INL/MIS-24-79170-Revision-0

Oxidation Resistant Graphite

July 2024

Changing the World's Energy Future

Timothy David Bragg, Michael Charles Barkdull

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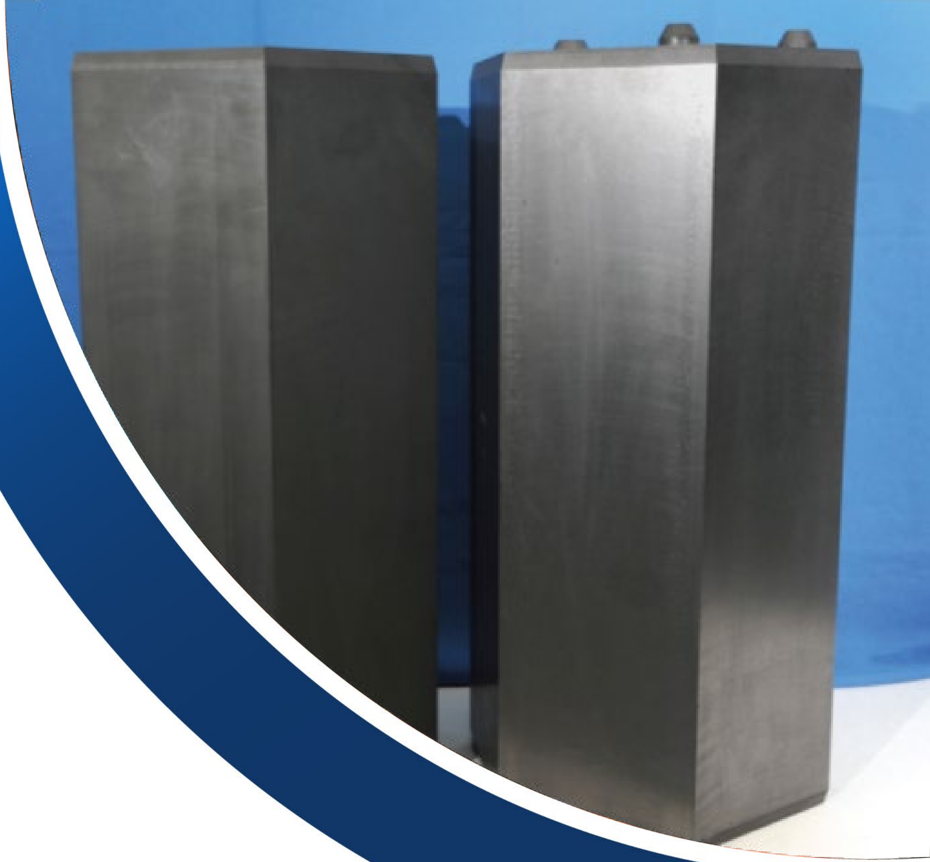
GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



