

Winter 3-10-2016

Field assisted sintering: Challenges in scale-up from buttons to body armor

Christopher Haines

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Christopher Haines, "Field assisted sintering: Challenges in scale-up from buttons to body armor" in "Electric Field Assisted Sintering and Related Phenomena Far From Equilibrium", Rishi Raj (University of Colorado at Boulder, USA) Thomas Tsakalakos (Rutgers University, USA) Eds, ECI Symposium Series, (2016). http://dc.engconfintl.org/efa_sintering/53

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U.S. Army Research, Development and Engineering Command

Field Assisted Sintering: Challenges in scale-up from “buttons” to body armor



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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²Applied Research Laboratory – Penn State University, State College, PA, USA

³Powder Technology Laboratory – San Diego State University, San Diego, CA, USA

Electric Field Assisted Sintering and Related Phenomena Far from Equilibrium – Tomar, Portugal 5-11 March 2016

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Outline of the Talk



- ARDEC Overview
- Motivation for FAST
- FAST Trends
- Applications in DoD
- Scalability Challenges
- Overheating Phenomenon
- Conclusions/Lessons Learned
- Acknowledgements

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Armament Research, Development & Engineering Center



Research



Development



Production



Field Support



Demilitarization



Vision:

Innovative Armaments Solutions for Today and Tomorrow

Mission:

To develop and maintain a world-class workforce to execute and manage integrated life-cycle engineering processes required for the research, development, production, field support and demilitarization of munitions, weapons, fire control and associated items

Advanced Weapons – line of sight/beyond line of sight fire; non line of sight fire; scalable effects; non-lethal; directed energy; autonomous weapons

Ammunition – small, medium, large caliber; propellants; explosives; pyrotechnics; warheads; insensitive munitions; logistics; packaging; fuzes; environmental technologies and explosive ordnance disposal

Fire Control – battlefield digitization; embedded system software; aero ballistics and telemetry

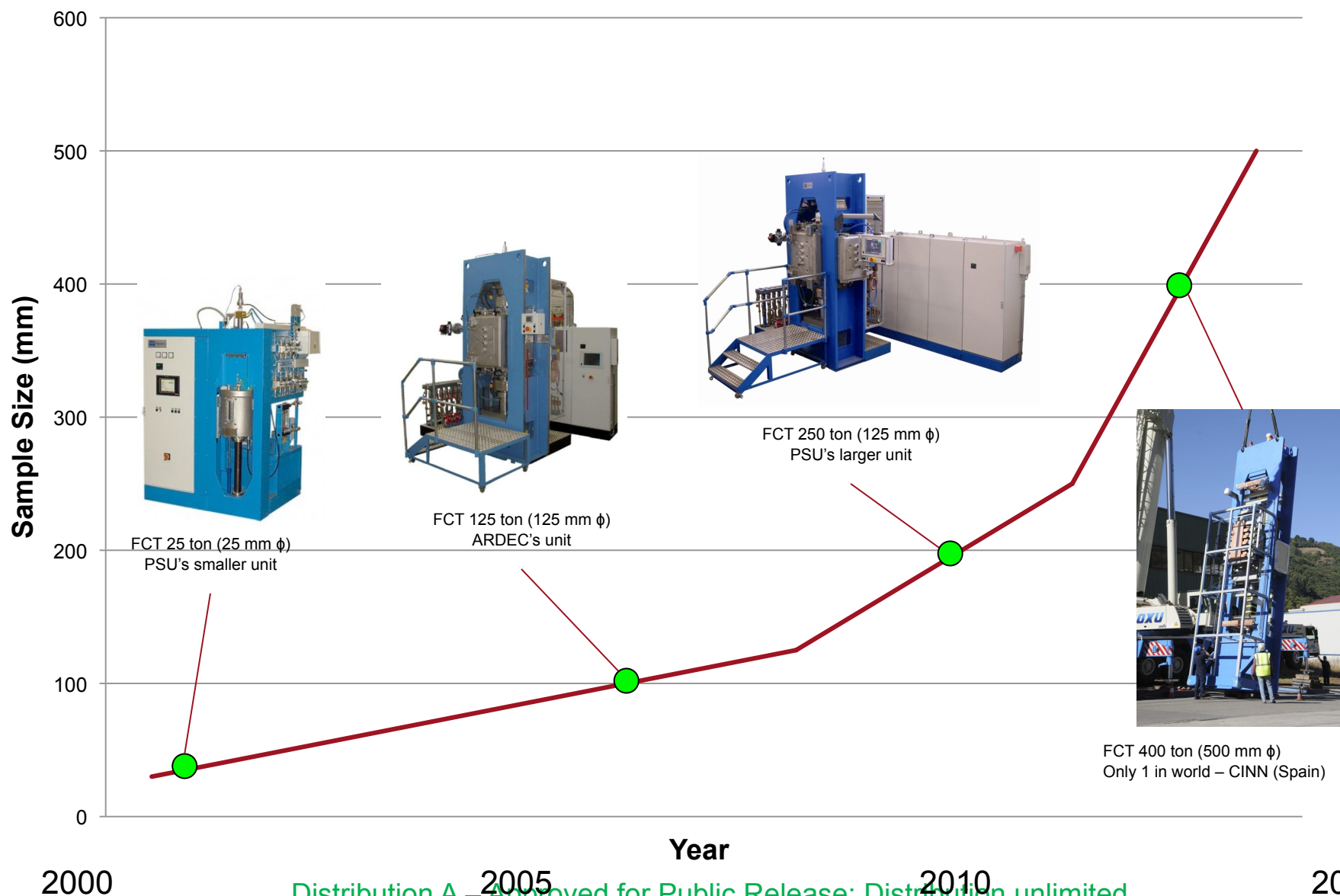
ARDEC Provides the Technology for Over 90% of the Army's Lethality; Significant support to other Services Lethality

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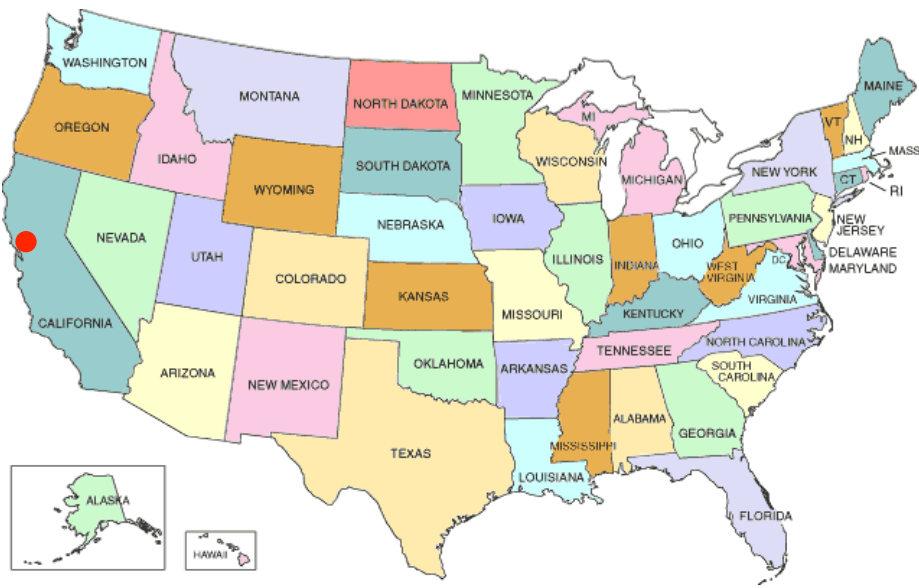
Increase in Size Capacity



