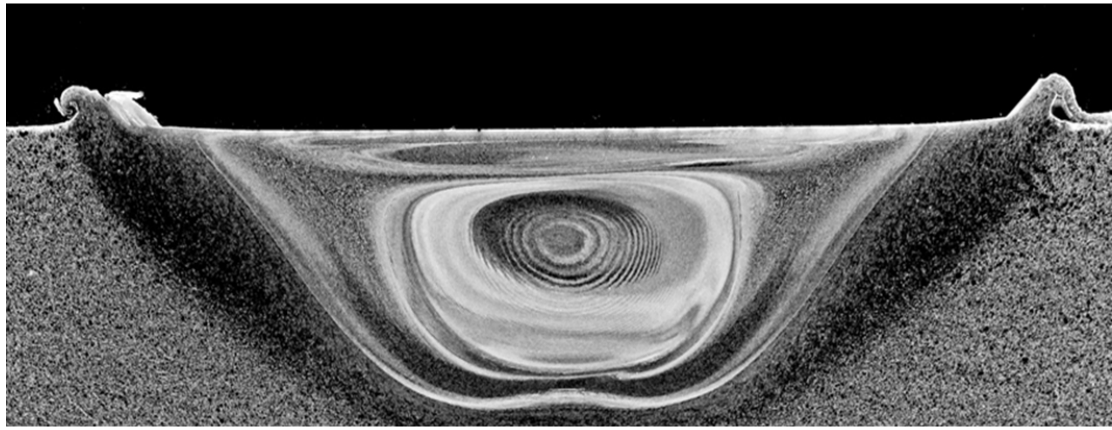
Corrosion Resistant Aluminum Components for Improved Cost and Performance of Ultra-Deepwater Offshore Oil Production



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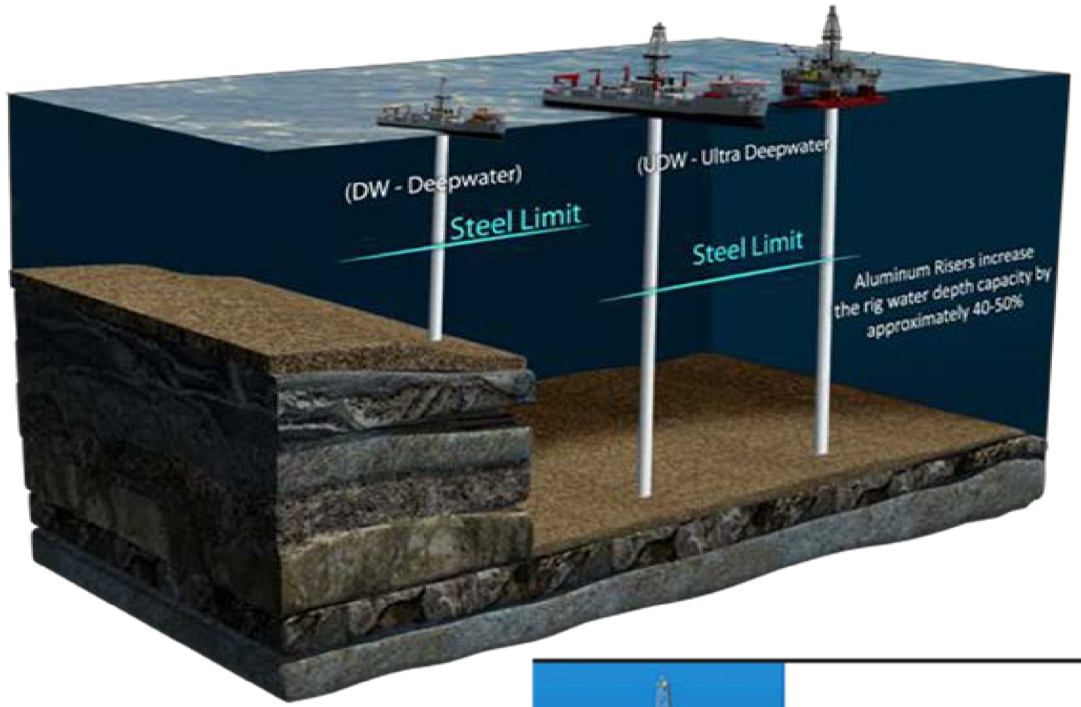
The Opportunity

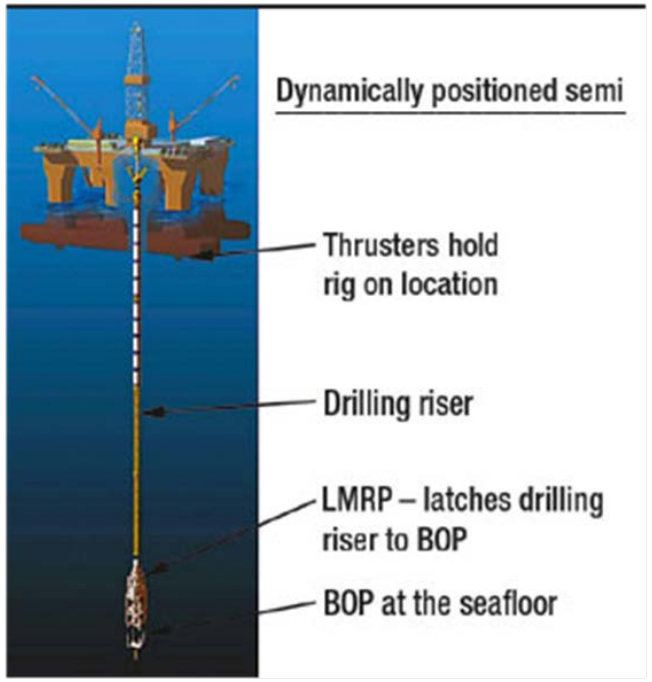
- A significant cost barrier for production of hydrocarbon resources from ultra deep water is the weight of the steel riser systems
- Replacing steel risers with aluminum can dramatically improve the economics of oil production from ultra-deepwater resources



Specific Advantages of Aluminum

- 40% lighter than Steel Riser.
  - Aluminum Slick Riser – 18,000 lbs.
  - Steel Slick Riser – 30,000 lbs
- 1/2 the buoyed weight of steel riser joint
  - 1/3 of joints require buoyancy vs. 95% of steel joints
- 46” versus 54” buoyancy diameter—reduced drag
- Allow floating rigs to increase depth 50% without extensive modifications
- For 12,000-foot water depth, Aluminum Riser will save more than 1,920,000 lbs of deck load.

