Evaluation of the physical, chemical, mechanical, and thermal properties of steam-cured PET/Polyester cured-in-place pipe (CIPP)

<u>Supplement</u>

S-1. Materials and Methodology

Analytical standards

Analytical standards for identification, confirmation and quantification of organic compounds by ^{1}H-NMR and gas chromatography/mass spectrometry (GC/MS) included dichloromethane ≥99.8% that contained 40-150 mg/L amylene as stabilizer (CAS# 75-09-2, Sigma-Aldrich), and hexane ≥97.0% (CAS# 110-54-3, Sigma-Aldrich) used for solid-liquid extraction experiments were used. Benzaldehyde ≥99.5% that was purified by redistillation (CAS# 100-52-7, Sigma-Aldrich), benzoic acid (CAS# 65-85-0, Supelco), methanol ≥99.9% (CAS# 67-56-1), phenol (CAS# 108-95-2, ACROS Organics), styrene ≥99% that contained 4-*tert*-butylcatechol stabilizer (CAS# 100-42-5, Sigma-Aldrich), 1-tetradecanol (CAS# 112-72-1, Sigma Aldrich).

Calibration curves were created separately for each extractant solvents. For methylene chloride extracts, styrene (R^2=0.9996 for low range (0.1 to 3 ppm) and R^2=0.9985 for high range (3 to 15 ppm), benzaldehyde (R^2=0.9992 & 0.9981 & 0.9954 for 0.06 to 20.88 ppm), benzoic acid (R^2=0.9968 for 2.53 to 10.12 ppm), 1-tetradecanol (R^2=0.996 & 0.9919 for 0.106 to 30.56 ppm), phenol (R^2=0.9996 for 0.44 to 17.6 ppm) were created. For hexane extracts, styrene (R^2=0.9998 for 0.6 to 7 ppm), benzaldehyde (R^2=0.9989 & 0.9913 for 0.13 to 48.72 ppm), 1-tetradecanol (R^2=0.9928 for 0.4 to 80 ppm) were created.

Curing temperature determination

The maximum curing temperature is at 103 °C for CIPP liner.

