RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

Defining Microstructural Tolerance Limits of Defects for SiC Armor – Jointly Funded with MCOE

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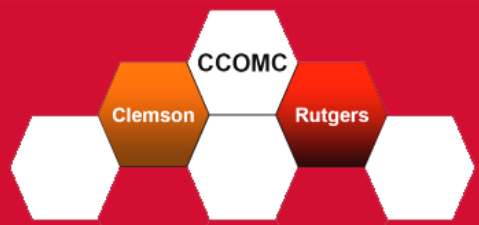
Ceramic, Composite, and Optical Materials Center
An NSF Industry/University Cooperative Research Center



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Long Range Objectives

- To correlate the relationship of non-destructive evaluation with microstructure for sintered SiC plates

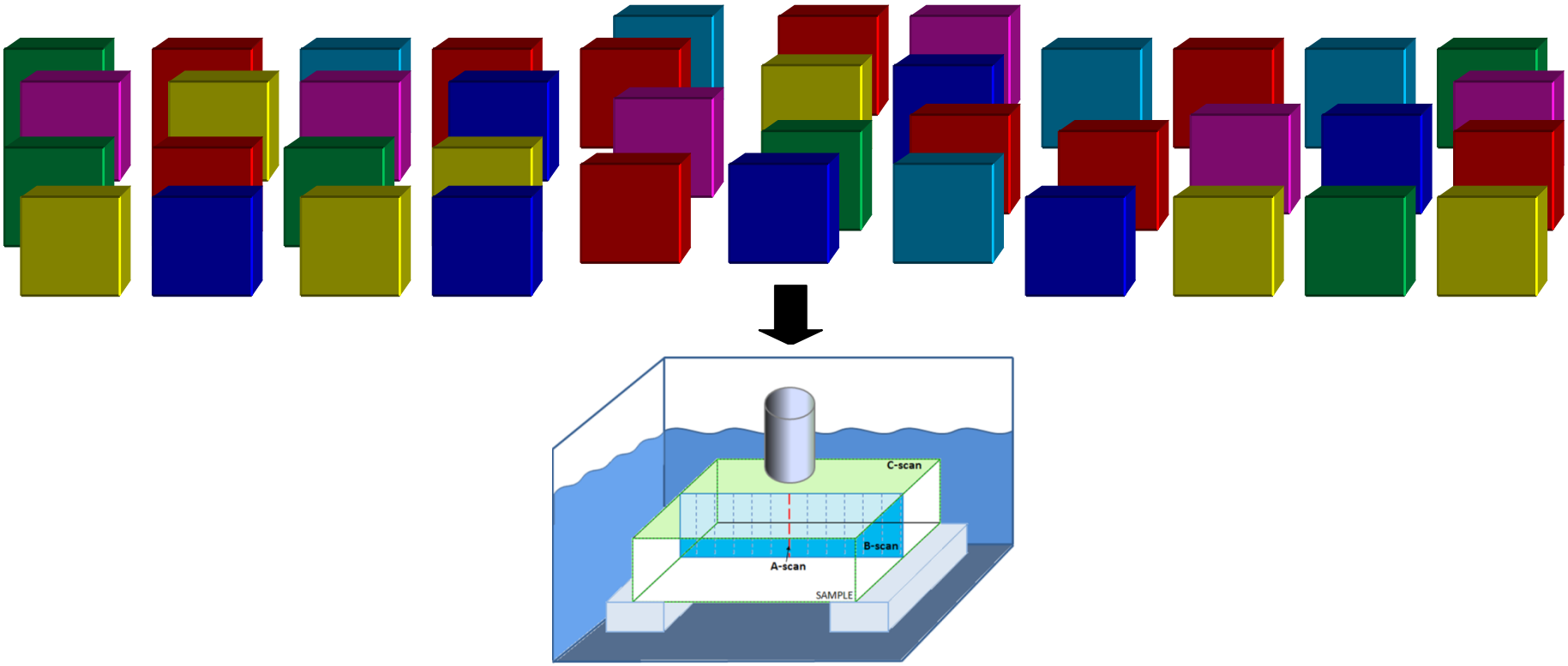
- To quantify the effect of microstructural variability in SiC materials on static properties

