PUBLIC Quarterly Report

Date of Report: *4th Quarterly Report-September 30th, 2025*
Contract Number: *693JK32410015POTA*
Prepared for: *DOT-PHMSA*
Project Title: *In-situ Rapid-Cured-in-Place Pipelining System for Rehabilitation of Metallic Gas Pipe*
Prepared by: *RapiCure Solutions*
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For quarterly period ending: *September 30th, 2025*

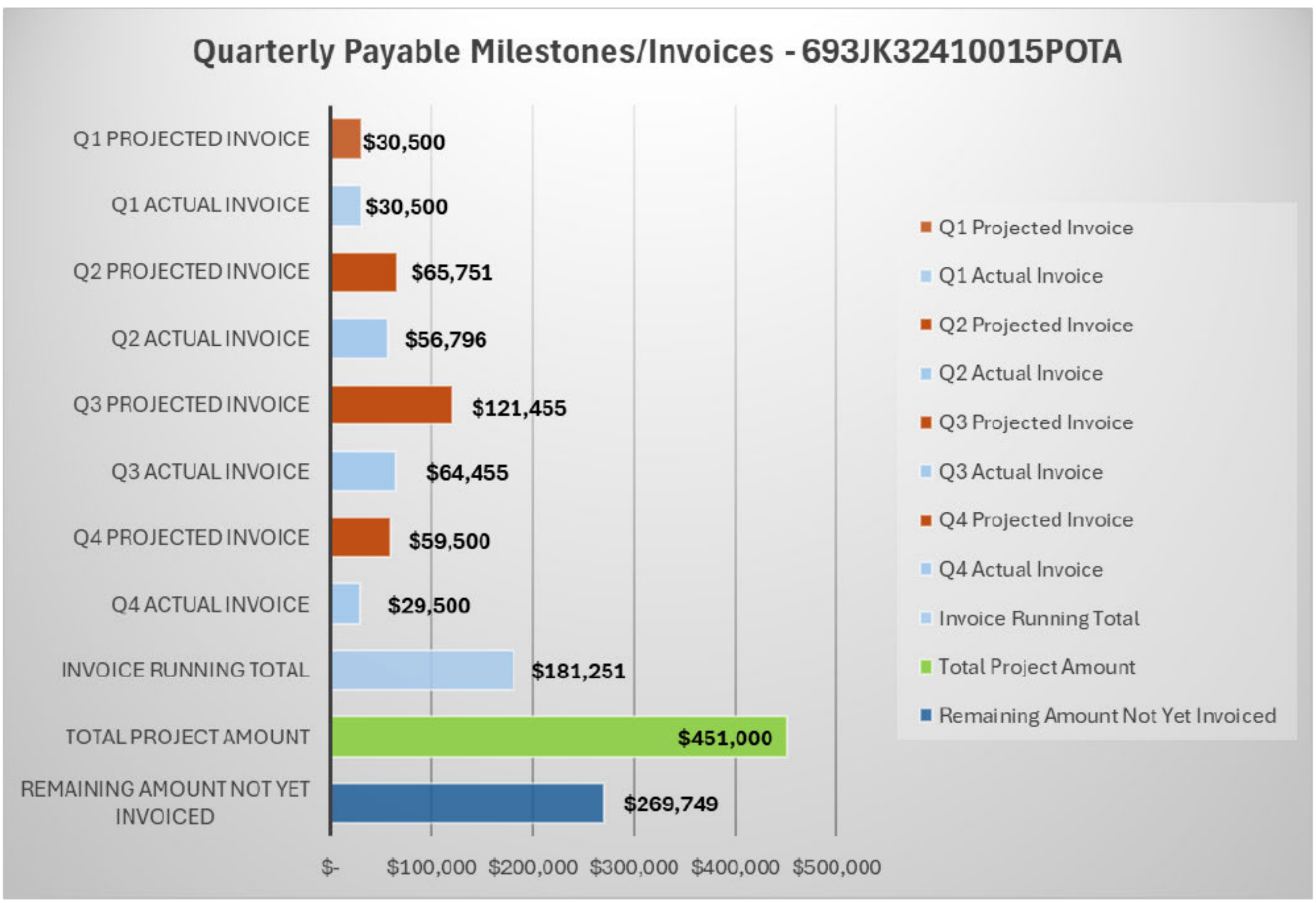
1: Items Completed During this Quarterly Period:

Item #	***Task #***	***Activity/Deliverable***	***Title***	[redacted]	[redacted]
1	***4&5***	***Material Characterization Part 16***	***ASTM D696 test result analyses***	[redacted]	[redacted]
2	***4&5***	***Material Characterization Part 18***	***ASTM D5868 test specimen preparation***	[redacted]	[redacted]
3	***4&5***	***Material Characterization Part 19***	***ASTM D5868 testing***	[redacted]	[redacted]
4	***4&5***	***Material Characterization Part 20***	***ASTM D5868 test result analyses***	[redacted]	[redacted]
5	***4&5***	***Material Characterization Part 26***	***ASTM D903 test specimen preparation***	[redacted]	[redacted]
6	***4&5***	***Material Characterization Part 27***	***ASTM D903 testing***	[redacted]	[redacted]
7	***4&5***	***Material Characterization Part 28***	***ASTM D903 test result analyses***	[redacted]	[redacted]
8	***4&5***	***Material Characterization Part 31***	***ASTM D4060 testing***	[redacted]	[redacted]
9	***4&5***	***Material Characterization Part 32***	***ASTM D4060 test result analyses***	[redacted]	[redacted]
10	***4&5***	***Material Characterization Part 34***	***ASTM G14 test specimen preparation***	[redacted]	[redacted]
11	***4&5***	***Material Characterization Part 35***	***ASTM G14 testing***	[redacted]	[redacted]
12	***4&5***	***Material Characterization Part 36***	***ASTM G14 test result analyses***	[redacted]	[redacted]
13	***12***	***Engineering Design Part 1***	***Engineering Design Part 1***	[redacted]	[redacted]
14	***10***	***Suggest Improvements***	***Suggest Improvements***	[redacted]	[redacted]
15	***14***	***4th Quarterly Report***	***4th Quarterly Report***	[redacted]	[redacted]

2: Items Not-Completed During this Quarterly Period:

Item #	*Task #*	*Activity/Deliverable*	*Title*	[redacted]	[redacted]
1	*15*	*Paper Submission*		[redacted]	[redacted]
2	*3*	*Engineering Design Part 2*	*Engineering Design Part 2*	[redacted]	[redacted]
3	*3*	*Develop Coating Part 4*	*Develop Coating Part 2 – 6' liners*	[redacted]	[redacted]
4	*3*	*Develop Coating Part 5*	*Develop Coating Part 2 – 6' liners*	[redacted]	[redacted]
5	*3*	*Develop Coating Part 6*	*Develop Coating Part 2 – optimized liner*	[redacted]	[redacted]
17	*9*	*Perform Tensile/4-point bend test*	*ASTM 2207-06 Preparations*	[redacted]	[redacted]

3: Project Financial Tracking During this Quarterly Period:



