Supply chain readiness for HAYNES® nickel-based alloys in sCO2 applications

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Member of the Acerinox group

Introduction

- Nickel alloy manufacturing capabilities at Haynes International, Inc.
- Three alloys are discussed: HAYNES® 233 ®, 282 ®, and 230 ® alloys
- Products forms relevant to sCO_2 applications
- ASME Code and alloy specification considerations
- Alloy properties and environmental resistance
- Welding and additive manufacturing accomplishments and initiatives

Wrought Product Manufacturing

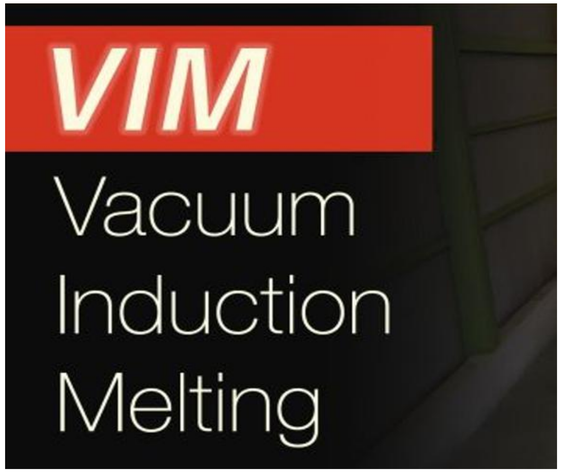
Followed by

All HAYNES® and HASTELLOY® alloys are double melted

and then

and then

Wrought Product Manufacturing



- VIM heat capacity = 25k lbs current plus new 50k lbs VIM furnace online 2028
- EAF+AOD heat size = 40k lbs
- ESR input = cylindrical or slab **electrodes**;
- ESR finished product are slab or round ingots
  - 10k lbs to 13k lbs, depending on alloy.
- Ingots = feedstock for forgings, plate, sheet, billet, bar, wire, tubulars, powder
- Hot working properties + machine strength mostly determine the limits of our manufacturing capabilities.
  - Ingot break down and wrought mfg process control are crucial to end product properties
  - Highly engineer and can take 5-10 years to develop for a new alloy

Wrought Product Manufacturing

Production Capabilities

Future

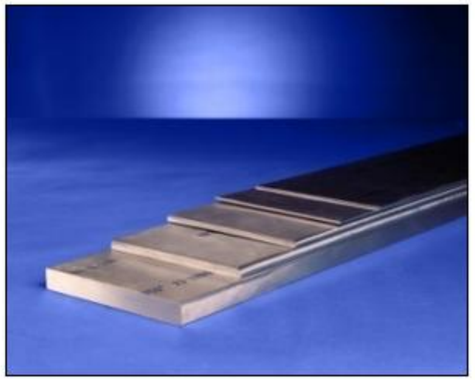
1 Radial Press
SMX-800/25MN

25 meganewton =
2549 ton-force [metric]
2810 ton-force [US short]

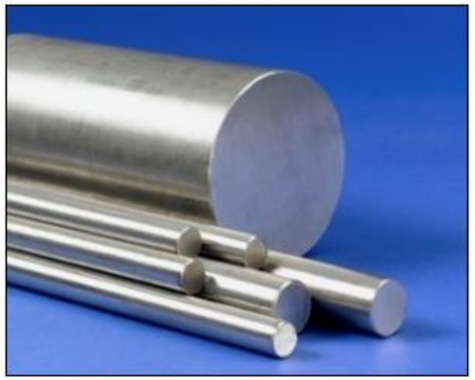
New Equipment – target on line date mid 2028

