Solid Oxide Fuel Cell Metallic Interconnect Systems

9th Annual SECA Workshop
5-7 August 2008, Pittsburgh PA
Project DE-FC26-05NT42513

J. M. Rakowski, ATI Allegheny Ludlum

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Overview

Project Description

- Evaluate materials for use as a basis for interconnect structures
  - Low-cost substrates
  - Functional modifications
- Low cost substrates
  - Commercially available ferritic stainless steels
  - Minor alloy modifications within specifications
- Functional modifications include
  - Coatings
  - Integral surface treatments

Project Description

- A large portion of the mass of a SOFC stack is metallic alloys (interconnects)
- The focus of this project is integration of commercially available ferritic stainless alloys (e.g. Type 441) into an interconnect system
- Current community focus on functional coatings (e.g. manganese cobaltite spinel) indicates use of less expensive substrates
- Modified processing designed to have minimal impact on cost

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Technical Approach

- The goal is to identify materials to serve as the basis for a high-performance interconnect system
- The deliverable is the selection of an alloy or alloys suitable for such
- The work to-date has focused on commercially available stainless steels and relies on well-established technologies such as surface coatings and minor element alloying additions
- Techniques used to identify good candidates include
  - High temperature oxidation testing – measurement of rate of oxide scale thickening
  - In-situ *area specific resistance* (ASR) testing

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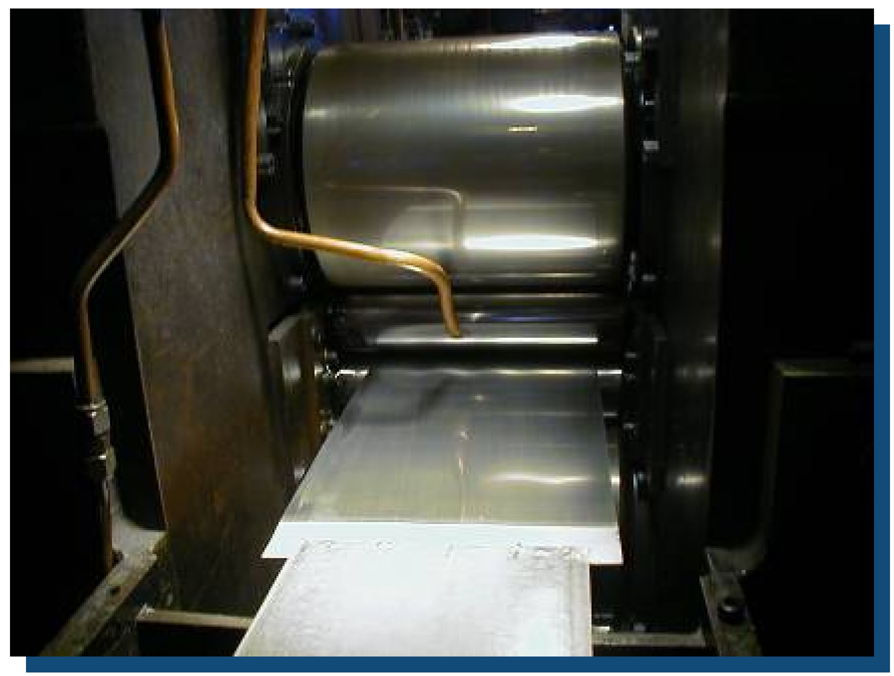
Materials

Melting and Processing

- Alloy development is done by melting experimental compositions in the laboratory
- Melting is via a 22 kg VIM process
- Processing is done by hot and cold rolling on a variety of small-scale rolling mills
- Material is comparable to that produced on a mill scale



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Melting and Processing

- Melted and processed a set of lab heats to thin strip

Element	T441	580-6	580-7	580-2	E-BRITE® alloy	580-5	580-8	580-9
Cr	17.6	17.0	17.0	17.0	26.0	26.0	23.0	24.0
Si	0.47	0.15	0.05	0.05	0.3	0.3	0.15	0.05
Ce+La	--	--	--	0.10	--	--	--	--
Al	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Ti	0.18	0.20	0.20	0.20	--	0.20	0.20	0.20
Nb	0.46	0.30	0.30	0.30	0.20	0.30	0.30	0.30
Mn	0.33	0.30	0.30	0.30	0.04	0.30	0.30	0.30
Mo	--	--	--	--	1.0	1.0	--	--

- Complementary to studies on production alloys (Type 441, E-BRITE® alloy)

Coatings

- Manganese cobaltite spinel (nominal $Mn_{1.5}Co_{1.5}O_4$) identified as effective interconnect coating
  - Electrically conductive
  - Oxidation barrier
- RE additions to heat-resistant alloys known to reduce oxide growth and increase oxide adherence
- Spinel was modified by addition of Ce as a surface treatment (based on NETL-Albany R&D) and then applied as a single-step coating
- Coated substrates provided by PNNL for testing

Silicon in Stainless Steels

- Silicon is typically present in most commercially-produced stainless steels
- By-product of the EAF/AOD steelmaking process
- Ferritic stainless steels generally contain about 0.3-0.6 % silicon by weight