4: Project Technical Status

Introduction/Background

The goal of this project is to develop a cost-effective commercial-ready near deployable product and solution for internal pipeline repair (cured in place pipe, CIPP) that enables service providers and pipeline operators to quickly protect their critical infrastructure immediately and for generations to come. During Quarters 1, 2, and 3 the team successfully manufactured pipeline liners with varying lengths, from 16 inches to 4 feet in length with up to 1-inch thickness and 12-inch diameter that can be slipped into place and secured using the same resin system akin to a caulk or a glue. In addition, a sprayable coating was developed while addressing several key challenges and questions. [redacted] After quick initiation of the cure at one end or even one spot, a curing front traveled across the liquid (akin to a wildfire) at a controlled rate, and hardened in just minutes, compared to hours or even days for legacy rehabilitation of metallic gas pipes. Multiple ASTM tests were started in Quarter 3 per ASTM F2207-06 and PCC-2-2022 Article 403 recommendations, Table 1. Out of 9 ASTM tests, 4 were completed and reported in 3rd Quarterly report. The remaining ASTM tests were performed, analyzed and compared with the legacy resin solutions available in the market herein Quarter 4. The project team also made significant progress towards commercialization with various meetings and discussions with commercial users. Lastly, the team added additional tests and planning to support upcoming in-field pilots.

ASTMs D790, D638, D2990 and D3165 were all completed and reported in Q3. Nevertheless, all "testing various resins" deliverable was also completed for all the remaining ASTMs; D696, D5868, D903, D4060 and G14 in Q3. Reported herein is the test specimen preparation, testing and test result analyses deliverables wherever appropriate and left incomplete from the previous quarter, Q3.

Table 1. Proposed ASTM list for testing per ASME PCC-2.

ASTM	Title	Results Reported
D790	Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials	Q3
D638	Tensile Properties of Plastics	Q3
D2990	Tensile, Compressive and Flexural Creep and Creep-Rupture of Plastics	Q3
D696	Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C with a Vitreous Silica Dilatometer	Q4
D3983	Measuring Strength and Shear Modulus of Nonrigid Adhesives by the Thick-Adherend Tensile Lap Specimen	

D5868	*Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding--- (Instead of D3983 after discussions with Prof. Brad Wham)*	Q4
D3165	Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies	Q3
D903	Peel or Stripping Strength of Adhesive Bonds	Q4
D4060	Abrasion Resistance of Pipeline Coatings by the Taber Abraser	Q4
G14	Impact Resistance of Pipeline Coatings	Q4

[Item 1] [Task 4&5][Material Characterization Part 16][ASTM D696 test result analyses]

ASTM D696 test result analyses.

ASTM D696 Coefficient of Linear Thermal Expansion (CLTE) of Plastics Between -30 °C and 30 °C with a Vitreous Silica Dilatometer covers the coefficient of linear expansion that measures the rate at which a given material expands as a function of temperature. This test is critical because this property can be used to design and/or test materials and structures that can withstand thermal stress and prevent failures. That is, extreme thermal expansion differences that develop internal stress which might cause failures.

As reported in Q3, Perkin Elmer Dynamic Mechanical Analyzer (DMA) 8000 was used for this test. However, the test runs were performed from 25 °C to 50 °C; ASTM 696 requires the test to be performed from -30 °C to 30 °C. Hence, ASTM specific specimens (≤1/2" wide x 2 ½" to 3" long and ≤1/4" thick) were cut with a diamond saw from the panels prepared and as detailed in Q3 and sent a third party for the required temperature range testing via Vitreous Silica Dilatometer. Note here that DMA specimens were cylindrical with 10 mm in length and 6.3 mm in diameter. A quartz standard was also measured as a reference material with the same dimensions alongside the specimen and used as baseline subtraction via DMA. See Q3 report for details and preparation of the specimens.

CLTE measured via DMA in RapiCure Solutions' laboratory yielded an average value of 8.0E-05 /°C after three replicate measurements. The 3rd party reported an average CLTE of 7.9E-05 /°C after two replicates. The obtained CLTE values are within error indicating that the cured resin is very stable with respect to different temperature ranges tested. The temperature can have an impact on CLTE values. Additionally, the specific type of thermoset resin and the addition of fillers can also change the CLTE value but, the same formulations were used for both measurements.

CLTE usually lies between 2.0E-05 /°C to 6.0E-05 /°C for thermoset resins but may be lower or higher depending on the specific resin type, used fillers and orientation/crystallization of the cured resin. Nevertheless, the desired CLTE value depends on the application, and we have not been able to find a reported/desired/required CLTE value/range for a resin used for inside pipeline coating. For reference though, epoxy-based resins usually have CLTE ranging from 4.0E-05 /°C to 8.0E-05 /°C; high density polyethylene 6.0E-05 /°C to 11.0E-05 /°C; polyamide 9.0E-05 /°C to 15.0E-05 /°C; polytetrafluoroethylene 7.0E-05 /°C to 20.0E-05 /°C. Yet, it was reported that the cured resin should have a maximum allowable CLTE of 10E-05 /°C for trenchless CIPP applications. All things considered, RapiCure Solutions' resin formulation is lower than this reported maximum allowable value while similar/better than common CIPP resins confirm its suitability for CIPP applications and likely exhibits similar CLTE performance most aligned with a PE or PTFE material.

Dilatometer	:	Tinius Olsen
Sample Preparation	:	Tested as received
Sample Conditioning	:	40+ hours at 23°C ± 2°C / 50%RH ± 10%
Sample Dimensions	:	3" x 0.46" x 0.11"

C.T.E. = a = DL / (Lo *DT) DT = T2-T1 Temperature T1 = Start T2 = Final
DL = L2-L1 Length L1 = Start L2 = Final

	Lo (in)	Lo (µm)	T1 (°C)	T2 (°C)	L1 (µm)	L2 (µm)	a (/°C)	Average a (/°C)	a (/°F)	Average a (/°F)
HVO47A										
Specimen 1	[redacted]									
Specimen 2										
							Average	7.92E-05		4.40E-05

Figure 1. The results of the ASTM D696 reported by a certified 3rd party lab.

[Items 2,3,4] [Task 4&5][Material Characterization Parts 18,19,20][ASTM D5868 test specimen preparation, ASTM D5868 testing, ASTM D5868 test result analyses]

As stated in Q3 report, "ASTM D3983 Measuring Strength and Shear Modulus of Nonrigid Adhesives by the Thick-Adherend Tensile Lap Specimen was recommended to be switched out with ASTM D5868 Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding. ASTM 3983 is not suitable for adhesives that have a high shear modulus in the cured state and that also require elimination of volatile constituents during cure. ASTM 3983 may still be considered at a future time. Instead, ASTM D5868 was determined to be better aligned for the ensuing project as it describes the strength of single lap adhesively bonded shear joints in Fiber Reinforced Plastic (FRP) adherends which may be critical information for the liner materials. The specimen is subjected to tension forces from opposite ends, till the shear joint fails. Plainly, the resin is used to adhere to carbon steel tabs together in single-lap-joint geometry and the tabs are pulled in opposite directions (tensile load) to further understand the shear strength of the resin between 2 layers of bonded surface – in this case carbon steel.