Defining Microstructural Tolerance Limits of Defects for SiC Armor

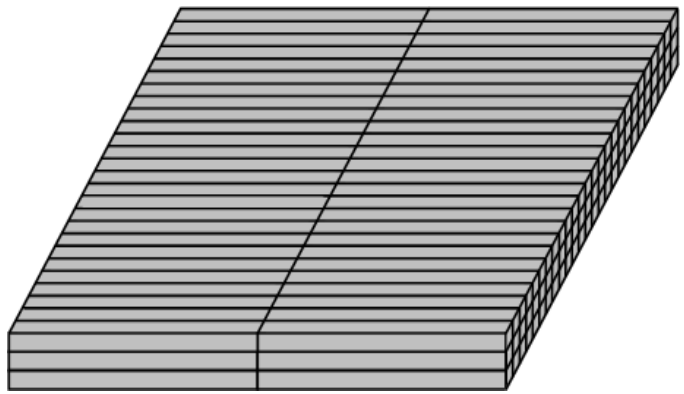
Testing Plan

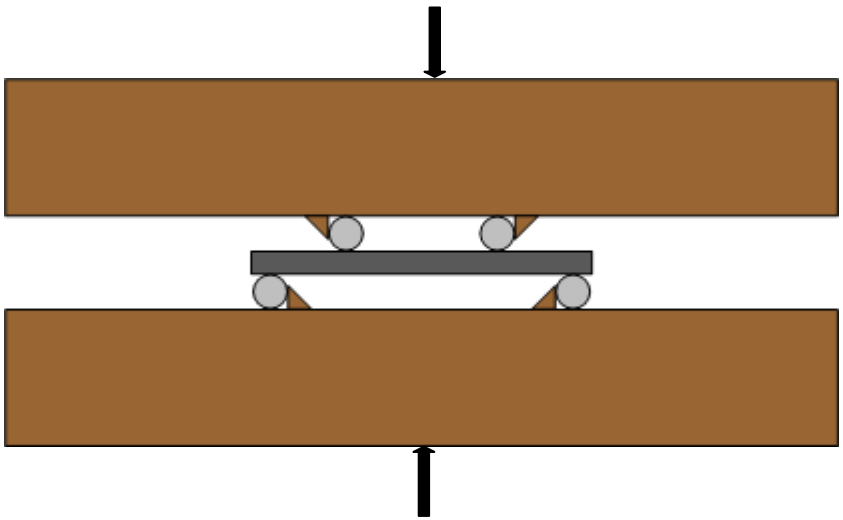
- Objective 1: Define Sample Sets for Experimentation
- Objective 2: Establish Parameters for Comparison
- Objective 3: Determination of Correlation

Commercial Samples



Mechanical Testing of Samples



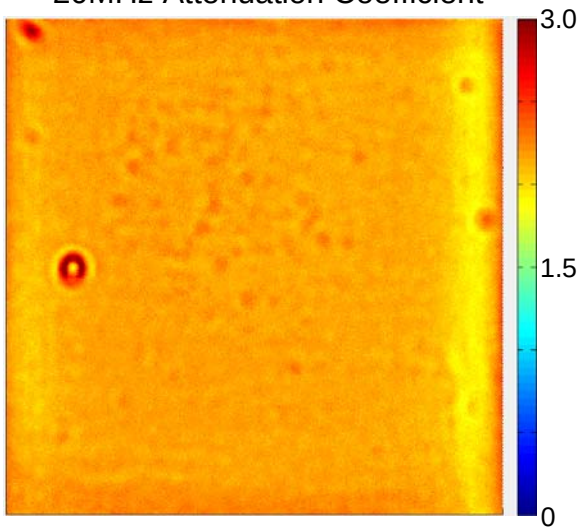


Tile A

Layer	Avg (MPa)	Std dev (MPa)	m
Top	452	47	11.5
Middle	454	56	9.7
Bottom	450	49	10.9
Entire Tile	453	50	10.9