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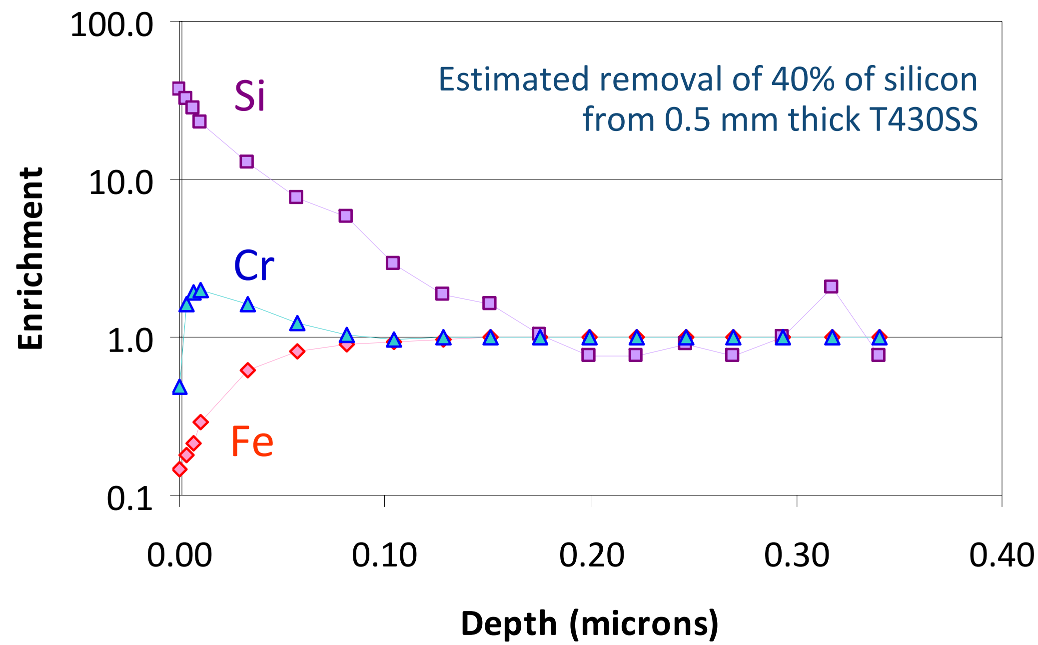
Silicon Removal Trials

- High-temperature pre-treatment with optional chemical component
- Tested using a variety of Fe-Cr stainless steels
- Formation/removal of an Si-rich surface oxide layer
- Short-term results show a 25-75% reduction in ASR



AES analysis with sputter depth-profiling

Oxidation Testing

Effect of Water Vapor

- Humidified air used to simulate the cathode environment in SOFC
- Dual atmosphere effect commonly noted for high temperature exposures where the plate separates a hydrogen-bearing atmosphere from an oxidizing atmosphere
- Hydrogen effect
  - Anomalously rapid oxidation at a given test temperature
  - Manifested by the formation of mixed iron and chromium oxides
- Two different environments – similar results

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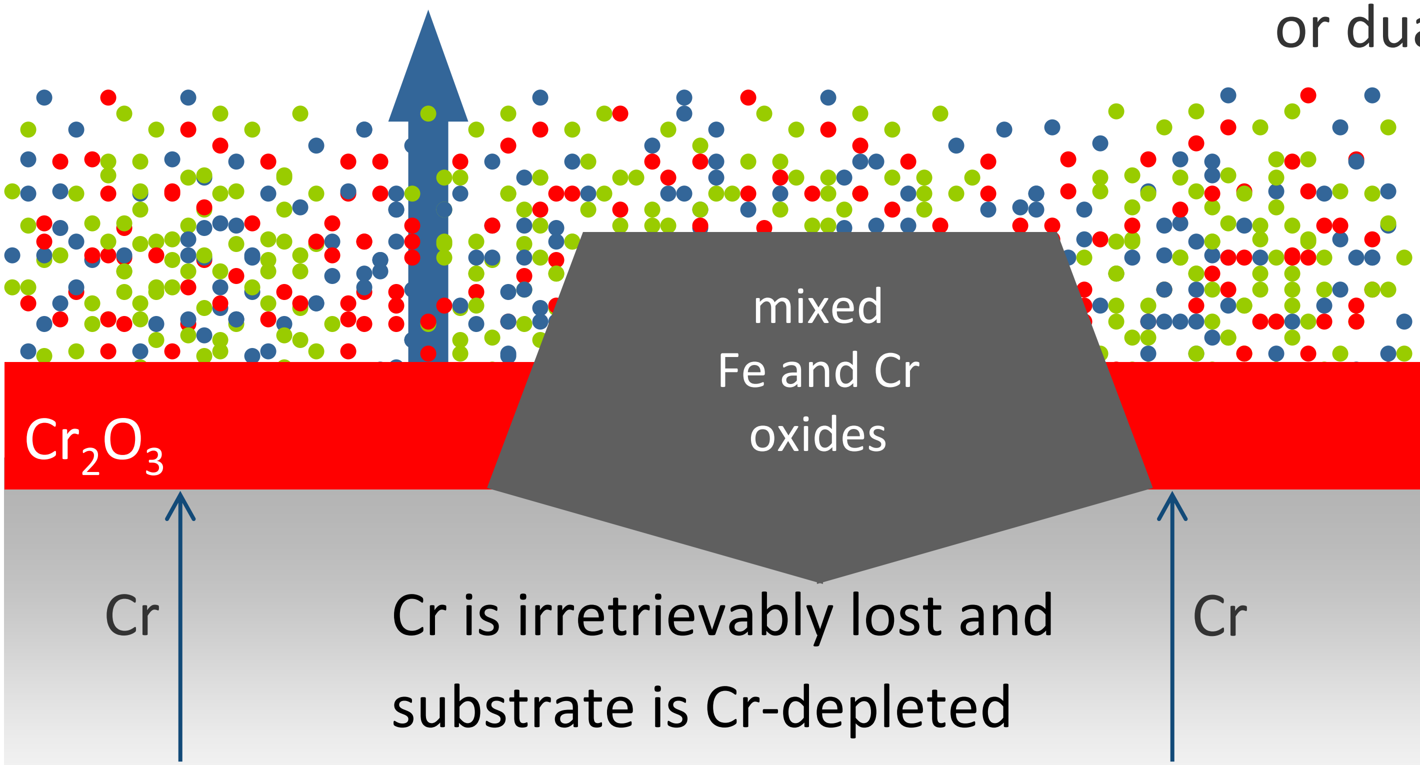
Effect of Water Vapor / H_2

$$2Cr_2O_{3(s)} + 3O_{2(g)} + 4H_2O_{(g)} \rightarrow 4CrO_2(OH)_{2(g)}$$

air + water vapor
or dual atmosphere



rapid degradation via the formation of mixed oxides is possible at high levels of Cr-depletion