A modified ASTM D3165 was performed and reported in Q3 wherein a tensile load in opposite directions were measured with respect to the overlap lengths that adhered carbon steel tabs together: 0.50, 0.75, 1.0 and 1.25 inches overlap. Herein, a modified ASTM D5868 was performed where carbon steel tabs were used instead of fiber reinforced plastic per ASTM D5868 since the resin will be applied to the carbon-steel natural gas pipes. Nevertheless, different from the ASTM D3165, the thickness of the resin varied from 0.1 to 0.2 inches while the overlap length was kept constant at 1.0 inch.

ASTM D5868 test specimen preparation

Test specimens were prepared like ASTM 3165 test specimens as reported in Q3. The same type "carbon steel sheets" were used to imitate pipes that are widely used in natural gas pipelines. The sheets were 16 gauge with a 0.060 inches thickness. One face of the sheet was sandblasted (where the resin is applied) to better mimic the internal roughness observed within carbon steel pipes (vs polished steel). Then, the sheets were cut into 7-inch by 1-inch coupons to prepare the test specimen. Three different resin thicknesses were chosen/targeted: 0.10”, 0.15” and 0.20”. More than three iterations showed thinner resin application than 0.10” is not feasible since the resin is not spreading homogeneously between the carbon steel tabs and thicker resin application than 0.20” requires further tooling/molding method development to prevent overflow/pooling since the viscosity of the resin does not allow to build up thickness in a small volume of 1” by 1”.

After more than four iterations, the group have been able to create molds to achieve the targeted thickness specimen preparations. Specifically, some aluminum foil was wrapped within blue painters’ tape (for sturdiness) which was then used to create 1” by 1” mold with varying depths on the carbon steel tabs. Then, these molds were filled with resin, the other carbon steel tab was placed on top and the resin was cured [redacted] For each thickness, five specimens were prepared. The measurements were performed the following day after removing the mold; that is, the aluminum wrapped blue painters’ tape was trimmed.

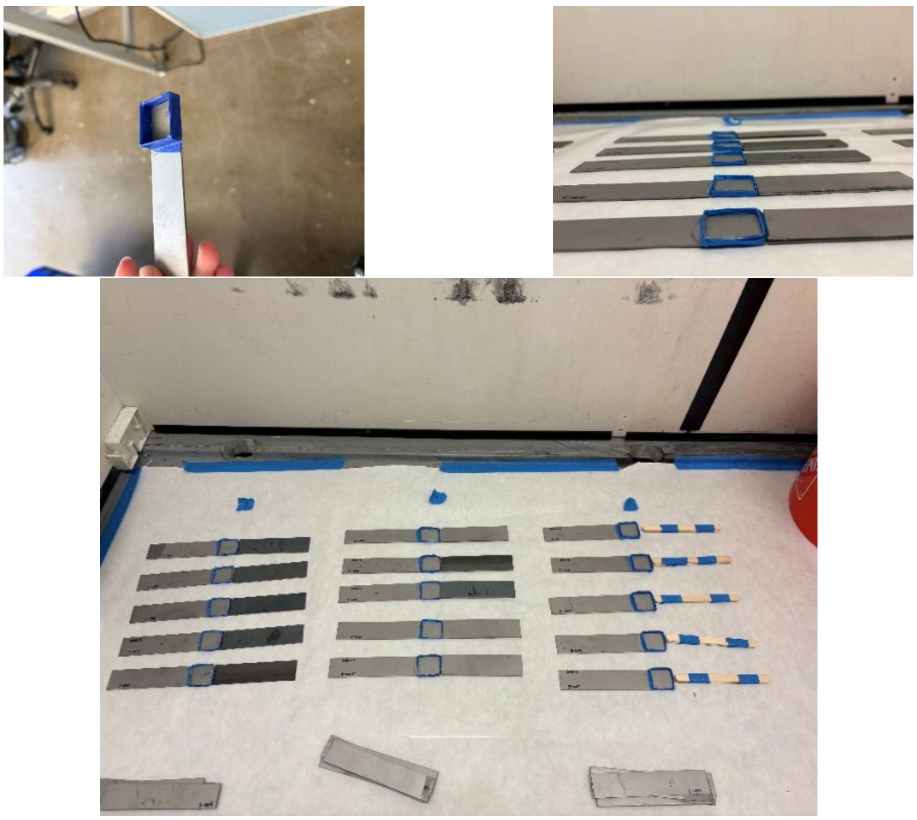


Figure 2. The prepared resin molds on carbon-steel tabs (top). A total of five specimens were prepared for three different thickness (bottom).

ASTM D5868 testing.

The test was performed at RapiCure Solutions laboratory via UTM instrument MTI 2K model. The test specimen was placed in the grips of the UTM so that the distance from the overlap to the grip jaw is 2.5 inches per ASTM. The load was applied until the failure. The software calculates and reports the raw data. A total of five specimens were tested for each thickness as given above and the results are analyzed in the following section.

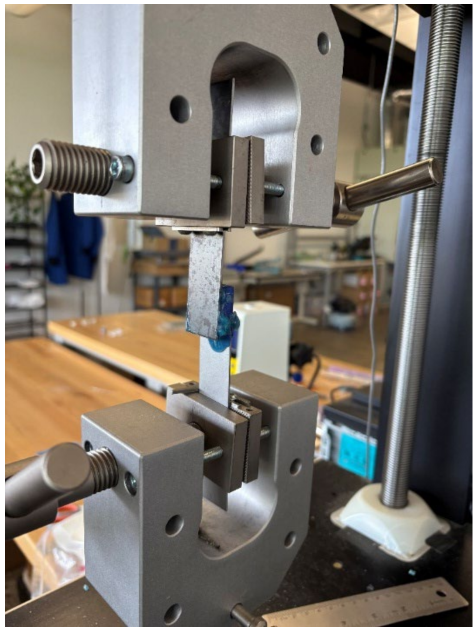


Figure 3. The prepared specimen is mounted to the jaws of the UTM instrument.

ASTM D5868 test result analyses.

The lap shear strength is measured with varying thicknesses showing lap shear strengths ranging from 1.12 MPa to 0.345 MPa (162-50 psi). The lap shear strength correlates with the thickness such that increased thickness yields lower lap shear. Nevertheless, this trend may not necessarily be true since the alternative hypothesis is that the high surface tension of the resin with strong cohesive intermolecular forces minimize the surface area especially with larger volumes (that is thicker resin trials) preventing effective spreading and inadequate bonding/adhering to the carbon steel tab put atop. This alternative hypothesis can also be supported with a large error bar/standard deviation with thicker resin specimens. Consistently, all adhesive failures happened with the carbon steel tab that had been put atop after filling the mold with resin.

For *composite materials*, ASME PCC-2 would require a minimum shear strength value of 4 MPa (580 psi). No value is provided for resin only coatings. If needed the shear strength can be improved using one of the methods determined in Q2. All the failures are adhesive. That is, the cured resin separates from one of the bonded surfaces. After our team meeting the technical advisory panel stated that optimal bonding may not necessarily be the highest lap shear strength as there are some instances where under impact shock, or heavy load, debonding may prevent unwanted rupture of the liner coating or even the pipe itself.

