Performance of Dissimilar Metal Welds in Supercritical CO_2 Power Cycles

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Evaluation of Welding Issues in Ni Alloys and Stainless Steels For Advanced Energy Systems

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Disclaimer

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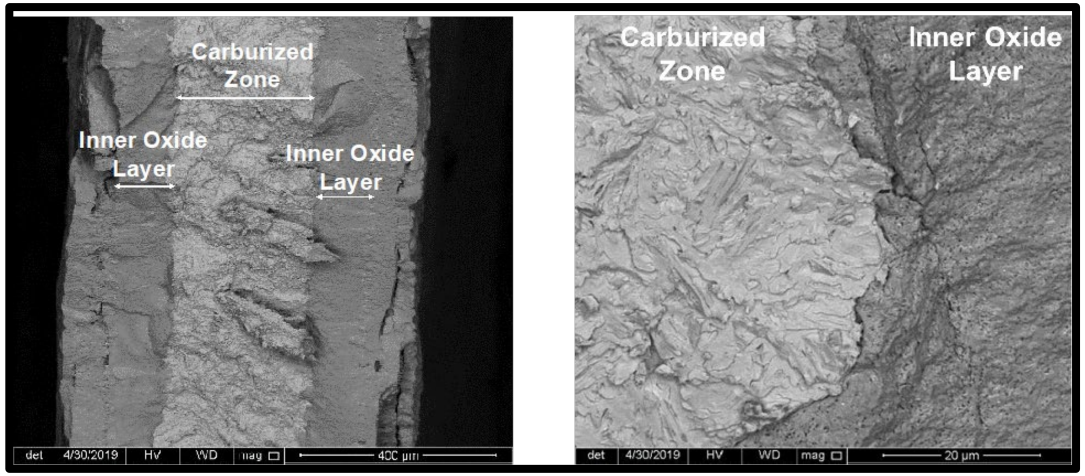
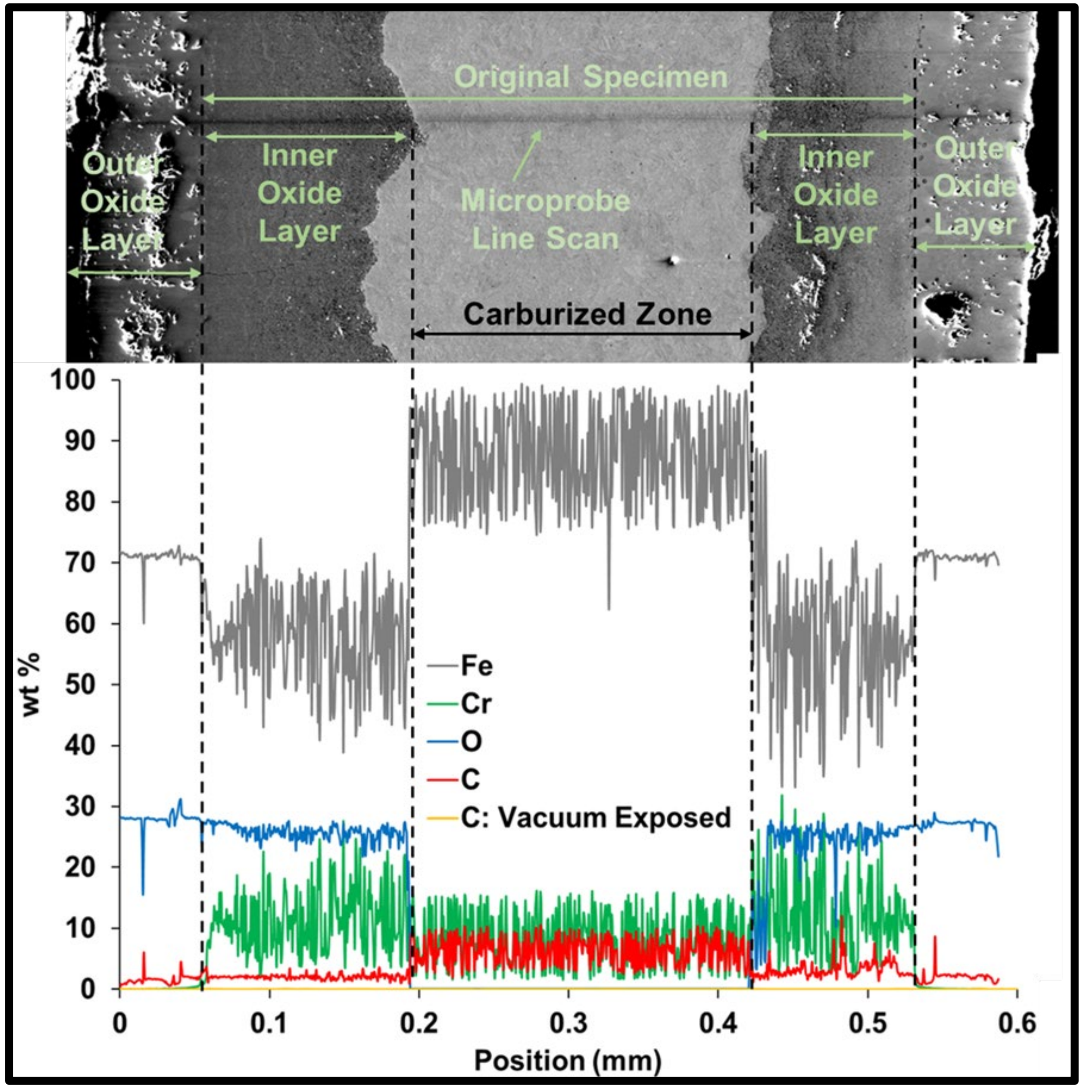
Degradation of materials in sCO_2

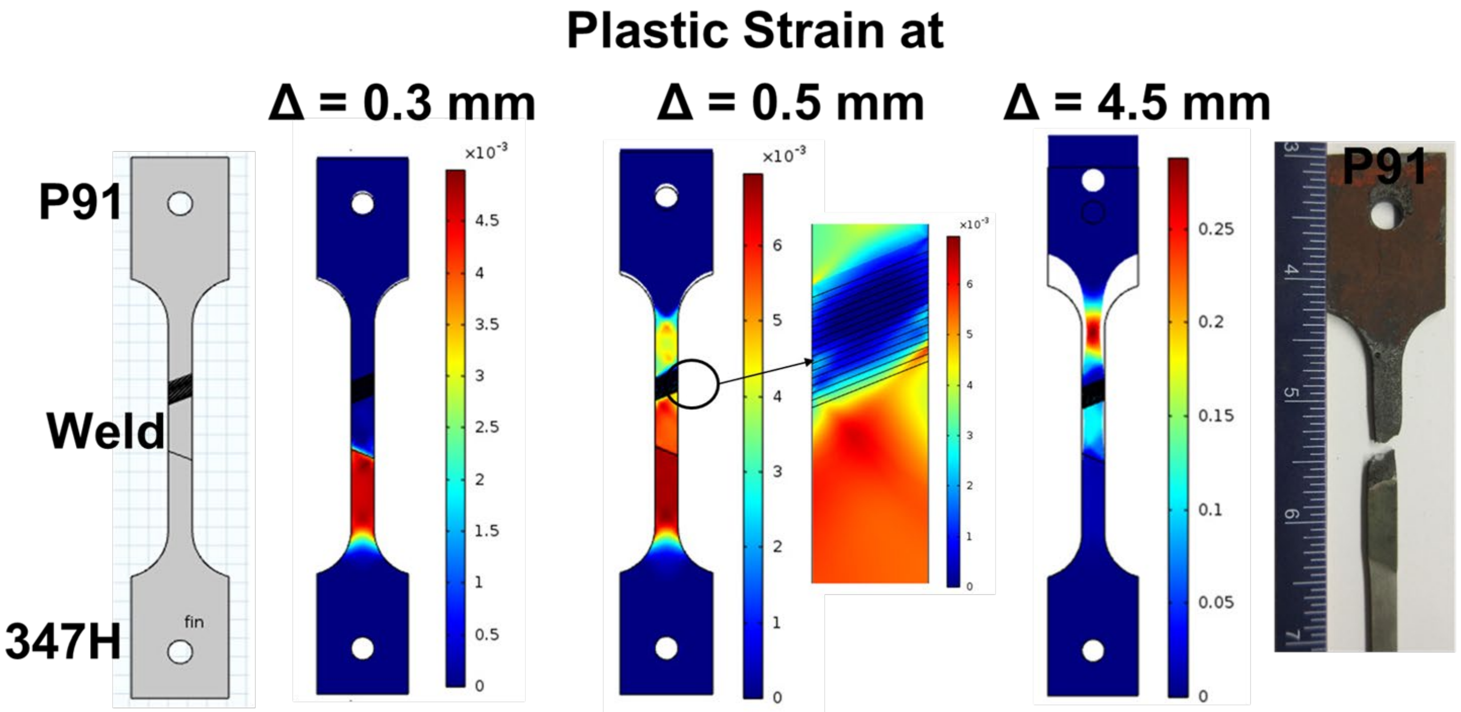
- Last few years, significant amount of data have been generated on materials performance in sCO_2 power cycle environments.
- Degradation in Ni alloys due to sCO_2 power cycle conditions is minimal. Ni alloys form thin protective chromia scales which prevent excessive oxygen and carbon penetration.
- Steels, on the other hand, are more susceptible to the sCO_2 power cycle environments. When they can form continuous chromia scales (higher Cr content), they perform well. However, lower Cr steels oxidize and carburize extensively.





