CAAP Quarterly Report

January 22, 2026

Project Name:
Selection and Development of Safer Polymer and Composite Pipeline Liners through Microstructural and Macroscopic Study of Materials and Designs

Contract Number: 693JK32250001CAAP

Prime University: Brown University

Prepared By:
Ryan Poling-Skutvik, Edith Mathiowitz, and Vikas Srivastava

Ryan Poling-Skutvik, Ph.D.
Email: ryanps@uri.edu
Phone: 401-874-2627

Edith Mathiowitz, Ph.D.
Email: edith_mathiowitz@brown.edu
Phone: 401-863-1358

Vikas Srivastava, Ph.D.
Email: vikas_srivastava@brown.edu
Phone: 401-863-2863

Reporting Period: Q11

Project Activities for Reporting Period

During this quarter, in Poling-Skutvik's laboratory, we continued our experiments by exposing additional polymer samples to the NG2 gas mixture (containing oxygen contaminants) at room temperature. Our previous work showed that activation energy decreases much faster under NG2 than NG1, reaching a minimum within 7 days compared to 30 days under NG1. After this initial drop, activation energy plateaus. To address gaps in the earlier dataset, the remaining NG2 exposure experiments were completed at both room temperature and elevated temperature, enabling a comprehensive comparison of thermal effects on activation energy. Figure 1 presents this complete side-by-side comparison, showing that samples aged at high temperature experience a larger decrease in activation energy than those exposed at room temperature, consistent with thermally accelerated degradation processes in the polymer.

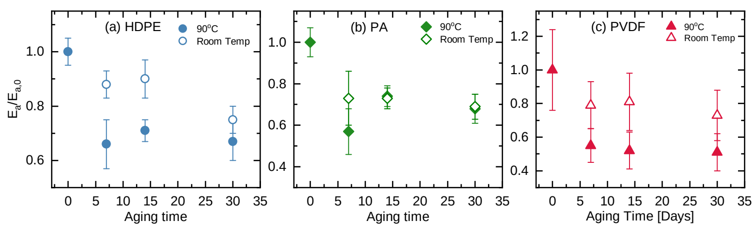


Figure 1: Normalized activation energy $E_a/E_{a,0}$ for (a) HDPE, (b) PA and (c) PVDF.

Figure 2 shows the side-by-side comparison of normalized activation energy for NG1 and NG2. While both conditions exhibit similar overall trends, PA displays less recoverable behavior in the presence of oxygen. Under NG1, the activation energy of PA returns to its original value only after approximately 12 days of storage in the laboratory environment prior to testing; in contrast, samples aged in the presence of oxygen show noticeably reduced recovery over the same time period.

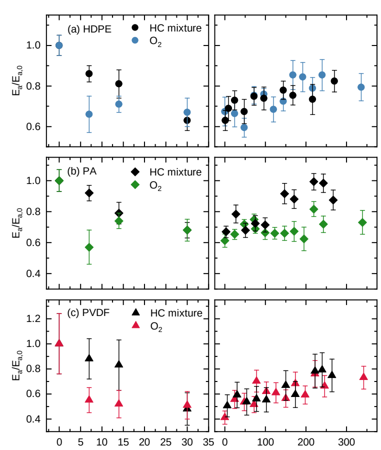
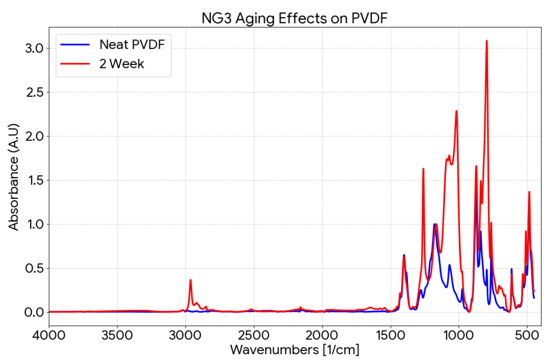


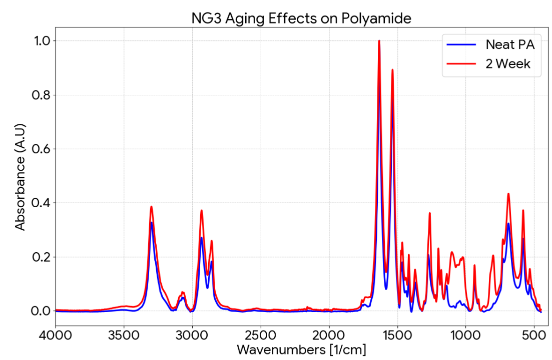
Figure 2: Normalized activation energy $E_a/E_{a,0}$ and recovery for (a) HDPE, (b) PA and (c) PVDF.

