Quarterly Report – Public Page

Date of Report: *2nd Quarterly Report-March 31st, 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: *March 31st, 2025*

1: Items Completed During this Quarterly Period:

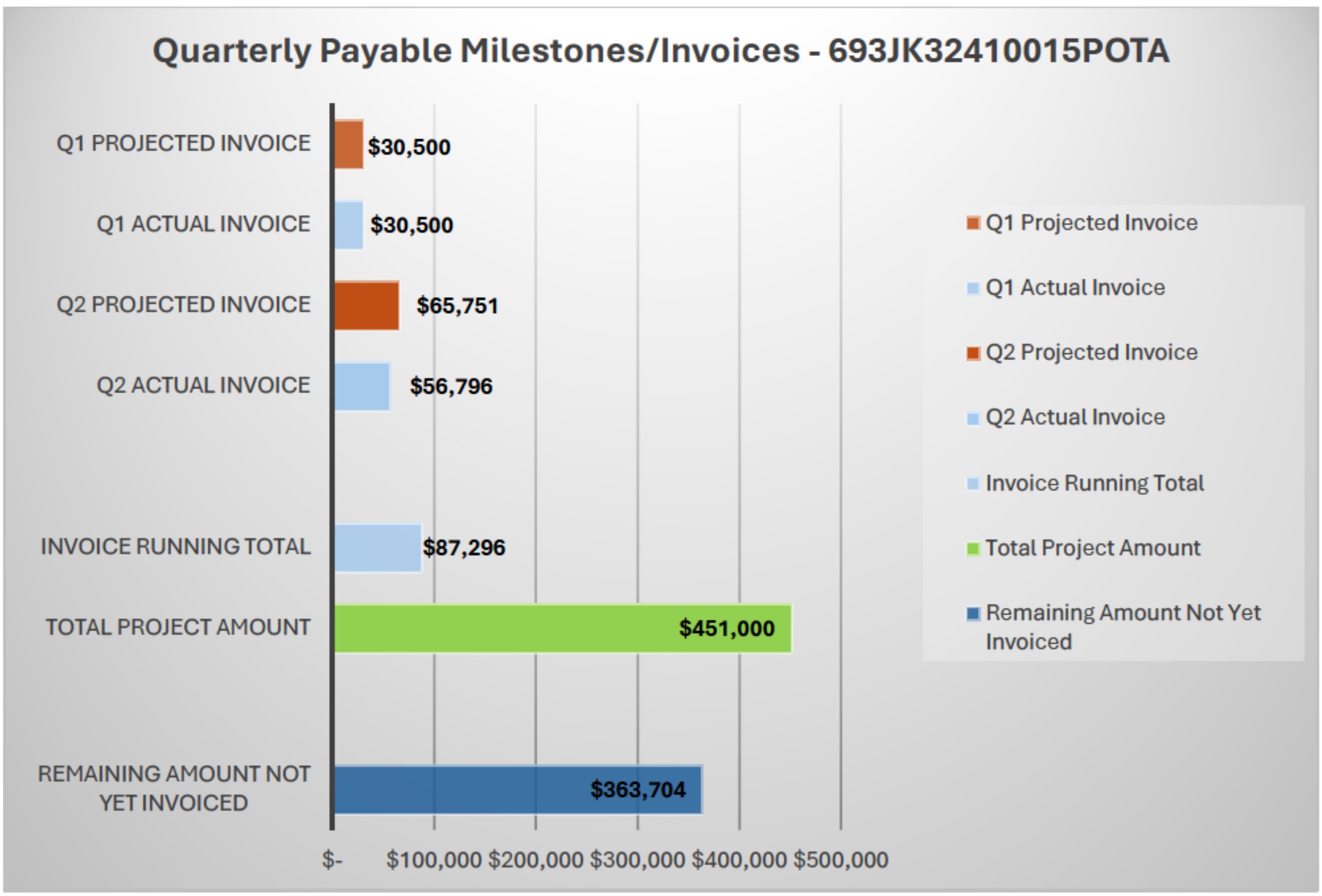
Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
1	*6*	*Deliverable resin coating via spray applicator. Part 1*	*Spray Coating (Personnel, Materials, 5 liners, consumables)*	[redacted]	[redacted]
2	*6*	*Deliverable resin coating via spray applicator. Part 2*	*Spray Coating (Personnel, Materials, 5 liners, consumables)*	[redacted]	[redacted]
3	*6*	*Deliverable resin coating via spray applicator. Part 3*	*Spray Coating (Personnel, Materials, 5 liners, consumables)*	[redacted]	[redacted]
4	*6*	*Deliverable resin coating via spray applicator. Testing Part 1*	*Deliverable resin coating via spray applicator. Testing Part 1*	[redacted]	[redacted]
5	*6*	*Deliverable resin coating via spray applicator. Testing Part 2*	*Deliverable resin coating via spray applicator. Testing Part 2*	[redacted]	[redacted]
6	*6*	*Deliverable resin coating via spray applicator. Testing Part 3*	*Deliverable resin coating via spray applicator. Testing Part 3*	[redacted]	[redacted]
7	*13*	*Team Meetings*		[redacted]	[redacted]
8	*10*	*Suggest Improvements*	*Suggest Improvements*	[redacted]	[redacted]
9	*14*	*2nd Quarterly Status Report*	*2nd Quarterly Status Report*	[redacted]	[redacted]
10	*6*	*Deliverable resin coating via spray applicator. Industry Outreach*	*Deliverable resin coating via spray applicator. Industry Outreach*	[redacted]	[redacted]