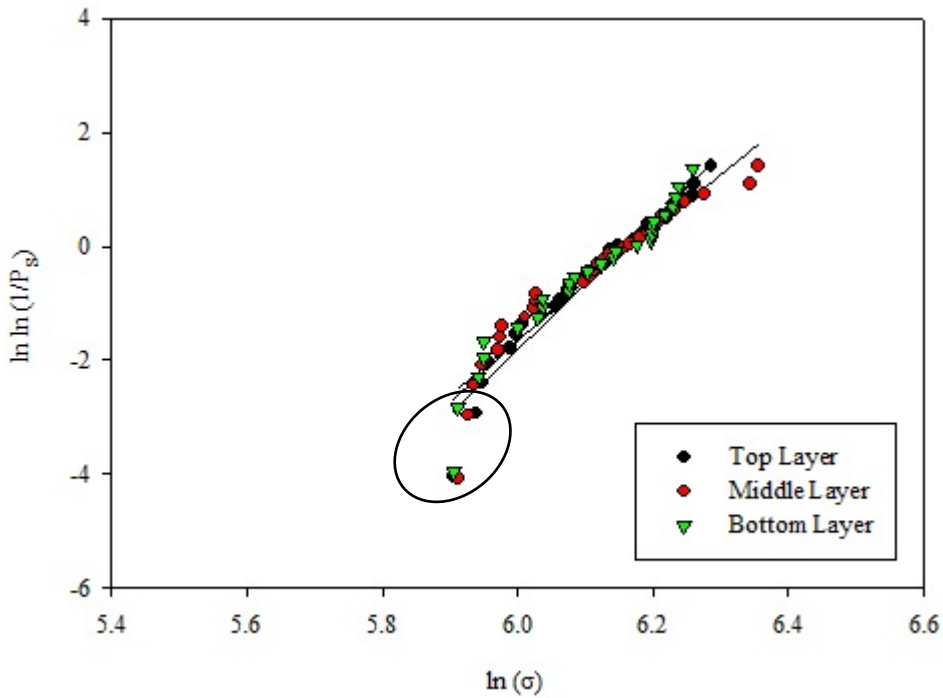
- Tile A → lowest average flexure strength
  → lowest average attenuation coefficient

