numerous settings and variables. Because of the large number of variables, examples being: part orientation, grid spacing, support structures, tip style, resolution, step levels, surface finish, patterns, laminate angles, reinforcement layers, thicknesses, fill density, etc, each part has to have its own CAD to CAM operator analyze and use best judgment on the qualities that are demanded by the PI.



1.1.3 The third phase is manufacturing operations. The 3-D printing machines are predominantly autonomous, but require some operator assistance. During this phase, the operator loads the CAM file as well as the raw material spools, adjusts settings as required, and monitors the print job for defects and errors. An additional responsibility of the operator is to halt the print process to inlay embedded components such as encapsulated nuts, studs, alignment dowels, and anything else desired by the PI. Once the print is finished, it is the operator’s responsibility to remove the product and separate it from any support structure created during the print process. The product is then packed and shipped according to the PI’s requirements.

1.1.4 The final phase is post-processing. Once the product is printed, there are chemical application processes available such as epoxy impregnation and surface sealing. NASA Ames has conducted research on possible application materials as well as processes to improve material characteristics. Results of this research will be addressed later in this document.

1.2 Slosh Product Damage Theories

1.2.1 Slosh Damage Evidence

The fractured piece of Ultem 9085 found by the crew members on the ISS can be seen in figure one. As shown in the photo, the damage was found around a countersunk screw located close to the corner edge of the avionics box. A piece of Ultem 9085 is missing and assumed as foreign object debris (FOD). Originally, the fracture was assumed to have occurred during launch or crew handling, but later it was found to have happened on the ground before flight, as can be seen in the photograph of the pre-flight damage in figure seven. The immediate solution by the ISS crew was to apply Kapton tape to the damaged area. After contacting the PI and the manufacturer of the 3-D printed Ultem 9085 components, several possible contributing factors were identified.



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Figure 1: Image of the broken 3-D printed part onboard the ISS
*Image property of NASA SPHERES



Figure 2: Images of the countersunk screw hole *

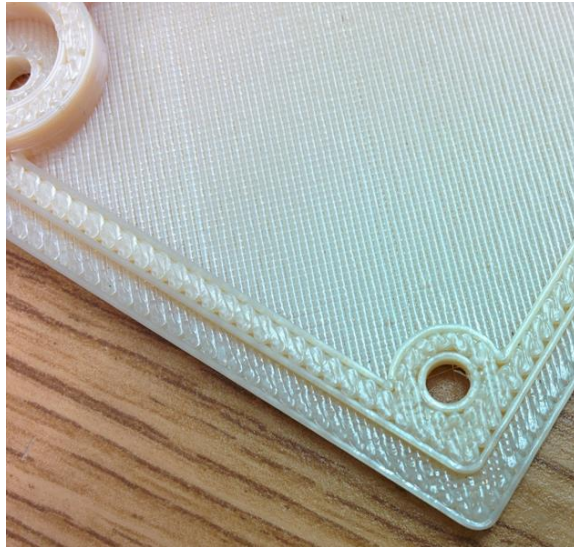


Figure 3: Images of the countersunk screw hole *

The first identified contributing factor was the countersunk flat-head screw. The broken component in question was a flat plate, which was screwed down using a flat-head screw. This was intended to be recessed or flush to the surface plate so as to avoid sharp edges. Flat-head screws have a conical shaped head, which have certain traits that a designer must understand to utilize. Unlike a pan-head screw, countersunk flat-head screws force the countersunk material to align with the screw head. Any error in the alignment of two or more holes will result in deformation due to stretching or shrinking of the material between them. This causes radial stress around the hole on the material being secured. However, in the Slosh design, the screw in question is threaded into an aluminum standoff and not directly into another piece of Ultem. This implies that any force of misalignment was not a contributing factor in the case of Slosh.

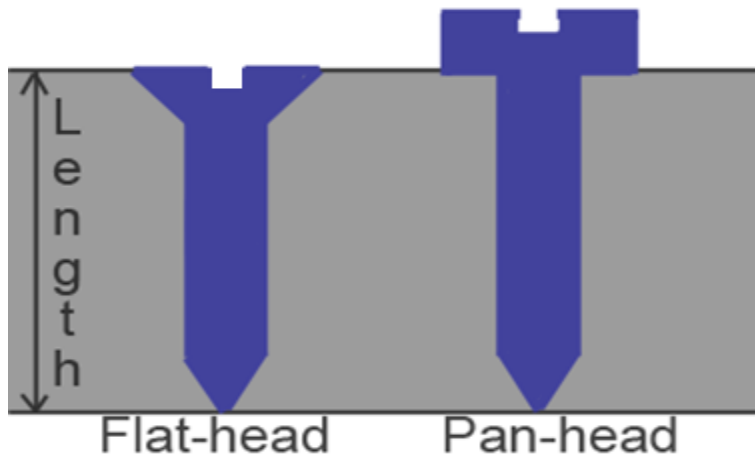


Figure 4: Countersunk flat-head versus pan-head

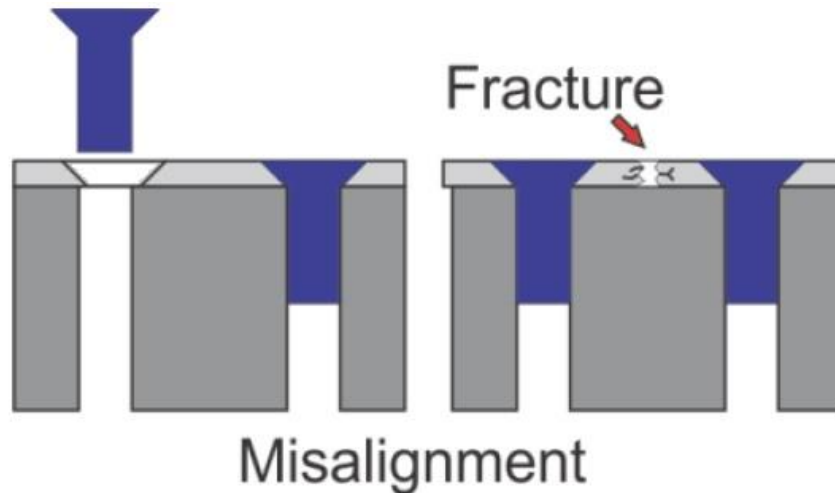
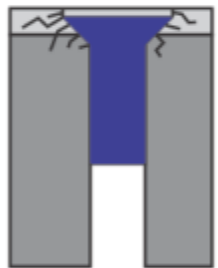
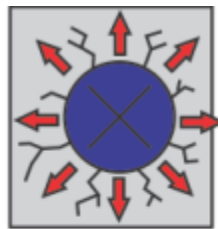


Figure 5: Countersunk flat-head out of alignment causing fracture

An additional issue with countersunk flat-head screws is the nature of the torque required to secure the load. Because the head is conical in shape, it is essentially a wedge. If the wedge is driven too far it will cause radial forces to stretch or break the hole being tightened.



Over Torqued

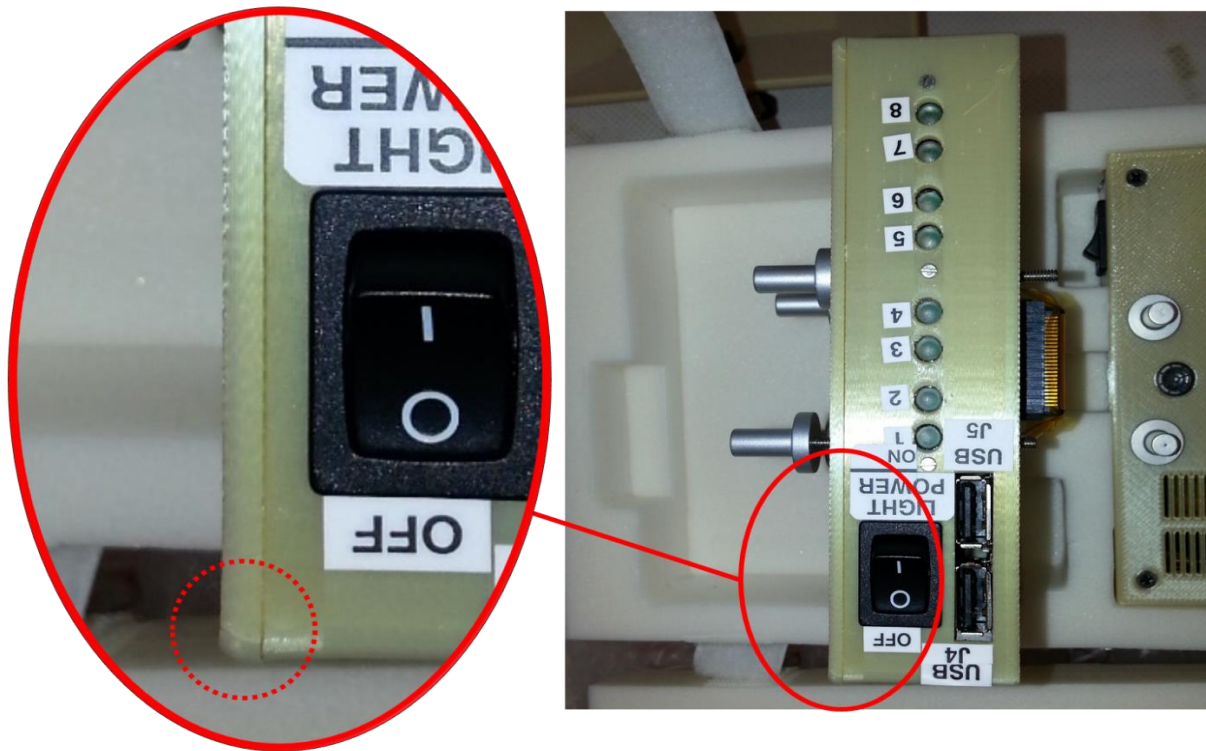
Figure 6: Illustration of a countersunk screw radiating force outwards if over torqued.

Torque specifications can typically be found through standards organizations. Proper torque specs can be found through testing as well [12]. It is unknown if the screw in question had proper torque value applied, or if it was torqued with a satisfactory tool with the correct resolution and accuracy for this application. Often there can be a mentality of “tight is tight”

among certain technicians, but this cannot be quantified nor reproduced with precision, especially among different technicians.

An additional identified contributing factor is the location of the screw hole. The thickness of the material as well as the proximity of the hole's location to the edge of the product suggests this design was susceptible to damage at this point.

Figure seven shows a photograph taken of the damaged Slosch avionics box at KSC (Kennedy Space Center) before launch. In the photograph, there is a visible fracture at the location where the damage occurred. These cracks are visible only in certain lighting conditions and were not observed during packing.



*Figure 7: Photograph taken of Slosch box S/N 002 during packing for launch **

A final possible contributing factor to the damage of the Ultem 9085 on the Slosch hardware was the CAD to CAM process used. After contacting the company responsible for the production of the Slosch products, it was discovered that the production log was not saved nor requested by the PI. However, the operator recalled the particular print job and recalled that the CAD to CAM



process used the default quick print option. He also stated that no further design modifications were implemented.

1.2.2 Slosh Damage Theory Summary

In summary, the cause of the Slosh payload damage cannot be confirmed due to its inaccessibility. However, it is believed a mix of screw hole location, improper torque, poor printing instructions, and possible material defects are likely causes for the damage. The inherent nature of 3-D printed parts with so many production variables makes it incredibly difficult to have a stable set of design and manufacturing rules. Every part will require different needs to ensure a quality product. Due to geometry, machine settings, design, support structures, and manufacturing errors, every part is inherently non-homogenous. Because of this, it is unrealistic to set any design or manufacturing rules and standards.

Given the low structural importance of the Slosh part in question along with the evidence shown, it was determined that the Slosh assembly on station is not a safety concern.

1.3 Future Ultem 9085 Applications

The International Space Station Spheres Integrated Research Experiments (InSPIRE II) payload consists of two experiments, the SPHERES Docking Ports (SDP) and Halo, both of which plan on utilizing 3-D printed Ultem 9085 in various aspects of their design. This is the same material responsible for the incident that occurred in spring of 2013 when a crew member found a slightly damaged component on the SPHERES payload (Slosh) during the unpacking inspection aboard the ISS. To prevent further incidents from happening, the SPHERES engineering team at NASA Ames Research Center has conducted three point beam tests on Ultem 9085 samples that have been treated with various sealants and epoxies in the hopes of finding better material characteristics. Please see the Destructive Testing Procedures in Appendix A for details of the test. Halo will use a large volume of 3-D printed Ultem 9085. SDP, on the other hand, will use a small volume of Ultem 9085, but these 3-D printed parts will be fragile due to their geometries. The large volume of 3-D printed material on Halo and the fragile geometry of SDP both raise concerns about structural failure.



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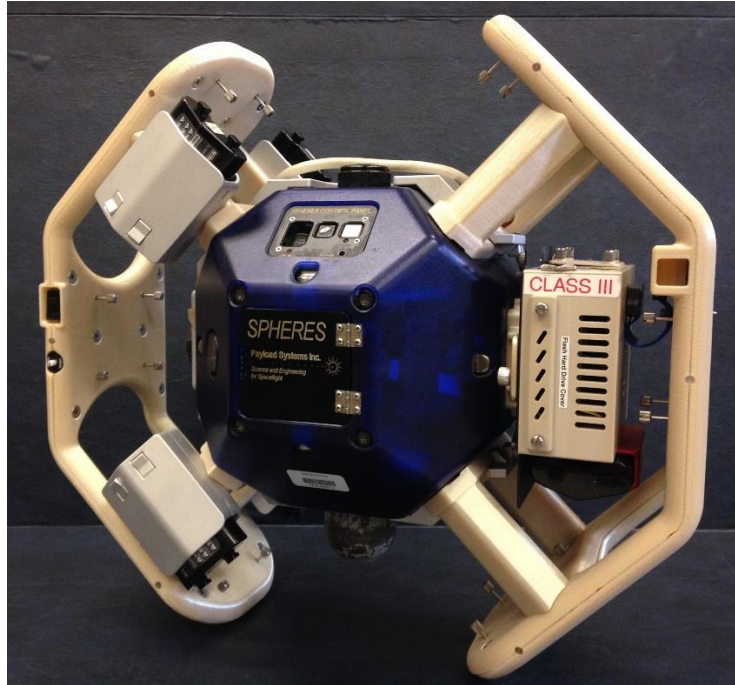


Figure 8: The image above shows Halo's large 3-D printed parts in tan *



Figure 9: SDP has thin 3-D printed parts with fragile geometries shown in tan *



2.0 Three Point Beam Testing

2.1 Mechanics of Materials

It is important to understand the distinction between elastic deformation and plastic deformation, especially for this experiment. Elastic deformation is reversible. Once forces on an object are no longer being applied, the object returns to its original shape [6]. This is not true for plastic deformation, where objects will not return to their original shape. The plastic region occurs after the elastic region, varying in size from material to material. For thermoplastics such as Ultem 9085, the plastic region is relatively large. Ceramic, on the other hand, has a very small plastic region [6].

Both the plastic and elastic regions can be easily seen on a stress strain plot. The linear portion of the curve signifies that the material is undergoing elastic deformation, and the non-linear portion signifies plastic deformation. The point at which the material begins to plastically deform is called the yield strength or yield point. Critical to understanding and quantifying these regions are the **Tensile Modulus**, **Flexural Modulus**, and **Secant Modulus**. Tensile modulus, synonymous with Young's modulus, is used to define the elastic, or linear, region of a stress strain curve. From the plots in this study, it was observed that the stress strain curve is never linear. However, the three point bending test that was conducted placed the Ultem samples in both tension and compression. The behavior observed in the samples is therefore a combination of elastic and plastic behavior [6].

In order to describe the bending stiffness of a plastic beam under three point loading, the plastic industry uses a term called the Flexural Modulus, which is completely a product of the experiment. This phenomenon is geometry dependent, and cannot be applied to other loading conditions. The Flexural Modulus is typically used to compare the relative bending stiffness of various plastics with same geometry under the same loading conditions.

The Secant Modulus is also used to describe plastic behavior beyond the yield limit. The secant modulus can be applied at any strain level, but like the Flexural Modulus, it depends on the geometry, material, and strain level.

Both of these properties are important to Finite Element Analysis (FEA) of plastics, as most FEA packages cannot model plastic behavior accurately, although some do [10]. Instead, most FEA software can only handle linear models, so the best one can do is perform an approximation with a guess on strain level and the corresponding secant modulus for that particular strain. The



current limitations on modeling plastic behavior underlines the importance of conducting experiments, where one may get a more realistic understanding of how these materials behave under loads.

2.2 Relation to Ultem 9085

The SPHERES team at NASA Ames Research Center conducted its own three point destructive testing on Ultem 9085. The results of this test were found to be considerably different than the material properties found on the manufacturer’s (Stratasys) data sheets. Although the objective of the test was not to compare measured values, the explanation of the difference between these values is important. As stated above, the modeling and comparison of plastic behavior is not straightforward. This is complicated even more by the fact that the 3-D print settings determine much of a samples performance under a three point load. Stratasys performed their test in accordance with the ASTM D790 standards, which defines dimensions for the samples to be tested. The SPHERES team performed the test on samples which were closer to the actual geometries found on flight hardware, thus the discrepancy in measured values can be attributed to the difference in geometry, speed of the test, micro gaps between extrusion paths in the 3-D printed pattern, and methods for gathering data. For example, what strain value was used to determine the Flexural Modulus? Was the Secant Modulus used? Where was the Tensile Modulus measured? The ASTM D790 test also dictates that the test will conclude when the sample has deflected by 5% of its original shape or has broken [17]. Again, it is important to ask what strain value was used for gathering data. These are all important factors to consider when gathering data about plastic materials. For details of the test performed at NASA Ames, please see the Destructive Sample Testing in Appendix A.

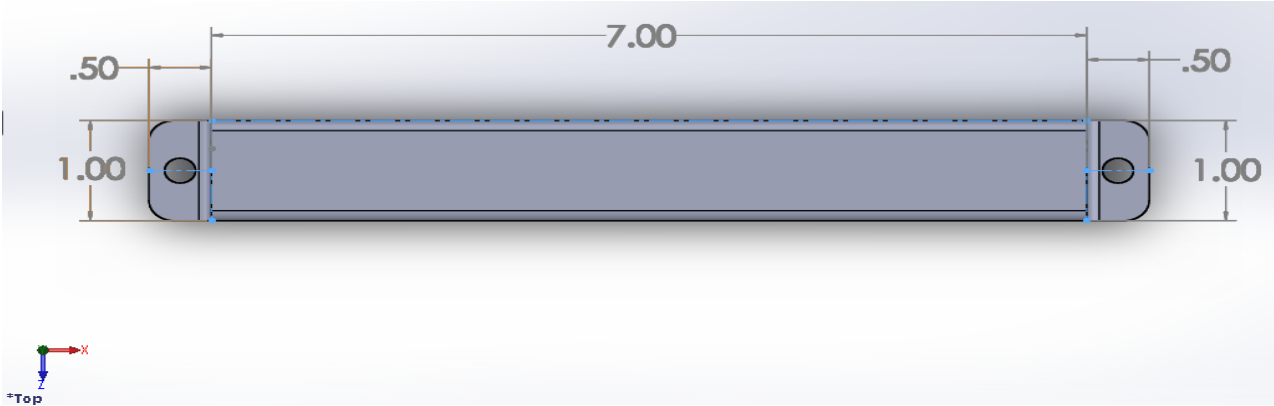


Figure 10: Top view of the Ultem bar (dimensions in inches)

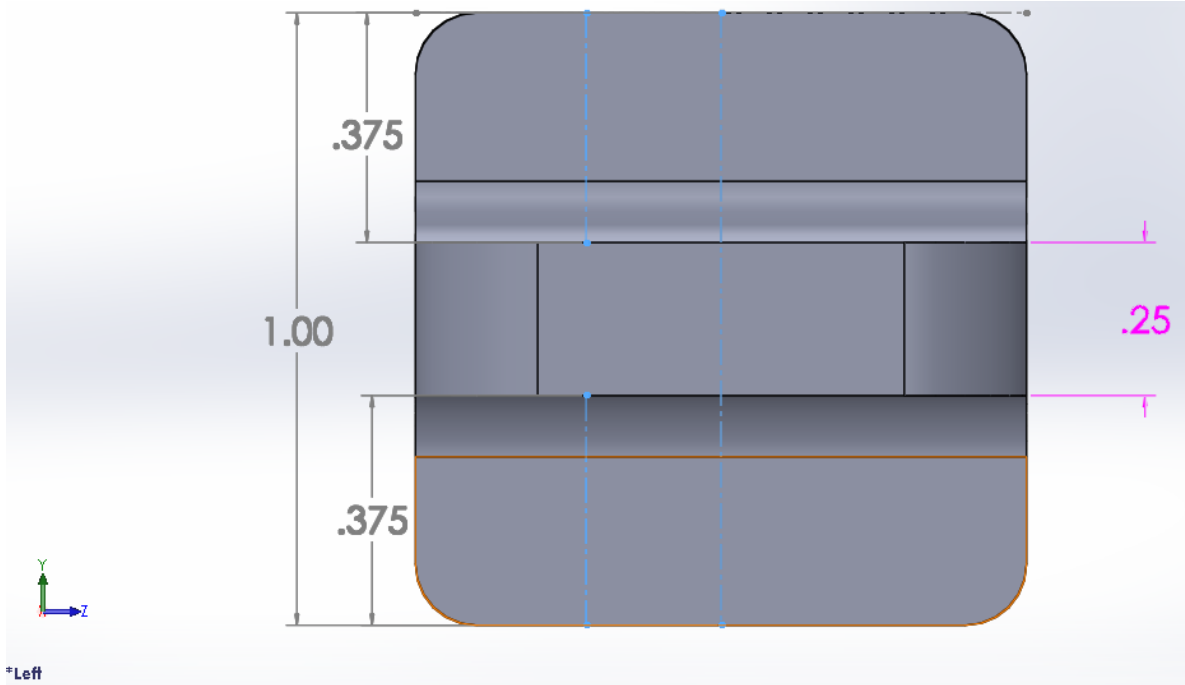


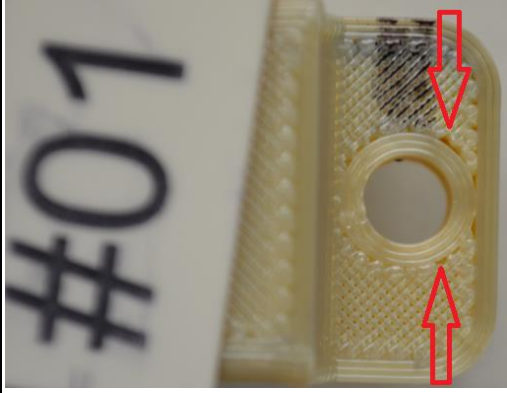
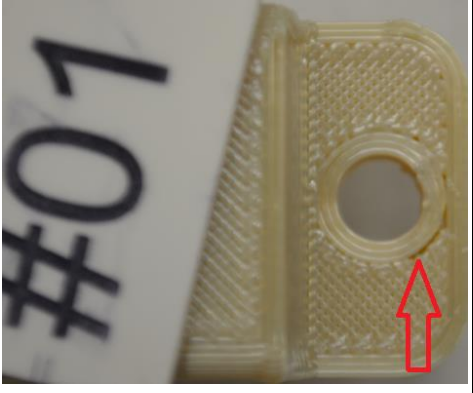
Figure 11: Image showing cross section of the Ultem 9085 bar (dimensions in inches)

2.3 3-D Printing Limitations, Defects, and Deviations within the Batch

49 samples were ordered from RedEye for use in the three point beam test. Numerous defects were found within each of the 49 samples that emphasized the limits of the Fortus 900, the printer used by Stratasys to manufacture the Ultem samples. For detailed printer information please reference Appendix C. In order to attach labeling tags to each sample, a hole was present on each end tab. When the samples were manufactured, a reinforced contour structure was extruded around this hole as seen in table one. These reinforced parts would address concerns about force in a radial direction, but they were poorly attached to the surrounding raster region of the sample. This meant that these reinforced sections were able to be pushed out without much effort. In addition to this, defects such as scratches, burns, dents, and bumps were found on various samples. It was presumed that these defects were results of the inconsistency of the extrusion process. One of the most common defects were gaps surrounding the reinforced holes.



*Table 1: An example of some of the defects that were observed around the reinforced holes. The red arrows indicate the defects in the contour sections **

Sample Type	Top left	Top Right
Control Gapped		

2.4 Applicant Selection

The phases of design and manufacturing are too specific and unique to offer build requirements or design rules that fully blanket all applications. After speaking with the Stratasys application engineer, the topic of post processes was raised [19]. Depending on the application, Stratasys and other vendors suggest several post processing options with the goal of improving strength and deflection characteristics. Ultem 9085 has the capacity to be media blasted, glued, electroplated, heat polished, sanded, tapped, filed, machined, as well as coated with adhesives. For applications related to future SPHERES payloads for use inside the ISS environment, the use of adhesives was of interest to this assessment.

Five applicants were selected to be used with the objective of improving the overall characteristics of 3-D printed Ultem 9085. Applicants were chosen based on previously published data as well as multiple conversations held with application engineers at respected corporations [4]. The viscosity, FST, offgassing, outgassing, mechanical properties and chemical properties were all taken into account for the selection process.

In addition to the applicants selected, two different print settings were selected for the samples of Ultem 9085. 3D printers have the ability to alter the density of their prints. It was reasoned that more gaps between extrusion paths would allow adhesives to impregnate the samples easier. Samples with a 0.004 inch gap were dubbed “gapped” and samples with a 0.000 inch gap were dubbed “solid.” The different print settings would also allow for an analysis on the strength properties of gapped versus solid samples.



Table 2: Table of the various applicant, observations, and post working methods

Applicant	Application Method	Observations	Post work
Control	N/A	Smooth	N/A
Arathane 5750 A/B	Dip	Sticky, Tacky	Razor Blade/Filed
Hysol E-20HP	Brush	Smooth yet bumpy	Sanded/Filed
ProBuild Marine	Brush	Smooth yet bumpy	Sanded/Filed
Loctite 5110	Dip	Greasy	Kimwipe
BJB TC-1614	Dip/Vacuum	Smooth	Sanded/Filed

Table 3: Notes on work characteristics of applicants

Applicant	Notes
Arathane 5750 A/B	Arathane 5750 was very easy to work with. Before dipping, the correct ratio of part A to part B was measured out and combined according to the safety data sheets. The 3-D printed parts were submerged in plastic containers for 10 minutes. Parts were left to cure on hanging racks for 24 hours. Arathane 5750 stayed viscous during the entire work process. However, the viscous nature of Arathane 5750 led to the formation of drops that hardened on one edge of the sample. After curing, the samples were very sticky/tacky. Dried bumps of this applicant were easily removed using razor blades.
Hysol E-20HP	Hysol E-20HP is packaged in cartridges for use with a caulking gun. After the epoxy was squeezed out onto the sample, it was brushed on. This epoxy was hard to work with because of its high viscosity. It became tacky in approximately 5 minutes, so it had to be brushed completely on by then. It was left to dry, but it was clear that the surface of the sample would have evidence of brush strokes on it, leaving a bumpy finish. This was the most viscous of all the applicants. Excess E-20HP was sanded and filed off.
Pro Build Marine	Pro Build Marine came in two parts, the hardener and the resin. Both parts were combined as recommended. The 3-D printed part was then dipped. The work time was 50 minutes which is reasonable, because modifications and brushing off the excess epoxy was done in that time. Excess Pro Build Marine was also sanded and filed.
Loctite 5110	Loctite 5110 was the least viscous applicant tested. It was extremely easy to

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	work with, but this sealant did not cure properly. A week after application, this epoxy was still not dry. It left the 3-D printed sample wet and slightly greasy. Kimwipes were used to remove the excess 5110 that had built up on the surface.
BJB TC-1614	BJB was easy to apply to the 3-D printed part because it had a medium viscosity. The 3-D part was dipped and and vacuumed for 10 minutes. The working time for a 100 gram mass at 77F (25°C) is 2 hours; this gives plenty of time to apply it and brush off the excess correctly. After the applicant cured, drops similar to the Arathane 5750 samples were found on the samples. Excess BJB was sanded and filed.

2.5 Test Procedure

Industry standard for flexural testing is conducted according to the American Society for Testing and Materials (ASTM) D790 “Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials”. The common size of the test specimens is 0.5” x .125” x 5”.

The purpose of this testing was not to revalidate Stratasys material property values, but to evaluate application of adhesives, their response to deflection on the surface area, and the resultant effect on foreign object debris. The ASTM D790 sample size would not offer a favorable geometry to witness the desired goals.

It was decided that 1” x 1” x 8” test specimens would be used instead to give more surface area as well as represent a similar thickness to some of the SPHERE Inspire II components. The ASTM Standards dictates the constant deflection rate as seen in the equation below. In addition, the geometry for the ASTM test is commonly a rectangular cross section, whereas the SPHERES engineering team chose a square profile. It was a conscious decision to do this, as it would give more resultant surface area for inspection.

$$R = ZL^2/6d \quad (1)$$

where:

R = rate of crosshead motion, mm (in.)/min,

L = support span, mm (in.),

d = depth of beam, mm (in.), and

Z = rate of straining of the outer fiber, mm/mm/min (in./in./min). **Z** shall be equal to 0.01.

Figure 12: Formula to find the suggested rate of crosshead motion [17].

The calculated result for the 1”x 1” x 6” (6” point to point span, 8” length) according to the ASTM formula was to have a deflection rate of 0.06”/min which would result in samples taking over 10 minutes per break. Considering the large volume of samples to be tested as well as the cost

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factor of using testing facilities the team decided to increase the cross head motion (z movement) to a more accelerated value. This accelerated value would most likely lead to different stress strain curves than listed in the Stratasys data sheet. This was an accepted delta as the goal was to utilize testing resources efficiently and evaluate relative strengths versus industry comparisons.

Table 4: Rate of the crosshead motion used in the NASA ARC Ultem testing

Rate of crosshead motion	0.005 in/sec = 0.3 in/min
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* The test procedure used can be found in Appendix A.

2.6 Performance Comparison of Applicants

2.6.1 Change in Mass

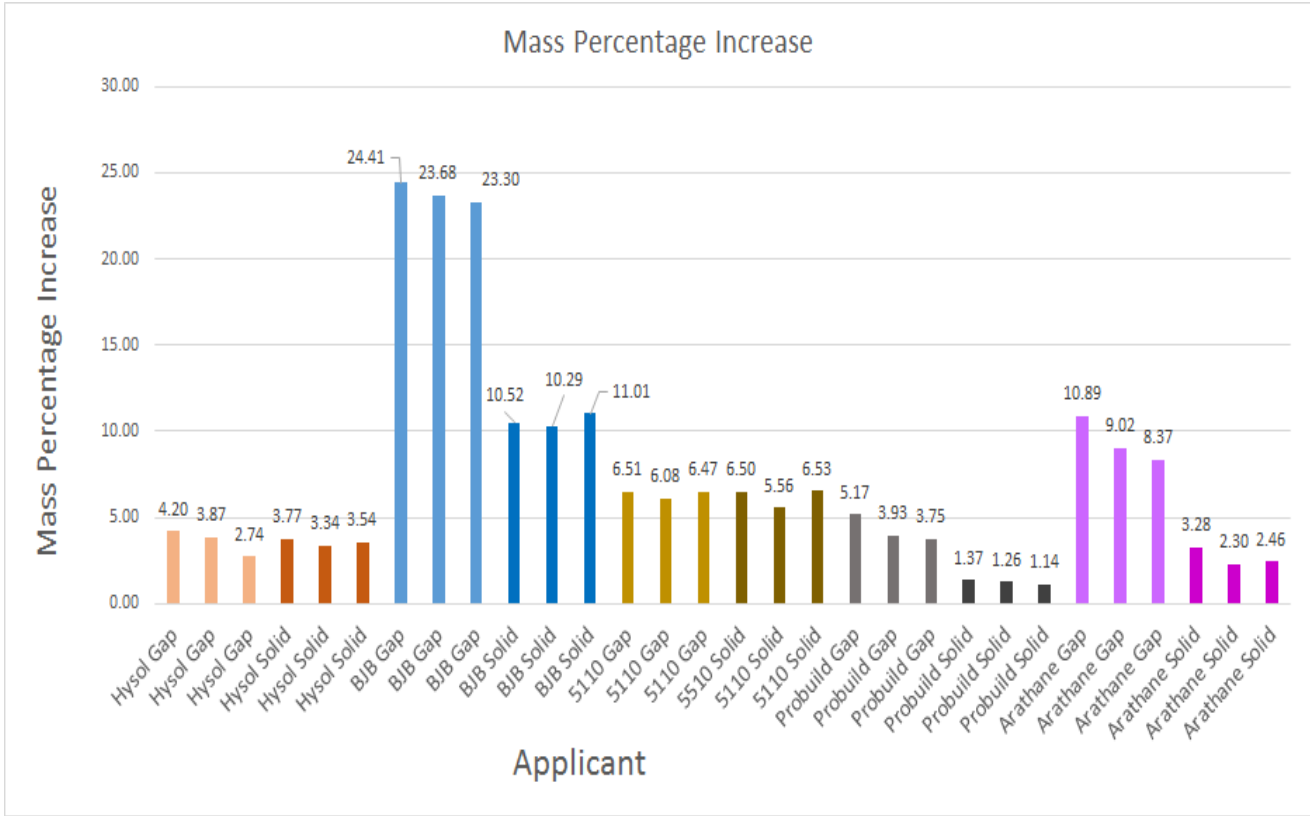


Figure 13: Change in mass of each Ultem bar as a percentage of its original mass



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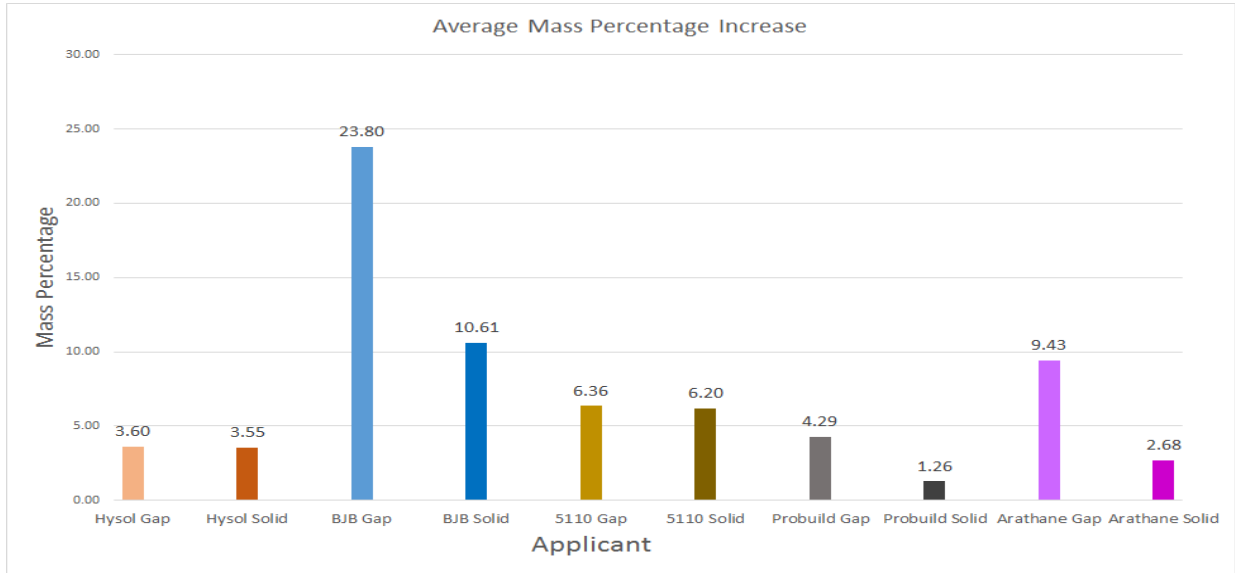


Figure 14: Average mass change of the Ultem samples post application

2.6.2 Change in Dimension

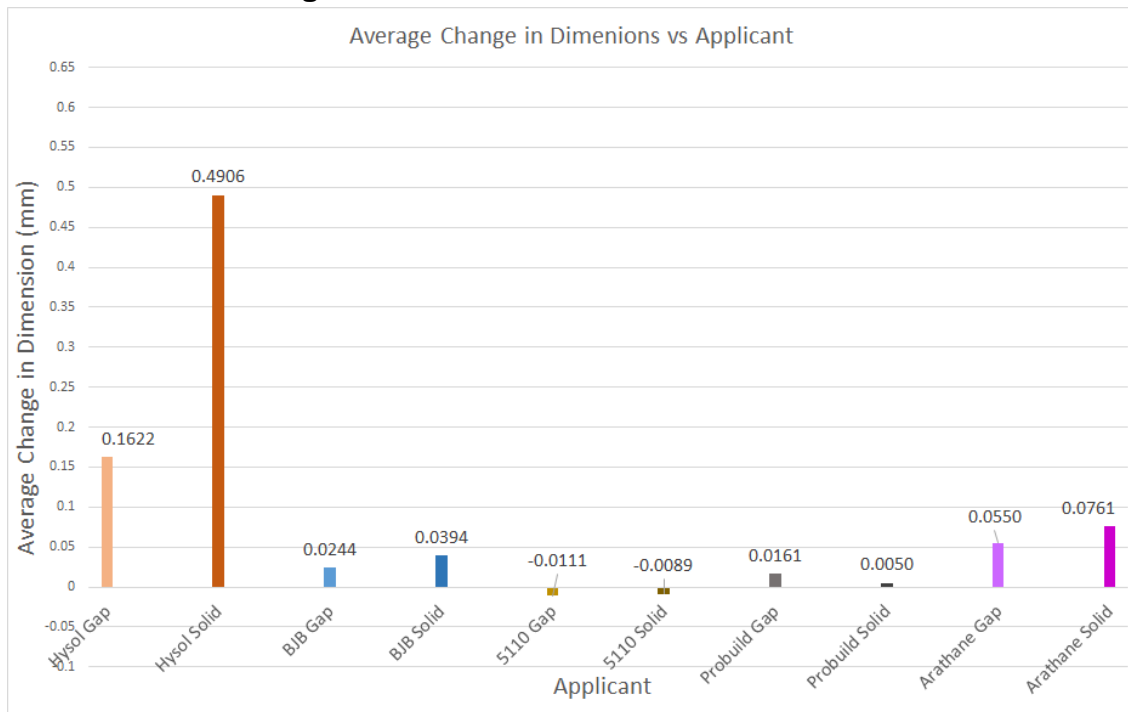


Figure 15: Average dimensional change of the Ultem samples post application

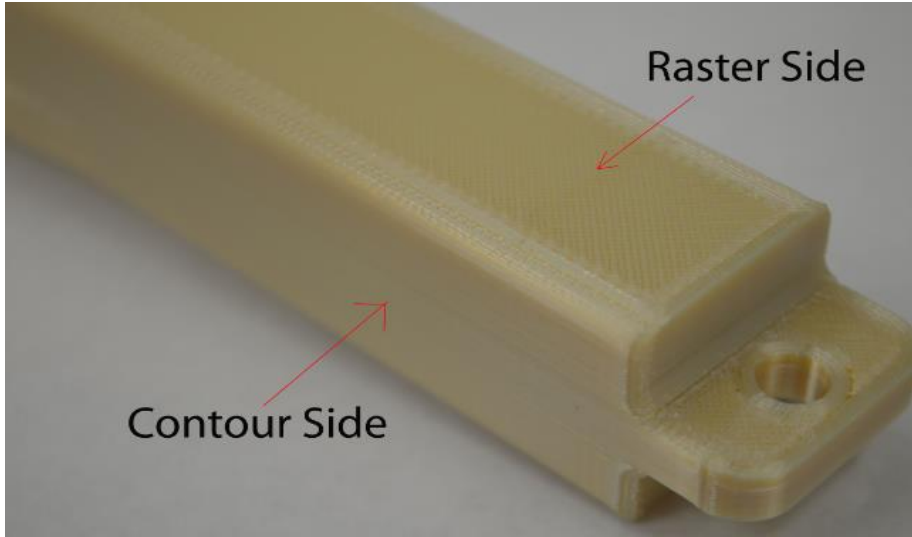


Figure 16: The top/bottom of the Ultem bars are rastered and the sides are contoured *