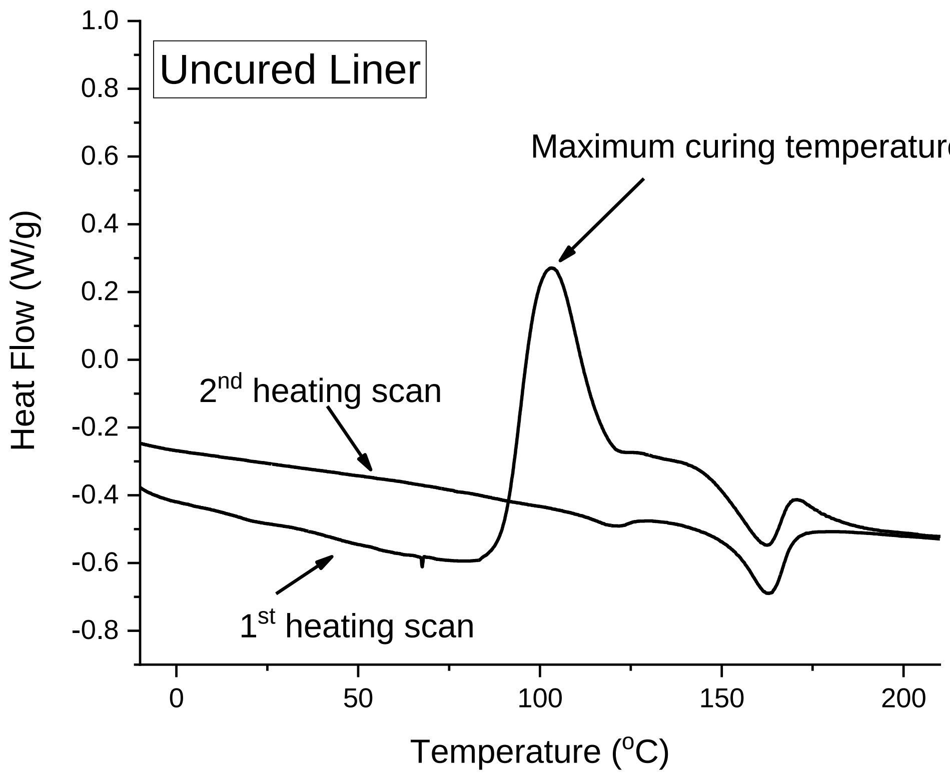

Figure SI-1. DSC thermogram of uncured resin liner for determining curing temperature.

Porosity Measurement

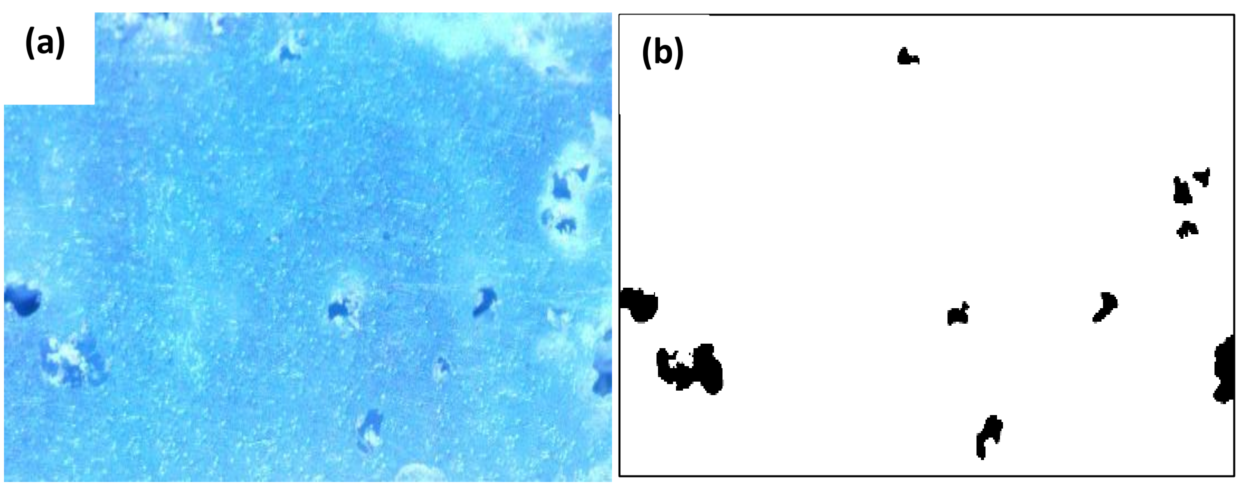

Figure SI-2. (a) Optical microscopic image of CIPP liner, (b) Image J processed image.

S-3. Results and Discussions

Thermal Analysis

As shown in Figure SI-3, The uncoated PET felt show sharp endothermic peak (Melting temperature) around 250 °C. In contrast, coated PET felt shows two endothermic peaks at 120 and 160 °C, indicating the melting temperature of polyethylene/polypropylene bilayer coating [1]. The cooling scan shows two exothermic peaks representing recrystallization of bilayer coating.

