BUREAU OF RECLAMATION

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Cavitation Resistant Materials

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Cavitation Overview

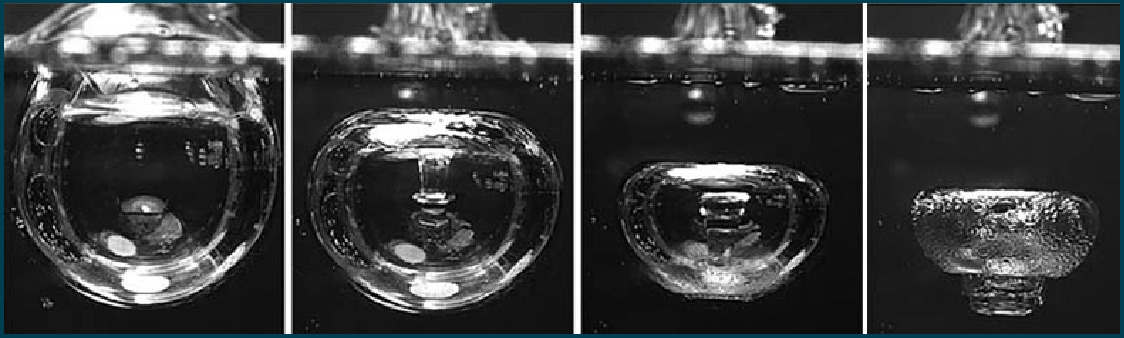
Cavitation is rapid formation and collapse of vapor bubbles in water with sudden pressure changes

- Ex. water accelerated to high velocities
- Ex. Rapid bends in water direction

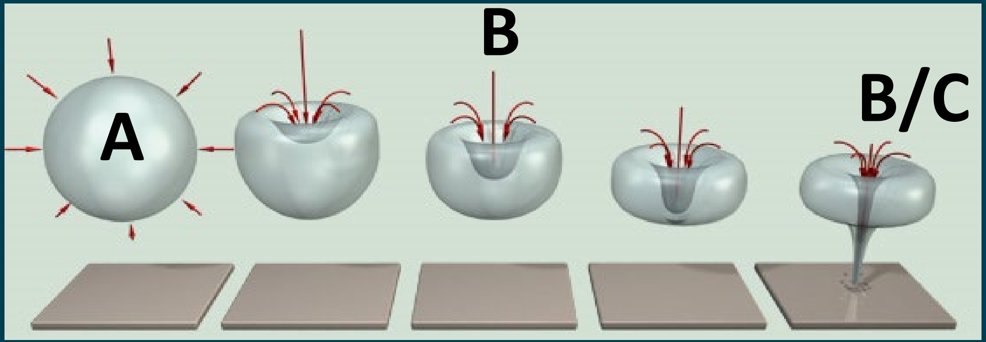
A) Pressure of liquid drops to vapor pressure

B) As these vapor bubbles enter area of higher pressure, the bubbles implode/suddenly collapse.

C) High energy shock waves



Reproduced from " Hydrodynamic cavitation and its application in the fuel industry," GlobeCore, 2021. [Online]. [Accessed Sep 2021].



