Interconnect Alloys Metallurgy and Manufacturing

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ATI Allegheny Ludlum

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Introduction

- Environmental exposure conditions can lead to oxidation/functional degradation of interconnects and adjacent components
- Alloy and process development to reduce contribution to SOFC performance degradation

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Overview

- Phase I results and timeline
- Current focus of Phase II
  - Silicon removal trials
  - Oxidation of commercially available ferritic stainless steels
  - Production of novel ferritic stainless steels
- Ongoing work

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Phase I Review

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Results to Date – Phase I

- Timeline
  - 12 month period
  - Calendar year 2006
- Proof of concept for solid-state silicon removal
- Melting, processing, and testing of concept alloys
- Testing/analysis of commercially available stainless steels
- Testing/analysis of various oxidation-resistant coatings on commercially available stainless steels

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Phase II Status

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Silicon in Stainless Steels

- Silicon is present in most readily available stainless steels
- By-product of the AOD steelmaking process
- Commercially available stainless steels generally contain approximately 0.5 wt. % silicon

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Silicon Removal Trials

- High-temperature pre-treatment with optional chemical component
- Tested using a variety of Fe-Cr stainless steels (T430, T439, T441HP™ alloys)
- Formation/removal of an SiO_2 surface film

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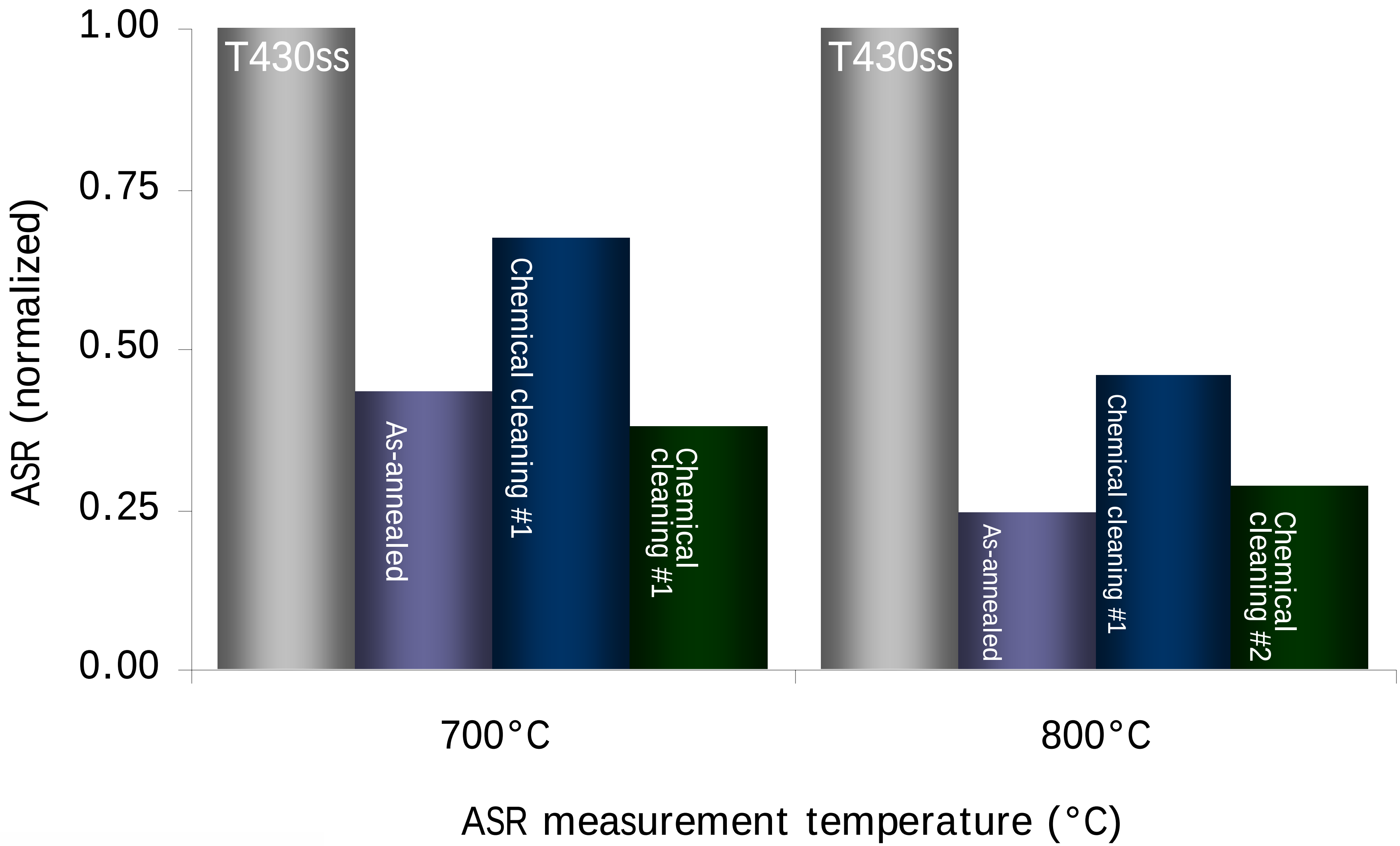
Effect on ASR – Prior Work



samples pre-oxidized in air for 500 hours at 800°C

Silicon Removal

- Production of larger test panels
  - Third party testing and analysis
  - Internal evaluation
- Characterization of treated surface
- Oxidation testing
- Long-term electrical evaluation

