Materials Performance in CO_2 and in CO_2-Steam Environments

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Outline

- ***Background***
- ***Objectives***
- ***Materials and experimental procedure***
- ***Alloys for evaluation***
- ***Corrosion performance of alloys***
- ***Project Summary***

What and why Oxy-fuel Combustion

- ***Global climate change - One of the causes identified is CO_2 increase in atmosphere - one of the source for CO_2 is exhaust from fossil fuel combustion plants***
- ***Energy production (in particular, electricity) is expected to increase due to population increase and per capita increase in energy consumption***
- ***To meet the energy needs fossil fuels (coal, gas, oil, etc.) will play a major part in production even with a projected increase from alternate sources***
- ***To minimize CO_2 emission - current systems emphasize capture from power plants and sequestration***
- ***Oxy-fuel combustion systems - recycle CO_2 to the compressor, use novel gas turbines, and emphasize reuse***

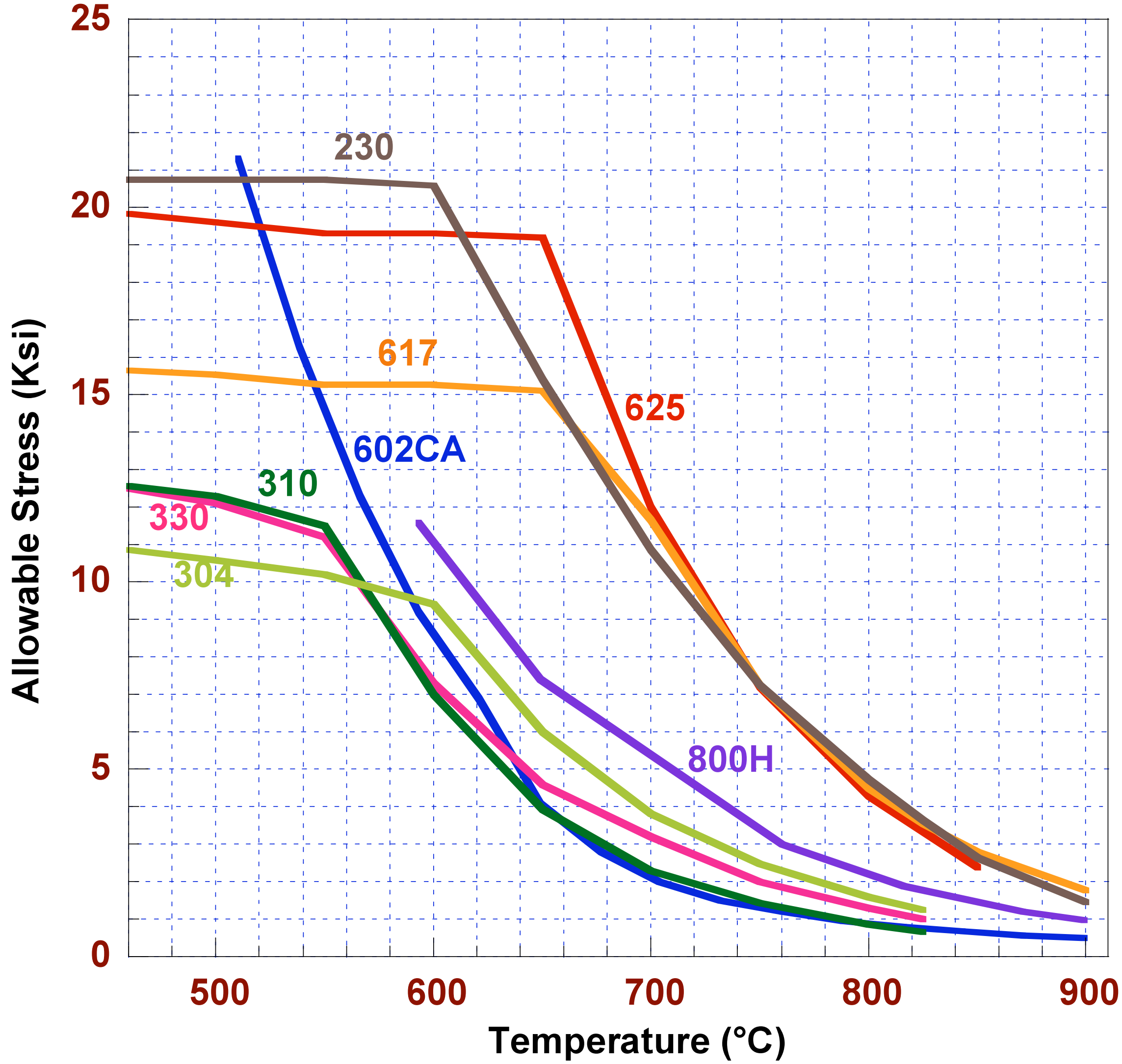
ANL Program Objectives

- Evaluate oxidation/corrosion performance of metallic structural alloys in pure CO_2 and in CO_2-steam environments over a wide temperature range
- Establish the kinetics of scaling and internal penetration, if any, and develop correlations for long term performance
- Evaluate the effect of coal ash with trace concentrations of alkali, sulfur, and chlorine compounds on the corrosion performance
- Identify viable alloys for structural and gas turbine applications
- Evaluate the influence of exposure environment on the mechanical properties (especially creep, fatigue, and creep-fatigue) of the candidate alloys

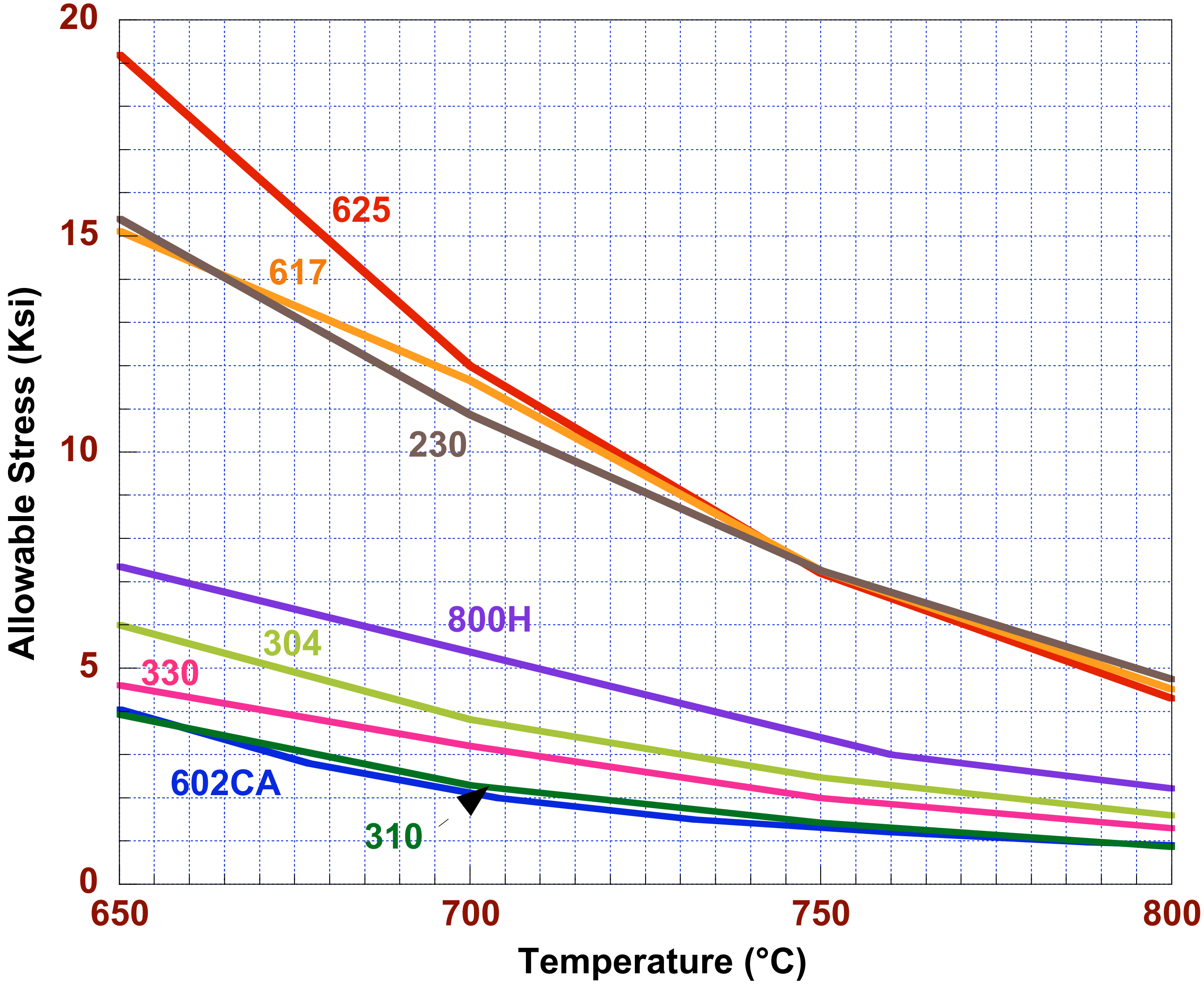
Current List of Alloys in the Study

Material	C	Cr	Ni	Mn	Si	Mo	Fe	Other
800H	0.08	20.1	31.7	1.0	0.2	0.3	Bal	Al 0.4, Ti 0.3
330	0.05	10.0	35.0	1.5	1.25	-	Bal	-
333	0.05	25.0	45.0	-	1.0	3.0	18.0	Co 3.0, W 3.0
617	0.08	21.6	53.6	0.1	0.1	9.5	0.9	Co 12.5, Al 1.2, Ti 0.3
625	0.05	21.5	Bal	0.3	0.3	9.0	2.5	Nb 3.7, Al 0.2, Ti 0.2
602CA	0.19	25.1	62.6	0.1	0.1	-	9.3	Al 2.3, Ti 0.13, Zr 0.19, Y 0.09
230	0.11	21.7	60.4	0.5	0.4	1.4	1.2	W 14, Al 0.3, La 0.015
693	0.02	28.8	Bal	0.2	0.04	0.13	5.8	Al 3.3, Nb 0.67, Ti 0.4, Zr 0.03
740	0.07	25.0	Bal	0.3	0.5	0.5	1.0	Co 20.0, Ti 2.0, Al 0.8, Nb+Ta 2.0
718	-	19.0	52.0	-	-	3.0	19.0	Nb 5.0, Al 0.5, Ti 0.9, B 0.002
MA956	-	20.0	-	-	-	-	Bal	Al 4.5, Ti 0.5, Y_2O_3 0.6

