Test Results for the Field Aged & Mechanically Aged Composite Liner System

Starline© 2000

By

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Tested Samples

6 in. CI Pipe

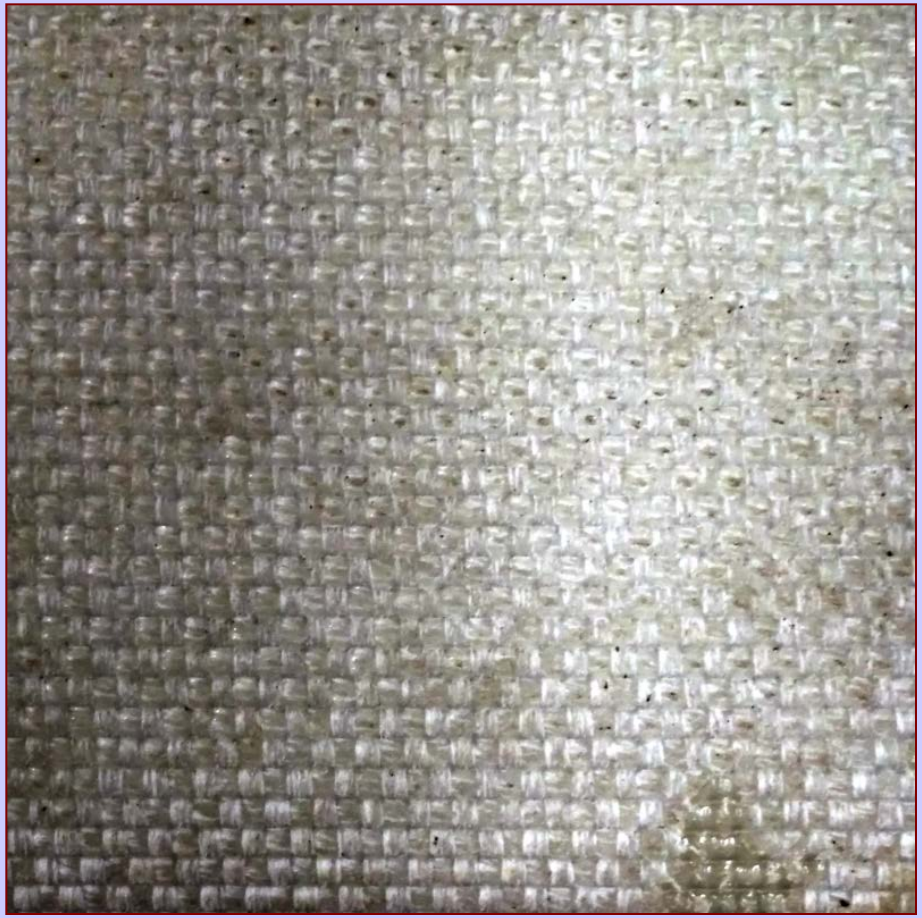
- ✓ Field Aged for 16 yrs
- ✓ Field Aged for 16 yrs + Mechanically Aged at Cornell - No. 1
- ✓ Field Aged for 16 yrs + Mechanically Aged at Cornell - No. 2

12 in. CI Pipe

- ✓ Field Aged for 10 yrs
- ✓ Field Aged for 10 yrs + Mechanically Aged at Cornell - No. 1
- ✓ Field Aged for 10 yrs + Mechanically Aged at Cornell - No. 2

Image of a Typical Composite Liner

Longitudinal Direction



Thread Count:
21.03 per inch for 6” pipe
16.31 per inch for 12” pipe

Transverse (Hoop)

Thread Count:
15.96 per inch for 6” pipe
16.68 per inch for 12” pipe

Composite Liner Components

Polyester (PET) Fabric
- **Strength component**

Tough Polyurethane (PU) Membrane
- **Impervious component**

Tests Conducted
(For Residual Properties)

Composite Liner

Tension Tests (Impregnated Liner, Bonded, *at the pipe*)

- Longitudinal (ASTM D 3039)
- Transverse (ASTM D 3039)

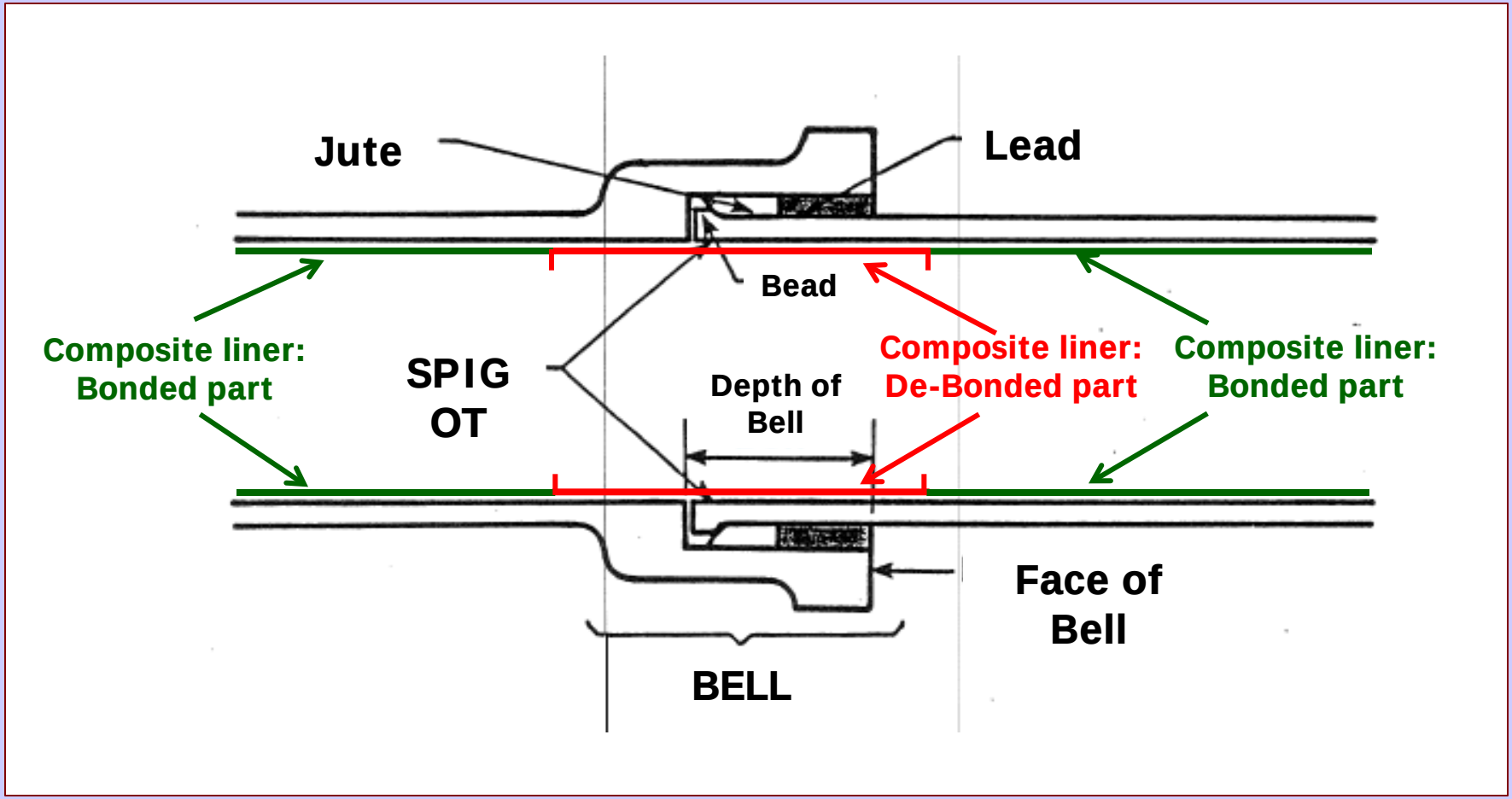
Tension Tests (Impregnated Liner, De-bonded, *at the joint*)

- Longitudinal (ASTM D 3039)
- Transverse (ASTM D 3039)

Composite Liner Adhesion to CI pipe

- Lap Shear (ASTM D 3164)
- Peel (ASTM D 1876)

Typical 6-in. CI Pipe and Joint with Composite Liner



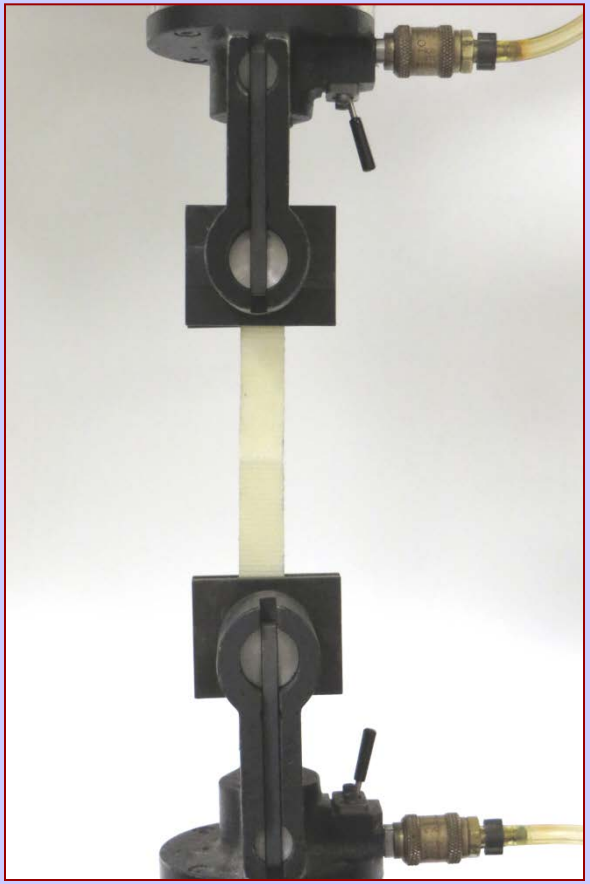
Composite Liner Tension Test in Longitudinal Direction

(Impregnated Composite Liner – 6 in. CI Pipe)

Test parameters*

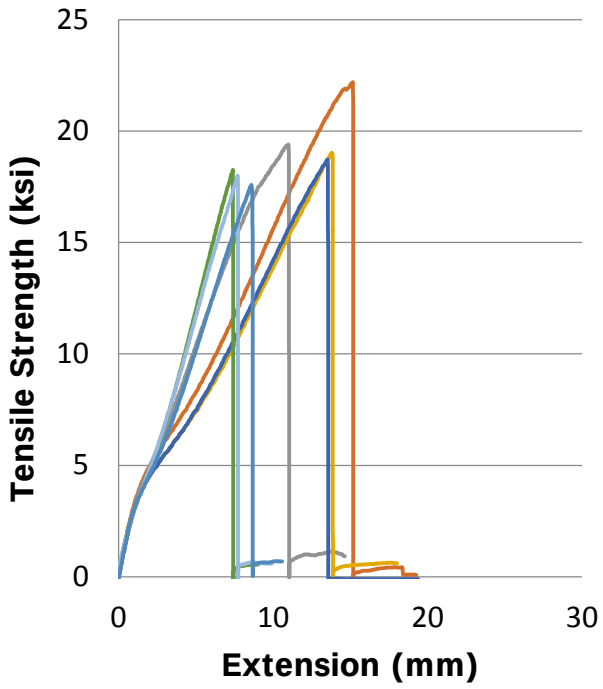
Gauge Length (mm)	Crosshead Speed (mm/min)	Width (mm)	Thickness (mm)	Length (mm)
60	20	15	~1.25	200

***Same parameters were used in 2002-2003 tests on Starline© 2000 Composite Liner**

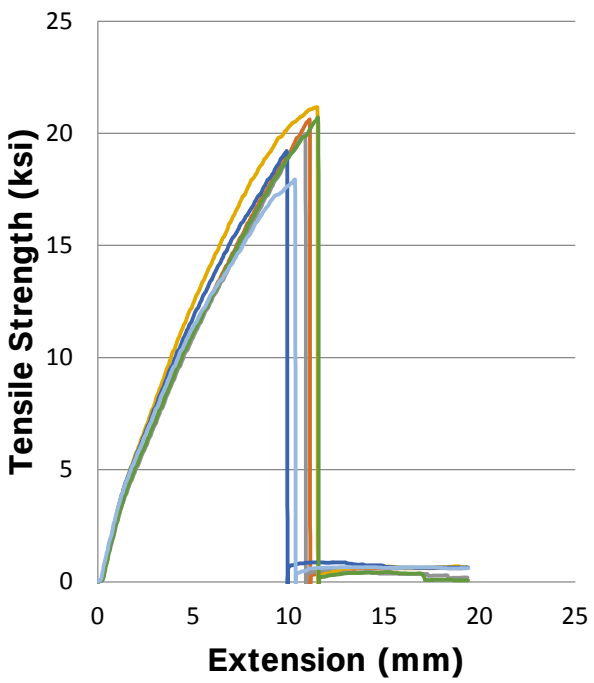


Composite Liner Tension Test Longitudinal Direction

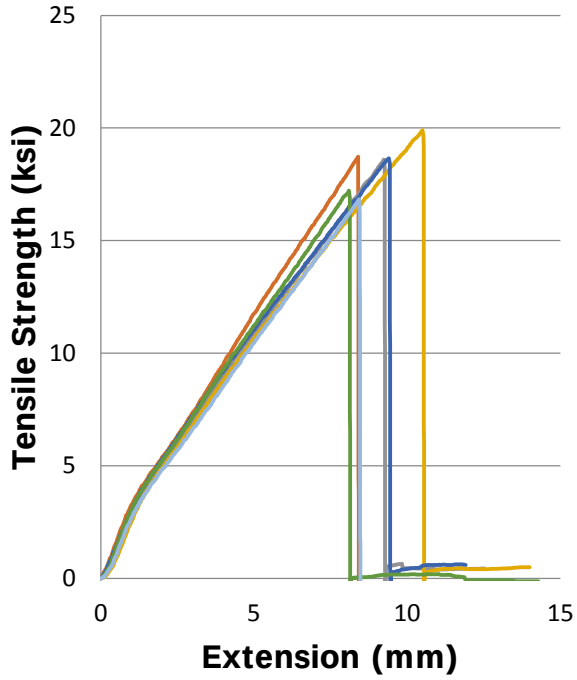
(Impregnated Composite Liner – 6 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (De-Bonded) No. 1