Wednesday, July 17, 2024

Oxidation Resistant Graphite

Tim Bragg and Michael Barkdull

INL

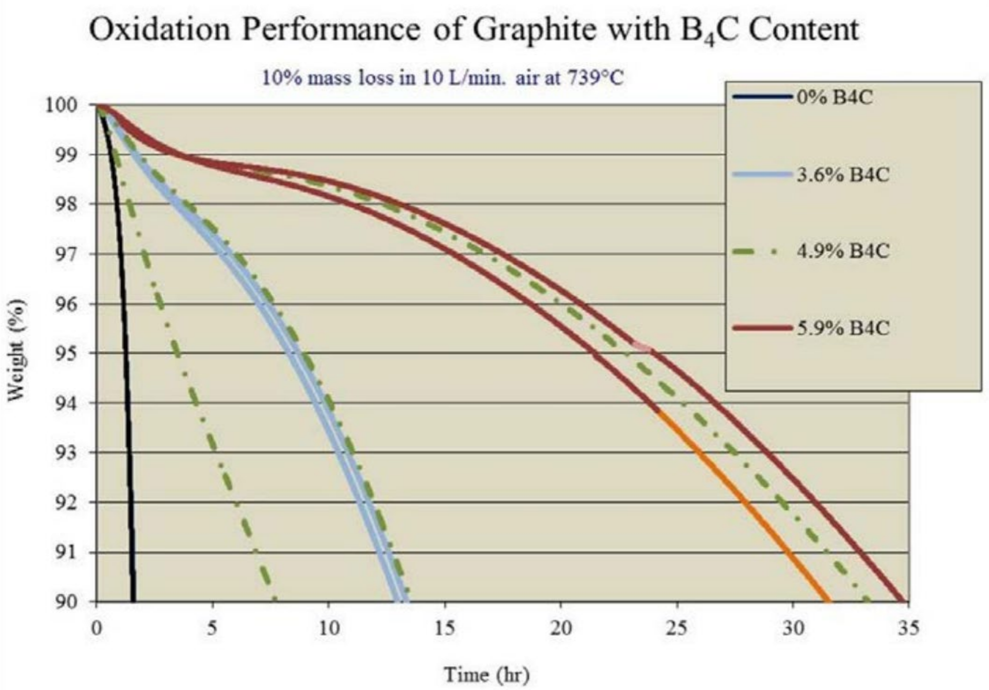
DOE ART GCR Review Meeting

Hybrid Meeting at INL

July 16–18, 2024

Introduction

- Current Research:
  - Coat graphite with boron based materials to resist oxidation
  - Understand the coating mechanics
- Prior research:
  - Abnormally low rates of oxidation observed
  - Cause determined to be boron based doping
  - Prompted current research in oxidation resistance



Why we are doing this

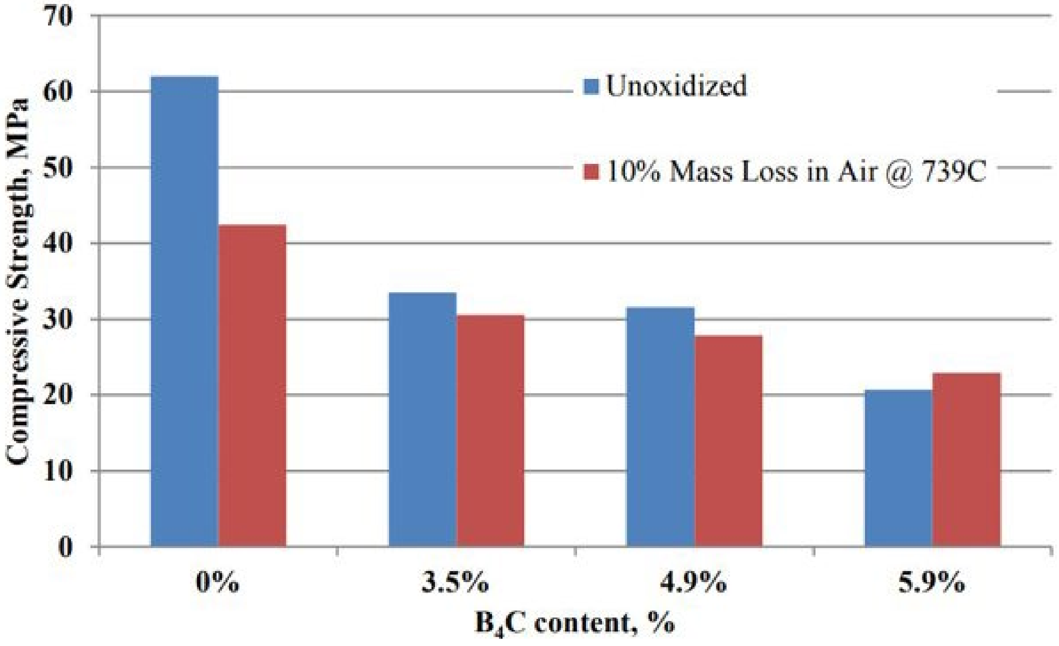
- Possibility of Air-Ingress Accident Scenarios puts reactors components at risk of oxidation
  - Oxidation reduces mechanical strength of graphite, compromising reactor core components
  - At high temperatures, graphite can quickly be compromised
  - Work in oxidation seeks to understand and mitigate risks of oxidation in reactors

Original work

- 2010's study on oxidation resistance
  - Graphite dopped with boron carbide
  - Graphite dopped in manufacturing
- Boron Carbide reduced mechanical strength loss after oxidation
- As fabricated strength decreased nearly 50% when dopped over 3.6%
- Strength decrease after oxidation was only 11% compared to 30% when not dopped

The benefits of doing this work

- Oxidation decreases mechanical properties of graphite
- In the case of an air-ingress accident high oxidation can cause the core of the reactor to become structurally unstable