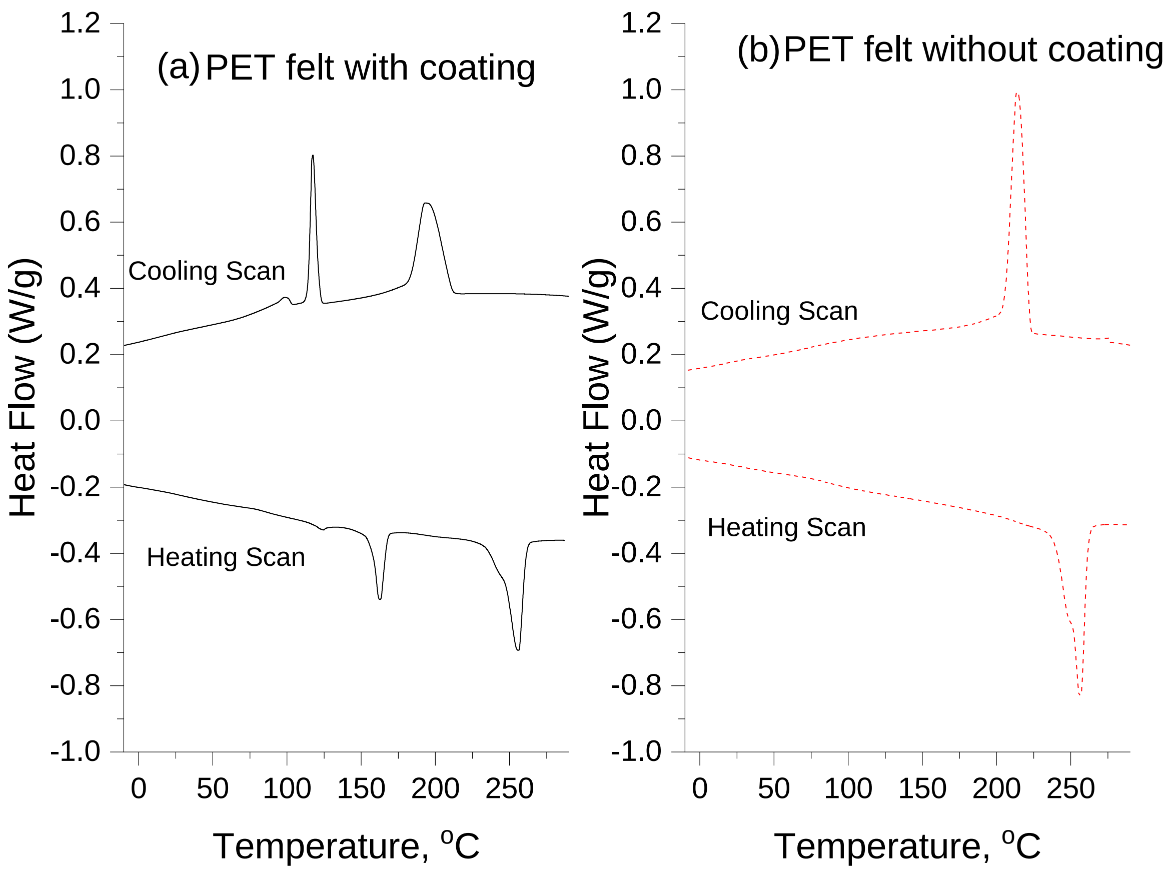

Figure SI-3. DSC thermogram of (a) PET felt without coating layer, and (b) PET felt with coating layer.

As shown in Figure SI-4(a), the main decomposition peak at 436 °C was due to the structural decomposition of PET felts followed by burn off carbon residue at 540 °C. Coated PET felt exhibits two more decomposition peaks representing the decomposition of bilayer coating.

