Concrete Cavitation- Low-Cost Lining Materials

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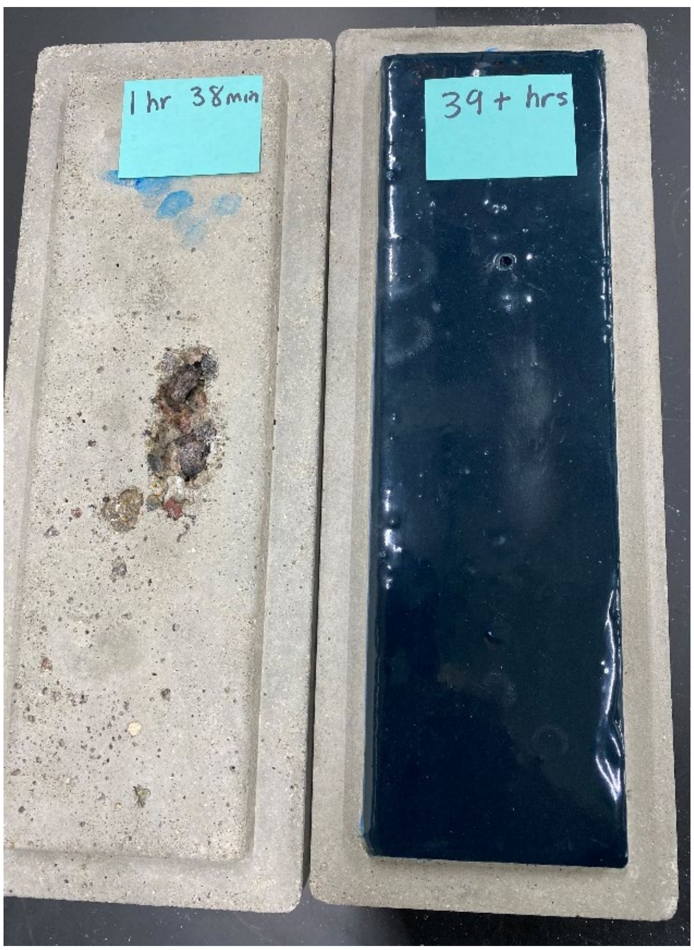

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14. ABSTRACT
The Bureau of Reclamation has a strong need for cavitation resistant materials for use on concrete hydraulic structures, such as spillways and tunnels. The S&T Project 20024 "Evaluation of Field Repairable Materials and Techniques for Cavitation Damage," has compared potential materials for cavitation resistance in a high-pressure cavitation environment and found strong performance with elastomeric cavitation resistant coatings for steel substrates. Some elastomeric coating materials absorb the cavitation energy, which appears to become more important as the substrate becomes more brittle. A preliminary test to compare coated versus uncoated concrete had promising results, with little damage to the coated concrete. This research performed a literature review of elastomeric coatings that could protect concrete surfaces without damage to the underlying concrete.

15. SUBJECT TERMS
Cavitation, cavitation resistance, elastomeric coating, hydraulic concrete structures, impact resistance, protective coatings

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acknowledgements

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Cover Photo: photo on left is concrete subjected to cavitation for 1 hour 38 minutes, photo on right is a concrete sample coated with a cavitation resistant coating after 39 hours (Photo credit: Reclamation, Allen Skaja).

Peer Review

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Acronyms and Abbreviations

%	percent
NL	not listed
PLI	pounds per linear inch
psi	pounds per square inch
Reclamation	Bureau of Reclamation
S&T	Science & Technology

Contents

Page

Executive Summary

The intent of this project was to evaluate commercially available cavitation-resistant coating products for concrete infrastructure that were cost effective, could be applied to larger structures, and could resist cavitation damage. However, during the literature review phase, researchers were unable to identify products that warranted investigating in laboratory testing. The literature review investigated 63 different products from 24 manufacturers and compared their material properties to a predefined criteria with results as follows:

- 26 met the elongation baseline,
- 35 met the tensile strength baseline,
- 21 met the tear resistance baseline,
- and 8 met all three material properties baselines.

All eight products that met all three material properties baselines were ruled out because:

- three products were previously evaluated in S&T project 20024 and performed acceptably, however, they were cost prohibitive for coating large concrete surface areas, at an approximate cost of $1200 per 6 square feet of surface area [1].

