SPH-04-XS-100

# 3-D Printed Ultem 9085 Testing and Analysis

June 17, 2015

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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 ($CO_2$) 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 Slosh during the unpacking inspection aboard the ISS. Several components of the Slosh 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 Slosh 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.

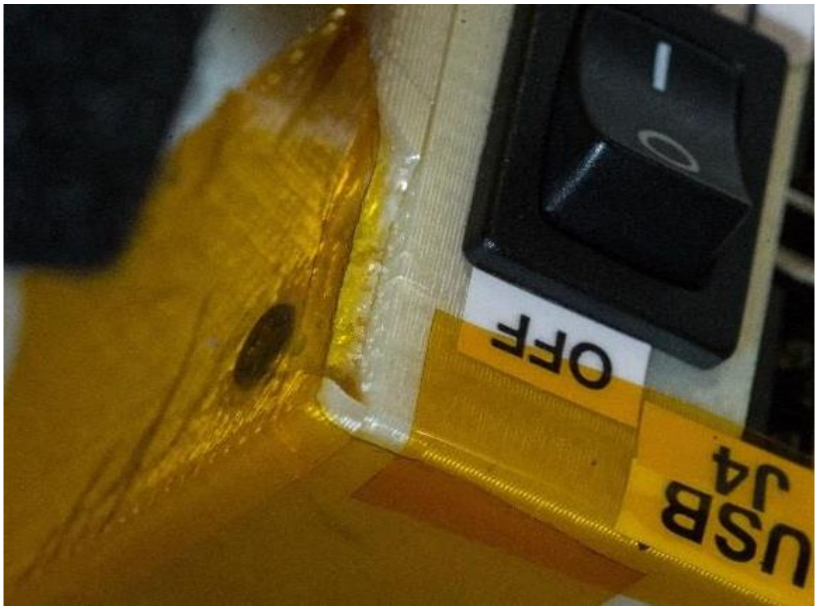


*Figure 1: Image of the broken 3-D printed part onboard the ISS*
**Image property of NASA SPHERES*


*Figure 2: Images of the countersunk screw hole **

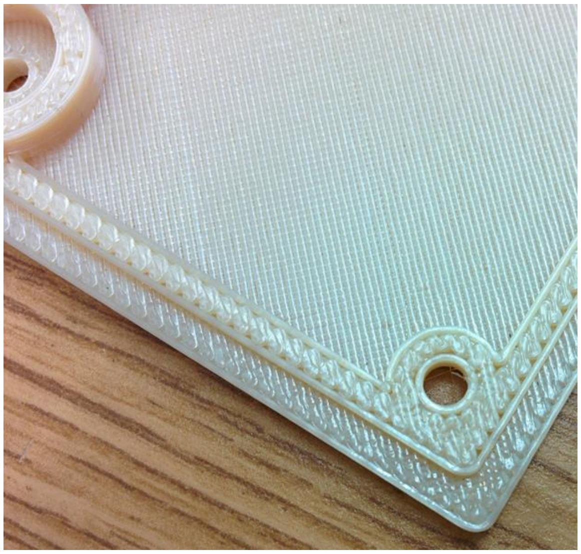


*Figure 3: Images of the countersunk screw hole **

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.

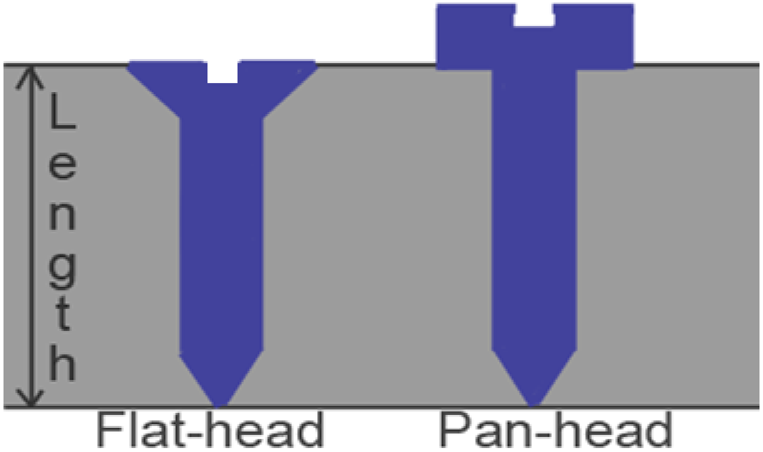



*Figure 4: Countersunk flat-head versus pan-head*

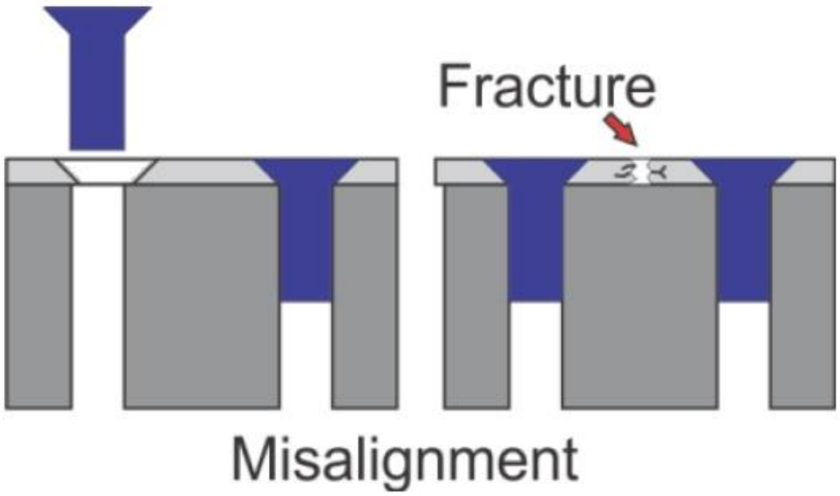



*Figure 5: Countersunk flat-head out of alignment causing fracture*

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.

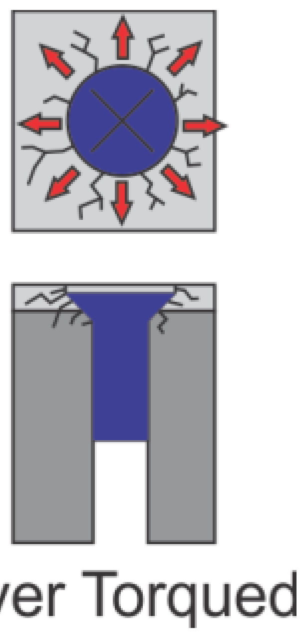



*Figure 6: Illustration of a countersunk screw radiating force outwards if over torqued.*

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 Slosh 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.

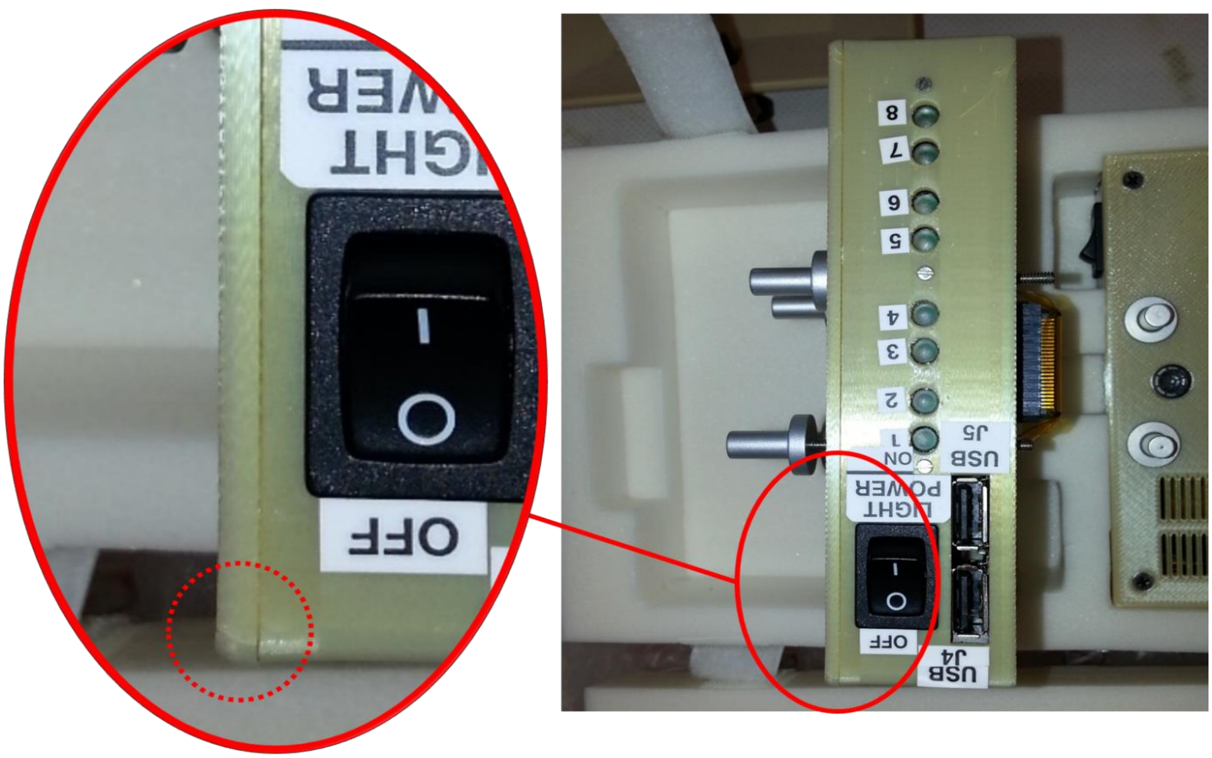


*Figure 7: Photograph taken of Slosh box S/N 002 during packing for launch **

A final possible contributing factor to the damage of the Ultem 9085 on the Slosh hardware was the CAD to CAM process used. After contacting the company responsible for the production of the Slosh 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.

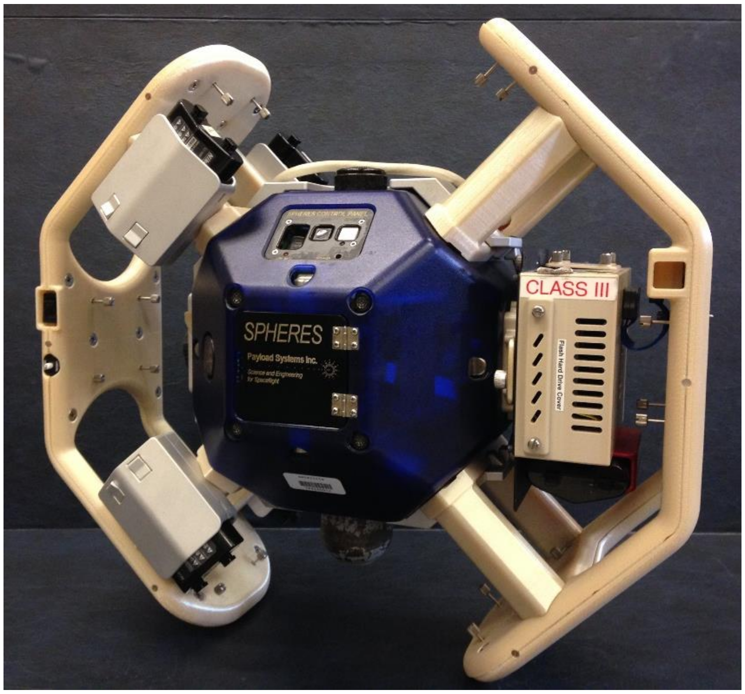



*Figure 8: The image above shows Halo's large 3-D printed parts in tan **

*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.

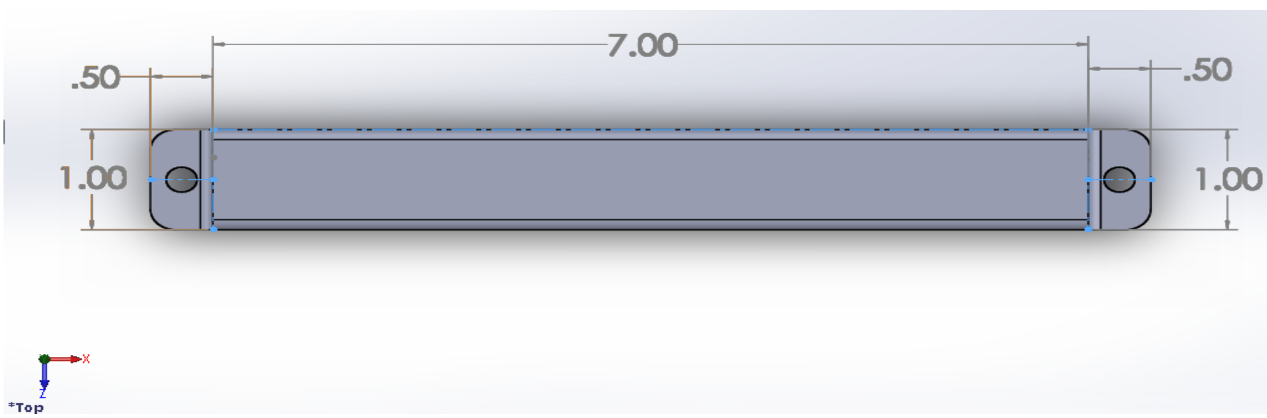



*Figure 10: Top view of the Ultem bar (dimensions in inches)*

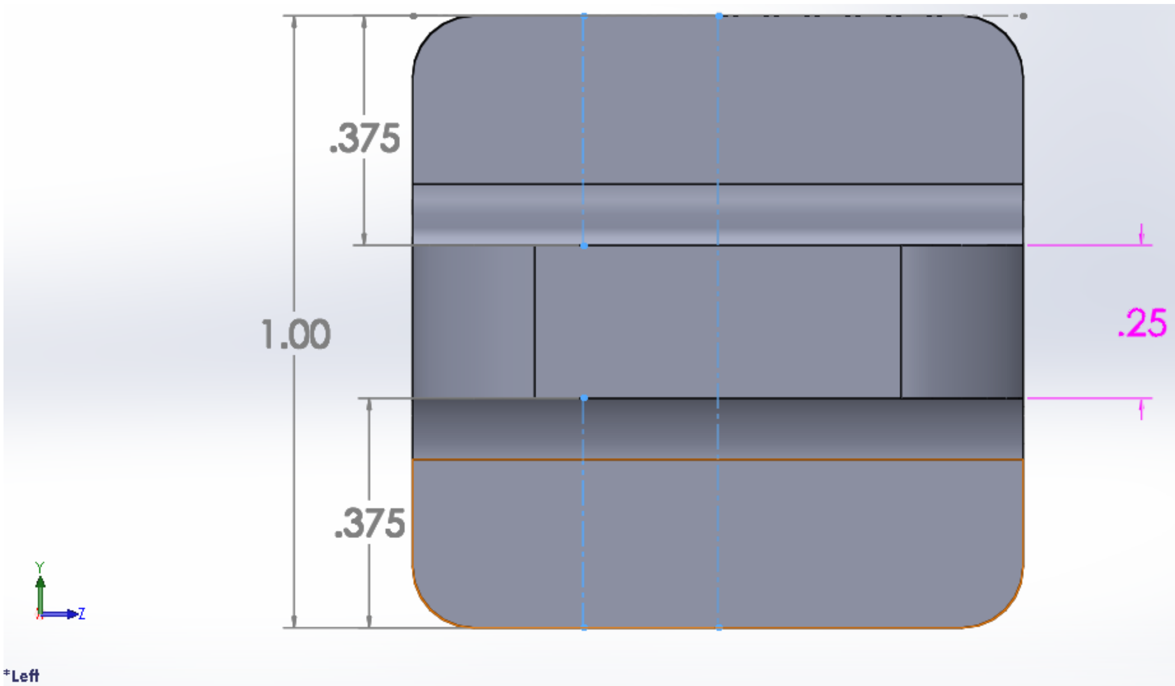
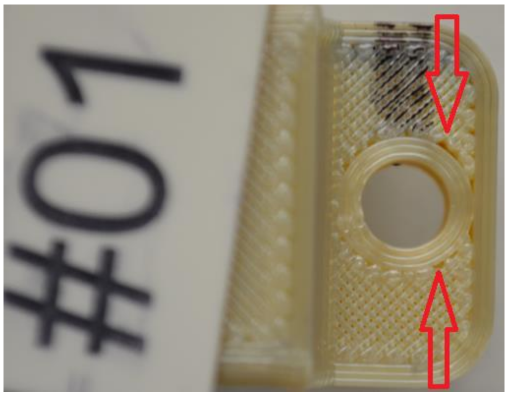
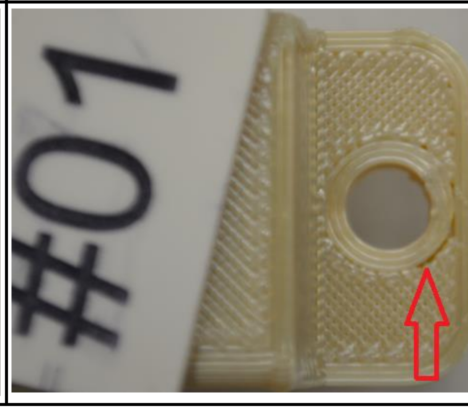



*Figure 11: Image showing cross section of the Ultem 9085 bar (dimensions in inches)*

## 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 |

| | |
|---|---|
| | 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.

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

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 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 |

* The test procedure used can be found in Appendix A.

## 2.6 Performance Comparison of Applicants

### 2.6.1 Change in Mass

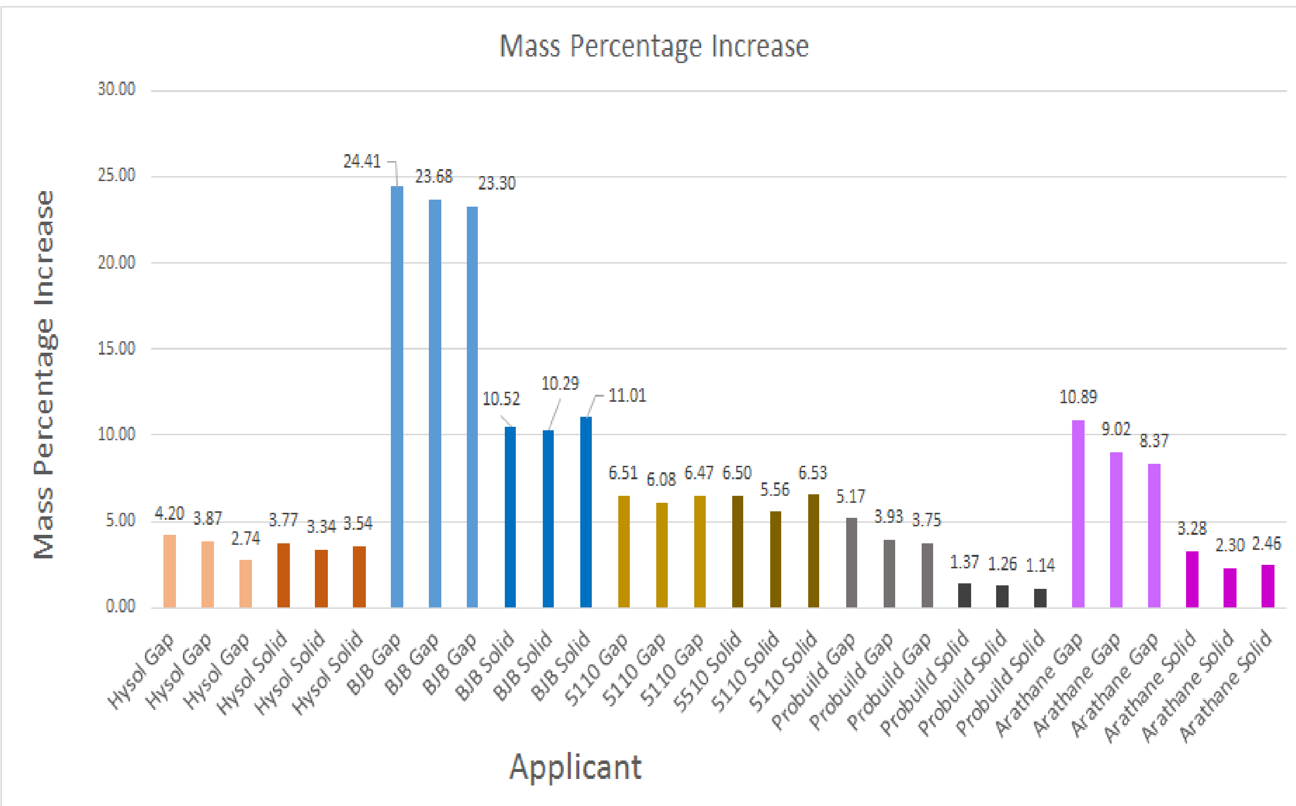



*Figure 13: Change in mass of each Ultem bar as a percentage of its original mass*

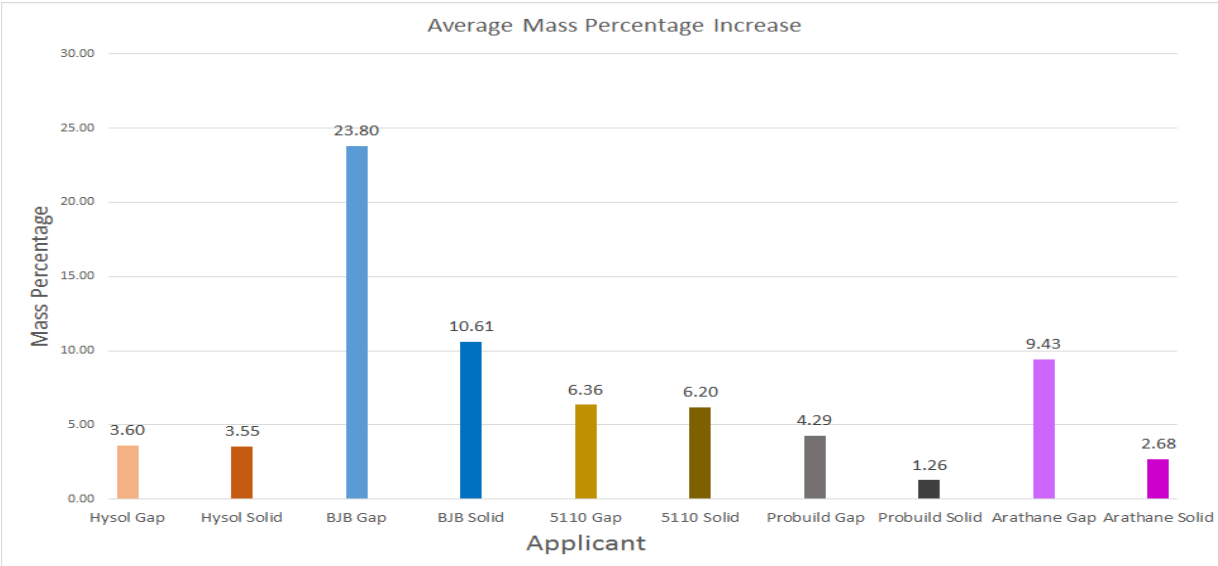



*Figure 14: Average mass change of the Ultem samples post application*

### 2.6.2 Change in Dimension

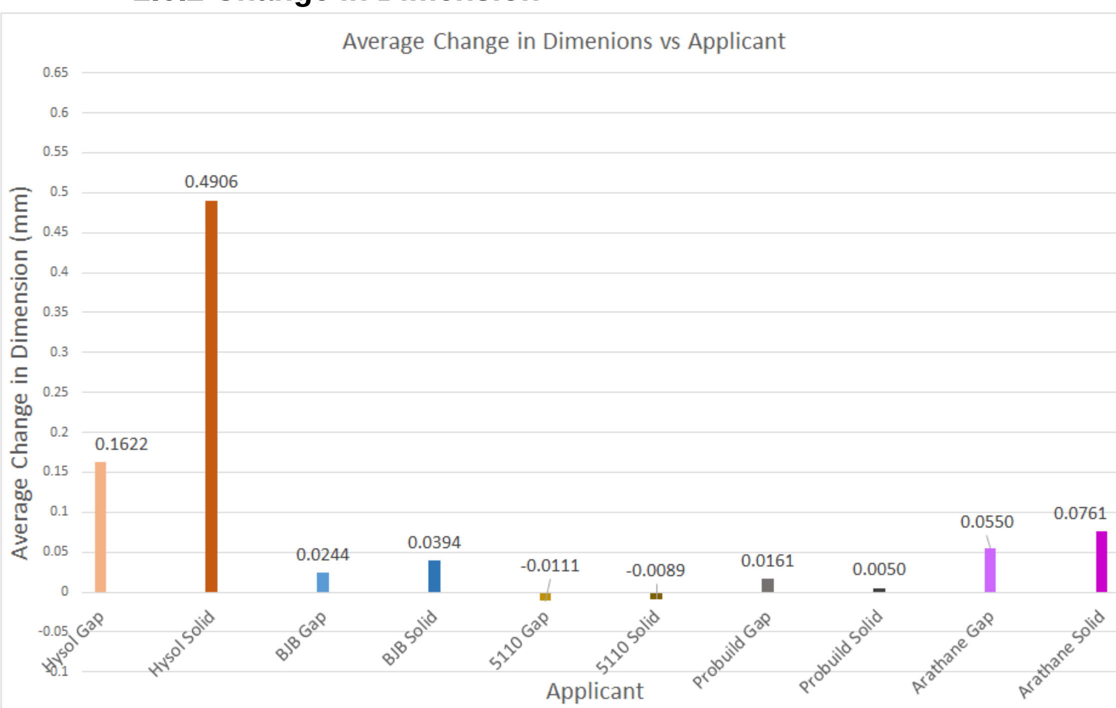



*Figure 15: Average dimensional change of the Ultem samples post application*

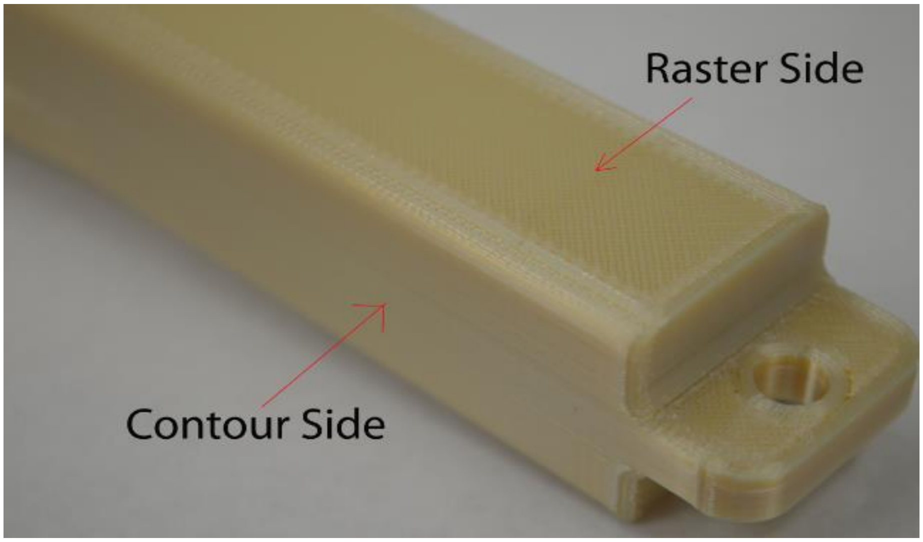



*Figure 16: The top/bottom of the Ultem bars are rastered and the sides are contoured **