Field + Mechanically Aged: FMA (De-Bonded) No. 2

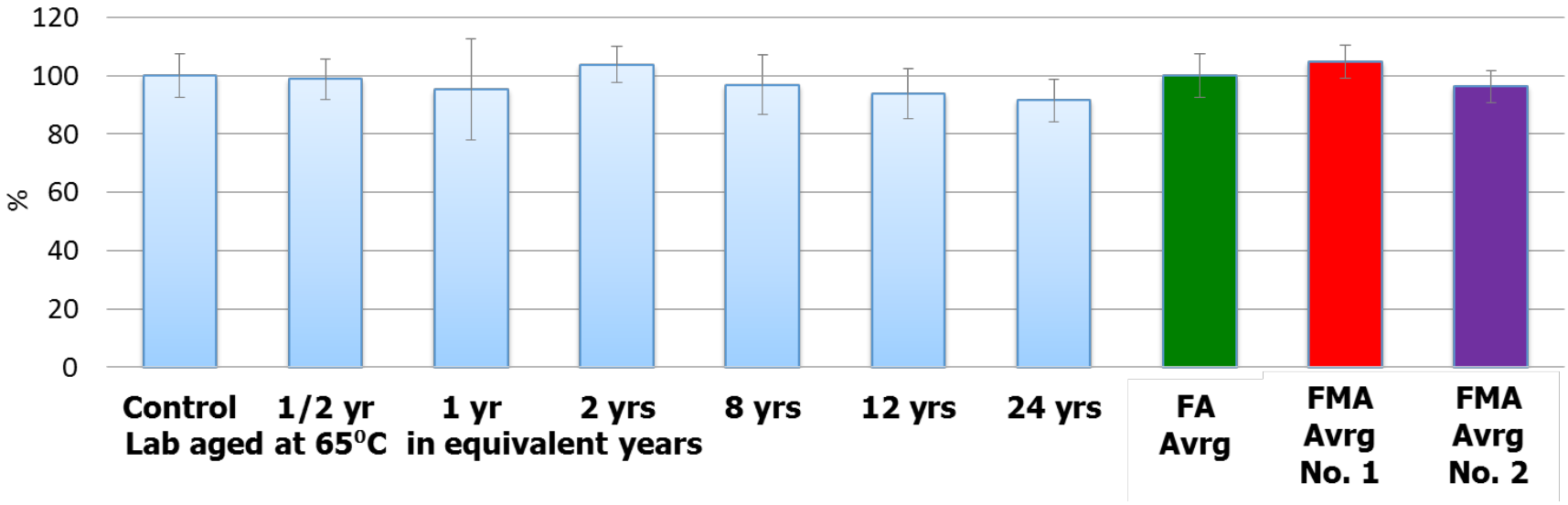
FA = Field aged for 16 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test in Longitudinal Direction

(Not debonded Composite Liner FA and De-Bonded FMA – 6 in. CI Pipe comparison)

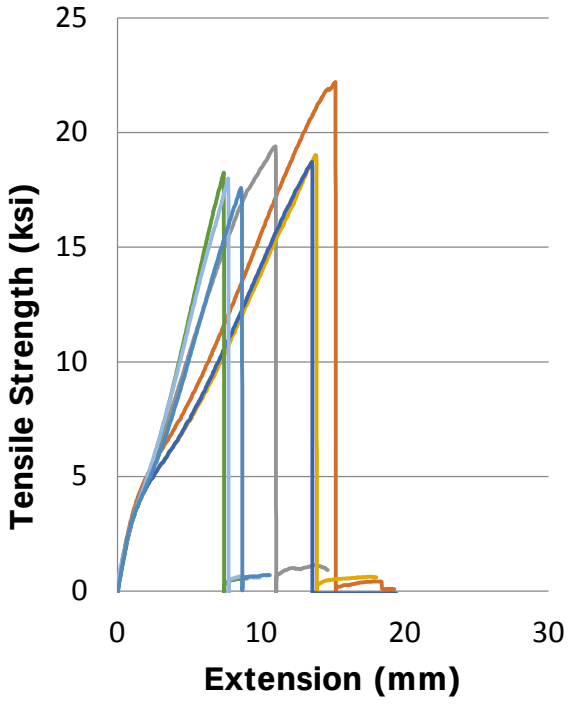
	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) De-Bonded No. 1	Average 6 in. Pipe (FMA) De-Bonded No. 2
ksi	19.03	19.94	18.33
CV %	7.44	5.46	5.59



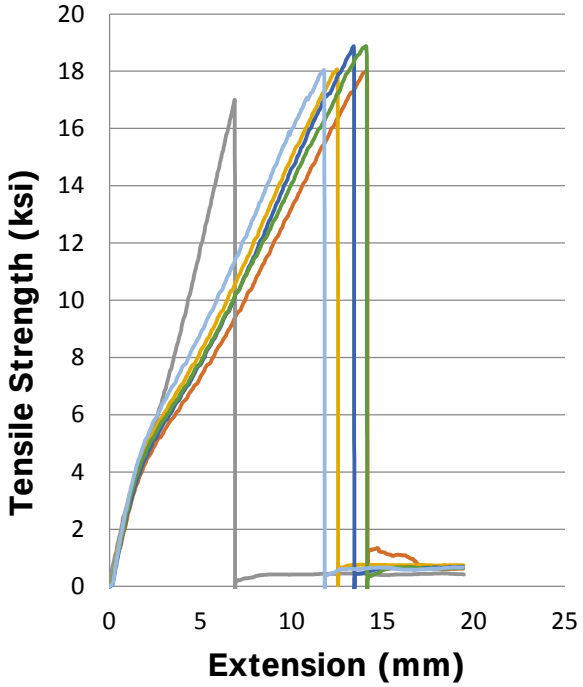
No change is seen after mechanical aging at Cornell University

Composite Liner Tension Test in Longitudinal Direction

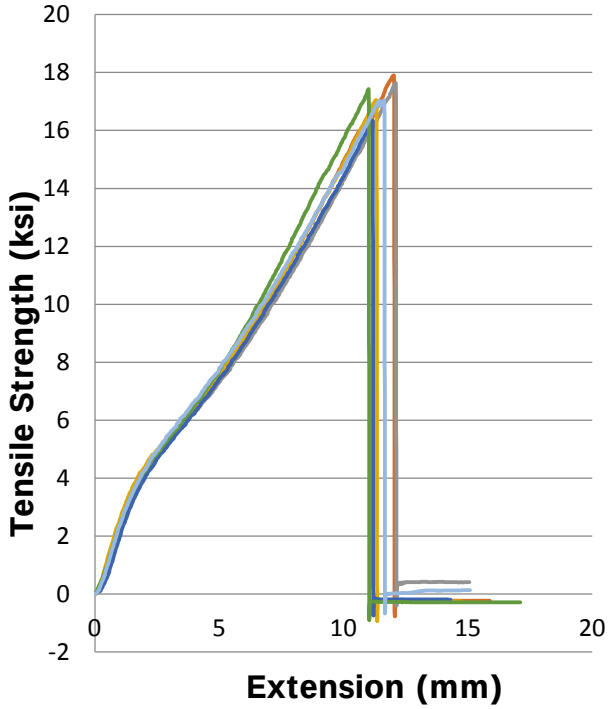
(Impregnated Composite Liner – 6 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



Field + Mechanically Aged: FMA (Bonded) No. 2

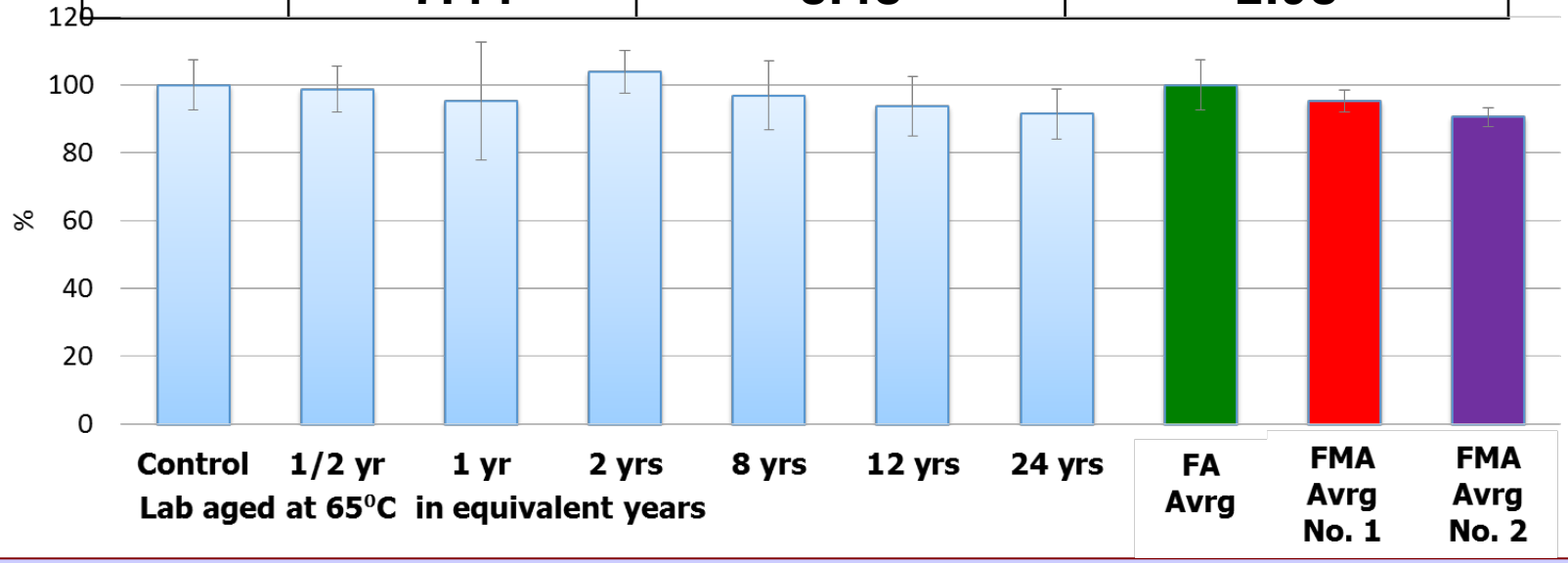
FA = Field aged for 16 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Longitudinal Direction

(Impregnated Composite Liner FA and Bonded-FMA – 6 in. CI Pipe comparison)

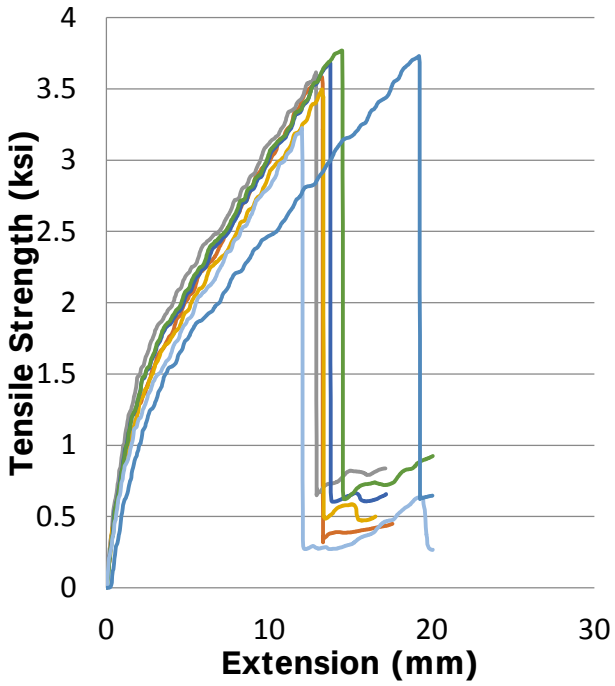
	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) Bonded No. 1	Average 6 in. Pipe (FMA) Bonded No. 2
ksi	19.03	18.15	17.23
%CV	7.44	3.48	2.93



