Mechanical Properties of Permanent Foaming Fixatives for Deactivation & Decommissioning Activities

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DOE-FIU Science and Technology Workforce Development Program

Applied Research Center

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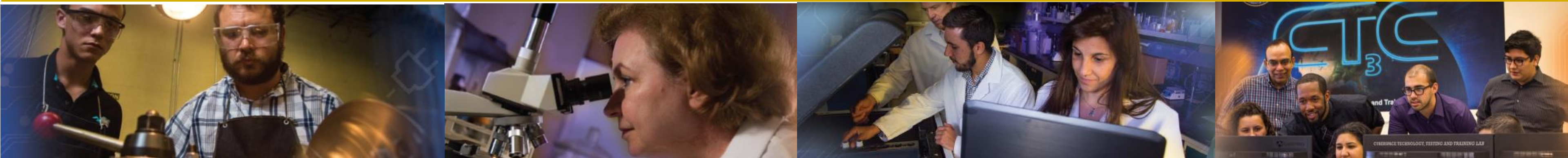

Project Description

- There is a high operational requirement across the DOE-EM complex for a fixative that can immobilize residual contamination and/or encapsulate three-dimensional void volumes (pipes, glove boxes, drums, etc.) during deactivation and decommissioning (D&D) activities.
- Application of this fixative must be simple, cost-effective, and safe in order to ensure worker's safety.

Cleaning up 235 F PuFF Hot Cell

Contaminated Pipes at Hanford

Project Description cont.

Basis of Interim Operation (BIO) documents postulate contingency scenarios involving seismic activity that can occur at DOE sits during D&D. These events insinuate that current and future fixative technologies must have sufficient mechanical properties to withstand earthquakes, blunt trauma, free fall, etc. in order to prevent a potential release of residual contamination [1].

Table 1. Types of Accidents (and Frequencies) Summarized

DOE Site/Facility	Fire Events	Explosion Events	Loss of Confinement (Spill) Events	Natural Phenomena Hazards	Other Events
RFETS Bldg 440	• ***1,200 Drum Fire (EU)*** • ***15 Crate Fire (U)*** • Truck Fire (EU)		• LLW Repack Spill (U) • Drum Spill (A)	• *Earthquake Collapse (U)*	• ***Aircraft Crash (EU)***
RFETS Bldg 664	• ***3 Drum Fire (U)*** • ***15 Crate Fire (U)*** • *336 Drums + 72 Crates Fire (EU)* • Truck Fire (EU)		• *Multi-Container Drop*	• *Earthquake Collapse (U)*	• ***Aircraft Crash (worst-case) (EU)*** • ***Aircraft Crash (realistic case) (EU)***
SRS APSF	• *Accountability Msmt. Room Fire (U)*	• *Explosion in Repackaging Area (A)*		• *Seismic Induced Full Facility Fire (U)*	
SRS HB-Line	• Full Facility Fire (EU) • Full Facility Fire & Secondary Events (EU) • ***Intermediate Fire (U)*** • ***Intermediate Facility Fire & Secondary Events (EU)***		• Spill (A)	• Earthquake with Secondary Events (EU)	
SRS Bldg 235-F	• Fire – Best Case (U) • Fire – Worst Case (U)			• Design Basis Earthquake (EU)	
SRS SWMF	• ***TRU Pads - Internal Culvert Drum Fire (U)***	• ***TRU Pads - Culvert Explosion (U)***	• TRU Pads - High Energy Vehicle Impact (EU) • ***TRU Pads - Dropped Steel Box (A)***	• TRU Pads -Tornado (EU)	• 634-7E Buried Waste Helicopter Crash (EU)
Hanford WRAP Facility	• *4 Drum Fire (U)* • *Single Drum Fire in Glovebox (U)*	• ***Drum Explosion with 4 Drum Fire (U)*** • *Single Drum Explosion in Glovebox (U)*	• Solid Waste Box Failure (A)	• ***Design Basis Earthquake (U)*** • Beyond DBE (EU)	
INEEL RWMC	• ***Vehicle Fire (U)***	• *Drum Explosion (A)*	• *Box Spill (A)*	• Design Basis Earthquake (U)	
LANL RAMROD Facility	• Small Fire (A) • Medium Fire (EU) • Large Fire (EU)	• Small Natural Gas Explosion (A) • Large Natural Gas Explosion (EU)	• Coring Glovebox Spill (A)	• Design Basis Earthquake (U)	• Aircraft Crash (EU)

Note: Scenarios in *Italics* are risk dominant events, based on Risk Class I or II for the collocated worker. ***Bold Italics*** denotes that it is also risk dominant for the public.

Scope

Polyurethane (PU) foams are currently being investigated by DOE-EM to immobilize residual contamination and/or encapsulate three-dimensional void volumes (gloveboxes, pipes, tanks, etc) during Deactivation and Decommissioning activities (D&D).

- ASTM E3191 *Standard Specification for Permanent Foaming Fixatives Used to Mitigate Spread of Radioactive Contamination* [2] was recently developed for the intended use of this technology.

Goal: Update the performance criteria of Section 5 of ASTM E3191.

5. Mechanical Properties

5.1 The foaming fixative shall be compatible with at least one of the following conventional or remote application systems:

5.1.1 spraying,

5.1.2 complete pouring, or

5.1.3 incremental pouring.

