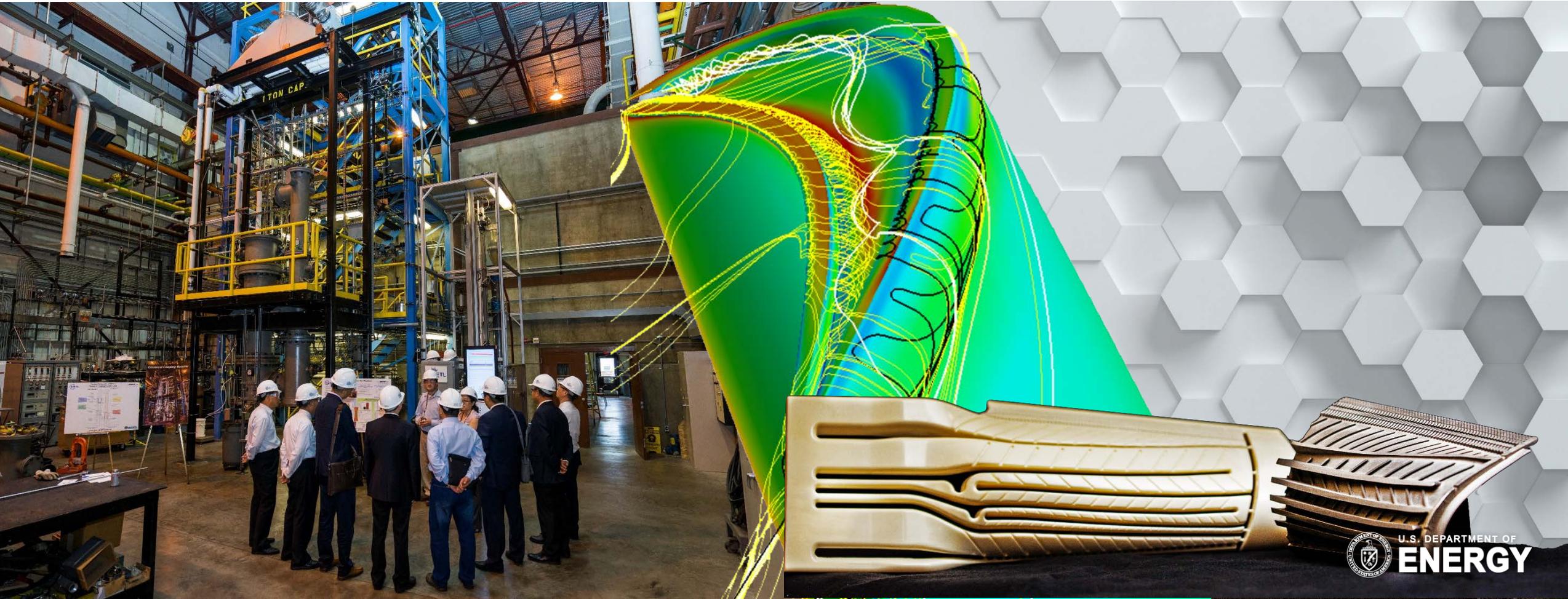


Corrosion behavior of Fe and Ni commercial alloys in direct-fired supercritical CO₂ power cycle environments



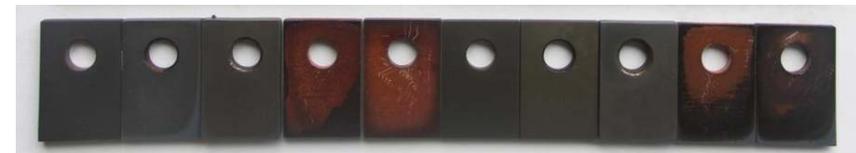
Joseph Tylczak, Richard Oleksak, Gordon Holcomb, and Ömer N. Doğan

Solutions for Today | Options for Tomorrow



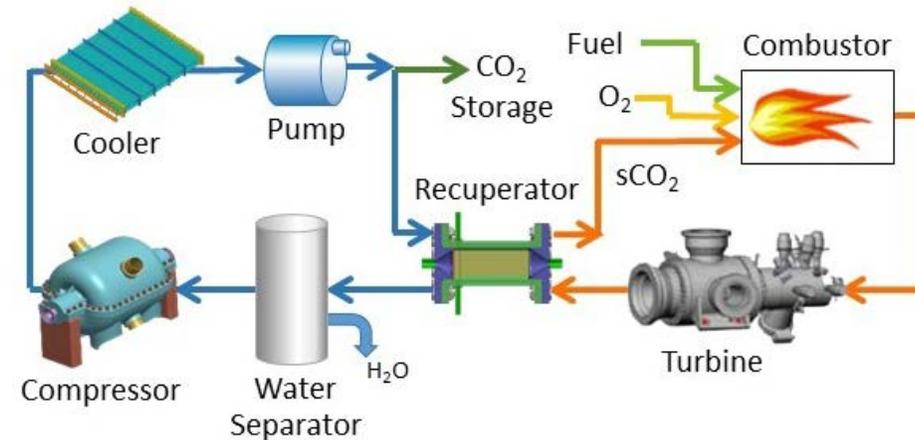
Outline

- **Exposure testing**
 - Alloys
 - Condition
- **Visual observations**
- **Gravimetric results**
 - Iron based alloys
 - Nickel based alloys
- **SEM results**
 - Cross sections of Ni alloys
 - Scale thickness



Objective of this work

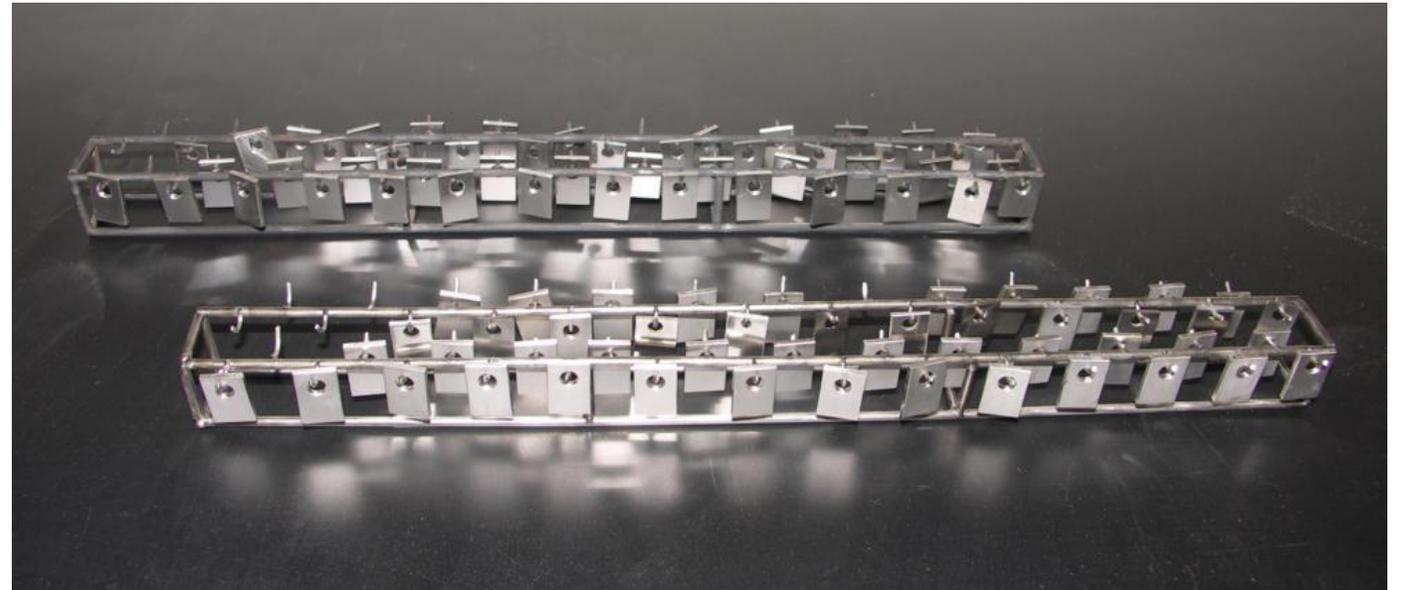
- High temperature boiler materials have been developed for steam/combustion gas conditions. Are these materials appropriate for direct sCO₂ cycle conditions, and which are the best* at resisting high temperature corrosion?