Fe-Cr or Fe-Cr-Ni alloy

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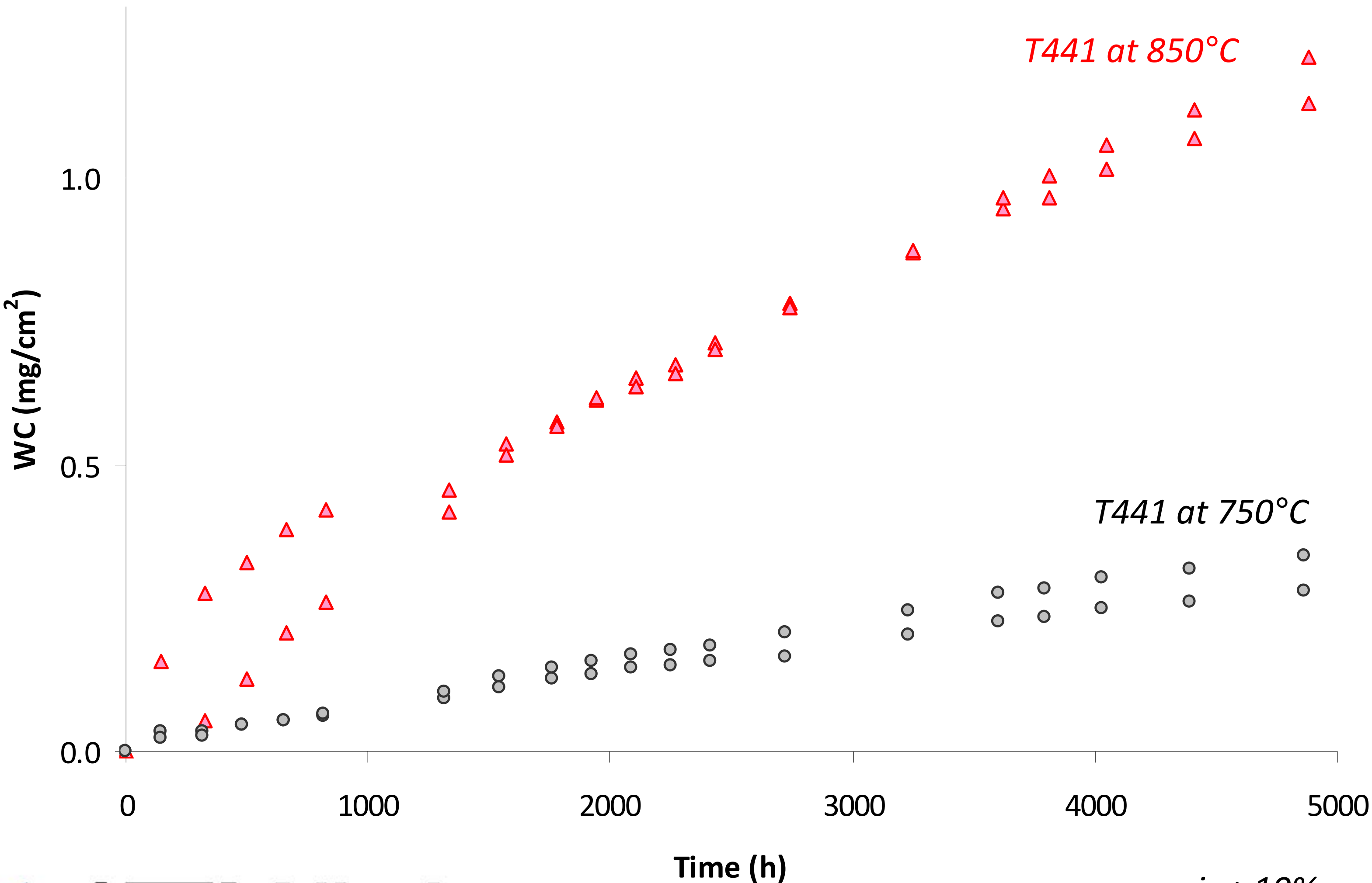
Results of Oxidation Testing