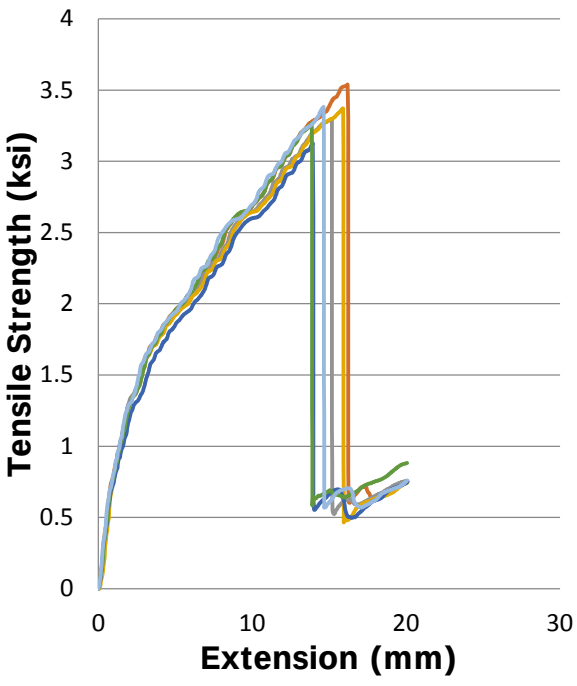
Negligible change is seen after mechanical aging at Cornell University

Composite Liner Tension Test Transverse (Hoop) Direction

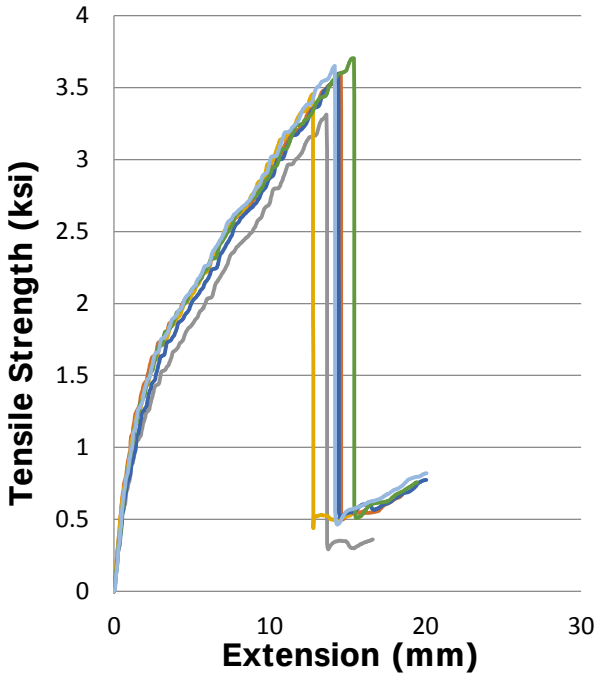
(Impregnated Composite Liner – 6 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



Field + Mechanically Aged: FMA (Bonded) No. 2

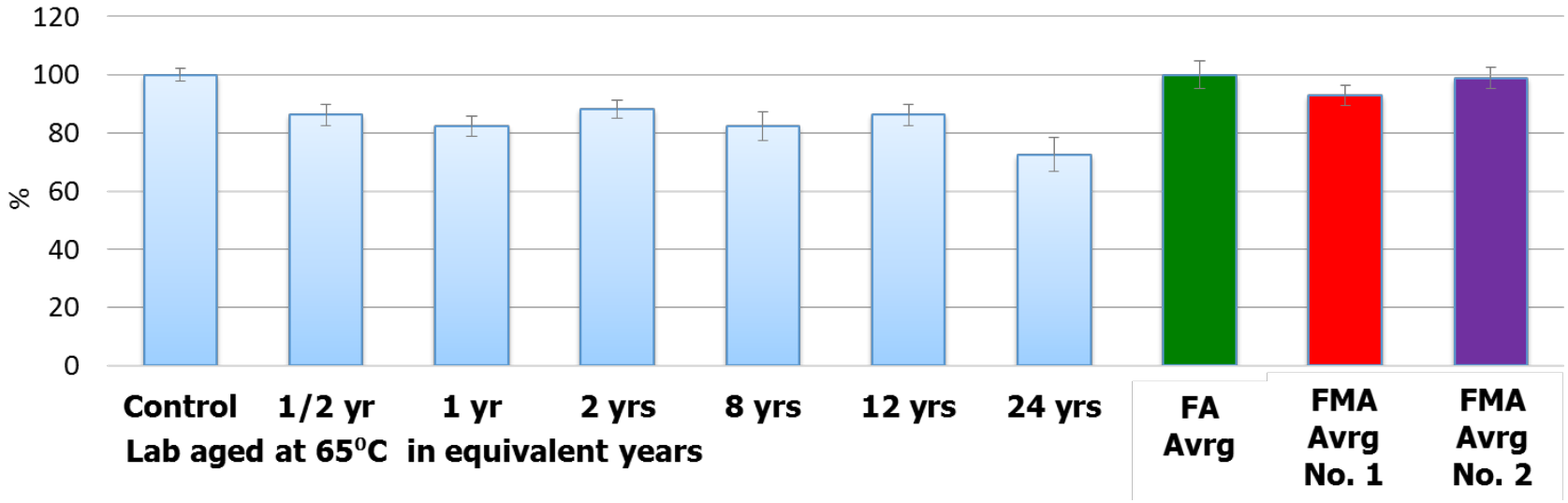
FA = Field aged for 16 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Transverse (Hoop) Direction

(Impregnated Composite Liner FA and Bonded FMA – 6 in. CI Pipe comparison)

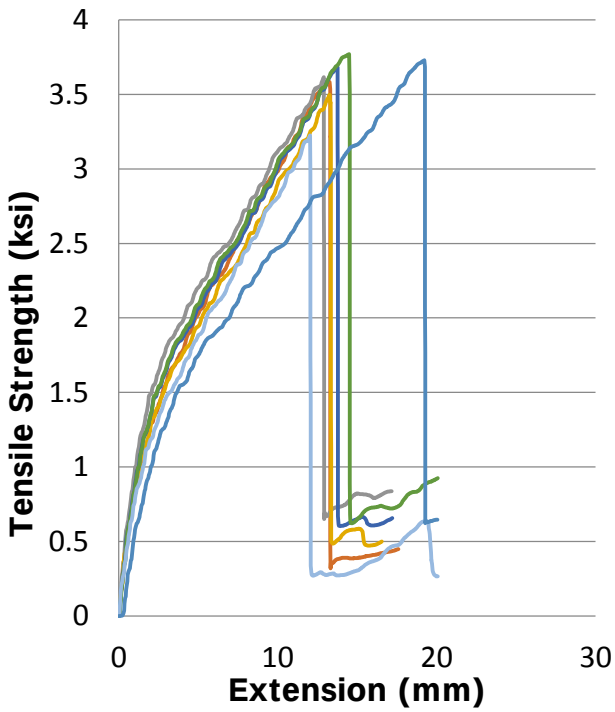
	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) Bonded No. 1	Average 6 in. Pipe (FMA) Bonded No. 2
ksi	3.59	3.33	3.55
%CV	4.74	3.75	3.72



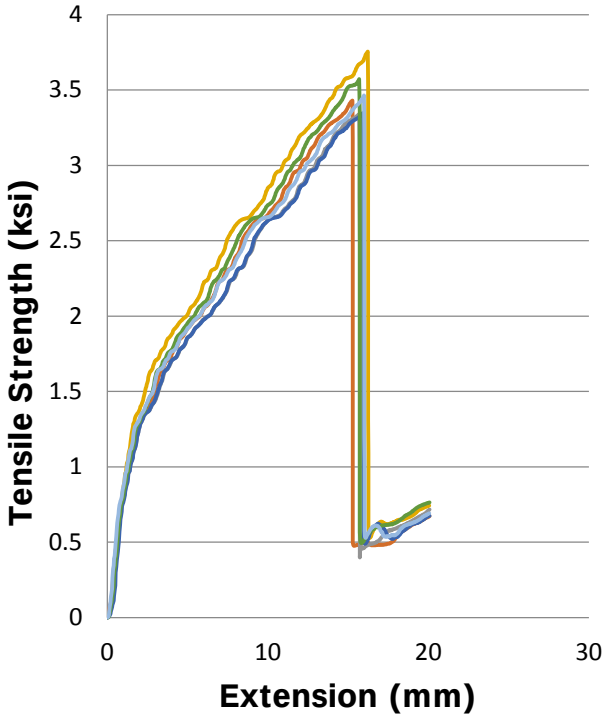
Negligible change is seen after mechanical aging at Cornell University

Composite Liner Tension Test Transverse Direction

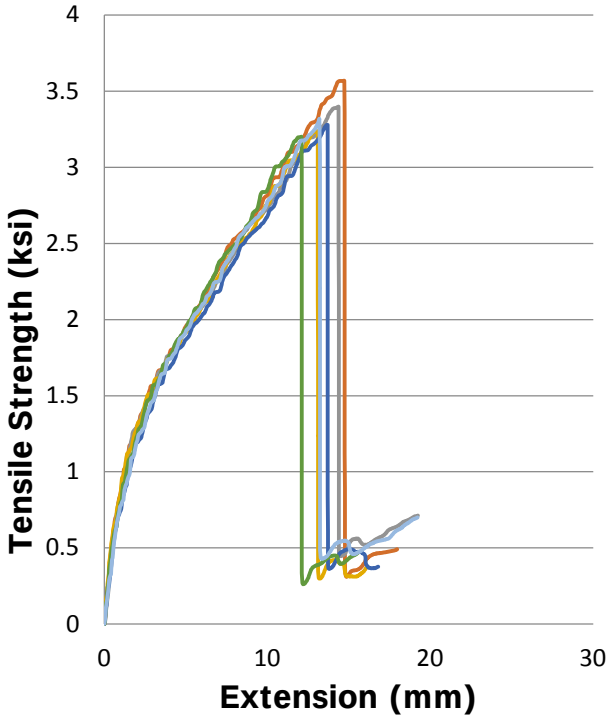
(Impregnated Composite Liner – 6 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (De-Bonded) No. 1



Field + Mechanically Aged: FMA (De-Bonded) No. 2

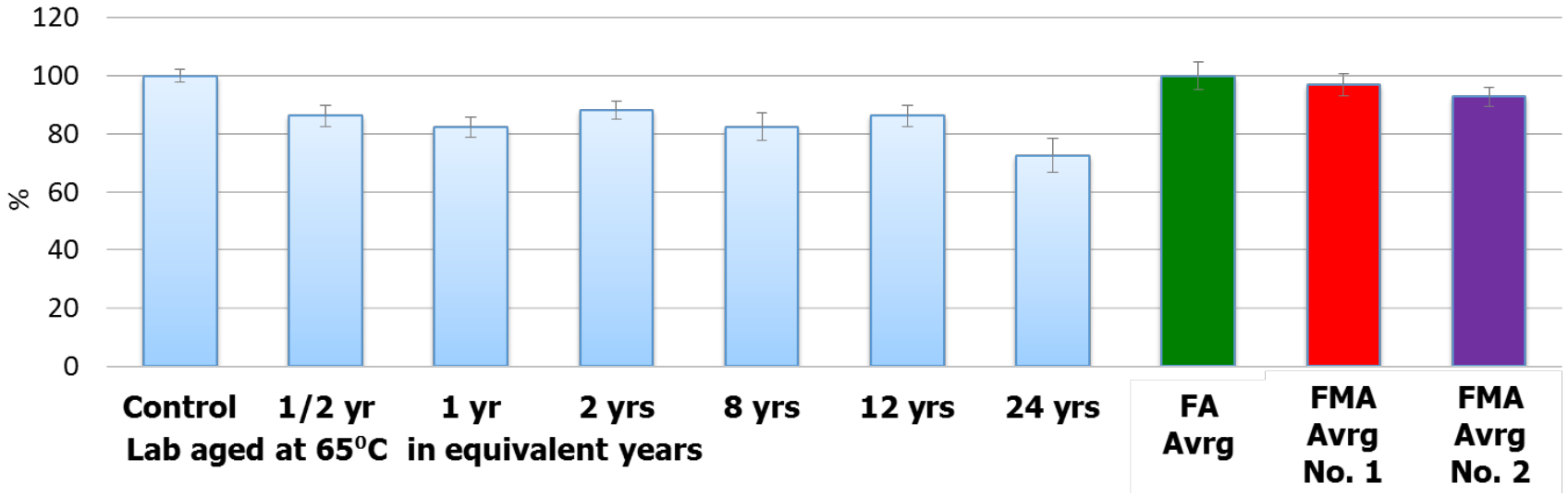
FA = Field aged for 16 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Transverse Direction

(Impregnated Composite Liner FA and De-Bonded FMA – 6 in. CI Pipe comparison)

	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) De-Bonded No. 1	Average 6 in. Pipe (FMA) De-Bonded No. 2
ksi	3.59	3.48	3.33
CV %	4.74	4.11	3.66



