HEAT EXCHANGER WORLD CONFERENCE & EXPO AMERICAS

2022

Tube to Tube Joint Heat Exchanger tube

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Webco Industries

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Topics of the Discussion

I. Background of dis-similar metal weld

II. Mock-up weld study

III. Test Results
   1. Welding procedure and Qualification test
   2. Metallurgical analysis
   3. Corrosion performance

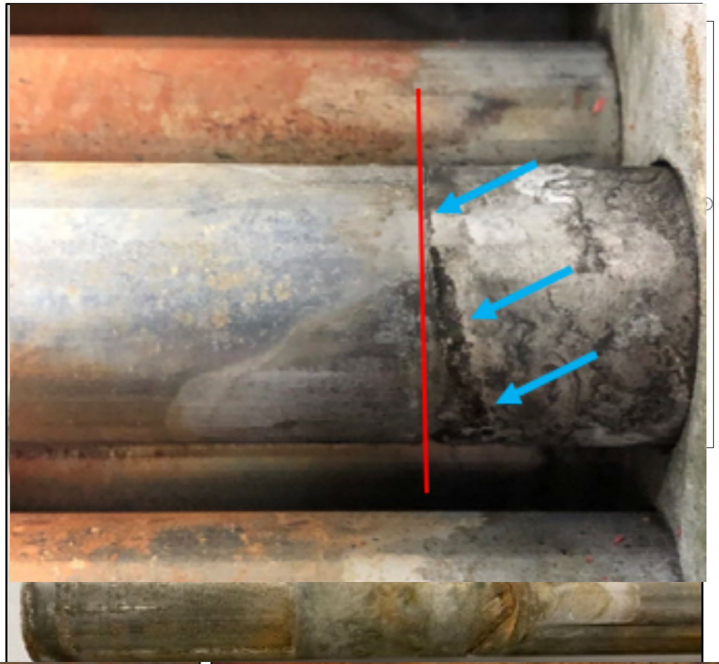
IV. Discussion

I. Background of Dis-similar Metal Orbital Weld

UNIT:

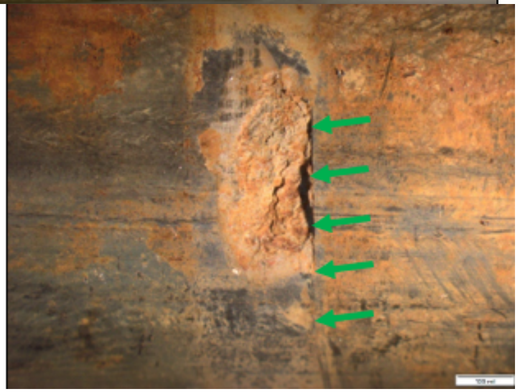
- A part of kettle reboiler, heat exchanger unit for ethanol bio-refining process
- Horizontal unit with U bend tubes inserted to vertical orientation. *Tube side is steam, Shell side is Ethanol bio-product*
- Operate at 350 - 400°F, 150 psi pressure.

Boiling temperature of the 95% Ethanol is approximately 173°F



FAILURE and ROOT CAUSE:

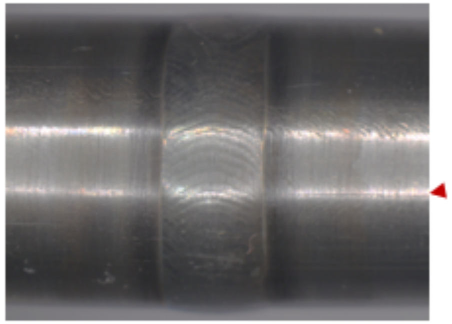
- Failed prematurely due to the leaking tubes from shell side
- Crevice pitting corrosion at the back face of the tubesheet, steam-inlet half of the unit

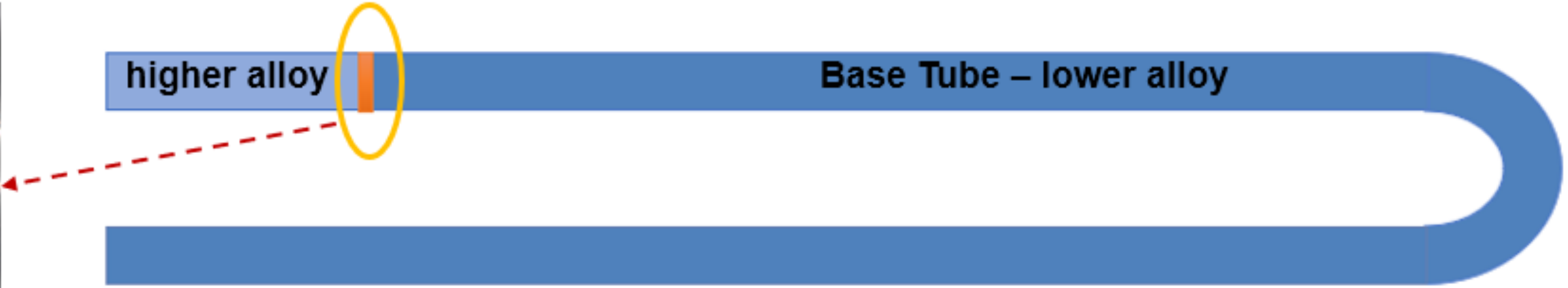


I. Background of Dis-similar Metal Weld

OPTION for IMPROVMENT:

- An option of orbital welding a 2 ft. length of higher alloy tubing to stainless steel base tube at of the steam inlet side of the U bent tube
- Base tube (304L, 2205) to 316L, S32750(2507), N08825, N06625 high alloy tube





POTENTIAL UNKNOWN:

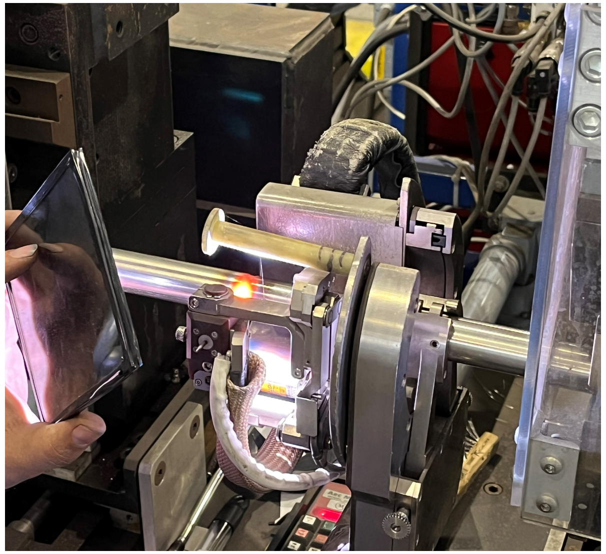
1. Development of acceptable Welding Procedure Specification for dis-similar metals and Procedure Qualification testing method
2. Corrosion potential at the Weld & HAZ compared to dis-similar base metals

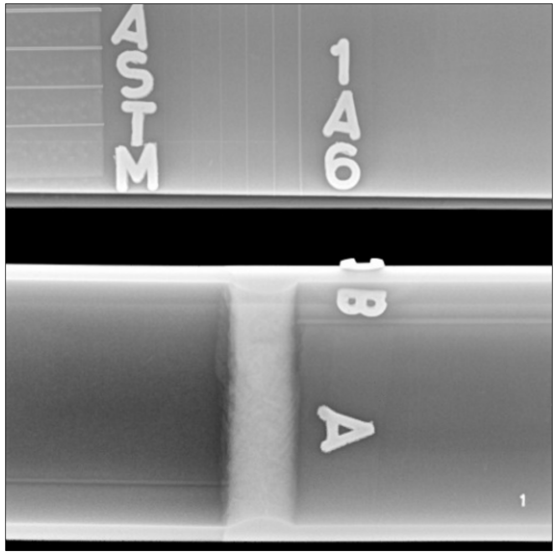
1. Material:

Group	Filler wire
Group A 304L(S30403) to 625 (N06625)	625 filler wire - AWS A5.14 ERNiCrMo-3
	Autogenous (No filler wire)
Group B 304L(S30403) to 2205 (S32205)	2507 filler wire - 25.10.4.L EN 25 9 4 N L
	Autogenous (No filler wire)
Group C 2205 (S32205) to 625 (N06625)	625 filler wire - AWS A5.14 ERNiCrMo-3
	Autogenous (No filler wire)
Group D 304L (S30403) to 2507 (S32750)	2507 filler wire - 25.10.4.L EN 25 9 4 N L

2. Welding Procedure Development:

- Automatic GTAW (5G), 1 Pass autogenous or 2 Pass J-Bevel w/ Filler wire
- Qualification Test: Guided bend, Tensile, Burst Pressure Test and Radiographic Inspection





3. Metallurgical Analysis:

- Due to the difference in chemistry between grades, etching solution for each samples were reviewed for proper metallurgical evaluation.
- NaOH was selected for etching samples based on its ability to color ferrite and sigma phases while austenite is unaffected.

4. Corrosion Performance of Weld:

- To determine the corrosion rate differences, three tests were performed, including ASTM G28 Method A, G48 Method A, and A262 Practice C.
- ASTM tests deviated occasionally due to a variety of dis-similar grades and the results were used as qualitative data to compare the relative corrosion rates.

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Automatic GTAW per ASME IX Welding Variables Procedure Specifications (WPS) – GTAW