Moreover, an additional set of samples was aged under NG3 conditions, which contain BTEX contaminants (benzene, toluene, ethylbenzene, and xylenes) in the gas composition.

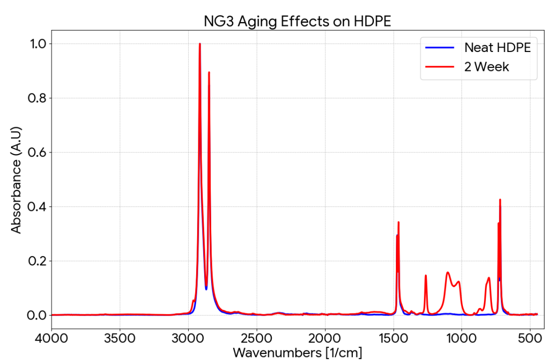
In Mathiowitz lab, the first experience with NG3 aging showed significant changes in all three polymers on the FTIR spectra, as presented in Figure 3. The appearance of new peaks, as well as increased intensities at the natural gas hydrocarbon peaks at 2915 cm^{-1} and 1465 cm^{-1}, indicates that, at least preliminarily, all three polymers exhibit physical adsorption, if not chemical susceptibility, to the NG3 constituents. The appearance of new peaks across all three polymers gives good indication that this in not simply an artifact or contamination. The primary regions that show new activity are at 1260 cm^{-1}, 1110-1020 cm^{-1}, and 810 cm^{-1} however these are not the traditional peaks associated with oxidative and thermal degradation so additional investigations will have to be done on other aged samples.



(a)



(b)



(c)

Figure 3: The effects of NG3 gas aging on the 3 study polymers after 2 weeks of aging at 90°C.

The X-ray and DSC data revealed more limited changes in the spectra and did not exhibit a clear trend across all three polymers, unlike the FTIR data.

In this quarter, in the Srivastava lab, we completed the mechanical testing on polymer samples exposed to the NG3 gas mixture at 90°C for 14 days. We compare the results obtained with previous gas exposures of NG1 (pure hydrocarbon) and NG2 (hydrocarbon with an oxygen contaminant) at 90°C for 14 days. We did not observe any significant changes in the deformation response of HDPE (Figure 4a, 4b, and 4c) and PVDF (Figure 4g, 4h, and 4i) across the three different strain rates of $0.0005s^{-1}$, $0.005s^{-1}$, and $0.05s^{-1}$, and across different gas exposure. We observe a reduction in the peak stress of PA material and its overall deformation mechanical response for the samples exposed to NG1 and NG3 when compared to the baseline material and NG2 exposure (Figure 4d, 4e, and 4f).