ASME Code Allowable Stress Values



ASME Code Allowable Stress Values at 650-800°C



Laboratory Test Details

Key variables: Temperature, time, alloy composition

Materials: Fe- and Ni-base alloys, coatings

Environment: Pure CO_2 and CO_2-steam mixtures

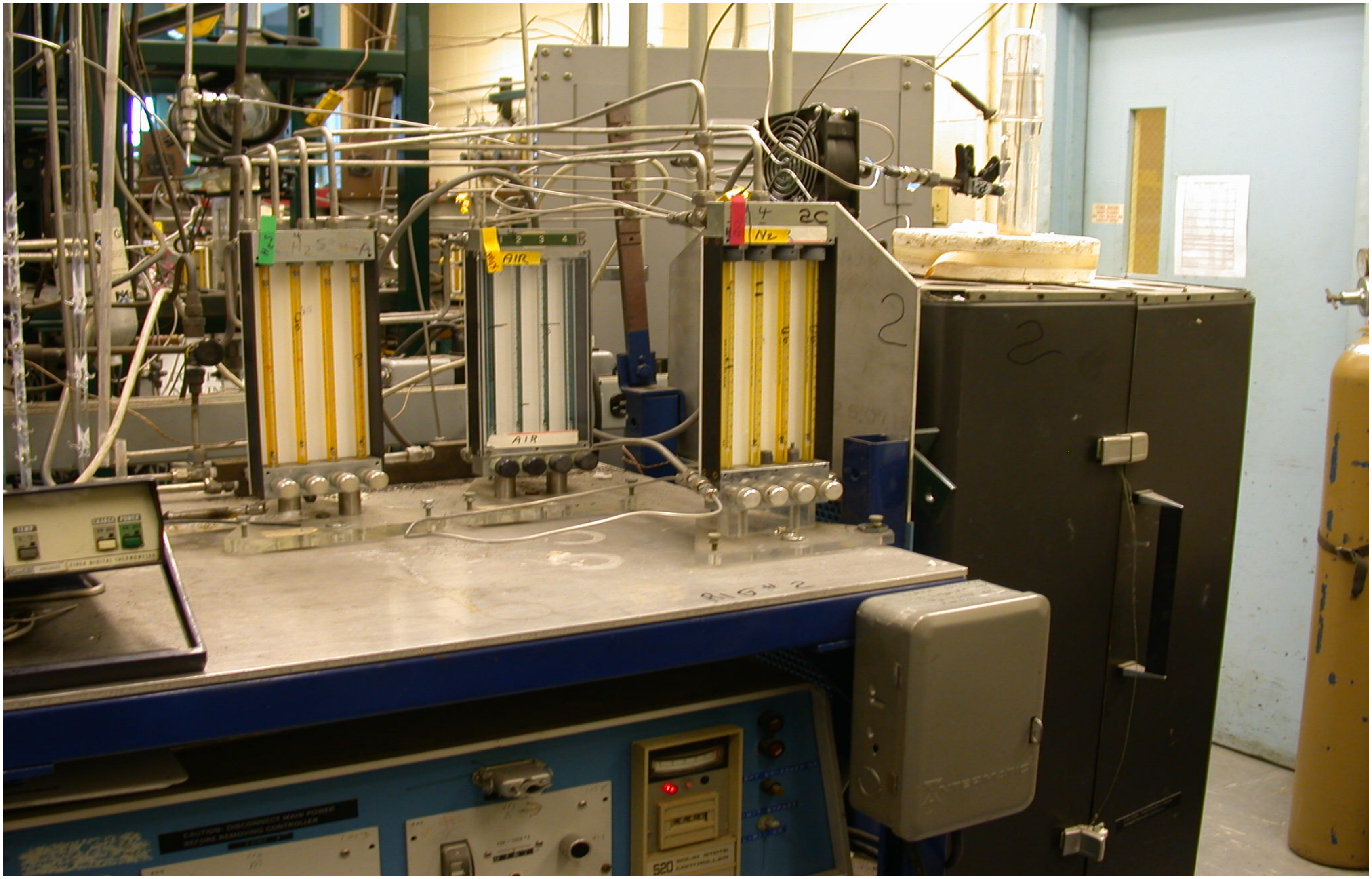
Deposits: Coal ash, alkalis, sulfur, chlorine

Test temperature range: 650-1000°C

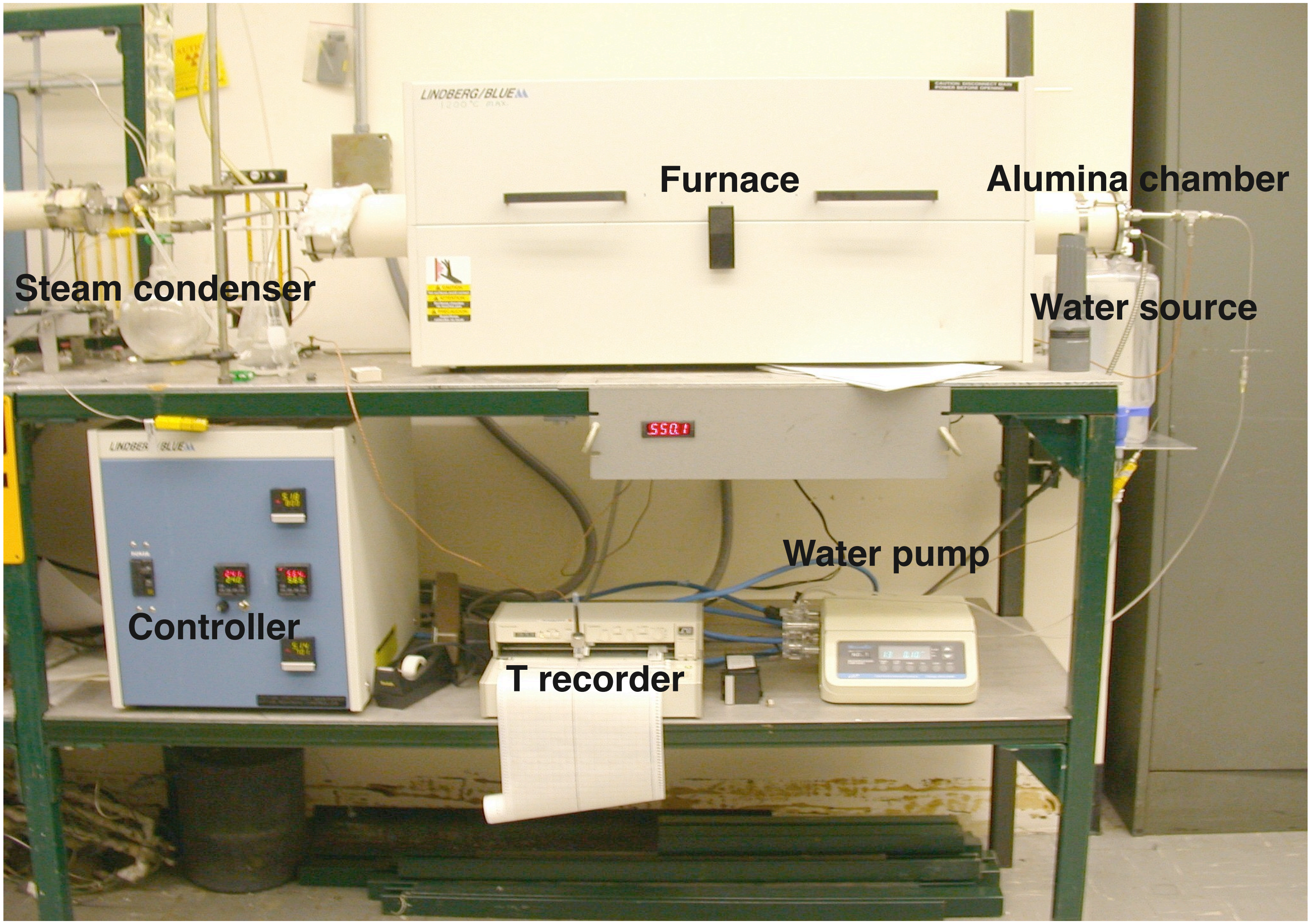
Test times: up to 10,000 h

Specimen evaluation: weight change
scanning electron microscopy
energy dispersive X-ray analysis
X-ray diffraction
synchrotron nanobeam analysis