Aluminum risers can increase rig water depth by approximately 42.5%



Favorable Economics

Steel risers in deep and ultra deep water requires that rigs be significantly modified to increase deck load capacity.

- Aluminum avoids tensioning system upgrades
- Avoids rotary table and top drive upgrades
- Avoids estimated ~$44M for equipment upgrades
- Easier maintenance—no descaling or painting
- Lower marine growth
- Easier to handle

- In one deep water application analyzed, extending the offshore depth from 4000 feet to 9000 feet would cost an estimated $33M using aluminum risers compared to $200-300M with conventional steel risers

What is the Challenge?

In 12,000-foot Water Depth the riser load rating can be as high as 3.2 million pounds in tension

The primary challenge is the strength of aluminum and specifically, the strength and corrosion performance of aluminum welds

Successes and Challenges from the past

- Commercial oil production from conventional deepwater (<7000 feet) resources has been successfully demonstrated on three separate 6xxx aluminum riser systems.
  - More than 12 years of continuous service at depths up to 7200 feet have shown that low strength aluminum risers are viable in seawater environments.

- But, moving aluminum riser technology to ultradeep water (>7000 ft) presents a large challenge:
  - Riser strength- The relatively low strength of 6xxx aluminum alloys are insufficient for ultra-deepwater.
    - Low strength 6xxx aluminum in ultra-deepwater applications, would require the flange and pipe wall thicknesses to be significantly increased
    - This added mass would entirely negate all of the weight saving advantages of aluminum

Higher strength aluminum alloys, such as 7XXX alloys, are required for achieving ultra-deep water drilling and production

The Problem with High Strength Aluminum

7xxx alloys are difficult or impossible to fusion (arc) weld

- Melting during conventional fusion (arc) welding of 7xxx alloys can significantly degrade weld strength and corrosion performance
- Many 7xxx alloys are un-weldable due to weld induced cracking.

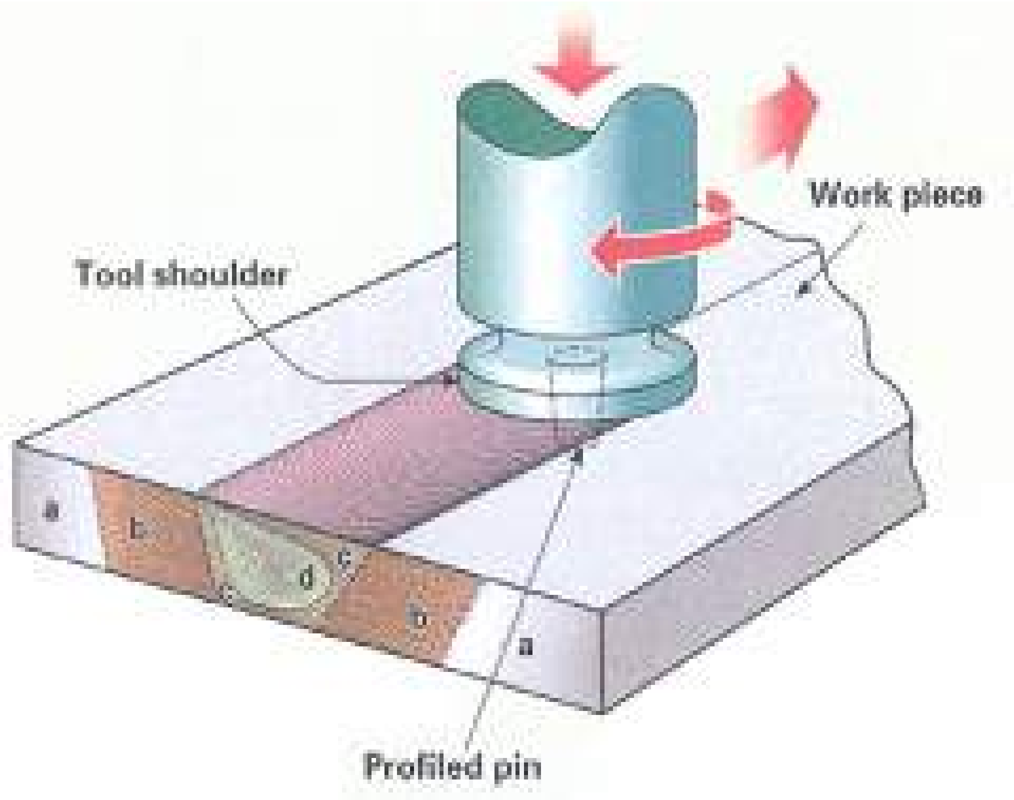
The Solution

Develop a new weld process that does not suffer from the problems created by fusion welding. This project will develop a solid state joining process, friction stir welding, for the flange-to-pipe and pipe to pipe weld, and will establish the necessary post-weld heat treatment schedule in a 7XXX series alloy selected by the team.

What is Friction Stir Welding?

Solid-Phase joining processes
(no material melting)

- Spinning, non-consumable tool is plunged into the surface of a material.
- Friction and plastic work energy heats the material sufficiently to lower the flow stress.
- When material softens, the tool is then translated along the joint line causing material in front of the pin to be deformed around to the back, and forged into the gap behind the traveling pin
- The resulting joint is characterized by:
  - A “Nugget” composed recrystallized and transformed grains (d)
  - Surrounded by a mechanically deformed heat affected zone (c) and an undeformed heat affected zone (b)



FSW in 1 inch thick 7xxx alloy

Project Summary

Aluminum risers increase rig water depth by approximately 42.5%

Overview

- ❑ Develop the FSW process and characterize the mechanical and corrosion performance of the weldments
- ❑ Fabricate subscale and full scale risers for qualification testing

Project Approach

- Task 1 Develop a friction stir welding process for joining 7XXX aluminum alloys.
- Task 2 Establish a post-weld heat treatment schedule for 7XXX aluminum joints to improve corrosion resistance and strength of the weld.
- Task 3 Explore cold spray as a corrosion mitigation strategy.
- The project will conclude by fabricating 7xxx riser assemblies for performance evaluation by the project partners.