Radial Press SMX-800/25MN
and rail bound manipulator

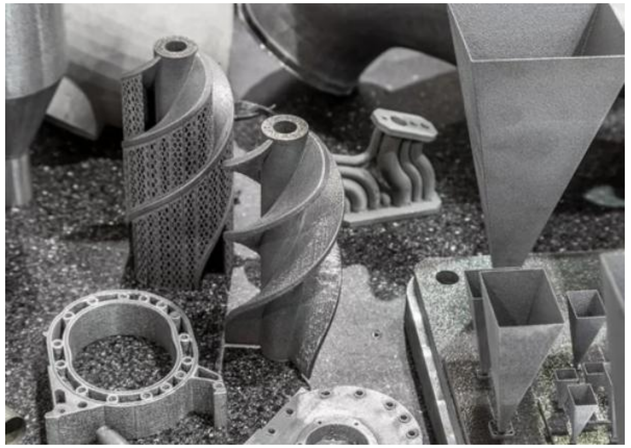
Wrought Product Manufacturing



Hot and Cold Rolled
Plate, Sheet and Coil



Bar & Billet Products



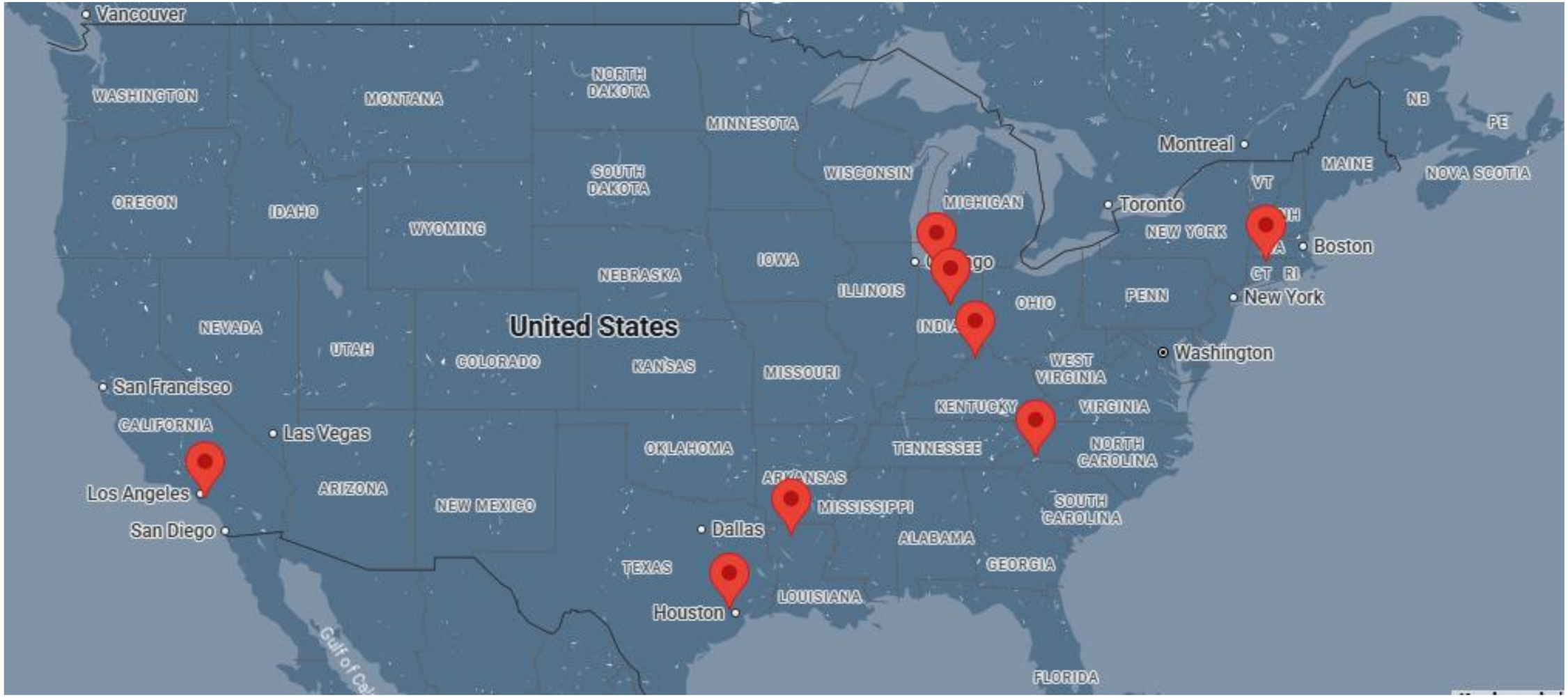
Alloy Powder

Welding Consumables

Seamless & Welded
Tubular Products

Fittings and Flanges

Made in the USA



Plus international sales and service centers

Alloys for sCO_2

Alloy	Ni	Co	Fe	Cr	Mo	W	Mn	Si	Al	Ti	C	Others
233	bal.	19	1.5*	19	7.5	0.3*	0.4*	0.20*	3.3	0.5	0.1	Ta-0.5, Y-0.025*
282	bal.	10	1.5*	20	8.5	–	0.3*	0.15*	1.5	2.1	0.06	–
230	bal.	5*	3*	22	2	14	0.5	0.4	0.3	0.1*	0.1	La-0.02

* maximum

Alloys for sCO_2

- Wrought product forms available for the respective alloy
  - Paper contains lists codes and specifications