5.2 The foaming fixative shall have sufficient mechanical properties to withstand long-term wear associated with incidental impact, abrasion, or vibration that are likely to cause loss of containment of the isolated contaminant.

5.3 The foaming fixative should be readily applied within the desired void space without significant preparation (cleaning, sanding, primer layer, etc.). This does not supersede a facilities decision for gross decontamination prior to application of the foaming fixative.

5.4 The foaming fixative should have sufficient mechanical properties to withstand contingency events such as earthquakes as outlined in a facilities' safety design basis document.

Section 5 of ASTM E3191

Motivation

Three recent examples pertaining to contamination release have occurred due to issues with contaminant fixation or containment that have reach national news.

1. A cleanup incident at Hanford had loose plutonium dust that gave lifetime radioactive doses to 42 workers as well as coating workers' cars [3].
2. In 2018, radioactive dust was found in communities around Hanford, Los Alamos and Rocky Flats. Invisible particles of plutonium, thorium, and uranium were found in household dust, automotive air cleaners, and hiking trails [4].
3. The recent disaster that contaminated 35% of the area at the WIPP facility was a result of using kitty litter to protect nuclear waste tanks [5].

Cleanup mission at Hanford that was stalled

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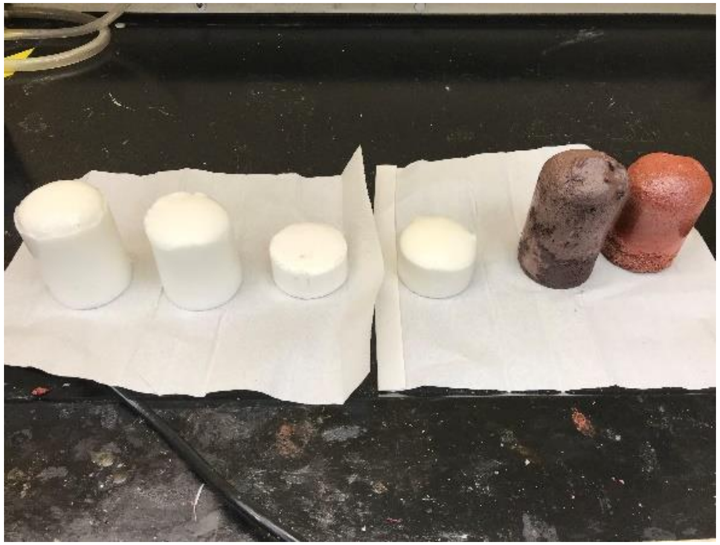
Objective 1

1. Identify the mechanical properties of 6 commercial-off-the-shelf polyurethane foams in terms of tensile, adhesion, and compressive strength.

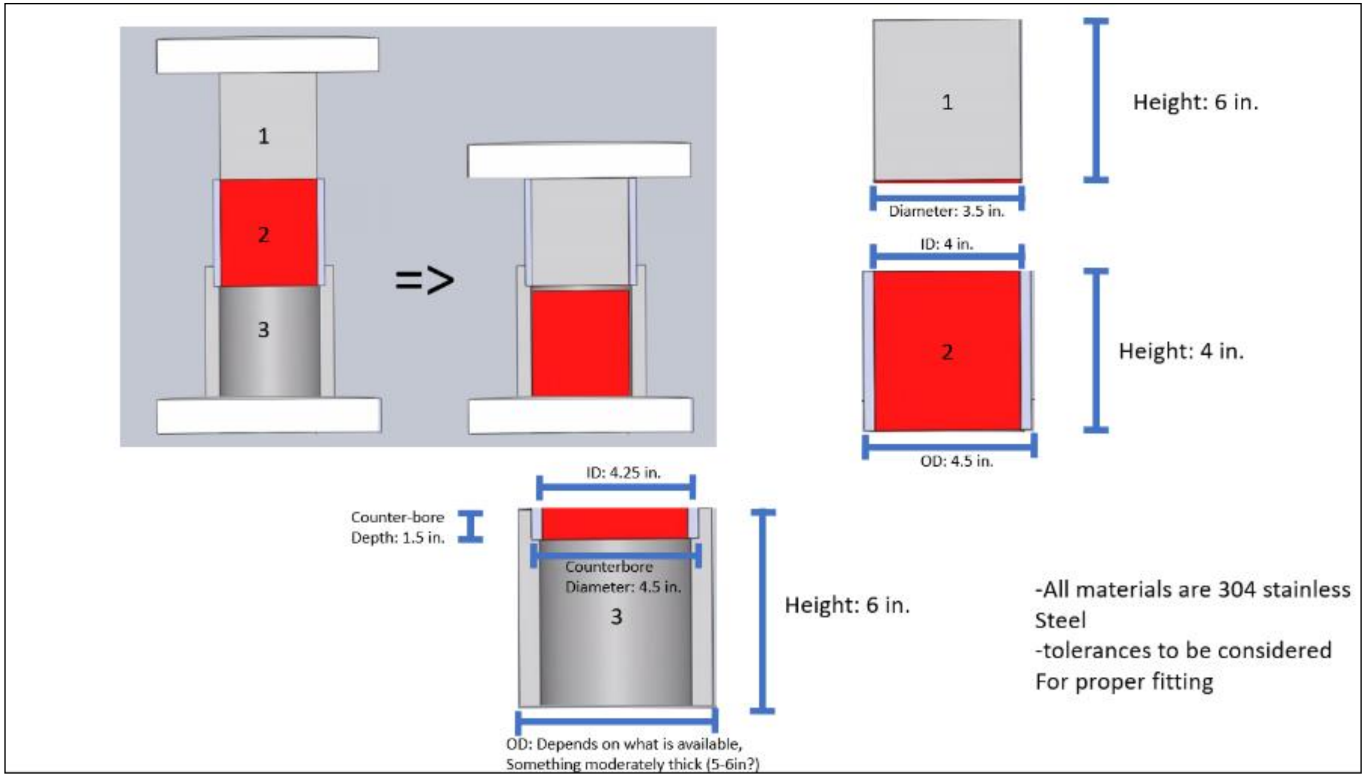
Test	Flexible	Rigid
Tensile	ASTM 3574 *Flexible Cellular Materials – Slab, Bonded, and Molded Urethane Foams* Test E	ASTM D1623 *Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics B*
Adhesion	ASTM D1623 *Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics C*	ASTM D1623 *Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics C*
Compression	ASTM 3574 *Flexible Cellular Materials – Slab, Bonded, and Molded Urethane Foams* Test C	ASTM D1621 *Compressive Properties of Rigid Cellular Plastics*