Degradation of welded materials in sCO_2

- Dissimilar metal welds exhibit a complex behavior under load without the effect of environment
- High-temperature oxidation and carburization of dissimilar metal welds in sCO_2 power cycle environment will be presented.
- Environmental effect on mechanical properties of dissimilar metal welds will be discussed.



Dissimilar and Similar Metal Welds

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	Fe	Ni	Cr	Co	Mo	Nb	V	Mn	Si	Al	Ti	Cu	C
Gr22 BM	95.5	0.2	2.3		0.9		0.01	0.5	0.2	0.03		0.2	0.1
Gr91 BM	89.3	0.09	8.4		0.9	0.07	0.2	0.5	0.3			0.09	0.09
347H BM	70.2	9.0	17.3	0.2	0.4	0.6		1.5	0.4			0.4	0.05
263 BM	0.4	50.7	20.3	19.7	5.8			0.4	0.02	0.4	2.2	0.04	0.06
Gr 91 FM	88.5	0.1	9.2		0.9	0.07	0.2	0.6	0.3			0.01	0.1
347H FM	72.4	8.5	15.8		1.1			1.7	0.2			0.09	0.04
625 FM	0.2	64.7	22.0		9.0	3.6			0.04	0.3	0.2	0.02	0.01

FACE

ROOT

Weld	Filler Metal
Gr91-Gr91	Gr91
347H-347H	347H
Gr91-347H	625
Gr22-263	625

POST WELD HEAT TREATMENT

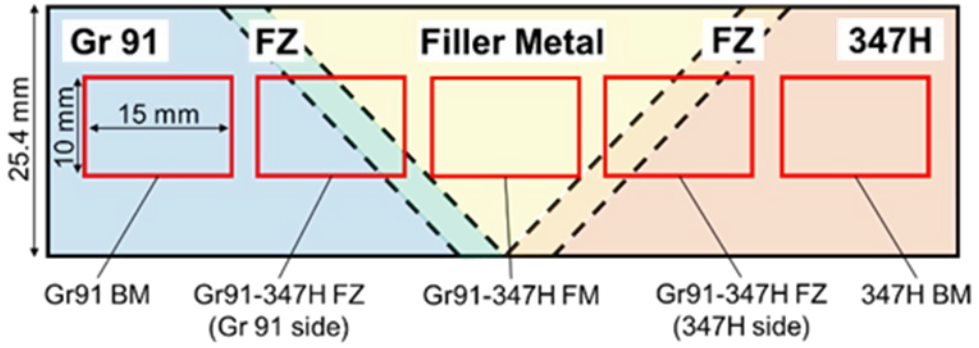
Weld	PWHT
Gr91-Gr91	2 h at 760°C
347H-347H	NA
Gr91-347H	2 h at 746°C
Gr22-263	Alloy 263 after buttering 8 h at 800°C
	Complete weld 1 h at 732°C

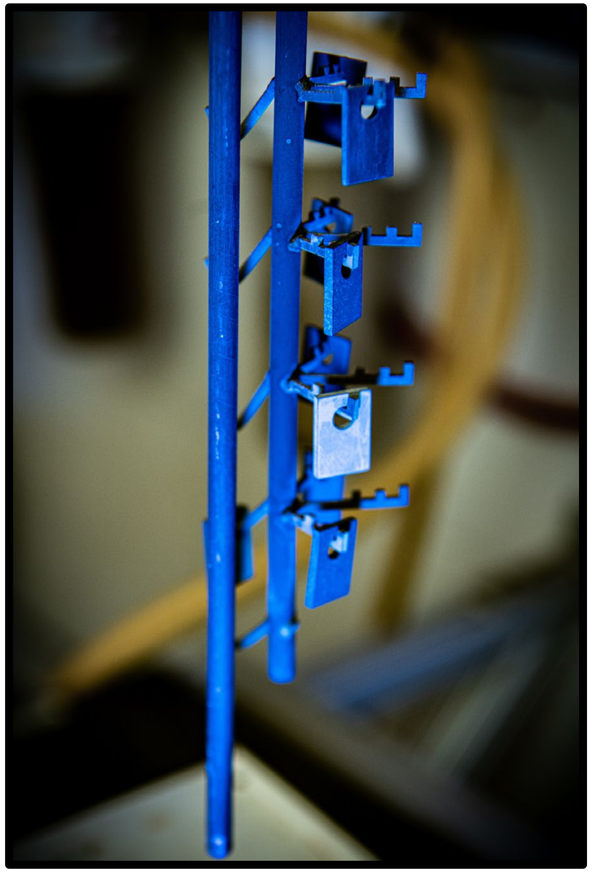
Welding was performed at Edison Welding Institute using gas tungsten arc welding according to the requirements for pressure vessels fabricated per ASME Boiler & Pressure Vessel Code, Section IX.