2: Items Not-Completed During this Quarterly Period:

After speaking with the project team, the Spray Coating item Part 4 will be revisited after the pigging trials in subsequent quarters. The engineering design Part 1 will be invoiced when appropriate from project partners.

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
1	*12*	*Engineering Design Part 1*	*Engineering Design Part 1*	[redacted]	[redacted]
2	*6*	*Deliverable resin coating via spray applicator. Part 4*	*Spray Coating (Personnel, Materials, 5 liners, consumables)*	[redacted]	[redacted]

3: Project Financial Tracking During this Quarterly Period:



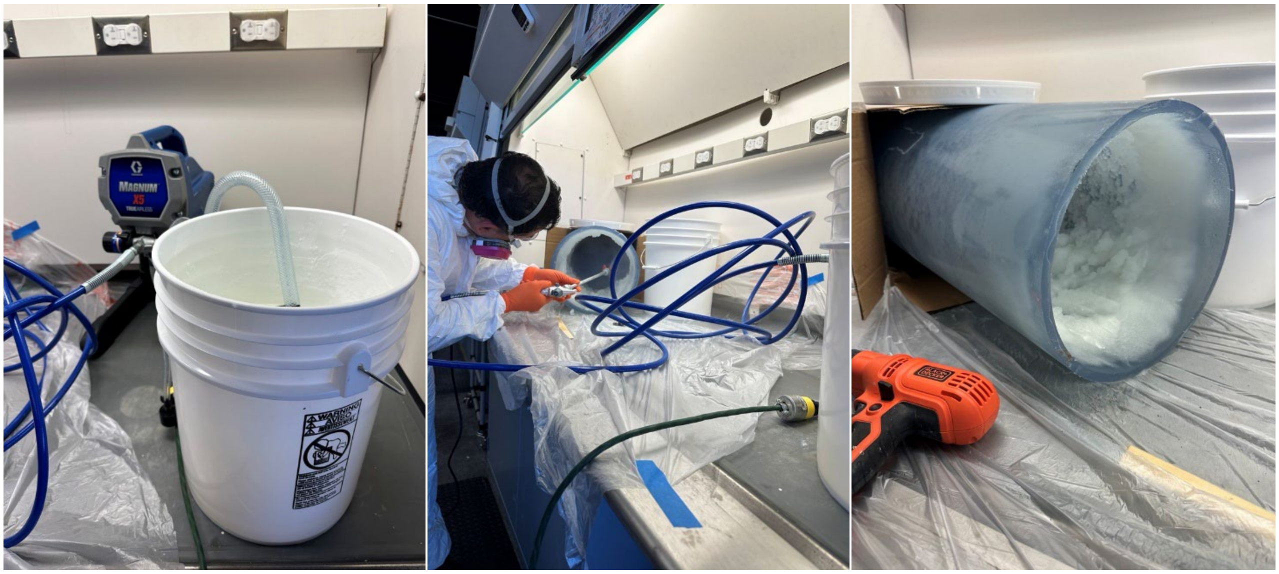
4: Project Technical Status –

Introduction/Background

The goal of this project is developing a cost-effective commercial-ready near deployable product and solution for internal pipeline repair that enables service providers and pipeline operators to quickly protect their critical infrastructure immediately and for generations to come. Towards this end Q2 was focused on developing a sprayable solution and addressing several key challenges and questions that were discovered. This process required iterative tuning of the resin system and system optimization. [redacted]. The team determined that choosing the right mixing process and subsequent sprayer will be the critical development hurdles for a sprayable liner. Discussed in more detail below, the 4 steps towards a sprayable liner include: Step 1: evaluate spray nozzles, sag, viscosity, sprayer type, pressure, distance, thickness, applicator (paint, spray, extrude); Step 2: evaluate 2 line/part mixing solutions (mixing to happen closer to the spray nozzle); Step 3: using composite fabric to prevent sag and offset viscosity challenges. Testing was simultaneously performed to evaluate the resin after any tuning and to address the greatest risks for success which included Surface bonding, Surface Adhesion and Mechanical Performance.

In Q1, RapiCure manufactured pipeline liners from 16 inches – 4 feet in length and 1 in thickness with 12-inch external diameter. The liners were obtained via an iterative process that started with small prototypes and grew to larger liners. The development used RapiCure Solutions' [redacted] frontally polymerizing resin products, cured only by heating at one end of the liner. 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 the coating in just minutes, compared to hours or even days. The resin systems used in Q1 served as the baseline formulation for the sprayable coating in Q2.

