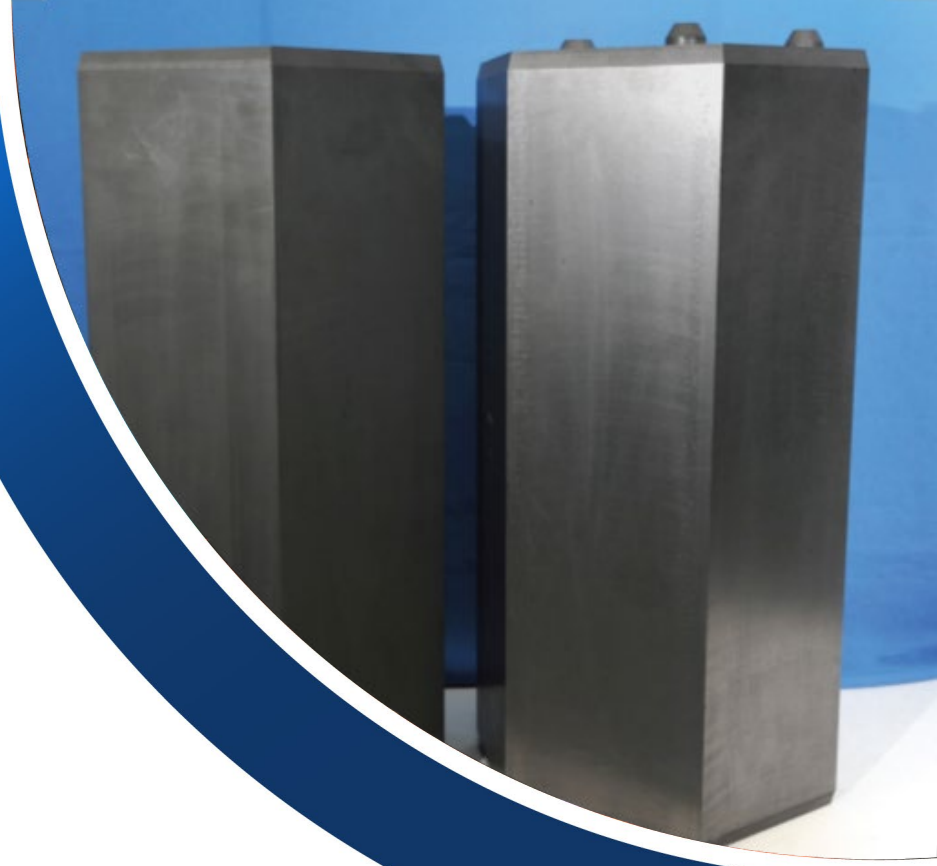
GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



Wednesday, July 17, 2024

Oxidation Resistant Graphite

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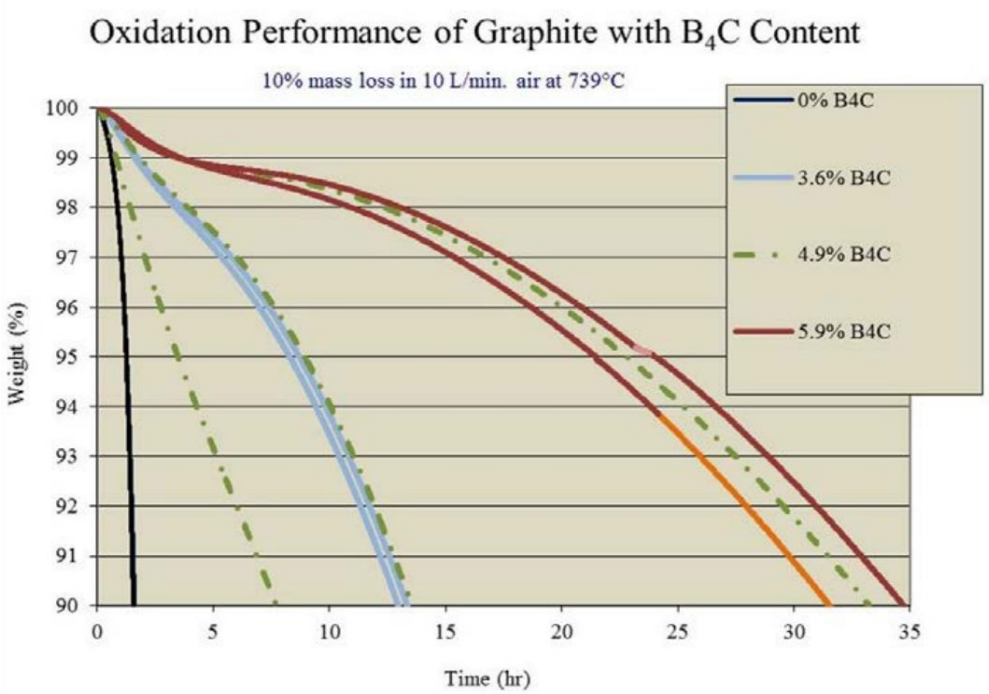
INL