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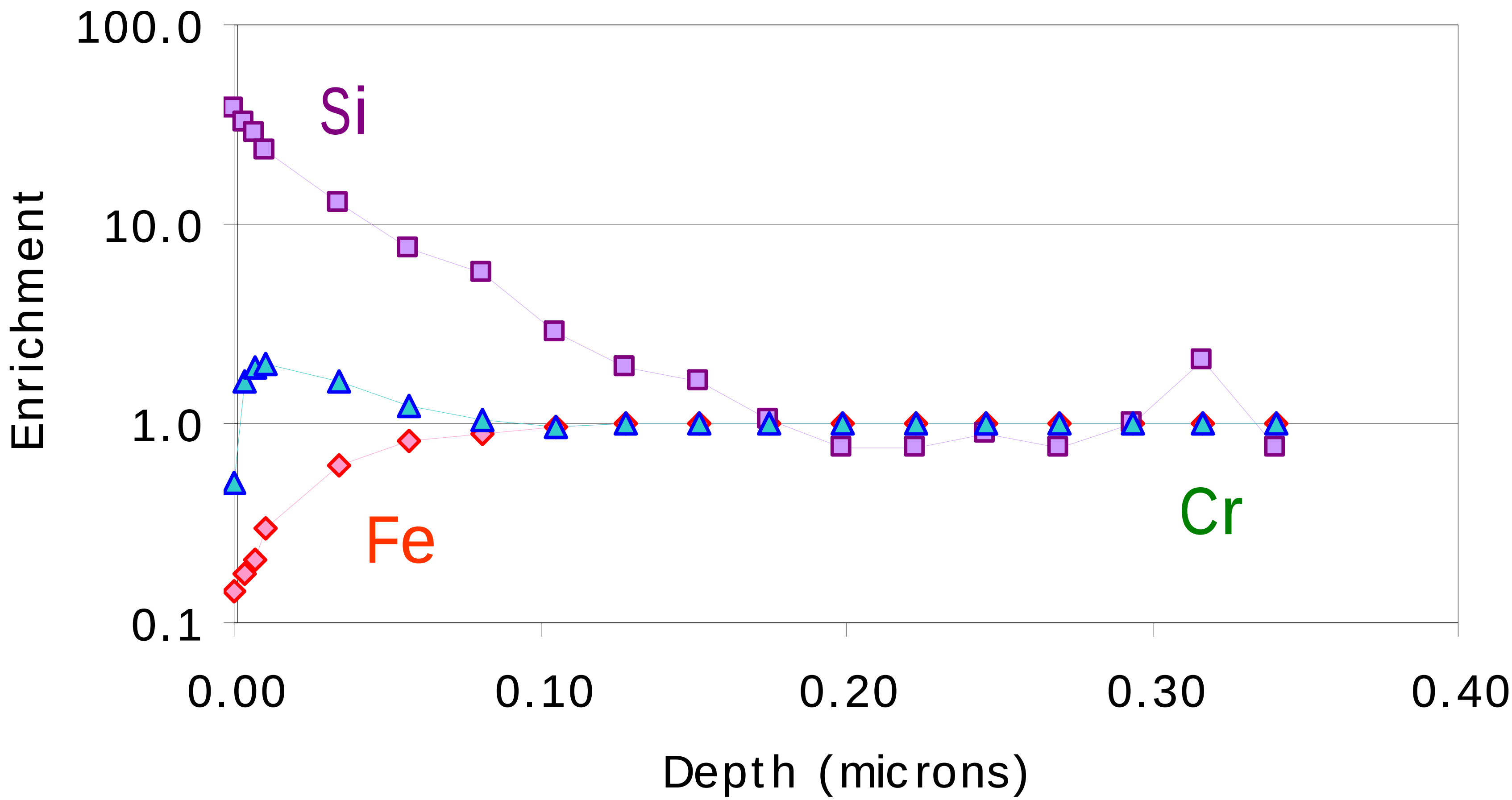
Post-Treatment Characterization



T430 post-treatment samples
AES analysis with sputter depth-profiling

Effect of Substrate Thickness

- Thermally activated process
- More effective for thinner samples
  - Absolute quantity of Si removed is a function of temperature, surface area
  - Amount of silicon available for removal (reservoir) is a function of substrate thickness
- Evaluation
  - Rolling trial (0.08-0.15 mm thick T430 samples)
  - Calculations

Effect of Substrate Thickness

starting with an "infinite sheet"

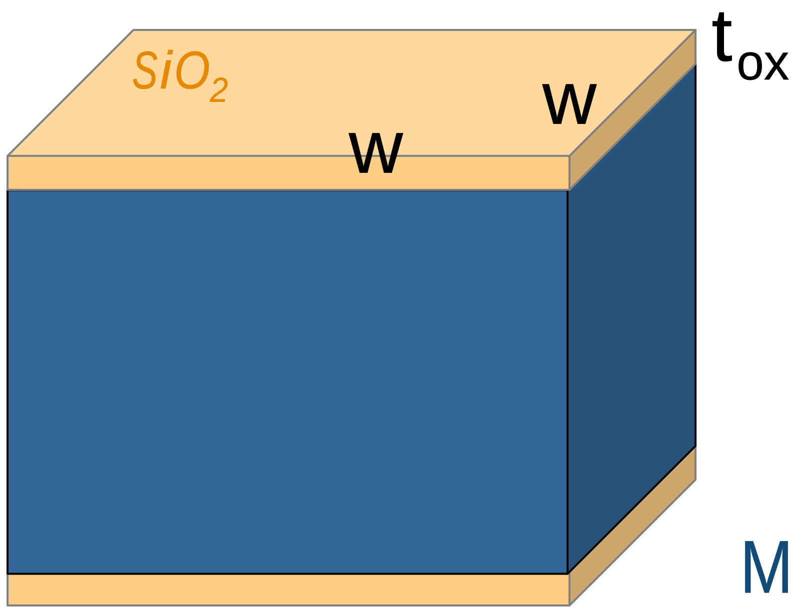
Establish volume element

Set surface area = 1

$2w^2 = 1$

$V_M = w^2 x_M = 0.5x = M_M / \rho_M$

Effect of Substrate Thickness



Allow the sample to oxidize on both sides

$V_{ox} = 2w^2 t_{ox} = M_{ox} / \rho_{ox}$

M_{ox} allows for the determination of Si consumption / residual M_{Si} in the volume element after the formation of an oxide layer of thickness t_{ox}