Project Team and Roles

- PNNL - Weld process and corrosion barrier development
- XYMAT Engineering - Full scale aluminum riser fabrication, materials
- OTTO FUCHS – materials, mechanical testing

- **Project Duration: FY19-FY21**
- **DOE-FE Funding: $1.5M**
- **Industry Cost-Share: $4.0M**

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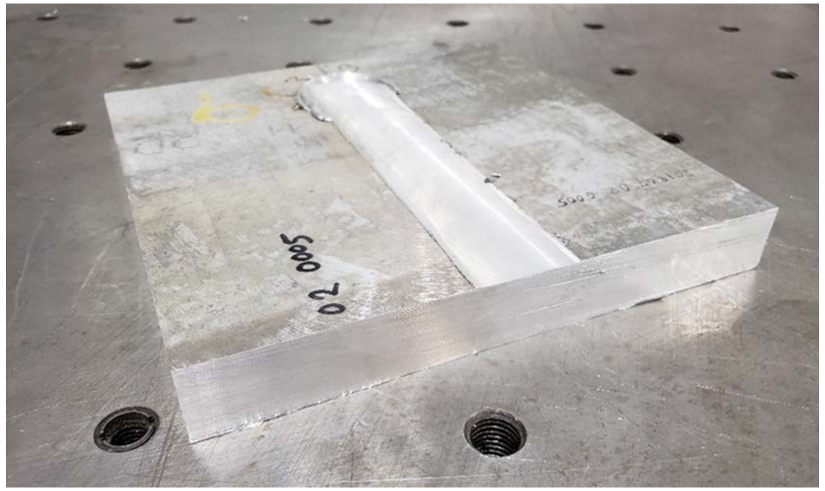
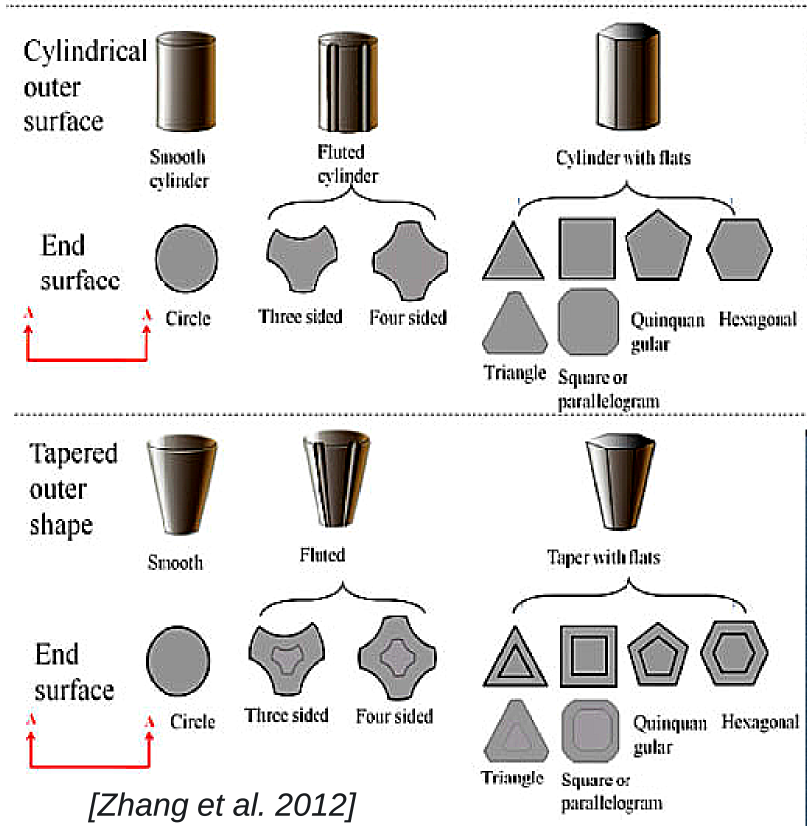
Task 1: FSW Process Development

- **Develop FSW process parameters and tooling for generating fully consolidated, indication free, welds made in AA7175**
  - Task 1.1 - Design and fabricate FSW pin tools within integrated temperature sensors
  - Task 1.2 - Develop temperature control and process parameters for 1.2” thickness
  - Task 1.3 - Perform mechanical property testing
  - Task 1.4 - Perform optical microscopy as screening tool for detecting indications

