Quarterly Report – Public Page

Date of Report: *3rd Quarterly Report-June 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: *June 30th, 2025*

1: Items Completed During this Quarterly Period:

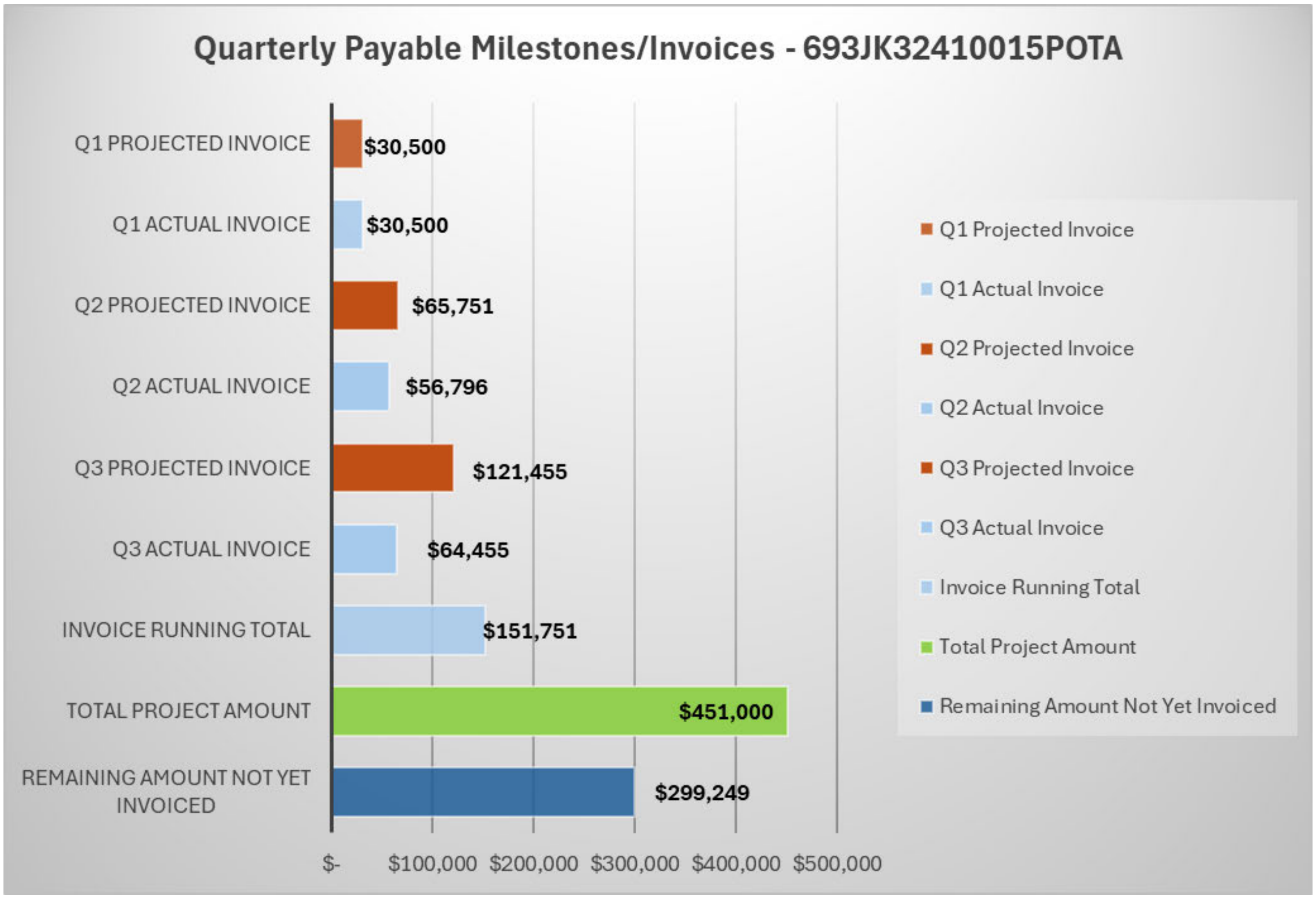
Item #	Task #	Activity/Deliverable	Title	Federal Cost	Cost Share
1	6	Deliverable Resin coating spray applicator. Part 4	Spray Coating (Personnel, Materials, 1-5 liners, consumables)	[redacted]	[redacted]
2	4&5	Material Characterization Part 1	Testing various resins for ASTM D790	[redacted]	[redacted]
3	4&5	Material Characterization Part 2	ASTM D790 test specimen preparation	[redacted]	[redacted]
4	4&5	Material Characterization Part 3	ASTM D790 testing	[redacted]	[redacted]
5	4&5	Material Characterization Part 4	ASTM D790 test result analyses		
6	4&5	Material Characterization Part 5	Testing various resins for ASTM D638	[redacted]	[redacted]
7	4&5	Material Characterization Part 6	ASTM D638 test specimen preparation	[redacted]	[redacted]
8	4&5	Material Characterization Part 7	ASTM D638 testing	[redacted]	[redacted]
9	4&5	Material Characterization Part 8	ASTM D638 test result analyses		
10	4&5	Material Characterization Part 9	Testing various resins for ASTM D2990	[redacted]	[redacted]
11	4&5	Material Characterization Part 10	ASTM D2990 test specimen preparation	[redacted]	[redacted]
12	4&5	Material Characterization Part 11	ASTM D2990 testing	[redacted]	[redacted]

13	4&5	Material Characterization Part 12	ASTM D2990 test result analyses	[redacted]	[redacted]
14	4&5	Material Characterization Part 13	Testing various resins for ASTM D696	[redacted]	[redacted]
15	4&5	Material Characterization Part 14	ASTM D696 test specimen preparation	[redacted]	[redacted]
16	4&5	Material Characterization Part 15	ASTM D696 testing	[redacted]	[redacted]
17	4&5	Material Characterization Part 17	Testing various resins for ASTM D5868	[redacted]	[redacted]
18	4&5	Material Characterization Part 21	Testing various resins for ASTM D3165	[redacted]	[redacted]
19	4&5	Material Characterization Part 22	ASTM D3165 test specimen preparation	[redacted]	[redacted]
20	4&5	Material Characterization Part 23	ASTM D3165 testing	[redacted]	[redacted]
21	4&5	Material Characterization Part 24	ASTM D3165 test result analyses	[redacted]	[redacted]
22	4&5	Material Characterization Part 25	Testing various resins for ASTM D903	[redacted]	[redacted]
23	4&5	Material Characterization Part 29	Testing various resins for ASTM D4060	[redacted]	[redacted]
24	4&5	Material Characterization Part 30	ASTM D4060 test specimen preparation	[redacted]	[redacted]
25	4&5	Material Characterization Part 33	Testing various resins for ASTM G14	[redacted]	[redacted]
26	13	Team meetings	Team meetings	[redacted]	[redacted]
27	10	Suggest Improvements	Suggest Improvements	[redacted]	[redacted]
28	14	3rd Quarterly Status Report	3rd Quarterly Status Report	[redacted]	[redacted]

