# Corrosion Resistant Weld Overlays for Pipelines, Oil and Gas, and Petrochemical Installations


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PRCI LEADING PIPELINE RESEARCH


## Background

**Problem:** Pipeline failure due to corrosion. (top right image)

**Relevant Industries:** Pipeline, Oil and Gas, Petrochemical.

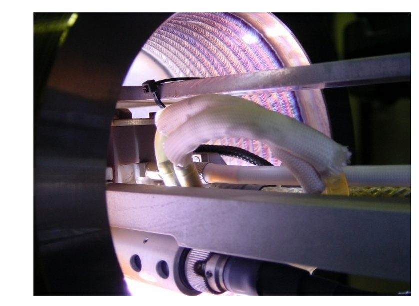
**Current Solution:** Apply corrosion-resistant nickel or stainless steel weld overlay to inner diameter of pipe using HW-GTAW or similar process. (bottom right image)

**Literature:** Cold Metal Transfer (CMT) process produces weld overlays which corrode up to ten times slower than overlays produced with GTAW, with up to four times higher deposition rates.

**Industry Need:** Majority of research into weld overlays produced with the CMT process has been done solely with respect to nuclear applications, need for process optimization directed towards oil and gas applications.

**Research Question:** Can more efficient weld overlays be produced using the CMT process without sacrificing quality?

"Corroded Section of Prudhoe Bay Oil Field Pipeline ." *The Denver Post*, The Associated Press, 6 Aug. 2006, www.denverpost.com/2006/08/06/bp-closing-alaska-oil-operation-indefinitely/.



"Internal Weld Overlay of Pipe and Tube Components." *AREVA Forward-Looking Energy*, AREVA, 2015, uddcomb.se/en/weld-overlay/oil-gas-industry.

## Objective

Reduction in production cost, extension of service life, and improvement of structural integrity of weld overlays of corrosion-resistant alloys in oil and gas pipelines.

## Approach

### CMT Setup

- Filler Metal: Ni-686 ERNiCrMo-14 0.040" Wire
- Filler Metal: Ni-825 ERNiFeCr-1 0.045" Wire
- Base metal: X65 Steel
- Fronius CMT Advanced 4000 MV R Power Supply
- Fronius RCU 5000i Pendant
- Yaskawa Motoman MA1400 Robotic Arm

Initial Weld Testing → Design of Experiments → Characterization/ Modeling → Comparison to GTAW

### Fractional Factorial Design of Experiment

Fractional Factorial: (2 levels^4 factors)*(2 replicates) + (4 for linearity check) = 36 samples

Factors: Wire feed speed, Travel speed, Weave amplitude, Weave frequency → System → Responses: Bead penetration, Bead width, Bead height, Toe angle, Dilution

| Factor | Travel Speed | | | Wire Feed Speed | | | Weave Amplitude | | | Weave Frequency | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| Value | 8 IPM | 11 IPM | 14 IPM | 300 IPM | 350 IPM | 400 IPM | 4 mm | 5 mm | 6 mm | 2.5 Hz | 3.2 Hz | 3.9 Hz |
| DoE Value | -1 | 0 | 1 | -1 | 0 | 1 | -1 | 0 | 1 | -1 | 0 | 1 |

### Metallurgical Characterization/Modeling

- **Metallurgical characterization:** measure bead geometry to validate predicted optimal parameters
- **Optical microscopy:** detect flaws, analyze microstructure for swirls and planar growth region
- **Hardness Testing:** determine whether PWHT is necessary
- **EDS:** measure interdendritic spacing as well as dilution across fusion boundary
- **ThermoCalc™ computational modeling:** predict solidification ranges and partitioning coefficients

### Comparison

- **Processes:** CMT, HW-GTAW
- **Filler metals:** Ni-686, Ni-825
- **Factors:** defects, deposition rate, dilution, hardness, microstructure, corrosion resistance