High-Temperature Oxidation in Supercritical CO_2

NATIONAL ENERGY TECHNOLOGY LABORATORY

- 550°C
- 20 MPa
- 2500 hours
- Flowing High-purity CO_2

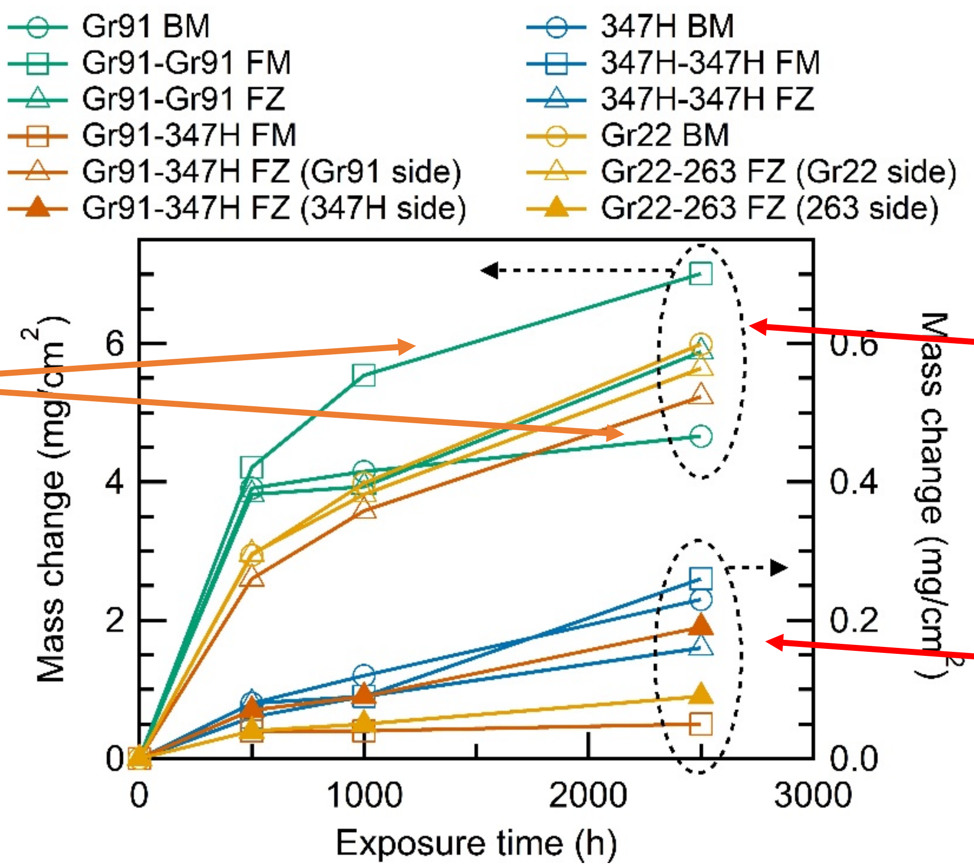




High-Temperature Oxidation in Supercritical CO_2

- 550°C
- 20 MPa
- 2500 hours
- Flowing High-purity CO_2

Grain size difference - Grain size is much larger in the filler metal of Gr91?

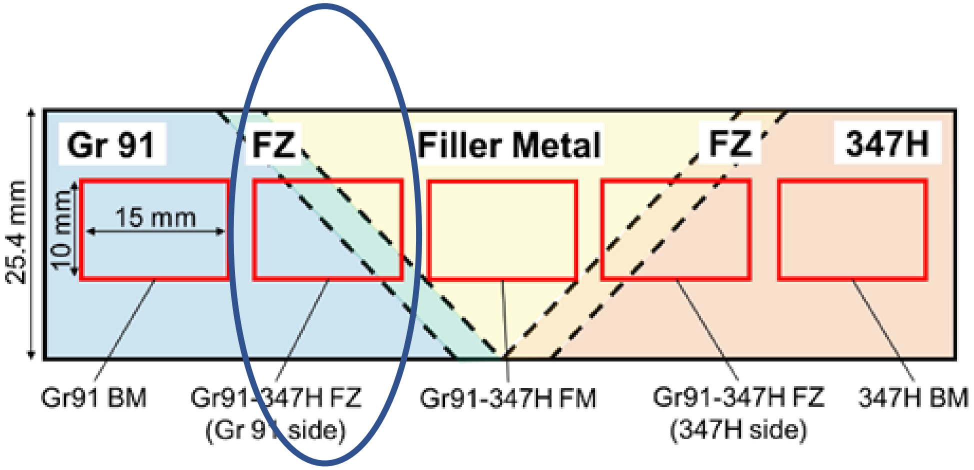


- BM: Base Metal
- FZ: Fusion Zone
- FM: Filler Metal

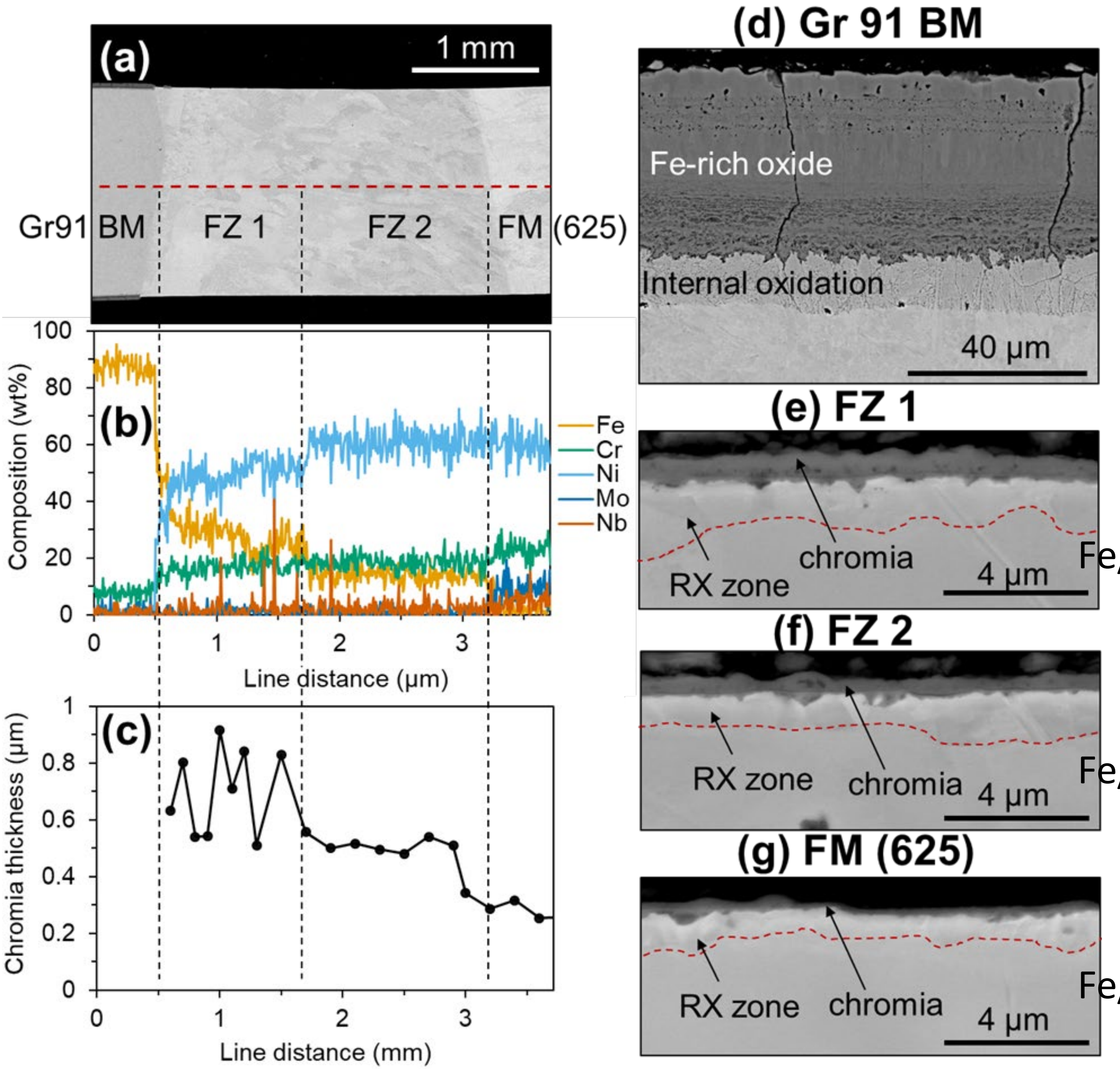
- High mass gains
  - Fe-rich oxide growth
- Low mass gains
  - Cr-rich oxide growth

Gr91-347H

Oxidation



For a Cr content of ≈ 20 wt%, a change in Fe/Ni weight ratio from 0.26 in FZ2 to 0.53 in FZ1 resulted in an 80% increase in growth rate of the chromia scale.



