PI: Jorgen Rufner, Ph.D.

Arin Preston, Ph.D.

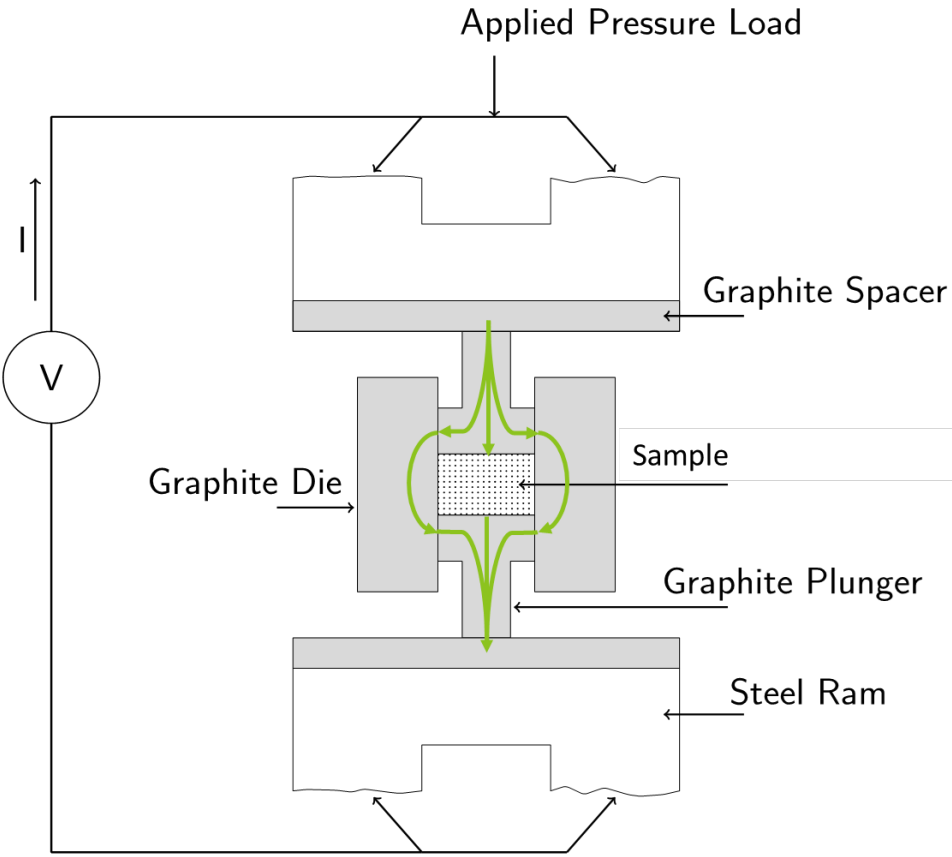
Aug. 24, 2023
INL/MIS-23-74330

3D Printed Carbon-Carbon Manufacturing as Alternative Die Materials for Electric Field Assisted Sintering