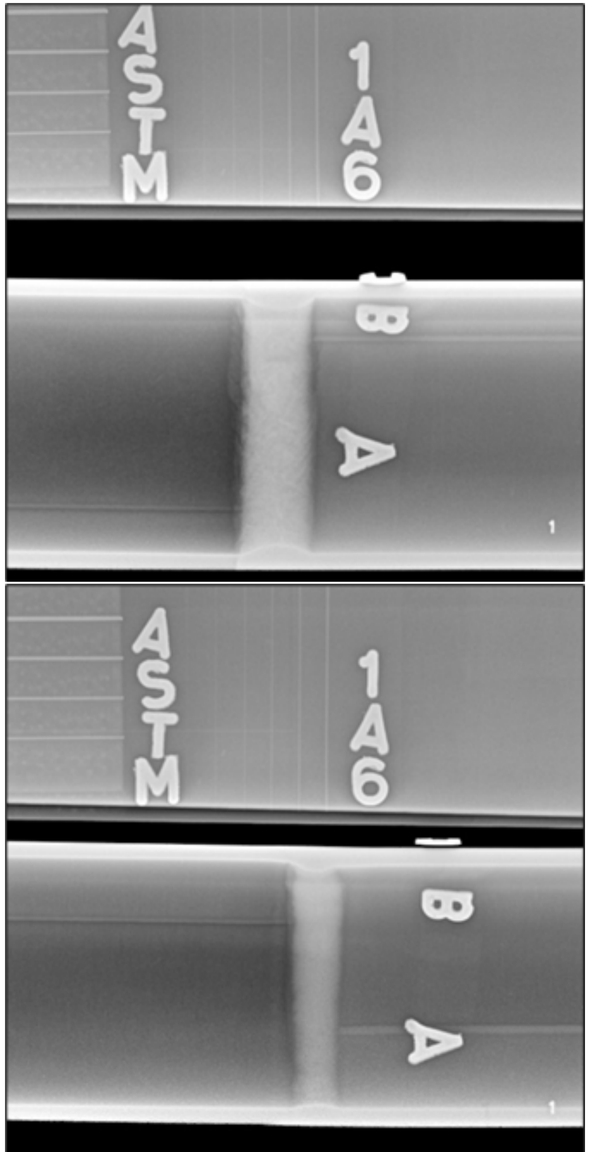
Tube Size: 1.000” OD x 0.065” W

Base Metals	Joints Design	Filler wire	No. of Pass	Shielding & Backing Gas	Heat Input KJ/mm
304L to 625	J-Bevel	625 filler wire	2	100% Argon //100% N_2	0.495
	Square Butt	No filler wire	1	100% Argon //100% N_2	0.186
304L to 2205	J-Bevel	2507 filler wire	2	97%Ar./3%N_2//100% N_2	0.530
	Square Butt	No filler wire	1	97%Ar./3%N_2//100% N_2	0.200
304L to 2507	J-Bevel	2507 filler wire	2	97%Ar./3%N_2//100% N_2	0.530
2205 to 625	J-Bevel	625 filler wire	2	97%Ar./3%N_2//100% N_2	0.630
	Square Butt	No filler wire	1	97%Ar./3%N_2//100% N_2	0.212

Automatic GTAW per ASME IX Welding Variables Procedure Specifications (WPS) – GTAW

Tube Size: 1.000” OD x 0.065” W

	Tensile Property			Bend	Burst Test		ID Bead Height [in]	
	Yield (psi)	Ultimate (psi)	E %	Root & Face	Burst psi and Location		0 Deg	180 Deg
304L/625 w/wire	47,800	85,410	45	Pass	Base	8,684	0.057	0.019
304L/625 no wire	46,530	90,100	58	Pass	Weld	9,474	0.011	0.010
304L/2205 w/wire	60,910	80,530	47	Pass	Base	9,079	0.025	0.015
304L/2205 no wire	42,680	80,600	59	Pass	Weld	9,474	0.009	0.011
304L/2507 w/wire	43,410	78,570	45	Pass	Weld	9,079	0.029	0.029
2205/625 w/wire	91,480	122,800	22	Pass	Weld	17,763	0.021	0.043
2205/625 no wire	82,790	114,200	9	Pass	Weld	17,763	0.010	0.006

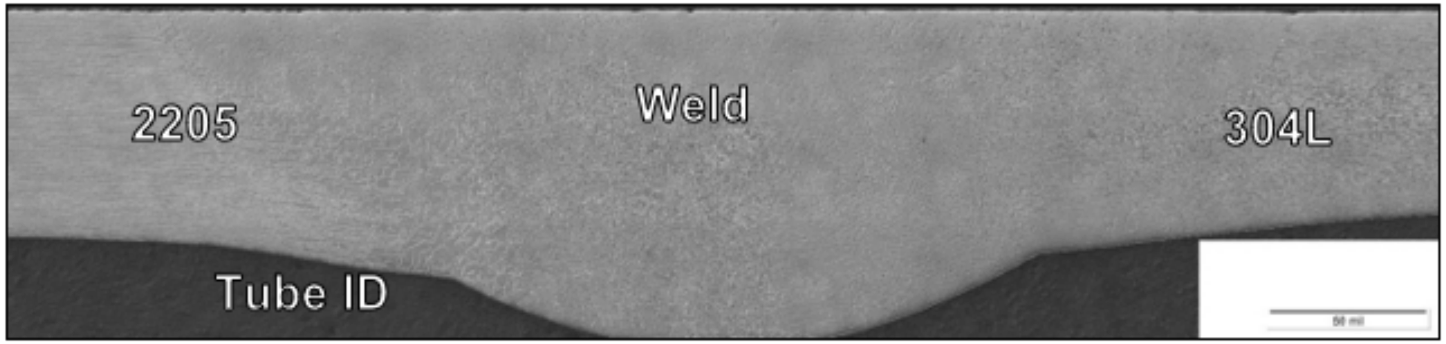


X Ray Examples - 304L to 625 (Top), 304L to 2507 (Bottom)