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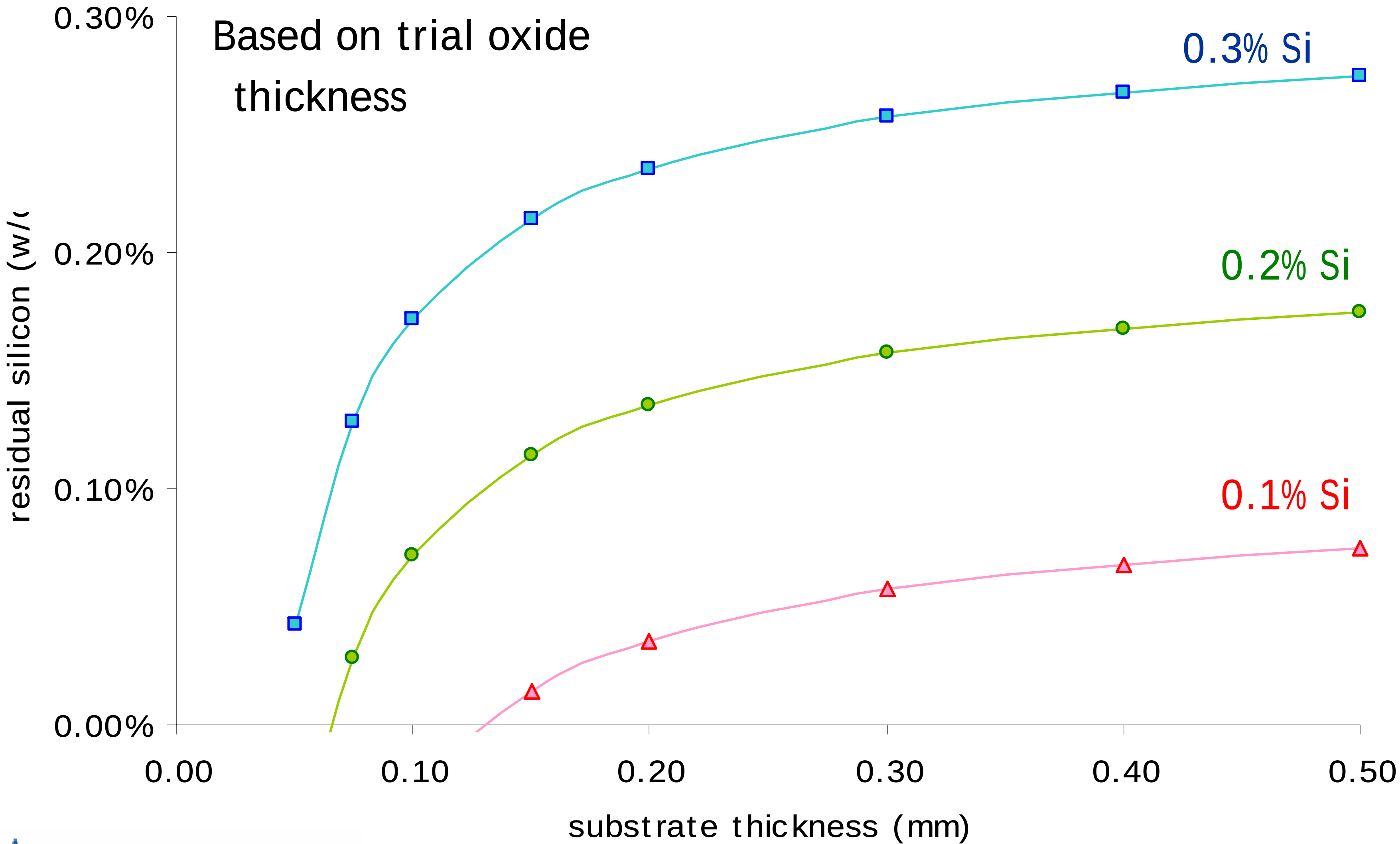
Effect of Substrate Thickness



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Oxidation Testing

- Oxidation testing carried out in a variety of environments
  - Ambient air
  - Air + 10% water vapor
  - 4%H_2 + 10% water vapor in argon carrier
- Testing using duplicate specimens at 800°C
  - T430, T430 De-Si
  - T439, T439 De-Si
  - T441HP™ alloy, T441HP De-Si
  - E-BRITE® alloy

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Alloy Compositions

Element	T430 S43000	T439 alloy S43035	T441HP™ alloy S44100	E-BRITE® alloy S44627
C	0.015	0.015	0.015	0.001
Mn	0.4	0.4	0.3	0.05
Si	0.4	0.7	0.5	0.2
Cr	16.5	17.5	17.5	26.0
Al	0.05	0.05	0.05	0.05
Mo	-	-	-	1.0
Cb	-	-	0.46	0.15
Ti	-	0.4	0.2	-
N	0.015	0.015	0.015	0.005

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Oxidation Testing

- Type 430 exhibited good oxidation resistance in ambient air but one sample (desiliconized) exhibited breakaway oxidation in humidified air.
- Type 439 exhibited a consistent tendency for spallation in the as-received condition. Spallation did not occur in desiliconized Type 439.
- T441HP™ alloy exhibited the best general resistance to oxidation.

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Oxidation Testing

- E-BRITE® alloy exhibited a tendency towards weight loss in humidified air, which is consistent with past work (this alloy was not tested in ambient air).
- The exposure to simulated anode gas ($Ar-H_2-H_2O$) was the least aggressive of all of the test exposures. De-siliconization was uniformly beneficial in the SAG composition tested.

