Influence of Aggressive Environmental Aging on Mechanical and Thermo-Mechanical Properties of UV-Cured CIPP Liner

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Supporting Information

Table SI-1. List of detected and unidentified compounds obtained from headspace GC-MS analysis of the different exposure solutions.

Detected but unidentified (U.I.) compound – Retention time (min)	*m/z*	Solution type, Number of replicates the compound was detected, Response area					
		Deionized Water		Salt Water		Pore Water	
		n	**Area, a.u.**	***n***	**Area, a.u.**	***n***	**Area, a.u.**
U.I. – 4.157, 4.238	91	1	206,557	0	-	1	139,790
U.I. – 4.43, 4.909	105	2	11,688,621, 11,340,969	0	-	1	76,337
U.I. – 5.429	105	1	115,408	0	-	0	-
U.I. - 6.287, 6.356	91	0	168,849	0	-	2	79,040, 116,064
U.I. – 6.045, 6.574	105	3	184,000- 245,000	0	-	2	98,805, 103,394
U.I. – 6.49	105	0	-	0	-	1	156,089
U.I. – 6.165, 6.691	91	0	-	3	379,000-457,000	1	61,245
U.I. - 6.729	105	2	1,110,682, 1,138,409	0	-	0	-
U.I. – 6.287, 6.356, 6,846, 6.882	77	3	168,000 - 255,000	0	-	3	54,500-116,100
U.I. – 6.15, 7.068	105	0	-	0	-	2	596,805, 83,531
U.I. – 6.567, 6.599, 7.075	105	3	246,600-287,000	1	76,896	0	-
U.I. – 6.821, 6.847, 6.851, 6.882, 7.329	105	3	690,000-915,800	3	154,000 - 188,600	3	209,400-452,100
U.I. - 7.435	105	2	90,401, 126,656	0	-	0	-
U.I. – 7.158, 7.184, 7.212, 7.621, 7.632	105	3	4,687,900 - 5,885,460	3	1,967,490 - 3,793,130	3	1,967,490 - 3,793,130
U.I. – 7.423, 7.446, 7.471, 7,858, 7.867	57	3	143,000 - 176,700	3	51,440- 61,140	3	56,860 - 91,260

NOTES: *n* = number of solution replicates where a compound was detected; Results shown only represent chromatogram signals greater than 50,000 a.u. Styrene eluted at a RT of about 5.3 min and was confirmed with an analytical standard. Styrene was detected in every solution replicate for all solutions.

SI. 1. Interlaminar Shear Strength (ILSS) Measurement

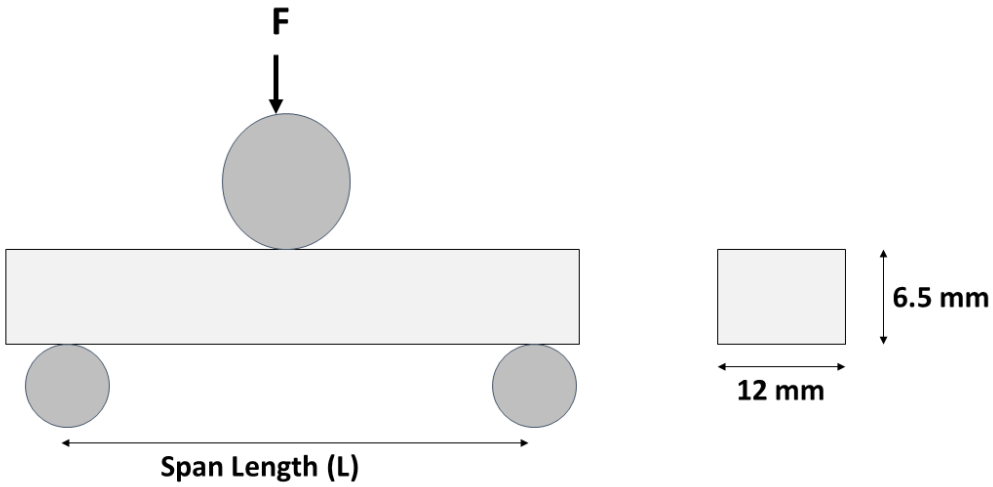

Fig. SI-1. ILSS test setup and test specimen.

SI. 2. Curing temperature determination by DSC

The uncured CIPP liner of 10-12 mg was taken in a DSC aluminum hermetic pan. Heat-cool-heat cycle scans were performed at a ramp rate of 20 °C/min from -25 °C to 200 °C. Heating and cooling curves were examined to understand curing behavior of liners.

Uncured CIPP resin tube was collected from the installation site and the curing behavior was investigated using DSC analysis. As shown in Figure SI-F1, the exothermic peak around 160°C in the first heating cycle, indicated maximum curing temperature of the uncured resin tube. The absent of exothermic peak in the second heating cycle indicated that the resin was fully cured after 1st heating cycle.