Fe/Ni=0.53

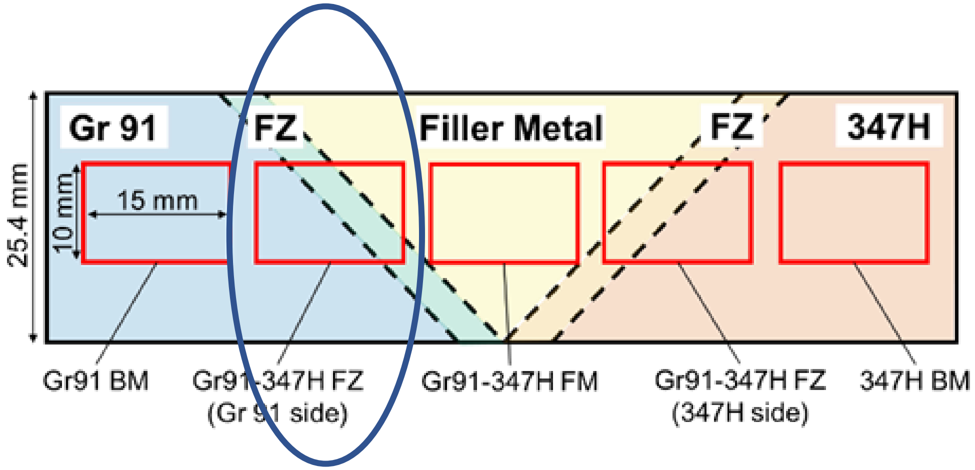
Fe/Ni=0.26

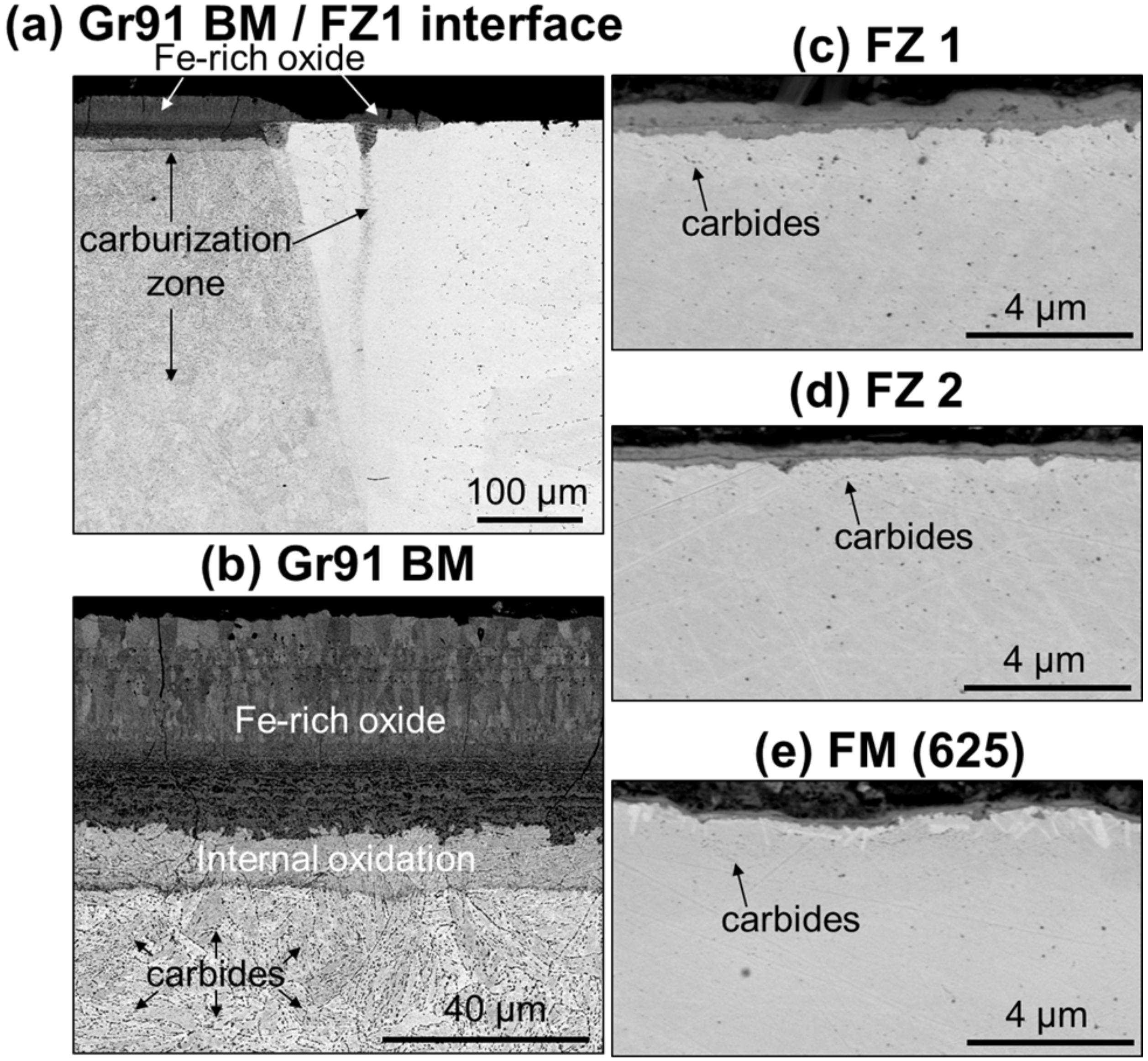
Fe/Ni=0.02

Gr91-347H

Carburization

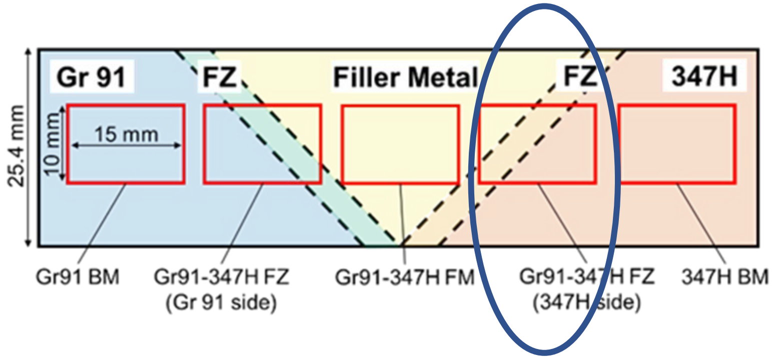
In general, considerable carburization accompanies the growth of Fe-rich oxide scales, whereas chromia scales are a much better (albeit imperfect) barrier to carbon ingress.