## Conclusions

**Optimized CMT parameters:**

- About 5% dilution or less (more than 4x lower than HW-GTAW)
- Deposition rate of 7.88 lbs/hr (more than 3x higher than HW-GTAW)
- Extremely narrow planar growth region with very low swirl density
- Fine microstructure with dendritic spacing of 4.3-5.1 micrometers (more than 3x lower than HW-GTAW)
- As-welded HAZ with average hardness below 250 $HV_{0.1}$ (would not require PWHT as HW-GTAW would)

## Future Work

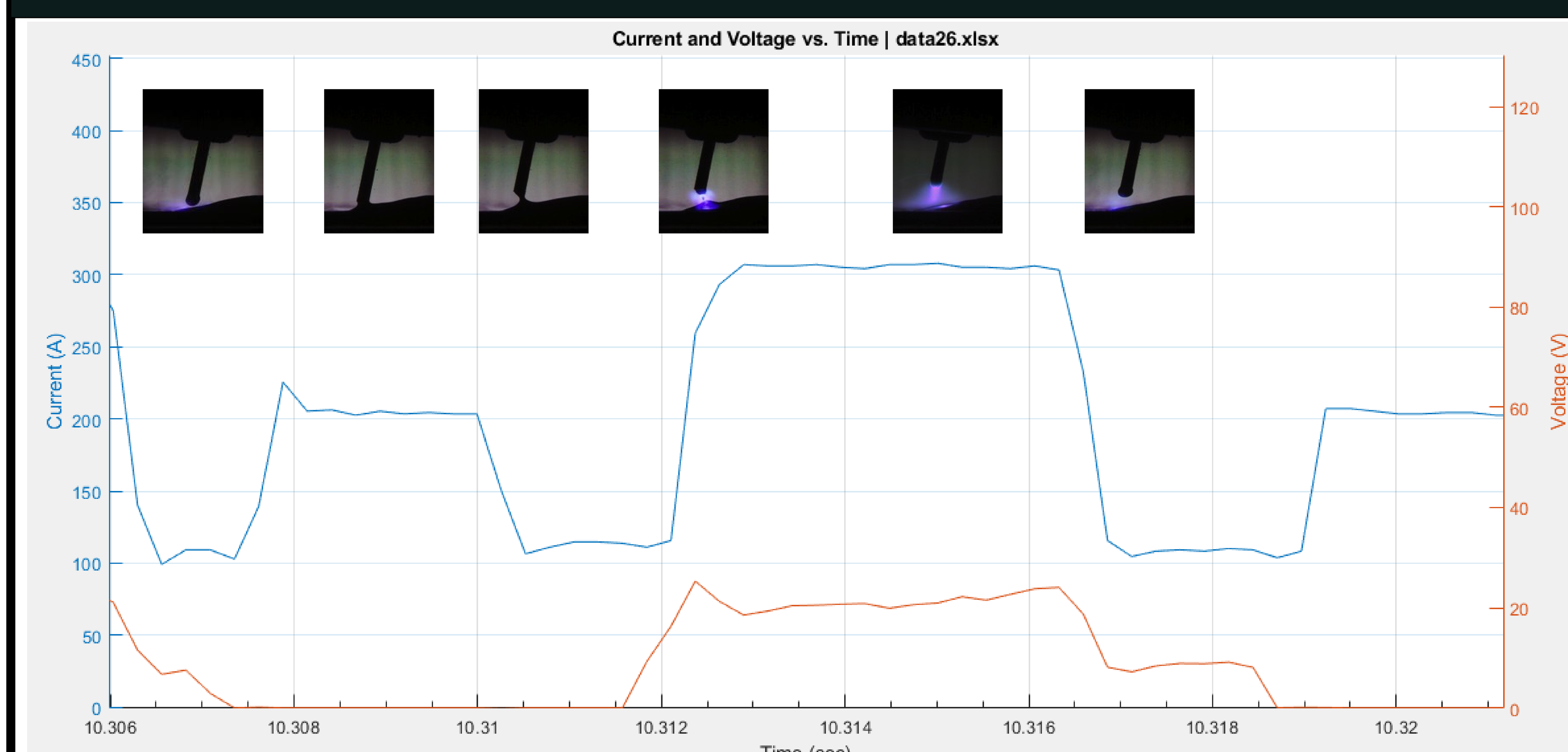
**In-Depth Analysis**

- EDS: Line scans across fusion boundary to determine distance from fusion boundary where Fe content reaches <5%