*Foams to be Tested On (F1, R1, F2, F3, I-F2, R2)
*The I denote intumescence, F denotes flexible and R denotes rigid in this naming convention.

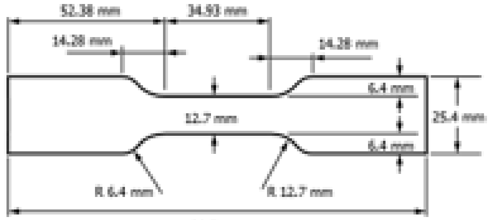
Objective 2

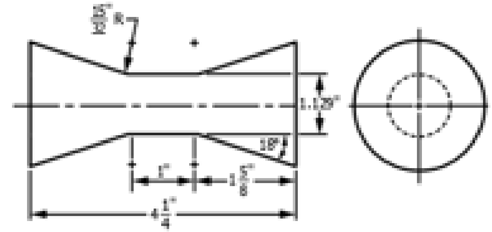
2. Test the adhesion of the best permanent foaming fixative candidate in an operational volume while subjected to compression



Experimental Design with component dimensions

Objective 1
Tensile Testing-Sample Prep





Left picture: Tensile Dye Using ASTM D374-F (Flexible); Right picture: Tensile Dye Using ASTM D1623 (Rigid)

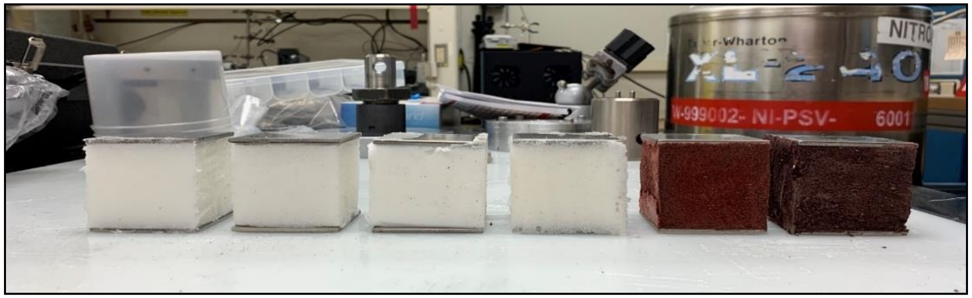
Flexible Foam Fabrication Process

Rigid Foam Fabrication Process

F1, F2, F3, I-F2, , R1, I-R2

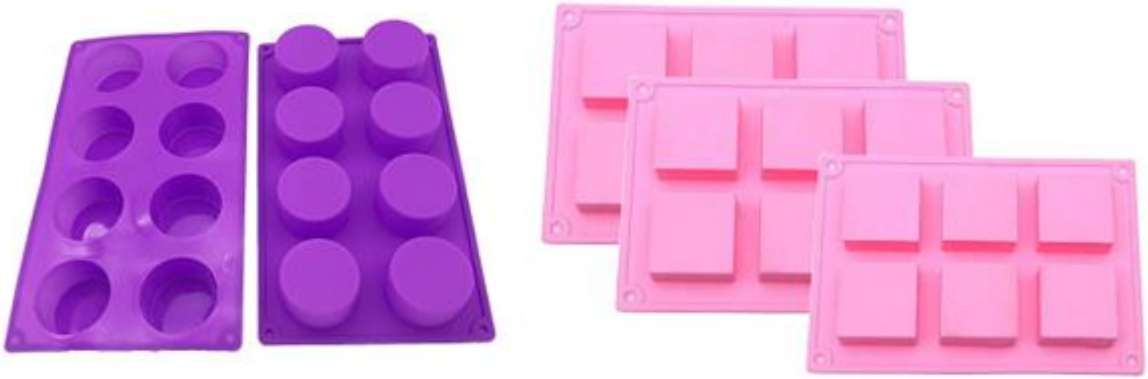
Objective 1
Adhesion Testing – Sample Prep