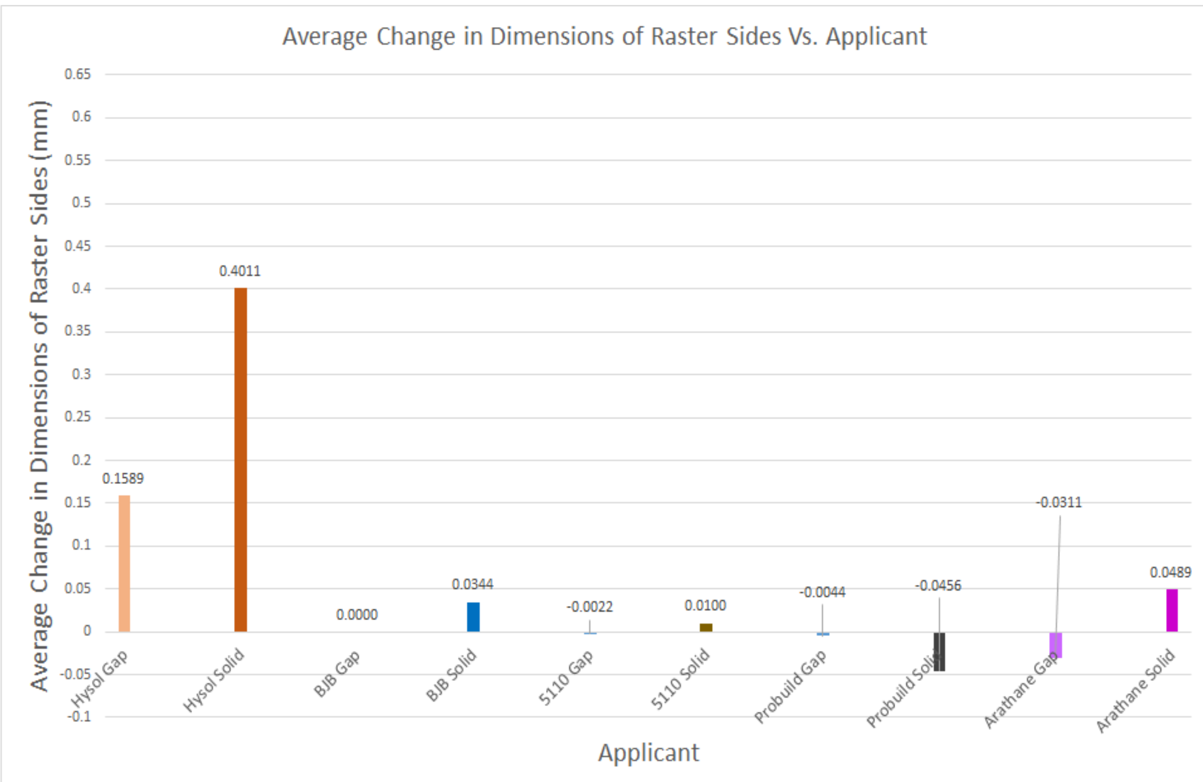



*Figure 17: Average change in dimension of the raster sides*

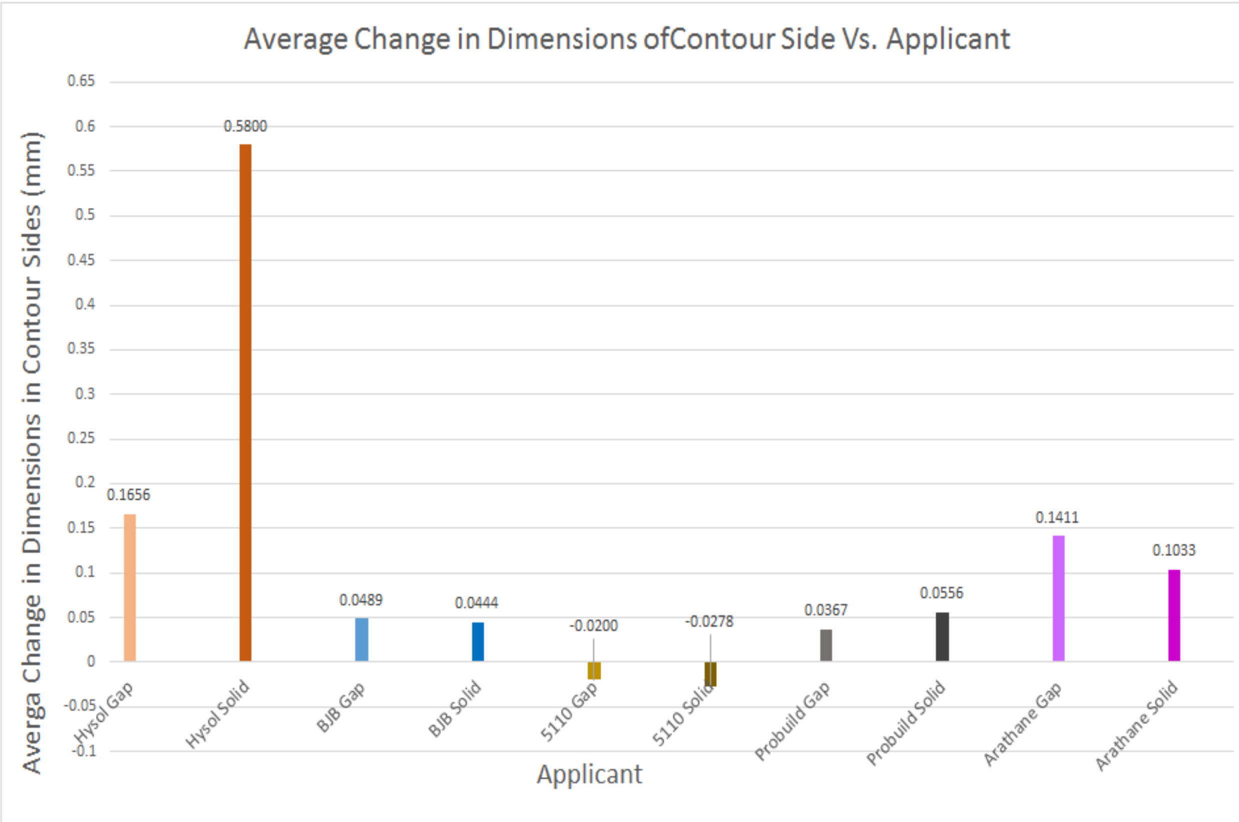



*Figure 18: Average change in dimension of the contour sides*
*Note: Dimensions were measured with the calipers found in Appendix C*

### 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.

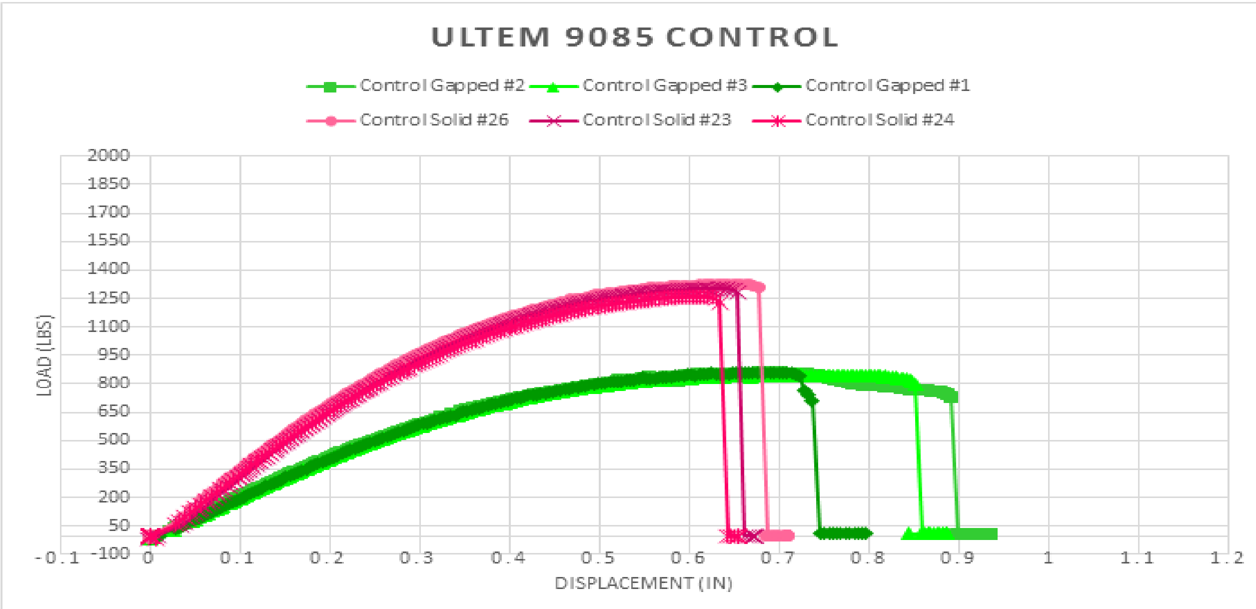



*Figure 19: Displacement vs load of six Ultem 9085 samples (3 solid & 3 gapped)*

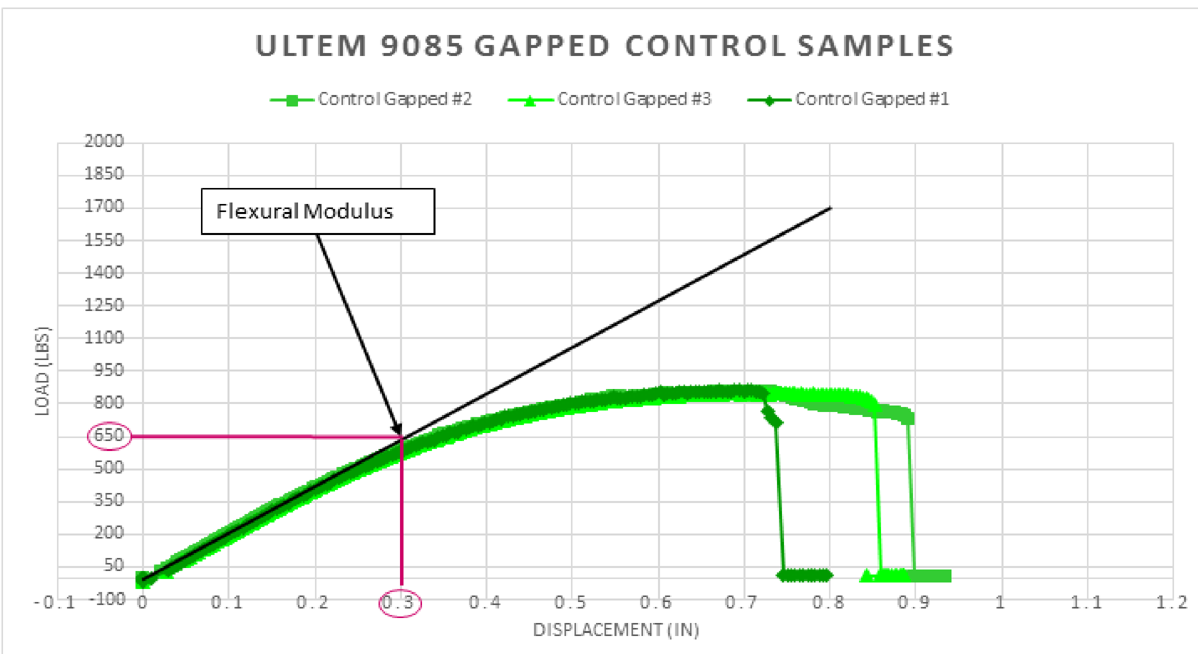



*Figure 20: Average Flexural Modulus of the gapped samples*

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

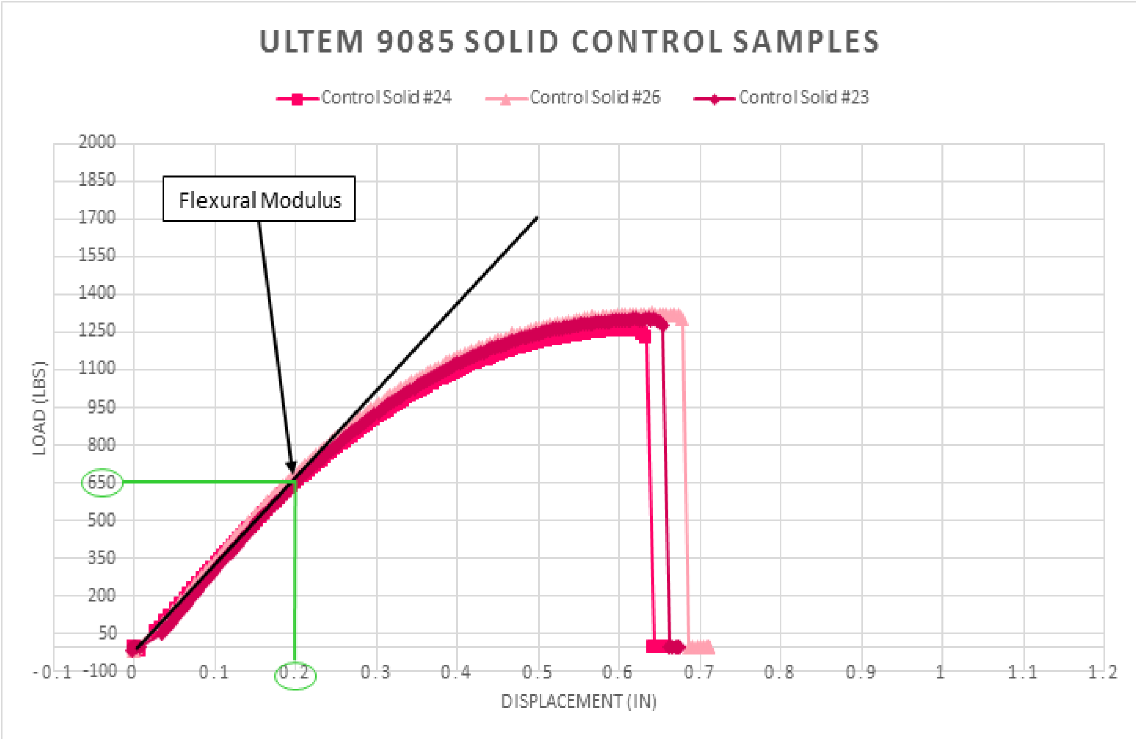



*Figure 21: Average Flexural Modulus of the solid samples*

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

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

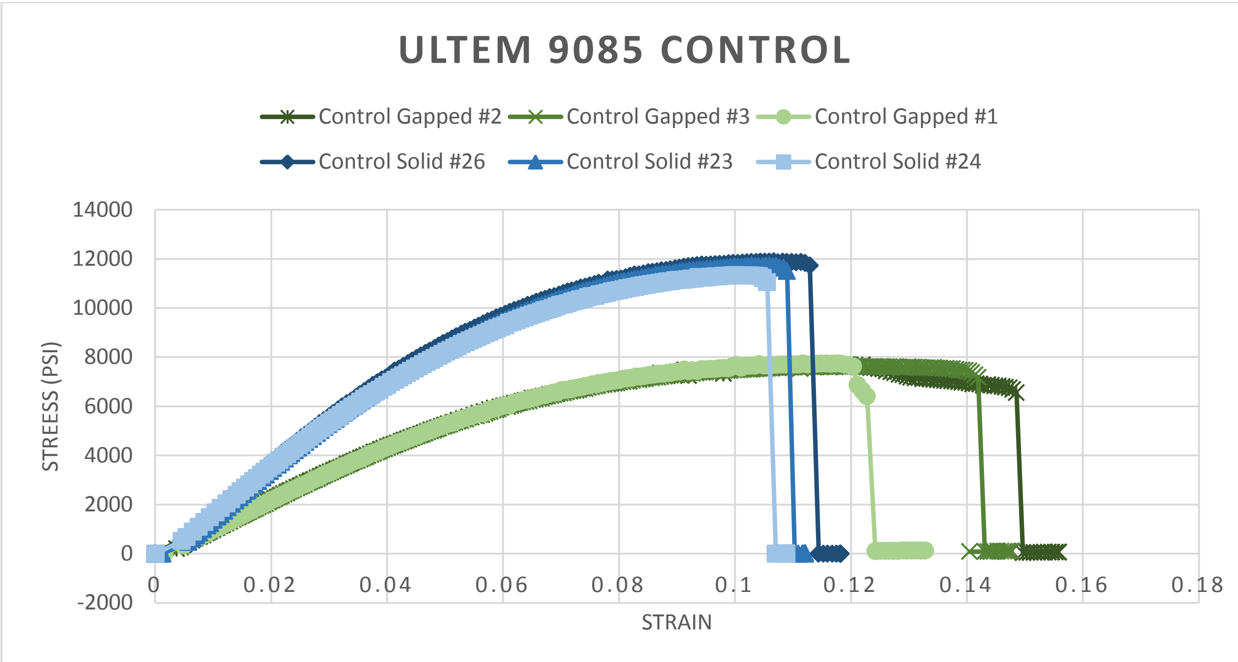



*Figure 22: Stress vs. Strain of six Ultem 9085 samples (3 solid & 3 gapped)*

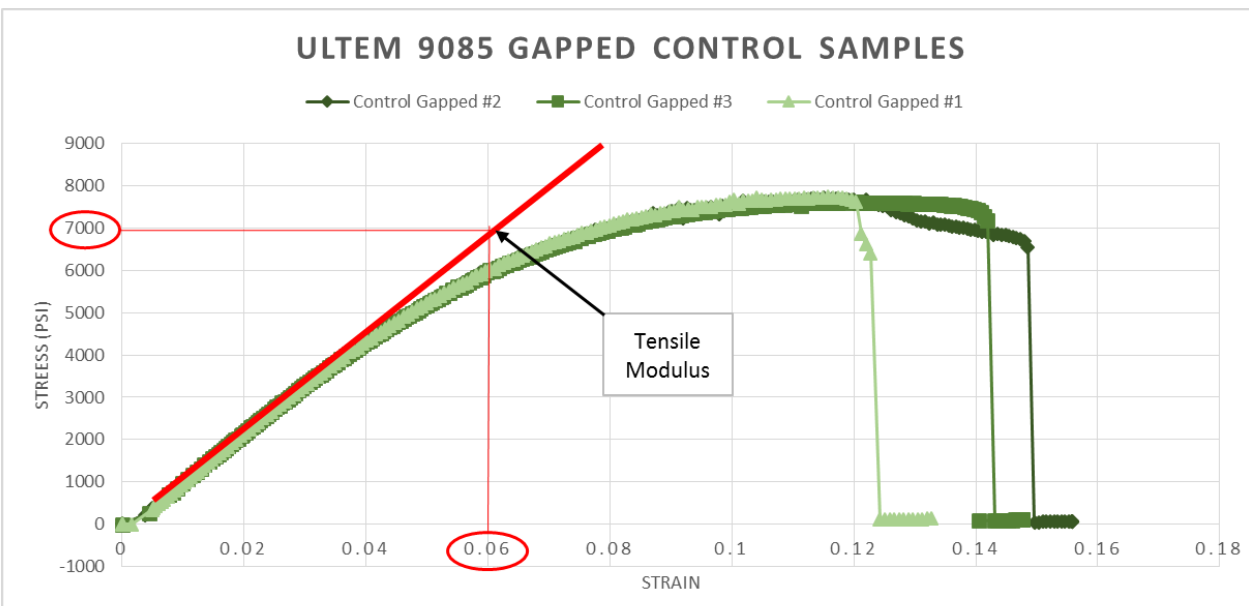



*Figure 23: Average Tensile Modulus of the gapped samples*

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

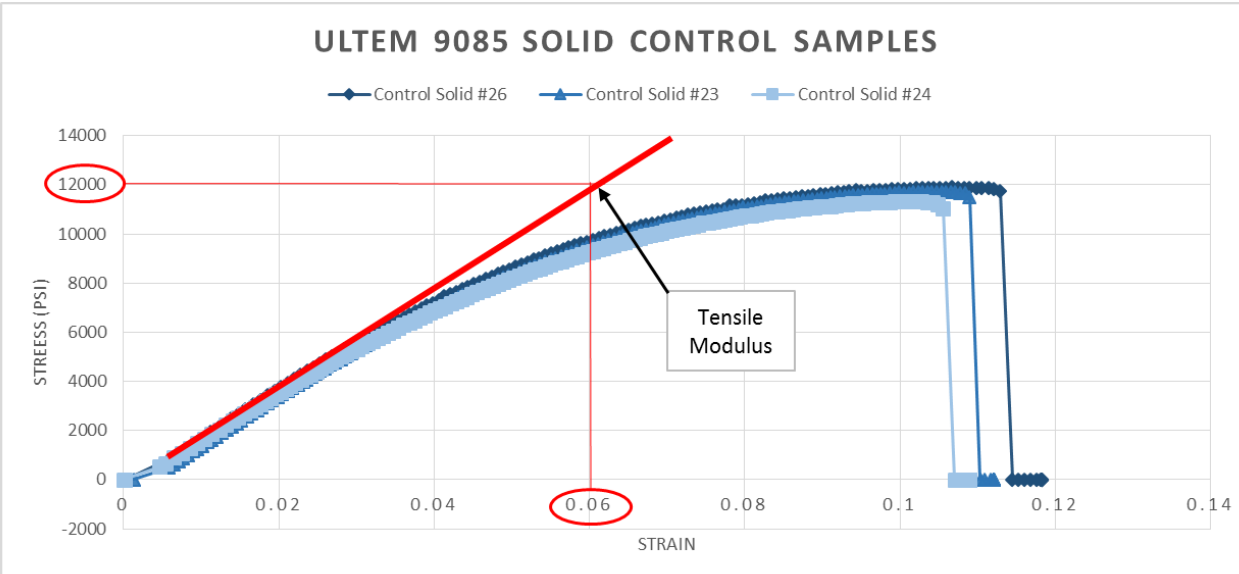
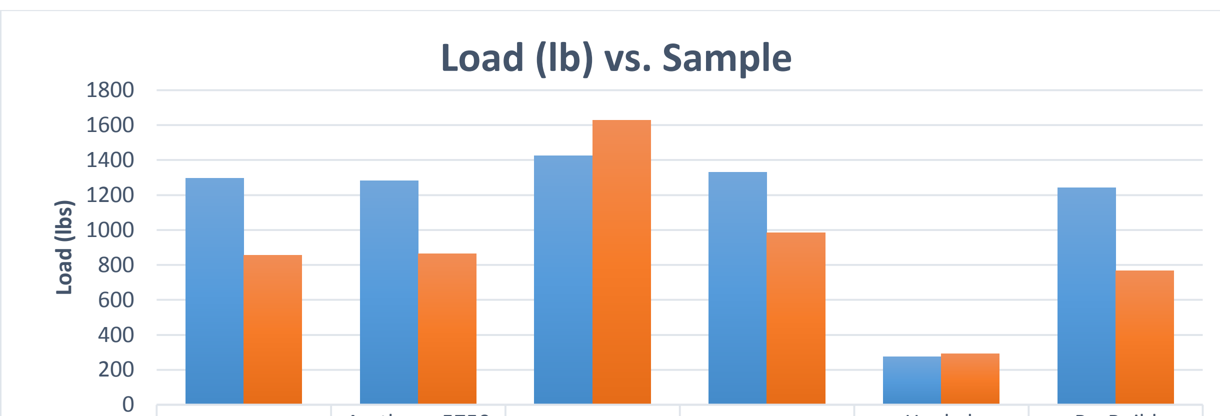



*Figure 24: Average Tensile Modulus of the solid samples*

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

* See Appendix C for the Stratasys and Sabic data sheets.




| | Control | Arathane 5750 AB | BJB TC-1614 | Hysol E-20HP | Henkel Locktite 5110 | ProBuild Marine Epoxy |
|---|---|---|---|---|---|---|
| Solid | 1294.482 | 1281.471 | 1424.491 | 1330.504 | 273.156 | 1240.839 |
| Gapped | 855.441 | 864.038 | 1628.122 | 984.352 | 292.062 | 766.667 |

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

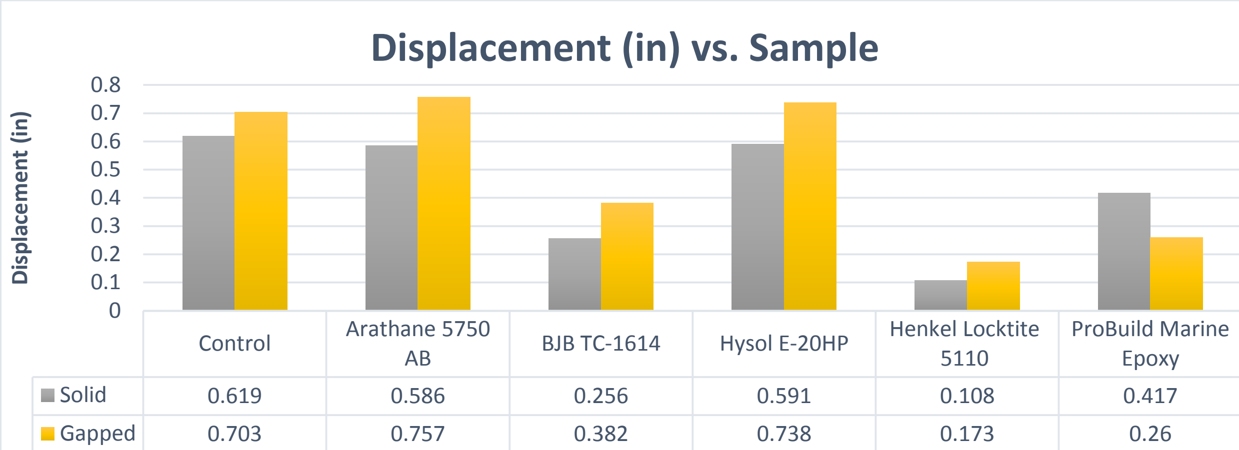



*Figure 26: Average displacement for gapped and solid samples of each applicant*

*Table 8: Comparison of the Flexural modulus from various resources*

| Data Type | Flexural Modulus (kpsi) | Tensile Modulus (kpsi) | Notes |
|---|---|---|---|
| Sabic | 423.0 | 498.0 | (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**.<br>(2) Only typical data for selection purposes. Not to be used for part or tool design.<br>(3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.<br>(4) Internal measurements according to UL standards.<br>(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.<br>(6) Needs hard coat to consistently pass 60 sec Vertical Burn. |
| Stratasys | 362.6 | 322.0 | **ASTM D790**<br>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 |

| | | | |
|---|---|---|---|
| | | | 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 |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 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

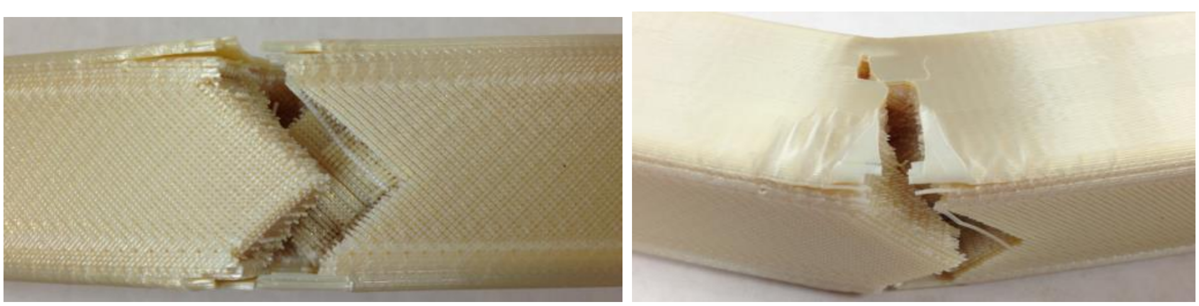


*Figure 27: Gapped control sample post break **

# 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 system load standards described in the table below. The 3-D printed part was subjected to loading for 30 seconds, during which it was be 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 |
|---|---|---|---|
| Levers, 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 the 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.