2: Items Not-Completed During this Quarterly Period:

Item #	Task #	Activity/Deliverable	Title	Federal Cost	Cost Share
1	3	Engineering Design Part 2	Engineering Design Part 2	[redacted]	[redacted]
2	3	Develop Coating Part 4	Develop Coating Part 2 – 6' liners	[redacted]	[redacted]
3	3	Develop Coating Part 5	Develop Coating Part 2 – 6' liners	[redacted]	[redacted]
4	3	Develop Coating Part 6	Develop Coating Part 2 – optimized liner	[redacted]	[redacted]
5	4&5	Material Characterization Part 16	ASTM D696 test result analyses	[redacted]	[redacted]
6	4&5	Material Characterization Part 18	ASTM D5868 test specimen preparation	[redacted]	[redacted]
7	4&5	Material Characterization Part 19	ASTM D5868 testing	[redacted]	[redacted]
8	4&5	Material Characterization Part 20	ASTM D5868 test result analyses	[redacted]	[redacted]
9	4&5	Material Characterization Part 26	ASTM D903 test specimen preparation	[redacted]	[redacted]
10	4&5	Material Characterization Part 27	ASTM D903 testing	[redacted]	[redacted]
11	4&5	Material Characterization Part 28	ASTM D903 test result analyses	[redacted]	[redacted]
12	4&5	Material Characterization Part 31	ASTM D4060 testing	[redacted]	[redacted]
13	4&5	Material Characterization Part 32	ASTM D4060 test result analyses	[redacted]	[redacted]
14	4&5	Material Characterization Part 34	ASTM G14 test specimen preparation	[redacted]	[redacted]
15	4&5	Material Characterization Part 35	ASTM G14 testing	[redacted]	[redacted]
16	4&5	Material Characterization Part 36	ASTM G14 test result analyses		
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 and 2, 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 [redacted]. In addition, a sprayable coating was developed while addressing several key challenges and questions, respectively. Both processes required iterative tuning of the resin system and system optimization for RapiCure Solutions' frontally polymerizing resin products, cured only by heating at one end or spot of the coating. 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.

Towards project deliverables 4 & 5, and activities 4 & 5, this quarter focused primarily on material analysis and mechanical performance testing to meet ASTM F2207-06 and PCC-2-2022 Article 403 recommendations. Reported herein are the results of the several ASTM tests outlined in ASME-PCC-2 document section entitled "Article 403 Nonmetallic Internal Lining for Pipe: Sprayed Form for Buried Pipe." Specifically, Article 403 "…concerns the use of thermoset polymers as protective or structural lining for buried pipe in sprayed form." Section 403-3.5 Material Property Determination lists the ASTMs (or compatible ISO where available) in two formats: *shall be determined* and *may be determined*. The team proposed to perform all listed ASTMs in Section 403-3.5 for RapiCure Solutions' resin system to be used for pipeline coating. Towards this end, the team held two separate meetings with the TAP members to consult on specifically the "may be determined" ASTM tests, and TAP members concurred the "shall be determined" ASTMs should be performed and prioritized. ASTM D3983 was replaced with ASTM D5868, which is more straightforward while providing the same information. Note here also that Attachment 3 of the proposal inadvertently listed ASTM D1465 instead of ASTM D3165, which is originally listed in ASME-PCC-2 document and corrected here, Table 1.

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

ASTM	Title
D790	Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D638	Tensile Properties of Plastics
D2990	Tensile, Compressive and Flexural Creep and Creep-Rupture of Plastics
D696	Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C with a Vitreous Silica Dilatometer
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)*
D3165	Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies
D903	Peel or Stripping Strength of Adhesive Bonds
D4060	Abrasion Resistance of Pipeline Coatings by the Taber Abraser
G14**	Modified** Impact Resistance of Pipeline Coatings

[Item 1] [Task 6][Deliverable Resin coating spray applicator. Part 4] [Spray Coating (Personnel, Materials, 1-5 liners, consumables]

It was reported in 2nd Quarterly report that "…the team would like to simply delay/move this deliverable to later in the project plans, pushing 'resin coating via spray applicator-Part 4'" for an upcoming quarter, Quarter 3 or 4 or possibly later." The team has been able to finish several critical and important derisking experiments enroute to commercialization of the RapiCure Solutions' resin system for pipeline coating. These experiments were important to further optimize the resin formulation to use with an applicator, such as a spraying tool that may be custom designed by our engineering partner. A few key spray trials were performed to verify that the modified resin system will be optimal for subsequent trials. Thus, minimal and also key experiments were performed to fulfill deliverable Part 4 spray coating. Additional liner development initially planned for this quarter are still suspended for a later date, possibly after pigging trials (Q4/Q5 2025). Additional resin coating via spray applicator efforts were supported this quarter including industry outreach, material review and project planning. [redacted]

During panel manufacturing for this quarter, RapiCure Solutions observed that the resin formulation used for spraying and reported in Quarter 2 was exhibiting defect sites, which was compromising the mechanical performance of the panels. To prevent any unwanted large-scale defects anticipated during in-field processing, the team modified the system following nearly 15 iterative tuning tests of the formulation. Note that the new tested system did not impact the spraying performance of the resin; the main components remain the same. The formulation that will be used moving forward yielded comparable mechanical and chemical properties compared to the previous one used and there are no longer defects in the resin panels from this additve, Table 2.

Table 2. Comparison of the sprayable resin formulation used in Q2 and the revisited formulation [redacted]

Formulation	[redacted]	[redacted]	[redacted]	Shore D Hardness	Tensile Strength (MPa)	Elongation at Break (%)	[redacted]	[redacted]
Q2 Formulation	[redacted]	[redacted]	[redacted]	85	32 ± 2	5.0 ± 0.5	[redacted]	[redacted]
Q3 Formulation	[redacted]	[redacted]	[redacted]	84	40 ± 2	6.2 ± 0.5	[redacted]	[redacted]

Several efforts were made to move the project towards commercial scaling and integration. Long-term stability and storage studies were also initiated in packaging which is necessary for subsequent in-field trials. Additionally, several in-person meetings were held with TAP member that resulted in sharing key industrially relevant insights and recommendations regarding the needs and boundaries for long-term stability studies of the resin system being used herein.

[redacted] early 20 iterations were evaluated, and the resin system optimized for subsequent pigging and lining trials. The modified formulation was used to spray liners inside a 12-inch diameter steel pipe that had been sand-blasted to create some industry relevant surface roughness (as detailed in the 2nd Quarterly report). Figure 1 shows the frontally-cured liner [redacted].