Adhesion Samples Fabrication



F1, R1, F2, F3, I-F2, I-R2

Objective 1
Compression Testing – Sample Prep



Compression Molds

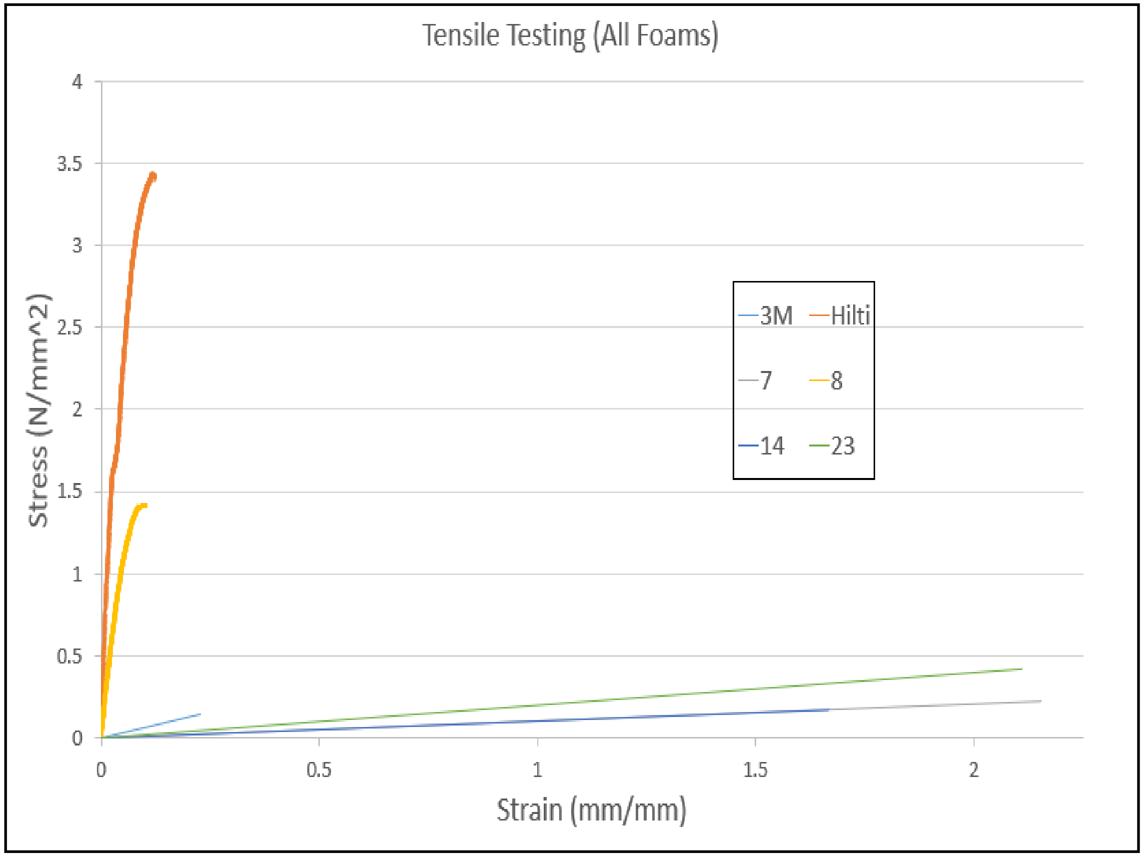
Cylindrical and Rectangular Samples

Cubic Samples (F1, R1, F2, F3, I-F2, I-R2)

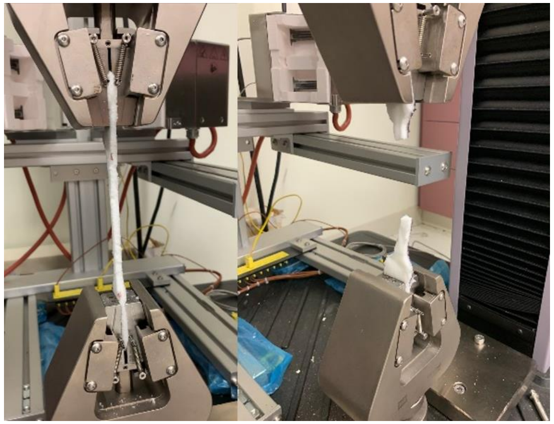
Objective 1
Tensile Testing-Results

Tensile Testing Values

Foam Identifier	Peak Load (N)	Peak Stress (N/mm^2)	Strain at Break (mm/mm)	Modulus (N/mm^2)
F-1	21.52	0.22	2.15	0.10
F-2	16.44	0.17	1.67	0.10
F-3	40.61	0.42	2.11	0.69
IF-4	13.83	0.14	0.23	0.63
R-1	328.020	1.42	0.1	25.5
IR-2	794.640	3.44	0.12	71.85