* For some definition of “best”

Alloys

- Fe based
 - Ferritic:
 - Grade 22, Grade 91 , E-Brite
 - Austenitic
 - 304H, 310S, 347H
- Ni based
 - Solution strengthened
 - 230, 617, 625
 - Age Hardenable
 - 263, 282, 740H



Direct fired testing conditions

Condition	CO ₂ , vol %	H ₂ O, vol %	O ₂ , vol %	SO ₂ , vol %	Temp, °C
DF4-Fe	95	4	1	--	550
DF4S-Fe	95	4	1	0.1	550
DF4-Ni	95	4	1	--	750
DF4S-Ni	95	4	1	0.1	750
DF11-Ni	88	11	1	--	750

Tests at atmospheric pressure.

Surface visual, iron based



No SO₂

347H

310S

304H

Grade 22

Grade 91

347H

310S

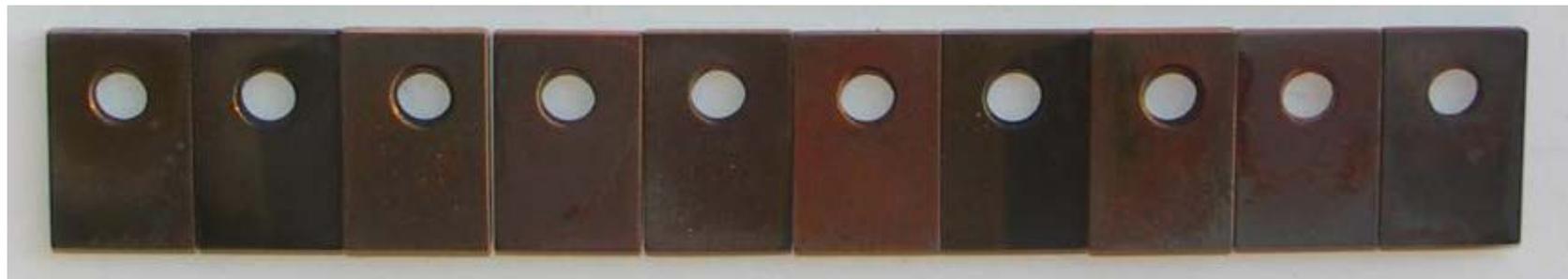
304H

Grade 22

Grade 91

DF4-Fe

- 550 °C
- 95 vol % CO₂
- 1 vol % O₂
- 4 vol % water



With SO₂

2500 h

Surface visual, Ni based

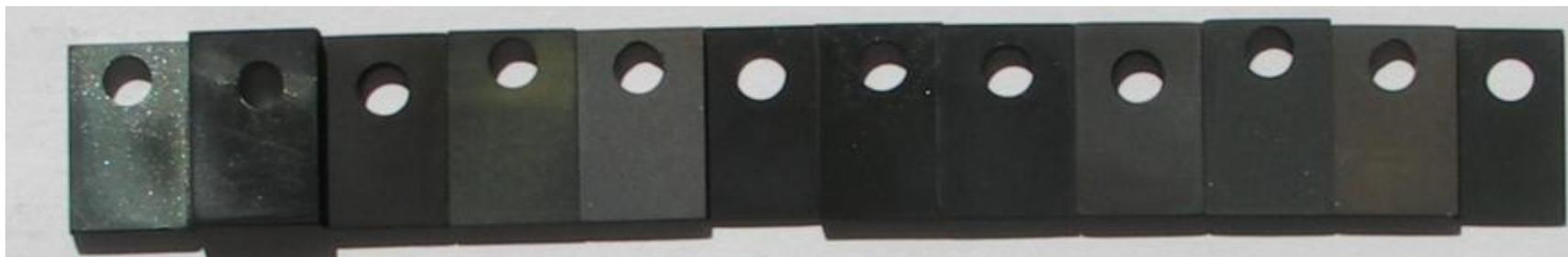


