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Arathane 5753 HVB: An Alternative to EN-7/EN-8 Encapsulants

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ABSTRACT

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Arathane 5753 HVB: An Alternative to EN-7/EN-8 Encapsulants

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Conathane EN-7 (referred to as EN-7) has been used for decades to pot electrical connectors, providing mechanical support for solder joints in cables. Unfortunately, the EN-7 formulation contains a suspect carcinogen and chemical sensitizer, toluene diisocyanate (TDI). Because of this, various groups have been formulating replacement materials, but all have come up short in final properties or in processing. We propose Arathane 5753 HVB as a replacement for EN-7. The properties compare very well with EN-7 and the processing has both advantages and disadvantages over EN-7 as discussed in detail below.

ACKNOWLEDGEMENTS

We would like to thank Chris Turner for working through the growing pains of using a new material in a real part. Kirsty Leong performed the outgassing analysis. Matt Selter (KCNSC) provided early feedback from the processing and production side. Mark Wilson (KCNSC) also provided materials feedback from the production side. Chris Meyer at Specialty Polymers & Services, Inc. formulated A/B kits and convinced Huntsman Chemicals to let him be the sole distributor of this new compound they knew nothing about but was based on one of their commercial formulations. Many thanks to Adriana Pavia Sanders and Nalini Menon for many helpful conversations regarding use and processing of Arathane 5753 HVB.

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1. INTRODUCTION

Polyurethane elastomers are used for a wide variety of applications commercially. Sandia National Laboratories specifies their use in the potting of cables and connectors to provide mechanical integrity to the solder joints and wires. These polyurethanes are particularly good at protecting against shock and vibration. Some cables and connectors transmit high voltages and require the polyurethane elastomer to have excellent dielectric properties as well. Many formulations have been used over the years

[1] with all of them having short comings. The initial materials were made with carcinogenic chemicals, while replacement formulations had more complicated processing due to the starting materials being solids at room temperature. Most of these replacement formulations also had limited utility due to their decreased ability to provide adequate standoff to high voltage. The exception was Conathane EN-7/EN-4, commonly shortened to EN-7 (produced by Cytec). EN-7 has liquid ingredients and outstanding high voltage breakdown strength.[2] However, it contains toluene diisocyanate (TDI), a suspect carcinogen and chemical sensitizer.[3] The weapons complex has been unsuccessfully trying to find a suitable replacement for many years. It is getting more and more difficult to find vendors that are willing to work with this hazardous material. In addition, the Kansas City National Security Complex (KCNSC) has recently decided against using TDI in production if possible.

1.1. Scope and purpose

Due to favorable processing compared with other available formulations, EN-7 was being specified for applications that did not require the benefit of its high voltage properties. The initial goal of this project was to develop a new material with favorable processing that would be used for the lower voltage applications, reserving EN-7 specifically for high voltage applications. To keep costs down, we also wanted to start with a commercial formulation that we could modify or at a minimum use all commercially available chemicals in the formulation. However, testing of our new material revealed a high voltage breakdown strength that matched EN-7. It appears that this new material can effectively replace EN-7 and all the other polyurethane elastomer formulations in most applications for potting of connectors. This of course will have to be proved on a case by case basis.

To develop a new material for potting cables and connectors there are many desirable properties to match. The physical properties include having a T_g below the application use temperature to minimize stresses at interfaces, low outgassing to minimize compatibility concerns, and good aging behavior over decades. Mechanically, the material should have good adhesion to materials of interest (for example stainless steel, PEEK, and aluminum) and have a Shore A hardness of approximately 90 to provide sufficient support for the solder joints and wires. Ideally, the high voltage breakdown strength would meet or exceed that of EN-7. In addition to using commercially available constituents that are liquid at ambient temperature and free of TDI, the uncured mixture should have a low viscosity to allow easy bubble-free flow around wires, a 30-60 minute pot life and a 24-48 hour cure at ambient temperature (with an acceptable shorter cure at elevated temperature).

1.2. Prior work

Domeier *et. al.*[1] gives an extensive review of the history and development of castable polyurethane elastomers from ~1970 through 2000 and suggests some chemical origins of the high voltage properties of EN-7 (Figure 1.1). In the early 1970's, Sandia worked with Conap to develop EN-7 as a non-mercury catalyzed castable polyurethane elastomer to replace Adiprene L-100/MOCA. For lack of a non-TDI equivalent, EN-7 has been the material of choice for potting of cables and connectors for approximately 40 years. EN-7 has outstanding electrical and mechanical performance and acceptable processing, albeit a little short on pot life (~15 minutes). A significant processing advantage over many of the materials that were formulated to replace EN-7 is that the constituents are liquid at room temperature. This seemingly small difference was enough to make some prefer to work with the carcinogenic EN-7 over the more difficult to process replacement materials.

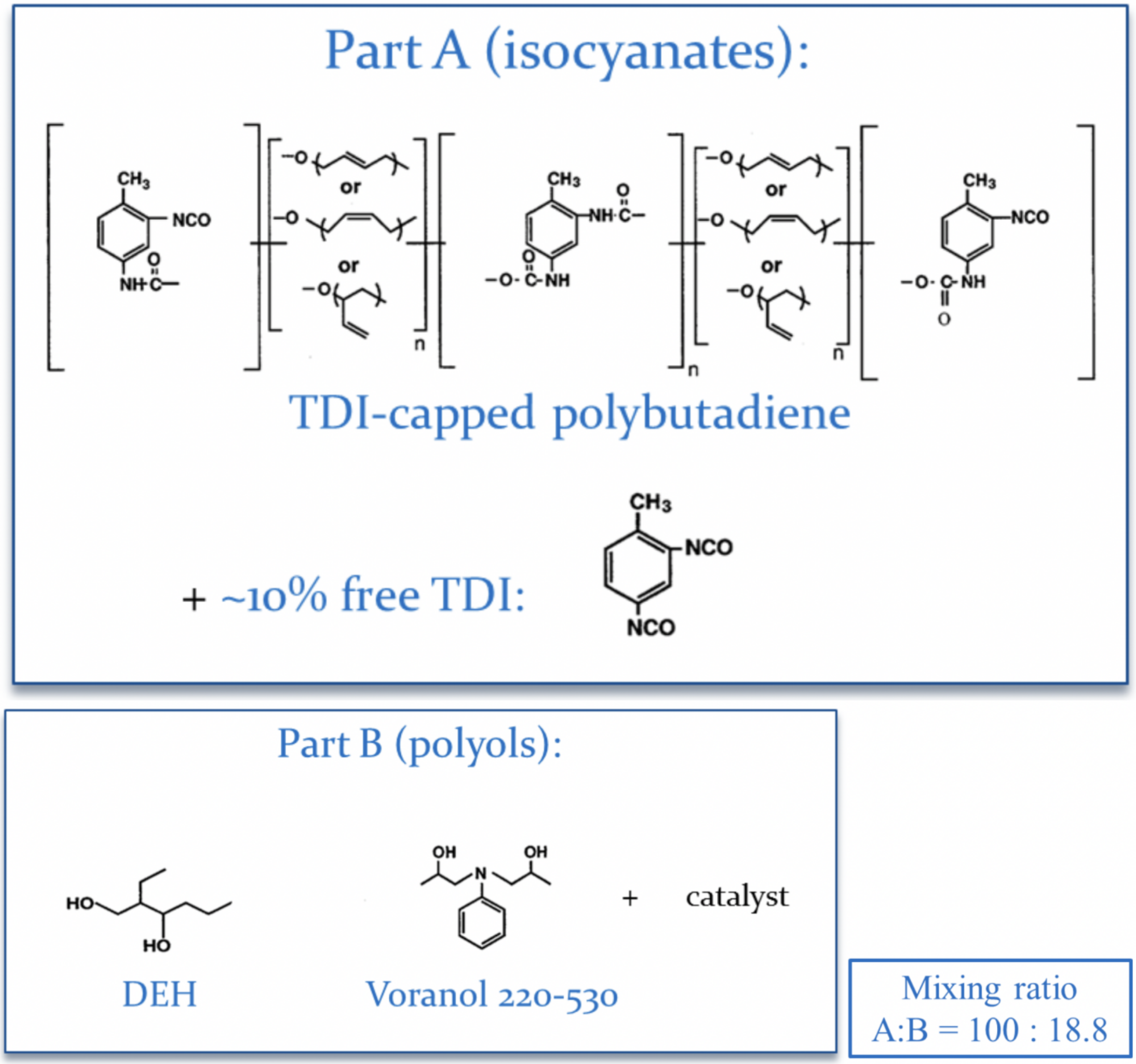

Figure 1.1. Cytec's Conathane EN-7 Formulation.

Arathane 5753 (from Huntsman Chemical-Advanced Materials) is a relatively soft (Shore A of 55-60) castable polyurethane elastomer that has been used substantially in the aerospace industry. It is based on methylene diphenyl diisocyanate (MDI) and does not contain any TDI. From a processing perspective it matches very well with the desired characteristics of the ideal material for potting applications (liquid constituents and a greater than 30-minute pot life). Unfortunately, it is too soft to provide adequate support and its high voltage breakdown strength is only half of that of EN-7.

1.3. New Elastomer Formulation

Our simple approach was to add a short chain diol to Arathane 5753 to stiffen it up so it would provide better support to solder joints and wires, initially not expecting to replace EN-7, only the difficult-to-process material options. Several short chain diols were examined along with several loading levels. Based on availability and Shore A hardness, the down selection was quickly made to add 11% of 2-ethyl-1,3-hexanediol (DEH for dihydroxy ethylhexane). Formulation comparisons of Conathane EN-7, Arathane 5753, and Arathane 5753 HVB are shown in Table 1.1. Surprisingly, the new formulation, now called Arathane 5753 HVB (for High Voltage Breakdown) had electrical properties that matched EN-7 and it still maintained the favorable processing characteristics of the parent Arathane 5753.

Table 1.1. New TDI-free formulation.

Formulations (by mass)			
Component	**EN-7**	**Arathane 5753 LV**	**Arathane 5753 HVB**
	Part A	Part A	Part A
Arathane 5753 A	---	20	61.05
EN-4	100	---	---
	Part B	Part B	Part B
EN-7	18.8	---	---
Arathane 5753 B	---	100	100
DEH (2-ethyl-1,3-hexanediol)	---	---	20

2. EXPERIMENTAL DETAILS

2.1. Processing

2.1.1. Preparation of Arathane 5753 HVB

Arathane 5753-part B (100 parts) are mixed with DEH (20 parts) by hand for 30-60 seconds. Arathane 5753-part A (61 parts) are added, and the mixture is mixed by hand for 1-2 minutes, becoming a creamy yellow-white mixture. The mixture is degassed to 150 mtorr, then poured or injected into the desired mold, which should be preheated at 71°C for 2 hours. The material is cured in the mold for 4 hours at 71°C.

2.1.2. Properties

To fully characterize this new material, many properties have been measured in-house as well as sent out for testing as needed. A short summary of the most critical properties is summarized in Table 2.1 with the remainder and additional details provided in the following sections.

Table 2.1. A summary of material properties for EN-7, Arathane 5753, and Arathane 5753 HVB.

Property	EN-7	Arathane 5753	Arathane 5753 HVB
Physical			
T_g (°C)	-77	-69 *(lit)*	-64 *(rheo)*
CTE (ppm/°C)	168 *(exp & lit)*	170 *(lit)*	143
Outgassing total mass loss[a] (%)	0.251 ± 0.011	0.673 ± 0.017	0.659 ± 0.014
Mechanical			
Hardness, Shore A	94	60	90
Tensile strength (MPa)	8.0	2.0	12
Elongation (%)	220	210	150
Tear strength[b] (lbf/in)	430 ± 30	84 ± 6	230 ± 52
Electrical			
Breakdown strength[c] (kV/mm)	30.0 ± 0.6	14 *(lit)*	29.1 ± 2.7
Processing			
Pot life[d] (min)	10-15	~30	25-30

[a] ASTM E595; NASA requirement for outgassing is total mass loss < 1.0%
[b] ASTM D624, Die C
[c] ASTM D149; 1 mm thickness
[d] time to reach 20,000 cP

2.2. Processing characteristics

2.2.1. Viscosity and pot life

The initial viscosity of the liquid mixture is important because if the viscosity is too high, it can cause trapped bubbles that can result in insufficient support for solder joints and wires or increase the probability of a high voltage breakdown if the bubble is near a high voltage conductor. A low viscosity is preferred to minimize these concerns. From our measurements, EN-7 has an initial viscosity of approximately 18,000 cP, allowing it to barely meet our threshold for good flow in these applications of 20,000 cP. As can be seen in Figure 2.1, Arathane 5753 HVB has an initial mix viscosity below 5,000 cP and should result in fewer bubbles being trapped during processing. However, the technical datasheet (TDS) for EN-7 lists the initial mix viscosity at 5500 cP. We do not have an explanation for the difference but feel the side by side comparison in our experiment gives a good relative assessment.

If we use this value of 20,000 cP as our cutoff for acceptable work time, then EN-7 has a very short pot life of just under 10 minutes as opposed to the "working life" of 30-35 minutes stated on the TDS. That 10-minute working time or pot life is more consistent with what is observed in the lab. Using this same 20,000 cP threshold, Arathane 5753 HVB has a pot life of just less than 30 minutes, much better suited for potting applications.

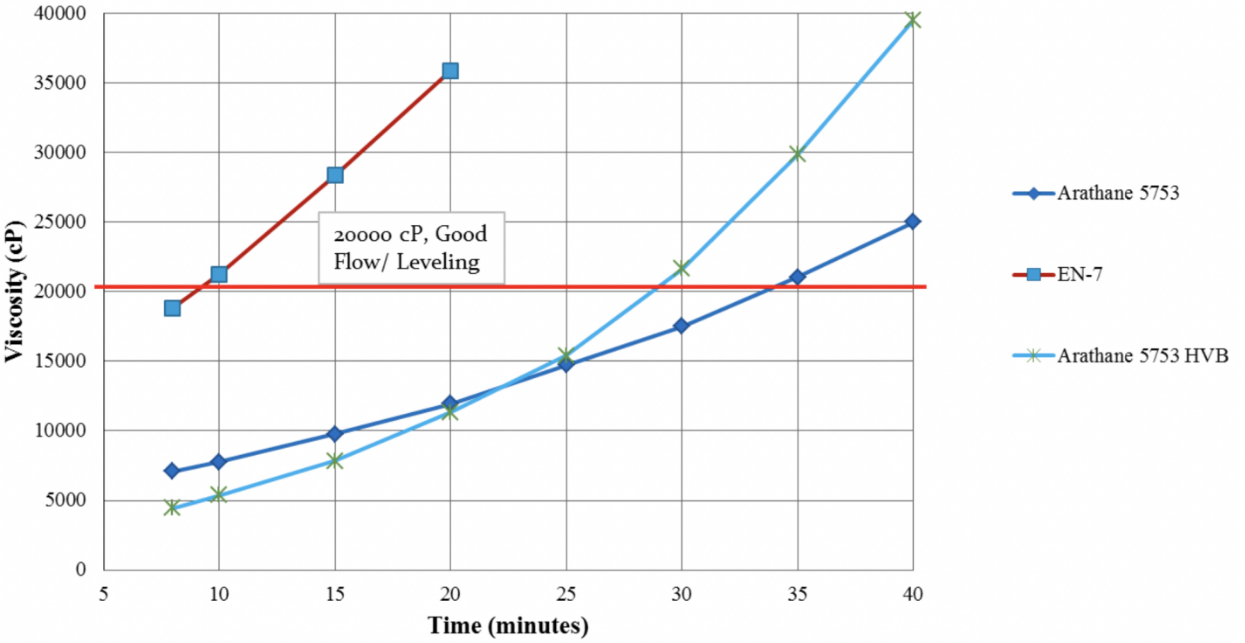

Figure 2.1. Pot life and viscosity comparison of various polyurethane formulations.

In an attempt to make processing for manufacturing even easier, a couple of alternatives were investigated. The first was to pre-mix the constituents, degas, and transfer to syringes before quickly freezing the syringes. This was all done at Specialty Polymers & Services, Inc. in Valencia, CA. This approach ran into several difficulties. The pot life was shortened because the constituents were reacting until the material was frozen. Matt Selter at KCNSC found that the shelf life of the mix was approximately 2 weeks if stored at -20°C and 4-6 weeks at -40°C. We do not know if the materials were processed differently after this initial batch at Specialty Polymers & Services, but later batches all had dramatically shorter shelf lives and higher starting viscosities. Due to these observations, we do not currently recommend using frozen pre-mixed syringes of Arathane 5753 HVB. Specialty Polymers & Services, Inc. also tried to find a way to use dual cartridge syringes with a static mixer. Unfortunately, they were unsuccessful due to the volumetric ratio of the 2 parts not matching commercially available cartridges.

