

Measurement of mechanical properties of three epoxy adhesives at cryogenic temperatures for CCD construction

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November 6, 2006

Abstract

Materials testing of an adhesive for bonding Silicon to a substrate is presented. Test results include Young's Modulus, Poisson's Ratio, and the coefficient of thermal expansion at temperatures ranging from room temperature to 100 K. Data for 3 epoxies (Tra-Con F113, Epotek 301-2, Hysol 9361) are presented.

1 Introduction

The SNAP CCD focal plane has to meet stringent performance requirements, especially on flatness. As the CCDs are manufactured at room temperature and will operate at 130 K in space, it is necessary to characterize their behavior as a function of temperature. In addition, it is expected that the CCD focal plane will undergo thermal cycles in space. As the construction materials (Si, AlN, SiC) have different coefficients of thermal expansion (CTE), there may be stress on all of the epoxy joints. NASA has criterion on the stress/strength relation for such joints [1]. This note details tensile strength tests and coefficient of thermal expansion measurements on proposed epoxies for use in the CCD assembly.

Tensile strength tests to measure Young's Modulus and Poisson's Ratio [2] were performed at Precision Measurements and Instruments Corporation (PMIC) [3] at 5 temperatures (295K, 250K, 200K, 150K, 100K). An additional measurement was made at Fermilab at 295K. Measurements of the CTE from 77 K to 295 K were made at Fermilab.

Three epoxies were measured, Hysol 9361, Tra-Con F113, and Epotek 301-2. The Hysol is being considered for the AlN-SiC joint, the Tra-Con and Epotek for the CCD-AlN joint. In Table 1, we summarize the properties of the glue joints as reported by the manufacturer.

The Hysol sets in 24 hours, with a full cure in 7 days at room temperature. The epoxy samples used in the tensile strength tests had a 7 day cure. For the Hysol CTE measurements, we used a sample with an accelerated 2 day cure. For the Epotek and Tra-Con CTE measurements, measurements were made with samples with both a 2 day cure and a 7 day cure. The Epotek epoxy has an additional manufacturing specification on residuals ions (salts) in the resin which is important for silicon bonding applications.

Epoxy	Modulus	Viscosity	CTE @ 295 K
Hysol 9361	723 MPa	1000 Pa s	-
Tra-Con F113	-	180 cps @25 C	55 ppm/C
Epotek 301-2	-	225-425 cps	37 ppm/C

Table 1: Epoxy properties as provided by the manufacturers.

Ambient			
Tra-Con F113	Elastic Modulus (psi)	356886 $\pm$ 12523	3.51%
	Poisson's Ratio	0.401 $\pm$ 0.003	0.64%
	Maximum Stress (psi)	2539 $\pm$ 86	3.40%
Epotek 301-2	Elastic Modulus (psi)	531427 $\pm$ 6166	1.16%
	Poisson's Ratio	0.358 $\pm$ 0.001	0.35%
	Maximum Stress (psi)	3751 $\pm$ 45	1.21%
Hysol 9361	Elastic Modulus (psi)	154678 $\pm$ 1526	0.99%
	Poisson's Ratio	0.433 $\pm$ 0.007	1.67%
	Maximum Stress (psi)	1153 $\pm$ 9	0.77%

Table 2: Epoxy properties as measured at ambient temperatures.

2 Tensile Tests

Tensile tests were performed by PMIC and also the Fermilab Material Testing Group. Both tests used samples prepared at Fermilab. The samples were dogbone shaped and machined out of cast plates of epoxy. The samples were degassed to minimize the number and size of air bubbles. We note that the Hysol samples did have visible bubbles on the machined surfaces.

PMIC measurements were performed per ASTM method D-638. Five dogbones of each epoxy were measured at 5 temperatures (295K, 250K, 200K, 150K, 100K). The sample modulus was calculated using the Secant Method at a 0.68% strain (or the highest strain achieved if the sample failed before that level). The Hysol samples did fail before 0.68% strain was achieved for the lower temperature measurements. Tables 2, 3, 4, 5, and 6 summarize the measurements. The full report from PMIC is included as Appendix 1.

The Fermilab Material Testing group also performed a tensile measurement at ambient temperature on the three epoxies. The steepest slope over a series of ranges was used to calculate

250 K			
Tra-Con F113	Elastic Modulus (psi)	519361 $\pm$ 16547	3.19%
	Poisson's Ratio	0.372 $\pm$ 0.005	1.25%
	Maximum Stress (psi)	3527 $\pm$ 120	3.41%
Epotek 301-2	Elastic Modulus (psi)	595903 $\pm$ 16547	3.19%
	Poisson's Ratio	0.365 $\pm$ 0.004	1.05%
	Maximum Stress (psi)	4115 $\pm$ 79	1.91%
Hysol 9361	Elastic Modulus (psi)	239242 $\pm$ 4375	1.83%
	Poisson's Ratio	0.435 $\pm$ 0.004	1.02%
	Maximum Stress (psi)	1736 $\pm$ 35	2.02%

Table 3: Epoxy properties as measured at 250 K.

200 K

Tra-Con F113	Elastic Modulus (psi)	615588 $\pm$ 26807	4.35%
	Poisson's Ratio	0.368 $\pm$ 0.003	0.69%
	Maximum Stress (psi)	4272 $\pm$ 198	4.64%
Epotek 301-2	Elastic Modulus (psi)	648860 $\pm$ 12482	1.92%
	Poisson's Ratio	0.349 $\pm$ 0.005	1.32%
	Maximum Stress (psi)	4471 $\pm$ 99	2.22%
Hysol 9361	Elastic Modulus (psi)	560786 $\pm$ 11976	2.14%
	Poisson's Ratio	0.357 $\pm$ 0.005	1.27%
	Maximum Stress (psi)	3912 $\pm$ 84	2.15%

Table 4: Epoxy properties as measured at 200 K.