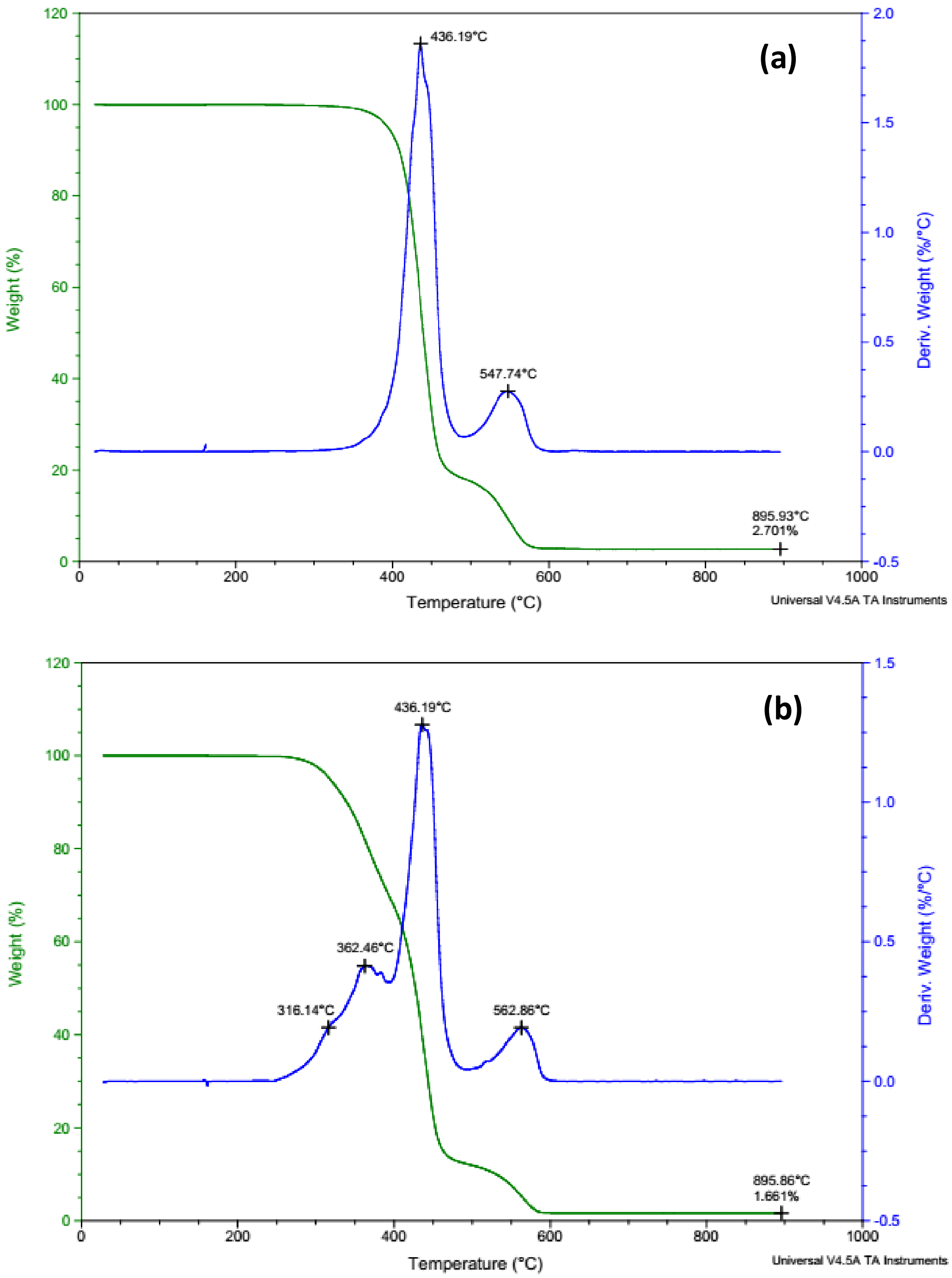

Figure SI-4. TGA thermogram of (a) PET felt without coating layer, and (b) PET felt with coating layer.

^{1}HNMR Analysis

Figure SI-5 shows the ^{1}HNMR spectra of uncured resin liner, onsite cured (inner and outer layer) and oven cured CIPP.

