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Dynamic Modeling and Characterization of Nuclear-grade Graphite

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Changing the World's Energy Future

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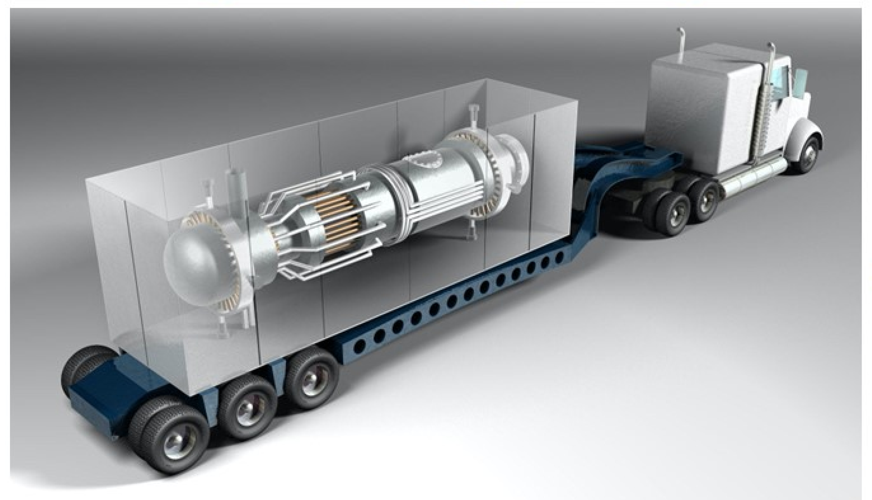
Problem Statement | *Picture this…*

Idaho National Laboratory spearheads the world's efforts to create innovative solutions to the global energy crisis. The **environments** of operation may include…

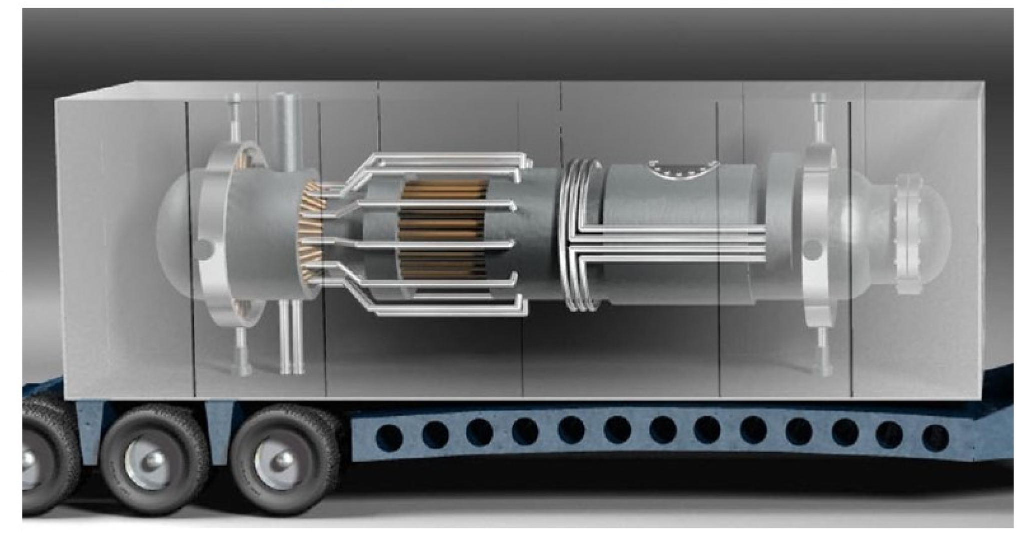
Unlike more common environments, each of these adds to the requirements of a design. The mystery of how our designs will perform in such extreme circumstances remains a barrier to the design process.

Engineering Design



Dynamic Environment

Design Performance



?

Objective | *How can we model this?*

Constitutive Modeling of Graphite in MOOSE

A **constitutive model** is a means of describing how a material will respond to any given stimuli or environments. These models allow for materials to be **simulated** by various finite element analysis tools such as **MOOSE**. The objective here is to accurately produce, observe, and numerically capture the dynamic **behavior** of a nuclear-grade graphite known as PCEA.