Very small change is seen after mechanical aging at Cornell University

Lap Shear Test

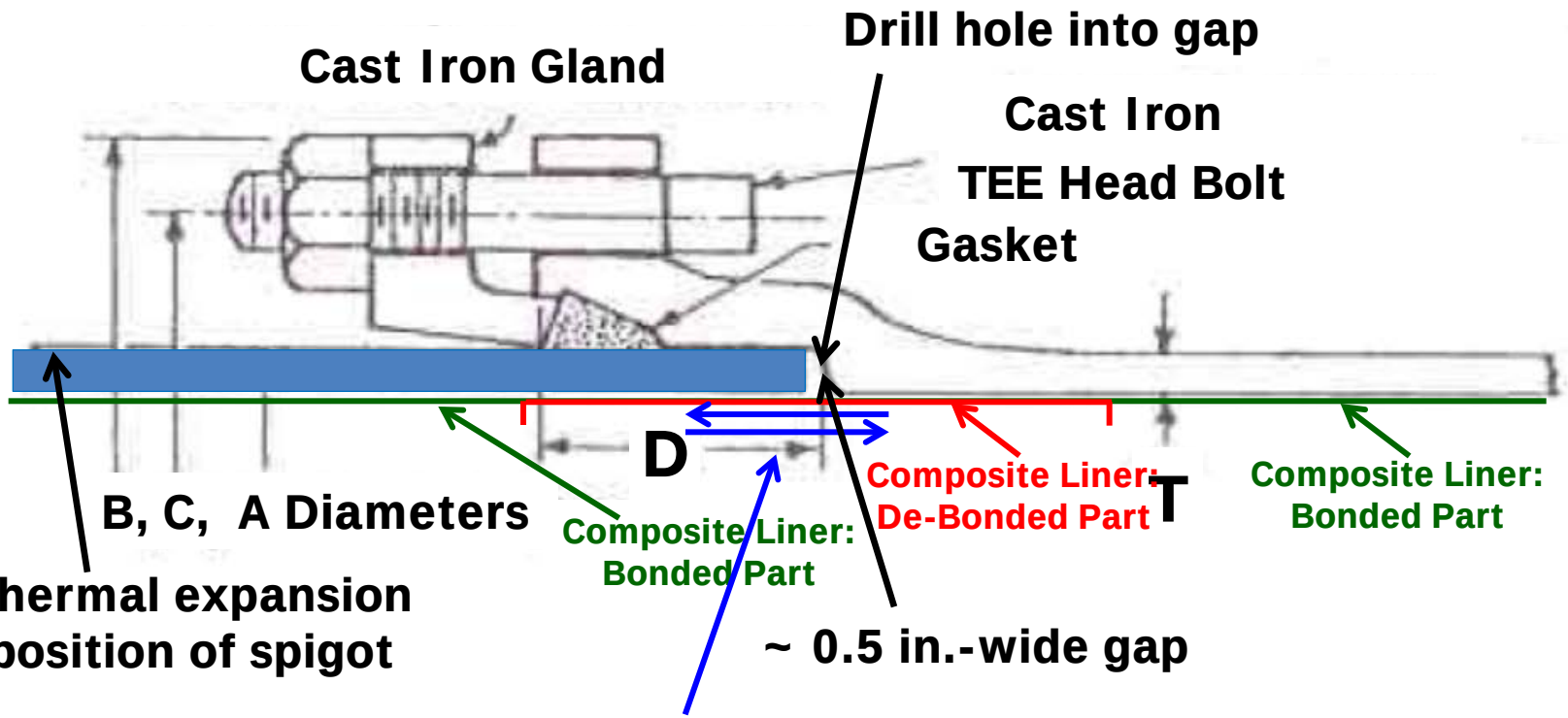
(Impregnated Composite Liner– 6 in. CI Pipe)

Primary Test for Adhesion

Test parameters

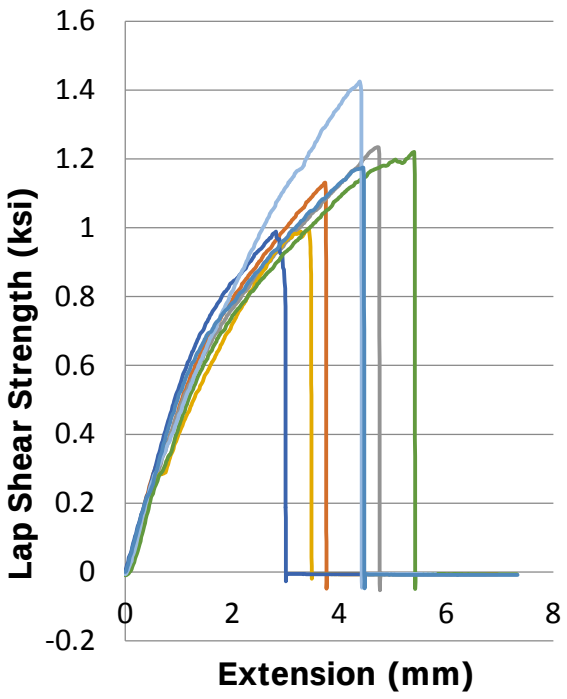
Gauge Length (mm)	Crosshead Speed (mm/min)	Width (mm)	Thickness (mm)	Length (mm)	Overlap (mm)
80	10	25.4	~1.25	152.4	8

Typical CI Pipe with Mechanical Joint Section with Composite Liner

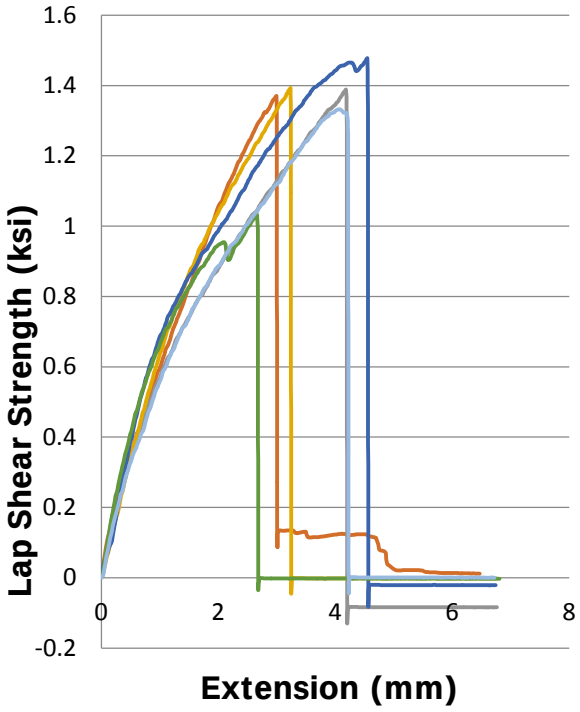


Lap Shear Test

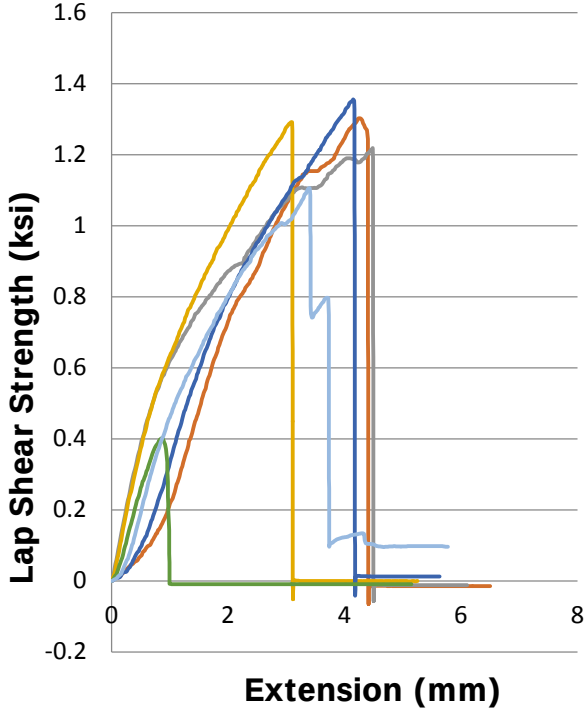
(Impregnated Composite Liner – 6 in. CI Pipe)
(Individual Results)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



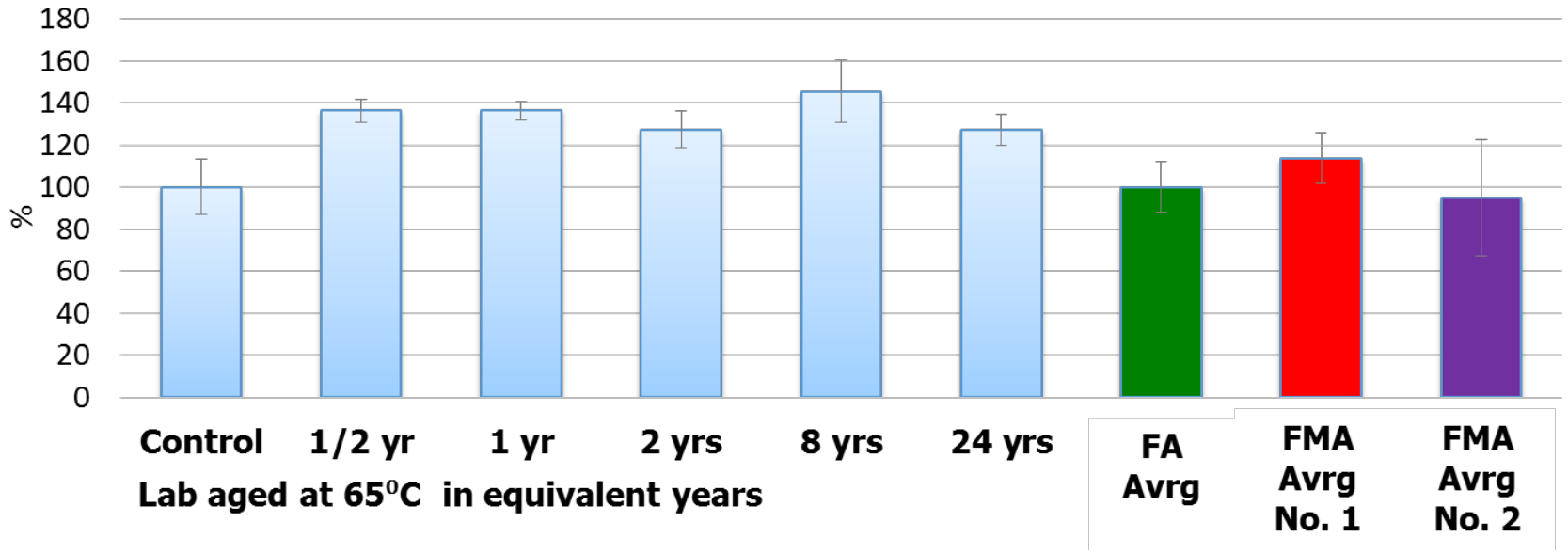
Field + Mechanically Aged: FMA (Bonded) No. 2

FA = Field aged for 16 yrs
MA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Lap Shear Test

(Impregnated Composite Liner FA and Bonded FMA – 6 in. CI Pipe comparison)

	Control	48 weeks	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) Bonded No. 1	Average 6 in. Pipe (FMA) Bonded No. 2
ksi	1.1	1.4	1.17	1.33	1.11
%CV	13.2	5.7	11.91	10.56	29.41



No change is seen after mechanical aging at Cornell University

Peel Test in Longitudinal Direction

(Impregnated Composite Liner– 6 in. CI Pipe)

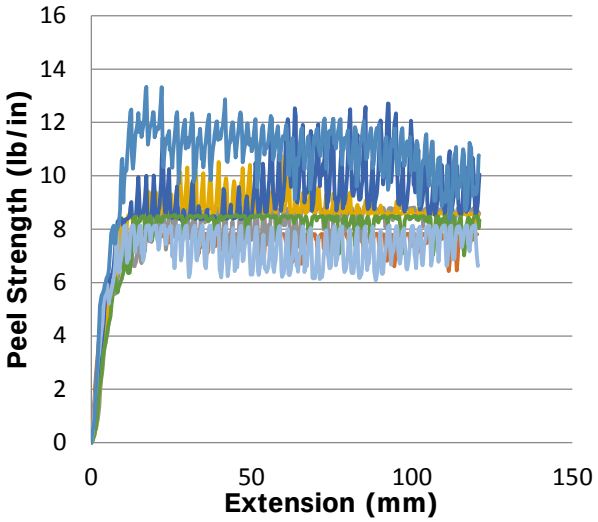
Secondary Test for Adhesion

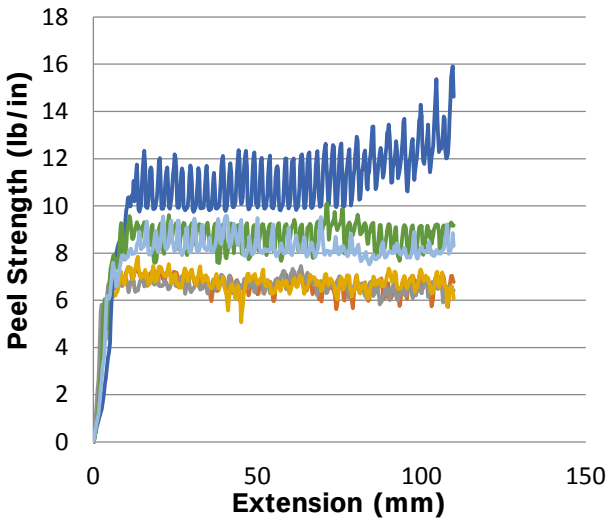
Test parameters

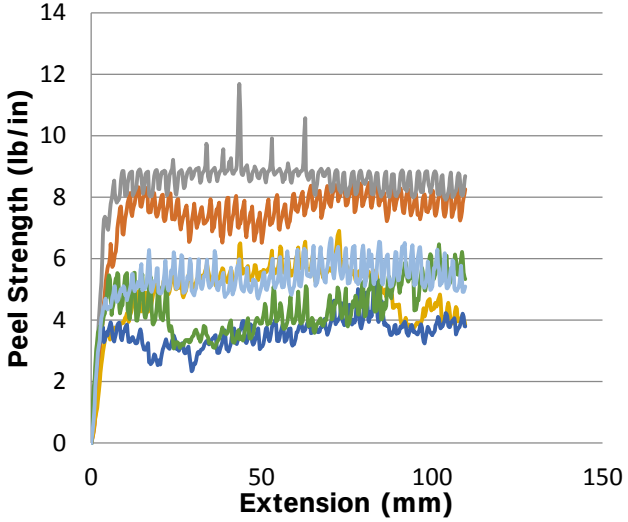
Gauge Length (mm)	Crosshead Speed (mm/min)	Width (mm)	Thickness (mm)	Length (mm)
260	150	25.4	~ 1.25	300