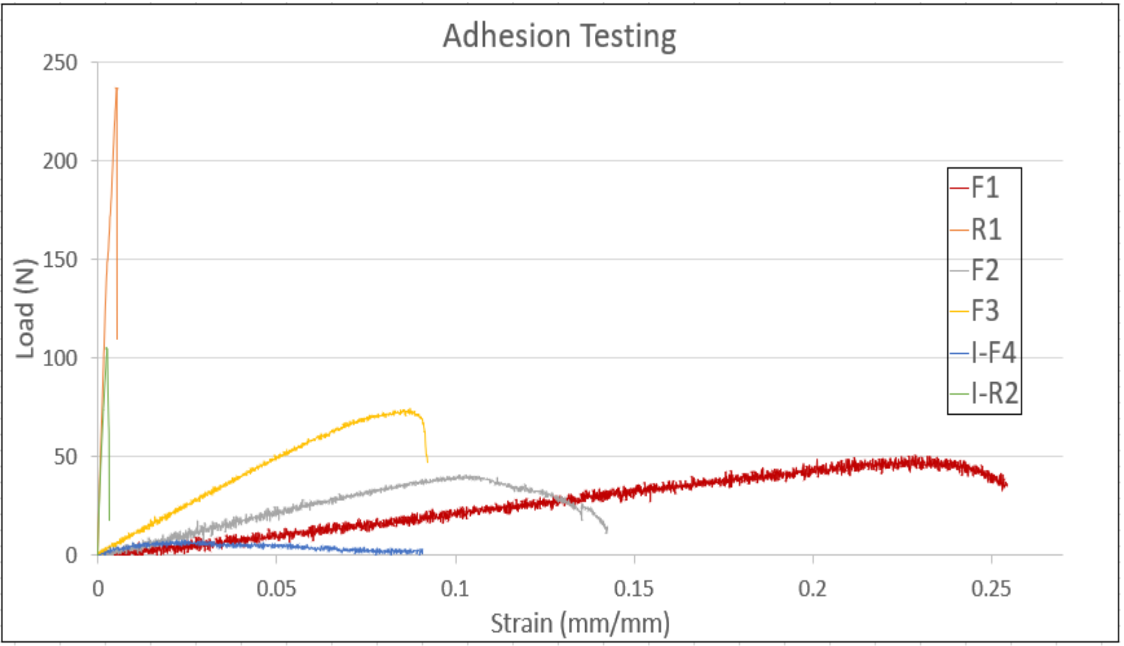


Tensile Testing Results



Tensile Testing Process

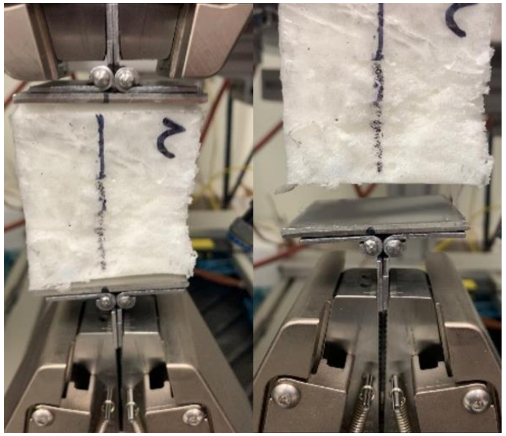
Objective 1
Adhesion Testing Results



Adhesion Graph

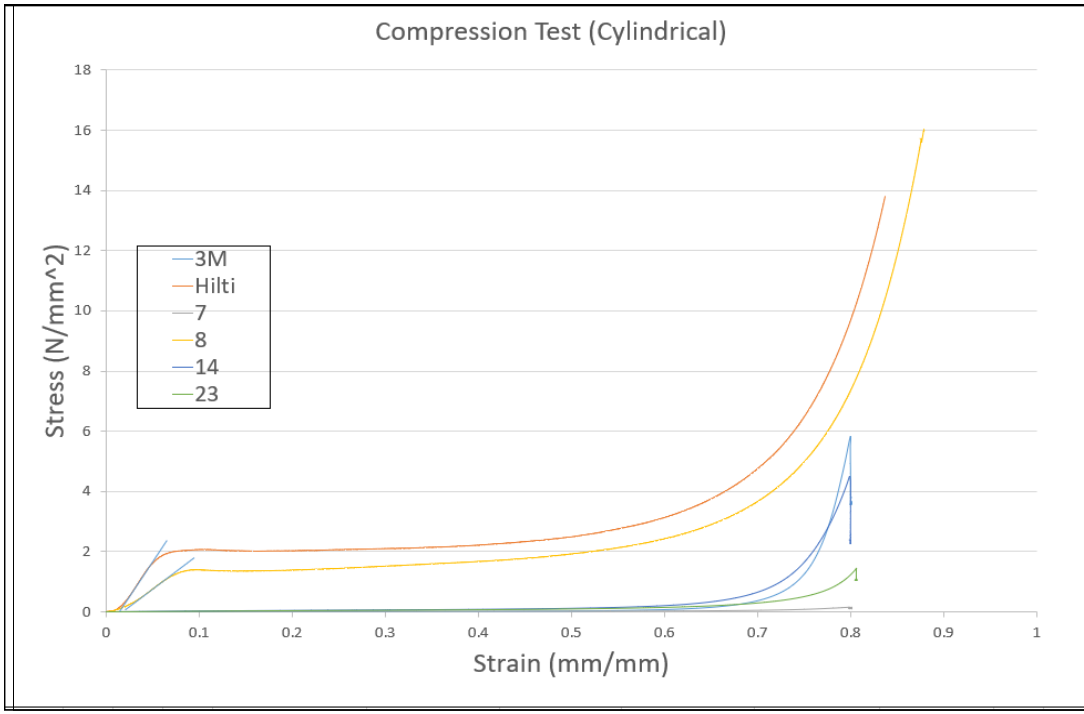
Adhesion Testing Values

Foam Identifier	Peak Stress (N/mm^2)	Peak Load (N)	Strain % (mm/mm)	Deformed Length (mm)
F-1	0.98	50.22	22.88	62.42
F-2	0.79	40.27	10.05	55.90
F-3	1.46	74.16	8.74	55.24
I-F4	0.13	6.82	2.36	51.99
R1	4.65	236.57	0.51	51.05
I-R2	2.06	104.85	0.25	50.92