150 K

Tra-Con F113	Elastic Modulus (psi)	886035 $\pm$ 40429	4.56%
	Poisson's Ratio	0.367 $\pm$ 0.008	2.28%
	Maximum Stress (psi)	5983 $\pm$ 264	4.42%
Epotek 301-2	Elastic Modulus (psi)	833220 $\pm$ 14089	1.69%
	Poisson's Ratio	0.334 $\pm$ 0.007	2.16%
	Maximum Stress (psi)	5681 $\pm$ 106	1.87%
Hysol 9361	Elastic Modulus (psi)	822654 $\pm$ 14072	1.71%
	Poisson's Ratio	0.357 $\pm$ 0.012	3.46%
	Maximum Stress (psi)	4641 $\pm$ 79	1.71%

Table 5: Epoxy properties as measured at 150 K.

100 K

Tra-Con F113	Elastic Modulus (psi)	1105895 $\pm$ 40675	3.69%
	Poisson's Ratio	0.348 $\pm$ 0.005	1.44%
	Maximum Stress (psi)	7092 $\pm$ 649	9.15%
Epotek 301-2	Elastic Modulus (psi)	1014310 $\pm$ 14384	1.42%
	Poisson's Ratio	0.350 $\pm$ 0.008	2.34%
	Maximum Stress (psi)	6783 $\pm$ 162	2.39%
Hysol 9361	Elastic Modulus (psi)	1132056 $\pm$ 13051	1.19%
	Poisson's Ratio	0.353 $\pm$ 0.016	4.55%
	Maximum Stress (psi)	4225 $\pm$ 201	4.76%

Table 6: Epoxy properties as measured at 100 K.

Ambient			
Tra-Con F113	Elastic Modulus (ksi)	384.84 $\pm$ 85.7	22.2%
	Ultimate Tensile Strength (psi)	4798.2 $\pm$ 569.1	11.9%
Epotek 301-2	Elastic Modulus (ksi)	650.6 $\pm$ 176.2	% 27.1
	Ultimate Tensile Strength (psi)	9664.2 $\pm$ 1769.6	18.3%
Hysol 9361	Elastic Modulus (ksi)	137.5 $\pm$ 17	12.3%
	Ultimate Tensile Strength (psi)	2400.4 $\pm$ 190.6	7.94%

Table 7: Epoxy properties as measured at ambient temperatures by the Fermilab Material Properties Testing group.

the modulus. The crosshead pull speed was greater than 0.05 inches per minute. The results are summarized in Table 2.

3 Coefficient of Thermal Expansion Measurements

CTE measurements were made at Fermilab. The measurements were performed in the spirit of ASTM-E831. Samples were approximately 8 mm $\times$ 8 mm $\times$ 20 mm, machined from samples cast in a mold. Each sample was vacuum degassed during the casting to minimize the size and number of trapped gas bubbles.

The CTE was measured by placing the sample in a holder inside of a cryostat. Liquid nitrogen is poured into the cryostat. Once the temperature stabilized at 77 K, a heater is used to ramp the temperature to ambient temperature with a rate of 1-2deg C/minute. An LVDT [4] at the top of the sample measured the change in sample length. The length and temperature were recorded during the cooldown and the warmup. In Figure 1, we show a picture of the sample in the holder. The LVDT is at the top of the picture, connected via quartz rods to the sample holder. The sample holder is installed inside the cryostat. We report the integral fractional change in length (dL/L) of the sample as a function of temperature in Table 8. In Figures 2, 3, and 4, we show the fractional change in length as a function of temperature for one sample of Tra-Con F113, Epotek 301-2, and Hysol 9361. In Figure 5, we show a representative time ramp for one of the measurements.

4 Stress/Strength Ratios

The NASA guideline for epoxy joints [1] is a safety margin of a factor of 2 on the stress. With the measured modulus and CTE, we can calculate the expected stress on the joint and compare to yield strength, using the following logic:

$$\begin{aligned}
 \text{Modulus} &= \frac{\text{Stress}}{\text{Strain}} \\
 \text{Strain} &= \frac{dL}{L} \\
 \frac{dL}{L} (\text{epoxy}) &= \text{CTE} (\text{epoxy}) \times \Delta T
 \end{aligned} \tag{1}$$

With the assumption that the CTE of the substrate is small compared to the epoxy, the stress on the joint is simply:

$$\text{Stress} = \text{Modulus} \times \text{CTE} (\text{epoxy}) \times \Delta T \tag{2}$$