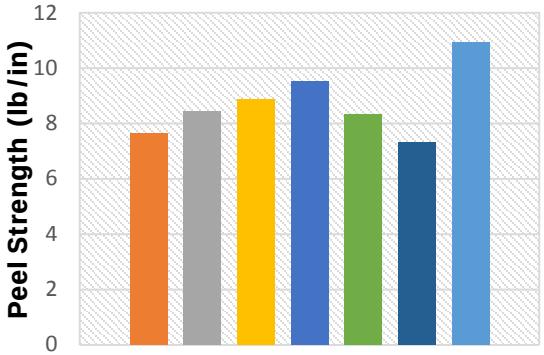
Peel Test in Longitudinal Direction

(Individual Results)

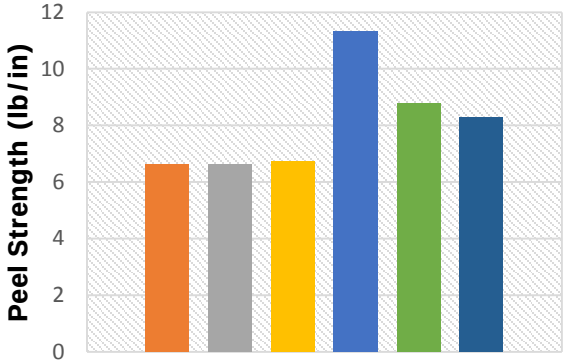




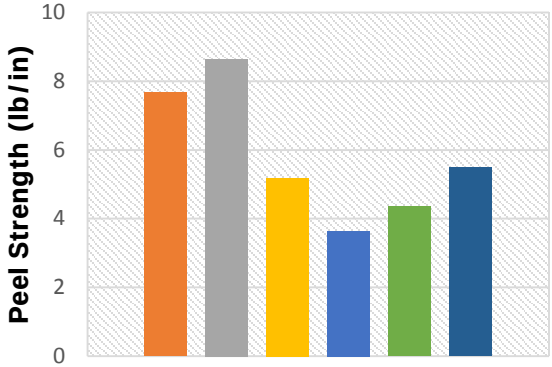




Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1

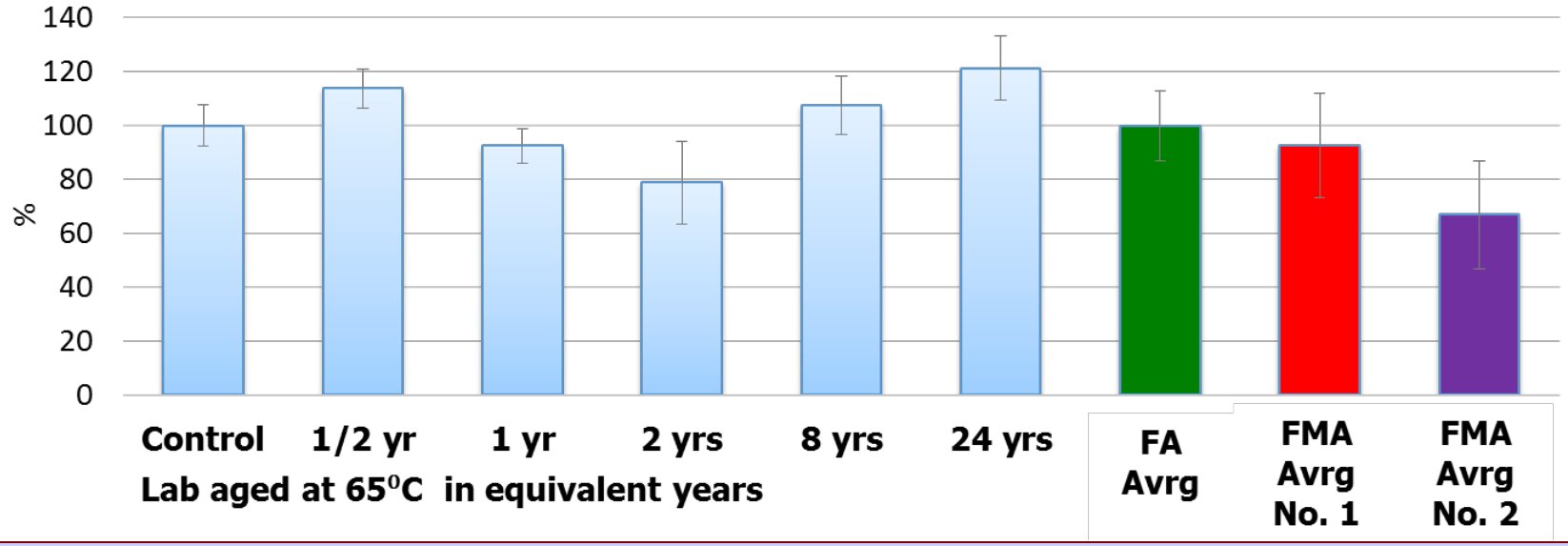


Field + Mechanically Aged: FMA (Bonded) No. 2

Peel Test in Longitudinal Direction

(Impregnated Composite Liner FA and Bonded FMA – 6 in. CI Pipe comparison)

	Control	48 weeks	Average 6 in. Pipe (FA)	Average 6 in. Pipe (FMA) Bonded No. 1	Average 6 in. Pipe (FMA) Bonded No. 2
ksi	8	9.7	8.72	8.06	5.83
%CV	7.6	9.9	12.96	21.01	30.08



Small change is seen after mechanical aging at Cornell University

- Large inherent variation

TENSILE STRENGTH

Are the longitudinal and hoop (bonded) tensile strengths from field aged specimens comparable to those of field & mechanically aged (bonded & de-bonded) specimens?

	6 in. Pipe
Longitudinal Tension	YES
Hoop Tension	YES

Conclusion: Liner tensile strength is not affected by 100 years mechanical aging for 6-in. pipe specimens.

LAP SHEAR AND PEEL STRENGTH

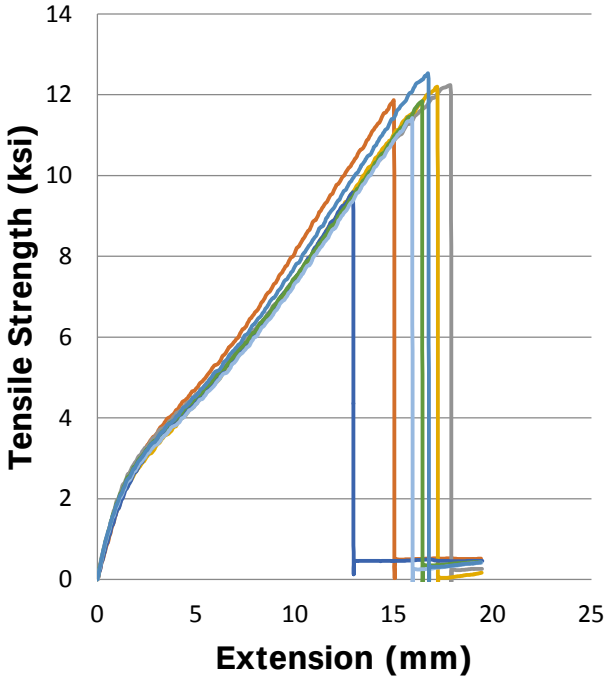
Are lap shear and peel strengths from field / mechanically aged specimens comparable to unaged specimens?

	6 in. Pipe
Lap Shear	YES
Peel Test	YES

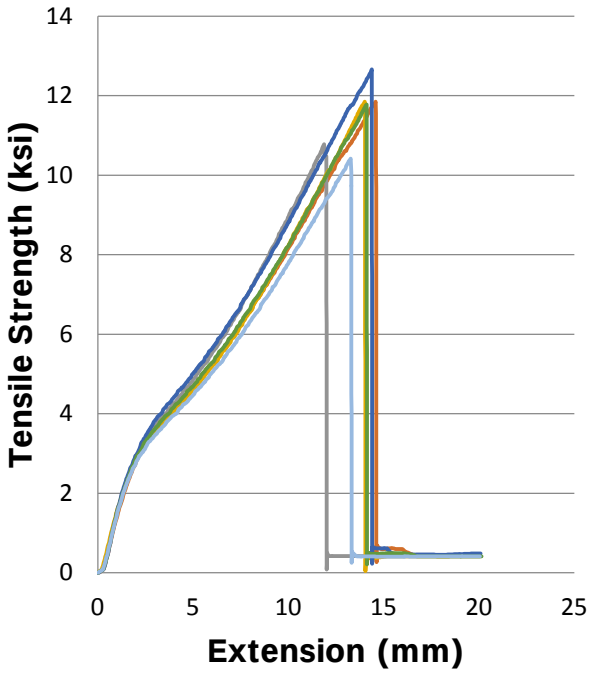
Conclusion: No evidence of significant reduction in lap shear or peel strength due to chemical and mechanical aging

Composite Liner Tension Test Longitudinal Direction

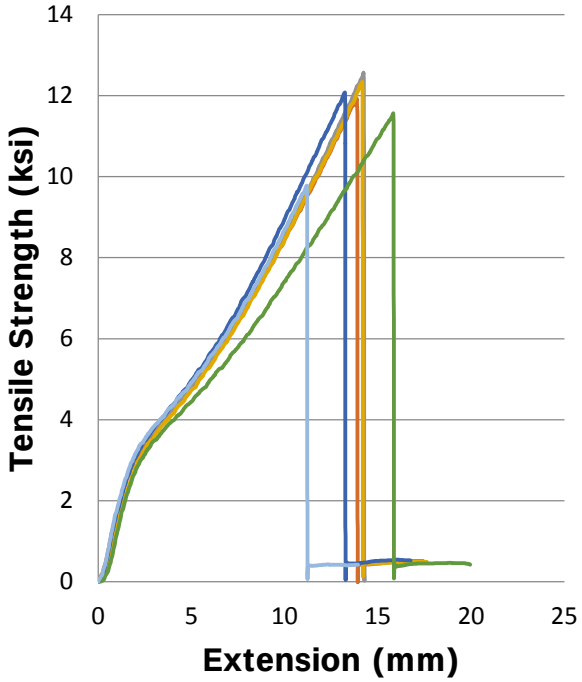
(Impregnated Composite Liner – 12 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (De-Bonded) No. 1



Field + Mechanically Aged: FMA (De-Bonded) No. 2

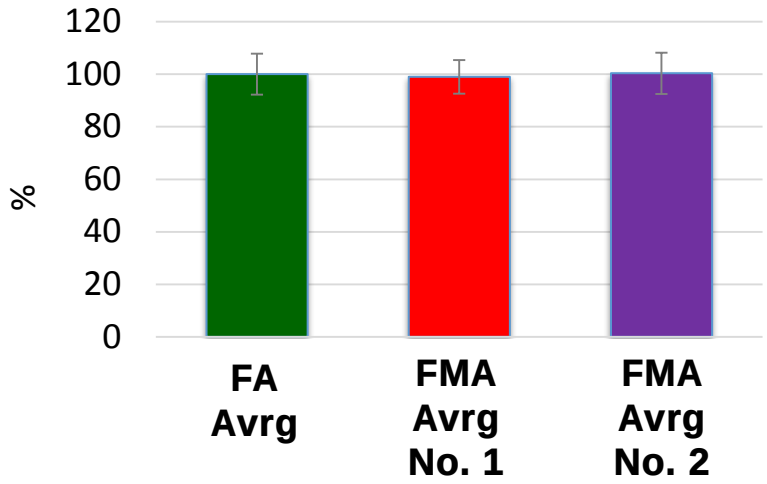
FA = Field aged for 11 yrs

MA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test in Longitudinal Direction

(Impregnated Composite Liner FA and De-Bonded FMA – 12 in. CI Pipe comparison)

