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Material performance of alloys in $NaNO_3/KNO_3$ at 600°C

Alan Kruizenga, David Gill

Summary

Descaled corrosion rates for nine alloys immersion tested in binary solar salt are reported. All rates were within 2.5-13.9 [mg/cm^2-yr], with regression determining best fit behavior. HR-214 showed the least corrosion after 3000 hours. It should be noted that several alloys had incomplete oxide layers and that fitting and extrapolations are inconclusive.

Energy Dispersive Spectroscopy (EDS) found formation found NiO as the primary outer oxide on most high nickel alloys, with the inner oxide layer varying based upon elemental alloying constituents.

Introduction

Concentrated Solar Power (CSP) currently uses sodium / potassium binary nitrate salts in central tower applications [1]. Materials containment and compatibility with nitrate salts at 600°C have been studied on a limited number of alloys.

The purpose of this document is to provide insight into nine alloys exposed to binary salts at 600°C, both in terms of corrosion rates and illustrate expected corrosion mechanisms.

Table 1: Nominal compositions of alloys in study

	Cr	Mo	Ni	Mn	Si	Ti	Fe	Co	W	Al	Cb	Cu	Zr	Y	La	Ta
321SS	16-18	2-3	10-14	2.00	0.75	0.70	balance	-	-	-	-	0.28	-	-	-	-
347SS	17.23	0.36	9.18	1.82	0.39	0.21	balance	-	-	-	-	-	-	-	-	-
230HA	22	2	57	0.5	0.4	-	3	5	14	0.3	-	-	-	-	0.02	-
HA242	7-9	24-26	balance	0.8	0.8	-	2	2.5	-	0.5	-	0.5	-	-	-	-
HA556	22	3	20	1	0.4	-	31	18	2.5	0.2	-	-	0.02	-	0.02	0.6
HR224	20	-	48.7	-	-	-	27.5	-	-	3.8	-	-	-	-	-	-
HR120	25	3	37	0.7	0.6	-	33	3	2.5	0.1	0.7	-	-	-	-	-
In625	20-23	8-10	58	0.5	0.5	0.4	5	1	-	0.4	3.15-4.15	-	-		-	-
HA214	16	-	75	0.5	0.2	-	3	-	-	4.5	-	-	0.1	0.01	-	-

Experimental Setup

Alloys were exposed to nitrate salt at 600°C for 3000 hours, where the cover gas is air. 600°C is the expected practical threshold for binary nitrate salts [2]. Based on feedback from industry, air is the expected cover gas that will be used.

Samples were tested in static corrosion retort simultaneously [3]. All samples were obtained from Special Metals and ground to 120 grit and prior to exposure in the salt. Pictures of samples before and after exposure are below.

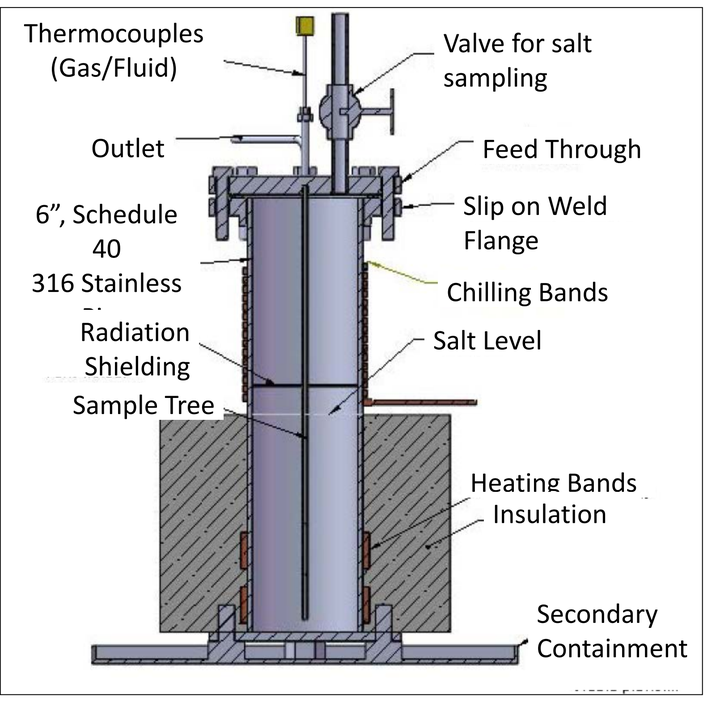

Figure 1: Schematic of experimental set up [3].

Samples were immersed in salt for up to 3000 hours.