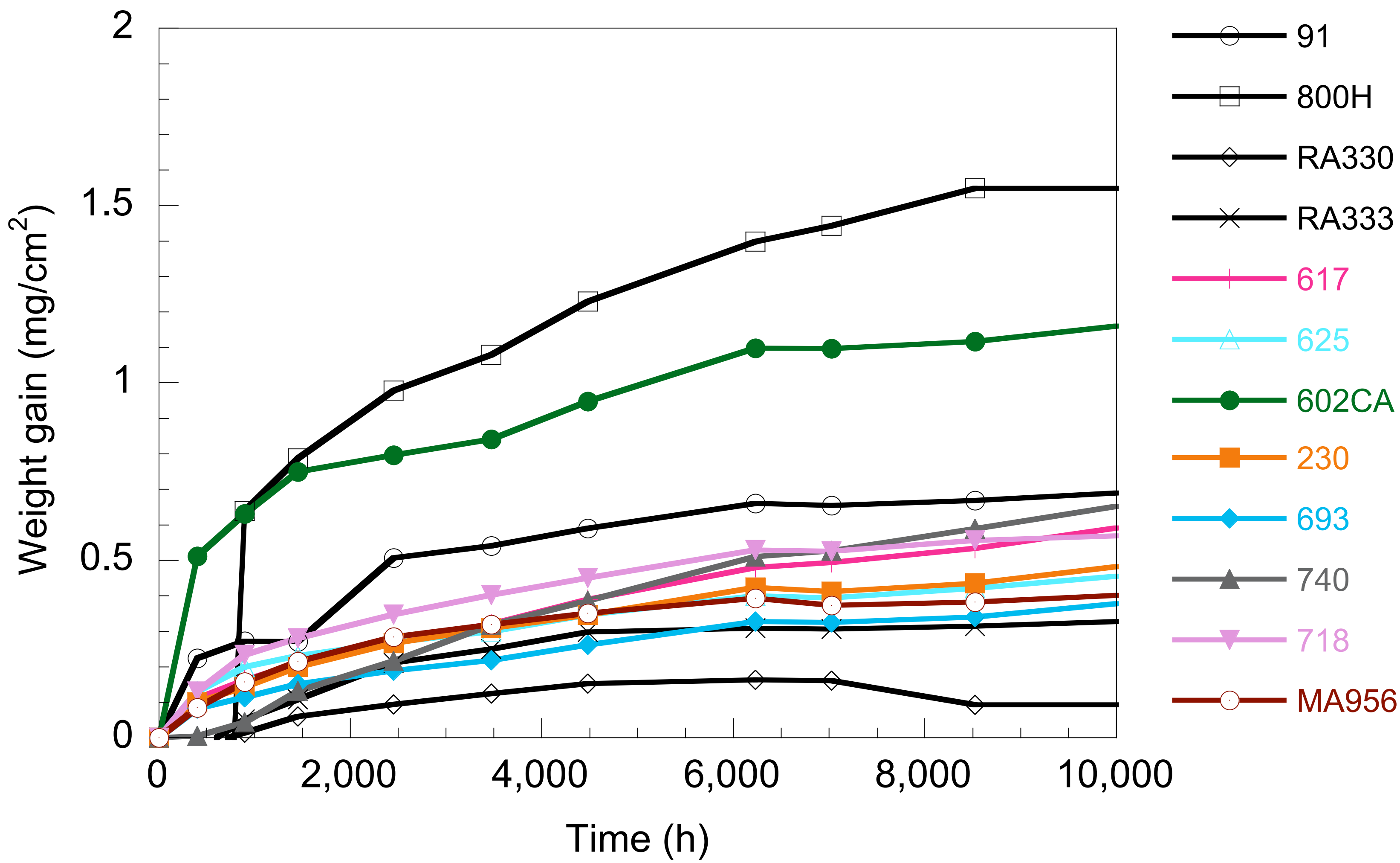
CO_2 Exposure Test Facility



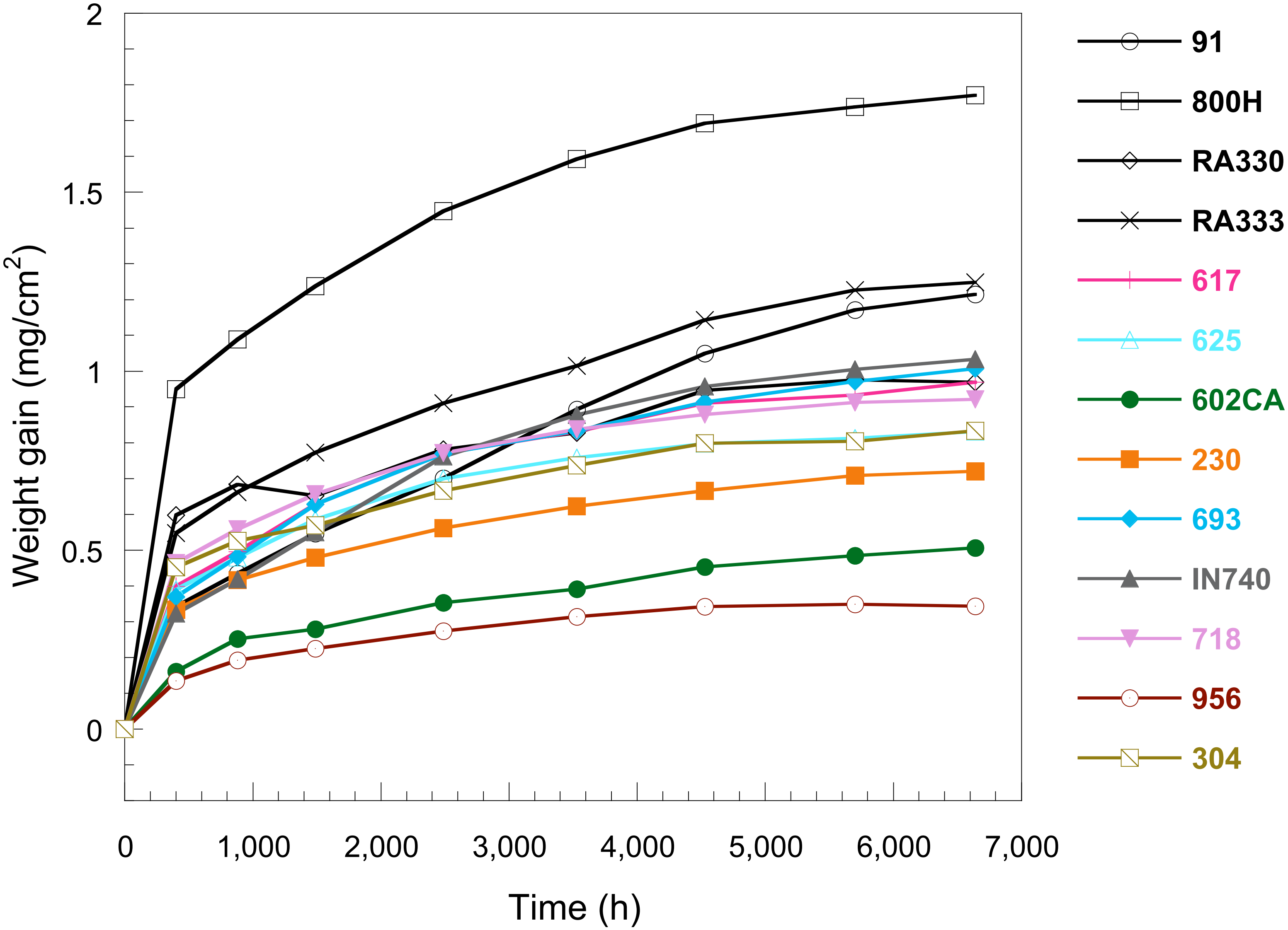
CO_2-Steam Exposure Test Facility



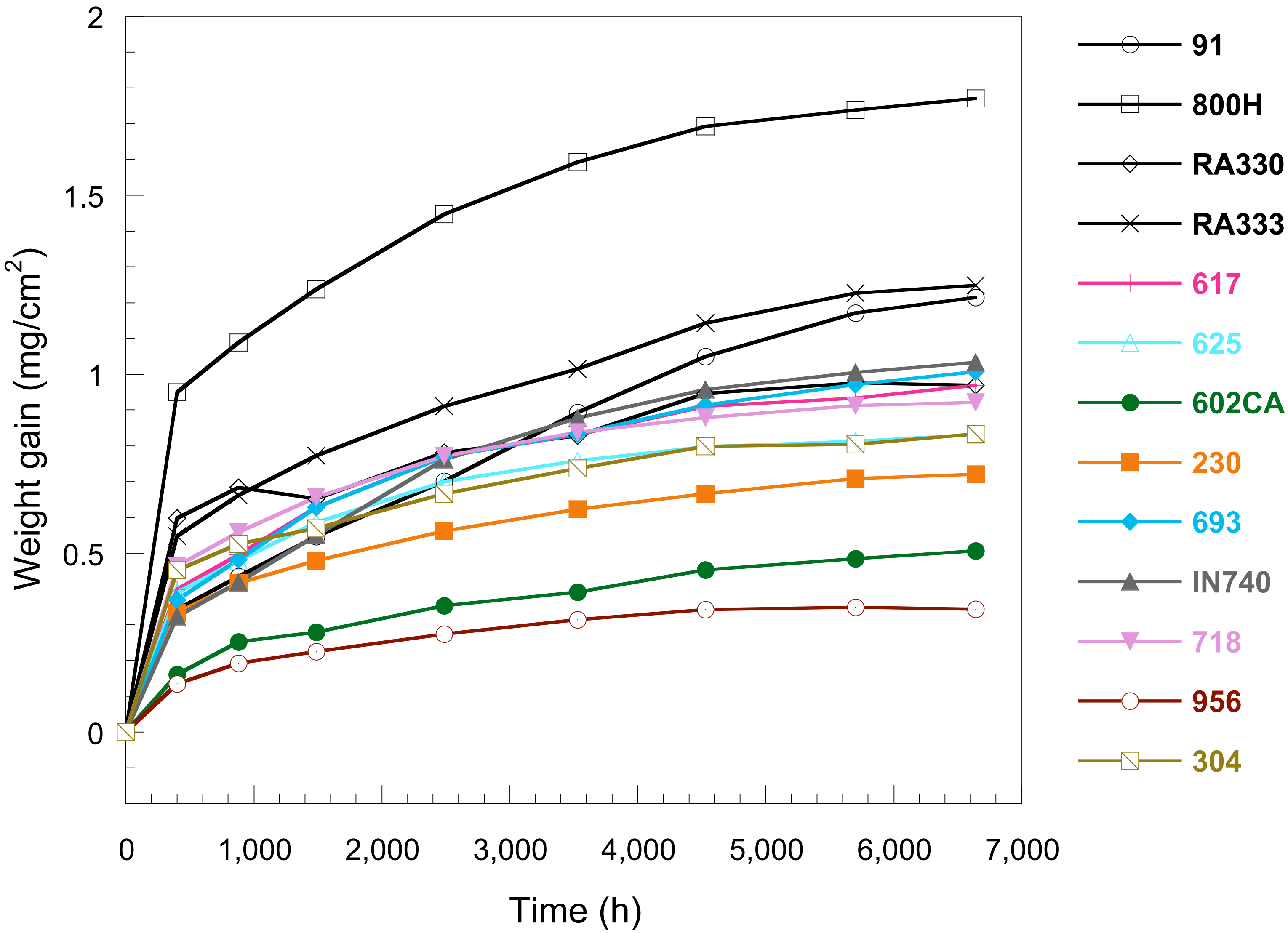
Oxidation Performance in Pure CO_2 at 750ºC



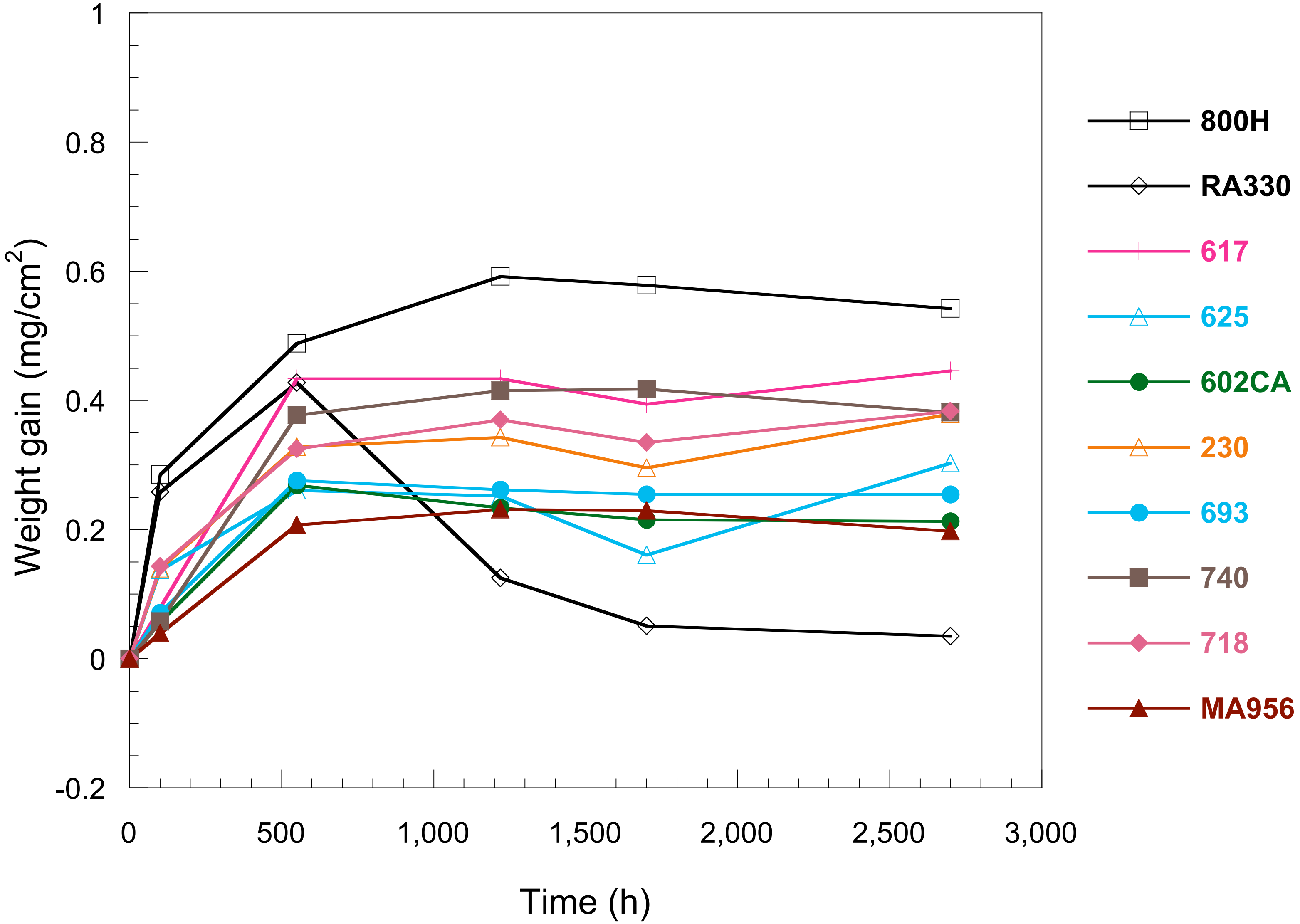
Oxidation Performance in 50% CO_2- 50% H_2O at 750°C