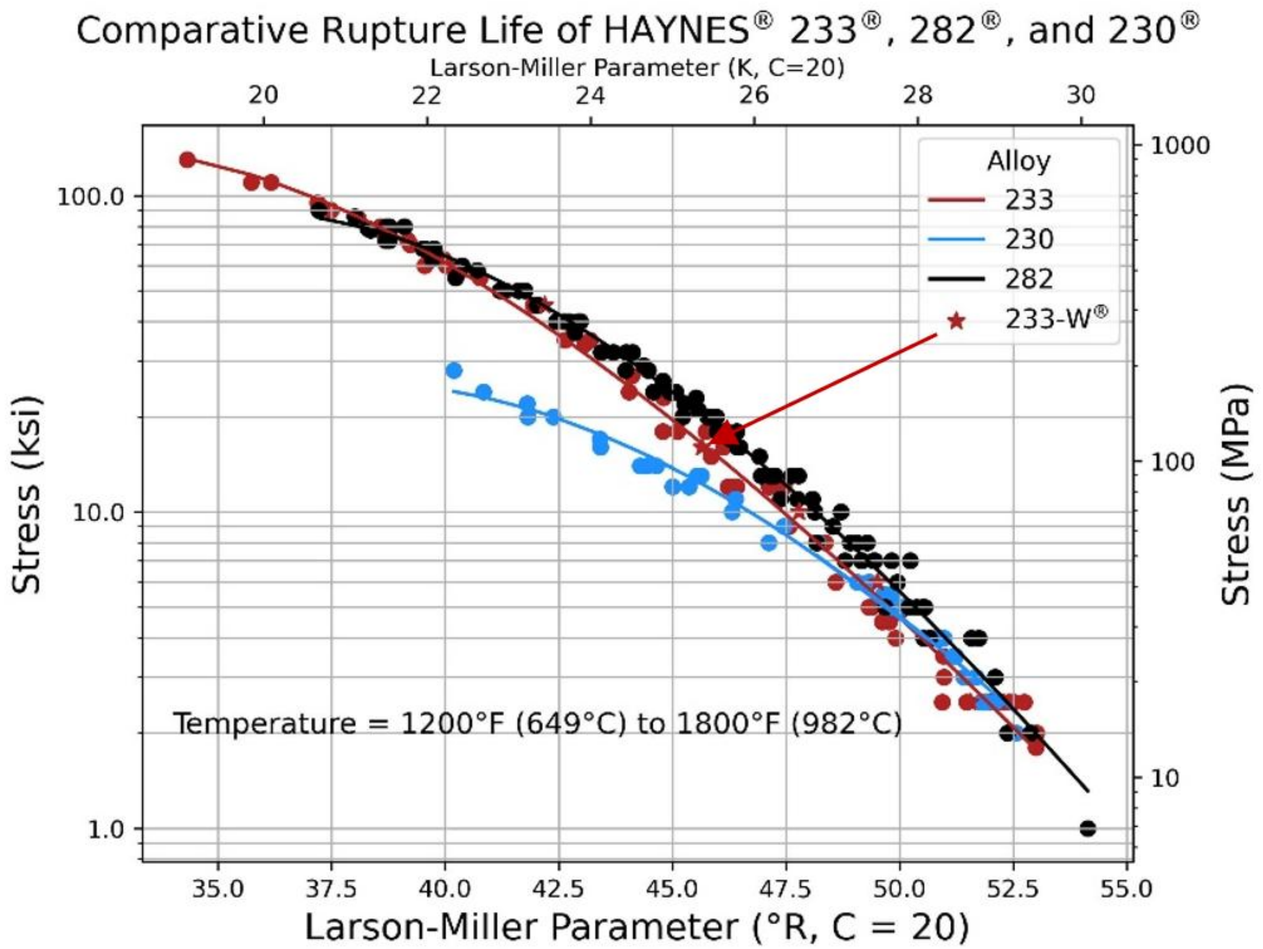
	230	282	233
ASME Tubulars	0.5” to 4" SCH80	0.5” to 8" SCH80	1” to 2" SCH40
Plate / Sheet	0.015 - 3"	0.015 - 2.25	0.015 - 2"
Foil	min. 0.002	min. 0.002	min 0.002
Bar / Billet	0.5 - 9"	0.5 - 9"	0.5 - 9"
Wire	0.49 - 0.025	0.49 - 0.025	0.49 - 0.025
Powder	yes	yes	yes
Forgings	up to 8,000 lbs	up to 8,000 lbs	up to 8,000 lbs