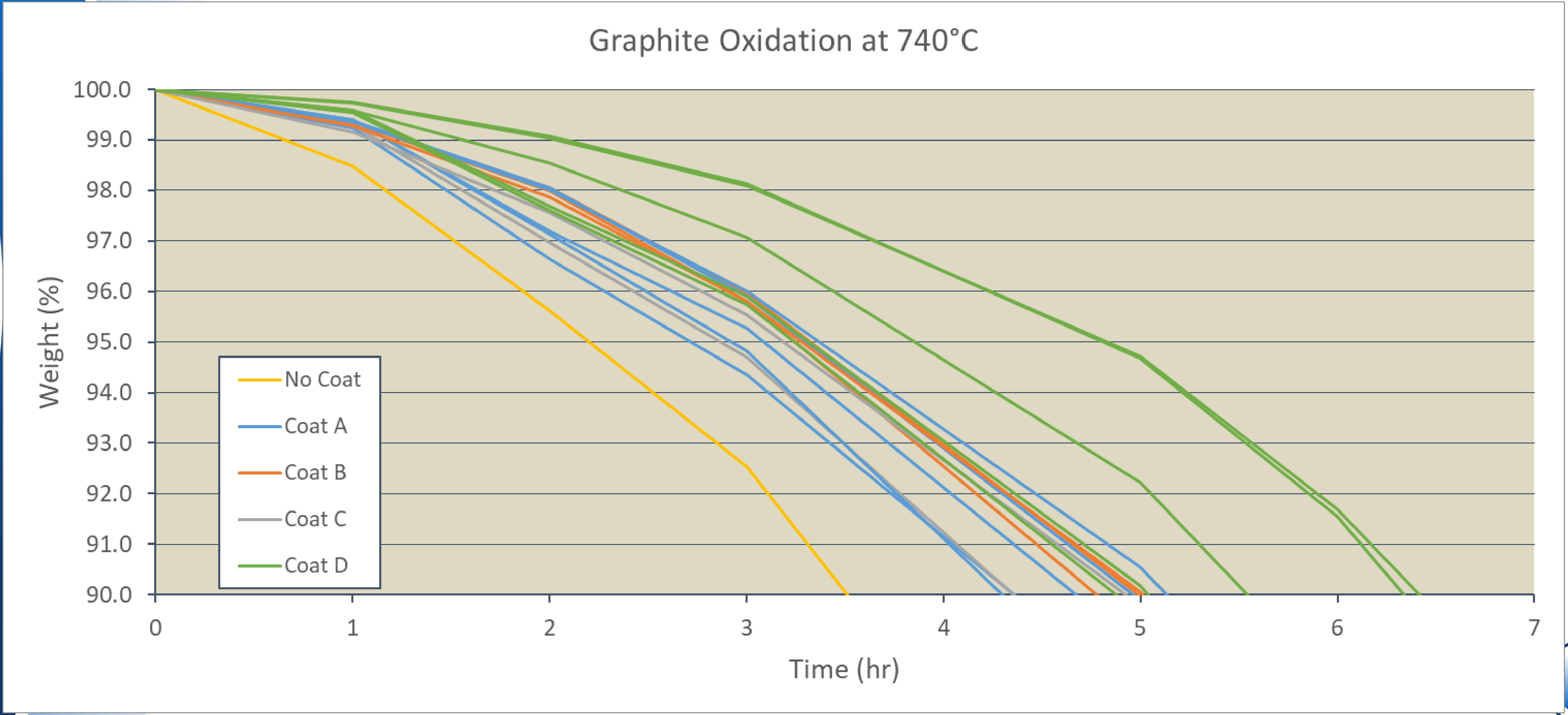
Things decided last summer

- Use simple, post graphitization introduction of boron using a boron based coating
- Factors considered:
  - Source of Boron
  - Concentration
  - Heat treatment time
  - Mechanism of application
  - Sequential applications
  - Heat treatment temperature