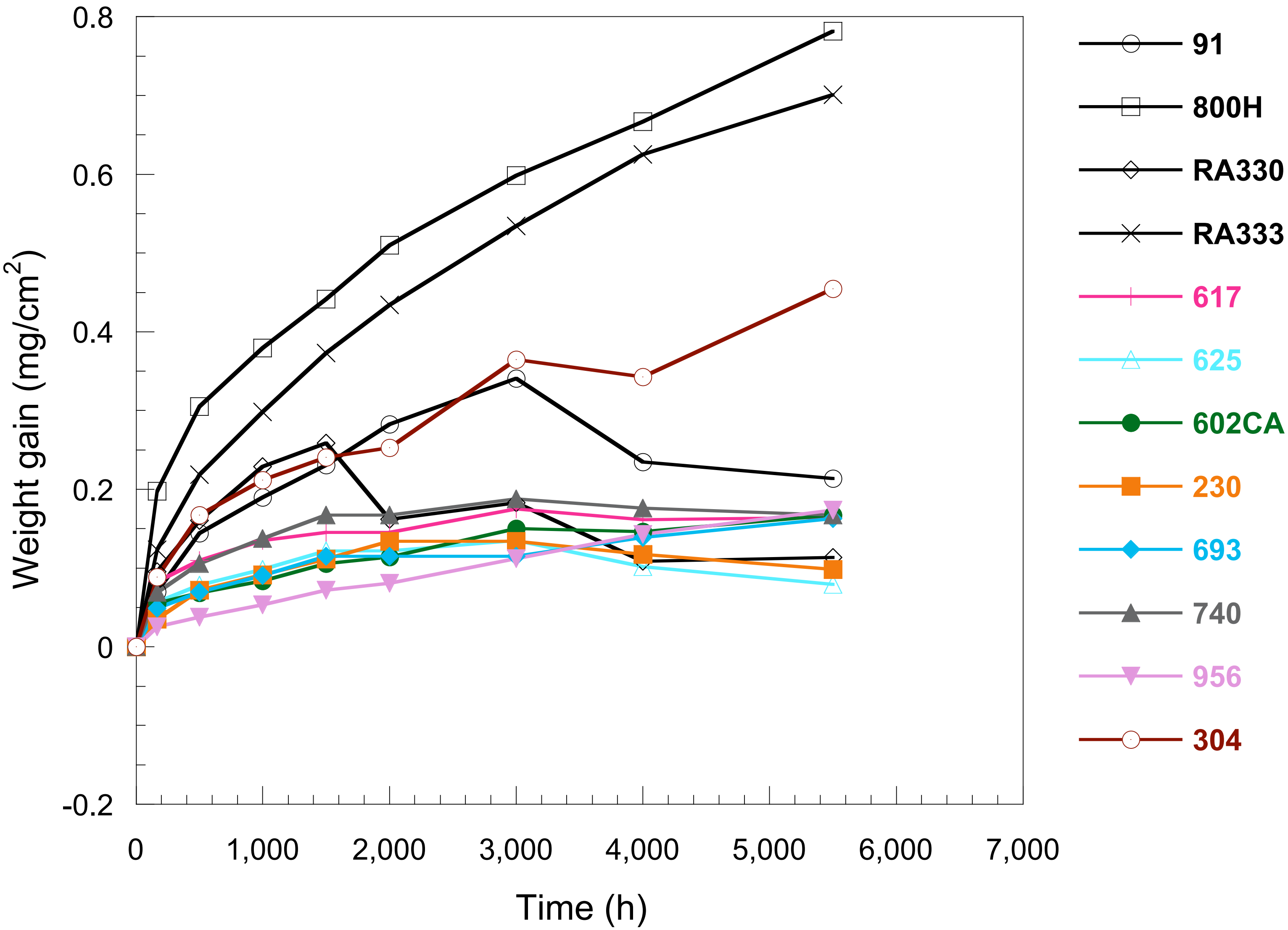
Oxidation Performance in 50% CO_2-50% H_2O at 750ºC



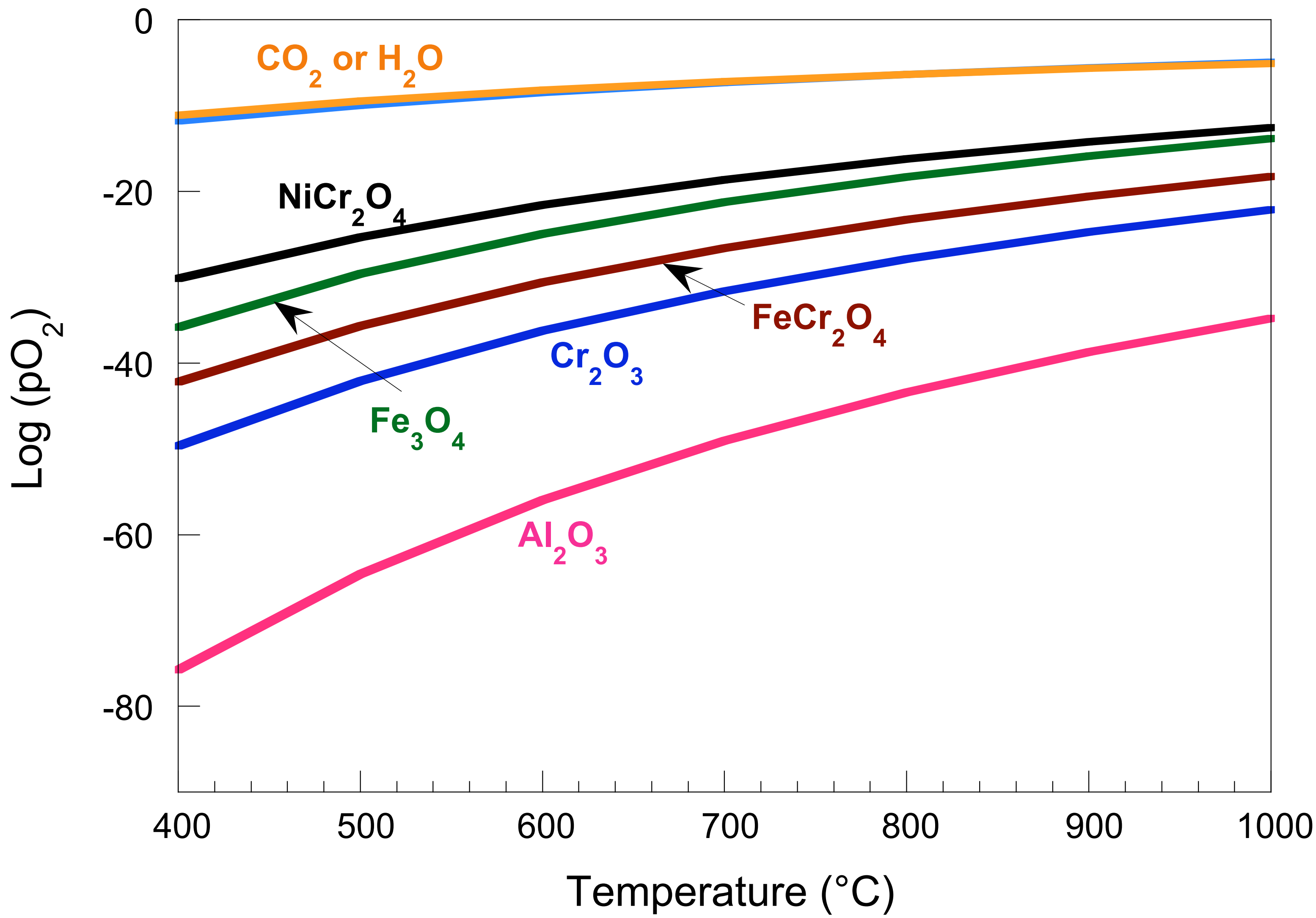
Oxidation Performance in Pure Steam at 725ºC