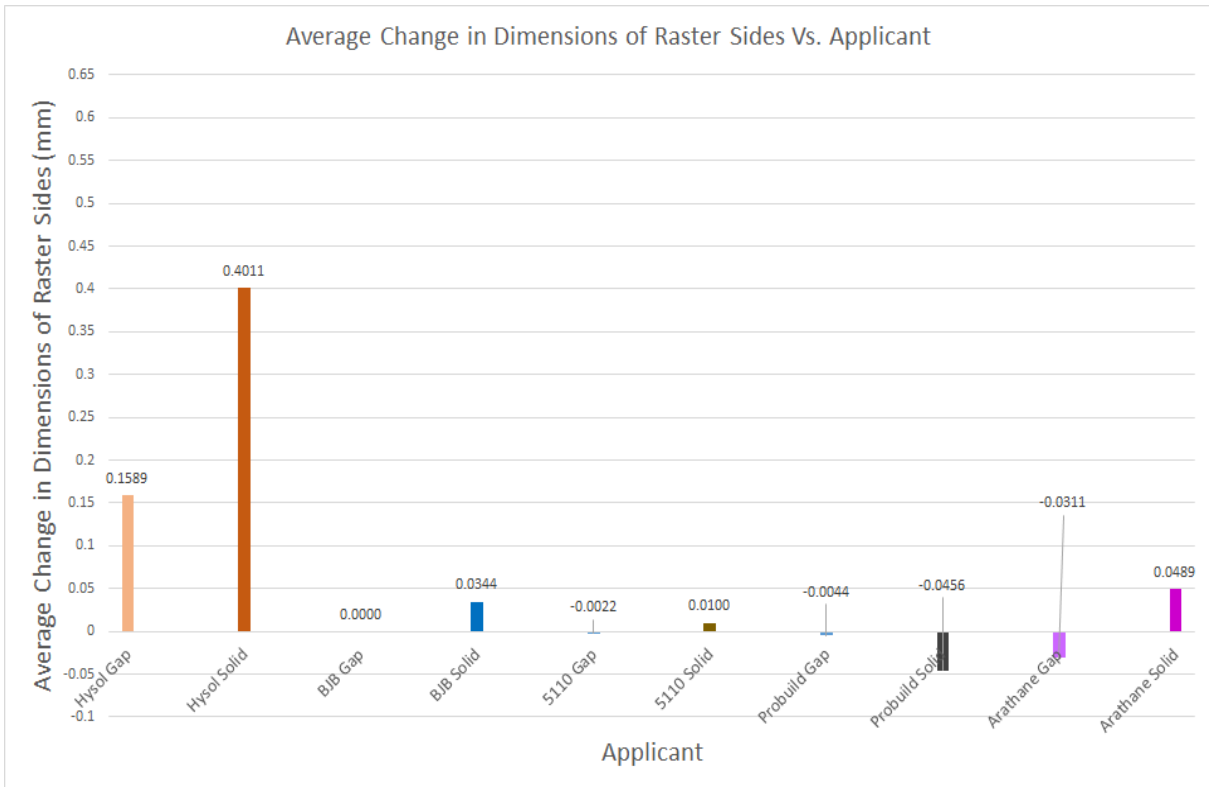


Figure 17: Average change in dimension of the raster sides



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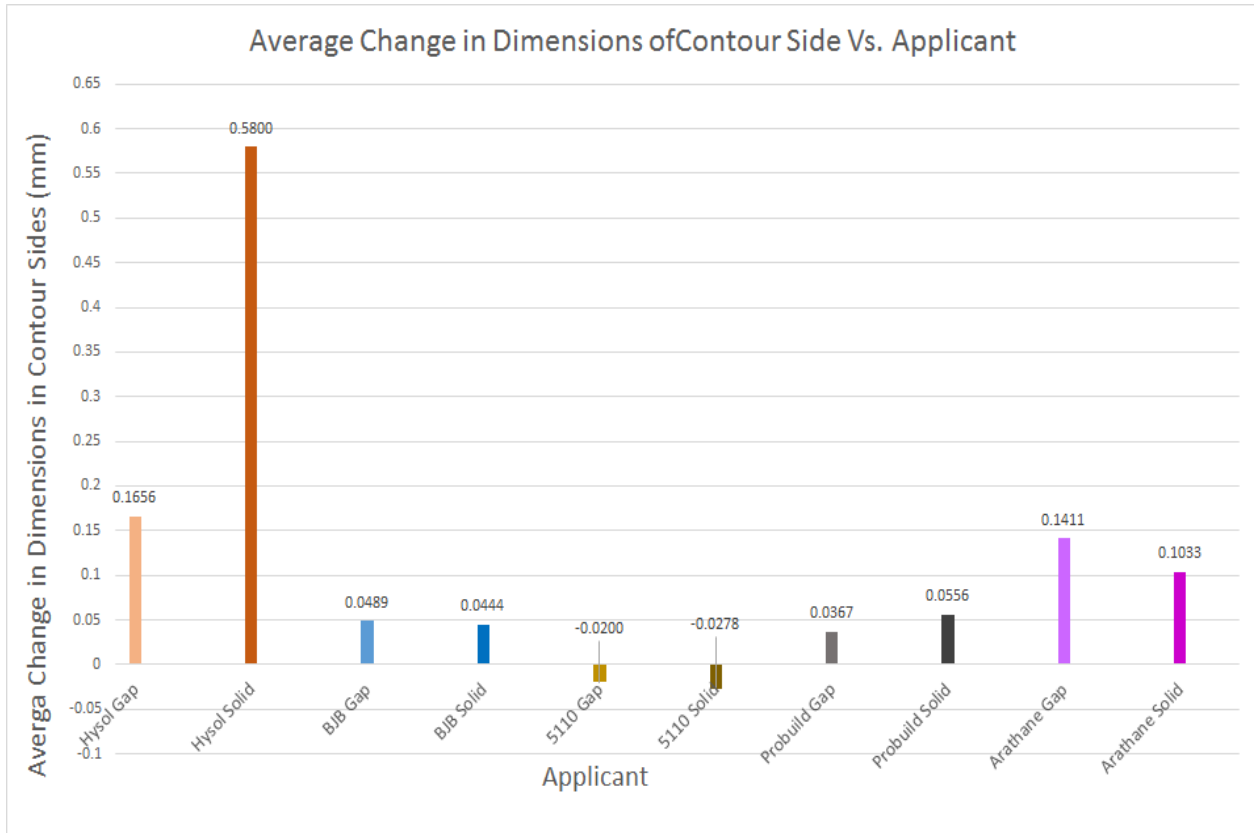


Figure 18: Average change in dimension of the contour sides
 Note: Dimensions were measured with the calipers found in Appendix C

2.6.3 Strength & Deflection/ Stress & Strain

Table 5: Difference between the fill of the Solid and Gapped samples

	Gapped Sample	Solid Sample
3D Print Fill Setting(in)	0.004	0.000

Note: For detailed labeling information, please see Sample Key Tables in Appendix A



Table 6: Gapped control results matrix

Specimen Number	1	2	3	Average	StDev
Max Load (lbs)	860.080	857.690	848.553	855.441	6.084
Displacement @ Max Load (in)	0.695	0.690	0.723	0.703	0.018
Load @ Break (lbs)	712.755	727.997	797.531	746.095	45.193
Displacement @ Break (in)	0.737	0.891	0.852	0.826	0.080
Time to Break (sec)	162.043	234.570	280.250	225.621	59.609
Max Stress	7740.720	7719.214	7636.973	7698.969	54.756
Strain	0.116	0.115	0.121	0.117	0.003

Table 7: Solid control results matrix

Specimen Number	23	24	26	Average	StDev
Max Load (lbs)	1302.392	1259.811	1321.242	1294.482	31.470
Displacement @ Max Load (in)	0.617	0.600	0.640	0.619	0.020
Load @ Break (lbs)	1278.333	1227.759	1303.162	1269.751	38.427
Displacement @ Break (in)	0.654	0.633	0.677	0.655	0.022
Time to Break (sec)	171.925	143.247	130.657	148.610	21.150
Max Stress	11721.520	11338.300	11891.170	11650.330	283.227
Strain	0.103	0.100	0.107	0.103	0.003

Note: Figures 19, 20, and 21 indicate the Load vs Displacement analysis of the control samples.



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ULTEM 9085 CONTROL

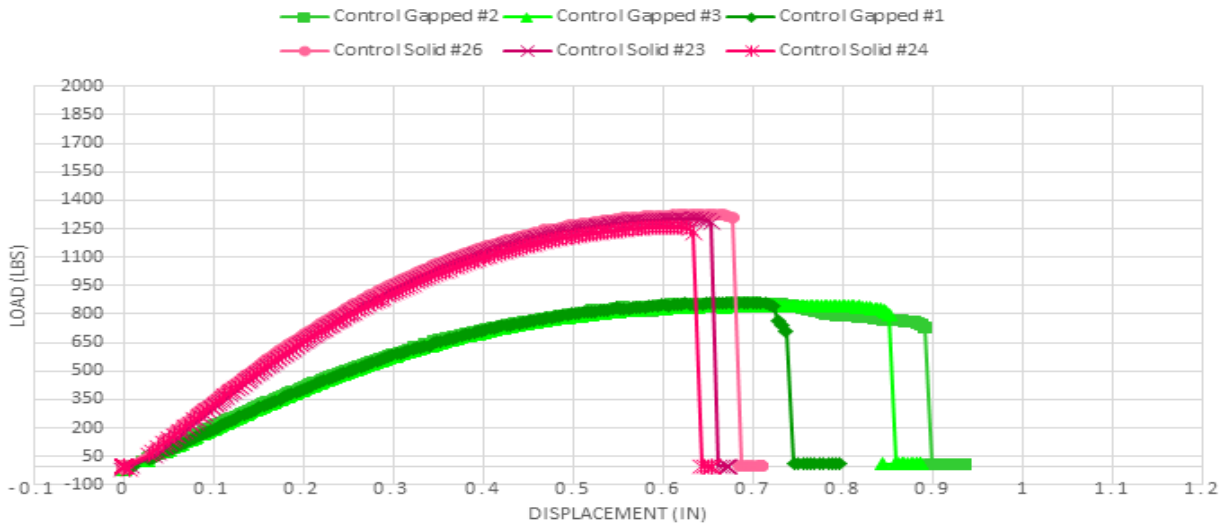


Figure 19: Displacement vs load of six Ultem 9085 samples (3 solid & 3 gapped)

ULTEM 9085 GAPPED CONTROL SAMPLES

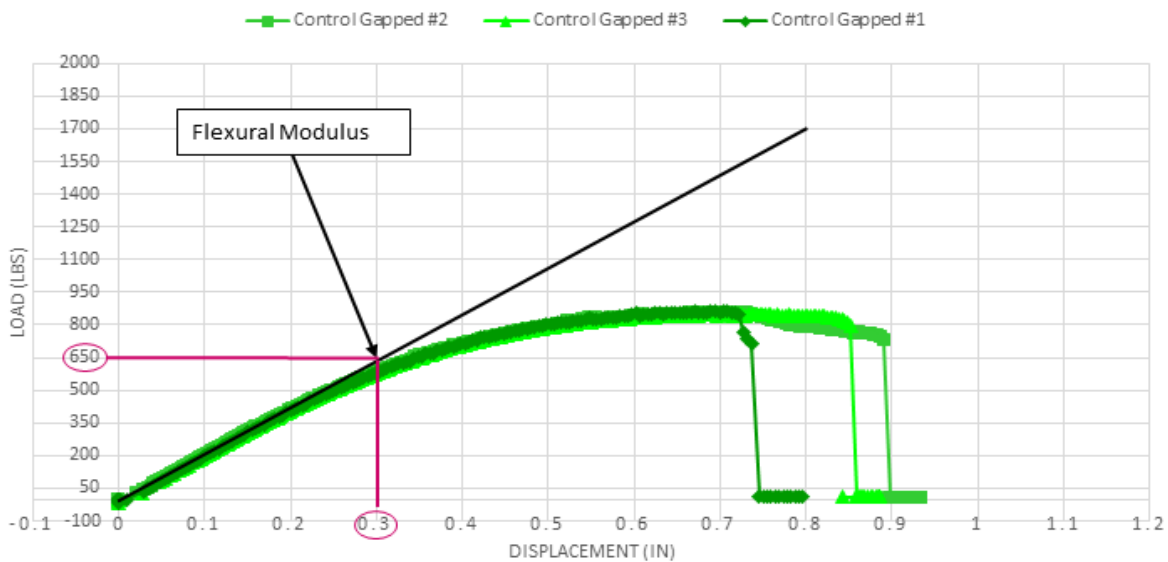


Figure 20: Average Flexural Modulus of the gapped samples

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 650 \text{ lbs}}{0.3 \text{ in}} = 117 \text{ kpsi}$$



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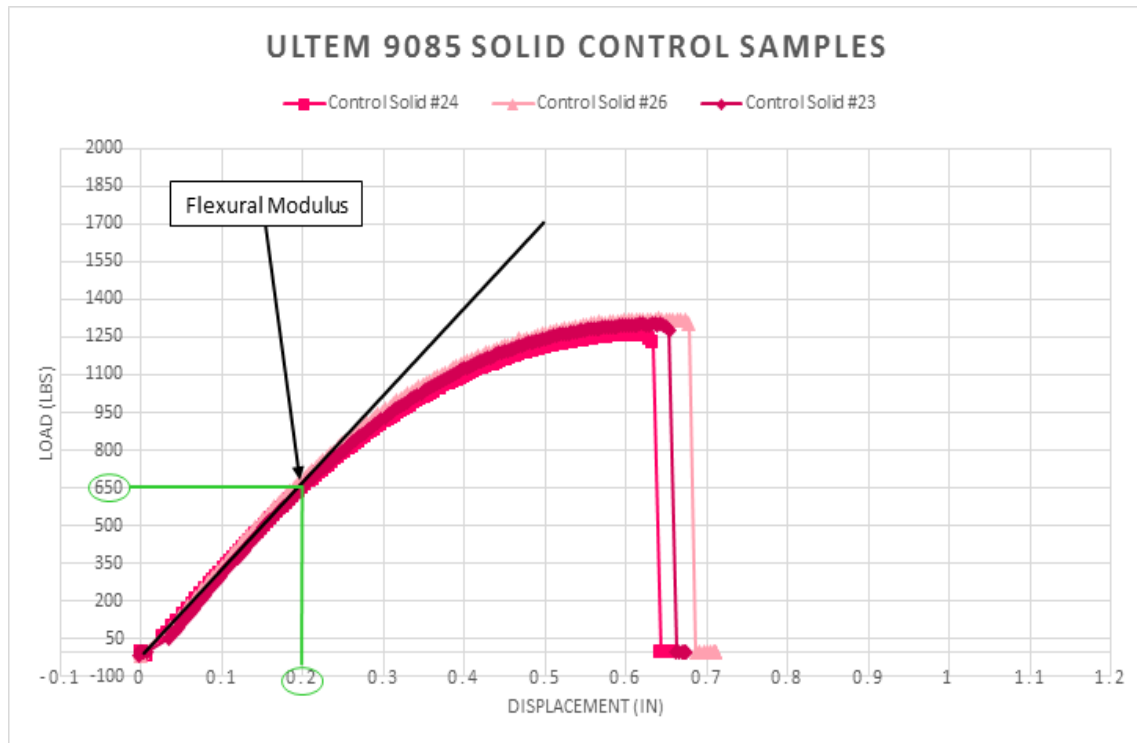


Figure 21: Average Flexural Modulus of the solid samples

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 650 \text{ lbs}}{0.2 \text{ in}} = 175.5 \text{ kpsi}$$

Note: Figures 22, 23, and 24 indicate the Stress vs. Strain analysis of the control samples.



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ULTEM 9085 CONTROL

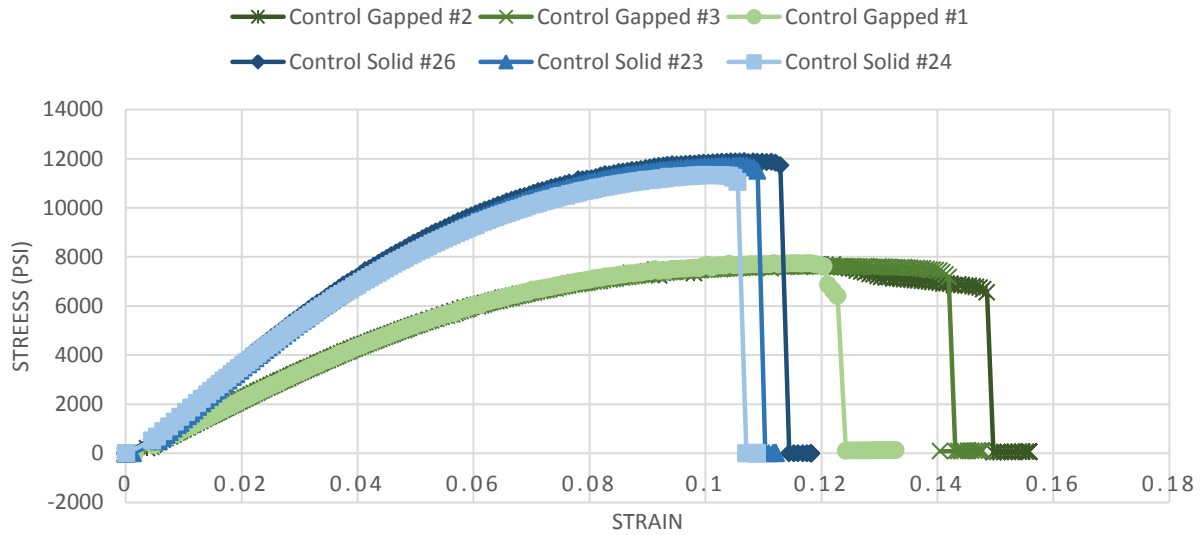


Figure 22: Stress vs. Strain of six Ultem 9085 samples (3 solid & 3 gapped)

ULTEM 9085 GAPPED CONTROL SAMPLES

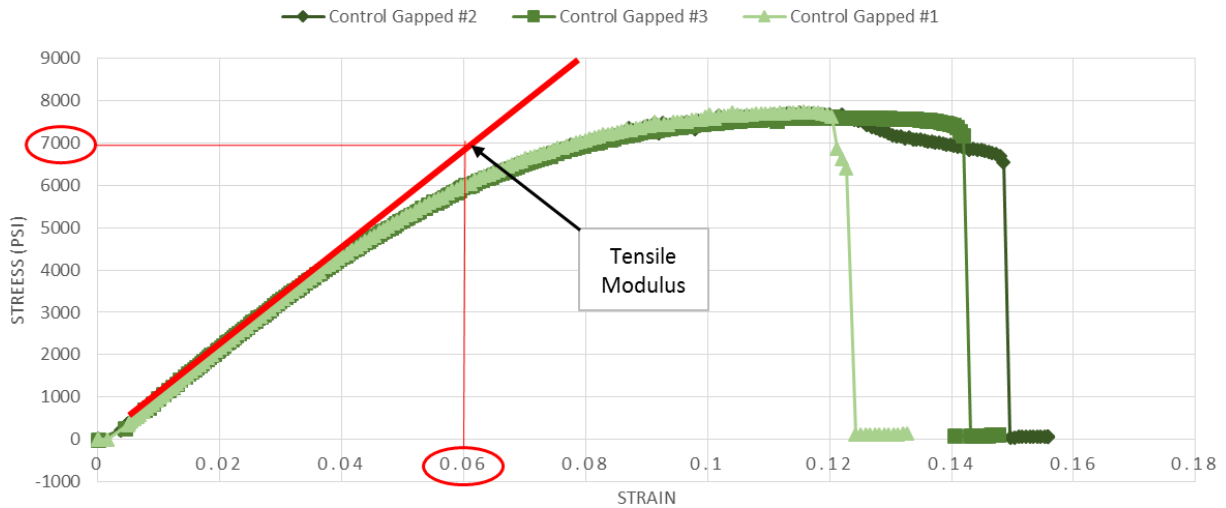


Figure 23: Average Tensile Modulus of the gapped samples

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{7000 \text{ psi}}{0.06} = 116.6 \text{ kpsi}$$



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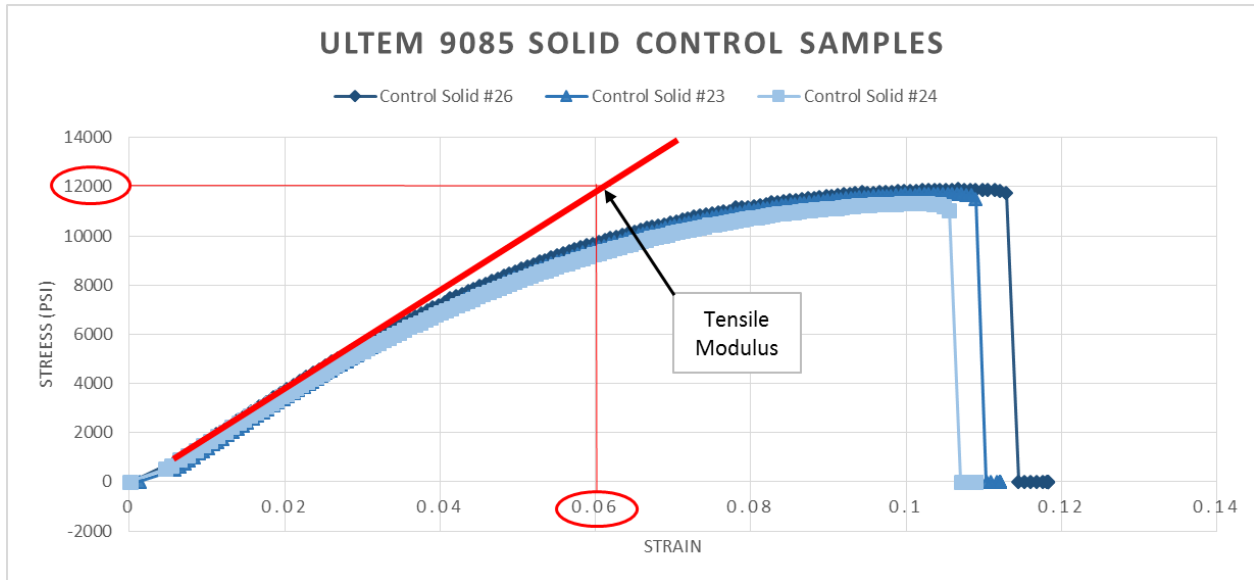


Figure 24: Average Tensile Modulus of the solid samples

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{12000 \text{ psi}}{0.06} = 200 \text{ kpsi}$$

* See Appendix C for the Stratasy and Sabc data sheets.

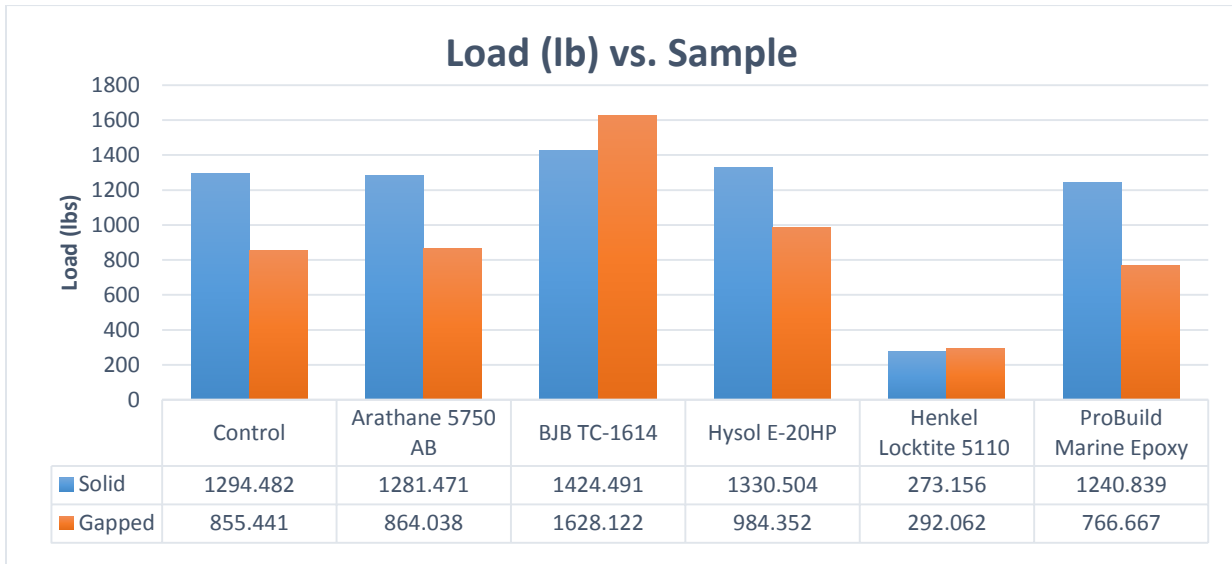


Figure 25: Max average load for gapped and solid samples of each applicant



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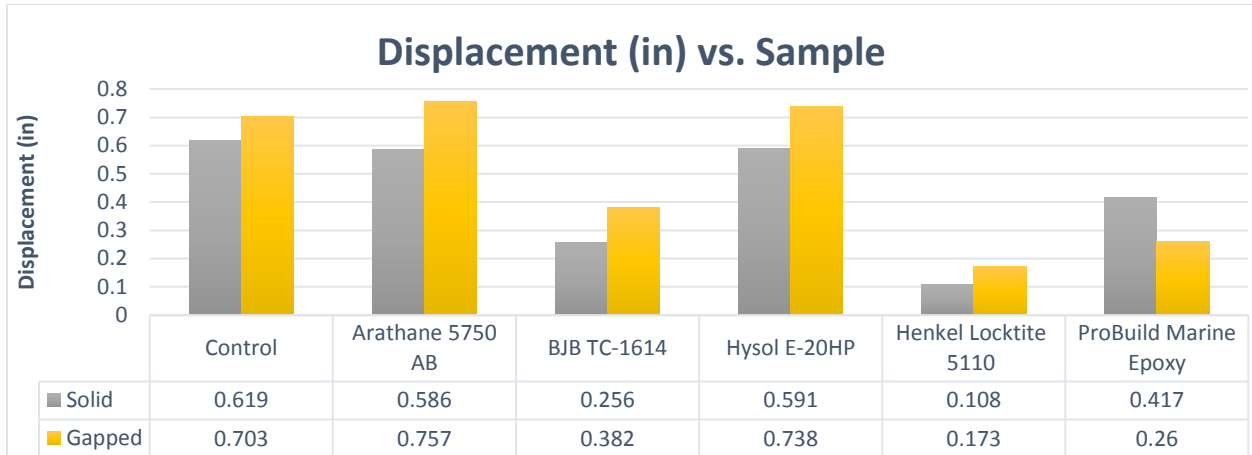


Figure 26: Average displacement for gapped and solid samples of each applicant

Table 8: Comparison of the Flexural modulus from various resources

Data Type	Flexural Modulus (kpsi)	Tensile Modulus (kpsi)	Notes
Sabic	423.0	498.0	<p>(1) Typical values only. Variations within normal tolerances are possible for various colors. All values are measured after at least 48 hours storage at 23°C/50% relative humidity. All properties, except the melt volume and melt flow rates, are measured on injection molded samples. All samples tested under ISO test standards are prepared according to ISO 294.</p> <p>(2) Only typical data for selection purposes. Not to be used for part or tool design.</p> <p>(3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.</p> <p>(4) Internal measurements according to UL standards.</p> <p>(5) Measurements made from laboratory test coupon. Actual shrinkage may vary outside of range due to differences in processing conditions, equipment, part geometry and tool design. It is recommended that mold shrinkage studies be performed with surrogate or legacy tooling prior to cutting tools for new molded article.</p> <p>(6) Needs hard coat to consistently pass 60 sec Vertical Burn.</p>
Stratasys	362.6	322.0	<p>ASTM D790 The performance characteristics of these materials may vary according to application, operating conditions, or end use. Each user is responsible for determining that the Stratasys material is safe, lawful, and technically suitable for the</p>



			intended application, as well as for identifying the proper disposal (or recycling) method consistent with applicable environmental laws and regulations. The information presented in this document are typical values intended for reference and comparison purposes only. They should not be used for design specifications or quality control purposes. End-use material performance can be impacted (+/-) by, but not limited to, part design, end-use conditions, test conditions, color, etc. Actual values will vary with build conditions. Tested parts were built on Fortus 400mc @ 0.010" (0.254 mm) slice. Product specifications are subject to change without notice. * Build orientation is on side long edge.
NASA ARC Solid Control	175.5	200.0	non-standard test
NASA ARC Gapped Control	117.0	116.6	non-standard test

2.6.4 Break Characteristics/FOD

Table 9: Gapped sample break characteristics

Applicant	FOD < 2mm	FOD > 2mm	Notes	Sharp Edges
Control	Yes	No	Stayed together (Shredded fibers)/Ductile	Yes
Arathane 5750 A/B	Yes	Yes	Gentle (shredded fibers)/Ductile	Yes
Hysol E-20HP	Yes	No	Unpredictable	Yes
ProBuild Marine	Yes	Yes	Energetic/Brittle	Yes
Loctite 5110	No	No	Very Gentle/Brittle	No
BJB TC-1614	Yes	Yes	Very Energetic/Brittle	Varies

Table 10: Solid sample break characteristics

Applicant	FOD/Size: Grain of Sand	FOD/size: Pebble or Larger	Notes	Sharp Edges
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Control	Yes	Yes	Energetic/ Brittle	Yes
Arathane 5750 A/B	Yes	Yes	Energetic/ Brittle	Yes
Hysol E-20HP	Yes	No	Energetic/ Brittle	Yes
ProBuild Marine	Yes	Yes	Very Energetic/ Brittle	Yes
Loctite 5110	No	No	Very Gentle/ Brittle	No
BJB TC-1614	Varies	Varies	Very Energetic/ Brittle	No

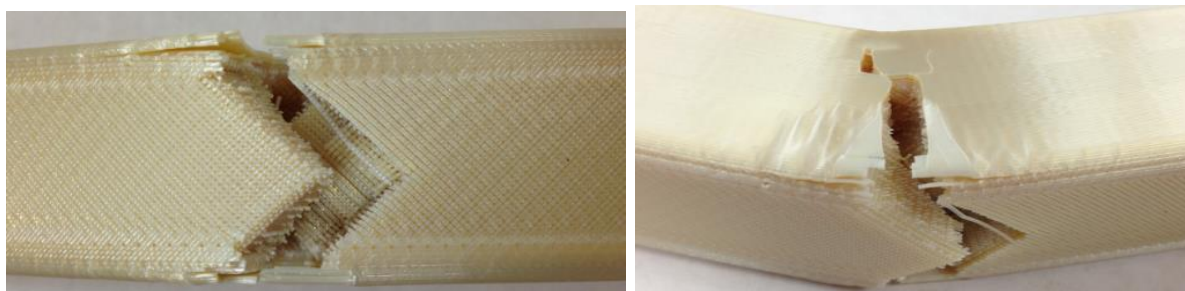
Unpredictable Break: The type of break varied greatly from sample to sample.

Very Gentle Break: The sample failed and fractured but did not separate into two pieces.

Very Energetic Break: The sample broke violently, impacting the walls of the test volume with considerable force.

Stayed Together: The sample broke but was held together by a thin strand of material as seen on the following page.

Sharp Edges: Edges were caught during the White glove test



*Figure 27: Gapped control sample post break **

3.0 SDP Enclosure Top Testing

The purpose of this test was to verify the simulations produced in SDP-PASR-001 by Aurora Flight Sciences (AFS) regarding the 3-D printed Ultem 9085 part being used for the Enclosure Top of the SPHERES Docking Port (SDP) onboard the International Space Station (ISS). As agreed with the NASA PSRP structural engineer at AFS, the SPHERES engineering team replicated a kick load (125 lb). The 125 lb kick load was determined by AFS as a “worst case scenario.” In reality, the kick load required was 50 lb, as it conformed to the NASA ISS crew

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system load standards described in the table below. The 3-D printed part was subjected to loading for 30 seconds, during which it was observed for any deflection or other behavior, and was then evaluated for any structural flaws. AFS has also produced a simulation using SolidWorks, and this test aimed to verify the results of the simulation.

Table 11 Crew induced loads from SSP57000

CREW SYSTEM OR STRUCTURE	TYPE OF LOAD	LOAD	DIRECTION OF LOAD
Lever, Handles, Operating Wheels, Controls	Push or Pull concentrated on most extreme edge	222.6 N (50 lbf), limit	Any direction
Small Knobs	Twist (torsion)	14.9 N-m (11 ft-lbf), limit	Either direction
Exposed Utility Lines (Gas, Fluid, and Vacuum)	Push or Pull	222.6 N (50 lbf)	Any direction
Rack front panels and any other normally exposed equipment	Load distributed over a 4 inch by 4 inch area	556.4 N (125 lbf), limit	Any direction
Legend: ft = feet, m = meter, N = Newton, lbf = pounds force			

The 3-D printed part held up to the 125 lb load without any abnormalities. The interesting results of the test came from the four screws that fastened the Enclosure top to the Adapter Plate. The screws were tightened in accordance to the manufacturing procedures at a torque value of 8 in-lb. When the screws were taken out, radial cracks around the screw holes could be seen on the Ultem surrounding two of the four threaded inserts. These were most likely due to the seating of the threaded inserts against the outside of the Ultem. This could have been prevented with the selection of a different threaded insert.



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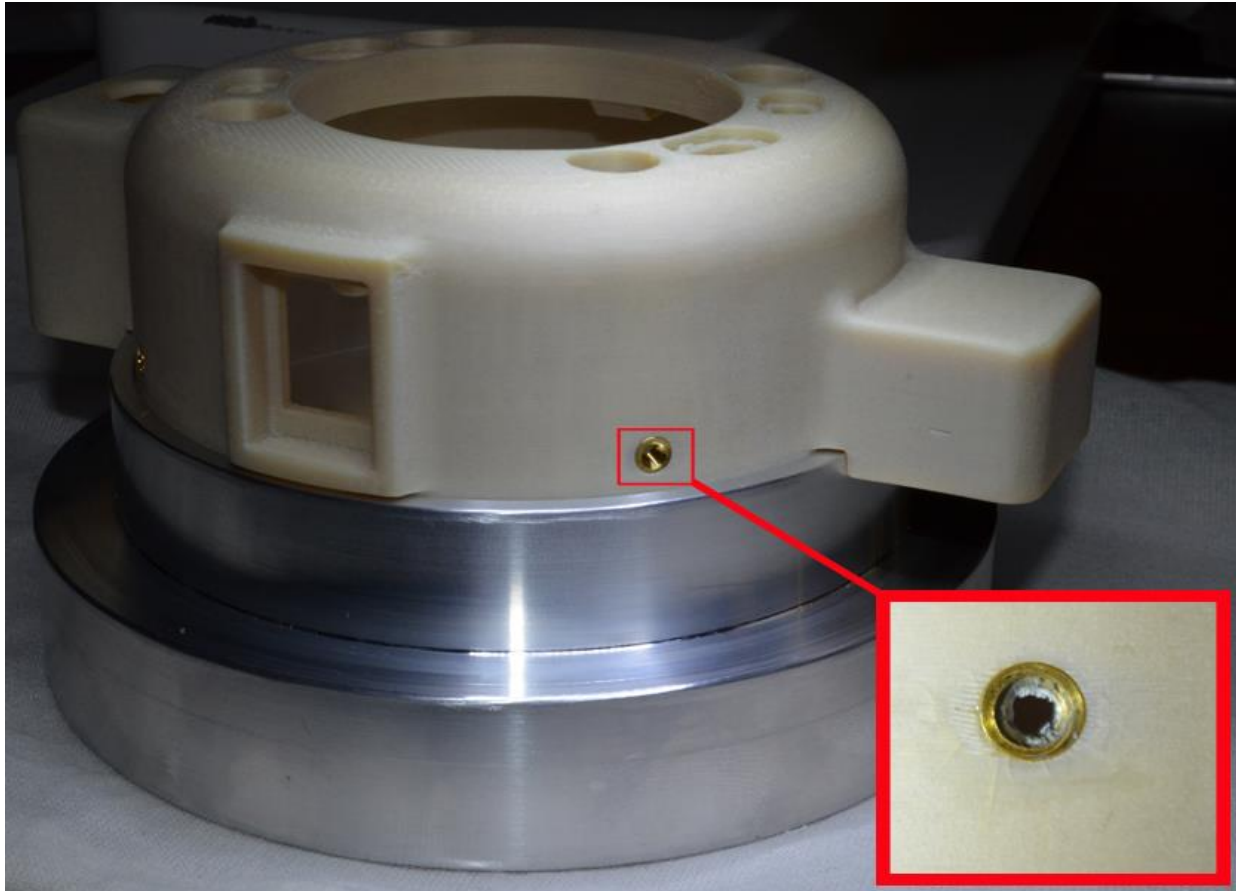


Figure 28: Radial cracks around the threaded insert *

4.0 Conclusion

The objective of the three point beam test was to gain some insight into how 3-D printed materials behave under loads, as well as how the production 3-D printed parts can be improved. Although the intended purpose was not to reproduce test results found on the Stratasys data sheets, the comparison and discussion on why these results are different is important. The tests performed indicate that the geometry and size of the sample, as well as the size of gaps as a result of different fill settings have a large effect on deflection behavior of a given sample. The three point beam tests performed by Sabic (the sole distributor and manufacturer of raw Ultem) were conducted on injection molded samples as described in the 'Notes' of Table 8. Stratasys' test was performed using the ASTM D790 standard for three point loading test. The test performed at NASA Ames was unique. From the stress strain plots of gapped and solid samples of Ultem 9085, the results show that the solid samples broke under a higher load, but deflected



less. As a result, the flexural modulus for the solid samples was higher. These results prove the correlation of the size of the gaps between the extrusion paths and deflection properties. Essentially, the larger the gaps between extrusion paths determined by the 3-D print setting, the more deflection there is, because the gaps between the extrusion paths allow the material to deflect more. Table 8 shows the different flexural moduli for the different tests. As stated before, the flexural modulus is heavily dependent on geometry, so the comparison of flexural moduli between different tests is invalid. The NASA team expects a solid injection molded sample of Ultem 9085 to have a higher flexural modulus than a 3-D printed one. The SDP Enclosure Top testing confirmed the danger of over torqueing screws into Ultem 9085. It also emphasized the importance of selecting proper threaded inserts when designing a part.