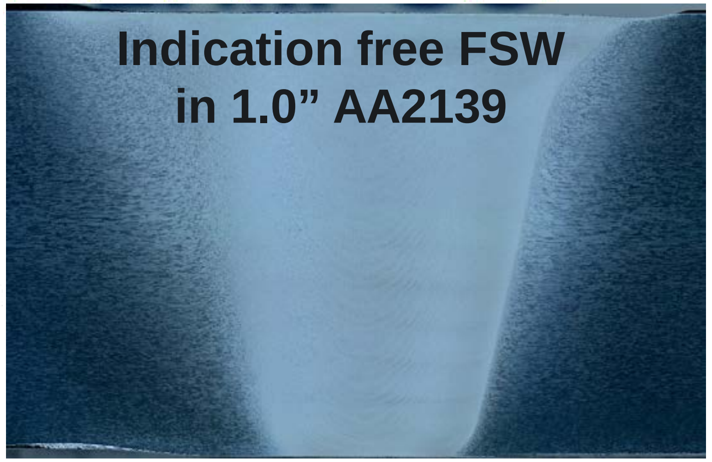


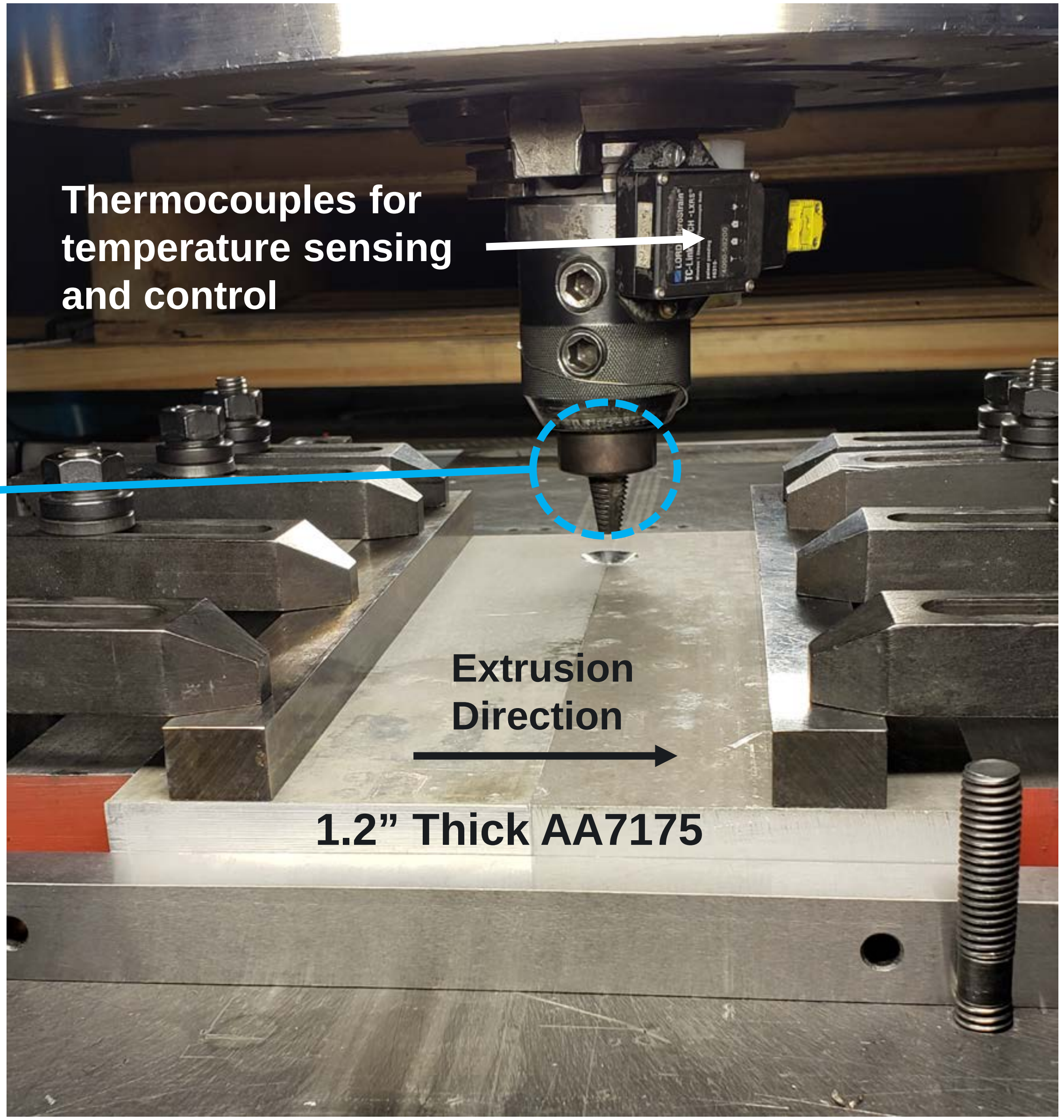
Task 1: FSW Process Development

Common pin shapes used in FSW



[Zhang et al. 2012]

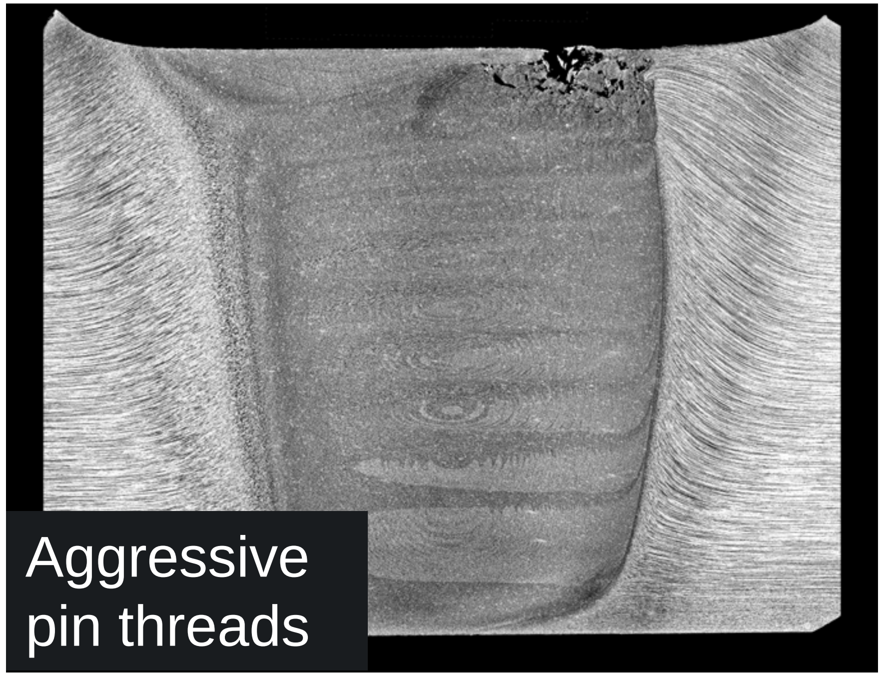




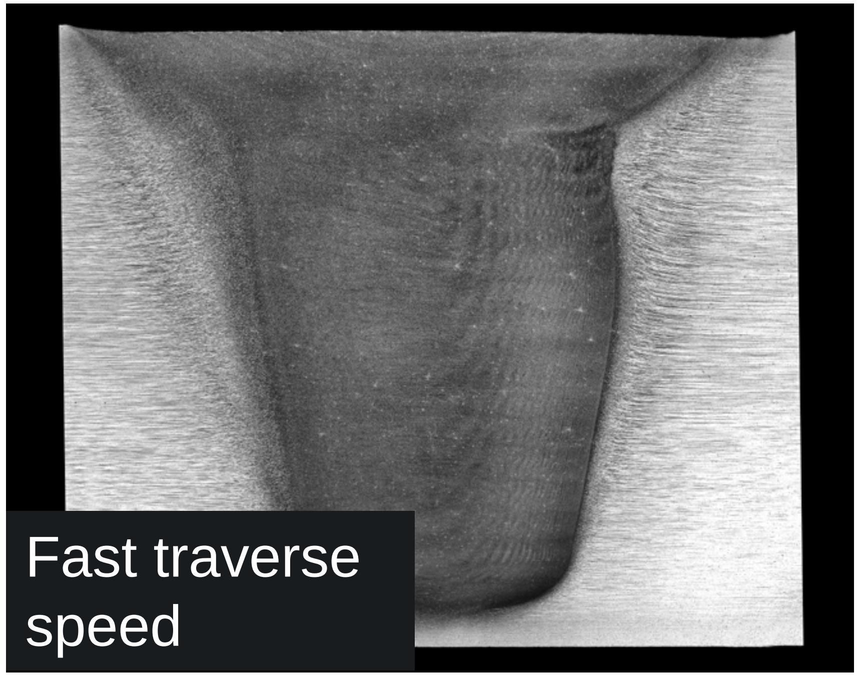
Task 1: FSW Process Development

A suite of tools have been designed and fabricated to determine a tool/process combination that results in welds with best properties