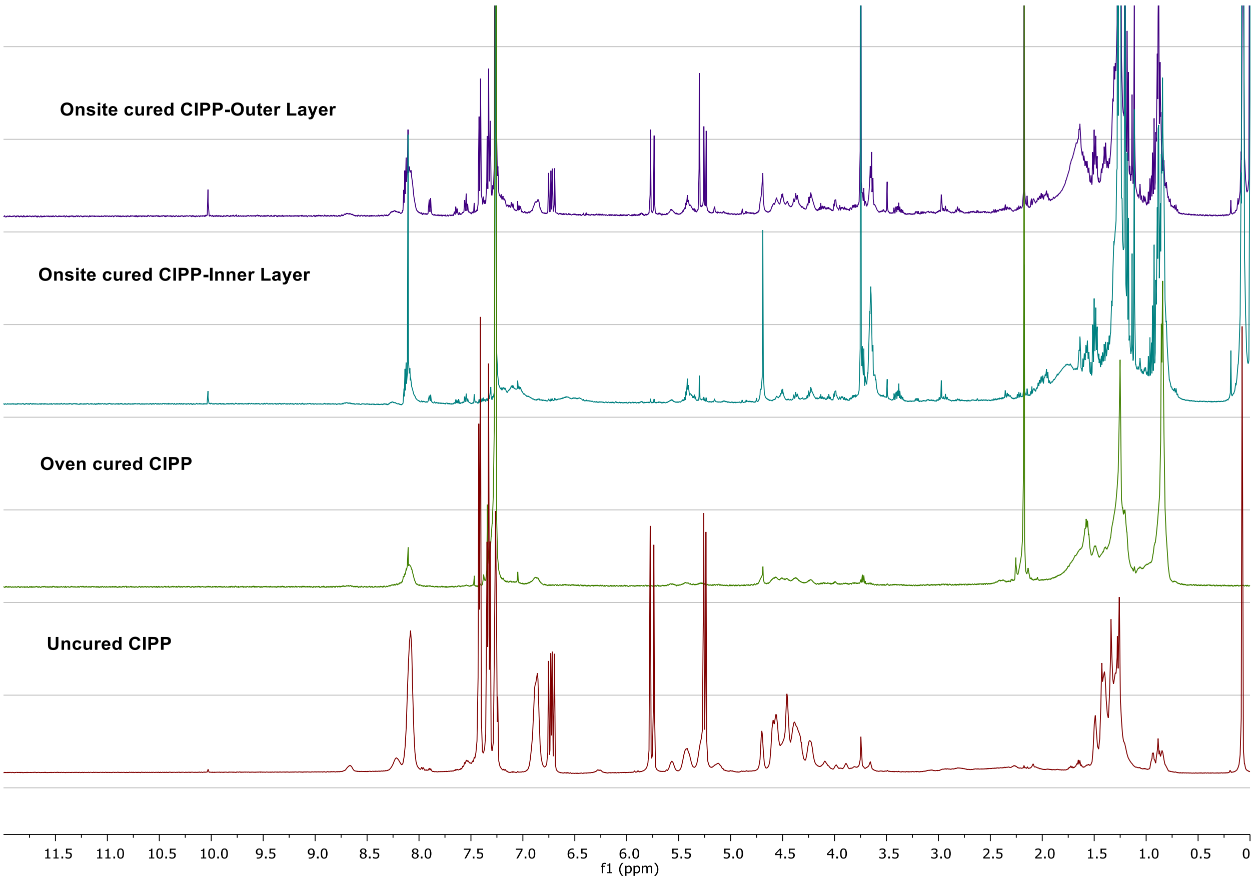

Figure SI-5. ^{1}HNMR Spectra of $CDCl_3$ leaching solution from uncured, onsite cured and oven cured CIPP specimens.

Figure SI-6 and SI-7 show the probable formation of styrene dimer and trimer, and oxidation products of styrene.