Method | *How can we make an accurate model?*

Dynamic Experimentation with Graphite

Split Hopkinson Pressure Bar (SHPB) Experiment
- Two long steel rods linear axial impact, crushing the specimen
- Creates dynamic loading scenario on specimen

Strain Gauge Sensors
- Measure strain wave travelling through the bars
- Generates stress and strain data as seen in Results

High Speed Video Footage (HSV)
- Captures close-up of specimen at up to 1,000,000 frames per second

Digital Image Correlation (DIC)
- Software tracks specimen strain throughout experiment (Figure 3)

Figure 1: Fractured PCEA-grade graphite specimen after SHPB test.

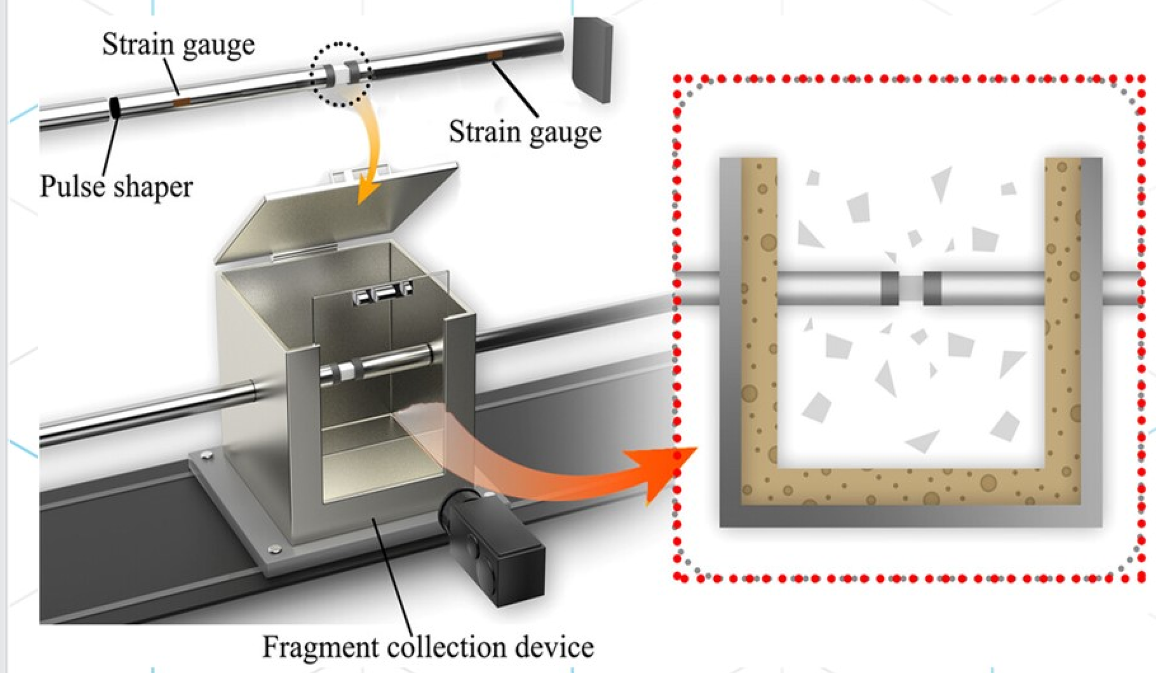


Figure 2: SHPB Experimental Setup.