- five products were not suitable for water immersion service.

The lack of commercially available products for use in mitigating concrete cavitation is an issue known to TSC researchers. To address this technology gap, there is ongoing research through other S&T-funded projects to develop products with superior cavitation performance:

- Investigating Rubberized Polysiloxane Coating Formulations to Improve Durability and Long-term Performance (S&T Project ID 23009) [2]

- Monitoring Field Trials and Optimizing Cavitation-Resistant Coating Systems (S&T Project ID 24005) [3]

Although these studies focus on cavitation resistant coatings for metallic infrastructure, laboratory testing has shown that these linings can effectively be applied to concrete substrates using the same primer systems, and the substrate does not impact the performance of the applied coating under laboratory cavitation testing. The materials being developed in the above projects are showing excellent cavitation resistance in laboratory testing and are currently in field trials to determine real world cavitation performance. However, the current formulations are not UV stable, and might require additional formulating to obtain UV stability and cavitation performance for use on concrete spillways.

1. Introduction and Background

The Bureau of Reclamation (Reclamation) manages a variety of concrete hydraulic structures, including spillways and tunnels. When water experiences sudden pressure decreases during flow, a process called cavitation can occur, which results in the creation and subsequent implosion of vapor bubbles that cyclically stresses and fatigues the surrounding material in localized areas. The pressure changes are typically created by factors like cracks, offsets, surface irregularities, or open joints. When cavitation does occur, there can be extensive damage over relatively short timescales, which can pose a high risk to Reclamation infrastructure. S&T project 21051 Hydraulic Concrete Surfaces for Water Resources Structures evaluated different concrete mixes to determine the cavitation performance for spillways. Concrete does not have excellent cavitation resistance, but some air entrainment helps resist cavitation damage [4][4].

Previous research findings from S&T project 20024 had identified several elastomeric coatings that provide improved cavitation resistance for steel [1]. The follow-on research described in this report sought to investigate elastomeric protective coatings that could be used to protect concrete surfaces from cavitation. The elastomers evaluated in project 20024 were expensive and the kits only covered six square feet, thus alternative materials would be needed to coat large concrete structures for cavitation resistance. This project plan was a three-stage approach with a literature review to determine if there were any commercially available elastomers that could be spray applied, followed by cavitation jet testing in the laboratory, and a field test on existing hydraulic concrete structures.

However, based on the literature review findings, laboratory and field testing were not pursued. This project will not meet the stated goals and will be terminated early, and funds returned to the Science and Technology Program.

2. Literature Review

Researchers searched literature of commercially available products and online for elastomers that showed potential for mitigating cavitation for concrete structures but that are presently used for other applications. Generally, the products that were investigated were identified by the manufacturers as suitable for application to concrete structures. The search criteria included the following coating characteristics which were deemed most indicative of cavitation performance based on the data collected in S&T Project 20024 [1]:

- Suitable for water immersion
- Material properties that meet or exceed the following benchmark [1]:
    - 500 percent elongation
    - 2,000 pounds per square inch (psi) tensile strength
    - 400 pounds per linear inch (PLI) tear resistance

The material properties baseline was established based on the prior research outcomes for coatings on steel substrates, with the successful elastomer materials meeting these minimum performance criteria.

3. Results and Discussion

The literature review results are included as Appendix A. Of the 63 products from 24 manufacturers that were identified and included as part of the literature review:

- 26 met the elongation baseline,
- 35 met the tensile strength baseline,
- 21 met the tear resistance baseline,
- and 8 met all three material properties baselines.

All eight products that met all three material properties baselines were ruled out because:

- three products were previously evaluated in S&T project 20024 and performed acceptably, however, they were cost prohibitive for coating large concrete surface areas, and approximately cost $1200 per 6 square feet of surface area [1].

- five products were not suitable for water immersion service.

In the proposal, one of the product criteria was that the materials should have UV stability. This criteria was removed as a requirement since there was no UV stable materials identified that had the three baseline material properties.

Since the literature review did not identify any promising products, the Science & Technology (S&T) Program and the research team decided that laboratory testing was not worth pursuing, and the project was concluded.