Preliminary investigations of the spray application of RapiCure's resin via a commercially available airless sprayer showed promising results that yielded up to an inch thickness resin applied in a 12" internal diameter (ID) pipe without any sagging, Figure 1. This set up utilized a premix resin solution with approx. 30 min workable/sprayable lifetime. Herein, is discussed different spray trials as well as initial test results to derisk the formulation and spray tool to be ready for Quarter 3 where we will be investigating an in-depth mechanical property testing of the resin formulation according to ASME-PCC-2 2022 document and continuing the discussion with our engineering support team.



(a) (b) (c)

Figure 1. (a) The spraying set up utilizing an airless sprayer. The bucket contains the mixed resin system. (b)Spraying [redacted] with an extended sprayer nozzle in a 12” ID PVC pipe. (c) The spraying yielded up to an inch thickness resin applied in a 12’ ID pipe without any sagging [redacted]

First and foremost, the resin formulation for sprayer trials as stated in Q1 report “The final resin used herein may be further tuned during the next phase of spray and pigged coatings in subsequent development tasks”. After initial evaluation it was determined that [redacted] the same formulation used in Q1 was prepared and sprayed to a sand-blasted stainless-steel plate and all the sprayed resin material flowed to the bottom with little adhesion to the surface, i.e, the resin was sagging significantly and not building properly to the desired thickness.

Since we obtained very promising results in our initial trials with the airless sprayer, *vide supra*, the team revisited the resin formulation. This approach resulted in a sprayable resin solution that adhered to the sand-blasted stainless-steel substrate. Hence, all different sprayer trials used this “revisited/updated/revised” resin formulation, *vide infra*. Importantly, the mechanical properties of the “revisited/updated/revised” resin formulation were evaluated and yielded very comparable results of the resin formulation used in Q1, Table 1, confirming no negative effect on the chemical and mechanical properties.

Table 1. Comparison of the resin formulation used in Q1 (liner) and the "revisited/updated/revised" sprayable formulation used herein, Q2.

Formulation	[redacted]	[redacted]	*Tf (°C)*	*Shores Hardness*	*Tensile Strength (MPa)*	*Elongation at Yield (%)*	*Elongation at Break (%)*	*TanD* [redacted]
Q1 (Liner)	[redacted]	[redacted]	*200*	*84*	*48 ± 2*	*6.4 ± 0.7*	*8.5 ± 2.3*	[redacted]
Q2 (Spray)	[redacted]	[redacted]	*195*	*85*	*44 ± 4*	*6.2 ± 0.5*	*6.9 ± 0.8*	[redacted]

[Item ***#1****] [Task 6][Deliverable resin coating via spray applicator. Part 1][Spray Coating (Personnel, Materials, 5 liners, consumables)]*

The "revisited/updated/revised" formulation was prepared and tested via high volume low pressure (HVLP) gravity feed spray gun, Figure 2.

Figure 2. A commercially available high volume low pressure (HVLP) gravity feed spray gun was used in Part 1.