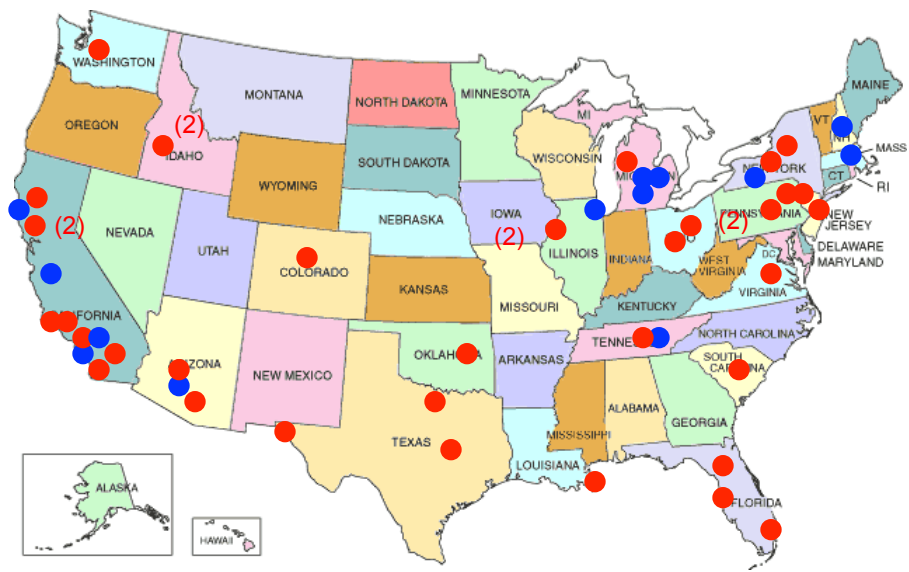
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2000

2015



1



60+

- Academia or Gov't Lab
- Industry

*Actual locations are not precise due to proprietary agreements between vendors and equipment purchasers.



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Applications in DoD



Soldier Protection



Lethality



Functional Components



Layered Structures



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Soldier Protection

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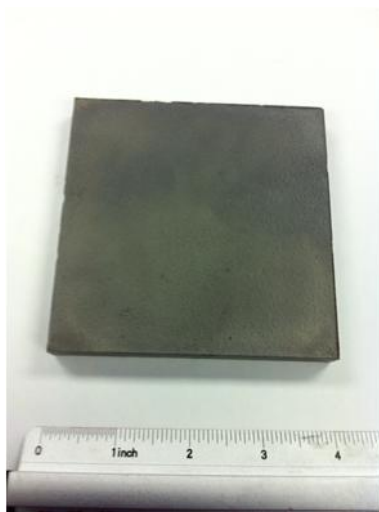


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Soldier Protection



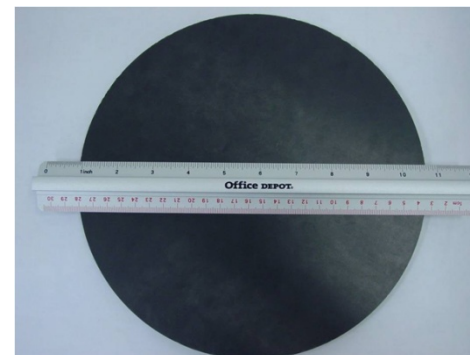
Initial Small (3" Dia.) Samples



Scaled up 4" x 4" Plates



Conducted Ballistic Testing



250 mm Dia. Plates



Sub-scale SAPI



We Are Here



Full Scale SAPI Plates

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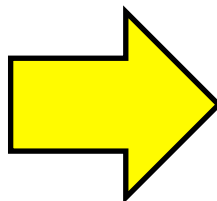
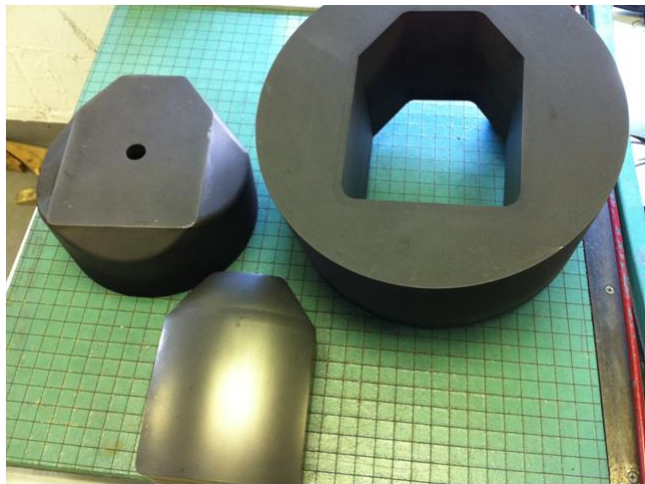
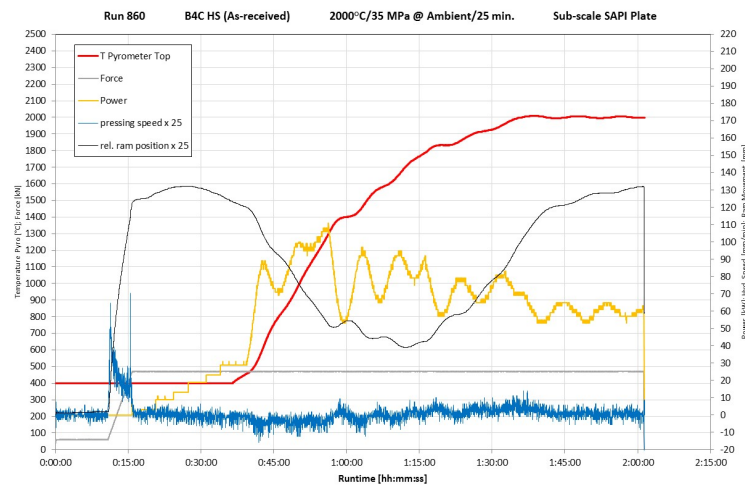
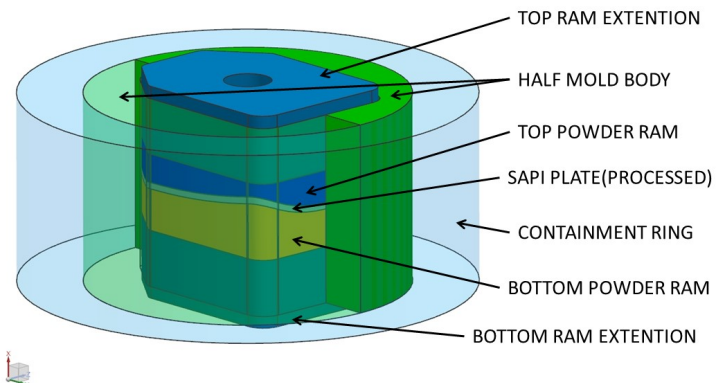
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Subscale SAPI



95% Dense, Cracked Tooling



99% Dense, Tooling Intact

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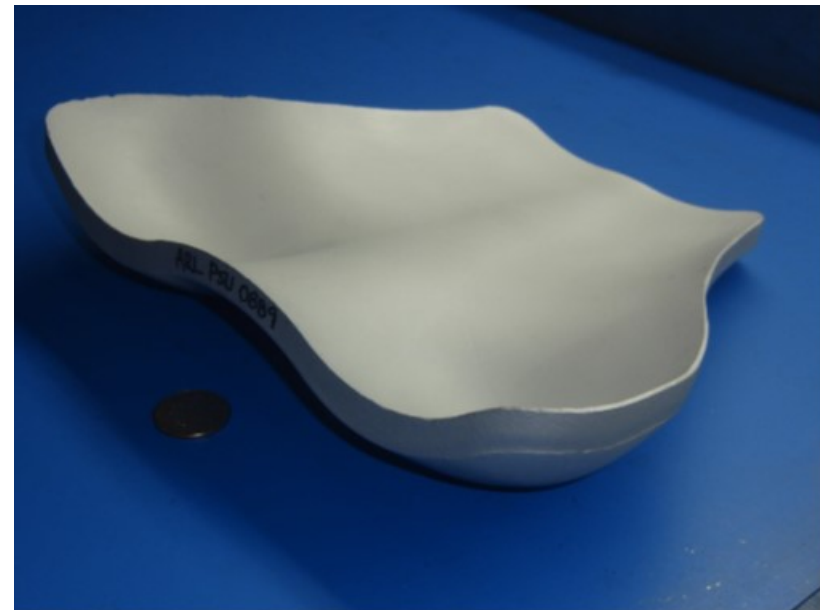