The work last summer

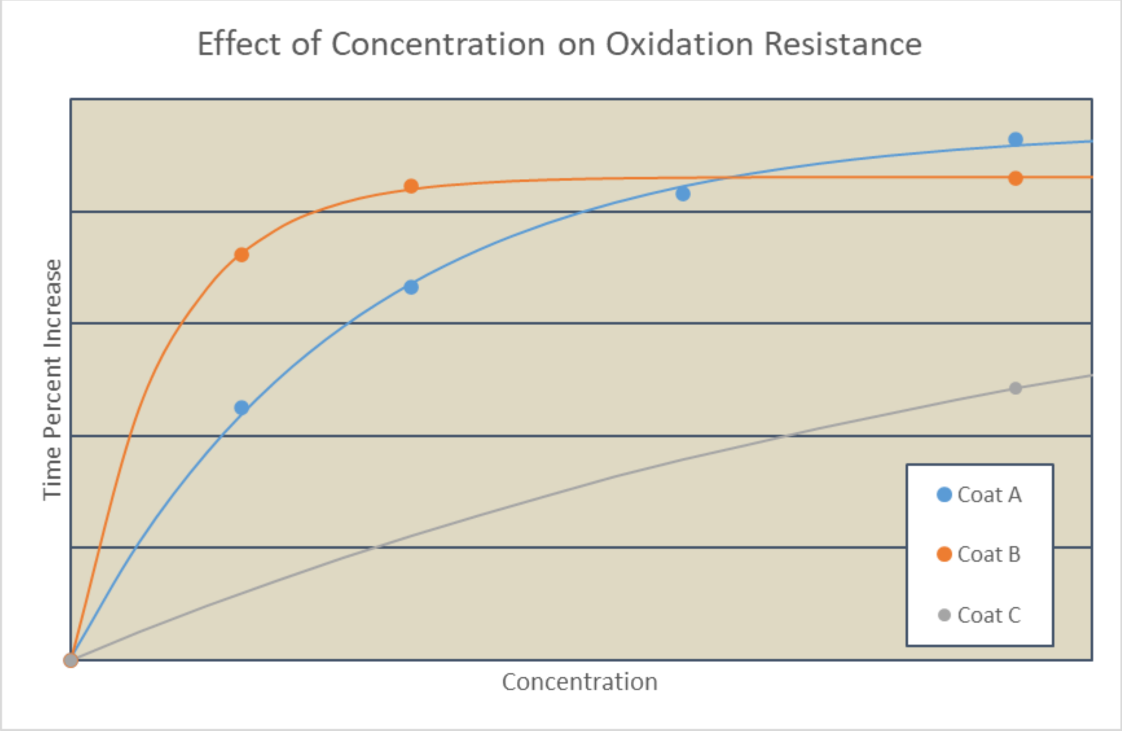
- What works and what stands out
- Wide Sweep
  - Various settings for the factors
  - Oxidized at 740 °C
- Initial imaging via SEM-EDS:
  - Attempt to determine boron content and location
    - Layered coating vs graphite structure
    - No clear indication of boron seen

The results: Oxidation times



The results: Patterns

- Time increase has an apparent exponential trend with concentration



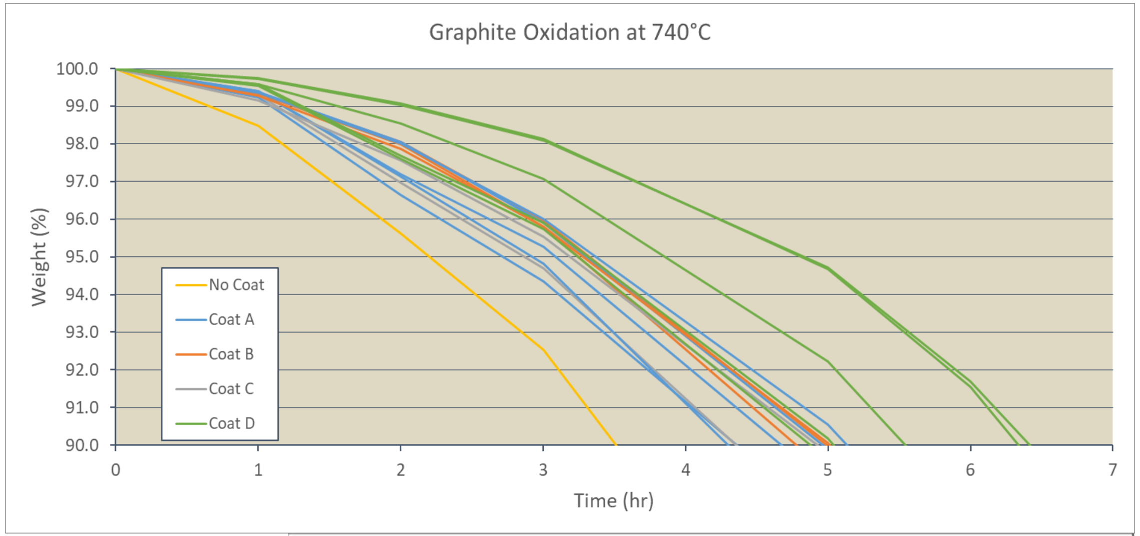
- Difference in the oxidation distribution