Then, the orifice size, compressor pressure, squeegee use and distance to spray variables were evaluated to find the optimum conditions for spraying.

(a) Orifice size is the size of the opening at the nozzle of the sprayer. A variety of available sizes were tested ranging from 1.3 mm to 1.8 mm. All the nozzles evaluated allowed for resin spray; however, due to the nature of the particle sizes of some of the resin components a 1.8 mm orifice was determined for optimal spray patterns and created a thick coating.

(b) The pressure of the compressor attached to the spraying gun was evaluated from 30 psi to 90 psi and it was determined that 60-75 psi is the optimum pressure with 1.8 mm orifice. This provides enough pressure to spray while spraying enough material to coat without dispersion. Higher pressures prevent the buildup of a thicker coating.

(c) The squeegee, Figure 3, was implemented to smooth the surface of the resin since the cured/hardened resin was exhibiting significant orange-peel texture. This type of texture is undesirable since it might create unwanted weak spots, crevasses and/or resistance for the high-pressure gas flow once the repaired natural gas line becomes operational. The squeegee's use created a smooth surface after curing.

(d) The spraying distance was tested from 3" to 12" with 60-75 psi pressure and 1.8 mm orifice. It was found that 3" is too close to the surface such that after initial spray, the pressure disperses the initial layer and prevents a build up for thicker coating. A 12" distance of the spray nozzle to the surface seems too far away, as it created a non-uniform spraying pattern. It was determined that 4”- 6” distance of the nozzle to the surface is optimal under these conditions.

Figure 3. The squeegee is used to smooth the resin after application before the cure to prevent orange-peel/popcorn texture and can be integrated into the final spray tool if needed.

Several liners (7) were sprayed onto sand-blasted 12” ID galvanized steel pipe additional spray trials were performed on flat steel panels. Each liner or panel that was sprayed was subsequently cured by frontal polymerization where the coating cure was initiated in one spot or area (3” x 3” maximum). Each liner took <5 minutes to deposit, was cured ~1 minute later, and the curing time on a 12” liner was approximately, 2 minutes regardless of the thickness. Note that the resin was sprayed into the pipe at an angle since the sprayer was larger than the pipe and could not fit inside, meaning that for these trials the optimal distance and angle may not have been used. Figure 4 shows the first trial results where a 0.5 mm coating was obtained.

Figure 4. The initial trials to form liners in 12” ID sand blasted galvanized steel pipe.

Figure 5. Coatings of 1.0 mm thickness (ideal for bonding).

Figure 6. Thicker liners were formed, 1.5-2.0 mm thickness via spray coating.

Overall, it was shown that the sprayable formulation exhibited good mechanical performance and a promising formulation to spray via a simple HVLP gun. The spray pattern was not heavily dependent on the orifice size range tested herein; 1.3-1.8 mm with optimum pressure of 60-75 psi. No sagging or flowing was observed as almost a 5 mm thickness coating was achieved. The use of squeegee after spraying mitigates orange-peel/popcorn texture after curing. The distance to spray should be around 4”-6” as more close spraying prevents thick coating due to pressure while longer distances failed to create a good spray pattern with loose adhesion.

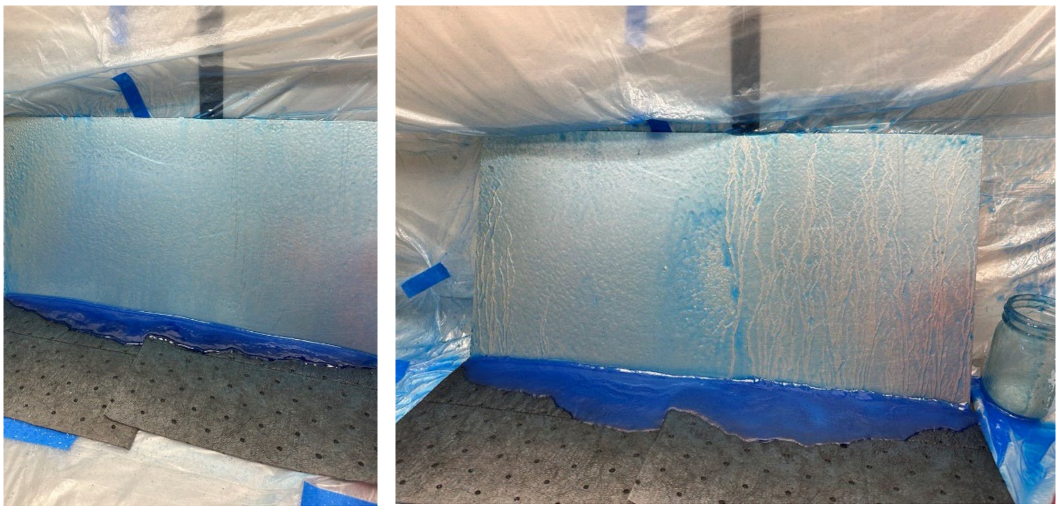
[Item #2] [Task 6][Deliverable resin coating via spray applicator. Part 2][Spray Coating (Personnel, Materials, 5 liners, consumables)]