The TAP clarified that stronger bonding may only be needed in specified areas. TAP members commented that this value is okay to be a low value (<4 MPa) and that the lap shear performance may not necessarily reflect the lap shear/adhesion strength as a coating since the resin is applied between two metal coupons for the lap shear test, whereas the rehabilitation of metallic gas pipes detailed herein will includes only one metal-resin interaction. The TAP was encouraged that the adhesive failure is a good sign for such application since the resin-metal interaction/bonding should be less than metal-metal interaction (cohesive failure occurs when the resin splits and both metal specimens have bonded resin pieces). In summary, we have fulfilled the required test for ASTM D5868, and the results are promising for CIPP lining with RapiCure's system.

Table 2. Tabulated results of the lap shear strength per modified ASTM D5868.

Thickness (inch)	Average Load at Failure (MPa)	Type of Failure
0.104 (actual)	1.12±0.29	Adhesive
0.133 (actual)	0.438±0.19	Adhesive
0.199 (actual)	0.345±0.20	Adhesive

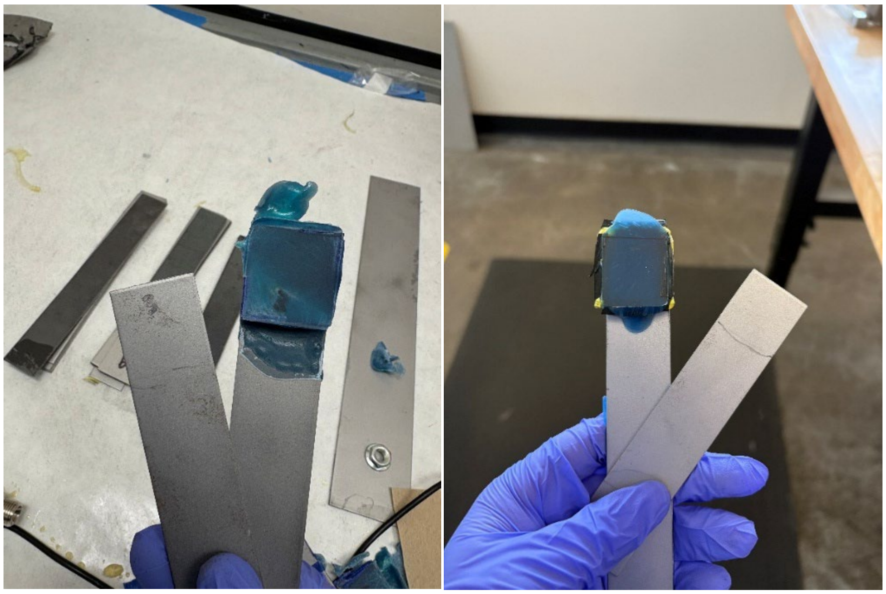


Figure 4. All the failures of the ASTM D5868 are adhesive.

[Items 5,6,7] [Task 4&5][Material Characterization Parts 26,27,28][ASTM D903 test specimen preparation, ASTM D903 testing, ASTM D903 test result analyses]

ASTM D903 test specimen preparation

This test method determines the comparative peel off/stripping characteristics of adhesive bonds. Specifically, ASTM D903 requires the material to be tested as *flexible* which "indicates a material of the proper flexural strength and thickness to permit a turn back at an approximate 180° angle in the expected loading range of the test without failure." However, with the desired/required thickness for the CIPP applications (at least 1/8"), RapiCure Solutions' cured resin *does not* bend 180° to allow the measurement of this test. Thus, a modified version of the ASTM was performed. Multiple (>6) iterations were performed to obtain the maximum thickness of resin applied on carbon steel tabs of 10" by 1" that also spreads and adheres to the tab without any pooling/overflow as it contributes to the applied peel off force by UTM after curing. This thickness was determined to be 0.03". Five specimens were prepared where the carbon steel tabs are coated with resin about 0.03" thickness and cured [redacted] After cooling, one end of the coating was slowly peeled about an inch and this end of the resin was secured with blue painters' tape. Then, about 15"-20" blue painters' tape was applied and secured from this end. The other end of the tape was rolled and used to attach to the upper clamp of the UTM instrument.

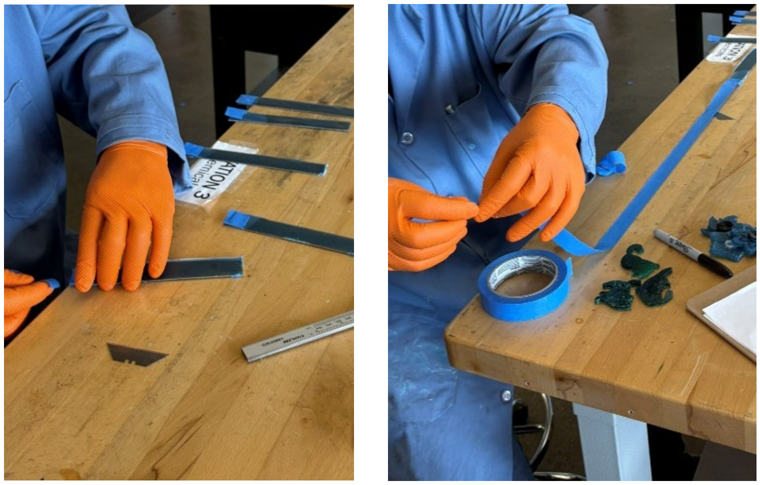


Figure 5. The sample preparation for ASTM D903 testing.

ASTM D903 testing

The test was performed at RapiCure Solutions laboratory via UTM instrument MTI 2K model. The test specimen was secured in the lower grip of the UTM. That is, the one end of the carbon steel tab where the coating was gently peeled about an inch. Then, the attached blue painters' tape was attached to the upper grip without any further peeling of the coating. The load was applied, and the coating started to peel off. However, as can be seen from figure, the peel off angle was not quite 180° but rather closer to 45° and the UTM *did not* register any force since the coating peels off easily via this method.

Figure 6. ASTM D903 testing trials with prepared specimens. *Left*: Attached specimen to the UTM instrument. *Center*: During the measurement/peeling. *Right*: Specimens after the test.

ASTM D903 test result analyses

As stated above, UTM did not register any value for the peel off force applied. It is our recommendation that this test is not appropriate for testing the adhesive properties of a pipeline coating as this test specifically designed for adhesives/tapes for quality control and failure analysis of the adhesives/tapes. TAP members confirmed that this test may not be applicable to thick applications as it applied only to 'flexible' adhered samples, and D3165 was already performed and reported in Q3 yielding acceptable results per discussions with the TAP members.

[Item 8,9] [Task 4&5][Material Characterization Part 31, 32][ASTM D4060 testing, ASTM D4060 test result analyses]

ASTM D4060 is a standardized test method to evaluate the abrasion resistance of coatings using a Taber Abraser. This test measures a coating's ability to withstand abrasive wear by tracking material loss after controlled, repeated abrasion. Abrasion resistance is a crucial property of coatings or liners for pipeline coating herein, as it significantly influences the durability and longevity of the coating. The ability of the coating to withstand abrasion can determine how well it will perform over time, maintain its protective qualities and overall performance. One key customer concern raised is if the pipes are cleaned with abrasive pigs or other area of pipe have build-up that breaks free how might this impact the coating/pipe? To accurately assess this property, ASTM D4060 is employed as the standard test method. This method involves subjecting the coating to a rotating wheel equipped with abrasive particles, which will simulate the wear and tear that the coating might encounter in the pipeline. By doing so, it provides a reliable measure of the coating's resistance to abrasion.