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

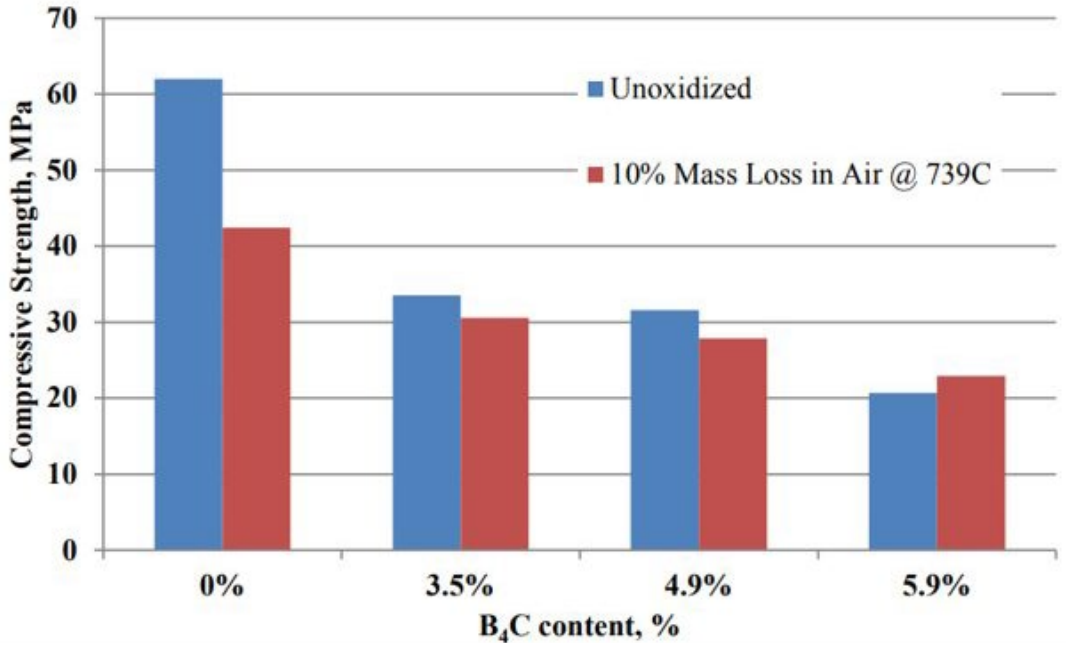
Original work

- 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



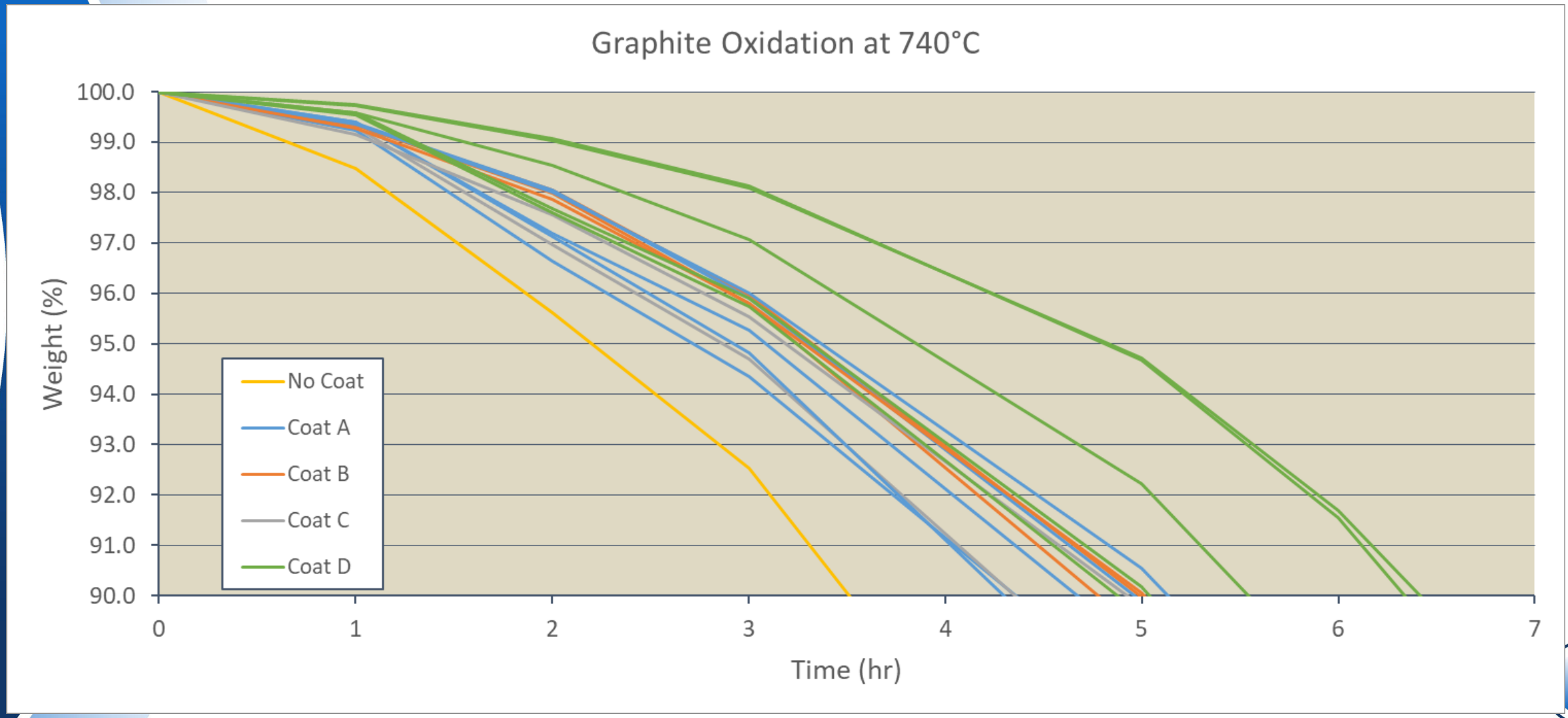
Things decided last summer

- 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