4. Conclusions and Future Work

The intent of this project was to evaluate inexpensive products that could be applied to larger concrete infrastructure to potentially help resist cavitation damage. However, during the literature review phase, researchers were unable to identify any promising products worth investigating in laboratory testing.

The lack of commercially available products for use in mitigating cavitation is a known issue for TSC researchers. To address this technology gap, there is ongoing research through other S&T-funded projects to develop products with superior cavitation performance:

- Investigating Rubberized Polysiloxane Coating Formulations to Improve Durability and Long-term Performance (S&T ID 23009) [2]

- Monitoring Field Trials and Optimizing Cavitation-Resistant Coating Systems (S&T ID 24005) [3]

Results from these research efforts are expected to be published in Fiscal Years 2025 and 2026, respectively. For more information, please contact the Principal Investigator, Allen Skaja (askaja@usbr.gov, 303-445-2396).

Although these studies focus on cavitation resistant coatings for metallic infrastructure, laboratory testing has shown that these linings can effectively be applied to concrete substrates using the same primer systems, and the substrate does not impact the performance of the applied coating under laboratory cavitation testing. The materials being developed in the above projects are showing excellent cavitation resistance in laboratory testing and are currently in field trials to determine real world cavitation performance. However, the current formulations are not UV stable, and might require formulating to obtain UV stability and cavitation performance for concrete spillways.

5. References

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6. Appendix A

The table below provides the published tensile strength, elongation, and tear strength for products identified during the literature review. The products are listed and numbered in no particular order. Green cells indicate values above baseline, red cells indicate values below baseline, and "NL" indicates that the value was not listed.

Table A-1.—Literature Review Results

No.	Product Name	Reference	Tensile Strength (psi)	Elongation (%)	Tear Strength (lbf/in) or (PLI)	Immersion (Y/N)
1	Sikalastic 710/715/735 AL System	5	3,900	260	*NL*	
2	Sikalastic 726 Balcony One Shot	5	2,400	*NL*	300	
3	Sikalastic 710 Base	5	800	*NL*	170	
4	#302 Rubber Coat Asphalt Emulsion	6	172	1,223	23	
5	Diathon HT Roof Coating	7	500	500	*NL*	
6	Elastuff 101	8	1,000	500	125	
7	Elastuff 103	8	2,500	400	285	
8	Karnak 501 Elasto-Brite	9	259	237	82	
9	Acryshield 550 HT	10	361	573	105	
10	3M Scotch-Weld Elastomeric Coating EC-5816	11	2,000	350	250	
11	Nukote ALU-FR	12	2,100	60	400	
12	VFI-2839 95 A Aliphatic Spray Coating	13	1,200	300	400	
13	VFI-270 70 A Polyurea Spray Coating	13	1,050	600	175	
14	VFI-3119 70 A Polyurea Hybrid Spray Coating	13	1,200	800	240	
15	VersaFlex VF 380™FR, elastomeric polyurea	14	1,800	350	300	
16	VersaFlex Aliphatic Clearcoat+, polyaspartic pure polyurea	14	5,945	5	460	N
17	VersaFlex GELFLEX® 1115	14	4,500	5.5	600	Y
18	VersaFlex AquaVers™ 201, polyaspartic polyurea	14	2,500	115	500	
19	Raven® 171FS	15	4,900	12	*NL*	
20	Starken Aqua Elastic 990, high elastic waterproofing coat	16	170	100	*NL*	Y
21	GacoFlex U91	17	2,600	350	360	