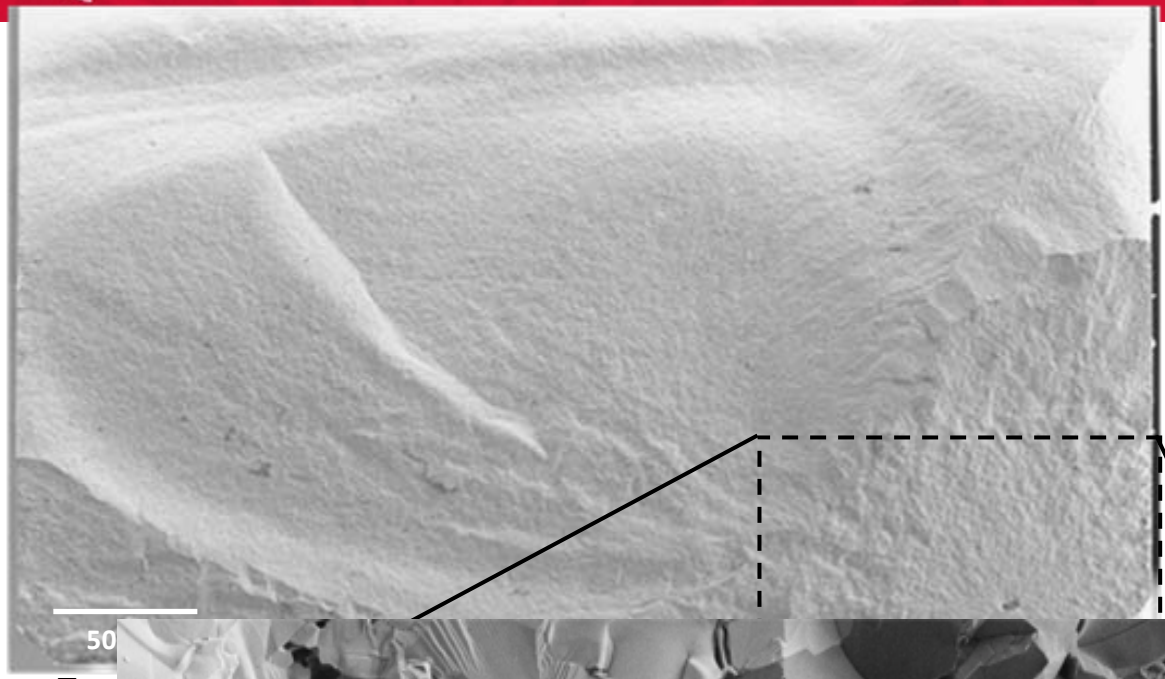
20MHz Attenuation Coefficient



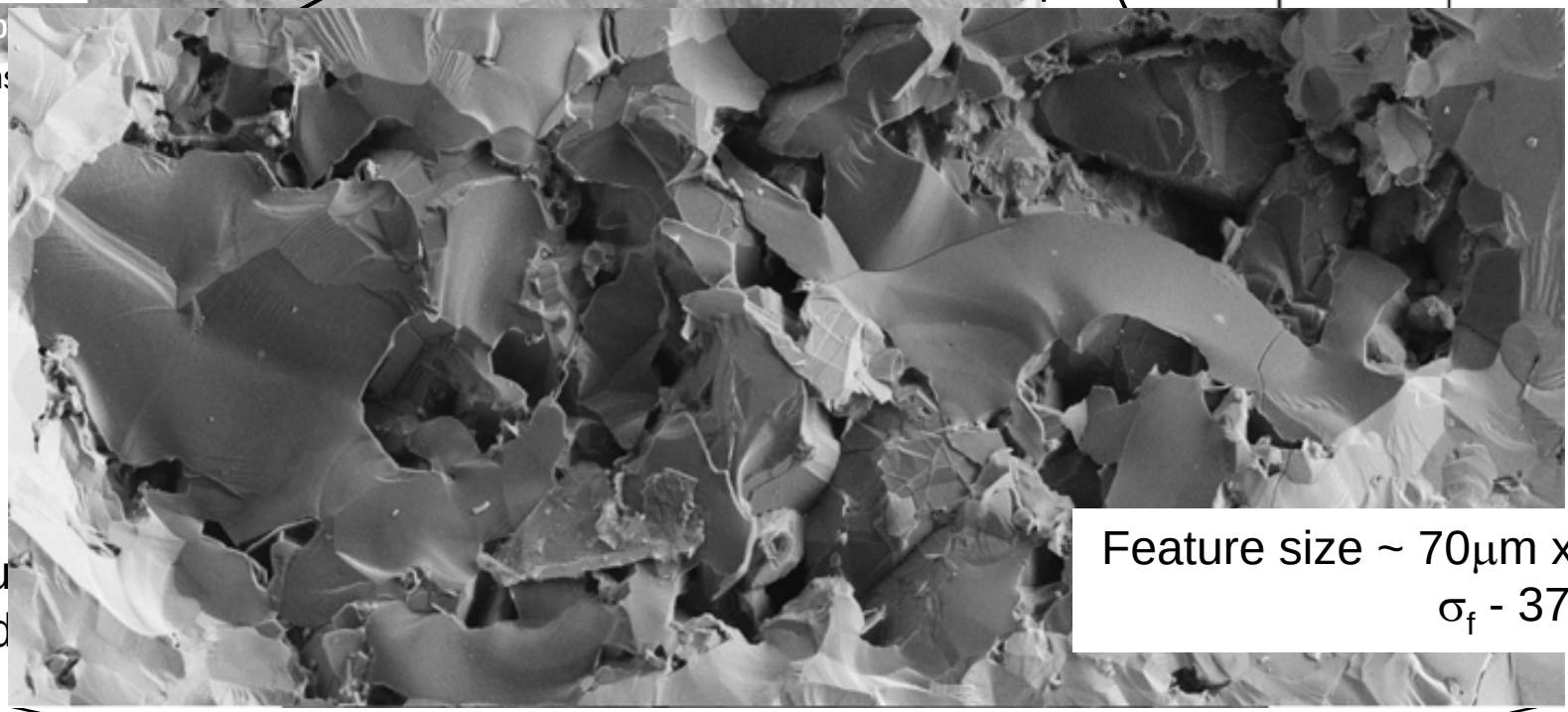
Group D – Low Mean Attenuation Coefficient