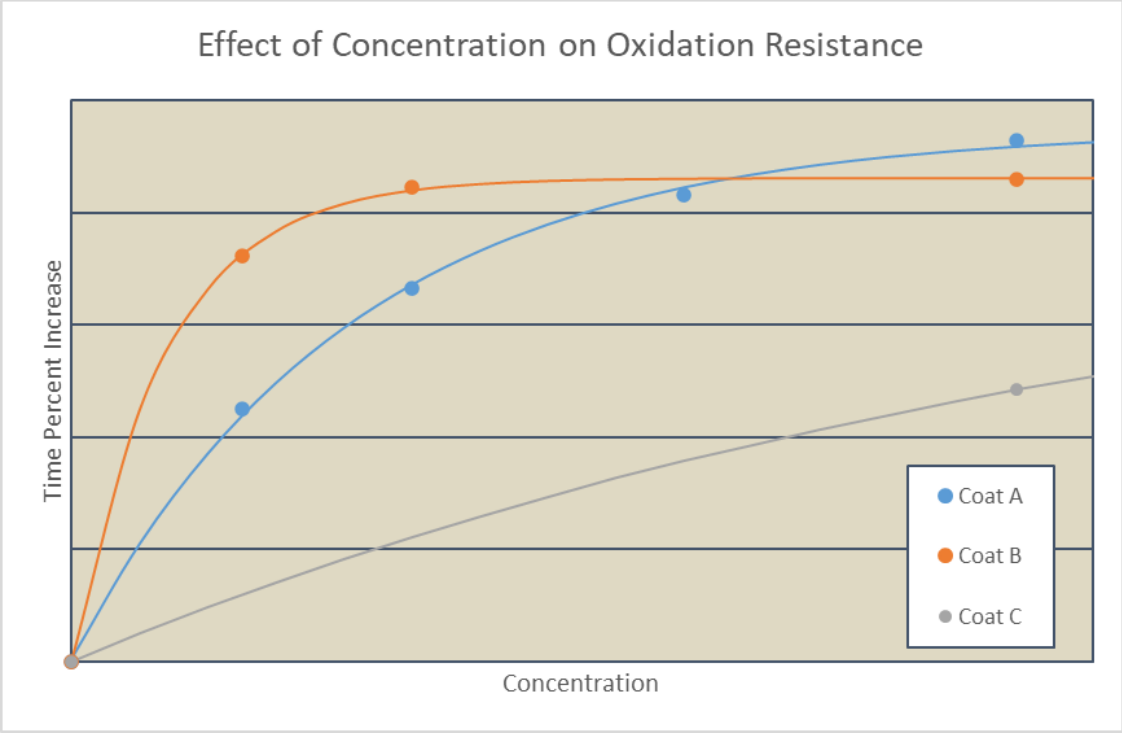
- What works and what stands out
- Wide Sweep
  - Various settings for the factors
  - Oxidized at 740 °C
- Initial imaging via SEM-EDS:
  - Attempt to determine boron content and location
    - Layered coating vs graphite structure