5.0 InSPIRE II

InSPIRE II products are using 3-D printed Ultem 9085 and have addressed the concerns stated above. Modifications of the design were done early in development from lessons learned from the Slosh incident. These design improvements include locating screw holes farther from the edge.

The following design enhancements are incorporated in the InSPIRE II design:

1. An FEA structural analysis was performed on all 3-D printed Ultem components and local stress concentrations near countersunk screw holes identified and mitigated by adding material, moving holes, changing screw contact areas, changing build orientations etc.
2. Where appropriate, counterbore holes were implemented in lieu of countersunk holes to alleviate radial stresses.
3. The designer has experience in designing 3-D printed parts as part of the NASA Langley Research Center's N+3 program where a 14 ft, 230 lb wind tunnel model was designed, built and successfully tested in NASA's 14x22ft wind tunnel at 70 mph. The entire fuselage, wings and tail was fabricated from 3-D printed ABS-M30 plastic, adhering to NASA's strict wind tunnel model safety specifications.
4. Aurora has a close working relationship with Stratasys, the company who produces these FDM parts. This includes design iterations to optimize component design, support structure layout and build orientation for machinability, strength and robustness.
5. Stratasys performed in-house coupon testing of Ultem samples printed in various orientations, developing a comprehensive datasheet with the actual strength characteristics of 3-D printed Ultem as opposed to injection molded Ultem.



6. Thorough usage and testing at MIT has proven that the designs perform as expected without any structural issues.

Integration procedures were written to ensure that the assembly of the InSPIRE II vehicles shall abide by the imposed torque specifications within their documentation. This ensures proper levels of torque and process.

Currently MIT/AFS has a rapport with the 3-D printing manufacturing company. They requested a skilled CAD to CAM operator to adjust the settings to ensure the best product possible. While there are no established design and manufacturing rules, it is assumed human review will be superior to the default print settings.

6.0 Recommendations

During manufacturing operations, requirements may be instilled on the operator by the PI, such as single operator use, single machine use, and batch production coupons. Single material spool per production or additional batch coupons may be required. The final products should be handled accordingly and a copy of the printer logs should be delivered to the PI. The previous implementations are indented as preventative measures to improve product quality. Destructive coupon testing will serve as the main solution to prevent any further concerns with 3-D printed parts onboard the ISS. Many products within the aerospace industry designed for space flight application often require a coupon or sample to be analyzed, tested, or saved for future evaluation. Given that Ultem 9085 is a product dependent on processes, it is applicable to the same requirements as the other products with these similar traits of deviations in the products.

The SPHERES engineering team, together with the InSPIRE II payload developers, feel the best way to ensure the quality of the 3-D printed Ultem 9085-based product is to require a coupon (per batch) that will have to be proven. The proof required would be to identify the portion of the component receiving the highest stress, replicate that portion as a coupon as part of that batch, and destructively test the coupon. The resultant force for deflection and yield of the product would be matched against simulation. Additionally, the product would have to break with an established safety factor and match analysis simulation within an established range of expectation. Lastly, a final inspection looking for cracks will be performed prior to final packaging.



6.0 Appendices

Appendix A: Three Point Beam Testing

Sample Key Tables



Ultem 9085 Sample Impregnation Key

Coating/Impregnation Name	Solid Sample #	Sample ID	Gapped Sample #	Sample ID
Control – Unmodified	Solid Sample #1	23	Gapped Sample #1	1
	Solid Sample #2	24	Gapped Sample #2	2
	Solid Sample #3	26	Gapped Sample #3	3
Arathane 5750 A/B (LV) Description: Urethane based conformal coating indented for PCB encapsulation, Dip method with vacuum assistance.	Solid Sample #1	27	Gapped Sample #1	4
	Solid Sample #2	28	Gapped Sample #2	5
	Solid Sample #3	29	Gapped Sample #3	6
BJB TC-1614 Description: Designed for 3d printed parted to seal porous to semi-porous materials. Dip method with vacuum assistance	Solid Sample #1	30	Gapped Sample #1	7
	Solid Sample #2	32	Gapped Sample #2	8
	Solid Sample #3	33	Gapped Sample #3	9
Hysol E-20HP Description: 2 part medium viscosity industrial grade epoxy. Epoxy 2:1 gun used then applied via brush/tool	Solid Sample #1	34	Gapped Sample #1	10
	Solid Sample #2	35	Gapped Sample #2	11
	Solid Sample #3	37	Gapped Sample #3	12
Hysol EA9396 <i>EJB #2</i> Description: Low viscosity, 2 part epoxy. Dip method with vacuum assistance	Solid Sample #1	38	Gapped Sample #1	13
	Solid Sample #2	39	Gapped Sample #2	14
	Solid Sample #3	40	Gapped Sample #3	15
Loctite 5110 Description: Low viscosity liquid sealant designed for electronic assemblies. Dip method with vacuum assistance	Solid Sample #1	41	Gapped Sample #1	16
	Solid Sample #2	42	Gapped Sample #2	17
	Solid Sample #3	43	Gapped Sample #3	18
Probuild Marine Epoxy Description: General purpose epoxy. Dip method with vacuum assistance	Solid Sample #1	44	Gapped Sample #1	19
	Solid Sample #2	45	Gapped Sample #2	20
	Solid Sample #3	46	Gapped Sample #3	21

Arathane #2

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Pre-Application dimension tables



Ultem 9085 Pre-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass (grams)	Solid or Gapped	Photos Taken	Notes:
1	25.51	25.40	25.51	25.40	25.50	25.42	112.02	Gapped		
2	25.51	25.42	25.53	25.35	25.48	25.33	112.04	Gapped		
3	25.50	25.40	25.48	25.38	25.49	25.40	112.32	Gapped		
4	25.46	25.32	25.46	25.32	25.46	25.40	114.11	Gapped		
5	25.60	25.43	25.55	25.36	25.54	25.40	111.62	Gapped		
6	25.47	25.41	25.48	25.37	25.51	25.41	113.93	Gapped		
7	25.51	25.44	25.52	25.41	25.54	25.42	112.26	Gapped		
8	25.50	25.42	25.50	25.38	25.49	25.40	114.30	Gapped		
9	25.48	25.42	25.49	25.40	25.48	25.38	114.22	Gapped		
10	25.52	25.40	25.52	25.40	25.52	25.41	112.10	Gapped		
11	25.51	25.49	25.49	25.38	25.49	25.37	113.75	Gapped		
12	25.50	25.43	25.51	25.41	25.49	25.40	113.45	Gapped		
13	25.51	25.32	25.49	25.36	25.51	25.38	111.56	Gapped		
14	25.51	25.37	25.53	25.37	25.52	25.39	111.77	Gapped		
15	25.49	25.42	25.49	25.42	25.48	25.40	113.67	Gapped		
16	25.52	25.42	25.50	25.40	25.46	25.33	113.64	Gapped		
17	25.51	25.42	25.52	25.36	25.53	25.35	111.81	Gapped		
18	25.49	25.36	25.50	25.37	25.48	25.42	113.70	Gapped		
19	25.52	25.41	25.55	25.40	25.54	25.42	111.62	Gapped		
20	25.52	25.40	25.50	25.40	25.52	25.40	111.61	Gapped		

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Ultem 9085 Pre-Application Data Log

Technician Full Name: Darryl LeVasseur Technician Initial: DL Date: 4-12-14
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 04/11/2014

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Ultem 9085 Pre-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass (grams)	Solid or Gapped	Photos Taken	Notes
21	25.50	25.93	25.50	25.41	25.50	25.42	113.46	Gapped		
22	25.48	25.44	25.49	25.40	25.49	25.41	113.46	Gapped		
23	25.44	25.31	25.45	25.37	25.48	25.40	132.11	Solid		
24	25.51	25.38	25.49	25.34	25.54	25.36	132.11	Solid		
25	25.51	25.34	25.52	25.30	25.52	25.35	113.31	Gapped		
26	25.45	25.36	25.45	25.40	25.46	25.45	132.11	Solid		
27	25.47	25.44	25.48	25.40	25.47	25.40	133.46	Solid		
28	25.46	25.45	25.48	25.43	25.48	25.44	132.03	Solid		
29	25.51	25.28	25.50	25.24	25.50	25.25	131.14	Solid		
30	25.48	25.37	25.51	25.36	25.51	25.38	132.66	Solid		
31	25.53	25.27	25.54	25.27	25.54	25.31	113.73	Gapped		
32	25.47	25.36	25.51	25.36	25.55	25.47	133.59	Solid		
33	25.49	25.41	25.48	25.38	25.47	25.40	133.37	Solid		
34	25.50	25.42	25.48	25.44	25.48	25.39	132.76	Solid		
35	25.50	25.42	25.47	25.35	25.47	25.35	132.44	Solid		
36	25.52	25.25	25.51	25.17	25.50	25.20	113.74	Gapped		
37	25.48	25.40	25.56	25.41	25.47	25.43	132.32	Solid		
38	25.54	25.46	25.55	25.30	25.55	25.31	131.86	Solid		
39	25.48	25.42	25.47	25.44	25.47	25.42	133.25	Solid		
40	25.50	25.43	25.50	25.41	25.48	25.43	132.28	Solid		

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Ultem 9085 Pre-Application Data Log

Technician Full Name: Darryl Lolassee Technician Initial: DL Date: 4-11-14
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 04/11/2014

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Ultem 9085 Pre-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass (grams)	Solid or Gapped	Photos Taken	Notes:
41	25.52	25.35	25.48	25.40	25.51	25.43	132.00	Solid		
42	25.48	25.44	25.47	25.44	25.46	25.35	132.93	Solid		
43	25.53	25.42	25.47	25.41	25.48	25.39	132.21	Solid		
44	25.48	25.35	25.45	25.37	25.48	25.41	132.13	Solid		
45	25.49	25.32	25.49	25.35	25.49	25.42	132.09	Solid		
46	25.49	25.39	25.49	25.39	25.49	25.41	132.24	Solid		
47	25.52	25.30	25.53	25.19	25.54	25.19	131.97	Solid		
48	25.47	25.41	25.49	25.42	25.49	25.40	132.82	Solid		
49	25.49	25.46	25.46	25.48	25.49	25.41	132.65	Solid		
50										

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Ultem 9085 Pre-Application Data Log

Technician Full Name: Darryl LeVasseur Technician Initial: DL Date: 4-18-14
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 04/11/2014

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date April 11, 2013
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Application Procedures

SPH-ULT-MT001

Rev. A

SPHERES Ultem 9085 Material Testing

Applications Procedures



March, 2014



National Aeronautics and Space Administration
 Ames Research Center
 Moffet Field, CA

<p>Organization SPHERES National Lab</p>	<p>Title/Subject ULTEM 9085 Testing</p>	<p>Number SPH-04-XS-100</p>	<p>Date June 17, 2015</p>	<p>Page 43</p>
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Written by:

Daniel Andres Aguilar Martel 3/25/2014
 Daniel Andres Aguilar Martel Date
 Aerospace Engineering Student
 San Jose State University

Sean David Christensen 3/25/2014
 Sean David Christensen Date
 Aerospace Engineering Student
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Emmet John Fox 3/25/2014
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 Aerospace Engineering Student
 San Jose State University

Approved by:

Darryl William LeVasseur 3/25/2014
 Darryl William LeVasseur Date
 System Engineer II
 Metis Technologies

Organization SPHERES National Lab	Title/Subject Applications Procedures	Number SPH-ULT-MT001	Date March 25, 2013	Page 1
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Organization SPHERES National Lab	Title/Subject ULTEM 9085 Testing	Number SPH-04-XS-100	Date June 17, 2015	Page 44
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Safety Equipment:

- Safety Glasses
- Breathing Masks
- Gloves

Procedure Steps:

1. Fully submerge samples in 99% isopropyl alcohol bath and agitate samples for a minimum of 10 seconds. Remove from alcohol bath and use a wire hanger through one of the holes located in the samples.
2. Hang samples vertically in oven (120 C) for 30 minutes.
3. Label each piece to identify the particular specimen by attaching a tag with a Ziploc color coded to the solid or gapped specimens by tagging through the hole in the specimen.
 - 3.1. Label Samples 1-42 with a Ziploc tag
 - 3.1.1. 1 - 21 solid
 - 3.1.2. 2 - 42 gapped
 - 3.1.3. Apply sharpie mark to top/front/left side as indicated in image:1 below
4. Place each sample into a single bag.
5. Weigh each piece and record the results into the Pre Application log
6. Measure the dimensions of each piece using calipers. Measure at 3 points (left, middle, right) and record the results into the Pre Application log.

Note: Left, middle, and right is with respect to the mark made in 3.1.3

7. Inspect and note each piece and record the results into the Pre Application log.
8. Photograph each specimen and record the results into the Pre Application log.

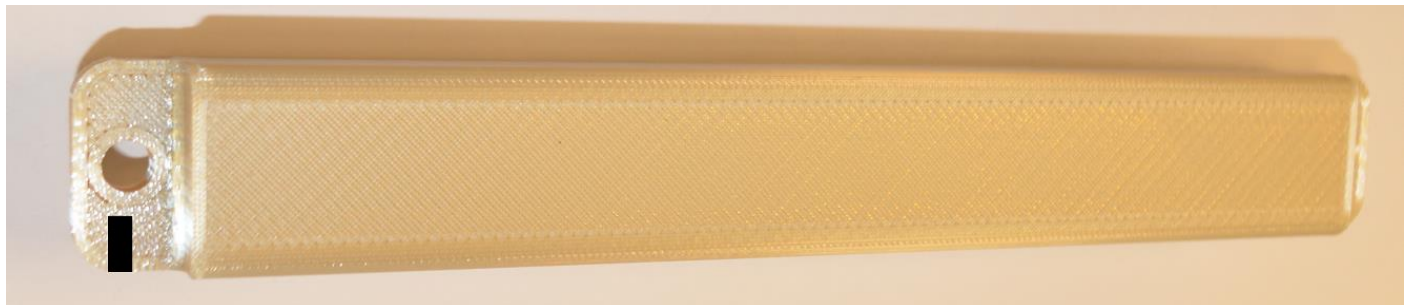


Figure.1: Sharpie mark location indicates samples top/front/left orientation



Application Procedures

1. 6 samples- 3 of the solid core, and 3 of the gapped core shall have one of the application processes below applied according to manufacturer's recommendations.
2. Only 3 samples of a core type and application type may be worked on at one time to make sure no samples are mixed up once the identification label is removed. Apply the material/chemical/adhesive and then re-apply the label immediately post cure and re-bag individually.
3. Remove identification tag for process

Arathane 5750-A/B (LV)

Applications: Dip, Vacuum, Cure in oven

Work Time: @ 25°C (100g), 2 hours

Cure Time:

Recommended cure times*

Temp., °C	Gelation (min)	Tack free (hours)	Full cure (hours)
25	120	24	7 days
65	45	2	9
100	25	1.5	4
125	15	1	2

* Above data was generated on two coatings of 1.5 mil (3.8 x 10⁻²mm) each, dip-applied on epoxy laminate printed circuit boards. High component density boards may require slightly longer cure schedules. Maximum insulating resistance, interfacial adhesion, and protection from corrosion are obtained with heat curing.

Mix Ratio: By Weight: Arathane 5750 A: 18 parts
 Arathane 5750 B (LV): 100 parts

Required Materials and Machinery: Plastic tub, Vacuum, Oven, Hanging rack

Procedure:

System Preparation:

1. The 3D printed part should be clean and free of grease, dirt, or other contaminants. Solvent cleaning is generally sufficient. Arathane 5750 A/B (LV) may be sprayed or applied by dipping.
2. Exposure of Part A to low temperatures for prolonged periods may cause crystallization. Part A must be liquefied by heating to 50°C (120°F) maximum. **DANGER! Do not heat above 50°C! Extreme Explosion and Fire Hazard.**



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3. Heat Part A until clear amber solution is achieved. Remove container from oven. Do not disturb contents. Allow to cool to 25-40°C in a controlled environment; do not force cool.
4. Measure height of the precipitate from outside of bottle. Do not use if level of precipitate is above 3/8 inches (0.6 cm), or if liquid remains cloudy or contains gelled particles. Contact our Customer Service Department with lot number, date received and condition of bottle.
5. Material is ready for use if level of precipitate is below 3/8 inches. Do not agitate. Slowly decant clear resin out of the bottle without disturbing the precipitate. Enough material has been packaged to allow for any precipitate and to assure sufficient Part A. For best results, filter Part A through nylon tricot, 10-25 micron size.
6. Use entire bottle so remaining material will not be contaminated with moisture. If this is not possible, any remaining material must be well blanketed with dry nitrogen or argon and the cap tightened securely. Store at 25-40°C for best long-term stability.

Mixing:

1. Container should be plastic, glass, or metal. Paper and wooden containers or utensils are not recommended because of high moisture content.
2. Weigh Part B into container first. Add Part A to container. (Do not use Part A if precipitate level is greater than 3/8 inches.)
3. Slow machine mixing or hand stirring will minimize air entrapment. Complete and thorough mixing of Parts A and B is essential for optimum end properties.
4. A brief vacuum may be applied to remove bubbles; however, some solvent will also be removed. Vacuum should be equipped with solvent trap to prevent damage to pump.

Dipping:

1. Arathane 5750 A/B (LV) must be thinned with 5750 Thinner to control coating thickness. Coating thickness depends upon amount of solvent added to reduce viscosity and dipping rate. To achieve a one to one and one-half (1 – 1.5) mil thickness (2.5-3.8 x 10-2mm) coat per dip, reduce mixed viscosity to approximately 100 cPs. (Refer to previous recommendations for reducing viscosity).
2. Allow mixture to stand 15-30 minutes for bubbles to dissipate. A suggested solvent blend is recommended above. Adjust dipping rate to achieve desired thickness. This allows for complete wetting of all surfaces and minimizes runoff during cure.

*Multiple applications two or more coats must be applied for optimum protection of parts. Allow enough time at curing temperature for each application to gel. Allow solvent to escape at ambient temperatures for 15-30 minutes prior to elevate temperature curing. This will minimize bubble entrapment. An alternative to air drying or curing between layers is to place 3D printed part in a 15-15mm Hg Vacuum for 5-10 minutes for a dense, bubble-free coating.

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any areas of pooled epoxy with a gloved finger or brush. Monitor any sags or drips for the next hour or until epoxy has gelled.

*Note: Mixing a large mass of epoxy can produce an increase in chemical reaction shortening work time and increasing exotherm (heat) as it sits. Do not leave a large, concentrated mass of epoxy in a container unattended. After soaking the part, it may be best to split up a large batch (over 200-300g) by draining the tub into 2-3 separate small containers and allow to harden.

Henkel Loctite 5110

Applications: Dip, Vacuum

Work Time: To be tested

Cure Time: 5 - 30 minutes, depending on temperature

Mix Ratio: None

Required Materials and Machinery: Plastic tub, Vacuum, Hanging rack

Procedure:

1. Typically, a basket of parts is submerged in sealant. Air is expelled out of the porosity under vacuum.
2. A pressure increase causes the sealant to flow into the pore. Ambient pressure is typical but may be augmented.
3. The basket is lifted and spins to reclaim excess sealant.
4. The parts basket is washed in water with agitation as necessary to achieve good cleaning.
5. Parts cure and dry at room temperature.
6. Use UV light to inspect part

*Note: Porosity sealants typically require catalyzation and must be handled with chemically compatible materials and equipment.

Hysol Loctite E-20HP

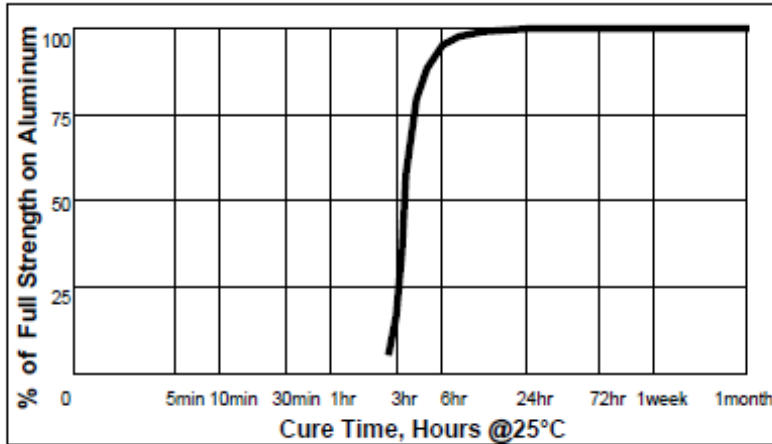
Applications: Brush, Cure in oven

Work Time: 20 minutes (@ 77F)

Cure Time: Varies by temperature



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Mix Ratio: By Weight: Resin: 100 parts
Hardener: 55 parts
By Volume: Resin: 2 parts
Hardener: 1 part

Required Materials and Machinery: Applicator Gun, Mixing Nozzle, Brush, Oven, Hanging Rack

Procedure:

1. For high strength structural bonds, removal of surface contaminants such as paint, oxide films, oils, dust, mold release agents and all other surface contaminants.
2. Use gloves to minimize skin contact. DO NOT use solvents for cleaning hands.
3. Dual Cartridges: To use simply insert the cartridge into the application gun and start the plunger into the cylinders using light pressure on the trigger. Next, remove the cartridge cap and expel a small amount of adhesive to be sure both sides are flowing evenly and freely. If automatic mixing of resin and hardener is desired, attach the mixing nozzle to the end of the cartridge and begin dispensing the adhesive. For hand mixing, expel the desired amount of the adhesive and mix thoroughly. Mix approximately 15 seconds after uniform color is obtained. Bulk Containers: Mix thoroughly by weight or volume in the proportions specified in Properties of Uncured Material section. Mix vigorously approximately 15 seconds after uniform color is obtained.
4. Application to the substrates should be made within 20 minutes. Larger quantities and/or higher temperatures will reduce this working time.
5. Allow to cure at 25°C (77°F) for 24 hours for high strength. Heat up to 93°C (200°F), will speed curing.
6. Excess uncured adhesive can be cleaned up with ketone type solvents.

Post-Application Processing

<u>Applicant</u>	<u>Pre-Process</u>	<u>Post-Process</u>
<p><u>BJB</u></p>		
<p><u>BJB</u></p>		



SPHERES



BJB



BJB





Post-Application Dimension Tables



Ultem 9085 Post-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass Pre work (grams)	Mass Post work (grams)	Solid or Gapped	Photos Taken	Notes:
1											
2											
3											
4											
5											
6											
7											
8											
9											
10	25.56	25.57	25.84	25.55	25.87	25.69	116.95	116.81			Minimal work on left. Far face has some longitudinal defects. Right side - minimal work. Fix the hole
11	25.83	25.64	25.73	25.68	25.65	25.58	118.24	118.15			Minimal work on left. Minimal work on right. Fix right hole
12	25.51	25.47	25.46	25.66	25.52	25.45	116.58	116.56			Minimal work on left. Minimal work on right. Fix right hole
13	25.56	25.4	25.51	25.4	25.5	25.44	138.81	138.79			Bumps on left. Needs sanding on corners. Right side hole needs to be filed out.
14	25.5	25.4	25.49	25.4	25.49	25.44	138.99	138.49			Drip and bump on left. Minor wire residue on right.
15	25.53	25.43	25.48	25.43	25.47	25.53	140.37	140.15			Minor residue on left. Multiple bumps on right.
16	25.50	25.37	25.50	25.31	25.47	25.33	121.04	121.04			
17	25.53	25.37	25.53	25.39	25.49	25.30		118.61			
18	25.51	25.35	25.47	25.38	25.49	25.43		121.06			
19	25.53	25.46	25.54	25.41	25.52	25.42	117.49	117.39			Right hole needs rework. Left end has residue bubble
20	25.54	25.6	25.51	25.39	25.51	25.47	116.07	116			Residue on right end. Work to be done on left

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Ultem 9085 Post-Application Data Log

Technician Full Name: Daniel Aguilar Technician Initial: DA Date: 6/5/2014
 Technician Full Name: Emmet Fox Technician Initial: EF Date: 6/5/2014
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 06/05/2014

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Ultem 9085 Post-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass Pre work (grams)	Mass Post work (grams)	Solid or Gapped	Photos Taken	Notes:
21	25.48	25.42	25.47	25.4	25.51	25.45	117.73	117.72			Built up residue on right end. Has a few bumps on the left
22	24.45	25.64	25.5	25.61	25.46	25.5	126.11	125.82			Right Hole needs to be reworked. Bump on Left
23											
24											
25	25.54	25.41	25.43	25.42	25.52	25.56	123.7	123.53			Left hole needs work. Right edge has a lot of residue
26											
27											
28											
29											
30											
31	25.48	25.5	25.49	25.44	25.47	25.3	123.42	123.25			Right hole needs work. Left tab has a bump
32											
33											
34	25.9	26	25.96	26.32	25.66	25.96	137.89	137.76			Both sides need minimal work. Fix right side hole
35	25.87	25.86	26.01	25.93	25.96	26.07	136.94	136.87			Minimal work on left. Minimal work on right. Fix hole.
36											
37	25.88	25.73	26.09	26	25.71	25.96	137.15	137.01			Left side minimal work. Right side minimal work. Right hole needs work
38	25.6	25.32	25.57	25.32	25.52	25.42	146.21	145.73			Minor sanding on left. Bumps, bubbles, and drips on right.
39	25.5	25.41	25.56	25.46	25.59	25.59	147.31	146.96			Left end needs sanding. One bump on right end. Right hole needs to be filed out.
40	25.46	25.44	25.54	25.53	25.53	25.53	147.39	146.85			Minor sanding on left tab. Bumps and drips on right. Right hole is blocked.

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Ultem 9085 Post-Application Data Log

Technician Full Name: Emmet Fox Technician Initial: EF Date: 6/5/14
 Technician Full Name: Daniel Aguilor Technician Initial: DA Date: 6/5/14
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 06/05/2014

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Ultem 9085 Post-Application Data Log

Sample #	Dimension: Left top-bottom (mm)	Dimension: Left side-side (mm)	Dimension: Center top-bottom (mm)	Dimension: Center side-side (mm)	Dimension: Right top-bottom (mm)	Dimension: Right side-side (mm)	Mass Pre work (grams)	Mass Post work (grams)	Solid or Gapped	Photos Taken	Notes:
41	25.43	25.38	25.51	25.38	25.53	25.40		140.58			
42	25.49	25.38	25.52	25.33	25.52	25.32		140.32			
43	25.53	25.42	25.46	25.43	25.49	25.40		140.84			
44	25.41	25.44	25.43	25.46	25.46	25.4	134.13	133.94			Left tab residual drop. Right tab has small residue
45	25.44	25.4	25.44	25.43	25.43	25.48	133.87	133.76			Left edge has a bump. Imperfection in right hole due to wire
46	25.45	25.45	25.44	25.41	25.44	25.44	133.8	133.75			Right hole needs to be worked
47	25.58	25.44	25.51	25.27	25.54	25.23	135.93	135.78			Right hole needs work. Left tab bump
48	25.72	25.47	25.49	25.56	25.54	25.63	136.02	135.87			Left hole needs work. Right tab has bump
49	25.48	25.35	25.56	25.6	25.52	25.64	135.98	135.91			Left hole needs work. Right tab needs work. Right top edge needs work
50											

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Ultem 9085 Post-Application Data Log

Technician Full Name: Emmet Fox Technician Initial: EF Date: 6/5/14
 Technician Full Name: Daniel Aguilar Technician Initial: DA Date: 6/5/14
 Technician Full Name: _____ Technician Initial: _____ Date: _____
 Operations Engineer (OE) Full Name: ROBERT HANSON OE Initial: RH Date: 06/05/2014

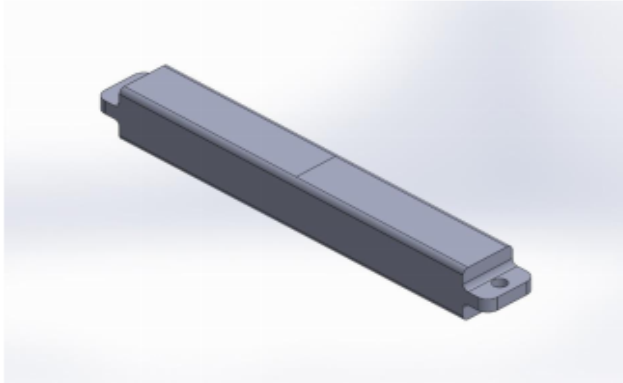
Organization SPHERES National Lab	Title/Subject ULTEM 9085 Pre-Application Data Log	Number SPH-ULT-MT001	Date June 5, 2013
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Finite Element Analysis



Simulation of ultem stick

Date: Wednesday, June 25, 2014
Designer: Solidworks
Study name: Static ARC EEL
Analysis type: Static

Table of Contents

- Description 1
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- Model Information 2
- Study Properties 3
- Units 4
- Material Properties 4
- Loads and Fixtures..... 5
- Connector DefinitionsError! Bookmark not defined.
- Contact InformationError! Bookmark not defined.
- Mesh Information 6
- Sensor Details ... Error! Bookmark not defined.
- Resultant Forces 7
- Beams Error! Bookmark not defined.
- Study Results 8
- Conclusion Error! Bookmark not defined.

Description
No Data



SOLIDWORKS Analyzed with SolidWorks Simulation

Simulation of ultem stick 1

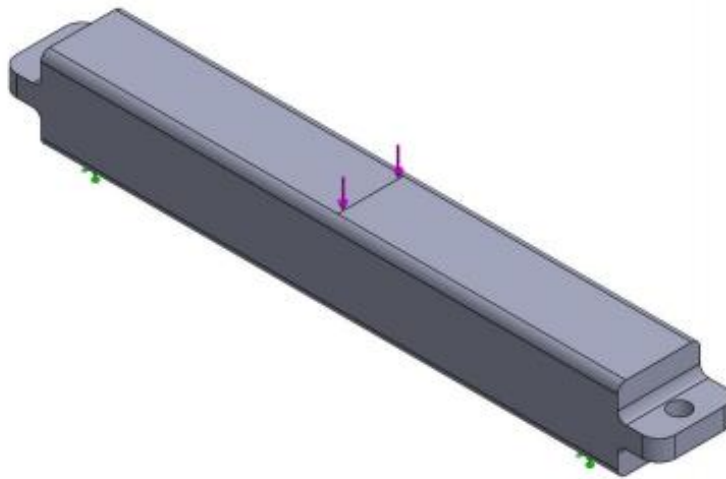


SPHERES



Assumptions

Model Information



Model name: ultem stick
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
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SOLIDWORKS

Analyzed with SolidWorks Simulation

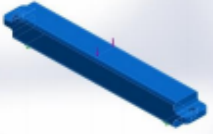
Simulation of ultem stick

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SPHERES



<p>Split Line2</p> 	<p>Solid Body</p>	<p>Mass:0.346804 lb Volume:7.16537 in³ Density:0.0484 lb/in³ Weight:0.346569 lbf</p>	<p>C:\Users\Gabriel\Desktop\ Ultem Stuff\FW__3D_Print_NAS A_Ames_Testing\ultem stick.SLDPRT Jun 23 11:05:58 2014</p>
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Study Properties

Study name	Static ARC EEL
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	77 Fahrenheit
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	On
Compute free body forces	Off
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (c:\users\gabriel\appdata\local\temp)



SOLIDWORKS

Analyzed with SolidWorks Simulation

Simulation of ultem stick

3

<p>Organization SPHERES National Lab</p>	<p>Title/Subject ULTEM 9085 Testing</p>	<p>Number SPH-04-XS-100</p>	<p>Date June 17, 2015</p>	<p>Page 59</p>
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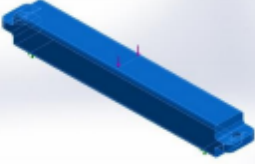
SPHERES



Units

Unit system:	English (IPS)
Length/Displacement	in
Temperature	Fahrenheit
Angular velocity	Rad/sec
Pressure/Stress	psi

Material Properties

Model Reference	Properties	Components
	Name: Ultem Isotropic (6) Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 12700 psi Tensile strength: 12700 psi Elastic modulus: 104714 psi Poisson's ratio: 0.44 Mass density: 0.0484 lb/in ³ Thermal expansion coefficient: 2.03704e-005 /Fahrenheit	SolidBody 1(Split Line2)(ultem stick)
Curve Data:N/A		

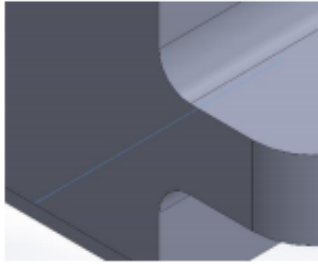
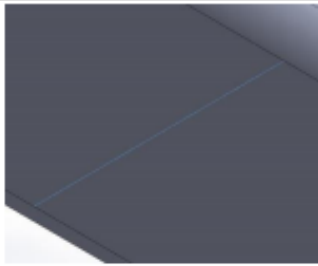


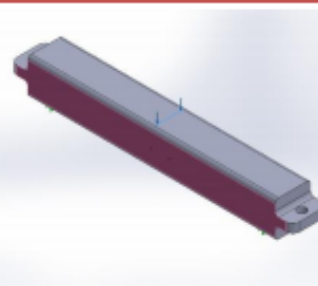
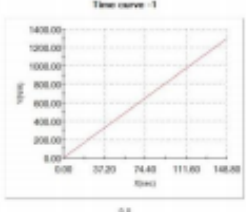


SPHERES



Loads and Fixtures

Fixture name	Fixture Image	Fixture Details		
Fixed-2		Entities: 1 edge(s) Type: Fixed Geometry		
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(lbf)	-1285.12	531.198	0.462297	1390.58
Reaction Moment(lbf.in)	0	0	0	0
Fixed-3		Entities: 1 edge(s) Type: Fixed Geometry		
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(lbf)	1292.24	537.291	0.909232	1399.48
Reaction Moment(lbf.in)	0	0	0	0

Load name	Load Image	Load Details	Function Curve
Force-2		Entities: 1 edge(s) Reference: Face< 1 > Type: Apply force Values: ---, 1269.75, --- lbf Phase Angle: 0 Units: deg	 <p>Time curve -1</p>



SOLIDWORKS

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Simulation of ultem stick

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Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 in
Minimum element size	0 in
Mesh Quality	High

Mesh Information - Details

Total Nodes	74979
Total Elements	50990
Maximum Aspect Ratio	4.4843
% of elements with Aspect Ratio < 3	99.9
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh:mm:ss):	00:00:02
Computer name:	10NASAT



SOLIDWORKS

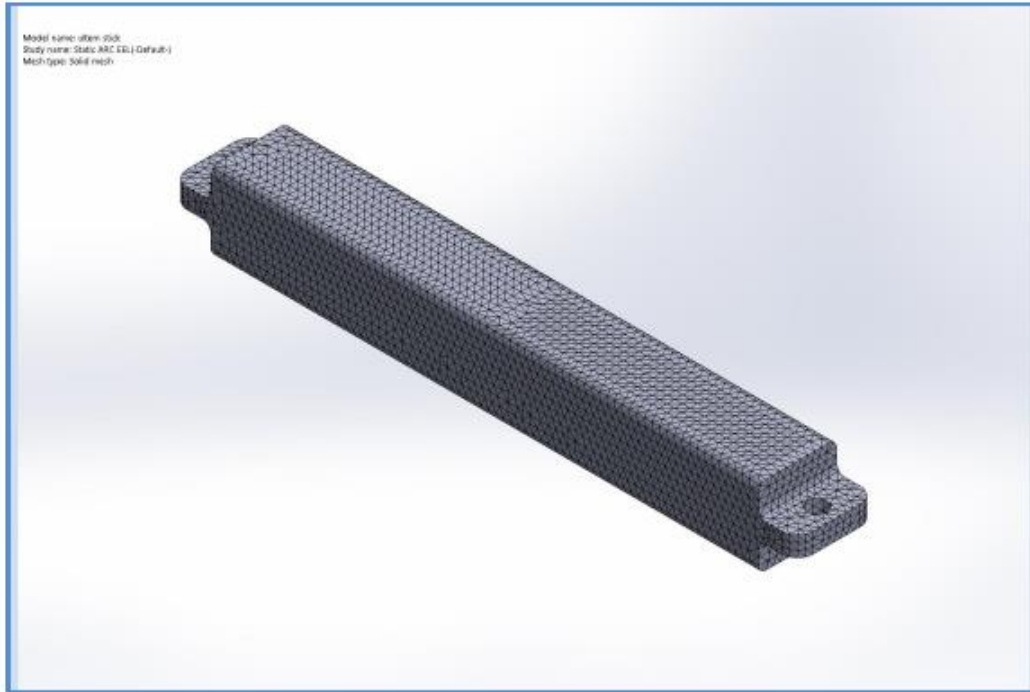
Analyzed with SolidWorks Simulation

Simulation of ultem stick

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SPHERES



Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf	7.11572	1068.49	1.37153	1068.51