Adhesion Testing

Objective 1 Compression Testing – Results (Cylindrical)



Compression Testing Results (Cylindrical)

Compression Testing Values (Cylindrical)

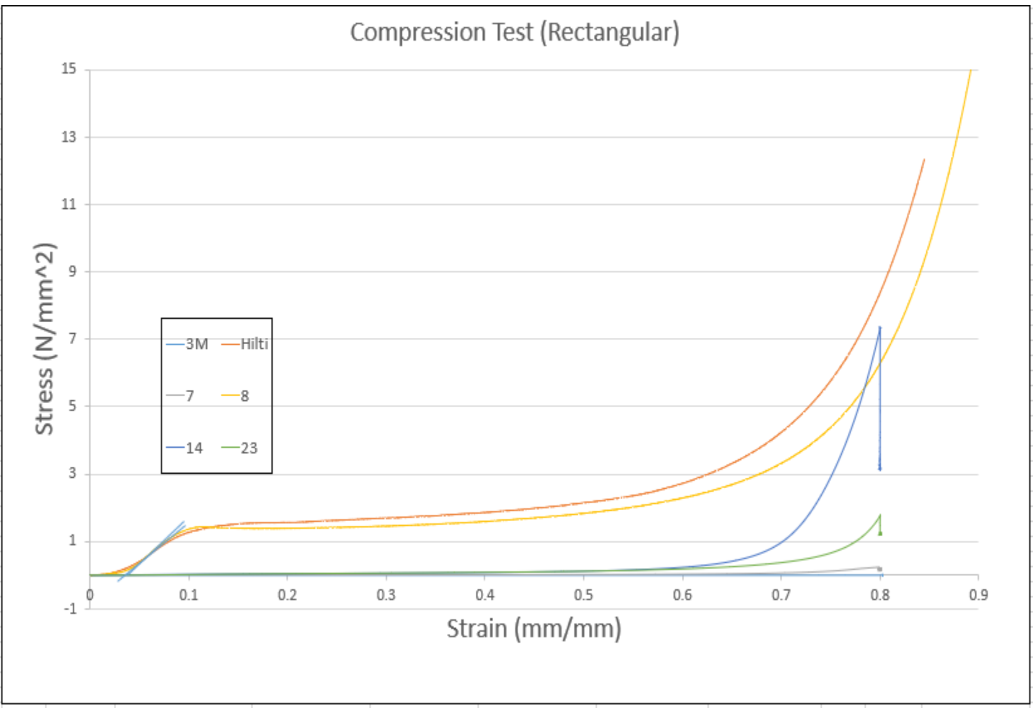
Foam Sample	50% Deflection Stress (MPa)	50% Deflection Load (N)	80% Deflection Stress (MPa)	80% Deflection Load (N)	Thickness Decrease (%)	Final Thickness (mm)
F-1	0.019	47.83	0.15	389.55	-0.15	20.031
F-2	0.117	293.10	4.39	10994.71	0.14	19.97
F-3	0.095	237.43	1.23	3083.20	13.86	17.22
IF-4	0.026	64.66	5.83	14583.28	11.63	17.67
R-1	1.921	4802.16	7.34	18360.05	71.75	5.65
IR-2	2.487	6218.37	9.68	24213.22	71.76	5.64

Compression Testing

Compression Testing Rigid Foam Values

Rigid Foam	Zero-Point Reference	10% Stress (N/mm^2)	10% Load (N)	Modulus (N/mm^2)
8	.01803,.00245	1.37	3415.95	14.51
Hilti	.02,.17	2.05	5125.00	27.09

Objective 1
Compression Testing – Results (Rectangular)



Compression Testing Results (Rectangular)

Compression Testing Values (Rectangular)