The resin [redacted] were poured into separate cups that are attached to the spraying gun and pressurized. The pressurized cups push [redacted] spray them separately via a dual sprayer nozzle which are angled in such a way that to facilitate mixing of these two components in the spray stream.

(a) (b)

Figure 7. The front (a) and the top (b) view of the dual cup dual sprayer tool used for Part 2. The tool has two separate cups [redacted]

The first problem encountered was that the main resin component would not spray but rather was squirting out akin to a garden hose, even after iterative efforts to change the pressure, spray pattern and the amount to be sprayed. Although the spraying guns look similar, the working principles are fundamentally different: the HVLP gravity sprayer gun uses gravity and creates vacuum through the flowing pressure of the gun, whereas, both cups in the dual cup are pressurized to push the resin and the catalyst components separately in Part 2. The low pressure of this set up was not enough force to spray the resin component. Early conversations with a sprayer manufacturer suggest that a more sophisticated tool may be required. These results have been discussed with outside engineering support and are expected to influence the final spray tool.



(a) (b)

Figure 8. Sprayed resin does not adhere to the surface when dual cup dual sprayer spraying tool was used. The picture on the left shows the sand blasted steel plate when the spraying is done and the picture on the right shows 2 minutes later.

Table 2. Airless Sprayer vs Dual Cup

Airless Sprayer	**Dual cup Dual sprayer**
[redacted]	[redacted]
Mixed resin is sucked and pressurized to the hose and then spraying gun	Cups are pressurized; the knobs adjust how much is sucked from the cups separately
Aerosolizes	Non-aerosolization
0.015" orifice	**0.050" orifice**
2500-3000 psi	**60-75 psi**
Premix, no metering	Metering is required
No sagging, gell-like viscosity at/after spray nozzle	**Not sprayable and clogging the sprayer nozzle; sprayable resin was attained but at the expense of sagging (low viscosity liquid)**
Pot-life is important	Pot-life is not as important

The preliminary results with Airless Sprayer yielded up to a 1.5” coating that does not sag. The dual-cup sprayer was not spraying the resin well and there was significant sag and viscosity issues with the same formulation. The main differences between the airless sprayer and dual cup dual sprayer. Importantly, the applied pressure difference is up to 50-fold.

In the Dual-Cup evaluations, the second problem encountered was metering the components. The utilized tool herein was perhaps not resolved enough to yield adequate mixing ratios. Thus, a more sophisticated tool is needed. [redacted]

[Item #3] [Task 6][Deliverable resin coating via spray applicator. Part 3][Spray Coating (Personnel, Materials, 5 liners, consumables)]

Often a fabric like a felt or similar fiber can be used to hold the resin in place. In Part 3 chopped fiber was added to prevent resin sag and also evaluated for performance.

Figure 9. Chopped fibers into the sprayed resin.

The resultant liner would not detach from the surface with approximately 2.5-3.0 mm thickness, Figure 10.

Figure 10. Chopped fiber were used in 12" ID sand blasted galvanized steel pipe.

Overall, the results showed the chopped fiber can successfully be included in CIPP applications. Sprayer guns with chopped fiber attachments are available in the market and these results demonstrate the potential for glass fiber to combat and sag challenges. These findings will be discussed with the external engineering team, and other TAP members for guidance.

[Item #4,5,6] [Task 6][Deliverable resin coating via spray applicator. Testing Part 1,2,and 3][Deliverable resin coating via spray applicator. Testing Part 1,2, and 3]

The second half of this quarter involved 1. significant material evaluation for performance with iterative resin tuning, 2. surface bonding evaluations, and 3. surface adhesion testing and development. Details are below.