Avg – 2.15 dB/cm





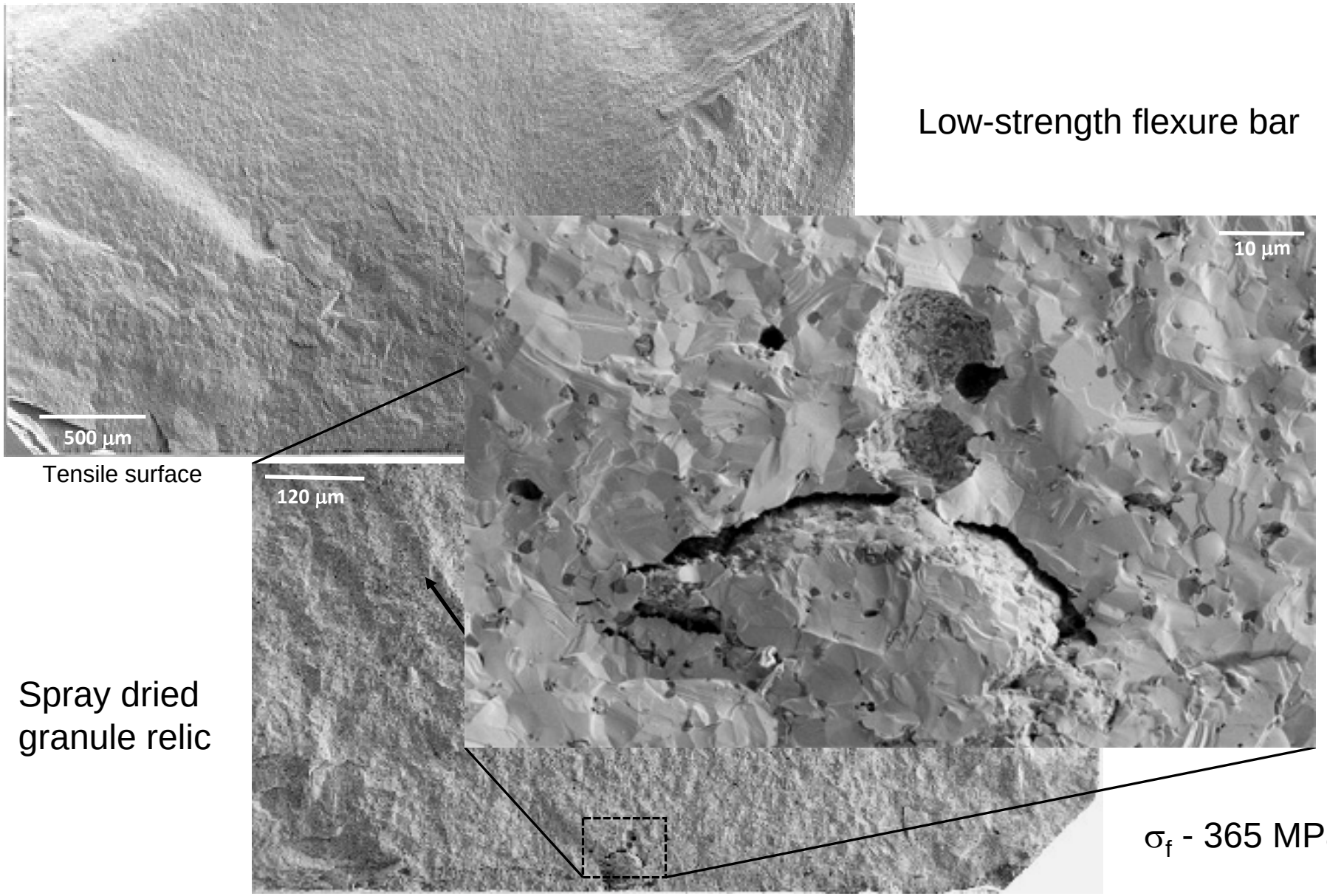
Low-strength flexure bar



Feature size ~ 70μm x 30μm
σ_f - 378 MPa

Porou
carbid

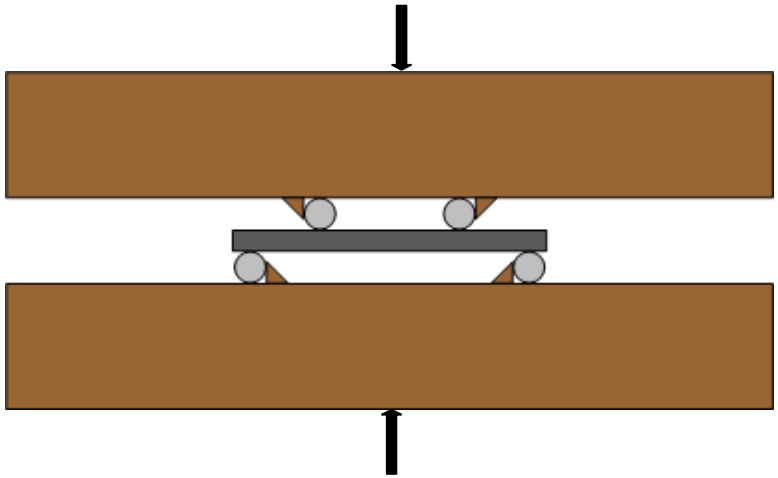
Low-strength flexure bar