No.	Product Name	Reference	Tensile Strength (psi)	Elongation (%)	Tear Strength (lbf/in) or (PLI)	Immersion (Y/N)
22	GacoFlex UA60	17	3,000	180	480	
23	GACOFLEX™ UA7090	17	7,500	325	600	Y
24	Devcon® R-Flex®	18	1,462	421	270	Y
25	Devcon® Flexane® 80 Putty	18	1,700	300	300	Y
26	Devcon® Flexane® Brushable	18	3,500	600	400	Y
27	Devcon® Flexane® High Performance Putty	18	4,500	600	400	Y
28	Devcon® Flexane® 80 Liquid	18	2,100	650	350	Y
29	Devcon® Flexane® 94 Liquid	18	2,800	500	415	Y
30	Devcon® Flexane® Fast Cure Putty	18	2,400	500	275	Y
31	Devcon® Flexane® Fast Cure Liquid	18	3,300	450	430	Y
32	Northstar Ester base high-performance polyurethanes – Ester "Quasi" System MSS-A95BQ	19	5,500	700	913	N
33	Northstar Ester base high-performance polyurethanes – Ester "Quasi" System MSS-A85BQ	19	6,200	800	720	N
34	Northstar Ester base high-performance polyurethanes – Ester "Quasi" System MSS-A80AQ	19	6,000	900	600	N
35	Northstar Ester base high-performance polyurethanes – Ester "Quasi" System MSS-A70GQ	19	4,200	800	300	N
36	Northstar Ester base high-performance polyurethanes – Ester "Full Prepolymer" System MSB-D60A	19	6,125	300	950	N
37	Northstar Ester base high-performance polyurethanes – Ester "Full Prepolymer" System MSB-A95A	19	4,266	400	700	N
38	Northstar Ester base high-performance polyurethanes – Ester "Full Prepolymer" System MSS-A90A	19	4,200	650	600	N
39	Northstar Ester base high-performance polyurethanes –	19	5,800	725	725	N

No.	Product Name	Reference	Tensile Strength (psi)	Elongation (%)	Tear Strength (lbf/in) or (PLI)	Immersion (Y/N)
	Ester "Full Prepolymer" System MSS-A85C					
40	Northstar Room Temperature Curable Polyurethane Casting System MPP-A25E	19	389	995	90	
41	Northstar Room Temperature Curable Polyurethane Casting System MPP-A30A	19	260	550	40	
42	Northstar Room Temperature Curable Polyurethane Casting System MPP-A40E	19	867	1037	134	
43	Northstar Room Temperature Curable Polyurethane Casting System MPP-A47A	19	450	520	90	
44	Northstar Room Temperature Curable Polyurethane Casting System MPP-A50A	19	248	130	45	
45	Northstar Room Temperature Curable Polyurethane Casting System MPP-A50E	19	1301	708	248	
46	Northstar Room Temperature Curable Polyurethane Casting System MPP-A60A	19	366	157	118	
47	Northstar Room Temperature Curable Polyurethane Casting System MPP-A65A	19	480	180	92	
48	Northstar Room Temperature Curable Polyurethane Casting System MPP-A80E	19	1,100	180	140	
49	Northstar Room Temperature Curable Polyurethane Casting System MPP-A90A	19	1,800	350	250	
50	Northstar Room Temperature Curable Polyurethane Casting System MPP-D65A	19	1,250	34	388	
51	Northstar Room Temperature Curable Polyurethane Casting System MPG-D70A	19	3,600	60	880	
52	Northstar Room Temperature Curable Polyurethane Casting System MPP-D80B	19	8,000	5	*NL*	
53	Northstar Room Temperature Curable Polyurethane Casting System MPP-A80H	19	1,818	813	427	

No.	Product Name	Reference	Tensile Strength (psi)	Elongation (%)	Tear Strength (lbf/in) or (PLI)	Immersion (Y/N)
54	Chesterton ARC CS2 (Concrete Protection)	20	3,380	4.7	*NL*	
55	ChestertonARC SL-E (Industrial Floors)	20	4,200	1.01	*NL*	
56	Chesterton ARC SD4i (Erosion/Corrosion Resistant)	20	3,800	2.8	*NL*	
57	Rust-Oleum 1085 Polyurethane Roof Coating	21	3,480	313	266	
58	3M Scotchkote Urethane Roof Coating SD 650	11	2900	230	314	
59	Aquathane R100	22	725	500	*NL*	
60	ARMORROOF LIQUID RUBBER ROOF COATING	23	1000	500	*NL*	
61	Kymax Coating "PVDF Fluoropolymer"	24	1,050	150	200	
62	7490 (478JB) Aliphatic Urethane Roof Coating	8	3042	263	400	
63	Dureflex® A4700 (optical grade adhesive film)	25	5500	500	250	

Notes: psi=pounds per square inch, %=percent, PLI=pounds per lineal inch, NL=not listed.