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Body Armor – Future Concepts



Proof of Concept Female SAPI plates made via FAST

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Lethality

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Lethality



There exists a *major* cost benefit for NNS warheads due to minimization of scrap. Conventional CNC machining or forging yields very high % of scrap with raw materials in the \$100's/lb range



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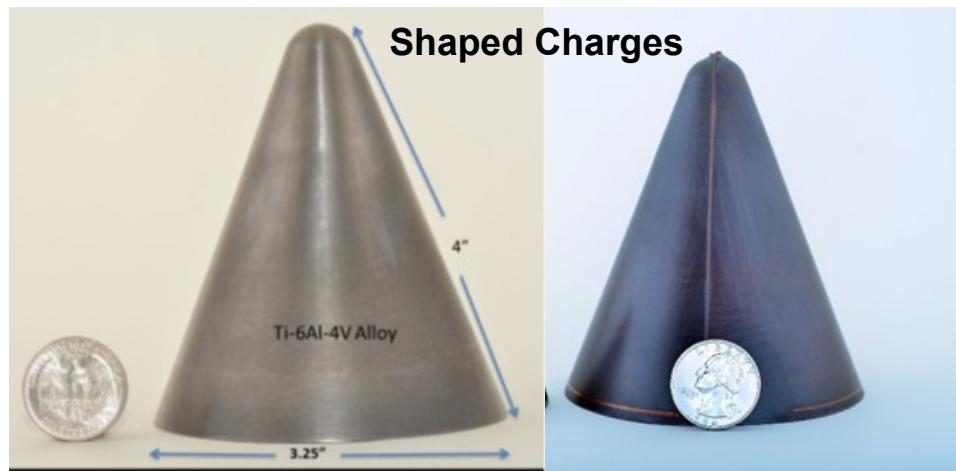
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Lethality



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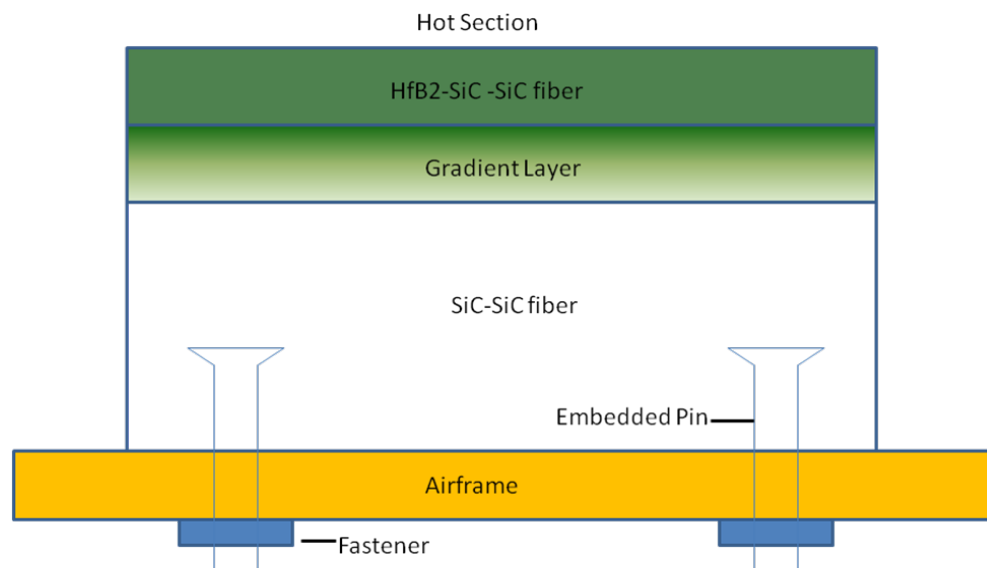
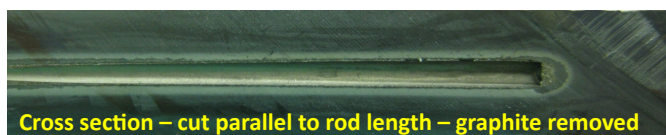
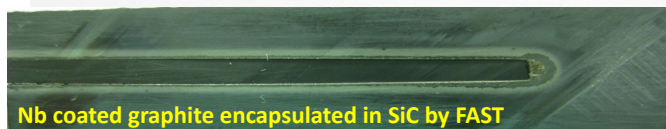
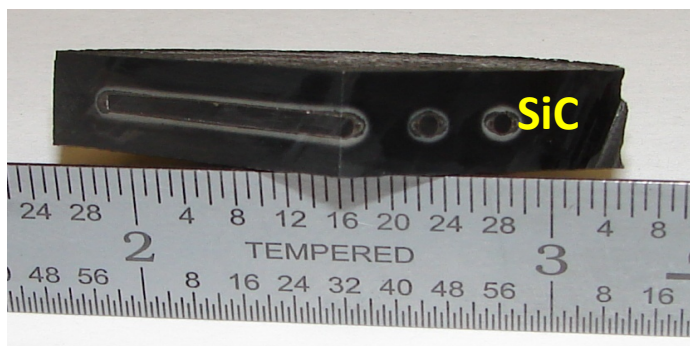
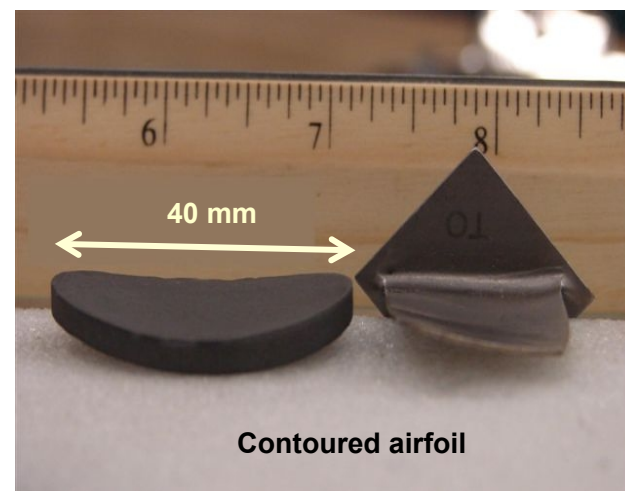
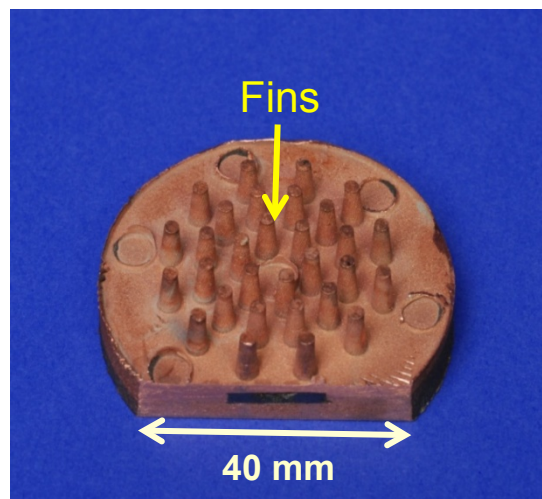
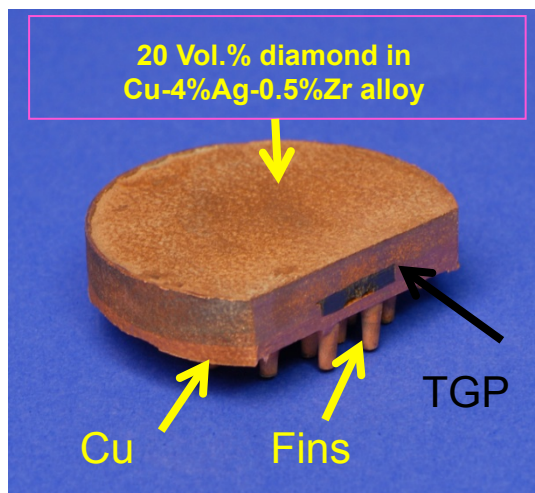
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Functional Components