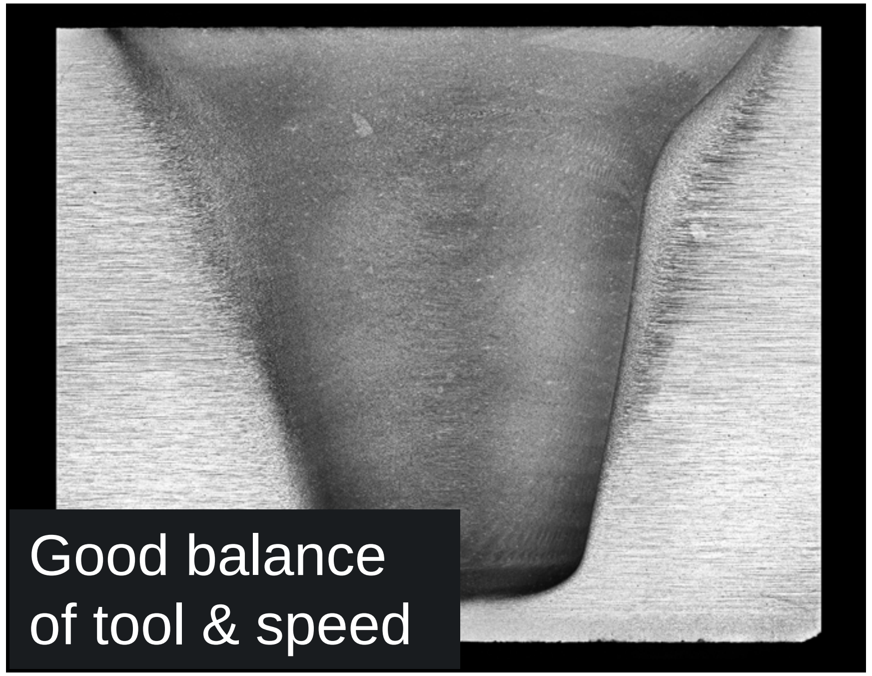
Task 1: FSW Process Development



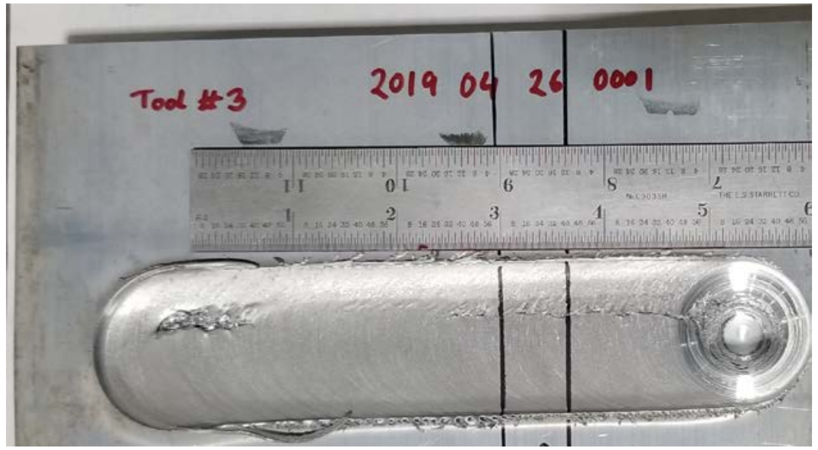
Aggressive pin threads



Fast traverse speed



Good balance of tool & speed



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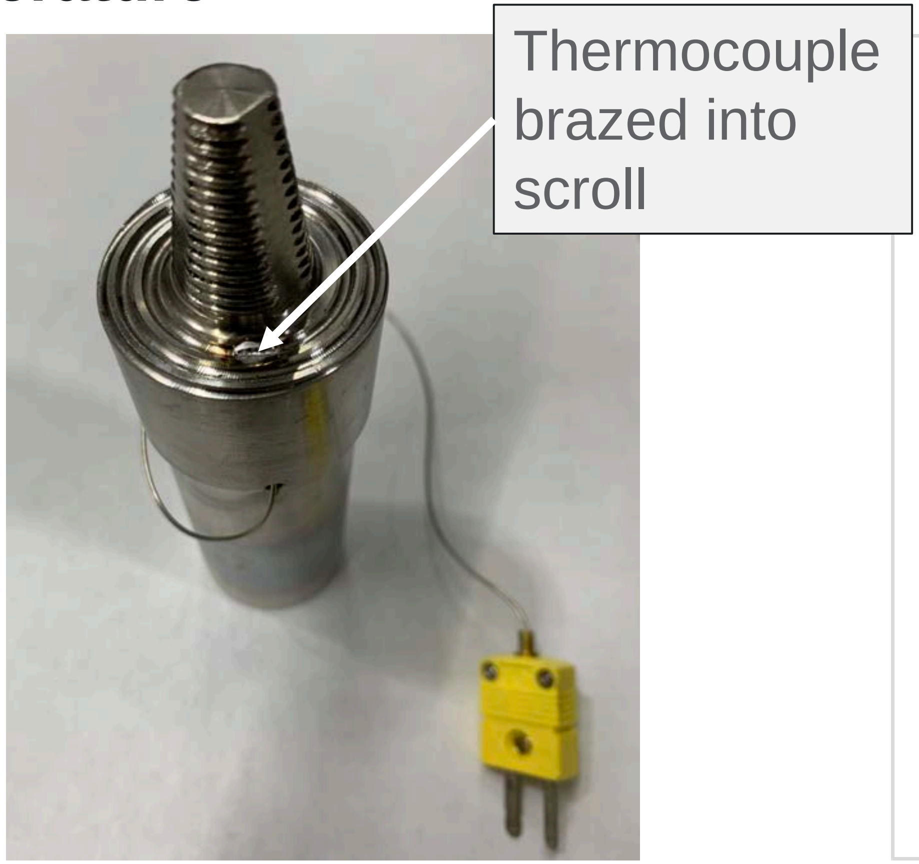
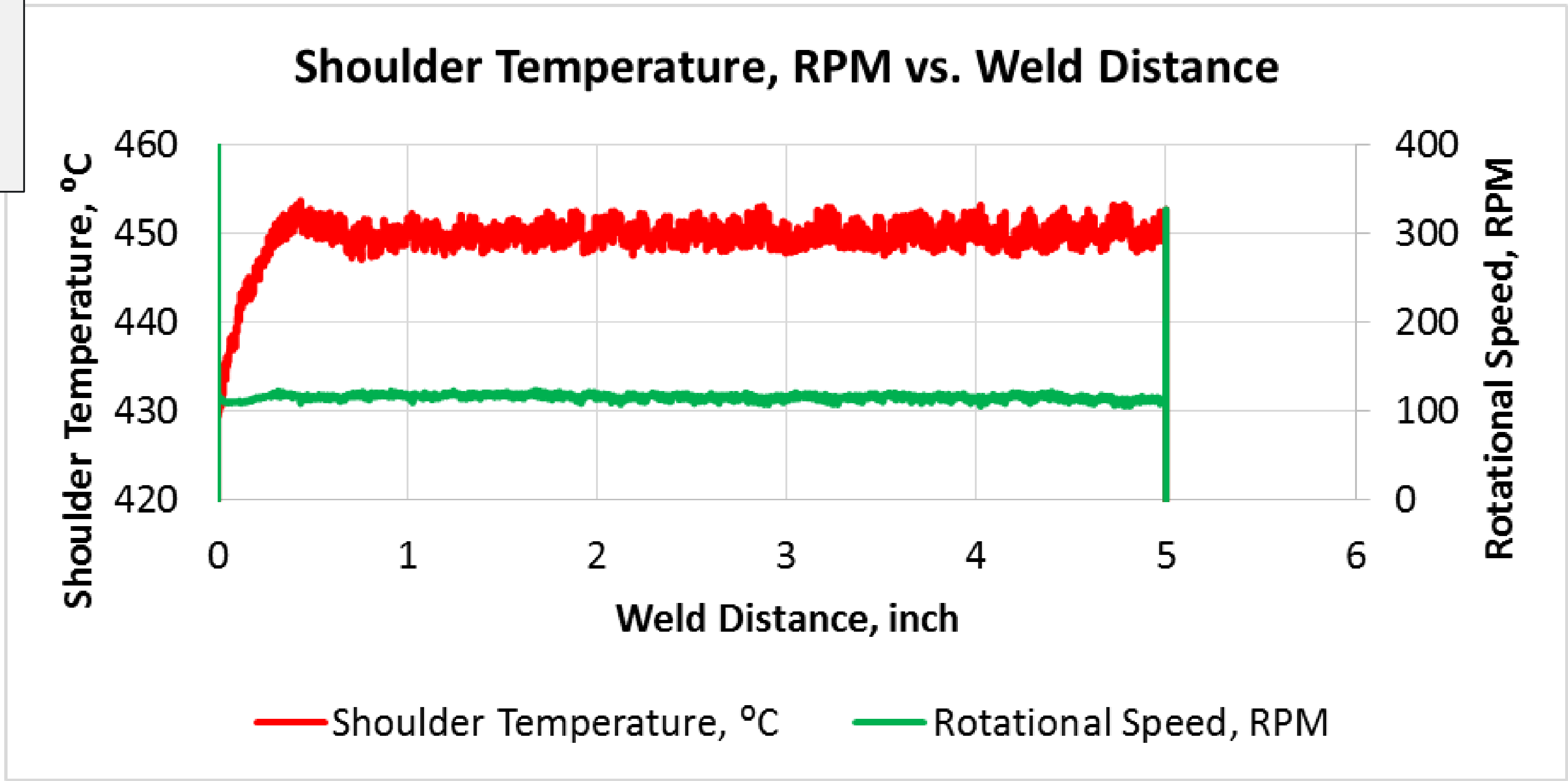