ASTM D4060 testing.

As detailed in the Q3 report, multiple panels were produced, cut into ASTM D4060 specific dimensions specimens via waterjet cutting (6.5 mm hole in the center with a 100 mm diameter and less than 6.5 mm thickness), and provided to a 3rd party lab for testing. The test was performed according to the CS-17 standard. That is, 1000 cycles with 1000 grams load. Following the wear index I is calculated using $I = \frac{(\mathrm{A}-\mathrm{B})1000}{\mathrm{C}}$ where: A = weight of test specimen before abrasion in mg, B = weight of test specimen after abrasion in mg, and C = number of cycles of abrasion recorded.

ASTM D4060 test result analyses

The 3rd party lab provided the results of the Taber Abrasion test as given in the figure below. A wear Index *I* was reported to have an average of 66.6 mg ± 8.6 mg (n = 3) via CS-17 standard. Our literature research showed that the lowest *I* is best for coating applications. We did not find a maximum allowable material loss after ASTM D4060 test for inside pipeline coating materials, but 3M Scotchkote epoxy based thermosetting resin used for pipeline coating from outside of the pipe reports a wear index of 260 mg to 375 mg. Sherwin-Williams Pipeclad amine epoxy resin reports 136 mg. Poly-cote polyurethane-based resin reports 100 mg while Protal epoxy pipe coating reports 93 mg. All results are reported according to the CS-17 standard. Denso reports that their Protal Abrasion Resistance Pipeline Coating, a go-to industry standard for outer pipeline protection to exhibit a wear index of 99 mg. The abrasion resistance of RapiCure's material was closest in performance to a polyurethane-like coating. RapiCure Solutions' resin formulation with average wear index of 66.6 mg is in some cases 2 – 5X better performing than industry incumbents, and outperforms the go-to outer pipeline coatings, suggesting that this material will offer improved abrasion performance for CIPP applications over existing epoxy technologies. The team will not make any attempt to increase the abrasion resistance, but has identified additional strategies to increase abrasion resistance if needed using simple compatible additives.

DESCRIPTION OF SAMPLES:

Part Description:	HV047A
Material Submitted:	Three (3) prepped plastic discs
Material Specification:	ASTM D4060-25
Condition of Samples:	Production

TEST PROCEDURE:

Test Method:	ASTM D4060-25
Conditioning:	48 hours minimum at 23±2°C, 50±5%RH
Abrasive Wheels:	CS-17
Number of Cycles:	1000
Load:	1000g
Evaluations:	Visual with mass measurements every 500c
Number of Samples:	Three (3)

ACCEPTANCE CRITERIA:

Per ASTM D4060-25

- None stated

RESULTS:

Table 1: Taber Abrasion Results Table

SPECIMEN	[redacted]	WEAR INDEX (mg)	OBSERVATIONS
1	[redacted]	79.5	Gloss decrease, visible wear path
2	[redacted]	59.0	
3	[redacted]	61.3	

Figure 7. The results of the Taber Abrasion test reported by 3rd party.

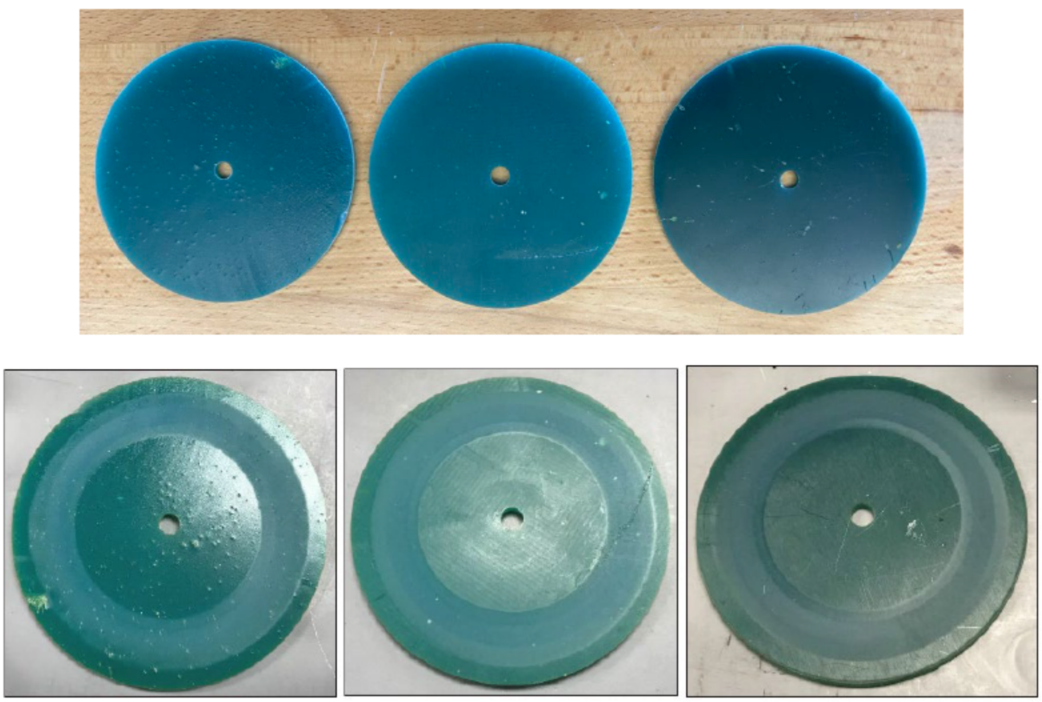


Figure 8. The images of the prepared discs for the abrasion test before (top) and after (bottom).

[Items 10,11,12] [Task 4&5][Material Characterization Parts 34,35,36][ASTM G14 test specimen

preparation, ASTM G14 testing, ASTM G14 test result analyses]

This test method determines the energy required to rupture coatings applied to pipe under specified conditions of impact from a falling weight. This test is important because it will reveal the resin system's ability to withstand impact.

During the Q3 update meeting [redacted] the TAP panel recommended performing this test with modification. Specifically, according to ASTM G14, the test specimen shall be a 16 in. long piece of Schedule 40, 2.375 in. outside diameter coated pipe prepared with its surface preparation and coating procedures equivalent to that of production coated pipe. However, this proposal aims rehabilitation of metallic gas pipes from inside the pipe and the curvature of the pipe is not anticipated to affect the impact performance of the resin, and resin only testing may be more insightful. Thus, a modified G14 test was performed as detailed below.

ASTM G14 test specimen preparation

Multiple panels were produced (>5) with 0.25" thickness that represents the anticipated coating thickness for the rehabilitation of the metal gas pipes. These panels were produced on a Schedule 40 sand blasted carbon steel sheets of 12" by 3" dimensions. A mold was formed via blue painters' tape around the edges of the steel sheet as can be seen in the figure below. The prepared resin was poured slowly into this mold [redacted] After the cure and cooling, pre-tests and tests were performed as detailed in the in the testing section below.