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	lbf.in	0	0	0	0



SOLIDWORKS Analyzed with SolidWorks Simulation

Simulation of ultem stick 7



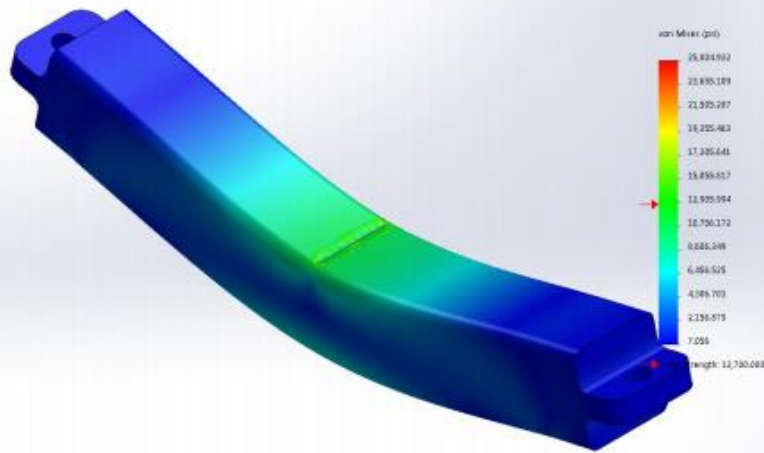
SPHERES



Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.05646 psi Node: 67663	25804.9 psi Node: 70747

Model name: ultem stick
 Study name: Static ARC CELL-Default3
 Plot type: Static modal stress Stress1
 Deformation scale: 1



Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in Node: 387	0.622447 in Node: 95



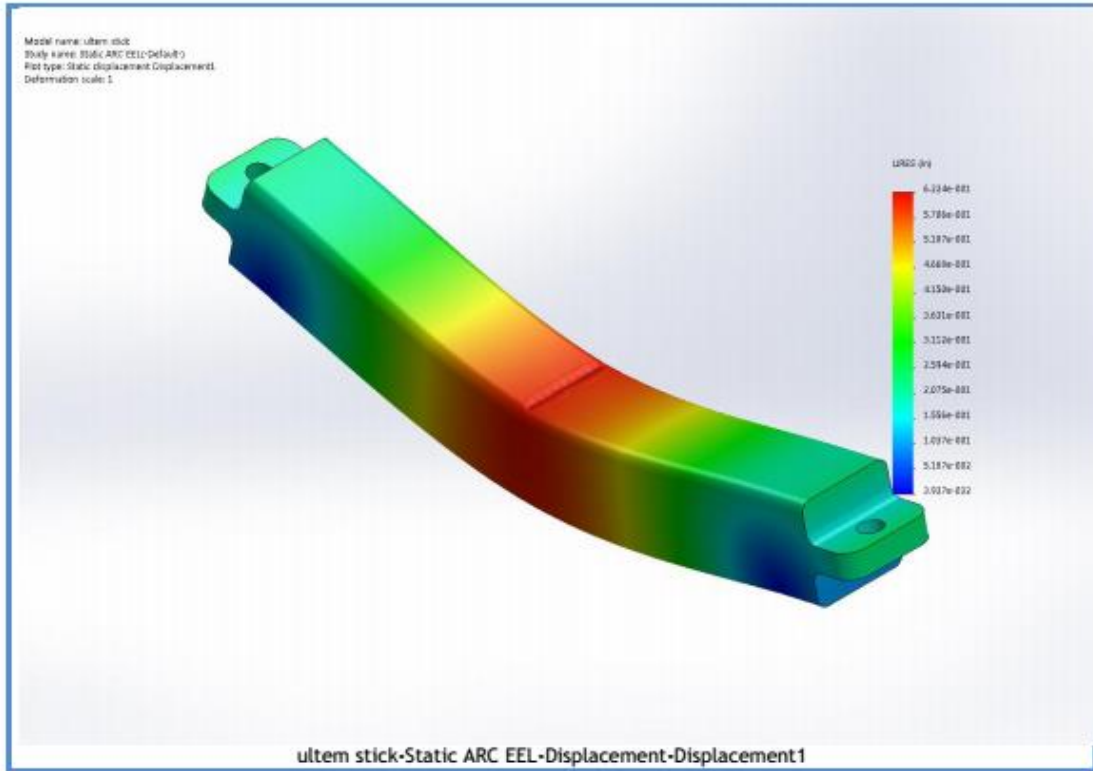
Analyzed with SolidWorks Simulation

Simulation of ultem stick

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Testing	Number SPH-04-XS-100	Date June 17, 2015	Page 64
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Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0.000153842 Element: 6228	0.211564 Element: 9294



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Simulation of ultem stick

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Destructive Sample Testing

SPH-ULT-MT001

Rev. A

SPHERES Ultem 9085 Material Testing

Destructive Sample Testing

June, 2014



National Aeronautics and Space Administration
Ames Research Center
Moffet Field, CA

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Testing	Number SPH-04-XS-100	Date June 17, 2015	Page 66
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Written by:

Daniel Andres Aguilar Martel 6/10/2014
 Daniel Andres Aguilar Martel Date
 Aerospace Engineering Student
 San Jose State University

Sean David Christensen 6/10/2014
 Sean David Christensen Date
 Aerospace Engineering Student
 San Jose State University

Emmet John Fox 6/10/2014
 Emmet John Fox Date
 Aerospace Engineering Student
 San Jose State University

Approved by:

Darryl William LeVasseur 6/10/2014
 Darryl William LeVasseur Date
 System Engineer II
 Metis Technologies

Safety Equipment:

-Safety Glasses

Procedure steps:

1. Prepare the Testing Apparatus

1.1. Verify that the 5000 lb load cell on the Southwark Emery has been installed.



Figure 1: Image of the 5000 lb load cell

Load Cell	Tolerance
5000 lb	+/- 1 lb

1.2. Connect the computer which will record the data from the test.

1.3. Set the pressure gauge on the Southwark Emery to “medium” (12,000 lb max).



Figure 2 & 3: (Left) Force indicator set to 12,000lb max load. (Right) Image of the pressure gauge knob set to “medium”.



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- 1.4. Set up the safety plywood on the sides of the test section to prevent specimen particulates from escaping the confined test volume.
- 1.5.
 - 1.5.1. Place the Rubbermaid collection tub on the base of the Southwark Emery testing platform.
 - 1.5.2. Place the acrylic alignment jig assembly on the collection tub.
 - 1.5.3. Insert the black support fixture inside the rectangular acrylic cutout. Center, align, and fasten the acrylic alignment jig to the base plate using two allen wrench bolts.

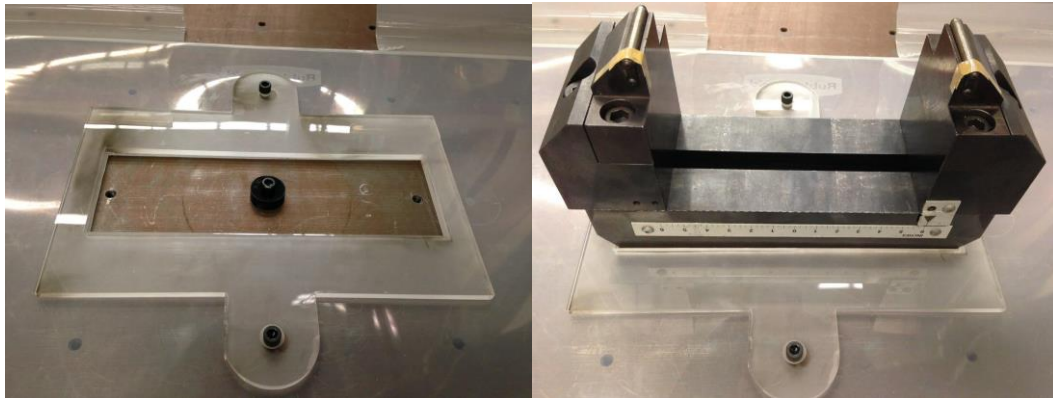


Figure 4 & 5: (Left) Alignment jig placed on the collection tub. (Right) Black support fixture placed inside the alignment jig.

- 1.6. Place the specimen to be tested on the fixed black support structure. To ensure the sample is centered and seated properly on the support, use the acrylic end jig on one side of the sample so that 0.5inches overhangs on both sides of the supports



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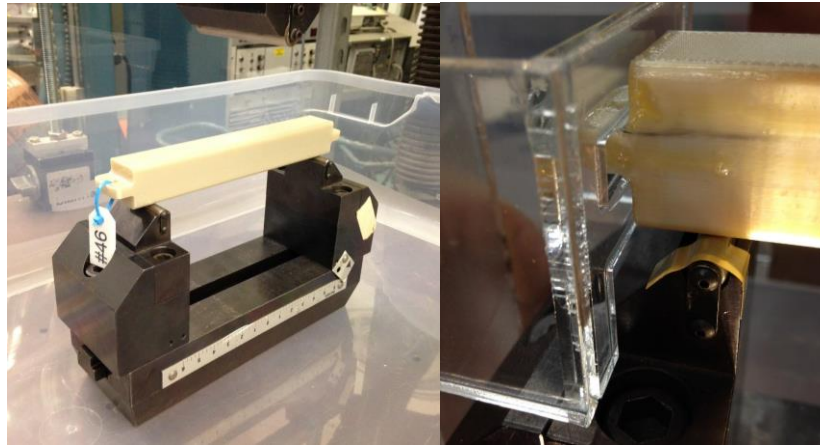


Figure 6 & 7: (Left) Specimen on the black support fixture. (Right) End jig centers the specimen on the black support fixture. Packing tape on the supports aligns the specimen on the supports.

- 1.7. Lower the loading pin onto the sample leaving a spacing of 0.001 inches between the pin and sample. This can be done by sliding a piece of paper between the pin and sample (shim test).

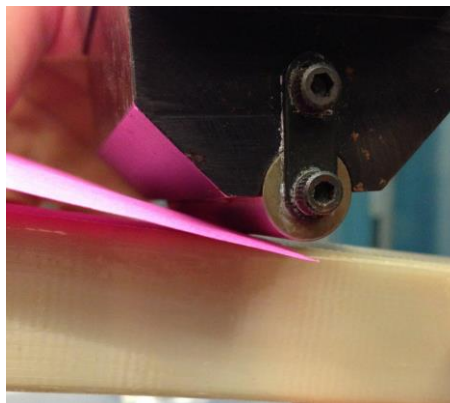


Figure 8: Paper shim test

Shim Test Spacing	.001 inch
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- 1.8. Set up the Nikon camera on a tripod behind the glass on the backside of the test section.
- 1.9. Attach the GoPro to the glass on the nearside using the suction cup.



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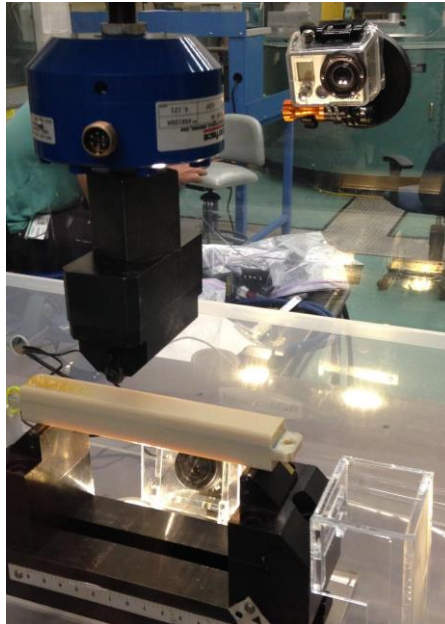


Figure 9: GoPro mounted with suction cup on safety glass

- 1.10. Place the black and white live feed camera at the base of the fixed black support structure on the near side of the test section. Set up the LED lights around the black support fixture to provide the necessary lighting for the cameras.

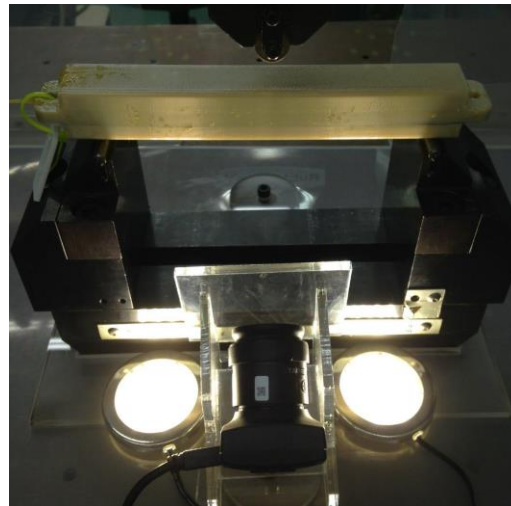


Figure 10: Black and white camera with LED lighting

- 1.11. Zero the displacement on the Southwark Emery

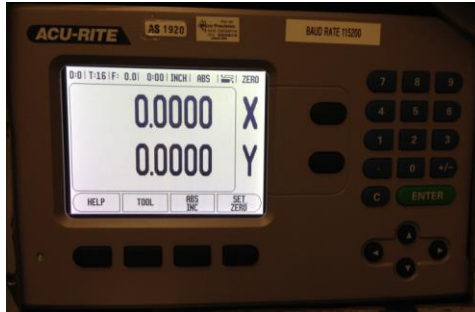


Figure 11: Zero the measuring device

2. Commence with testing procedures

- 2.1. Start the video cameras.
- 2.2. Use a cue card to identify which sample is being tested.

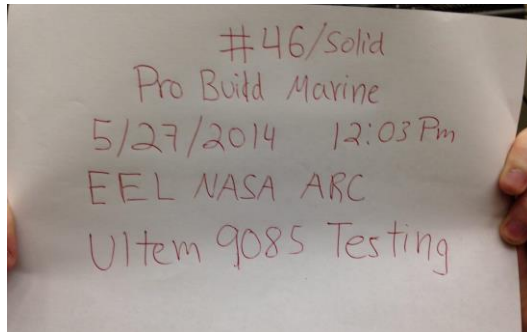


Figure 12: Example of a video cue card

- 2.3. Verify the computer is reading the data.
- 2.4. Using a displacement rate of 0.005 inch/sec, lower the loading pin until the sample breaks.

Displacement Rate	0.005 inch/sec
-------------------	----------------

- 2.5. Save the testing data
- 2.6. Stop video recording
- 2.7. End of test.

3. Post Break

- 3.1. Visually inspect the sample for break characteristics.
- 3.2. As the next sample is being prepared, remove the broken pieces of Foreign Object Debris (FOD) using a brush and sweep them to the front left corner of the

collection tub. Sweep the FOD contents into the respective Ziploc bag.



Figure 13: Image of the collection tub corner flap used to sweep FOD into Ziploc bag

- 3.3. Clean the collection tub for the next sample using an air hose.
- 3.4. Repeat break procedure for every sample.

Strength and Deflection Tables and Graphs

Control

Table 12: Gapped control samples.

Specimen Number	1	2	3	Average	StDev
Max Load (lbs)	860.080	857.690	848.553	855.441	6.084
Displacement @ Max Load (in)	0.695	0.690	0.723	0.703	0.018
Load @ Break (lbs)	712.755	727.997	797.531	746.095	45.193
Displacement @ Break (in)	0.737	0.891	0.852	0.826	0.080
Time to Break (sec)	162.043	234.570	280.250	225.621	59.609
Max Stress	7740.720	7719.214	7636.973	7698.969	54.756
Strain	0.116	0.115	0.121	0.117	0.003



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Table 13: Solid control samples.

Specimen Number	23	24	26	Average	StDev
Max Load (lbs)	1302.392	1259.811	1321.242	1294.482	31.470
Displacement @ Max Load (in)	0.617	0.600	0.640	0.619	0.020
Load @ Break (lbs)	1278.333	1227.759	1303.162	1269.751	38.427
Displacement @ Break (in)	0.654	0.633	0.677	0.655	0.022
Time to Break (sec)	171.925	143.247	130.657	148.610	21.150
Max Stress	11721.520	11338.300	11891.170	11650.330	283.227
Strain	0.103	0.100	0.107	0.103	0.003

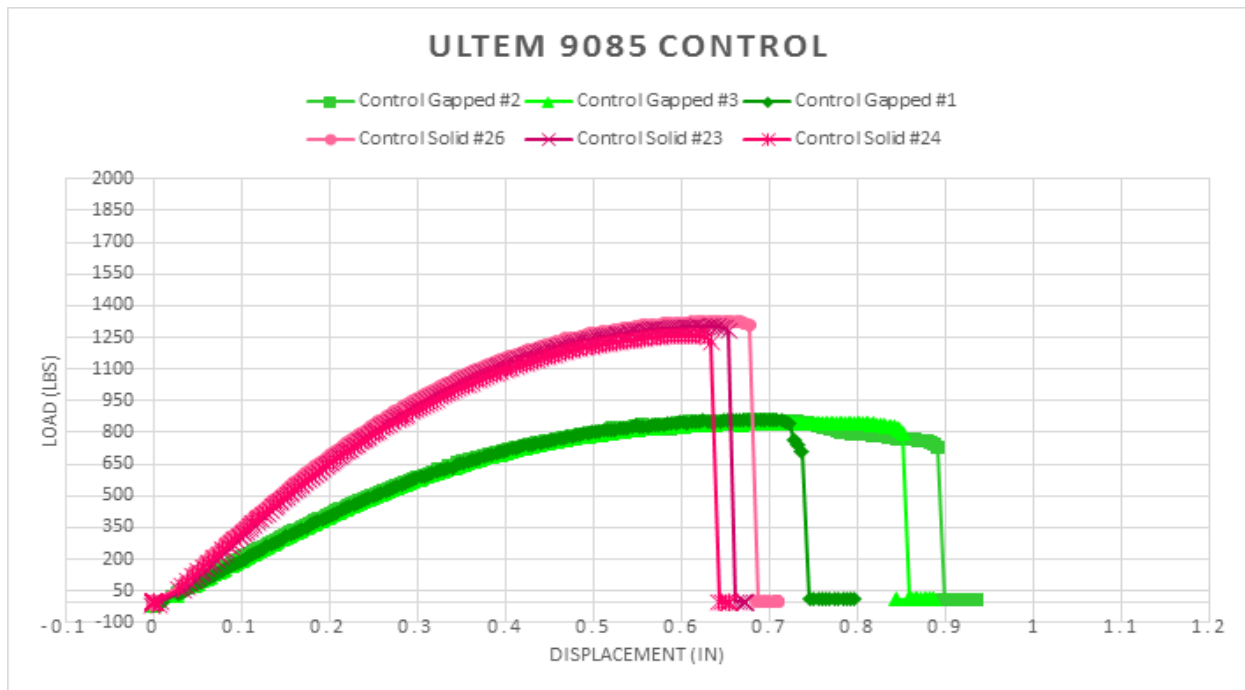


Figure 27: Strength and deflection curves for the control samples.



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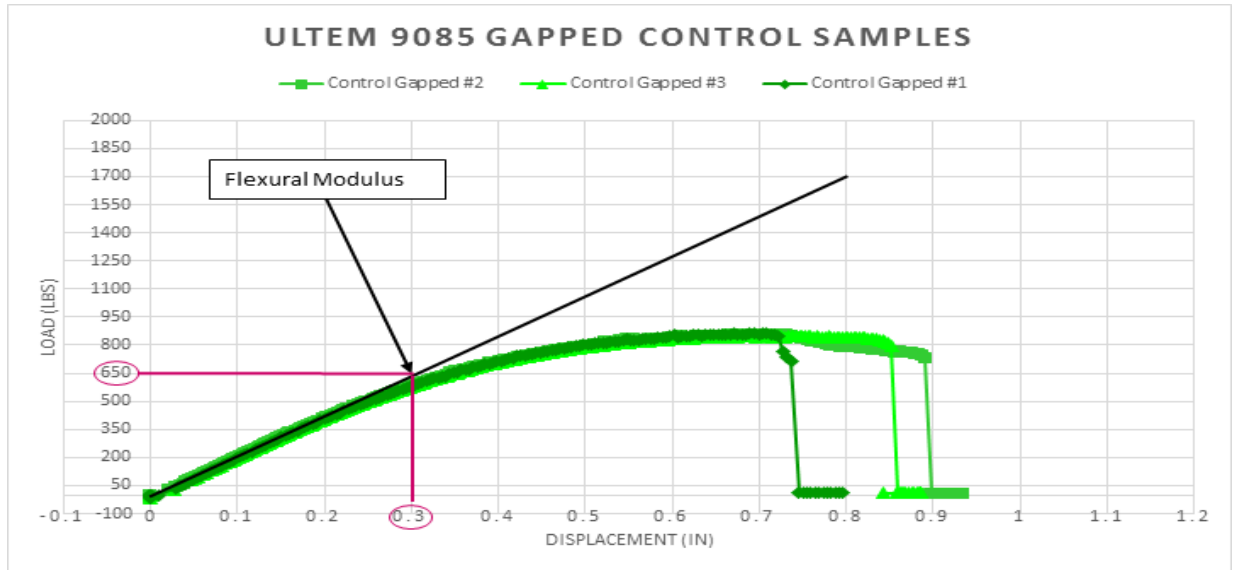


Figure 28: Average Flexural modulus for gapped control samples.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 650 \text{ lbs}}{0.3 \text{ in}} = 117 \text{ ksi}$$

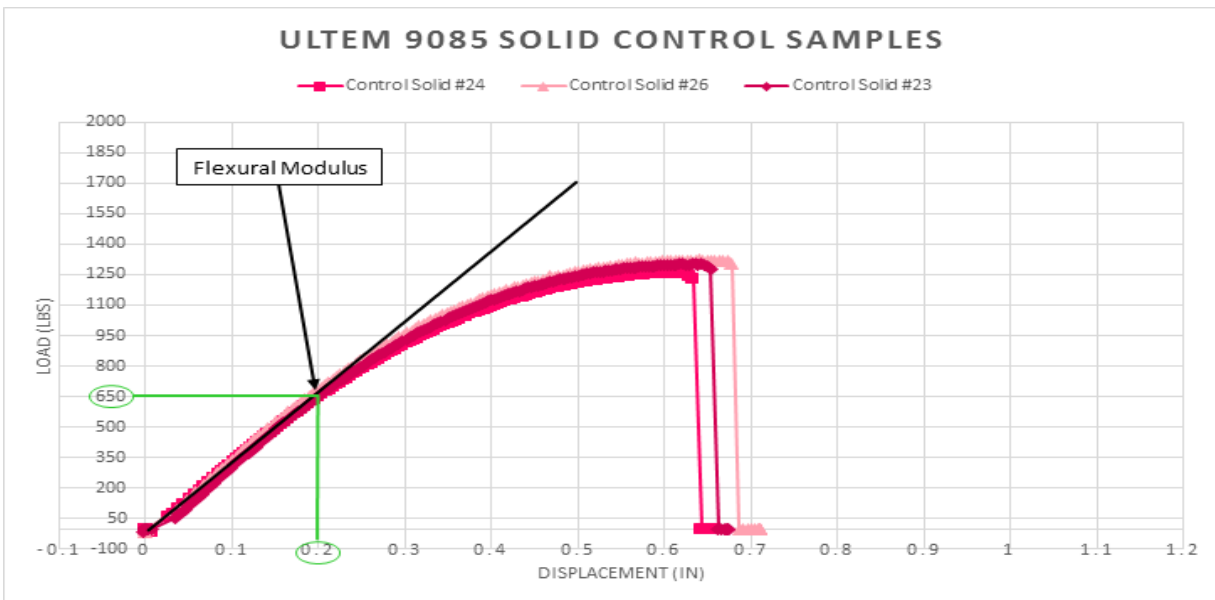


Figure 29: Average Flexural modulus for solid control samples.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 650 \text{ lbs}}{0.2 \text{ in}} = 175.5 \text{ ksi}$$



Arathane 5750-A/B (LV)

Table 14: Gapped samples with Arathane 5750.

<i>Specimen Number</i>	22	25	31	Average	StDev
Max Load (lbs)	885.216	857.979	848.917	864.038	18.893
Displacement @ Max Load (in)	0.786	0.778	0.708	0.757	0.043
Load @ Break (lbs)	839.523	819.034	784.066	814.207	28.042
Displacement @ Break (in)	1.044	0.841	0.767	0.884	0.144
Time to Break (sec)	191.747	166.385	174.228	177.453	12.985
Max Stress	7966.946	7721.813	7640.257	7776.339	170.033
Strain	0.131	0.130	0.118	0.126	0.007

Table 15: Solid samples with Arathane 5750.

Specimen Number	47	48	49	Average	StDev
Max Load (lbs)	1270.091	1270.597	1303.726	1281.471	19.275
Displacement @ Max Load (in)	0.534	0.607	0.616	0.586	0.045
Load @ Break (lbs)	1254.364	1265.756	1298.073	1272.731	22.674
Displacement @ Break (in)	0.544	0.621	0.633	0.600	0.048
Time to Break (sec)	110.815	115.440	93.041	106.432	11.825
Max Stress	11430.820	11435.370	11733.530	11533.240	173.474
Strain	0.089	0.101	0.103	0.098	0.007



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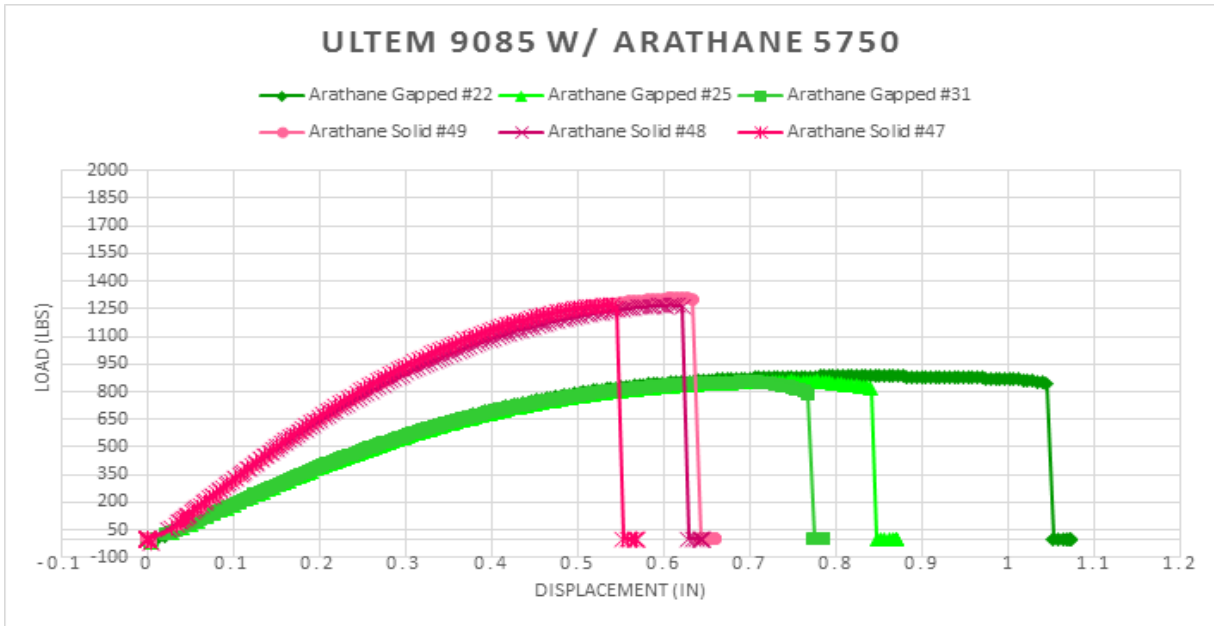


Figure 30: Strength and deflection curves for samples with Arathane 5750-A/B (LV).

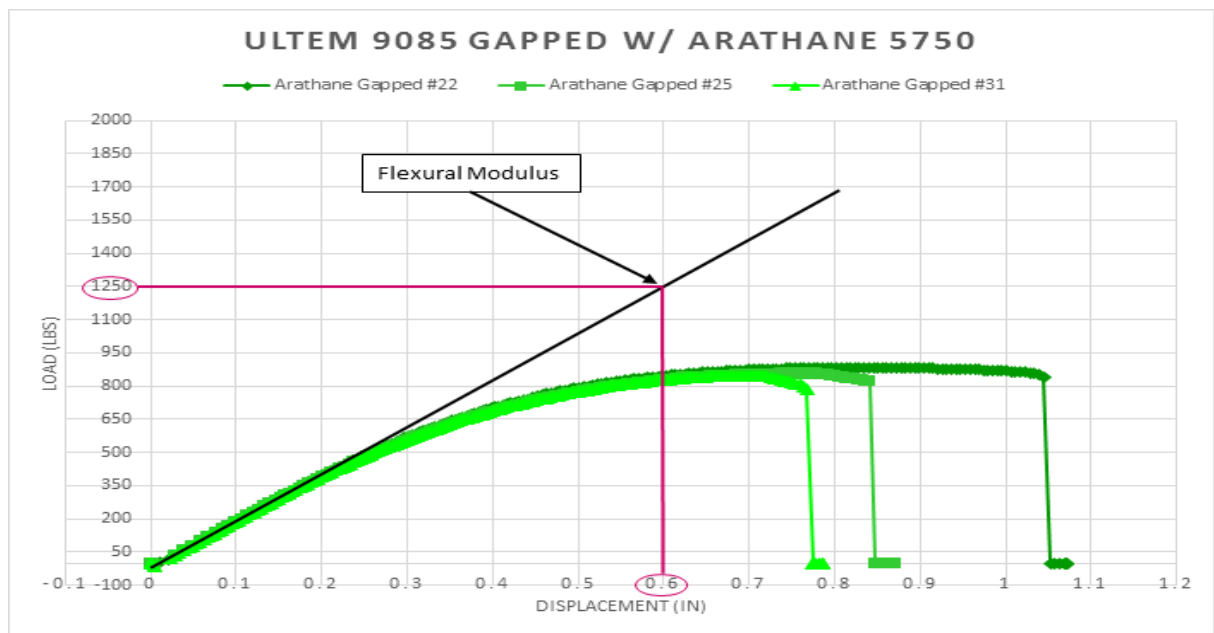


Figure 31: Average Flexural modulus for gapped samples with Arathane 5750-A/B (LV).

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1250 \text{ lbs}}{0.6 \text{ in}} = 112.5 \text{ ksi}$$



SPHERES

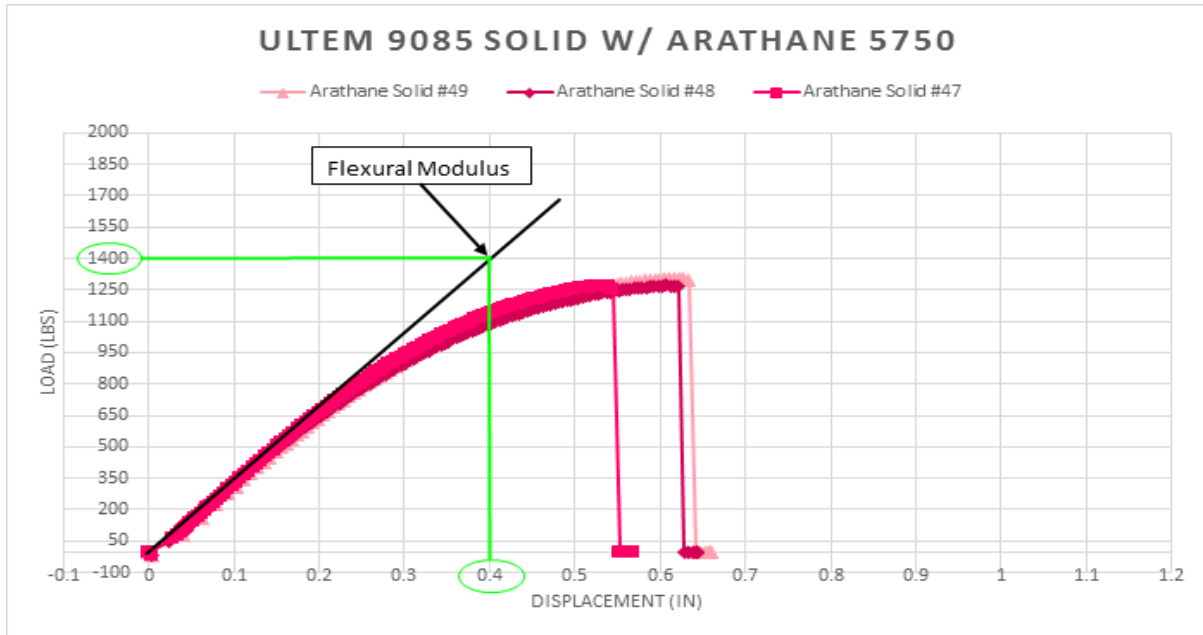


Figure 32: Average Flexural modulus for solid samples with Arathane 5750-A/B (LV).

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1400 \text{ lbs}}{0.4 \text{ in}} = 189 \text{ ksi}$$

BJB TC-1614

Table 16: Gapped samples with BJB TC-1614.

Specimen Number	13	14	15	Average	StDev
Max Load (lbs)	1541.034	1856.965	1486.366	1628.122	200.060
Displacement @ Max Load (in)	0.314	0.546	0.287	0.382	0.142
Load @ Break (lbs)	1541.034	1851.565	1486.366	1626.322	196.972
Displacement @ Break (in)	0.314	0.558	0.287	0.387	0.149
Time to Break (sec)	70.040	132.358	65.112	89.170	37.483
Max Stress	13869.310	16712.690	13377.290	14653.090	1800.544
Strain	0.052	0.091	0.048	0.064	0.024



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Table 17: Solid samples with BJB TC-1614.

Specimen Number	38	39	40	Average	StDev
Max Load (lbs)	1321.716	1415.870	1535.886	1424.491	107.345
Displacement @ Max Load (in)	0.233	0.258	0.278	0.256	0.022
Load @ Break (lbs)	1321.716	1415.870	1535.886	1424.491	107.345
Displacement @ Break (in)	0.233	0.258	0.278	0.256	0.022
Time to Break (sec)	68.119	53.577	64.536	62.077	7.576
Max Stress	11895.450	12742.830	13822.970	12820.420	966.102
Strain	0.039	0.043	0.046	0.043	0.004

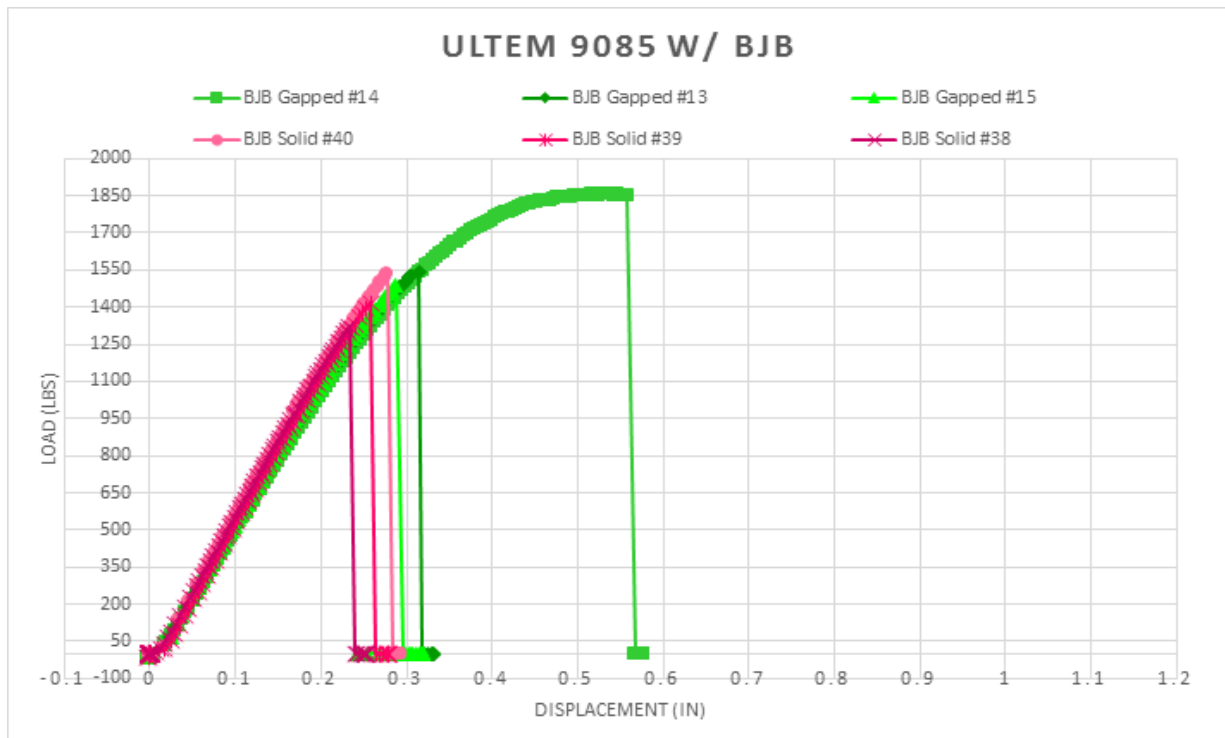


Figure 33: Strength and deflection curves for samples with BJB TC-1614.