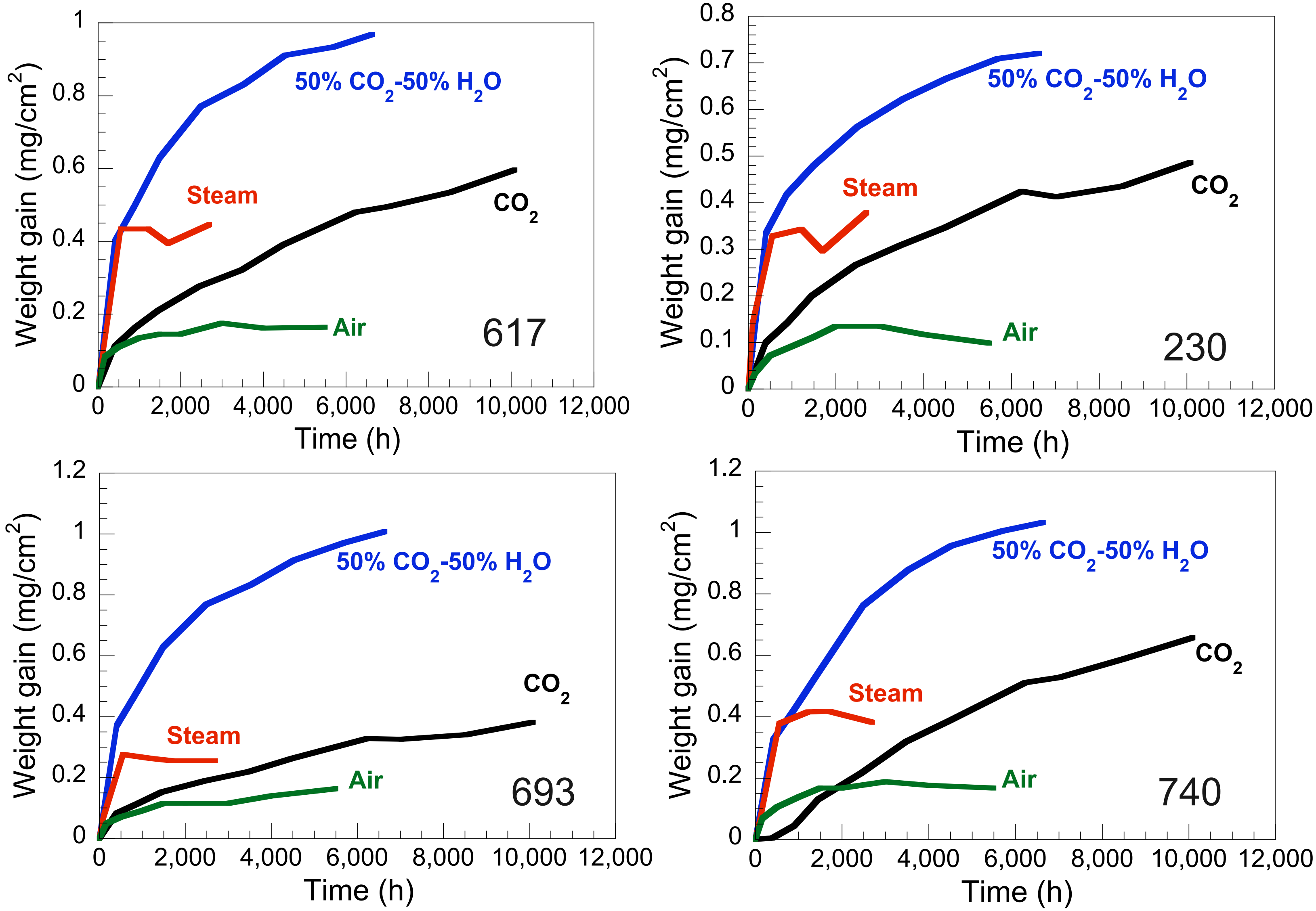
Oxidation Performance in Air at 750°C



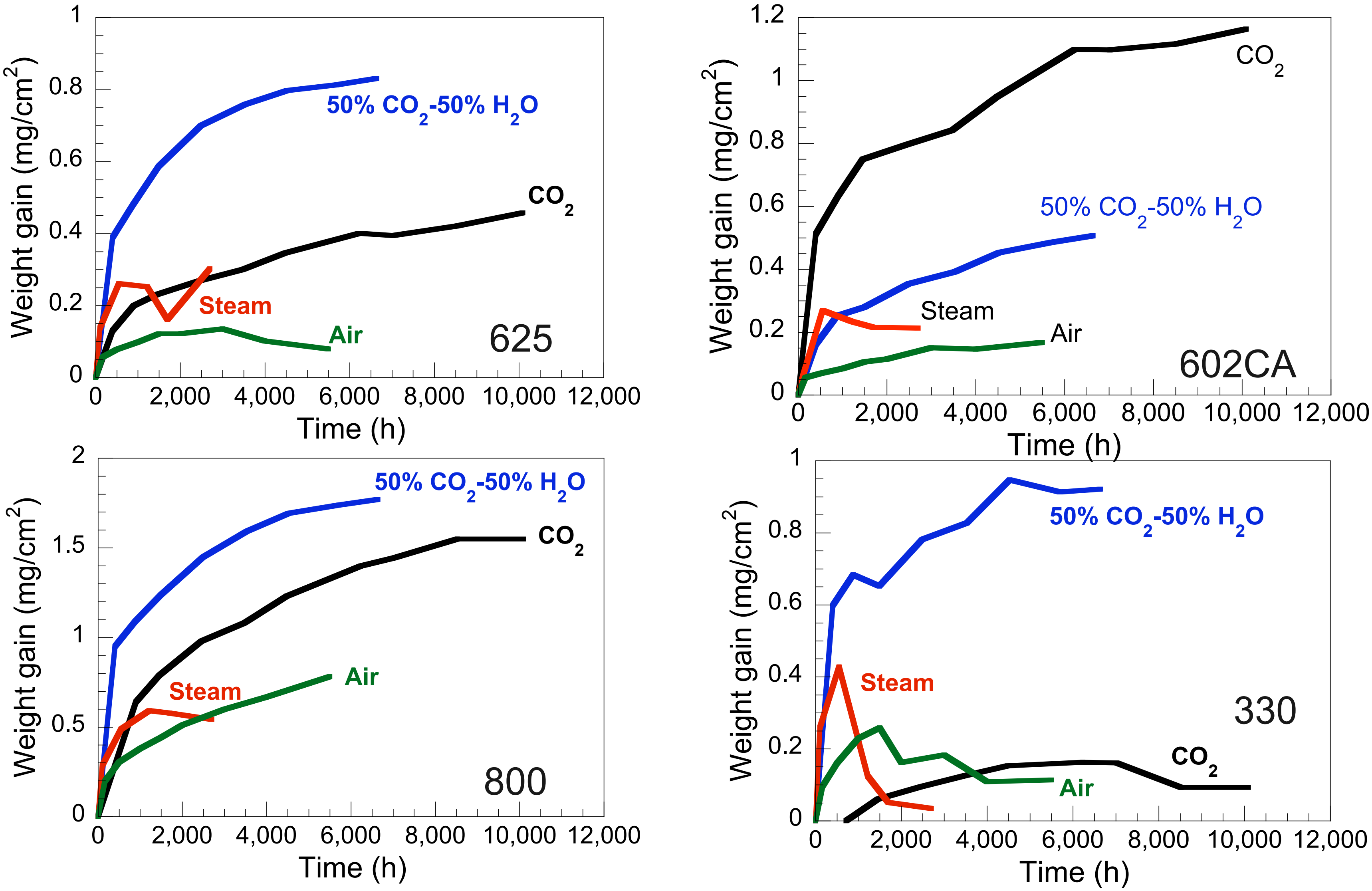
Thermodynamic Stability of Oxide Phases in the Scale



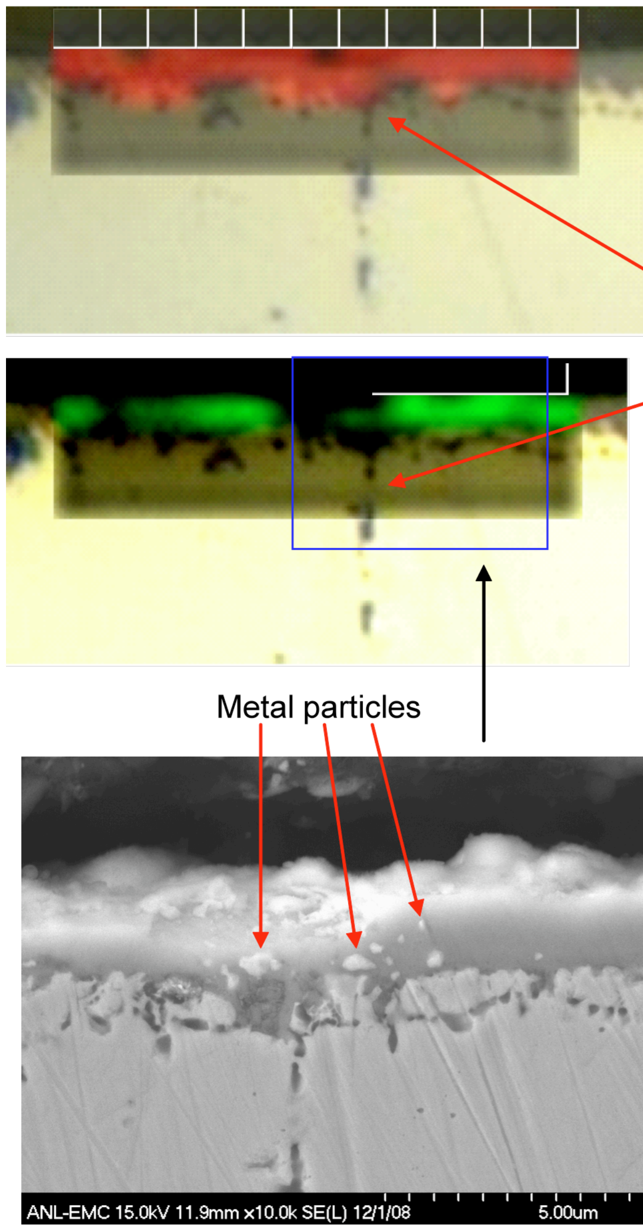
Oxidation Performance in Various Environments at 750ºC