2.2.2. Cure schedule options

Shore A durometer was used to determine the hardness of samples to monitor the extent of cure as well as changes in hardness after aging. As shown in Figure 2.2, Arathane 5753 HVB completes the final cross-linking relatively slowly at room temperature. The material can be considered acceptable for gentle handling after 24 hours and fully cured after 7 days at room temperature. The ASTM procedure specifies that the durometer value should be recorded 10 seconds after applying load to the gauge. To determine if this was necessary for our material and give an idea of the creep characteristics, we recorded the data immediately after application of the load as well. As shown, especially in the early times when the material is still quite soft, there is a significant difference between the 2 measurements, indicating that the 10 second wait is justified. The data shows the material is cured after approximately 7 days at room temperature. The small increase in hardness shown after 27 days is likely due to moisture absorption. Often, we think of water absorption leading to a plasticizing effect in polymers and indeed that is usually the case with cross-linked glassy polymers. However, the opposite has been observed with elastomers.[4] Additionally, the last data point (30 days) was heated for 2 hours at 71°C to show that additional heat would not cause additional cure.

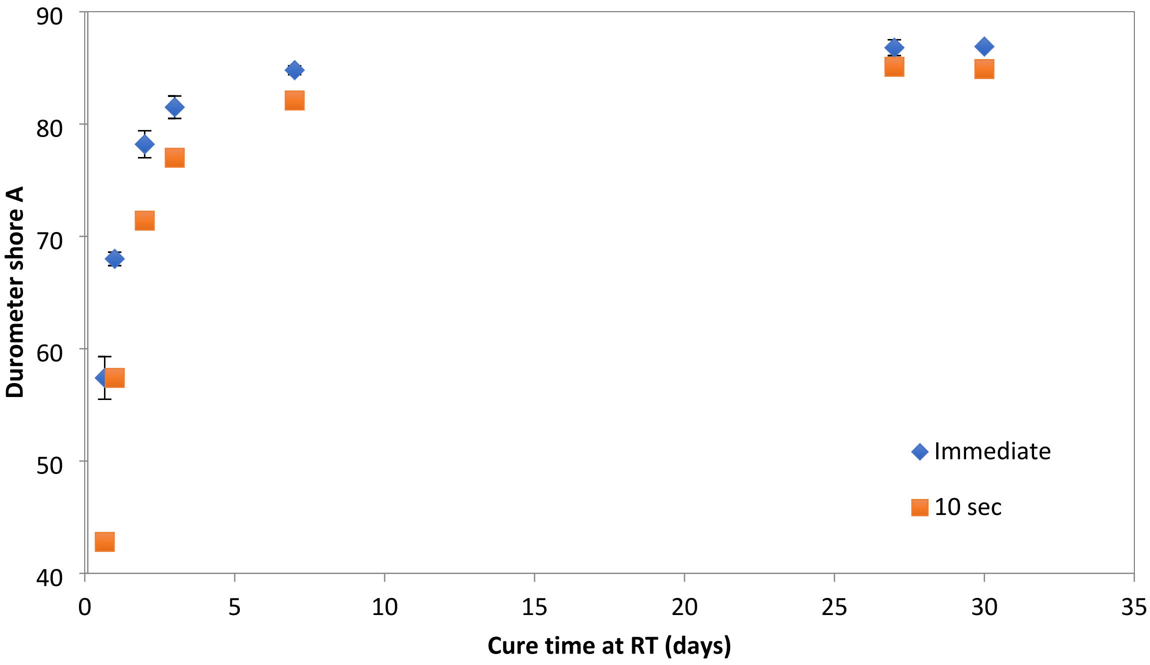

Figure 2.2. Arathane 5753 HVB cured at RT. Samples at "30 days" were cured at 71°C for 2 hours.

An alternate method to determine the extent of cure is by monitoring the glass transition temperature (T_g) of the material. As a material continues to polymerize and cross link the T_g will increase up to a point called T_g max when it is fully reacted and 100% cross linked. There are a number of ways to record the T_g of a material, including the Tan Delta Peak (Figure 2.3), the onset of the Storage Modulus (Figure 2.4), and the onset of the Loss Modulus Peak (Figure 2.5). The data were collected on a TA Instruments Q800 DMA using the Dual Cantilever clamp with 20 µm amplitude, 10 Hz frequency, and a heating rate of 2°C per/min. The data in these graphs are very consistent and show that Arathane 5753 HVB is completely cured after 2 hours at 71°C. Accelerated cure schedules were also examined. Cure temperatures of 71°C, 80°C, and 93°C were examined between 2 and 24 hours. DMA analysis showed less than 1°C difference in the T_g of samples cured for 2 hours at 71°C and 24 hours at 93°C. The conclusion of this study is that the material is fully cured after 2 hours at 71°C. Times shorter than 2 hours were not explored.

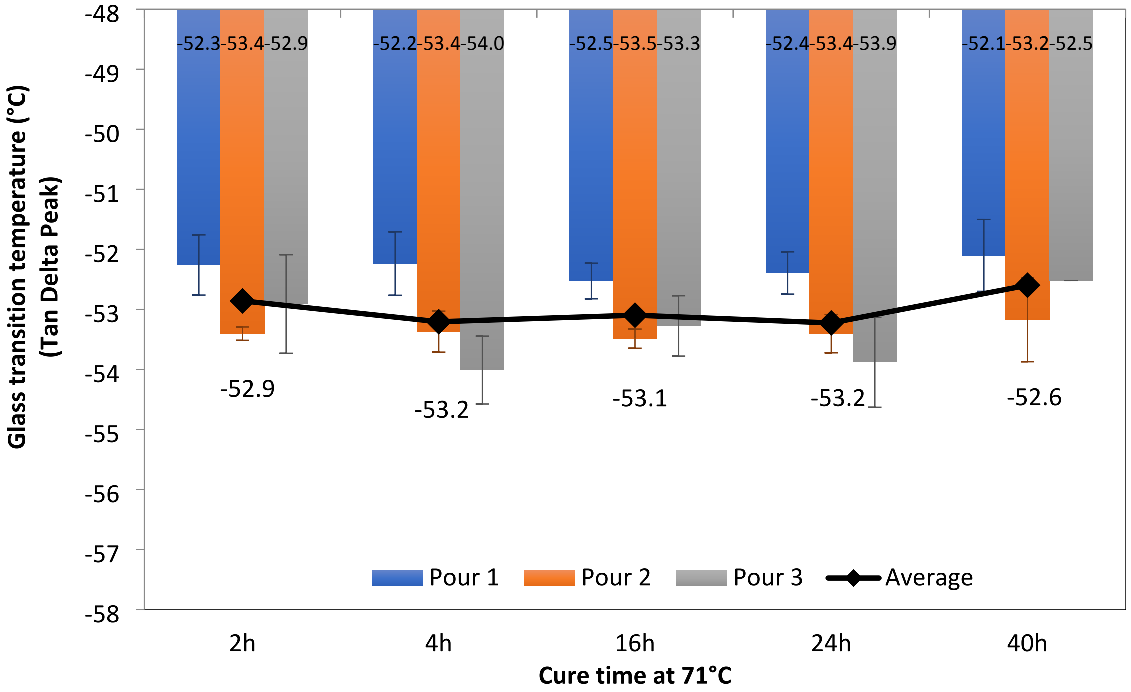

Figure 2.3. Tan delta glass transition data for Arathane 5753 HVB cured at 71°C shows it to be cured after 2 hours.

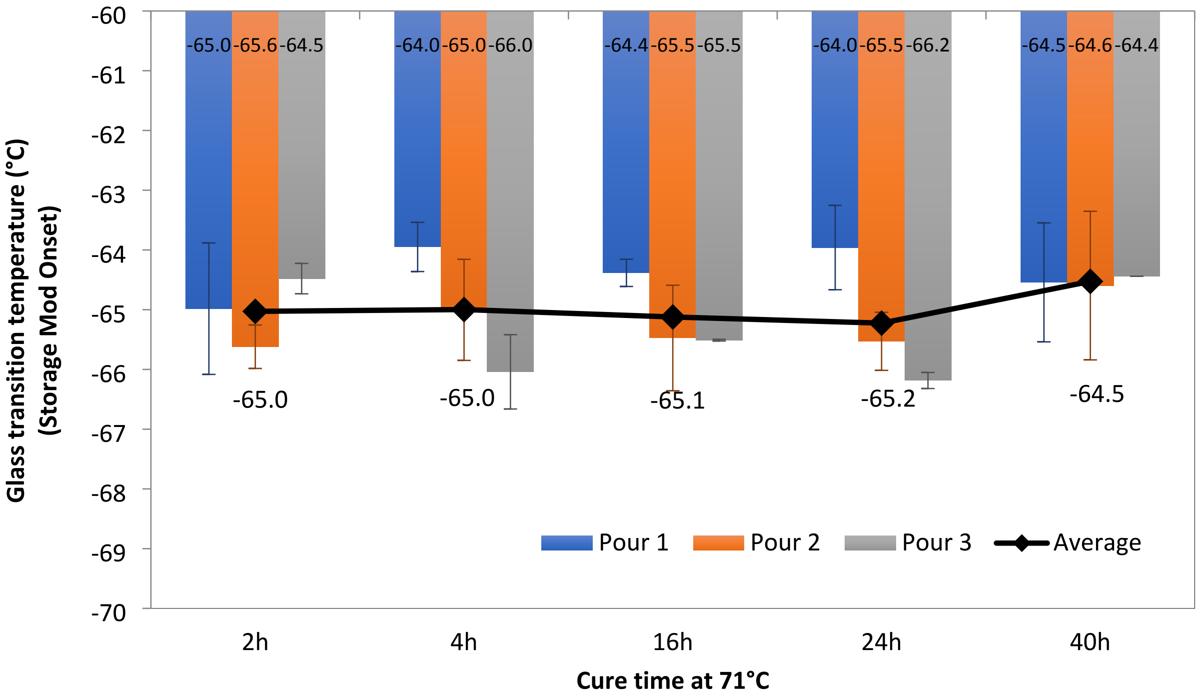

Figure 2.4. Storage modulus glass transition data for Arathane 5753 HVB cured at 71°C shows it to be cured after 2 hours.

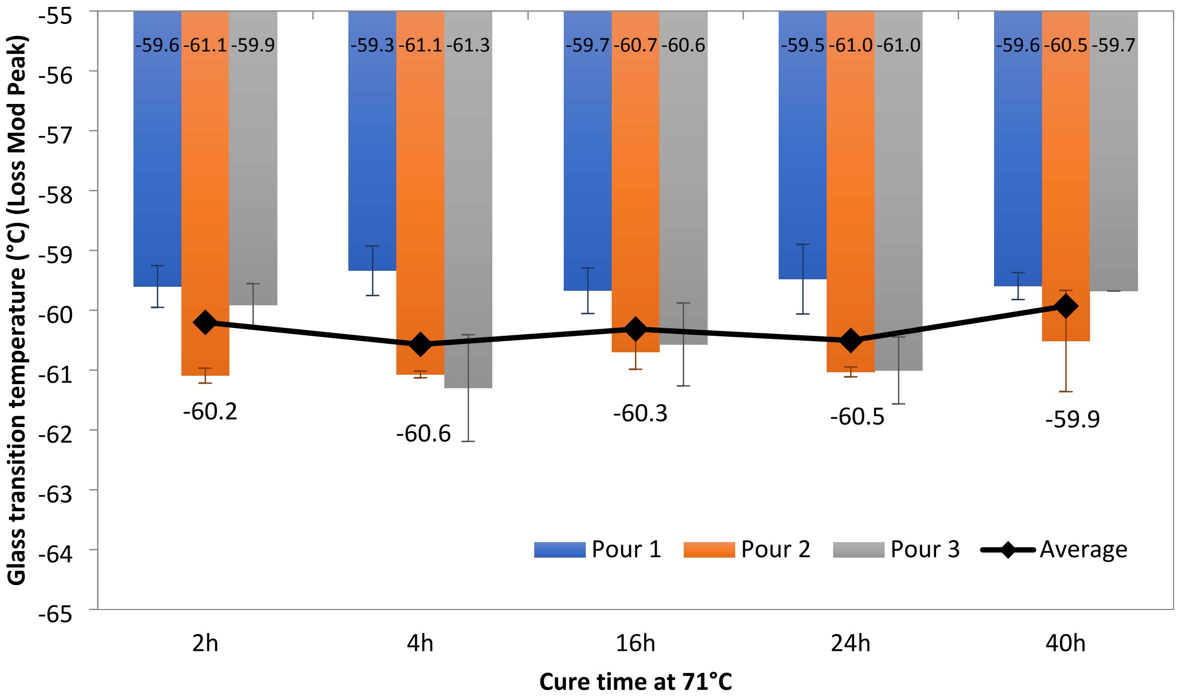

Figure 2.5. Loss Modulus Glass Transition data for Arathane 5753 HVB cured at 71°C shows it to be cured after 2 hours.

2.2.3. Cure shrinkage

Although not usually critical for the applications currently envisioned, cure shrinkage was measured for both Arathane 5753 HVB and EN-7. Samples for both materials were prepared in the same way. This is not an ASTM method. The internal volume of a cylindrical mold was calculated from the diameter and length and compared to the calculated volume of the molded parts after post-cure and removal from the mold. Two samples were made per material in a mold that was 3.58 cm diameter by 1.28 cm tall. The mold was preheated to 71°C. The cure was 15 minutes at RT, followed by 4 hours at 71°C. As shown in the table below, Arathane 5753 HVB has a slightly lower volumetric shrinkage than EN-7.

Table 2.2. Volumetric shrinkage results showing Arathane 5753 HVB as slightly lower than EN-7.

Encapsulant	Volumetric shrinkage
Arathane 5753 HVB	1.70% ± 0.13%
EN-7	2.31% ± 0.17%

2.3. Physical properties

2.3.1. Glass transition temperature

As seen previously in Section 2.2.2, the T_g of Arathane 5753 HVB is between -53°C and -65°C depending on method selected for recording. To get a picture of the modulus over a wide temperature range, a dynamic thermomechanical analyzer (DMTA) (TA Instruments DHR-2) was used with a rectangular sample in torsion (0.005% strain, 1 Hz, 2°C/min heating) and is shown in Figure 2.6. This data shows an interesting plateau region in EN-7 that is not present in either of the Arathane materials.

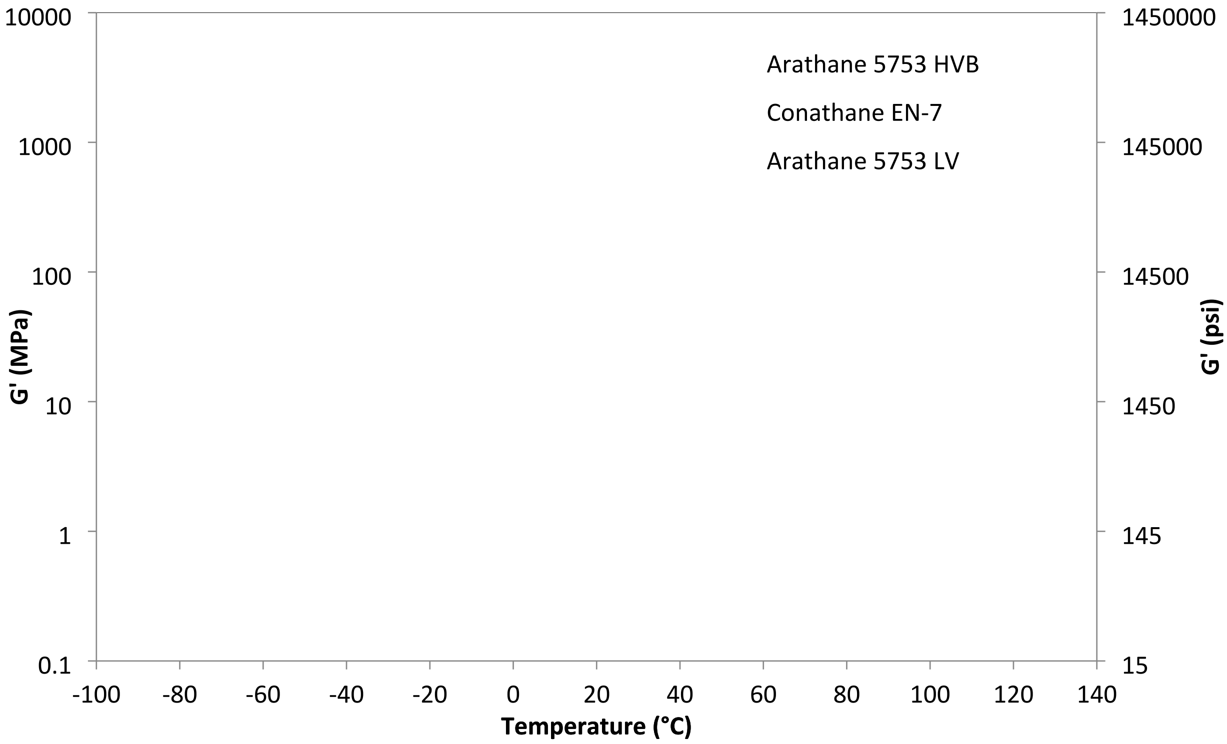

Figure 2.6. Storage modulus as a function of temperature.