Task 1: FSW Process Development

Friction stir welding tool with thermocouple brazed inside shoulder for controlling the process on temperature



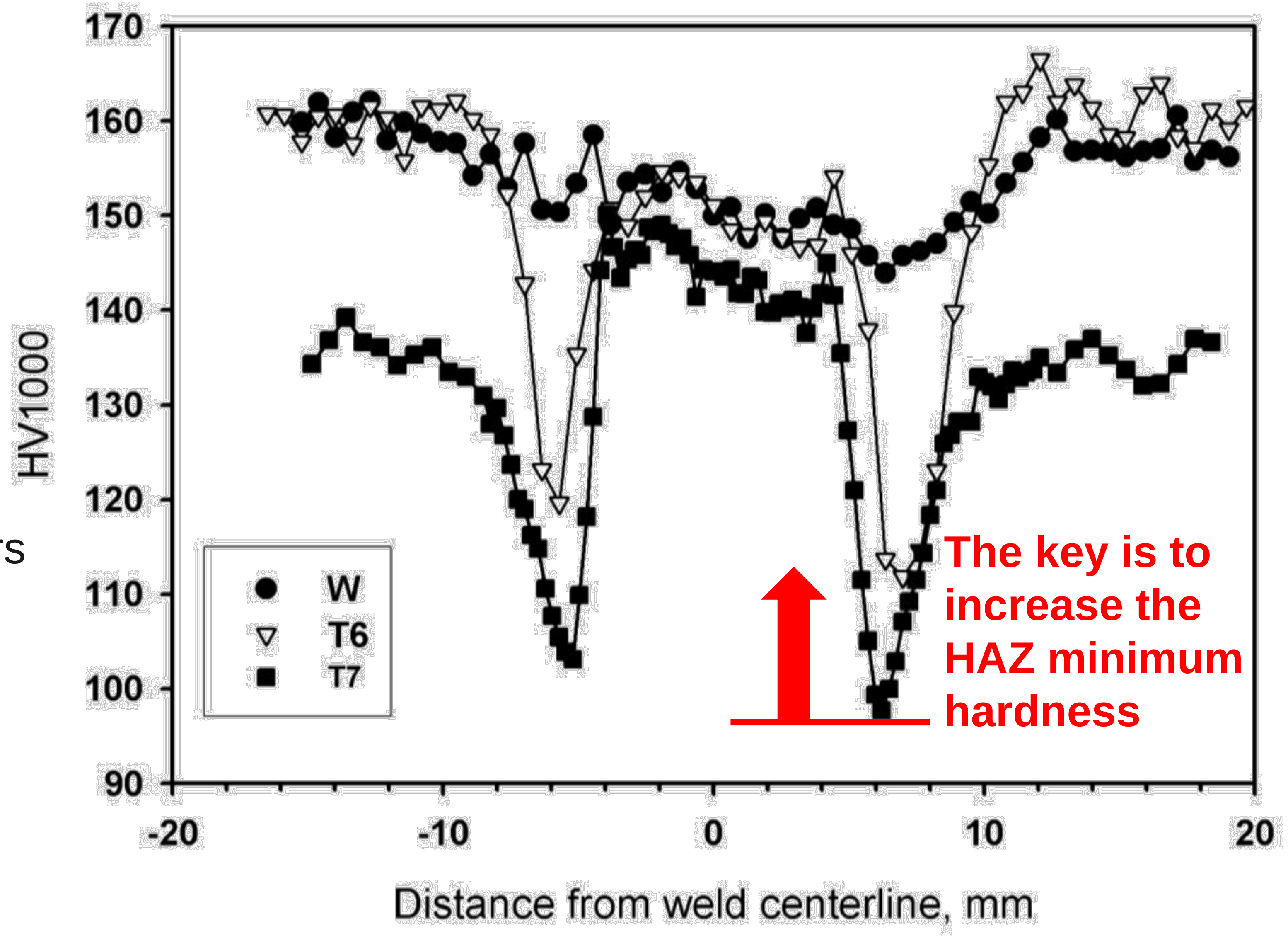
Complex temperature control algorithms and instrumented tooling to run FSW welds at a prescribed temperature