- Thermocalc Modeling:
  - Psuedo-Binary Phase Diagram: Between 686-X65 and 825-X65 to determine solidification range and susceptibility to solidification cracking
  - Partition Coefficients: Determine dendritic core and interdendritic composition
- Mechanical Testing: Bend Testing, Peel Testing: make sure welds will perform in service

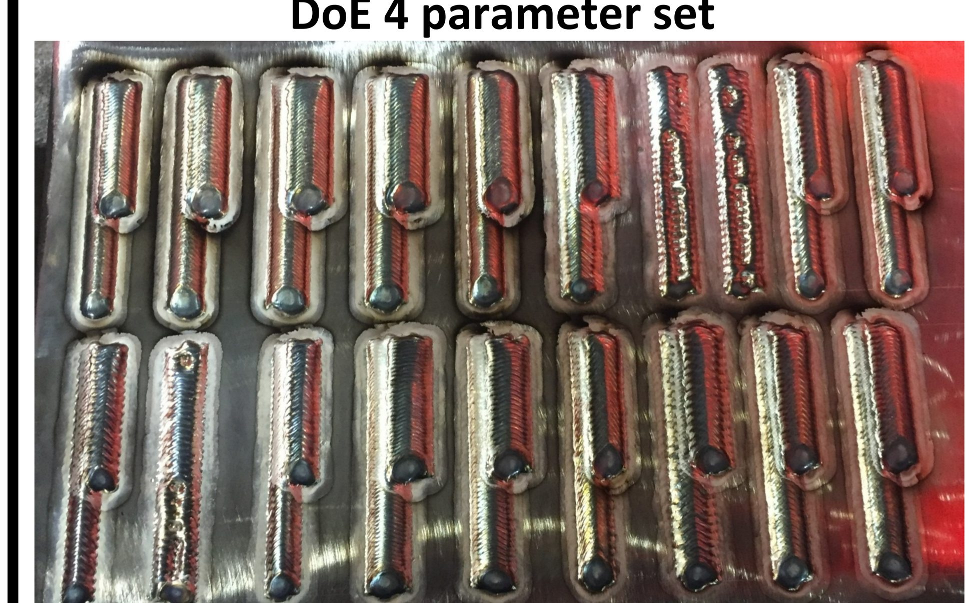
**Future Work: Corrosion**

- Corrosion testing of samples
  - CPT immersion
  - CPT electrochemical
  - PDP Potentio-dynamic Polarization
- Corrosion testing of buttons with dendritic core and interdendritic compositions