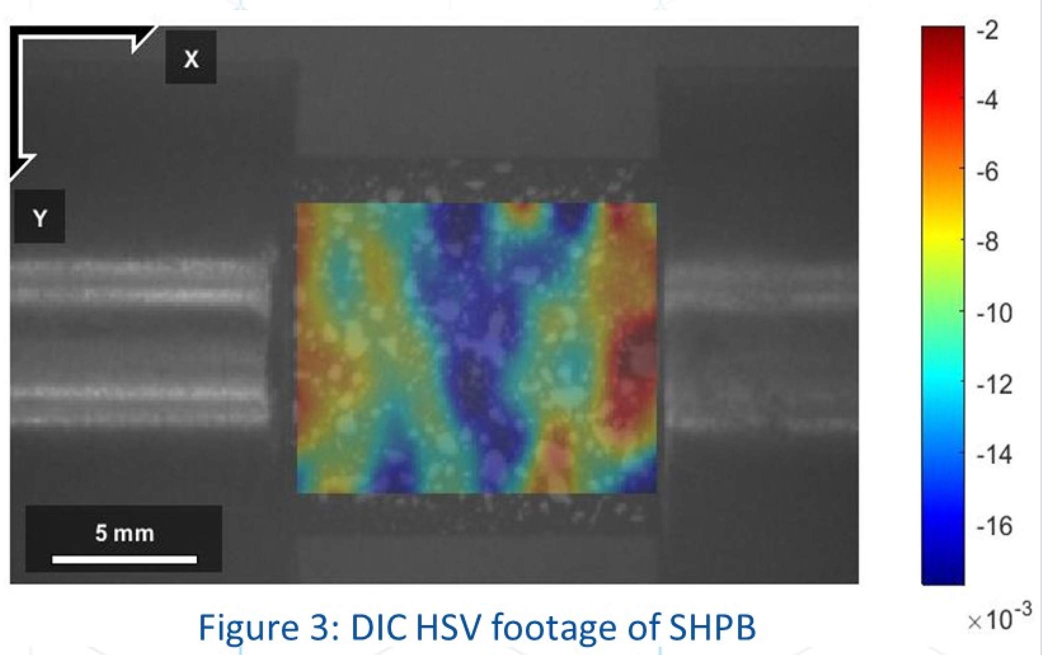


Figure 3: DIC HSV footage of SHPB impact on graphite specimen.

Results | *Observations & Analysis*

Strain gauge data from the experiments produces the stress, strain, and time data that can be used to construct the insights shown below into the **stress-strain behavior, ultimate strength, and average strain rate of the graphite experiment.**

Together, these insights serve as part of the foundation for building a robust constitutive model for the most accurate simulations. Of course, the more accurate data points - the better the model, so it is important to conduct a wide range of experiments as seen in Figures 4 and 5 below.