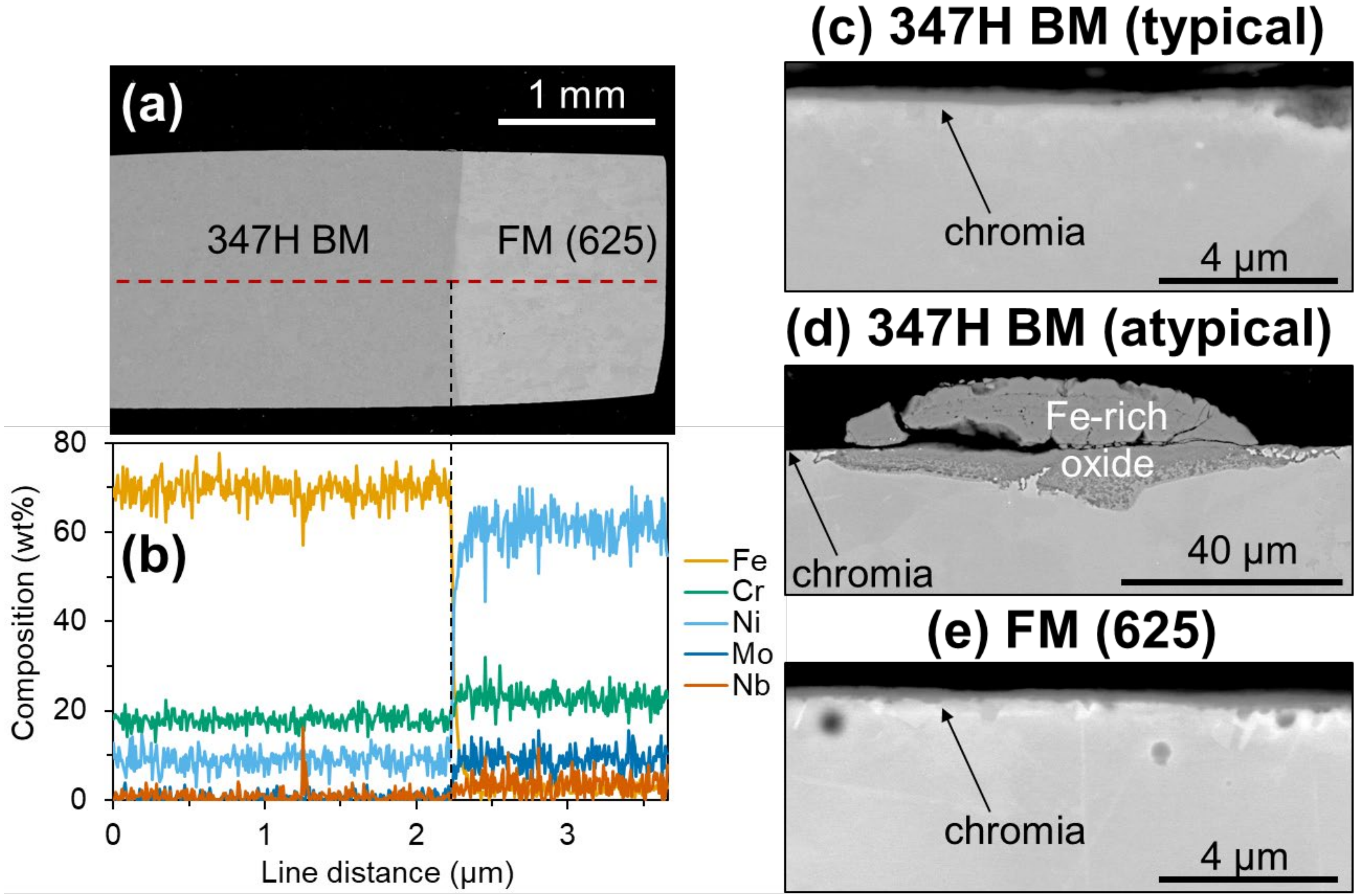


Gr91-347H

Oxidation

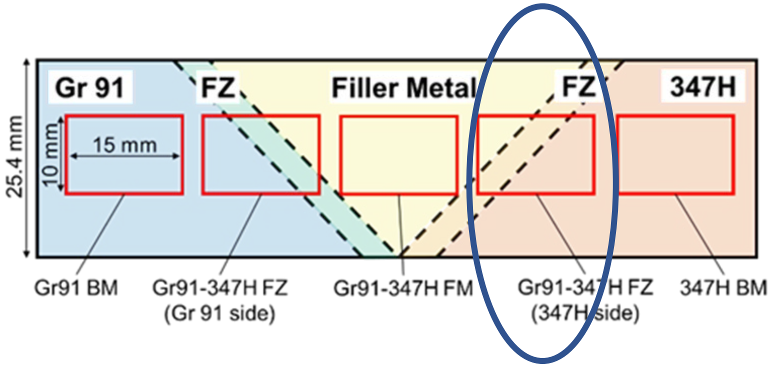


- No compositional transition zones between the base metal (347H) and filler metal (625).
- Most of the 347H surface formed a chromia scale while Fe-rich oxide nodules formed occasionally.
- The 625 FM formed a chromia scale with no evidence of nodule formation.