III. Test Results – Metallurgical Analysis

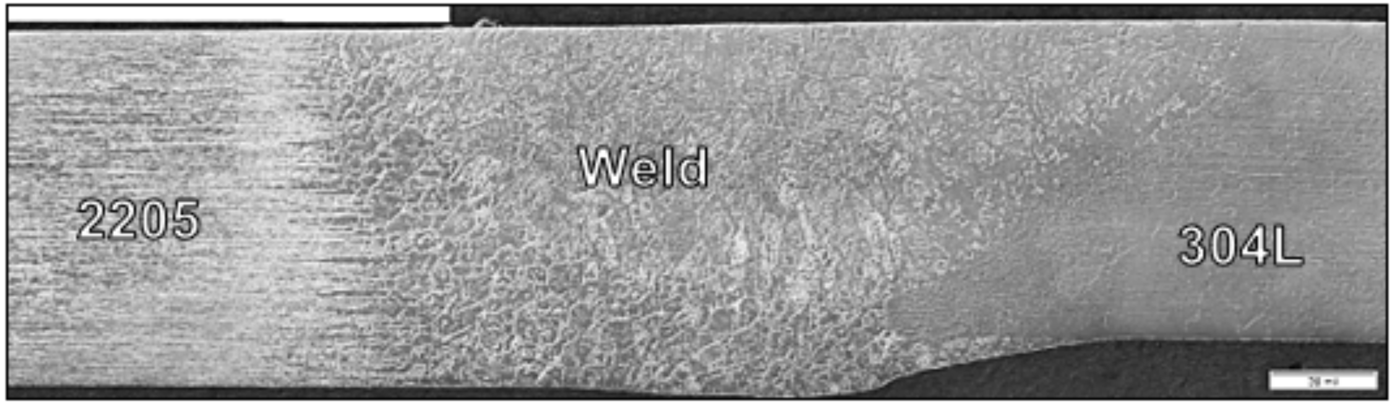
304L Welded to Duplex 2205:

- All metallic components used in the weld had the same or similar thermodynamic properties, resulting in a completely penetrated weld.



Cross-sectional weld image of dis-similar metal of 304L - 2205 joint with 2507 filler wire.

- One minor notable difference was the texture and phase balance of the weld. The 2205 base metal was seen to extend along the length of the weld on the ID side



Cross-sectional weld image of dis-similar metal of 304L - 2205 joint with no filler wire

III. Test Results – Metallurgical Analysis

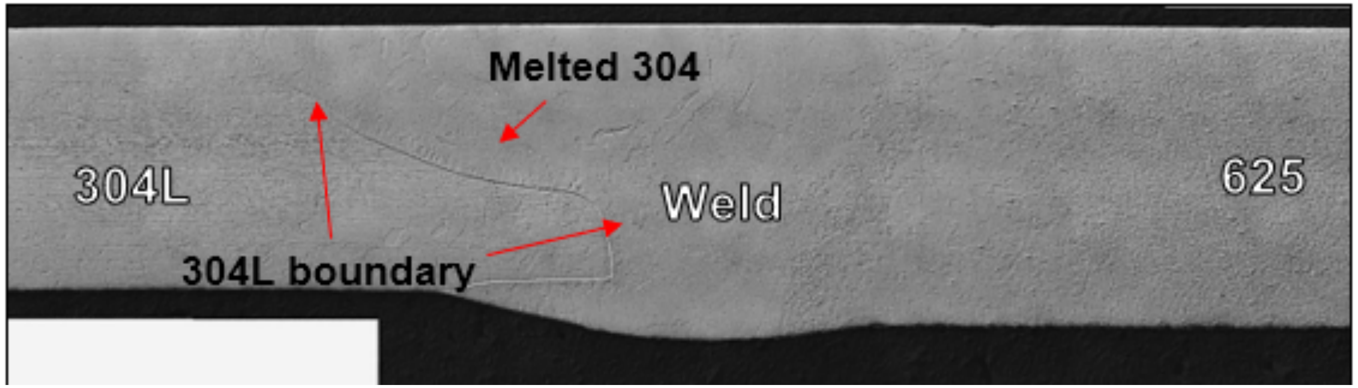
304L Welded to Nickel alloy 625:

- No visible weld imperfections except 304L weld boundary remnant regardless autogenous or with filler wire where welded to 625 nickel alloy.

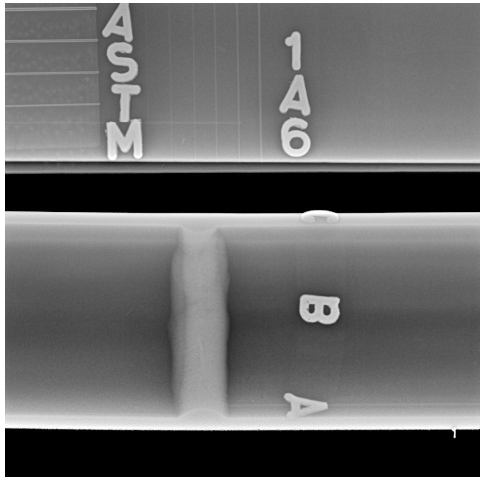
- This is due to the difference in thermodynamic properties between 625 and 304L.