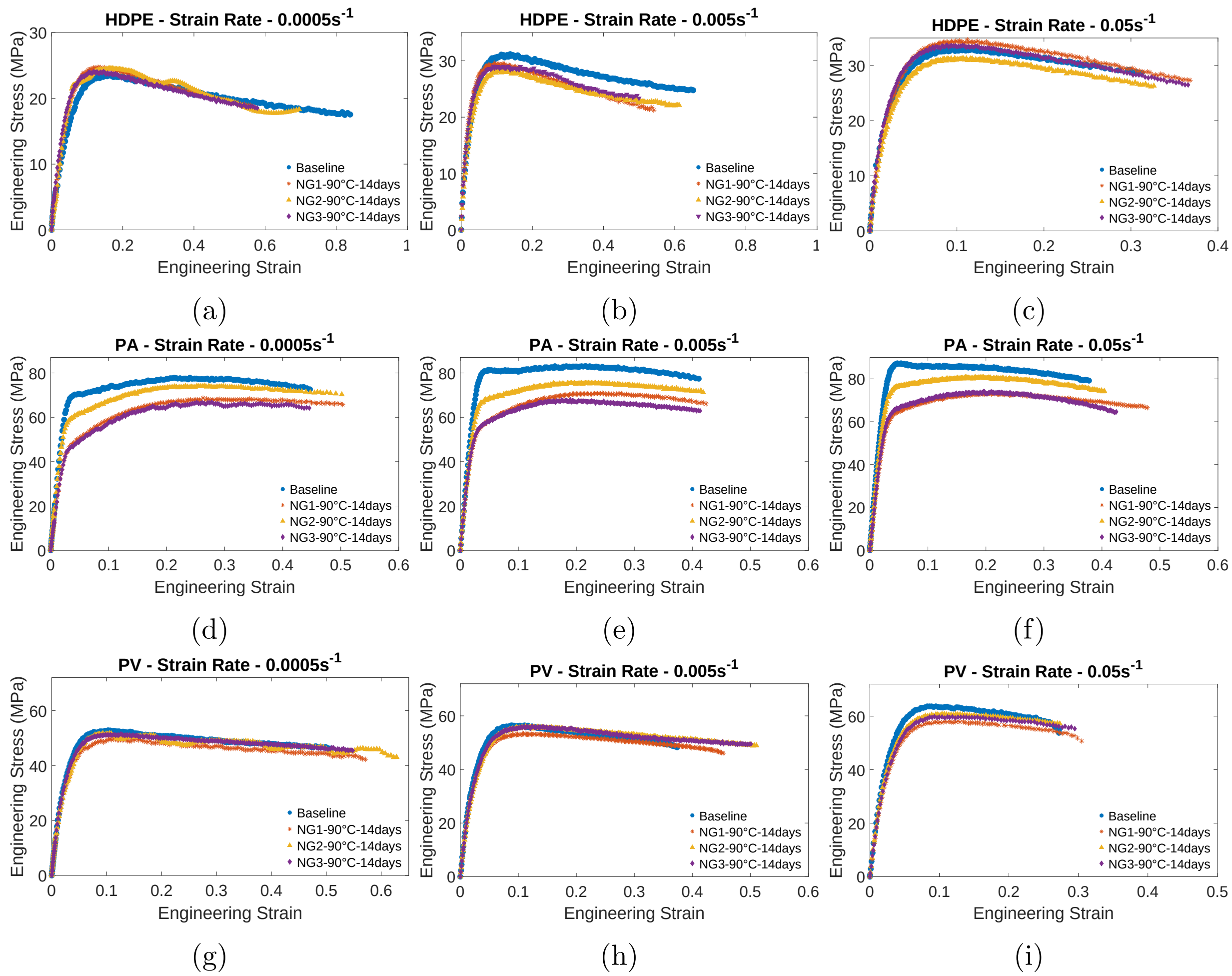


Figure 4: Stress-strain response of (a-c) HDPE, (d-f) PA, and (g-i) PVDF at strain rates of $0.0005s^{-1}$, $0.005s^{-1}$, and $0.05s^{-1}$, respectively.

Moreover, we performed a suite of finite element simulations to study the influence of a liner on the rehabilitation of a corroded cast-iron pipe subjected to an internal pressure of 1 MPa. For this study, PA was used as the model liner material. Due to overall symmetry, only a quarter of the pipe and pipe-liner assembly was simulated. The corrosion material loss was idealized as a rectangular cross-section, with the flaw length, width, and depth as variable parameters, as shown in Figure **??**. The host pipe geometry has been listed in

Table 1. Subsequently, a parametric study was performed for various flaw geometries and liner thicknesses; the details are listed in Table 2.