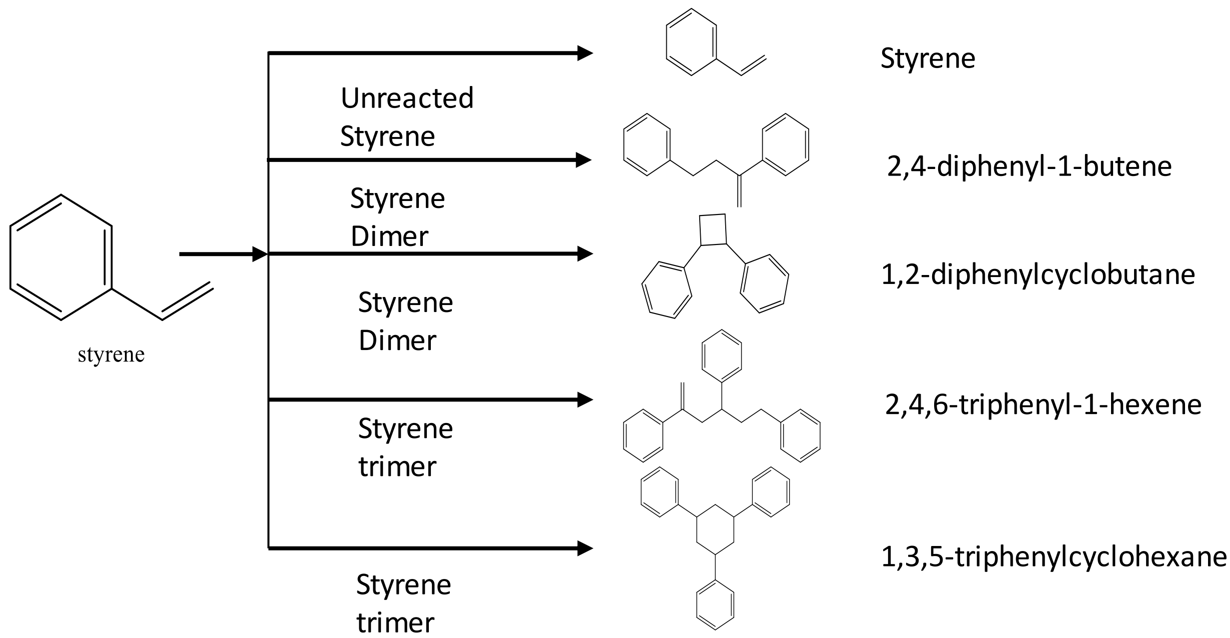

Figure SI-6. dimer and trimer formation of styrene.