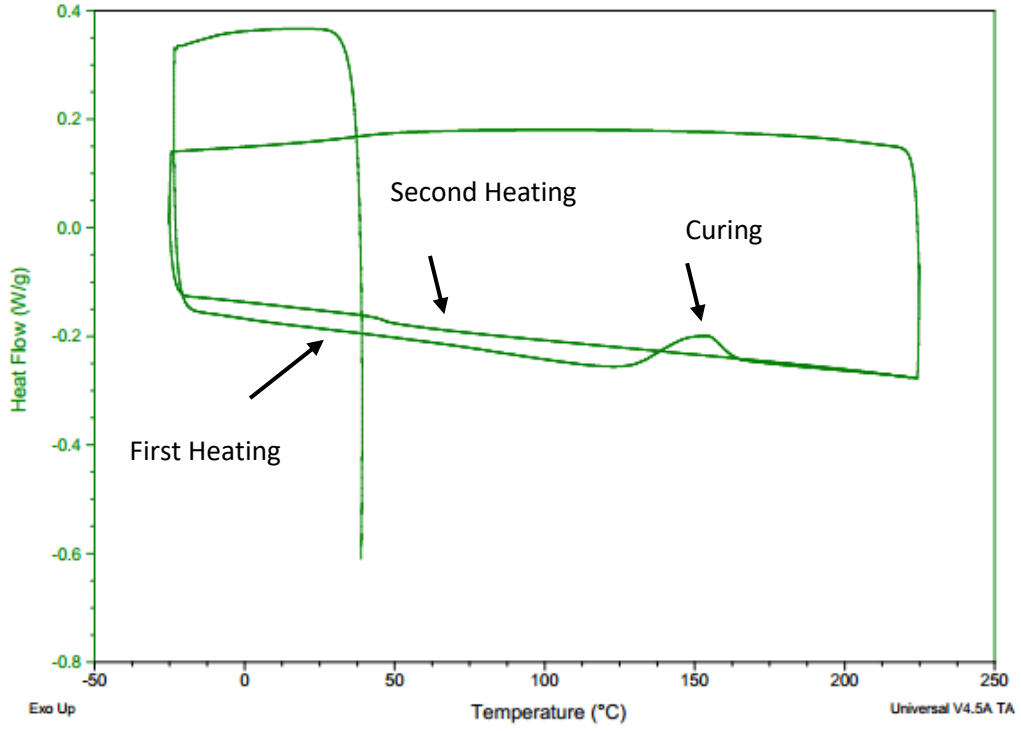

Fig. SI-2. DSC analysis of uncured resin tube.

SI. 3. Thermogravimetric Analysis

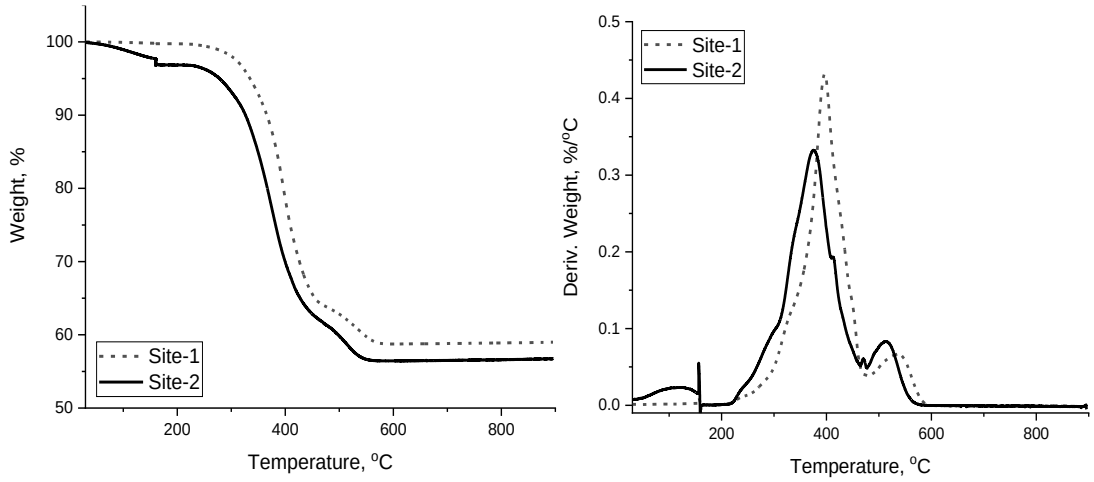

Fig. SI-3. TG and DTG curves of CIPP liners from installation site 1 and 2.

SI. 4. Aging test of CIPP specimens

The accelerated aging time was calculated according to ASTM F1980-16:

$$Accelerated\ Aging\ Time\ (AAT) = \frac{Desired\ Real\ Time\ (RT)}{Q_{10}[\frac{T_{AA} - T_{RT}}{10}]} \qquad \text{(SI-1)}$$

Desired real time = 96 days

Accelerated aging time (T_{AA}) = 15 days

Room Temperature (T_{RT}) = 23 °C

Aging Factor, Q_{10} = 2.0

SI.5. Ion Chromatography

The presence of ions in tap and DI water was investigated using Ion chromatography. The mobile phase (eluent) is pumped through the system with a constant flow rate. The sample is injected into it. The mobile phase carries the sample through the static phase (separator) where the sample is split up into its component ions. In the detector, single components are recognized by a change in conductivity.

The ions are effectively separated according to their charge/size ratio as they interact with the exchange groups in the column:

- Ions with a smaller charge/size ration elute earlier
- Ions with a larger charge/size ratio elute later

SI. 6. Experimental conditions to run our samples

Cation eluent - Oxalic acid (Conc.: 3.5 mM)

Cation Conductivity: 745 - 765 uS/cm

Cation Flow rate: 0.9 mL/min

Anion eluent - Equal mix of Sodium carbonate (Conc.: 3.2 mM) and Sodium bicarbonate (Conc.: 1 mM)

Anion Conductivity: 0.5 - 2 uS/cm

Anion Flow rate: 0.7 mL/m

Tape water and DI water contained cations and anions (Table SI-1), which may ingress into composite body during processing of the specimens for the experiments.

Table S1-2. Presence of anions and cations in tap and DI water.

Ions	Tap Water	DI water
F-	0	0.01
Cl-	40.13	0.28
Br-	0.1	0
NO3-	0.21	0.01
PO43-	0.57	0
SO42-	0	0
LI+	0	0
K+	3.35	0.02
MG2+	35.26	0.36
Ca2+	109.29	1.65