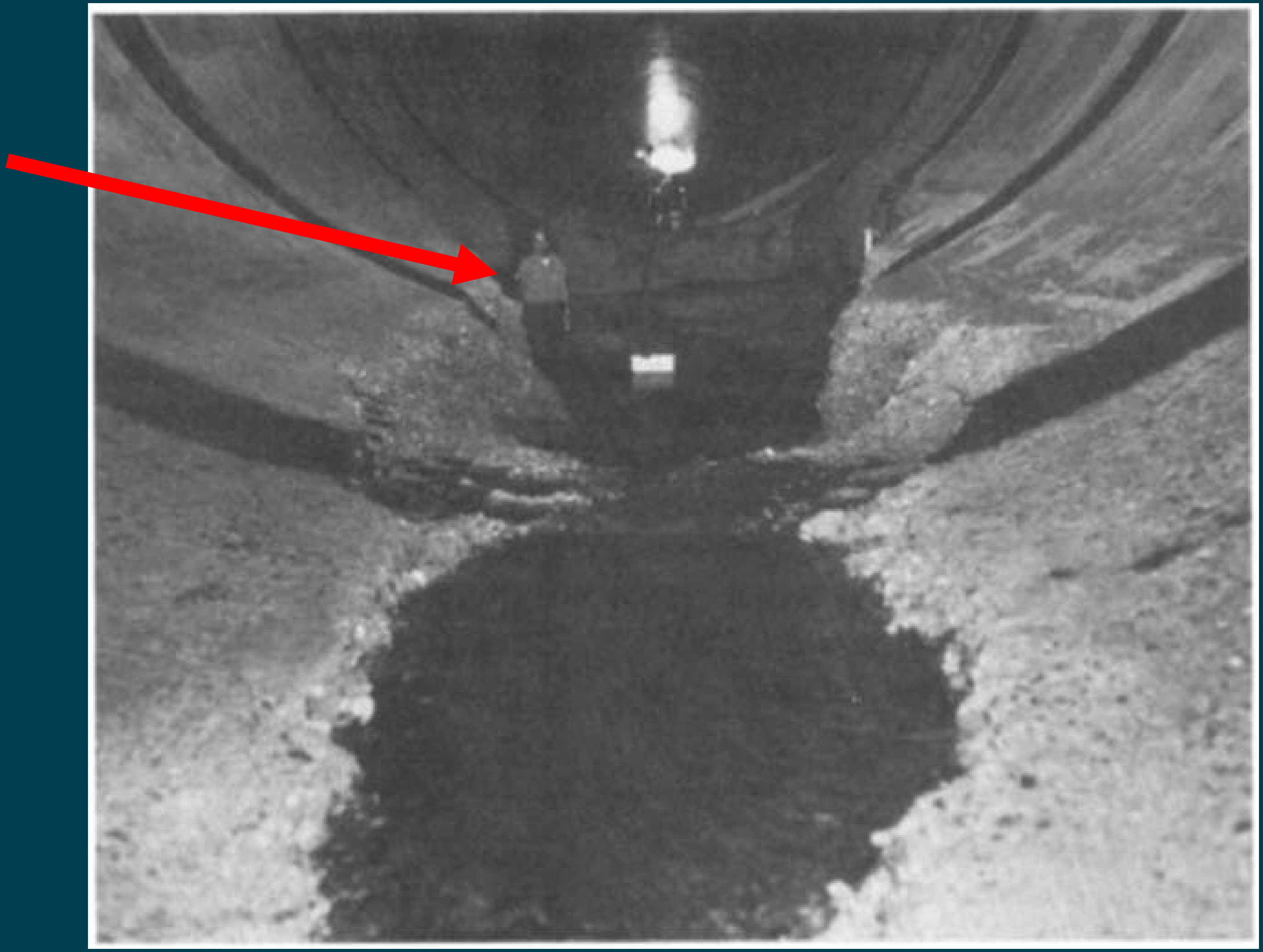
Series of graphics depicting a cavitation model. Reproduced from "Cavitation," Focus-It, LLC, 2012. [Online]. Available: http://eswt.net/cavitation. [Accessed July 2019].

Cavitation Overview

- Microscopic impacts erode the structural surface
- Micro-fractures the surface and creates pits
- Material failure through fatigue

The Glen Canyon dam spillway damage 1983

Cavitation Overview



Cavitation damage to spillway tunnel of Yellowtail Dam.

Arndt, Roger. (2003). Cavitation in Fluid Machinery and Hydraulic Structures. Annual Review of Fluid Mechanics. 13. 273-326. 10.1146/annurev.fl.13.010181.001421.