No SO₂

625 617 600 282 263 230 625 617 600 282 263 230

DF4-Ni

- 750 °C
- 95 vol % CO₂
- 1 vol % O₂
- 4 vol % water



With SO₂

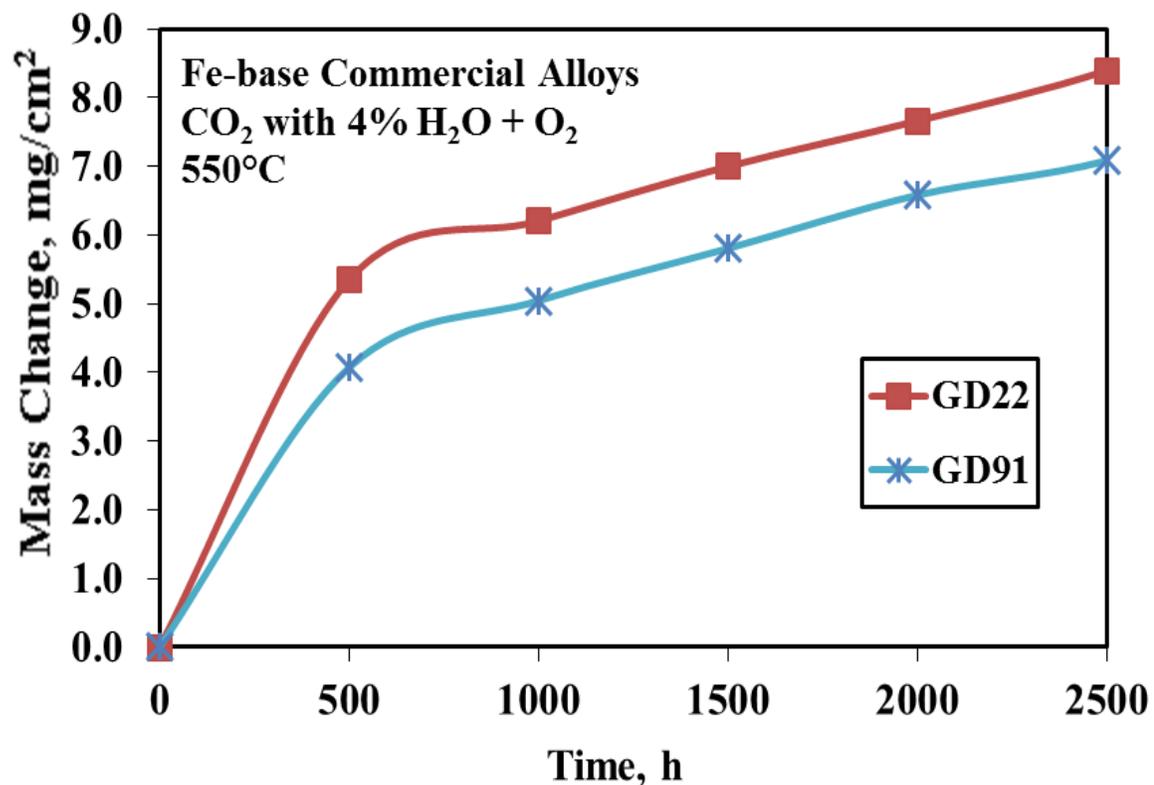
2500 h

Gravimetric results

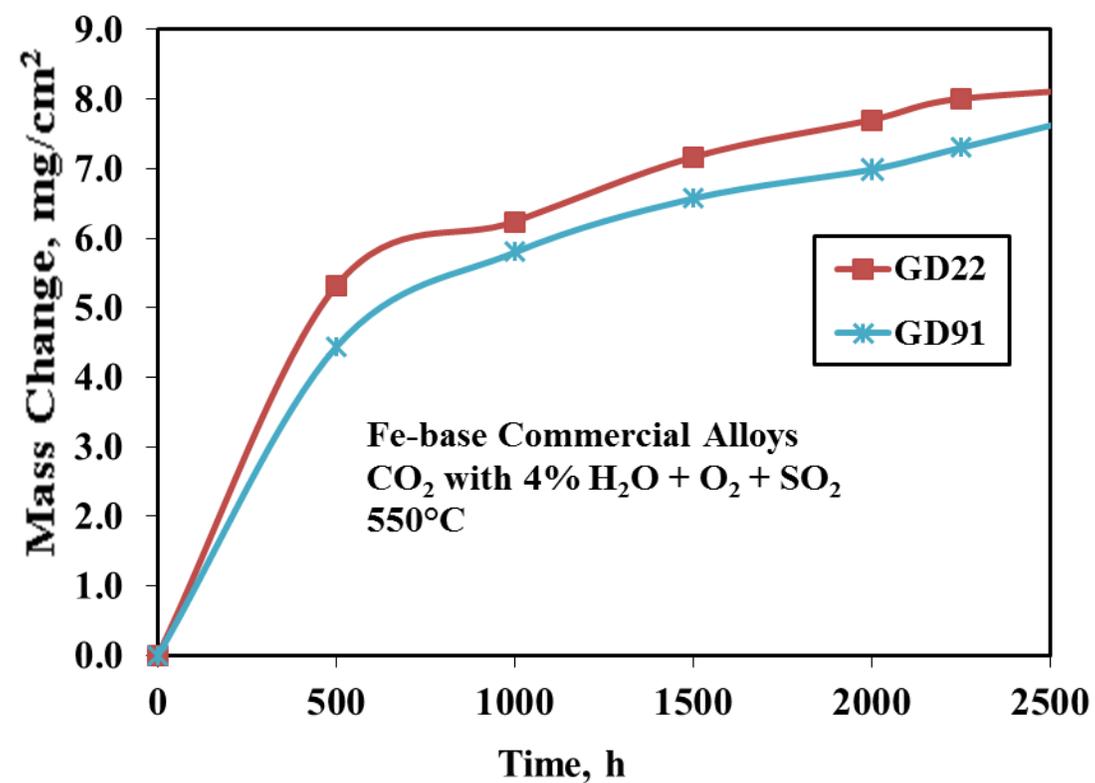


Fe based commercial alloys

No SO₂



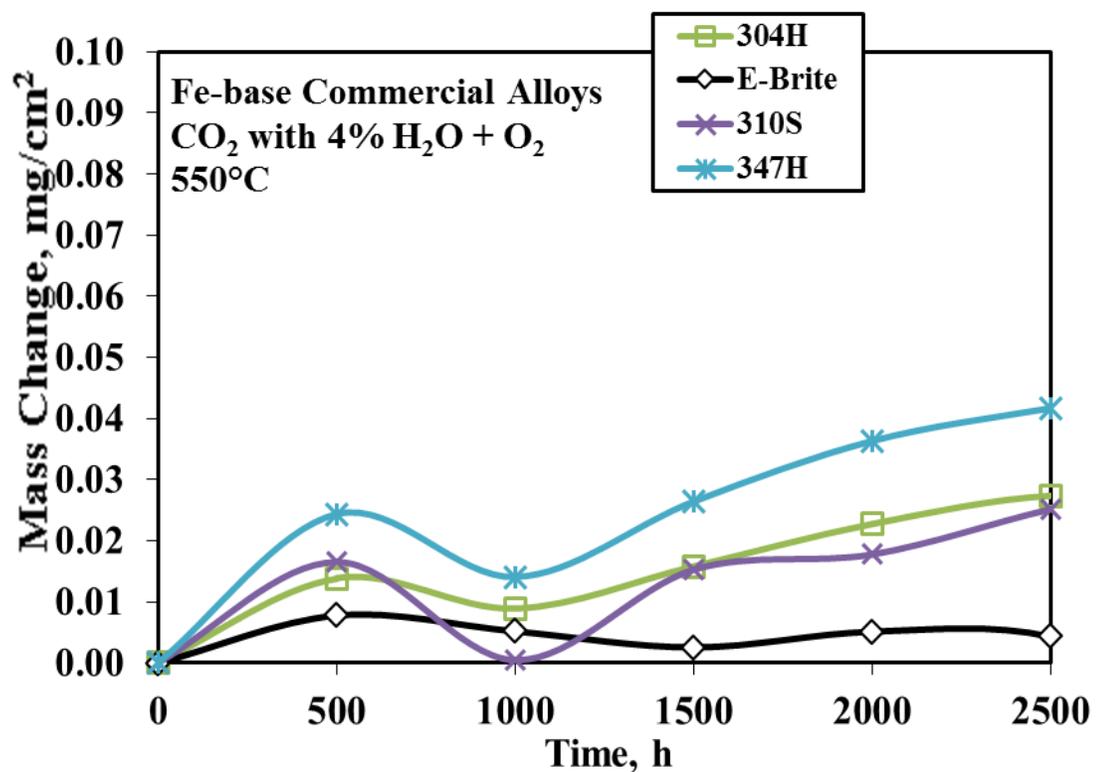
With 0.1 vol % SO₂



550 °C
95% CO₂
1% O₂
4% water