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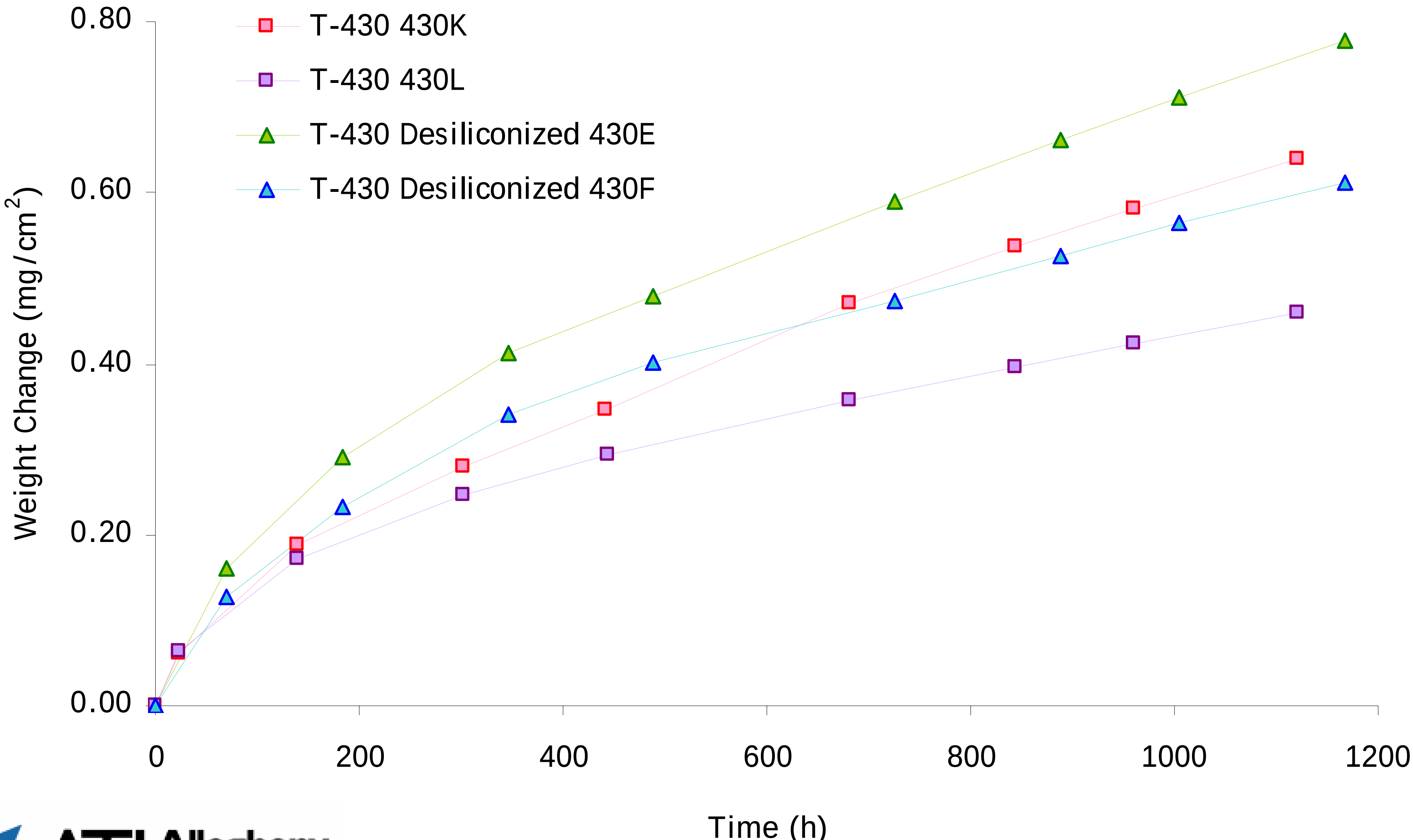
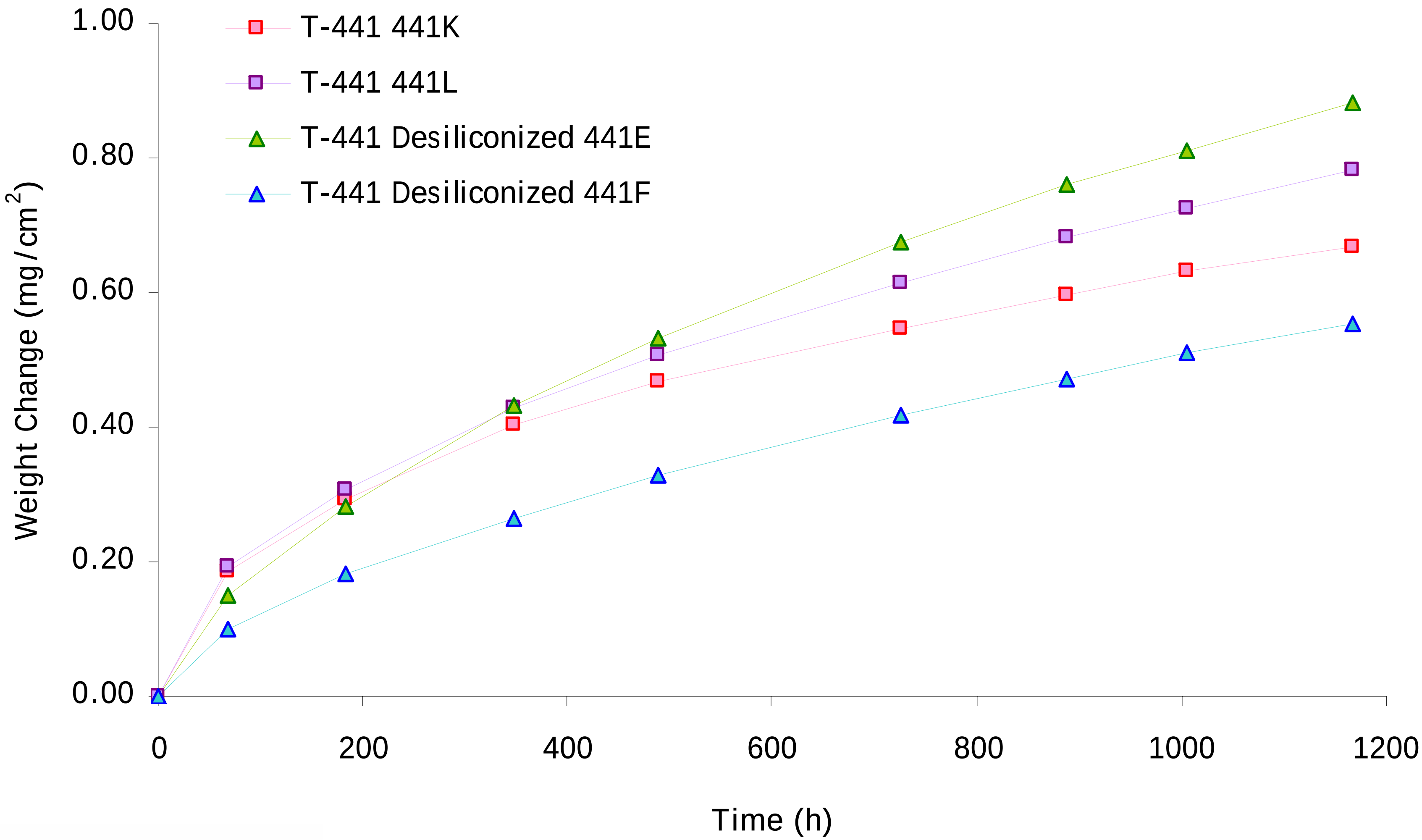
Oxidation Test Results