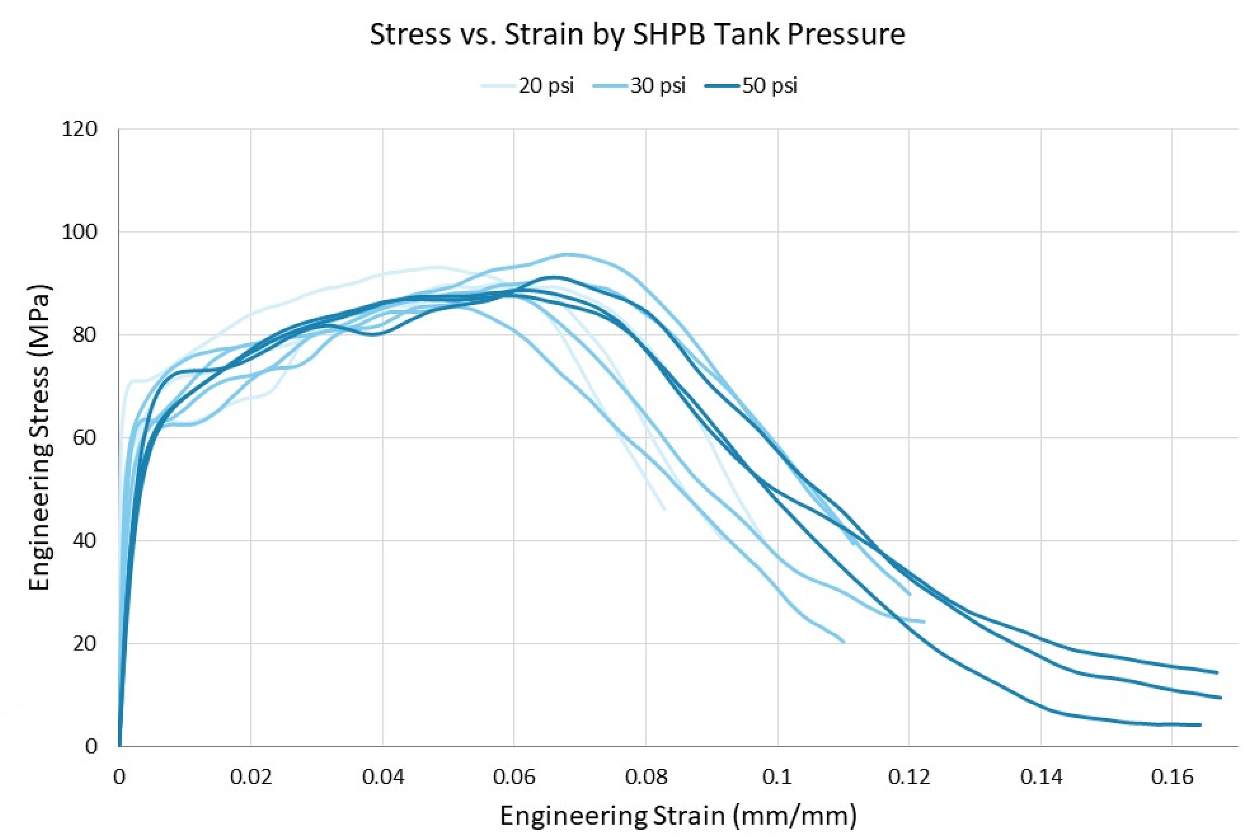


Figure 4: Stress-strain curves of each specimen tested at 3 different pressure charges of 20, 30, and 50 psi.