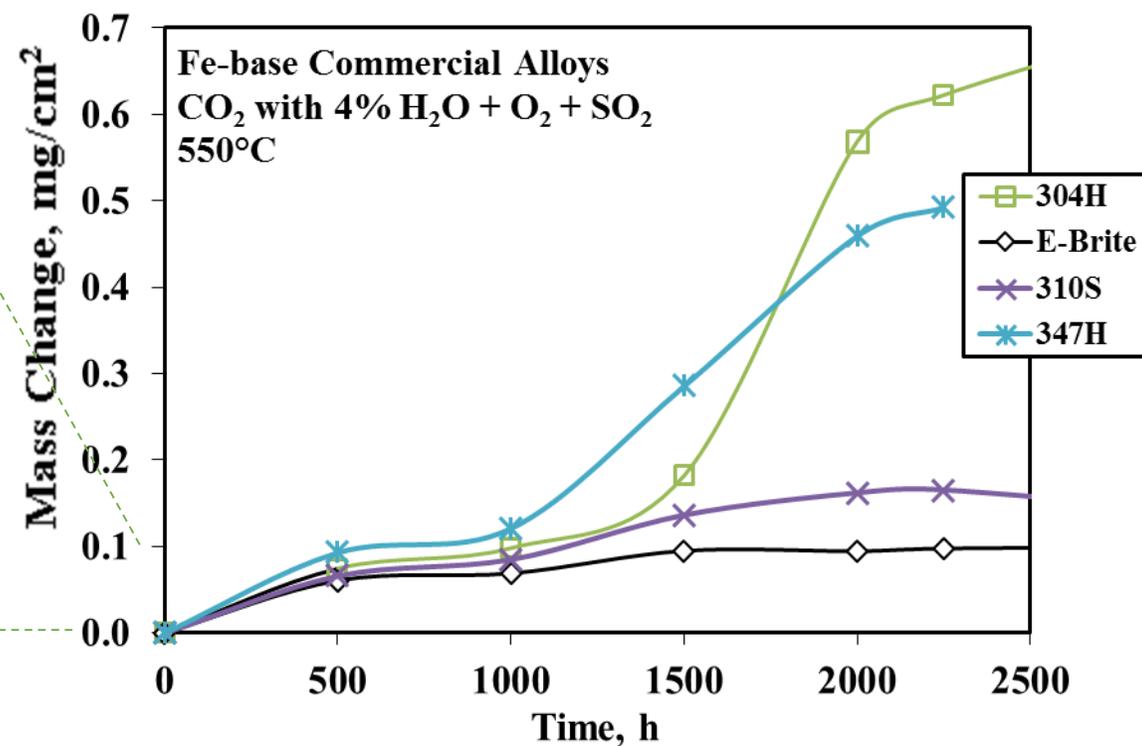
Fe based high Cr commercial alloys

No SO₂



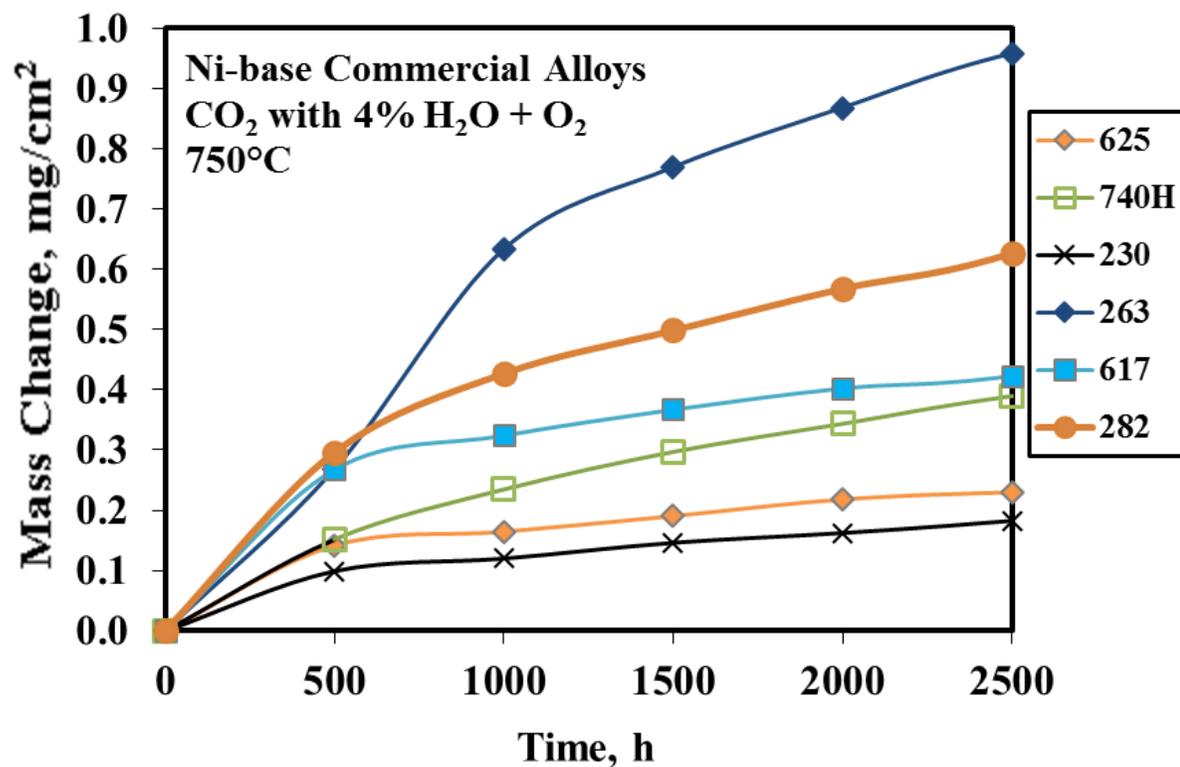
With 0.1 vol % SO₂

550 °C
95% CO₂
1% O₂
4% water



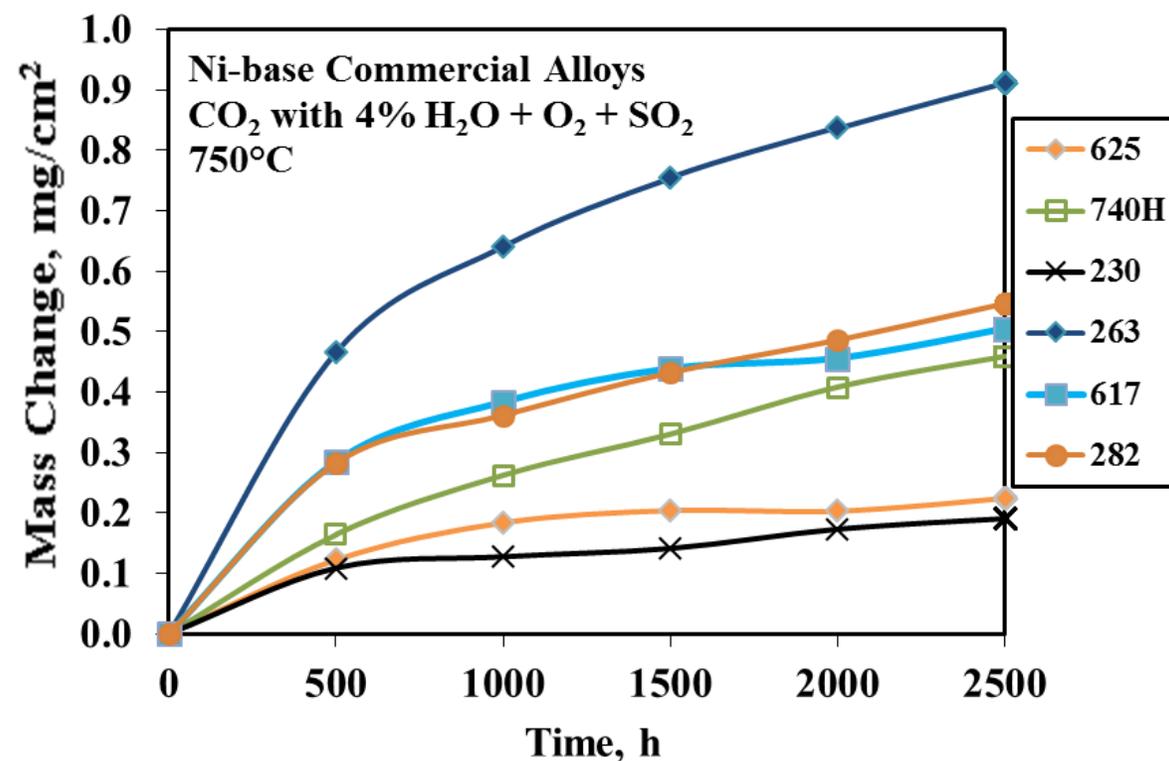
Ni based commercial alloys

No SO₂



With 0.1 vol % SO₂

750 °C
95% CO₂
1% O₂
4% water

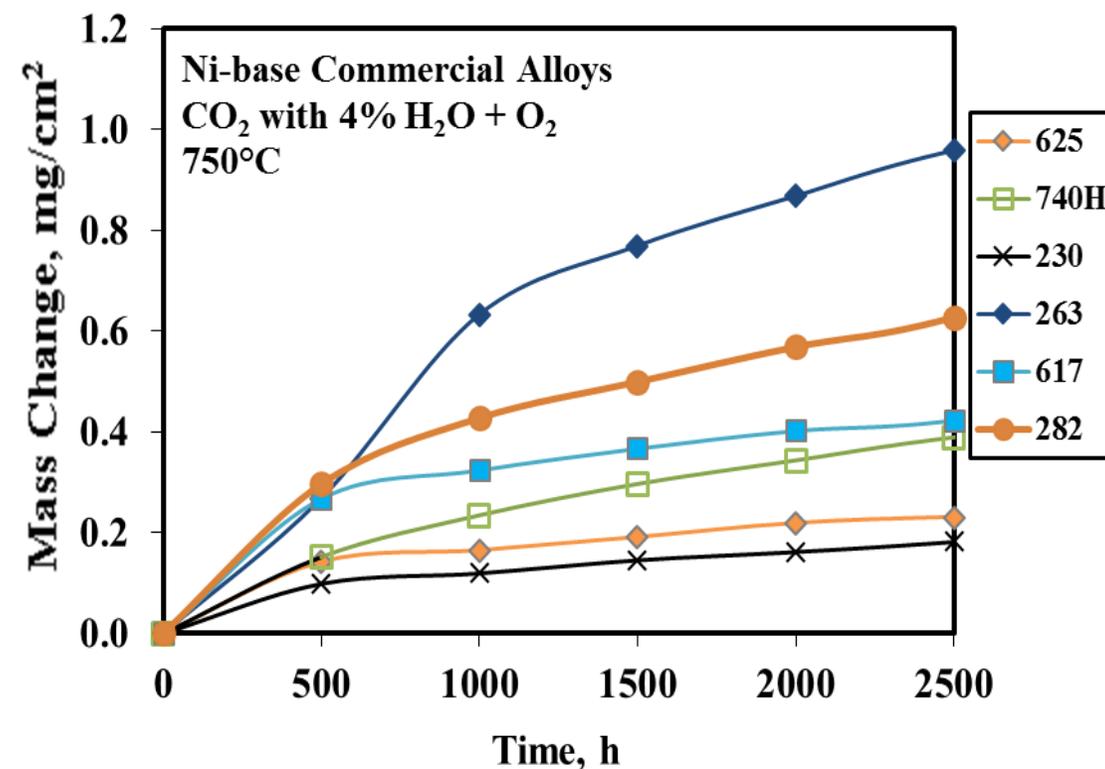
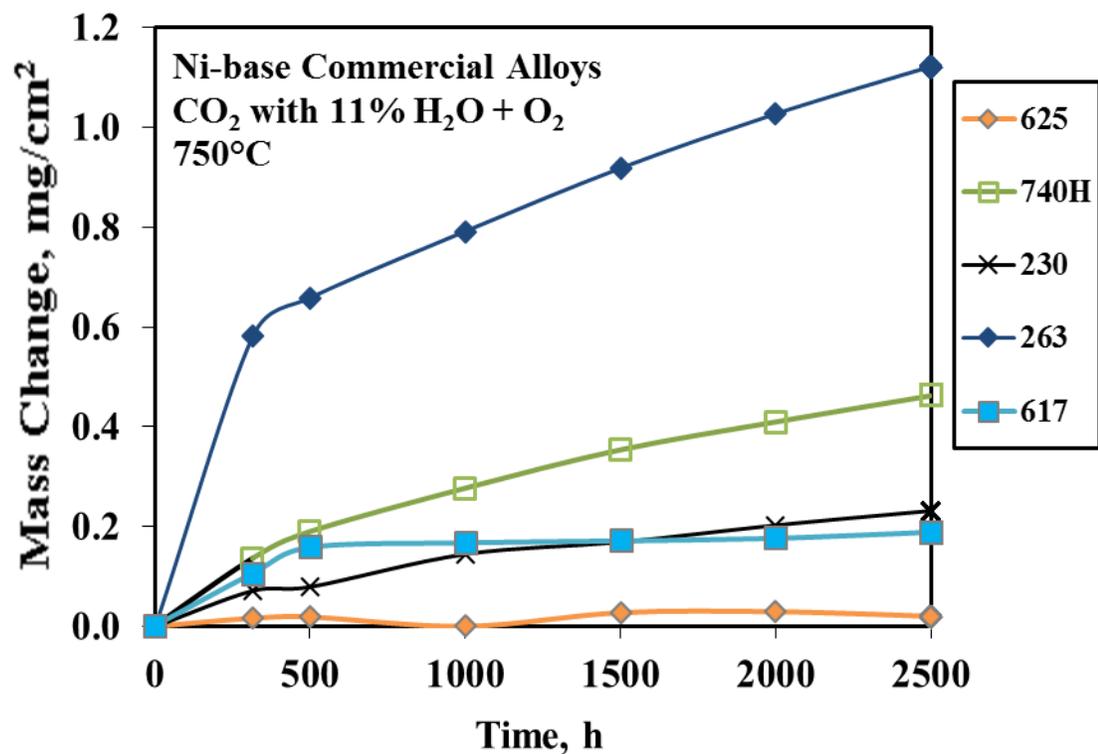