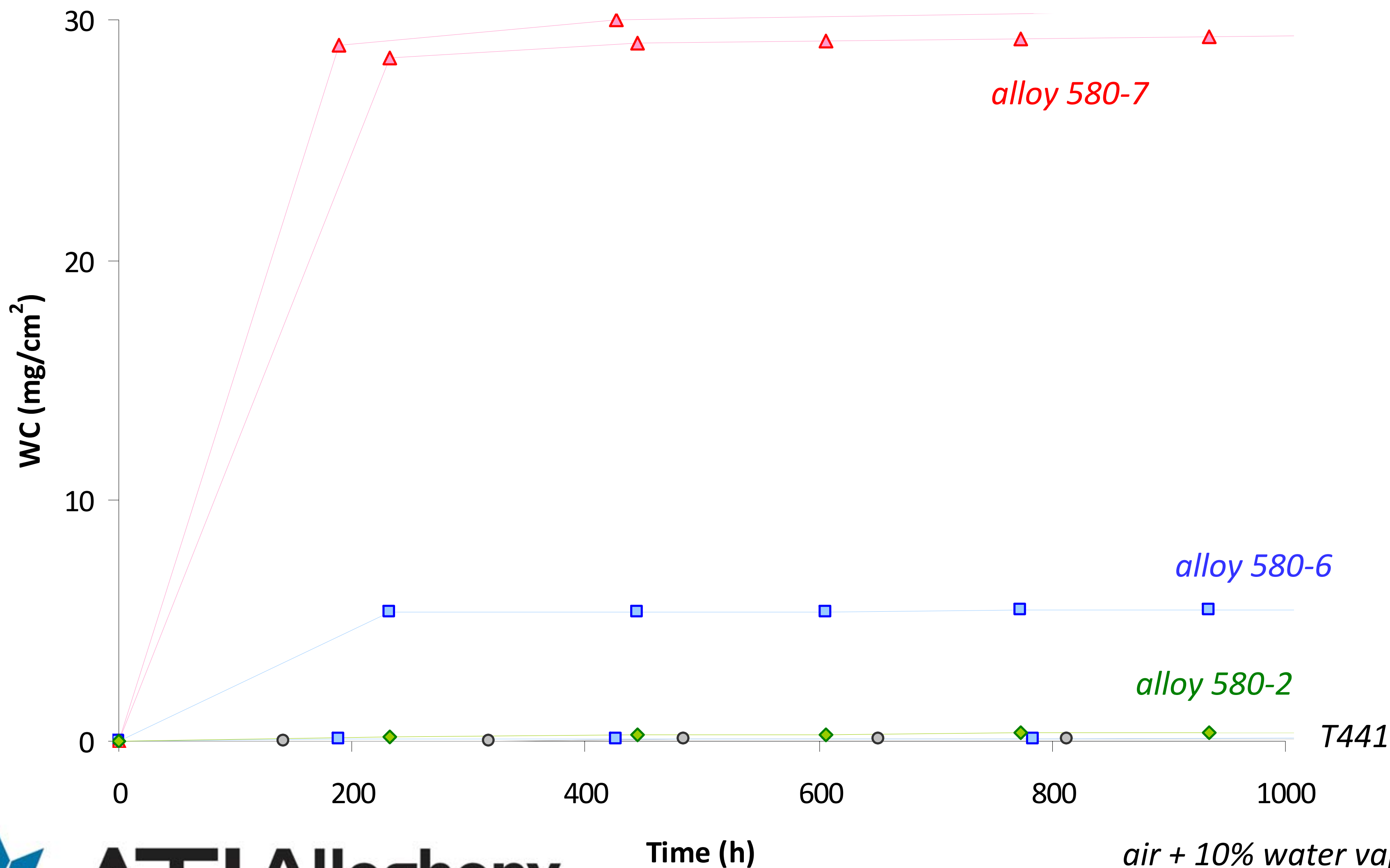
- Strong dependence of oxidation resistance on chromium content
- Effect of silicon
  - Very low silicon-content alloys show an added tendency towards rapid oxidation
  - Alloys processed to remove silicon do not show an added tendency towards rapid oxidation
- Manganese critical to reduce oxide scale evaporation in air containing water vapor
- Testing informs alloy selection and development