21A1050-096FP

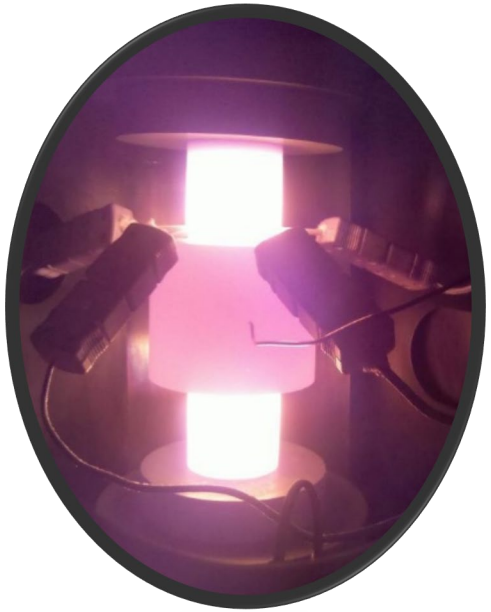
Idaho National Laboratory

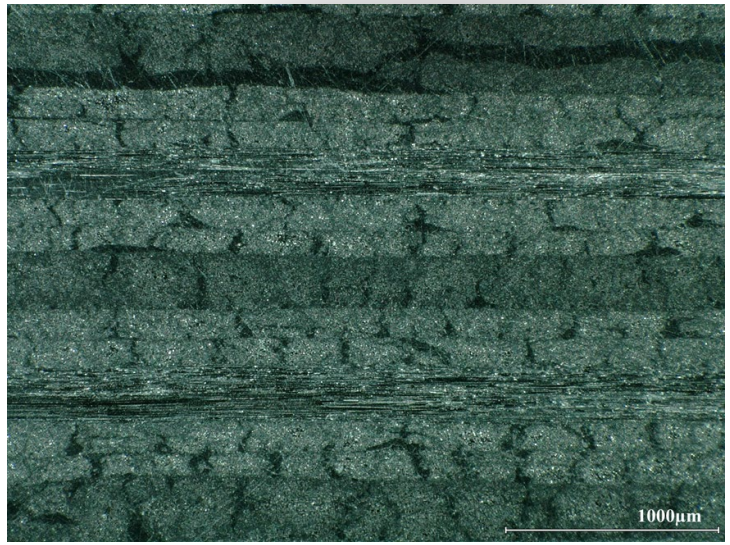
EFAS Tooling (Graphite vs Carbon-Carbon)



Schematic of EFAS technique rams, tooling, and powder[1]

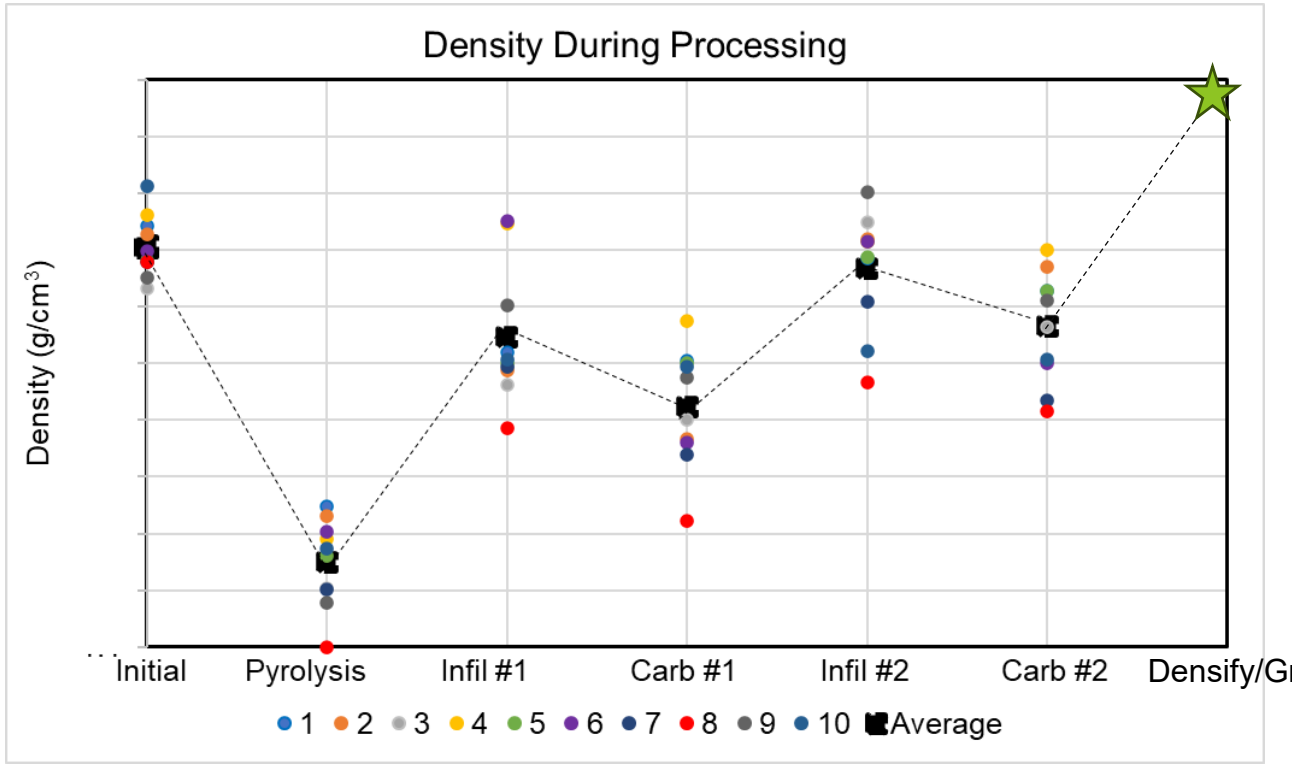
- High temp resistance
- Electrical and thermal conductivity
- Graphite mold material.
  - Suboptimal for scale up.
  - Cost and low fracture toughness.
- Carbon-Carbon (C-C)
  - Stronger, Tougher
  - Tailorable, anisotropic properties