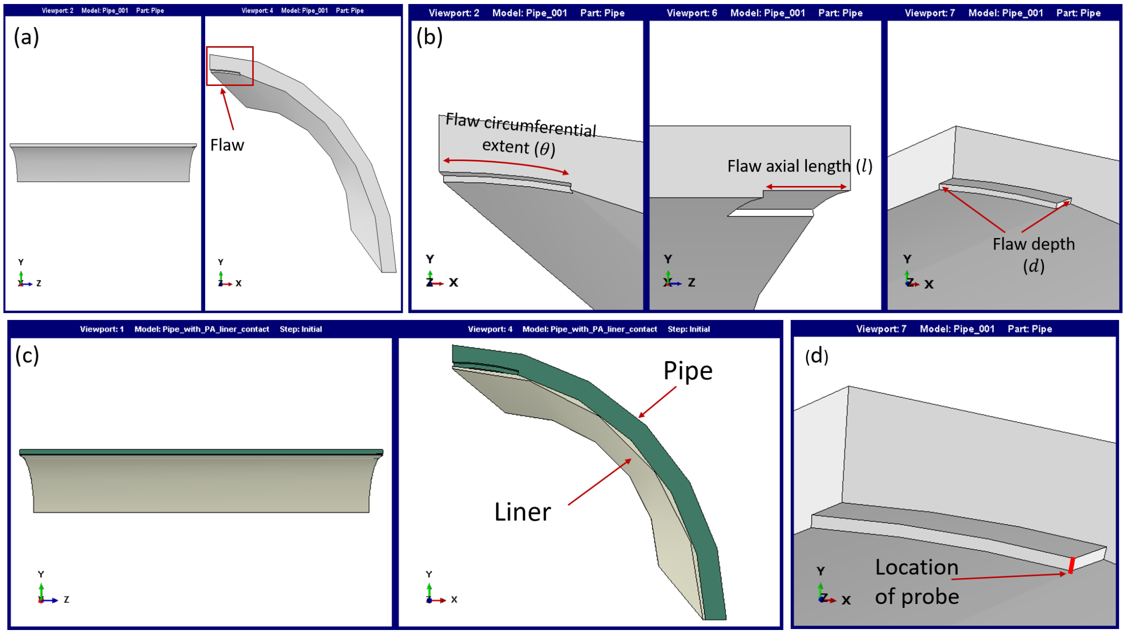


Figure 5: (a) Simulated host pipe geometry. View which is parallel to the pipe axial direction (left). View which is perpendicular to the pipe axial direction (right). (b) Geometry of the corrosion defect. (c) Host pipe-liner assembly. (d) Line (highlighted in red) located at the corner of the corrosion flaw, used as the stress probe over which the von Mises stress is averaged.

Parameter	Symbol	Values used	Units
Inner Diameter	D_i	317.7	mm
Thickness	t	12.7	mm
Length	L	1900	mm

Table 1: Host pipe geometry

It was observed that maximum stress concentration occurred at the corner of the flaw. Hence, the average of the Mises stress across the corner, as shown in Figure **??**c, was computed. For comparison, the ratio of the averaged stress in the presence of a liner to that in the host pipe alone was computed. In Figure 6, we have presented the case where a reduction in the stress concentration was observed for a specific flaw geometry for at least two different liner thicknesses. Based on this preliminary study, it was found that the liner is effective in minimizing stress concentration at the flaw corner only for the smallest flaw length, 31 mm in our case. These cases will serve as the baseline for subsequent refinements and extensions of the finite element study.

Parameter	Symbol	Definition	Values Used	Units
Flaw depth ratio	d/t	Corrosion depth normalized by pipe wall thickness	0.10, 0.20, 0.40	–
Flaw length normalization parameter	C	$C = l/\sqrt{D_i t}$	0.5, 1.5, 3.0	–
Flaw axial length	l	Axial length of corrosion defect	31, 93, 186	mm
Flaw circumferential extent	θ	Angular width of corrosion defect	20, 30, 60	degree
Liner thickness ratio	t_l/t	Liner thickness normalized by host pipe wall thickness	0.10, 0.20, 0.30	–