Structures Affected by Cavitation

- Turbine runners
- Draft tubes
- Butterfly valves

- Produces rotational force that is converted into power.
- Blades capture the kinetic energy from the water.
- Rust look is from galvanic corrosion- SS weld overlay pops off

Structures Affected by Cavitation

- Turbine runners
- Draft tubes
- Butterfly valves

- Tube fitted at end of runner
- Increases efficiency of the hydro-turbine
- Increases the pressure of exiting fluid by decreasing exit velocity

Structures Affected by Cavitation

- Turbine runners
- Draft tubes
- Butterfly valves

- Used as on-off valves
- Have a rotating leaf (disc)
- Safety and maintenance device for penstocks, turbines
- Cavitation happens as flow velocity changes rapidly

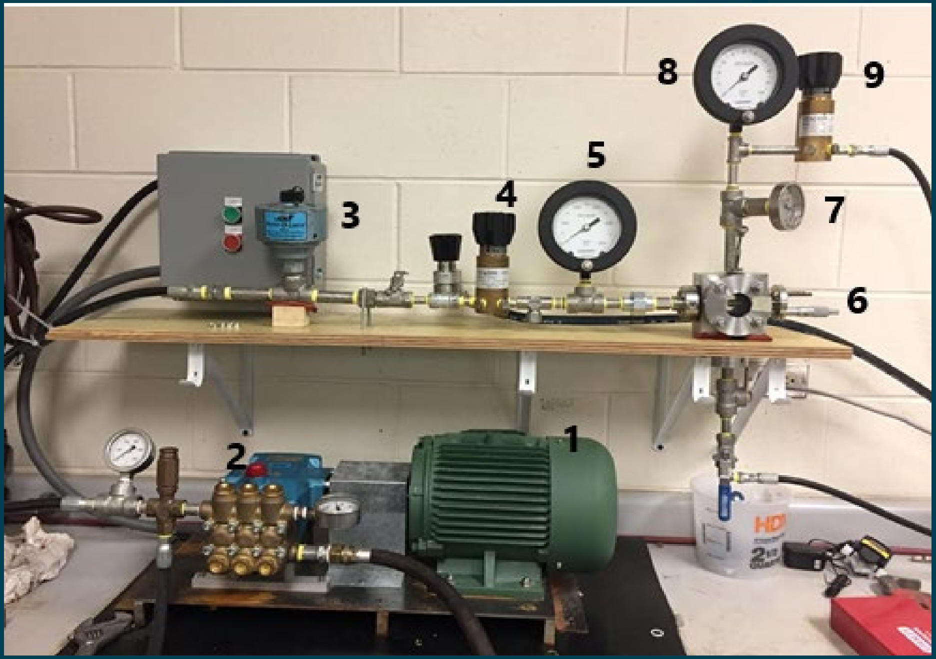
What does Reclamation currently use for Cavitation Resistance?

- Stainless steel
- Stainless steel weld overlays
- Elastomeric cavitation repair material
- Ceramic filled epoxy

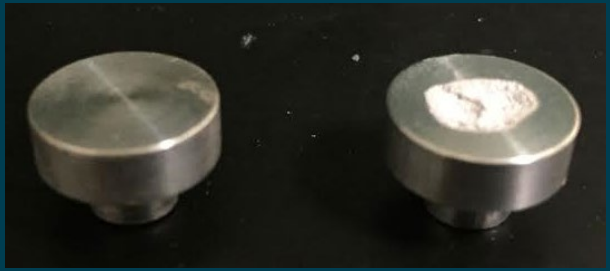
Test Procedure Development

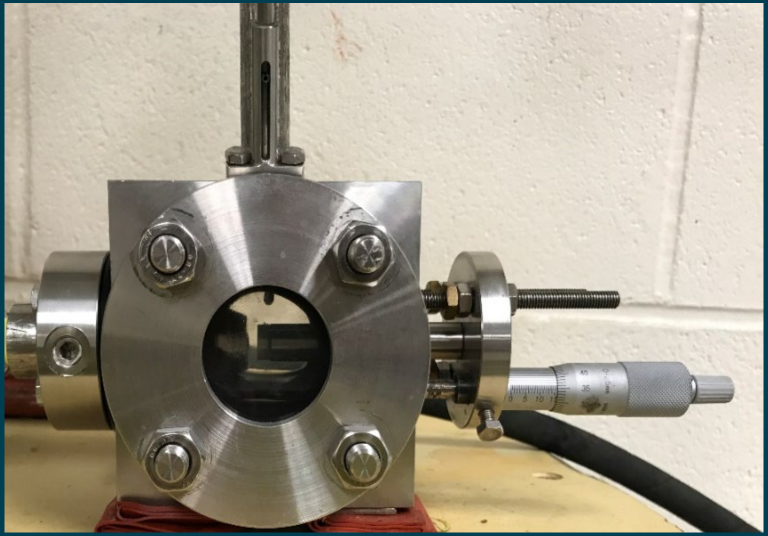
FY2016-FY2019

- Development of test procedure
  - ASTM jet cavitation
  - Venturi cavitation apparatus
  - Pressure washer jet test