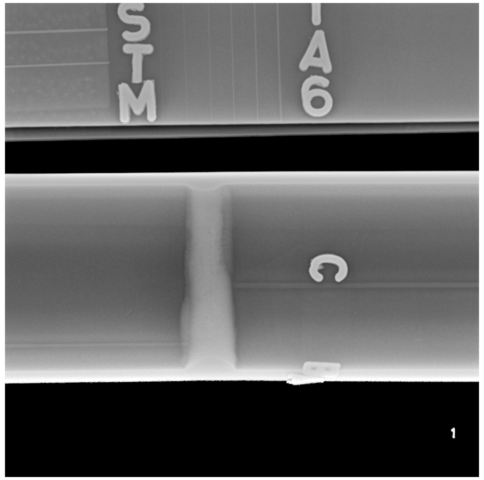
(the melting temp. of 625 is 110° C lower and a lower specific heat capacity)

- No X-Ray indication of abnormality including fusion boundary



Grade		Melting Temp. (°C)	Specific Heat Capacity (J/(g*°C)
S30403	304L	1,400	0.48
S32205	2205	1,400	0.48
S32750	2507	1,400	0.48
N06625	625	1,290	0.44

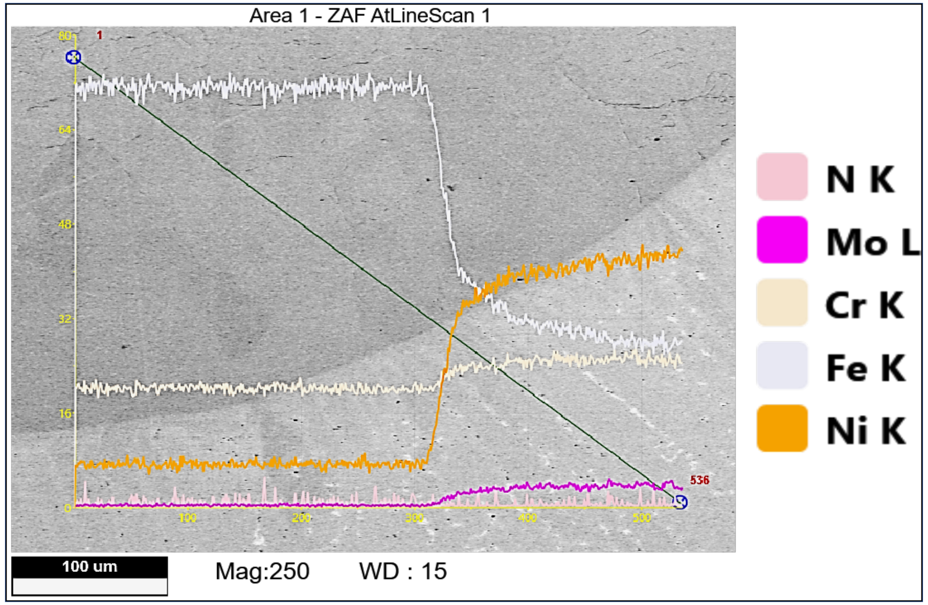




III. Test Results – Metallurgical Analysis

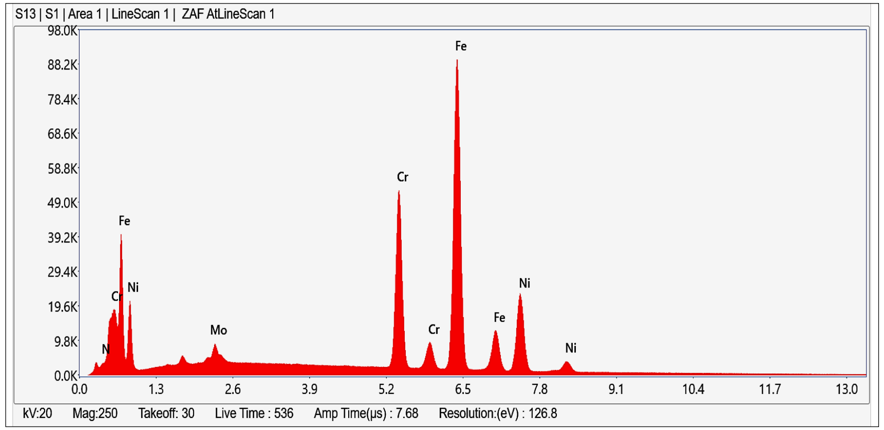
304L Welded to Nickel alloy 625

- EDS analysis of the weld fusion line showed chemical gradient proportional to observed microstructural weld boundary.
- Materials of differing chemical composition will likely have a different tribological response from polishing - causing the base metal to appear raised/lowered with respect to the weld.