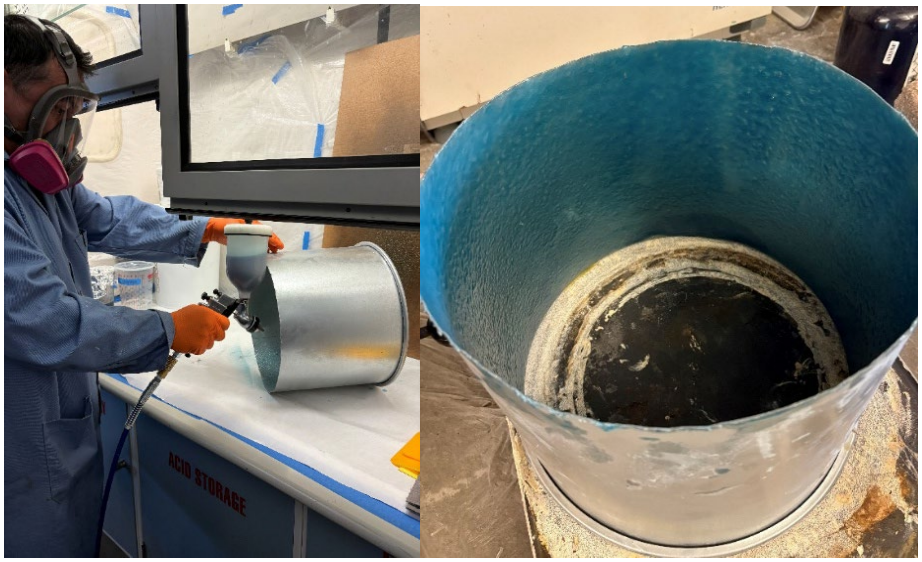


Figure 1. Spraying of the RapiCure Solutions' resin after the improvements (Left) and the cured resin in 12-inch steel pipe (Right).

Industry outreach continued this quarter.

RapiCure Solutions

Business Development

- American Gas Association, Denver – gathering of natural gas utility and transmission company operations management from across North America and the world
- American Water Works Association - ACE, Denver the essential gathering for the water community, featuring keynote speakers, continuing education, exhibitors, and competitions.
- OTC, Houston – connected with companies – for pipeline coatings

6/8-11 - 350 exhibitors and 1,000 booths featuring leading water technology providers and cutting-edge innovations

AGA
American Gas Association

5/4-8 - 250 domestic/international venders occupying 50,000+ square feet of Exhibit Space, including large islands

6/8 - 14 international pavilions and almost 1,300 exhibitors across 257,350+ sq ft

Panel Preparations for ASTM Studies

During this quarter, specimen preparation for significant ASTM testing of the resin system to be used was performed. Figure 2 shows the panel manufacturing process used in-house. After curing, the panel is removed from the mold and inspected. Some method development was performed to reduce unwanted air bubbles, Figure 3. Resin was ultimately slowly poured after degassing at ~25 psi for about

3 minutes, Figure 3. A total of 45 panels were manufactured during these iterations and 8 high quality panels were picked to cut into ASTM specific specimens/coupons via waterjet cutting, Figure 4.

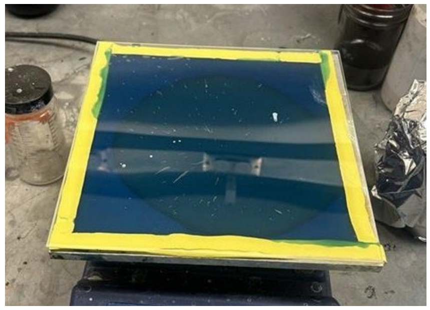


Figure 2. Panel manufacturing prior to cutting. The resin curing started from the center of the panel and moved outwards to the edges via frontal polymerization.

Figure 3. Initial injection mold panels showed air bubbles (Left). Air-free panels (Right).

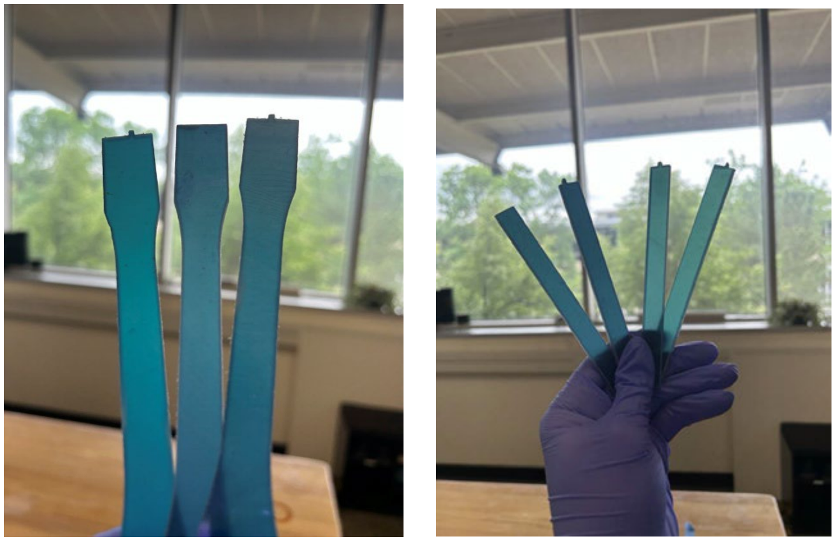


Figure 4. The coupons/specimens were cut from the panels via waterjet cutting.

[Items 2,3,4,5] [Task 4&5][Material Characterization Parts 1,2,3,4][Testing various resins for ASTM D790, ASTM D790 test specimen preparation, ASTM D790 testing, ASTM D790 test result analyses]

Figure 5. Universal testing machine (UTM) with the attached fixture to measure flexural properties of the specimens.

Testing various resins for ASTM D790 Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials is used to measure the flexural properties of unreinforced/reinforced plastics and electrical insulating materials via a three-point loading system to apply a load to a simply supported specimen/coupon. Flexural modulus is a measure of the initial stiffness of a material in bending and flexural strength describes the ultimate stress that the material can support in bending. The Universal testing machine was utilized in 3-point bend with the fixture attached for ASTM D790 measurements, Figure 5. Various resin formulations were screened to possibly yield the highest flexural strength, >30 MPa usually required in the industry. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after performing hundreds of prior resin curing optimizations.

ASTM D790 test specimen preparation. As detailed in the Panel Preparations for the ASTM Studies section above, after several iterative trials (10+ iterative trials), multiple panels were produced via modified injection molding method. Then, these panels were cut into ASTM D790 specific dimensions coupons/specimens for measurement via waterjet cutting, Figure 6. The preferred specimen dimensions were "molding materials" per ASTM as it includes thermoplastics and thermosets (RapiCure Solutions' resin is a thermoset resin). That is, 12.7 mm (0.5 in.) wide, 3.2 mm (0.125 in.) thick, and 127 mm (5.0 in.) long.