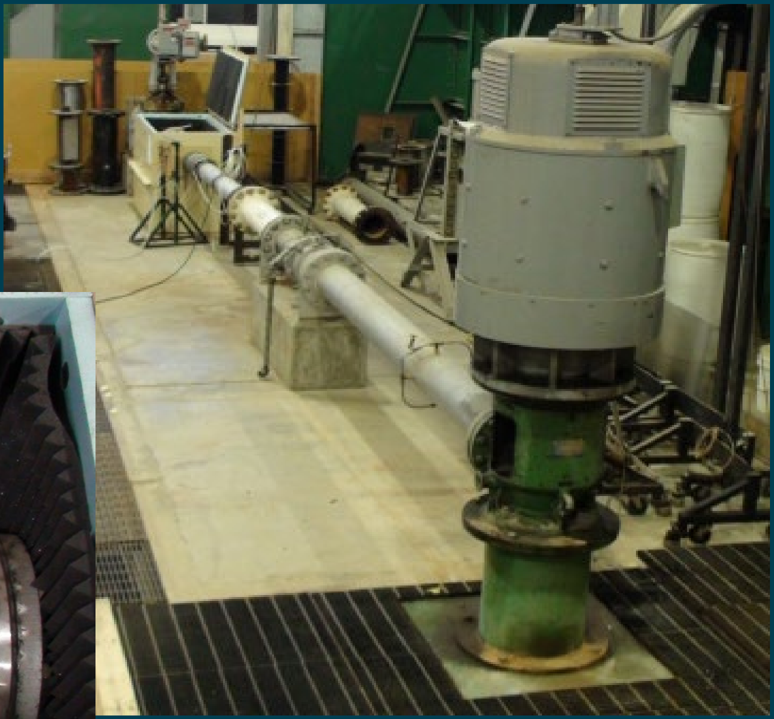


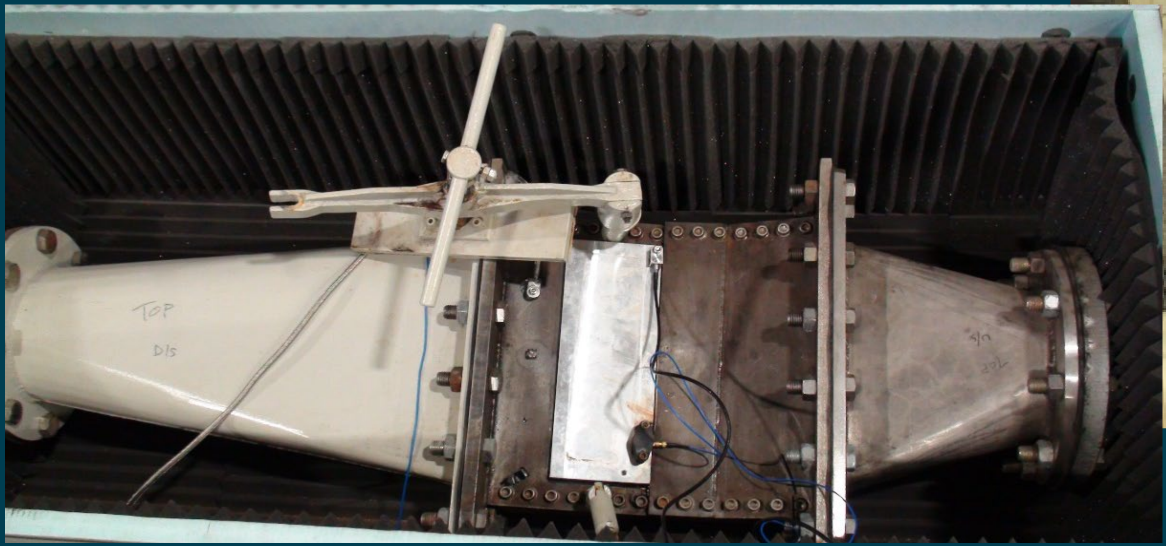
1. Cumbersome to get operational (standoff distance an issue)
2. Not representative of field sample size and test conditions