Task 2: Post-Weld Heat Treatment

- **AA7175 extrusions provided in:**
  - T4 (Pipe), T79 (Pipe)
  - T74 (Flange)

- **Optimize post-weld heat treatment to increase tensile properties and hardness**
  - Explore welding on different starting tempers including W !



Corrosion performance is also critical

- 7XXX aluminum risers were used to achieve water depths of 9,900 feet in the Perdido Oil Field, but corrosion issues encountered during the project prevented long term use of the aluminum riser string.
- Standard practice sacrificial anodes alone may be too risky for ultra-deepwater applications due to the increased surface area of the longer riser string.
- To mitigate this risk, a defense-in-depth approach is proposed where a corrosion protection strategy will employ both a weld process (plus PWHT) developed for corrosion performance, sacrificial anodes, and a corrosion mitigation system applied to the fabricated riser.
- This project will investigate a new solid phase process, cold spray, which has been shown in other industries to be able to produce robust corrosion protection metallic layers on aluminum.

Task 3: Corrosion Mitigation Technology

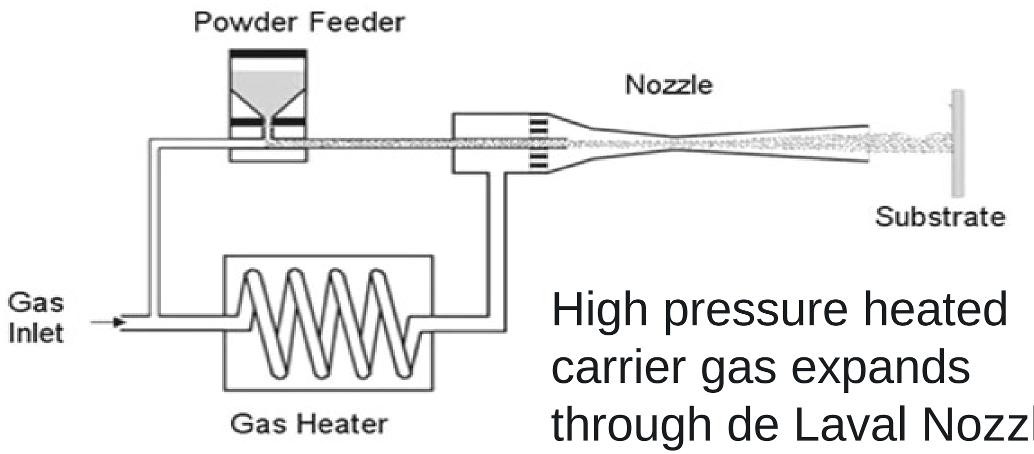
Cold Spray

- Proven technology for producing corrosion resistant coatings on surfaces
- State-of-the-art ultra-high velocity system recently installed at PNNL
- Solid-phase process propels 5-50µm particles up to 3000 m/s in nitrogen/helium carrier
- Deposition rates in the kg/min range for aluminum and nickel
- Robust metallurgical bonding
- Augment anodic protection of Al riser