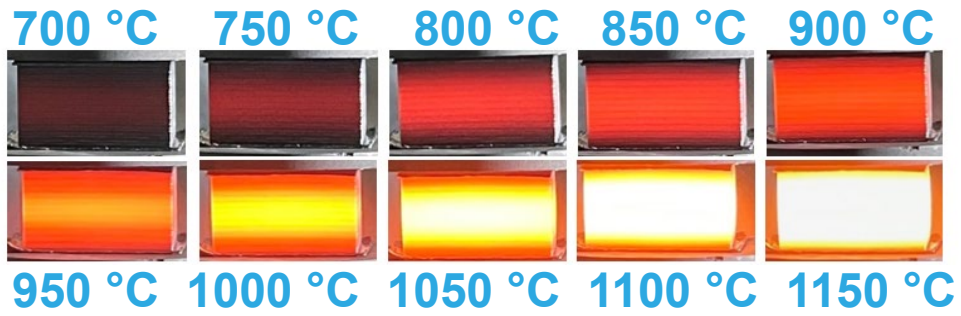




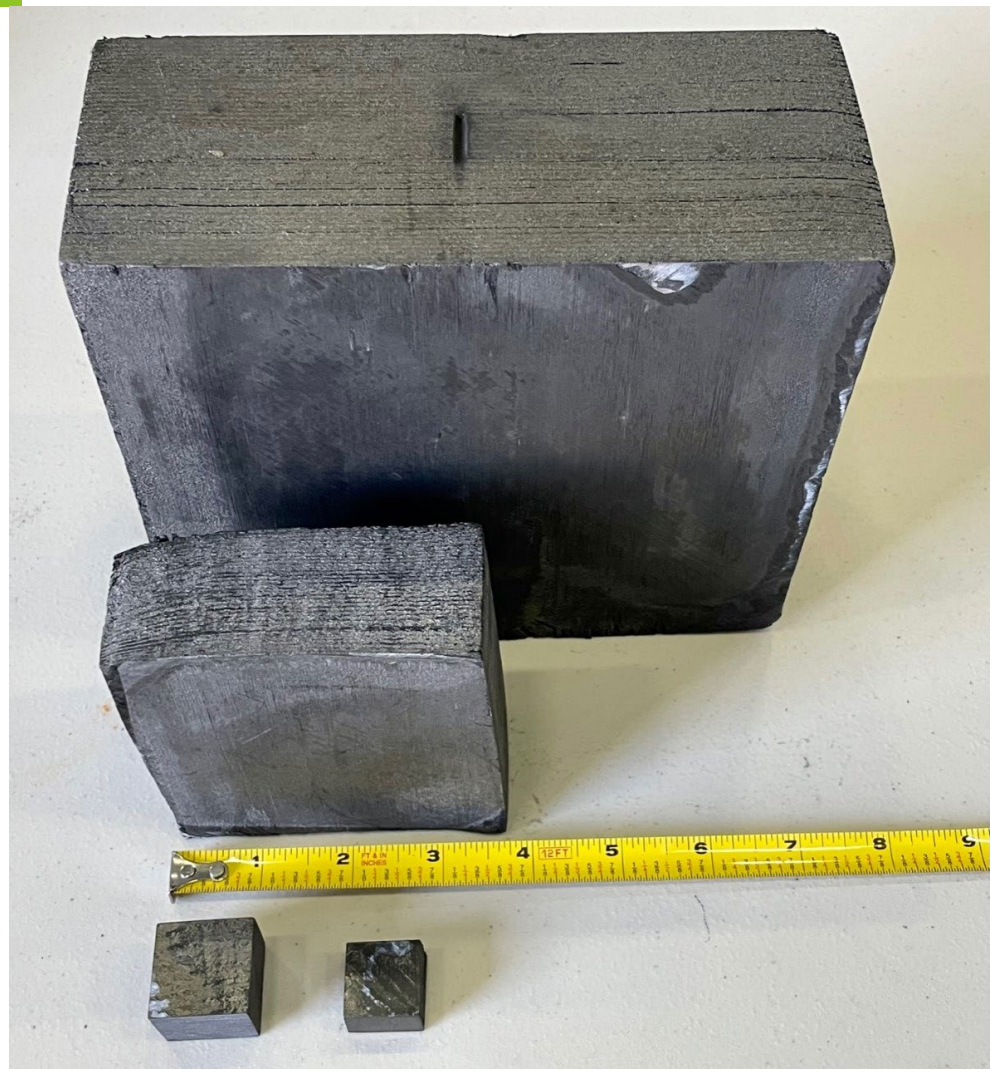
C-C Manufacturing

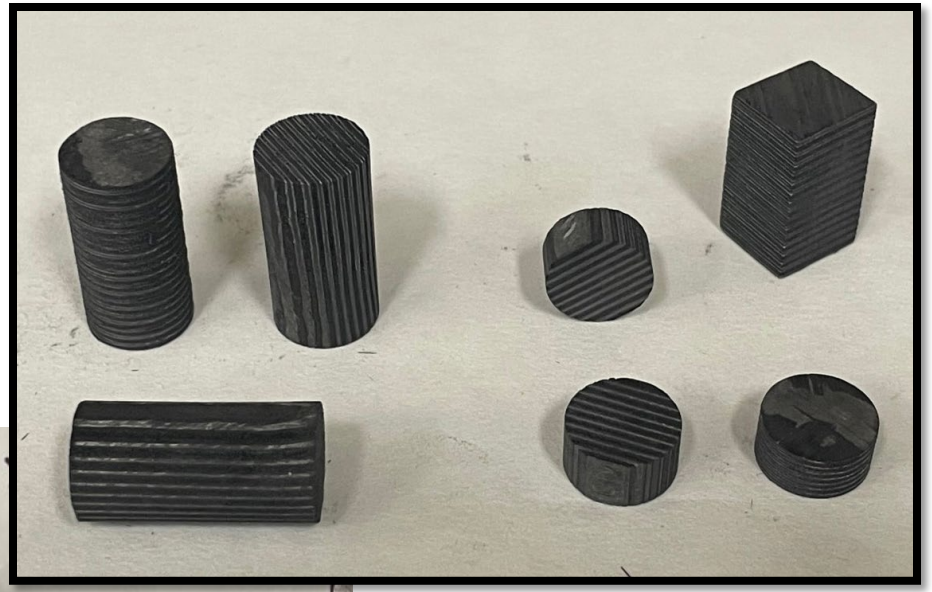
Commercial processes can take weeks to months.
INL process has decreased that processing time considerably