- Development of test procedure
  - ASTM jet cavitation
  - Venturi cavitation apparatus
  - Pressure washer jet test

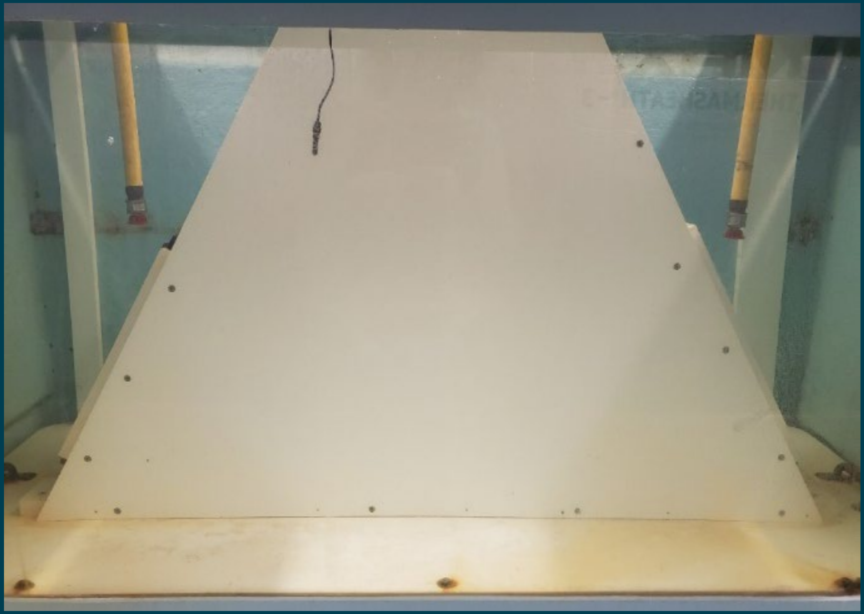




1. Very slow test (180 hrs for single Aluminum sample)
2. Not practical for obtaining enough statistically relevant samples (triplicate for each sample type)

- Development of test procedure
  - ASTM jet cavitation
  - Venturi cavitation apparatus
  - Pressure washer jet test

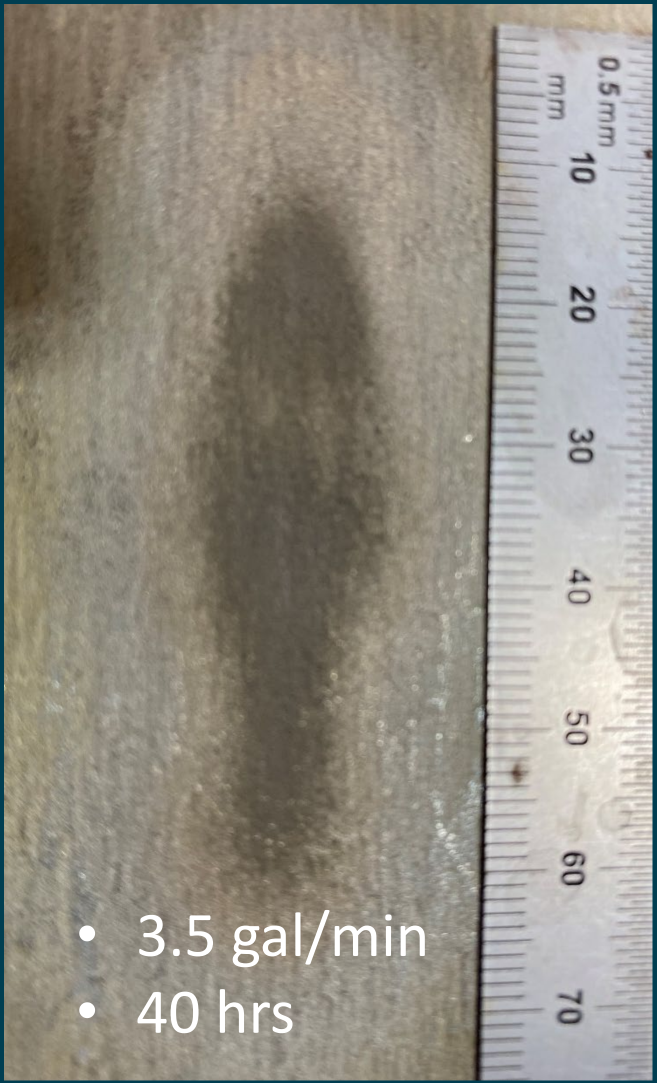
1. Good rate of testing to allow for many samples
2. Field representable size
3. Can run 2 tests at the same time in tank
4. Jet nozzle fixed in place.