Testing Parts-1 & 2

Iterative testing was performed throughout the quarter. The resin system was modified slightly from the exact system used in the liners from Q1 to yield a more appropriate sprayable system with less sag. The resin was evaluated for viscosity, pot life, rate of cure, tensile strength and maximum operating temperature. Additionally, fibers were added to the resin system, and the tensile strength, rate of cure and other properties were reevaluated.

Table 3. Mechanical performance of sprayable resin vs liner resin.

	[redacted]	[redacted]	[redacted]	[redacted]	Max Temp	Shore D Hardness	Tensile Strength	Elongation at Yield	Elongation at Break	[redacted]
Target	[redacted]	[redacted]	-	-	>150	>70	≥ 30	≥1	≥1	[redacted]
Units	[redacted]	[redacted]	[redacted]	[redacted]	°C	-	MPa	%	%	[redacted]
Liner-1	[redacted]	[redacted]	[redacted]	[redacted]	190	83	45 ± 2	6.56 ± 0.2	7.5 ± 0.8	[redacted]
Liner-2	[redacted]	[redacted]	[redacted]	[redacted]	200	84	48 ± 3	6.57 ± 0.7	9.0 ± 2.8	[redacted]
Sprayable	[redacted]	[redacted]			**195**	**85**	**44 ± 4**	**6.2 ± 0.5**	**6.9 ± 0.8**	[redacted]

[redacted])

Table 3 (above) shows the final properties of the optimal resin system for spraying. Importantly, the hardness is consistently high, the tensile strength was within optimal range (relative to commercially available epoxy resins), and the elongation at break is impressively above 6% with a maximum operating temperature well above 100C. It is notable that the frontal curing velocity was slightly lower than that used with the liners; however, as shown before, we expect a larger coating to cure significantly faster.

In addition to mechanical performance testing on the resin alone, the project team noted that adhesion to metallic surfaces to be quite variable during the spray trials. The technical advisory panel clarified that optimal bonding is not necessarily permanent bonding. Meaning, that it may be okay with some repairs or liners, for the coating or liner to exhibit stronger bonding in only specified areas. Notably, the beginning and ending of a liner may require a higher level of adhesion. Having a liner that can debond if necessary can prevent unwanted cracking of the liner upon subsequent fatigue or impact. [redacted] the team evaluated and successfully identified several adhesion promoting strategies for the resin system which may be integrated later with the spray, line, and/or pigging processes.

Table 4. Summary of ASTM 3359A trials with a variety of adhesion promoters [redacted]

Sample ID	ASTM D3359A Average Score (0-5)	Test Iterations
Sprayable Resin only	3.9	9
[redacted] Solutions 1-4	5.0	36
Sprayable Resin Mod. 1	5.0	3
Sprayable Resin Mod. 2-3	3.3	6

The sprayable resin system demonstrated an adhesive score of 3.9. Overall, most adhesive systems performed at the target metric, scoring an average of 4 or above for ASTM D3359A meaning that most methods applied by the team to improve adhesion did in fact yield enhanced adhesion to metallic surfaces and therefore may be useful for the final liner integration at commercial scale. [redacted]

Figure 11. Partitioned sample coupons on grit-blasted steel sheet [redacted]

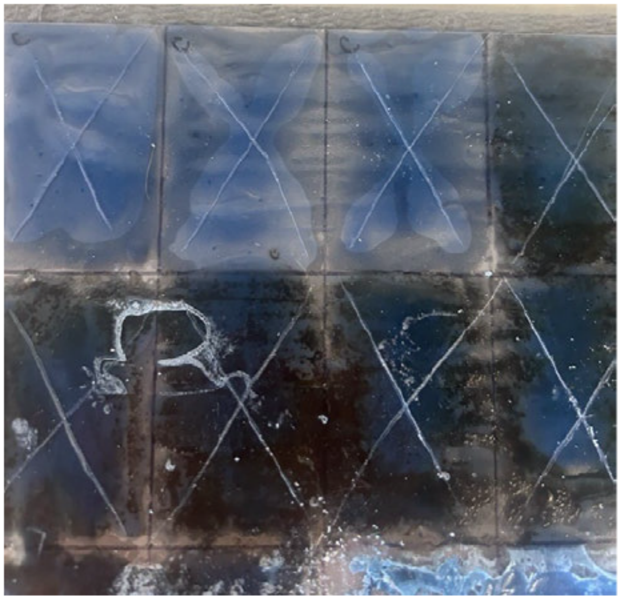
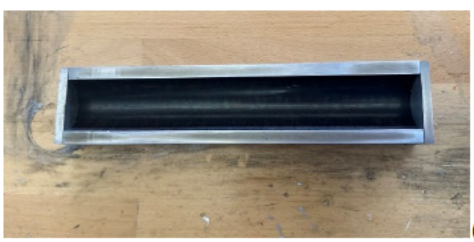