Results of Oxidation Testing



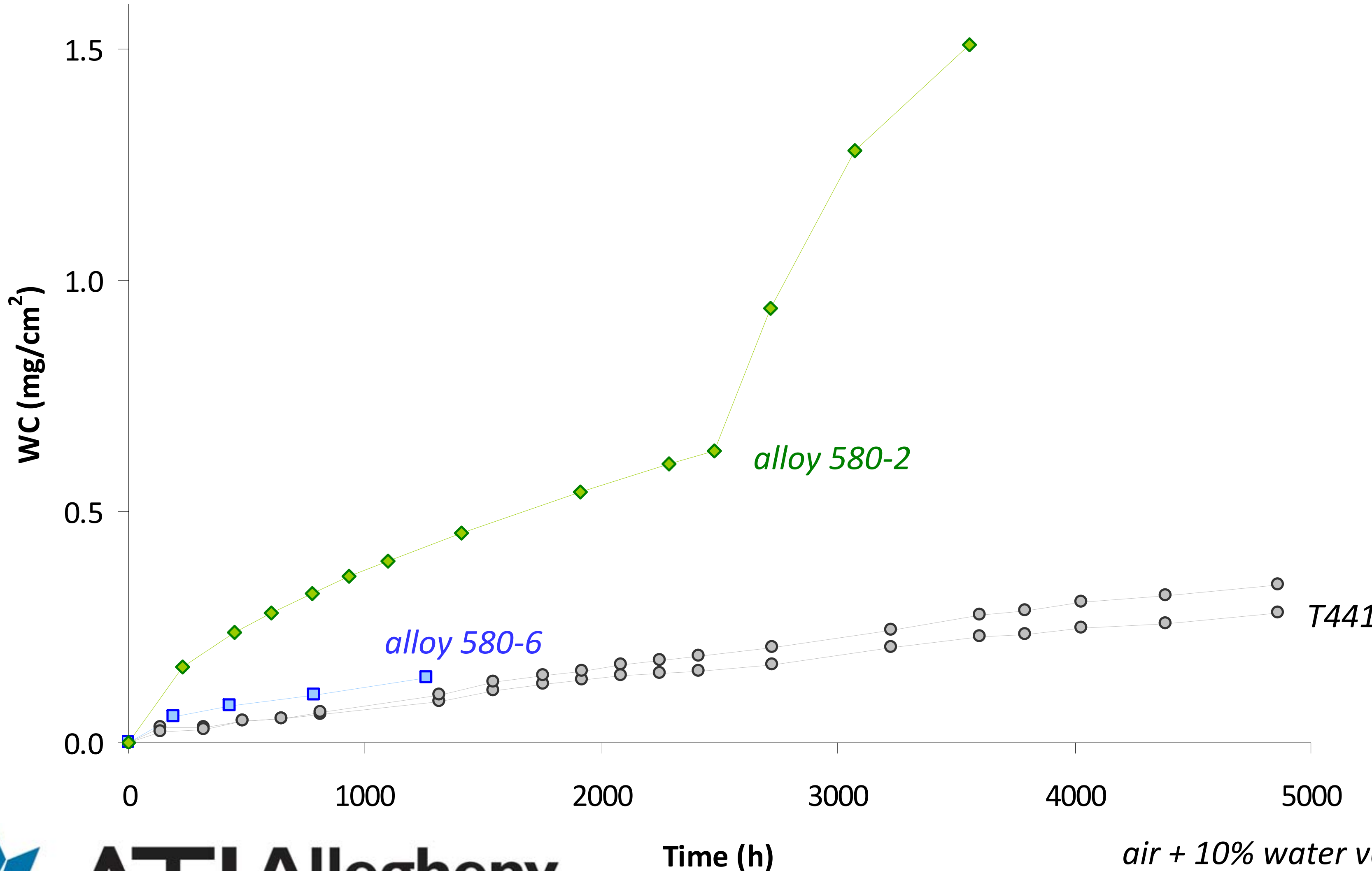
air + 10% water vapor

Results of Oxidation Testing



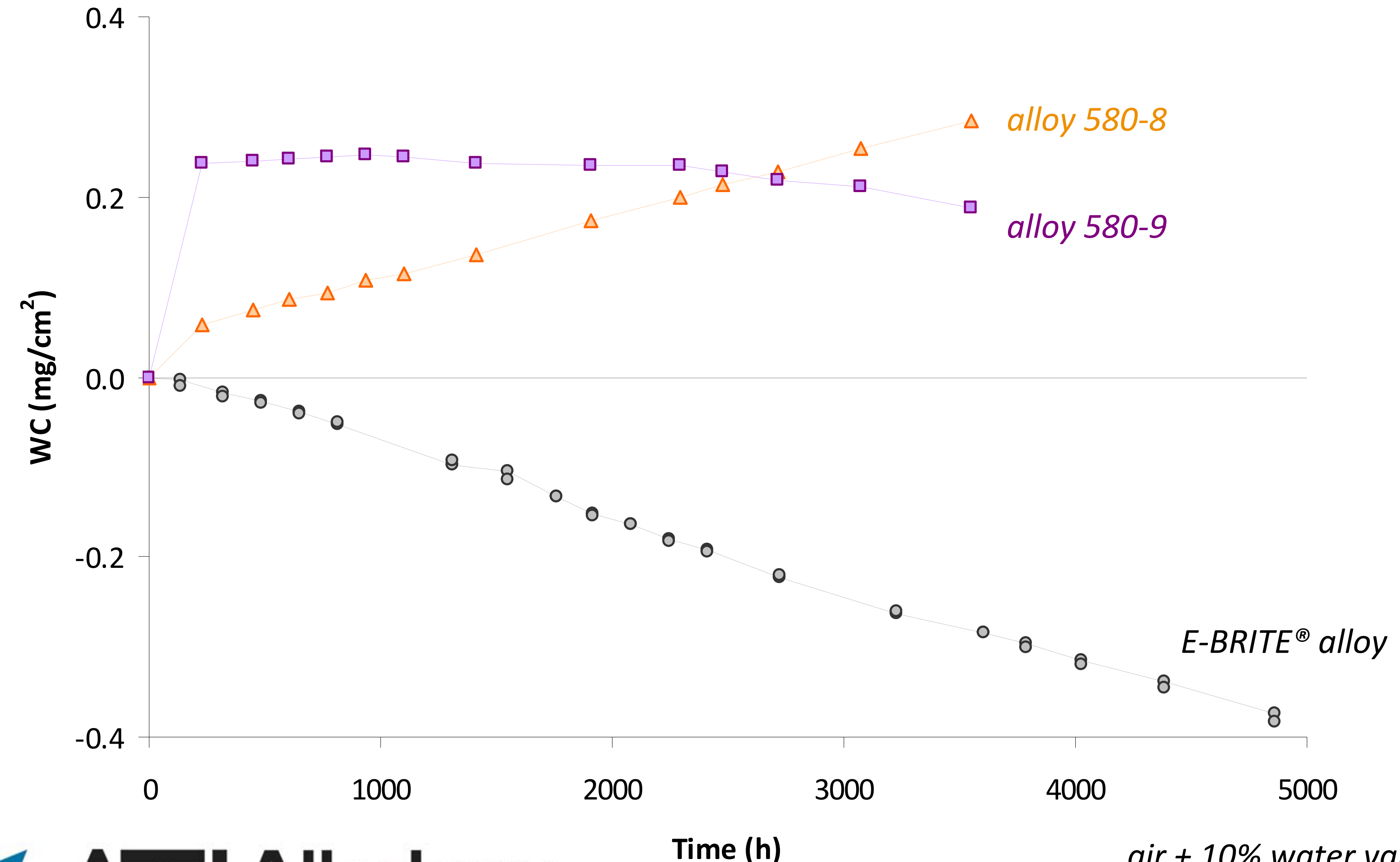
air + 10% water vapor
750°C

Results of Oxidation Testing



air + 10% water vapor
750°C

Results of Oxidation Testing



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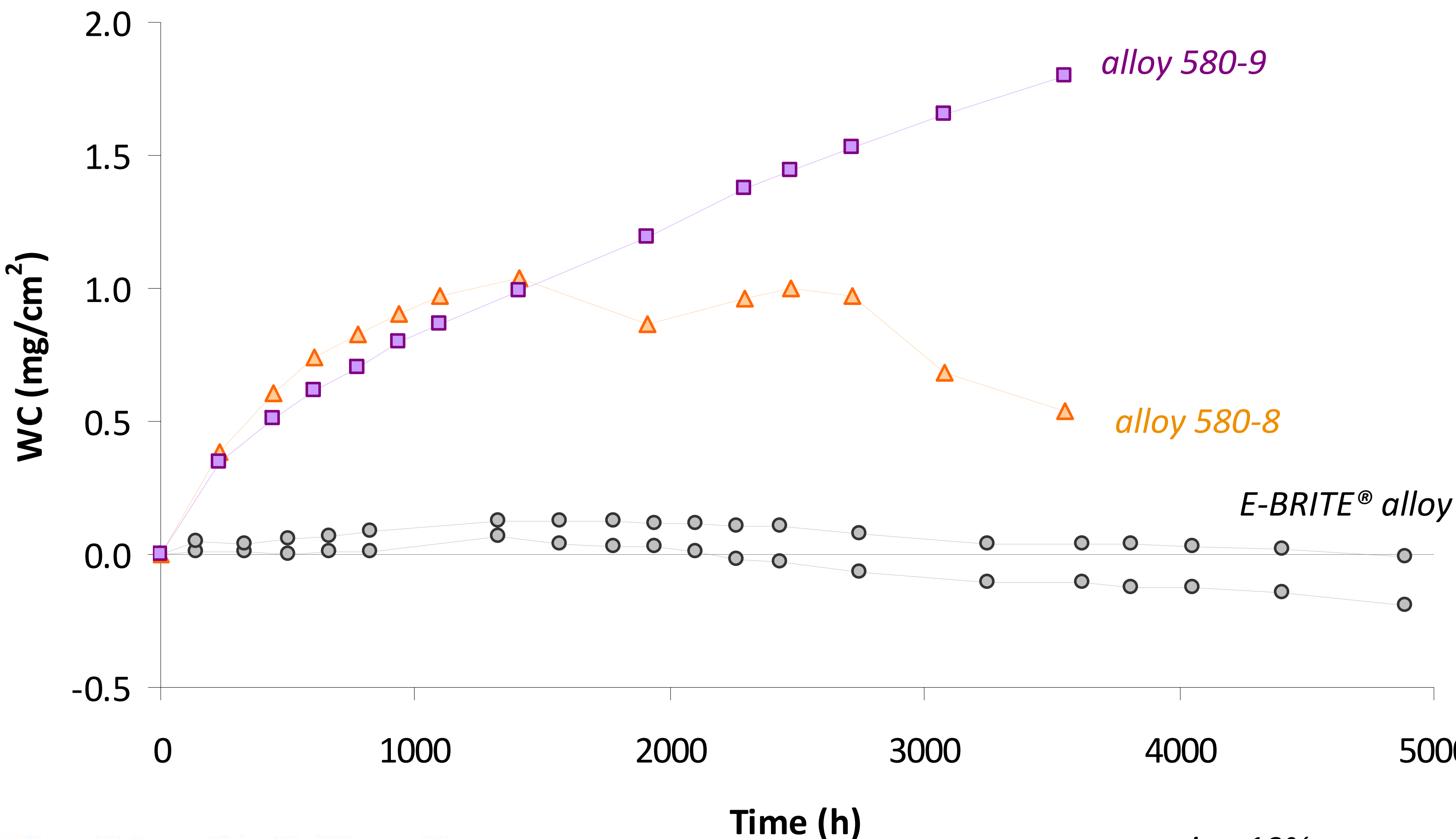