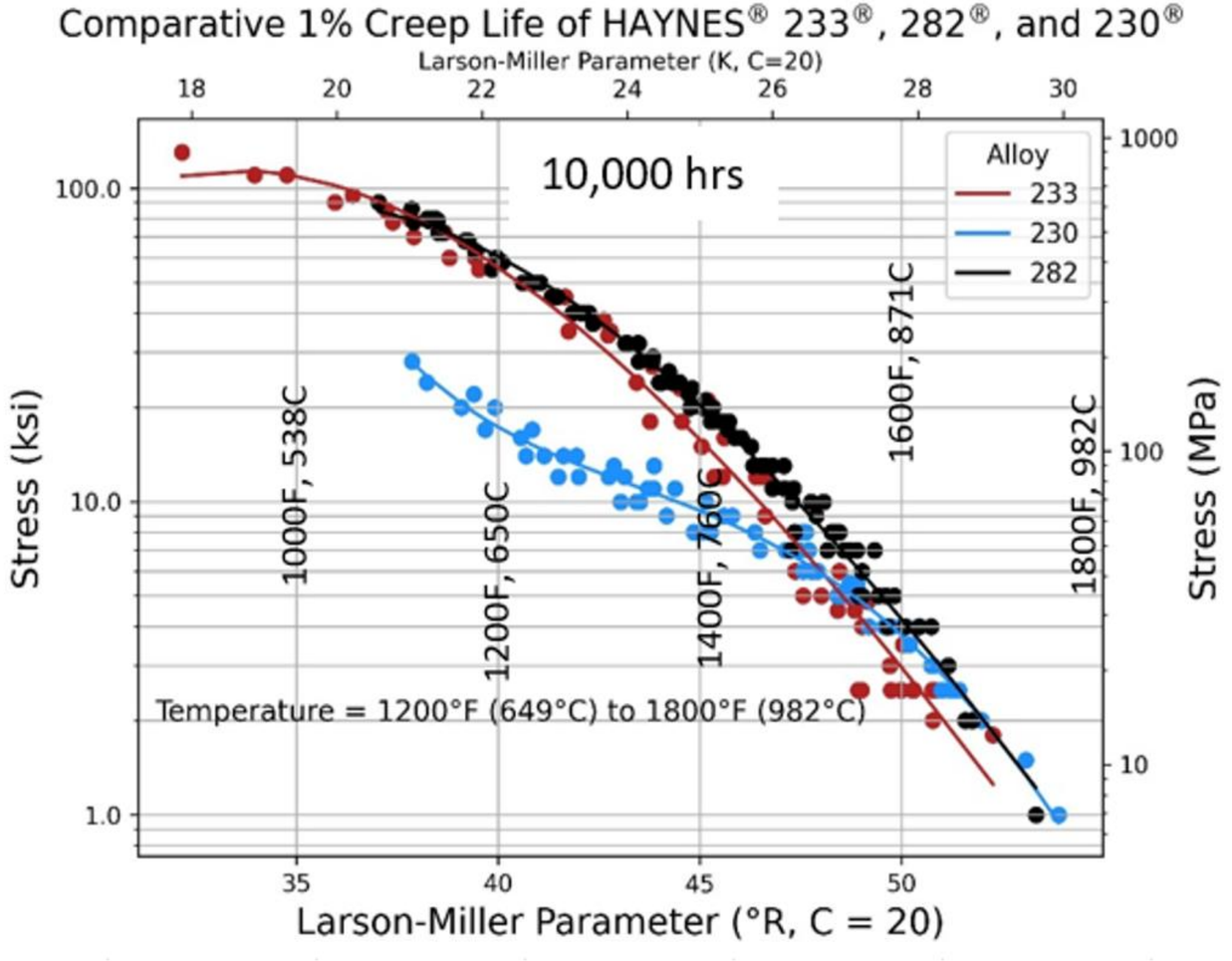
ASME Considerations

- 282 alloy : Section I and Section VIII Division I ASME Code Case 3024
  - maximum use temperature is 1600°F (871°C).
- 230 alloy is covered by Section 1 and Section VIII Division I ASME by Code Cases 2063 and 2671, respectively
  - Maximum use temperature is 1800°F (982°C)
- 233 alloy Code Case: finish data collection ~ 2028
  - Data collection began Q4 2024; effort supported by several industry partners
  - Sol'n annealed: Likely maximum T 1800°F (982°C)
  - Precipitation strengthened condition: Likely maximum T 1600°F (871°C)

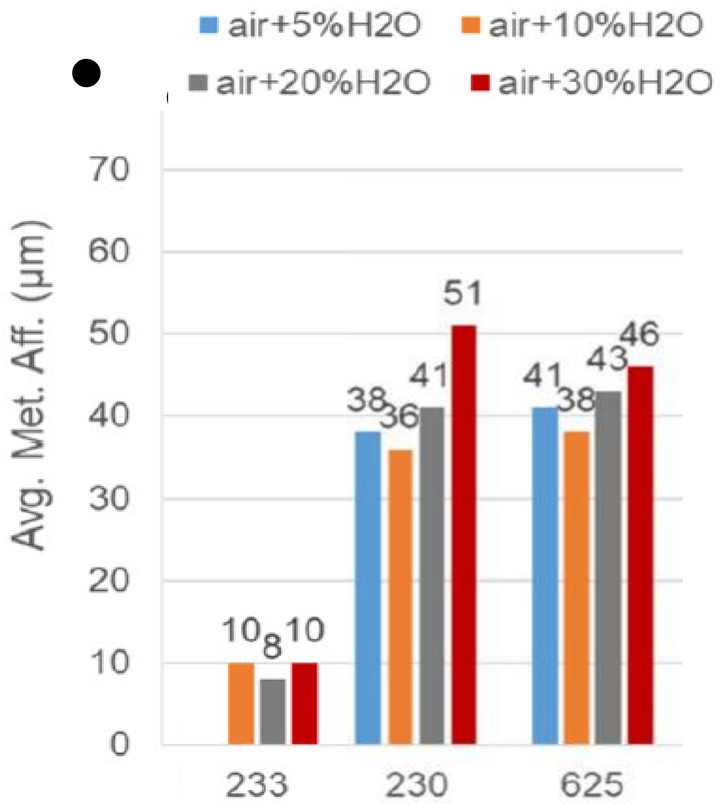
		UNS N06230	UNS N07208
		HAYNES® 230®	HAYNES® 282®
T, ° F	T , ° C	Code Case 2671	Code Case 3024
1100	593.3	20.9	41.7
1200	648.9	15.6	32.6
1250	676.7	12.9	26.0
1300	704.4	10.6	20.3
1350	732.2	9.5	15.4
1400	760.0	6.7	11.3
1450	787.8	5.3	7.8
1500	815.6	4.1	5.2
1550	843.3	2.9	2.4
1600	871.1	2.1	1.6
1650	898.9	1.5	not permitted
1700	926.7	1.1	
1750	954.4	0.7	
1800	982.2	0.45	