Ambient air, 800°C

Oxidation Test Results



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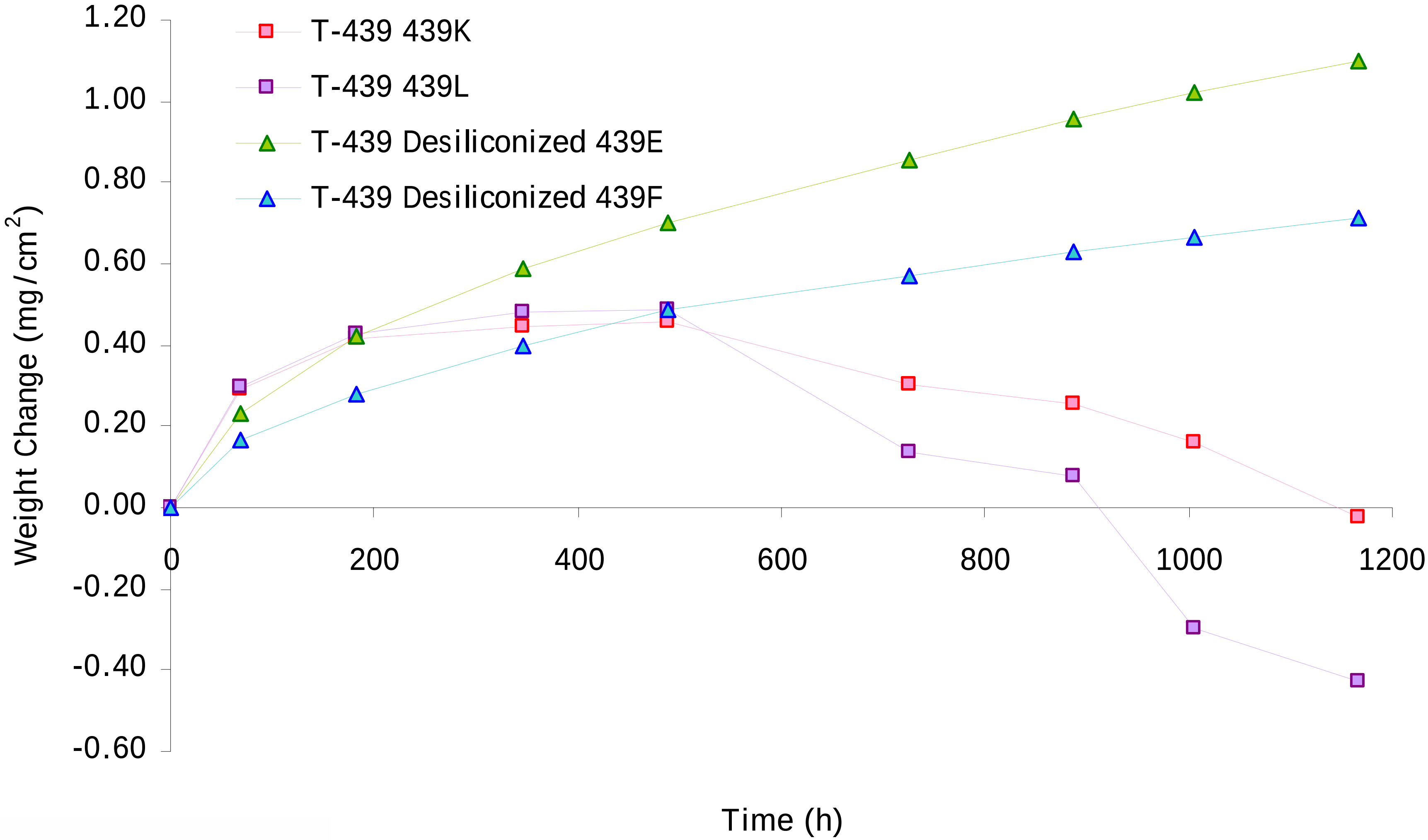
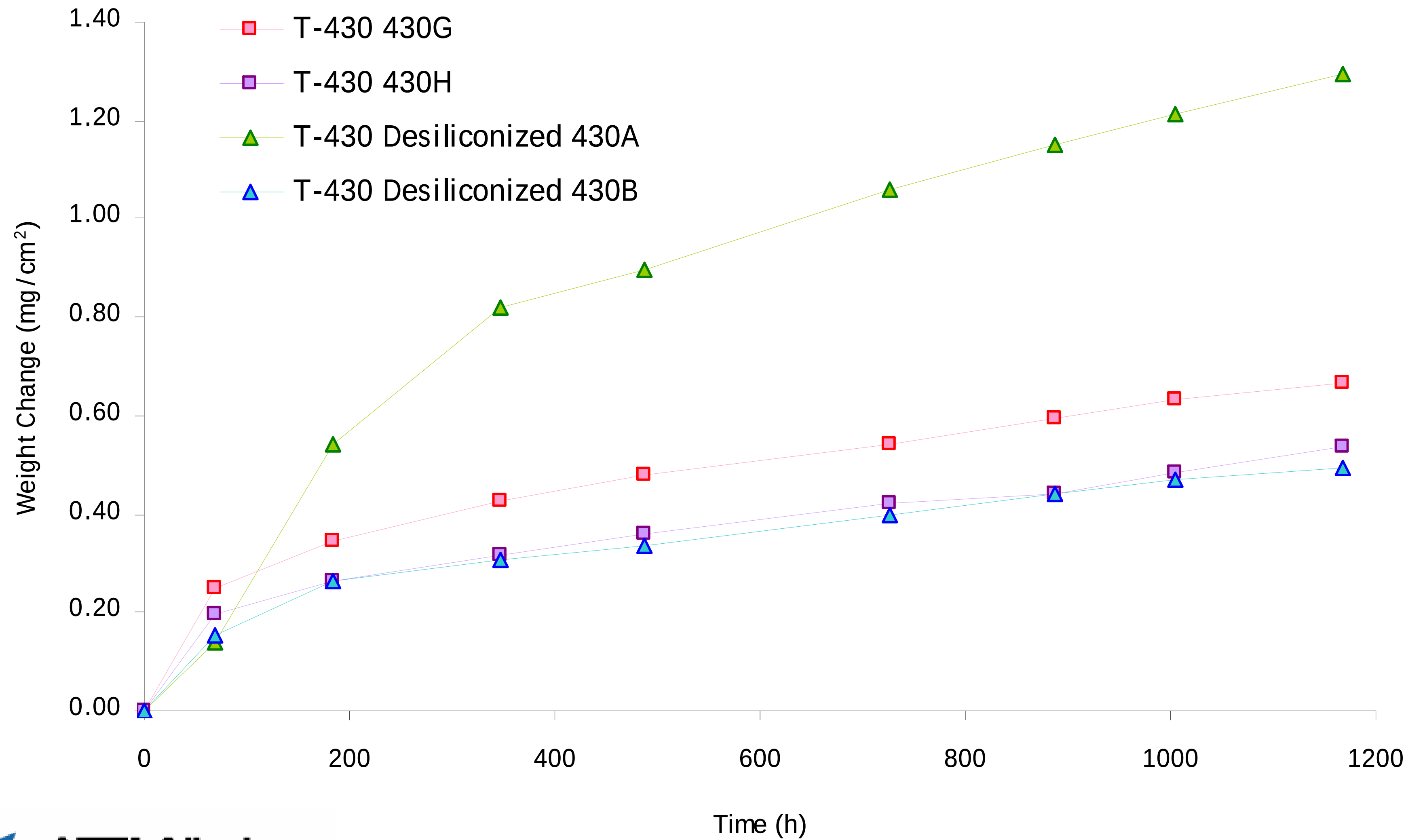
Ambient air, 800°C