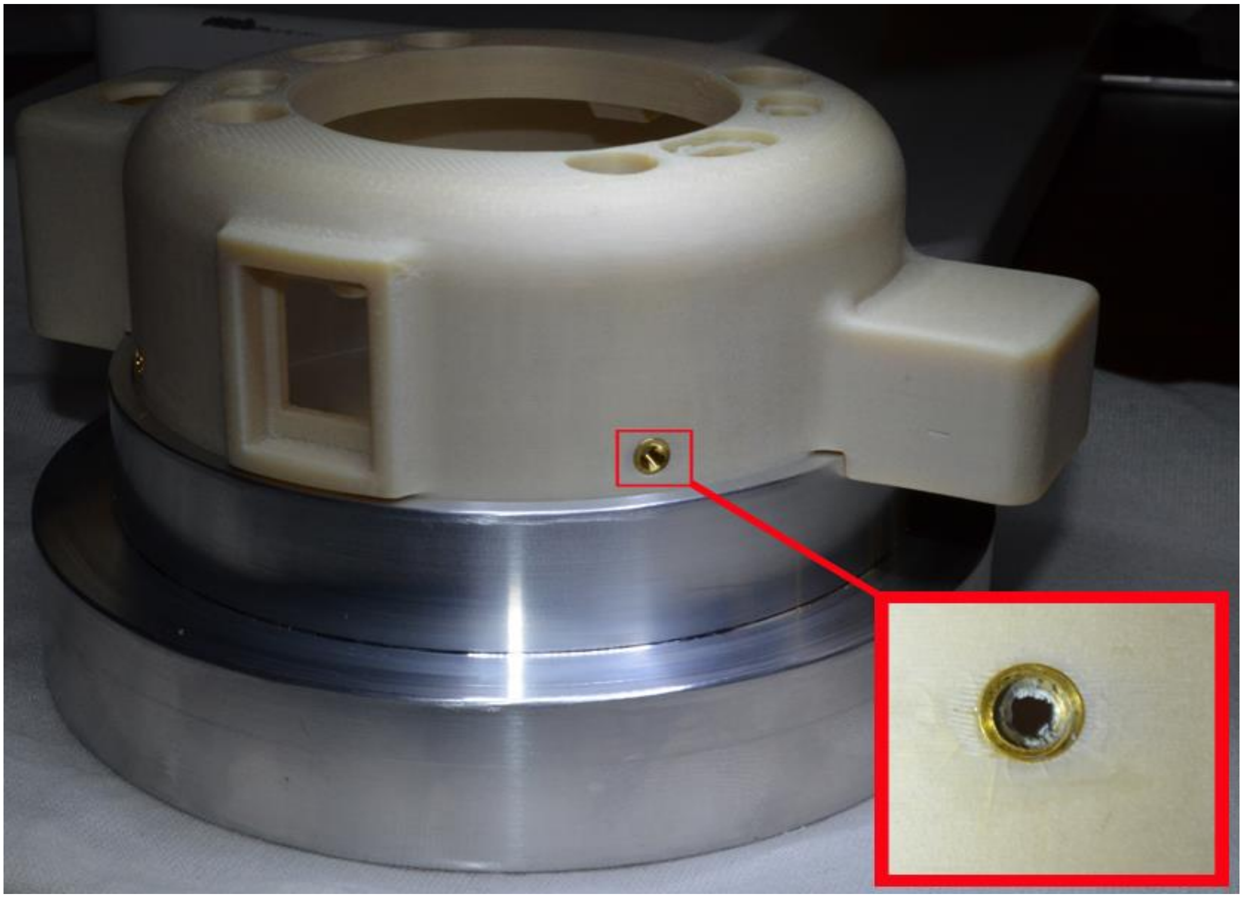


*Figure 28: Radial cracks around the threaded insert **

## 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

SPHERES

**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~~ BJB #2 ~~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 | | 47 | | 22 |
| | | 48 | | 25 |
| | | 49 | | 31 |
| | | | | 36 |

| Organization | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Sample Impregnation Key | SPH-ULT-MT002 | April 15, 2013 |

## Pre-Application dimension tables

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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: |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 25.50 | 25.49 | 25.38 | 25,49 | 25.37 | 113.75 | Gapped | | |
| 12 | 25,50 | 25.43 | 25,51 | 25.41 | 25.48 | 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 | 111.97 | 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 | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | 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: [signature] Date: 04/11/2014

| Organization | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | 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 | 25.43 | 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 | 25.39 | 25.51 | 25.36 | 25.51 | 25.38 | 132.66 | Solid | | |
| 31 | 25.53 | 25.29 | 25.54 | 25.27 | 25.54 | 25.31 | 113.73 | Gapped | | |
| 32 | 25.47 | 25.36 | 25.51 | 25.36 | 25.55 | 25.44 | 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 | 25.49 | 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 | 25.49 | 25.42 | 133.25 | Solid | | |
| 40 | 25.50 | 25.43 | 25.50 | 25.41 | 25.48 | 25.43 | 132.28 | Solid | | |

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

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## Ultem 9085 Pre-Application Data Log

Technician Full Name: Darryl LaVasseur Technician Initial: [illegible] 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: [illegible] Date: 04/11/2014


| Organization | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | 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 | 25.45 | 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 | 131.47 | Solid | | |
| 48 | 25.49 | 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 | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | April 11, 2013 |

SPHERES

**Ultem 9085 Pre-Application Data Log**

Technician Full Name: Darryl LeVasseur Technician Initial: [illegible] 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: [illegible] Date: 04|11|2014



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

## 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

SPHERES

Written by:

3/25/2014

Daniel Andres Aguilar Martel
Aerospace Engineering Student
San Jose State University

Date

3/25/2014

Sean David Christensen
Aerospace Engineering Student
San Jose State University

Date

3/25/2014

Emmet John Fox
Aerospace Engineering Student
San Jose State University

Date

Approved by:

3/25/2014

Darryl William LeVasseur
System Engineer II
Metis Technologies

Date

| Organization | Title/Subject | Number | Date | Page 1 |
|---|---|---|---|---|
| **SPHERES National Lab** | **Applications Procedures** | **SPH-ULT-MT001** | **March 25, 2013** | |

**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: @ 25ºC (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.**

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.

## BJB TC-1614

Applications: Dip, Vacuum, Cure in oven

Work Time: (100-gram mass) @ 77F (25°C) 2 hours

Cure Time: 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

Mix Ratio: By Weight: Part A: 100 parts
Part B: 20 parts
By Volume: Part A: 100 parts
Part B: 23 parts

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

Procedure:

1. 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).
2. 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.
3. Place a small 3D printed part into a plastic tub and fill with an appropriate amount of epoxy. A tub that is too large will require more volumetric amounts of epoxy. Fully submerge part.
4. Allow the part to soak in the epoxy for roughly 20-25 minutes. A recommended optional procedure would be to place tub 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.
5. Once part has soaked for allotted time, pull part out of tub and drain excess epoxy off of part.
6. Place part in vacuum for 5 - 10 minutes.
7. 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.
8. 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.
9. 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.

*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

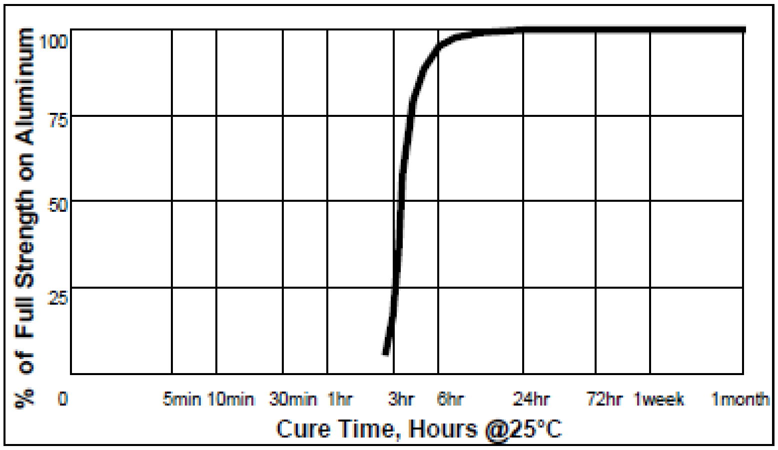
*Note: Porosity sealants typically require catalyzation and must be handled with chemically compatible materials and equipment.

### Hysol Loctite E-20HP

Applications: Brush, Cure in oven

Work Time: 20 minutes (@ 77F)

Cure Time: Varies by temperature




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 contaminates.
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.

## ProBuild Marine Epoxy

Applications: Brush, Vacuum, Cure in oven

Work Time: 50 minutes @ 77F

Cure Time: 24 hours

Mix Ratio: By weight: Resin: 100 parts
Hardener: 28 parts
By volume: Resin: 3 parts
Hardener: 1 part

Required Materials and Machinery: Brush, Vacuum, Oven, Hanging rack

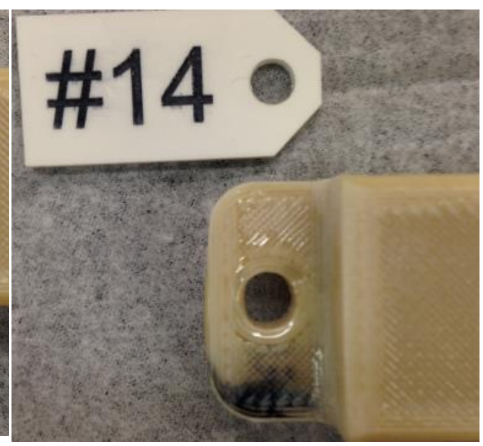
Procedure:

1. Mixing - Combine Part A and Part B in the correct ratio and mix thoroughly. THIS IS IMPORTANT! Heat buildup during or after mixing is normal. Do not mix quantities greater than 450 grams as dangerous heat buildup can occur causing uncontrolled decomposition of the mixed adhesive. TOXIC FUMES CAN OCCUR, RESULTING IN PERSONAL INJURY. Mixing smaller quantities will minimize the heat buildup.
2. Brush on a .020" - .030" layer of Epoxy Surface Coat that is properly catalyze and thoroughly mixed. Allow to tack.
   a. Customer preference may be to apply a single surface coat layer of .060", however applying a single coating at this thickness could result in pinholes on the surface of the mold.
   b. Tack refers to a curing phase of the resin as follows; the resin will not stick to your finger when touched, but is soft enough to leave a fingerprint.
3. Allow to cure

### Post Application

1. Re-weigh each piece and record the results into the Post-Application log.
2. Re-measure the dimensions of each piece using calipers at 3 points (left, middle, right) and record the results into the Post-Application log.
3. Inspect and note each piece with characteristics of the applied material if noteworthy.
4. Photograph each specimen.

## Post-Application Processing

| Applicant | Pre-Process | Post-Process |
|---|---|---|
| **BJB** |  |  |
| **BJB** |  |  |

| | | |
|---|---|---|
| **BJB** |  |  |
| **BJB** |  |  |

# Post-Application Dimension Tables

SPHERES

### 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 | 25.34 | 25.49 | 25.32 | | 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 | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | June 5, 2013 |

SPHERES

### Ultem 9085 Post-Application Data Log

Technician Full Name: Daniel Aguilar Technician Initial: D.A 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 | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | June 5, 2013 |

SPHERES

## 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. |



SPHERES

## 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

SPHERES

### 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 | 25.35 | 25.51 | 25.35 | 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 | Title/Subject | Number | Date |
|---|---|---|---|
| SPHERES National Lab | ULTEM 9085 Pre-Application Data Log | SPH-ULT-MT001 | June 5, 2013 |

SPHERES

### Ultem 9085 Post-Application Data Log

Technician Full Name: Emmet Fox Technician Initial: EF Date: 6/5/14

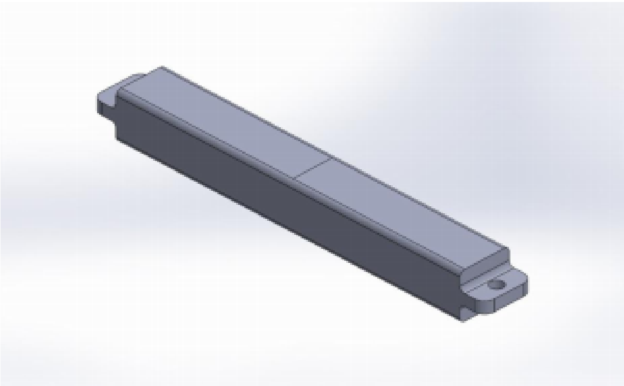
Technician Full Name: Daniel Aguilar Technician Initial: DA Date: 6/5/14

Technician Full Name: _____ Technician Initial: _____ Date: _____

Operations Engineer (OE) Full Name: Robert Hanson OE Initial: RH Date: 06/05/2014


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

# 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

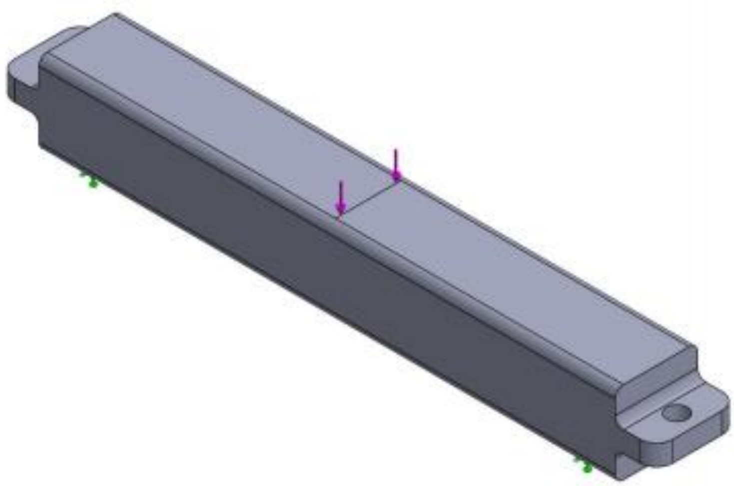
Description ........................................... 1
Assumptions ........................................... 2
Model Information ........................................... 2
Study Properties ........................................... 3
Units ........................................... 4
Material Properties ........................................... 4
Loads and Fixtures ........................................... 5
Connector Definitions**Error! Bookmark not defin**
Contact Information**Error! Bookmark not define**
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

## Assumptions

## Model Information



**Model name:** ultem stick
**Current Configuration:** Default

| Solid Bodies | | | |
|---|---|---|---|
| **Document Name and Reference** | **Treated As** | **Volumetric Properties** | **Document Path/Date Modified** |

| | | | |
|---|---|---|---|
| Split Line2  | Solid Body | Mass:0.346804 lb<br>Volume:7.16537 in^3<br>Density:0.0484 lb/in^3<br>Weight:0.346569 lbf | C:\Users\Gabriel\Desktop\Ultem Stuff\FW__3D_Print_NASA_Ames_Testing\ultem stick.SLDPRT<br>Jun 23 11:05:58 2014 |

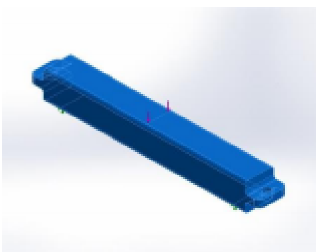
## Study Properties

| | |
|---|---|
| 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) |

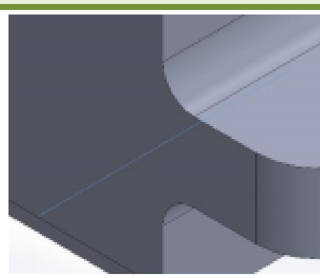
## Units

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

## Material Properties

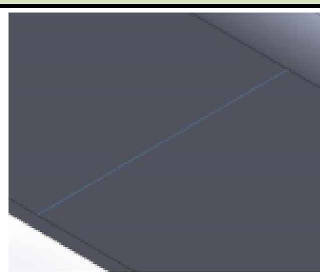
| Model Reference | Properties | Components |
|---|---|---|
|  | **Name:** Ultem Isotropic (6)<br>**Model type:** Linear Elastic Isotropic<br>**Default failure criterion:** Max von Mises Stress<br>**Yield strength:** 12700 psi<br>**Tensile strength:** 12700 psi<br>**Elastic modulus:** 104714 psi<br>**Poisson's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

## Loads and Fixtures

| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-2 |  | Entities: 1 edge(s)<br>Type: Fixed Geometry |

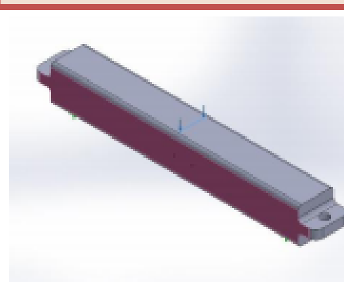
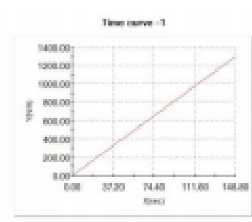
Resultant Forces

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Reaction force(lbf) | -1285.12 | 531.198 | 0.462297 | 1390.58 |
| Reaction Moment(lbf.in) | 0 | 0 | 0 | 0 |

| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-3 |  | Entities: 1 edge(s)<br>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 |

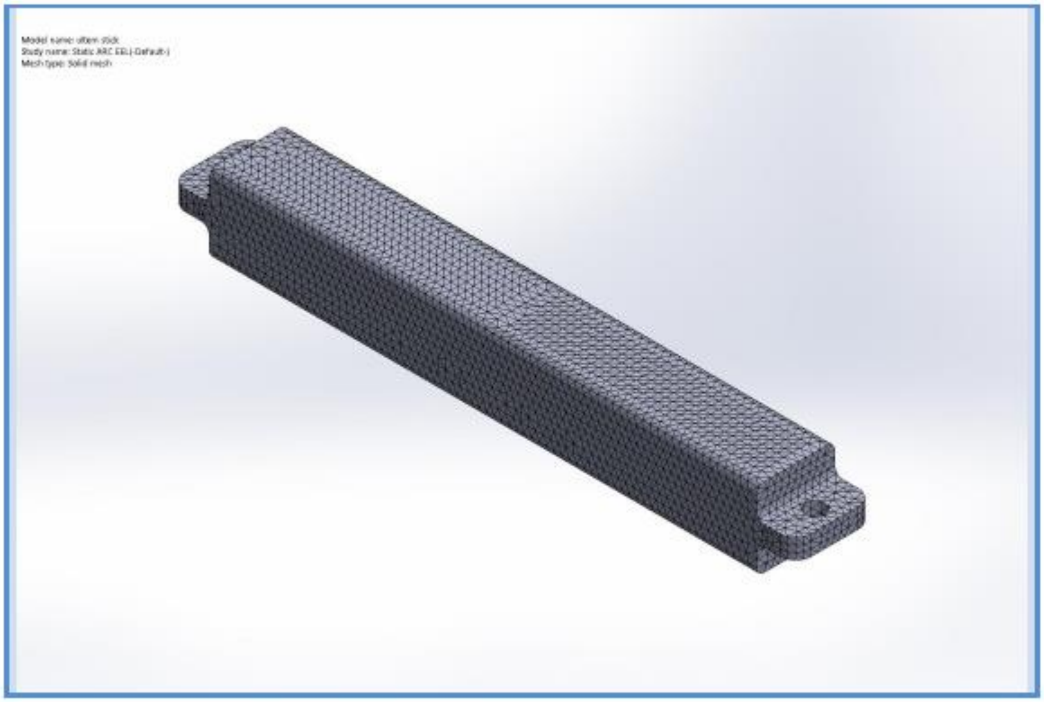
| Load name | Load Image | Load Details | Function Curve |
|---|---|---|---|
| Force-2 |  | Entities: 1 edge(s)<br>Reference: Face< 1 ><br>Type: Apply force<br>Values: ---, 1269.75, --- lbf<br>Phase Angle: 0<br>Units: deg | <br>Time curve -1 |

## 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 |




## Resultant Forces

### Reaction Forces

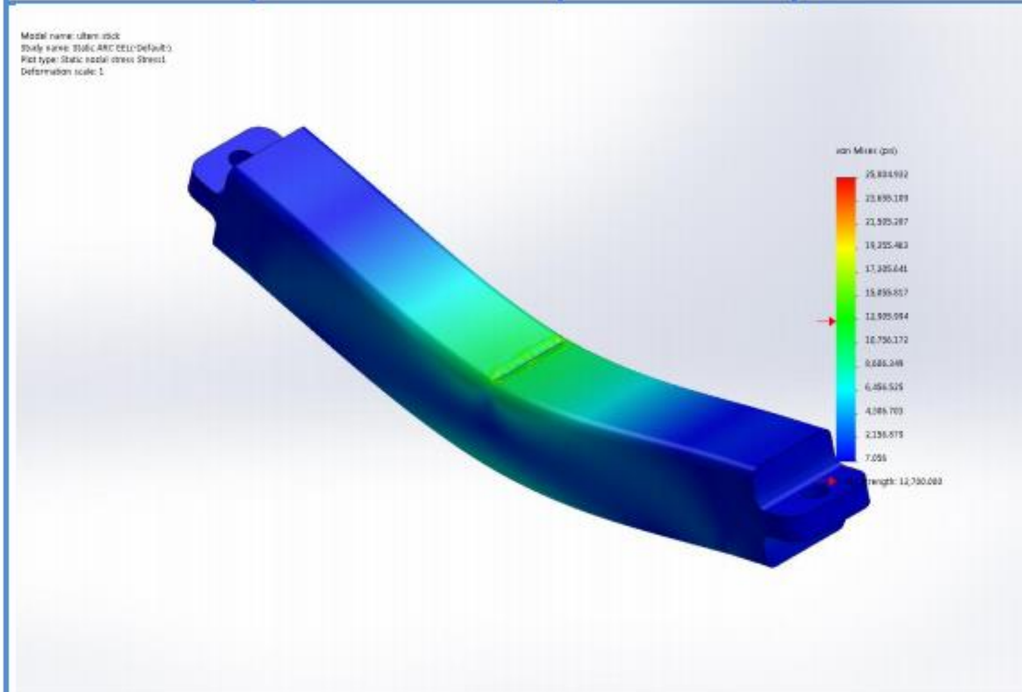
| Selection set | Units | Sum X | Sum Y | Sum Z | Resultant |
|---|---|---|---|---|---|
| Entire Model | lbf | 7.11572 | 1068.49 | 1.37153 | 1068.51 |