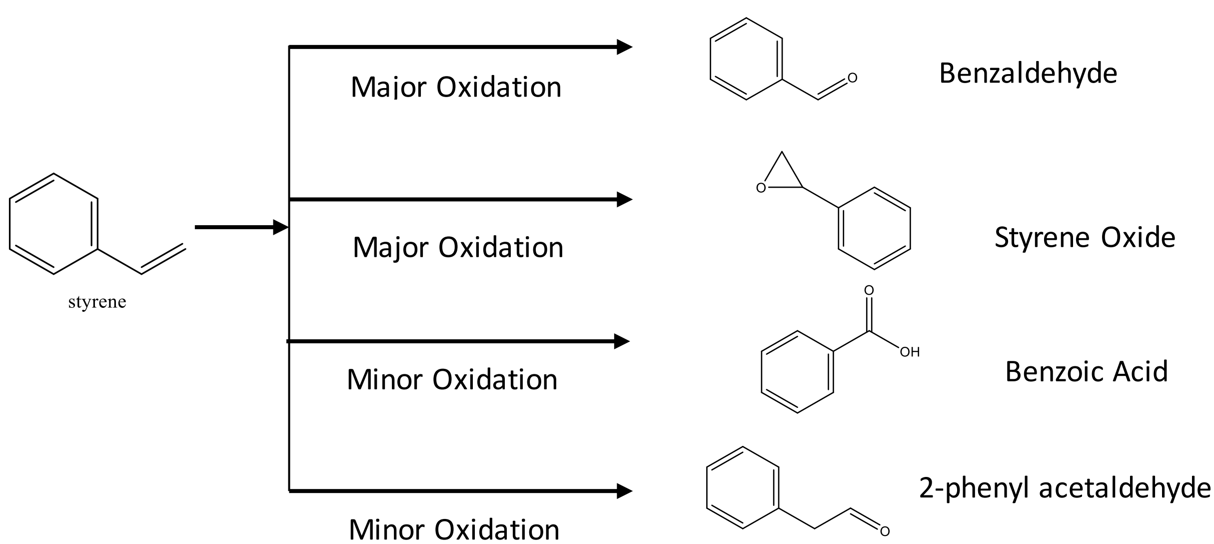

Figure SI-7. dimer and trimer formation of styrene.

Table SI-1. Compounds identified from GC-MS of leachate solutions of CIPP liners.

Compounds	Uncured resin	Onsite cured CIPP	Oven cured CIPP
	mg/g	mg/g	mg/g
Styrene	114.4442±6.3097*	0.7583±0.0351	0.0167±0.0007
Benzaldehyde	1.3672	0.0625±0.0053	0.3085±0.0341
1-tetradecanol	0.1048	0.0677±0.0121	0.1016±0.0126
Phenol	……………	0.0020±0.0001	0.0020±0.0001
Benzoic acid	……………	0.0244±0.0004	0.0331±0.0023

Asterix (*) represents 1000 times dilution, all other results represent 10 times

Figure SI-8. Water diffused through the thickness of the CIPP liner during CIPP installation

Conditioning of CIPP specimens

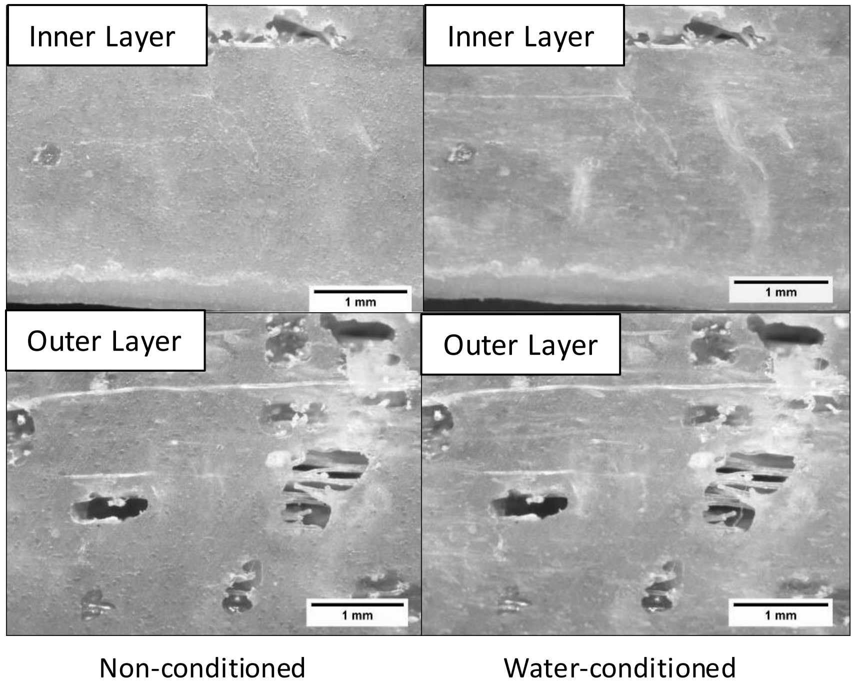

Figure SI-9. (a) Inner and (b) Outer layers of non-conditioned and water-conditioned CIPP specimes.

Mechanical Characterization of CIPP

The non-conditioned samples show toughened behavior. During the experiment, these samples were not fractured. They were bend as shown in Figured S-10. In contrast, water conditioned samples exhibited brittle behaviors and fractured Figure S-11.