Oxidation Performance in Various Environments at 750ºC



Alloy 617

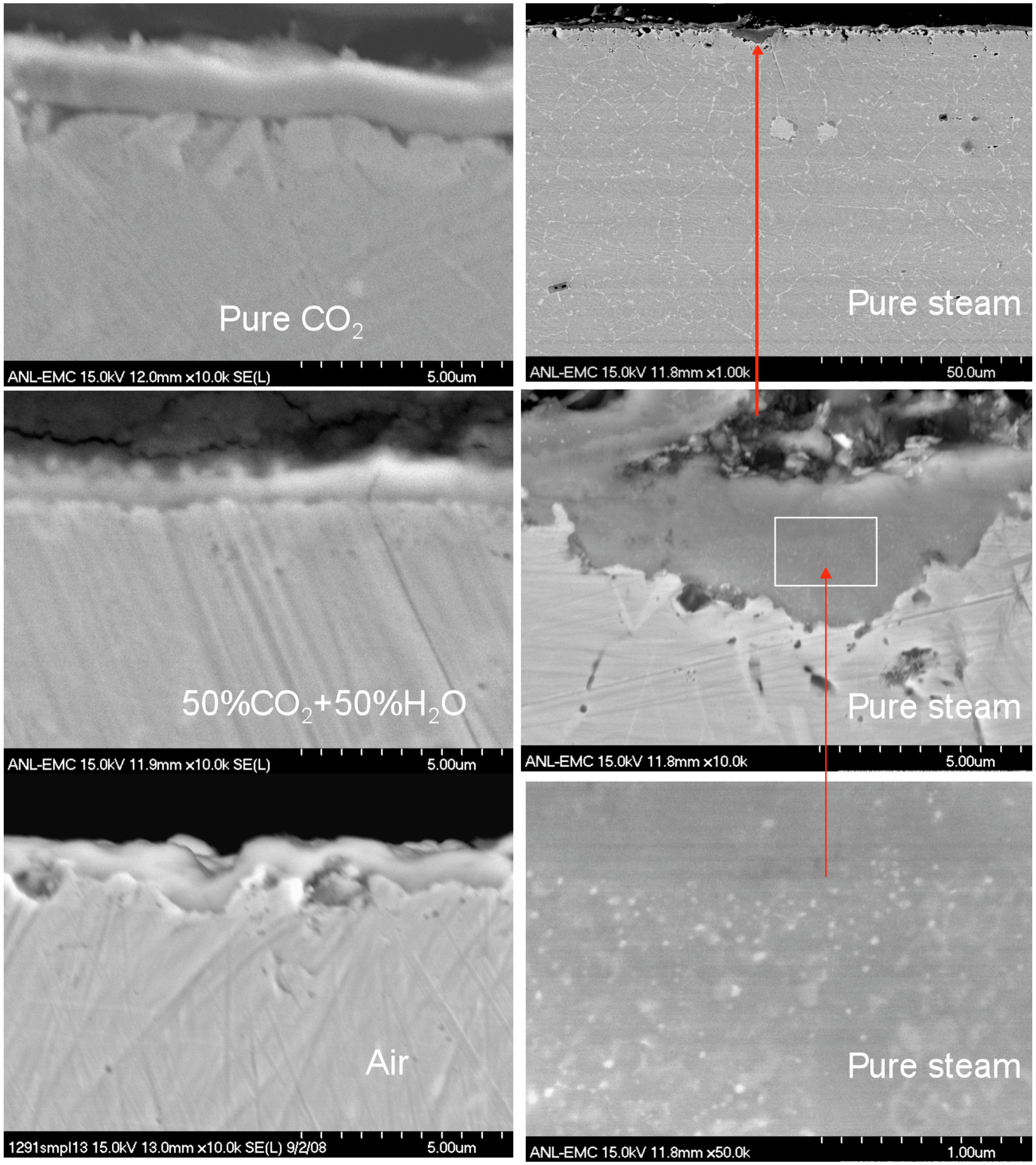


Spinel distribution

Damaged area

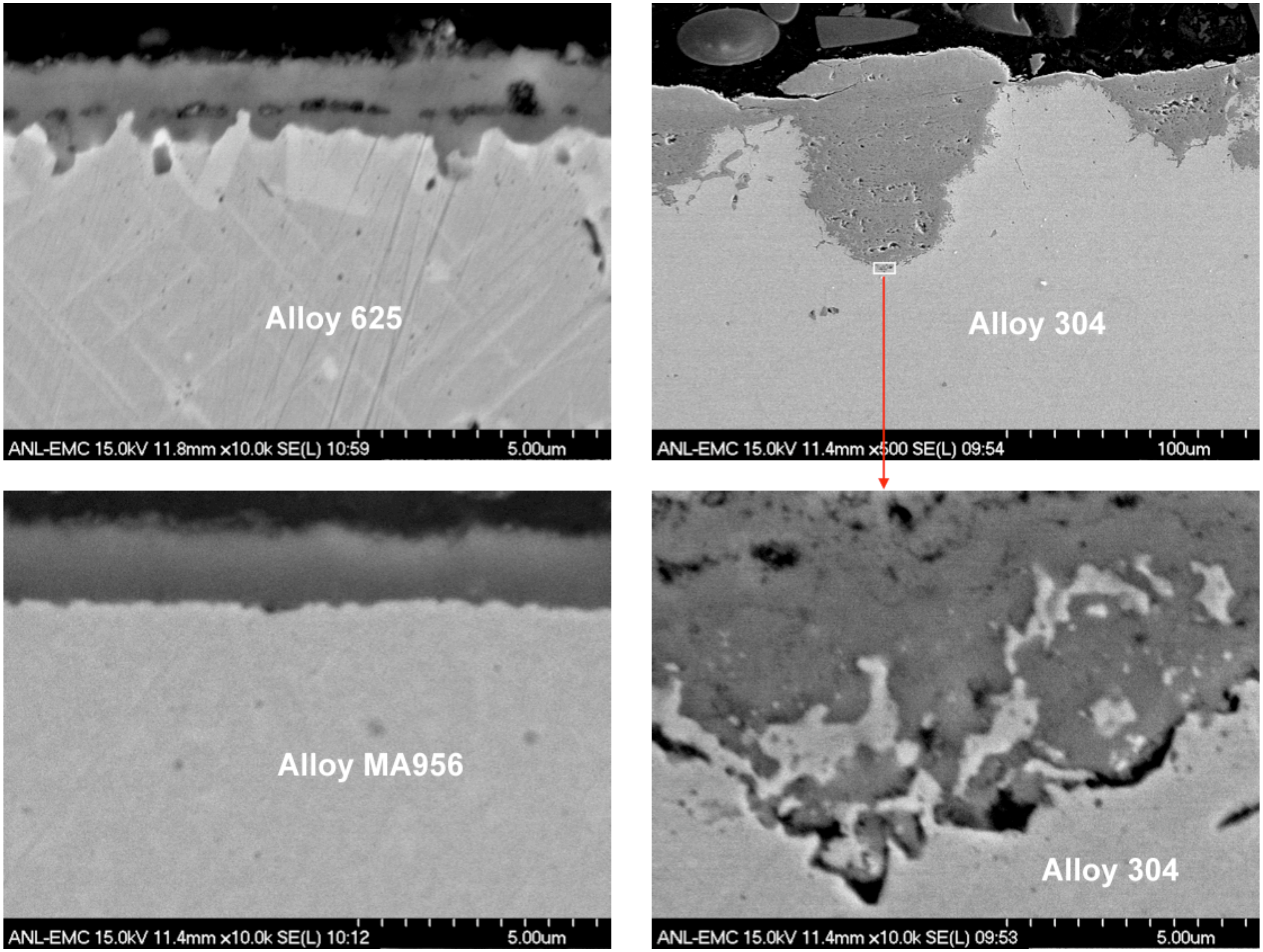
Cr_2O_3 distribution

SEM image at the box of Above image



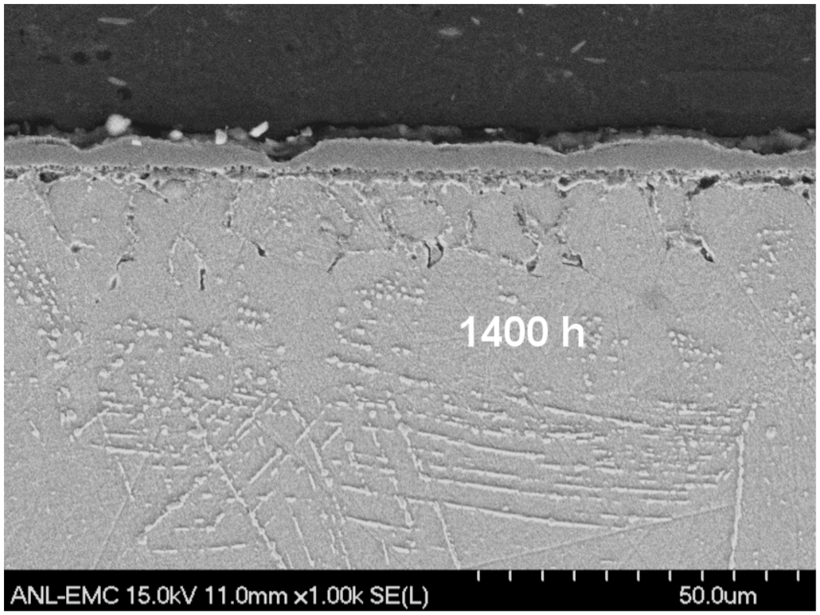
Pure CO_2
ANL-EMC 15.0kV 12.0mm x10.0k SE(L) 5.00um
Pure steam
ANL-EMC 15.0kV 11.8mm x1.00k 50.0um
50%CO_2+50%H_2O
ANL-EMC 15.0kV 11.9mm x10.0k SE(L) 5.00um
Pure steam
ANL-EMC 15.0kV 11.8mm x10.0k 5.00um
Air
1291smpl13 15.0kV 13.0mm x10.0k SE(L) 9/2/08 5.00um
Pure steam
ANL-EMC 15.0kV 11.8mm x50.0k 1.00um