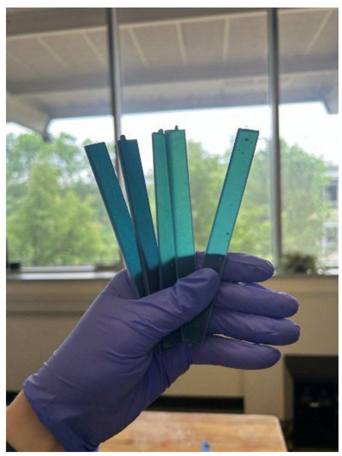


Figure 6. The water jet cut coupon/specimen from the prepared panel for ASTM D790 measurement.

ASTM D790 testing. The test was performed at RapiCure Solutions laboratory, Figure 7. The specimen was placed on the fixture, centered on the support with the long axis of the specimen is perpendicular to the loading nose and supports. The load is applied to the specimen and the measurement raw data was recorded by the software and reported. A total of seven specimens were tested, and the results are analyzed in the following section.

Figure 7. UTM with the attached fixture to measure flexural properties of the specimen. The waterjet cut specimen is centered on the support.

ASTM D790 test result analyses. ASME PCC-2 document does not provide any threshold/minimum value requirement for the flexural strength. The literature search on Cured-in-Place-Pipe (CIPP) resin material/liner specifications indicates that a minimum value for flexural strength is typically 4500 psi (about 31 MPa) for unreinforced resin.[1,2,3,4,5,6] RapiCure Solutions' resin formulation surpasses and more than doubles the minimum flexural strength value [redacted]. No rupture failures were experienced upon testing (up to 5% fixture limit), signifying that this material will keep its resilience and strength presumably more than 5% strain. Overall, ASTM D790 results build confidence that the current formulation would be ideal for CIPP applications.

Table 3. Flexural strength results per ASTM D790-17, including the rate of crosshead motion, flexural strain at yield, and the modulus.

Specimen No.	[redacted]	[redacted]	[redacted]	[redacted]	Method of Failure	Tangent [redacted]
1	[redacted]	[redacted]	[redacted]	[redacted]	Yield	[redacted]9
2	[redacted]	[redacted]	[redacted]	[redacted]	Yield	[redacted]
3	[redacted]	[redacted]	[redacted]	[redacted]	Yield	[redacted]
4	[redacted]	[redacted]	[redacted]	[redacted]	Yield	[redacted]
5	[redacted]	[redacted]	[redacted]	[redacted]	Yield	0[redacted]
6	[redacted]	[redacted]	[redacted]	[redacted]	Yield	0[redacted]
7	[redacted]	[redacted]	[redacted]	[redacted]	Yield	0[redacted]

Average	[redacted]	[redacted]	N/A	N/A	N/A	[redacted]
Standard Deviation	[redacted]	[redacted]	N/A	N/A	N/A	[redacted]
%CV	[redacted]	[redacted]	N/A	N/A	N/A	[redacted]

[Items 6,7,8,9] [Task 4&5][Material Characterization Parts 5,6,7,8][Testing various resins for ASTM D638, ASTM D638 test specimen preparation, ASTM D638 testing, ASTM D638 test result analyses]

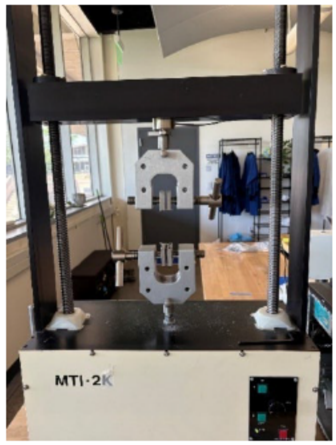


Figure 8. Universal testing machine with fixed and movable grips for holding the specimen.

Testing various resins for ASTM D638 Tensile Properties of Plastics. ASTM D638 is the standard test method for tensile properties of plastics in the form of standard dumbbell-shaped (dog-bone) test specimens. The UTM is utilized with fixed and movable grips for holding the specimen, Figure 8. Various resin formulations were screened that possibly yield the highest tensile properties, >20 MPa usually required in the industry. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

ASTM D638 test specimen preparation. As detailed in the Panel Preparations for the ASTM Studies section above, after several iterative trials (10+ iterative trials), multiple panels were produced via modified injection molding method. Then, these panels were cut into ASTM D638 specific dimensions (Type I) coupons/specimens for measurement via waterjet cutting, Figure 9. That is 13 mm width of narrow section, 57 mm length of narrow section, 19 mm overall width, 165 mm overall length, 50 mm gage length, 115 mm distance between grips, and 76 mm outer radius.

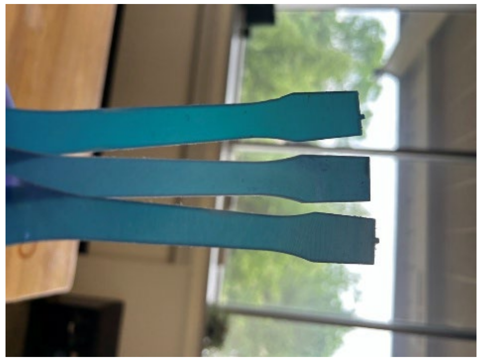


Figure 9. The water jet cut coupon/specimen (aka dog-bone) from the prepared panel for ASTM D638 measurement.

ASTM D638 testing. The test was performed at RapiCure Solutions laboratory. A total of five specimens were tested after measuring the width, length, and thickness of each specimen via a caliper. The specimen was then placed in the grips of the UTM while carefully aligning the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine as detailed in the ASTM document, Figure 10. After setting the rate of crosshead motion in the software of the UTM (0.2 in./min.), the testing started. The software calculates and reports the raw data that was analyzed in the following section.

Figure 10. The close view of the UTM grips with the loaded specimen.

ASTM D638 test result analyses. ASME PCC-2 document does not provide any threshold/minimum value requirement for the tensile strength though it requires >1% for strain to failure. The tensile strength is also critical in the hoop stress equation that dictates required coating thickness requirements. The literature search on CIPP resin material/liner specifications yielded a typical literature minimum range for tensile strength as 3000-3500 psi (21-24 MPa).[6,7,8] However, higher values are favored/desired since the tensile strength directly determines the required thickness of the CIPP resin material per hoop stress equation. That is, the higher the tensile strength the thinner the liner thickness required for the CIPP application. This not only saves the total cost for the material but also does not sacrifice the inside diameter/volume of the pipe section where the liner/repair is applied. Nevertheless, the application of a thin resin via an applicator, such as spraying or pigging, is advantageous since it minimizes resin sagging and does not require multiple runs to achieve the desired coating thickness.

The test results of the five specimens yielded an average tensile strength [redacted] verall, along with ASTM D790 results given above, ASTM D638 results asserts that RapiCure Solutions' resin system is well-aligned regarding tensile properties and performance for CIPP applications.