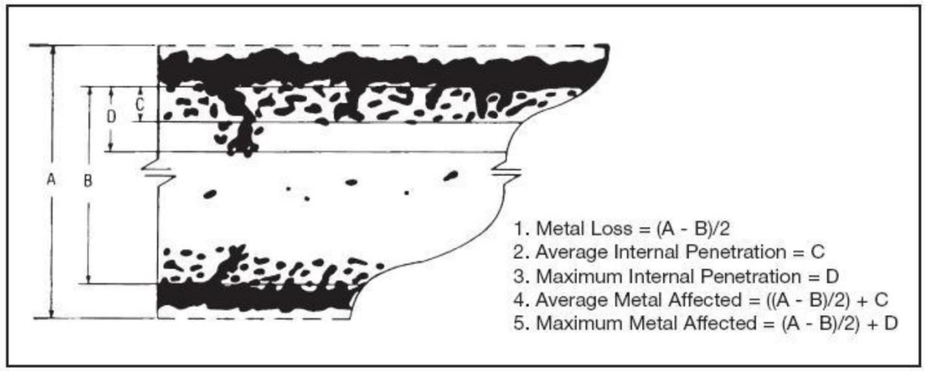
Creep Strength

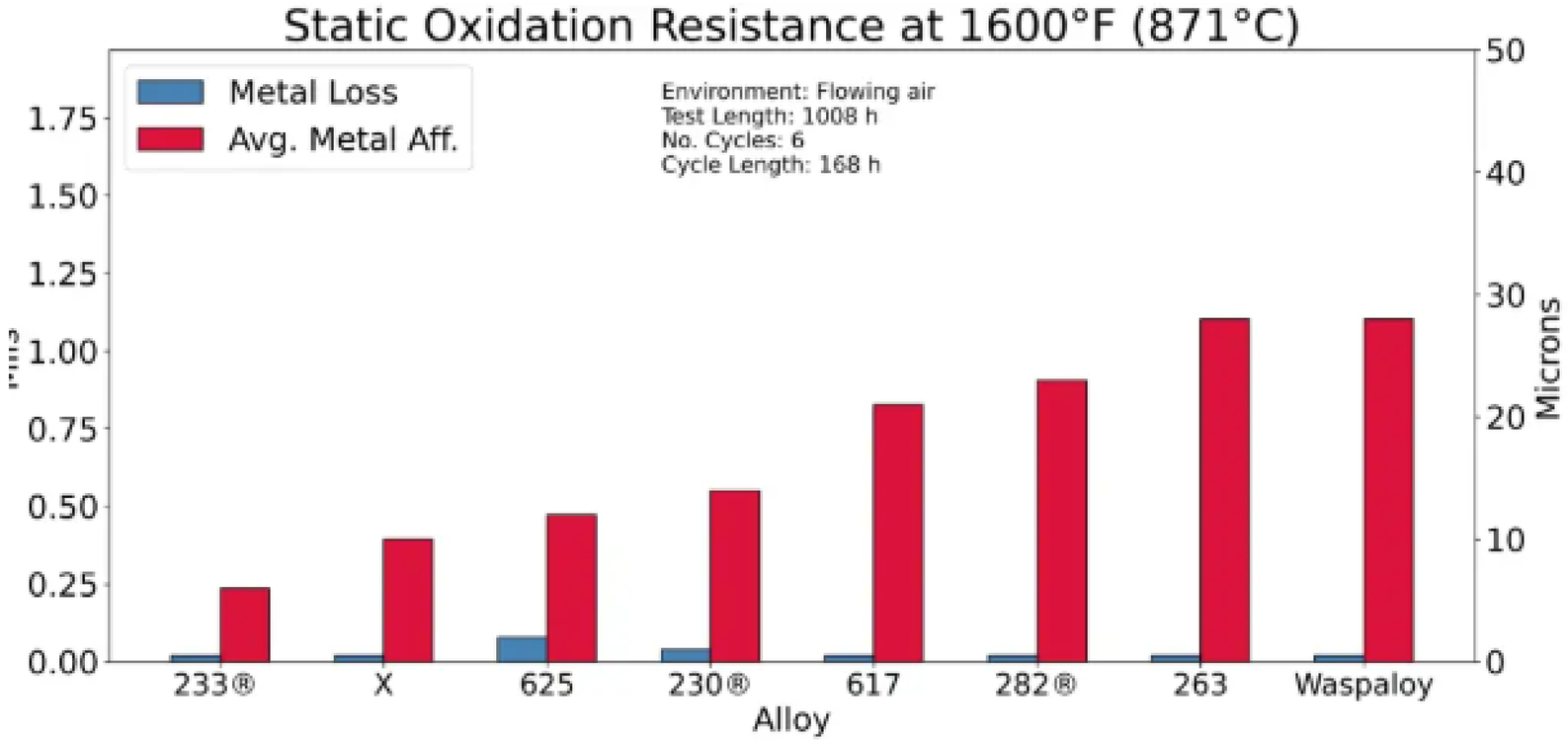