Ni based Commercial Alloys

11 % water

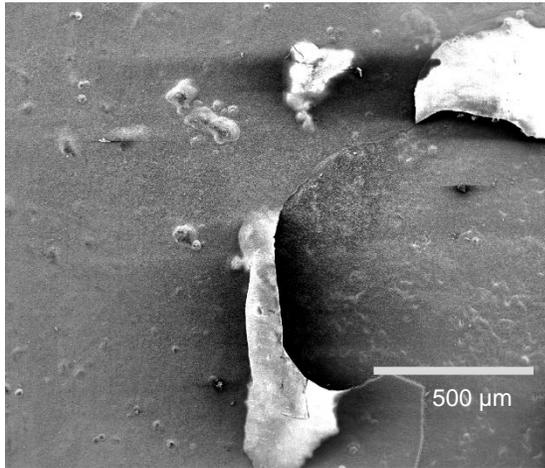
4 % water

750 °C
95 % CO₂
1 % O₂



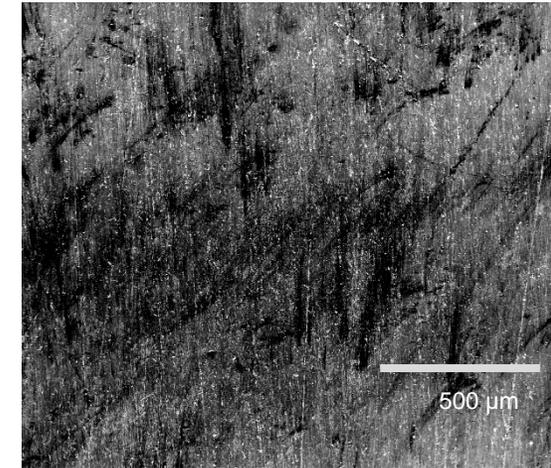
Iron alloy surfaces, GD 91, 310S

GD 91

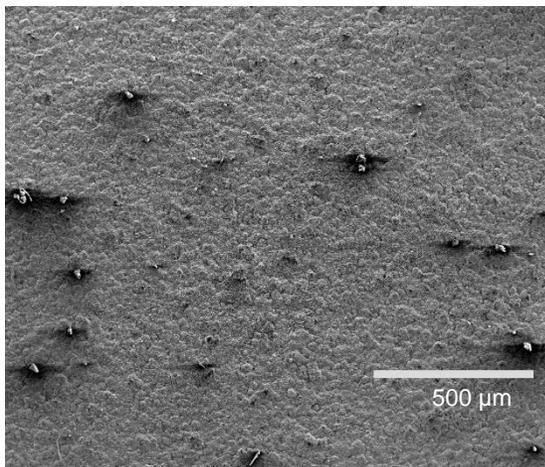


No SO₂

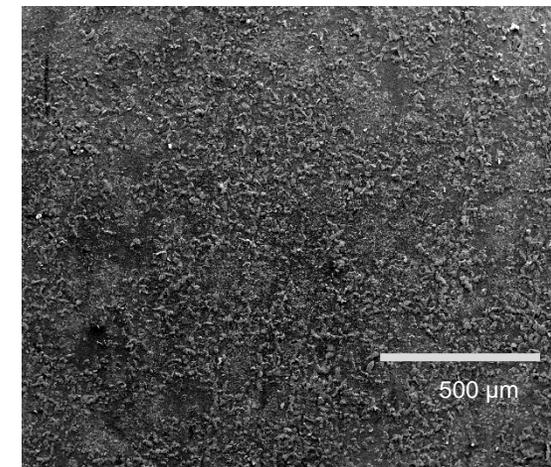
310S



750 °C
95 vol % CO₂
1 vol % O₂
4 vol % water

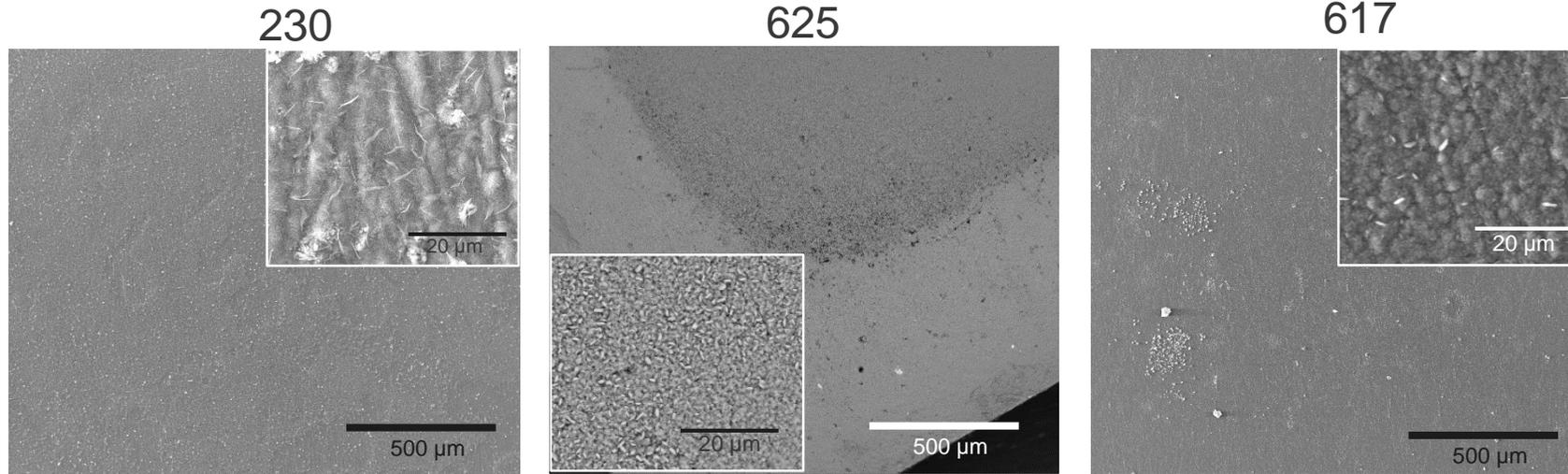


With 0.1 vol % SO₂