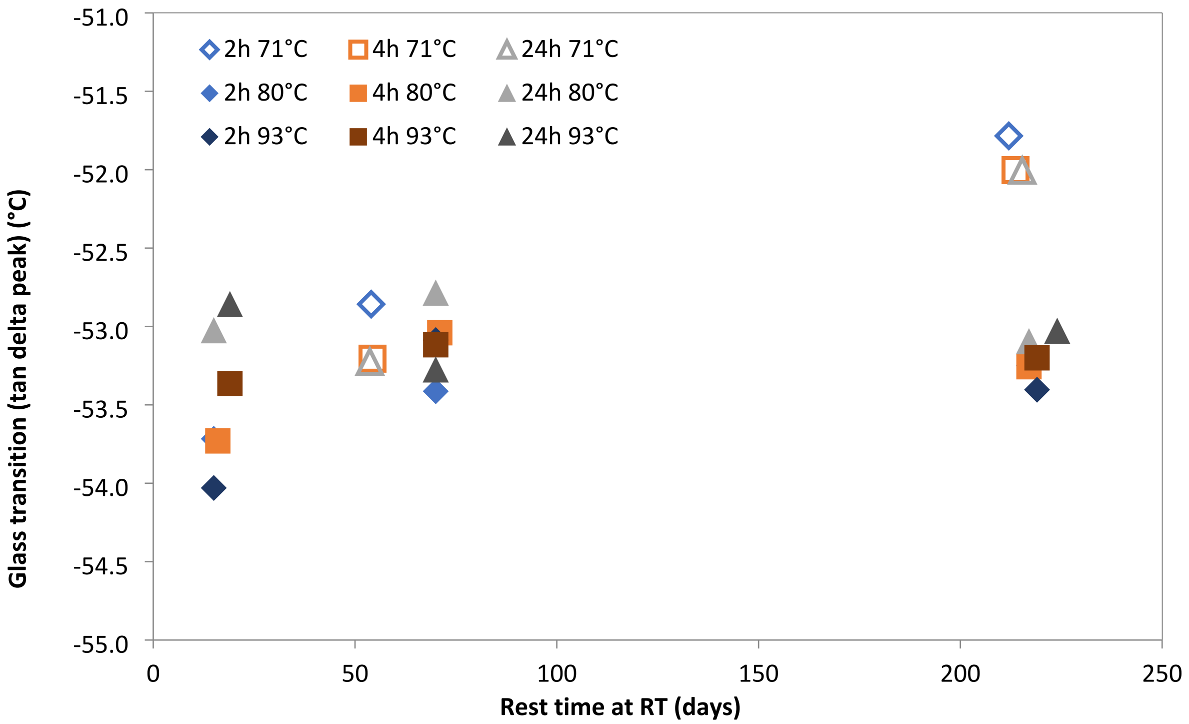

Figure 2.7. A slight increase in T_g for samples that were cured at the lowest temperatures as they sit around in ambient conditions for months.

The T_g of samples cured at 71°C, 80°C, and 93°C for 2, 4, and 24 hours is shown in Figure 2.7. Although the data for the samples cured at higher temperature have not been measured, the samples cured at lower temperature show a slight (~1°C) increase in T_g after several months at ambient conditions in the lab. This is most likely due to absorption of water. As stated in "*Castable Polyurethane Elastomers*" by I.R. Clemitson, (2008) p. 68: "The purist of the polyurethane processors will maintain that the polyurethanes should then be rested at room temperature for 1 to 2 weeks for the ultimate in properties. The explanation for this is that the polyurethanes will slowly absorb water from the air, which will assist the formation of very strong bonds."

2.3.2. Coefficient of thermal expansion (CTE)

CTE can be important for encapsulants depending on the application. Ideally, the CTE of the encapsulant would match the CTE of the materials it is encapsulating. This can be very hard to do. Often, a metal housing or backshell are being encapsulated. These metals have approximately three times lower CTE than most elastomers. In some circumstances, negative CTE fillers can be added to the liquid encapsulant to lower the overall CTE of the mixture. However, it takes quite a bit of the low CTE material to achieve the desired effect, in addition to the severe processing limitations presented by the fillers.

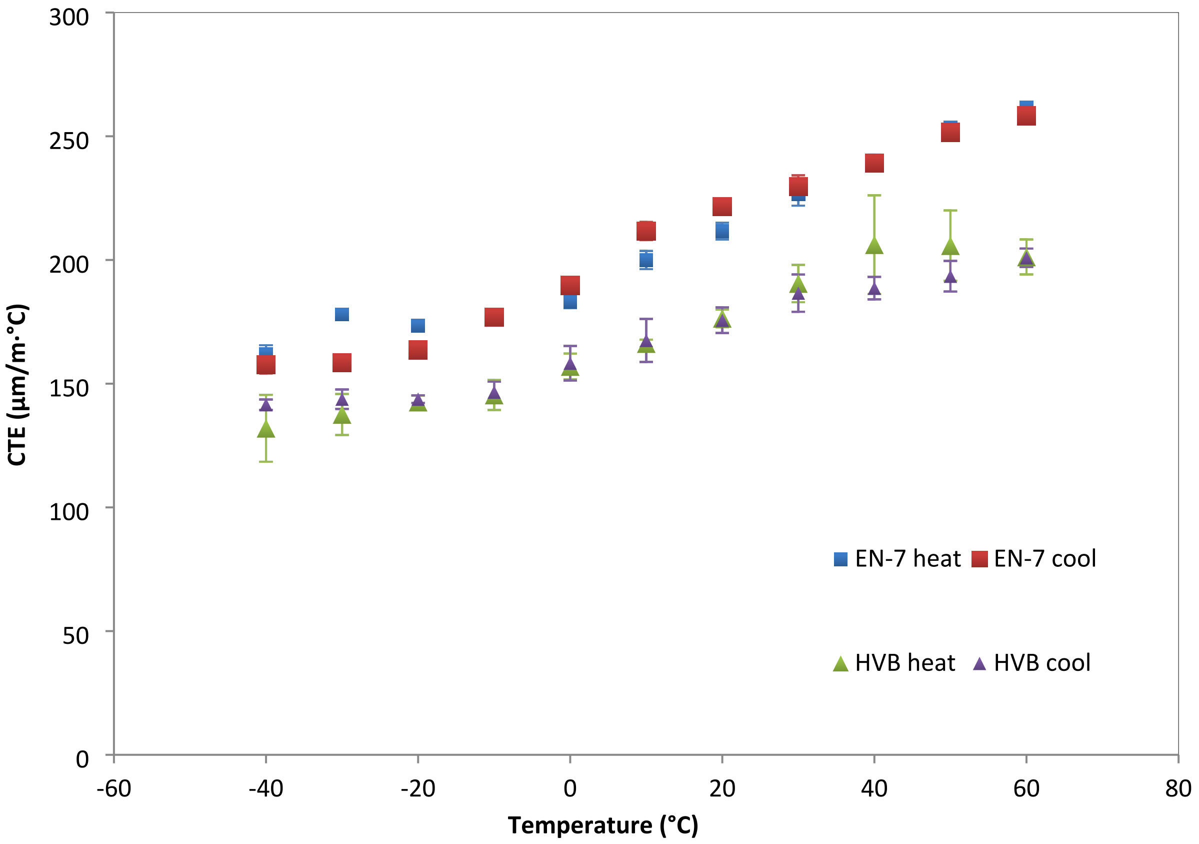

Figure 2.8. The CTE of Arathane 5753 HVB is slightly lower than EN-7 over the temperature range of -40°C and 60°C.

The data shown in Figure 2.8 was recorded on a TA Instruments Q400 TMA at 3°C/min. Data from the first temperature cycle was not used. The data shown is the average of 3 samples. Heating curves show good agreement with the cooling curves indicating that additional reactions are not occurring at the higher temperatures or between cycles. The CTE of Arathane 5753 HVB is slightly lower than EN-7 over the temperature range of -40°C and 60°C.

In addition to cure schedule, hardness was also used to determine the cure time of Arathane 5753 HVB at 71°C. This data is shown in Figure 2.9 and shows that the material is cured after 2 hours at 71°C. Three separate pours of the material were made and are represented by the different colors in the graph. Samples from Pour #3 were rested for 27 days prior to measurement, likely accounting for the slightly higher values. The average of at least 3 measurements is shown by the bar height and the deviation represented by the error bar at the top of each bar.

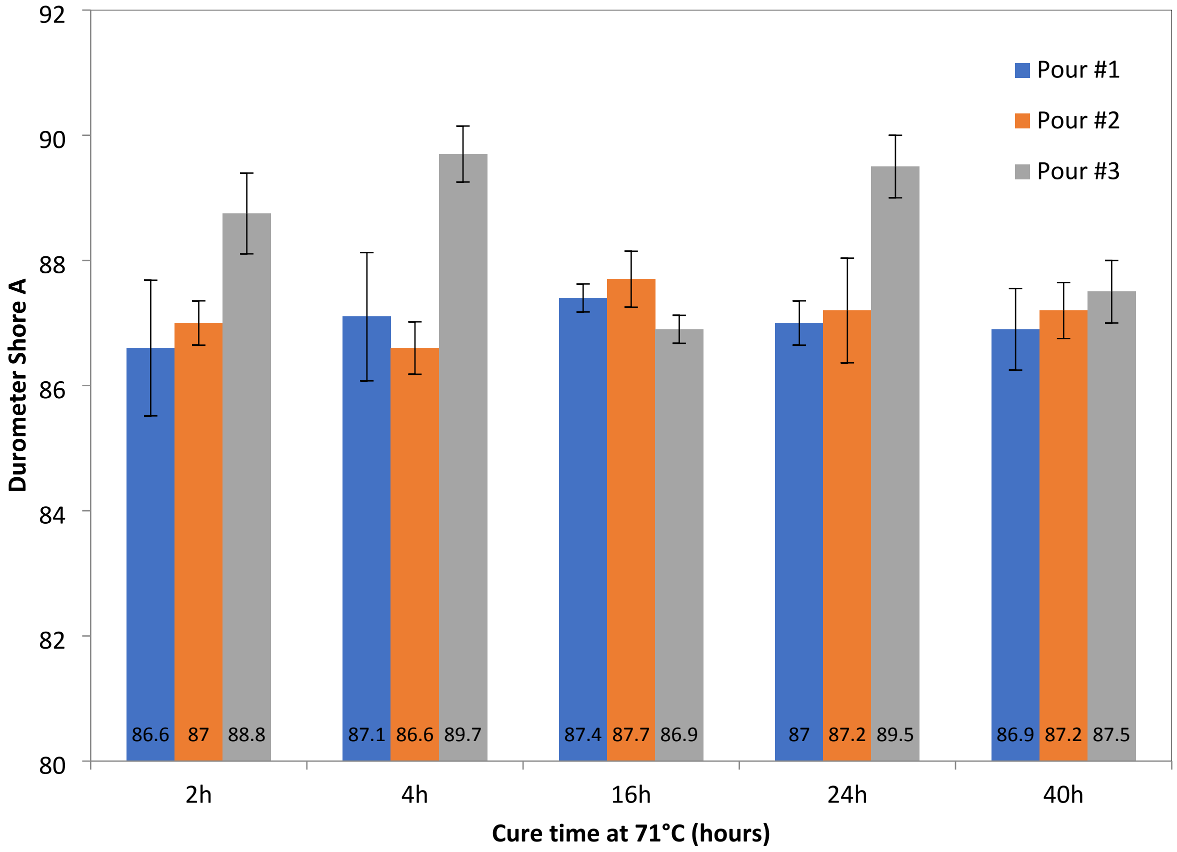

Figure 2.9. Shore A durometer measurements show that Arathane 5753 HVB is cured after 2 hours at 71°C.

The Shore A durometer of samples from the study shown in Figure 2.9 continued to be monitored as they sat in the lab at ambient conditions, as shown in Figure 2.10. The general trend is that the durometer increases for the first month and then levels off. Again, this is consistent with moisture permeation into the samples.

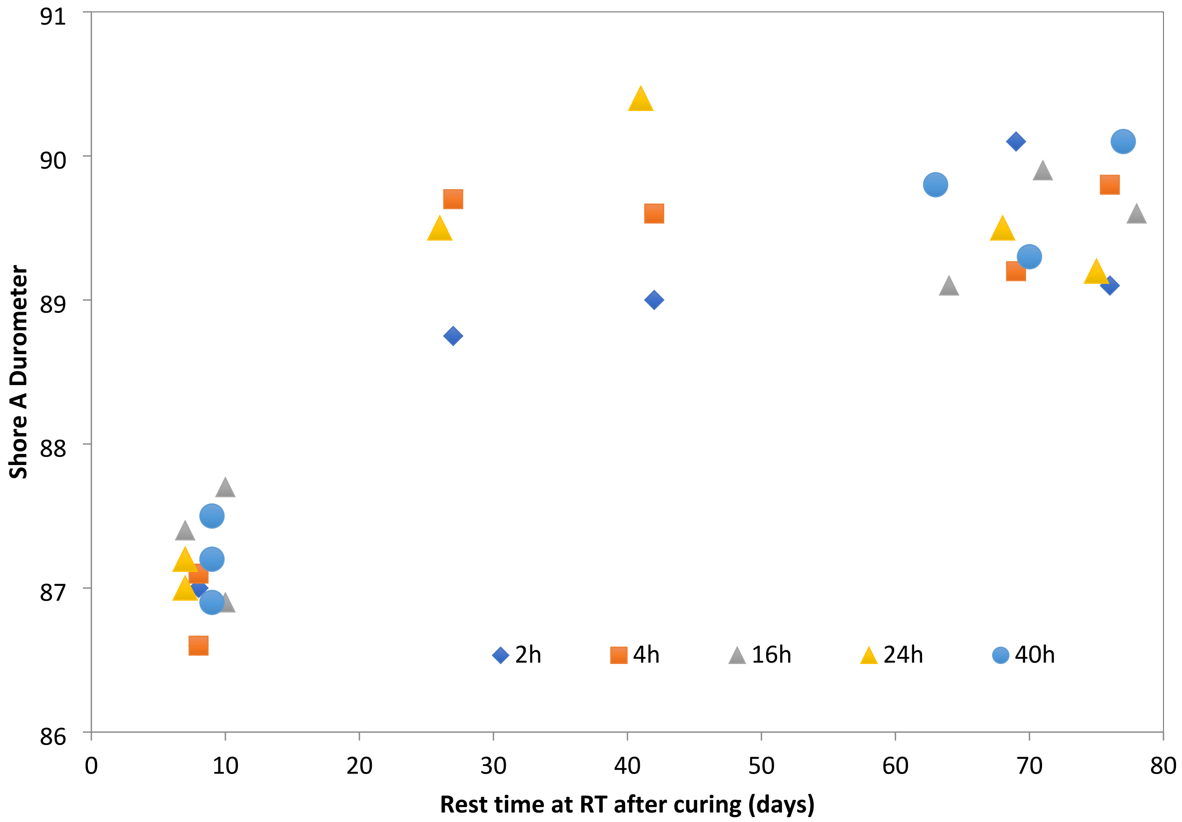

Figure 2.10. Durometer increases for the first month and then levels off, consistent with moisture permeation into the samples. Samples were stored in ambient lab air.