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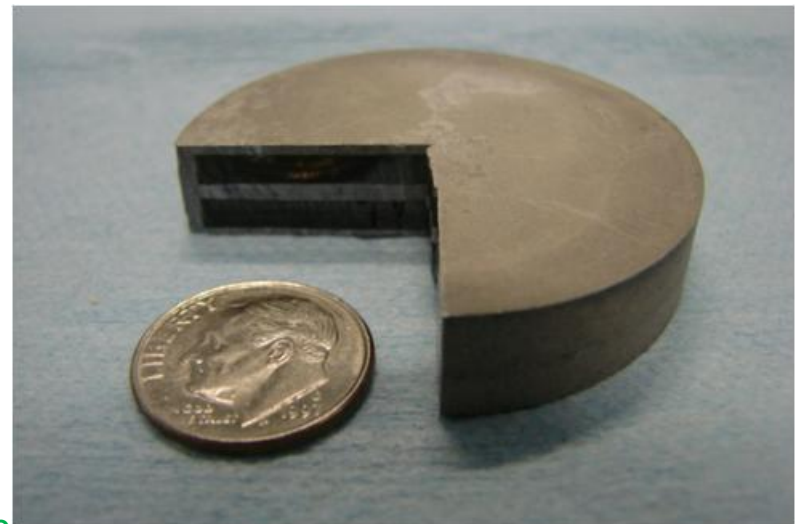
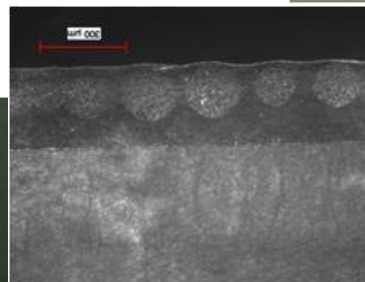
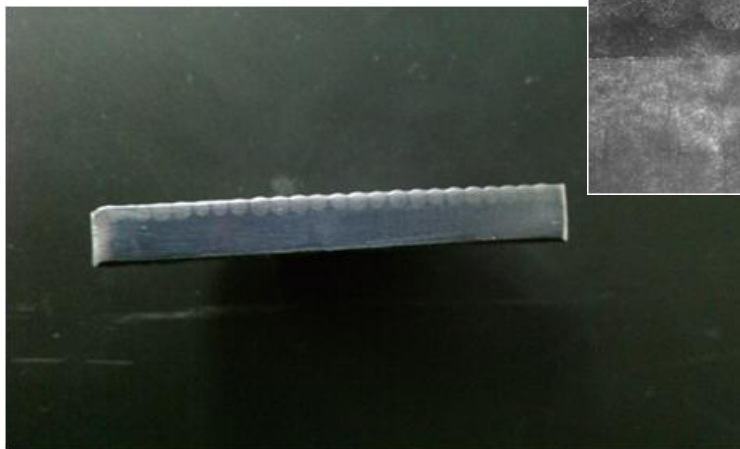


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Layered/Composite Materials



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Scalability Challenges

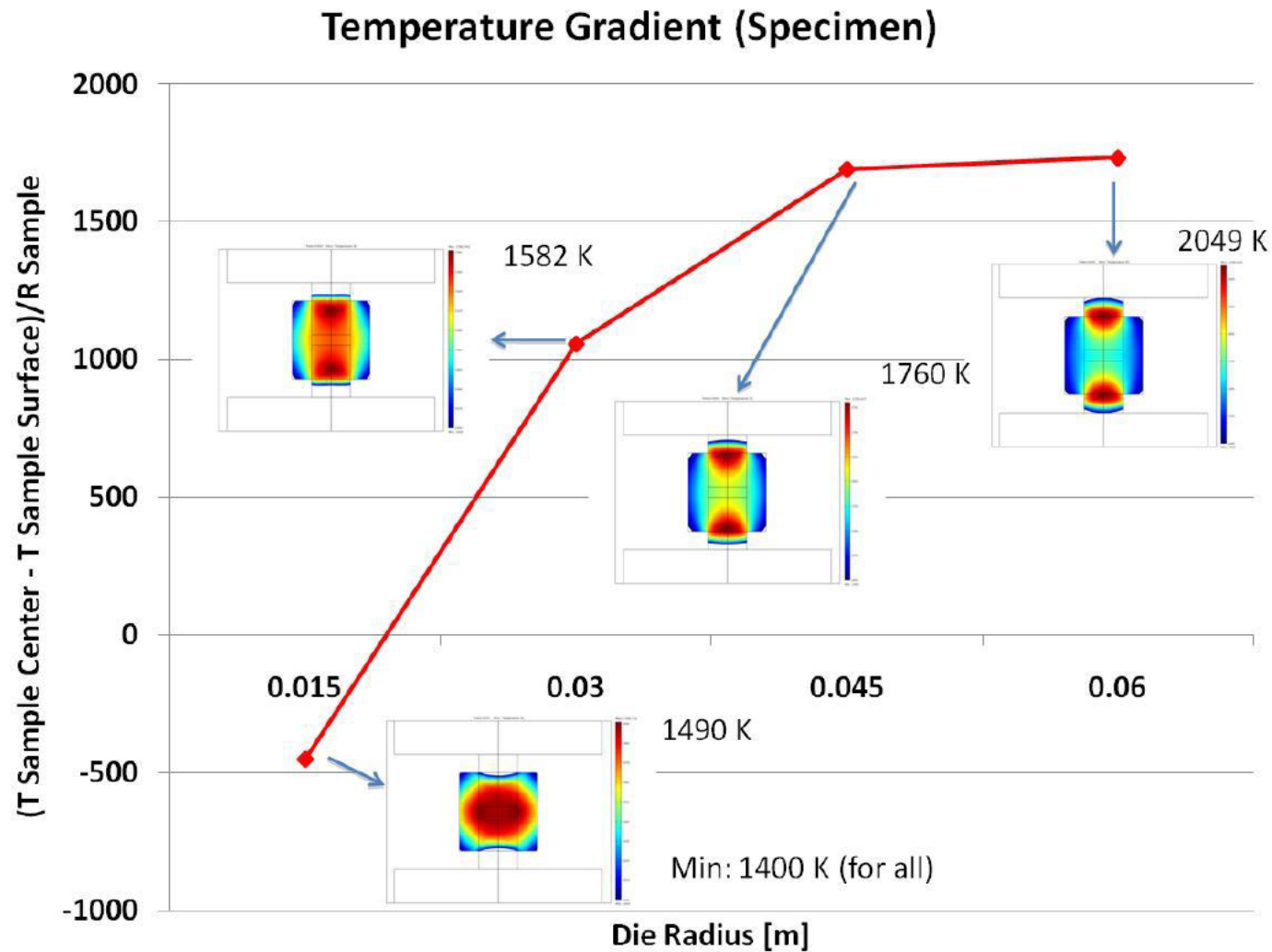
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Scalability Issues