Nickel alloy surfaces, 230, 625, 617

No SO₂



750 °C

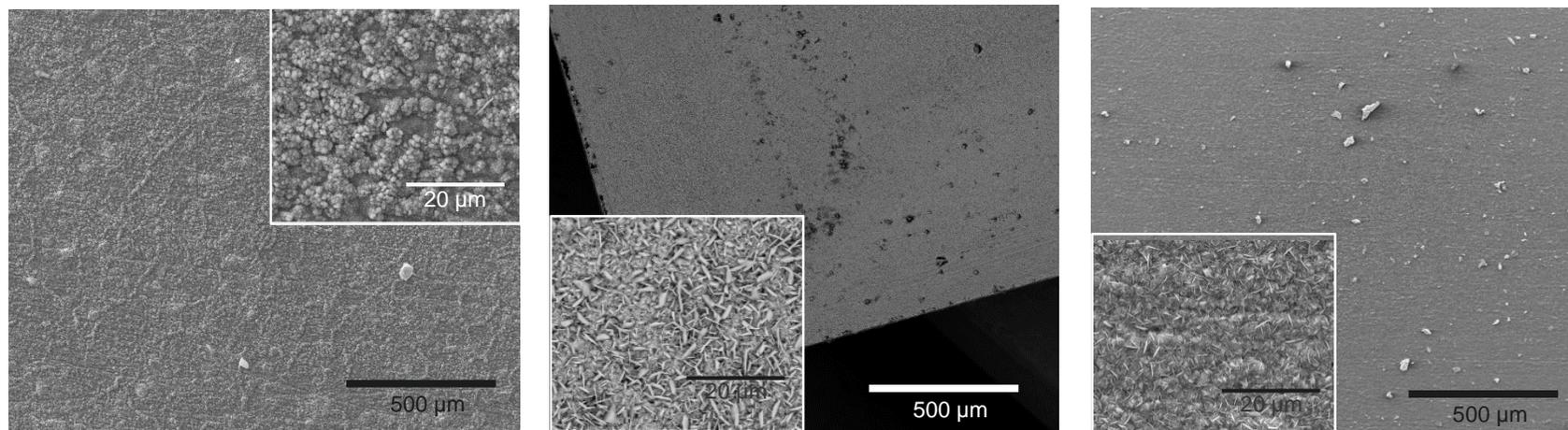
95 vol % CO₂

1 vol % O₂

4 vol % water

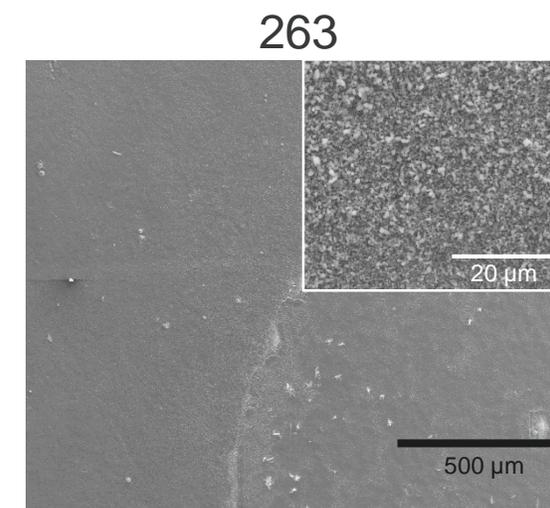
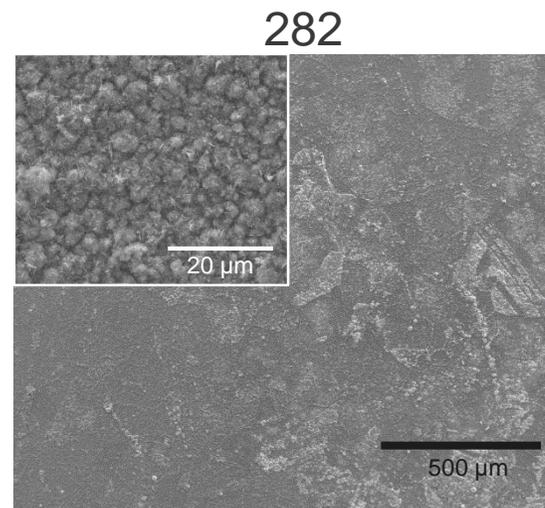
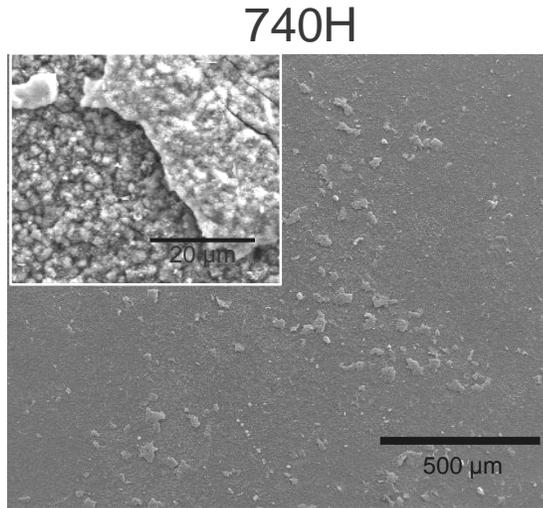
2,500h of exposure

With SO₂

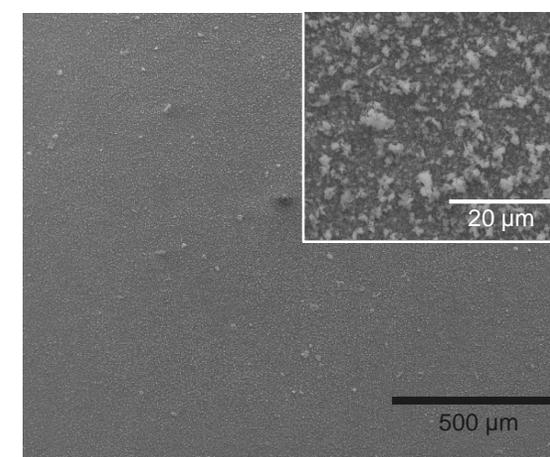
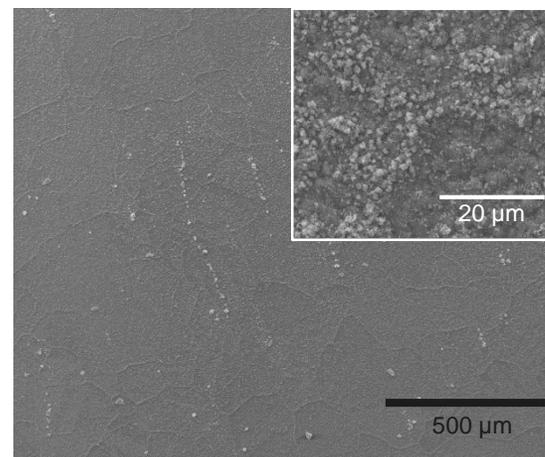
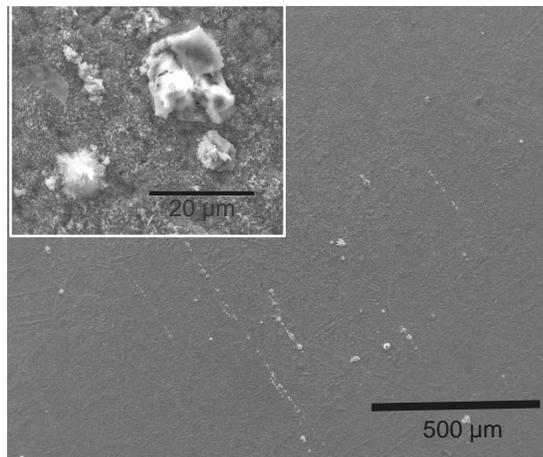