    - No clear indication of boron seen

The results: Oxidation times



The results: Patterns

- Time increase has an apparent exponential trend with concentration



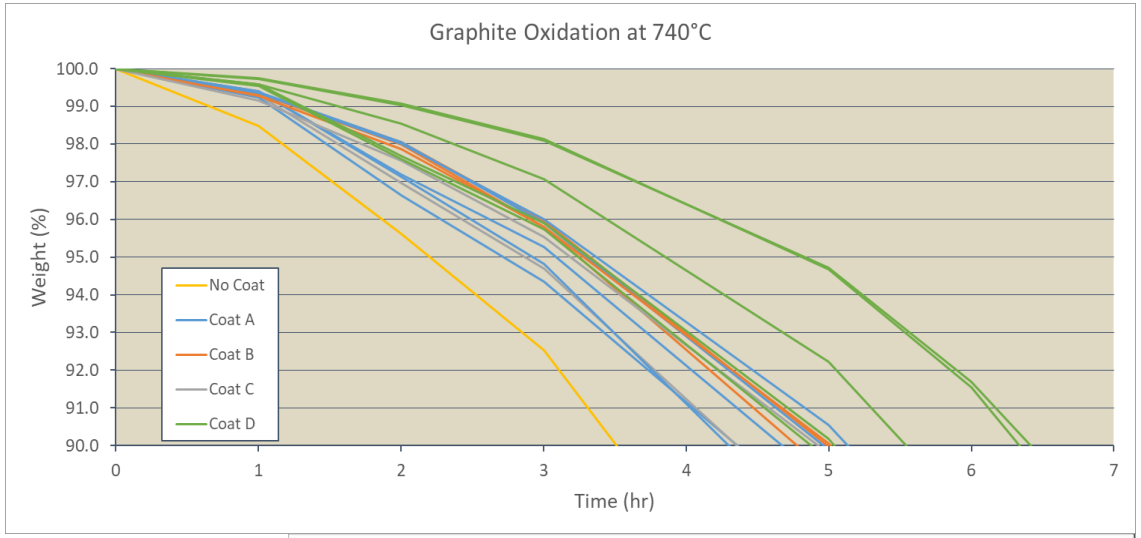
- Difference in the oxidation distribution