Air was maintained as the ullage gas during the study. Sparging prevented thermal stratification

Results

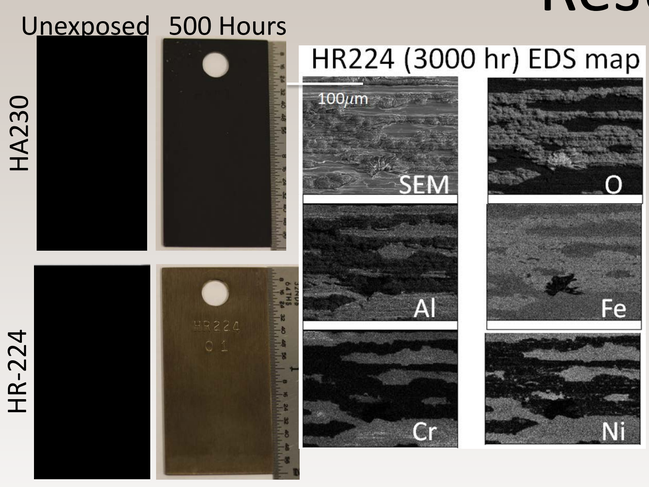

Figure 2: Unexposed and post molten salt after 500 hours of exposure.

Haynes 230: Yielded thick nickel oxide on the surface

HR-224: Returned only a partially corroded surface. Plan view EDS map shows a mixed aluminum, chromium, nickel oxide on the surface after 3000 hours

Table 2: Data were fit to appropriate functions (equations below) with the best fit reported.

$$X = k_{linear}t$$
$$X = k_{parabolic}t^{0.5}$$
$$X = k_{log}[log(t)]$$

X - oxide thickness, t – time

Weight loss extrapolated to a per year basis was given as a point of comparison.

Alloy	Equation	k value [units †]	Weight Loss [mg/cm^2-yr]
321SS	Linear	3.90e-7	12.3
347SS	Parabolic	1.1e-3	6.2*
HA230	Parabolic	2.47e-3	13.9
HA242	Parabolic	2.32e-3	13.0
HA556	Parabolic	1.53e-3	8.6
HR224	Linear‡	-	7.3
HR120	Log	-	5.5
In625	Linear‡	-	11.6*
HA214	Parabolic‡	-	2.5

† Linear [mg/cm^2-sec], Parabolic [mg/cm^2-sec$^{0.5}$]
‡ Oxide scale was incomplete, could not assess
*Indicates scattered data, needs further analysis

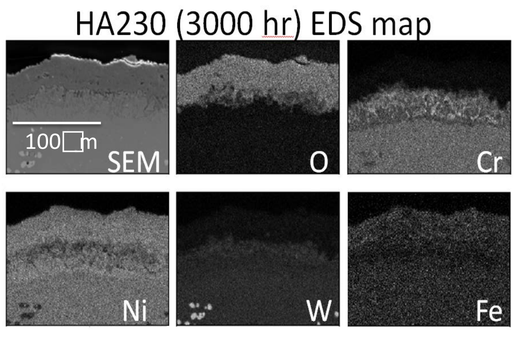

Figure 3: Cross sectional view of HA230 confirms primarily a NiO outer layer with a W/Cr enriched layer near the base/oxide interface.

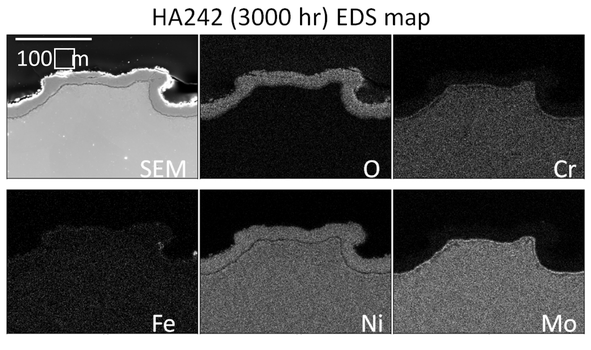

Figure 4: HA242 has a NiO as the outer layer with a thin and enriched Mo layer at the base/oxide interface.

Conclusions

Nine alloys were investigated for their material compatibility in 60/40 molten nitrate salts at 600°C. Oxide growth rates were found to be parabolic on most alloys with yearly weight loss ranging from 2.5-13.9 mg/cm^2.

Preliminary microscopy data shows formation of Cr/W oxide on HA230 and a very thin Mo oxide layer at the base/oxide interface on HA242.

Contact Information

Alan M. Kruizenga
Sandia National Laboratories
Materials Chemistry
Email: amkruiz@sandia.gov
Telephone: 925-294-3691

References

1. Burgaleta, J.I., S. Arias, and D. Ramirez, *GEMASOLAR, The First Tower Thermosolar Commerical Plant with Molten Salt Storage*, in *SolarPACES 2011*2011, SolarPACES: Granada, Spain.
2. Bradshaw, R.W. and D.E. Meeker, *High-temperature stability of ternary nitrate molten salts for solar thermal energy systems.* Solar energy materials, 1990. **21**(1): p. 51-60.
3. Gill, D.D., et al., *DESIGN, FABRICATION AND TESTING OF AN APPARATUS FOR MATERIAL COMPATIBILITY TESTING IN NITRATE SALTS AT TEMPERATURES UP TO 700°C*, in *5th International Conference on Energy Sustainability*2011, ASME: Washington, DC, USA. p. 6.

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NNSA National Nuclear Security Administration

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