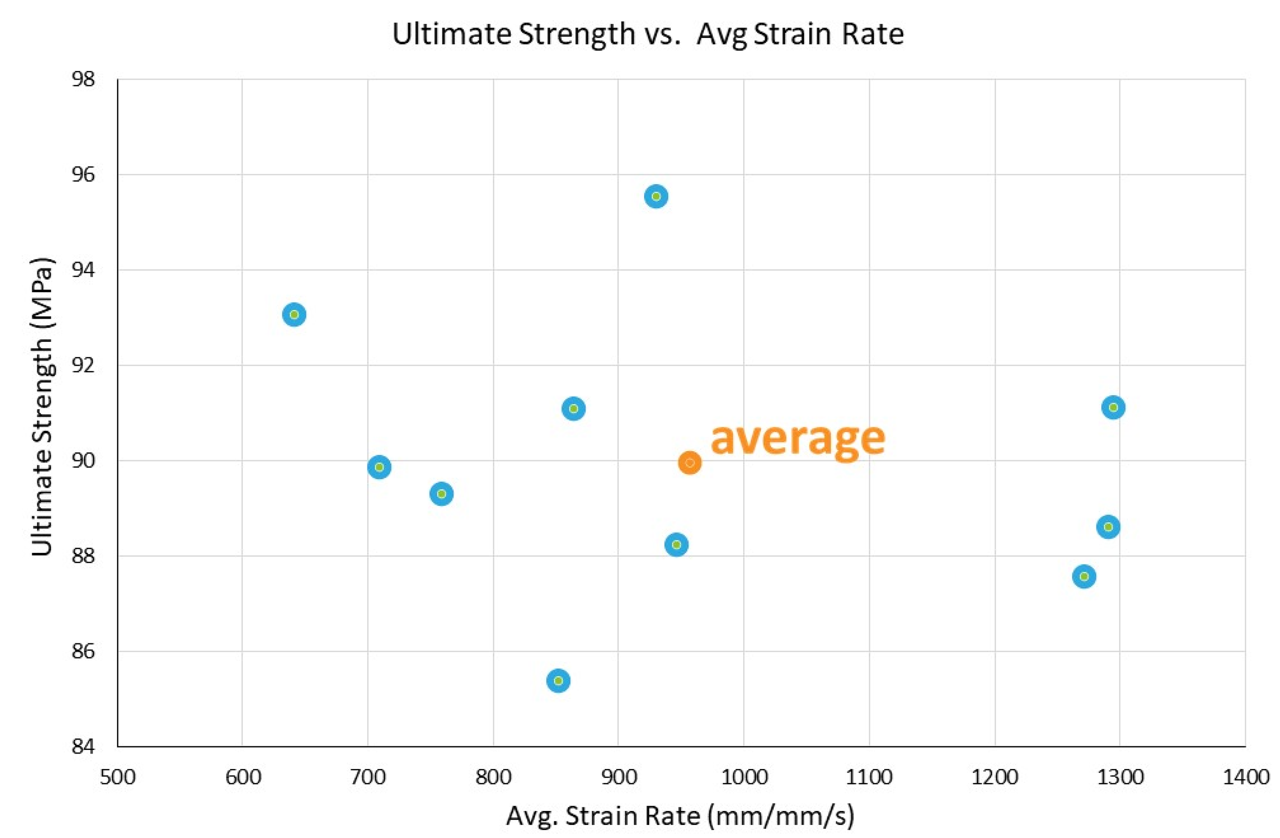


Figure 5: Ultimate strength against strain rate by sample. This shows material is likely not strain-rate dependent.

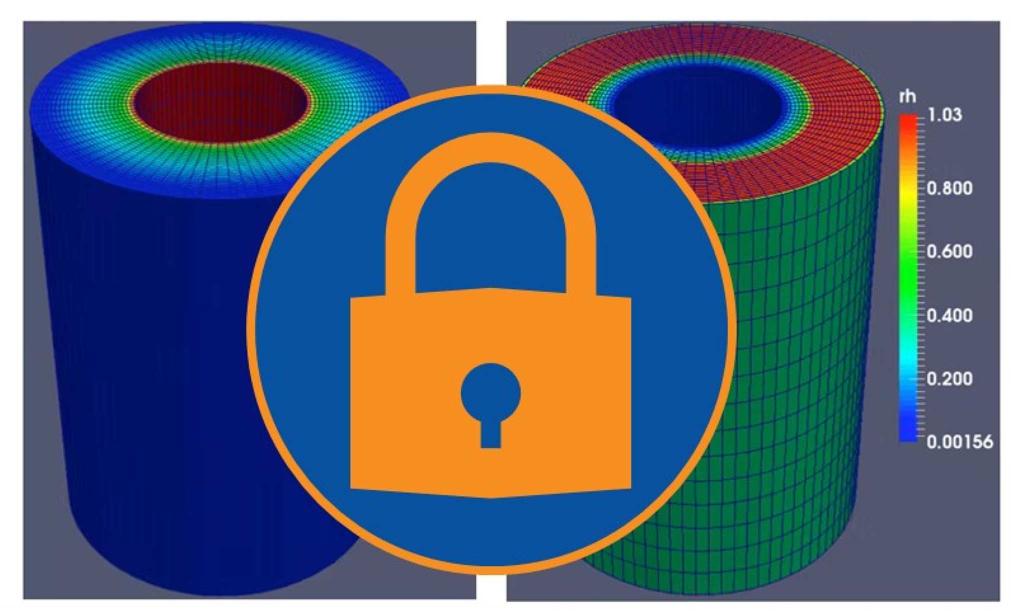
Conclusions | *Why does it matter?*

This research can be continued and expanded to produce a trustworthy and valuable constitutive model for nuclear-grade graphite. Constitutive models are critically important in the design process because they

1. **anticipate potential failures,**
2. **reduce need of physical prototypes,**
3. **and allow for design optimization**

Together, these capabilities significantly bolster the resilience, safety, and security of our designs. By conducting materials research like this to create constitutive models and use them in simulations, engineers can ensure that their designs are

resilient, secure, efficient, and safe for real-world use.



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