Oxidation Test Results



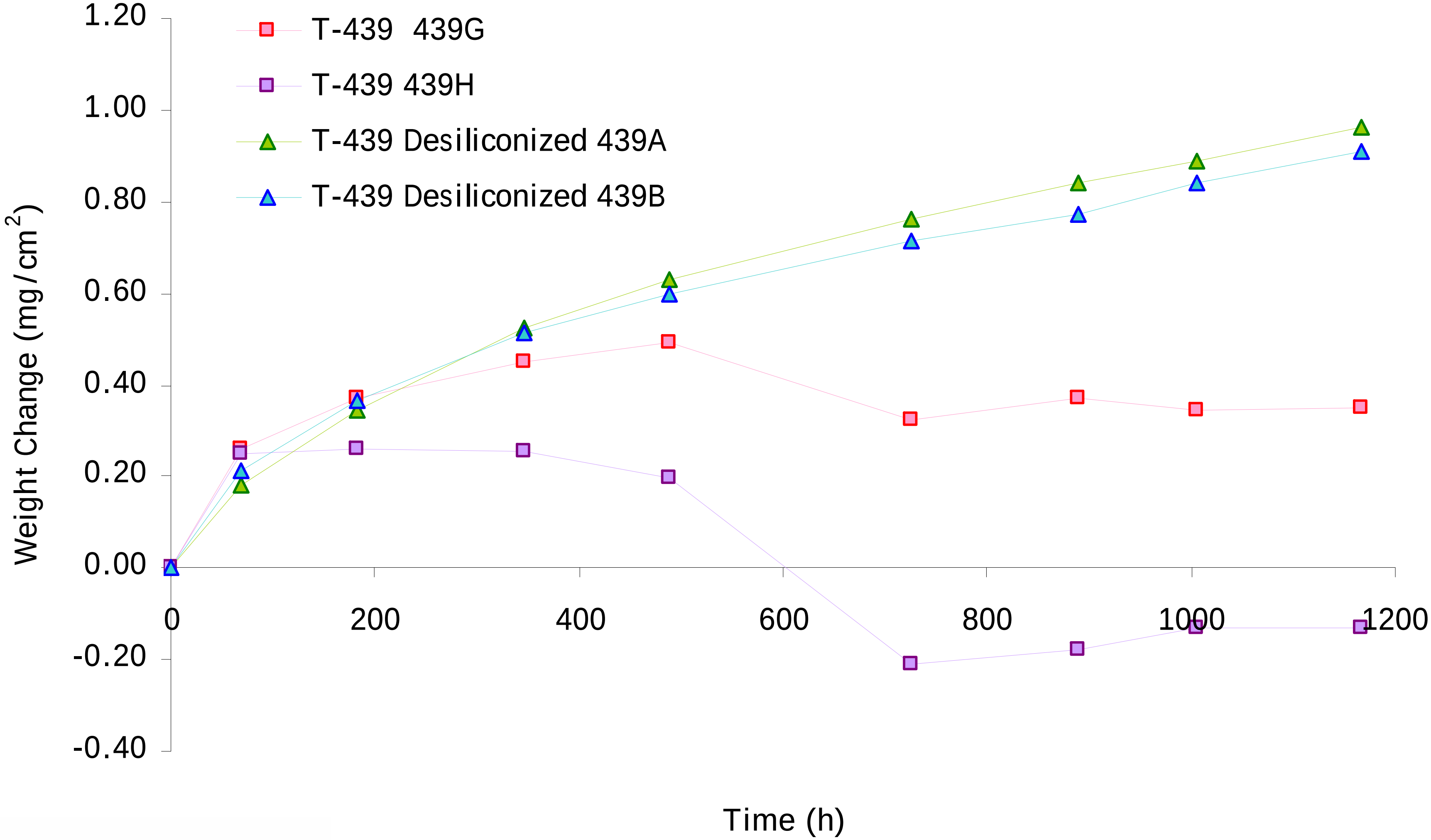
Ambient air, 800°C

Oxidation Test Results



Air + 10% water vapor, 800°C

Oxidation Test Results



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