eZAF Quant Result - Analysis Uncertainty: 3.51 %

Element	Weight %	MDL	Atomic %	Error %	Net Int.	R	A	F
N K	0.0	0.00	0.0	100.0	0.0	0.7951	0.0941	1.0000
Cr K	20.3	0.05	22.0	2.9	1236.0	0.8885	0.9373	1.1835
Fe K	56.7	0.07	56.9	2.5	2323.2	0.8988	0.9188	1.0545
Ni K	20.6	0.09	19.7	3.2	611.9	0.9099	0.8712	1.0362
Mo L	2.3	0.07	1.4	7.7	99.2	0.8502	0.5572	1.0083



EDS (Energy Dispersive Spectroscope)

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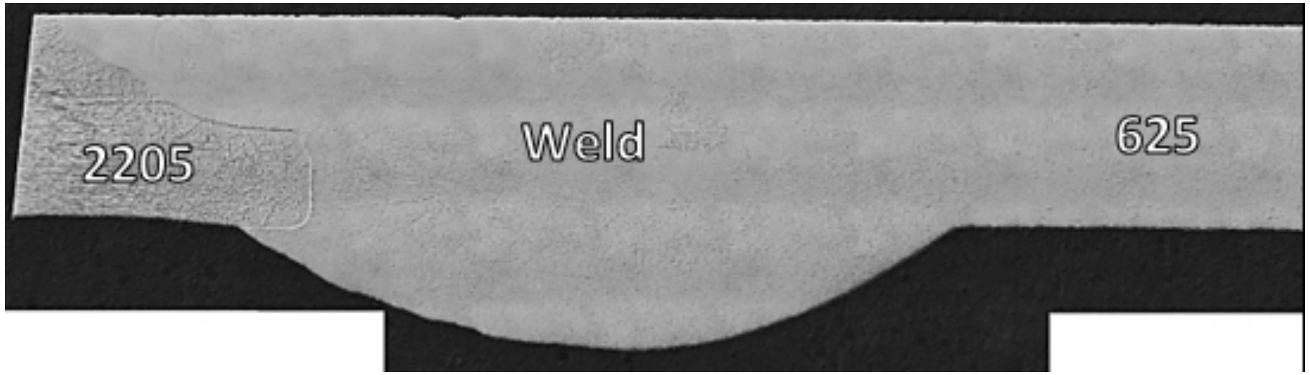
III. Test Results – Metallurgical Analysis

2205 Welded to Nickel alloy 625:

- **No visible weld imperfections except 2205 weld boundary remnant regardless autogenous or with filler wire where welded to 625 nickel alloy.**

- **Same observation as weld between 304L and 625.**

(the melting temp. of 625 is 110° C lower and a lower specific heat capacity)



Grade		Melting Temp. (°C)	Specific Heat Capacity (J/(g*°C)
S30403	304L	1,400	0.48
S32205	2205	1,400	0.48
S32750	2507	1,400	0.48
N06625	625	1,290	0.44

III. Test Results – Corrosion Performance

Sample	ASTM G28 Method A	ASTM G48 Method A	ASTM A262 Practice C
304L/625 w/625 filler wire			X
304L/625 w/o filler wire			X
304L/2205 w/ 2507 filler wire		X	X
304L/2205 w/ 625 filler wire		X	X
304L/2205 w/o filler wire		X	X
2205/625 w/625 filler wire	X	X	X
2205/625 w/o filler wire	X	X	X
304L/2507 w/2507 filler wire			X
304L base metal (Reference)			X
2205 base metal (Reference)	X	X	X
2507 base metal (Reference)		X	
625 base metal (Reference)	X		X

G28-A Detecting Susceptibility to Intergranular Corrosion in Wrought, Nickel-Rich, Chromium-Bearing Alloys

Method A - Ferric Sulfate—Sulfuric Acid Test

G48-A Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution

Method A - Ferric chloride pitting test

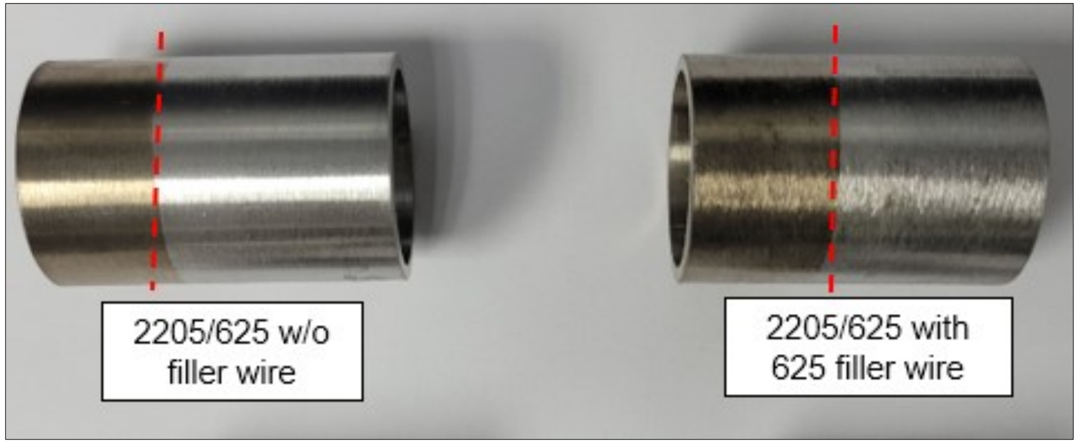
262-C Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steel

Practice C – Nitric Acid Test for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

III. Test Results – Corrosion Performance

G28 Method A: 2205 - 625 Weld with and without 625 filler wire

- Welded Section: Clear boundary, No Pitting
- Corrosion Rate: No major differences between 625, 2205 & Filler wire
- Reason for higher (110%) corrosion rate of 2205/625 w/625 filler wire to 2205 base or 2205/625 w/o filler wire is unknown.