Nickel alloy surfaces, 740H, 282, 263

No SO₂



With SO₂



750 °C

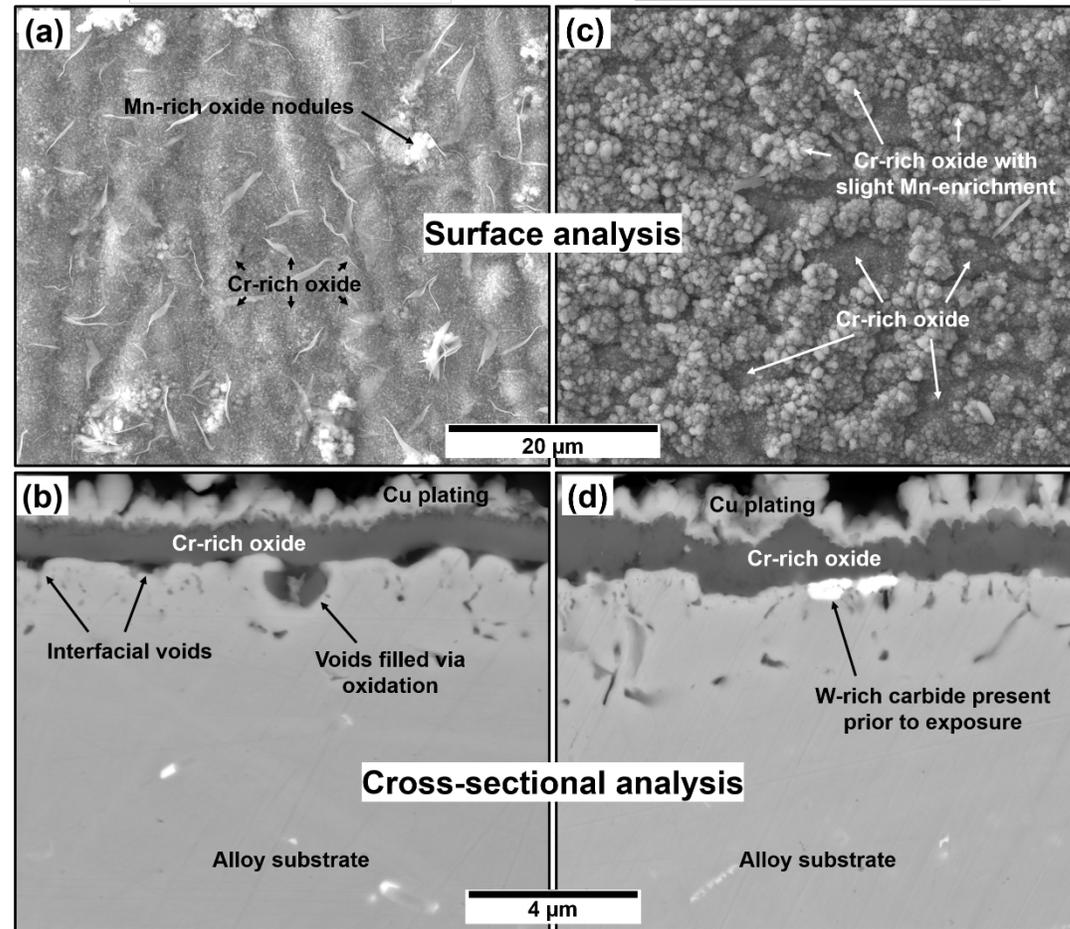
95 vol % CO₂

1 vol % O₂

4 vol % water

2,500h of exposure

230, least mass gain



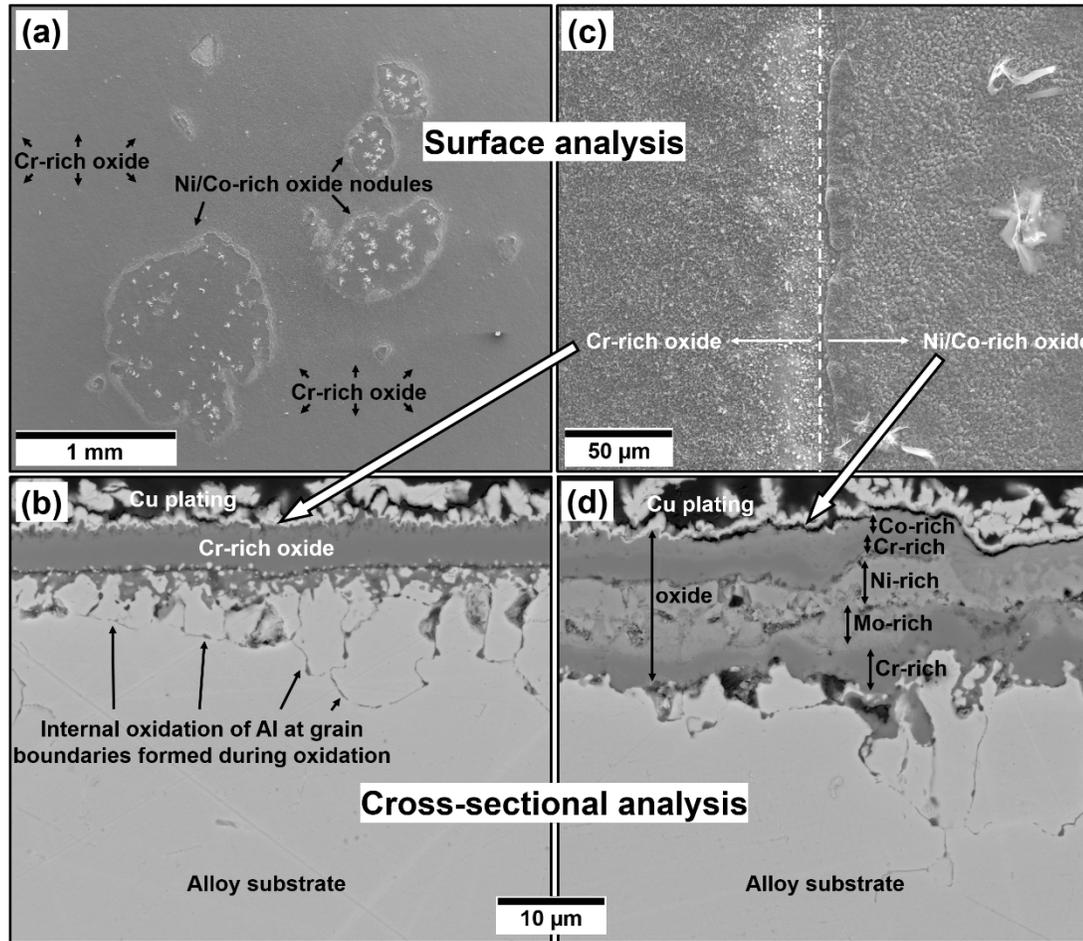
No SO₂

With SO₂

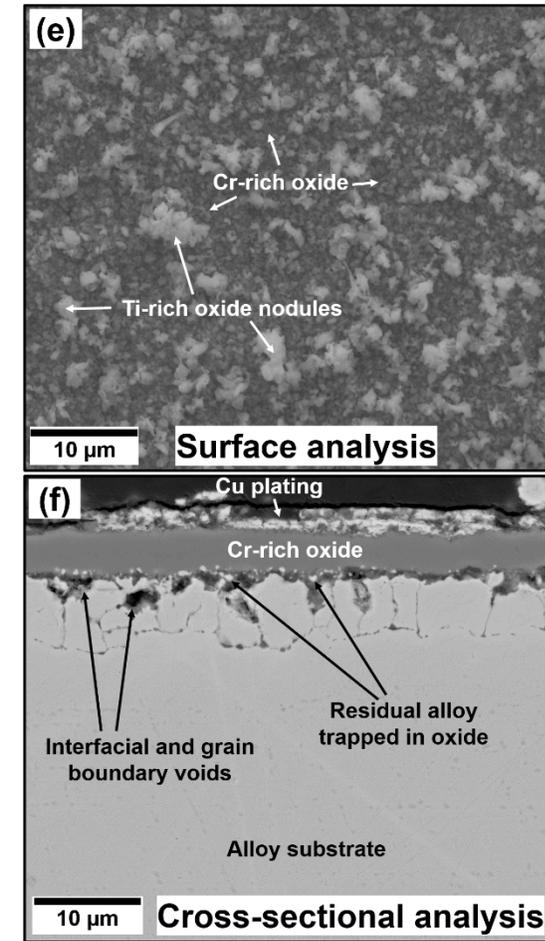
750 °C
 95 vol % CO₂
 1 vol % O₂
 4 vol % water

2,500h of exposure

263 most mass gain



No SO₂



750 °C
95 vol % CO₂
1 vol % O₂
4 vol % water

2,500h of exposure

With SO₂

Scale thicknesses

Alloy	DF4	DF4S	Calc DF4	Calc DF4S
230	1	1.2	1.1	1.1
625	1.4	1.4	1.4	1.4
740H	1.9	2.5	2.4	2.8
617			2.6	3.1
282	2.7	2.6	3.8	3.3
263	4	4.3	5.8	5.5
304H	0.1		0.2	4.6
310	0.1		0.2	1.2
347	0.1		0.3	3.6
Grade 91			52.2	53.8
Grade 22			61.9	59

Calc. thickness is assuming weight gain is due to metal converting to metal oxide.

Thickness in μm after 2,500 hr. of exposure.

Summary

- Fe and Ni based alloys were exposed to conditions intended to simulate the direct fired sCO₂ cycle (minus the elevated pressure.)
- Tests included gas streams with and without SO₂ additions
- No sulfur compounds identified on Ni alloys in the gas stream with SO₂
- Coupons in higher water or with SO₂ had more mass gain than lower water or without SO₂
- The austenitic steels with the highest Cr did well at 550 °C even when SO₂ was present
- Ni based solution strengthened alloys generally showed less mass gain than the age hardenable alloys

Acknowledgements

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Thank You.