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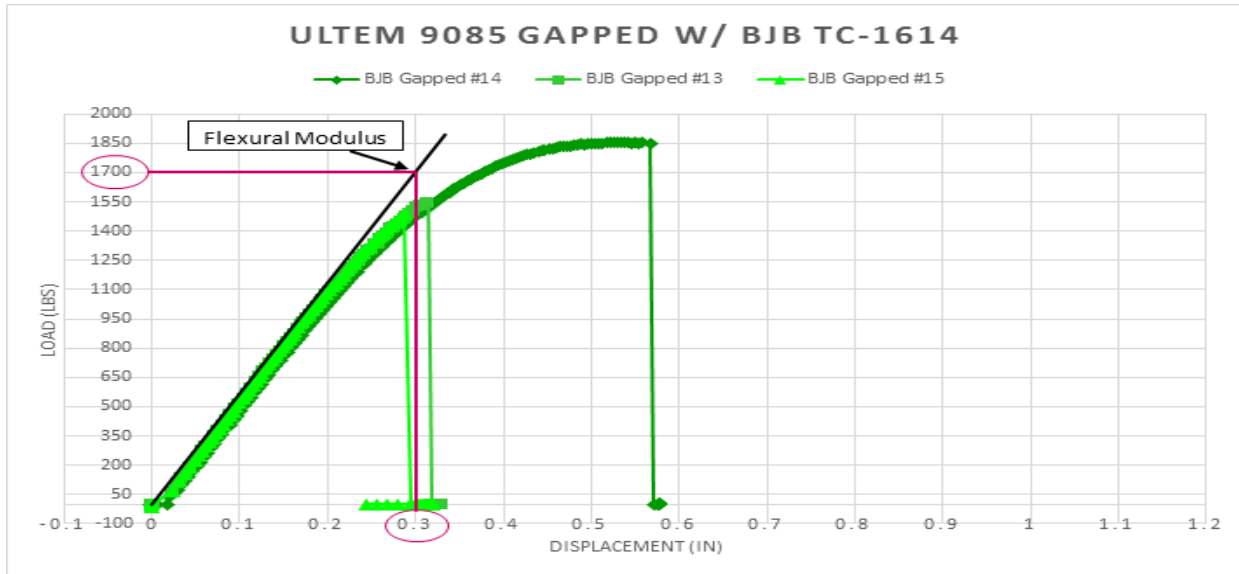


Figure 34: Average Flexural modulus for gapped samples with BJB TC-1614.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1700 \text{ lbs}}{0.3 \text{ in}} = 306 \text{ ksi}$$

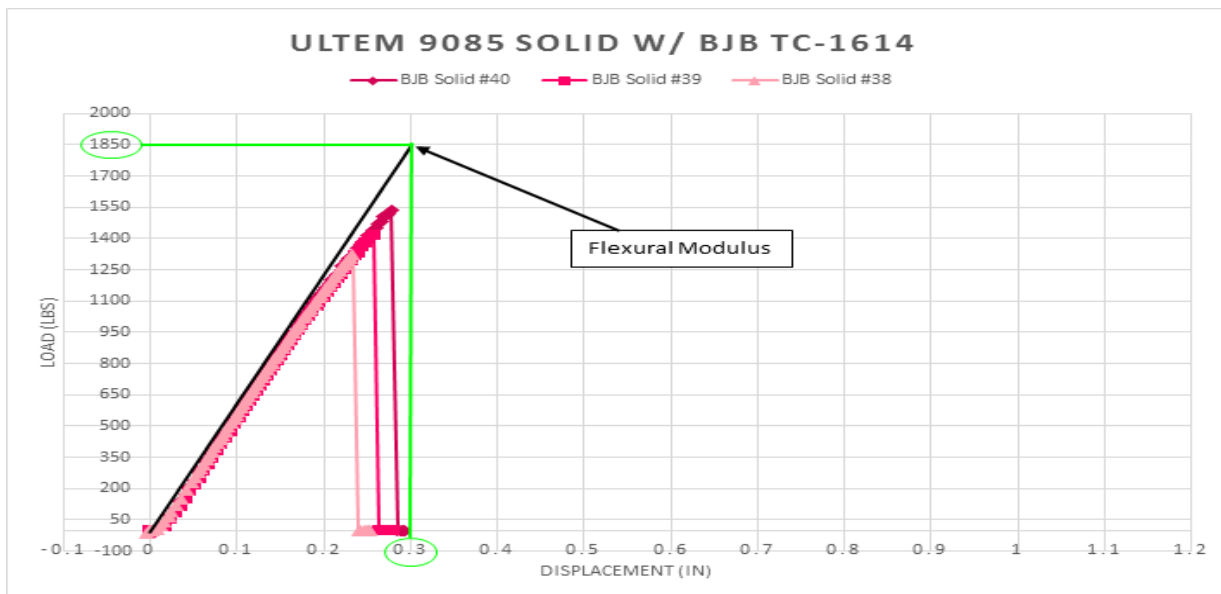


Figure 35: Average Flexural modulus for solid samples with BJB TC-1614.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1850 \text{ lbs}}{0.3 \text{ in}} = 333 \text{ ksi}$$



Hysol E-20HP

Table A7: Gapped samples with Hysol E-20HP.

Specimen Number	10	11	12	Average	StDev
Max Load (lbs)	1006.509	983.871	962.676	984.352	21.921
Displacement @ Max Load (in)	0.618	0.790	0.805	0.738	0.104
Load @ Break (lbs)	949.875	877.337	948.463	925.225	41.478
Displacement @ Break (in)	0.665	0.883	0.815	0.788	0.111
Time to Break (sec)	141.510	251.901	152.407	181.939	60.833
Max Stress	9058.582	8854.842	8664.0835	8859.169	197.285
Strain	0.103	0.132	0.134	0.123	0.017

Table 18: Solid samples with Hysol E-20HP.

Specimen Number	34	35	37	Average	StDev
Max Load (lbs)	1326.721	1328.293	1336.499	1330.504	5.251
Displacement @ Max Load (in)	0.580	0.548	0.646	0.591	0.050
Load @ Break (lbs)	1314.928	1320.829	1327.659	1321.139	6.371
Displacement @ Break (in)	0.600	0.553	0.683	0.612	0.066
Time to Break (sec)	148.173	102.707	148.482	133.121	26.339
Max Stress	11940.493	11954.636	12028.492	11974.540	47.255
Strain	0.097	0.091	0.108	0.099	0.008



SPHERES

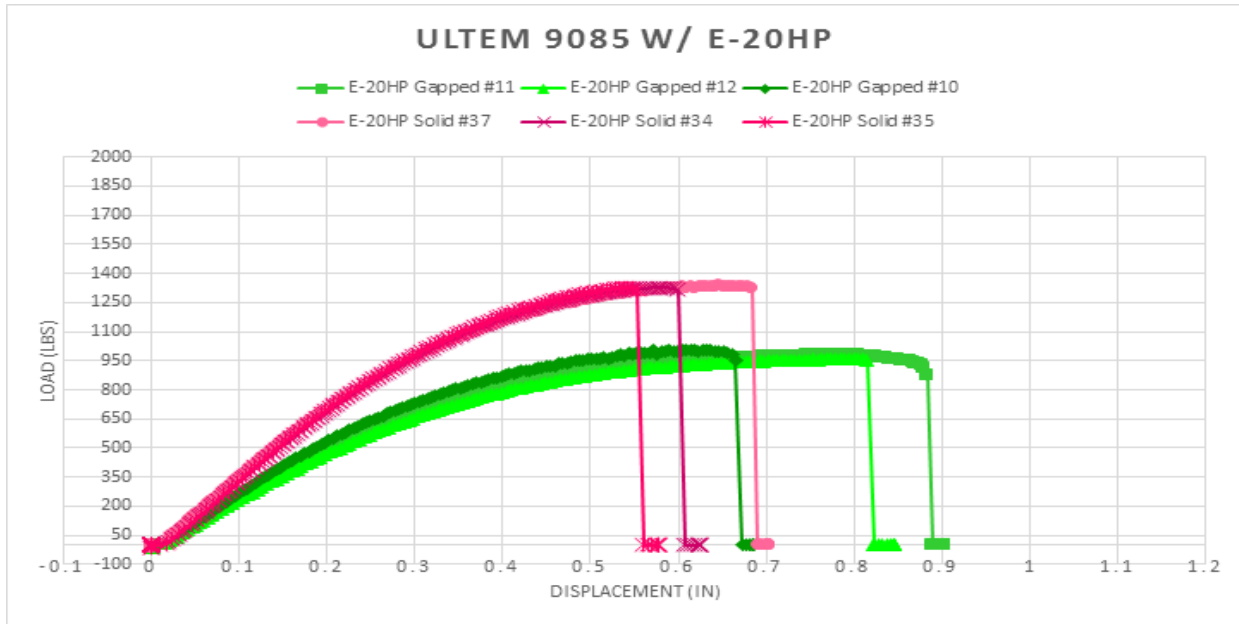


Figure 36: Strength and deflection curves for samples with Hysol E-20HP.

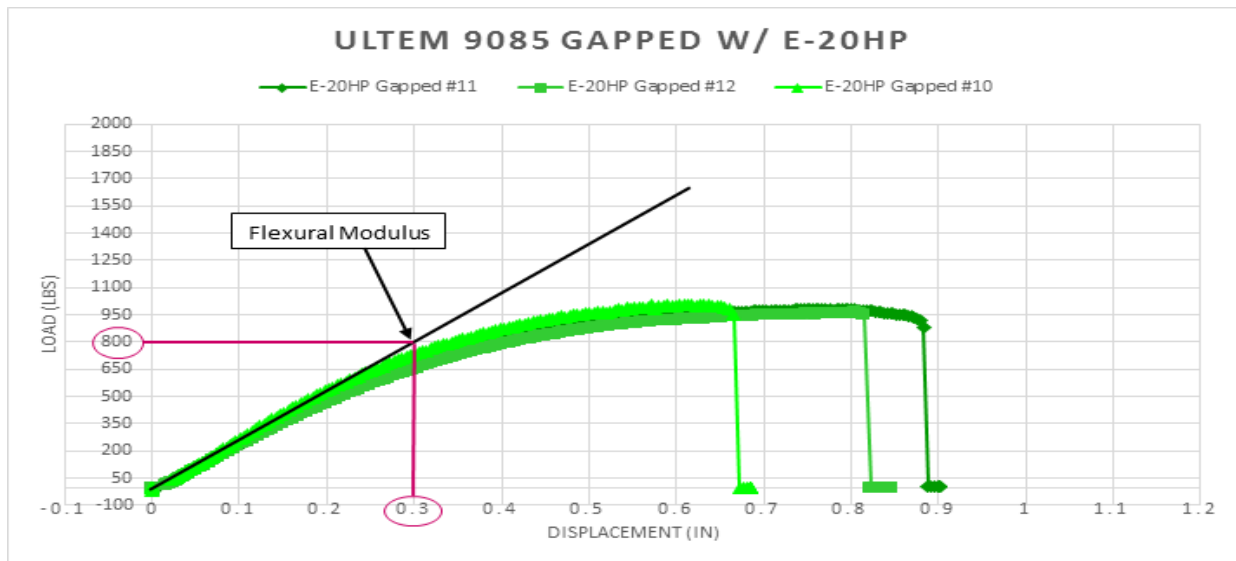


Figure 37: Average Flexural modulus for gapped samples with Hysol E-20HP.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 800 \text{ lbs}}{0.3 \text{ in}} = 144 \text{ ksi}$$



SPHERES

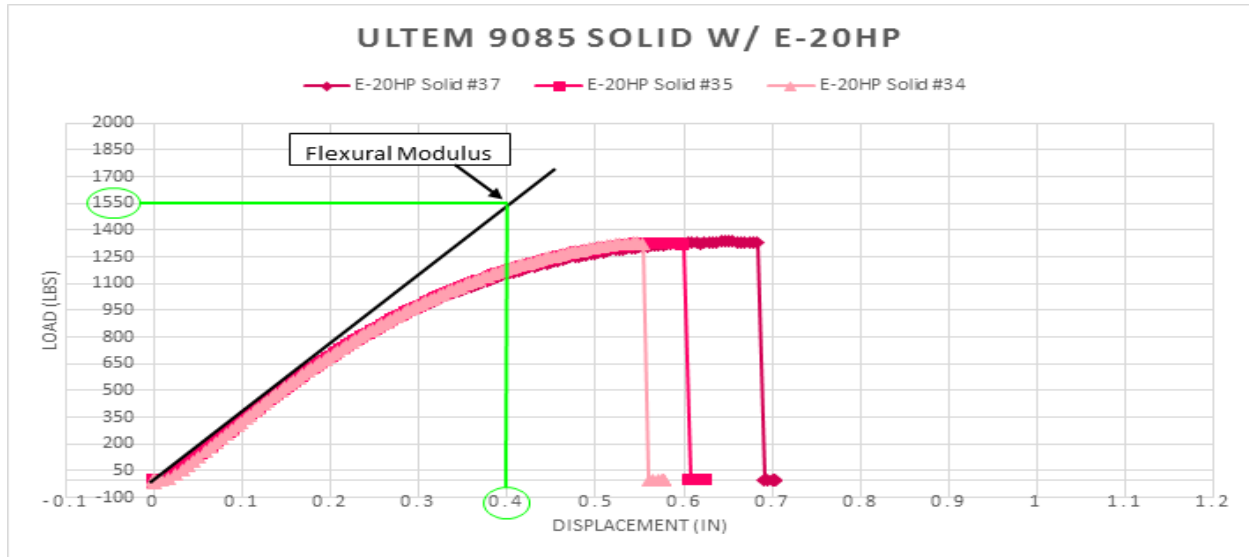


Figure 38: Average Flexural modulus for solid samples with Hysol E-20HP.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1550 \text{ lbs}}{0.4 \text{ in}} = 209.25 \text{ ksi}$$

Henkel Loctite 5110

Table 19: Gapped samples with Henkel Loctite 5110.

Specimen Number	16	17	18	Average	StDev
Max Load (lbs)	283.619	313.656	222.192	273.156	46.621
Displacement @ Max Load (in)	0.187	0.193	0.138	0.173	0.030
Load @ Break (lbs)	250.646	291.742	187.831	243.406	52.333
Displacement @ Break (in)	0.239	0.237	0.174	0.216	0.037
Time to Break (sec)	46.391	77.200	77.381	66.991	17.840
Max Stress	2552.570	2822.903	1999.730	2458.401	419.588
Strain	0.031	0.032	0.023	0.029	0.005



Table 20: Solid samples with Henkel Loctite 5110.

Specimen Number	41	42	43	Average	StDev
Max Load (lbs)	268.072	313.183	294.930	292.062	22.692
Displacement @ Max Load (in)	0.102	0.109	0.113	0.108	0.006
Load @ Break (lbs)	195.115	269.871	258.429	241.138	40.266
Displacement @ Break (in)	0.146	0.154	0.154	0.151	0.005
Time to Break (sec)	89.999	66.217	64.470	73.562	14.262
Max Stress	2412.644	2818.650	2654.373	2628.556	204.231
Strain	0.017	0.018	0.019	0.018	0.001

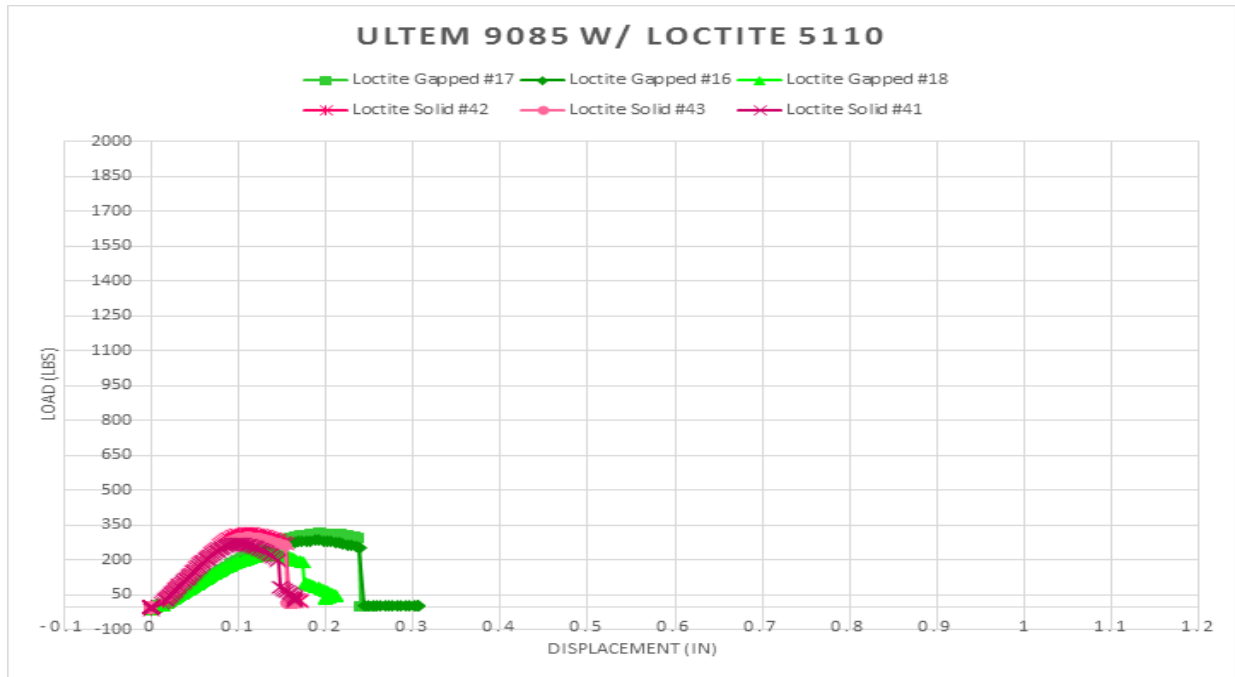


Figure 39: Strength and deflection curves for samples with Henkel Loctite 5110.



SPHERES

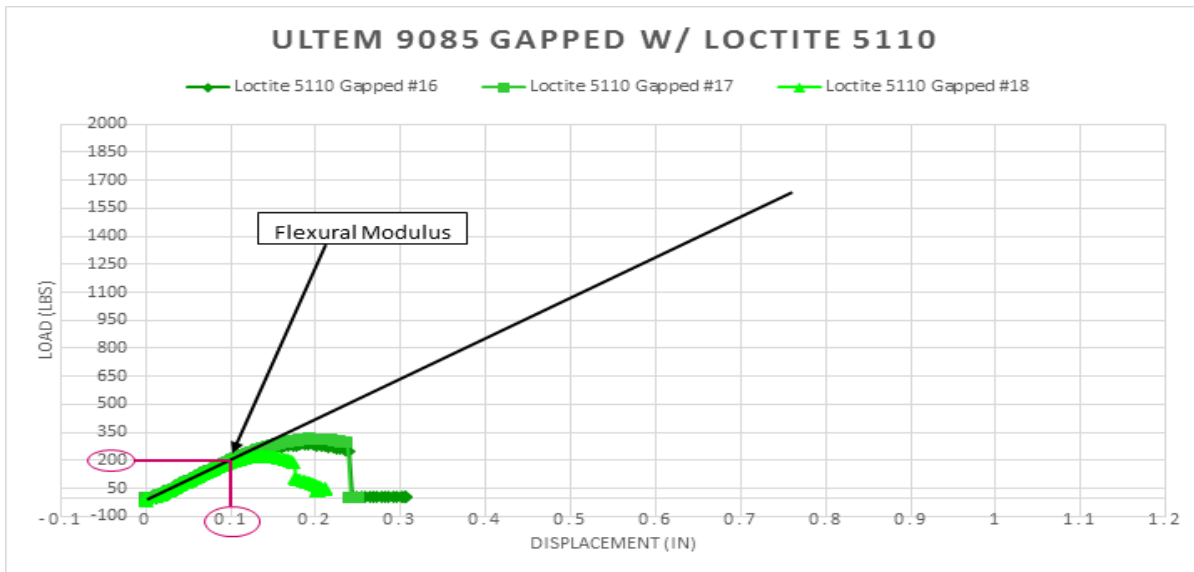


Figure 40: Average Flexural modulus for gapped samples with Henkel Loctite 5110.

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 200 \text{ lbs}}{0.1 \text{ in}} = 108 \text{ ksi}$$

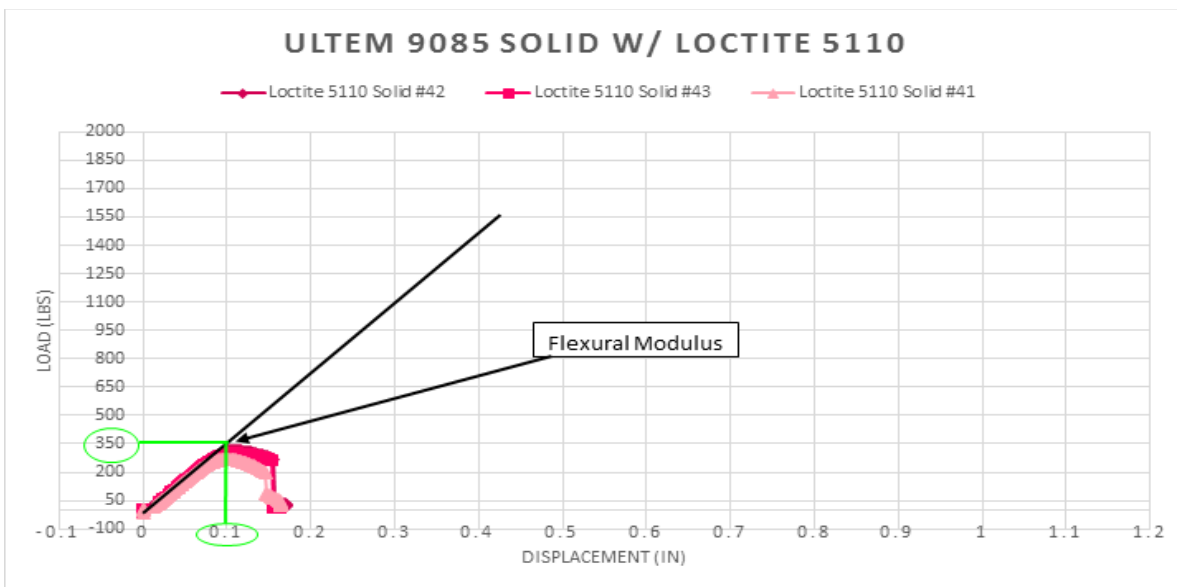


Figure 41: Average Flexural modulus for solid samples with Henkel Loctite 5110

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 350 \text{ lbs}}{0.1 \text{ in}} = 189 \text{ ksi}$$



ProBuild Marine

Table 21: Gapped samples with ProBuild Marine.

Specimen Number	19	20	21	Average	StDev
Max Load (lbs)	778.371	871.923	649.708	766.667	111.569
Displacement @ Max Load (in)	0.239	0.326	0.215	0.260	0.058
Load @ Break (lbs)	778.371	871.923	649.708	766.667	111.569
Displacement @ Break (in)	0.239	0.326	0.215	0.260	0.058
Time to Break (sec)	38.689	65.294	29.677	44.553	18.519
Max Stress	7005.342	7847.307	5847.369	6900.006	1004.122
Strain	0.040	0.054	0.036	0.043	0.010

Table 22: Solid samples with ProBuild Marine.

Specimen Number	44	45	46	Average	StDev
Max Load (lbs)	1308.953	1351.687	1061.878	1240.839	156.451
Displacement @ Max Load (in)	0.450	0.491	0.311	0.417	0.094
Load @ Break (lbs)	1284.487	1350.310	1061.878	1232.225	151.151
Displacement @ Break (in)	0.463	0.495	0.311	0.423	0.098
Time to Break (sec)	131.412	111.948	46.544	96.635	44.458
Max Stress	11780.580	12165.179	9556.905	11167.555	1408.057
Strain	0.075	0.082	0.052	0.070	0.016



SPHERES

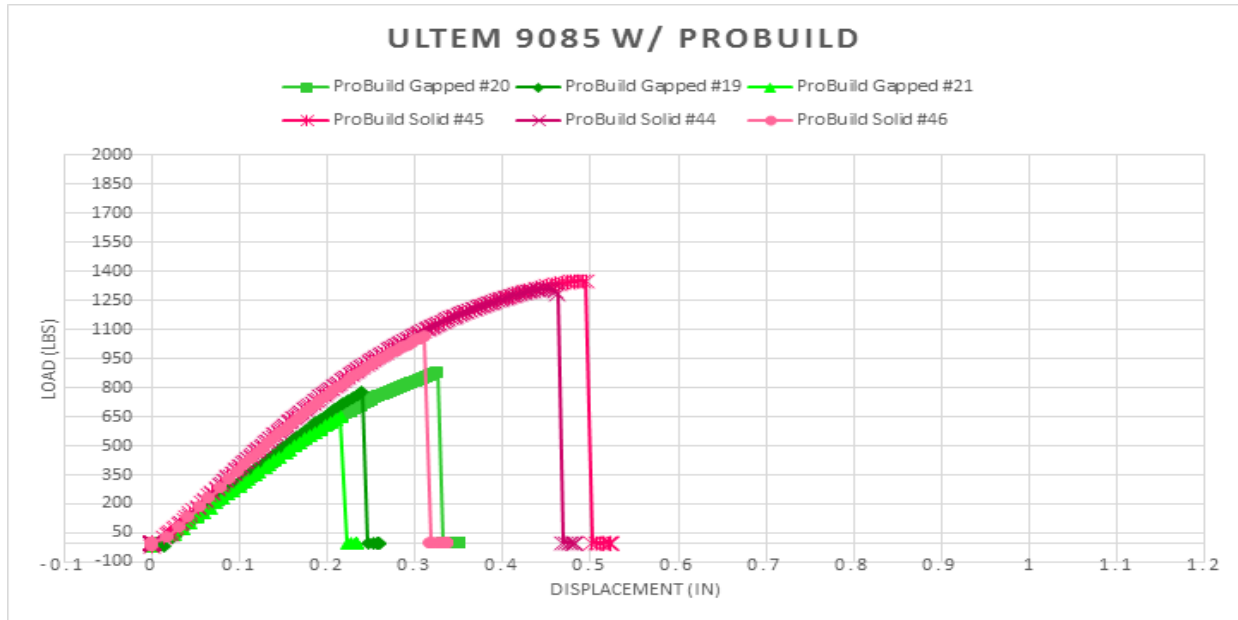


Figure 42: Strength and deflection curves for samples with ProBuild Marine

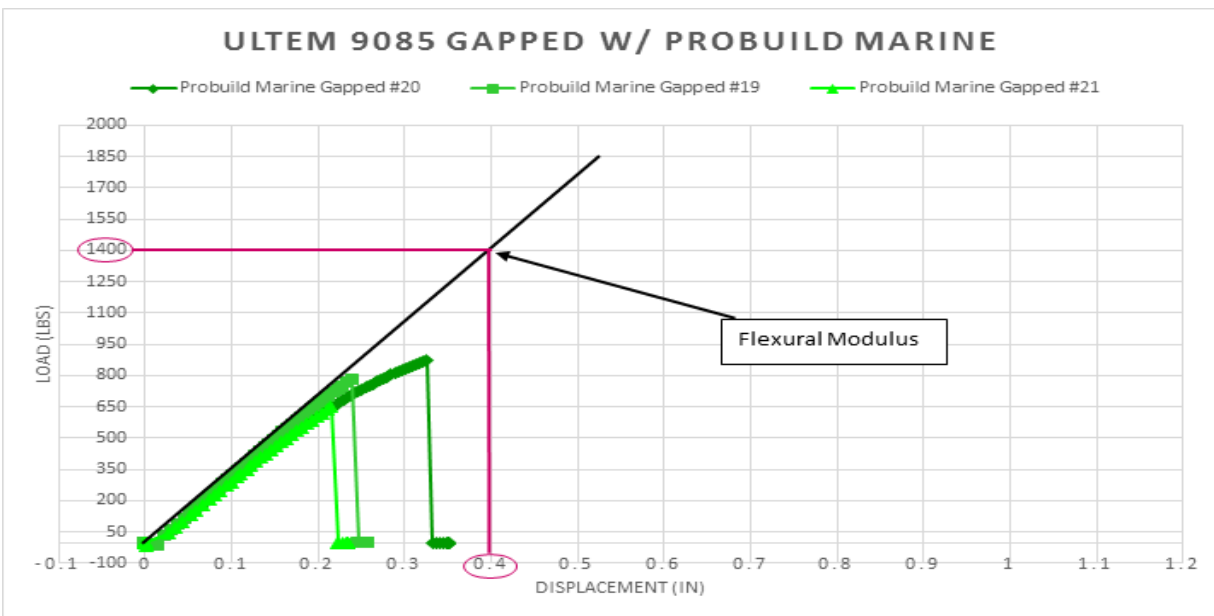


Figure 43: Average Flexural Modulus for gapped samples with ProBuild Marine

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1400 \text{ lbs}}{0.4 \text{ in}} = 189 \text{ ksi}$$



SPHERES

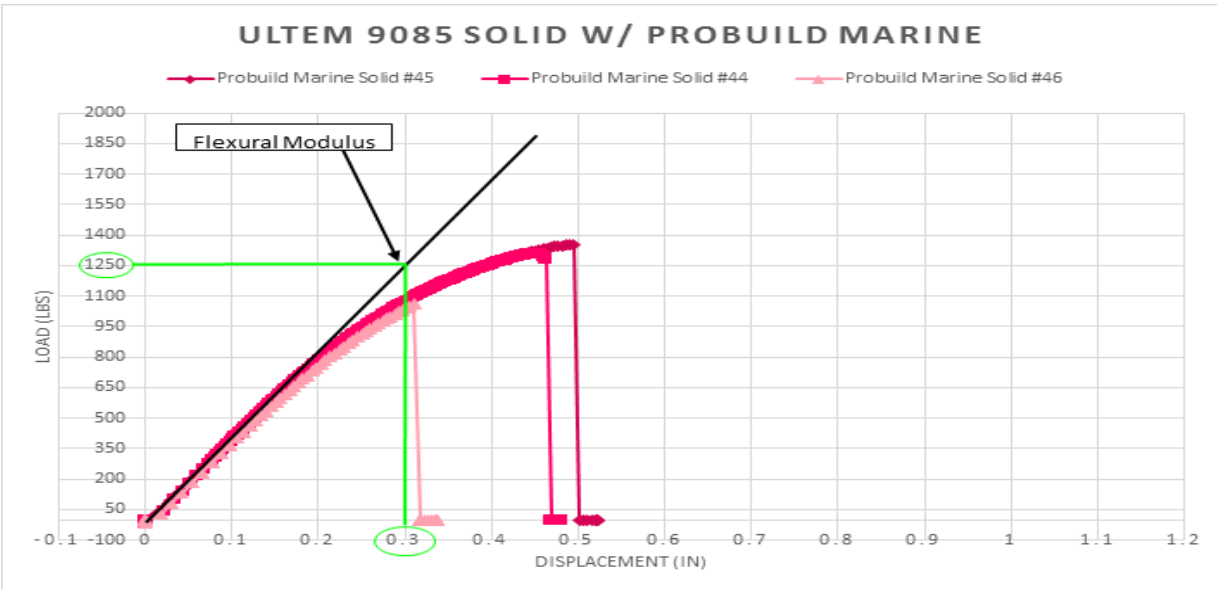


Figure 44: Average Flexural Modulus for solid samples with ProBuild Marine

$$E_{Flexural} = \frac{L^3 F}{4wh^3 d} = \frac{(6^3)F}{(4)(1)(1^3)d} = \frac{54F}{d} = \frac{54 * 1250 \text{ lbs}}{0.3 \text{ in}} = 225 \text{ ksi}$$

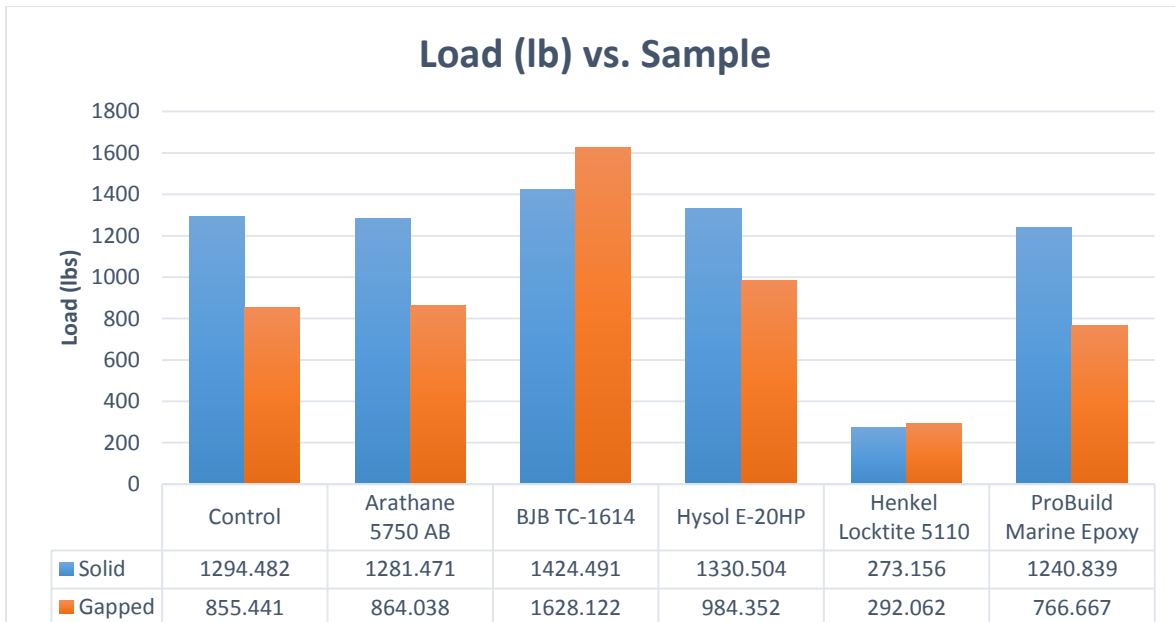


Figure 45 Average max load for gapped and solid samples of each applicant



SPHERES

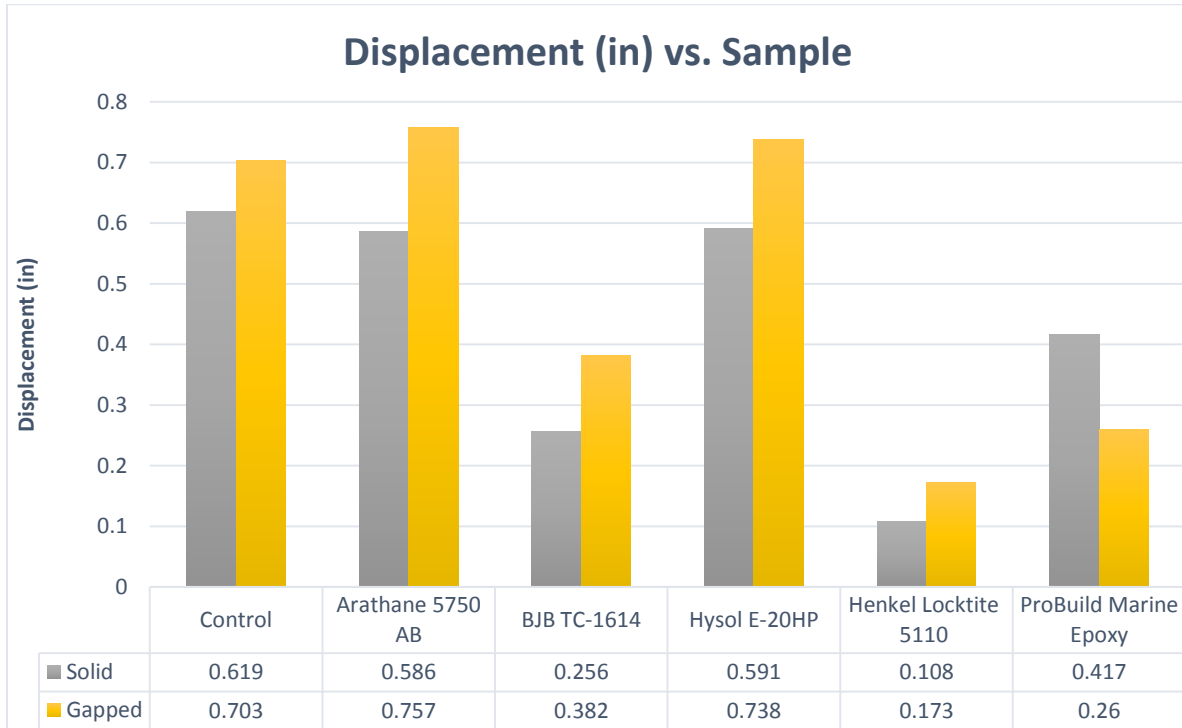


Figure 46 Average displacement for gapped and solid samples of each applicant

Stress vs. Strain Graphs

Control

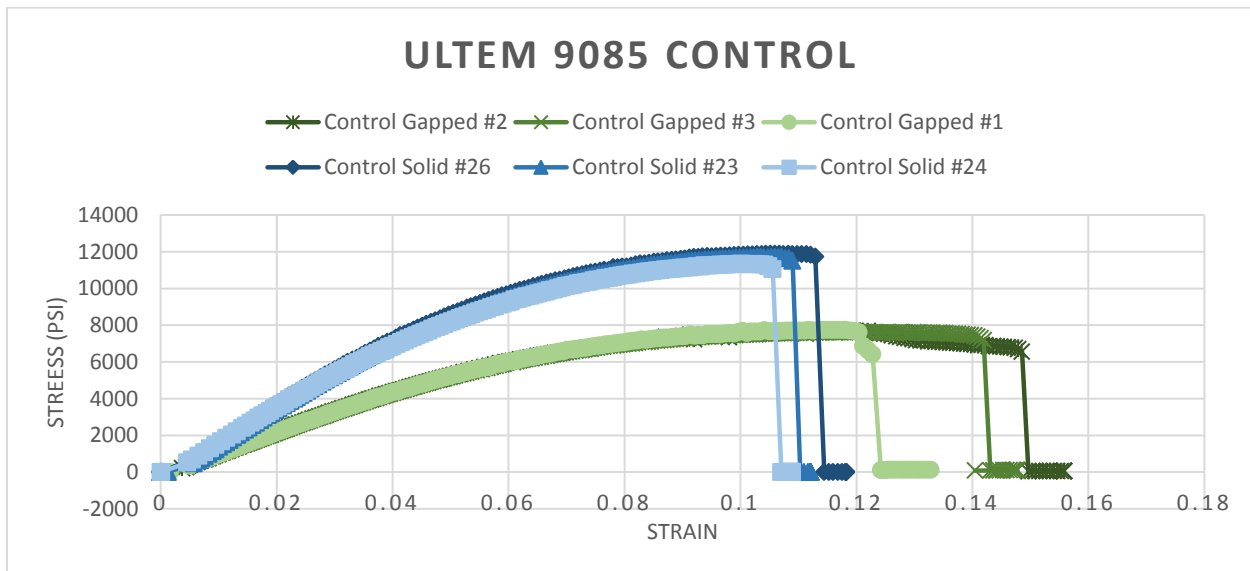


Figure 47: Stress vs. Strain curves for control samples



SPHERES



ULTEM 9085 GAPPED CONTROL SAMPLES

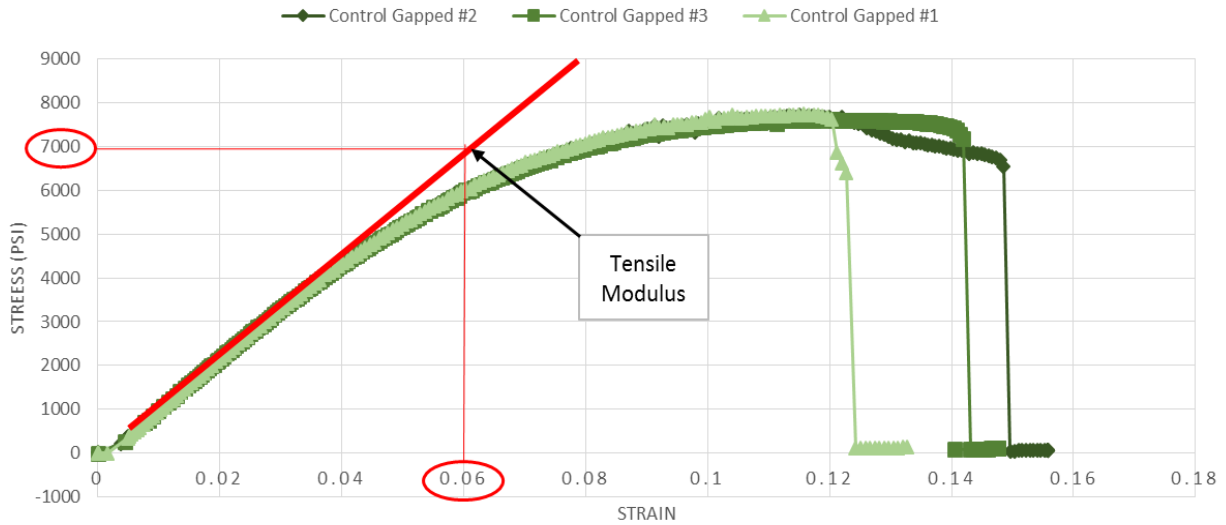


Figure 48: Average Tensile Modulus of the gapped control samples

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{7000 \text{ psi}}{0.06} = 116.6 \text{ kpsi}$$