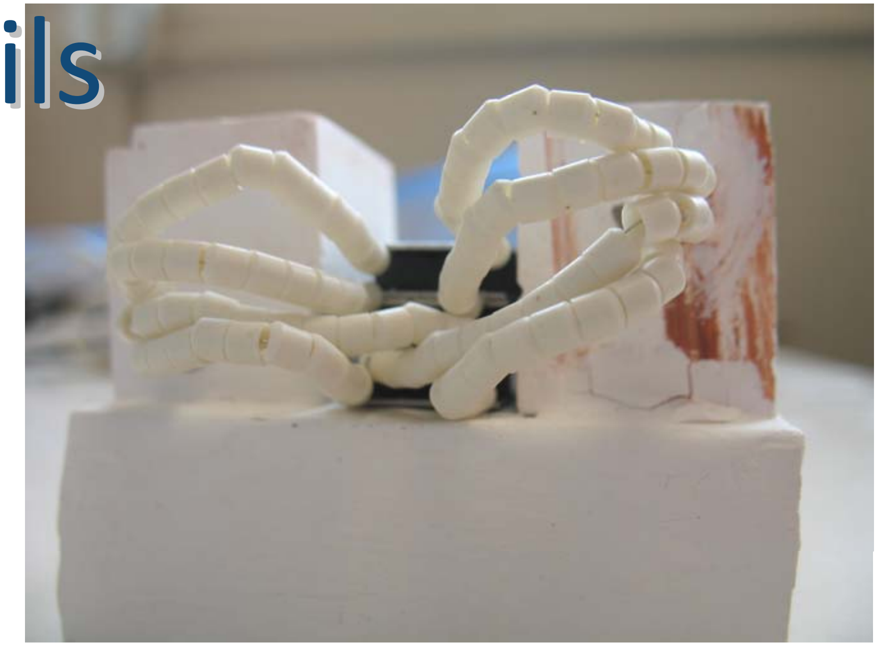
Results of Oxidation Testing



air + 10% water vapor
850°C

ASR Testing

Test Stack Details



- *LSM separator (Praxair)*
- *LSM contact ink*
- *Current density 0.5 A/cm^2*
- *Compaction force 0.2 psi*
- *Three stacks per fixture*
- *800°C test temperature*
- *Exposed in air*