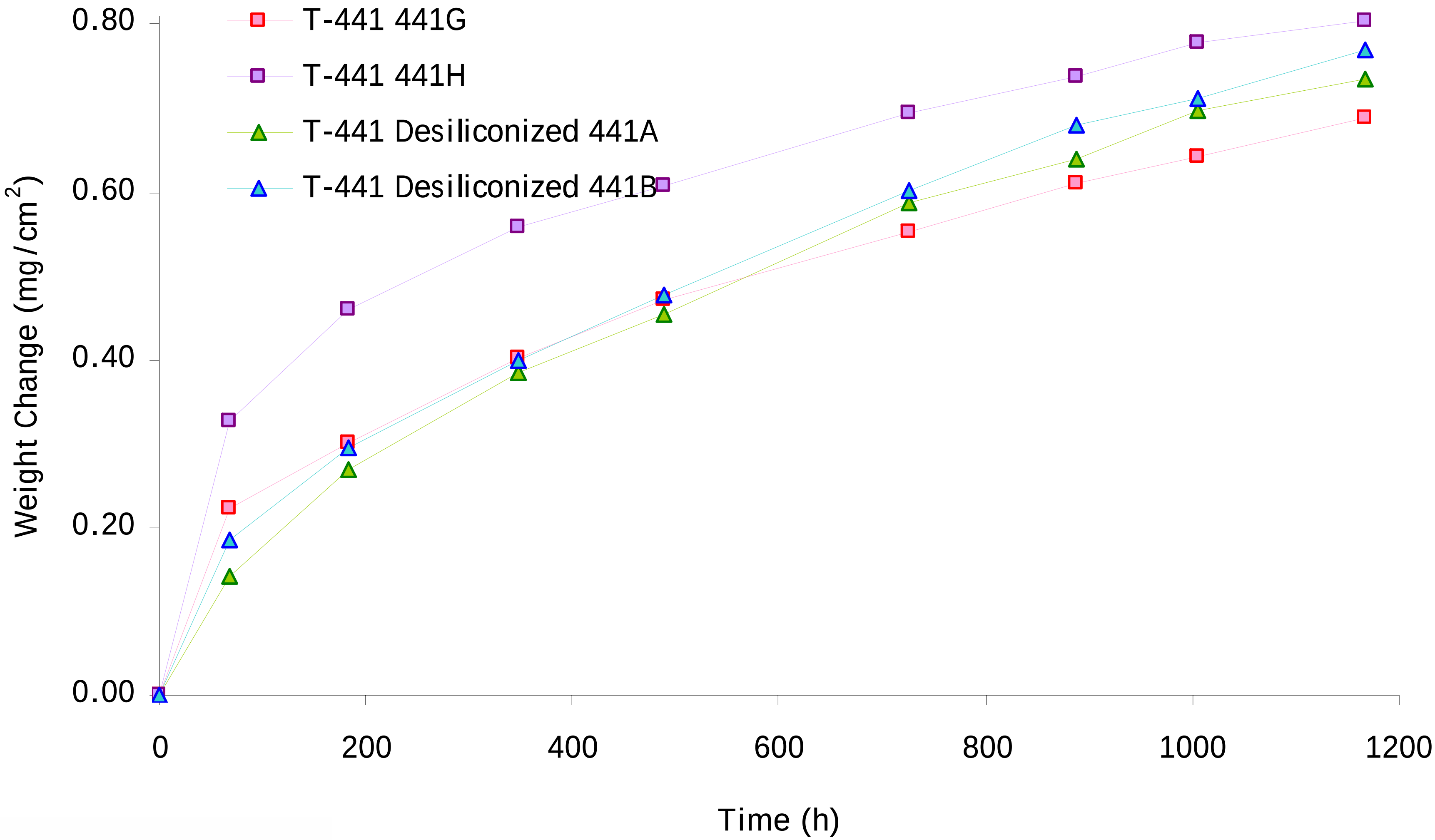
Oxidation Test Results



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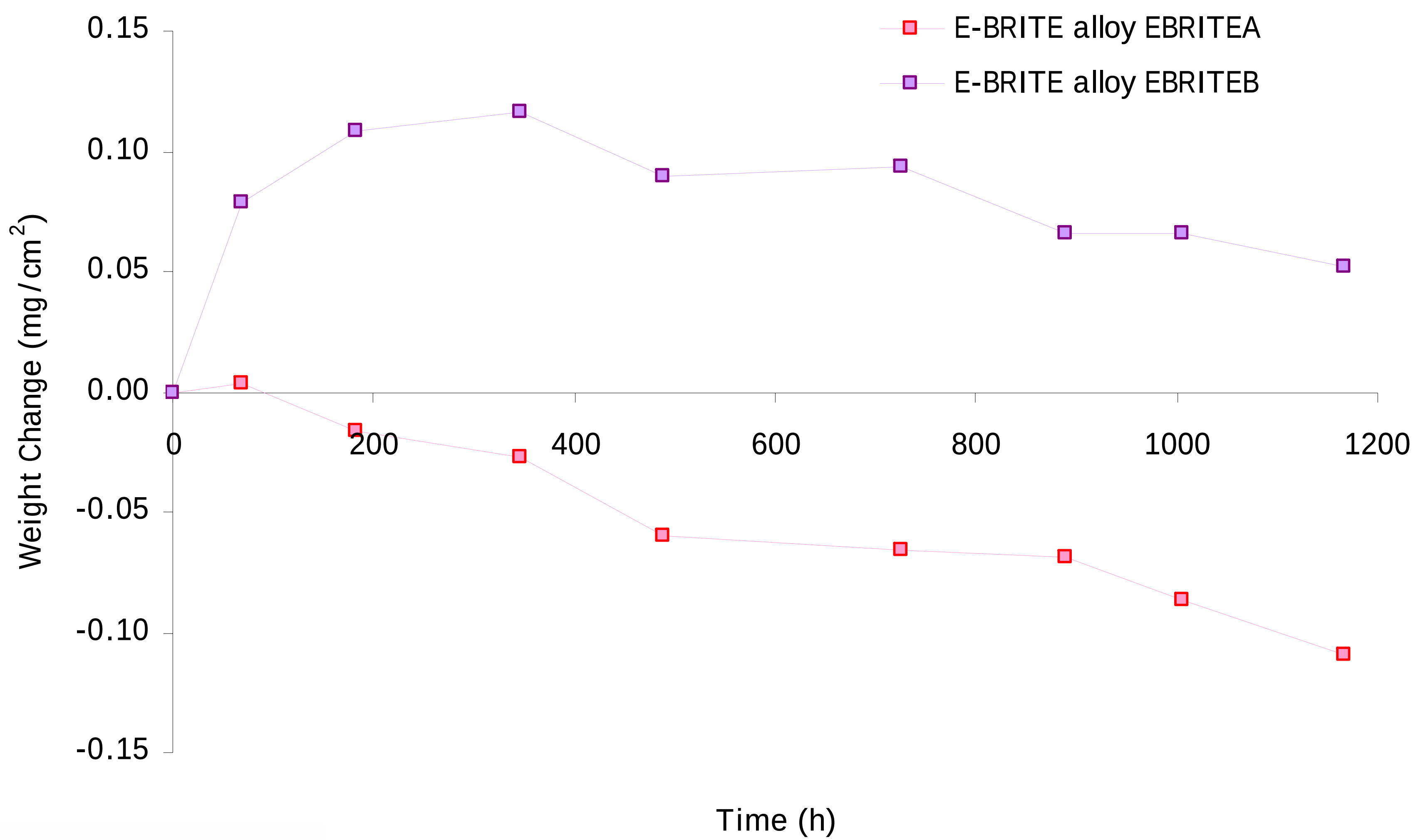
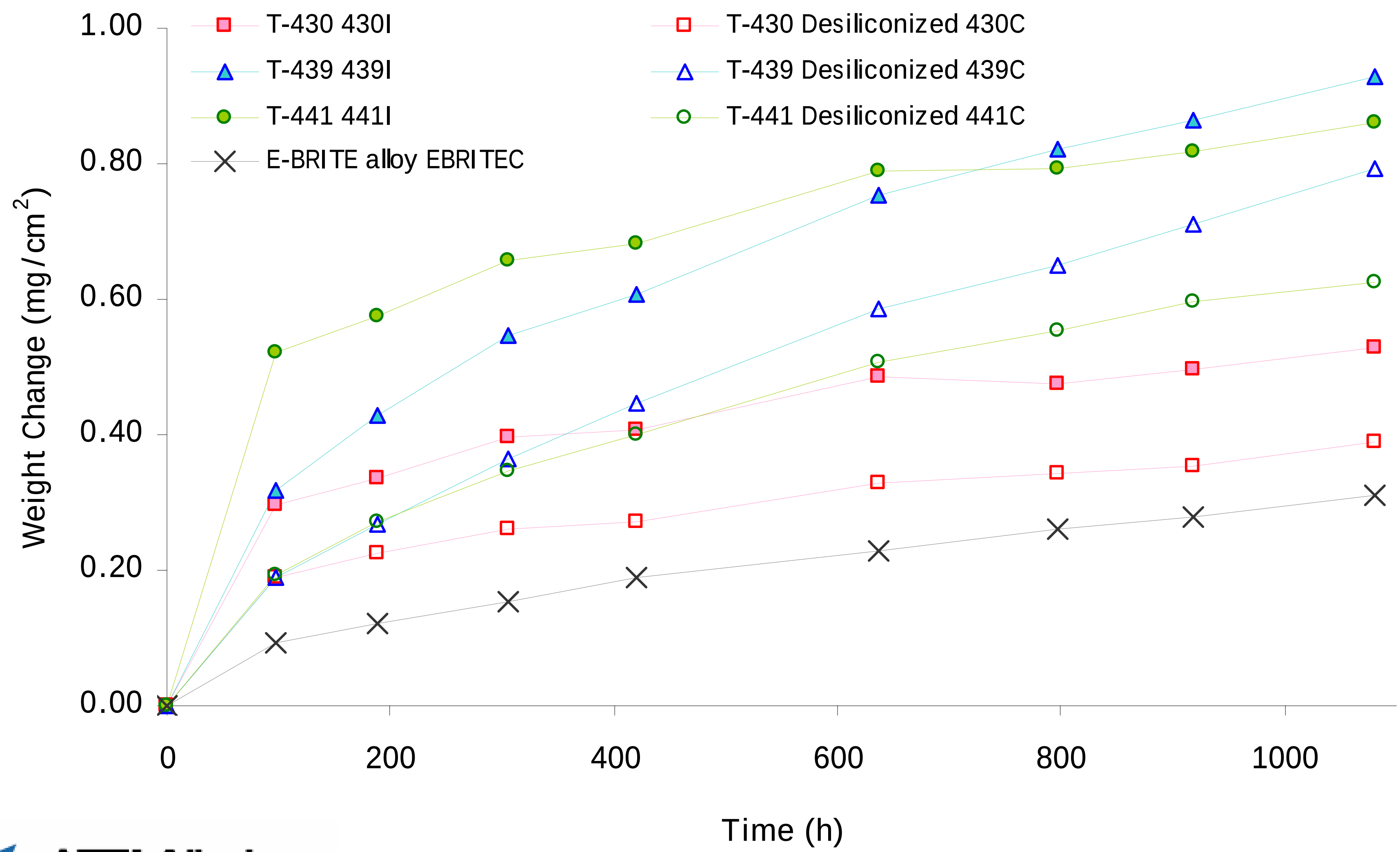
Air + 10% water vapor, 800°C