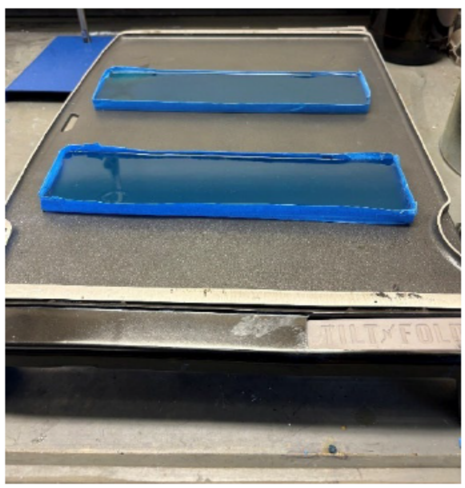


Figure 9. Sample preparation for the ASTM G14 drop test.

ASTM G14 testing

The test was performed at RapiCure Solutions laboratory via Pacific Scientific Gardner Impact Tester. The instrument has 4 lbs cylindrical weight in the tube which has a maximum height of 46". The dropped weight from a predetermined height hits the pin which causes failure or no failure to the specimen tested underneath. The test was performed by following ASTM G14 starting with the preliminary measurements. The purpose of preliminary test is to find the optimum height to drop the weight such that lower height than the optimum height does not cause failure, but higher height causes failure. Then, this height was used to start the test procedure. The adjacent strikes were done with about 3" apart and in a random manner per ASTM G14.

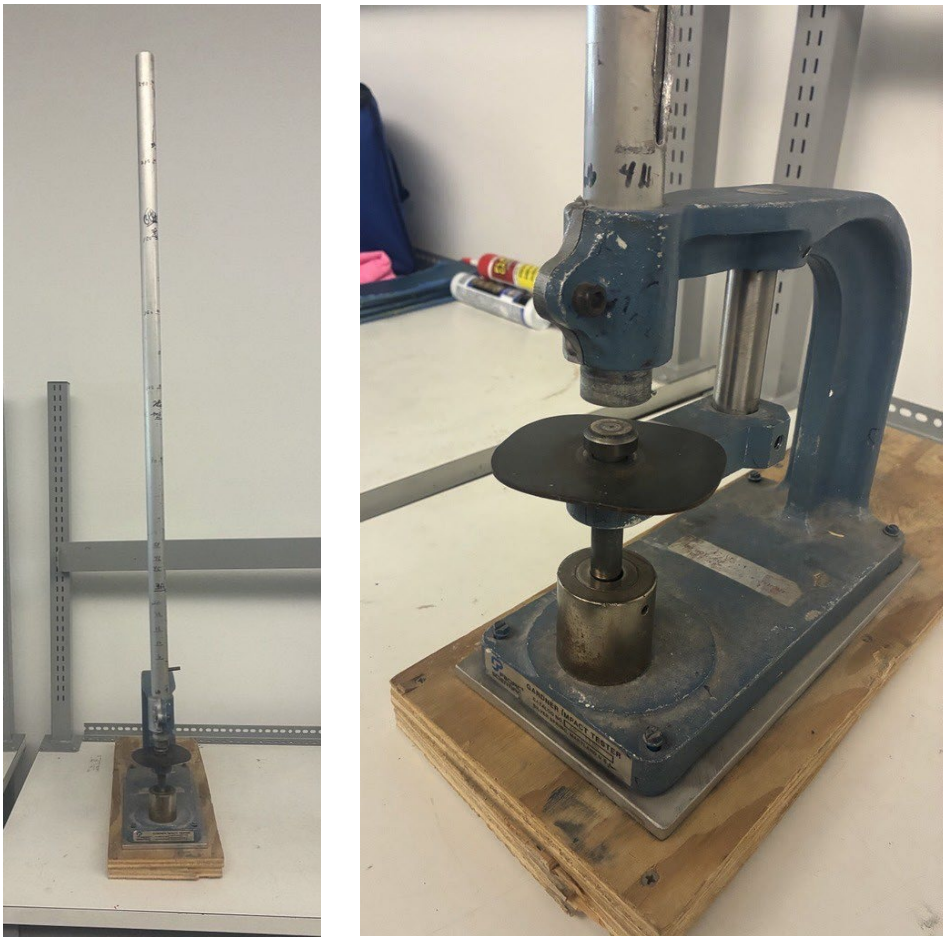


Figure 10. Pacific Scientific Gardner Impact Tester used for drop tests in RapiCure Solutions laboratory.

Per recommendation from the TAP members, the preliminary tests were performed for three different scenarios: (i) resin only, (ii) resin with steel plate back, and (iii) steel plate with resin back. All preliminary tests were started by dropping the weight (4 lbs) in the tube from the maximum height of 46”. As can be seen from the images below, when the strike was on the steel plate with the resin back, no failure was observed. Similarly, when the strike was on the resin with the steel plate back, no failure was observed though the pin created a small indent on the strike side. No damage/failure was observed on the other side of the resin or on the steel back. These results concluded the preliminary testing for these scenarios, and one cannot move to the test procedure as no failure was observed after striking from the maximum height of the instrument. The applied force for this test was calculated to be 5.33 Newton meaning, it requires more than 5.33 Newton force to cause a failure when the impact was on the resin with steel back or vice versa.

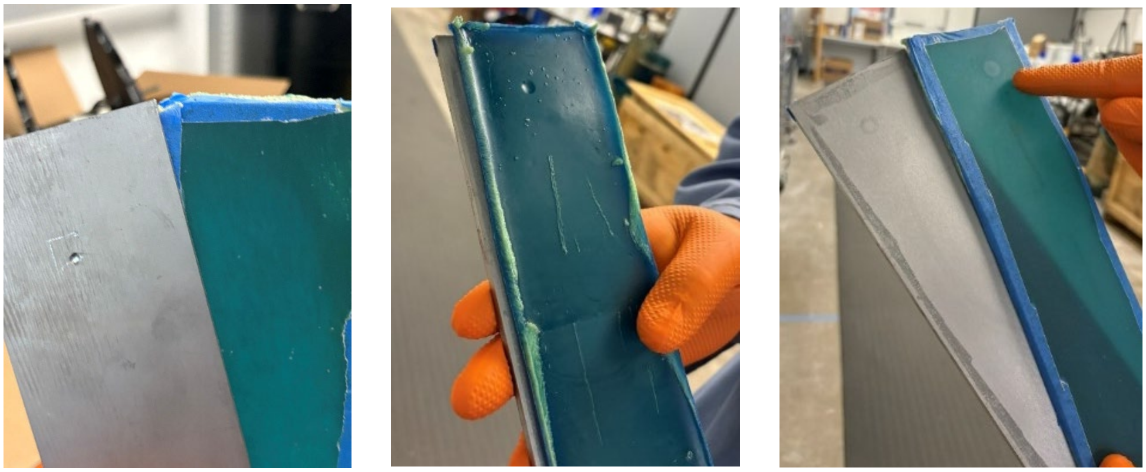
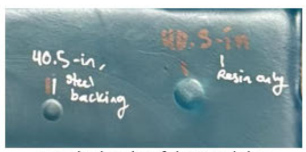


Figure 11. Preliminary test results when the strike was performed on the steel plate with resin back (left) and on the resin with steel plate back (center). The strike on the resin with steel back created a small indent after the impact but there was no damage at the back of the resin or on the steel plate (right).