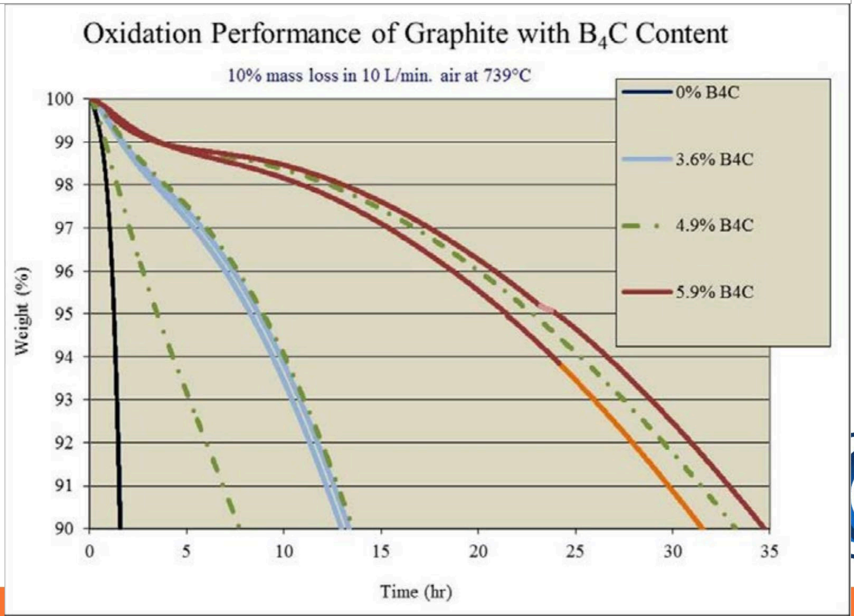
Uncoated

Coated

What we learned from the results

- All coating methods worked
- Option D seems to be the best option
- Has the ability to be scaled
- The results were in line with previous beliefs





What we are doing this summer

- We have set up a controlled application process
- Collecting data to feed into a computational model
- Investigating various with coating D compositions