### Reaction Moments

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

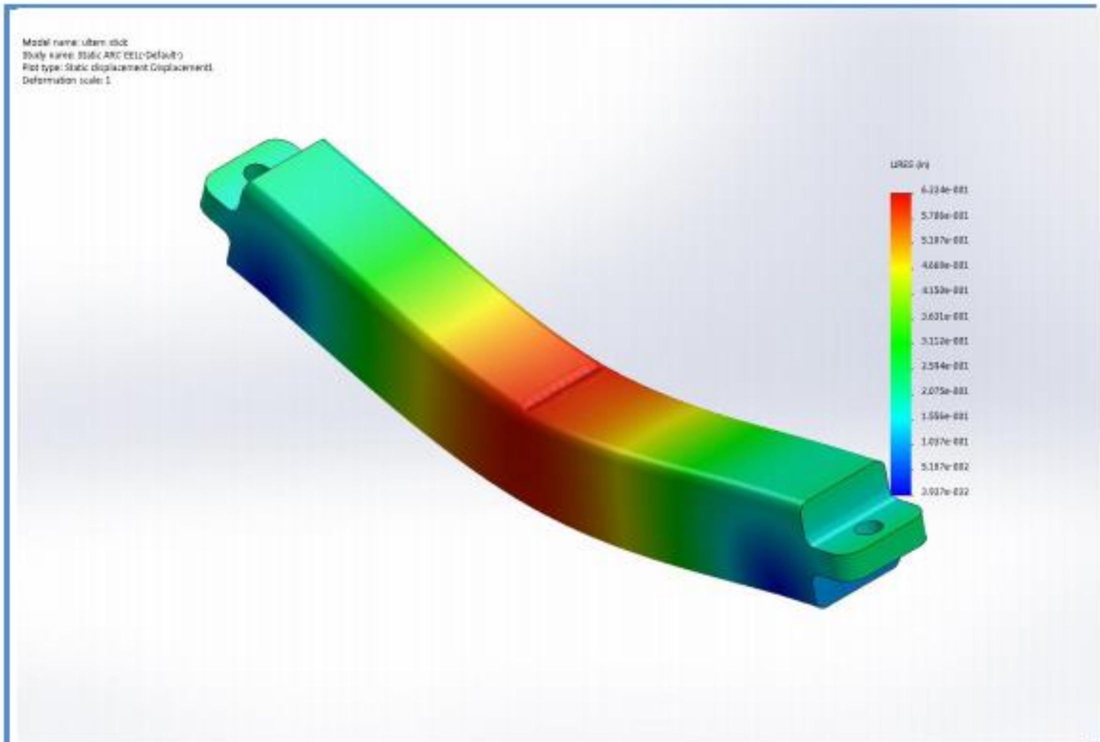
## Study Results

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 7.05646 psi<br>Node: 67663 | 25804.9 psi<br>Node: 70747 |




ultem stick-Static ARC EEL-Stress-Stress1

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 in<br>Node: 387 | 0.622447 in<br>Node: 95 |



ultem stick-Static ARC EEL-Displacement-Displacement1

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 0.000153842<br>Element: 6228 | 0.211564<br>Element: 9294 |

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

SPHERES

Written by:

6/10/2014

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Date

6/10/2014

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Date

Approved by:

6/10/2014

Darryl William LeVasseur
System Engineer II
Metis Technologies

Date

| Organization | Title/Subject | Number | Date | |
|---|---|---|---|---|
| SPHERES National Lab | Destructive Sample Testing | SPH-ULT-MT001 | June 10, 2014 | Page 1 |

**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).

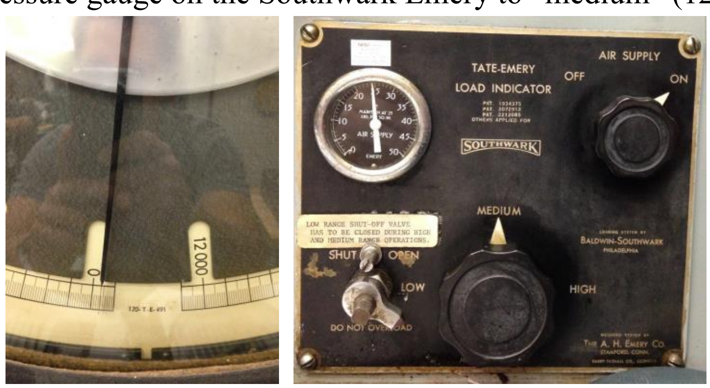



*Figure 2 & 3: (Left) Force indicator set to 12,000lb max load. (Right) Image of the pressure gauge knob set to "medium".*

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.

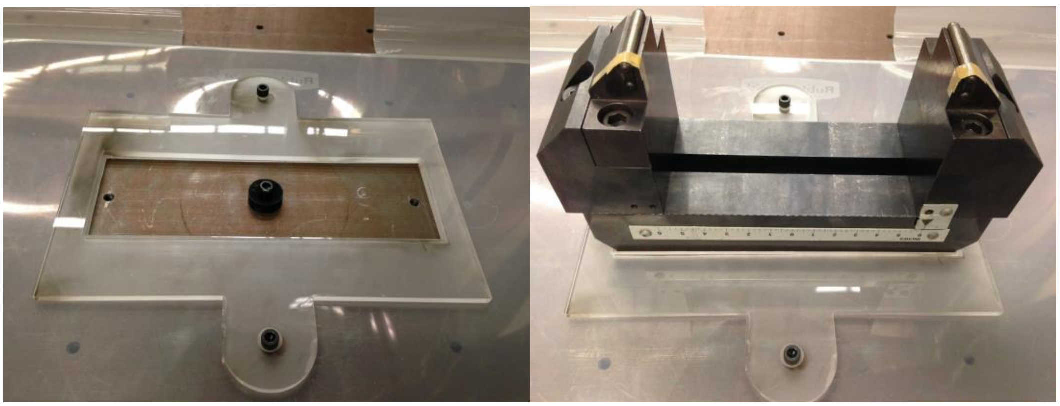


*Figure 4 & 5: (Left) Alignment jig placed on the collection tub. (Right) Black support fixture placed inside the alignment jig.*

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

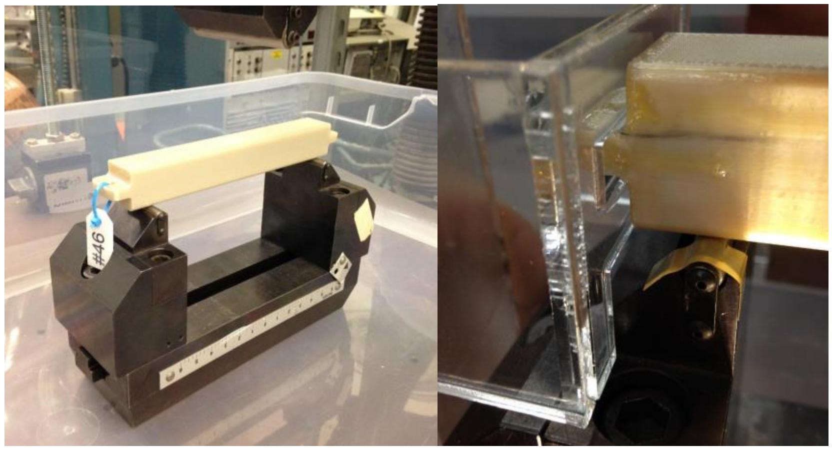



*Figure 6 & 7: (Left) Specimen on the black support fixture. (Right) End jig centers the specimen on the black support fixture. Packing tape on the supports aligns the specimen on the supports.*

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).

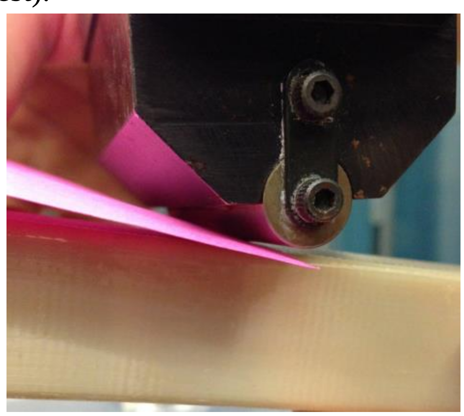


*Figure 8: Paper shim test*

| | |
|---|---|
| Shim Test Spacing | .001 inch |

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.

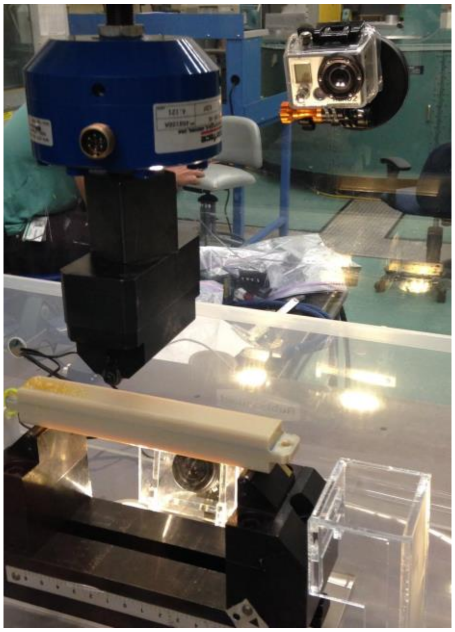


*Figure 9: GoPro mounted with suction cup on safety glass*

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.

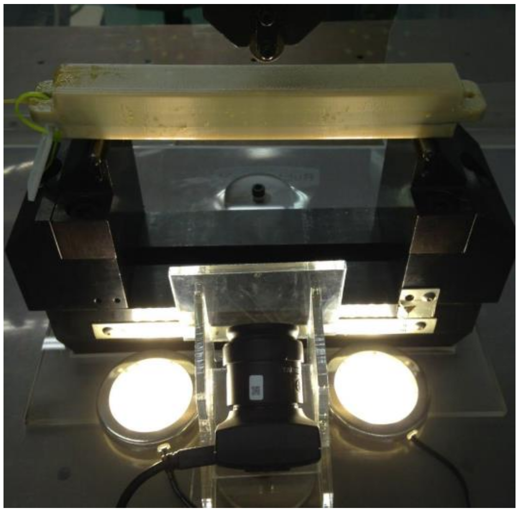


*Figure 10: Black and white camera with LED lighting*

1.11. Zero the displacement on the Southwark Emery

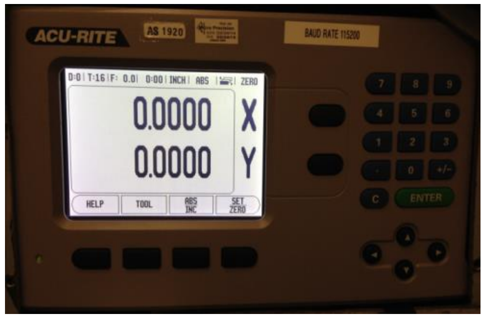



*Figure 11: Zero the measuring device*

2. **Commence with testing procedures**
   - 2.1. Start the video cameras.
   - 2.2. Use a cue card to identify which sample is being tested.

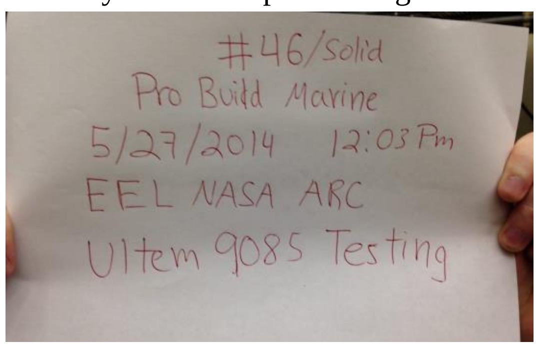



*Figure 12: Example of a video cue card*

   - 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.

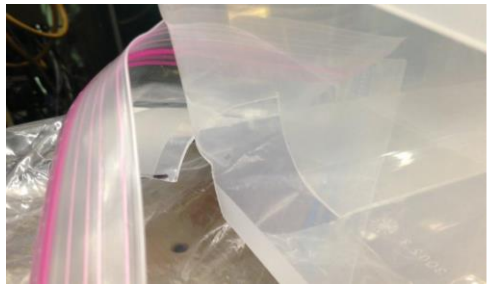


*Figure 13: Image of the collection tub corner flap used to sweep FOD into Ziploc bag*

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 |

*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 |

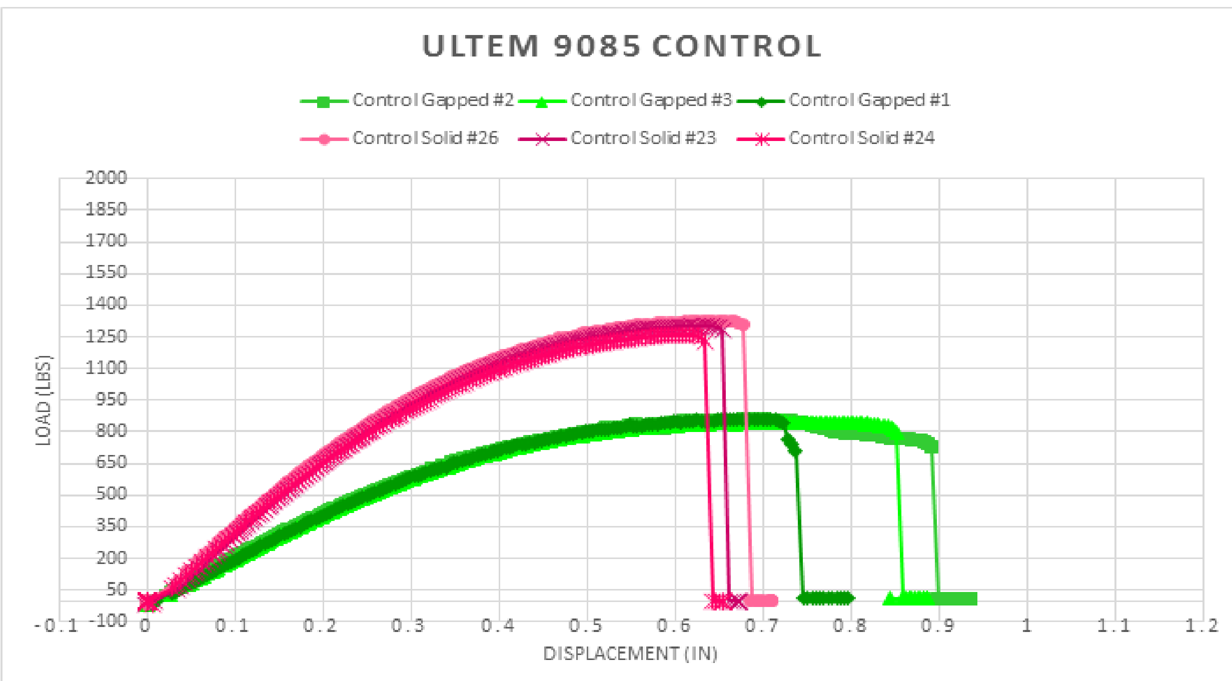



*Figure 27: Strength and deflection curves for the control samples.*

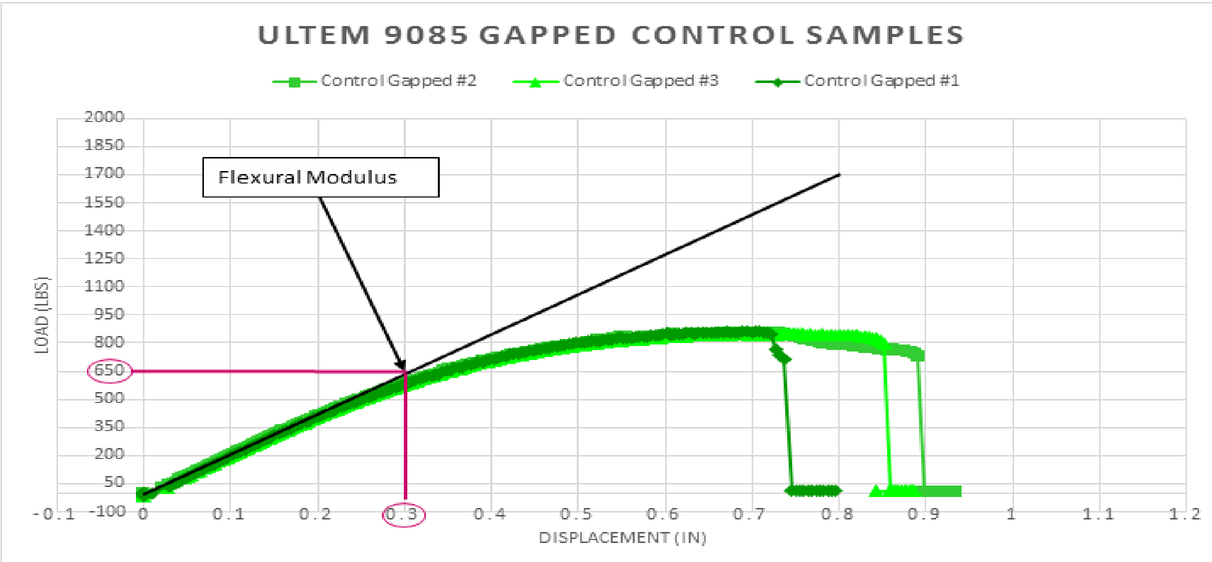



*Figure 28: Average Flexural modulus for gapped control samples.*

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

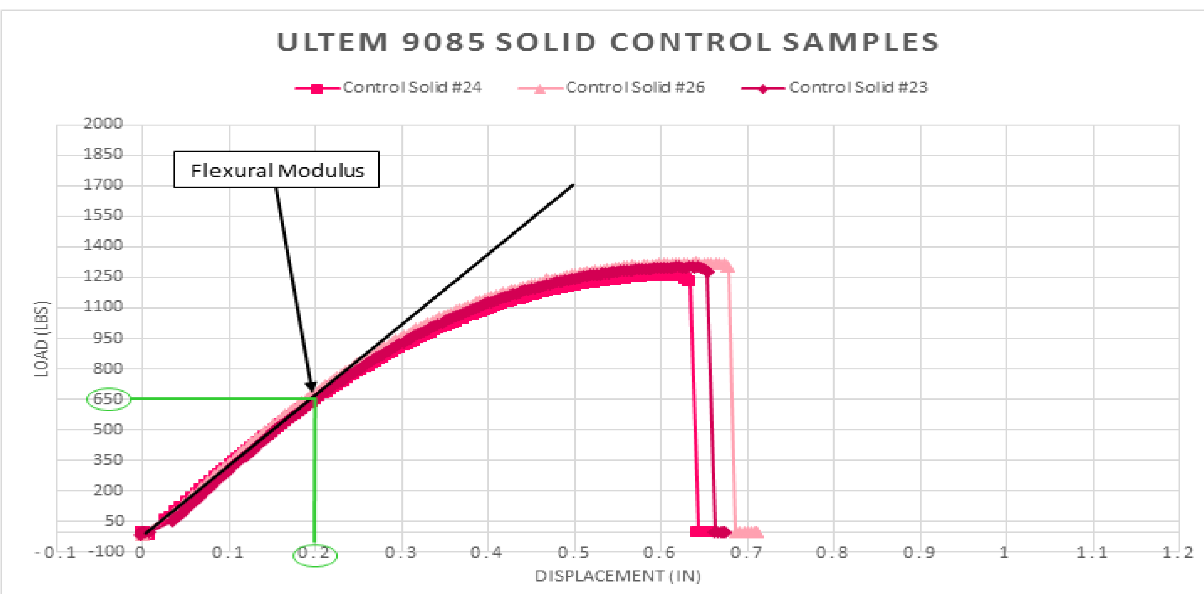



*Figure 29: Average Flexural modulus for solid control samples.*

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

## Arathane 5750-A/B (LV)

*Table 14: Gapped samples with Arathane 5750.*

| ***Specimen Number*** | ***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 |

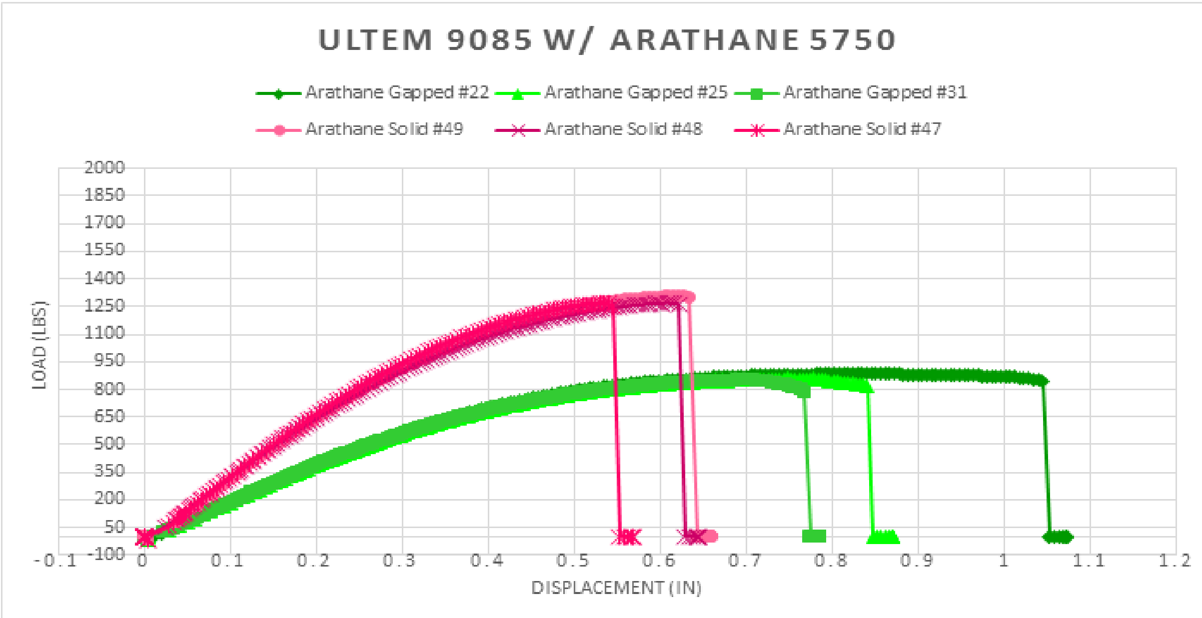



*Figure 30: Strength and deflection curves for samples with Arathane 5750-A/B (LV).*

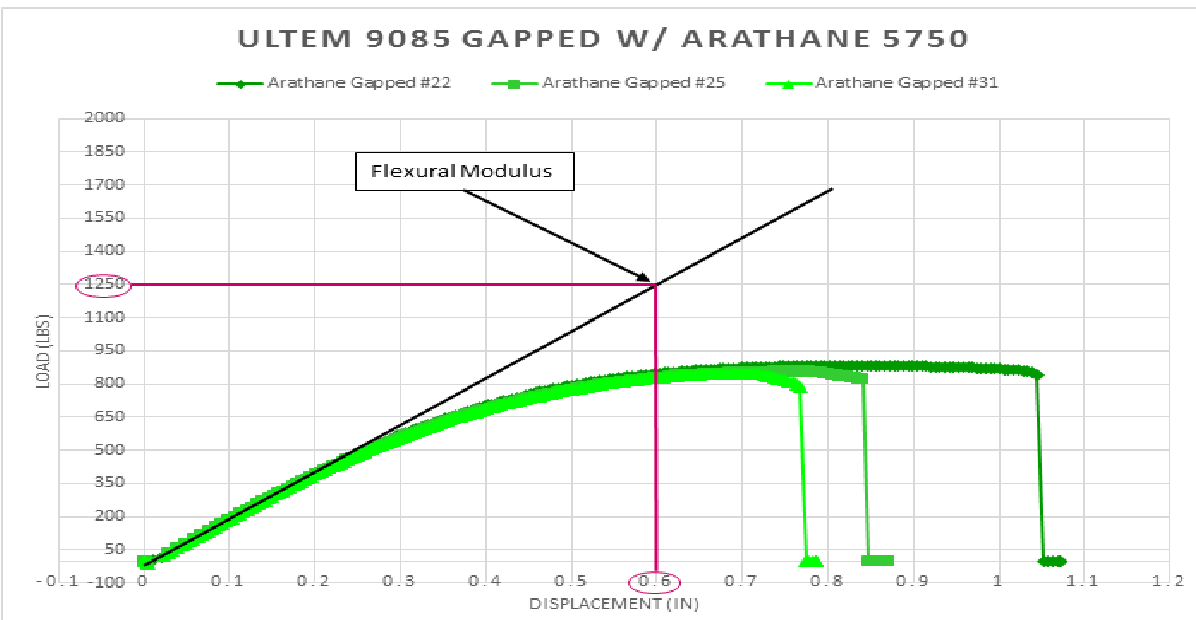



*Figure 31: Average Flexural modulus for gapped samples with Arathane 5750-A/B (LV).*