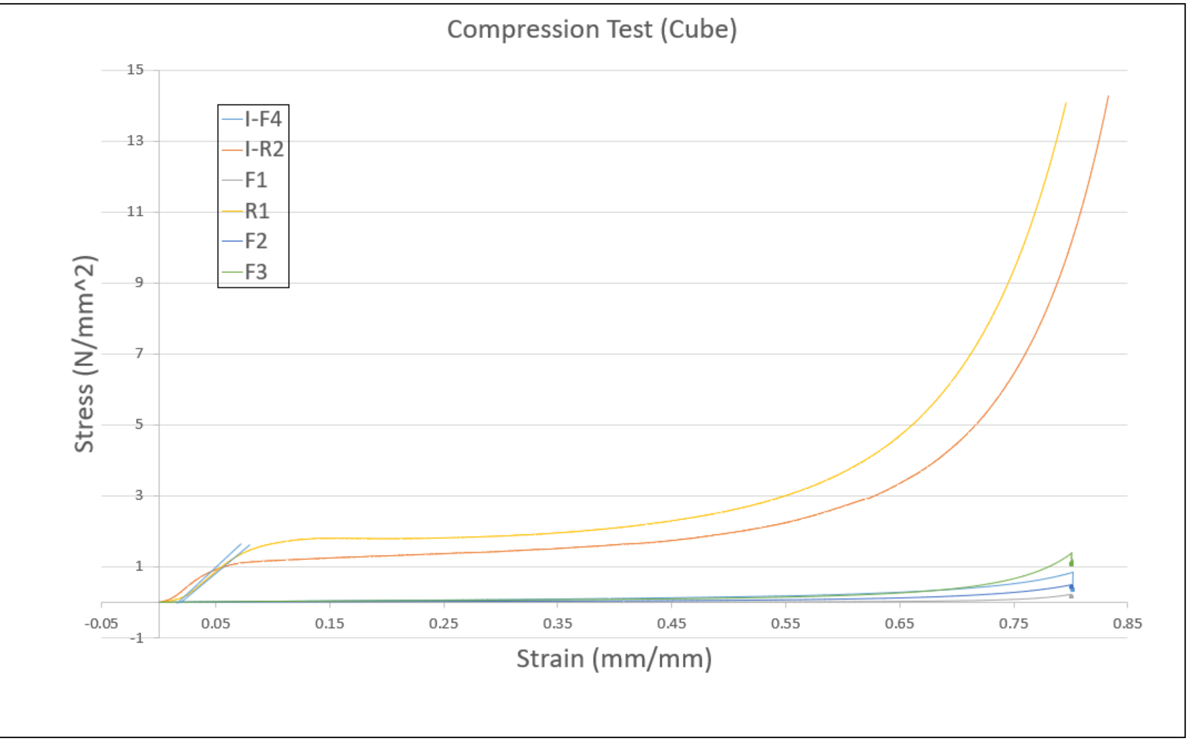
Foam Sample	50% Deflection Stress (MPa)	50% Deflection Load (N)	80% Deflection Stress (MPa)	80% Deflection Load (N)	Thickness Decrease %	Final Thickness (mm)
F-1	0.0207	51.92	0.24	602.60	1.76	19.64
F-2	0.12	307.76	7.33	18337.82	0.622	19.87
F-3	0.12	304.68	1.77	4447.93	0.335	19.93
IF-4	5.57E-05	0.13	0.00083	2.09	15.5	16.9
R-1	1.83	4587.85	6.28	15708.70	71.22	5.75
IR-2	2.14	5369.12	8.37	20941.27	72.9	5.42

Compression Testing

Compression Testing Rigid Foam Values

Rigid Foam	Zero-Point Reference	10% Stress (N/mm^2)	10% Load (N)	Modulus (N/mm^2)
8	.01803,.00245	1.42	3550.00	9.76
Hilti	.01357,.125312	1.36	3400.00	10.72

Objective 1
Compression Testing – Results (Cube)



Compression Testing Results (Cubic)

Compression Testing Values (Cubic)

Foam Identifier	50% Deflection Stress (MPa)	50% Deflection Load (N)	80% Deflection Stress (MPa)	80% Deflection Load (N)	Thickness Decrease (%)	Final Thickness (mm)
F-1	0.009	23.47	0.22	584.04	3.4	49.09
F-2	0.056	143.70	0.49	1282.56	1.24	50.16
F-3	0.117	301.89	1.38	3583.08	1.29	50.15
IF-4	0.151	389.06	0.83	2144.22	32.41	34.34
R-1	2.579	6652.71	14.079	36325.70	68.42	16.04
IR-2	1.949	5028.88	10.08	26028.43	74.75	12.82

Compression Testing

Compression Testing Rigid Foam Values

Rigid Foam	Zero-Point Reference	10% Stress (MPa)	10% Load (N)	Modulus (MPa)
R1	.017, .09	1.74	4498.36	14.38
I-R2	.0104,.0976	1.19	3068.53	16.84