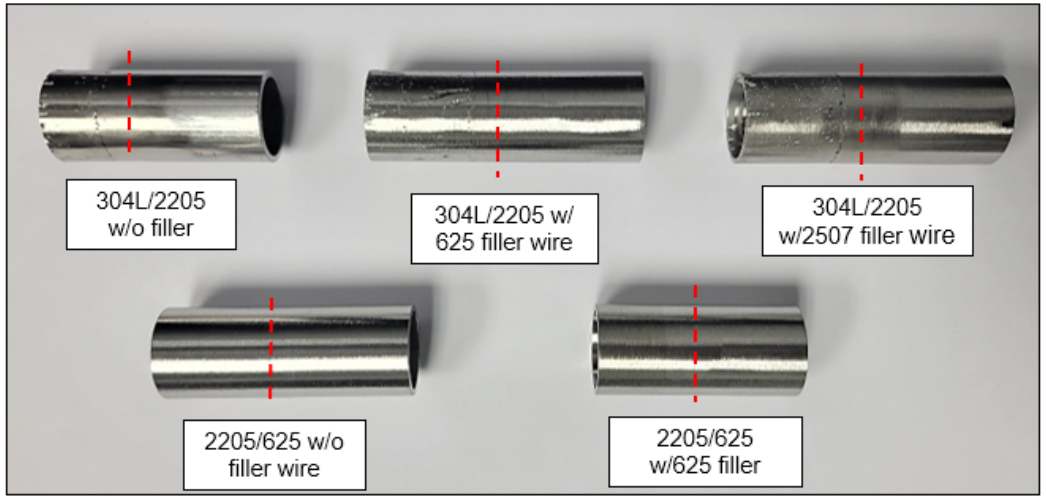


Sample	Corrosion Rate (Mpy: mils per year)	Pitting
2205/625 w/o filler wire	10.1	No
2205/625 w/625 filler wire	11.2	No
2205 base metal	10.1	No
625 base metal	10.0	No

III. Test Results – Corrosion Performance

G48 Method A: 304L - 2205 Weld with and without 2507 or 625 filler wire
2205 - 625 Weld with and without 625 filler wire

- The high corrosion rate containing 304L can be attributed to the fact that G48 Method A test is not designed for austenitic alloys and the critical pitting temperature of 304L is below the typical testing temp. 25°C.
- The orbital weld samples of 2205 and 625 experienced corrosion rates equal to or less than that of typical duplex stainless steels.