Alloy 625

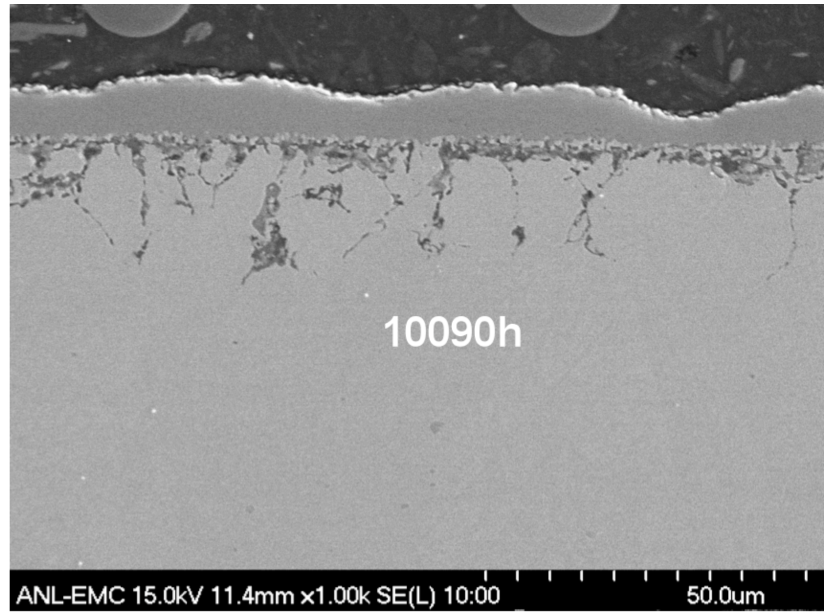


Pure CO_2 at 750°C for 10,090 h

Alloy 800 exposed to Pure CO_2 at 750°C

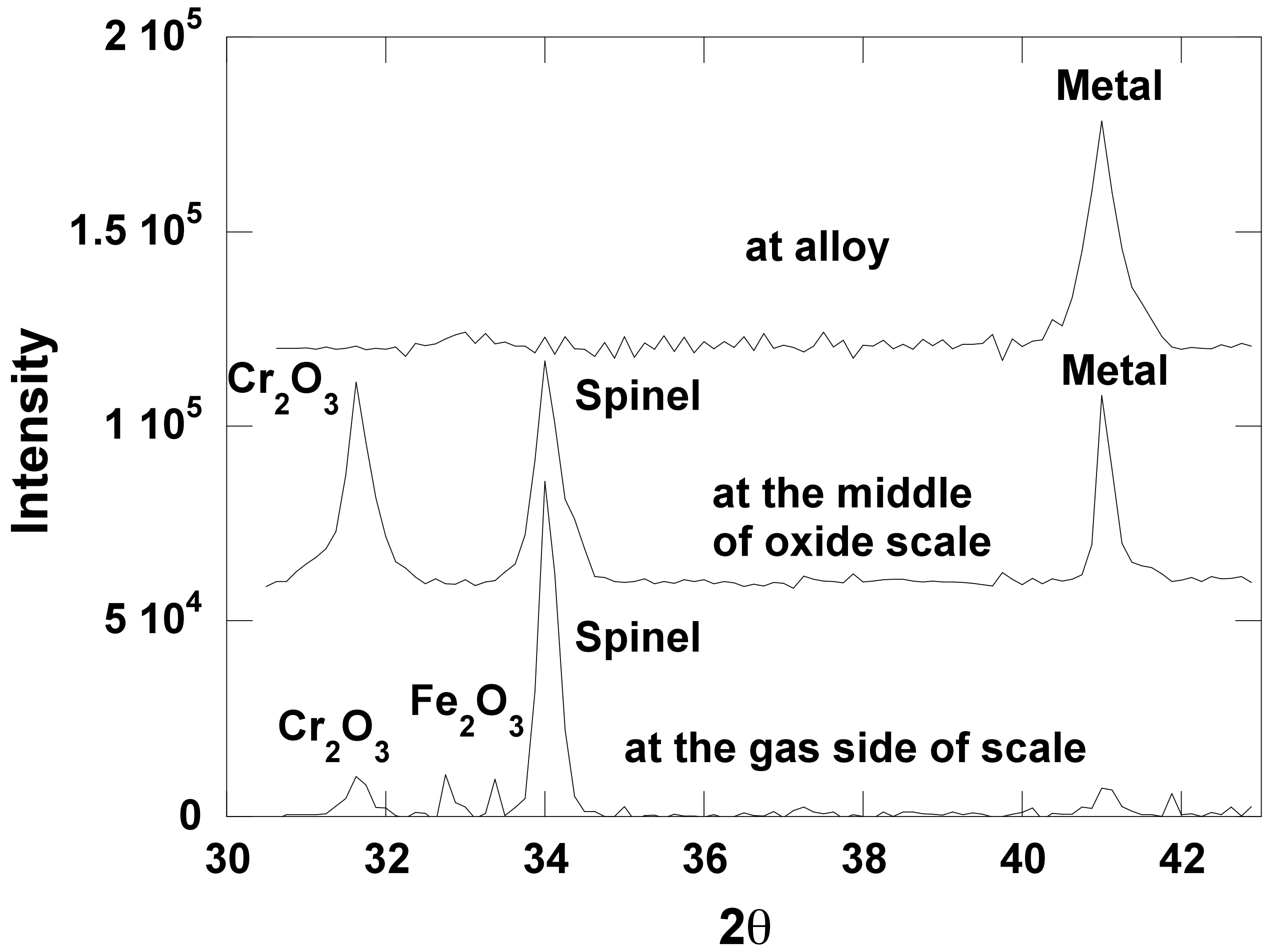


1452 h

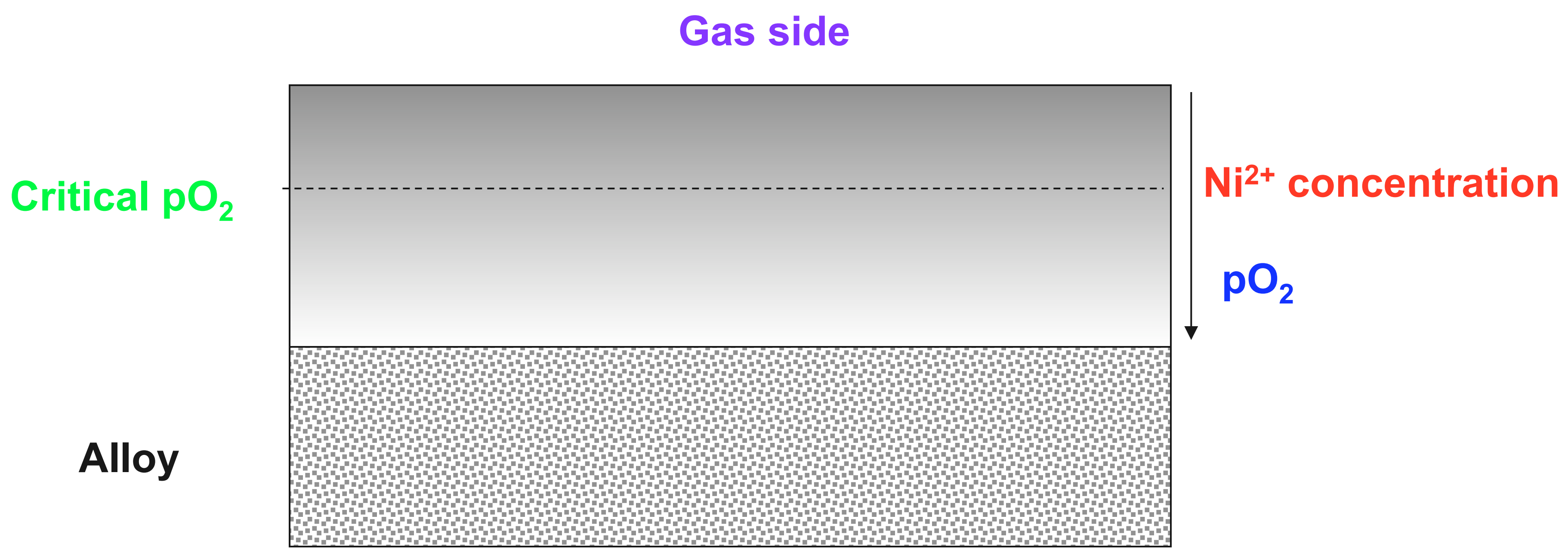


10,090 h

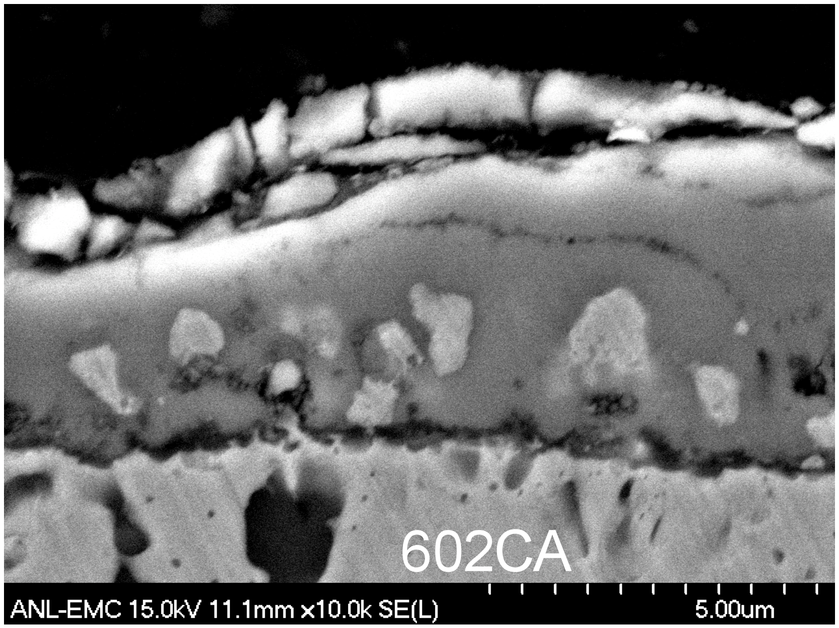
XRD at different locations of scale on the surface of Alloy 617 after 2,760-h exposure in 50%CO_2-50%Steam at 750°C



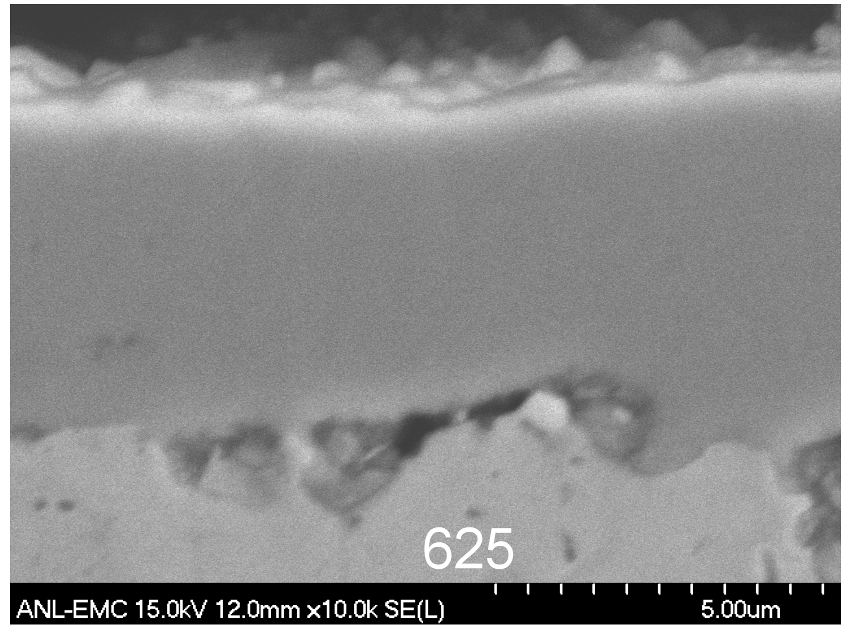
Effect of variation in p_{O2} on scale morphology