Task 3: Corrosion Mitigation Technology

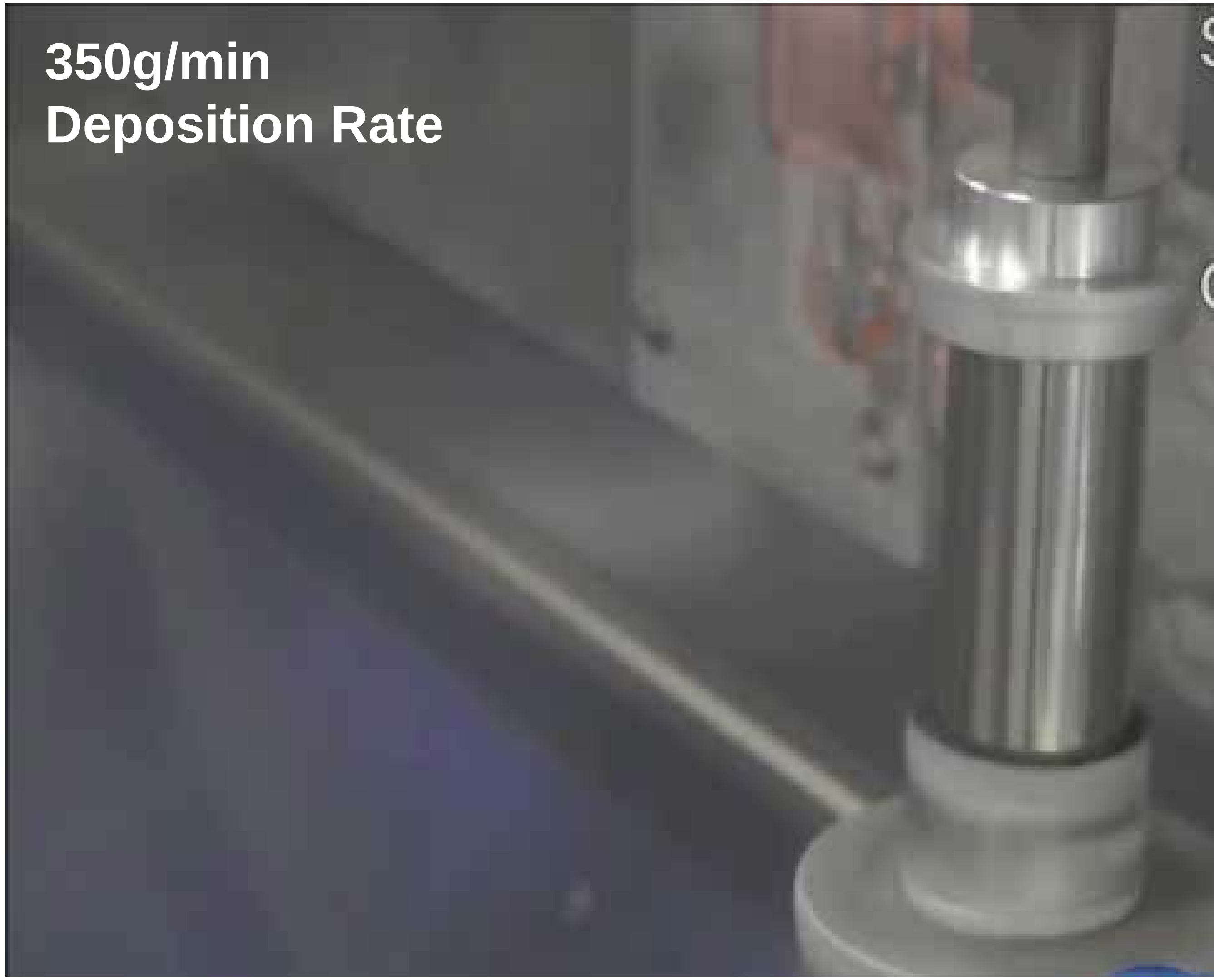
Cold Spray

- Use UHV cold spray to coat weld region or potentially entire riser
- Improve wear and corrosion resistance
- Subject test coupons to relevant salt water corrosion test standard

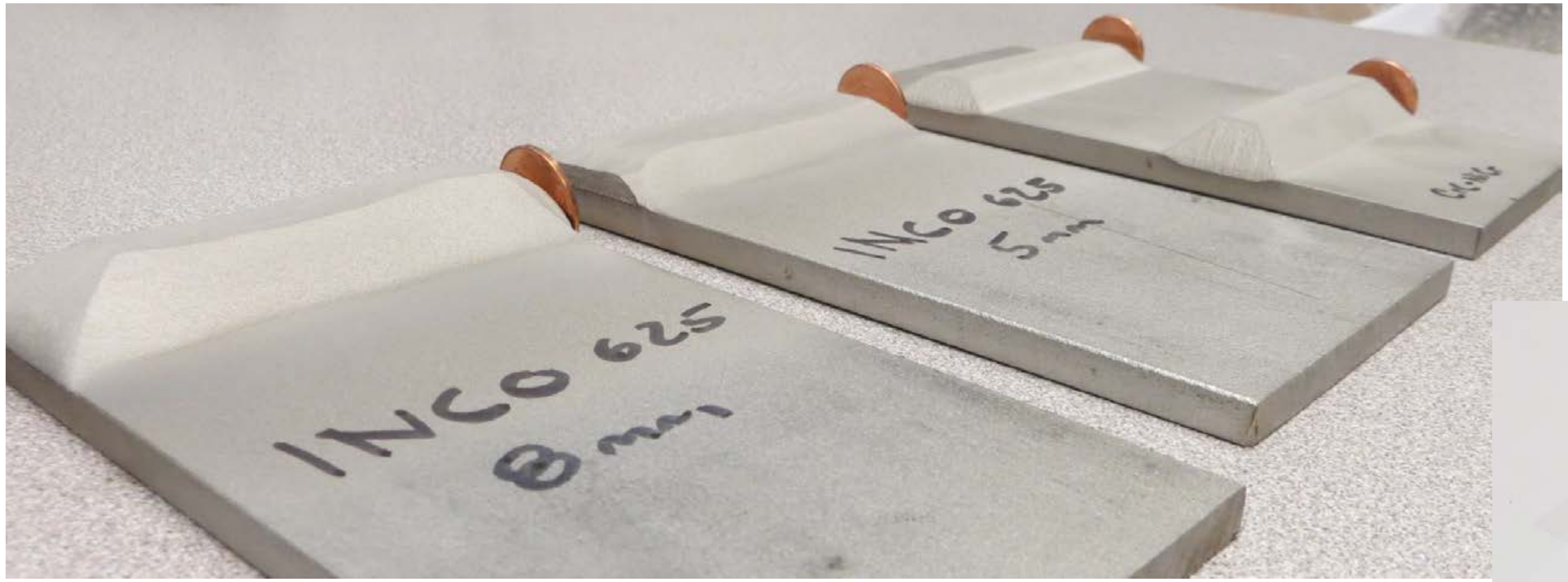


High pressure heated carrier gas expands through de Laval Nozzle to accelerate metal particles

Cold Spray of Inconel 625 on Rotating Stainless Steel Tube



Task 3: Corrosion Mitigation Technology



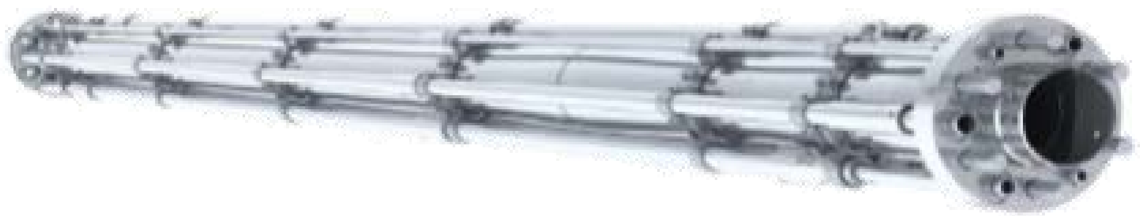
Examples of cold spray layers on steel and aluminum substrates

- ❑ Develop ultra-high velocity cold spray of pure nickel and/or aluminum as a new method of corrosion protection (on the weld region or full riser)
- ❑ Evaluate the corrosion performance of coated FSW coupons from Tasks 1 and 2.

Final Tasks
Fabricate Prototype and Full Sized Risers

- **Sub-scale riser section have been fabricated using FSW to demonstrate the process** **(Displayed at OTC in May 2019)**

Xymat Engineering will be fabricating full-scale AA7175 risers by the end of the program



We hope to move to fielded applications by 2021

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Thank you

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