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

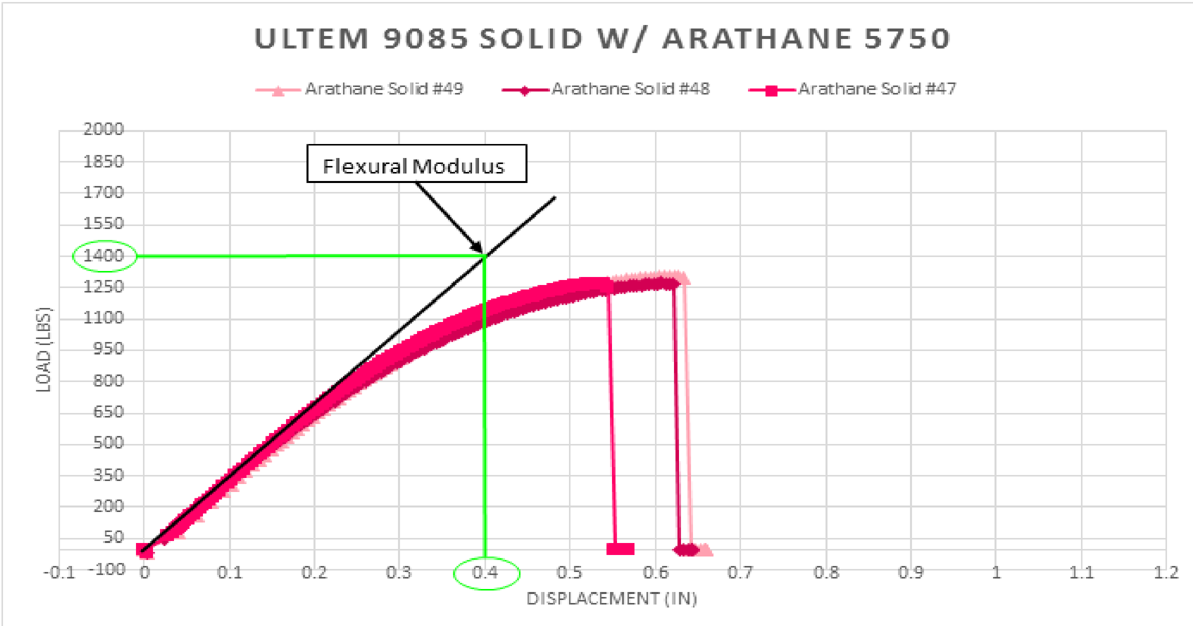



*Figure 32: Average Flexural modulus for solid samples with Arathane 5750-A/B (LV).*

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

## 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 |

*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 |

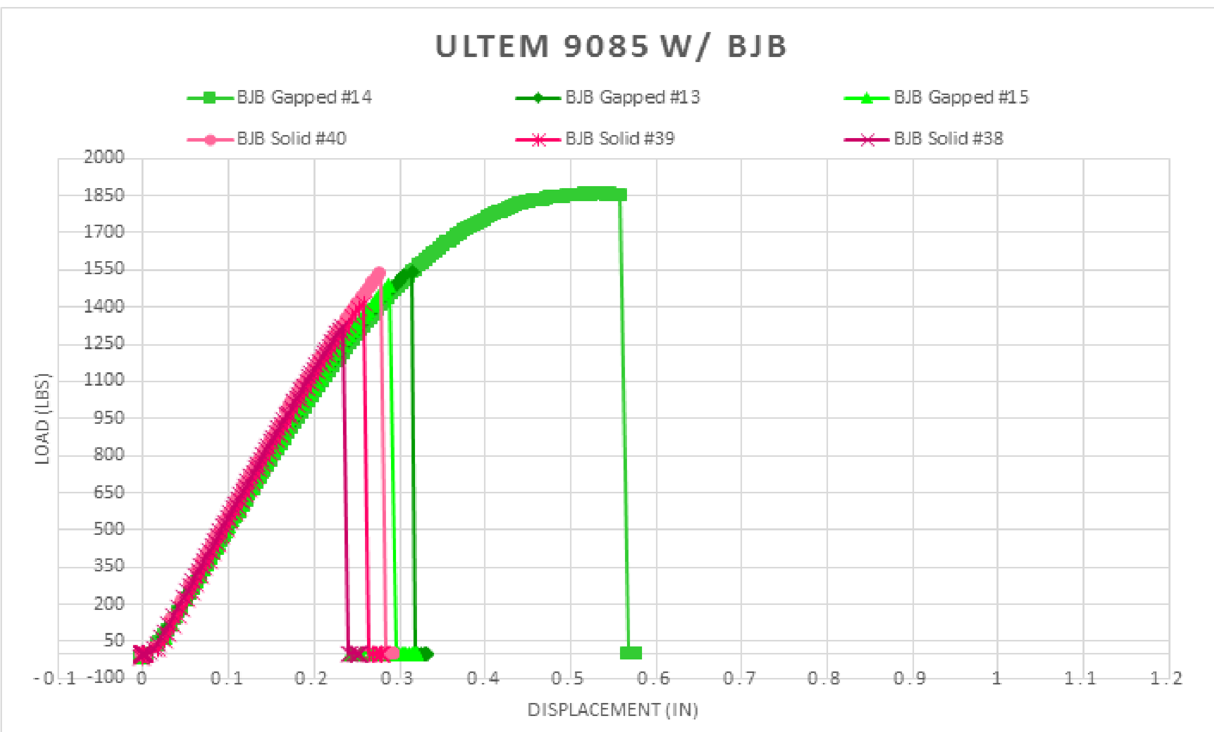



*Figure 33: Strength and deflection curves for samples with BJB TC-1614.*

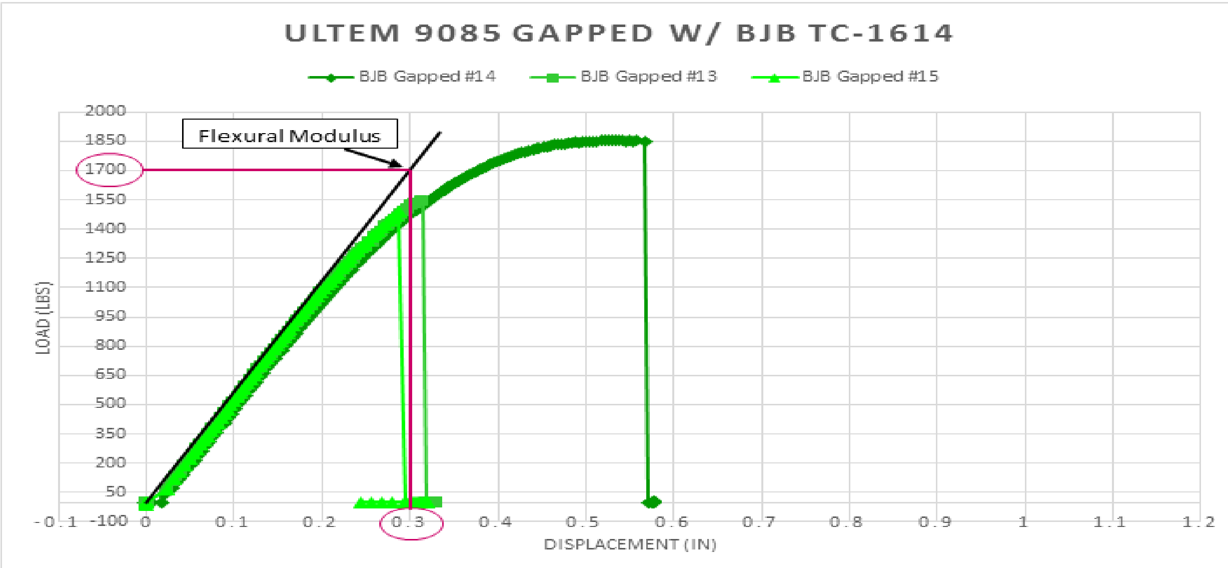



*Figure 34: Average Flexural modulus for gapped samples with BJB TC-1614.*

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

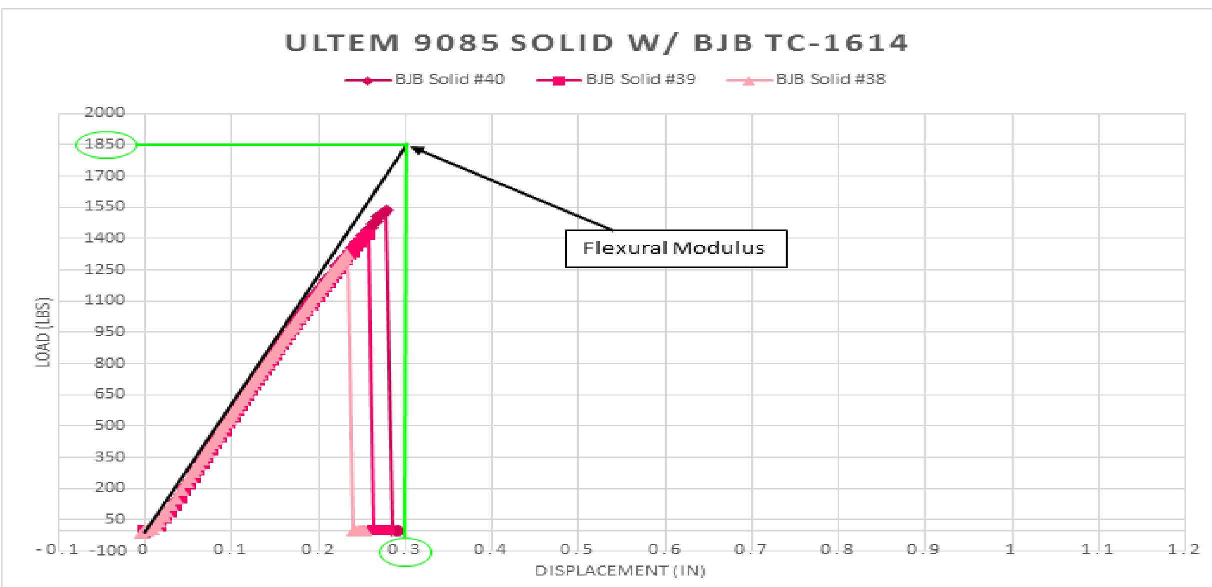



*Figure 35: Average Flexural modulus for solid samples with BJB TC-1614.*

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

## 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 |

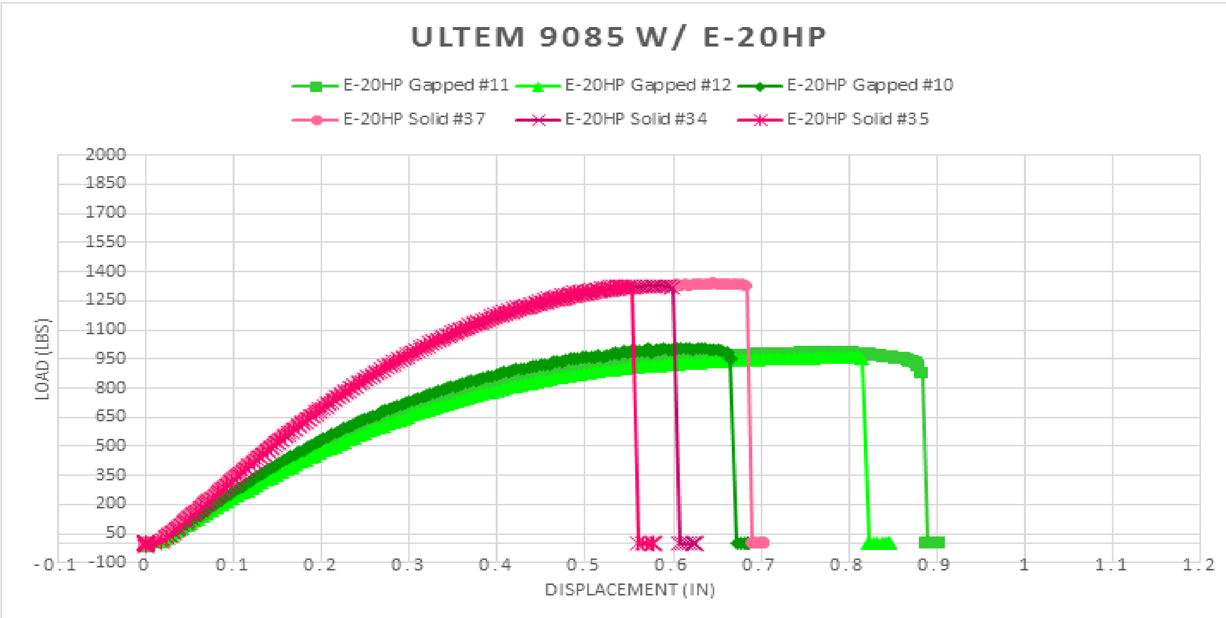



*Figure 36: Strength and deflection curves for samples with Hysol E-20HP.*

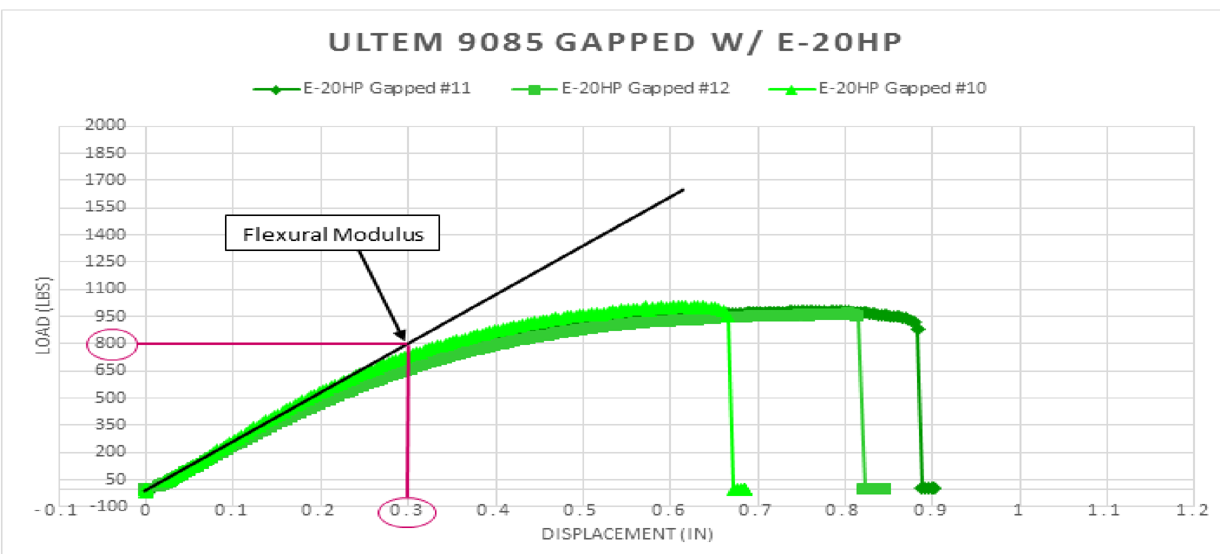



*Figure 37: Average Flexural modulus for gapped samples with Hysol E-20HP.*

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

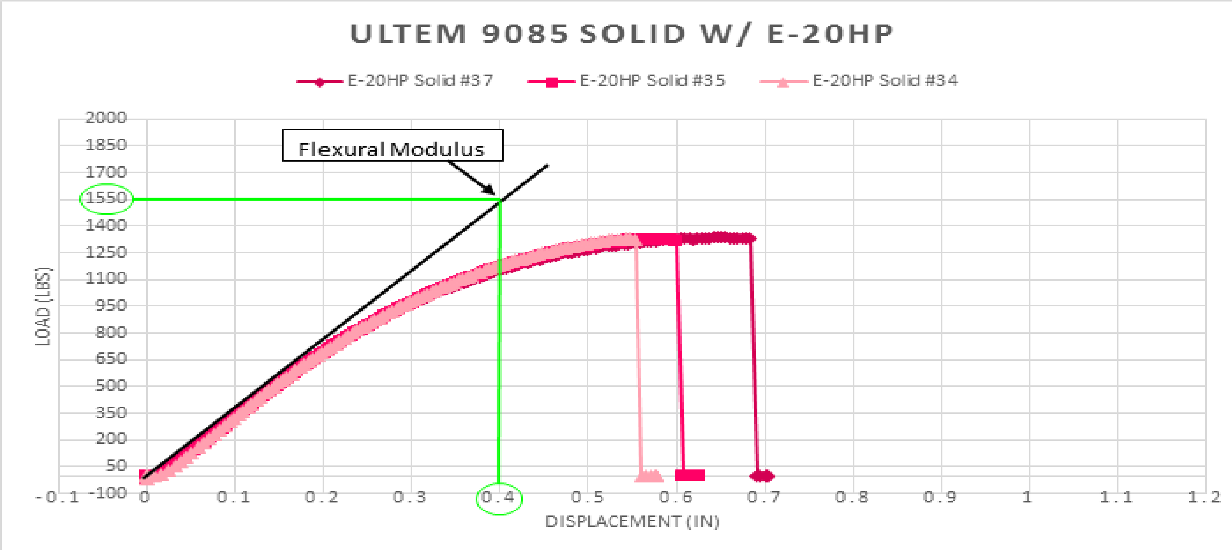



*Figure 38: Average Flexural modulus for solid samples with Hysol E-20HP.*

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

## 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 |

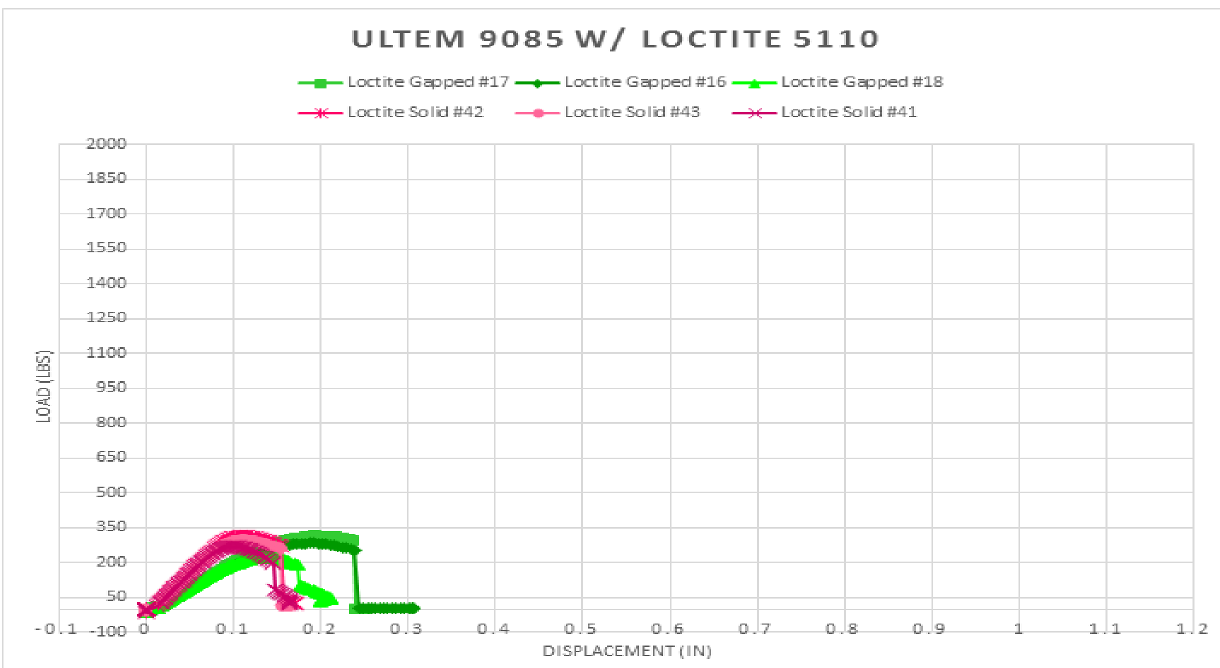



*Figure 39: Strength and deflection curves for samples with Henkel Loctite 5110.*

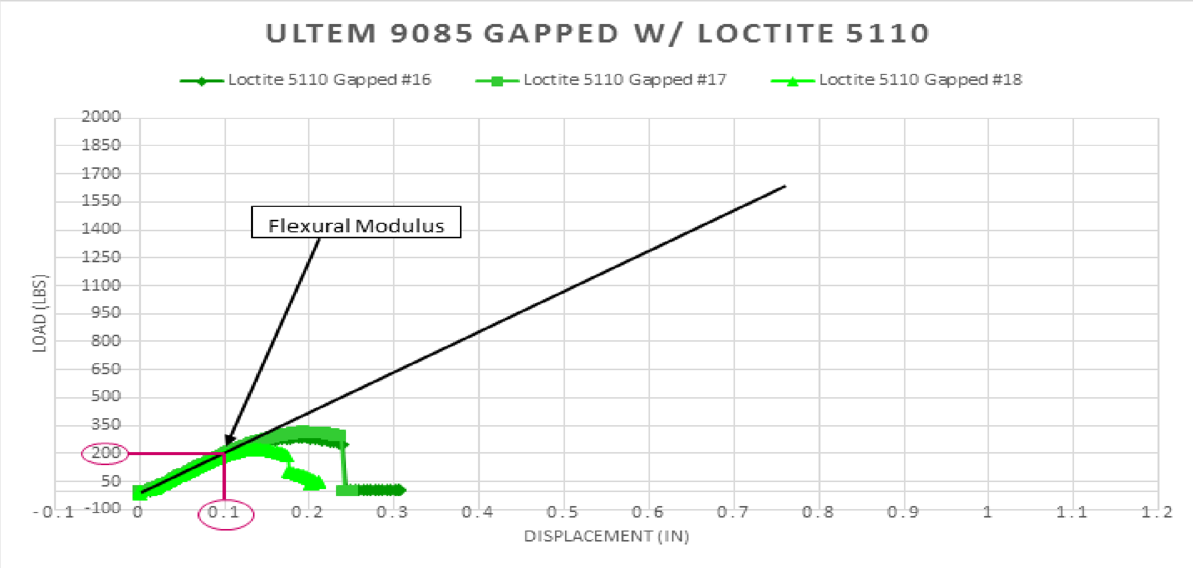



*Figure 40: Average Flexural modulus for gapped samples with Henkel Loctite 5110.*