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[Items 10,11,12,13] [Task 4&5][Material Characterization Parts 9,10,11,12][Testing various resins for ASTM D2990, ASTM D2990 test specimen preparation, ASTM D2990 testing, ASTM D2990 test result analyses]

Testing various resins for ASTM D2990 Tensile, Compressive and Flexural Creep and Creep-Rupture of Plastics. ASTM D2990 measures the creep properties of plastics. Creep is defined as the permanent deformation of a material under sustained stress at a given temperature. Ultimately, creep measures the material's long-term deformation and performance under stress, providing quality control and reliability in plastic applications like the coating and liner application. It's critical to understand creep performance when designing a CIPP liner because the liner should extend the life of a deteriorated pipe by at least 50 years. Thus, various resin formulations were screened that possibly yield the least creep deformation for CIPP applications, usually requiring strength retention of the material for 50 years. This was achieved by maintaining chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

ASTM D2990 test specimen preparation. The chosen resin formulation was used to prepare small pucks cut via a diamond blade saw to the specifications of the Dynamic Mechanical Analyzer (DMA) sample holder (model number Perkin Elmer DMA 800), Figure 11. That is, 3.5 mm width, 1.0 mm thickness and 10 mm long.

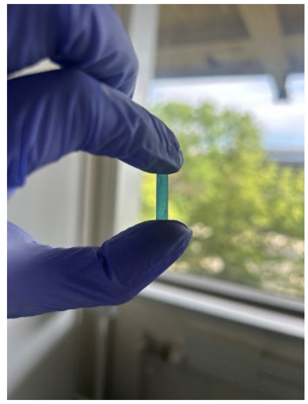


Figure 11. The prepared specimen for the measurement. The dimensions are 3.5 mm width, 1.0 mm thickness with 10 mm in length.

ASTM D2990 testing. The test was performed at RapiCure Solutions' laboratory via Perkin Elmer DMA 800. Figure 12 shows the sample holder of the instrument where the sample in Figure 11 was mounted. The test was performed at three different temperatures which were chosen to be close to the operational temperature per ASTM to imitate the operating conditions; 25, 50, and 70 °C. A total of 24 cycles of stress were run per test where each cycle consists of 5 minutes of stress followed by 20 minutes of recovery with 9 runs total for the creep analysis. That is, for each temperature, 3 different stress levels were selected to reflect specimen dimensions, thus three stress levels at 2, 3, and 4 Newtons were used for evaluation. The DMA instrument provides raw data which was analyzed in the following section.

Figure 12. Perkin Elmer DMA 800 instrument (Left). The prepared sample shown above was loaded with a DMA instrument for testing (Right).

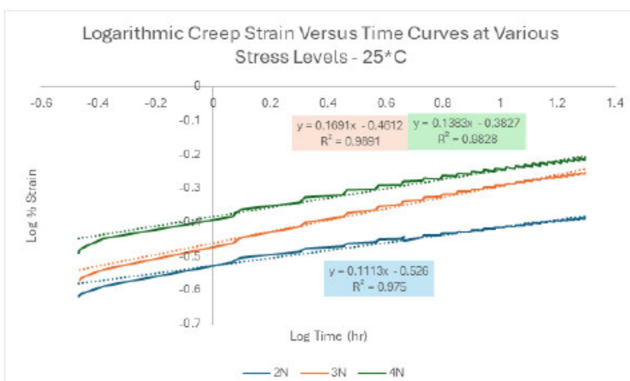
ASTM D2990 test result analyses. Materials utilized in infrastructure repairs are prone to impending loads and stress, thus it is critical to evaluate a material's ability under such conditions to avoid catastrophic failure while under load. CIPP applications usually require strength retention of the material for 50 years and typically around 50% of the initial flexural modulus.[9,10,11] Note here that the reported creep data is extrapolated to get 50-year initial strength retention value.

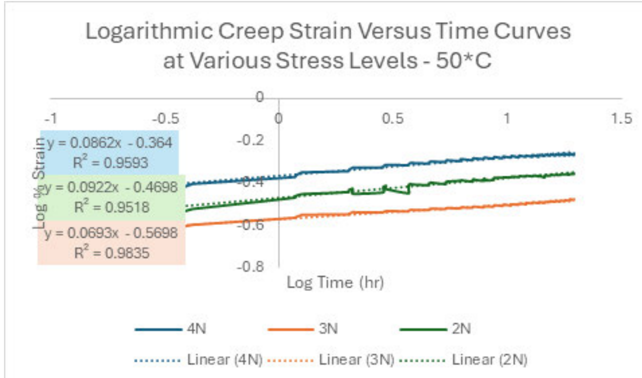
Samples were evaluated as the total % creep strain experienced in the run, providing an estimate of the creep-rate experienced. Table 5 tabulates the overall creep strain % for each test run, with the 4 N at 25 °C test run demonstrating the largest strain experienced at 0.618%. Additional testing may be performed to better understand aging performance.

Table 5. Overall % Creep Strain experienced for each test-run, accomplished over 20-hours per each test. % Strain derived from nominal strain corrected for specimen dimensions, converted into percentage.

[redacted]		[redacted]	
	[redacted]		[redacted]
[redacted]			
[redacted]			
[redacted]			

Figure 13 shows the logarithmic creep strain plotted over time curves for various stress levels evaluated at 25, 50, and 70 °C at different loading levels, 2, 3, and 4 Newtons. Besseling and coworkers[12] characterized and proposed a model (Burgers model) for creep and recovery (that is negative creep) for a thermoset resin nanocomposite. In another example, Falcone and coworkers[13] investigated short-term creep behavior of a thermoset polymer where they observed a negative creep on the unloading and proposed a model to explain such observation. All things considered, the material showed an overall expected low creep percentage for a thermoset resin and as such is anticipated to perform well as a pipeline coating.





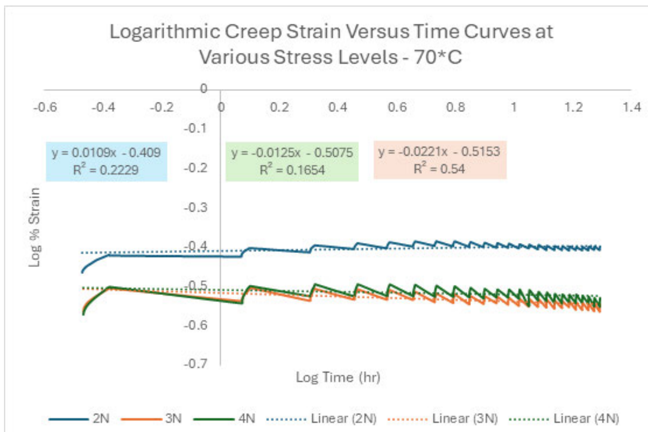


Figure 13. Logarithmic creep strain plotted over time curves for various stress levels evaluated at 25, 50, and 70 °C at different loading levels, 2, 3, and 4 Newtons.