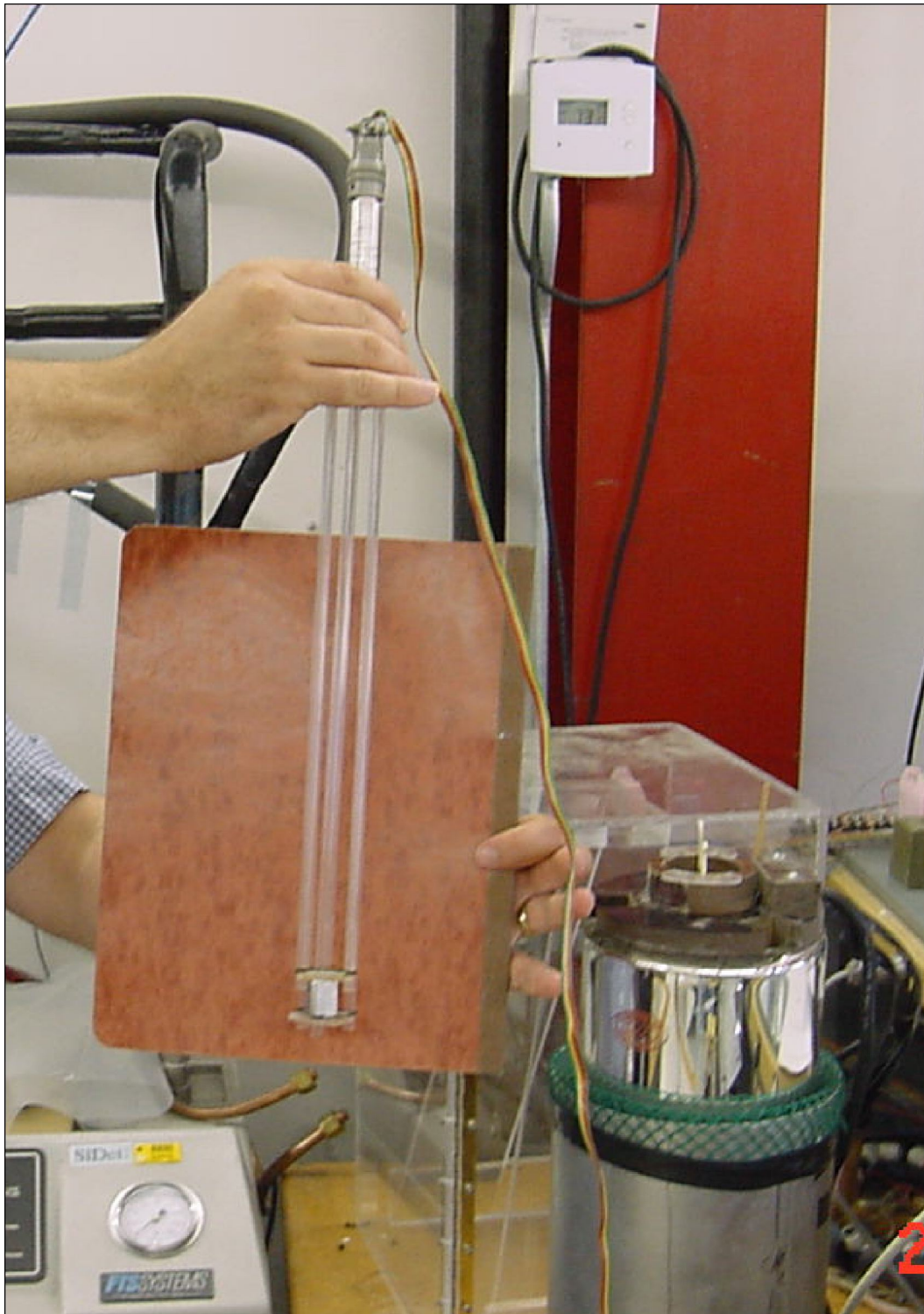


Figure 1: The sample holder for use in the dL/L measurements.

Ambient Temperature		
Tra-Con F113 dL/L ($\times 10^{-3}$)	—	—
Epotek 301-2 dL/L ($\times 10^{-3}$)	—	—
Hysol 9361 dL/L ($\times 10^{-3}$)	—	—
250 K		
Tra-Con F113 dL/L ($\times 10^{-3}$)	-3.27 ± 0.13	3.94%
Epotek 301-2 dL/L ($\times 10^{-3}$)	-2.83 ± 0.04	1.52%
Hysol 9361 dL/L ($\times 10^{-3}$)	-4.69 ± 0.04	0.8%
200 K		
Tra-Con F113 dL/L ($\times 10^{-3}$)	-6.20 ± 0.11	1.73%
Epotek 301-2 dL/L ($\times 10^{-3}$)	-5.45 ± 0.03	0.59%
Hysol 9361 dL/L ($\times 10^{-3}$)	-8.69 ± 0.02	0.3%
150 K		
Tra-Con F113 dL/L ($\times 10^{-3}$)	-8.71 ± 0.06	0.76%
Epotek 301-2 dL/L ($\times 10^{-3}$)	-7.70 ± 0.11	1.37%
Hysol 9361 dL/L ($\times 10^{-3}$)	-11.3 ± 0.003	0.2%
100 K		
Tra-Con F113 dL/L ($\times 10^{-3}$)	-10.7 ± 0.08	0.72%
Epotek 301-2 dL/L ($\times 10^{-3}$)	-9.66 ± 0.18	1.88%
Hysol 9361 dL/L ($\times 10^{-3}$)	-13.3 ± 0.03	0.2%

Table 8: Integral dL/L for the three epoxies as measured at the 5 temperatures.

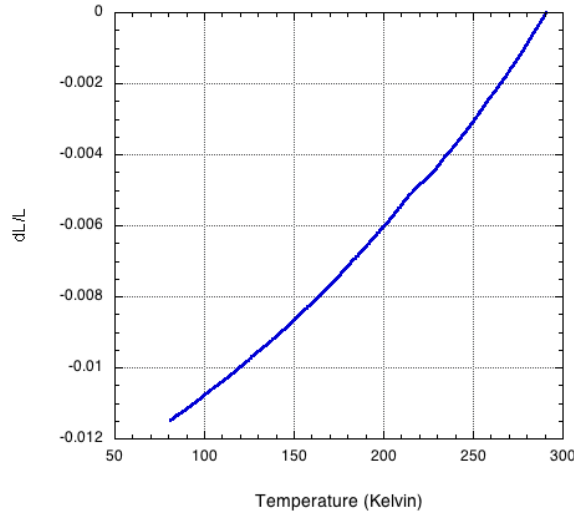


Figure 2: The integral dL/L vs temperature for a representative Tra-Con F113 sample.