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

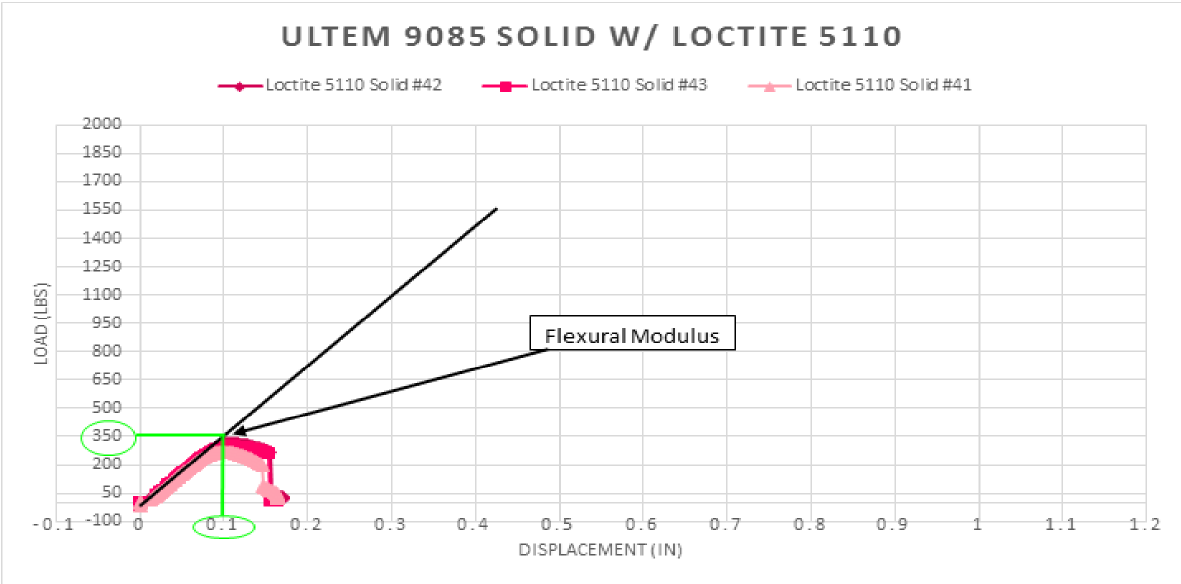



*Figure 41: Average Flexural modulus for solid samples with Henkel Loctite 5110*

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

## 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 |

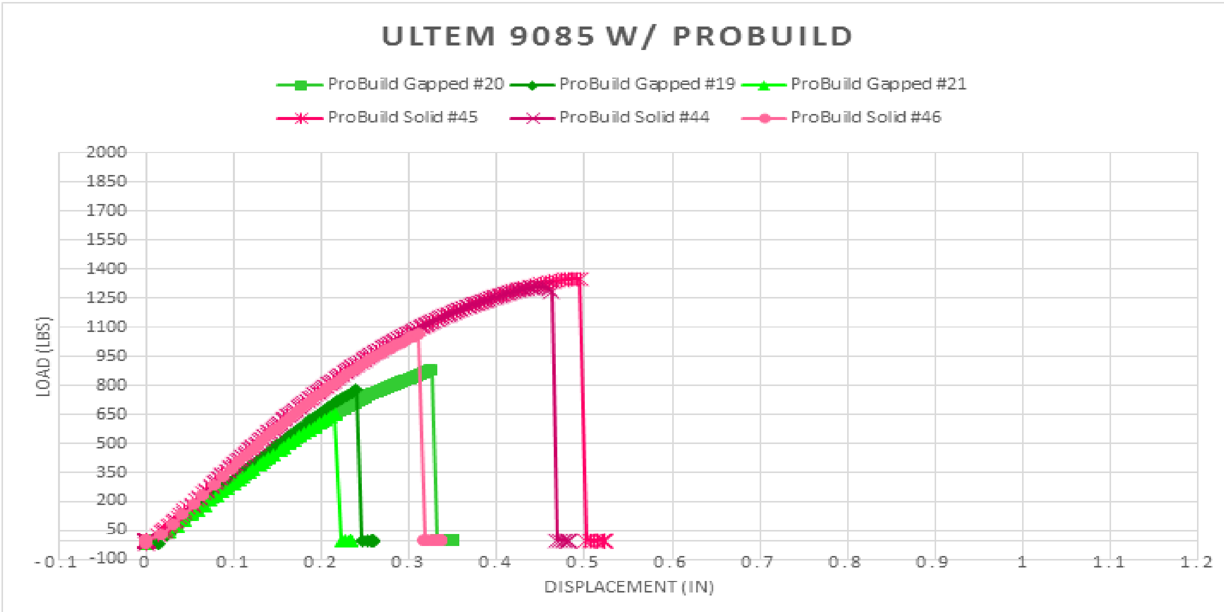



*Figure 42: Strength and deflection curves for samples with ProBuild Marine*

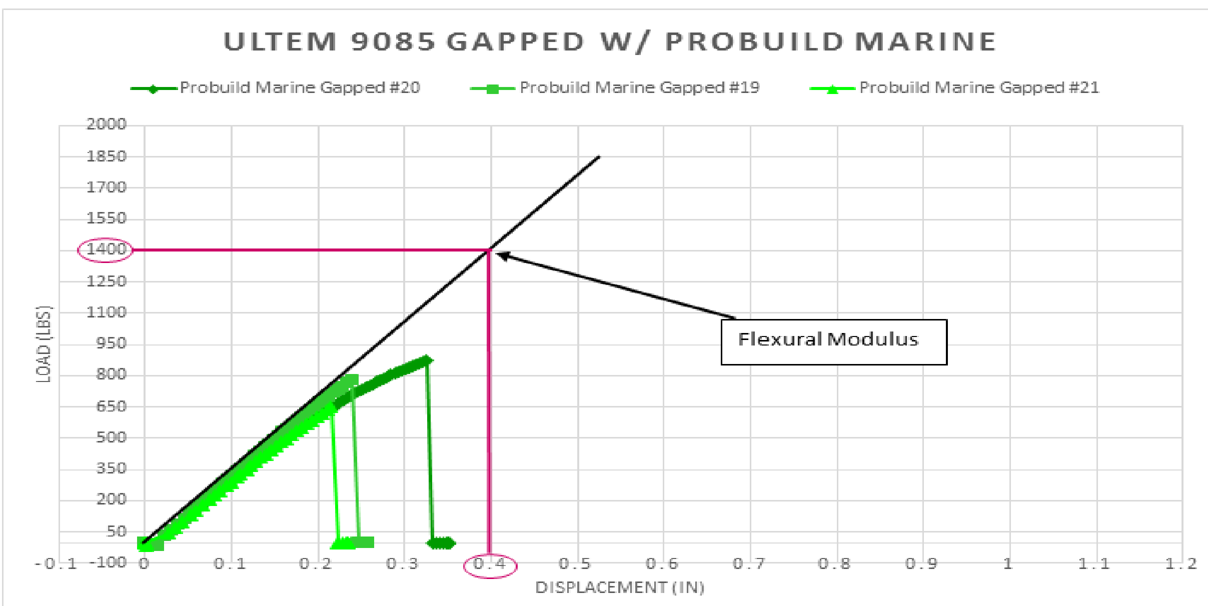



*Figure 43: Average Flexural Modulus for gapped samples with ProBuild Marine*

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

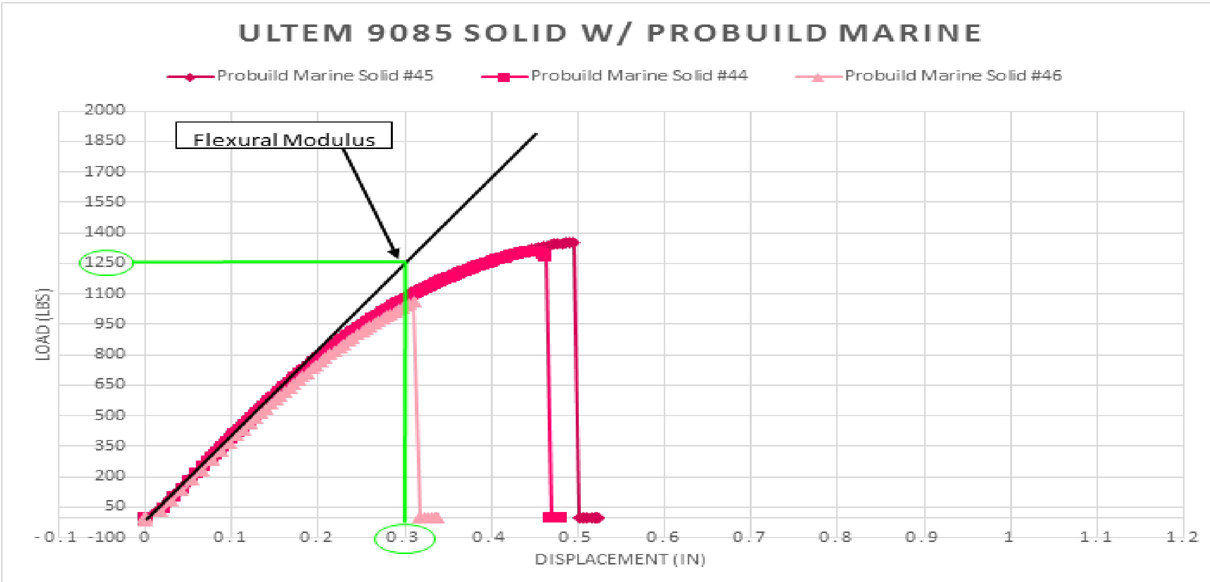
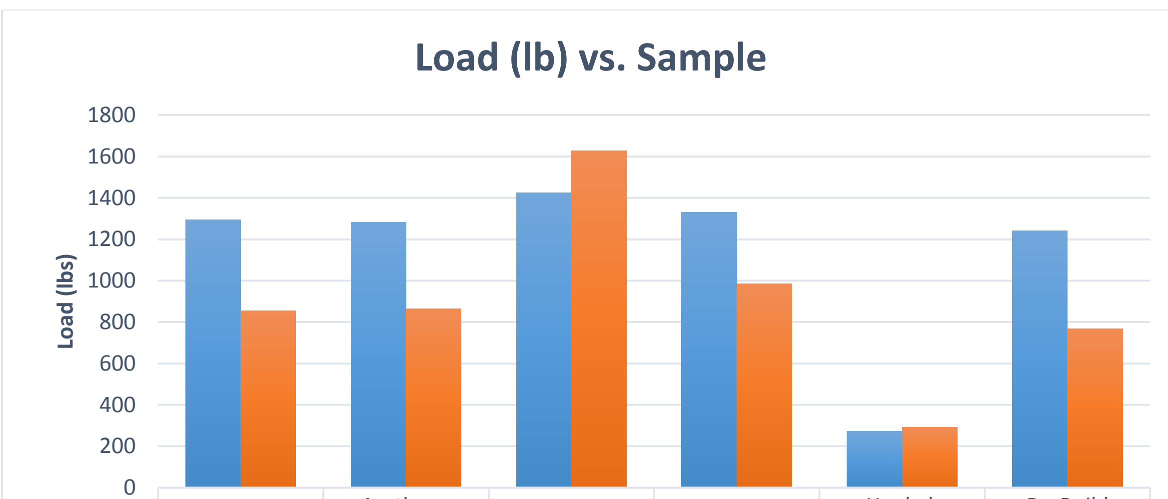


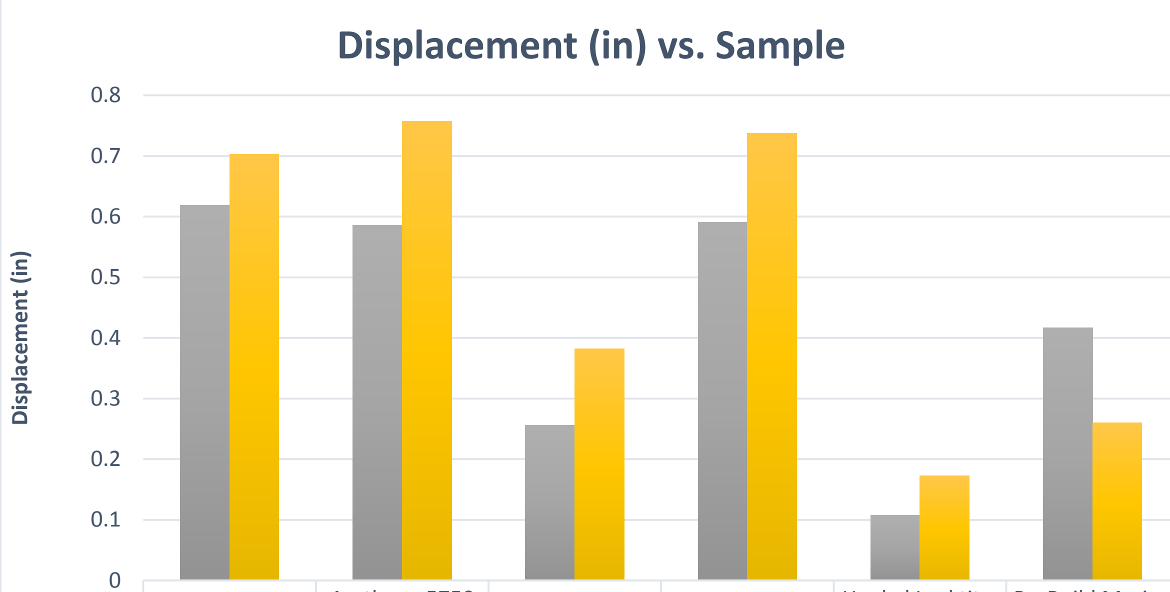

*Figure 44: Average Flexural Modulus for solid samples with ProBuild Marine*

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




| | Control | Arathane 5750 AB | BJB TC-1614 | Hysol E-20HP | Henkel Locktite 5110 | ProBuild Marine Epoxy |
|---|---|---|---|---|---|---|
| Solid | 1294.482 | 1281.471 | 1424.491 | 1330.504 | 273.156 | 1240.839 |
| Gapped | 855.441 | 864.038 | 1628.122 | 984.352 | 292.062 | 766.667 |

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




| | Control | Arathane 5750 AB | BJB TC-1614 | Hysol E-20HP | Henkel Locktite 5110 | ProBuild Marine Epoxy |
|---|---|---|---|---|---|---|
| Solid | 0.619 | 0.586 | 0.256 | 0.591 | 0.108 | 0.417 |
| Gapped | 0.703 | 0.757 | 0.382 | 0.738 | 0.173 | 0.26 |

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

# Stress vs. Strain Graphs

## Control

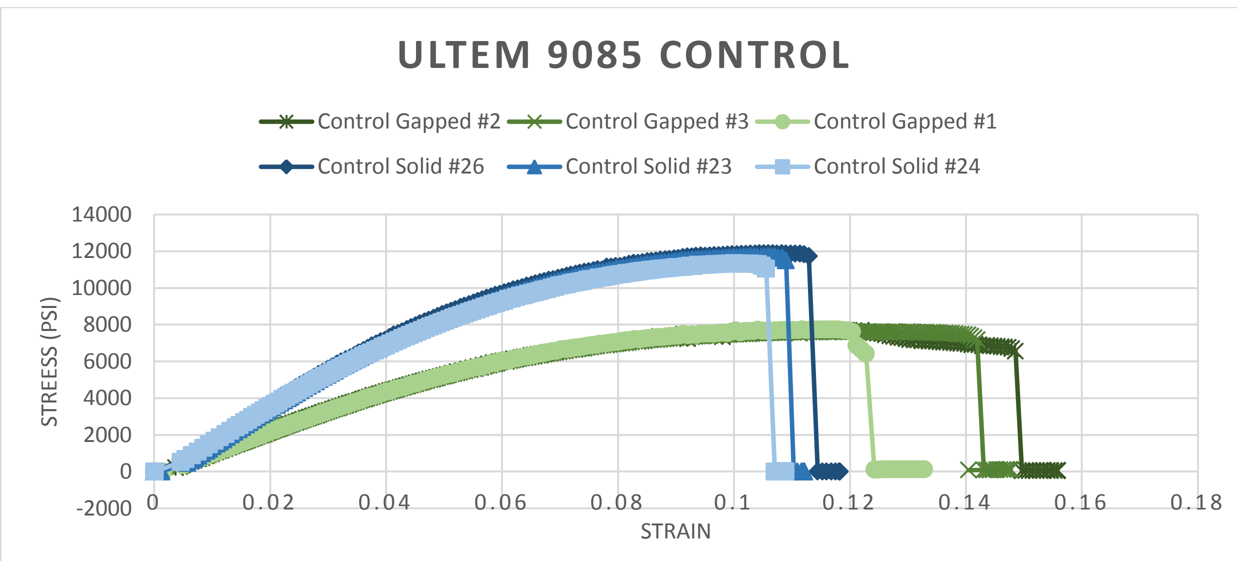



*Figure 47: Stress vs. Strain curves for control samples*

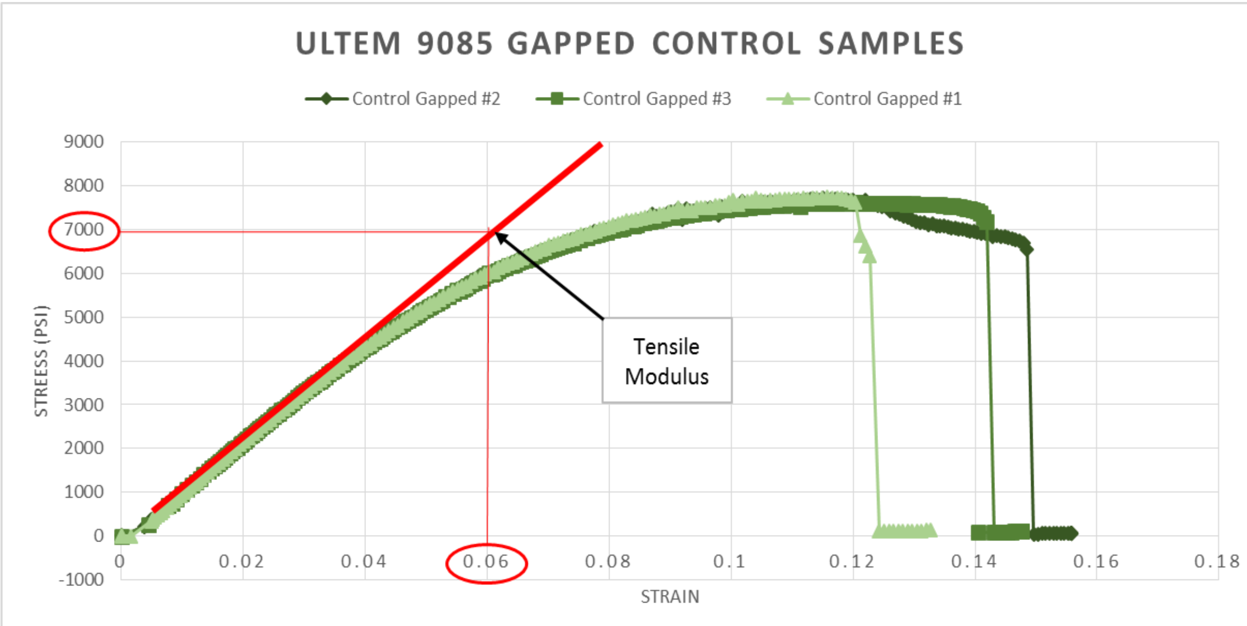



*Figure 48: Average Tensile Modulus of the gapped control samples*

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

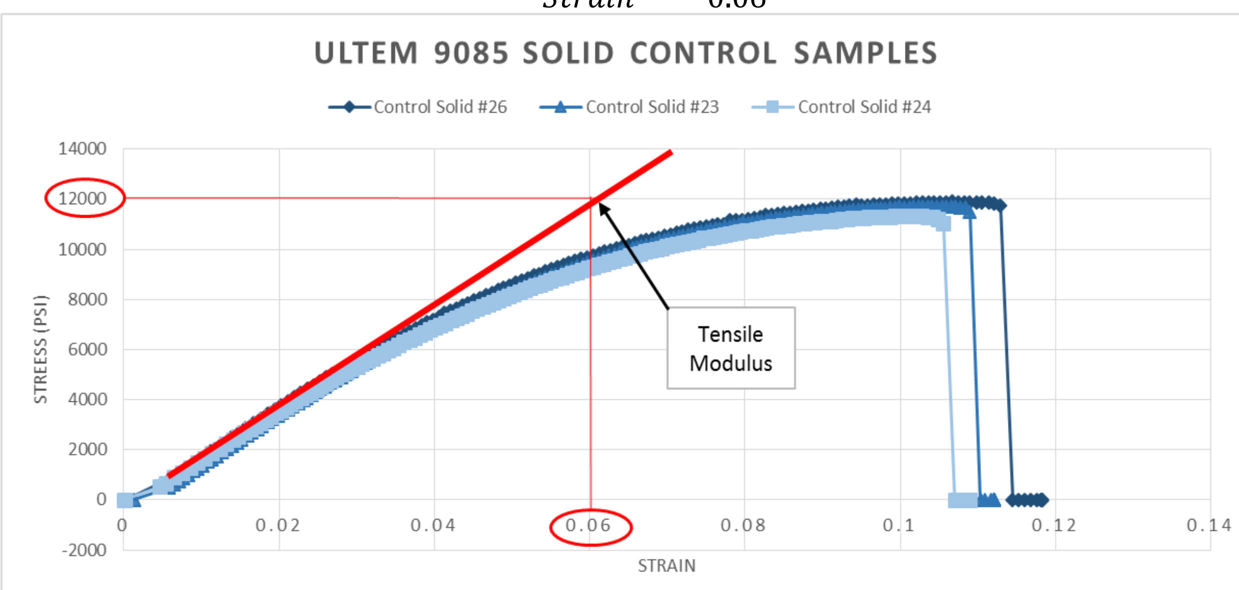



*Figure 49: Average Tensile Modulus of the solid control samples*

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

## Arathane 5750-A/B (LV)

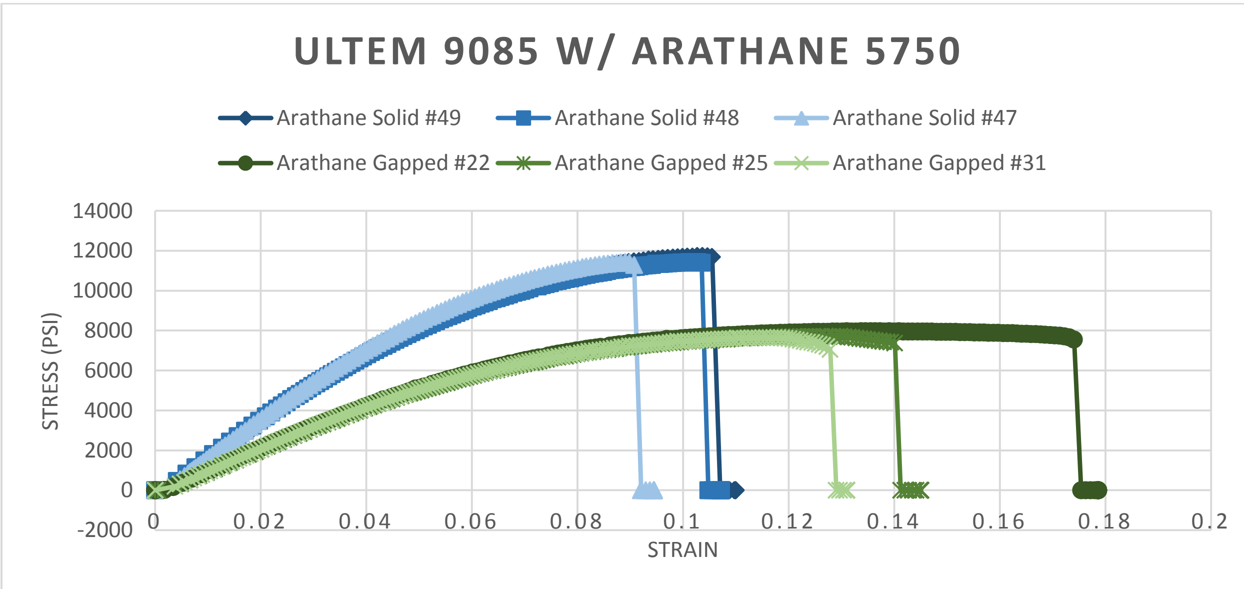



*Figure 50: Stress vs. Strain curves for samples with Arathane 5750-A/B (LV)*

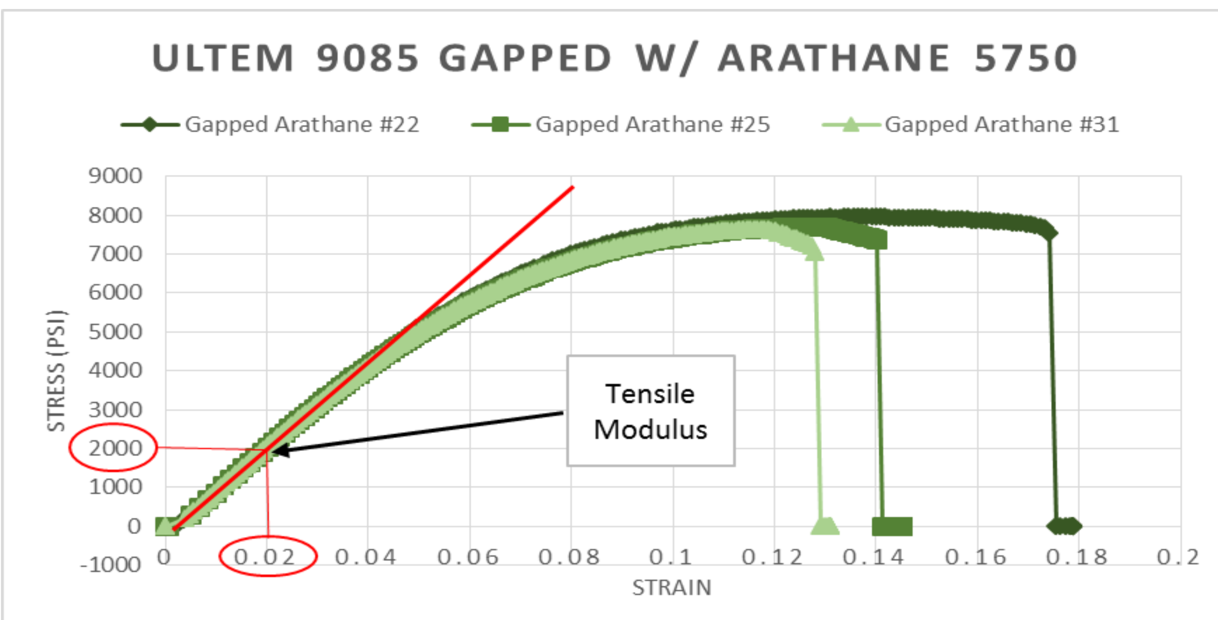



*Figure 51: Average Tensile Modulus for gapped samples with Arathane 5750-A/B (LV)*

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

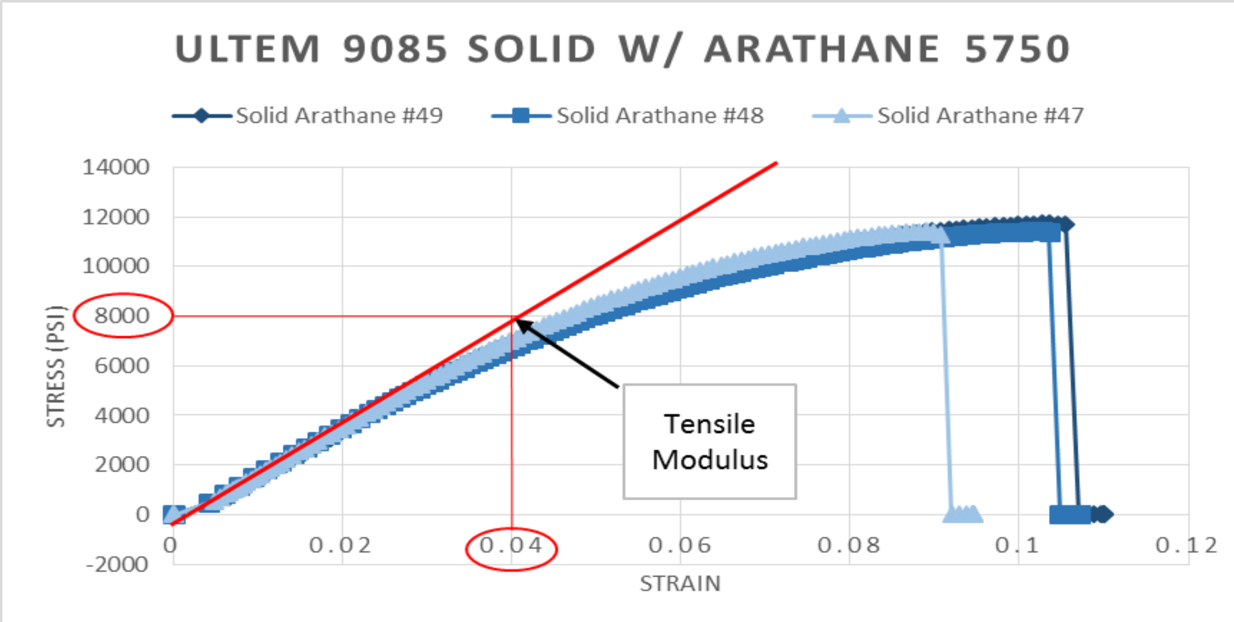



*Figure 52: Average Tensile Modulus for solid samples with Arathane 5750-A/B (LV)*