ULTEM 9085 SOLID CONTROL SAMPLES

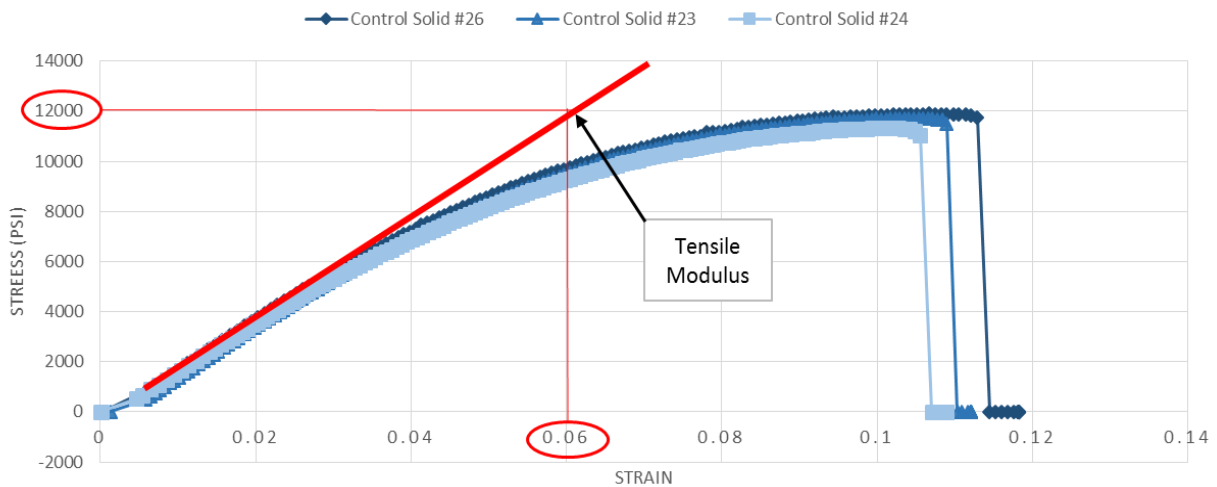


Figure 49: Average Tensile Modulus of the solid control samples

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{12000 \text{ psi}}{0.06} = 200 \text{ kpsi}$$



SPHERES



Arathane 5750-A/B (LV)

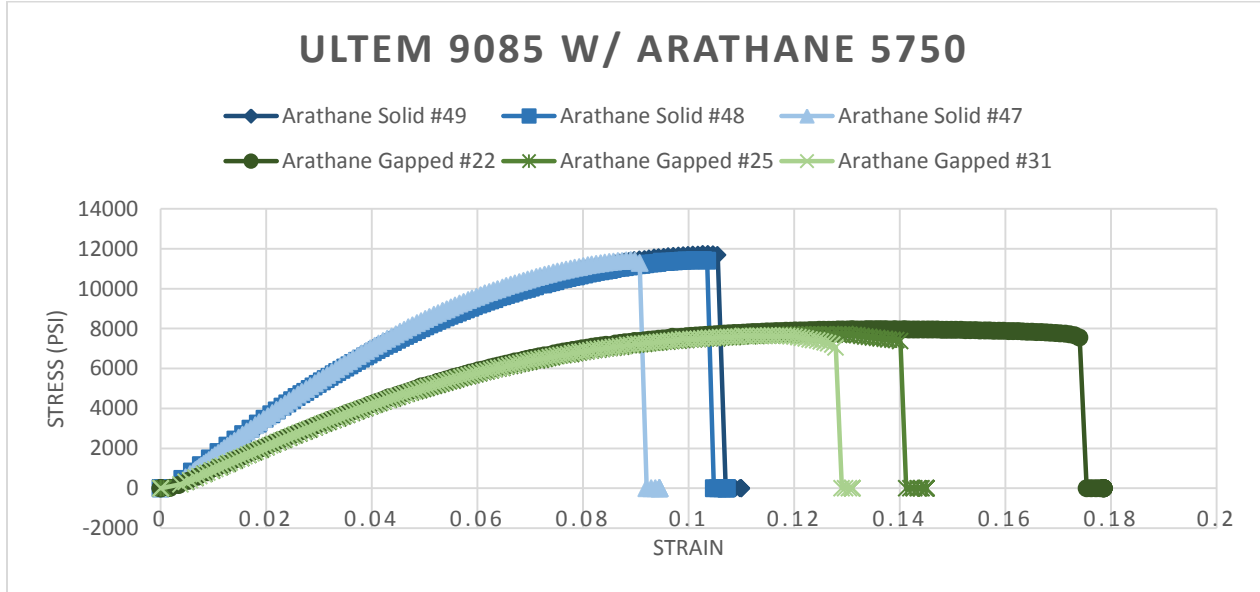


Figure 50: Stress vs. Strain curves for samples with Arathane 5750-A/B (LV)

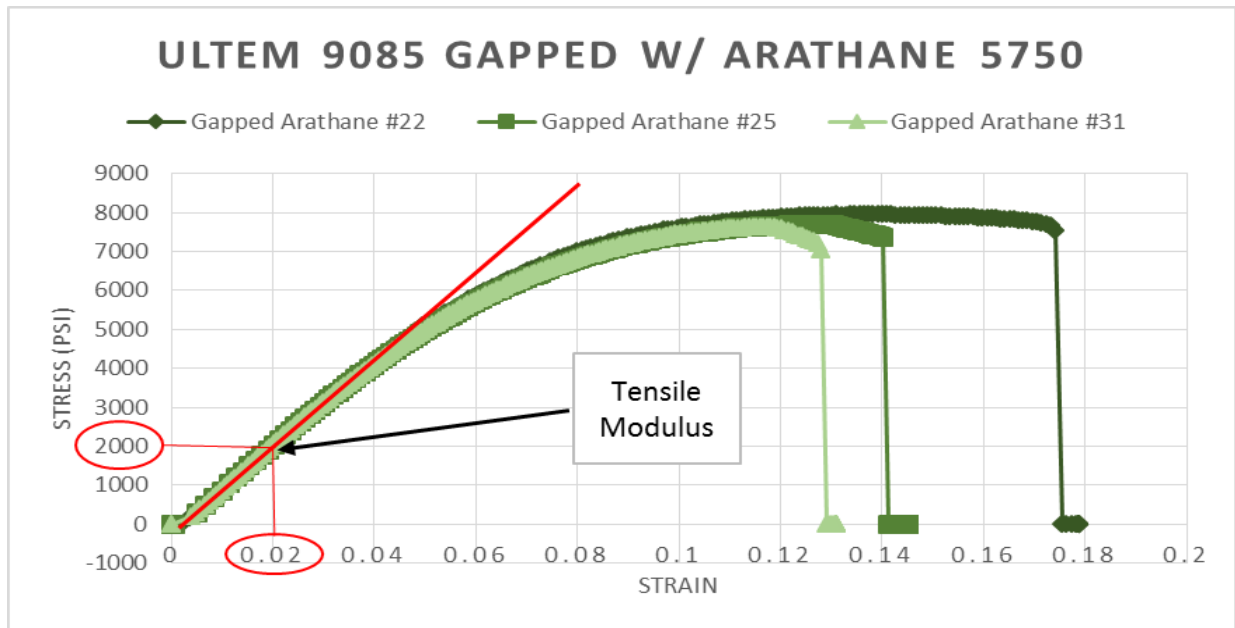


Figure 51: Average Tensile Modulus for gapped samples with Arathane 5750-A/B (LV)

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{2000 \text{ psi}}{0.02} = 100 \text{ kpsi}$$



SPHERES

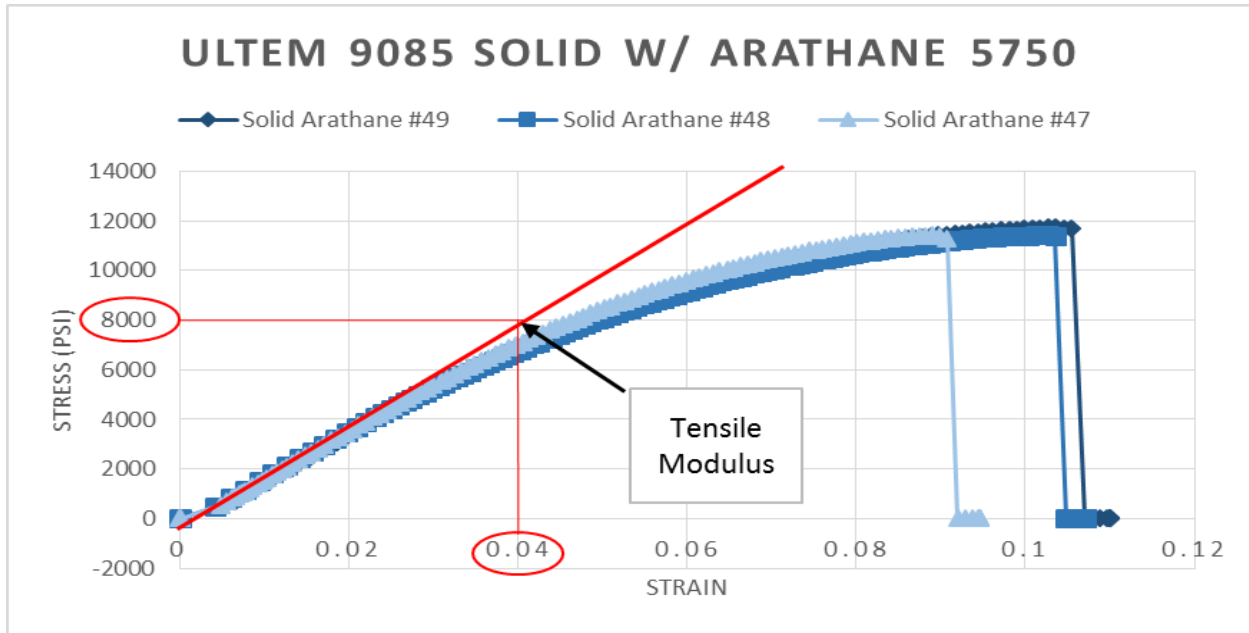


Figure 52: Average Tensile Modulus for solid samples with Arathane 5750-A/B (LV)

$$Tensile\ Modulus = \frac{Stress}{Strain} = \frac{8000\ psi}{0.04} = 200\ kpsi$$

BJB TC-1614

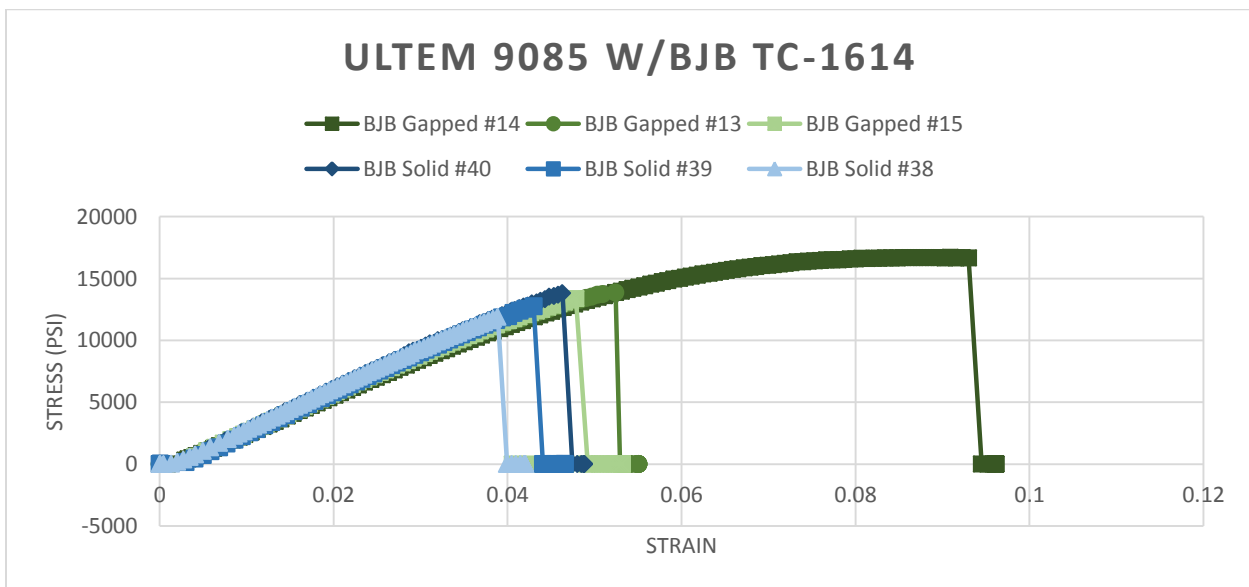


Figure 53: Stress vs. Strain curves for samples with BJB TC-1614



SPHERES

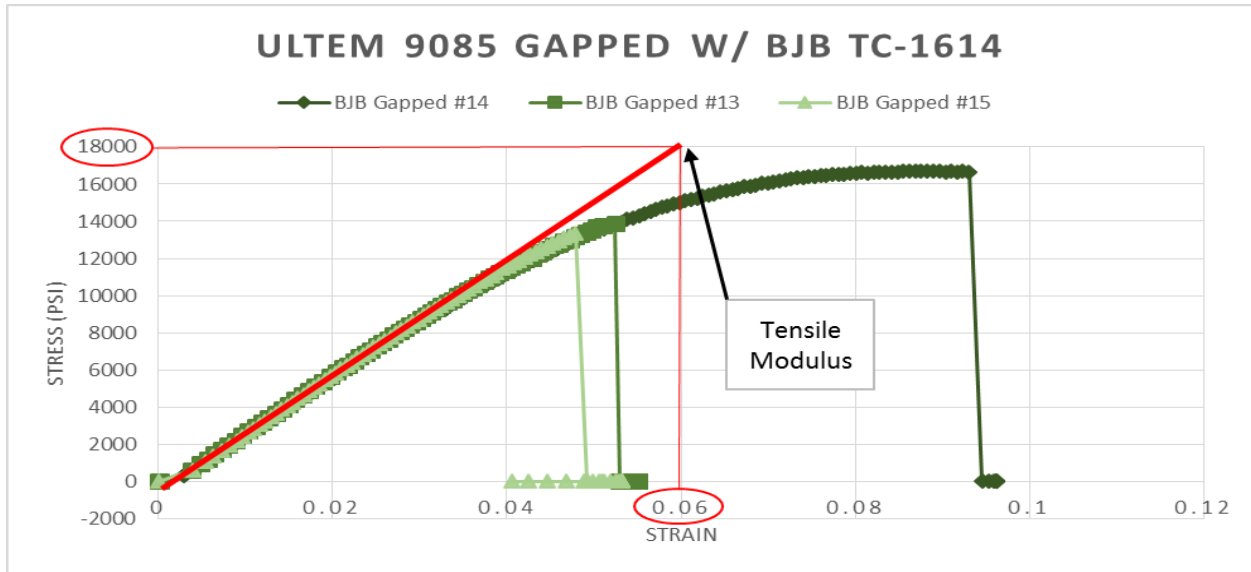


Figure 54: Average Tensile Modulus for gapped samples with BJB TC-1614

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{18000 \text{ psi}}{0.06} = 300 \text{ kpsi}$$

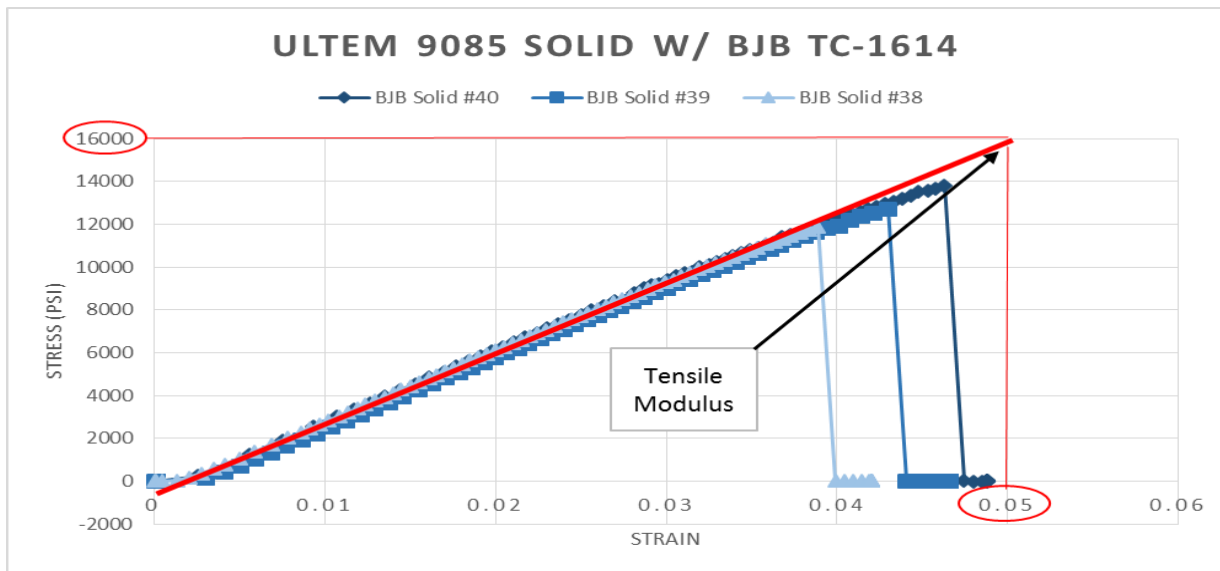


Figure 55: Average Tensile Modulus for solid samples with BJB TC-1614

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{16000 \text{ psi}}{0.05} = 320 \text{ kpsi}$$



SPHERES



Hysol E-20HP

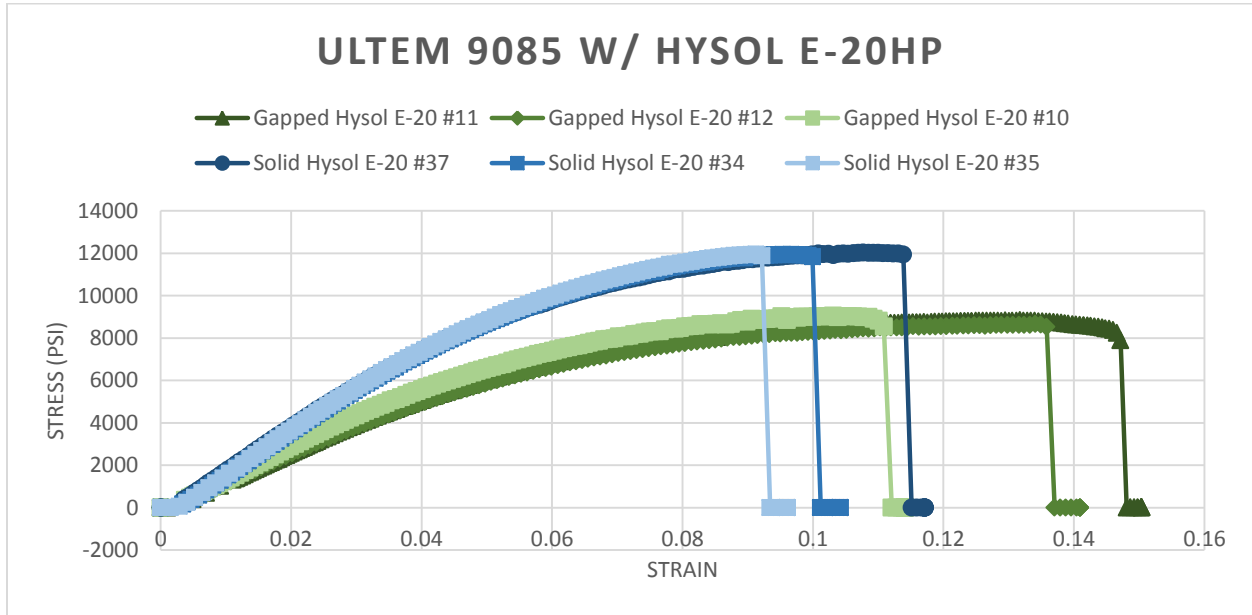


Figure 56: Stress vs. Strain curves for samples with Hysol E-20HP

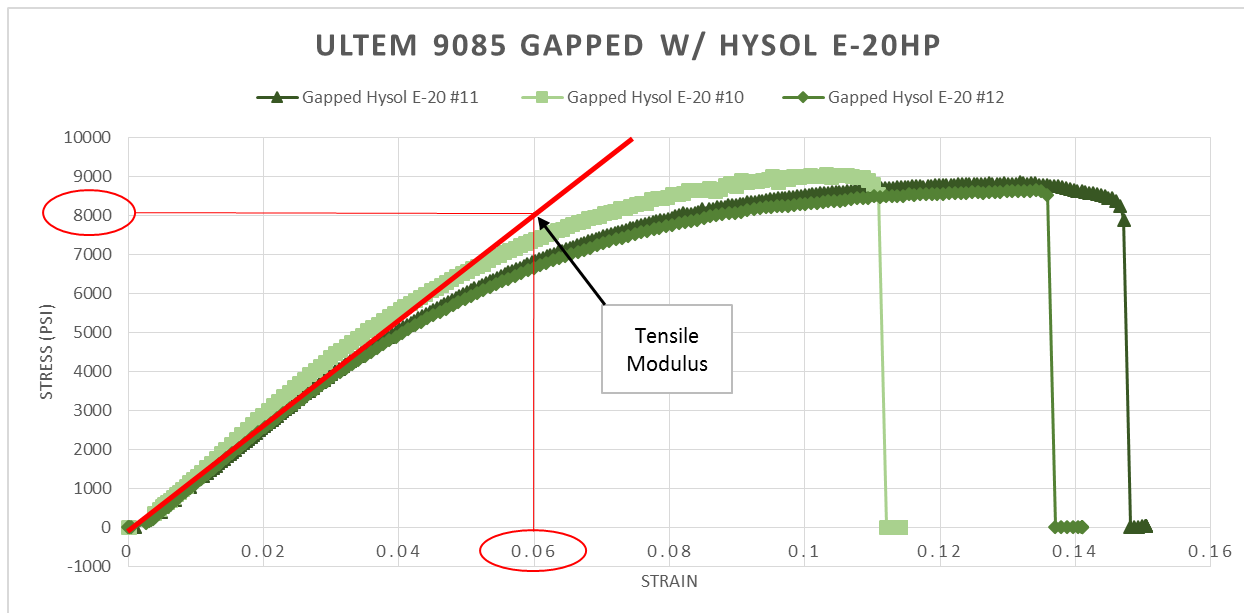


Figure 57: Average Tensile Modulus for gapped samples with Hysol E-20HP

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{8000 \text{ psi}}{0.06} = 133.3 \text{ kpsi}$$



SPHERES

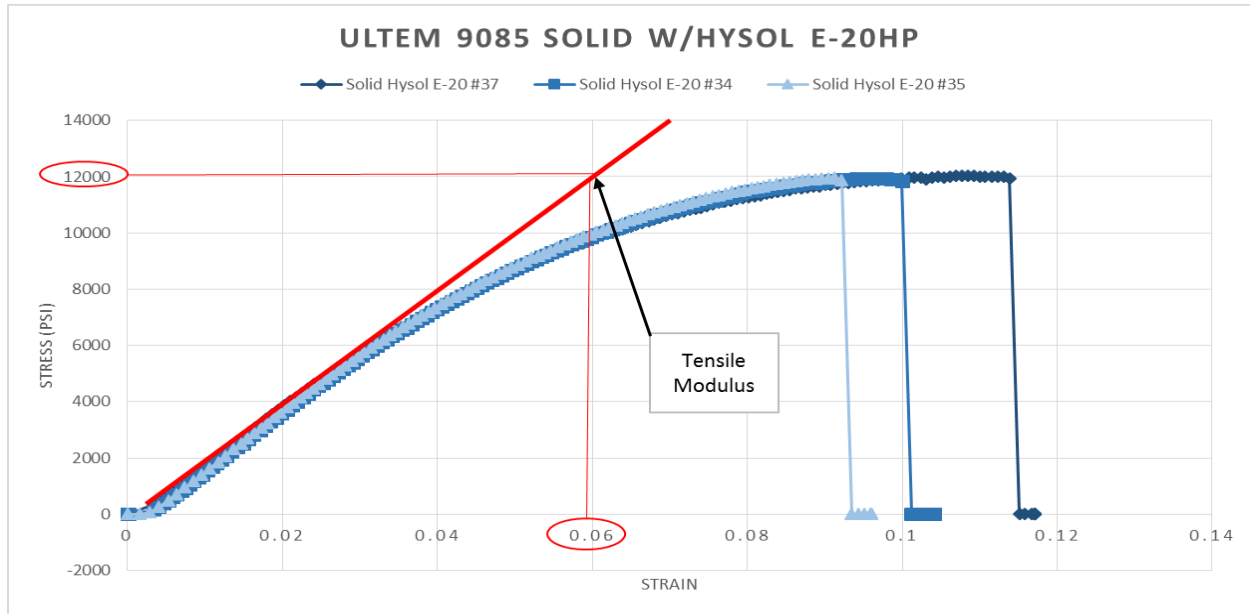


Figure 58: Average Tensile Modulus for solid samples with Hysol E-20HP

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{12000 \text{ psi}}{0.05} = 200 \text{ kpsi}$$

Henkel Loctite 5110

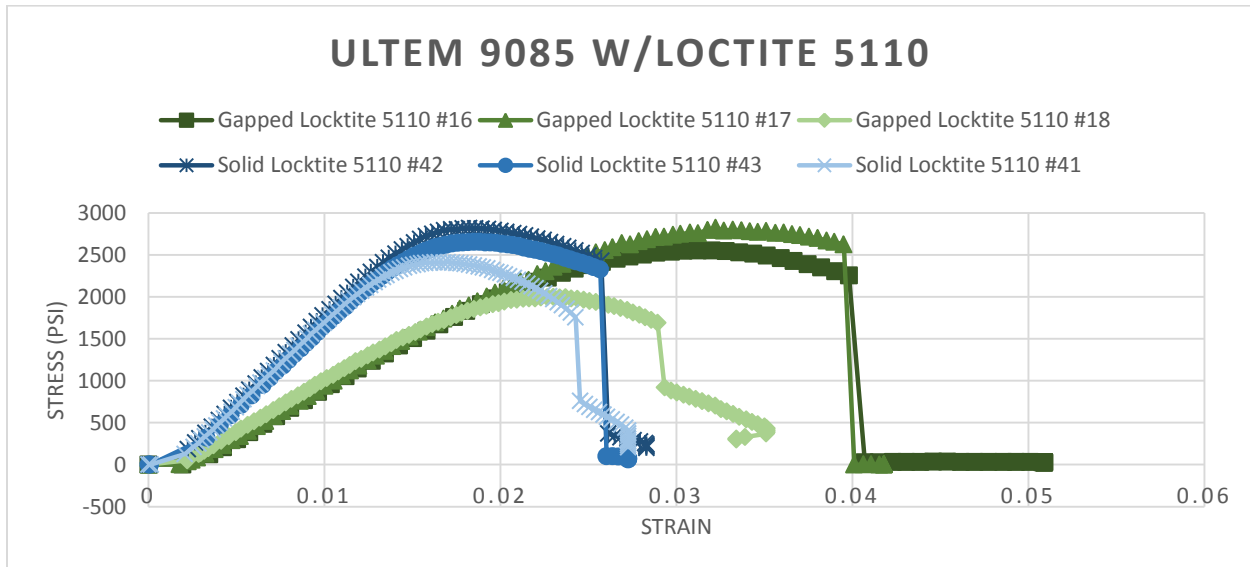


Figure 59: Stress vs. Strain curves for samples with Henkel Loctite 5110



SPHERES

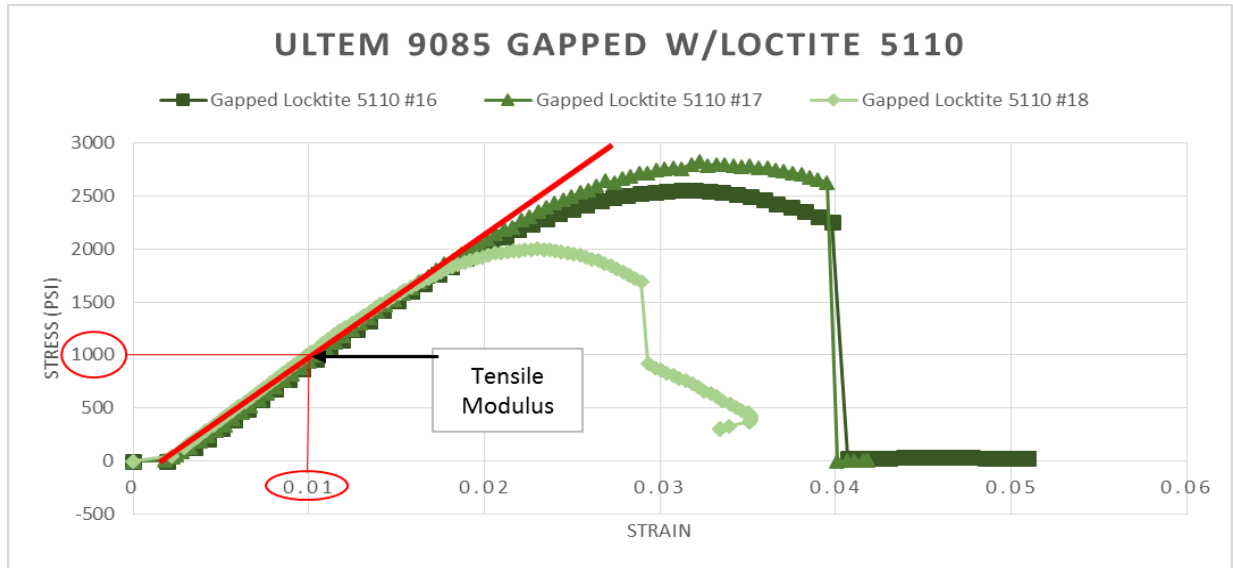


Figure 60: Average Tensile Modulus for gapped samples with Henkel Loctite 5110

$$Tensile\ Modulus = \frac{Stress}{Strain} = \frac{1000\ psi}{0.01} = 100\ kpsi$$

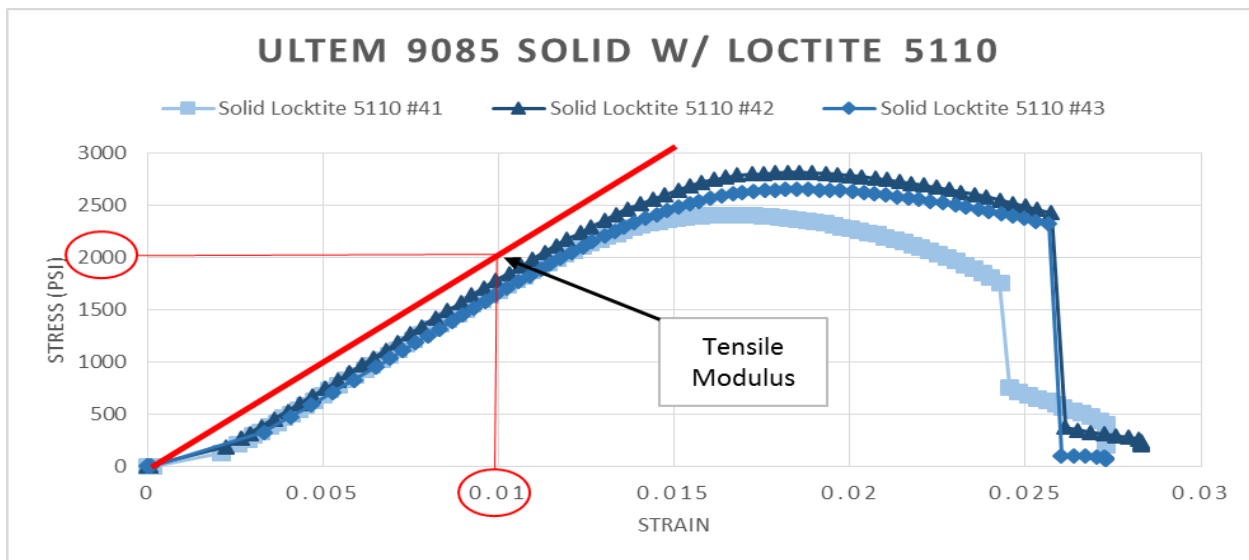


Figure 61: Average Tensile Modulus for solid samples with Henkel Loctite 5110

$$Tensile\ Modulus = \frac{Stress}{Strain} = \frac{2000\ psi}{0.01} = 200\ kpsi$$



SPHERES



ProBuild Marine

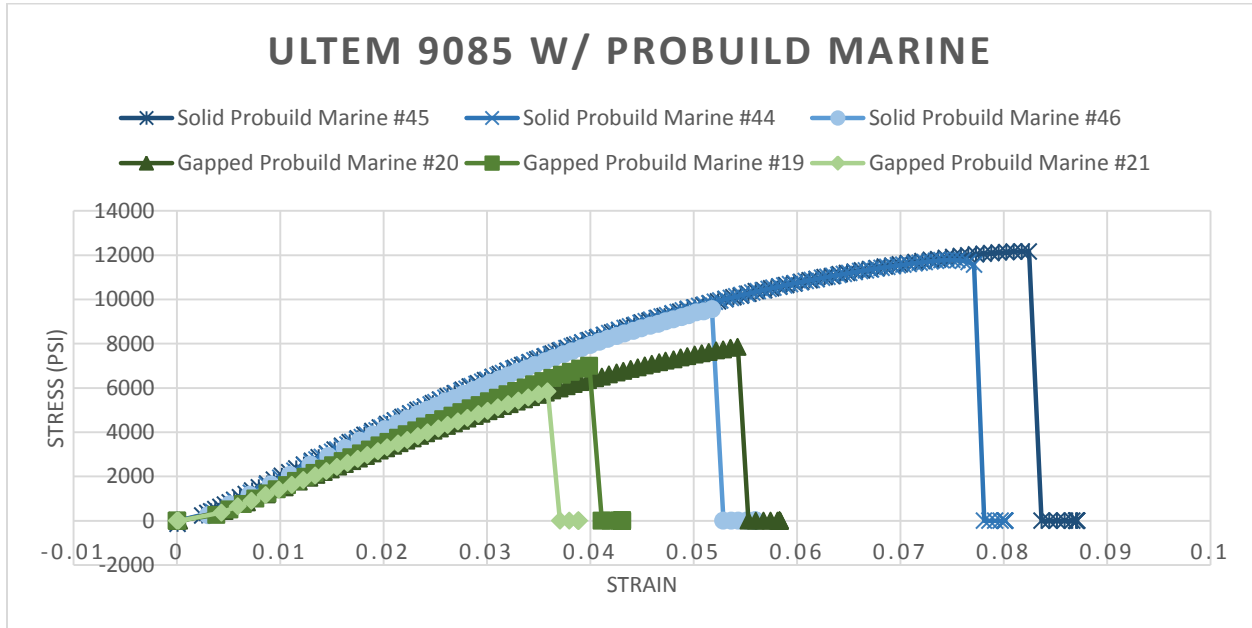


Figure 62: Stress vs. Strain curves for samples with ProBuild Marine

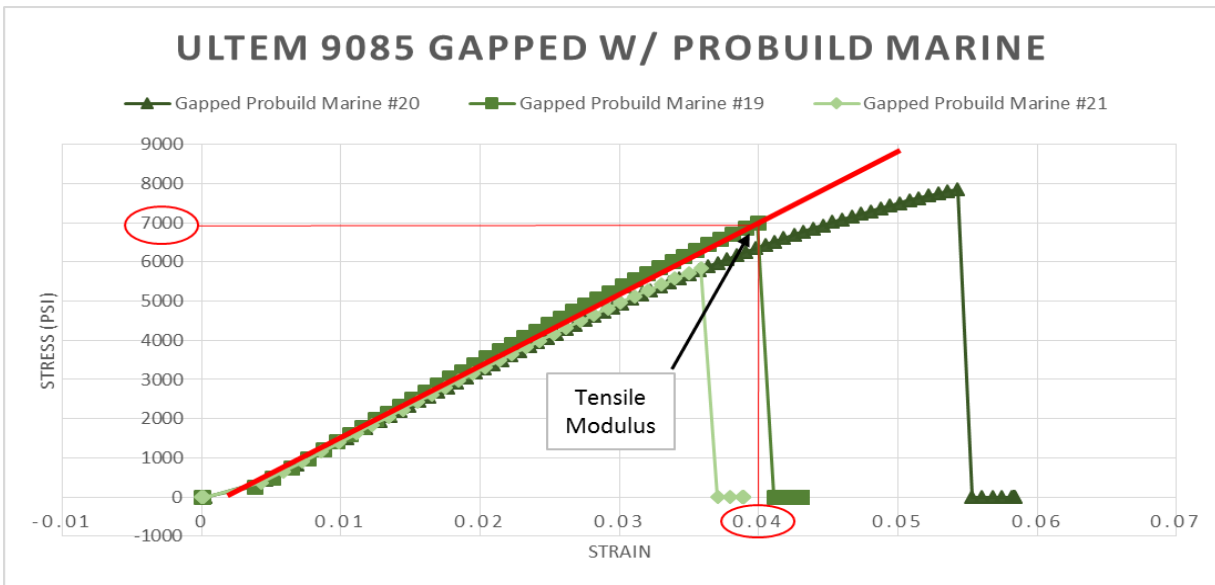


Figure 63: Average Tensile Modulus for gapped samples with ProBuild Marine

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{7000 \text{ psi}}{0.04} = 175 \text{ kpsi}$$



SPHERES

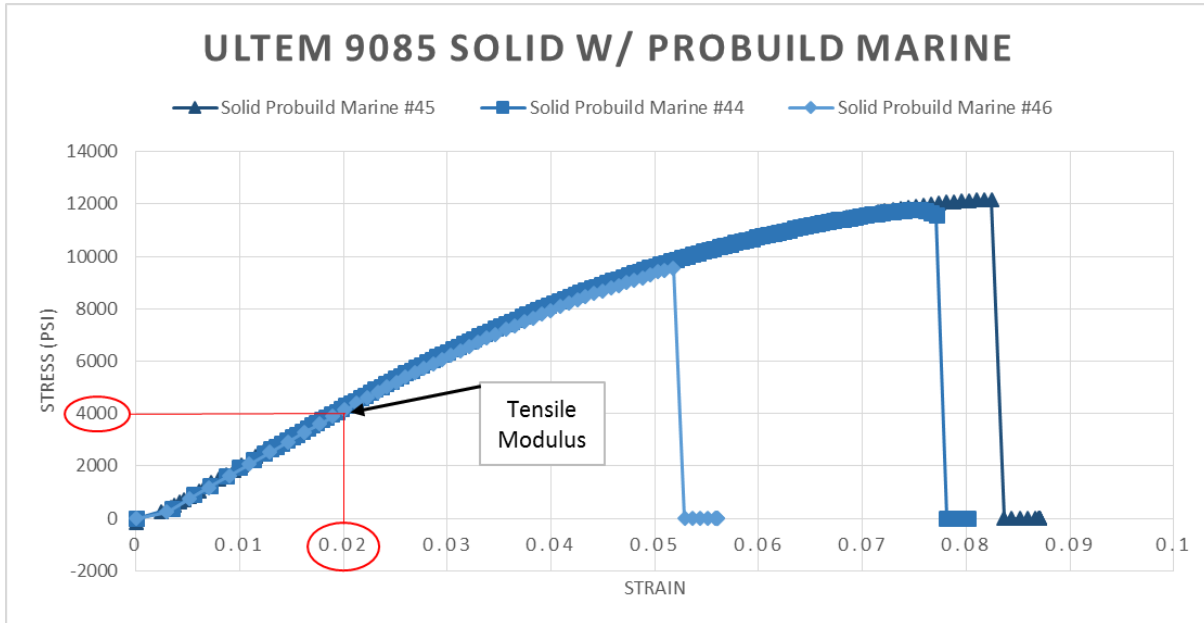


Figure 64: Average Tensile Modulus for solid samples with ProBuild Marine

$$\text{Tensile Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{4000 \text{ psi}}{0.02} = 200 \text{ kpsi}$$



SPHERES



Breaking Notes

SPHERES Ultem 9085 Sample Notes

Sample # 9

broke at 1160 lb with a δ_{max} of 0.24 inch. The sample broke in two pieces and flew across the room.