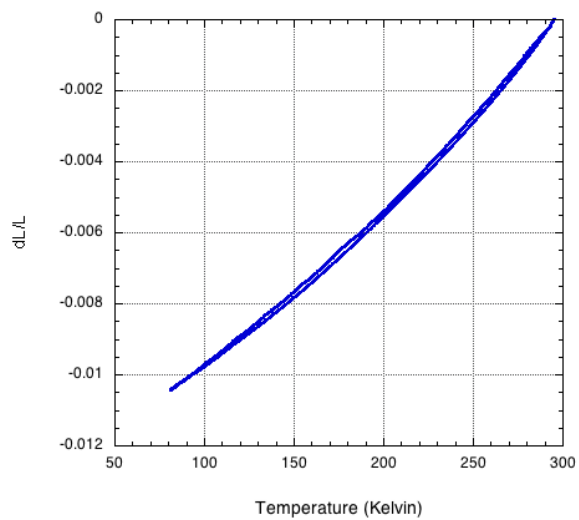


Figure 3: The integral dL/L vs temperature for a representative Epotek 301-2 sample.

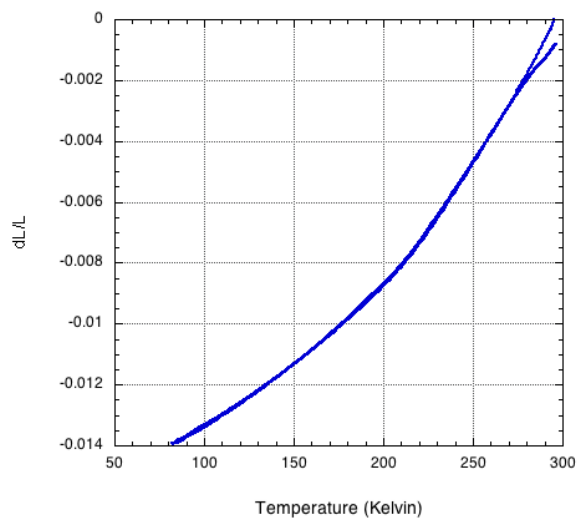


Figure 4: The integral dL/L vs temperature for a representative Hysol 9361 sample.

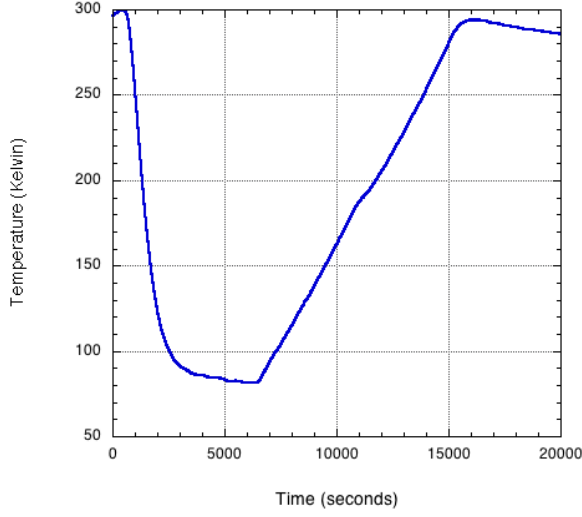


Figure 5: The temperature vs time for a representative CTE measurement.

	Ambient	250 K	200 K	150 K	100 K
Tra-Con F113	—	2.8	1.1	0.76	0.65
Epotek 301-2	—	5.9	2.7	1.5	1.0
Hysol 9361	—	2.1	0.83	0.5	0.29

Table 9: The ratio of strain to stress as defined in equation 3.

A criterion that the yield strength must be more than twice the stress leads to the requirement that

$$\frac{\text{yield strength (epoxy)}}{\text{Modulus} \times \text{CTE (epoxy)} \times \Delta T} > 2. \quad (3)$$

The stress reported in the data sets is not the epoxy yield strength, it is the strength at 0.68% strain. A conservative guideline can still be determined if the maximum stress achieved is used in the calculations as a proof stress. We will use either the room temperature ultimate strength or the maximum stress applied to the sample at temperature, whichever is larger. As the strength is known to increase with decreasing temperature, this selection is a conservative approach. In Table 9, we show the ratio of strength over stress as defined above.

The Epotek has the lowest bond strain and, at ambient temperature, the highest ratio of maximum strength to strength at 0.68%. Although none of the epoxies meet the criteria for temperatures below 200 K, it does not mean the joint will fail. We have chosen to take a conservative approach in the calculation of the maximum stress. In addition, the tensile strength data collected was taken at high pull rates (0.10 inch/minute for the PMIC tests). Epoxies, as with most plastics, are visco-elastic materials which respond differently based on how quickly the load is transferred to the material. The high rates of strain applied to the samples during testing will have a much higher modulus and stress than in the actual application. During flight, the CCD focal plane will have a cool down rate of 3 degrees per minute, taking at least 20 minutes to achieve operating temperature and allowing the epoxy to creep and relieve some

of the stresses.

5 Conclusions

We have presented measurements on epoxy properties for use in the SNAP CCD assembly, covering temperatures from ambient to 100 K. Test results on Young's Modulus, Poisson's Ratio, and integral dL/L have been presented. A criterion for the epoxy has been proposed.