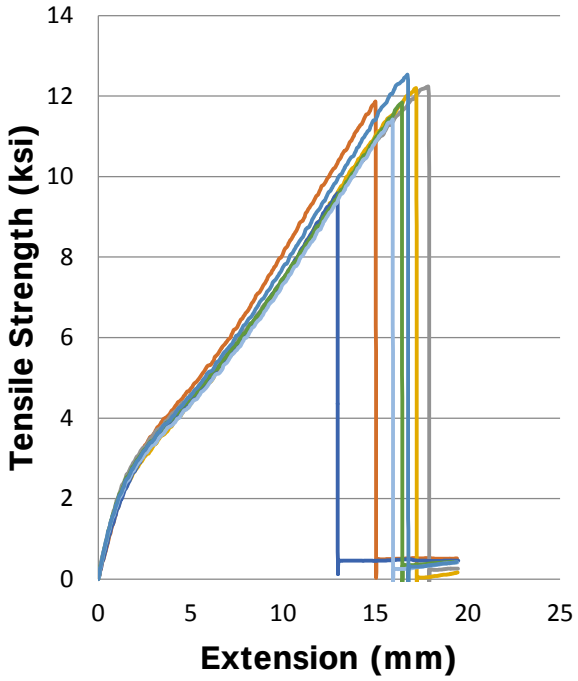
	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) De-Bonded No. 1	Average 12 in. Pipe (FMA) De-Bonded No. 2
ksi	11.67	11.55	11.71
%CV	7.82	6.45	7.84



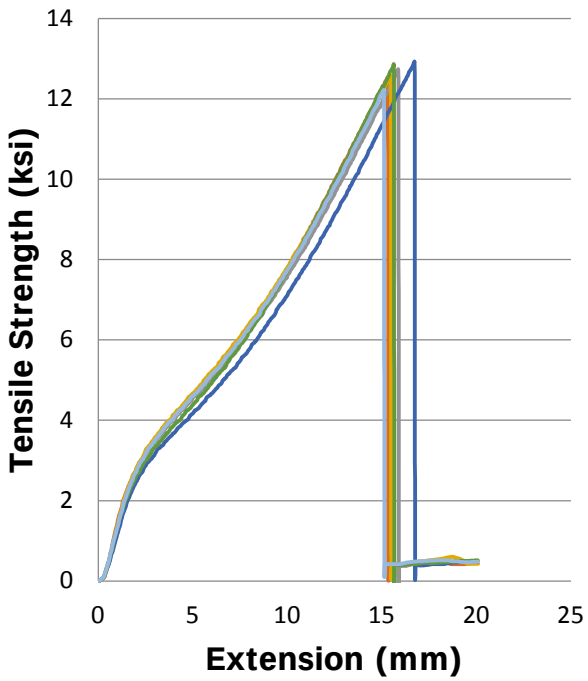
No change is seen after mechanical aging at Cornell University

Composite Liner Tension Test in Longitudinal Direction

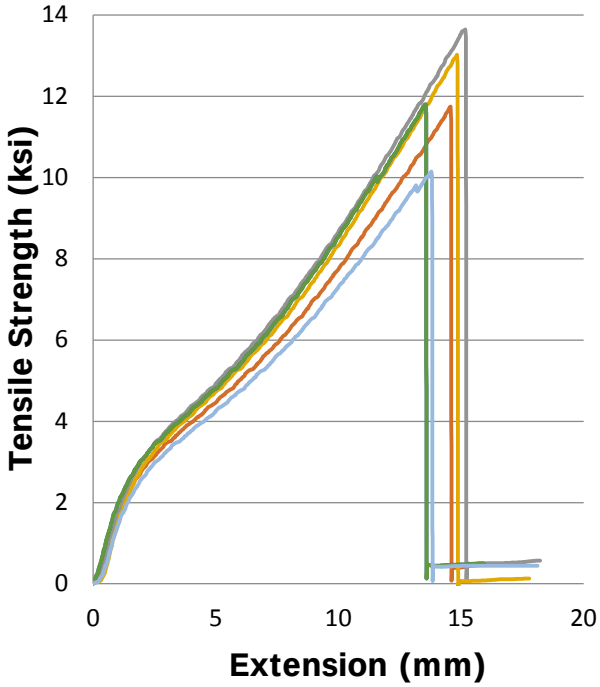
(Impregnated Composite Liner – 12 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



Field + Mechanically Aged: FMA (Bonded) No. 2

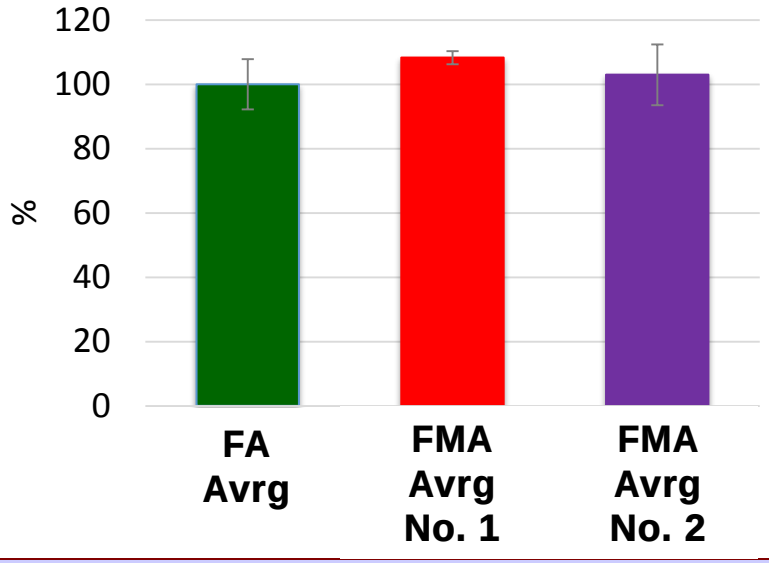
FA = Field aged for 11 yrs

MA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Longitudinal Direction

(Impregnated Composite Liner FA and Bonded-FMA – 12 in. CI Pipe comparison)

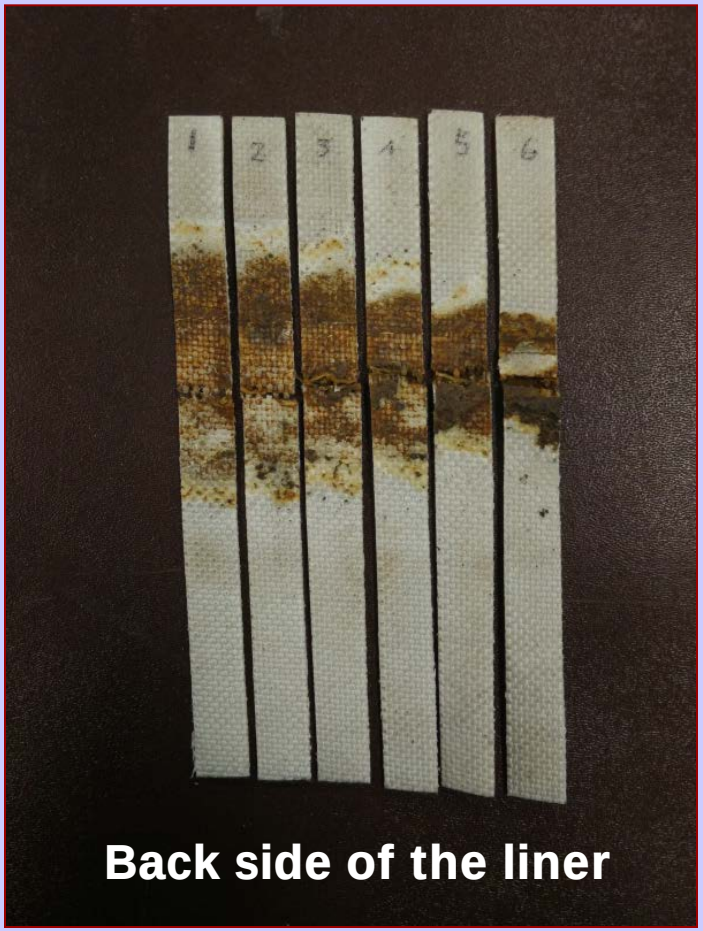
	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) Bonded No. 1	Average 12 in. Pipe (FMA) Bonded No. 2
ksi	11.67	12.64	12.02
%CV	7.82	1.86	9.19



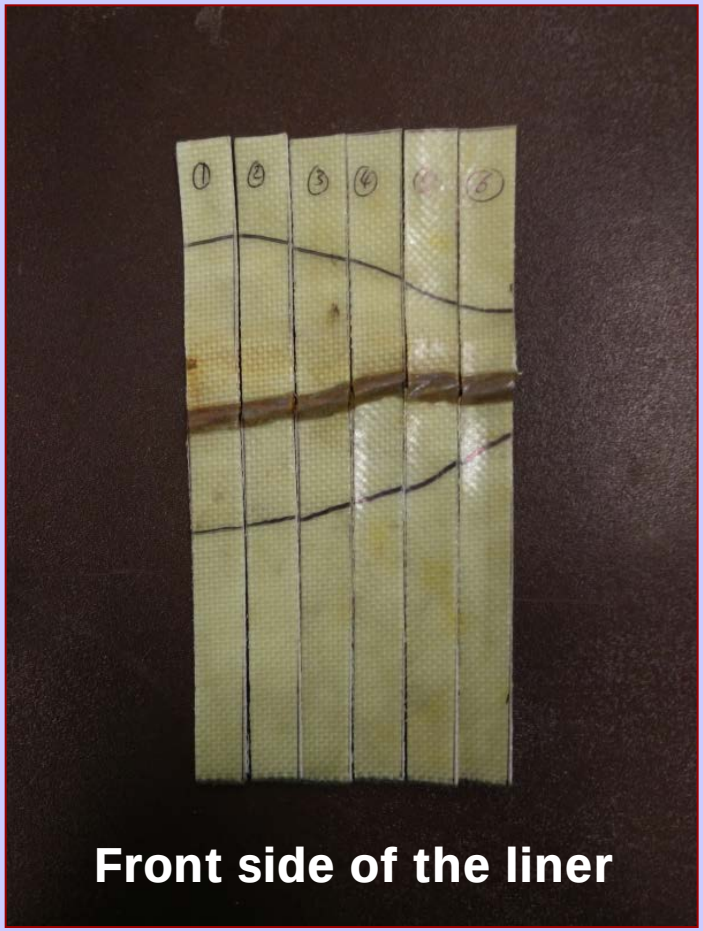
No change is seen after mechanical aging at Cornell University

Composite Liner Tension Test in Longitudinal Direction for Partially Damaged Section

(Impregnated Composite Liner – 12 in. CI Pipe)



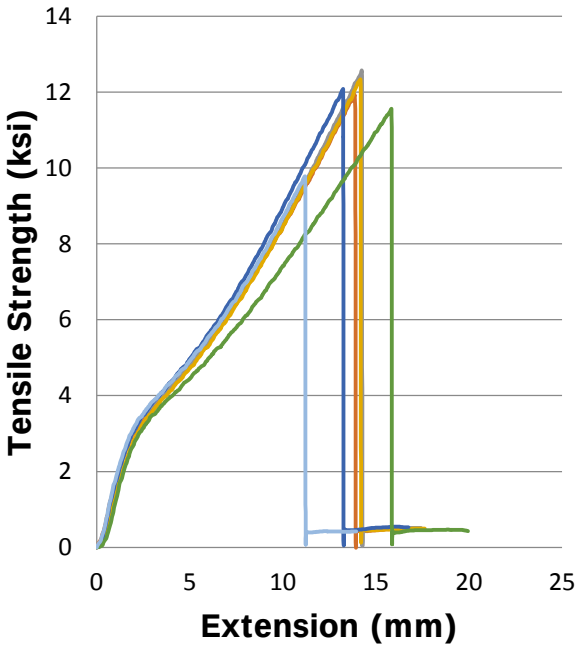
Back side of the liner



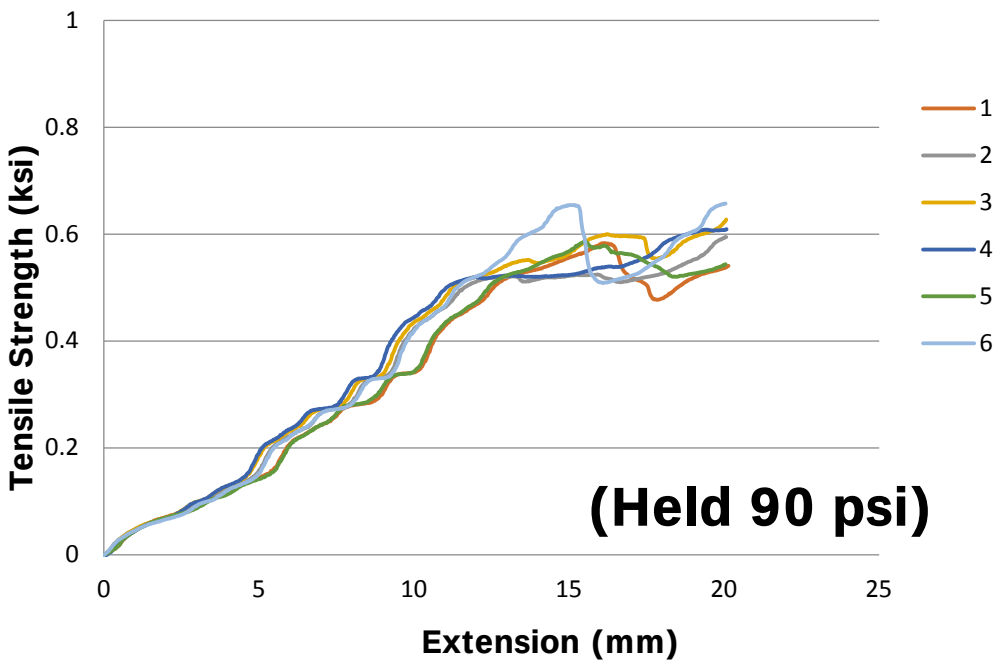
Front side of the liner

Composite Liner Tension Test in Longitudinal Direction for Partially Damaged Section