PHMSA Deliverable 4&5 – ASTM G14 Falling Weight Test

G14 Impact Strength Velocity 46-in drop (1.1684 m)	
Test	**Seconds**
1	0.66
2	0.71
3	0.71
4	0.63
5	0.56
6	0.55
7	0.60



Per the height of drop and the estimated mass of 4 lbs of weight travelling, we can assume that the force experienced by these two results was approximately 5.33 N

$$velocity = \frac{distance}{time}$$

$$1.85\frac{m}{s} = \frac{1.1684\ m}{0.63\ s}$$

$$Force(N) = mass\ (kg) \times acceleration\ (\frac{m}{s^2})$$

$$Acceleration = \frac{\Delta Velocity}{\Delta Time}$$

$$Force\ (N) = 1.8144\ kg \times (\frac{\frac{1.85m}{s}}{0.63\ s})$$

$$where\ mass = 4\ lbs = 1.8144\ kg$$

$$where\ the\ distance\ travelled = 46in = 1.1684\ m$$

$$Force = 5.328\ N$$

Figure 12. The calculation of the applied force from the maximum height (46”) with 4 lbs of weight.

When the preliminary test was performed on the *resin only* specimen (12” by 3” with 0.25” thickness) starting with 46” drop, a failure/damage was observed at the back of the resin while creating an indent at the strike zone though no rupture was observed. The preliminary test was continued as prescribed in the ASTM G14 document and it was determined that the optimum/approximate height should be 14” for the test procedure. The test procedure was performed on a new, unused resin plates where the strike was started from 14” followed by 0.25” increments up or down (that is, no failure means increase the height 0.25” for the next strike; failure means decrease the height 0.25” for the next strike). The results of the 20 strikes are tabulated on the table below. All strikes cause an indent on the strike zone, and a failure was recorded when at least a hairline crack was observed at the back of the resin, otherwise no failure was recorded. According to these measurements, the mean value of impact strength was calculated as 6.58 Joules or 58.25 in/lb (4.875 ft/lb).

Figure 13. The preliminary test was performed with the resin only specimen. Strike from 46” and 36” cause failure/damage at the back of the resin.

Figure 14. The back side of the testing with the resin only specimen.

Table 3. The results of the 20 successive impact readings.

Test #	Height of Drop (inches)	Fail? (Y or N)
1	14.00	Y
2	13.75	N
3	14.00	N
4	14.25	N
5	14.50	Y
6	14.25	Y
7	14.00	N

8	14.25	N
9	14.50	Y
10	14.25	N
11	14.50	N
12	14.75	N
13	15.00	Y
14	14.75	N
15	15.00	N
16	15.25	Y
17	15.00	Y
18	14.75	N
19	15.00	Y
20	14.75	N

$$m = [14 + 0.25(\frac{22}{8} - \frac{1}{2})] * 4$$
$$m = 58.25\, in/lb \; --> \; 6.58\, Joules$$

Figure 15. The calculation of the mean value of impact strength according to the ASTM G14.

ASTM G14 test result analyses

Three different scenarios were tested for ASTM G14 yielding *no failure* when RapiCure Solutions' resin is backed by a steel plate (Schedule 40) or the steel plate is backed by RapiCure Solutions' resin. The calculated applied force is 5.33 Newton meaning, it takes more force than this value to create a failure for those scenarios. With 3X the fracture toughness of standard epoxy resins, and available chemistry to dissipate impact forces, it is not surprising that when the impact/strike is on the resin with steel plate backing or on the steel plate with resin backing no failure was observed. *This is also a great result for this technology* indicating that as a coating this resin system will have excellent impact perfrmance.

When *only* RapiCure Solutions' resin is tested, the mean value of impact strength was calculated as 6.58 Joules or 58.25 in*lbf for a panel with thickness of 0.25" (6.35 mm). This last scenario imitates a structural failure of the pipe that was rehabilitated by RapiCure Solutions' resin previously. That is, if the coated pipe had a catastrophic failure exposing the resin, more than or equal to 6.58 Joules or 58.25 in*lbf energy required to cause a failure.

Nearly all literature results found reported a modified test, thus, it is difficult to truly compare to another material without performing this test in-house against another material standard. RapiCure may procure other commercial products for in-house evaluation. According to our literature search, we haven't been able to find a value/threshold for ASTM G14 test for inside pipe coating materials. However, 2004 Northern Area Western Conference report claims the mean value of impact strength should be greater than 1.5 Joules. Note that this value was reported for *outside* pipe coating and un-modified ASTM G14. Nevertheless, the search for technical data sheets of the legacy resins showed values ranging from 4 Joules to 18 Joules where most of them “modified” ASTM G14 tests and the modification was not necessarily disclosed. For example, 3M Scotchkote Fusion-bonded thermoset epoxy coating reports modified ASTM G14 results for 3.2 mm thick plate as 18.1 Joules and 9.5 mm thick plate as 6.7 Joules. ErgonArmor Novocoat SC2200 rapid set pipe coating reports ASTM G14 result as 8-9 Joules. Rocor Flint-Coat epoxy resin reinforced with flint aggregate wrap coating reports 4.1 Joules and Denso Protal 7200 High Build Pipeline Coating reports 8 Joules.

RapiCure Solutions’ resin formulation yields comparable mean value of impact strength for resin only ASTM G14 tests and shows no failure when backed with steel (or vice versa) within our testing capabilities, further strengthens our claim that the material is an excellent choice for CIPP applications to rehabilitate metal gas pipelines. Additional material testing may be warranted to understand the comparable performance of alternative products in the market.

Overall ASTM Results

The team finished the remaining ASTM tests from Q3 in this quarter per ASTM F2207-06 and ASME PCC-2-2022 Article 403 recommendations. The overall results are provided in the table below for the ASTM tests that we have been able to find comparable and/or typically required threshold values. All things considered, the resin formulation developed and tested for spray applications at RapiCure Solutions’ laboratories to rehabilitate gas pipelines showed very good performance and to be very well suitable for CIPP applications. Additional testing may be added later such as ASTM G57-20 for pipeline corrosion resistance or slurry abrasion resistance testing.

Table 4. Complete results of the ASTM tests performed for RapiCure Solutions’ resin formulation and comparison to the literature where a required minimum/maximum value is reported and/or comparable legacy resin results are reported via technical datasheets. For detailed information, please see the main text herein or Q3 report.