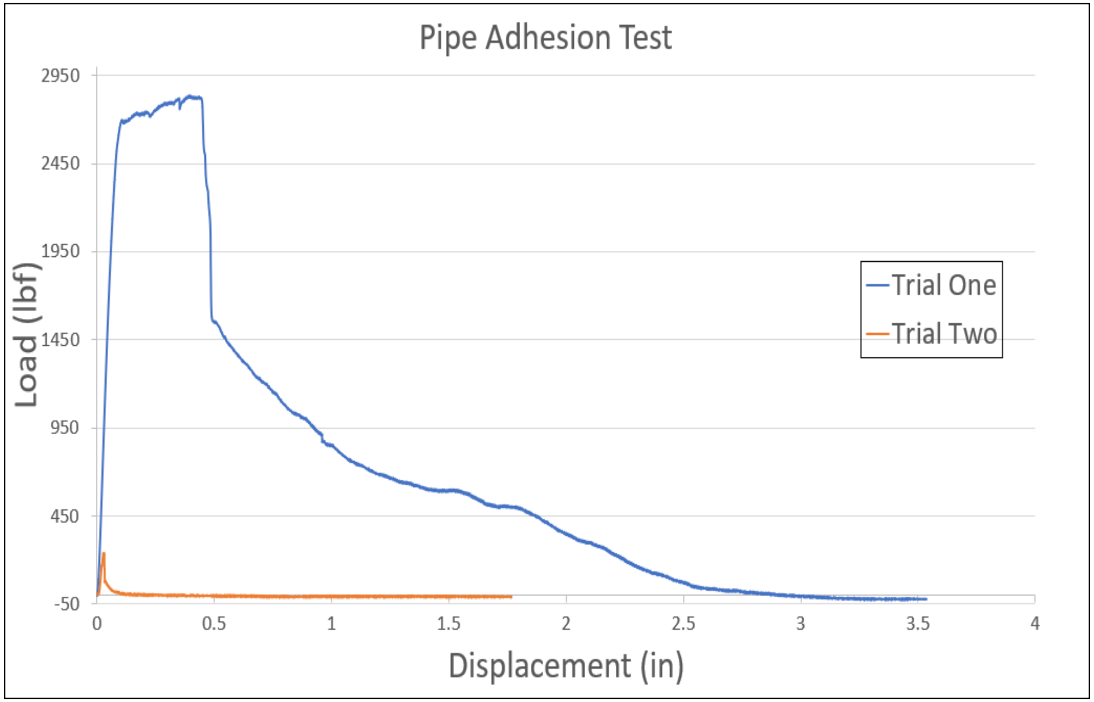
Objective 1
Adhesion Testing Results (ImageJ)

Scanned surfaces of coupons

ImageJ Results

Foam Identifier	Average (%)	Average (in^2)
F-1	4.05	0.16
F-2	0.00	0.00
F3	0.26	0.01
I-F4	61.45	2.46
R-1	7.38	0.30
I-R2	2.84	0.11

Objective 2
Adhesion Testing Results



Adhesion Graph

Experimental Design

Comparison of Both Samples

Conclusions

The I-R2 foam proved to be the best polyurethane foam out of the six candidates in terms of mechanical properties.

- It demonstrated excellent compression capabilities by reaching the load limit of the load cell (40 kN~9000 lbf) for all geometric configurations.
- Tensile testing results showed it experienced the least amount of strain while handling the highest payloads and stresses.
- The other rigid foam, R1, had better adhesion capabilities but some samples of I-R2 performed better before slipping of grips occurred. These results are promising in terms of adhesion.
- Almost 3000 pounds of force was required to extract the I-R2 foam out of the 304 stainless steel pipe which means an accidental impact must be greater than that amount for something catastrophic to occur.

Left picture: Encapsulation pipe experiment conducted at FIU-ARC; Right picture: Simulated contamination (green) inside pipe with foam (red)

Piece on the left shows adhesion qualities of permanent foaming fixative to substrate, 2nd piece shows no adhesion qualities to substrate

Future Work

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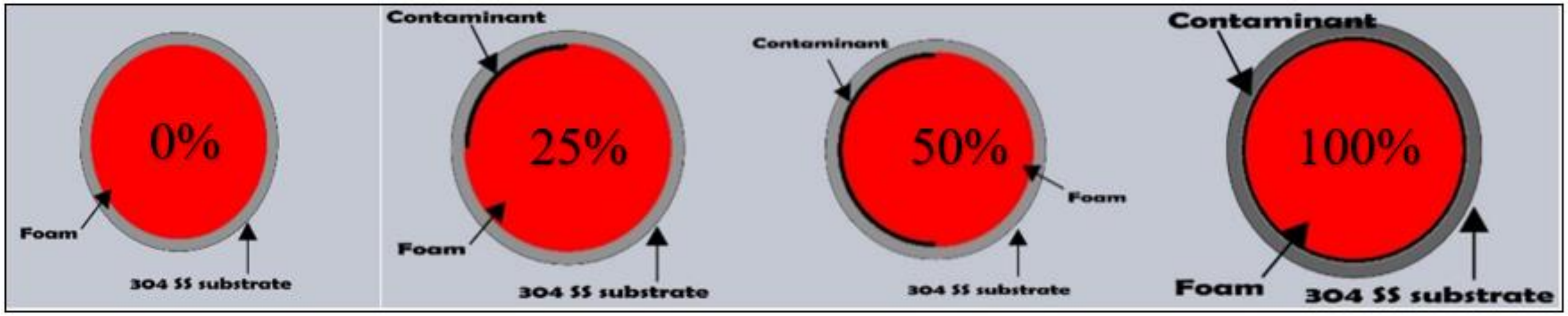
Determining what minimum contact the I-R2 shall have with a 304 stainless steel substrate for adequate adhesion results can also be performed.



1st picture on the left shows foaming fixative with no contaminant; 2nd picture shows the foaming fixative with 25% contamination coverage; 3rd picture shows the foaming fixative 50% contamination coverage; last picture shows the foaming fixative will 100% contamination coverage

Subsequent research will compress the permanent foaming fixative after being subjected to seismic stressors. The seismic stressors will include drop testing (ASTM D4169 and ASTM D5276), fire testing (IEC 60695-11-10), water pressure from a fire hose (NFPA 1962) and water flooding (ASTM D28320). Testing will also follow the same protocols SRNL did for the Model 9977.

All findings can potentially update ASTM E3191: *Standard Specification for Permanent Foaming Fixatives Used to Mitigate Spread of Radioactive Contamination* as a guide to conduct mechanical property testing.

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