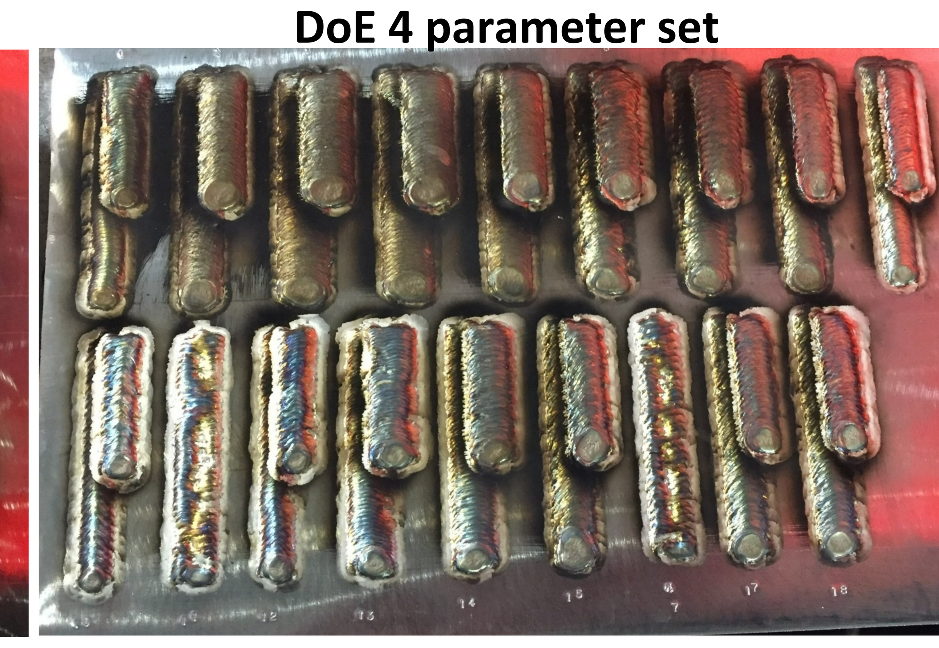
## Results & Discussion

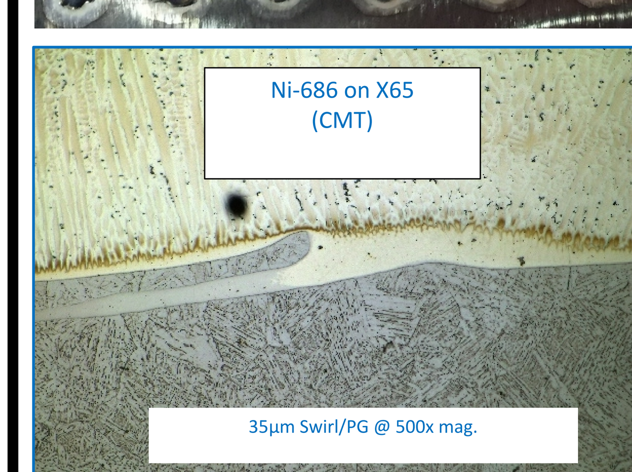


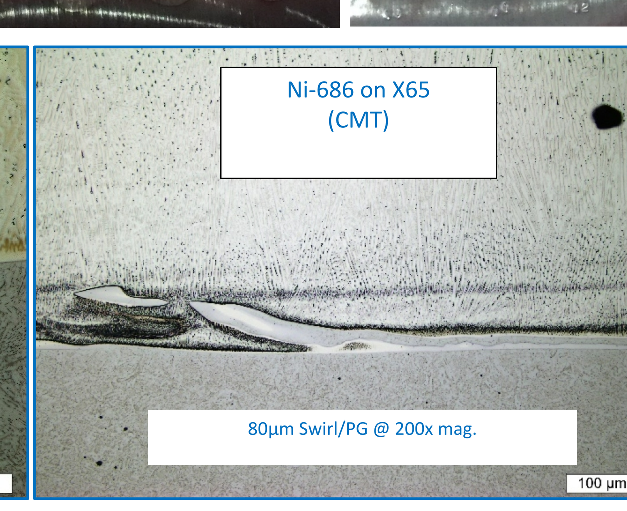

**Ni-686 Welds made on X65 Plate with DoE 4 parameter set**

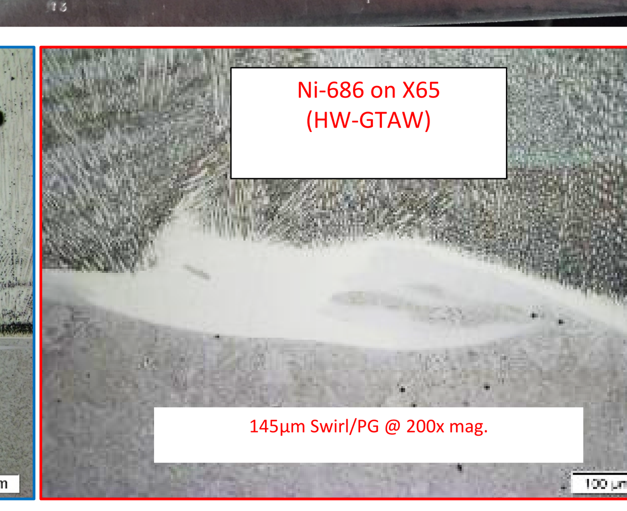


**Ni-825 Welds made on X65 Plate with DoE 4 parameter set**

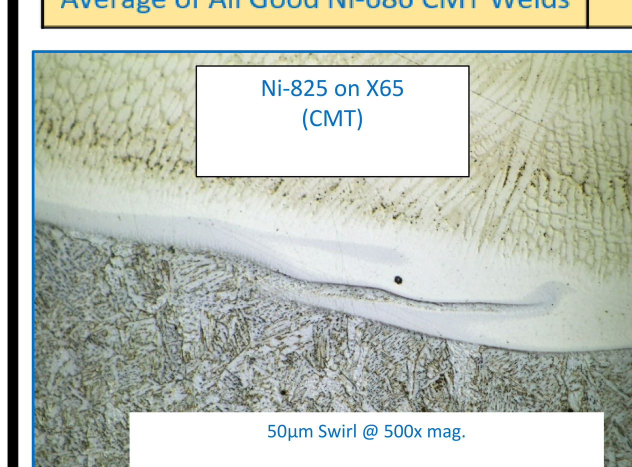




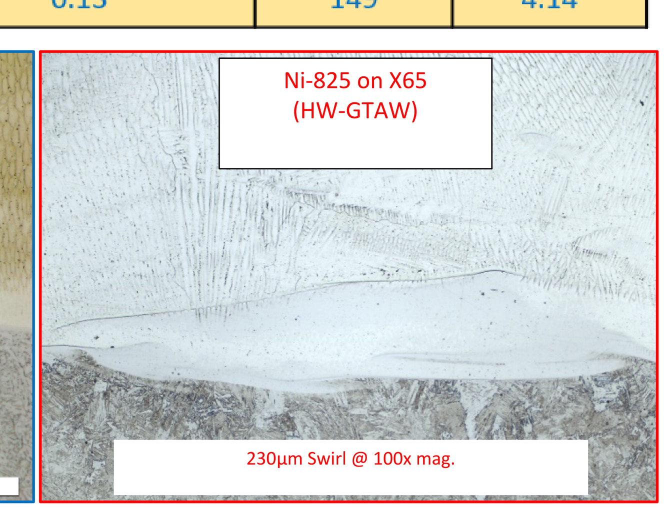




| Sample | Bead Width (mm) | Bead Height (mm) | Bead Penetration (mm) | Toe Angle (°) | Dilution (%) |
|---|---|---|---|---|---|
| Ni-686 HW-GTAW Single Bead | 6.61 | 1.71 | 0.37 | 142 | 19.48 |
| Average of All Good Ni-686 CMT Welds | 13.57 | 2.43 | 0.13 | 149 | 4.14 |








| Sample | Bead Width (mm) | Bead Height (mm) | Bead Penetration (mm) | Toe Angle (°) | Dilution (%) |
|---|---|---|---|---|---|
| Average of All Good Ni-825 CMT Welds | 12.55 | 2.3 | 0.14 | 151 | 1.33 |
| Ni-825 HW-GTAW Single Bead | 8.53 | 1.19 | 0.89 | 162 | 45.03 |


## Acknowledgments

- Vincent Decenso for assistance with many of the tedious tasks involved with making and analyzing welds
- Boian Alexandrov and Jorge Penso for superior guidance and information relating to topic
- CDME, especially Michael Gentil, who helped us water jet cut our samples which greatly reduced cutting time experienced with sample removal