References

- [1] NASA-STD-5001 - Structural Design and Test Factors of Safety for Spaceflight Hardware
- [2] Young's Modulus is the ratio of tensile stress to tensile strength and is a measure of how a material changes length under tension or compression. Poisson's Ratio is defined as the strain normal to an applied load divided by the strain in the direction of the applied load and is a measure of the material's tendency to get thinner as it is stretched or thicker as it is compressed.
- [3] Precision Measurements and Instruments Corporation, 3665 SW Deschutes Street, Corvallis, OR 97333
- [4] LVDT stands for Linear Variable Differential Transformer, outputting a voltage dependent upon physical displacement.

FERMILAB

PURCHASE ORDER NUMBER 565015

**ELASTIC PROPERTY MEASUREMENTS OF
EPOXY SPECIMENS**

February 28, 2006

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ELASTIC PROPERTY MEASUREMENTS OF EPOXY SPECIMENS

WORK CONDUCTED FOR FERMILAB
PURCHASE ORDER NUMBER 565015

February 28, 2008

Procion Measurements and Instruments Corporation measured the elastic properties of 75 epoxy resin specimens. Coupons were prepared for Modulus testing and Poisson's Ratio testing. Testing was conducted at 100K, 150K, 200K, 250K and ambient temperatures. Testing was performed per ASTM method D-838. Results are presented in the attached tables. A brief description of the test procedure, data analysis and comments on the results follow.

Specimen Description

Farmilab provided the following specimens.

Quantity	Description	Length	Width	Thickness
35	Tracon F113	8.0"	1.0"	0.125"
31	Epo-Tek 801-2	8.0"	1.0"	0.125"
33	Hysol ES 8561	8.0"	1.0"	0.125"

Test Procedure

• Specimen Check-In

The specimens were received on December 19th, January 11th and January 12th, via Federal Express. The specimens were inspected for damage. No damage was observed. However, it was noted that the Hysol specimens had bubbles visible on the machined surfaces. The specimens were stored at room temperature prior to measurement. A complete list of the specimens is located at the end of the report.

• Specimen Preparation

The specimen preparation and strain gage attachment procedures suggested by the strain gage supplier were followed. Micro-Measurements CEA 08-125UT-350 strain gages were used for both axial and lateral strain measurement on the specimens. Strain gages were bonded to each side of the specimen at corresponding positions, using Micro-Measurements M-Bond AE-10 adhesive. The specimens were clamped and cured for 8+ hours at 495°F. Each gage was then wired in series to the corresponding gage on the opposite surface to account for specimen bending. In a few cases the strain gages were shifted axially on the specimen to avoid placing them close to the bubbles.

• Test Procedure

The tensile test machine crosshead speed was set to 0.10 inch/minute. 2 VDC strain gage excitation was used. The specimens were first secured in the machine with the top wedge grip, centered and aligned with the direction of force. For the low temperature tests three dogbonds

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1/027
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were placed at three points in the vicinity of the strain gages. The gauge portion of the specimen was enclosed in an insulated chamber. Liquid nitrogen was used to achieve cooling for the 100 K, 150 K, 200 K and 250 K tests. The cryogen was directed close to the proximity of the specimens on either side by dual spray bars. Approximately 20-60 minutes was allowed for the specimens to equilibrate at the desired temperatures. At this point the strain gage conditioning circuitry was balanced, the lower wedge grip tightened and the test started. The load was applied to the specimens by movement of the upper grip until the limits of the strain gage were reached, failure occurred, or the specimens began to yield outside of the gauge section. Load, strain, and temperature data were recorded every half second.

• Analysis

The various elastic properties were calculated over certain strain ranges selected to coincide with a level obtained by all, or nearly all, specimens. The first data point used for all calculations was generally the first positive point after all slack was removed. The last data point was generally the limit of the axial strain gage electronics, ~6800 $\mu\text{in/in}$. In some cases the last point was limited by break-up or yielding outside of the temperature controlled zone. In a few cases the endpoints were shifted somewhat due to unusual temperature fluctuations. The secant modulus was calculated by taking the change in axial stress divided by the change in axial strain between the chosen endpoints. Poisson's Ratio was calculated by using the change in transverse strain divided by the change in axial strain at the same endpoints. The nominal dimensions were used in all of the calculations.

Test Results

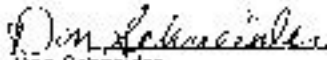
The results are presented in tabular format in Table 1. The stress and strain of the maximum endpoint at which each property is calculated are listed with the results. The properties may be determined for other strain ranges. The raw stress and strain data is being supplied to the requesting engineer.

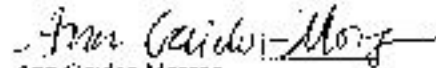
Some of the specimens broke during the test. The location of the break was always in the area of the specimen held by the upper grip or right beneath it. All but two of the broken specimens were in the Hysol group. In this group, three out of five of the 100 K specimens broke, all of the 150 K specimens broke, and one of the ambient specimens broke. This could have been due to bubbles which were visible in these specimens. In every case of a break, a bubble could be seen in the fractured surfaces. In one of the Hysol specimens the strain gage was slightly offset vertically in order to avoid a bubble. This specimen did not break. In addition, one of the Epo-Tek specimens broke, at 200 K, and one of the Incon specimens broke, at 100 K.

Possible sources of error include the presence of bubbles in the specimens, the impact of the strain gages on the material and temperature gradients. Digital control of the cryogen flow also induced some degree of temperature fluctuation, which is evident in some of the strain data.

Please contact our technical staff at (541) 753-0607 if you have any questions or require additional information regarding these measurements.