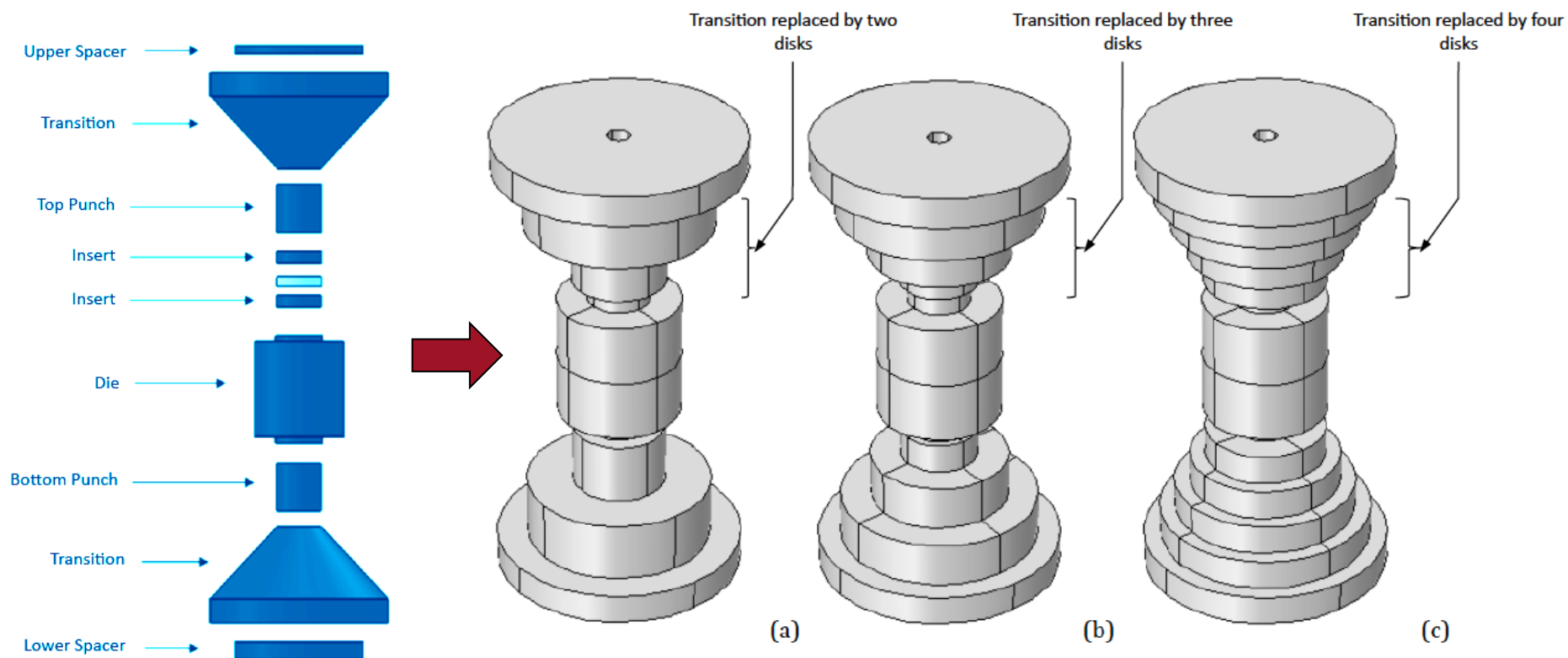


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Scalability Issues



D Giuntini, EA Olevsky, C Garcia-Cardona, AL Maximenko, MS Yurlova, CD Haines...Materials 6 (7), 2612-2632

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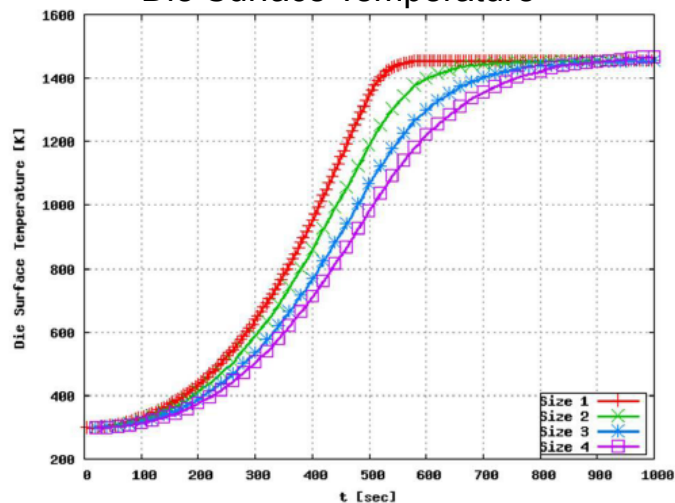


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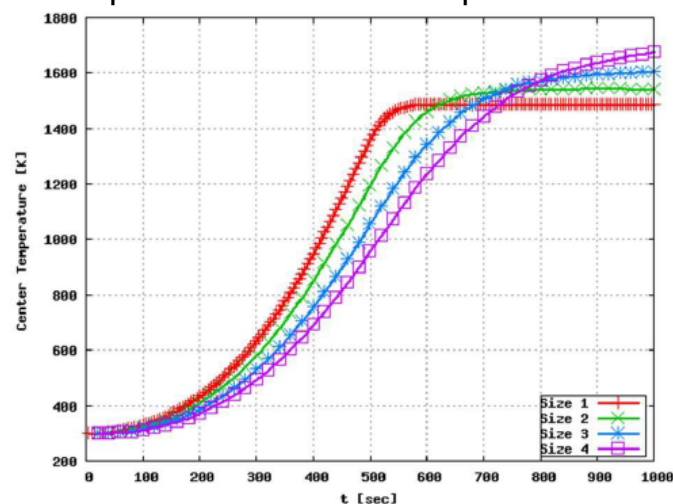
Scalability Issues



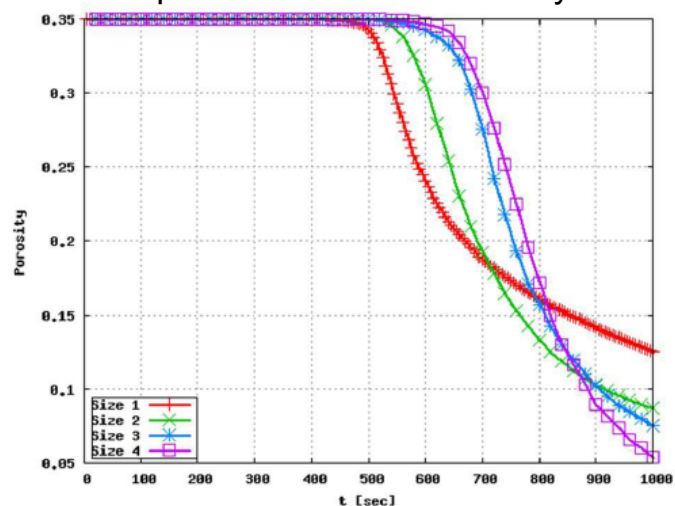
Die Surface Temperature



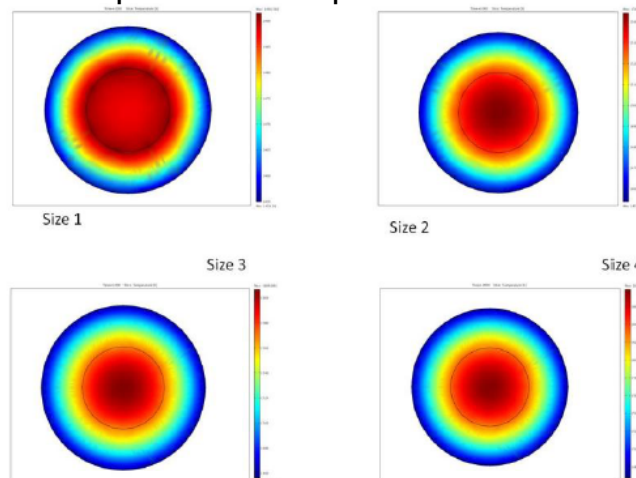
Specimen's Center Temperature



Specimen's Center Porosity



Specimen Temperature Profile



D Giuntini, EA Olevsky, C Garcia-Cardona, AL Maximenko, MS Yurlova, CD Haines...Materials 6 (7), 2612-2632

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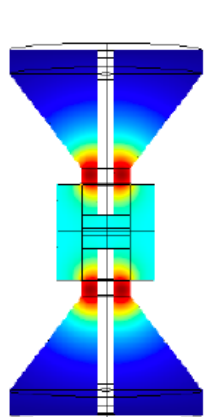
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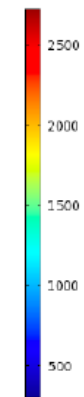
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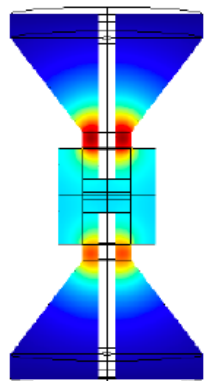
Overheating Phenomenon



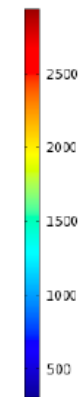
▲ 2722



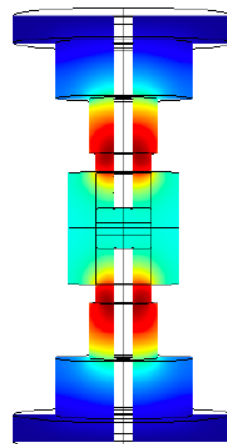
▼ 300 (a)