Figure 14 shows % creep strain plotted over time curves for various stress levels evaluated at 25, 50, and 70 °C at different loading levels, 2, 3, and 4 Newtons. The fits are used to calculate extrapolated 50-year strength retention.[2] That is how much strain is anticipated under the given conditions; 25, 50, and 70 °C at different loading levels, 2, 3, and 4 Newtons. The results showed that <2% strain is anticipated at all temperatures and loads tested, meaning, >98% of the initial strength is expected to be retained after 50 years, Table 6, further confirming the durability of the RapiCure Solutions' resin formulation. Moreover, <2% extrapolated strain for 50 years is still less than flexural strain at yield reported above via ASTM D790, >5%. This means no catastrophic failure is anticipated for 50 years or more (under these conditions) building further confidence that this coating system would be ideal for CIPP applications.

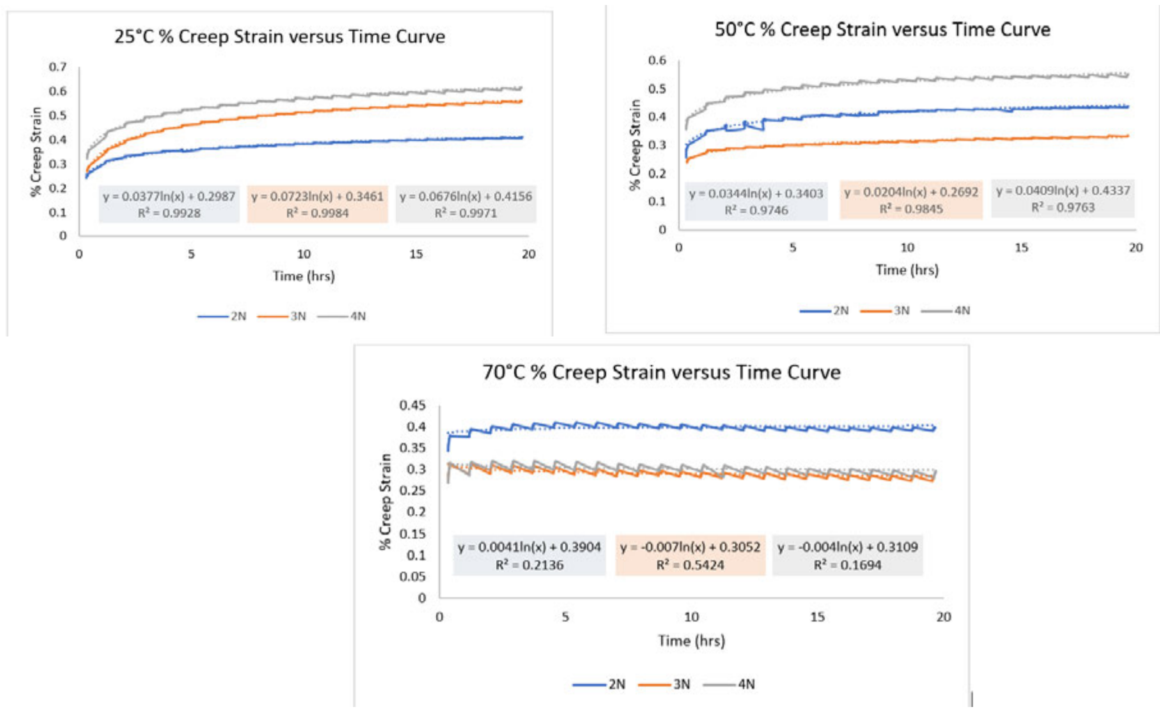


Figure 14. Percent creep strain plots with time and the natural logarithmic fits used to calculate 50-year strength retention for each condition tested herein: 3, 4, and 4 Newtons load at each temperature, 25, 50, and 70 °C.

Table 6. 50-year extrapolated % creep strains calculated from the natural logarithm fit of the % creep strain data with time.

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[Items 14,15,16] [Task 4&5][Material Characterization Parts 13,14,15][Testing various resins for ASTM D696, ASTM D696 test specimen preparation, ASTM D696 testing]

Testing various resins for ASTM D696. ASTM D696 Coefficient of Linear Thermal Expansion 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. Depending on the application, the desired/required values vary. For example, the City of Rifle in Colorado requires the coefficient of thermal expansion to be 0.000003 in./in. °F for expanded-in-place pipe liner (EIPP) for PVC when used for the rehabilitation of sewer pipelines.[14] This test is critical because this property can be used to design materials and structures that can withstand thermal stress and prevent failures. Various resin formulations were screened that possibly yield low expansion properties in the given temperature range. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

ASTM D696 test specimen preparation. The chosen resin formulation was used to prepare the specimen so that the dimensions match the cylindrical quartz standard sample (reference material), Figure 15. A simple in-house mold was manufactured at RapiCure and the resin cast. The specimen obtained was cut via diamond saw to be 10 mm in length and 6.3 mm in diameter.

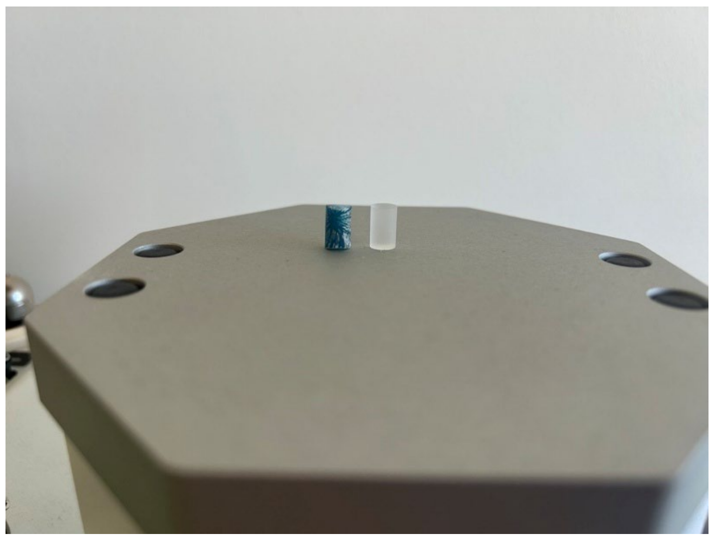

Figure 15. The prepared specimen on the left and the quartz standard sample on the right.

ASTM D696 testing. The coefficient of linear thermal expansion (CTE) was tested at the RapiCure Solutions laboratory with a Perkin Elmer Dynamic Mechanical Analyzer (DMA) 8000. While a silica dilatometer is can be used for testing CTE, the DMA offers a streamlined approach with low error, due to the frequency of data collection and consistent processing of the sample dimensions, thus offering accurate modeling and ease of use for calculating the CTE. Data was collected utilizing the tension fixture in compression mode for sample processing, with a temperature range of 25 to 50 °C ramping at 1°C/min. A slightly negative static force was applied for stabilizing the sample within the fixture, which has no impact on data collection. For the standard reference material, a quartz standard was tested alongside the sample material via a baseline subtraction, provided a slope which could then be used in calculating the CTE.