2.4. Mechanical performance

2.4.1. Tensile Testing

As mentioned earlier, DEH was added to the commercial Arathane 5753 LV formulation to increase the modulus to be comparable with EN-7. The data in Figure 2.11 shows the stress strain curves for each of these materials in tension. The modulus of Arathane 5753 LV, defined as the tangent to the initial linear portion of the loading curve, was significantly increased upon addition of the DEH. However, there was a price to pay. The Arathane 5753 HVB is no longer as ductile. The measurements of Arathane 5753 HVB appear less consistent, but this could be due to the flaw sensitivity of the tensile test.

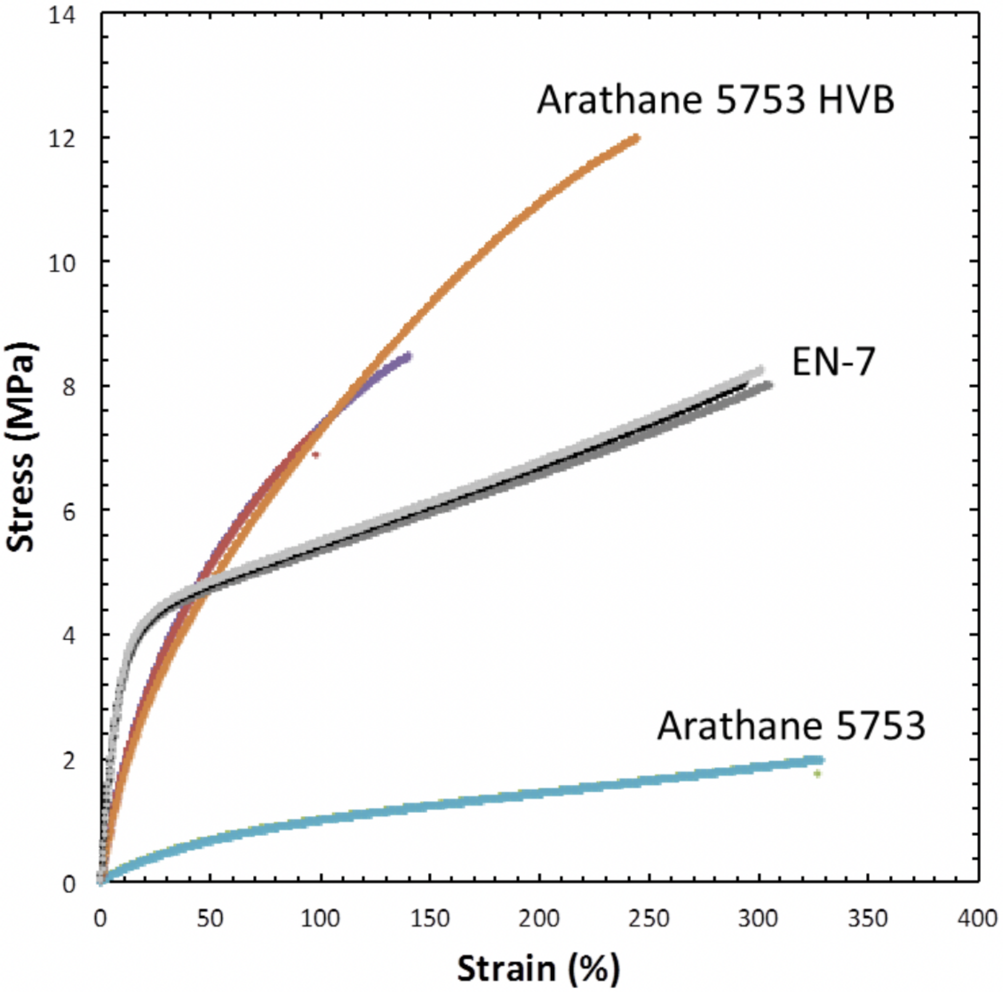

Figure 2.11. The modulus of Arathane 5753, defined as the tangent to the initial linear portion of the loading curve, was significantly increased upon addition of the DEH.

2.4.2. Tear strength

Tear strength is not usually considered a critical property for a potting material, but there may be some applications where it is useful. The curved tear strength samples shown in Figure 2.12 were prepared by pressing a corresponding die through a 0.125” thick sheet of the materials. The samples were then pulled at a constant quasi-static rate while load and displacement were recorded.

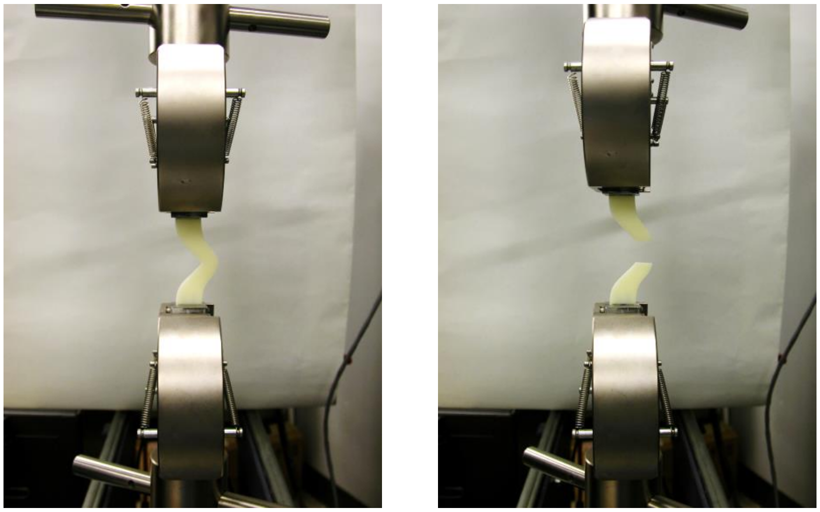

Figure 2.12. Images show a sample before and after testing.

Figure 2.13 shows the tensile loading curves for the three different materials with three replicates each. The tear strength was not calculated per se, but the sample were all of the same dimensions and tested at the same rate as to give a relative comparison. The main conclusion from this data is that Arathane 5753 HVB is not as tear resistant as EN-7. However, this should not be a problem for most encapsulation or potting applications.

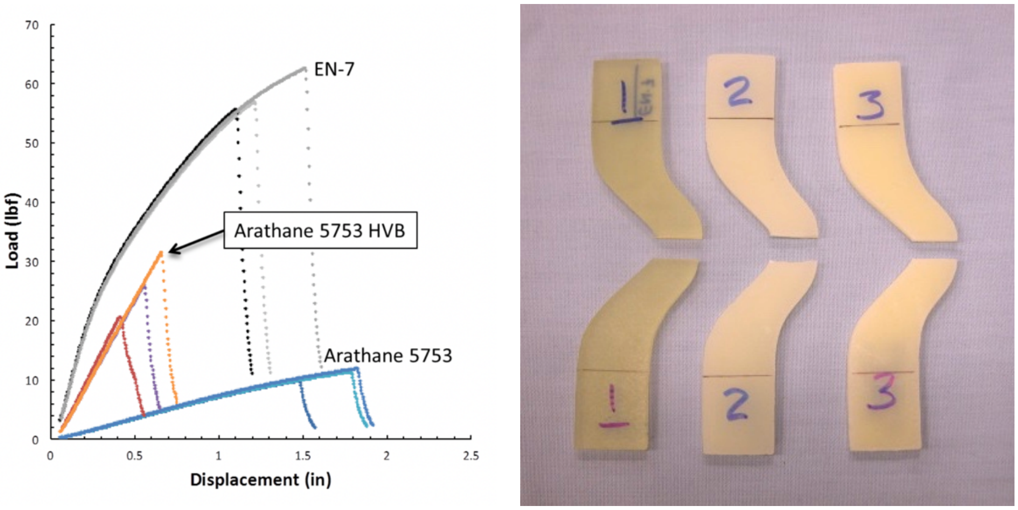

Figure 2.13. Arathane 5753 HVB is not as tear resistant as Arathane 5753 LV or EN-7.

2.4.3. Adhesion

Adhesion of encapsulants to surfaces is critical in providing mechanical support.[5] Single lap shear coupons of the geometry shown in Figure 2.14 were used to compare adhesive strengths.

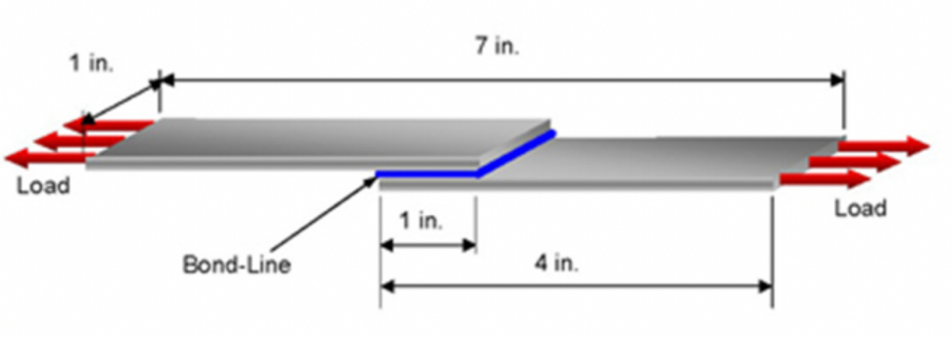

Figure 2.14. The geometry of single lap shear samples used to measure adhesive strength.

The aluminum adherends were made from Al 6061-T6 and Alodine coated to replicate a common surface in weapons. Minimum bond lines were ensured by incorporating 0.5 wt% of 0.005 inch diameter glass beads into the adhesive. To understand the measurement or sample variability, three specimens per adhesive were measured. Each specimen was cured in the assembly fixture at ambient temperature for 24 hours. Specimens were then aged at least 6 additional days at ambient temperature inside a sealed plastic bag.

The results in Table 2.3 show Arathane 5753 HVB has almost 3X higher load to failure and peak shear stress compared to Arathane 5753 LV. All samples failed in a cohesive fashion, thus placing a lower bound on the strength of the actual bond, it is stronger than the material itself under these constraints and for this geometry. Unfortunately, comparable measurements for EN-7 were not performed.

Table 2.3. Single lap shear data with aluminum adherends.

Encapsulant	Average peak load (Kg-force)	Average peak shear stress (MPa)
Arathane 5753 LV	123 ± 17	1.88 ± 0.26
Arathane 5753 HVB	347 ± 55	5.27 ± 0.83

2.5. Electrical performance

2.5.1. Dielectric breakdown strength

Dielectric breakdown strength is a critical property for encapsulants involving high voltage (>5kV). If the breakdown voltage of the material is too low, it will allow current to pass shorting out the conductor to ground or another conductor. The high breakdown voltage observed for EN-7 is why it was specified for high voltage applications and why it was so difficult to develop a replacement material. Sheets of the materials (1.0 mm thick) were used for the measurements. Exova, Inc made the breakdown measurements following ASTM D149 at 500V/sec at 23 ± 2°C.

Table 2.4. Reported values are means ± standard deviation for breakdown voltage and breakdown strength.

Material	Breakdown Voltage (kV)	Breakdown Strength (kV/mm)
EN-7	31.4 ± 0.6	30.0 ± 0.6
Arathane 5753 HVB	29.7 ± 2.9	29.1 ± 2.7

2.5.2. Volume resistivity

Volume resistivity was measured using sheets of Arathane 5753 HVB and EN-7 cast at 1 mm thickness, using the Keithley Model 6517B Electrometer and Model 8009 Resistivity Test Chamber, as shown in Figure 2.15 and Figure 2.16. Readings were collected after 1 minute at 500 volts. A summary of the volume resistivity values for the two materials can be found in Table 2.5.

Figure 2.15. High Resistance Measurements using Keithley's Model 6517B Electrometer and the Model 8009 Resistivity Test Chamber.

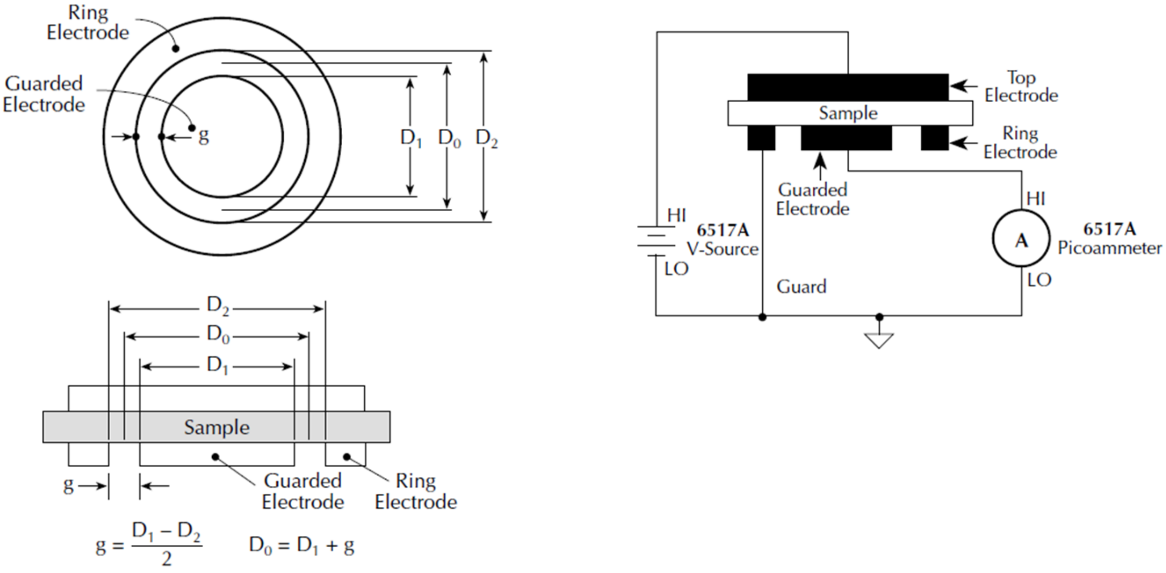

Figure 2.16. Measurement configuration used in the Model 8009 Resistivity Test Chamber to determine the volume resistivity.

Table 2.5. Volume resistivity values at 500V, average/standard deviation calculated from 9 values each.

Material	Volume resistivity at 500V (ohm-cm)
Arathane 5753 HVB	$2.1 \times 10^{16} \pm 0.6 \times 10^{16}$
EN-7	$1.0 \times 10^{16} \pm 0.4 \times 10^{16}$

2.6. Compatibility

2.6.1. Outgassing

2.6.1.1. NASA requirements

When materials outgas it can be a problem for the original material or for another material within the system. This is demonstrated regularly in cars where the dashboard material has dioctyl phthalate (DOP) in it as a plasticizer, keeping it somewhat soft, pliable and preventing cracking. When enough of the DOP volatilizes away it leaves the dashboard material brittle and susceptible to cracking. Some of that volatilized DOP then condenses on the wind shield resulting in a foggy layer that reduces visibility. It could cause other issues with other materials as well. In addition, some species are more problematic than others. For instance, a material that outgassed hydrochloric acid would be very bad even in small quantities due to corrosion concerns, but a little bit of DOP might be acceptable in some applications. In general, we try to use materials that have very low outgassing properties.[6]

Arathane 5753 HVB and EN-7 were sent to an external lab (Exova, Inc) for testing (ASTM E595) in triplicate. Results in Table 2.6 show that both materials pass the NASA standard. Arathane 5753 HVB showed a higher TML, but EN-7 had a higher CVCM.

Table 2.6. Total Mass Loss (TML), Collected Volatile Condensable Materials (CVCM), and Water Vapor Regain (WVR) data collected by Exova, Inc.

Material	TML (%)	CVCM (%)	WVR (%)
NASA Limit	1.00	0.10	N/A
EN-7	0.251 ± 0.011	0.013 ± 0.003	0.113 ± 0.004
Arathane 5753 HVB	0.659 ± 0.014	0.006 ± 0.002	0.115 ± 0.009

2.6.2. Moisture absorption

Over the course of the water absorption study color differences were observed between the Arathane HVB specimens exposed to 100% relative humidity, by placing the specimens in sealed stainless-steel containers including open dishes of water. Samples held at higher temperatures became a deep orange color with less color for lower temperature samples.

It is common for polyurethanes and most organic materials to absorb moisture over time. As noted in “Castable Polyurethane Elastomers” by I.R. Clemitson, (2008) p. 68: “The purist of the polyurethane processors will maintain that the polyurethanes should then be rested at room temperature for 1 to 2 weeks for the ultimate in properties. The explanation for this is that the polyurethanes will slowly absorb water from the air, which will assist the formation of very strong bonds.”