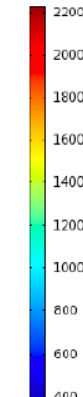
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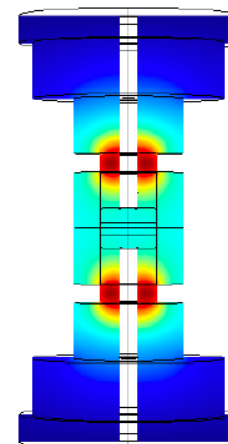
▼ 300 (b)



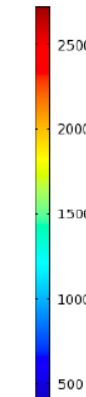
▲ 2222.9



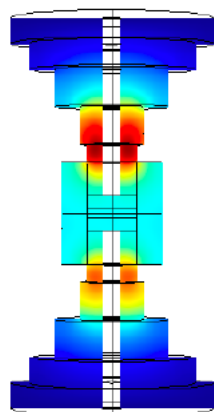
▼ 300 (a)



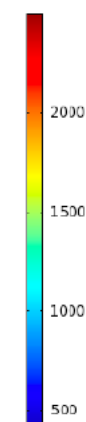
▲ 2726.5



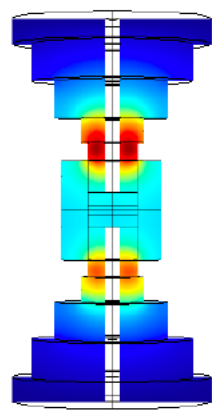
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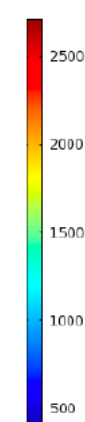
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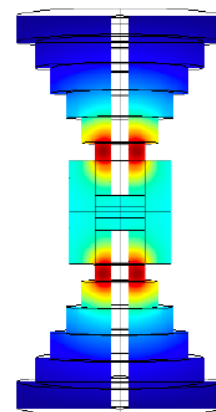
▼ 300 (a)



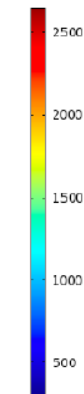
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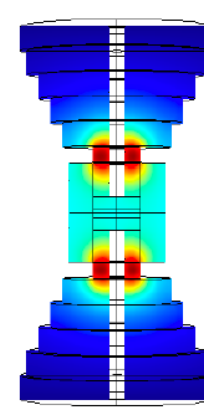
▼ 300 (b)



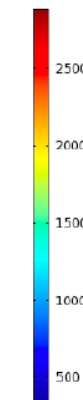
▲ 2643.1



▼ 300 (a)



▲ 2880.3



▼ 300 (b)

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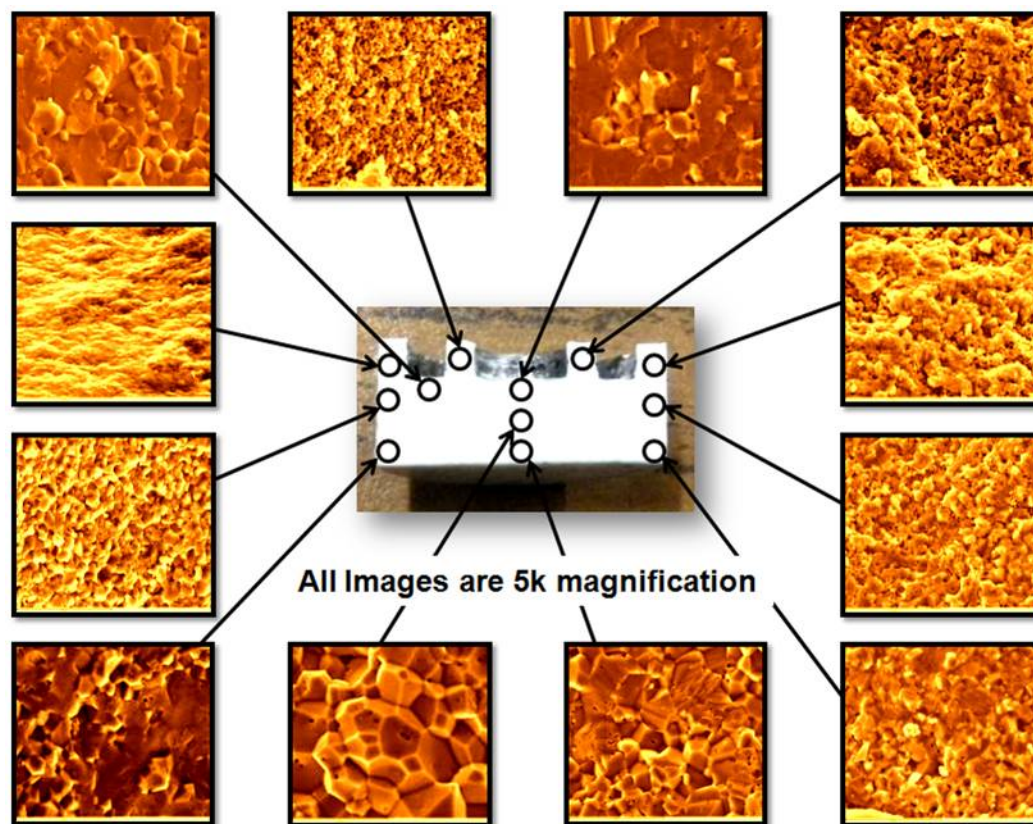
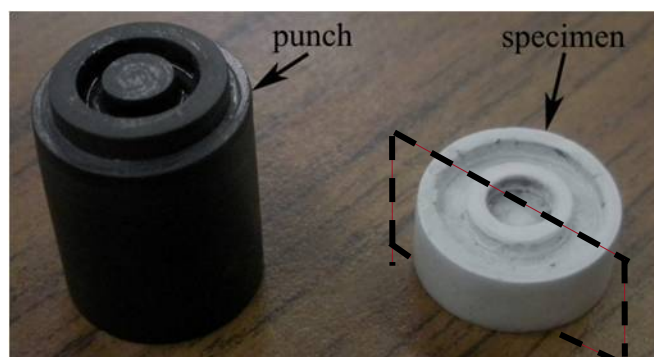
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Microstructure Variation



Y.-S. Lin, M. A. Meyers, and E. A. Olevsky, Adv. App. Ceram., 111, 269-274 (2012)