Submitted by:


Don Schneider
Project Engineer


Ann Gaidoe-Morgan
Test Technician

Production Measurements and Performance Data reported herein were obtained by testing as based on relevant ASTM standards, calibrations with NIST standard reference materials and/or published procedures. These measurements are solely for test results to establish a record of the current test result.

TABLE 1. ELASTIC MODULUS AND POISSON'S RATIO

Ambient (295 K)					
Specimen	Elastic Modulus psi	Poisson's Ratio	Maxim. Strain %	Max. Stress psi	Max. Strain %
TR 5-1	322,203	0.382	0.80	2,324	2.324
TR 8-4	365,837	0.437	0.69	2,637	2.637
TR 9-4	360,047	0.436	0.69	2,771	2.771
TR 9-5	369,232	0.403	0.78	2,611	2.611
TR 11-5	323,016	0.396	0.59	2,352	2.352
ave	366,886	0.401	—	2,521	2.521
st dev	28,002	0.006	—	—	—
ET 1-5	641,517	0.352	0.69	3,404	3.404
ET 2-5	637,259	0.358	0.69	3,791	3.791
ET 7-5	642,096	0.362	0.68	3,652	3.652
ET 9-5	610,372	0.359	0.68	3,669	3.669
ET 20-5	624,758	0.350	0.65	3,758	3.758
ave	631,427	0.358	—	3,699	3.699
st dev	63,767	0.003	—	5,751	5.751
HS 2-5	155,524	0.452	0.59	1,736	1.736
HS 5-5	159,330	0.434	0.50	1,775	1.775
HS 16-5	150,287	0.406	0.58	1,422	1.422
HS 17-5	155,575	0.403	0.68	1,162	1.162
HS 18-5	152,374	0.428	0.60	1,119	1.119
ave	154,678	0.433	—	1,521	1.521
st dev	3,413	0.016	—	—	—

250 K					
Specimen	Elastic Modulus psi	Poisson's Ratio	Maxim. Strain %	Max. Stress psi	Max. Strain %
TR 5-1	515,354	0.369	0.27	2,479	2.479
TR 8-4	522,770	0.358	0.66	3,261	3.261
TR 9-4	545,348	0.375	0.67	3,403	3.403
TR 9-5	555,162	0.383	0.69	3,927	3.927
TR 11-5	467,474	0.373	0.67	3,179	3.179
ave	519,361	0.372	—	3,527	3.527
st dev	37,930	0.010	—	—	—
ET 1-5	637,270	0.365	0.67	4,355	4.355
ET 2-5	571,447	0.384	0.65	4,012	4.012
ET 7-5	624,021	0.359	0.63	4,235	4.235
ET 9-5	635,354	0.357	0.68	3,673	3.673
ET 20-5	597,128	0.379	0.63	4,246	4.246
ave	595,936	0.366	—	4,121	4.121
st dev	23,022	0.009	—	—	—
HS 2-5	233,015	0.442	0.58	1,990	1.990
HS 5-5	225,658	0.425	0.50	1,842	1.842
HS 17-5	241,043	0.445	0.60	1,512	1.512
HS 18-5	245,875	0.438	0.70	1,813	1.813
HS 19-5	241,677	0.434	0.66	1,724	1.724
ave	239,240	0.433	—	1,794	1.794
st dev	4,752	0.010	—	—	—

TABLE 1. ELASTIC MODULUS AND POISSON'S RATIO

200 K					
Specimen ID	Elastic Modulus (psi)	Poisson's Ratio	Maximum Strain (%)	Maximum Stress (psi)	
1B-0-3	607,155	0.267	0.80	4058	
1B-6-3	613,755	0.270	0.68	4235	
1B-8-3	637,905	0.271	0.85	4519	
1B-11-3	522,508	0.262	0.84	3510	
1B-16-3	581,552	0.274	0.87	4838	
ave	615,689	0.269		4177.2	
st dev	59,843	0.006			
1E-1-2	634,489	0.342	0.64	4427	
1E-2-2	678,992	0.358	0.59	4732	
1E-7-2	653,711	0.333	0.56	4181	
1E-16-2	654,135	0.331	0.58	4372	
1E-20-2	627,985	0.357	0.58	4842	
ave	648,980	0.349		4477	
st dev	27,818	0.010			
1H-14-2	703,702	0.347	0.59	4229	
1H-15-2	626,600	0.351	0.62	3734	
1H-17-2	591,845	0.365	0.65	3601	
1H-18-2	561,774	0.388	0.64	3570	
1H-19-2	559,852	0.381	0.69	3825	
ave	588,766	0.357		3717	
st dev	26,780	0.010			

150 K					
Specimen ID	Elastic Modulus (psi)	Poisson's Ratio	Maximum Strain (%)	Maximum Stress (psi)	
1B-0-2	870,858	0.355	0.60	5003	
1B-6-2	911,889	0.359	0.62	5242	
1B-8-2	939,737	0.368	0.67	6264	
1B-9-2	946,310	0.369	0.63	6383	
1B-11-2	791,770	0.350	0.62	4957	
ave	886,035	0.367		5474	
st dev	90,402	0.019			
1E-1-2	925,968	0.327	0.46	5104	
1E-2-2	893,247	0.361	0.48	5745	
1E-7-2	852,552	0.375	0.60	5802	
1E-16-2	755,872	0.322	0.69	5507	
1E-20-2	852,372	0.352	0.66	5614	
ave	853,220	0.334		5474	
st dev	31,565	0.015			
1H-14-2	731,235	0.322	0.52	4612	
1H-15-2	658,534	0.325	0.54	4893	
1H-17-2	617,872	0.354	0.55	4869	
1H-18-2	619,142	0.395	0.54	4730	
1H-19-2	608,535	0.338	0.55	4358	
ave	628,854	0.357		4677	
st dev	91,467	0.028			