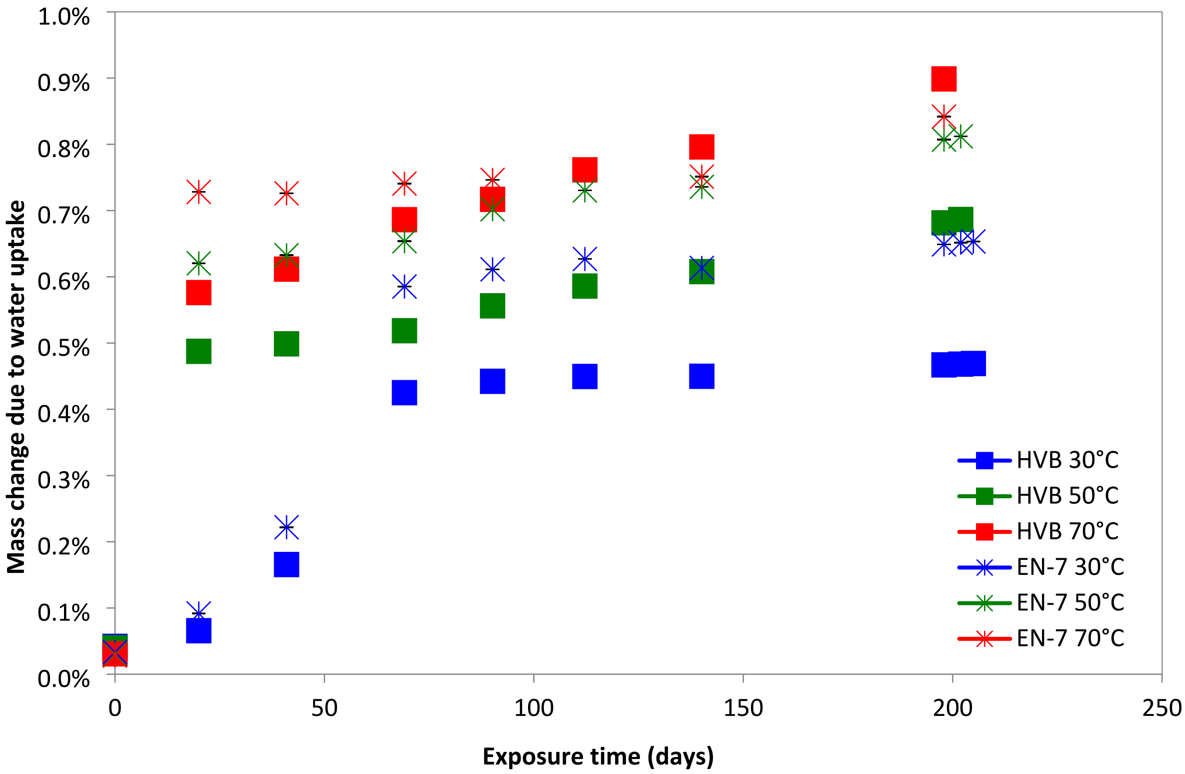

Figure 2.17. The data shows Arathane 5753 HVB absorbs less water and at a slower rate than EN-7. Samples were all 0.125" thick. Vessels equilibrated at 100% humidity. Water reservoir in 30C (blue) vessel went dry after <20 days.

As would be expected, both materials absorb more water at higher temperature. As shown in Figure 2.17 above, Arathane 5753 HVB absorbs water at a slightly slower rate than EN-7. The Arathane 5753 HVB also absorbs less water at 30°C and 50°C. These final values do not represent full equilibrium values but, based on the leveling out of the curves, they are close. The differences in water absorption between the two materials could also be due to differences in the residual isocyanate content of each although this has not been investigated.

2.6.3. Material compatibility

2.6.3.1. Small core test results

Small core tests are coupon-level tests that weapon systems use to identify material incompatibilities. In these tests, the coupons are designed to have some kind of characterization performed before and after the test. Sometimes several types of characterization can be performed on the same coupon, saving space, time and money. In the B61-12 LEP, eight stainless steel cans were loaded with relevant materials, sealed and then exposed to isothermal (cans, 1, 3, 4, 5, 7, and 8) or thermal cycling (cans 2 and 6). In addition, small open dishes containing select solvents were placed cans 3 and 7 prior to sealing and biologics and humidity were added to cans 4 and 8. After 6 months, cans 1-4 were opened and evaluated, with the remaining cans opened after 24 months.

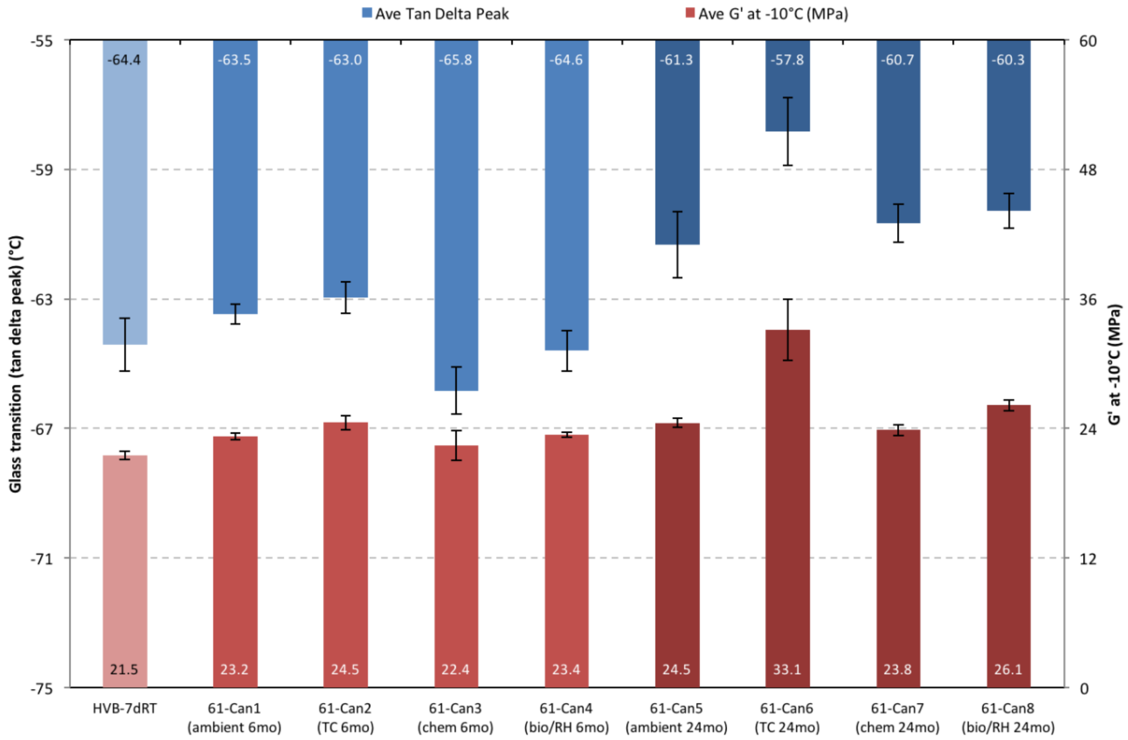

Figure 2.18. Average T_g (blue/top) and storage modulus (G', red/bottom) values for Arathane 5753 HVB specimens after curing 7 days at RT, small core aging for 6 months, and small core aging for 24 months.

The data in the left bar of the graph is for material that was measured after 7 days at room temperature (7dRT). Seven days at room temperature provides an unaged and unexposed experimental control for comparison.

The storage modulus is indicated by red bars in the graphs and does not appear to be affected by 6 months in the small core cans for either material. The glass transition temperature (defined as the tan delta peak for this work) is indicated by blue bars in the graphs and shows some small change with environment. The Arathane 5753 HVB appears to show a little more variation between the different cans; however, these differences are very small and are not of concern.

After 24 months of aging, both materials show a change of +3°C in glass transition temperature across all cans. The thermally cycled Arathane 5753 HVB specimens show a more dramatic change in glass transition temperature, accompanied by an increase in storage modulus. The effect of the solvents in the chemical can appears to be minimal after 24 months as compared to 6 months aging. As noted for the specimens at 6 months aging, the Arathane 5753 HVB appears to show more variation between the different cans after 24 months. We do not expect these differences to have an impact during deployment of the material.

2.7. Aging

2.7.1. *Long term thermal aging study*

Sandia has significant experience investigating the effects of aging on materials. [7] The aim of this study is to measure decline in important properties associated with oxidative degradation of Arathane 5753 HVB and EN-7. We are not interested in the projected lifetime of the materials so much as the ability of Arathane 5753 HVB material to withstand conditions at least as well as EN-7.

Test methods

- practice for heat aging of plastics (ASTM D3045)
- durometer (hardness Shore A, ASTM D2240)
- volume resistivity (ASTM D257)
- mass (can use resistivity samples for this)
- T_g (DMTA)

Procedure

- Prepare and cure sheets of EN-7 and Arathane 5753 HVB. Condition samples for one week at room temperature.
- If using multiple pours, cut specimens of each type from as many pours as possible and randomize the temperature to which they will be exposed.

Test conditions

- air exposure at room temperature
- five samples per condition
    - many are nondestructive measurements so fewer specimens are needed
- Temperatures: Air atmosphere at 105°C, 50°C, and lab conditions (23°C)
- Durations: as given in Table 1 of ASTM D3045. Follow schedule D for 105°C and schedule A for 50°C and 23°C
    - The temperature for Schedule D of 105°C is well above typical use temperatures, but it was decided to try it anyway and stick with the ASTM temperatures and times.
- Schedule D—2, 4, 8, 16, 32 days
- Schedule A—3, 6, 12, 24, 48 weeks

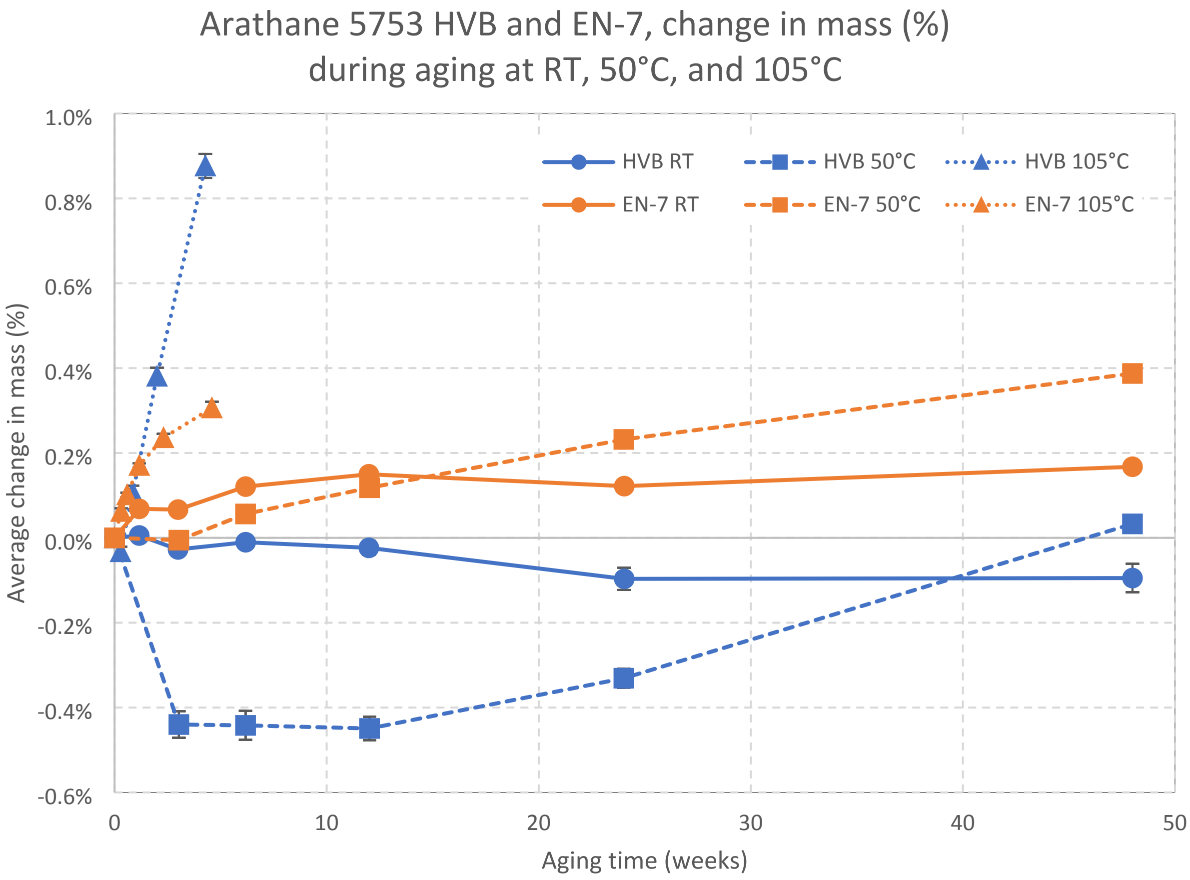

Figure 2.19. Arathane 5753 HVB and EN-7 display similar mass change over time.

The details of the mass change data in Figure 2.19 are not fully understood. Since 105˚C is well beyond the design temperature, we choose to ignore that data, but include it for completeness. If we assume the initial mass loss at 50˚C is due to loss of absorbed moisture, the behavior of the two materials is similar.

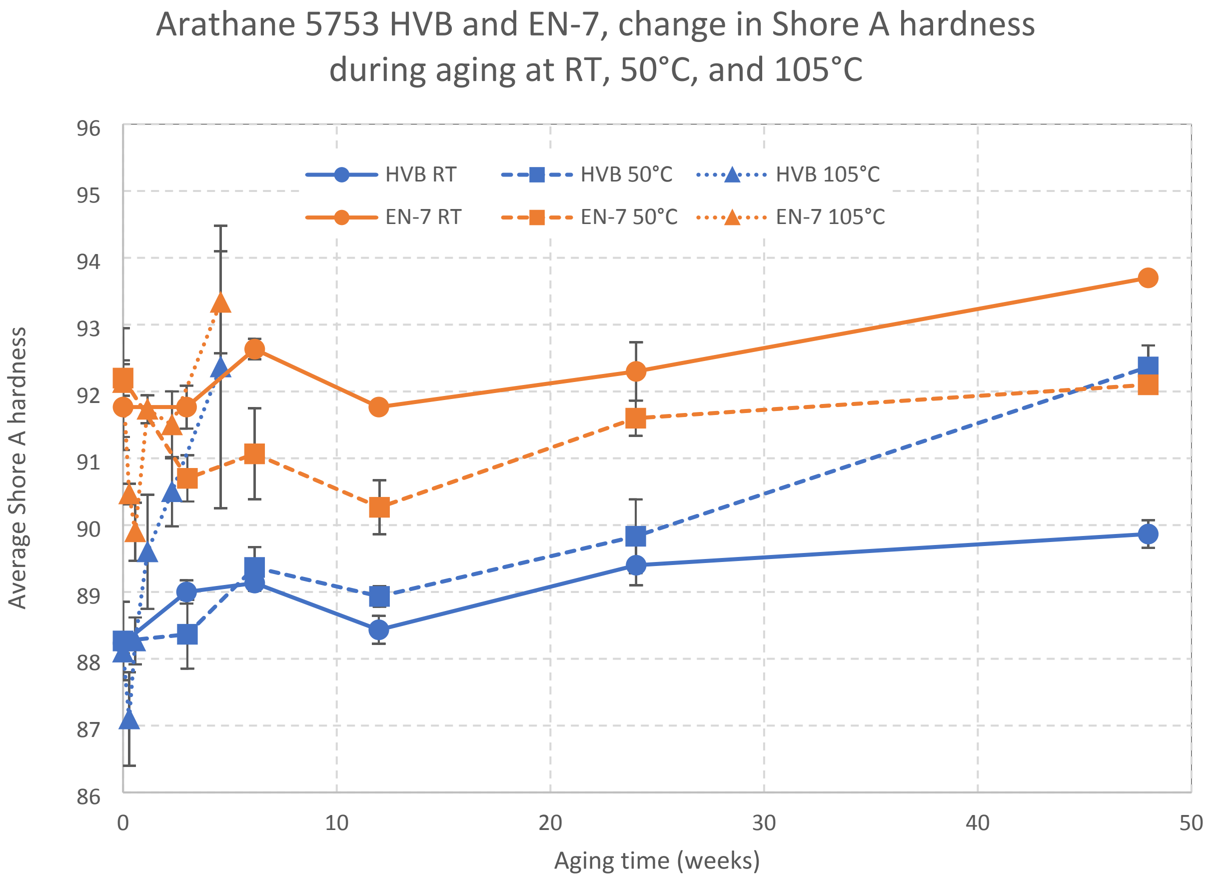

Figure 2.20. Both Arathane 5753 HVB and EN-7 show slight hardening over 1 year of aging.