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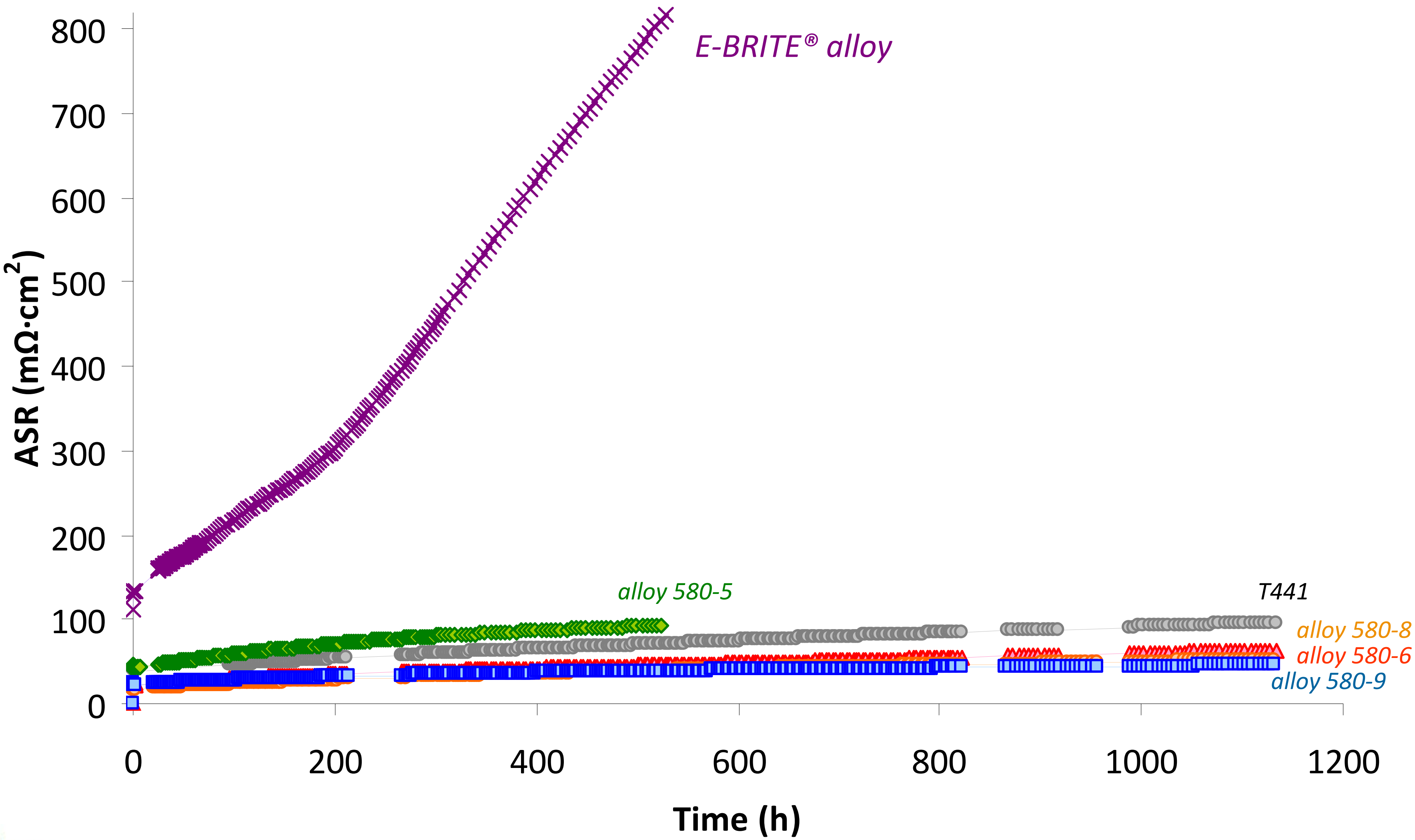
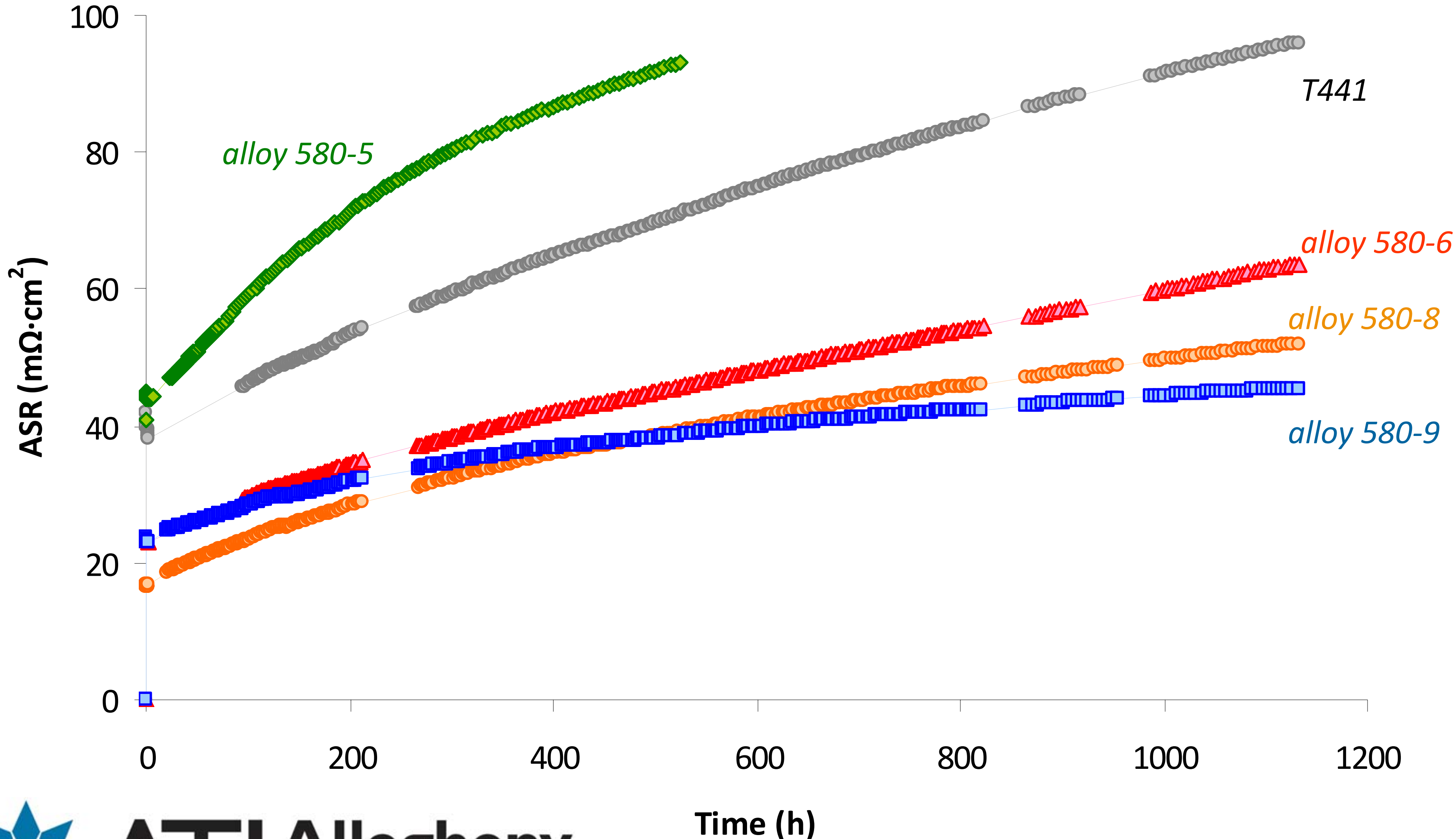
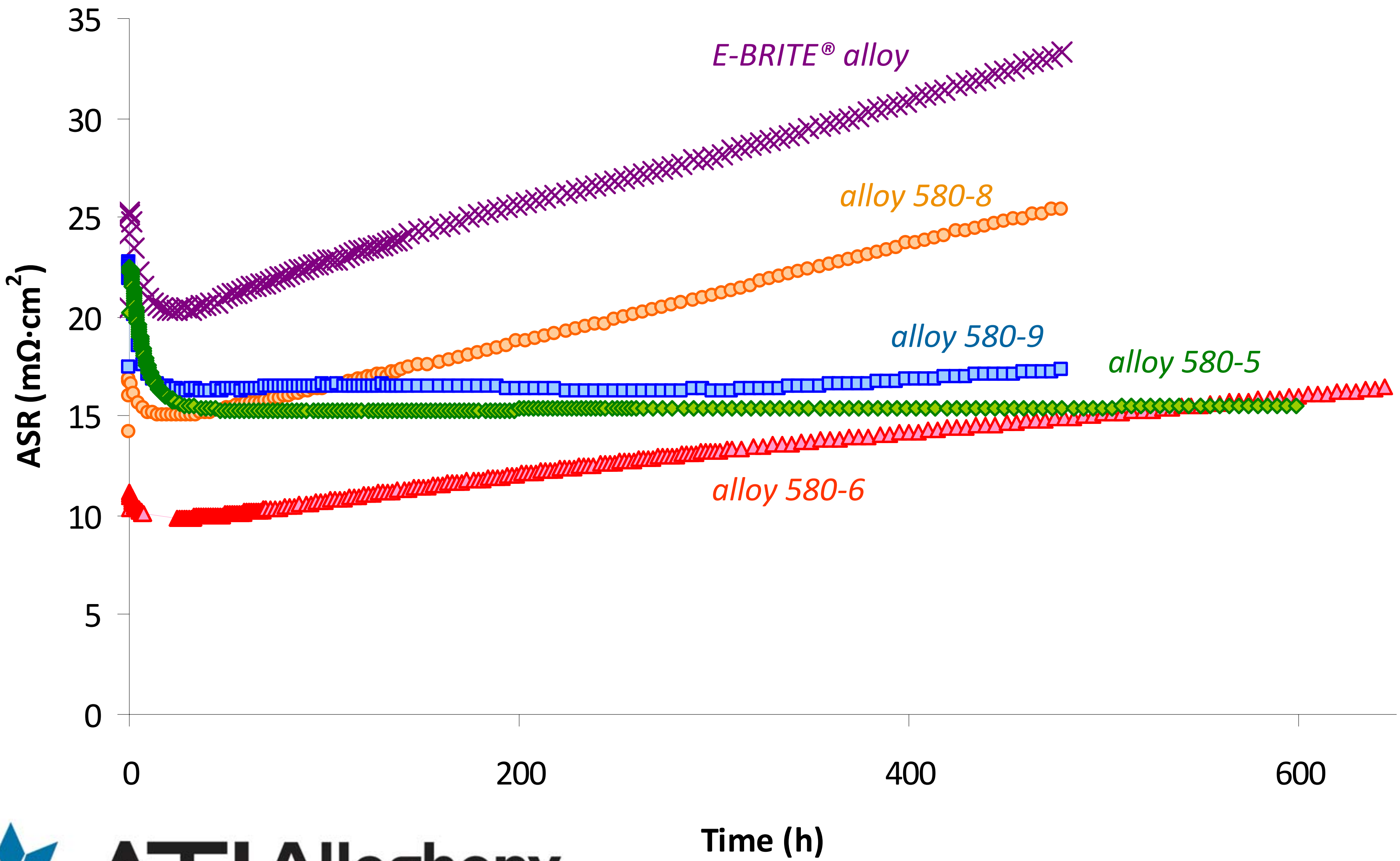
Bare Alloy Substrates