(Impregnated Composite Liner – 12 in. CI Pipe)



Field + Mechanically Aged: FMA (De-Bonded) 12 in. pipe No. 2

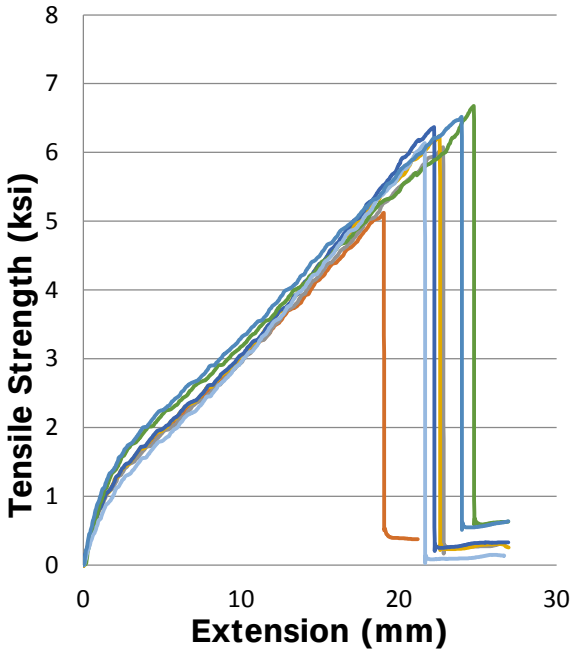


Field + Mechanically Aged: FMA (De-Bonded) 12 in. pipe No. 2 Damaged Section*

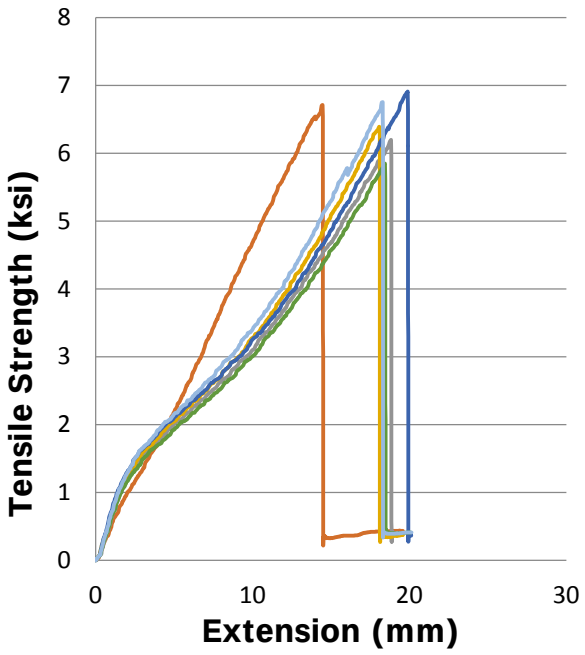
*Plots indicate the properties of the PU membrane

Composite Liner Tension Test Transverse Direction

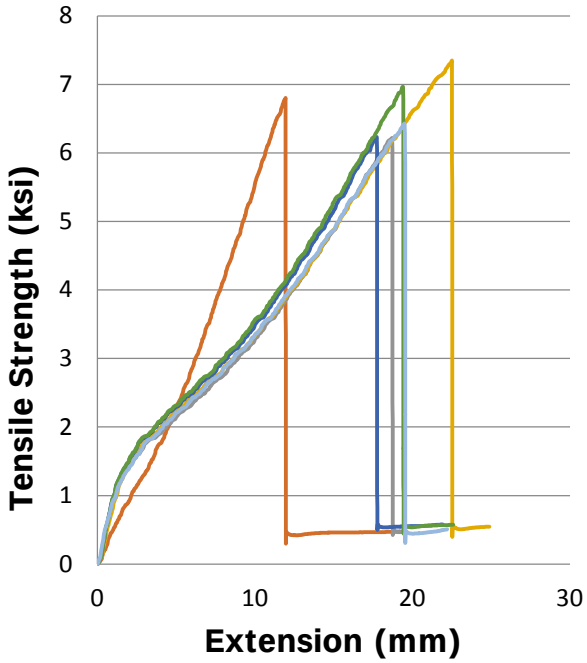
(Impregnated Composite Liner – 12 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



Field + Mechanically Aged: FMA (Bonded) No. 2

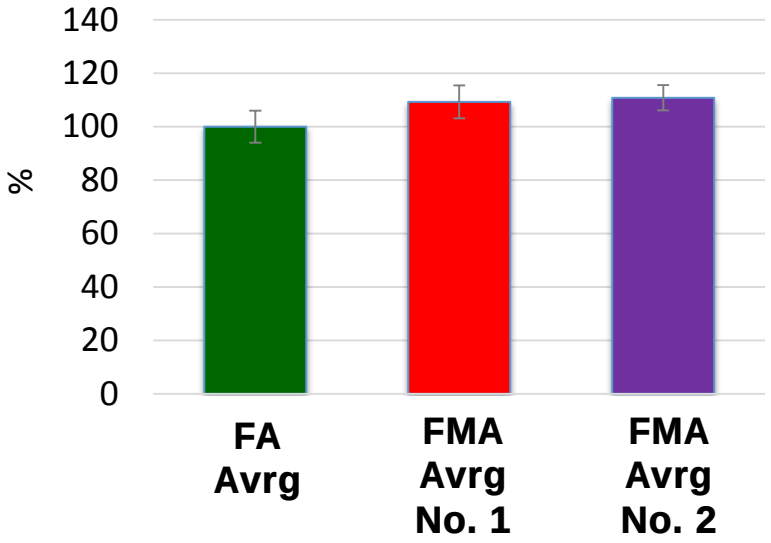
FA = Field aged for 11 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Transverse Direction

(Impregnated Composite Liner FA and Bonded FMA – 12 in. CI Pipe comparison)

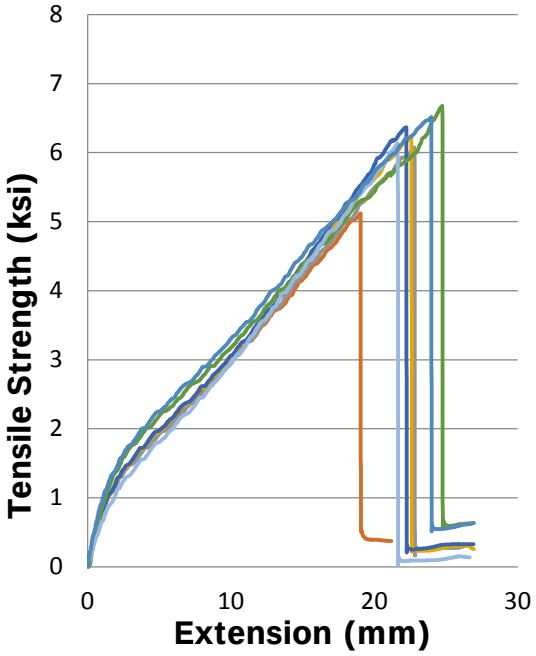
	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) Bonded No. 1	Average 12 in. Pipe (FMA) Bonded No. 2
ksi	5.92	6.47	6.56
%CV	6	5.63	4.3



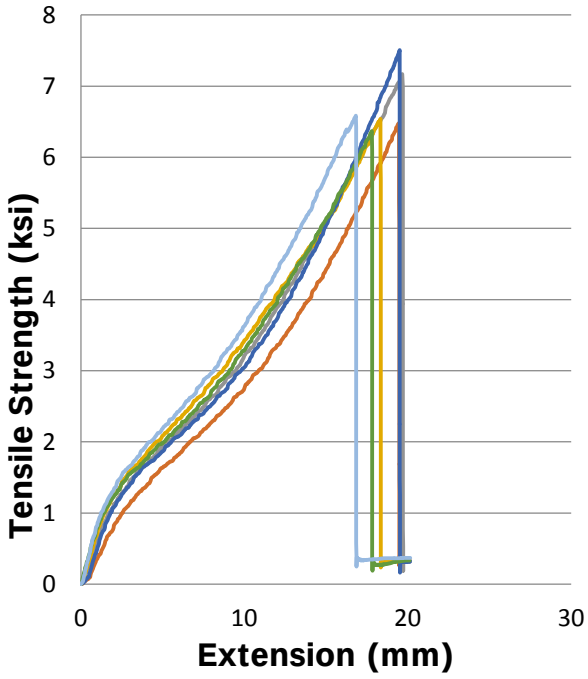
No change is seen after mechanical aging at Cornell University

Composite Liner Tension Test Transverse Direction

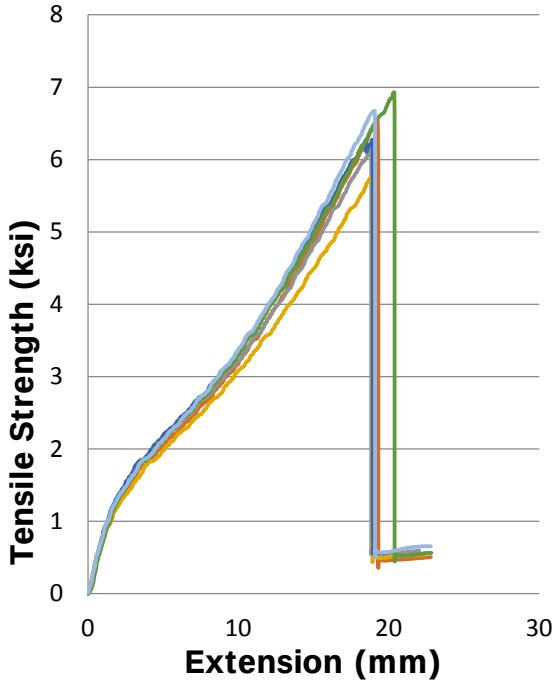
(Impregnated Composite Liner – 12 in. CI Pipe)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (De-Bonded) No. 1



Field + Mechanically Aged: FMA (De-Bonded) No. 2

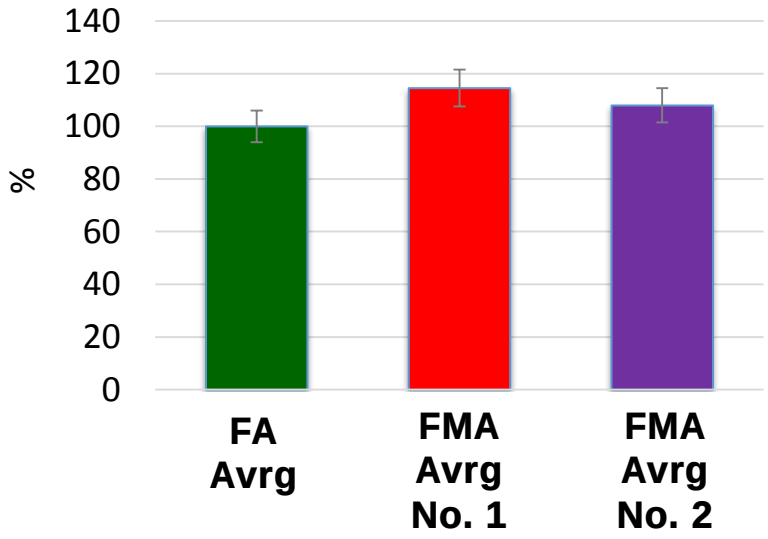
FA = Field aged for 11 yrs

FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Composite Liner Tension Test Transverse Direction

(Impregnated Composite Liner FA and De-Bonded FMA – 12 in. CI Pipe comparison)

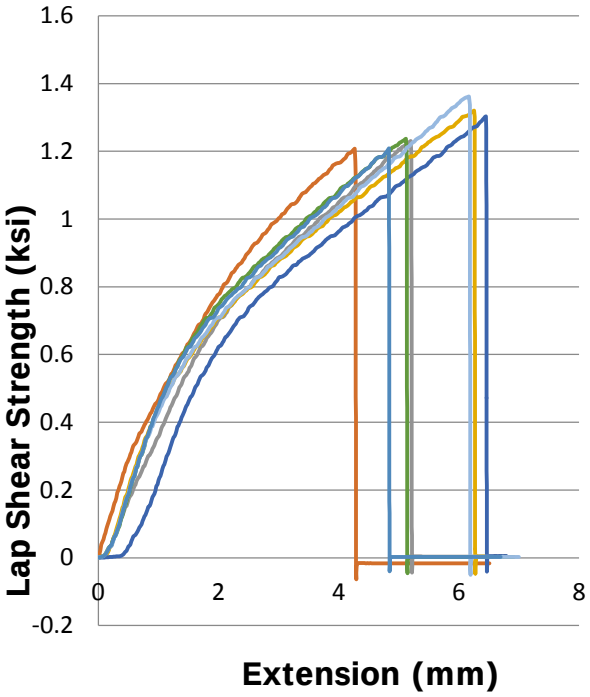
	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) De-Bonded No. 1	Average 12 in. Pipe (FMA) De-Bonded No. 2
ksi	5.92	6.78	6.39
CV %	6	6.14	6