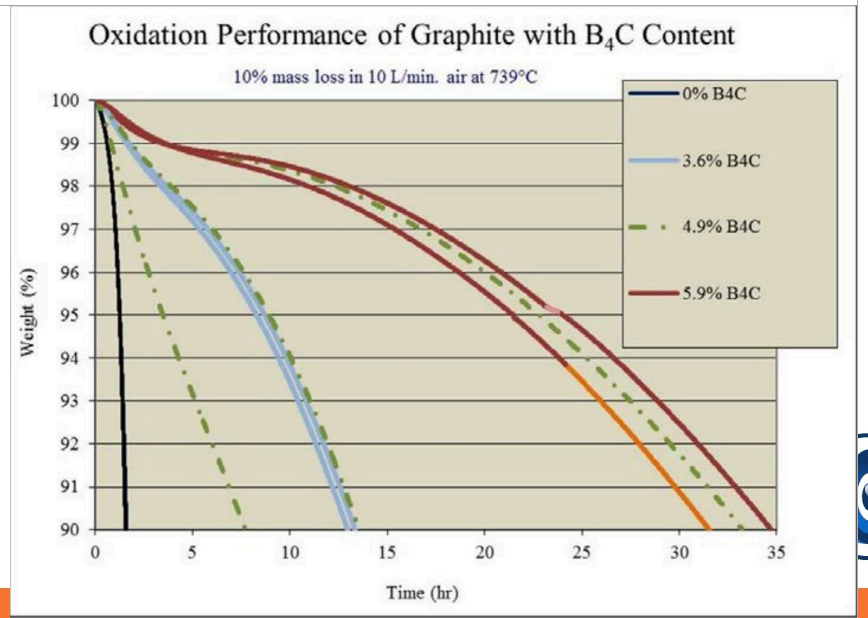
Uncoated

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

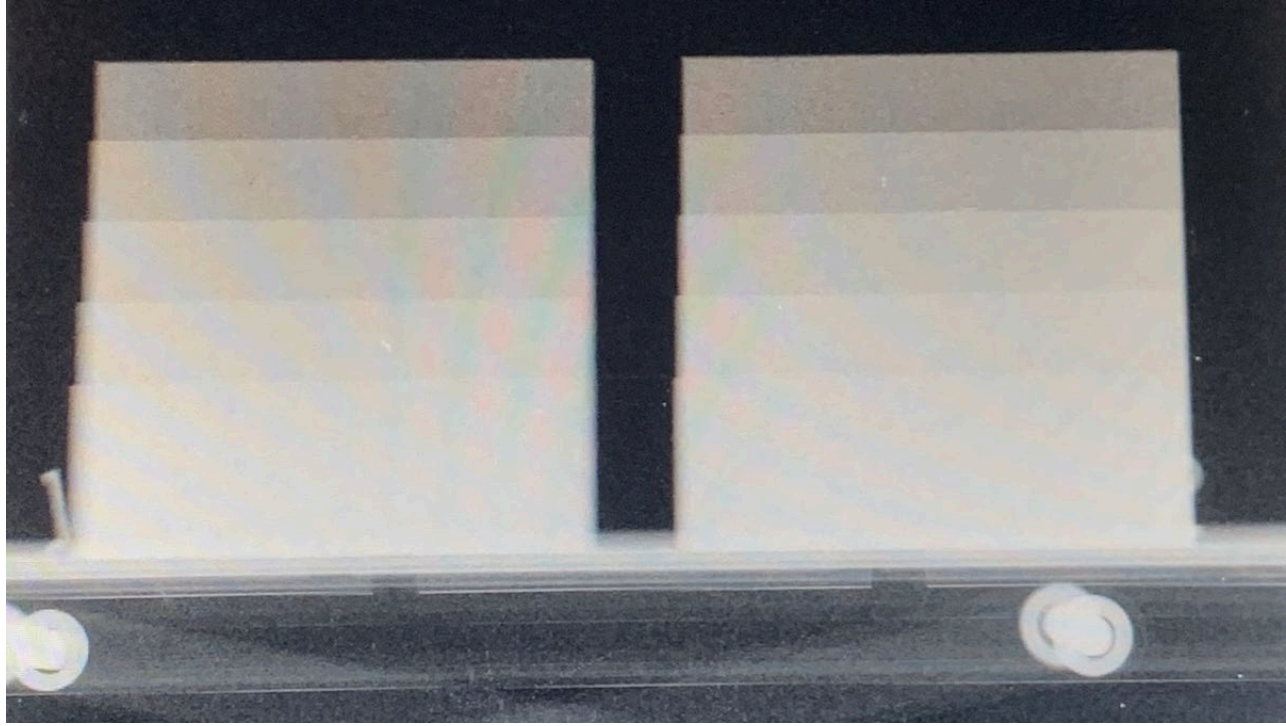
- We have set up a controlled application process
- Collecting data to feed into a computational model
- Investigating various with coating D compositions

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

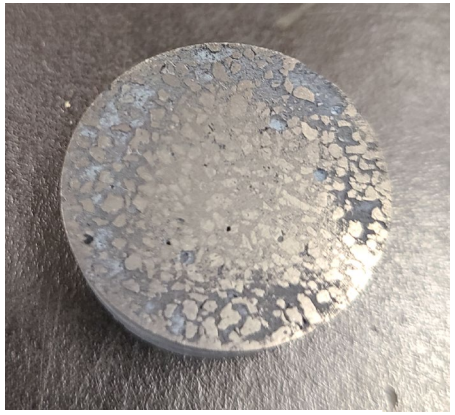
- Working to set up parametric study
  - Boron concentration & Thickness
  - Heat treat & oxidation temp
  - Heat treatment & oxidation time