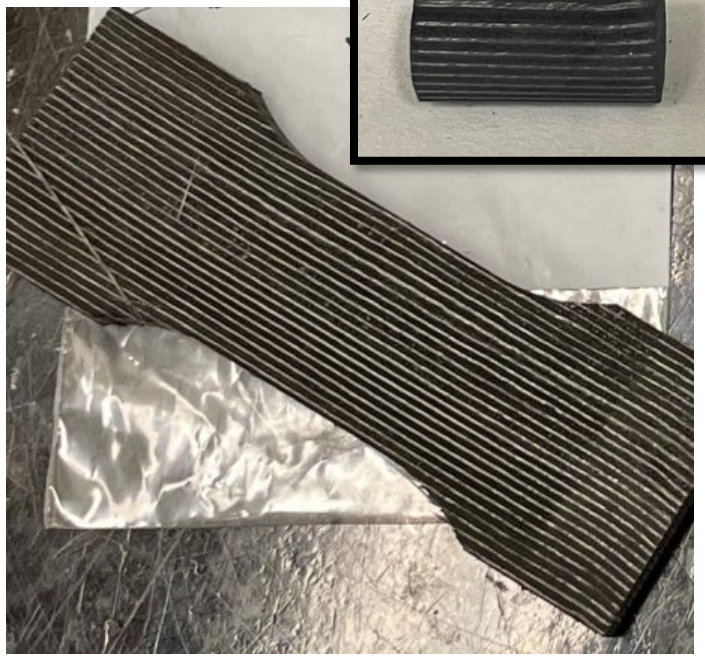




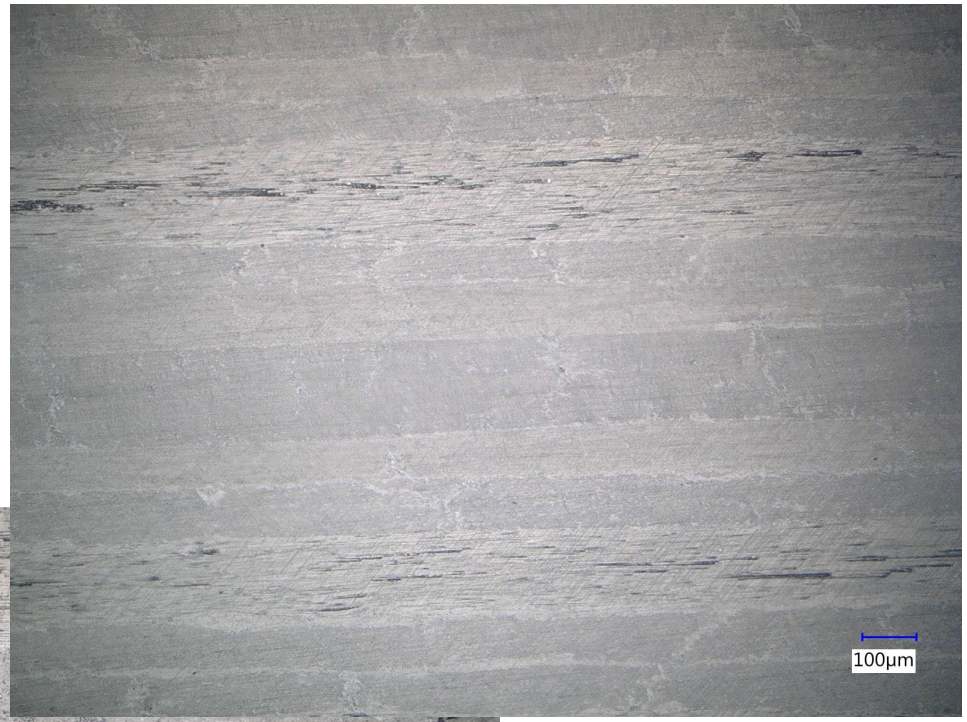
Graphitized C-C

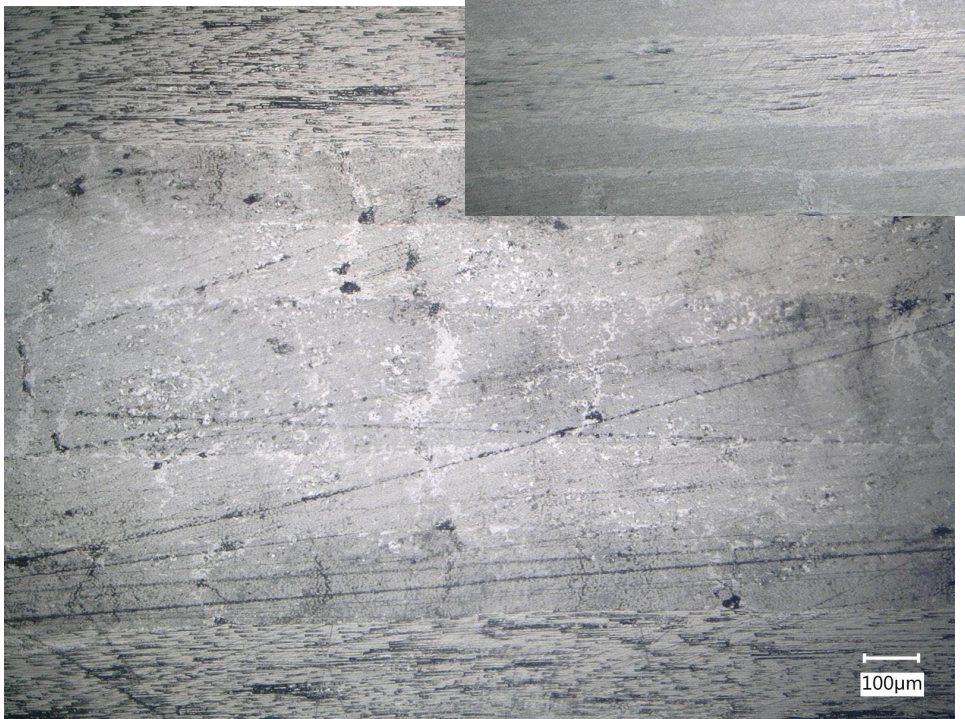