As shown in Figure 2.20, both materials show a slight increase in hardness over the 1 year of aging. By design Arathane 5753 HVB is slightly more compliant than EN-7. One might expect an elastomer to become harder more quickly at an elevated temperature as additional crosslinking occurs. In addition, oxidation could be contributing to the increase in hardness over time.

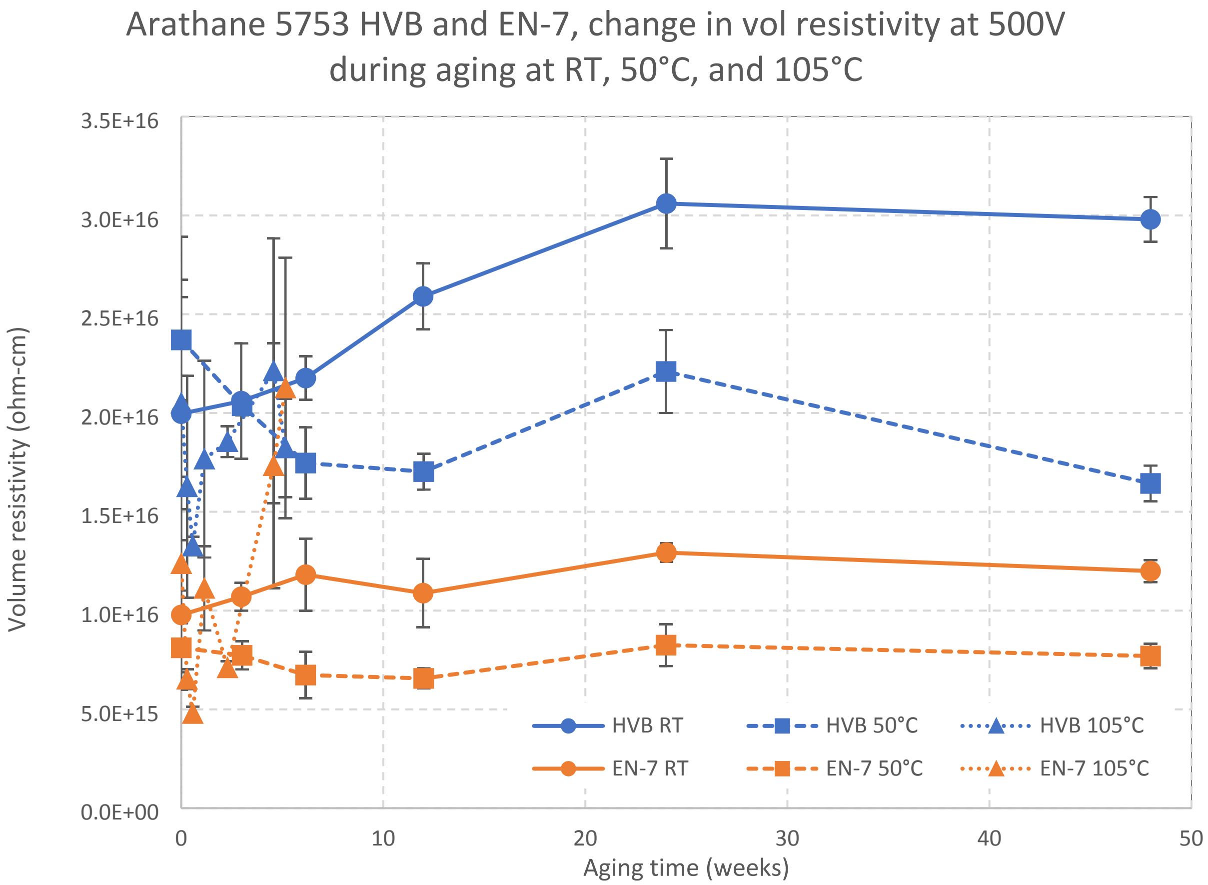

Figure 2.21. No significant changes in volume resistivity were observed upon aging.

At first glance, the data in Figure 2.21 appears to show great differences in the materials. In fact, the y-axis is extremely magnified, and all these materials are very highly resistive, with Arathane 5753 HVB being slightly better than EN-7.

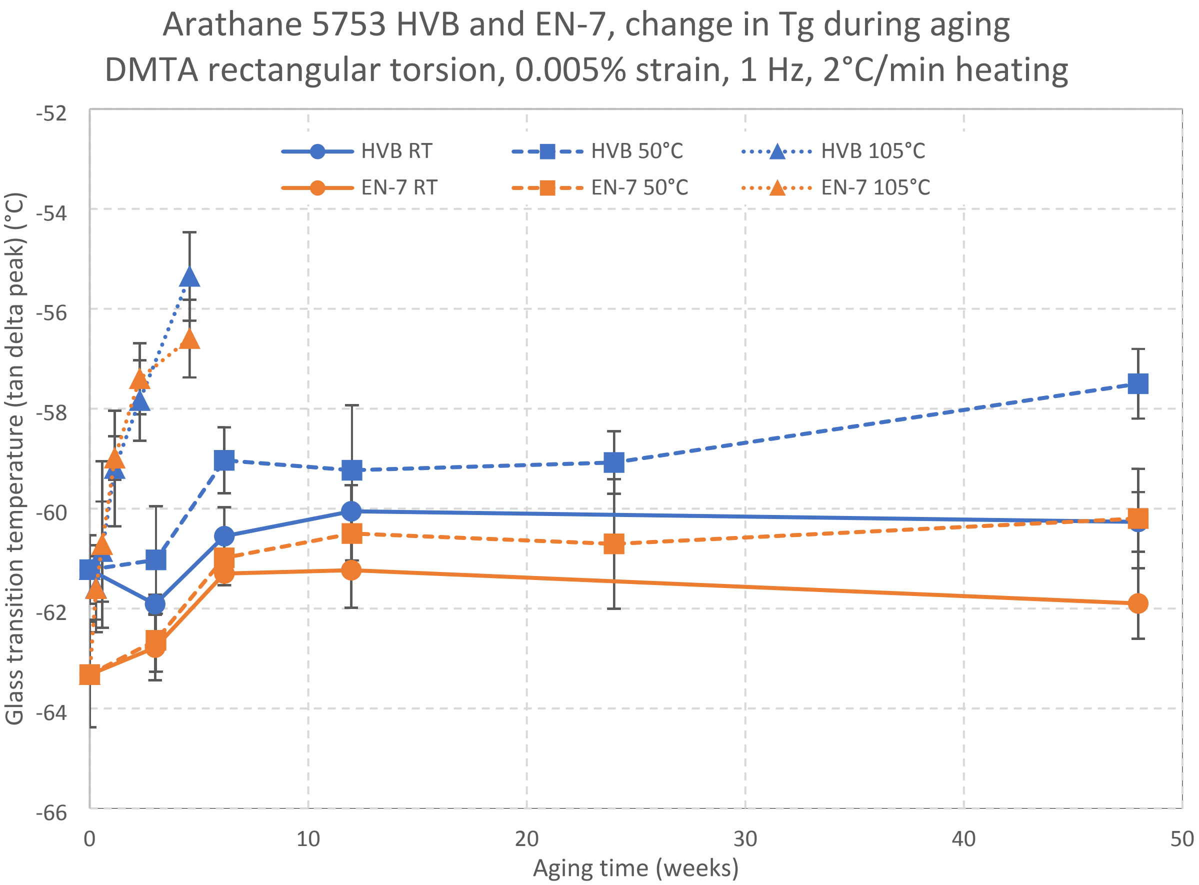

Figure 2.22. Aging results in little change in T_g of the two materials.

If we again ignore the 105°C data, both materials are well-behaved and show minor changes in T_g with aging. As expected, there is slightly more change with aging at higher temperatures.

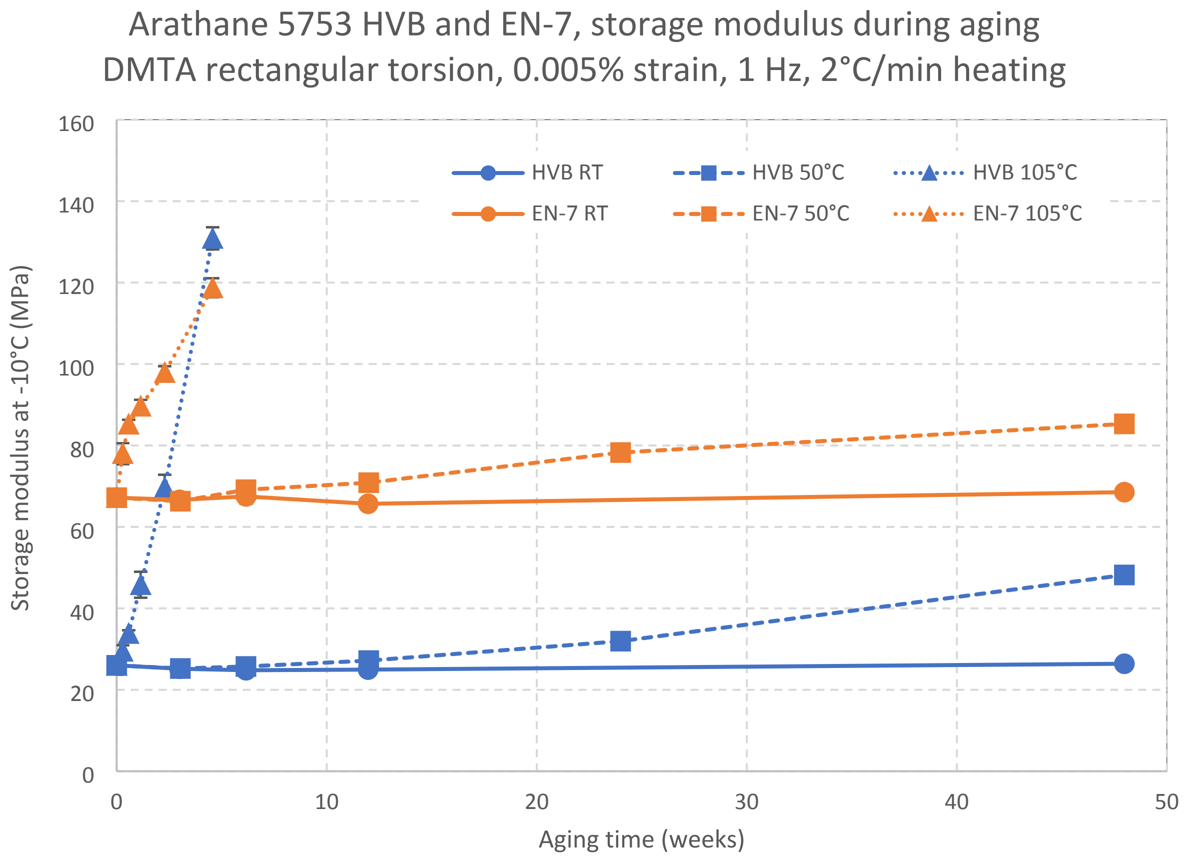

Figure 2.23. Storage modulus of both materials behaving as expected over time.

As shown in Figure 2.23, the storage moduli of both materials are not significantly changed. Again, by design, Arathane 5753 HVB is less stiff than EN-7.

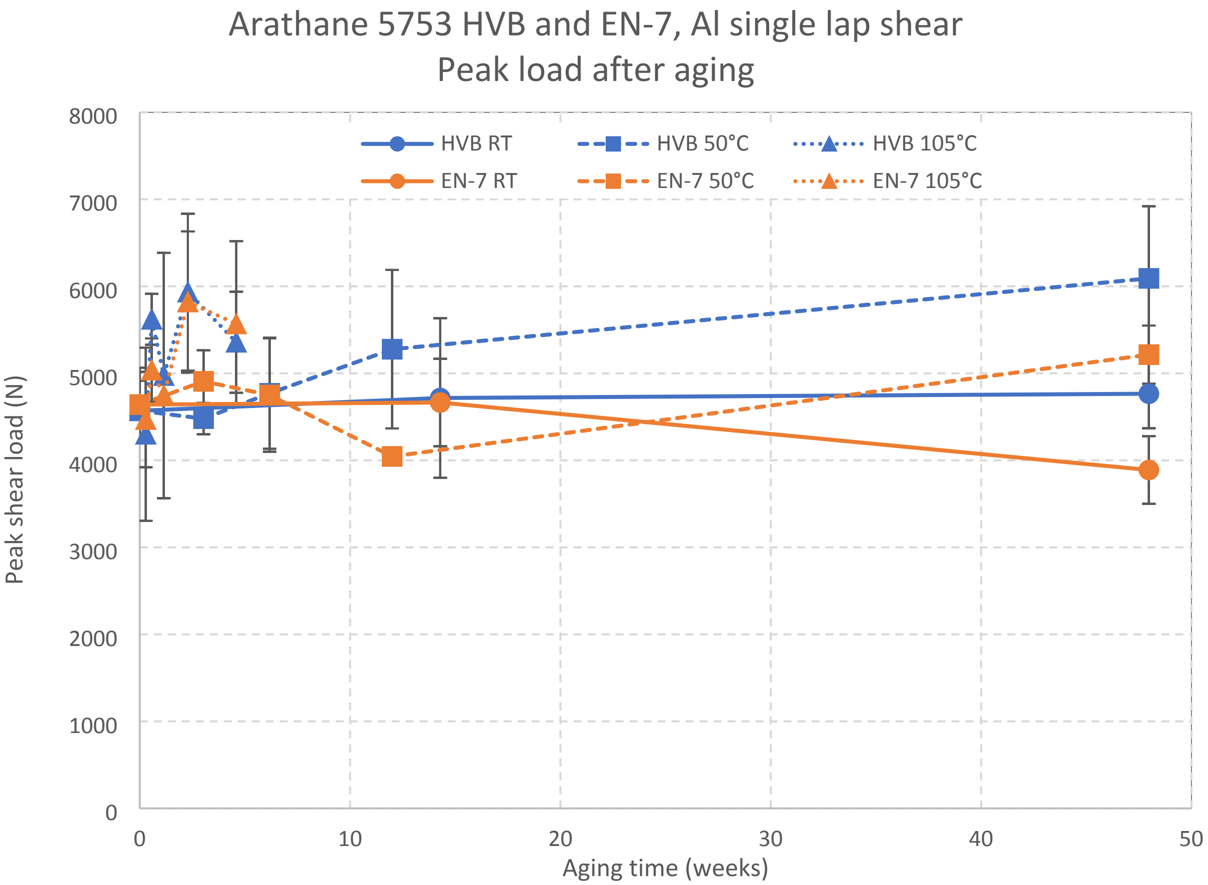

Figure 2.24. Good adhesion was observed for both materials as a function of age.

The adhesion of both materials to aluminum 6061 (Oakite cleaned, no abrasion, no primer) showed little change with time and temperature. As expected, samples aged at higher temperature showed stronger bonding. The EN-7 may have a slightly weaker bond after one year at ambient.