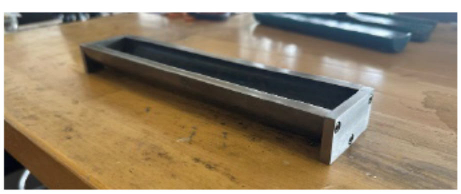
Figure 12. Sample coupons on grit-blasted steel sheet complete with scoring and conditioning requirements. Controls are visible in the top left three coupons.

Testing Part 3

Further testing was performed in Q2 on the resin system including linear cure shrinkage and Lap Shear testing. [redacted] Therefore, different cure methods (from one end, from both ends) were performed and the linear cure shrinkage percentage was determined. Linear cure shrinkage of the sprayable resin formulation was tested, Figure 14.



(a)



(b)

Figure 14. The casting tool used to measure the linear cure shrinkage percentage (a) top view (b) front view.

In the first curing method, the resin is cured by applying a touch of heat from both ends of the casting tool right after casting. As can be seen from Figure 15, 2 curing fronts were initiated and the frontal polymerizations met in the middle of the sample. The second and the third methods consist of initiating the cure with a touch of heat from one end only.

Figure 15. *Top*: The cured resin when the frontal polymerization was initiated from both ends of the casting tool. Both fronts merged in the middle. *Middle*: The cured resin when the frontal polymerization was initiated from one end only. *Bottom*: The cured resin when the frontal polymerization was initiated from one end right after pouring.

Table 5. The average linear cure shrinkage percentages for three different methods of curing.

Method of curing	Both ends	One end	One end
Average linear cure shrinkage	1.37 ± 0.30%	1.11 ± 0.07%	0.98 ± 0.30%

Despite variable aesthetics from the cured resin with each process the results were very similar and within error of one another, Table 5. The average of the three different methods' measurements yielded 1.15% linear cure shrinkage. For reference, epoxy-based resins typically shrink 2% up to 7%. RapiCure Solutions' resin formulation showed lower linear cure shrinkage than the minimum typical shrinkage of epoxy-based resin.

Testing Part-3 (Continued)

Shear strength of the sprayable resin was measured in Testing Part-3 via ASTM D3163. Sample coupons were prepared from sand blasted steel and bonded at 1"x1" area per ASTM. The sample thickness was modulated and then cured with a heat-gun for approximately 1 minute. A resulting lap shear sample is illustrated in Figure 13. Samples were run on the Universal Testing Machine (UTM) per ASTM D3136 requirements, with a preloaded force of 1 lb. A control resin-only sample coupon was also prepared and ran in addition to all primed surfaces for cross comparison.

PCC-2 document does not provide any threshold value for resin-only lap shear testing yet recommends 4 MPa for composite samples (i.e., resin+fiber).

Table 5 details the average lap shear strength values after multiple measurements for each set. Interestingly, the resin-only application demonstrated 3.52 MPa adhesion (per ASTM 3395A, Test 1) which nearly meets the composite threshold.

Table 5. Lap shear strength results per ASTM D3163. No primer use.

Sample	Surface	Failure Mechanism	Lap Shear Strength (MPa)
Control, [redacted]	Sand blasted stainless steel	Adhesive	3.52

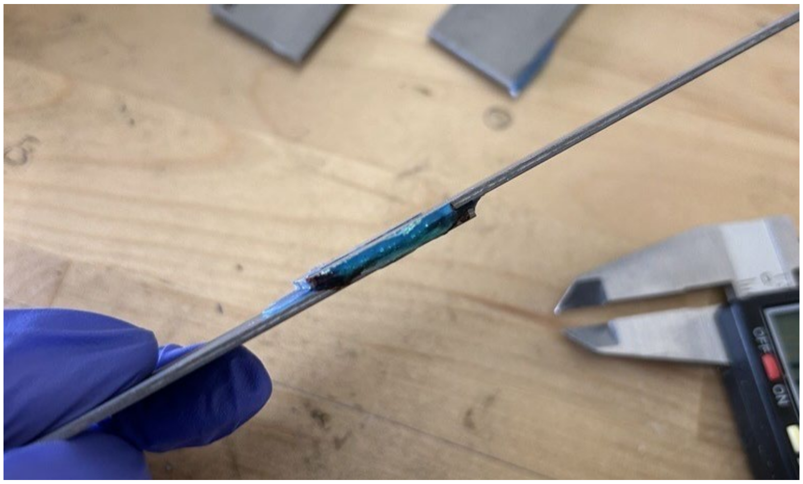


Figure 13. A lap-shear test specimen.