Sample # 7 6/10/14 11:05pm

First Break of the day. Used as a trial run to dial-in the procedures.

Break: 1115 lb
 δ_{max}



SPHERES



6/16/14

SPHERES Ultem 9085 Sample Notes

Sample # 1

11:15 am

Broke around \approx 850 lb

δ_{max} around \approx 0.75 in

"Shredded Wheaties"

no FOD

Gripped

Sample # 2

11:22 am

Gripped control sample

break load = 855 lb

break δ = 0.83 in

"Shredded wheaties"

no FOD



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 3

11:34am

Gapped control sample

Break load = 845 lb

Break δ = 0.85 in

"Shredded wheaties"

No FOD

Sample # 23

11:46am

Solid control sample

Break load = 1300 lb

Break δ = 0.67 in

explosive break

multiple FOD

* Sample collected dust and dirt when
it escaped the confined test volume



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 24

11:54 am

Solid Control Sample

Break load = 1260 lb

Break δ = 0.6594 in

explosive break

minimal fod - grains of sand size

* sample collected dust & dirt when it escaped the confined test volume

Sample # 26

12:04 pm

Solid control Sample

Break load = 1320 lb

Break δ = ~~0.68 in~~ 0.68 in

explosive break - did not escape test volume

minimal fod - grains of sand size



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 13

1:25 pm

BJB gapped sample

Break load = 1535 lb

Break δ = 0.320 in

Very explosive break
FOD was present

* sample collected dust & dirt when it escaped the confined test volume

Sample # 14

1:32 pm

BJB gapped sample

Break load = 1830 lb

break δ = 0.565 in

Very energetic break
FOD everywhere

* multiple samples flew out of the confined test volume and collected dust, dirt, & oil.



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SPHERES Ultem 9085 Sample Notes

Sample # 15

1:45 pm

BJB gapped sample

Break load = 1490 lb

Break δ = 0.290 in

explosive break

FoD was substantial

* sample flew out of confined test volume

Sample # 38

1:50 pm

BJB solid sample

Break load = 1330 lb

Break δ = 0.249 in

Very explosive break

FoD minimal - grain of sand/rice

* stayed within test chamber



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 39

~~2:01 pm~~ 2:01 pm

BSB solid sample

Break load = 1410 lb

Break δ = 0.26 lb

explosive break
FOD everywhere

* Sample flew out of

Sample # 40

2:08 pm

BSB solid sample

Break load = 1525 lb

Break δ = 0.2968 in

Very energetic break
I small piece of FOD

* Sample did not fly out but did bounce around the test volume quite a bit.



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 22

2:15 pm

Arathane 5750 gapped

Break load = 890 lb

Break δ = 1.05 in

gentle controlled break
NO FOD

Sample # 25

2:25 pm

Arathane 5750 gapped

Break load = 865 lb

Break δ = 0.84 in

gentle controlled break
I thin "water" FOD



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 31

2:31 pm

Arathane 5750 gapped

Break load = 850 lb

Break δ = 0.77 in

gentle break
NO FOD

Sample # 47

2:38 pm

Arathane 5750 solid

Break load = 1280 lb

Break δ = 0.540 in

explosive break
pebble sized FOD



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 48

2:45 pm

Arathane 5750 solid

Break load = 1290 lb

Break δ = 0.618 in

explosive break
FOD everywhere

* sample escaped the confined test volume
collected dust & dirt

Sample # 49

2:51 pm

Arathane 5750 solid

Break load = 1305 lb

Break δ = 0.6638 in

explosive break
FOD substantial

* Sample escaped the test volume collected
dust & dirt



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 10

3:01pm

E-20HP gapped sample

Break load = 1000 lb

Break δ = 0.650 in

explosive break

1 tiny FOD = grain of sand

Stayed within the test volume

Sample # 11

3:06pm

E-20HP gapped sample

Break load = ~~1000 lb~~ 990 lb

Break δ = ~~0.90 in~~ 0.88 in

gentle controlled break
No FOD



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 12

3:14 pm

E-20 HP gapped sample

Break load = 955 lb

Break δ = 0.815 in

gentle break
minimal FOD

Stayed in confined space

Sample # 34

3:21 pm

E-20 HP solid sample

Break load = 1340 lb

Break δ = 0.620 in

explosive break
multiple FOD - small granular pieces

Stayed in confined space



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 35

3:28 pm

E-20 HP solid sample

Break load = 1340 lb

Break δ = 0.55 in

explosive break

minimal FOD - small granular pieces

Sample # 37

2:34 pm

E-20 HP solid sample

Break load = 1345 lb

Break δ = 0.68 in

explosive break

1 piece of FOD - small pebble

Stayed within test volume



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 19

3:45 pm

Probuild Marine gapped sample

Break load = 760 lb

Break δ = 0.24 in

explosive break

minimal FOD - clean break

stayed in confined space

Sample # 20

"slower rate"
↓

3:49

Probuild Marine gapped sample

Break load = 870 lb

Break δ = 0.34 in

explosive break

minimal FOD - small pebbles

stayed in confined space



SPHERES



SPHERES Ultem 9085 Sample Notes

Sample # 21

3:54

Probuild Marine gapped sample

Break load = 615 lb

Break δ = 0.23 in

explosive break
NO FOD

Stayed in confined space

Sample # 44

3:59

Probuild Marine solid sample

Break load = 1310 lb

Break δ = 0.48 in

very explosive break

Stayed in confined space



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SPHERES Ultem 9085 Sample Notes

Sample # 45

4:05 pm

Probuild Marine, solid sample

Break load = 1350 lb

Break δ = 0.49 in

explosive break
large FOD ~~is~~

Stayed in confined space

Sample # 46

4:11 pm

Probuild Marine solid sample

Break load = 1035 lb

Break δ = 0.315 in

very explosive
NO FOD

Stayed in confined space
and bounced around



Appendix B: SDP Enclosure Top Test

SPH-SDP-PRO

Rev. A

SPHERES Ultem 9085 Material Testing

SPHERES Docking Port Enclosure Top Testing

July, 2014



National Aeronautics and Space Administration
 Ames Research Center
 Moffet Field, CA

<p>Organization SPHERES National Lab</p>	<p>Title/Subject ULTEM 9085 Testing</p>	<p>Number SPH-04-XS-100</p>	<p>Date June 17, 2015</p>	<p>Page 115</p>
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 Daniel Andres Aguilar Martel
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7/30/2014
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Approved by:


 Darryl William LeVasseur
 System Engineer II
 Metis Technologies

7/30/14
Date

Organization SPHERES National Lab	Title/Subject SDP Enclosure Top Test	Number SPH-SDP-PRO	Date July 30, 2014	Page 1
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Organization SPHERES National Lab	Title/Subject ULTEM 9085 Testing	Number SPH-04-XS-100	Date June 17, 2015	Page 116
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Procedure

Materials:

- *SDP-SP-102-SDP Enclosure Top*
- Custom machined SDP Adapter Plate
- Calipers
- Loctite 242
- Four #4-40 $\frac{3}{8}$ " 18-8 stainless steel button-head socket cap screws
- Weight disks (125 lb total)
- Cameras

Safety Equipment:

- Safety Glasses -Gloves

1. Pretest procedures

- 1.1. Place the 3-D printed Ultem 9085 Enclosure Top in the SDP Adapter Plate
- 1.2. Make sure it is seated properly by checking for screw hole alignment.
- 1.3. Using Loctite 242 (medium strength liquid), applying a very small drop to the first two threads on the tip of the screw. Ensure that only about a quarter of these threads are covered.
- 1.4. Fasten the Enclosure Top to the SDP Adapter Plate using the four #4-40 screws that are 18-8 stainless steel button-head socket cap screws, 4-40 thread, 3/8" length, torqued to 8.0 in-lbs using the torque screw driver.
- 1.5. Allow to cure for 24 hours.



Figures 1, 2, and 3: SDP Enclosure Top getting attached to the SDP Adapter Plate.

2. Prepare the Testing Apparatus

- 2.1. Set up the cameras to record the test.
- 2.2. Clean the flat Contact Disk with Isopropyl Alcohol and Kimwipes to prevent contamination of the 3-D printed Ultem 9085 Enclosure Top.
- 2.3. Place the testing platform on the flat table as seen below.

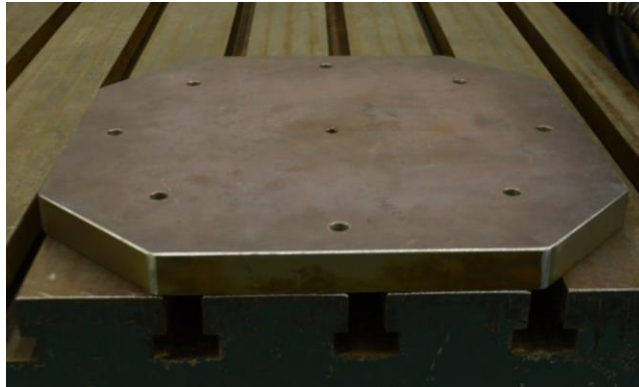


Figure 4: Testing Platform set on a flat table.

- 2.4. Place the machined SDP Adapter Plate with the attached 3-D printed Ultem 9085 Enclosure Top onto the Testing Platform.

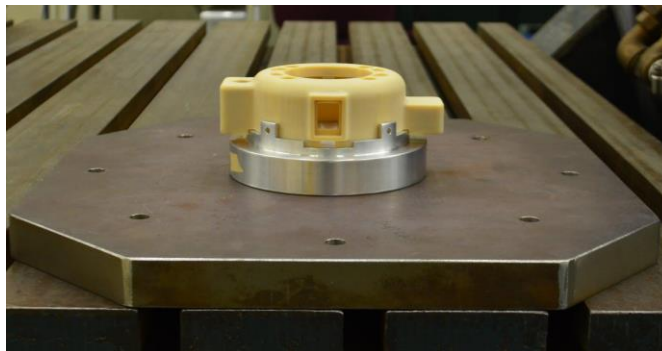


Figure 5: SDP Adapter Plate with attached 3-D printed Ultem 9085 Enclosure Top on the Testing Platform.

3. Commence with testing procedures

- 3.1. Start the video cameras.

Table 1: Measurements of the weights taken on the EEL Shadowgraph.

Name	Weight
Flat Disk	7.99 lbs
Large weights: 25 lb weights (x2)	50.00 lbs
Smaller weights: 2 lb weights (x8) 1 lb weight (x1)	17.01 lbs
Total Weight	125.00 lbs

Note: Be sure to stack the weight using minimal acceleration when placing each weight down. Make sure all weights are in place within 60 seconds of stacking the first plate. Also be sure to place the weights parallel to the testing surface.

- 3.1.1. Begin by placing the Contact Disk on top of the SDP Enclosure Top so that the 125 lb load is evenly distributed.
- 3.1.2. Next set a 50 lb weight on top of the Contact Disk.

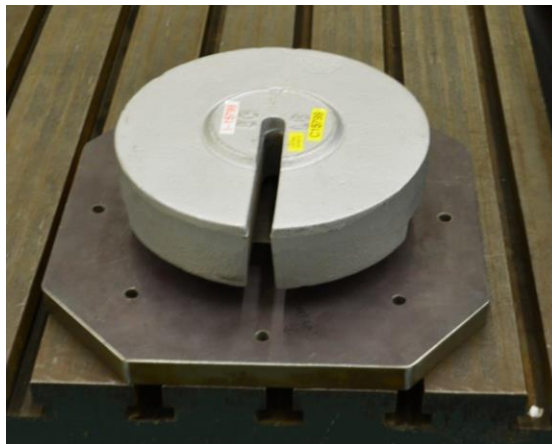


Figure 6: A 50 lb weight set on top of the Contact Disk.

- 3.1.3. Stack another 50 lb weight on top of the previous 50 lb weight so that it sits snugly in the protruding center so that they interlock.
- 3.1.4. Set a 2 lb weight on top of the protruding center of the second 50 lb weight. Perform this step eight times so that each of the 2 lb weights interlock with one another.
- 3.1.5. Set the 1 lb weight on the top of the stack of 2 lb weights so that it

interlocks.

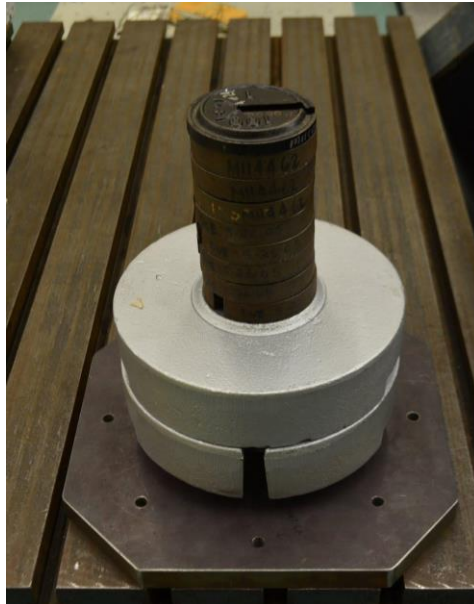


Figure 7: The final stack of 125lbs will appear like this.

- 3.2. Leave the weights in place for 30 sec.
- 3.3. Carefully remove the weights off the Enclosure Top one-by-one.
- 3.4. Stop the video recording.

4. Post Break

- 4.1. Visually inspect the sample for deformation, deflection and other abnormalities not previously observed.
- 4.2. Measure and record the dimensions of the Enclosure Top on document SPH-SDP-LOG to check for any discrepancies.

5. Results

The SDP part withstood the 125 lb load with no abnormalities. It did not deform, and a small increase in mass posttest was simply due to the Loctite residue that can be seen in the figure below. After the test was completed, the screws were backed out using the torque screw driver. A torque value of around 5 in-lb was found to be sufficient to remove the screws. Cracks radiating from the threaded inserts were found on two of the

four screws, most likely due to the initial torquing of the screw.

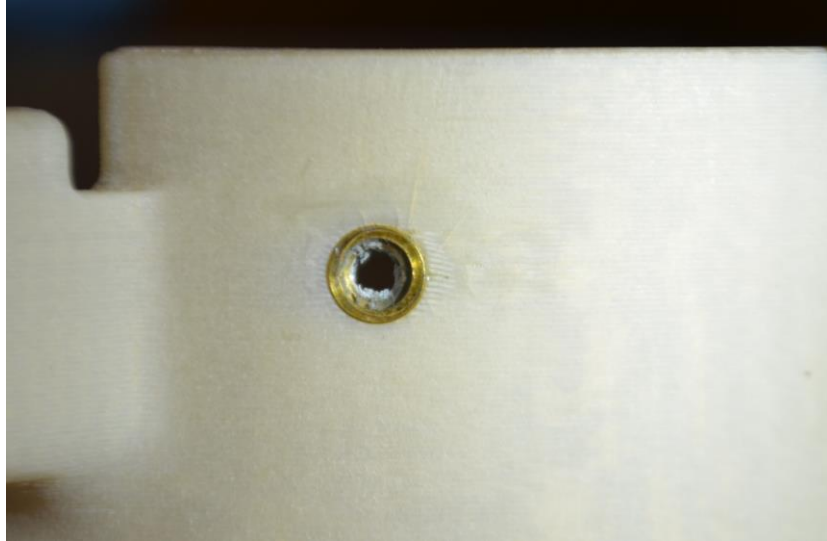


Figure 8: Radial cracks around the threaded insert



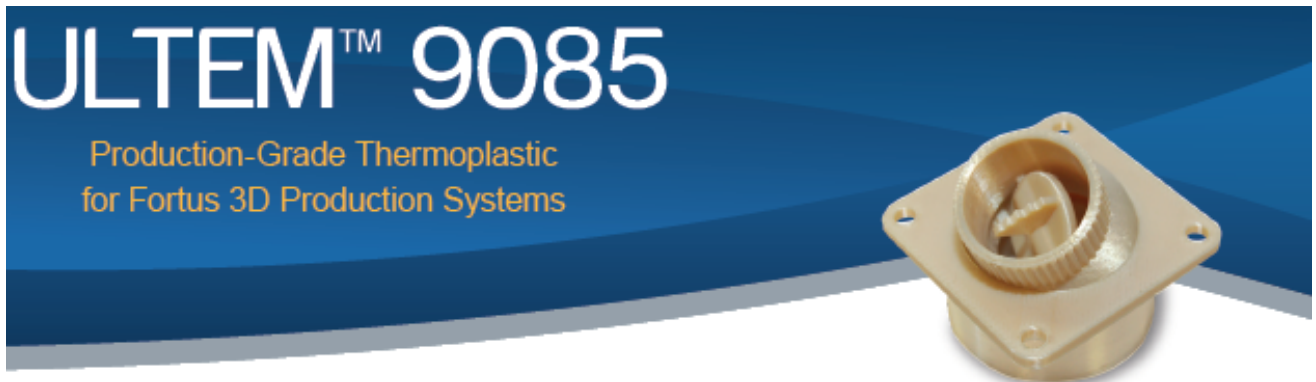
SPHERES



Appendix C: Data Sheets

Ultem 9085

Stratasys



ULTEM™ 9085 resin is a flame-retardant high-performance thermoplastic for digital manufacturing and rapid prototyping. It is ideal for the transportation industry due to its high strength-to-weight ratio and its FST (flame, smoke and toxicity) rating. This unique material's certifications make it an excellent choice for the commercial transportation industry – especially aerospace, marine and ground vehicles. Combined with a Fortus® 3D Production System, ULTEM 9085 resin allows design and manufacturing engineers to produce fully functional parts that are ideal for advanced functional prototypes or end use without the cost or lead time of traditional tooling.

Mechanical Properties ¹	Test Method	English		Metric	
		XZ Orientation	ZX Orientation	XZ Orientation	ZX Orientation
Tensile Strength, Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	6,800 psi	4,800 psi	47 MPa	33 MPa
Tensile Strength, Ultimate (Type 1, 0.125", 0.2"/min)	ASTM D638	9,950 psi	6,100 psi	69 MPa	42 MPa
Tensile Modulus (Type 1, 0.125", 0.2"/min)	ASTM D638	312,000 psi	329,000 psi	2,150 MPa	2,270 MPa
Tensile Elongation at Break (Type 1, 0.125", 0.2"/min)	ASTM D638	5.8%	2.2%	5.8%	2.2%
Tensile Elongation at Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	2.2%	1.7%	2.2%	1.7%
Flexural Strength (Method 1, 0.05"/min)	ASTM D790	16,200 psi	9,900 psi	112 MPa	68 MPa
Flexural Modulus (Method 1, 0.05"/min)	ASTM D790	331,000 psi	297,000 psi	2,300 MPa	2,050 MPa
Flexural Strain at Break (Method 1, 0.05"/min)	ASTM D790	No break	3.7%	No break	3.7%



Sabic



ULTEM™ Resin 9085
Americas: COMMERCIAL

High flow Polyetherimide blend. Meets FAR 25.853 and OSU 65/65 with low toxicity, smoke and flame evolution.

TYPICAL PROPERTIES ¹	TYPICAL VALUE	Unit	Standard
MECHANICAL			
Tensile Stress, yld, Type I, 0.2 in/min	12100	psi	ASTM D 638
Tensile Stress, brk, Type I, 0.2 in/min	10700	psi	ASTM D 638
Tensile Strain, yld, Type I, 0.2 in/min	7	%	ASTM D 638
Tensile Strain, brk, Type I, 0.2 in/min	72	%	ASTM D 638
Tensile Modulus, 0.2 in/min	498000	psi	ASTM D 638
Flexural Stress, yld, 0.05 in/min, 2 in span	20000	psi	ASTM D 790
Flexural Modulus, 0.05 in/min, 2 in span	423000	psi	ASTM D 790
Tensile Stress, yield, 5 mm/min	88	MPa	ISO 527
Tensile Stress, break, 5 mm/min	71	MPa	ISO 527
Tensile Strain, yield, 5 mm/min	6.7	%	ISO 527
Tensile Strain, break, 5 mm/min	50	%	ISO 527
Tensile Modulus, 1 mm/min	3050	MPa	ISO 527
Flexural Stress, yield, 2 mm/min	90	MPa	ISO 178
Flexural Modulus, 2 mm/min	2750	MPa	ISO 178



Applicant MSDS and TDS

Arathane 5750-A/B (LV)



Advanced Materials
Electrical Insulation Materials

DATA SHEET

Arathane[®] 5750-A/B (LV)

Urethane Conformal Coating

General

Arathane 5750-A/B (LV) is a translucent, soft, repairable, two-component urethane system designed specifically for insulating printed circuit boards and electronic components.

Arathane 5750-A/B (LV) exhibits excellent reversion resistance under heat and high humidity conditions. As a cured coating, this material displays very low outgassing properties critical for applications in outer space and high vacuum environments.

Applications

Protective coating for printed wiring boards
Dip, spray, and spread applications

Advantages

Low outgassing
Repairable
Low modulus
Mil spec MIL-I-46058C approved
IPC CC 830 Amendment 1 Type UR class 3 approved



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Typical Properties*

Arathane 5750 A	
Viscosity, cPs	50
Specific gravity, g/cm ³	1.21
Flash point, open cup, °C	7
Percent solids	90 ± 3
As supplied form	Amber Liquid

Arathane 5750 B (LV)	
Viscosity, cPs	600
Specific gravity, g/cm ³	0.92
Flash point, open cup, °C	17
Percent solids	82 ± 3
As supplied form	Translucent Liquid

* Typical properties are based on Huntsman's test methods. Copies are available upon request.

Packaging & Storage

Arathane 5750-A/B (LV) are flammable liquids. These materials are moisture sensitive and should be stored in a dry place and, whenever possible, in the tightly closed original containers at 25°-40°C. Under these conditions, shelf life will be 6 months from the day of shipping. Partial containers should be resealed using dry nitrogen or argon. Contact Customer Service for packaging information.

System Preparation

The printed circuit board or electronic circuitry should be clean and free of grease, dirt, or other contaminants. Although solvent cleaning is generally sufficient, if excess flux is evident, techniques such as vapor degreasing may produce better cleaning. Arathane 5750 A/B (LV) may be sprayed or applied by dipping.

For Teflon™ coated wires and other Teflon™ surfaces, abrade with non-chlorinated steel wool and etch with sodium before applying customized adhesion agents or primers. Allow all coated surfaces to dry completely prior to applying Arathane 5750 A/B (LV).

Exposure of Part A to low temperatures for prolonged periods may cause crystallization. Part A must be reliquified by heating to 50°C (120°F) maximum. **DANGER! Do Not heat above 50°C! Extreme Explosion and Fire Hazard.**

Heat Part A until clear amber solution is achieved. Remove container from oven. Do not disturb contents. Allow to cool to 25-40°C in a controlled environment; do not force cool.

Measure height of the precipitate from outside of bottle. Do not use if level of precipitate is above 3/8 inches (0.6 cm), or if liquid remains cloudy or contains gelled particles. Contact our Customer Service Department with lot number, date received and condition of bottle.

Material is ready for use if level of precipitate is below 3/8 inches. Do not agitate. Slowly decant clear resin out of the bottle without disturbing the precipitate. Enough material has been packaged to allow for any precipitate and to assure sufficient Part A. For best results, filter Part A through nylon tricot, 10-25 micron size.



SPHERES



Use entire bottle so remaining material will not be contaminated with moisture. If this is not possible, any remaining material must be well blanketed with dry nitrogen or argon and the cap tightened securely. Store at 25-40°C for best long-term stability.

Mixing

Container should be plastic, glass, or metal. Paper and wooden containers or utensils are not recommended because of high moisture content.

Weigh Part B into container first. Add Part A to container. (Do not use Part A if precipitate level is greater than 3/8 inches.)

Slow machine mixing or hand stirring will minimize air entrapment. Complete and thorough mixing of Parts A and B is essential for optimum end properties.

A brief vacuum may be applied to remove bubbles; however, some solvent will also be removed. Vacuum should be equipped with solvent trap to prevent damage to pump.

Mix ratios

	Parts by weight
Arathane 5750 A	18
Arathane 5750 B (L V)	100

Processing

Initial viscosity, cPs 550

Pot life at 25°C (100g), hours 2

Recommended cure times*

Temp., °C	Gelation (min)	Tack free (hours)	Full cure (hours)
25	120	24	7 days
65	45	2	9
100	25	1.5	4
125	15	1	2

* Above data was generated on two coatings of 1.5 mil (3.8×10^{-2} mm) each, dip-applied on epoxy laminate printed circuit boards. High component density boards may require slightly longer cure schedules. Maximum insulating resistance, interfacial adhesion, and protection from corrosion are obtained with heat curing.



SPHERES



Spraying

Some spray systems are able to apply the high-solids Arathane 5750 A/B (LV) as received to provide up to 8 mils thickness per pass.

For most conventional spray systems, a viscosity of 100-250 cP is desired. To dilute Arathane 5750 A/B (LV) for optimum spraying viscosity, use 5750 Thinner.

Suggested procedure for reducing viscosity of Arathane 5750 A/B (LV):

- To 100 pbw of Arathane 5750 B (LV) add 20 pbw of 5750 Thinner, mix well.
- To above mixture add 18 pbw of Arathane 5750 A, mix well.

Spray equipment manufacturers:

- Zicon, Mount Vernon, NY – airless inert carrier system
- Binks, Franklin Park, IL – conventional air system
- DeVilbiss, Toledo, OH – conventional air system

Dipping

Arathane 5750 A/B (LV) must be thinned with 5750 Thinner to control coating thickness. Coating thickness depends upon amount of solvent added to reduce viscosity and dipping rate. To achieve a one to one and one-half (1 – 1.5) mil thickness (2.5-3.8 x 10-2mm) coat per dip, reduce mixed viscosity to approximately 100 cPs. (Refer to previous recommendations for reducing viscosity).

Allow mixture to stand 15-30 minutes for bubbles to dissipate. A suggested solvent blend is recommended above. Adjust dipping rate to achieve desired thickness. This allows for complete wetting of all surfaces and minimizes run-off during cure.

Multiple applications

Two or more coats must be applied for optimum protection of parts. Allow enough time at curing temperature for each application to gel. Allow solvent to escape at ambient temperatures for 15-30 minutes prior to elevated temperature curing. This will minimize bubble entrapment. An alternative to air drying or curing between layers is to place board in a 15-15mm Hg Vacuum for 5-10 minutes for a dense, bubble-free coating.

Removal

Note: Cured Arathane 5750 A/B (LV) conformal coating may be removed from the printed circuit board using the following mechanical or chemical methods.

Mechanical removal

Due to the soft, flexible nature of cured Arathane 5750 A/B (LV), it may be easily cut with a sharp knife and then scraped or peeled from component leads, solder pads, and devices. Desolder and remove components, lightly sand down rough edges of intact coating, and wipe repair area clean with fresh isopropyl alcohol. Allow to dry 15 minutes. Replace component and solder in place. Wipe clean all solder flux with cloth dipped in isopropyl alcohol and allow to dry at least 15 minutes at 80°C before recoating.



SPHERES



Mix fresh Arathane 5750 A/B (LV) per instructions and apply to repair area with a clean, dry, acid brush or equivalent, making sure that fresh coating overlaps the intact coating. The repaired board may be put back into service after a 4 hour cure at 100°C (or alternative cure schedule).

Note: This procedure is not advised for other than field or temporary repair. Using a sharp knife to scrape the coating may also cause damage to the printed circuit board, circuitry, or other components.

The cured coating may be burned through directly with a soldering iron if only the solder joints are involved. Any coating on the leads may be easily sliced with a razor knife to facilitate part removal. Remove the burned residue and sand smooth rough burned edges of intact coating. Wipe away debris and solder new part in place. Remove dirt/resin flux with clean cloth dipped in isopropyl alcohol. Dry for 30 minutes at 65–80°C before recoating. Mix fresh Arathane 5750 A/B (LV) and apply a thin coat over repair area. Make sure to overlap original coating. Cure 4 hours at 100°C (or see alternative cure schedules).

Note: Toxic gases from burning cured urethane systems may be evolved. Perform this procedure only in well-ventilated areas.

Chemical removal

Use our Arathane 5750 Stripper for selective or total removal of cured compound.

Important: Laboratory tests indicate that if suggested procedures are followed, there will be little or no adverse effects to the printed circuit board or components. However, since each application is different, users should test a representative board that has been coated and fully cured to determine deleterious effects of stripper.

Localized chemical removal

Prepare printed circuit board by masking off area to remain intact. If possible, dam up repair area beyond component level to prevent 5750 Stripper from spreading to unwanted areas.

Using an acid brush, apply generous amounts of 5750 Stripper over components in repair area. Do not allow to dry. Keep applying stripper until coating starts to swell and flake off (approximately 5–10 minutes). While keeping repair area saturated, periodically brush away loosened coating. If necessary, a blunt tool may be used to remove thick sections of coating. After 20 minutes exposure to stripper, drain board and allow to dry. Scrape away any loose coating close to or under components. If further cleaning is necessary, apply fresh stripper and repeat process for an additional 15 minutes.

Follow same procedure for underside of board. Remove masking/damning materials and replace defective parts. When removing part, scrape away any coating remaining beneath it prior to replacing. Remove flux and wash area with deionized water. Dry with isopropyl alcohol and dry board 2 hours at 80°C. Apply fresh Arathane 5750 A/B (LV) and follow recommended cure schedules.

Total coating removal

Place board into a container of 5750 Stripper. Agitation will increase stripper efficiency. For safety reasons, use 5750 Stripper at room temperature. (Heating up to 50°C in a laboratory hood environment will reduce time to remove coating.) Leave board in 5750 Stripper bath for 15 minutes. The coating will swell and start to fall off the board. Brush board with stiff brush periodically while in bath. Remove and inspect board and brush or scrape away any remaining coating. For excessively thick areas, an additional



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soak/brushing in fresh 5750 Stripper may be necessary. When coating is removed, replace defective components. Clean board with deionized water and isopropyl alcohol washes. Dry board for 2 hours at 80°C. Remove as much remaining coating as possible, although any unremoved coating will not adversely affect board performance. New Arathane 5750 A/B (LV) coating will encapsulate the old coating to seal and protect the board and components. Follow directions for applying and curing Arathane 5750 A/B (LV).

Note: Effectiveness of 5750 Stripper will decrease with use. Do not use if amber color or other contaminants become visible. Use only explosion-proof equipment. Keep away from flame and sparks.

Physical Properties (typical values)

Hardness, Shore A*	50
Tensile strength, psi (N/mm ²)	350 (2.4)
Elongation, %	150
Tg, °C	< -70
Fungus resistance	Non-nutrient
Maximum continuous use temperature, °C	130
Flame resistance	Self-extinguishing
Flexibility	No cracking/crazing
Outgassing at 10⁻⁸ Torr	
Total Mass loss, %	0.41
Collectible volatile condensable materials, %	0.03

* Data obtained from cast specimens of 100% solids version of Arathane 5750 A/B (LV)

Electrical Properties (typical values)

Insulation resistance, Ω	> 1.0 x 10 ¹⁵
Volume resistivity, ohms-cm	
@ 25°C	9.3 X 10 ¹⁵
@ 95°C	2.0 X 10 ¹³
Dielectric strength,	
3mil thickness, V/mil	> 1,500
7.5 x 10 ⁻² mm thickness, V/mil	> 59,000
Dielectric constant	
@ 25°C, 1 KHz (100 KHz)	2.5 (3.0)
@ 100°C, 1 KHz (100 KHz)	3.6 (3.2)
Dissipation factor	
@ 25°C, 1 KHz (100 KHz)	0.022 (0.025)
@ 100°C, 1 KHz (100 KHz)	0.024 (0.027)
Percent change in Q resonance, %	
1 KHz (50 KHz)	4.5 (3.1)
Moisture resistance, Ω	8.2 x 10 ¹¹



SPHERES



Handling/Safety Precautions

Mandatory and recommended industrial hygiene procedures should be followed whenever our products are being handled and processed. For additional information please consult the corresponding material safety data sheets

Arathane 5750 A/B (LV)

Warning! Flammable. Contains organic isocyanate. Causes severe eye and skin irritation and possible eye burns. Vapor or mist harmful if inhaled. Harmful if swallowed. May cause allergic respiratory reaction.

Work in a well ventilated area and use clean, dry tools for mixing and applying. For two component systems, combine the resin and hardener according to mix ratio. Mix together thoroughly and use immediately after mixing. Material temperature should not be below 65°F (18°C) when mixing.



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First Aid

In case of contact:

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

Skin: Immediately wash with mild soap and water.

Inhalation: Remove person to fresh air. Administer oxygen or artificial respiration if necessary. Call a physician.

Ingestion: If conscious, give plenty of water to drink. Call a physician.

Other: Referral to physician is recommended if there is any question about the seriousness of an injury

Important

The following shall supersede any provision in Buyer's forms, letters and papers. **THERE IS NO WARRANTY OR CONDITION, WHETHER EXPRESS OR IMPLIED BY ANY STATUTE OR OTHERWISE, INCLUDING WARRANTIES AND CONDITIONS OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE, FOR THE PRODUCT OR PRODUCTS REFERRED TO HEREIN. TECHNICAL ADVICE FURNISHED BY THE SELLER SHALL NOT CONSTITUTE A WARRANTY OR CONDITION, STATUTORY OR OTHERWISE, WHICH IS EXPRESSLY DISCLAIMED, ALL SUCH ADVICE BEING GIVEN AND ACCEPTED AT BUYER'S RISK.** While the information contained herein is believed to be accurate, Seller makes no representations as to the reliability of the results or as to the results of Buyer or as inducements to infringe any relevant patent, now or hereafter in existence. Testing for intended use is the sole responsibility of Buyer. The product(s) has not been tested for, and is therefore not recommended for, uses for which prolonged contact with mucous membranes, abraded skin, or blood is intended, or for uses for which implantation within the human body is intended. **UNDER NO CIRCUMSTANCES SHALL SELLER BE LIABLE FOR INCIDENTAL, CONSEQUENTIAL OR OTHER DAMAGES FROM ALLEGED NEGLIGENCE, BREACH OF WARRANTY OR CONDITION, STRICT LIABILITY OR ANY OTHER LEGAL THEORY, ARISING OUT OF MANUFACTURE, SALE, USE OR HANDLING OF THE PRODUCT OR PRODUCTS REFERRED TO HEREIN.** The sole remedy of Buyer and the sole liability of Seller for any claims shall be limited to Buyer's purchase price of the product(s) which is the subject of the claim or the amount actually paid for such product(s), whichever is less.

Note

Arathane® is a registered trademark of Huntsman LLC or an affiliate thereof in one or more countries, but not all countries.

Huntsman Advanced Materials
Americas Inc.
281 Fields Lane
Brewster, New York 10509
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Arathane 5750-A/B (LV)
January, 2004

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BJB TC 1614



EPOXY RESIN SYSTEMS

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

TC-1614 A/B HIGH SOLIDS CONTENT EPOXY PENETRATING SEALING AND COATING RESIN SYSTEM

PRODUCT DESCRIPTION:

TC-1614 A/B is an unfilled high solids content epoxy resin system. It is designed to seal porous to semi-porous substrates developing remarkable strength. As the penetrative depth increases the TC-1614 A/B also has exceptional adhesive characteristics and is capable of continued use at temperatures up to 350°F. It can be used at temperatures up to 400°F intermittently.