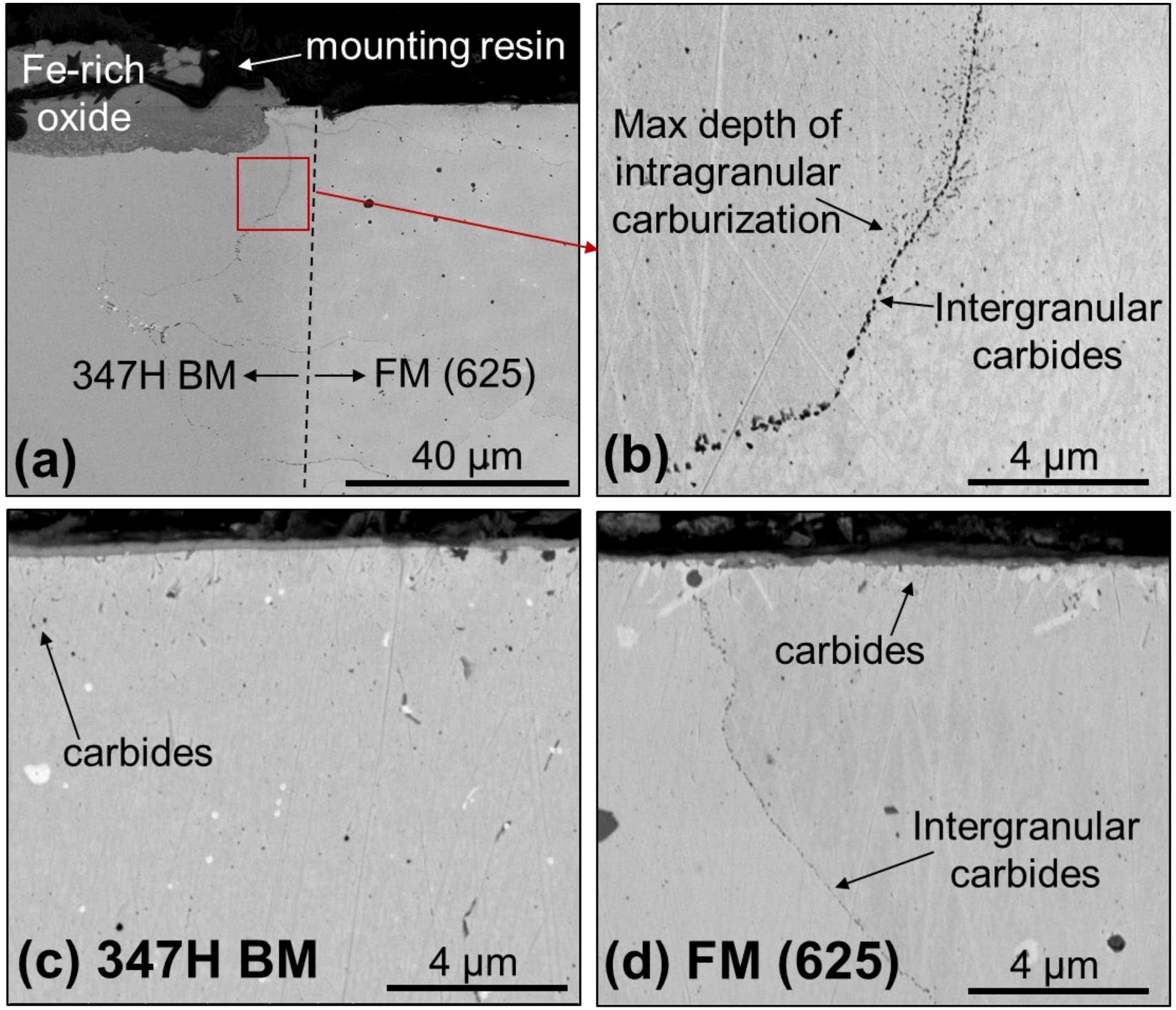


Gr91-347H

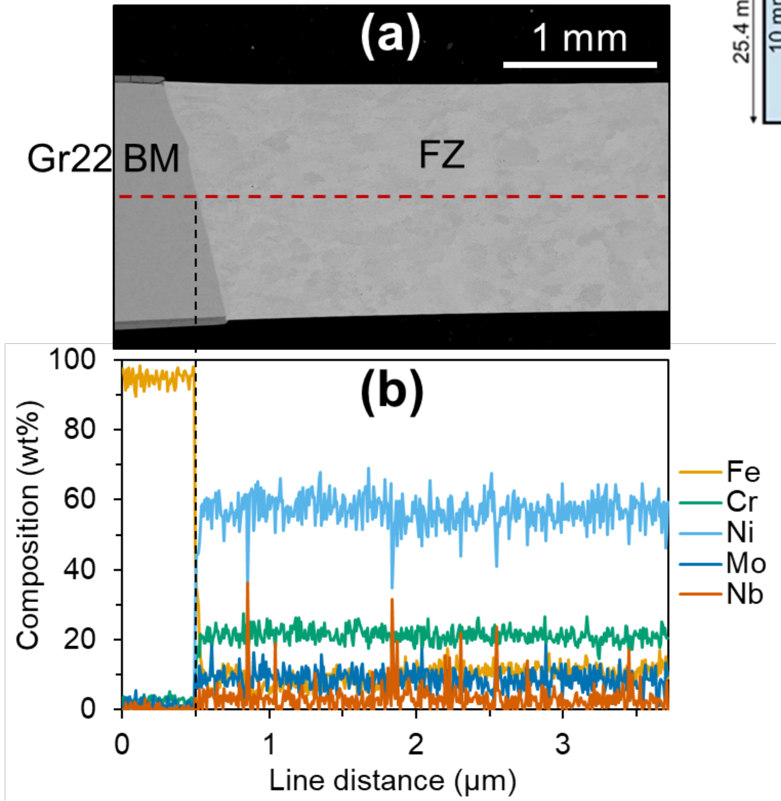
Carburization

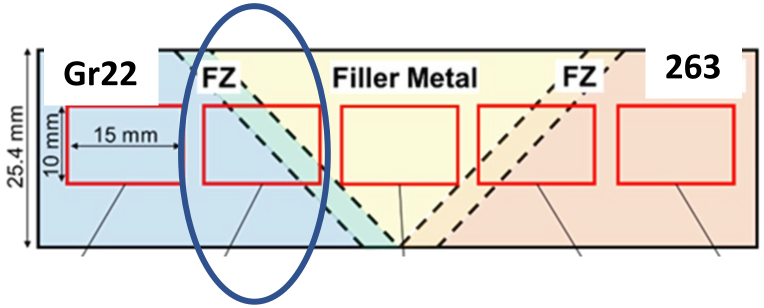


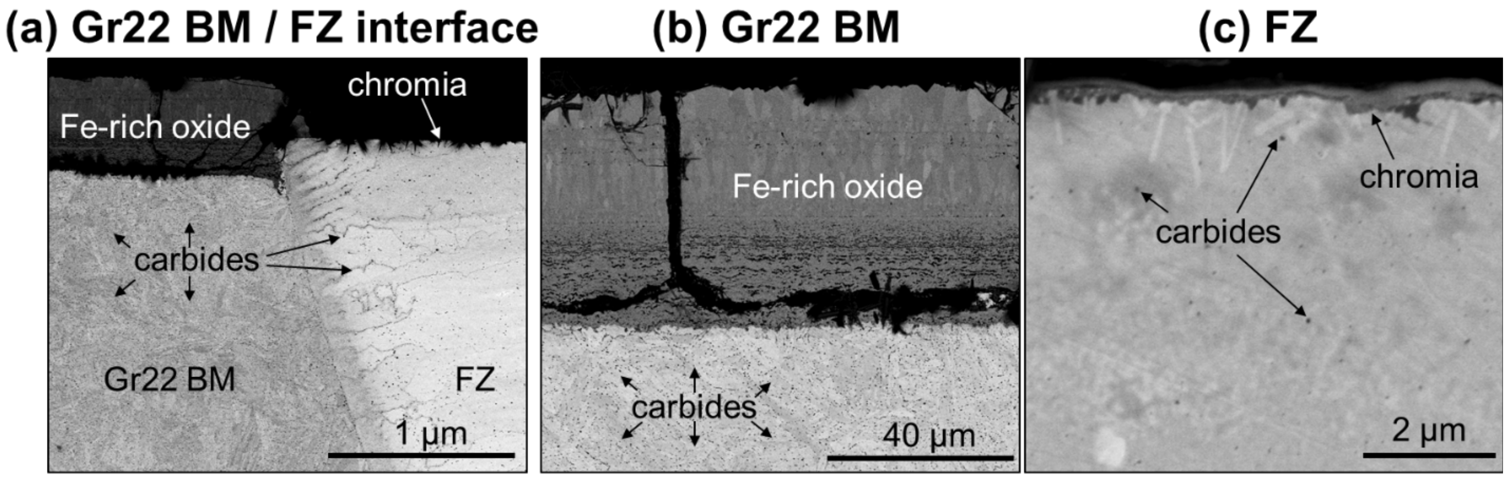
When an Fe-rich oxide formed on the surface, small carbides were also found within a narrow region (≈1 µm) surrounding the grain boundary. Further, these intragranular carbides were confined to a depth of ≈20 µm beneath the oxide.



Gr22-263





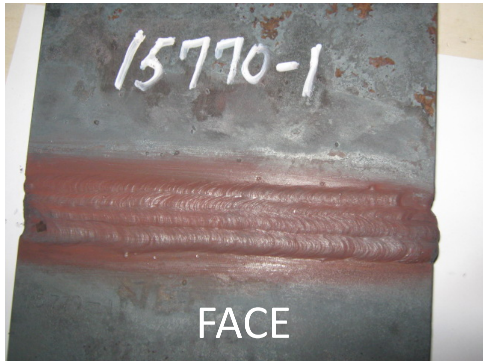


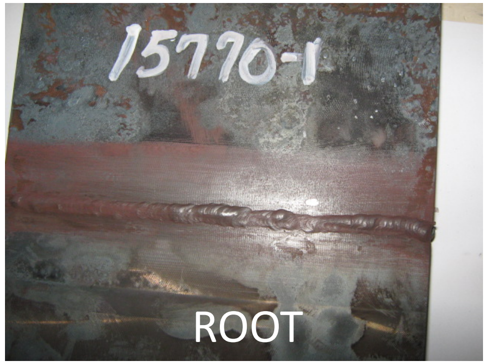
An Fe content across the entire Ni-rich region that is significantly higher (≈10 wt%) compared to that expected for the 625 FM (≈0.2 wt%). Therefore, the Ni-rich region was in fact a fusion zone that had incorporated a significant quantity of Fe from the Grade 22 BM during the welding process.