  - Diffusion & concentration

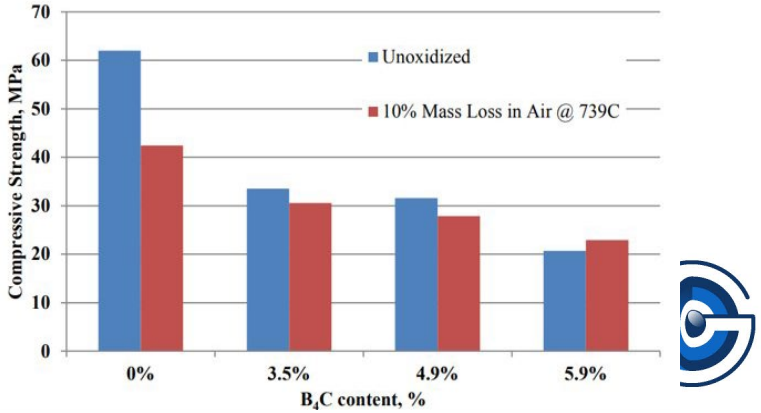
GRADE

$\times 10^{-3}$	2114	IG-110	IG-430	NBG-17	NBG-18	PCEA
$\frac{D_{eff\ N2}}{D_{N_2Ar}}$ **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
$\frac{D_{eff\ Ar}}{D_{ArN_2}}$ **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

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Thank you

Questions?

Thanks to Contributors:

W. Windes, R. Smith, A. Matthews, T. Yoder, A. Cunningham, M. K. Ames, J. Rufner, A. Salvador

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