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

**BJB TC-1614**

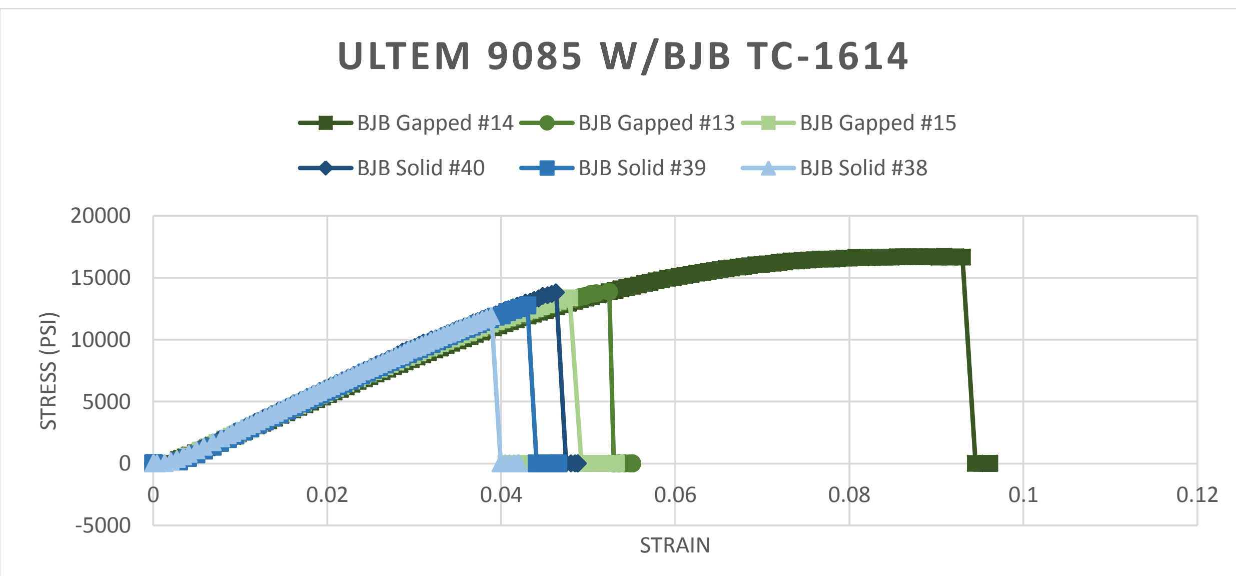



*Figure 53: Stress vs. Strain curves for samples with BJB TC-1614*

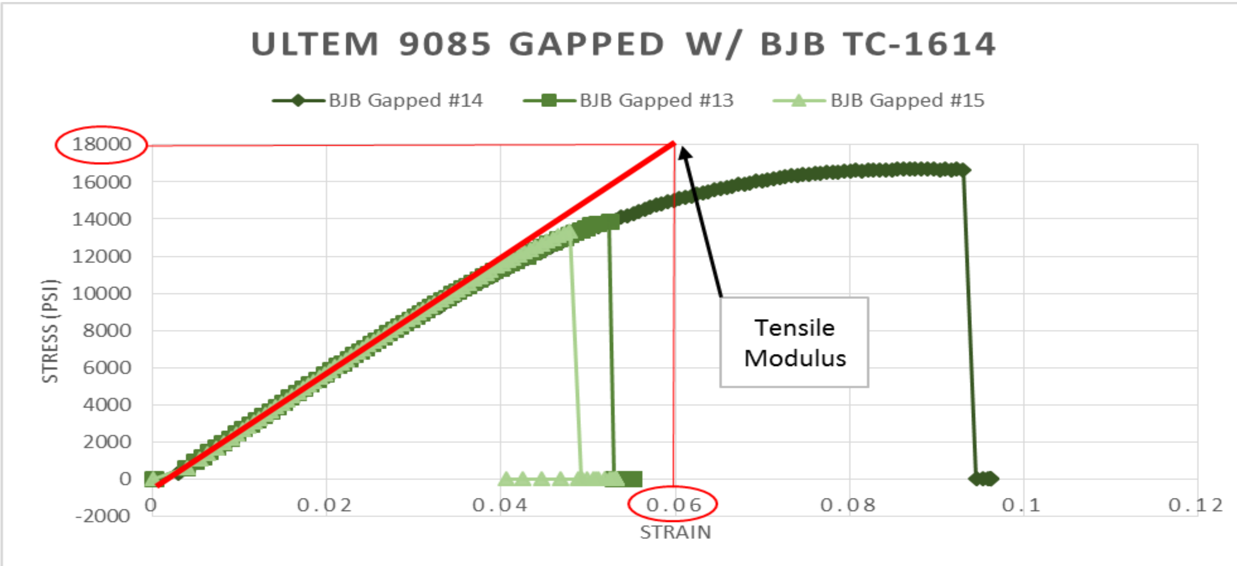



*Figure 54: Average Tensile Modulus for gapped samples with BJB TC-1614*

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

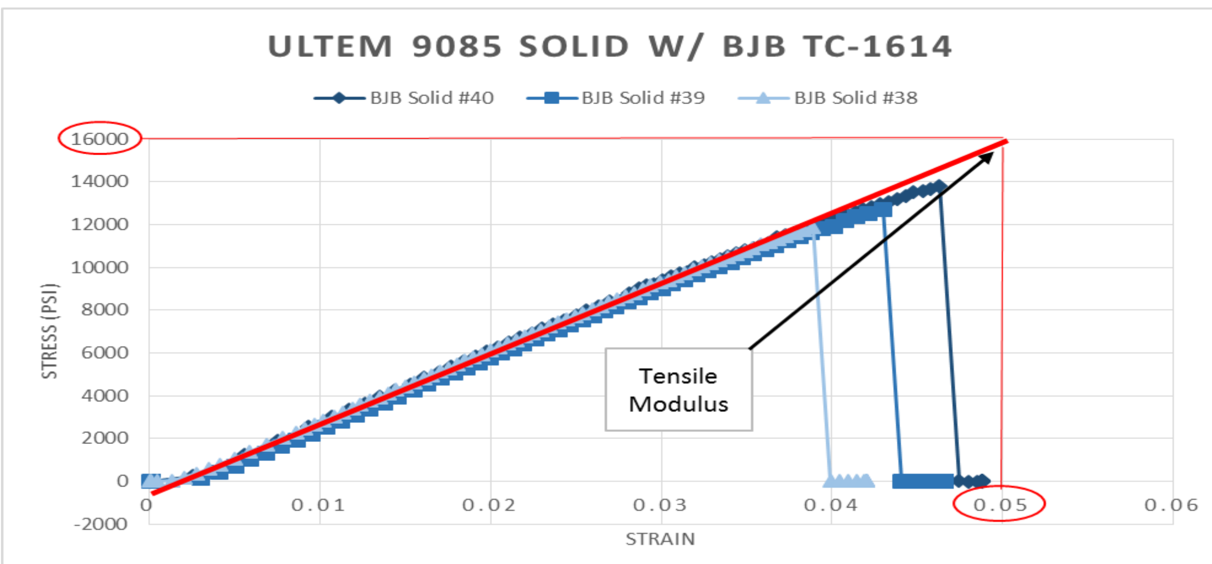



*Figure 55: Average Tensile Modulus for solid samples with BJB TC-1614*

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

## Hysol E-20HP

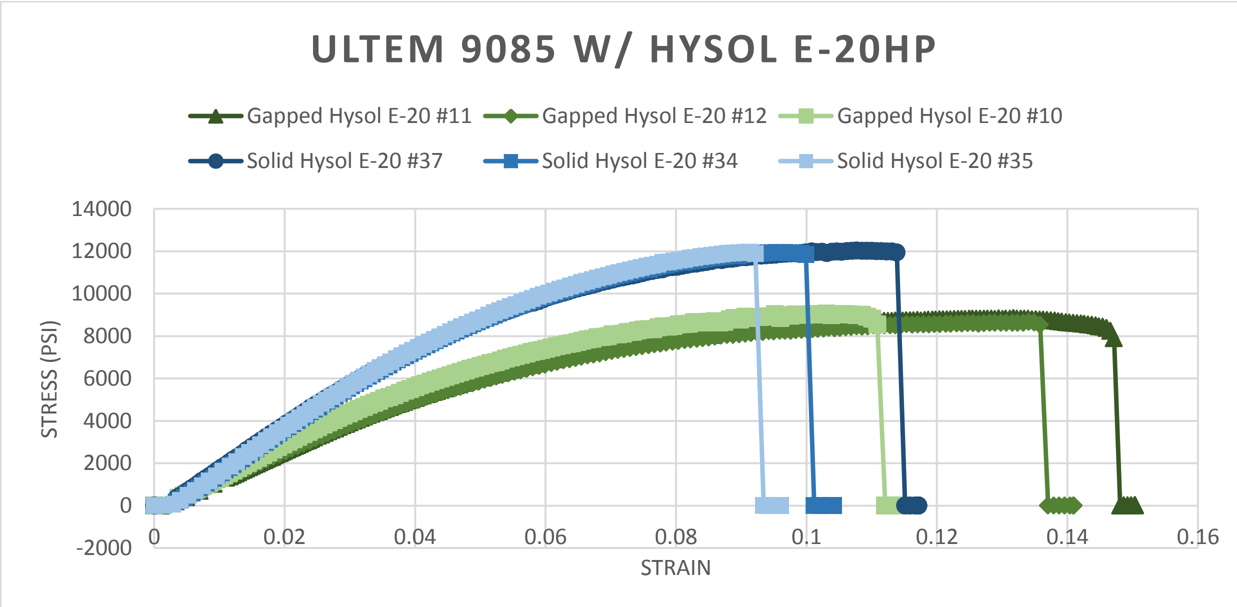



*Figure 56: Stress vs. Strain curves for samples with Hysol E-20HP*

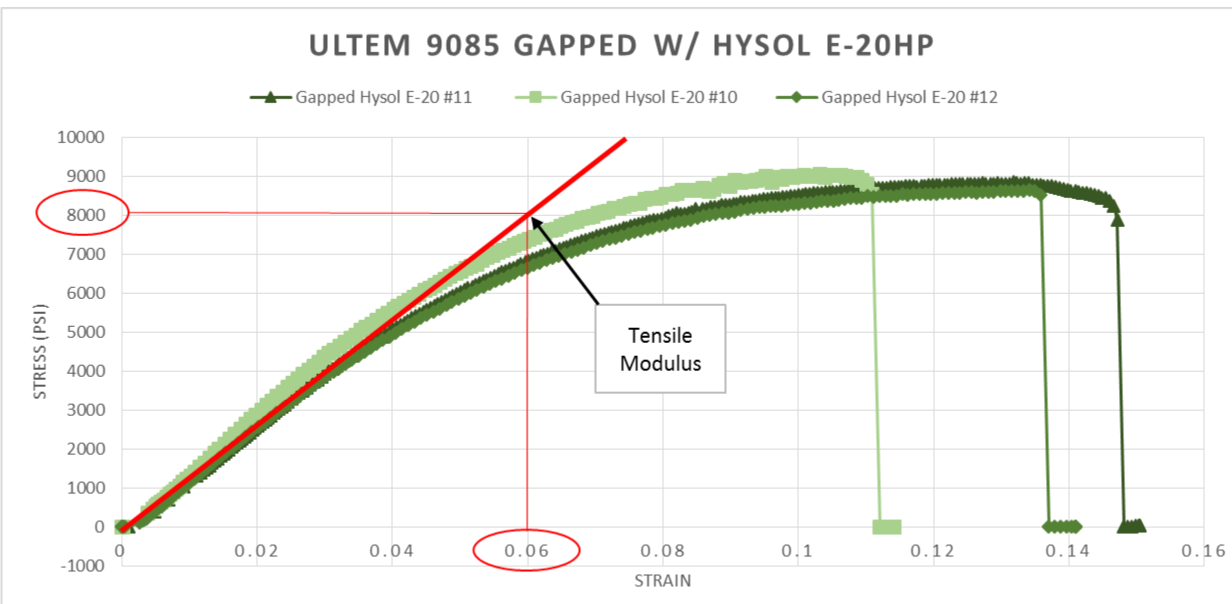



*Figure 57: Average Tensile Modulus for gapped samples with Hysol E-20HP*

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

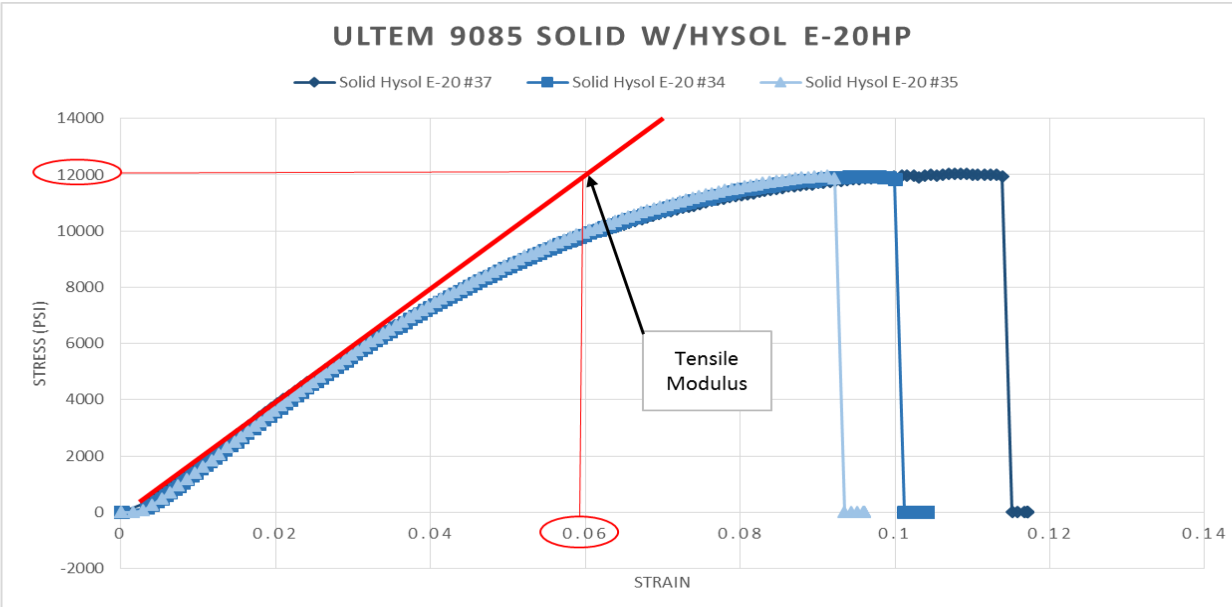



Figure 58: Average Tensile Modulus for solid samples with Hysol E-20HP

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

## Henkel Loctite 5110

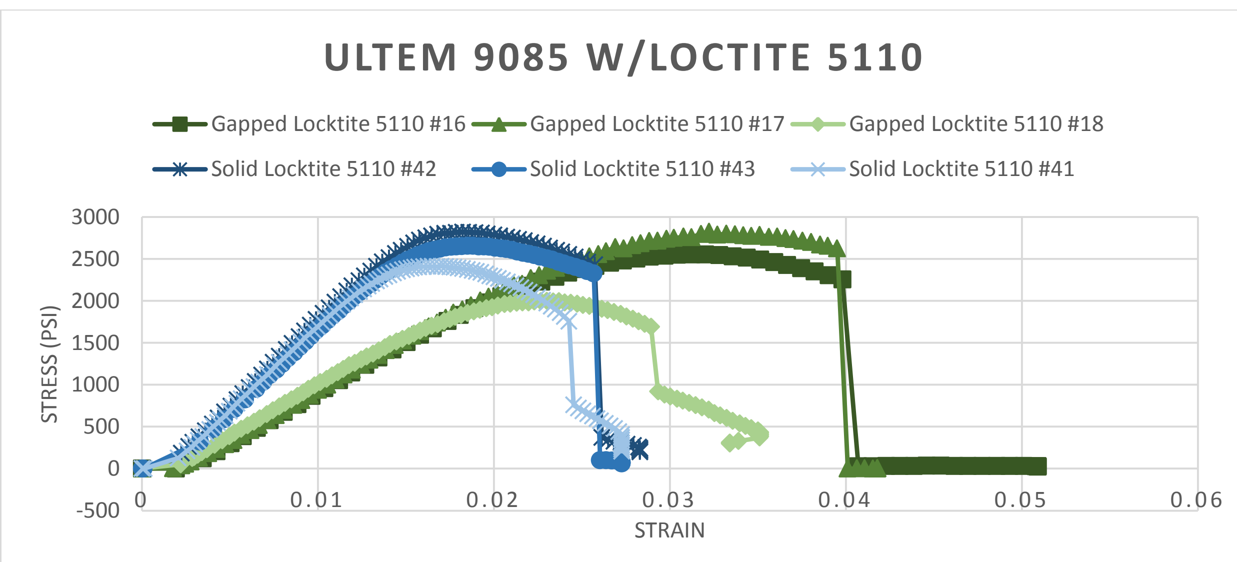



Figure 59: Stress vs. Strain curves for samples with Henkel Loctite 5110

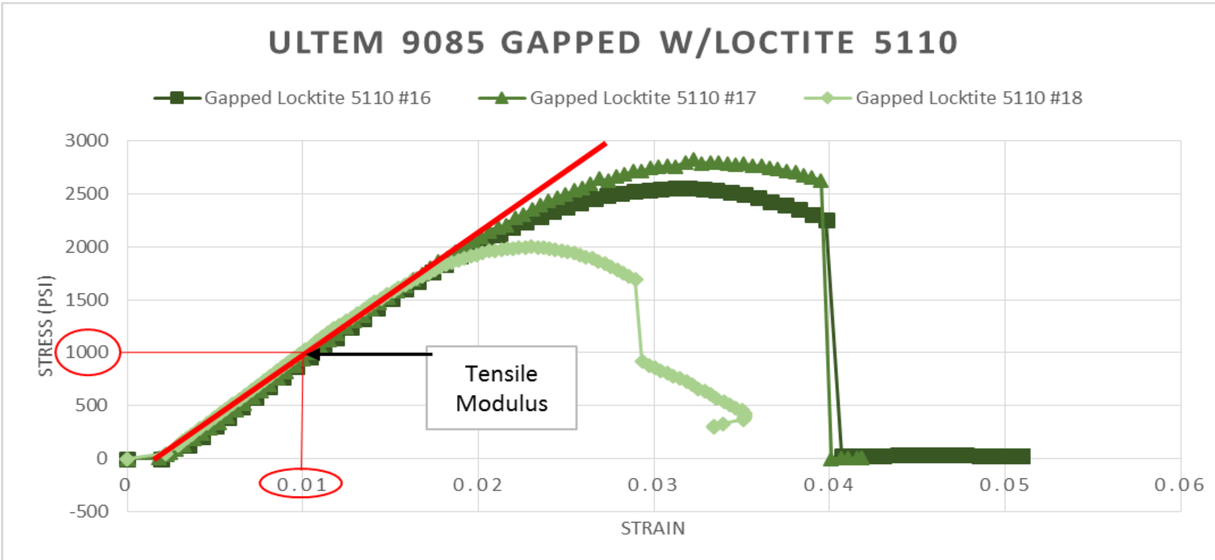



*Figure 60: Average Tensile Modulus for gapped samples with Henkel Loctite 5110*

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

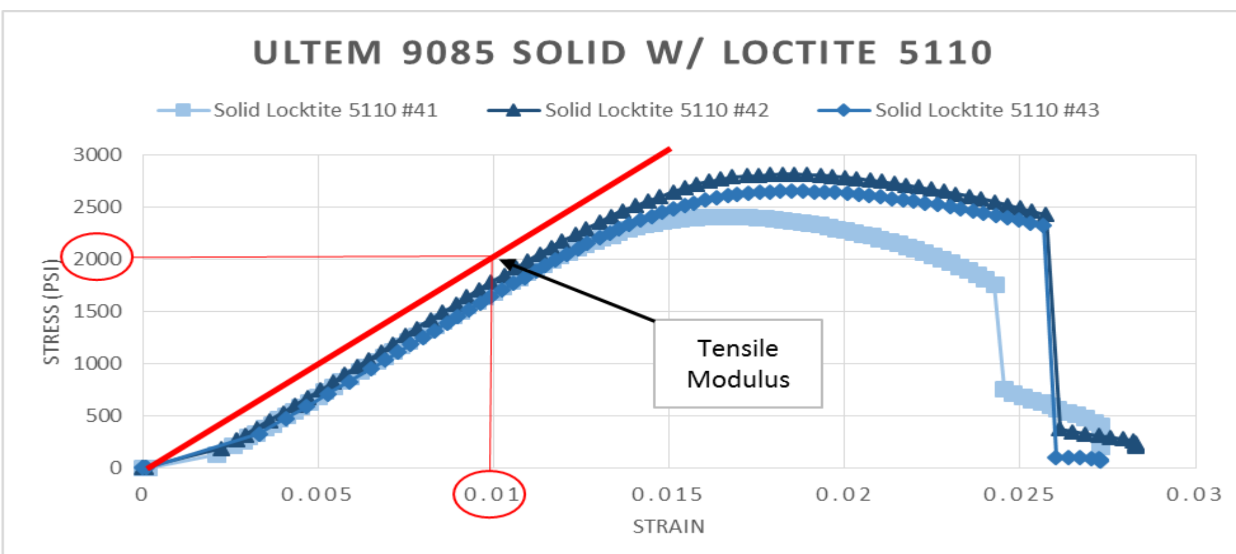



*Figure 61: Average Tensile Modulus for solid samples with Henkel Loctite 5110*

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

## ProBuild Marine

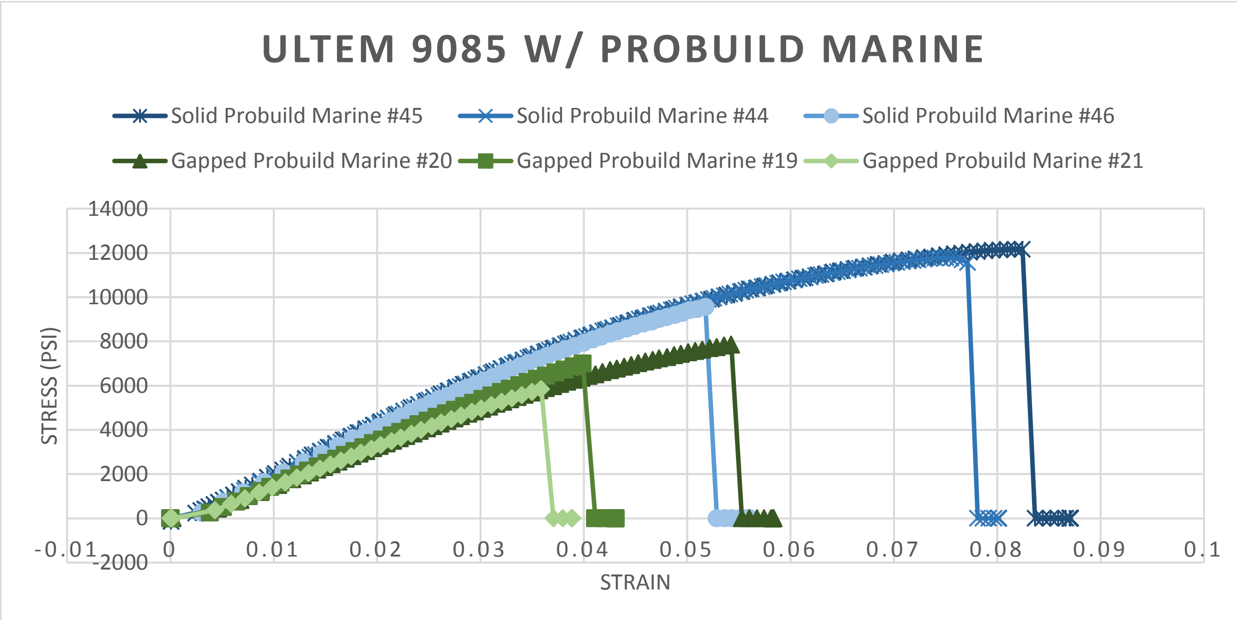



*Figure 62: Stress vs. Strain curves for samples with ProBuild Marine*

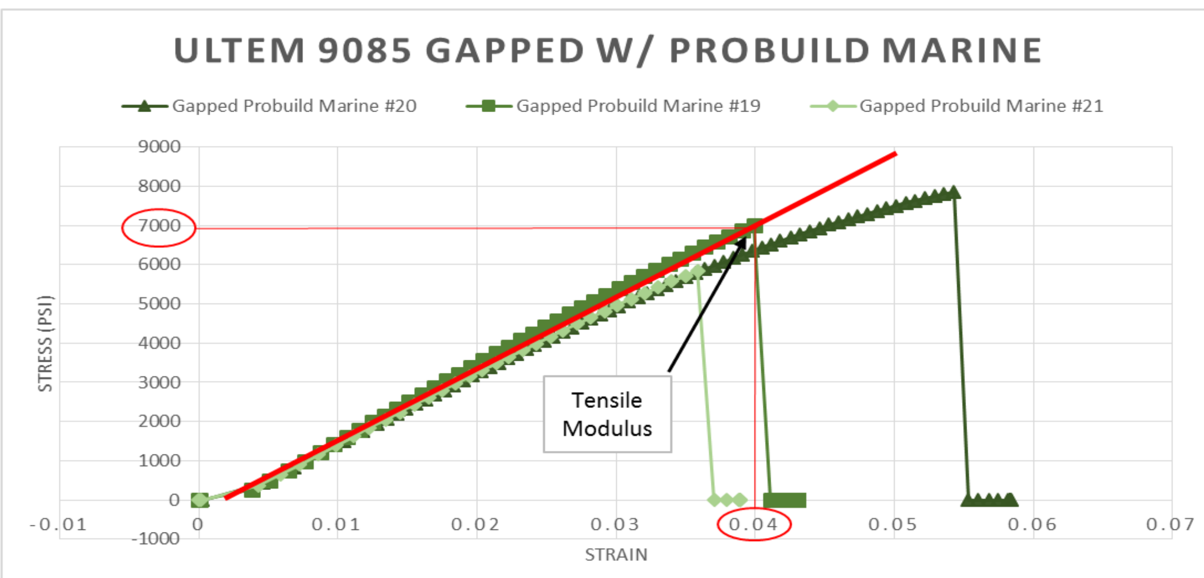



*Figure 63: Average Tensile Modulus for gapped samples with ProBuild Marine*

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

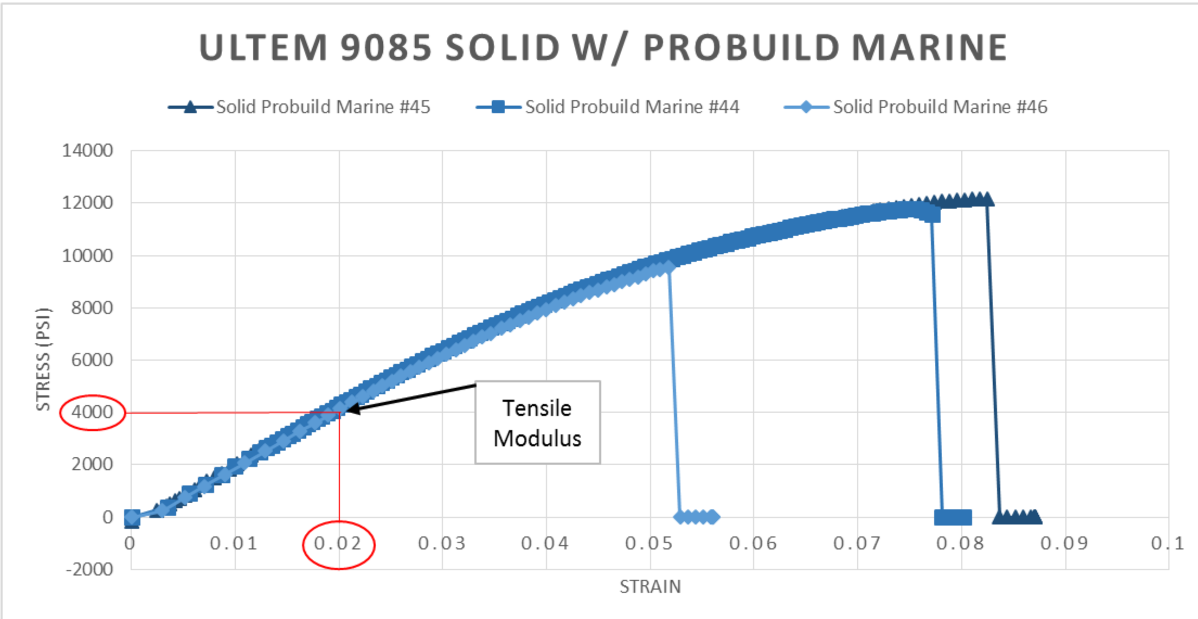



*Figure 64: Average Tensile Modulus for solid samples with ProBuild Marine*

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

## Breaking Notes

**SPHERES Ultem 9085 Sample Notes**

*Sample #* 9

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

6/10/14 11:05pm

*Sample #* 7

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

Break: 1115 lb

$\delta_{max}$

6/16/14

## SPHERES Ultem 9085 Sample Notes

Sample # 1 11:15am

Broke around ≈ 850 lb

δmax around ≈ 0.75 in

"Shredded Wheaties"