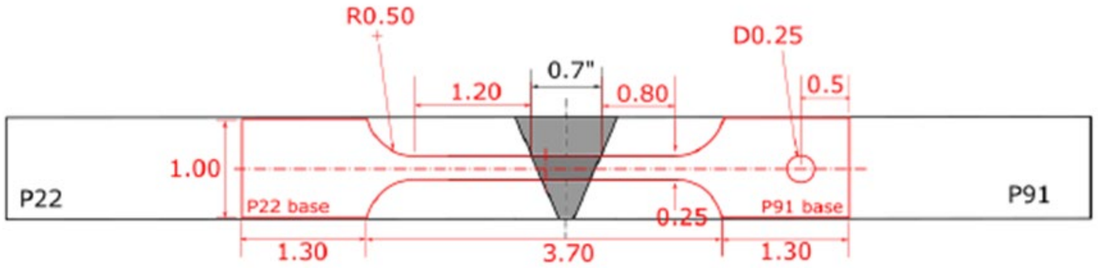
- No internal oxidation zone on Gr22 base metal
- Carbides are present entire cross-section of Gr22 indicating that these carbides formed prior to the exposure. Some increase in carbide size beneath oxide scale indicates carbon ingress.
- A continuous chromia scale formed on FZ and FM.

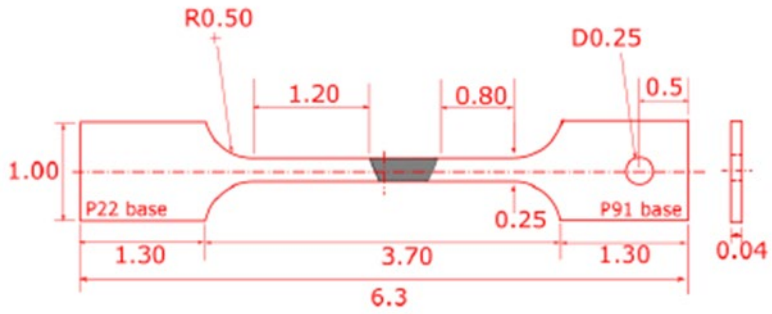
Mechanical Performance of Dissimilar Metal Welds After Exposure to Direct-Fired sCO_2 Power Cycle Environment

- P91 and P22 steel plates (8”x6”x1”) were welded using GTAW and a filler metal with similar composition to P22 (ER90S-B3/E9018-B3).
- Post weld heat treatment: 2 h at 746°C
- Tensile specimens were machined out of P22-P91 welded plate
- Tensile specimens were exposed to
  - DF4: Simulated direct-fired sCO_2 power cycle environment: CO_2+4%H_2O+1%O_2 at 600°C, 1 bar, 1000 hours
  - Vacuum at 600°C, 1000 hours
- Tensile tests were performed at room temperature. Strain was monitored by
  - Extensometry
  - Digital image correlation (DIC)