Materials Research

Steel baseline

Stainless steel baseline



Jet tests on Cold Spray 316 Stainless Steel

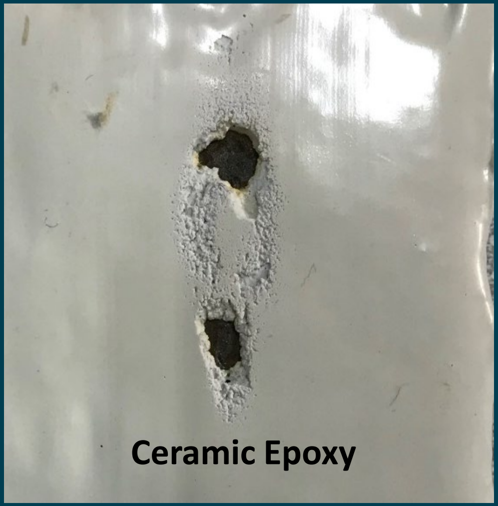
- Failure at 60 hrs
- Extensive cracking
- Tested at 5 gal/min
- Needs to be re-run at 3.5 gal/min.

Jet tests on Thermal Spray

- Super Nickel alloy
- Performance: Wore away 7 hrs and 5 hrs
- 5 gal/min
- Needs to be re-run at 3.5 gal/min.

Transition to Cavitation Resistant Coatings Research

- These ran at 2.6 gal/min
- Need re-run at 3.5 gal/min



- Materials tested:
  - Ceramic Epoxies
  - Polyurethane elastomer
  - USACE Vinyl system

2.6 gal/min

3.5 gal/min

FY2020 Results (prior to Covid):

2.6 gal/min - needs to be re-run at 3.5 gal/min

Product Name	Average Time to failure (hrs)	Average Thickness (mils)	Average Rate (mils/hr)
Ceramic filled epoxy 1	60	60	1
Ceramic filled epoxy 2	19	55	2.9
Ceramic filled epoxy 3	48	56	1.3
Ceramic filled epoxy 4	100	50	0.5
USACE Vinyl 5EZ new steel	7	12	1.8
USACE Vinyl 5EZ pitted steel	0.6	12	20
Ceramic filled epoxy 5	9	28	3
Ceramic filled epoxy 6	9	20	2.2
Ceramic filled epoxy 7	16	32	2
Ceramic filled epoxy 8	8.5	20	2.3
Polyurethane Elastomer	Greater than 200 hrs, terminated test due to no degradation	50	--

FY2021-22 Research:

- Tests revealed no damage to steel after testing at 2.6 gal/min.
- Test revealed that 5.0 gal/min was too aggressive.
- Testing adjustments were made to 3.5 gal/min.
- Focus shifted to elastomer coatings

- Planned tests:
  - Stainless steel weld overlay (CaviTec and 308 stainless steel)
  - 2 Polysulfide epoxy formulas (elastomer)
  - 7 Elastomeric cavitation repair materials
  - Re-run cold spray and thermal spray (if we can get some samples)

Research Conclusions

- Test procedure examines time to failure, since coatings cannot give a useful mass loss amount compared to mass of metal substrate.
- Thermal spray super nickel alloy and cold spray stainless steel samples should be re-run at 3.5 gal/min.
- Elastomers appear to work better than ceramic filled epoxies
- Add high flow adhesion testing to check delamination, which is an issue for some elastomers

QUESTIONS?

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