Table 2: Flaw and liner geometry parameters for finite element study

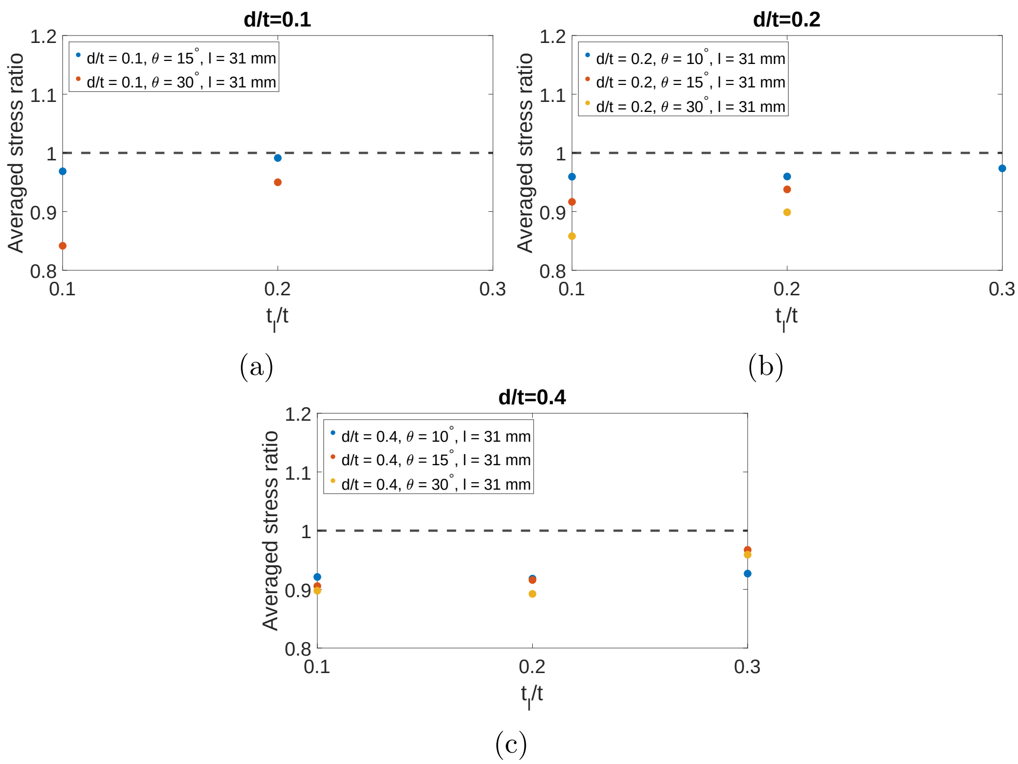


Figure 6: Averaged stress ratio for different liner thicknesses

Project Financial Activities

Costs associated with PI partial summer support, PhD graduate student support, equipment operations, shared facility use, and materials and supplies for experimental research work for the project were supported.

Table 1 Summary of Q11 DOT Funded Spending Annual Report-10/01/2025-12/31/2025				
Institution		Amount ($)	Amount ($)	Subtotal ($)
Brown University	Category	Salary ($)	Fringe ($)	
	PI	0.00	0.00	-
	Co-PI	2,080.78	624.23	2,705.01
	Postdoc			-
	Graduate Students	17,929.12	0.00	17,929.12
	Undergraduate Students			-
	Graduate Student Fees			(718.55)
	Facility Usage			2,213.50
	Purchased Services			-
	Materials and Supplies			1,172.37
	Travel			123.08
	Equipment			5,122.12
	Total Direct			28,546.65
	Indirect			14,365.19
	Subtotal			**42,911.84**
University of Rhode Island	Personnel	Salary ($)	Fringe ($)	
	Salaries	22,710.80	1,811.22	24,522.02
	Operating Expenditures			$849.37
	Travel			4,405.52
	Student Aid			9,994.50
	Total Direct			39,771.41
	Indirect			17,121.78
	Subtotal			**56,893.19**
Total				**99,805.03**

Table 2 Summary of Q11 Cost Sharing Spending Annual Report-10/01/2025-12/31/2025				
Institution		Amount ($)	Amount ($)	Subtotal ($)
Brown University	Category	Salary ($)	Fringe ($)	
	Graduate Student Tuition			53,775.00
	Subtotal			**53,775.00**
University of Rhode Island	Direct Costs			-
	Indirect			-
	Subtotal			**-**
Total				**53,775.00**

Project Activities with Cost Share Partners

Partial support for PhD. graduate student researchers have been provided in accordance with the cost-share agreement.

Project Activities with External Partners

The PI and Co-PI, and participating Ph.D. graduate researchers from Brown University and University of Rhode Island (URI) met on bi weekly basis this quarter to share the research results, discuss the outcomes and decide and plan future research steps. The team from URI and Brown University shared polymer samples with each other for collaborative testing and characterization.

Research outcomes of this project were presented in scientific posters at the following conferences -

- "Accelerated Aging of Polymers in a Hydrocarbon Environment" at Society of Engineering Sciences (SES) Annual Technical Meeting, October 2025, Atlanta, Georgia.
- "Accelerated Aging of Polymers in a Hydrocarbon Environment" at the AmeriMech symposium on Materials Under Extreme Environment, September 2025, Providence, Rhode Island (hosted by Brown University).

Potential Project Risks

As the research progresses and more experimental data is collected, since the work and findings for liner polymer materials will be new, there could be a risk of unanticipated new findings. This risk will be managed by adjusting the research methods as new data comes. Inconsistencies across individual samples may make morphological conclusions for more macroscopic samples difficult.

Future Project Work

Our future work will focus on continuing to test and complete the remaining tests during the last quarter of the project. We will test and characterize polymers after exposure to more corrosive gases, such as H_2S and BTEX. We will also be finalizing modeling work and its results during the last quarter. We will be preparing the final report for the project during the last quarter as well.

Potential Impacts to Pipeline Safety

Previous testing established changes in samples that were established by X-ray diffraction. This method is impractical in the field with XRD machines being bulky and imobile. If similar measurements can be made with an FTIR, which is a significantly more mobile tool, we can detect phase content changes that may be precursors to mechanical failure in the field. Additionally, extensive testing of individual samples shows changes in microstructure properties depending on the locations within the sample. This could be an indicator of regions that were impacted differently by the aging process or significant heterogeneity in samples. The fundamental understanding of liner polymer materials' response, materials properties, and safer liner material guidelines obtained through this collaborative research will help increase the understanding and safety of polymer liners for pipelines.