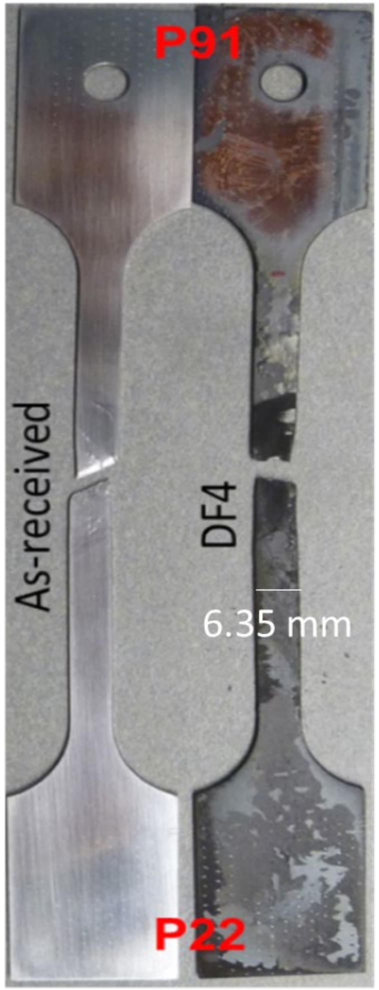


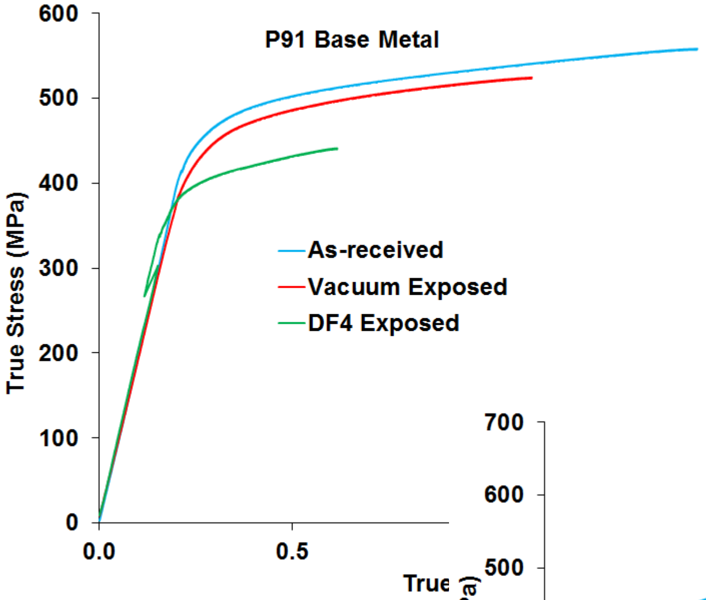


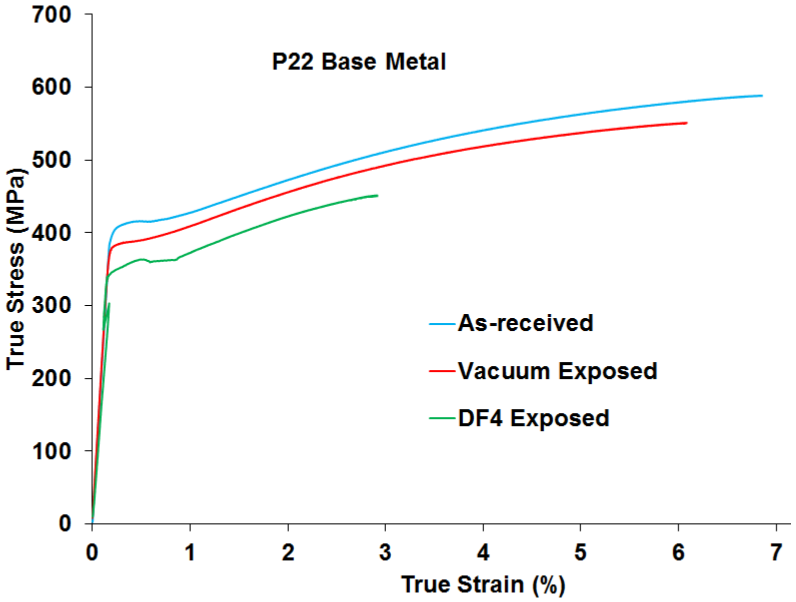


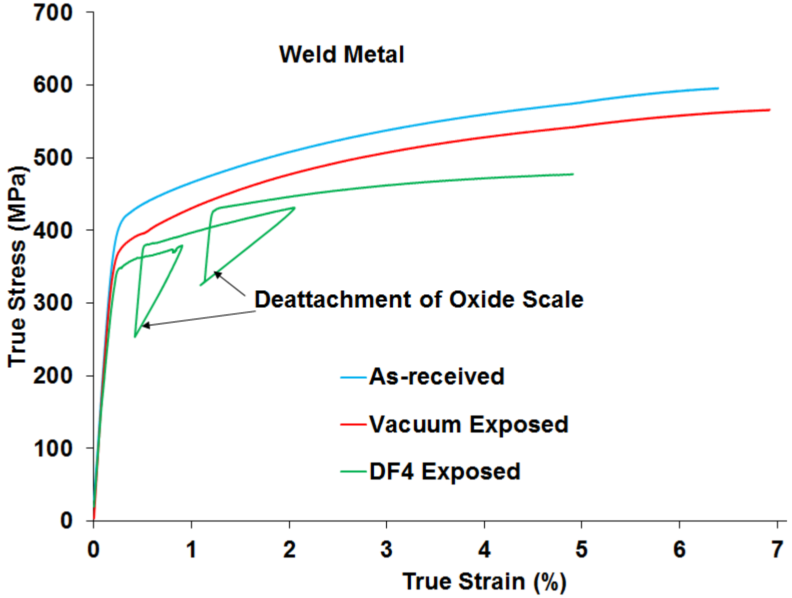


P91-P22 Weld Couple - Tensile Tests

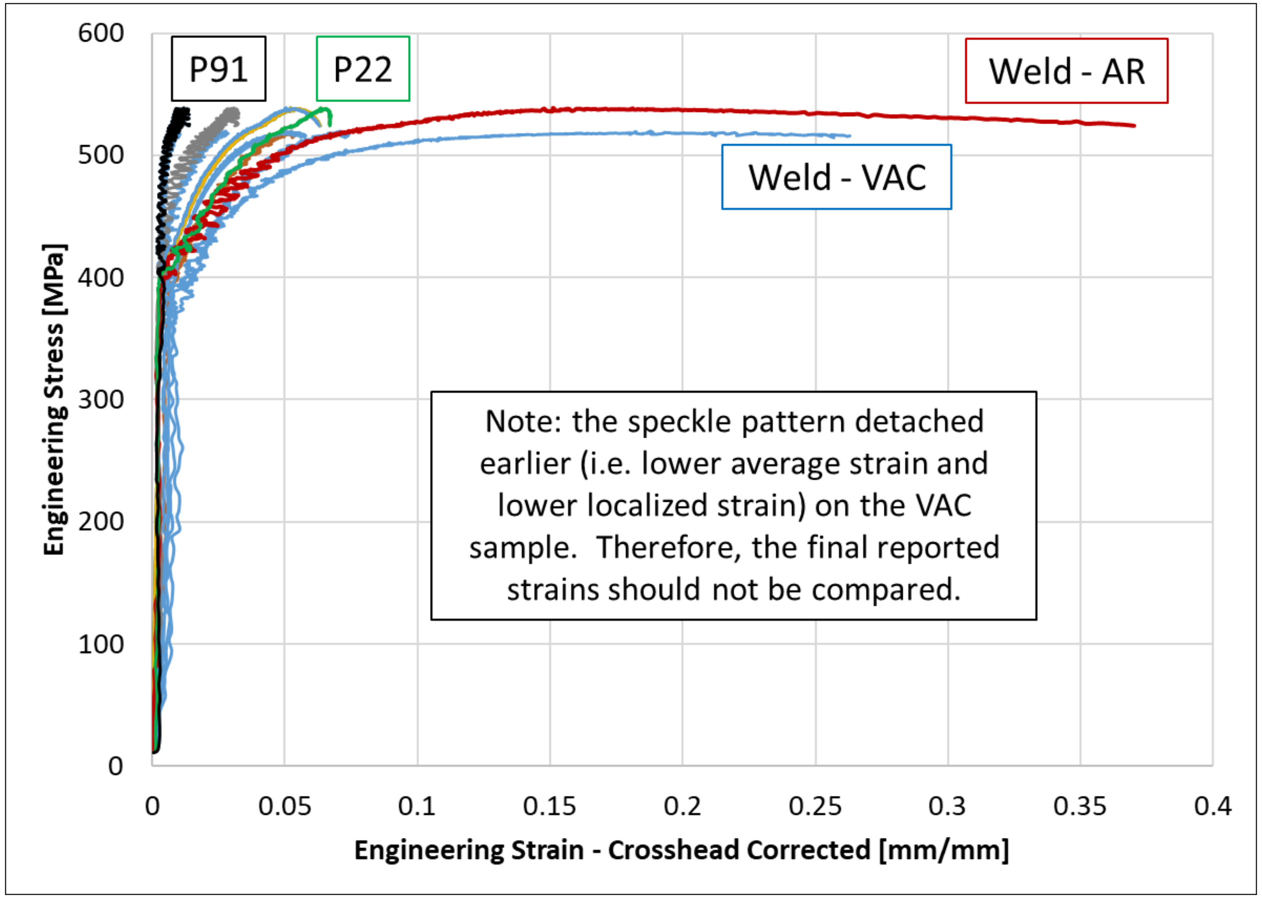


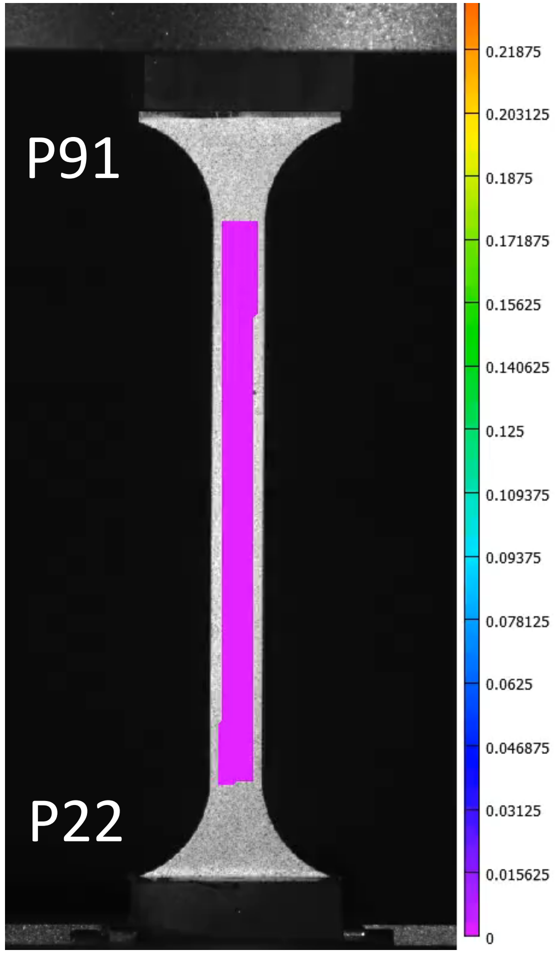






Tensile Tests with Digital Image Correlation (DIC)at University of North Texas





Summary

- Dissimilar metal welds were fabricated via gas tungsten arc-welding from Fe-based and Ni-based alloys that are candidate materials for construction of future sCO_2 power cycles.
- Samples were extracted from different regions of the weld, exposed to supercritical CO_2 at 550 °C, and characterized to understand their behavior in this environment.
- The local oxidation and carburization behavior was primarily dictated by Cr content in the underlying base metal or fusion zone.
- Fe-based alloys with relatively low Cr levels formed fast-growing Fe-rich oxide scales (Gr22 and Gr91) and appreciable carburization of the underlying alloy (Gr91),
- The base metal (347H), filler metal (625), and fusion zones with relatively high Cr levels all formed slow-growing chromia scales and minimal carburization.
- **From an application perspective, no exceptional oxidation behavior occurred at the interface of low-Cr and high-Cr alloy compositions, and therefore the oxidation lifetime of these types of dissimilar metal welds will be essentially dictated by that of the low-Cr base alloy.**
- **Reduction in strength and elongation was observed in the low Cr steels and weld after exposure to direct sCO_2 power cycle environment.**

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