[Item 17] [Task 4&5][Material Characterization Parts 17][Testing various resins for ASTM D5868]

Testing various resins for ASTM D5868.

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 may still be considered and run later. Instead, ASTM D5868 was determined to be more relevant 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. Various resin formulations were screened that possibly yield high lap shear adhesion properties. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined by us after hundreds of prior resin curing optimization and after prior adhesion studies.

[Items 18,19,20,21] [Task 4&5][Material Characterization Parts 21,22,23,24][Testing various resins for ASTM D3165, ASTM D3165 test specimen preparation, ASTM D3165 testing, ASTM D3165 test result analyses]

ASTM D3165 Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies determines the comparative shear strength in large area joints when tested on a single-lap-joint specimen and under specified conditions of preparation and testing. 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.

Testing various resins for ASTM D3165. Various resin formulations were screened to possibly yield high adhesive properties in shear. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

ASTM D3165 test specimen preparation. Test specimens were prepared according to the ASTM document. Instead of the recommended metals listed in the ASTM, the team purchased carbon steel sheets to imitate pipes that are widely used in natural gas pipelines, following feedback from the Q2 report. The sheets were 16 gauge with a 0.060 inches thickness that conforms with the ASTM requiring 0.064 ± 0.005 inches. One face of the sheet was sandblasted 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. Four different overlap lengths were chosen according to the formula given in the ASTM with assumptions (30000-45000 psi for the yield point of carbon-steel and 150-450 psi as 50% of the estimated average shear strength of the resin where the thickness of the metal is 0.060 inches): 0.50, 0.75, 1.0 and 1.25 inches, Figure. The length of the specimen in the clamps was 2.5 inches for all after bonding two coupons with an average of 0.2-inch-thick cured resin per ASTM.

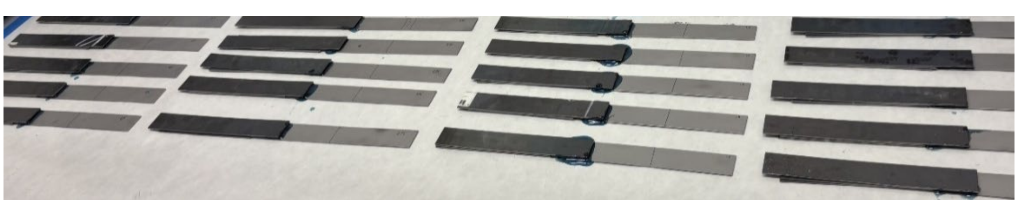

Figure 16. Four different overlap lengths were used (0.50, 0.75, 1.0, and 1.25 inches; from left to right, top image) and five specimens were prepared for each overlap length for measurement.

ASTM D3165 testing. The test was performed at RapiCure Solutions laboratory. 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, Figure 17. The load was applied until the failure. The software calculates and reports the raw data. A total of five specimens were tested for each overlap length as given above and the results are analyzed in the following section.

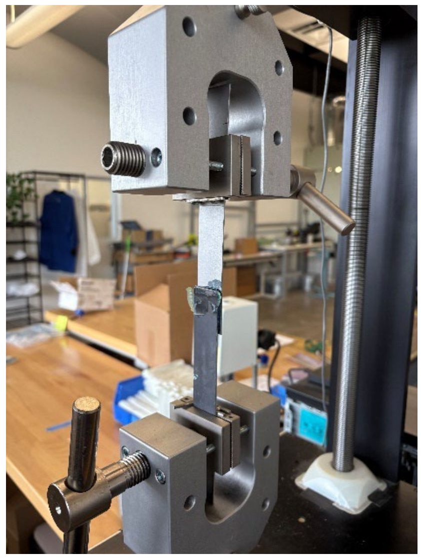

Figure 17. The prepared specimen is mounted to the jaws of the UTM instrument.

ASTM D3165 test result analyses. The lap shear strength is measured with varying overlap lengths per ASTM showing lap shear strengths ranging from 1.2 MPa to 1.7 MPa (175-245 psi), Table 7. 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 needs 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 1 metal-resin interaction. The TAP was encouraging 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 D3165, and the results are reasonable and within scope for CIPP lining with RapiCure's system.

Table 7. Tabulated results of the shear strength per ASTM D3165.

Overlap Length (inch)	***Sample No.***	***Lap Shear Strength (MPa)***	***Average Load at Failure (MPa)***	***Type of Failure***
0.5	1	1.22	1.7±0.6	*Adhesive*
	2	1.16		
	3	1.41		
	4	2.27		
	5	2.50		
0.75	1	1.38	1.2±0.3	*Adhesive*
	2	0.93		
	3	1.04		
	4	0.87		
	5	1.56		
1.0	1	0.75	1.5±0.6	*Adhesive*
	2	1.21		
	3	2.38		
	4	1.90		
	5	1.40		
1.25	1	1.91	1.7±0.2	*Adhesive*
	2	1.48		
	3	1.49		
	4	1.62		
	5	1.80		

[Item 22] [Task 4&5][Material Characterization Parts 25][Testing various resins for ASTM D903]

Testing various resins for ASTM D903 Peel or Stripping Strength of Adhesive Bonds. ASTM D903 is a standard test method that determines the peel or stripping strength characteristics of adhesive bonds. This test involves bonding an adhesive to a material and measuring the force required to peel it away at a specified angle under controlled conditions. This test method is important for understanding the coating adhesion and has been used to evaluate and differentiate the chemical composition of adhesives based on superior adhesive properties. Various resin formulations were screened that might yield the high adhesive properties. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization (such as frontal temperature of the curing, frontal velocity, Shores hardness, tensile strength, etc. and as given in Table 2). Also evaluated was the compatibility of the resin formulation optimized to reduce defects caused by a component crashing out of the Q2 system.

[Items 23,24] [Task 4&5][Material Characterization Parts 29,30][Testing various resins for ASTM D4060, ASTM D4060 test specimen preparation]

Testing various resins for ASTM D4060 Abrasion Resistance of Pipeline Coatings by the Taber Abraser. 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 future interaction may be with cleaning pigs or other materials that can build up or break free and potentially damage the coating in the future. 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, that 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. Various resin formulations were screened to possibly yield the best abrasion resistance properties. This was achieved by maintaining the chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

ASTM D4060 test specimen preparation. As detailed in the Panel Preparations for the ASTM Studies section above, after several iterative trials (10+ iterative trials), multiple panels were produced via modified injection molding method. Then, these panels were cut into ASTM D4060 specific dimensions specimens for measurement via waterjet cutting. That is, a disk with a 6.5 mm hole in the center with a 100 mm diameter and less than 6.5 mm thickness.