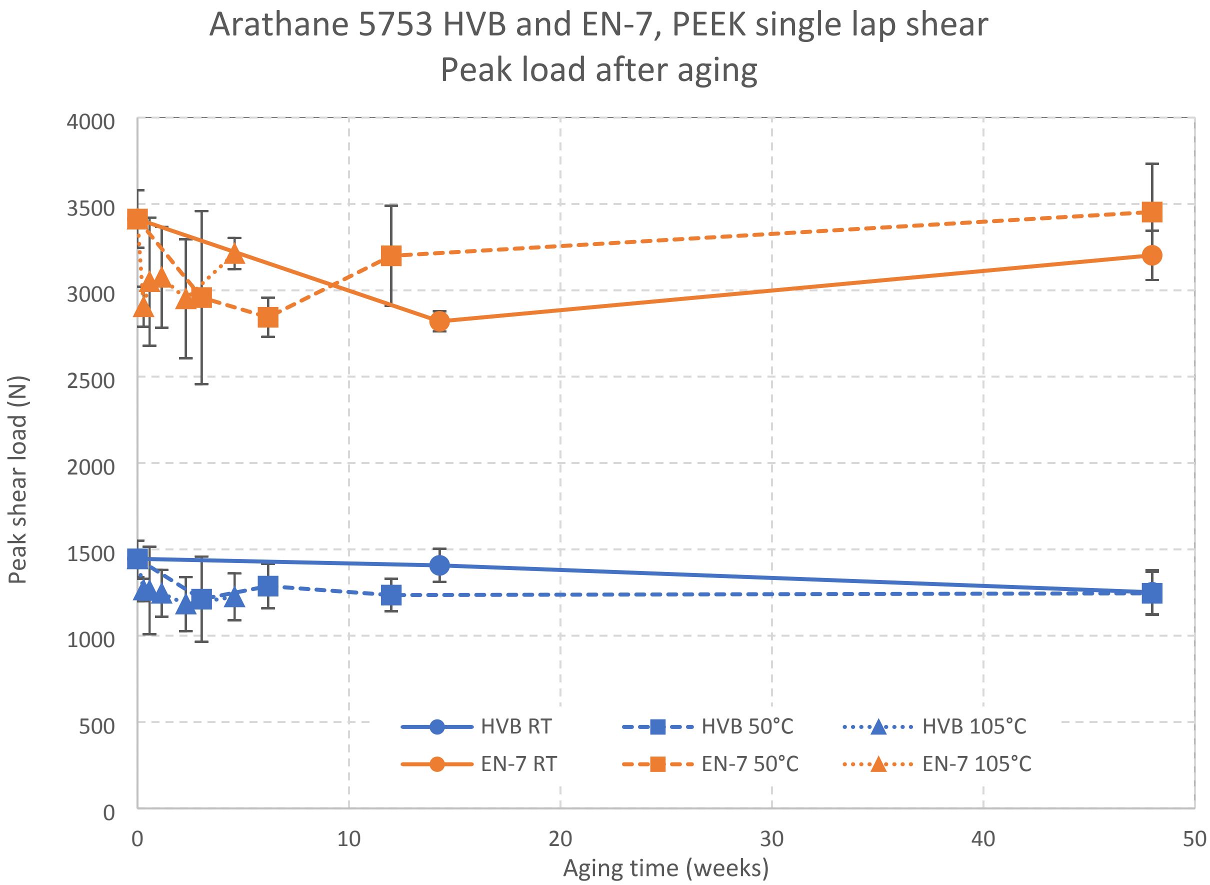

Figure 2.25. Both materials show little change over time, with EN-7 having significantly better bonding to PEEK.

EN-7 shows significantly better adhesion to PEEK than Arathane 5753 HVB. However, both materials show little change with time and aging temperature.

3. CONCLUSIONS

Arathane 5753 HVB shows promise as replacement for EN-7. The largest advantage of Arathane 5753 HVB is that it does not contain the suspect carcinogen and chemical sensitizer toluene diisocyanate (TDI). Arathane 5753 HVB has better processing characteristics, comparable or better properties, and demonstrated satisfactory aging and compatibility.

Arathane 5753 HVB kits are available from Specialty Polymers & Services, Inc. As an alternative, Arathane 5753 LV can be obtained from many distributors and DEH (2-ethyl-1,3-hexanediol) added to the B side to make a kit. If mixing a kit, use the formulation listed in the processing section of this report.

In contrast to most of the potential EN-7 replacement formulations developed over the previous 2-3 decades, Arathane 5753 HVB is made from all liquid starting materials. This may seem like a small detail, but it greatly reduces the complexity and planning required to preheat and melt constituents in a production environment. Another longstanding criticism of EN-7 is its limited pot life or work life. The pot life of Arathane 5753 HVB is at least twice that of EN-7.

The largest challenge that every previous replacement for EN-7 faced was matching the high voltage breakdown strength. Luckily, when the DEH was added to the Arathane 5753 LV to increase the cross-link density and thus the stiffness, it also increased the high voltage breakdown to match EN-7. To be able to do this without compromising processing or other properties was a significant advantage. Arathane 5753 LV was chosen as the starting point for this replacement because it had favorable processing and low outgassing, having been used for many years in satellites.[8] Minimal outgassing was also observed with Arathane 5753 HVB.

Materials Aging and Compatibility (MAC) testing for the B61-12 did not show any areas of concern. Additional isothermal aging studies also showed only minor changes in properties for 1 year at elevated temperature.

However, Arathane 5753 HVB is not a "drop-in" replacement for EN-7. The main differences with EN-7 is that Arathane 5753 HVB is cloudy in appearance and the shelf-life of the isocyanate (A) side is only 6 months. Being able to visually verify that there are no significant internal voids in key locations (between connector pins for example) in high voltage applications is an advantage of EN-7. Arathane 5753 HVB is slightly cloudy in appearance, allowing voids near the surface to be seen. The source of the cloudiness is under investigation. EN-7 has a 15-month shelf-life according to the manufacturer. This is longer than the 6-month shelf-life for Arathane 5753 HVB that was carried over from the LV version because the isocyanate (A side) was unchanged. This 6-month shelf-life poses difficulties for production. To date we have not investigated extending the shelf-life with testing as we do with many other isocyanates. This is an obvious solution that will be examined.

4. REFERENCES

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1. APPENDICES

1.1. Appendix I: Specification 2519614

CAGE CODE 14214

S. M. Torres 896KC
N. Menon 8223SL

(U) POLYURETHANE ENCAPSULATING COMPOUND, HIGH VOLATGE BREAKDOWN

Drawing Callout:	Polyurethane Encapsulating Compound per 2519614-(1).

(1) Insert Control Number Suffix.

CHANGE HISTORY

CONTROL NUMBER	ISSUE	RELEASE/CHANGE NO.	DATE
2519614-00	A	IER 20170563KC	04/18

1. GENERAL.

1.1. Scope. This specification covers Arathane 5753 HVB, a two-component catalyzed polyurethane encapsulating compound comprising Arathane 5753 LV combined with 2-ethyl-1,3-hexanediol (DEH) that has been premixed and packaged into a two-part kit.

2. DOCUMENTS.

ASTM D1475	Standard Test Method For Density of Liquid Coatings, Inks, and Related Products
ASTM D1084	Standard Test Methods for Viscosity of Adhesives
ASTM D2240	Standard Test Method for Rubber Property - Durometer Hardness

3. REQUIREMENTS.

3.1. Approved Products. The material (Arathane 5753A/5753HVB)shall be the following ingredients that have been premixed into a two-part kit:

Ingredient Product Designation	Mix Ratio (Parts by Weight)	Company
5753A (Part A)		
Arathane 5753 A	61	Huntsman
5753HVB (Part B)		
Arathane 5753 B (LV)	100	Huntsman
2-ethyl-1,3-hexanediol	20	Sigma-Aldrich

3.2. Two-Part Kit Mix Ratio. The mix ratio for the two-part kit material shall be the following:

Product Designation	Mix Ratio (Parts by Weight)
Arathane 5753A (Part A)	51
Arathane 5753HVB (Part B)	100

3.3. Uncured Material. The material shall conform to the following requirements.

3.3.1. Appearance.

3.3.1.1. Arathane 5753 A. Clear to Amber liquid with no contamination.

3.3.1.2. Arathane 5753HVB. Clear to Translucent Amber Liquid with no contamination

3.3.2. Viscosity.

3.3.2.1. Arathane 5753A. The initial viscosity of the material at 25 ± 1°C shall be 40 ± 15 centipoise when determined per 4.2.2. *in accordance with ASTM D1084 using the small sample adaptor* with a No. SC4-21 spindle at 50 rpm. The viscosity may be determined with an alternate, equivalent viscometer with associated methods, spindles, and speeds. In case of dispute, the first stated method shall govern.

3.3.2.2. Arathane 5753HVB. The initial viscosity of the material at 25 ± 1°C shall be 4,500 ± 2,500 centipoise when determined per 4.2.2. *in accordance with ASTM D1084 using the small sample adaptor with a No. 27 spindle at 20 rpm.* The viscosity may be determined with an alternate, equivalent viscometer with associated methods, spindles, and speeds. In case of dispute, the first stated method shall govern.

3.3.3. Pot life. The pot life, time to reach 30,000 centipoise, of the compound when tested in accordance with 4.2.2 shall be greater than 25 minutes.

3.3.3.1. Minimum Viscosity. Determine and report the minimum viscosity during the pot life test for Engineering information only.

3.3.4. Fourier Transform Infrared spectroscopy (FTIR). A Fourier Transform Infrared spectrum shall be run per 4.3 on each lot of Arathane 5753 A and Arathane 5753HVB submitted for acceptance testing. A report of conformance or non-conformance is required.

3.4. Cured Material. The compound, when cured as specified in 4.4, shall meet the following requirements.

Property	Value	Test Method
Hardness, Shore A, minimum, instantaneous	75	ASTM D2240

4. QUALITY ASSURANCE PROVISIONS.

4.1. Lot Definition. A lot shall consist of a homogeneous quantity of mixed materials listed in 3.1 that was produced in one manufacturing cycle under one set of conditions.

4.2. Lot Inspection and Testing. A representative sample from each lot shall be inspected and tested for the requirements listed below:

Appearance
Viscosity
Hardness
Pot Life
FTIR

4.3. Reconstitution of the Encapsulation Compound. Exposure of part A to low temperatures for prolonged periods may cause crystallization.

4.3.1. Prior to any testing, Part A must be re-liquified by heating at a nominal temperature of 158°F (70°C). Heat part A until a clear amber solution is achieved. Remove container from oven. Do not disturb contents. Allow material to cool to 77°F to 104°F (25°C - 40°C) in a controlled environment, do not force cool.

4.3.2. Measure height of any remaining precipitate from outside of the bottle. Reject material if level of precipitate is above 3/8 inches (0.6 cm) or if liquid remains cloudy or contains gelled particles.

4.3.3. 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 result, filter Part A through a nylon sieve, 10 - 25-micron size.

4.4. Protection from Moisture. If, at any time, containers of Part A or Part B are opened, the containers shall be flushed with dry nitrogen before resealing to help minimize the effect of ambient moisture on the reactivity of the polyurethane.

4.5. Test and Inspection Methods.

4.5.1. Test Conditions. Sample preparation and testing may be done at 18 to 30°C and 10 to 65% relative humidity.

4.5.2. Initial Viscosity and Pot Life.

4.5.2.1. Prepare sufficient quantity of mixed material to perform testing.

4.5.2.2. Dispense material sample into a small sample adapter apparatus.

4.5.2.3. Turn on viscometer and start timer.

4.5.2.4. Record viscosity every minute and adjust speed to keep reading within scale.

4.5.2.5. Turn off viscometer after reaching 30,000 cP.

4.5.2.6. Report the minimum viscosity value.

4.5.2.7. Report the time to reach 30,000 cP.

4.5.3. Fourier Transform Infrared Spectroscopy (FTIR). An FTIR spectrum shall be performed on each lot of material submitted for acceptance. The conditions for analysis should typically include: a capillary film between KBr plates, a range of 4000 to 700 cm-1 and a resolution of 4 cm-1. A typical spectrum for reference is to be kept on file. The reference and acceptance spectrum shall be saved in a retrievable, replot-able file format such as spa, jdx, ird, nic, csv, wmf, tif, etc

4.5.3.1. Report. The presence of extraneous peaks or absence of expected peaks in the sample spectrum, when compared to the qualified reference spectrum, shall be noted and may be the cause for rejection of the material. In the event of a non-conformance, the product engineer shall be notified and a joint decision shall be made in consultation with the Quality engineer and the design agency to either accept or reject the lot of material.

4.5.4. Preparation of Cured Test Specimens.

4.5.4.1. Thoroughly mix Parts A and B in their individual shipping containers.

4.5.4.2. Weigh 200 grams ±1 percent of Part A into a suitable mixing container (do not use untreated paper).

4.5.4.3. Add the requisite quantity, within 1 percent, of Part B to the mixing container. Thoroughly mix Parts A and B for 2.0 to 2.25 minutes by hand until the mixture is homogeneous.

1.) Deaerate the mixture by evacuating at a pressure of 3 torr maximum for at least 1 minute after the foam rise collapses. If the foam rise collapses before reaching 3 torr, then continue deaerating for at least 1 minute at 3 torr maximum.

2) Alternate processing by use of a vacuum mixer. Immediately after adding the curing agent, place the material in a suitable chamber and mix at a maximum pressure of 3 torr for at least 2 minutes or until the foam rise collapses. Allow the pressure to return to atmospheric. Mixing shall be completed within 3 minutes after combination of the curing agent and the

prepolymer. Introduce compound into molds which have been preheated at 71±3°C (160±5°F) for approximately 2 hours. Avoid air entrapment. Cure in a forced convection oven for 16.0 to16.5 hours at 71±3°C (160±5°F).

4.5.4.4. Specimens shall be tested 24 to 96 hours after completion of cure in a forced convection oven for 2.0 to 2.5 hours at 71±3°C (160±5°F).

5. PACKAGING, HANDLING AND STORAGE.

Lots of material are purchased as paired kits, tested as paired kits, and are to be used as paired kits.

NOTE: This does not mean that the two components will have the same lot number.

5.1. It is the responsibility of the Production Agency to establish site-specific processes to control shelf life, storage condition, documentation, and labeling.

Packaging, handling, storage conditions, and shelf life information shall follow the requirements listed in Section 5.2.

Site-specific processes that conform to the baseline conditions of Section 5.2 may be specified in an Information Engineering Release (IER).

If there are no requirements defined in Section 5.2, shelf life and storage conditions are specified in an Information Engineering Release (IER) and are based on the manufacturer’s recommendations, previous experience with similar materials, storage facilities, and available environments.

Shelf life and storage conditions at Subcontractor locations are based on the Manufacturer’s recommendations.

Packaging, handling, documentation, storage, and shelf life information for the Kansas City National Security Campus (KCNSC) is in IER 20170563KC.

The packaging, handling, storage, and shelf life conditions described herein are not required to be performed or met by the material producer or supplier, except when the KCNSC is the manufacturer.

5.2. Packaging, handling, storage conditions, and shelf life requirements are not applicable (see 5.1).

6. NOTES

This section is supplied for the convenience of the users of this specification and contains no mandatory provisions. Supplier.

6.1. The recommended supplier for this 2-part kit material is Specialty Polymers & Services, Inc. (SP&S).

6.2. Material Certification.

6.2.1. It is recommended that the Purchase Order Quality Requirements require the supplier to provide the Manufacturer’s Certificate of Analysis (COA) for each of the ingredients listed in 3.1.

6.3. Labeling. Each individual container of material is recommended to be marked with the following information as a minimum:

Material Specification Number
Manufacturer’s Product Designation
Name of Manufacturer
Manufacturer's Lot Number
Date of Manufacture
Storage Condition
Shelf Life

END OF TEXT

1.2. Appendix II: SDS for Arathane 5753 HVB

Safety Data Sheet

1. Product and Company Identification

Product Name: **Arathane® 5753HVB**
Material Uses: Adhesive, encapsulant, coating, & casting material
(M)SDS#: 5753HVB-20160822
Validation Date: Aug-22-2016
Supplier/Manufacturer: Specialty Polymers & Services, Inc. (SP&S, Inc.)
27822 Fremont Court
Valencia, California (CA) 91355, U.S.A.
Non-emergency phone number: (661) 294-1790 (7AM – 5PM PST)
E-mail: msds@spolymers.com

In case of emergency: Chemtrec (800) 424-9300 or (703) 527-3887

2. Hazards Identification

GHS CLASSIFICATION OF SUBSTANCE OR MIXTURE:

Eye damage: Category 1, H318

GHS LABEL ELEMENTS:

HAZARD SYMBOLS:

SIGNAL WORDS: DANGER!

HAZARD STATEMENTS:

H318 Causes serious eye damage

PRECAUTIONARY STATEMENTS:

PREVENTION:
P202 Do not handle until all safety precautions have been read and understood.
P260 Do not breathe mists.
P264 Wash hands thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P273 Avoid release to the environment.
P280 Wear protective gloves, clothing, and eye/face protection.

RESPONSE:
P301+P330+P331+P312 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting. Call POISON CENTER and/or doctor if you feel unwell.
P303+P361+P634+P353+P352 IF ON SKIN (or hair): Take off immediately all contaminated clothing and wash before reuse. Rinse skin with water/shower. Wash with plenty of soap and water.
P333+P313 If skin irritation or rash occurs: Get medical attention.
P304+P340 IF INHALED: Remove person to fresh air and keep comfortable for breathing.
P305+P351+P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P308+P313 IF exposed or concerned: Get medical attention.
P391 Collect spillage.