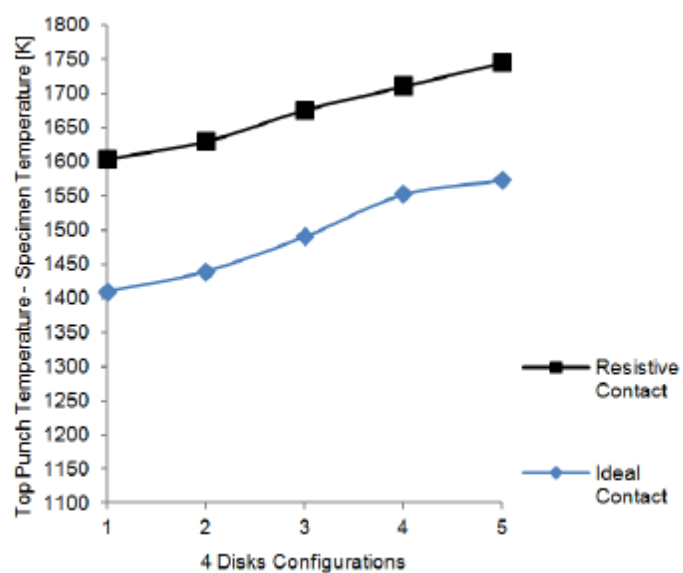
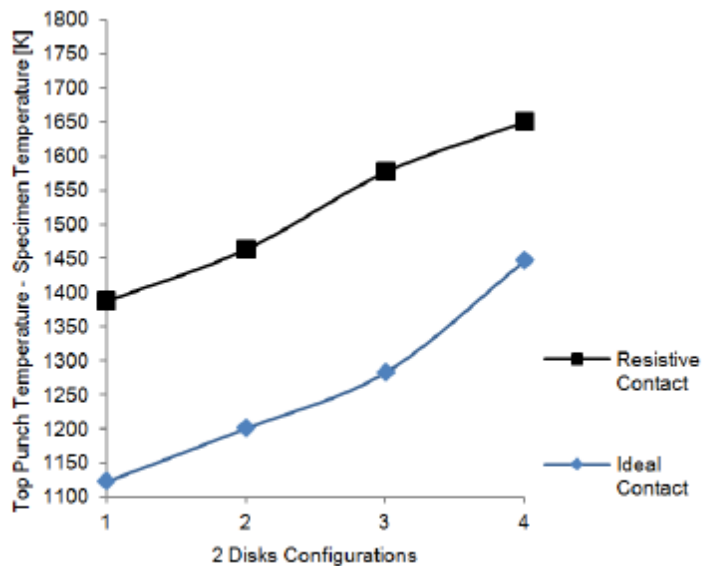
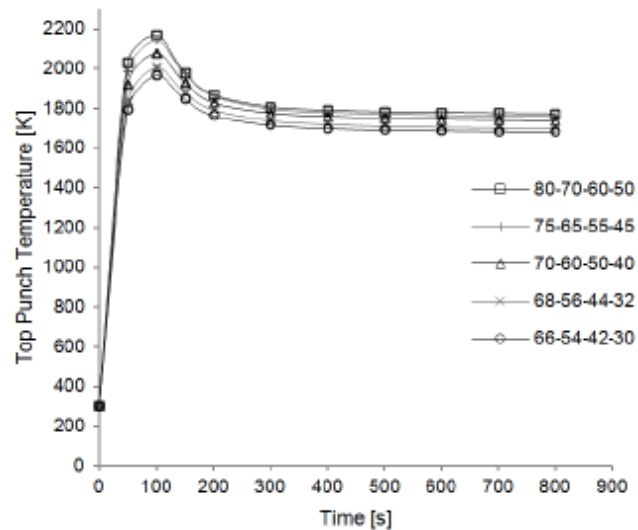
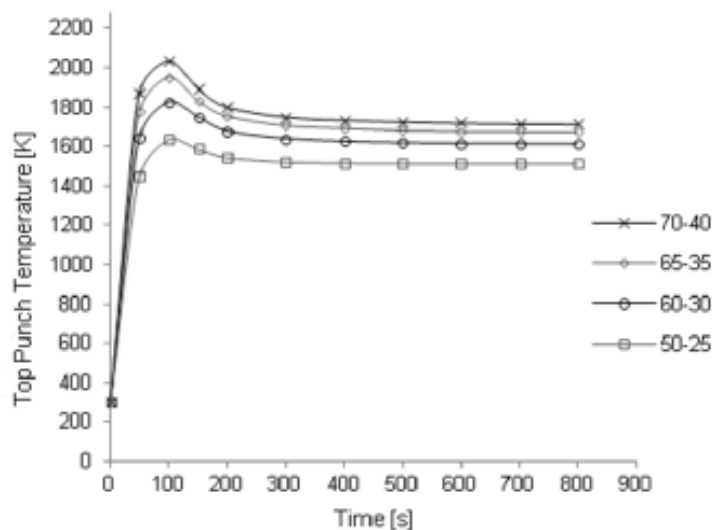
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Overheating Phenomenon



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When things go bad...

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Violent Reactions



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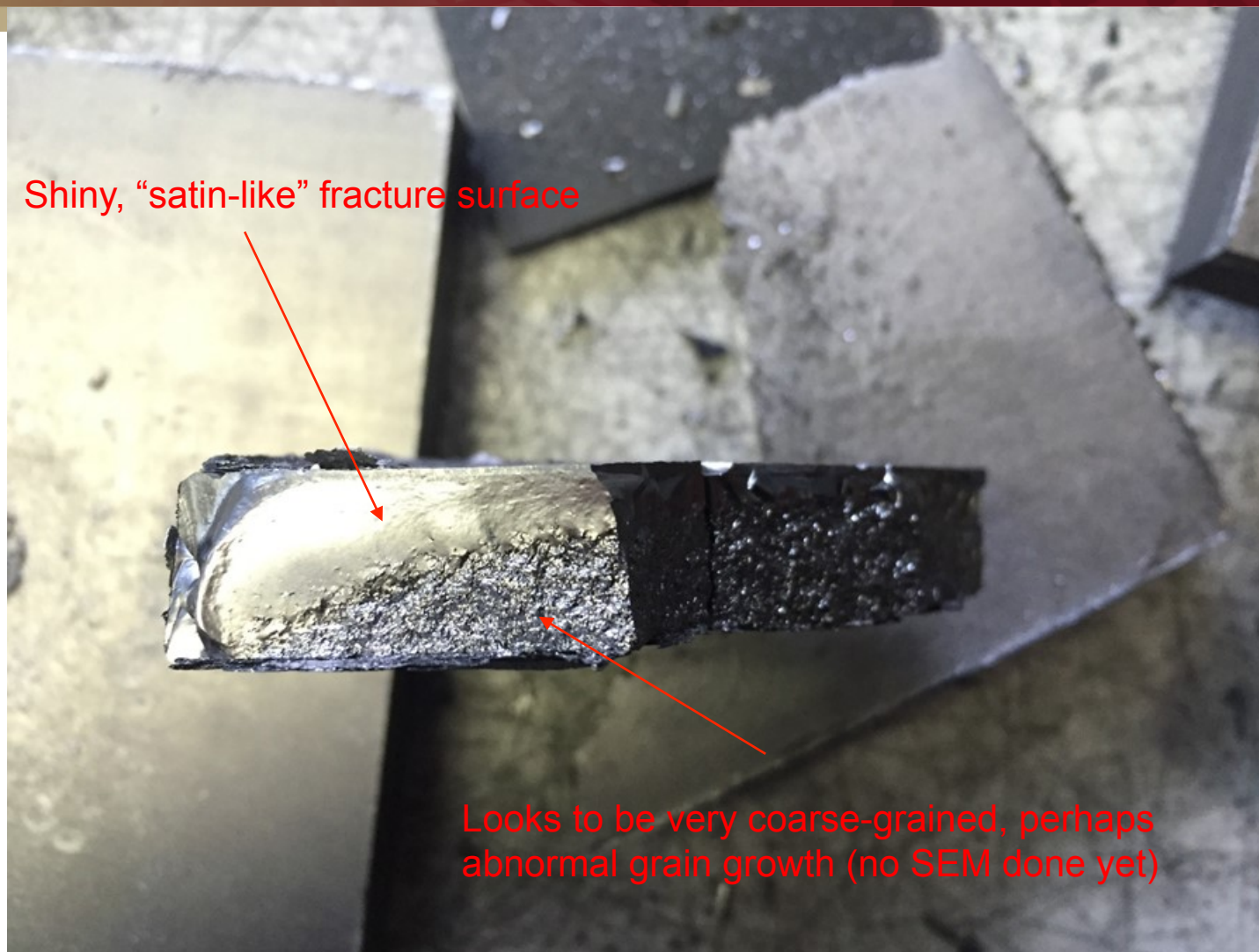
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B₄C Anomaly



Shiny, "satin-like" fracture surface



Looks to be very coarse-grained, perhaps
abnormal grain growth (no SEM done yet)