TABLE 11. ELASTIC MODULUS AND POISSON'S RATIO

Specimen ID	100 K				
	Elastic Modulus psi	Poisson's Ratio	Maximum Strain %	Maximum Stress psi	Max. Strain %
TE 8.1	1,118,875	0.357	0.88		7515
TE 8.2	1,284,833	0.357	0.69		7633
TE 8.3	1,175,767	0.331	0.85		7182
TE 8.4	1,152,017	0.352	0.83		7775
TE 1.1	952,414	0.344	0.45		4514
ave	1,105,893	0.348			7757
st dev	91,153	0.011			
ET 1.1	1,032,227	0.350	0.59		6360
ET 2.1	1,022,822	0.326	0.80		6870
ET 1.1	1,062,459	0.375	0.20		7327
ET 20.1	1,039,725	0.347	0.88		8215
ET 19.1	974,314	0.345	0.86		6794
ave	1,014,310	0.350			7151
st dev	32,184	0.016			
HS 2.1	1,285,670	0.367	0.35		4225
HS 3.1	1,121,850	0.314	0.35		4479
HS 9.1	1,177,250	0.317	0.41		3768
HS 17.1	1,141,758	0.394	0.51		3202
HS 18.1	1,123,786	0.371	0.40		4333
ave	1,132,056	0.363			4025
st dev	30,190	0.036			

The following table is a listing of the Tracon test specimens

1) Tracon F113 TB_5_1 (100K) 8" X 1" X 0.13"	10) Tracon F113 TB_8_4 (250K) 8" X 1" X 0.13"
2) Tracon F113 TB_5_2 (150K) 8" X 1" X 0.13"	19) Tracon F113 TB_8_5 (300K) 8" X 1" X 0.13"
3) Tracon F113 TB_5_3 (200K) 8" X 1" X 0.13"	20) Tracon F113 TB_8_1 (100K) 8" X 1" X 0.13"
4) Tracon F113 TB_5_4 (250K) 8" X 1" X 0.13"	21) Tracon F113 TB_8_2 (150K) 8" X 1" X 0.13"
5) Tracon F113 TB_5_5 (300K) 8" X 1" X 0.13"	22) Tracon F113 TB_8_3 (200K) 8" X 1" X 0.13"
6) Tracon F113 TB_5_6 (Spare) 8" X 1" X 0.13"	23) Tracon F113 TB_8_4 (Spare) 8" X 1" X 0.13"
7) Tracon F113 TB_5_7 (Spare) 8" X 1" X 0.13"	24) Tracon F113 TB_8_5 (300K) 8" X 1" X 0.13"
8) Tracon F113 TB_5_1 (100K) 8" X 1" X 0.13"	25) Tracon F113 TB_8_6 (Spare) 8" X 1" X 0.13"
9) Tracon F113 TB_5_2 (150K) 8" X 1" X 0.13"	26) Tracon F113 TB_11_1 (100K) 8" X 1" X 0.13"
10) Tracon F113 TB_8_3 (200K) 8" X 1" X 0.13"	27) Tracon F113 TB_11_2 (150K) 8" X 1" X 0.13"
11) Tracon F113 TB_8_4 (250K) 8" X 1" X 0.13"	28) Tracon F113 TB_11_3 (200K) 8" X 1" X 0.13"
12) Tracon F113 TB_8_5 (300K) 8" X 1" X 0.13"	29) Tracon F113 TB_11_4 (250K) 8" X 1" X 0.13"
13) Tracon F113 TB_8_6 (Spare) 8" X 1" X 0.13"	30) Tracon F113 TB_11_5 (300K) 8" X 1" X 0.13"
14) Tracon F113 TB_8_7 (Spare) 8" X 1" X 0.13"	31) Tracon F113 TB_11_6 (Spare) 8" X 1" X 0.13"
15) Tracon F113 TB_8_1 (100K) 8" X 1" X 0.13"	32) Tracon F113 TB_12_1 (Spare) 8" X 1" X 0.13"
16) Tracon F113 TB_8_2 (150K) 8" X 1" X 0.13"	33) Tracon F113 TB_12_2 (Spare) 8" X 1" X 0.13"
17) Tracon F113 TB_8_3 (200K) 8" X 1" X 0.13"	34) Tracon F113 TB_12_3 (Spare) 8" X 1" X 0.13"
	35) Tracon F113 TB_12_4 (Spare) 8" X 1" X 0.13"

The following table is a listing of the Epo-Tek 301-2 specimens.