[Item #7] [Task 13][Team meetings][Team meetings]

The internal team meetings (within RapiCure Solutions) were held 2X weekly to discuss the progress of the project as well as to get 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.

The team met on February 12th, 2025 to discuss the progress of the project and recommendations on ASTM measurements planned in Q3. Several external team meetings were held with members of the team to inform project decisions and industry feedback on the results and progress. On March 31th a quarterly team meeting was held with invites to all project team members and TAP members.

[Item #8] [Task 10][Suggest improvements][Suggest improvements Q2]

A critical development in this quarter was to tune the resin to yield very promising coatings with the HVLP gravity feed sprayer. Additionally, the spray trials identified the ideal viscosity, sag, and properties for the resin *and* then answered key questions needed to share with external experts to inform next steps on the project. Some improvements and evaluations for the material adhesion and testing were performed following conversations with key project personnel and TAP members who validated our concerns around cure shrinkage and adhesion.

Industry outreach was performed and several meetings held with key project personnel and often with additional industrial experts. After speaking with the TAP panel and industry experts, it was determined that the resin system and current developments may be “good enough” for commercial integration. In response, the team will wait until after the pigging trials to perform the final Spray Trial 4. Thus, while it may seem that the project team is delayed, this activity will be now performed simply out of order for larger/longer spray trials with an appropriate tool.

Contact with spray companies was initiated. The learnings from different sprayer tool trials will be communicated with the external engineering team and it is anticipated to yield additional suggested improvements next quarter.

[Item #9] [Task 14][2nd Quarterly Status Report][2nd Quarterly Status Report]

Careful discussion and considerations were made with discussions, milestone modifications, and reporting in Q2. All monthly reports were completed and emailed/updated. This 2nd Quarterly Status report details the progress of the project and images of the resin spraying development and related tasks.

[Item #10] [Task 6][Deliverable resin coating via spray applicator. Industry Outreach][Deliverable resin coating via spray applicator. Industry Outreach]

The project team completed significant industry outreach this quarte. Dr. Heather Rubin and Dr. Ercan Bayram visited project support teams on January 28th, 2025, to discuss the project. Support is able and committed to supporting the project. The facility houses hundreds of miles of used pipeline and will be critical for the next steps of product validation in-field and better coatings and liners on used metallic pipe surfaces. The support with spraying, pigging, and similar application processes will be leveraged.

Dr. Rubin and Dr. Bayram also attended the PPIM (Pipeline Pigging and Integrity Management) Conference and Exhibition [redacted] in Houston, TX. PPIM is an industry forum devoted exclusively to pigging for pipeline maintenance and inspection, engineering assessment, repair, risk management and NDE. The team met with manufacturers and many service providers and operators, gaining valuable insights..

The team is awaiting further feedback and possible next steps form a commercial sprayer manufacturer.

During this quarter additional outreach was supported by project team members to support the business development and provide industrial contacts and feedback on results and possible commercial integration opportunities and partners.

5: Project Schedule –

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

The Engineering Design item of the project initially proposed to be finished in Quarter 2 was not completed as the team needed to evaluate the resin and sprayable parameters before engaging the engineering team. 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. With the preliminary results of the spraying trials in hand, the team looks forward to next steps in Q2 with engineering support. This change is not expected to negatively impact/delay the overall project timeline.

[Item #2] [Task 6][Deliverable resin coating via spray applicator. Part 4][Spray Coating (Personnel, Materials, 5 liners, consumables)]

The team was able to accomplish the required resin tuning and initial evaluations in just 3 spray trials rather than 4. Thus, after communication with the project team, it was determined that the best next Spray Coating would be using a meaningful tool and perhaps following next steps. Therefore, 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. This change is not expected to negatively impact the project timeline.