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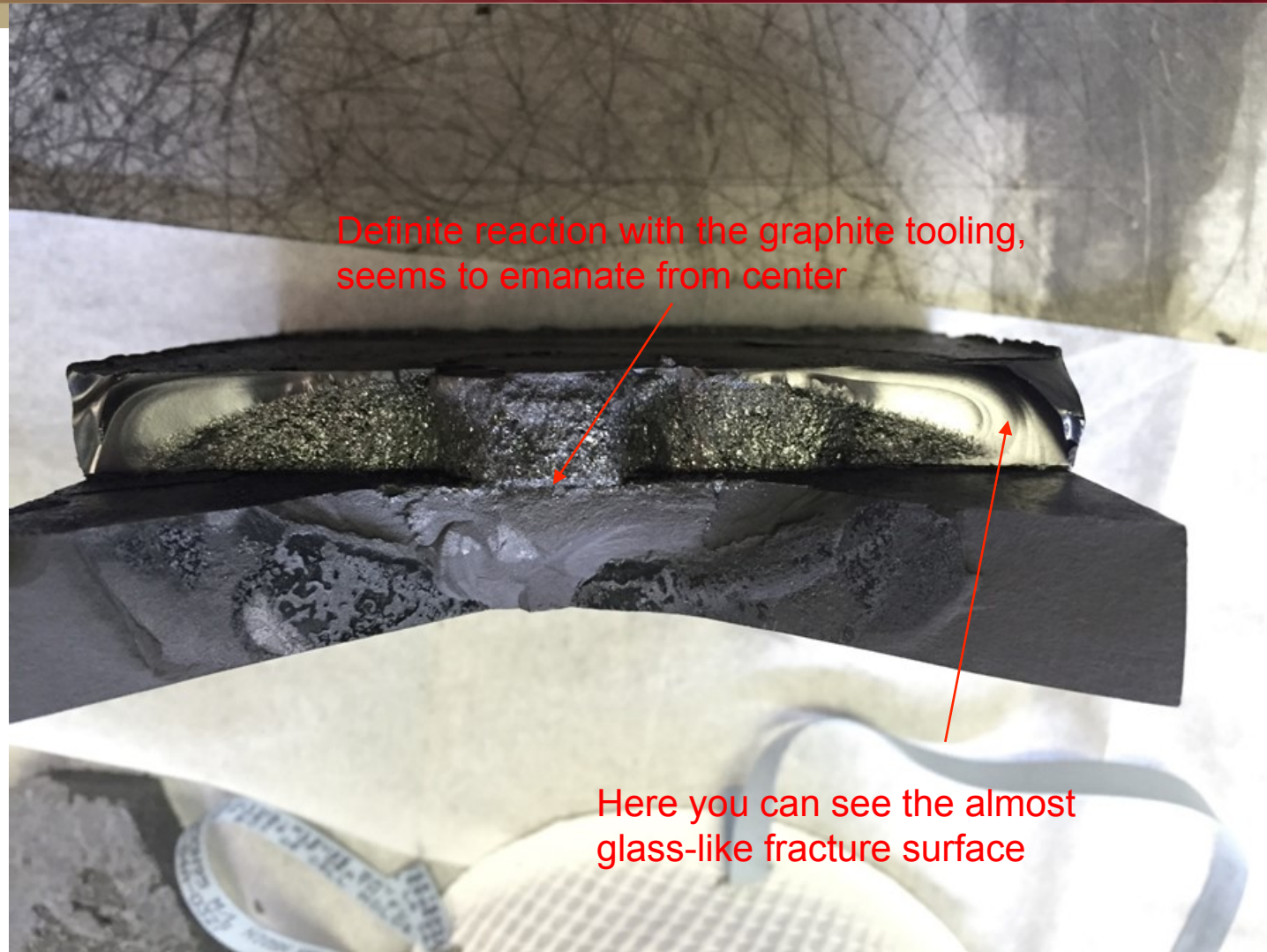


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B₄C Anomaly



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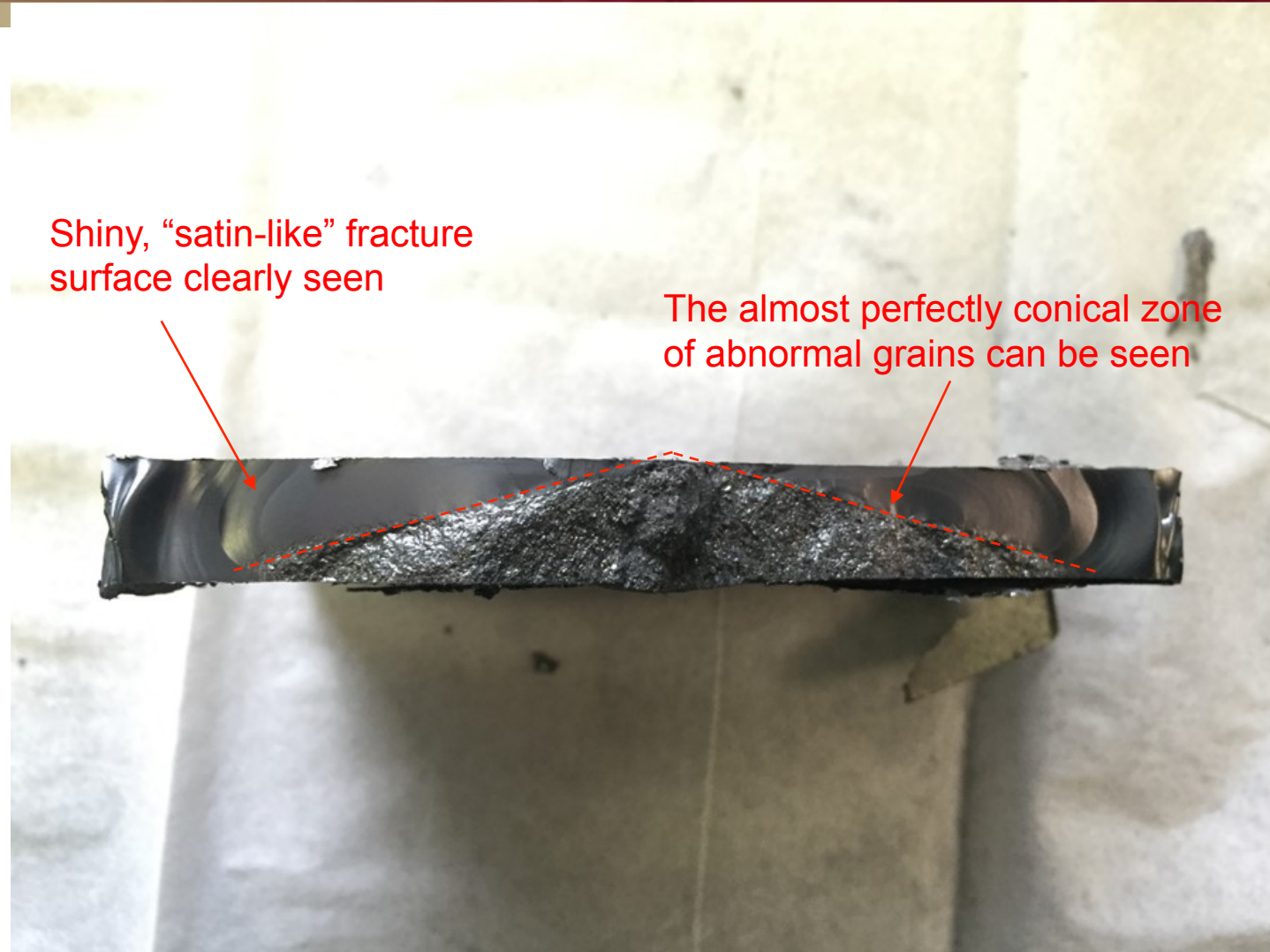


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B₄C Anomaly



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Overheating



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Conclusions



- FAST is a highly emerging technology, however there are major challenges with scale up
- It's applicability to DoD applications has been matured significantly over the past 5 years
- While FAST is starting to be utilized in industry, the fundamental mechanisms are still not completely understood (needs significant investment in M&S)
- FAST is quickly maturing into viable manufacturing technology for NNS, multifunctional and functionally graded materials

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Acknowledgements



- Funding for a majority of this work was from an OSD DMS&T program on Field Assisted Sintering Technology.
- Mr. Robert Aalund from Thermal Technology LLC for FAST/SPS locations and conversations on automation
- Mr Kendall Mills for being the “boots on the ground”



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