Bare Alloy Substrates



Coated Substrates



Summary

Technical Conclusions

- Commercially available ferritic stainless steels may be viable candidates for PSOFC interconnect applications
- Electrical performance is enhanced by the use of a surface coating (e.g. manganese cobaltite spinel with various modifications as developed at PNNL)
- Minor modifications to alloy chemistry can have value
  - Bulk (notably Nb, Mn, Si, and Cr)
  - Ultra-low Si may not be entirely beneficial
  - Surface (modified by Si removal)

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Balance of Project

- Continue oxidation testing to +5,000 hours time at temperature
- Currently working through a matrix of commercial and experimental alloys for ASR testing
  - Uncoated
  - Coated (with PNNL)
  - Desiliconized and other potential surface modifications
- It is expected that the majority of the work will be completed by 31 December 2008
- It is expected that the end result will primarily be guidance on materials selection for SOFC interconnects – potentially Type 441 stainless steel

Project Team Acknowledgement

- Allegheny Technologies (ATI)
- ATI Allegheny Ludlum
  - High Temperature Oxidation Test Laboratory at the Technical and Commercial Center (Natrona Heights, PA)
  - J. M. Rakowski, principal technical investigator
- ATI Wah Chang
  - Responsible for project administration (Albany, OR)
  - C. Jackson, R. Fletcher, J. Schra
- Significant collaboration with the Pacific Northwest National Laboratory (PNNL), NETL-Morgantown, and NETL-Albany
- Ayyakkannu Manivannan, Program Manager

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for additional information…

www.alleghenytechnologies.com
www.alleghenyludlum.com

James M. Rakowski
Manager, Product Technology
Market & Product Development
+724.226.6483
jrakowski@alleghenyludlum.com

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