no FOD

Gapped

Sample # 2 11:22 am

Gapped control sample

Break load = 855 lb

Break δ = 0.83 in

"Shredded Wheaties"

no FOD

## 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 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 = ~~0.7~~ 0.68 in

explosive break - did not escape test volume
minimal FOD - grains of sand size

## 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.

## 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 Ultem 9085 Sample Notes

*Sample #* 39 — 2:01 pm

BJB solid Sample

Break load = 1410 lb
Break $\delta$ = 0.26 lb

explosive break
FOD everywhere

* Sample flew out of

*Sample #* 40 — 2:08 pm

BJB solid sample

Break load = 1525 lb
Break $\delta$ = 0.2968 in

very energetic break
1 small piece of FOD

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

## SPHERES Ultem 9085 Sample Notes

Sample # 22 2:18pm

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
1 thin "wafer" FOD

## SPHERES Ultem 9085 Sample Notes

Sample # 31 2:31 pm

Arathane 5750 gapped

Break load = 850 lb
Break δ = 0.77 in

gentlebreak
NO FOD

Sample # 47 2:38 pm

Arathane 5750 solid

Break load = 1280 lb
Break δ = 0.540 in

explosive break
Pebblesized FOD

## 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 Ultem 9085 Sample Notes

Sample # 10 3:01pm

E20HP 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 Ultem 9085 Sample Notes

3:14 pm

Sample # 12

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 Ultem 9085 Sample Notes

Sample # 35 3:28pm

E-20 HP solid sample

Break load = 1340lb
Break δ = 0.55in

explosive break
- minimal FOD – small granular pieces

Sample # 37 2:34pm

E-20 HP solid sample

Break load = 1345lb
Break δ = 0.68in

explosive break
1 piece of FOD – small pebble
stayed within test volume

## 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 pebble

stayed in confined space

## SPHERES Ultem 9085 Sample Notes

3:54

Sample # 21

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

## 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

Stayed in confined space

Sample # 46 4:11pm

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

SPHERES

Written by:

7/30/2014

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Aerospace Engineering Student
San Jose State University
Date

7/30/2014

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Approved by:

7/30/14

Darryl William LeVasseur
System Engineer II
Metis Technologies
Date

| Organization | Title/Subject | Number | Date | Page 1 |
|---|---|---|---|---|
| SPHERES National Lab | SDP Enclosure Top Test | SPH-SDP-PRO | July 30, 2014 | |

# Procedure

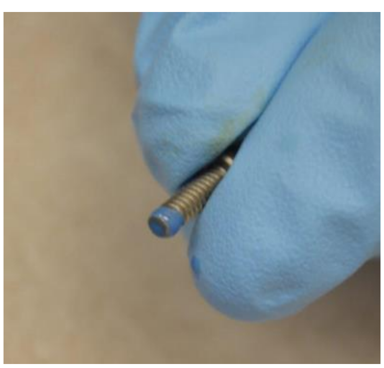
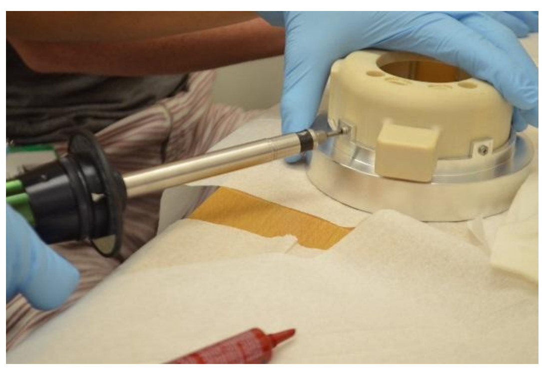
**Materials:**

- *SDP-SP-102-SDP Enclosure Top*
- Custom machined SDP Adapter Plate
- Calipers
- Loctite 242
- Four #4-40 ⅜" 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 treads 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.

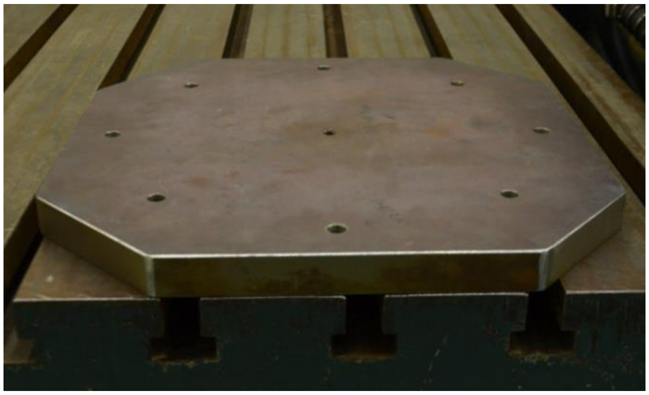


Figure 4: Testing Platform set on a flat table.

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

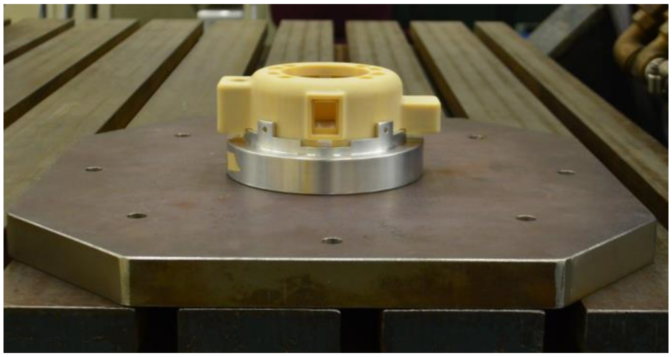


Figure 5: SDP Adapter Plate with attached 3-D printed Ultem 9085 Enclosure Top on the Testing Platform.

## 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.

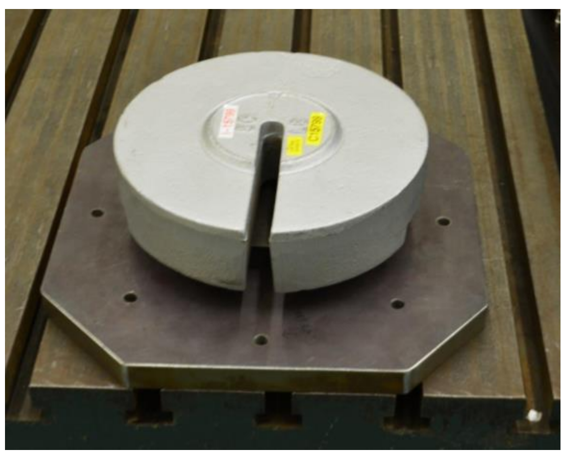


Figure 6: A 50 lb weight set on top of the Contact Disk.

3.1.3. Stack another 50 lb weight on top of the previous 50 lb weight so that it sits snuggly 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.

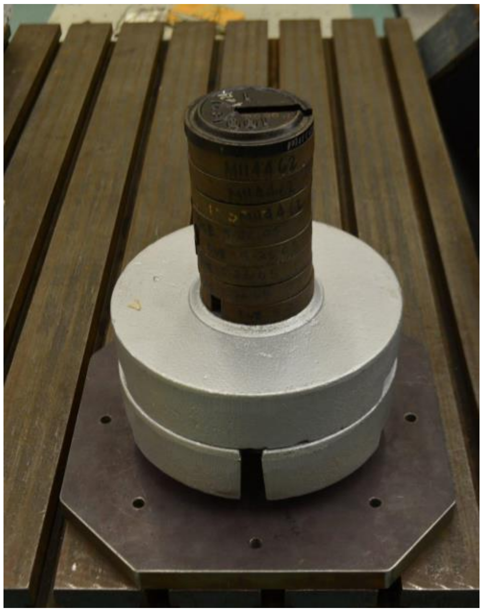


Figure 7: The final stack of 125lbs will appear like this.

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 torqueing of the screw.

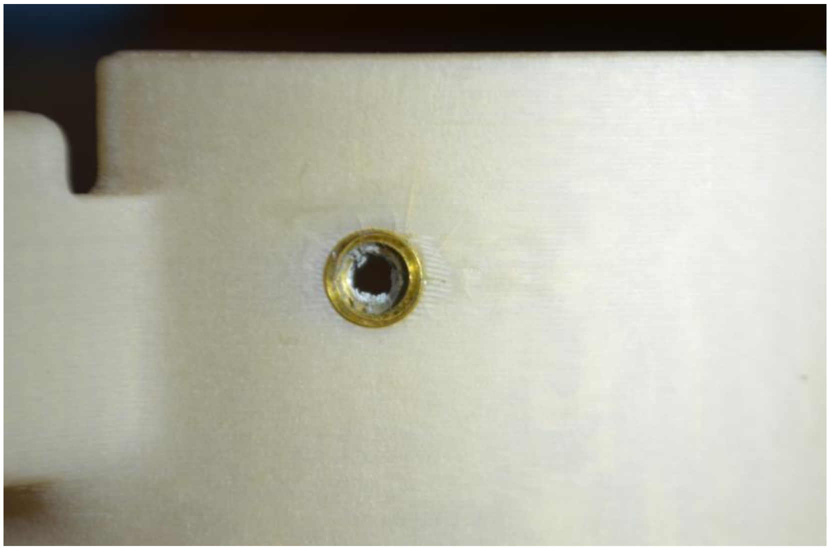


Figure 8: Radial cracks around the threaded insert

## 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)**

HUNTSMAN

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.<br><br>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<br>Dip, spray, and spread applications |
| **Advantages** | Low outgassing<br>Repairable<br>Low modulus<br>Mil spec MIL-I-46058C approved<br>IPC CC 830 Amendment 1 Type UR class 3 approved |

## 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.

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 25ºC (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 x $10^{-2}$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.

| | |
|---|---|
| **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.<br><br>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.<br><br>Suggested procedure for reducing viscosity of Arathane 5750 A/B (LV):<br>• To 100 pbw of Arathane 5750 B (LV) add 20 pbw of 5750 Thinner, mix well.<br>• To above mixture add 18 pbw of Arathane 5750 A, mix well.<br><br>Spray equipment manufacturers:<br>• Zicon, Mount Vernon, NY – airless inert carrier system<br>• Binks, Franklin Park, IL – conventional air system<br>• 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).<br><br>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. |

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 100ºC (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 65–80ºC 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 100ºC (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.<br>**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.<br>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.<br>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 80ºC. 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 50ºC 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 |

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 $10^{-6}$ 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 $10^{11}$ |

| 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<br><br>**Arathane 5750 A/B (LV)**<br>**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.<br><br>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. |
|---|---|

## 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 MERCHANTIBILITY 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, CONSEQUENTAL 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
Tel.: (914) 785-3000
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Arathane 5750-A/B (LV)
January, 2004

## BJB TC 1614

BJB ENTERPRISES

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 | $3.2 \times 10^5$ |
| Elongation, (%) ASTM D638 | 5 |
| Flexural Strength, (psi) ASTM D790 | 12,600 |
| Flexural Modulus, (psi) ASTM D790 | $3.8 \times 10^5$ |
| 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.

## 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



## 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.**

## 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.

## 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 adhesive 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) | 65,000 | 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 |
|---|---|
| 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**

| (@ 25°C unless noted) | Typical Value |
|---|---|
| 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-1706, 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 | |
|---|---|---|
| Lapshear | $N/mm^2$ | (psi) |
| 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 | $N/mm^2$ | (psi) |
|---|---|---|
| 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**

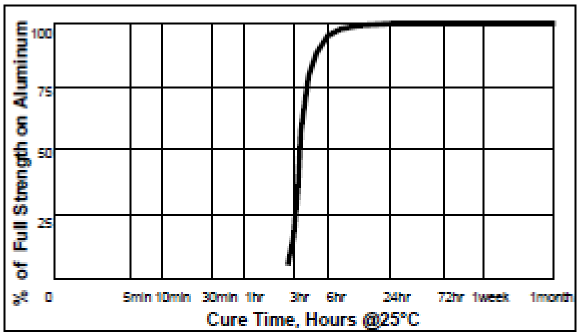
| | |
|---|---|
| Test procedure : | ASTM D-1002 |
| Substrate: | Abraded, acid etched aluminum |
| Bondline gap, mils: | 3 to 9 |
| Cure procedure: | 12 hours at 65°C & 4 hours at 22°C |

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.

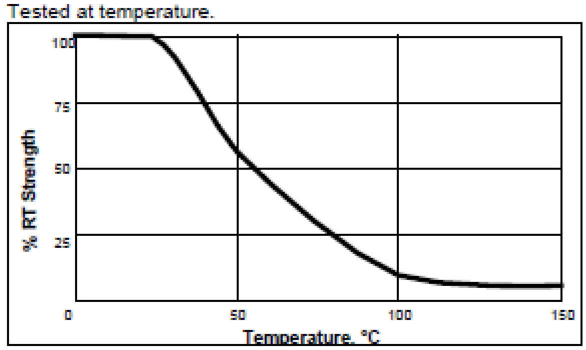



**TYPICAL ENVIRONMENTAL RESISTANCE**

**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 |

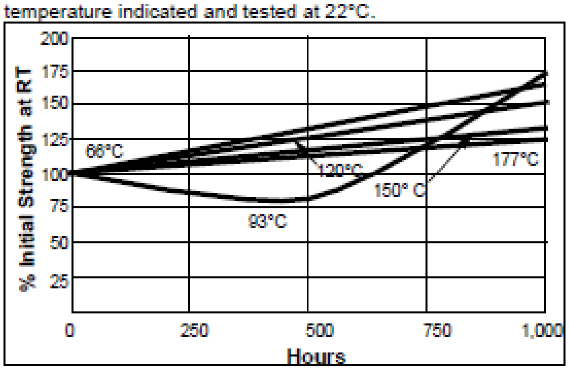
Tested at temperature.




**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 (860)-571-5473 DUBLIN, IRELAND FAX: +353-(1)-451 - 9959**

**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

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 contaminates such as paint, oxide films, oils, dust, mold release agents and all other surface contaminates.
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.

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 herein of various processes or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Loctite Corporation patents that may cover such processes or compositions. We recommend that each prospective user test his proposed application before repetitive use, using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.

## 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[LMS] |
| Fluorescence | Positive under UV light[LMS] |
| Emulsification | Disperses in water - does not seperate as oily layer[LMS] |
| 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 | $N/mm^2$<br>(psi) | 1,790<br>(260,000) |
| Flexural Modulus , ASTM D790 | $N/mm^2$<br>(psi) | 1,740<br>(250,000) |

**Electrical Properties**

| | |
|---|---|
| Volume Resistivity, IEC 60093, Ω·cm | $9\times10^{13}$ |
| 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.

## 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, $K^{-1}$ | $7.94 \times 10^{-5}$ |
| 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 160 °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.

| | | % of initial leak | | | |
|---|---|---|---|---|---|
| Environment | °C | 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
$N/mm^2$ 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

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**

## ProBuild Marine

PRODUCT BULLETIN

**PROBUILD MARINE EPOXY SYSTEMS**

LAMINATING SYSTEM

www.CASSpolymers.com 800.344.7776 ADTECH@CASSpolymers.com
31200 Stephenson Hwy Madison Heights MI 48071 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

| HANDLING CHARACTERISTICS @ 25°C/77°F | FAST | MEDIUM | SLOW | TROPICAL |
|---|---|---|---|---|
| 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.***

| PHYSICAL PROPERTIES (Cast Bar) | FAST | MEDIUM | SLOW | TROPICAL |
|---|---|---|---|---|
| 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

# Measuring Devices

## Interface Load Cell 5K lb Data Sheet

**SPECIFICATIONS**

| PARAMETERS | MODEL 1111 | MODEL 1111 | MODEL 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 to115 | 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 |

| | | | |
|---|---|---|---|
| **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 |

interface
ADVANCED FORCE MEASUREMENT

# LOAD CELL CALIBRATION CERTIFICATION

CONDITION: FINAL
MODEL: 1110AF-5K SERIAL: 468166 BRIDGE: A CAPACITY: 5 Klbf
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 Klbf | -Out to -Exc |
| COMPRESSION | 30.0 KOhm | -2.90223 mV/V | 3.5203 Klbf | -Out to +Exc |

*For models wired with +Sense, - Sense or -SCal 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 |

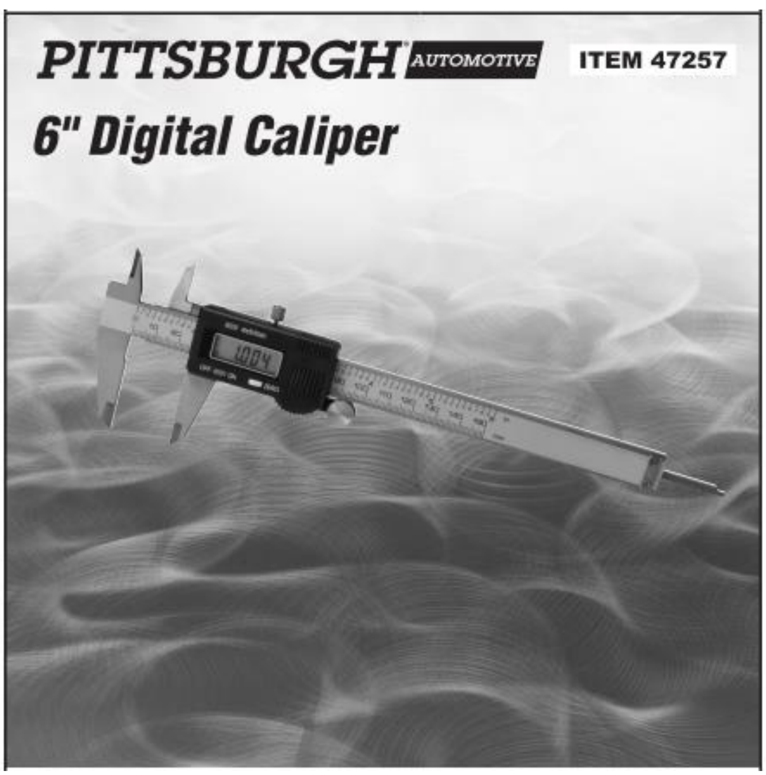
STATIC ERROR BAND (SEB) The band of maximum deviations of the ascending and descending calibration points from a best fit straight line through zero OUTPUT. It includes the effects of NONLINEARITY, HYSTERESIS, and nonreturn to MINIMUM LOAD.

| 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



## 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

## 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 |

**Shadograph**

*Figure C1: The Shadograph*


*Figure C2: Calibration information for the shadograph*

| | |
|---|---|
| Capacity | 75 lbs |
| Readability | 0.01 lb |

# 7.0 References

[1] “Arathane 5750,” Krayden [http://krayden.com/arathane-5750-lv/ Accessed 4/4/2014.]

[2] Bagsik, A., and Schöppner, V., “Mechanical Properties of Fused Deposition Modeling Parts Manufactured with Ultem 9085”, Annual Technical Conference, Boston, 2011, pp. 1294-1298.

[3] Davies, I., and Dong, C., “Flexural and Tensile Moduli of Unidirectional Hybrid Epoxy Composites Reinforced by S-2 glass and T700S Carbon Fibres”, Materials and Design, Vol. 54, 2014, pp. 893-899.

[4] Espalin, D., Arcaute, K., Anchondo, E., Adame, A., Medina, F., Winker, R. Hoppe, T., and Wicker, R., “Analysis of Bonding Methods for FDM-Manufactured Parts,” 21st Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, 2010, pp. 37-47.

[5] Fischer, M., and Schöppner, V., “Some Investigations Regarding the Surface Treatment of Ultem*9085 Parts Manufactured with Fused Deposition Modeling”, 24th International SFF Symposium - An Additive Manufacturing Conference, 2013, pp. 805-815.

[6] Hopman, C., and Klein, J., “Determination of Strain Rate Dependent Material Data for FEA Crash Simulation of Polymers using Digital Image Correlation.” Computational Materials Science, Vol. 100, 2015, pp. 181–190.

[7] “Loctite 5110 Porosity Sealant,” Henkel. [http://www.henkelna.com/product-search-1554.htm?nodeid=8797949788161. Accessed 4/4/2014.]

[8] “Loctite E-20HP Hysol Epoxy Structural Adhesive, Fast Setting,” Henkel. [http://www.henkelna.com/product-search-1554.htm?nodeid=8797912727553 Accessed 4/4/2014.]

[9] “Modulus of Elasticity,” Instron. [http://www.instron.us/wa/glossary/Modulus-of-Elasticity.aspx Accessed 5/13/2014.]

[10] Meng, M., Le, H., Rizvi, M., Grove, S., 3D FEA Modelling of Laminated Composites in Bending and Their Failure Mechanisms. Composite Structures. Vol. 119, 2015, pp. 693-708.

[11] Mujika, F., and Carbajal, N., Arrese, A., Mondragon, I., “Determination of Tensile and Compressive Moduli by Flexural Tests.” Polymer Testing. Vol. 25, 2006, pp. 766-771.

[12] Opperman, R. [ropperman@aurora.aero]. “3D Printed UDP Enclosure Top Testing.” Private e-mail message to Emmet Fox, [emmet.j.fox@nasa.gov]. 29 July 2014.

[13] Powers, E. C., “Outgassing Data for Selecting Spacecraft Materials,” NASA, December 2014. [http://outgassing.nasa.gov. Accessed 4/22/14.]

[14] “ProBuild Marine Epoxy Laminating Resin,” Axson Technologies. [http://www.adtechplastics.com/p-83-probuild-marine-epoxy-laminating-systems.aspx. Accessed 4/4/2014.]

[15] Sideridis, E., and Papadopoulos, G. A., “Short-beam and three-point-bending tests for the study of shear and flexural properties in unidirectional-fiber-reinforced epoxy composites”, Journal of Applied Polymer Science Vol. 93, 2004. [http://onlinelibrary.wiley.com/doi/10.1002/app.20382/pdf. Accessed 5/23/14.]

[16] “SPHERES: Mission Overview,” NASA. [http://www.nasa.gov/spheres/mission.html Accessed 3/22/2014].

[17] “Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials,”ASTM International. [http://www.astm.org/Standards/D790.htm. Accessed 7/20/2014.]

[18] “TC-1614 A/B: High Solids Content Epoxy Penetrating Sealing and Coating Resin System,” BJB Enterprises. [http://www.bjbenterprises.com/tc-1614-a-b/ Accessed 4/4/2014.]

[19] “Ultem 9085: 3D Print High-Performance Parts in Tan or Black,” Stratasys. [http://www.stratasys.com/materials/fdm/ultem-9085 Accessed 3/20/2014.]

[20] “Ultem Resin,” Sabic. [https://www.sabic-ip.com/gep/Plastics/en/ProductsAndServices/ProductLine/ultem.html Accessed 4/23/14.]

[21] Yagnik, D., “Fused Deposition Modeling – A Rapid Prototyping technique Product Cycle Time Reduction cost effectively in Aerospace Applications,” International Conference on Advances in Engineering & Technology, 2014, pp. 69-91.