Cross-Section of Graphitized C-C and Properties

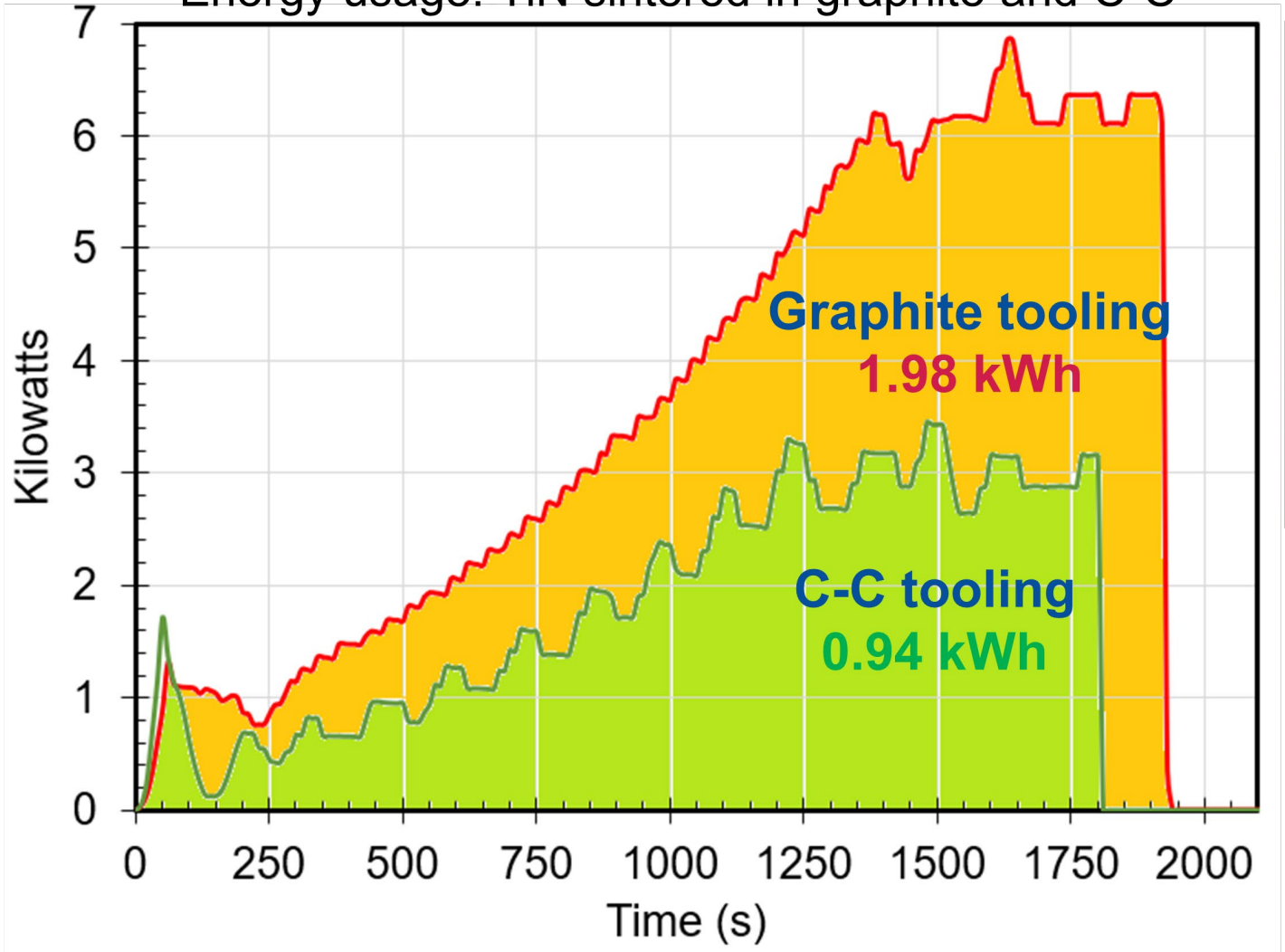




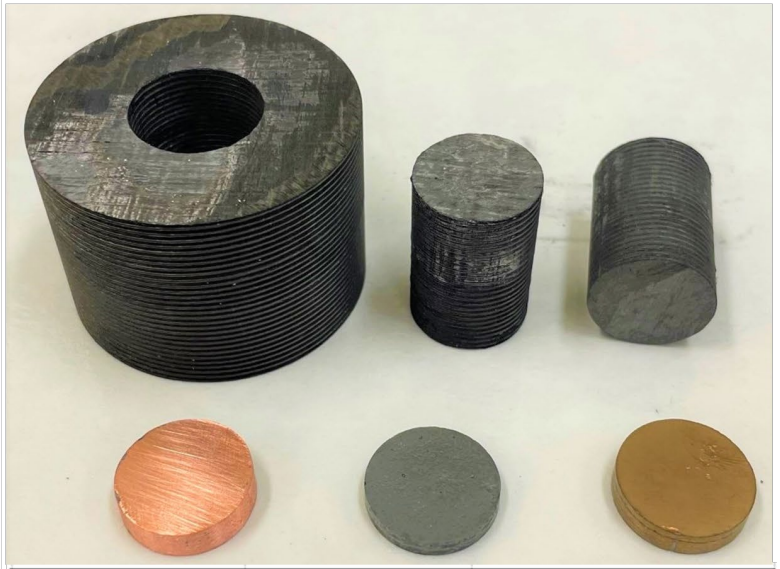
	INL Carbon-Carbon	Commercial Graphite
	Electrical Resistivity (µΩ*m)	
X/Y Plane	16.5	17
Z-Direction	121.2	13
	Thermal Diffusivity (25 °C)	
X/Y Plane	75	63
Z-Direction	5	82