Oxidation Test Results



Air + 10% water vapor, 800°C

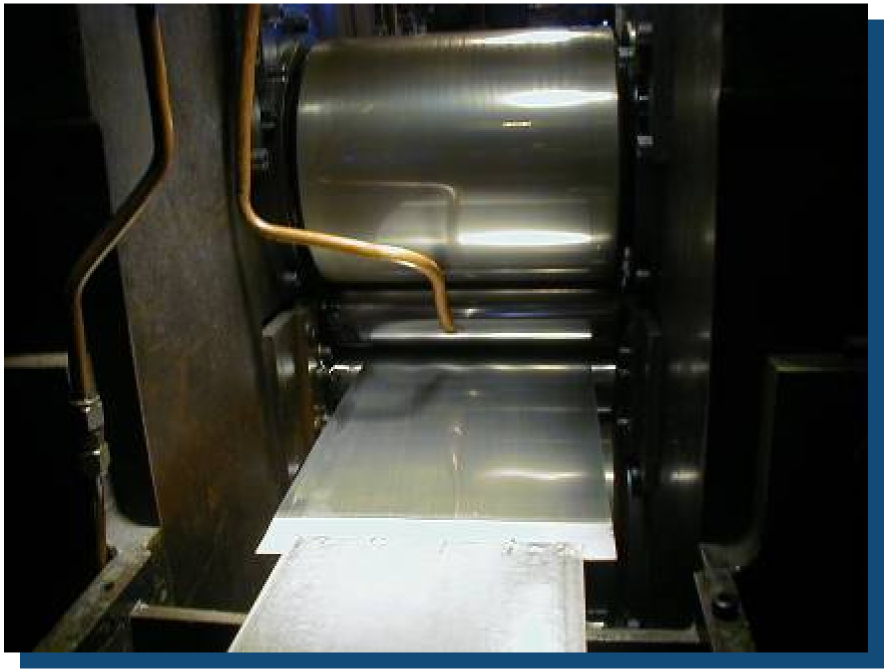
Oxidation Test Results



SAG, 800°C

Novel Ferritic Stainless Steels

- Currently processing a set of lab-melted VIM heats
- Optimized compositions
  - High- and low-chromium variants
  - Minor element control
  - Advanced processing



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Summary – Alloy Characterization

- Oxidation screening testing is complete
- Long-term oxidation testing ongoing
- ASR evaluation of a matrix of alloys has been initiated

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Summary – Current Development

- Compositional matrix melted and processed to sheet
- Silicon removal trials ongoing

Acknowledgements

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