[Item 25] [Task 4&5][Material Characterization Parts 33][Testing various resins for ASTM G14]

Testing various resins for ASTM G14 Impact Resistance of Pipeline Coatings. 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. With 3X the fracture toughness of standard epoxy resins, and available chemistry to dissipate impact forces, the team anticipates that this system will perform well under this test. Thus, various resin formulations were screened and the one chosen for testing is anticipated to have excellent impact resistance properties. This was achieved by maintaining chemical curing properties above the threshold value that had been pre-determined after hundreds of prior resin curing optimization.

[Item 26] [Task 13][Team meetings][Team meetings]

The internal team meetings (within RapiCure Solutions) were held two times each week to discuss the progress of the project as well as obtain feedback from other RapiCure team members about the progress of the project. Dr. Ercan Bayram and Dr. Heather Rubin hold weekly one-on-one meetings to discuss the progress of the project as well as planning to move forward with the project based upon results.

Elisabeth Kulesus, Dr. Ercan Bayram, and Dr. Heather Rubin met with project affiliates to discuss and prioritize the proposed list of ASTMs. Dr. Ercan Bayram also met with project affiliate to discuss and optimize which ASTMs for testing. Several external team meetings were held with members of the team either virtually or in-person to inform them of project decisions and discuss industry feedback on the results and progress.

[Item 27] [Task 10][Suggest improvements][Suggest improvements Q3]

A critical development in this quarter was the method for panel making. The team conducted several iterations and hypothesis-driven panel development to address air bubbles in the cured resin. We successfully produced quality panels, as detailed in the Introduction/Background section. Another improvement was to establish methodologies for ASTM testing where the team utilized the DMA instrument. Standard sample measurements were also performed that have known results to validate the methodology. One ASTM was also switched with another from the original plans per the TAP advice. Lastly, the input from TAP members led to thoughtful project planning for next quarter in-field trials and pig/spray trials.

[Item 28] [Task 14][3rd Quarterly Status Report][3rd Quarterly Status Report]

Careful discussion and considerations were made with discussions, milestone modifications, and reporting in Q3. All monthly reports were completed and emailed/updated. This 3rd Quarterly Status report details the progress of the project and related tasks.

5: Project Schedule –

<The AOR needs to understand and assess the project progress. A clear listing of Items not completed during this quarter will aid this determination. This section must itemize each Item from those reported in section 2 of this report as a sub-section for the narrative description of why the Item was not completed and its impact on the remaining project schedule. If the project is on time or ahead of schedule, a simple statement that the project is on time or ahead of schedule should be stated.>

[Item #1] [Task 3][Engineering Design Part 2][Engineering Design Part 2]

Communication with the external collaborator, who is designing the engineering design of the sprayer tool was initiated, and initial thoughts on the design were communicated. Previously, it was determined that it would be best to have some experimental trial results on how the resin behaves with different spraying techniques/tools/etc., prior to meaningful engagement. Thus, the preliminary results of the spraying trials were shared in this quarter. Specifically, Dr Heather Rubin and Dr Ercan Bayram met with the team on April 4th, April 28th, and June 18th and agreed on the proposed scope of work (SOW). This change is not expected to negatively impact/delay the overall project timeline.

[Items 2,3,4] [Task 3][Develop Coatings Parts 4, 5, and 6][Develop Coatings – 4' ,6' and optimized liners]

It was reported in Quarter 2 Quarterly Report that the team was able to accomplish the required resin tuning and initial evaluations in just 3 spray trials rather than 4. Thus, and specifically after the meeting held on March 31st, 2025, with the TAP members as well as representatives from US-DOT, it was concluded that the best next Spray Coating would be using a meaningful tool and perhaps following any future learnings. Therefore, the team simply delayed/moved this deliverable to later in the project plans, pushing "Develop Coatings Parts 4, 5, and 6" to upcoming quarters. The team is slightly ahead of schedule on discussions, development, and planning for resin application with pigs. This change is not expected to negatively impact/delay the overall project timeline.

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

The required reference material (10 mm quartz cylinder) for the test was received on June 25th, 2025, and the testing was performed after preparing the sample from RapiCure Solutions' resin. The raw data results were obtained which will be analyzed and reported in the upcoming quarter.

[Items 6,7,8][Task 4&5][Material Characterization Parts 18,19,20][ASTM D5868 test specimen preparation, ASTM D5868 testing, ASTM D5868 test result analyses]

The team engaged with multiple 3rd party labs with ISO certification that can perform ASTM D5868. The lead time, measurement time, as well as the cost are being considered to determine the best option. For the time being, 2-3 weeks turnaround time for this ASTM. The team will prepare the samples per ASTM requirements and will send them to the corresponding 3rd party laboratory. The results will be analyzed and reported in the upcoming quarter, Q4. This change is not expected to negatively impact/delay the overall project timeline.

[Items 9,10,11][Task 4&5][Material Characterization Parts 26,27,28][ASTM D903 test specimen preparation, ASTM D903 testing, ASTM D903 test result analyses]

The team engaged with multiple 3rd party labs with ISO certification that can perform ASTM D903. The lead time, measurement time, as well as the cost are being considered to determine the best option. For the time being, 2-3 weeks turnaround time for this ASTM. The team will prepare the samples per ASTM requirements and will send them to the corresponding 3rd party laboratory. The results will be analyzed and reported in the upcoming quarter, Q4. This change is not expected to negatively impact/delay the overall project timeline.

[Items 12,13][Task 4&5][Material Characterization Parts 31,32][ASTM D4060 testing, ASTM D4060 test result analyses]

The team engaged with multiple 3rd party labs with ISO certification that can perform ASTM D4060. The lead time, turnaround time, as well as the cost are being considered to determine the best option. For the time being, 2-3 weeks turnaround time for this ASTM. The team prepared and sent the panels for waterjet cutting per ASTM requirements and will send them to the corresponding 3rd party laboratory. The results will be analyzed and reported in the upcoming quarter, Q4. This change is not expected to negatively impact/delay the overall project timeline.

[Items 14,15,16] [Task 4&5][Material Characterization Parts 34,35,36][ASTM G14 test specimen preparation, ASTM G14 testing, ASTM G14 test result analyses]

During the Q3 update meeting held on June 25th, the TAP panel recommended to perform 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, 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 where multiple panels will be produced (as details given above) with varying thicknesses (that represent the anticipated coating thickness range for the rehabilitation of the metal gas pipes) with and without a metallic flat surface will be performed and tested via impact apparatus with different weights and distances at RapiCure next quarter. This change is not expected to negatively impact/delay the overall project timeline.

[Item 17] [Task 9][Perform Tensile/4-point bend test][ASTM 2207-06 Preparations]

ASTM 2207-06 covers requirements and the method of testing for materials, dimensions, hydrostatic burst strength, chemical resistance, adhesion strength and tensile strength properties for CIPP liners installed into existing metallic gas pipes. The preparation for this test has been discussed with the team. Sample coating is anticipated before the end of the year, and subsequent testing will be performed likely before the 6th Quarter of the proposal This change is not expected to negatively impact/delay the overall project timeline.

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