Reduced Energy Required

Energy usage: TiN sintered in graphite and C-C



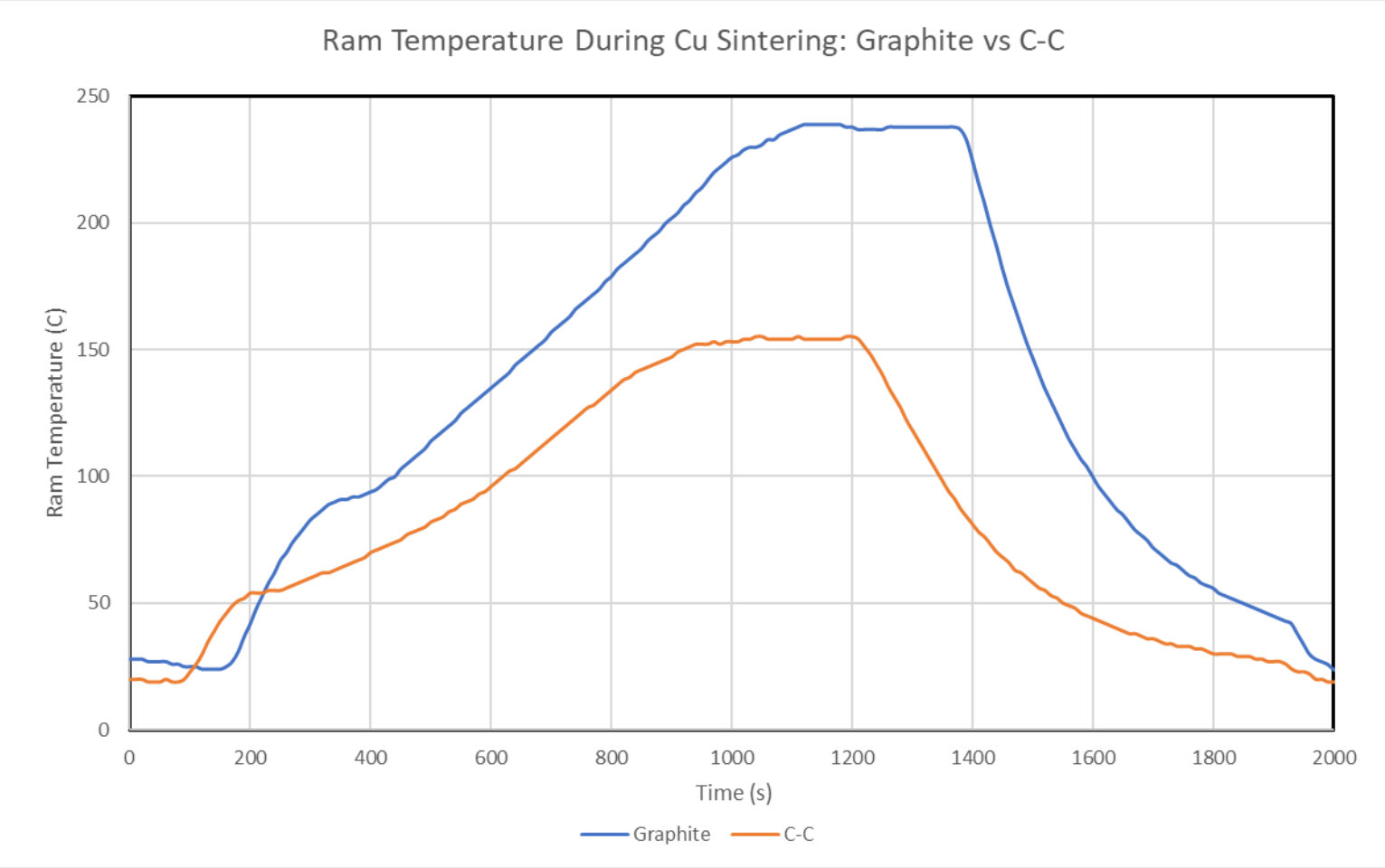
20 mm C-C tooling



Tooling Type	Sintered Material	Energy Used (kWh)
Graphite	Copper	0.828
C-C	Copper	0.457
Graphite	Alumina	2.095
C-C	Alumina	1.114

Less Ram Heating

- For Cu Sintering: 20MPa, 900 °C, 5 min. Ram temperature* comparison:

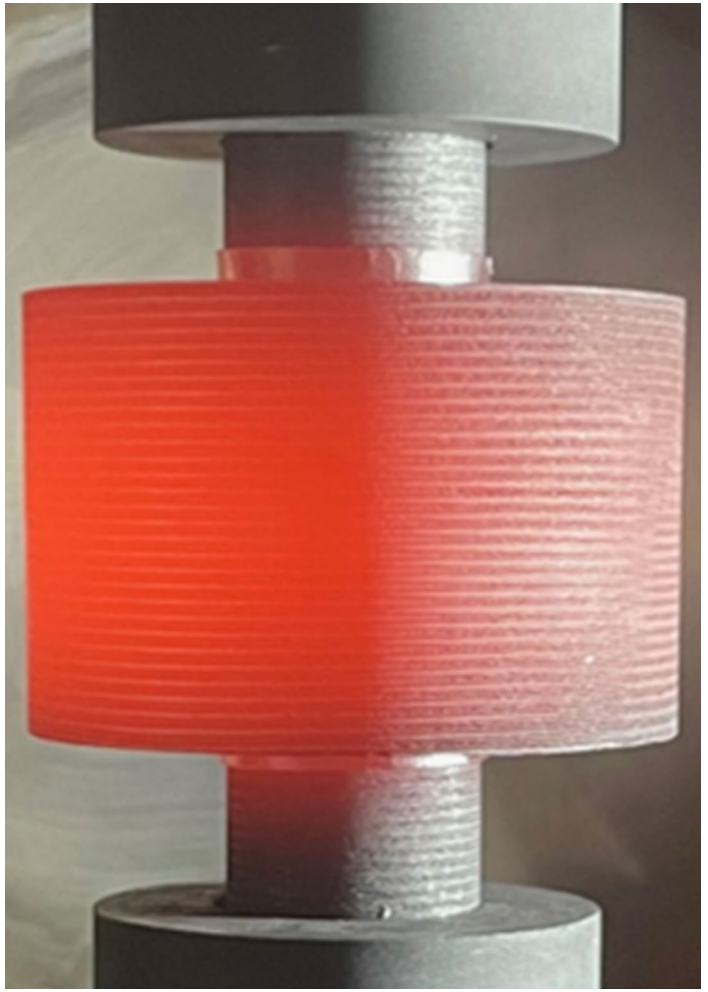


*Ram temperature is a limiting factor for EFAS:
if the rams exceed 400 C, damage to the equipment is likely.

Reducing ram temperature means that higher sample temperatures may be achieved, and for longer durations.

Take Away

- High resistivity in the Z-direction enables **more efficient Joule heating**.
- Low thermal diffusivity in the Z-direction means the **heat does not conduct away** as quickly; heat is effectively "trapped" where it is needed.
- 3D printed **C-C tooling is stronger**, and **more energy efficient** than identical graphite tooling.
- Compared to Tokai G535 graphite:
    - At least **2x stronger** in tension.
    - At least **3x stronger** in compression.
    - Uses **48% less energy**, 35% lower ram temps



Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.