Environmental Resistance







- 1008 hours in air + water vapor at 982°C

Environmental Resistance

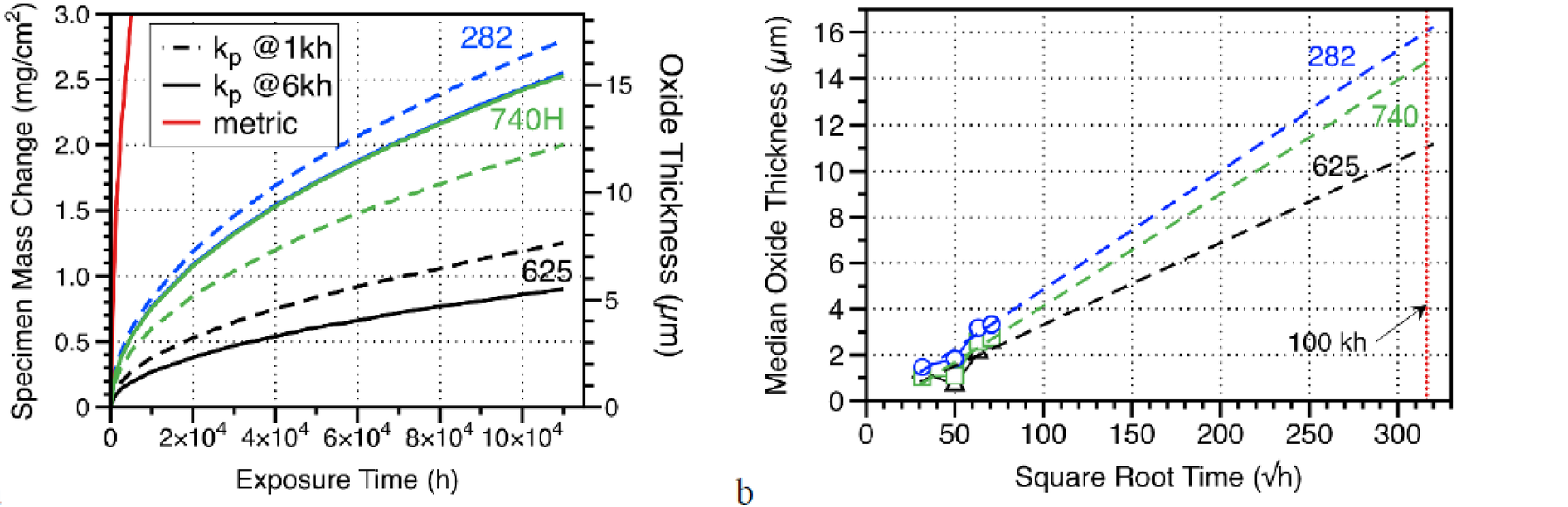
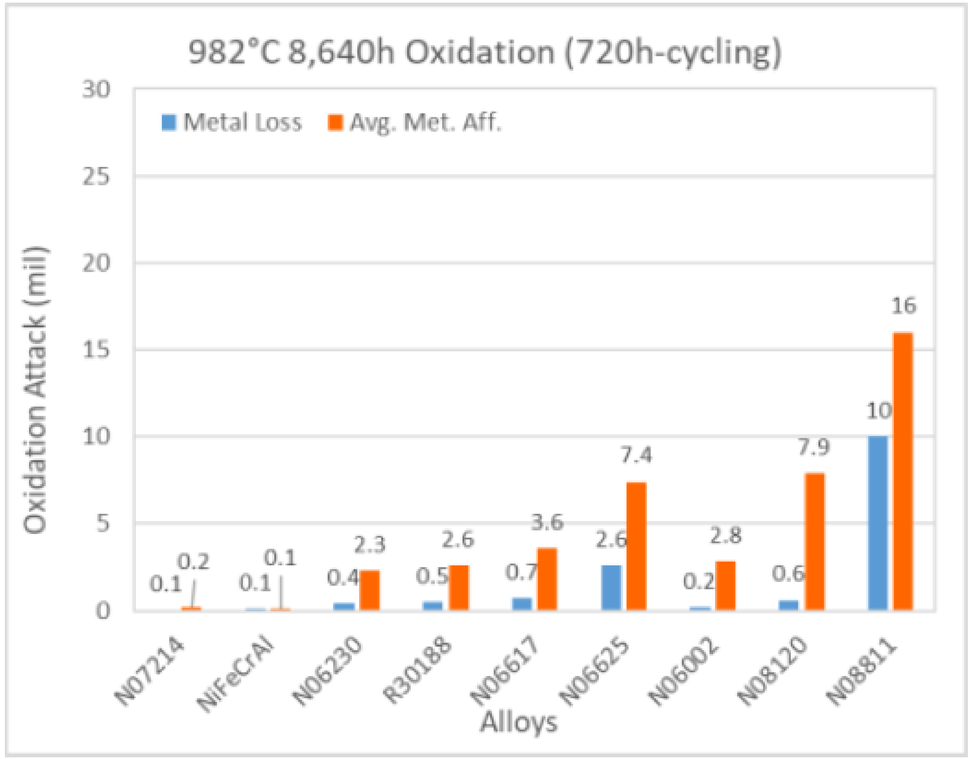
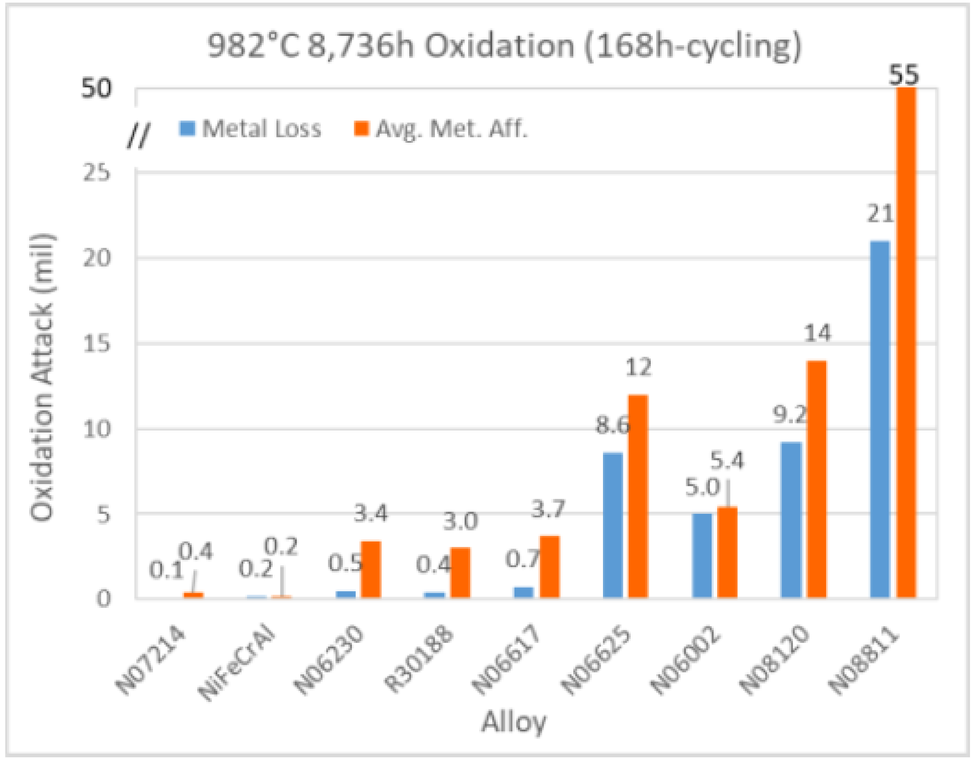