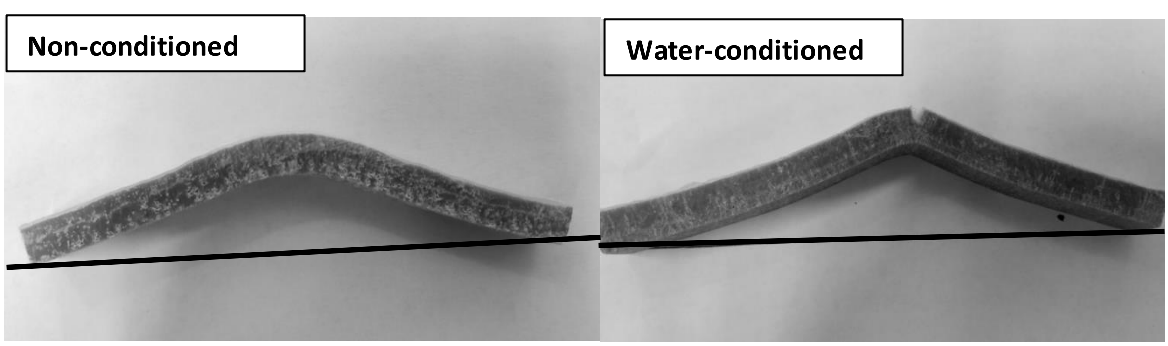

Figure SI-10. Specimens after mechanical testing

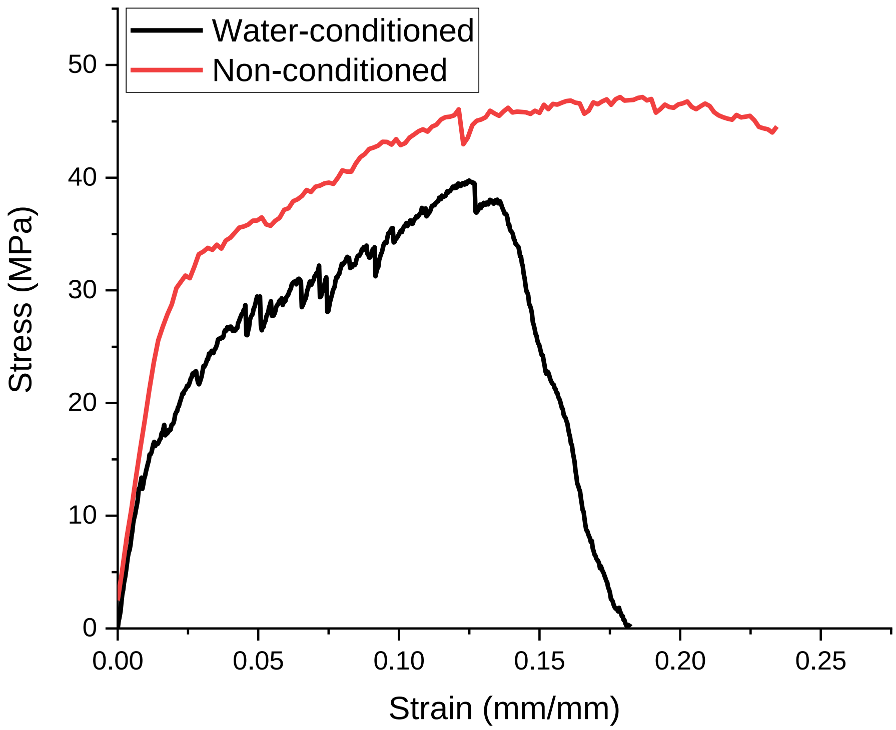

Figure SI-10. Stress-strain curve of non-conditioned and water-conditioned CIPP liners.

References

[1] Shanks RA, Li J, Yu L. Polypropylene-polyethylene blend morphology controlled by time-temperature-miscibility. Polymer (Guildf) 2000;41:2133–9. doi:10.1016/S0032-3861(99)00399-7.