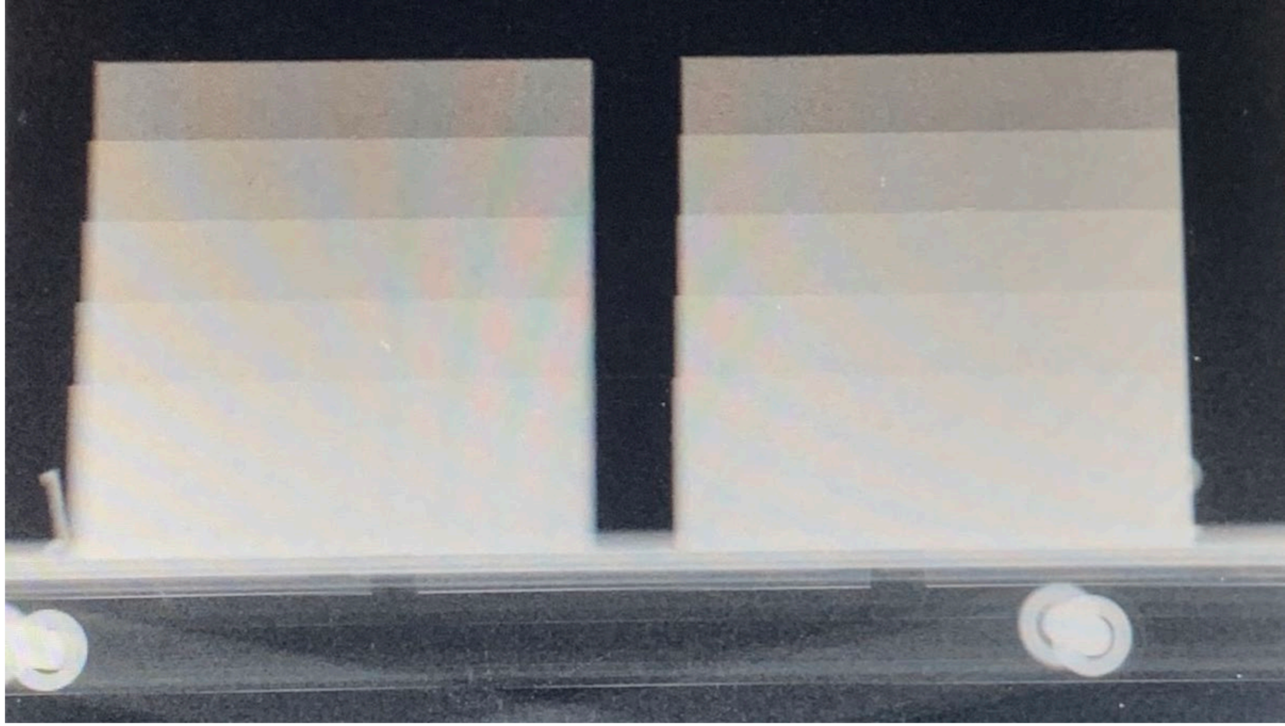
The next steps

- Oxidation rate reduction achieved, need to determine why and how it works and need to determine what are the consequences:
  - Coating Characterization
  - Mechanism Determination
  - Strength Testing
- With this information the coating process can then be optimized and scaled up

Imaging

- We are working with OSU to gather neutron imaging

- Imaging will provide
  - Initial boron content
  - Boron burn off
  - Boron penetration
  - Final boron content



Modeling

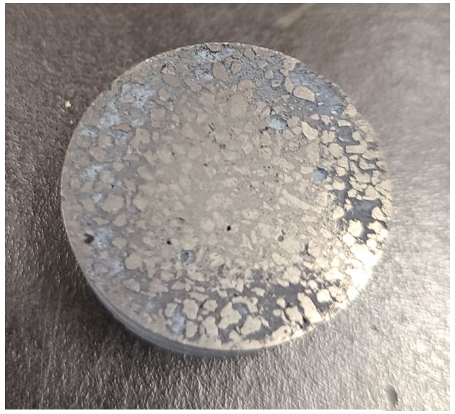
- Working to set up parametric study
  - Boron concentration & Thickness
  - Heat treat & oxidation temp
  - Heat treatment & oxidation time
  - Diffusion & concentration

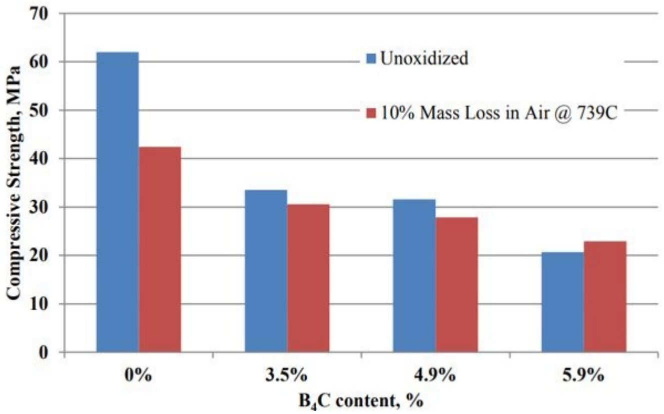
GRADE

	$\times 10^{-3}$	2114	IG-110	IG-430	NBG-17	NBG-18	PCEA
$\frac{D_{eff\ N2}}{D_{N_2 Ar}}$	**μ**	9.30	4.62	3.26	1.70	1.10	0.87
	σ	0.60	1.24	0.23	0.17	0.28	0.28
	Min	8.45	2.68	2.84	1.47	0.85	0.51
	Max	10.27	5.62	3.72	2.02	1.77	1.21
$\frac{D_{eff\ Ar}}{D_{Ar N_2}}$	**μ**	10.25	5.18	3.72	2.29	1.13	1.37
	σ	0.57	1.14	0.23	0.12	0.13	0.49
	Min	9.13	3.41	3.24	2.08	0.87	0.60
	Max	11.02	6.15	4.11	2.54	1.30	2.16

Strength work

- Concern in oxidation stems from reduced graphite strength
- Two strength measures/tests will be explored:
  1. Split Disc
  2. Compressive
- Questions to be answered:
  - Is strength compromised due to the coating process?
  - Is there a shift in where the graphite is weak?





Conclusion

- Our efforts to mitigate graphite oxidation through advanced coating technologies
  - Initial research indicates promising results
    - Coating shows similar results to doped in fabrication
  - Goals:
    - Optimize these coatings by leveraging mathematical models
    - Conducting mechanical testing
    - Employing imaging techniques

Thank you

Questions?

Thanks to Contributors:

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