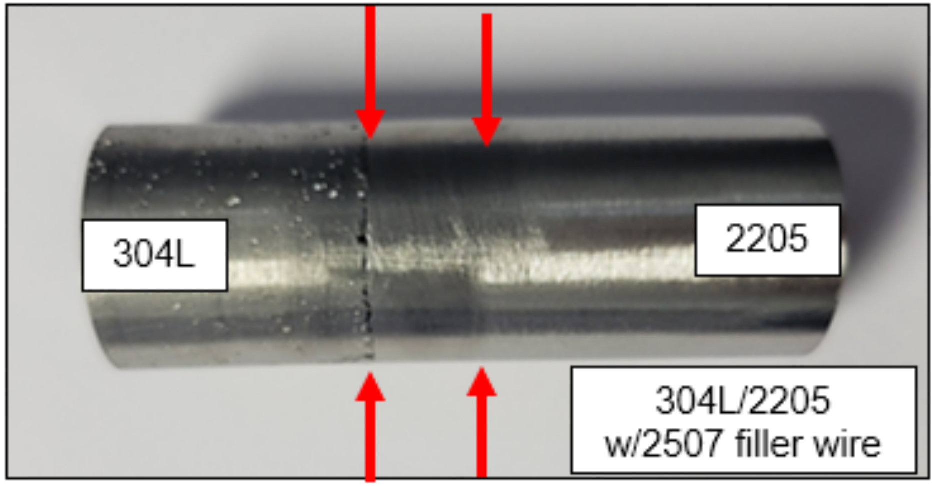


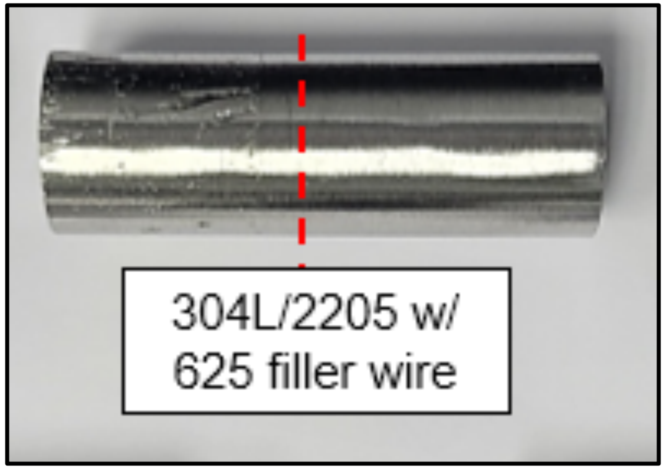
Sample	Test Temperature	Corrosion Rate (Mpy: mils per year)	Pitting
304L/2205 w/2507 filler wire	50° C	3,505	Yes
304L/2205 w/625 filler wire	25° C	2,750	Yes
304L/2205 w/o filler wire	25° C	2,041	Yes
2205/625 w/625 filler wire	25° C	1.0	No
2205/625 w/o filler wire	25° C	1.3	No
2205 base metal	25° C	2.4	No
2507 base metal	50° C	1.6	No

III. Test Results – Corrosion Performance

G48 Method A:

- The nickel / duplex portions and the fusion zone of each weld joint were able to pass the test while the 304L portions corroded heavily at the joint of the weld.
- Even without filler wire, the fusion zone will create a higher alloy due to the mixing of both base metals and higher corrosion resistance.
- The location of the pitting line were actual location of the 304L fusion line boundary
- General pits at 304L side of the base metal
- Not unusual for G48 test for austenitic grade.

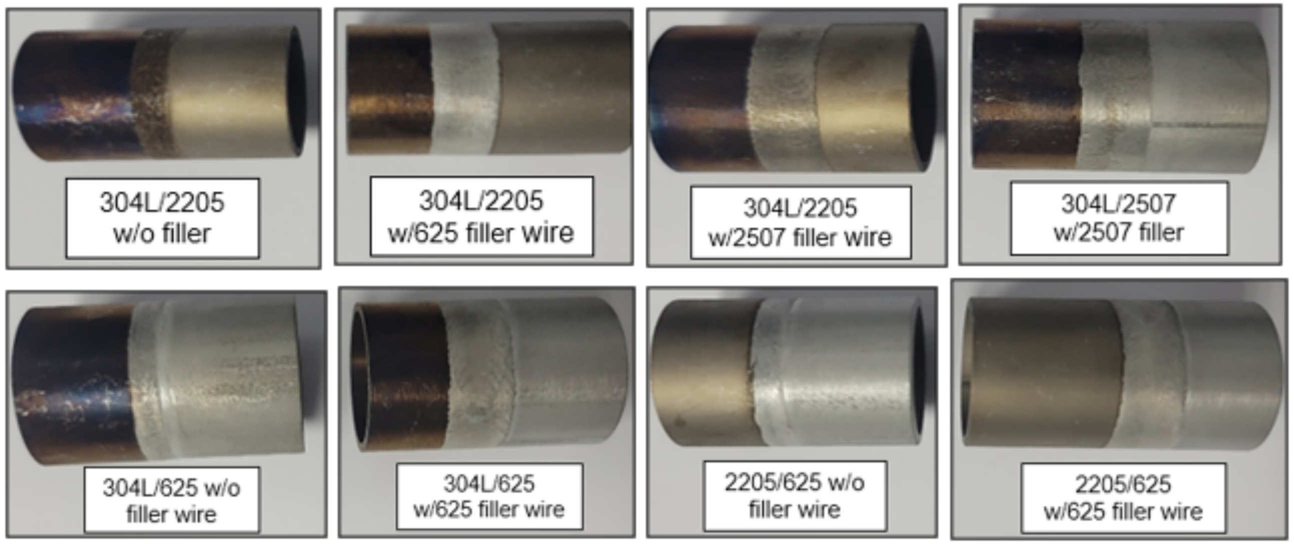




III. Test Results – Corrosion Performance

A262 Practice C:

- The austenitic test samples (a half of 304L orbital weld & base metal) experienced discoloration, while the duplex and nickel samples (2205, 2507, & 625) had a dulled surface finish.
- 304L stained more than other grades, they only experienced a little more corrosion than the 625 and retained a smooth surface (no pitting corrosion).



Sample	Test Period	Corrosion Rate (grams) (Mpy: mils per year)
304L/625 w/625 filler wire	240 Hrs. each test	16.6
304L/625 w/o filler wire		16.7
304L/2205 w/ 2507 filler wire		19.8
304L/2205 w/ 625 filler wire		21.3
304L/2205 w/o filler wire		21.6
2205/625 w/625 filler wire		23.9
2205/625 w/o filler wire		20.3
304L base metal		19.2
2205 base metal		32.1
625 base metal		18.0

IV. Summary and Discussion

Regarding “Tube Orbital weld Joining between Dis-similar grades:

1. **Welding Procedure can be developed with high performance results.**
2. **Metallurgical analysis did not show any detrimental phases between dis-similar metal joining by GTAW weld.**
3. **Corrosion resistance of the dis-similar metal was not compromised by the GTAW welding process and improved than lower alloy base metal.**
4. **With automatic welding and inspection/test capability, the consistency of the weld can be maintained.**
5. **Additional study dis-similar metal joining between Low Carbon Steel and Austenitic Stainless Steel is planned.**

Questions ?