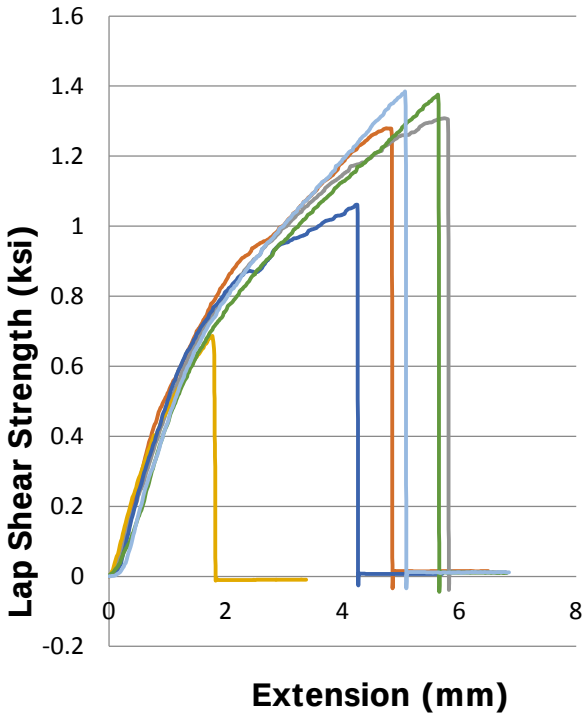
No change is seen after mechanical aging at Cornell University

Lap Shear Test

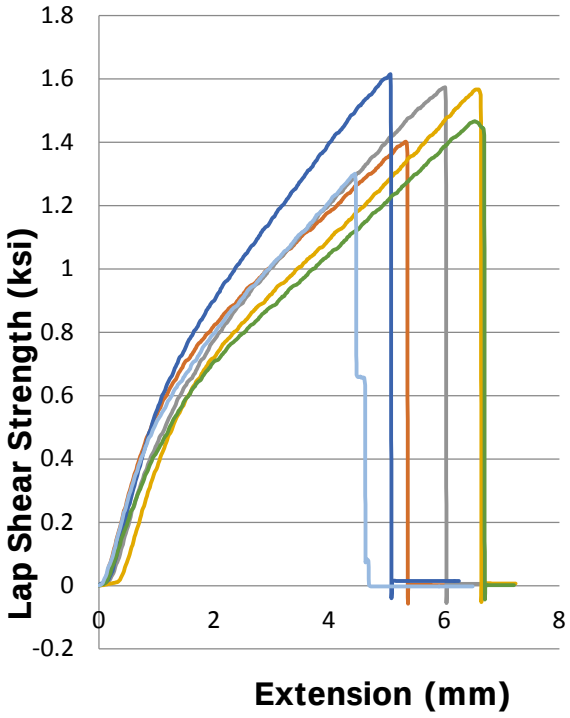
(Impregnated Composite Liner – 12 in. CI Pipe)
(Individual Results)



Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1



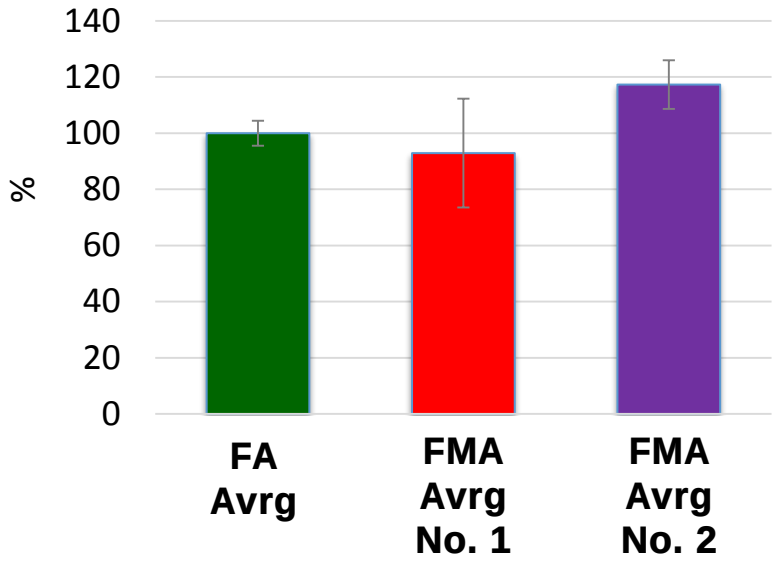
Field + Mechanically Aged: FMA (Bonded) No. 2

FA = Field aged for 11 yrs
FMA = Mechanically aged @ Cornell (equivalent to 100 yrs of traffic and 100 yrs of thermal cycling)

Lap Shear Test

(Impregnated Composite Liner FA and Bonded FMA – 12 in. CI Pipe comparison)

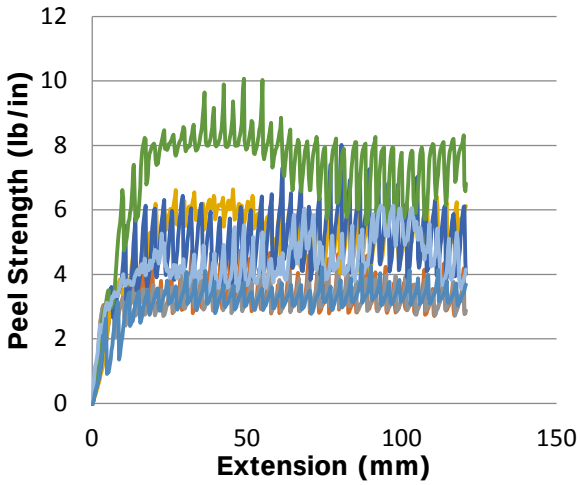
	Control	16 weeks	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) Bonded No. 1	Average 12 in. Pipe (FMA) Bonded No. 2
ksi	1.1	1.6	1.27	1.18	1.49
%CV	13.2	10.1	4.46	20.82	7.4

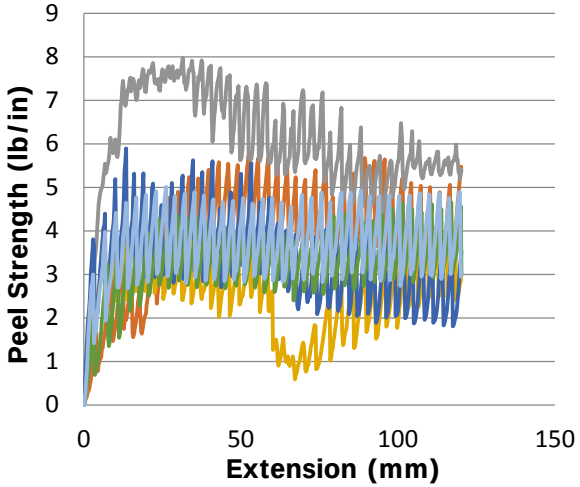


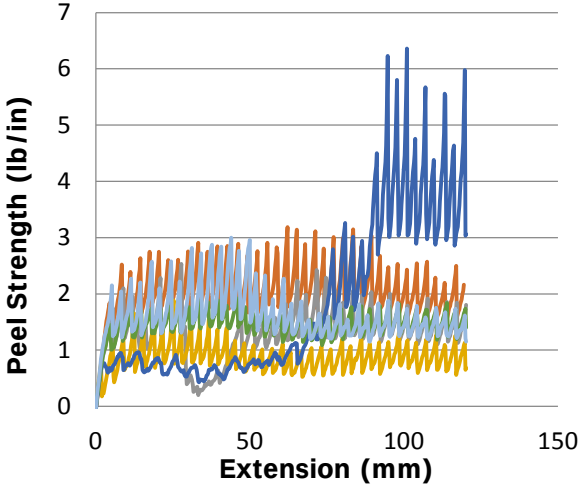
No change is seen after mechanical aging at Cornell University

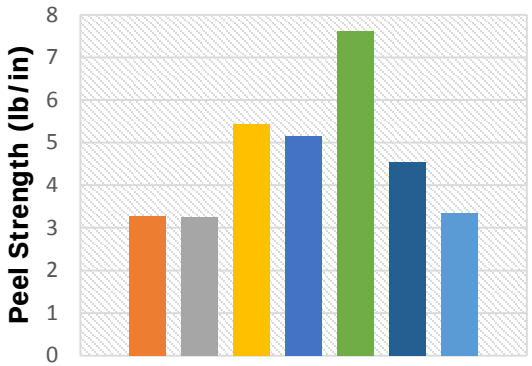
Peel Test in Longitudinal Direction

(Individual Results)

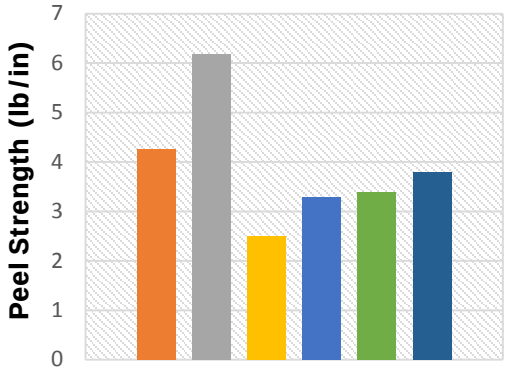




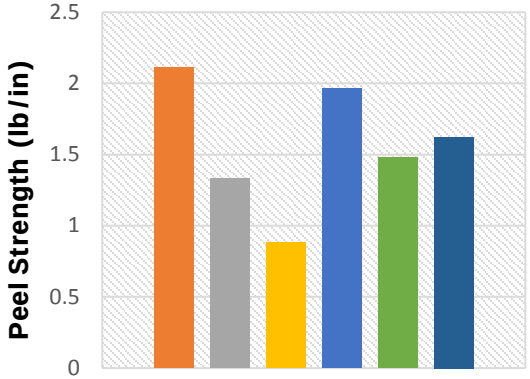




Field Aged: FA (Bonded)



Field + Mechanically Aged: FMA (Bonded) No. 1

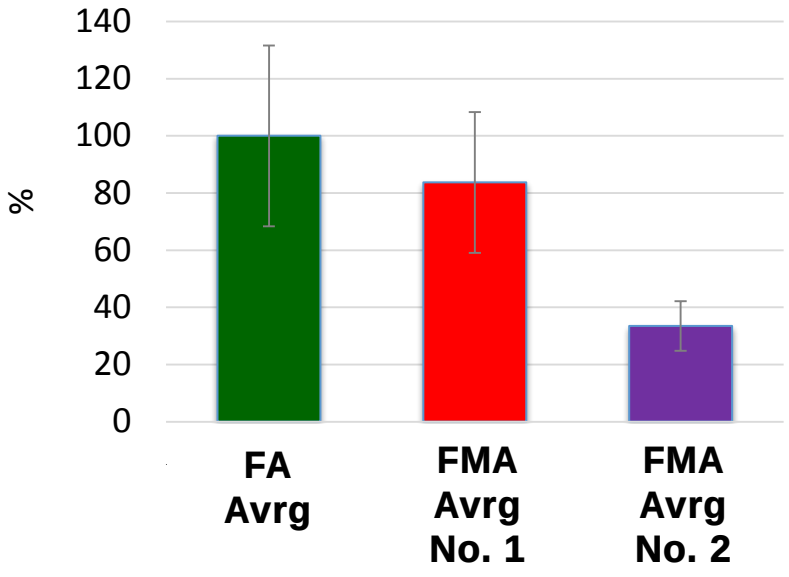


Field + Mechanically Aged: FMA (Bonded) No. 2

Peel Test in Longitudinal Direction

(Impregnated Composite Liner FA and Bonded FMA – 12 in. CI Pipe comparison)

	Control	16 weeks	Average 12 in. Pipe (FA)	Average 12 in. Pipe (FMA) Bonded No. 1	Average 12 in. Pipe (FMA) Bonded No. 2
ksi	8	8.6	4.66	3.9	1.56
%CV	7.6	10	31.61	29.48	25.88



Small change is seen after mechanical aging at Cornell University

- Large inherent variation

TENSILE STRENGTH

Are the longitudinal and hoop (bonded) tensile strengths from field aged specimens comparable to those of field & mechanically aged (bonded & de-bonded) specimens?

	6 in. Pipe	12 in. Pipe (Global)	12 in. Pipe (Local)
Longitudinal Tension	YES	YES	NO
Hoop Tension	YES	YES	NO

Conclusion: Liner tensile strength is not affected by 100 years mechanical aging for 6-in. pipe specimens. Local strength reduction for 12-in. pipe specimens.

LAP SHEAR AND PEEL STRENGTH

Are lap shear and peel strengths from field / mechanically aged specimens comparable to unaged specimens?

	6 in. Pipe	12 in. Pipe
Lap Shear	YES	YES
Peel Test	YES	Not Comparable

Conclusion: No evidence of significant reduction in lap shear or peel strength due to chemical and mechanical aging

Questions?

A single composite liner bonded to just 1” around the circumference of 6 in. pipe could lift a three 10,000 lb elephants without de-bonding

TENSILE STRENGTH

Are the longitudinal and hoop (bonded) tensile strengths from field aged specimens comparable to those of field & mechanically aged (bonded & de-bonded) specimens?

	6 in. Pipe	12 in. Pipe
Longitudinal Tension	YES	NO
Hoop Tension	YES	NO

Conclusion: Liner tensile strength is not affected by 100 years mechanical aging for 6-in. pipe specimens. Local strength reduction for 12-in. pipe specimens.