36) Epo-Tek 301-2 E1_1_1 (100K) 8" X 1" X 0.13"	53) Epo-Tek 301-2 ET_9_2 (Spare) 8" X 1" X 0.13"
37) Epo-Tek 301-2 E1_1_2 (150K) 8" X 1" X 0.13"	54) Epo-Tek 301-2 E1_7_1 (100K) 8" X 1" X 0.13"
38) Epo-Tek 301-2 E1_1_3 (200K) 8" X 1" X 0.13"	55) Epo-Tek 301-2 E1_7_2 (150K) 8" X 1" X 0.13"
39) Epo-Tek 301-2 E1_1_4 (250K) 8" X 1" X 0.13"	56) Epo-Tek 301-2 ET_7_3 (200K) 8" X 1" X 0.13"
40) Epo-Tek 301-2 ET_1_5 (300K) 8" X 1" X 0.13"	57) Epo-Tek 301-2 ET_7_4 (250K) 8" X 1" X 0.13"
41) Epo-Tek 301-2 E1_2_1 (100K) 8" X 1" X 0.13"	58) Epo-Tek 301-2 ET_7_5 (100K) 8" X 1" X 0.13"
42) Epo-Tek 301-2 ET_2_2 (150K) 8" X 1" X 0.13"	59) Epo-Tek 301-2 ET_19_1 (100K) 8" X 1" X 0.13"
43) Epo-Tek 301-2 ET_2_3 (200K) 8" X 1" X 0.13"	60) Epo-Tek 301-2 ET_19_2 (150K) 8" X 1" X 0.13"
44) Epo-Tek 301-2 E1_2_4 (250K) 8" X 1" X 0.13"	61) Epo-Tek 301-2 E1_19_3 (200K) 8" X 1" X 0.13"
45) Epo-Tek 301-2 E1_2_5 (300K) 8" X 1" X 0.13"	62) Epo-Tek 301-2 ET_19_4 (250K) 8" X 1" X 0.13"
46) Epo-Tek 301-2 ET_2_8 (Spare) 8" X 1" X 0.13"	63) Epo-Tek 301-2 ET_10_5 (300K) 8" X 1" X 0.13"
47) Epo-Tek 301-2 ET_3_1 (Spare) 8" X 1" X 0.13"	64) Epo-Tek 301-2 ET_10_6 (Spare) 8" X 1" X 0.13"
48) Epo-Tek 301-2 ET_3_2 (Spare) 8" X 1" X 0.13"	65) Epo-Tek 301-2 ET_20_1 (100K) 8" X 1" X 0.13"
49) Epo-Tek 301-2 ET_3_3 (Spare) 8" X 1" X 0.13"	66) Epo-Tek 301-2 ET_20_2 (150K) 8" X 1" X 0.13"
50) Epo-Tek 301-2 ET_3_4 (Spare) 8" X 1" X 0.13"	67) Epo-Tek 301-2 ET_20_3 (200K) 8" X 1" X 0.13"
51) Epo-Tek 301-2 ET_3_5 (Spare) 8" X 1" X 0.13"	68) Epo-Tek 301-2 ET_20_4 (250K) 8" X 1" X 0.13"
52) Epo-Tek 301-2 ET_4_1 (Spare) 8" X 1" X 0.13"	69) Epo-Tek 301-2 ET_20_5 (300K) 8" X 1" X 0.13"
	70) Epo-Tek 301-2 ET_20_6 (Spare) 8" X 1" X 0.13"

The following table is a listing of the HYSOL 9361 HS Specimens.

71) HYSOL 9361 HS_14_1 (100K) 8" X 1" X 0.13"	89) HYSOL 9361 HS_16_6 (Spare) 8" X 1" X 0.13"
72) HYSOL 9361 HS_14_2 (150K) 8" X 1" X 0.13"	90) HYSOL 9361 HS_16_7 (Spare) 8" X 1" X 0.13"
73) HYSOL 9361 HS_14_3 (200K) 8" X 1" X 0.13"	91) HYSOL 9361 HS_17_1 (100K) 8" X 1" X 0.13"
74) HYSOL 9361 HS_14_4 (250K) 8" X 1" X 0.13"	92) HYSOL 9361 HS_17_2 (150K) 8" X 1" X 0.13"
75) HYSOL 9361 HS_14_5 (300K) 8" X 1" X 0.13"	93) HYSOL 9361 HS_17_3 (200K) 8" X 1" X 0.13"
76) HYSOL 9361 HS_14_6 (Spare) 8" X 1" X 0.13"	94) HYSOL 9361 HS_17_4 (250K) 8" X 1" X 0.13"
77) HYSOL 9361 HS_15_1 (100K) 8" X 1" X 0.13"	95) HYSOL 9361 HS_17_5 (300K) 8" X 1" X 0.13"
78) HYSOL 9361 HS_15_2 (150K) 8" X 1" X 0.13"	96) HYSOL 9361 HS_17_6 (Spare) 8" X 1" X 0.13"
79) HYSOL 9361 HS_15_3 (200K) 8" X 1" X 0.13"	97) HYSOL 9361 HS_18_1 (100K) 8" X 1" X 0.13"
80) HYSOL 9361 HS_15_4 (250K) 8" X 1" X 0.13"	98) HYSOL 9361 HS_18_2 (150K) 8" X 1" X 0.13"
81) HYSOL 9361 HS_15_5 (300K) 8" X 1" X 0.13"	99) HYSOL 9361 HS_18_3 (200K) 8" X 1" X 0.13"
82) HYSOL 9361 HS_15_6 (Spare) 8" X 1" X 0.13"	100) HYSOL 9361 HS_18_4 (250K) 8" X 1" X 0.13"
83) HYSOL 9361 HS_15_7 (Spare) 8" X 1" X 0.13"	101) HYSOL 9361 HS_18_5 (300K) 8" X 1" X 0.13"
84) HYSOL 9361 HS_16_1 (100K) 8" X 1" X 0.13"	102) HYSOL 9361 HS_18_6 (Spare) 8" X 1" X 0.13"
85) HYSOL 9361 HS_16_2 (150K) 8" X 1" X 0.13"	103) HYSOL 9361 HS_18_7 (Spare) 8" X 1" X 0.13"
86) HYSOL 9361 HS_16_3 (200K) 8" X 1" X 0.13"	
87) HYSOL 9361 HS_16_4 (250K) 8" X 1" X 0.13"	
88) HYSOL 9361 HS_16_5 (300K) 8" X 1" X 0.13"	

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