STORAGE:
P403+P233 Store in a well-ventilated place. Keep container tightly closed.

DISPOSAL:	P501 Dispose of contents and containers in accordance with local, regional and international regulations.

Precautionary statements are listed according to the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS) – Annex III

See toxicological information (section 11)

General Information: Read entire MSDS for a more thorough evaluation of the hazards

3. Composition / Information on Ingredients

Name	CAS Number	%
Ethoexadiol	94-96-2	10% – 20%
2-Propanol-1,1'-Phenylaminobis	3077-13-2	1% – 10%

Amounts specified are typical and do not represent a specification. Remaining components are proprietary, non-hazardous, and/or present at amounts below reportable limits.

4. First Aid Measures

Eye Contact:	Check for and remove any contact lenses. Immediately flush eyes for at least 15 minutes with running water. Hold eyelids apart to ensure rinsing of the entire eye surface and lids with water. Get immediate medical attention.
Skin Contact:	In case of contact, wash affected areas with plenty of water, and soap, if available, for several minutes. Remove and clean contaminated clothing and shoes before re-use. Get medical attention if irritation occurs.
Inhalation:	Move exposed person to fresh air. If not breathing, give artificial respiration or oxygen. If breathing is difficult, transport to medical care and, if available, give supplemental oxygen. Loosen tight clothing such as a collar, tie, belt, or waistband. Get immediate medical attention.
Ingestion:	Wash out mouth with water. If swallowed dilute by giving two (2) glasses water to drink. Do not induce vomiting until direct to do so by medical personnel. Never give anything by mouth to an unconscious person. Get immediate medical attention.
Note to physician:	No specific treatment. Treat symptomatically. Call poison control center if large quantities were ingested

5. Fire-Fighting Measures

Flash point:	232°C (450°F) Pensky-Martin closed cup
Hazardous Thermal Decomposition Products:	Decomposition products may include the following materials: carbon dioxide, carbon monoxide, halogenated compounds, metal oxides and other oxides.
Extinguishing Media:	Carbon dioxide, foam, dry chemical, water spray as suitable for the surrounding fire.
Special Exposure Hazards:	Promptly isolate the scene by removing all persons from the vicinity of the fire. No actions shall be taken involving any personal risk or without suitable training.
Special Protective equipment for fire-fighters:	No Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

6. Accidental Release Measures

Personal Precautions:	No actions shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering area. Do not touch or walk through spilled material. Avoid breathing vapor or mist and provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment (see Section 8).
Environmental Precautions:	Avoid dispersal of spilled material and runoff that leads to contact with soil, waterways, drains, and sewers. Inform the relevant authorities if the product has caused environmental pollution.
Methods of Clean Up:	Stop leak if without risk. Move containers from spill area. Approach spill from up wind if possible. Prevent spill from entering sewers, rivers and other water courses, basements, or confined areas. Wash into effluent treatment plant or proceed as follows. Contain and collect spillage with non-combustible, absorbent material (e.g. sand, earth, vermiculite, or diatomaceous earth) and place in container for disposal according to local regulations. Dispose of only using a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilled product. Note: see section 1 for emergency contact information.

7. Handling and Storage

Handling:	Wear appropriate personal protective equipment (see Section 8) when handling. Eating, drinking, and smoking should be prohibited in areas where chemical are handled, stored, or processed. Workers should wash hands and face before eating, drinking, and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Persons with a history of skin sensitization problems should be employed in processes where this material is used. Keep in the original container or a suitable alternate made from a compatible material. Keep all containers tightly closed when not in use. Empty containers retain product residue and should be disposed of properly. Do not reuse empty containers for other purposes or to hold other materials.
Storage:	Store in accordance with local regulations. Store in original containers, at 10°C - 35°C. Keep away from incompatible materials (see Section 10) and food and drink. Keep all containers tightly closed when not in use and tightly re-seal after use. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination.

8. Exposure Controls / Personal Protection

Recommended Monitoring Procedures:	If this product contains ingredients with exposure limits, personal, workplace, atmospheric, or biological monitoring may be required to determine the effectiveness of the ventilation system or other control measures and/or to determine whether it is necessary to use respiratory protective equipment. It will also be necessary to reviewed national guidance documents for determining how to handle and relevant Hazardous Substances
Engineering measures:	No special ventilation requirements are necessary for this product. Good general ventilation should be sufficient to control worker exposure to airborne contaminants. If this product contains ingredients with exposure limits, use process enclosures, local exhaust ventilation, or other engineering controls to keep worker exposure below the recommended or statutory limits
Hygiene measures:	Wash hands, forearms, and face thoroughly after handling any chemical products, before eating, smoking, and using the lavatory and at the end of the work period. Appropriate techniques should be used to remove potentially contaminated clothing. Contaminated clothing should not be allowed out of the workplace. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal Protection

Respiratory:	In case of inadequate ventilation wear respiratory protection. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.
Hands:	Chemical Resistant, impervious gloves that comply with an approved safety standard should be worn at all times when handling chemical products if a risk assessment indicates that this is necessary. Consider the parameters specified by the glove manufacture and check gloves during use to ensure they are retaining their protective properties.
Eyes:	Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, or dusts. If contact is possible use chemical splash googles unless a higher degree of protection is required.
Skin:	Personal Protective equipment for the body should be selected based on the task being performed and the risks involved. Typical protective equipment includes non-absorbent lab coats, disposable protective sleeves, coats, or whole body suits. See a safety specialist to determine the appropriate level of protection for your task.
Environmental Exposure Controls:	Emissions from ventilation or work processes should be checked to ensure they comply with the requirements of environmental regulations. In some cases, fume scrubbers, filters, or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and Chemical Properties

Appearance:	Clear to milky liquid	Odor	Mild hydrocarbon
Boiling Point:	N/A	Freezing Point:	N/A
Flash Point:	232°C (449.6°F) close cup	pH:	N/A
Auto-ignition Temperature:	N/A	Flammable Limits:	N/A
Vapor Pressure:	<1 mm Hg at 25°C (77°F)	Water Solubility:	Partially soluble
Specific Gravity:	0.92	Vapor Density:	>1 (Air = 1)
Evaporation Rate:	<1 (butyl acetate =1)	VOC:	10 g/ L (estimated)
Viscosity:	4000 cps		

10. Stability and Reactivity

Chemical Stability:	This product is stable, under normal conditions of storage and use, hazardous reactions will not occur.
Hazardous Polymerization:	Under normal conditions of storage and use, hazardous polymerization will not occur.
Conditions to Avoid:	High temperatures and exposure to strong oxidizing agents, acids, and bases
Hazardous Decomposition	Under normal conditions of storage and use, hazardous decomposition products should not be produced.

11. Toxicological Information

Acute Toxicity

Product/Ingredient Name	Test	Endpoint	Species	Result
Ethoexadiol		LD50 Oral	Rat	1400 mg/kg
Ethoexadiol		LD50 Dermal	Rabbit	2000 mg/kg
2-Propanol-1,1'-Phenylaminobis	OECD 402 Acute Dermal Toxicity	LD50 Dermal	Rabbit	>2000 mg/kg
2-Propanol-1,1'-Phenylaminobis	OECD 420 Acute Oral Toxicity – Fixed Dose	LD50 Oral	Rat	3800 mg/kg

Irritation / Corrosion

Product/Ingredient Name	Test	Species	Result
Ethoexadiol		Rabbit	Skin – mild irritant
Ethoexadiol		Rabbit	eye – severe irritant
2-Propanol-1,1'-Phenylaminobis			Skin – mild irritant
2-Propanol-1,1'-Phenylaminobis			Eyes – severe irritant

Sensitizer

Product/Ingredient Name	Test	Species	Result
Not available			

Mutagenicity

Product/Ingredient Name	Test	Result
Not available		

Conclusion/ Summary: the weight of scientific evidence indicates that the components of this product are not genotoxic

Carcinogenicity

No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC, ACGIH,NTP or OSHA or :

Reproductive Toxicity

Product/Ingredient Name	Test	Species	Maternal Toxicity	Fertility	Developmental Effects
Not available					

Teratogenicity

Product/Ingredient Name	Test	Species	Results
Not available			

Potential Acute Health Effects

Inhalation:	May give off gas that is irritating to the respiratory system.
Ingestion:	May cause burns to mouth, throat, and stomach
Skin Contact:	Slightly irritating. No known critical hazards.
Eye Contact:	Severely irritating to eyes

Potential Chronic Health Effects

Product/Ingredient Name	Test	Endpoint	Species	Results
None Known				

General:	Once sensitized, an allergic reaction may occur when subsequently exposed to very low levels
Target Organs:	No known significant effects or critical hazards
Carcinogenicity:	No known significant effects or critical hazards
Mutagenicity:	No known significant effects or critical hazards
Teratogenicity:	No known significant effects or critical hazards
Developmental Effects:	No known significant effects or critical hazards
Fertility Effects:	No known significant effects or critical hazards

12. Ecological Information

Environmental Effects: No known significant effects or critical hazards.

Aquatic Ecotoxicity

Product/Ingredient Name	Test	Endpoint	Exposure	Species	Result
Not available					

Persistence and Degradability

Product/Ingredient Name	Test	Period	Result
Not available			

Product/Ingredient Name	Aquatic half-life	Photolysis	Biodegradability
Not available		-	

Bioaccumulative potential

Product/Ingredient Name	Log P_{ow}	BCF	Potential
Not available			

Other adverse effects: No known significant effects or critical hazards

Other information: BOD5: Not determined COD: Not Determined TOC: Not determined

13. Disposal Consideration

Waste Disposal Method: Disposal of this products, solutions, and by-products should at all times comply with the requirements of environmental and waste disposal legislation and any regional or local authority requirements. Dispose of surplus, non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed on untreated to the sewer system unless this is complaint with all applicable laws and regulations. Incineration by an approved and licensed contractor is the most common disposal method. Packaging materials that and absorbents containing the product can typically be landfilled or incinerated. Contact local authorities to determine the proper means of disposal in your area.

14. Transport Information

Not regulated for transportation purposes under 49CFR (US DOT), TDG (Canada), IATA, and IMDG regulations.

15. REGULATORY INFORMATION

US Federal Regulations:

Occupational Safety and Health Act (OSHA): This product is considered to be a hazardous chemical under the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Resource Conservation and Recovery Act (RCRA): This product is considered to be a hazardous waste under RCRA (40 CFR 261).

SARA Title III: Section 304 - CERCLA: This product does not contain chemicals regulated under Section 304 as extremely hazardous substance(s) for emergency release notification ("CERCLA" List):

SARA Title III: Section 311/312 - Hazard Communication Standard (HCS): Immediate (acute) health hazard

Delayed (chronic) health hazard

SARA Title III: Section 313 Toxic Chemical List (TCL): This product does not contains) a toxic chemical for routine annual Toxic Chemical Release Reporting under section 313 (40 CFR 372).

TSCA Section 8(b) - Inventory Status: All chemical(s) comprising this product are listed on the TSCA inventory.

TSCA Section 12(b) - Export Notification: This product does not contain chemicals which are subject to Section 12(b) export notification:

State Regulations:

California Proposition 65: ⚠ **WARNING**: This product can expose you to chemicals including vinylcyclohexene, 1,3-butadiene, which are known to the State of California to cause cancer and birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov.

International Regulations:

REACH Status (EC 1907/2006): This material has been registered, pre-registered, or is otherwise exempt from registration under REACH.
REACH Annex XIV (SVHC): No listed components as of validation date
Reach Annex XVIII (Restrictions on the manufacture, placing on the market & use of certain dangerous substances, mixtures, and articles): No list components as of validation date

WHMIS: Class D-2B: Material causing other toxic effects
Class E: Corrosive Material

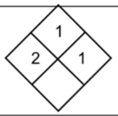
International Lists:

Australia Inventory (AICS):	all components are listed or exempt	Malaysia Inventory (EHS register):	not determined
Canadian Inventory (CEPA-DSL):	all components are listed or exempt	New Zealand Inv. of Chem. (NZIoC):	all components are listed or exempt
China Inventory (IECSC):	all components are listed or exempt	Philippines Inventory (PICCS):	all components are listed or exempt
Japan Inventory (ENCS):	all components are listed or exempt	Taiwan Inventory (CSNN):	not determined
Korea Inventory (ECL):	all components are listed or exempt		

16. OTHER INFORMATION

Hazardous Material Information System (HMIS) - USA	
Health	2
Flammability	1
Physical Hazards	1
Personal Protection	C*

National Fire Protection Association (USA):



*suggested minimum personal protection equipment. End user must determine appropriateness of these suggestions for their applications and usage conditions.

Reason Issued: New release
Prepared By: C. Meyer **Approved By:** **C. Meyer** Title: Vice President

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IN ALL CASES, IT IS THE RESPONSIBILITY OF THE USER TO DETERMINE THE APPLICABILITY OF SUCH INFORMATION AND RECOMMENDATIONS AND THE SUITABILITY OF PRODUCTS FOR THE USER'S PARTICULAR PURPOSE(S).

THIS PRODUCT MAY PRESENT HAZARDS AND SHOULD BE USED WITH CAUTION. WHILE CERTAIN HAZARDS ARE DESCRIBED IN THIS PUBLICATION, NO GUARANTEE IS MADE THAT THESE ARE THE ONLY HAZARDS THAT EXIST.

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.

NOTE: Arathane® is a registered trademark of Huntsman Advanced Materials. SP&S is the Authorized Distributor for the Arathane® 5753A/B(LV) and the manufacturer of Arathane® 5753HVB. Huntsman Advanced Materials does not in any endorse or certify any of the information presented herein, which is supplied solely by SP&S.

1.3. Appendix III: Exova Outgassing Report (cover page)

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T : +1(714) 630-3003
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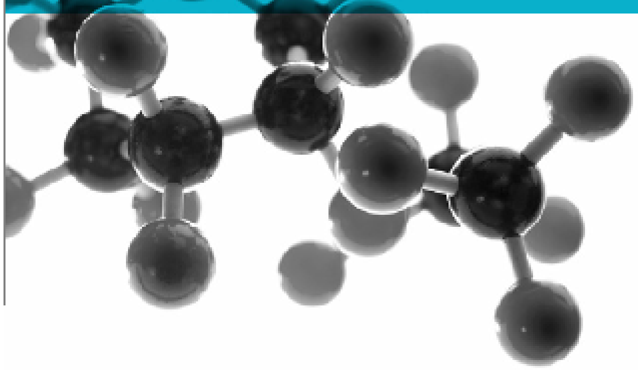
W : www.exova.ca

ASTM E595-07 Outgas Testing

Cured Resin Samples; P/N #'s: VM-03-34D, VM-03-35A, VM-03-EN7



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Issue Date: June 24, 2013
Original Due Date: July 04, 2013
Revision Letter:
Date Revised:

Exova OCM Report No: **330718**
Exova OCM Quote No: 13-240-1659
Purchase Order No: Credit Card: Visa

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Non Metallic Materials

Testing
Advising
Assuring

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ACCREDITED
Certificate # [illegible] Testing
ISO/IEC 17025

This report is issued in accordance with our terms and conditions, a copy of which is available on request.

1.4. Appendix IV: Exova Dielectric Strength Report (cover page)

Exova-OCM
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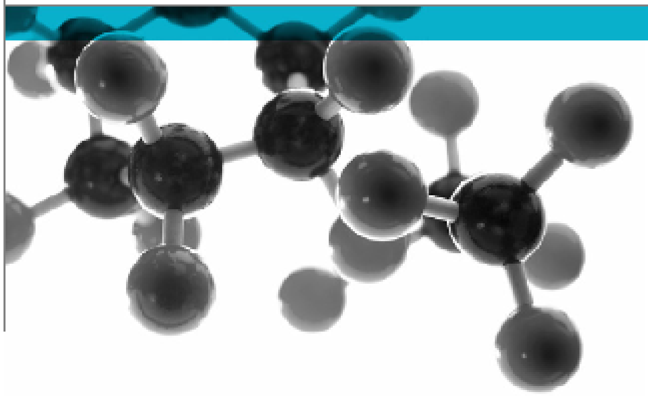
Exova OCM

Dielectric Strength Testing on Supplied Cured Polyurethane Film



Report prepared for: **Sandia National Laboratories**
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Issue Date: June 10, 2013
Original Due Date: May 09, 2013
Revision Letter:
Date Revised:

Exova OCM Report No: **330486**
Exova OCM Quote No: 13-240-1106B
Purchase Order No: Credit Card

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