ASTM	***RapiCure Solutions' resin***	***Remarks***
D790 Flexural Properties	67.9 MPa	>30 MPa is required
D638 Tensile Properties	46.1 MPa	>20 MPa is required
D2990 Creep Properties	>98% strength retention 50-year for all temperatures tested: 25, 50 and 70 °C under 2, 3, and 4 N force	≥50% expected to retain
D696 Coefficient of Linear Thermal Expansion	7.9E-05 /°C to 8.0E-05 /°C	<10E-05 /°C is needed for CIPP applications
D4060 Abrasion Resistance	66.6 mg loss (CS-17 standard)	≥100 mg loss is reported for legacy pipe coating resins
G14 Impact Resistance	6.58 Joules	>1.5 Joules required for *outside* pipe coating

[Item 13] [Task 12][Engineering Design Part 1][Engineering Design Part 1]

[redacted] During the on-site meeting, RapiCure team detailed the resin preparation, curing, and properties thereof; liner preparation procedure and produced liners; used sprayers, their properties, and results of spraying trials with each sprayer. The team also demonstrated resin preparation and curing to give an idea on the preparation and viscosity of the resin as well as the rate of curing after initiation and cured resin properties, such as Shore hardness. [redacted]

[redacted] questions regarding the performance of the resin if more than 1 layer of resin is applied. Meaning, if a layer of resin is applied and cured, and an additional layer is added will this impact the performance of the resin? Secondly, if the resin is applied, the process stops, resin is cured, and then application is continued later; effectively creating a seam between the process each time. Would this process have an impact on the performance of the resin? Thus, RapiCure tested the tensile properties of different seam geometries: vertical and horizontal seam formations. Vertical seam tests the scenario that when the resin application is completed and cured, can we continue to apply and cure resin while forming a seam in between? For this test, standard control tensile test specimens were prepared. The mold for the specimen was divided at the mid-gauge, the mold was filled and cured with the same batch resin. After cooling the cured resin, the divider was removed, and the other half of the mold was filled and cured creating a seam at the mid-gauge. Five specimens were prepared, however, two of them broke at the seam/joint before the measurement. The remaining three specimens were tested yielding 23.5 ± 15.8 MPa whereas the control specimens yielded 37.3 ± 5.4 MPa. Note here also that the tested three specimens broke at the seam/joint. The lower tensile strength of this geometry compared to standard control along with a wide error margin and failure at the seam/joint before the test dictates the seam in this scenario should have some overlap (that is horizontal seam, see below). That is, after the application and curing, the continuation of the resin application should start from the already cured resin, not immediately after. The optimal overlap distance (that is horizontal seam) needs to be tested and planned to perform later.

Horizontal seam scenario covers if multiple layers of resin need to be applied to achieve the desired thickness if initially applied resin thickness is not sufficient to withstand the pressure per Hoop's stress formula. For this purpose, a separate batch of resin was prepared, and standard control tensile test specimens were formed. Then, 1/3 of the mold was filled with resin, cured and cooled. Subsequently, the other 1/3 and then the last 1/3 of the mold was filled with resin, cured and cooled (that is layer-by-layer). The obtained specimens were tested yielding 39.1 ± 4.7 MPa tensile strength. The control specimens showed, again, 37.3 ± 5.4 MPa indicating that the horizontal, layer-by-layer resin curing does not sacrifice the tensile strength. Hence, this test confirms layer-by-layer resin application is feasible.

PHMSA Deliverable 12 – Engineering Design

Objective: Determining if vertical or horizontal resin-coating layering will impact the Hoop Stress (tensile strength). Vetting various modes of SIPP/CIPP/PIG applications.

Method:

- **Control – nominal dog bones**
- **Vertically bonded dog-bones (1-bond at mid. Gauge)**
  - Primary focus on adjacent pipe segment bonding
- **Horizontally bonded 'layered' dog-bones (3-layers of resin)**
  - Primary focus on resin-to-resin layered coating bonds
  - Dog-bone specimens were cooled before adding

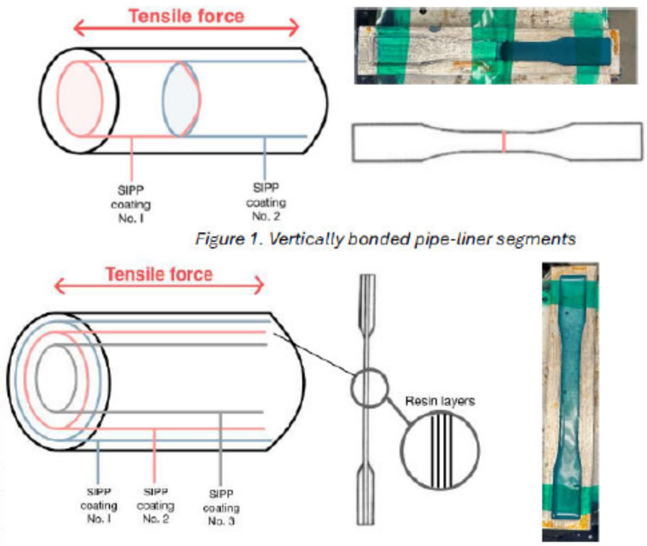


Figure 1. Vertically bonded pipe-liner segments

Figure 2. Horizontally bonded pipe-liner segments

Formulation HV-047A – RCS SIPP Resin

Exp.	Tensile Elong. At Failure (%)	Tensile Strength (MPa)
Control $_{N=5}$	4.8 ± 1.5	37.3 ± 5.4
Vertical $_{N=3}$	2.8 ± 2.0	23.5 ± 15.8*
Horizontal $_{N=5}$	5.8 ± 1.1	39.1 ± 4.7

*Two specimens break at the joint before measurement and the remaining three failed at the joint

RapiCure Solutions EK

Figure 16. The results of the different seam geometries tensile properties.

[redacted] i) the completion of design specifications after the second meeting, (ii) identifying existing technology that can be utilized, and (iii) identify system critical challenges. Several meetings are tentatively planned to move forward.

[Item 14] [Task 10][Suggest Improvements][Suggest Improvements]

Several critical developments were achieved in this quarter. The group established methodologies for ASTM testing where the team utilized the DMA instrument verified by third party laboratories. [redacted] nitial trials with pig pulling in RapiCure Solutions' laboratories showed further viscosity increase or layer-by-layer coating will be necessary for pig application. Studies are underway to adjust viscosity and evaluate layer-by-layer approaches without any compromise in the curing and mechanical properties of the resin.

[Item 15] [Task 14][4th Quarterly Report][4th Quarterly Report]

Careful discussion and considerations were made with milestone modifications, and reporting in Q4. All monthly reports were completed and emailed/updated. This 4th Quarterly Status report details the progress of the project and related tasks.

[Item 16] [Task 13][Team Meetings]

Various team meets were held this quarter with many TAP members, either virtual or in-person. These meetings led to additional improvements, testing, and commercialization-related outcomes. Additional outreach was performed with potential customers and experienced operators. A [redacted] pipe has been identified for trials before the end of the year. A [redacted] provider in the area has agreed to perform the trials and the project team is continuing to make every effort to commercialize the solution. To this end several key members and advisors on the team have attended related conferences and meetings. [redacted] additional SIPP/CIPP commercial entities are interested in supporting in-field trials in the coming months. The company also applied to speak out these results at next year's AGA meeting in Tampa. A white paper is in the works to discuss the results of this project along with general SIPP/CIPP technologies as a direct result of the research outcomes from this work.

5: Project Schedule –

The project is on time regarding testing and slightly delayed with respect to the in-field testing goals by month 12. These tests are planned in the coming quarter.

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