PRODUCT HIGHLIGHTS:

- Easy to use and apply
- Penetrates and seals porous surfaces with excellent adhesion
- Works great for sealing FDM and SLS parts
- Withstands temperatures in excess of 350°F.

PHYSICAL PROPERTIES:

Hardness, Shore D ASTM D2240	85 ± 2
Density, (g/cc) ASTM D792	1.14
Cubic Inches per Pound	25.1
Color/Appearance	Opaque yellow
Tensile Strength, (psi) ASTM D638	9,500
Tensile Modulus, (psi) ASTM D638	3.2 x 10 ⁵
Elongation, (%) ASTM D638	5
Flexural Strength, (psi) ASTM D790	12,600
Flexural Modulus, (psi) ASTM D790	3.8 x 10 ⁵
Shrinkage, (in/in) linear (12" x ½" x ½")	0.008
Izod Impact, (ft-lb/in) ASTM D256	0.44

Note: Reported physical properties based on elevated temperature cured test specimens.

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HANDLING PROPERTIES:

Mix Ratio (by weight):
 Part A 100 parts by weight
 Part B 20 parts by weight

Mix Ratio (by volume):
 Part A 100 parts by volume
 Part B 23 parts by volume

Quality Management
 System Registered
 to ISO 9001:2008

TC-1614 A/B Page 1 of 3
 For more information call BJB Enterprises, Inc. (714) 734-8450 Fax (714) 734-8929
 www.bjbenterprises.com

Date: 12/18/2013

HANDLING PROPERTIES (continued):

Specific Gravity @ 77°F (25°C):
 Part A 1.13
 Part B 0.98

Viscosity, (cps) @ 77°F (25°C) Brookfield:
 Part A 550
 Part B 250
 Mixed 600

Work Time, (100-gram mass) @ 77°F (25°C) 2 hours
 Gel Time 2.5 hours
 Demold Time @ 77°F (25°C) 24 hours

*Application Procedures – see page 3

POST CURING:

All physical property results are based upon post-curing this system. The following procedure provides the best results:

- 150° F (66° C) for 1.5 to 2 hours
- 250° F (121° C) for 2 hours
- 300° F (149° C) for 1 hour
- 350° F (177° C) for 1 hour

Allow to cool in the oven. This procedure provides further stabilization and eliminates possible thermal shocks for cavity tools that are temporarily clamped together for curing purposes.

PACKAGING:

5-Gallon Kits 40 lbs. A, 8 lbs. B
 Drum Kits 400 lbs. A, 80 lbs. B

STORAGE:

Store in a cool dry place. Unopened containers will have a shelf life of 12 months from date of shipment when properly stored at room temperatures. Purge opened containers with dry nitrogen before re-sealing.

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.

Quality Management
System Registered
to ISO 9001:2008

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Date: 12/18/2013

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

NON-WARRANTY "Except for a warranty that materials substantially comply with the data presented in Manufacturer's latest bulletin describing the product (the basis for this substantial compliance is to be determined by the standard quality control tests generally performed by Manufacturer), all materials are sold "AS IS" and without any warranty express or implied as to merchantability, fitness for a particular purpose, patent, trademark or copyright infringement, or as to any other matter. In no event shall Manufacturer's liability for damages exceed Manufacturer's sale price of the particular quantity with respect to which damages are claimed."



SPHERES



Product Application Procedure for 3D Printed Parts

Material: TC-1614 Epoxy

Purpose of Procedure: To impregnate rigid, porous 3D Printed Parts with epoxy. Infusing epoxy into the surface is a beneficial procedure to increase strength, improve handling qualities and in some parts improve aesthetics. Some systems will absorb more material than others.

Procedure:

- Pre-warm A&B material in separate containers to 90°-100°F maximum (32°-37°C max) in a temperature controlled industrial oven. This will help to lower the viscosity and increase the absorption rate of epoxy into the part (never use a household oven that may be in contact with food).
- You can also pre-warm the 3D printed part to aid in epoxy infiltration. 100°-120°F (37°-49°C) is a good range but refer to your 3D printed material recommendations for heat resistance in an effort to avoid distortion.
- Place a small 3D Printed Part into a self-sealing (zipper lock) plastic bag and fill with an appropriate amount of epoxy. A bag that is too large will require more volumetric amounts of epoxy. Squeeze out as much of the extra air in the bag to assure part is fully submerged and coated with epoxy then seal bag.
- Allow the part to soak in the epoxy for roughly 20-25 minutes. A recommended optional procedure would be to place bag with soaking 3D Printed part into 100°-120°F (37°-49°C) oven in a leak-proof, metal container, and allow to soak for 15-20 minutes. Check part at 5 minute intervals to monitor viscosity levels and for any exothermic reaction. Larger batches of mixed epoxy will have a shorter reaction time.
- Once part has soaked for allotted time, pull part out of bag and drain excess epoxy off of part.
- For larger parts, mix enough A&B together so you have sufficient material to brush an even coat over the part. Continue brushing drips and runs to keep part coated for 20-30 minutes. Then drain off excess epoxy and wipe down surface with clean, dry paper towels. Avoid using any solvents since it will affect the curing properties.

***Note that mixing a large mass of epoxy can produce an increase in chemical reaction shortening work time and increasing exotherm (heat) as it sits. Do not leave a large, concentrated mass of epoxy in a container unattended. After soaking the part, it may be best to split up a large batch (over 200-300g) by draining the bag into 2-3 separate small containers and allow to harden.**

- Hang part with wire over a cup or bucket to allow continued drainage of excess epoxy. Wipe off any areas of pooled epoxy with a gloved finger or brush. Monitor any sags or drips for the next hour or until epoxy has gelled.
- You can expedite curing of the epoxy in an oven at 100°-120°F (37°-49°C) and promote better physical properties of the finished material. You can also allow the epoxy to cure at room temperature but an elevated post cure will achieve the best results.

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SPHERES



Hysol E-20HP

LOCTITE

1001 Trout Brook Crossing
 Rocky Hill, CT 06067-3910
 Telephone: (860) 571-5100
 FAX: (860) 571-5465

KRAYDEN, INC.

AUTHORIZED DISTRIBUTOR
 HTTP://KRAYDEN.COM 1-800-448-0406

Technical Data Sheet Hysol® Product E-20HP

formerly Durabond E-20HP

Industrial Version, April 2004

PRODUCT DESCRIPTION

LOCTITE® Hysol® Product E-20HP is a toughened, medium-viscosity, industrial grade epoxy with a medium work life. Once mixed, the two-component epoxy cures at room temperature to form a tough, off-white, bondline that provides high peel resistance and high shear strengths. The fully cured epoxy is resistant to a wide range of chemicals and solvents, and acts as an excellent electrical insulator.

TYPICAL APPLICATIONS

The high performance epoxy provides excellent bond strengths to a wide variety of plastics and metals. Ideal for general purpose industrial assemblies. Used as adhesive for bonding dry concrete or limestone for architectural applications.

PROPERTIES OF UNCURED MATERIAL

Resin	Typical	
	Value	Range
Chemical Type	Epoxy	
Appearance	Pale yellow liquid	
Specific Gravity @ 25°C	1.00	0.9 to 1.1
Viscosity @ 25°C, mPa.s (cP)	85,000	40,000 to 90,000
Flash Point (TCC), °C (°F)	>93 (>200)	
Hardener		
	Typical	
	Value	Range
Chemical Type	Amine	
Appearance	Yellow liquid	
Specific Gravity @ 25°C	1.10	1.0 to 1.2
Viscosity @ 25°C, mPa.s (cP)	7,000	5,500 to 8,000
Flash Point (TCC), °C (°F)	>93 (>200)	
Mixture		
	Typical Value	
	Value	Range
Appearance	Off-white	
Specific Gravity @ 25°C	1.03	
Mix Ratio (R:H) by Weight	100 to 55	
by Volume	2 to 1	

TYPICAL CURING PERFORMANCE

Cure speed

The graph below shows the shear strength developed over time on abraded, acid etched aluminum lap shears with an average bondline gap of 3 to 9 mils and tested according to ASTM D-1002

Curing Properties

	Typical Value
(@ 25°C unless noted)	
Working Life, minutes	20
Tack Free time, minutes	40

TYPICAL PROPERTIES OF CURED MATERIAL

(@ 25°C unless noted)

Physical Properties	Typical Value
Dielectric Strength, Volts/Mil	500
Tensile Strength ASTM D638, psi	5,700
Tensile Elongation ASTM D-638, %	8
Hardness ASTM D-1708, Shore D	80
Glass Transition Temperature, Tg, °C	60

PERFORMANCE OF CURED MATERIAL

Shear Strength vs Substrate

(Substrates cured for 5 days @ 22°C)

Substrate	Typical Value	
	N/mm ²	(psi)
Lapshear		
Grit-Blasted Steel	22.6	3270
Aluminum (Abraded/Acid Etched, 3 to 9 mil gap)	28.2	4090
Aluminum (Anodized)	17.4	2530
Stainless Steel	22.0	3190
Polycarbonate	3.9	560
Nylon	1.8	260
Wood (Fir)	11.4	1660
Block Shear		
PVC	7.9	1140
ABS	10.4	1510
Epoxy	28.6	4140
Acrylic	2.0	290
Glass	32.3	4690

Concrete Strength by ASTM C881/C882-99

E-20 HP passes the requirements of a type IV epoxy. During testing the concrete fractured prior to the adhesive failing. The test was modified as we do not recommend it be used on wet surfaces.

TYPICAL ENVIRONMENTAL RESISTANCE

Hot Strength

Test procedure :	ASTM D-1002
Substrate:	Abraded, acid etched aluminum
Bondline gap, mils:	3 to 9
Cure procedure:	12 hours at 65°C & 4 hours at 22°C



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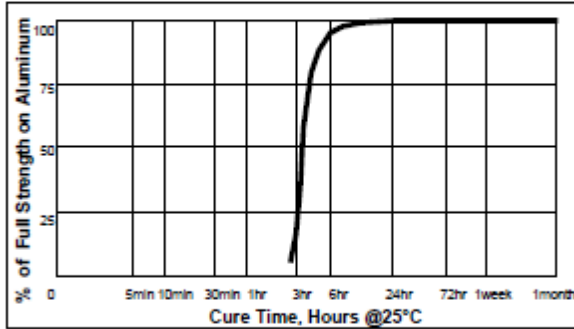


modified as we do not recommend it be used on wet surfaces.

TYPICAL CURING PERFORMANCE

Cure speed

The graph below shows the shear strength developed over time on abraded, acid etched aluminum lap shears with an average bondline gap of 3 to 9 mils and tested according to ASTM D-1002.

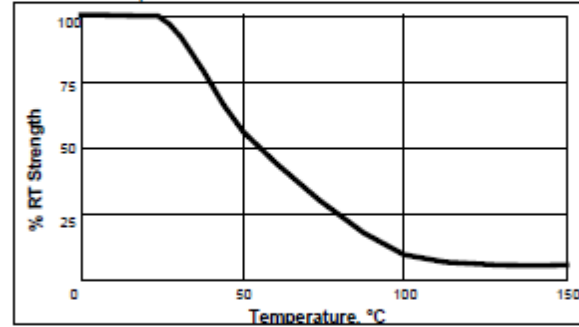


TYPICAL ENVIRONMENTAL RESISTANCE

Hot Strength

Test procedure : ASTM D-1002
 Substrate: Abraded, acid etched aluminum
 Bondline gap, mils: 3 to 9
 Cure procedure: 12 hours at 65°C & 4 hours at 22°C

Tested at temperature.



NOT FOR PRODUCT SPECIFICATIONS.
 THE TECHNICAL DATA CONTAINED HEREIN ARE INTENDED AS REFERENCE ONLY.
 PLEASE CONTACT LOCTITE CORPORATION QUALITY DEPARTMENT FOR ASSISTANCE AND RECOMMENDATIONS ON SPECIFICATIONS FOR THIS PRODUCT.
 ROCKY HILL, CT FAX: +1 (888)-671-6473 DUBLIN, IRELAND FAX: +353-(1)-461-9868



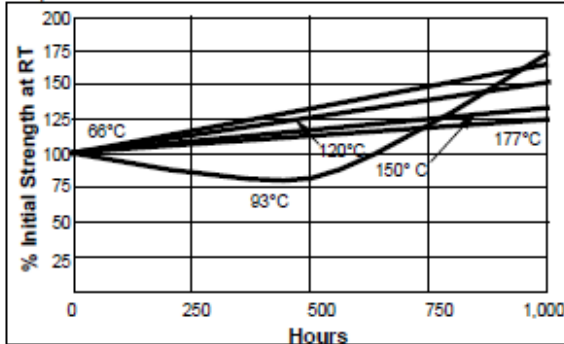
SPHERES



TDS Hysol E-20HP, August 2001

Heat Aging

Cured for 5 days at 22°C on steel with no induced gap, aged at temperature indicated and tested at 22°C.



Chemical / Solvent Resistance

Cured for 5 days at 22°C on steel with no induced gap, aged under conditions indicated and tested at 22°C.

Solvent	Temp.	% Initial Strength retained at	
		500 hr	1000 hr
Air	87°C	-	137
Motor Oil (10W-30)	87°C	164	171
Unleaded Gasoline	87°C	108	82
Water/Glycol (50%/50%)	87°C	121	125
Salt/Fog ASTM B-117	22°C	-	73
95% Relative Humidity	38°C	-	100
Condensing Humidity	49°C	-	90
Water	22°C	-	81
Acetone	22°C	76	95
Isopropyl Alcohol	22°C	87	125

GENERAL INFORMATION

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Material Safety Data Sheet, (MSDS).

Directions for use

1. For high strength structural bonds removal of surface

4. For maximum bond strength apply adhesive evenly to both surfaces to be joined.
5. Application to the substrates should be made within 20 minutes. Larger quantities and/or higher temperatures will reduce this working time.
6. Join the adhesive coated surfaces and allow to cure at 25°C (77°F) for 24 hours for high strength. Heat up to 93°C (200°F), will speed curing.
7. Keep parts from moving during cure. Contact pressure is necessary. Maximum shear strength is obtained with a 3-9 mil bond line.
8. Excess uncured adhesive can be cleaned up with ketone type solvents.

Storage

Product shall be ideally stored in a cool, dry location in unopened containers at a temperature between 8°C to 28°C (46°F to 82°F) unless otherwise labeled. Optimal storage is at the lower half of this temperature range. To prevent contamination of unused product, do not return any material to its original container. For further specific shelf life information, contact your local Technical Service Center.

Data Ranges

The data contained herein may be reported as a typical value and/or range. Values are based on actual test data and are verified on a periodic basis.

Note

The data contained herein are furnished for information only and are believed to be reliable. We cannot assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production methods mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof. In light of the foregoing, Loctite Corporation specifically disclaims all warranties expressed or implied, including warranties of merchantability or fitness for a particular purpose, arising from sale or use of Loctite Corporation's products. Loctite Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits. The discussion



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Chemical / Solvent Resistance

Cured for 5 days at 22°C on steel with no induced gap, aged under conditions indicated and tested at 22°C.

Solvent	Temp.	% Initial Strength retained at	
		500 hr	1000 hr
Air	87°C	-	137
Motor Oil (10W-30)	87°C	184	171
Unleaded Gasoline	87°C	108	82
Water/Glycol (50%/50%)	87°C	121	125
Salt/Fog ASTM B-117	22°C	-	73
95% Relative Humidity	38°C	-	100
Condensing Humidity	49°C	-	90
Water	22°C	-	81
Acetone	22°C	76	95
Isopropyl Alcohol	22°C	87	125

GENERAL INFORMATION

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Material Safety Data Sheet, (MSDS).

Directions for use

- For high strength structural bonds, removal of surface contaminants such as paint, oxide films, oils, dust, mold release agents and all other surface contaminants.
- Use gloves to minimize skin contact. DO NOT use solvents for cleaning hands.
- Dual Cartridges:** To use simply insert the cartridge into the application gun and start the plunger into the cylinders using light pressure on the trigger. Next, remove the cartridge cap and expel a small amount of adhesive to be sure both sides are flowing evenly and freely. If automatic mixing of resin and hardener is desired, attach the mixing nozzle to the end of the cartridge and begin dispensing the adhesive. For hand mixing, expel the desired amount of the adhesive and mix thoroughly. Mix approximately 15 seconds after uniform color is obtained. **Bulk Containers:** Mix thoroughly by weight or volume in the proportions specified in Properties of Uncured Material section. Mix vigorously approximately 15 seconds after uniform color is obtained.

contamination of unused product, do not return any material to its original container. For further specific shelf life information, contact your local Technical Service Center.

Data Ranges

The data contained herein may be reported as a typical value and/or range. Values are based on actual test data and are verified on a periodic basis.

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Henkel Loctite 5110

Technical Data Sheet



LOCTITE[®] 5110[™]

April 2006

PRODUCT DESCRIPTION

LOCTITE[®] 5110[™] provides the following product characteristics:

Technology	Acrylic
Chemical Type	Methacrylate monomers
Appearance (uncured)	Transparent liquid ^{LM5}
Fluorescence	Positive under UV light ^{LM5}
Emulsification	Disperses in water - does not separate as oily layer ^{LM5}
Components	One component - requires no mixing
Viscosity	Low
Cure	Anaerobic
Application	Sealing

LOCTITE[®] 5110[™] is a low viscosity liquid sealant designed for sealing interfacial leak paths in rigid electronic assemblies. It may also be used to enhance dielectric strength or seal porosity in passive materials. LOCTITE[®] 5110[™] sealant is typically applied with a vacuum impregnation process that removes air from the internal void and then saturates the part with liquid sealant. Excess liquid sealant is rinsed from the outside of the part with an aqueous solution effectively leaving no surface build up. In the absence of circulating air, the liquid rapidly polymerizes to form a tough thermoset polymer that permanently seals gaps in the assembly. Parts processed with LOCTITE[®] 5110[™] are sealed internally but remain cosmetically and dimensionally unchanged. Typical applications include sealing or unitizing overmolded electrical components against leakage of air, water, coolants, oils and other fluids. Connectors, high temperature coils, and lamination stacks in brushless motors, solenoids, and sealed enclosures have been sealed successfully. As a good insulator, LOCTITE[®] 5110[™] may also be used to improve the dielectric strength across gaps between high voltage conductors.

Compressive Modulus, ISO 604	N/mm ²	1,790
	(psi)	(260,000)
Flexural Modulus, ASTM D790	N/mm ²	1,740
	(psi)	(250,000)

Electrical Properties

Volume Resistivity, IEC 60093, Ω-cm	9x10 ¹³
Dielectric Breakdown Strength, IEC 60243-1, kV/mm	39.4
Dielectric Constant, IEC 60250:	
100Hz	4.0
1 kHz	4.0
1 MHz	3.8

TYPICAL ENVIRONMENTAL RESISTANCE

Data shown herein should not be used in place of actual part testing. Sealing performance depends as much upon the surrounding substrate as it does upon the sealant. The parent material provides substantial protection against oxygen and pressure loads. Smaller pores, longer leak paths and lower differential pressures yield better durability. The testing described herein provides standard comparisons of LOCTITE[®] sealants on a consistent interface. *Predicting the performance of real world applications using extrapolations from this data is not recommended.* The performance of any sealant should be experimentally validated against the specific demands of a particular application, preferably using actual production methods.

Durability Performance

Standard test pieces were sealed with LOCTITE[®] 5110[™] and subjected to accelerated life testing under adverse conditions. The test specimen was 3.2 mm thick FC0208 sintered powder metal of 6.8 g/mL density (12% porous substrate). Samples were tested at 4 atmospheres internal pressure. Leak rates were measured using volume/time at pressure under water. Initial leak rates were over 10,000 mL/minute.



SPHERES



TYPICAL PROPERTIES OF UNCURED MATERIAL

Specific Gravity @ 25 °C	1.09
Surface Tension, ASTM D 1590, dynes/cm	42.3
Flash Point - See MSDS	
Viscosity, Brookfield - RVT, 25 °C, mPa·s (cP):	
Spindle 2, speed 50 rpm	36 to 66 ^{LMS}

TYPICAL PROPERTIES OF CURED MATERIAL

Physical Properties

Coefficient of Thermal Expansion, K ⁻¹	7.94x10 ⁻⁶
Density @ 25 °C, g/cm ³	1.21
Shore Hardness, ISO 868, Durometer D	89
Design Limit, Continuous Temperature, °C	205
Design Limit, Temperature Exposure less than 24 hours, °C	232

High Temperature Resistance

At temperatures above 180 °C, organic polymers may react with available oxygen. In porosity, the surrounding substrate typically protects the sealant from air. Oxidation may cause the sealant to discolor without compromising the seal. Exterior surfaces are affected first; therefore, cross-sections that are thicker than 3.2 mm enjoy proportionately higher resistance. Applications that include working fluids other than oxygenated air resist elevated temperatures better.

Conditioning	Environment	% Leak
4100 hours salt fog	40 °C, Condensing	0
1000 Thermal Cycles	-40 °C to + 121 °C, 2 hour period	0.1
Acid Exposure	24 hours in pH 1 sulfuric acid	0
Caustic Exposure	24 hours in pH 13 sodium hydroxide	0
Hot Strength	100 psi air, part @ 176 °C	0

GENERAL INFORMATION

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Material Safety Data Sheet (MSDS).

Directions for use

Porosity sealants typically require catalyzation and must be handled with chemically compatible materials and equipment.

Use of process equipment designed, built and maintained to LOCTITE[®] standards is recommended to ensure consistent performance. Consult a LOCTITE[®] Porosity Sealing Specialist for specific application assistance, process development and equipment selection.

Environment	°C	% of initial leak			
		500 h	1000 h	2000 h	4100 h
21% Oxygenated Air (control)	23	0	0	0	0
Unleaded gasoline	23	0	0	0	0
Motor oil (10W-30)	121	0	0	0	0
ATF (Dexron III)	121	0	0	0	0
Water/glycol 50/50	121	0	0	0	0
Brake Fluid (Dot 3)	121	0	0	0	0
21% Oxygenated Air	121	*0.0	*0.0	*0.0	*0.0

* 0.0% signifies a leak that is too small to quantify (<0.01%)

Loctite Material Specification^{LMS}

LMS dated June 30, 2005. Test reports for each batch are available for the indicated properties. LMS test reports include selected QC test parameters considered appropriate to specifications for customer use. Additionally, comprehensive controls are in place to assure product quality and consistency. Special customer specification requirements may be coordinated through Henkel Quality.

Storage

Store product in the unopened container in a dry location. Storage information may be indicated on the product container labeling.

Optimal Storage: 8 °C to 21 °C. Storage below 8 °C or greater than 28 °C can adversely affect product properties. Material removed from containers may be contaminated during use. Do not return product to the original container. Henkel Corporation cannot assume responsibility for product which has been contaminated or stored under conditions other than those previously indicated. If additional information is required, please contact your local Technical Service Center or Customer Service Representative.

Conversions

(°C x 1.8) + 32 = °F
 kV/mm x 25.4 = V/mil
 mm / 25.4 = inches
 µm / 25.4 = mil
 N x 0.225 = lb
 N/mm x 5.71 = lb/in
 N/mm² x 145 = psi
 MPa x 145 = psi
 N·m x 8.851 = lb·in
 N·m x 0.738 = lb·ft
 N·mm x 0.142 = oz·in
 mPa·s = cP



SPHERES



1. Typically, a basket of parts is submerged in sealant. Air is expelled out of the porosity under vacuum.
2. A pressure increase causes the sealant to flow into the pore. Ambient pressure is typical but may be augmented.
3. The basket is lifted and spins to reclaim excess sealant.
4. The parts basket is washed in water with agitation as necessary to achieve good cleaning.
5. Parts cure and dry at room temperature.

Anaerobic Cure Mechanism

Liquid LOCTITE® 5110™ cures in the absence of freely available oxygen. Surface bleedout normally associated with hot water cure is eliminated.

Cure rate depends on the part temperature, dimension and chemical activity of the surrounding porosity. In general, parts can be pressure tested within 5 to 30 minutes after processing.

Waste Rinse Water Disposal

Waste rinse water generated during the porosity sealing process can, in general, be adequately handled by conventional biological treatment methods. Since both the circumstances of use and local environmental requirements vary, waste disposal recommendations are location specific. Depending on the particular parameters, a LOCTITE® Porosity Sealing Specialist can characterize effective waste disposal options for a wide range of solutions from passive handling to zero discharge.

Note

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ProBuild Marine



PROBUILD MARINE EPOXY SYSTEMS

PRODUCT BULLETIN



LAMINATING SYSTEM

www.CASSpolymers.com
31200 Stephenson Hwy

800.344.7776
Madison Heights MI 48071

ADTECH@CASSpolymers.com
Ph 248.588.2270 Fax 248.588.5909

DESCRIPTION

ProBuild Marine Epoxy Systems are convenient, easy-to-use, 100% solids systems developed solely for building, repairing or restoring any type of marine vessel. The versatility of the ProBuild epoxy systems make them ideal for use in standard wet lay-up, vacuum bagging or resin infusion operations with a wide range of reinforcements. These systems can also be mixed with a variety of fillers for fairing, filleting or bonding applications. ProBuild marine epoxy systems consist of one base resin and a selection of four separate hardeners to suit your application needs. These systems are all mixed at convenient 3:1 volumetric mix ratios and can be metered through our calibrated push pumps or various types of dispensing equipment, which eliminates the need for scales or guesswork associated with other types of epoxy systems. In addition to the high strength and durability of the ProBuild epoxy systems, the low viscosity allows for better wet-out resulting in lighter, stronger, void-free parts without experiencing run out on vertical surfaces. The unique chemistry of the ProBuild systems provides maximum physical properties, reduces curing exotherm and minimizes blush, making these systems more trouble free than ever for the marine craftsman and architect. For long term performance and lower maintenance, try one of the ProBuild systems today.

ProBuild Marine Epoxy Systems:

ProBuild Resin: High performance resin specifically formulated for use with any of the following hardeners to produce the highest quality marine laminating system:

Fast & Cold Weather Hardener (cures at temps down to 5°C/40°F)	14 minute work life at 25°C/77°F
Medium Hardener	34 minute work life at 25°C/77°F
Slow Hardener	50 minute work life at 25°C/77°F
Tropical Hardener	125 minute work life at 25°C/77°F

BENEFITS

- Above or Below Water Line Applications
- Convenient volumetric mix ratios
- Can be used in various applications including laminating, bonding, fairing, wood coating or sealing
- Unique chemistry resulting in higher physical properties while minimizing blush
- Ideal for use with a variety of reinforcements including fiberglass, Kevlar and carbon fiber
- Excellent wet-out and air release attributes resulting in less resin usage, saves money
- 100% Solids – No Solvents
- UV Stabilized



SPHERES



<u>HANDLING CHARACTERISTICS @ 25°C/77°F</u>	<u>FAST</u>	<u>MEDIUM</u>	<u>SLOW</u>	<u>TROPICAL</u>
Mix Ratio (parts by weight).....	100R/28H.....	100R/28H.....	100R/28H.....	100R/28H.....
Mix Ratio (parts by volume).....	3R/1H.....	3R/1H.....	3R/1H.....	3R/1H.....
Mixed Viscosity (Brookfield).....	900-1100 cps ..	900-1100 cps ..	900-1100 cps ..	460 cps ..
Pot Life	14 minutes	34 minutes	50 minutes	125 minutes
Mixed Density	9.3 lbs/gal.....	9.3 lbs/gal.....	9.3 lbs/gal.....	9.3 lbs/gal.....
Mixed Density.....	0.040 lbs/in ³ ..	0.040 lbs/in ³ ..	0.040 lbs/in ³ ..	0.040 lbs/in ³ ..
Specific Gravity	1.11 grams/cc ..	1.11 grams/cc ..	1.11 grams/cc ..	1.11 grams/cc ..
Sanding Time	5-7 hours	12-16 hours.....	24 hours.....	24 hours.....
Color.....	Lt Amber	Lt Amber	Lt Amber	Lt Amber
Complete Cure	7 days	7 days	7 days	7 days
V.O.C.....	none	none	none	none
Shelf Life R & H (in original unopened containers).....	2 years	2 years	2 years	2 years

Page 2 of 2
ProBuild Tech

PRODUCT BULLETIN CONT.

<u>PHYSICAL PROPERTIES (Cast Bar)</u>	<u>FAST</u>	<u>MEDIUM</u>	<u>SLOW</u>	<u>TROPICAL</u>
Tensile Strength (ASTM D-638.94b).....	7,643 psi	6,631 psi	8,543 psi	8,954 psi
Tensile Elongation (ASTM D-638.94b)	1.74%	1.34%	1.98%	1.73%
Tensile Strength* (ASTM D-638.94b)	33,171 psi	30,269 psi	31,910 psi	25,900 psi
Flexural Strength (ASTM D-790.92)	12,876 psi	10,422 psi	10,330 psi	12,820 psi
Flexural Strength* (ASTM D-790.92)	20,936 psi	34,896 psi	30,690 psi	26,070 psi
Flexural Modules (ASTM D-790.92)	520,500 psi	523,500 psi	529,500 psi	542,900 psi
Compressive Strength (ASTM D-695.91)	17,761 psi	17,789 psi	17,461 psi	14,660 psi
Impact Strength (ASTM D-256.93a)	6.86 in-lbf/in	4.25 in-lbf/in	4.45 in-lbf/in	8.76 in-lbf/in
Heat Deflection Temp (ASTM D-648.82).....	54°C/129°F	49°C/121°F	47°C/118°F	46°C/115°F
Ultimate Tg by DSC (cured 12 hours @ 75°C)	na	na	86.8°C/188°F	na
Moisture Absorption (ASTM D-570.81).....	0.36%	0.38%	0.37%	0.31%

(*)Denotes testing conducted on a 6 ply/10oz laminate



SPHERES



Measuring Devices

Interface Load Cell 5K lb Data Sheet

SPECIFICATIONS

PARAMETERS	MODEL		
	1111	1111	1121
	CAPACITY		
U.S. Models (lbf)	1K, 2K	5K, 10K	25K, 50K
Metric Models (kN)	5, 10	25, 50	100, 250
ACCURACY – (MAX ERROR)			
Static Error Band-% FS	±0.02	±0.03	±0.03
Nonlinearity-% FS	±0.03	±0.04	±0.04
Hysteresis-% FS	±0.02	±0.04	±0.04
Nonrepeatability-% RO	±0.01	±0.01	±0.01
Creep, in 20 min-%	±0.025	±0.025	±0.025
Side Load Sensitivity-%	±0.1	±0.1	±0.1
Eccentric Load Sensitivity-%/in	±0.1	±0.1	±0.1
TEMPERATURE			
Compensated Range-°F	15 to 115	15 to 115	15 to 115
Compensated Range-°C	-10 to 45	-10 to 45	-10 to 45
Operating Range-°F	-65 to 200	-65 to 200	-65 to 200
Operating Range-°C	-55 to 90	-55 to 90	-55 to 90
Effect on Zero-%RO/°F – MAX	±0.0004	±0.0004	±0.0004
Effect on Zero-%RO/°C – MAX	±0.0007	±0.0007	±0.0007
Effect on Output-%/°F – MAX	±0.0008	±0.0008	±0.0008
Effect on Output-%/°C – MAX	±0.0015	±0.0015	±0.0015
ELECTRICAL			
Rated Output-mV/V (Nominal)	2.0	4.0	4.0
Excitation Voltage-VDC MAX	20	20	20
Bridge Resistance-Ohm (Nominal)	350	350	350
Zero Balance-% RO	±1.0	±1.0	±1.0
Insulation Resistance-Megohm	5000	5000	5000



SPHERES



MECHANICAL			
Safe Overload-% CAP	±150	±150	±150
Deflection @ RO-inch	0.002	0.004	0.004
Deflection @ RO-mm	0.05	0.10	0.10
Base Part Number (Ref)	B101	B102	B103
Natural Frequency-kHz	4.5, 6.4	4.3, 6.1	4.1, 4.6
Weight-lb	3.3	7.3	21.5
Weight-kg	1.5	3.3	9.8
Connector	PC04E-10-6P	PC04E-10-6P	PC04E-10-6P
Calibration	Compression	Compression	Compression



LOAD CELL CALIBRATION CERTIFICATION

CONDITION: FINAL
 MODEL: 1110AF-5K SERIAL: 468166 BRIDGE: A CAPACITY: 5 Kibf
 PROCEDURE: C-1257 Mounting Per Interface Installation Instruction 15-5

INPUT RESISTANCE: 350.5 Ohm OUTPUT RESISTANCE: 350.4 Ohm
 ZERO BALANCE: 0.265 %RO

TEST CONDITIONS

TEMPERATURE: 74 °F HUMIDITY: 33% EXCITATION: 10 VDC

TRACEABILITY

FORCE STANDARD: STD-22 NIST #: 681/281224-11 DUE: 15-SEP-2015
 STANDARD INDICATOR: BRD106 NIST #: 656414
 TEST INDICATOR: BRD300 NIST #: 656414

SHUNT CALIBRATION

	Shunt (+/- .01%)	Output	Straight Line Conversion	Connections*
TENSION	30.0 KOhm	2.90143 mV/V	3.5206 Kibf	-Out to -Exc
COMPRESSION	30.0 KOhm	-2.90223 mV/V	3.5203 Kibf	-Out to +Exc

*For models wired with +Sense, - Sense or -S-Cal leads, resistor connections are actually to these leads in place of +Exc, -Exc or -Out respectively.

8.2412 E-7

PERFORMANCE

	Rated Output	SEB Output	Nonlinearity	Hysteresis	SEB
TENSION	4.12036 mV/V	4.12065 mV/V	-0.009 %FS	0.024 %FS	±0.012 %FS
COMPRESSION	-4.12299 mV/V	-4.12218 mV/V	-0.028 %FS	0.031 %FS	±0.020 %FS

STATIC ERROR BAND (SEB) The band of maximum deviations of the ascending and descending calibration points from a best fit straight line through zero OUTPUT. It includes the effects of NONLINEARITY, HYSTERESIS, and nonreturn to MINIMUM LOAD.

Organization SPHERES National Lab	Title/Subject ULTEM 9085 Testing	Number SPH-04-XS-100	Date June 17, 2015	Page 146
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SPHERES



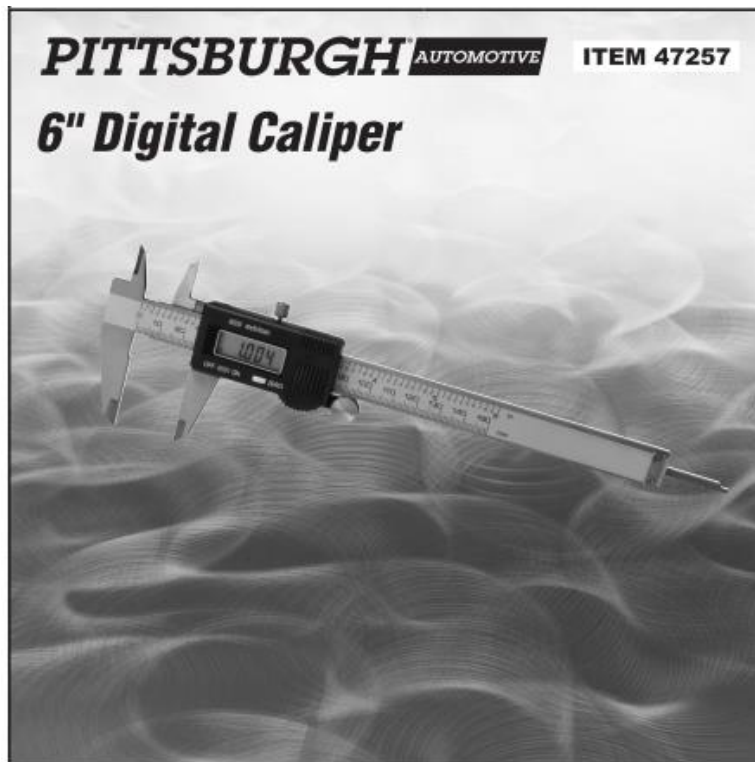
TEST LOAD APPLIED (Klbf)	RECORDED READINGS (mV/V)	
	Tension	Compression
0	.00000	.00000
1	.82382	-.82385
2	1.64776	-1.64806
3	2.47191	-2.47277
4	3.29616	-3.29772
5	4.12036	-4.12299
2	1.64876	-1.64933
0	.00010	-.00008

Interface Inc. certifies that all calibration measurements are traceable to NIST. Estimated uncertainty of measurements is 0.040% RDG. Results relate to serial 468166 only.
DO NOT REPRODUCE THIS REPORT except in full or with Interface Inc. written approval.

TECHNICIAN :  Benjamin O'Ram

CALIBRATION DATE : 05-JUN-2013

Harbor Freight 6" Digital Caliper



	<h1>SPHERES</h1>	
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Description

PITTSBURGH

This digital caliper's stainless steel construction allows you to get metric or SAE decimal readings even in harsh conditions. The easy-to-read digital display allows you to measure and convert from SAE to metric quickly and easily. Features include an automatic shut-off and a storage case for easy transport. This digital caliper is ideal for getting exact measurements of width and thickness of your project!

- Use for inside, outside, depth and step measurements
- Accurately measure within +/- 0.001 in. or 0.03mm
- Measures up to 6 in.
- Jaw depth: 1-9/16 in. (outside jaws) / 11/16 in. (inside jaws)
- Large high resolution LCD display
- Smooth stainless steel construction



SPHERES



Specifications

Name	6 in. Digital Caliper
SKU	47257
Brand	Pittsburgh
Accuracy	+/- 0.001 in. or 0.03mm
Battery type	Silver oxide
Battery(s) Included (y/n)	Yes
Material	Steel
Quantity	1
Range (in./mm)	0-6 in., 0-150mm
Resolution (in.)	0.0005 in.
SAE or Metric	SAE & Metric
Battery size	SR44
Shipping Weight	0.73 lb.
Size(s)	6 in.
Throat depth (in.)	1-9/16 in. (outside jaws) / 11/16 in. (inside jaws)
Accessories Included	batteries and storage case
Warranty	90 Day
Available Only on Web	No



SPHERES



Shadograph



Figure C1: The Shadograph



Figure C2: Calibration information for the shadograph

Capacity	75 lbs
Readability	0.01 lb

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