Figure 14. (a) Extrapolation of the rate constants determined at 750°C after 1,000 and 6,000 h exposures in 300 bar sCO_2. The mass gain can be converted to an oxide thickness assuming a dense Cr_2O_3 reaction product. (b) Extrapolation of the oxide thickness data observed at 1,000-5,000 h in 300 bar sCO_2 to 100,000 h assuming parabolic behavior. The oxide thickness values in (a) and (b) are similar and represent very thin oxides after extended service in this environment.

Environmental Resistance

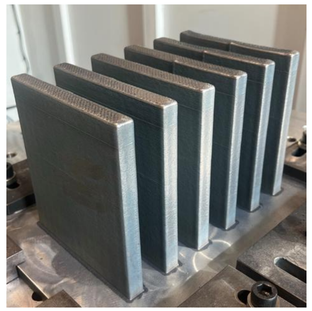


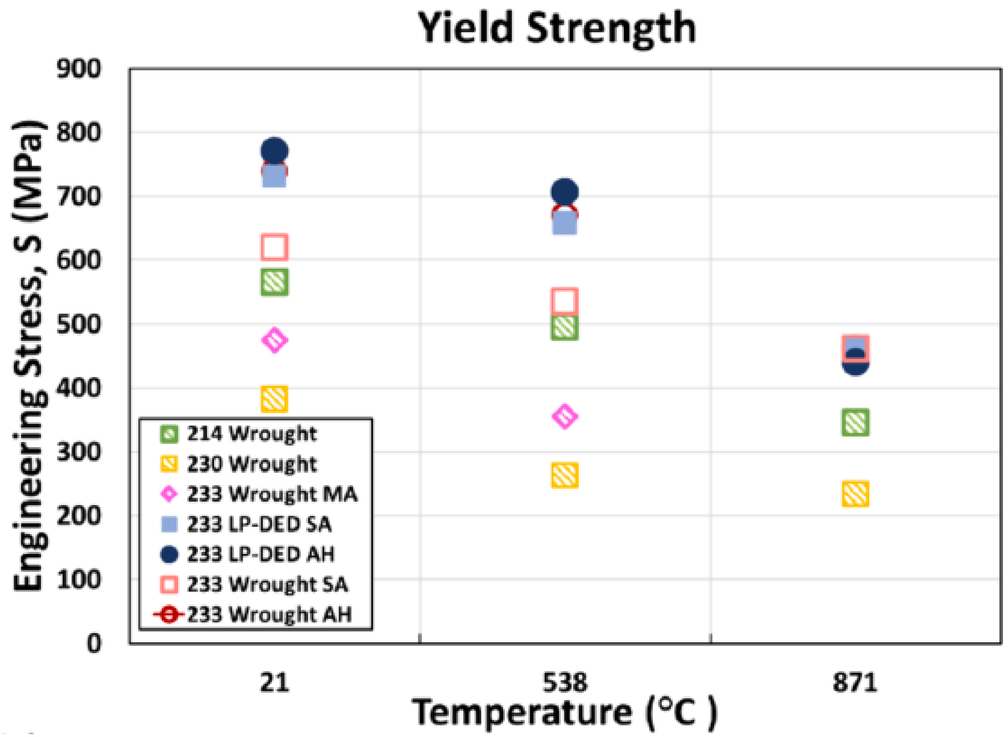


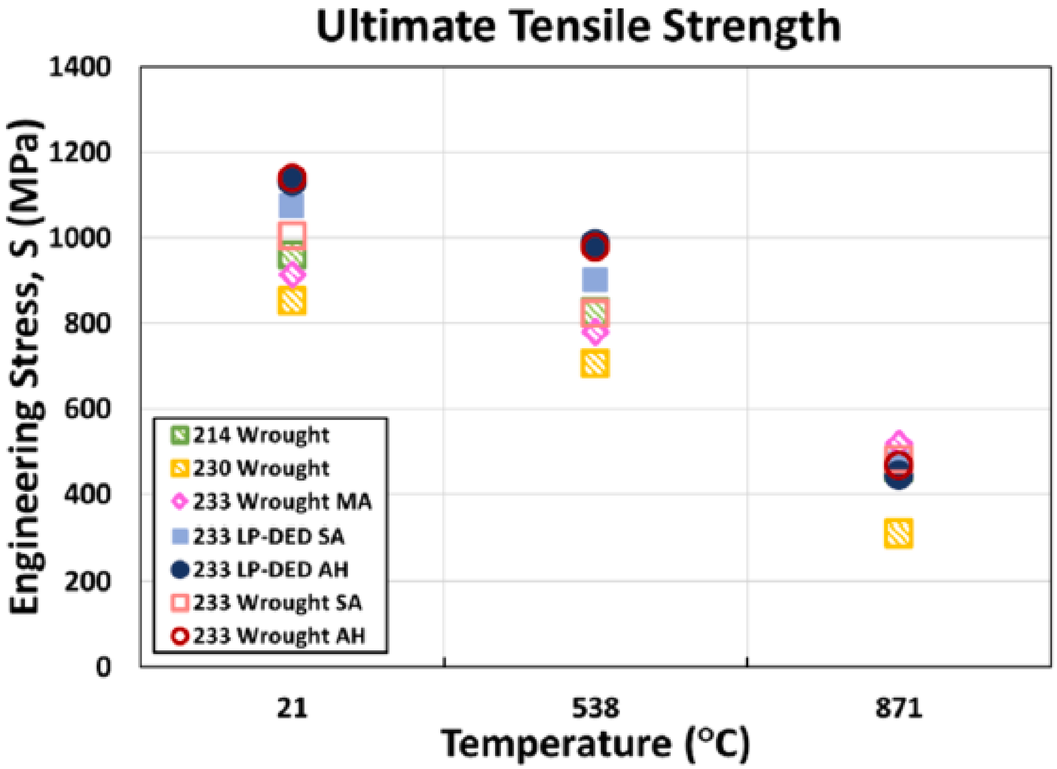
Long-term oxidation attack (Metal Loss and Avg. Met. Aff.) in 720h or 168h thermal cycling at 982°C

Mechanical Properties

- Yield and ultimate strength of additively manufactured 233® alloy







Summary

- The supply chain for wrought nickel alloy products in commercial applications is strong and many product forms are available.
- The tensile strength, creep resistance, and environmental resistance of 282 alloy and 233 alloy are suitable for sCO_2 service.
- Extensive research on 282 alloy is easily found in literature and ASME Code acceptance of 282 alloy shows that the alloy has been thoroughly vetted by Haynes, national laboratories, and industry.
- 233 alloy is a next-generation alumina forming alloy that will be a candidate for an ASME code case once the data has been generated. Code application is expected between 2028-2030.
- Additive manufacturing of 282 alloy using powder and wire products is widespread in academia and industry. 233 alloy additive manufacturing parameters and test data are being actively pursued due to its superior oxidation resistance and excellent creep strength.