Effect of Fe content in alloy on the oxidation scale morphology

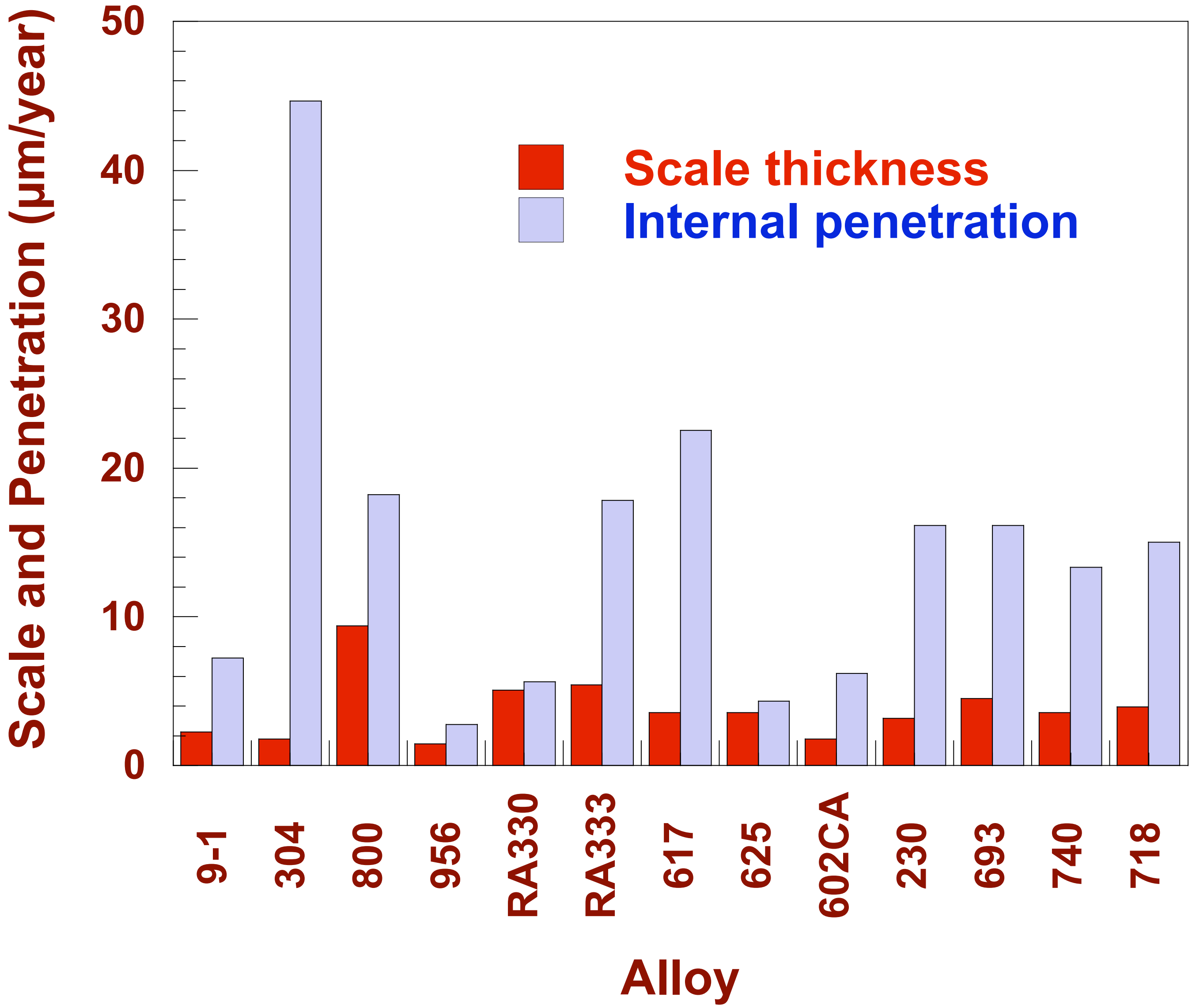


9.3 wt.% Fe

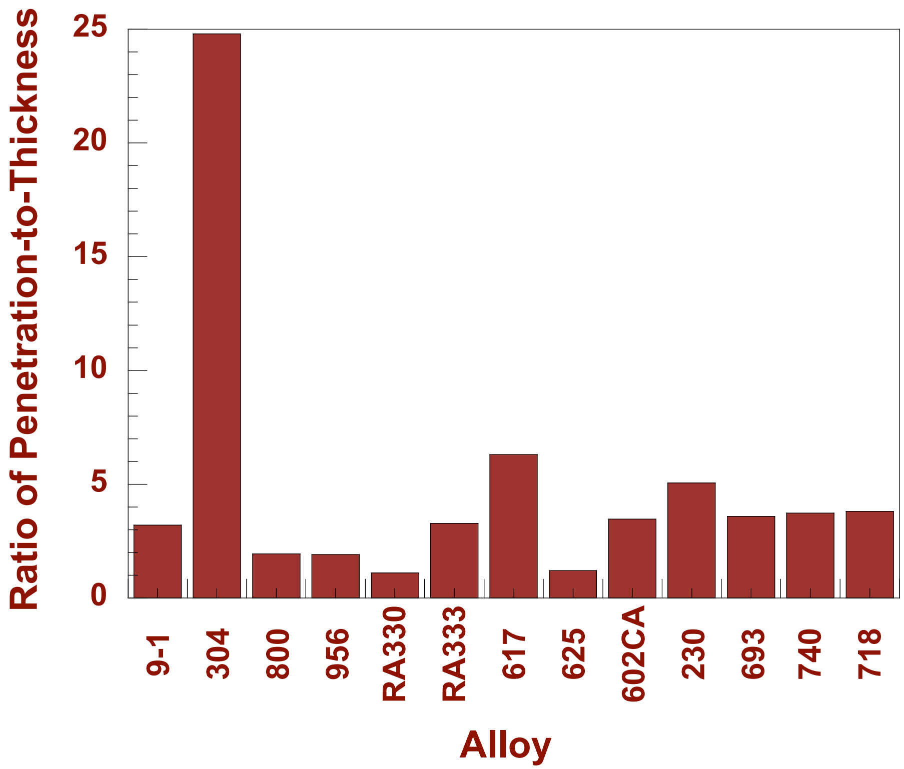


2.5 wt.% Fe

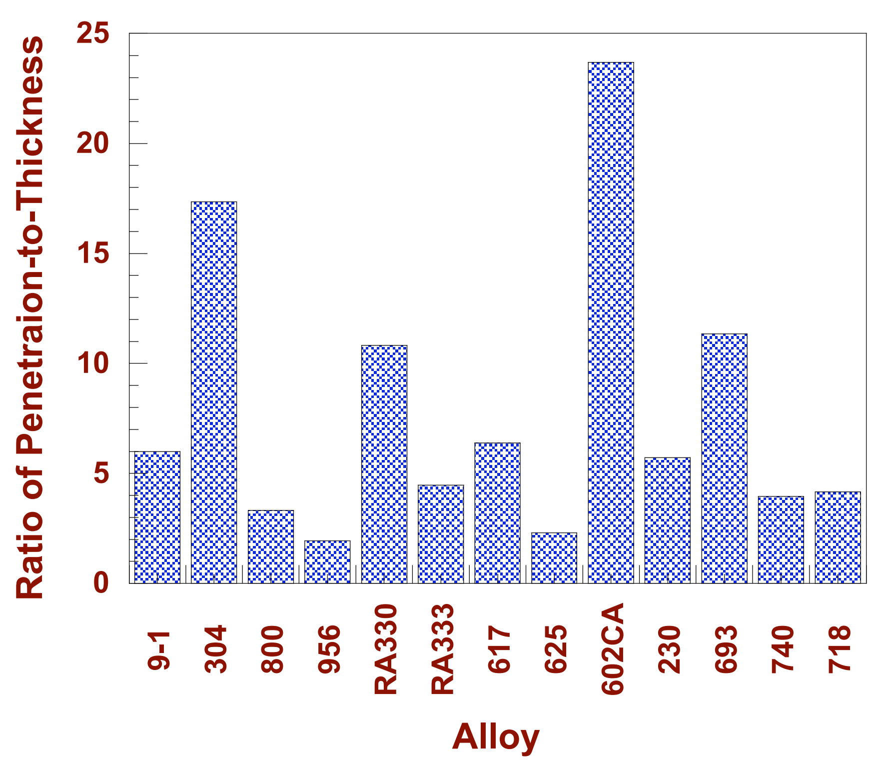
Scaling and Alloy Penetration Rates at 750ºC in 50%CO_2-50%Steam



Ratio of Alloy Penetration to Scale Thickness at 750ºC

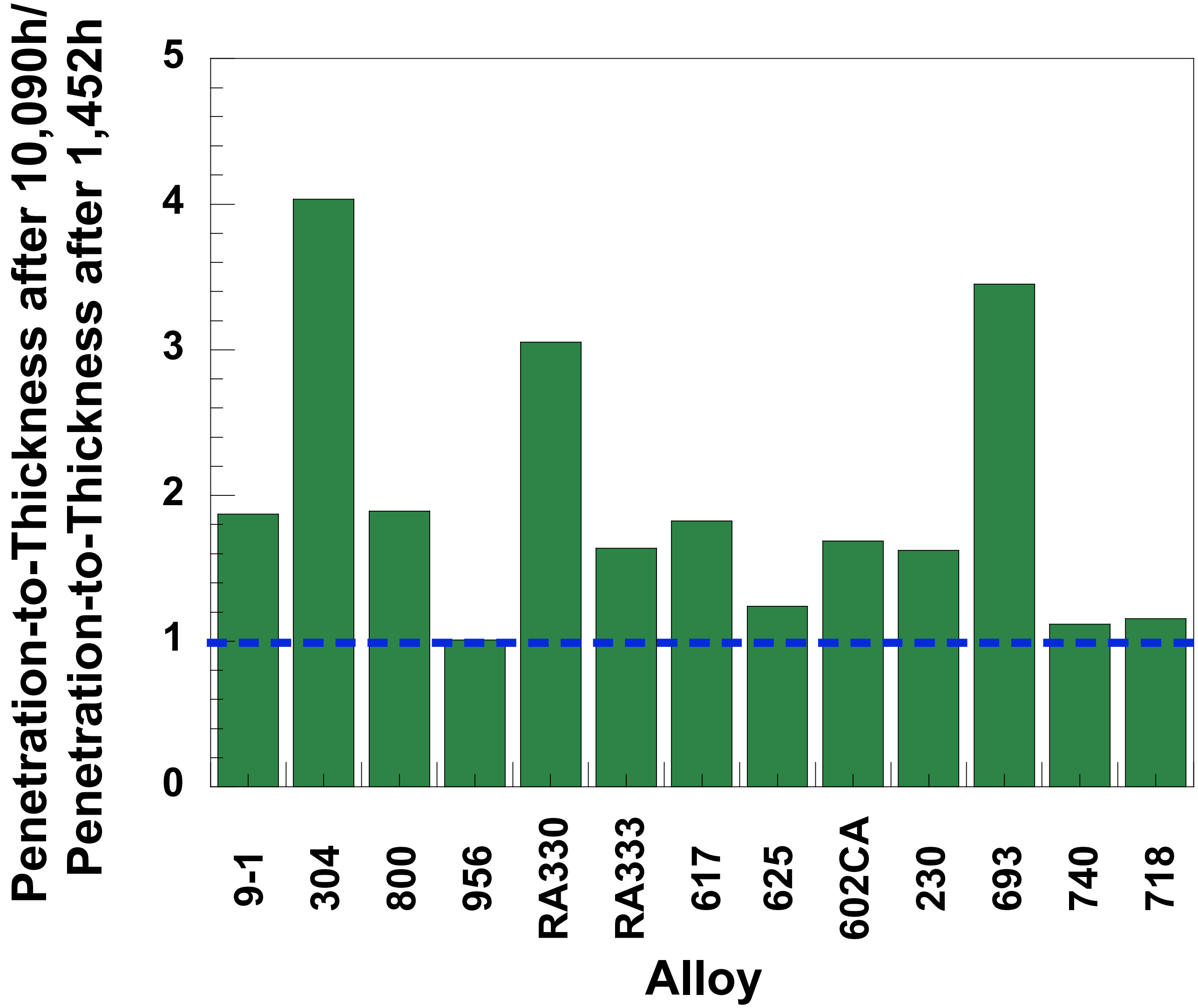


50%CO_2-50%Steam



Pure CO_2

Effect of Exposure time on the Ratio of Alloy Penetration to scale Thickness in Pure CO_2 at 750ºC



Project Summary

- **We have conducted a study to evaluate the oxidation performance of structural alloys in CO_2 and CO_2-steam environments at temperatures up to 1000°C. We believe the corrosion rates in these environments are acceptable for service. However, the effect on mechanical properties is not established.**
- **Results indicate that the oxide scales that develop on the alloys are not that protective and internal carburization of the substrate can occur**
- **The formation of nano-particles of metals such as Fe, Ni, and Co can act as continuous channels for the transport of carbon through the oxide scale**
- **At present, we are conducting tests in oxy-fuel environments with coal ash, alkali sulfates, and alkali chlorides. The integrity of the scales in resisting S, Cl, and coal ash attack will dictate the use of these alloys.**