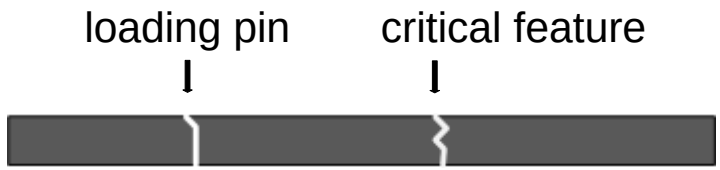


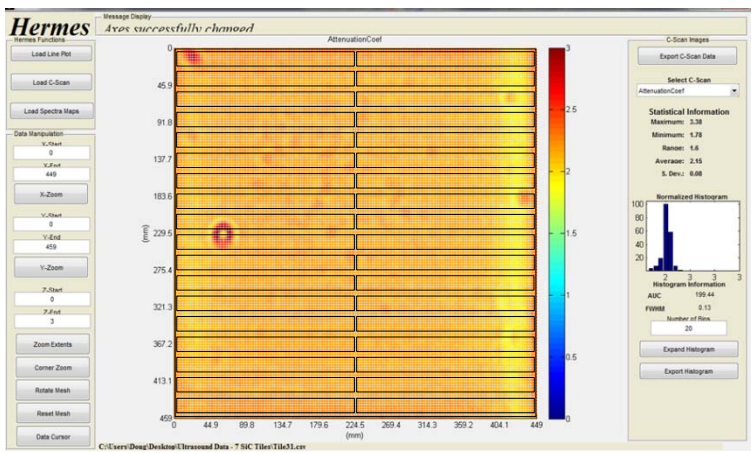
Spray dried granule relic

σ_f - 365 MPa

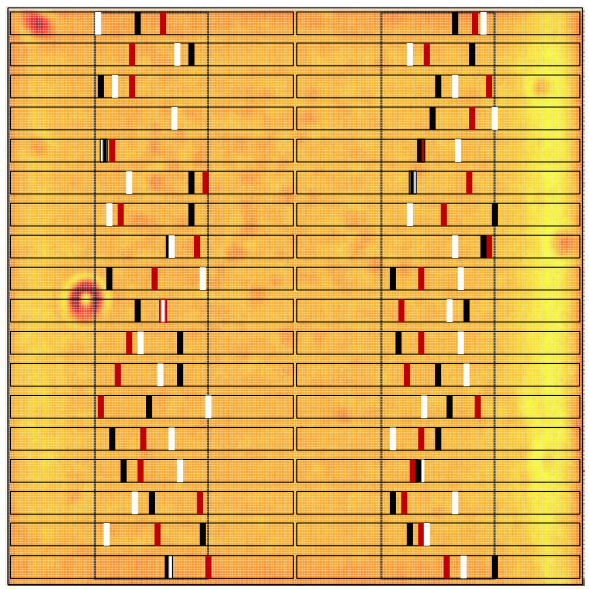
Post Testing Analysis and Correlation Evaluation

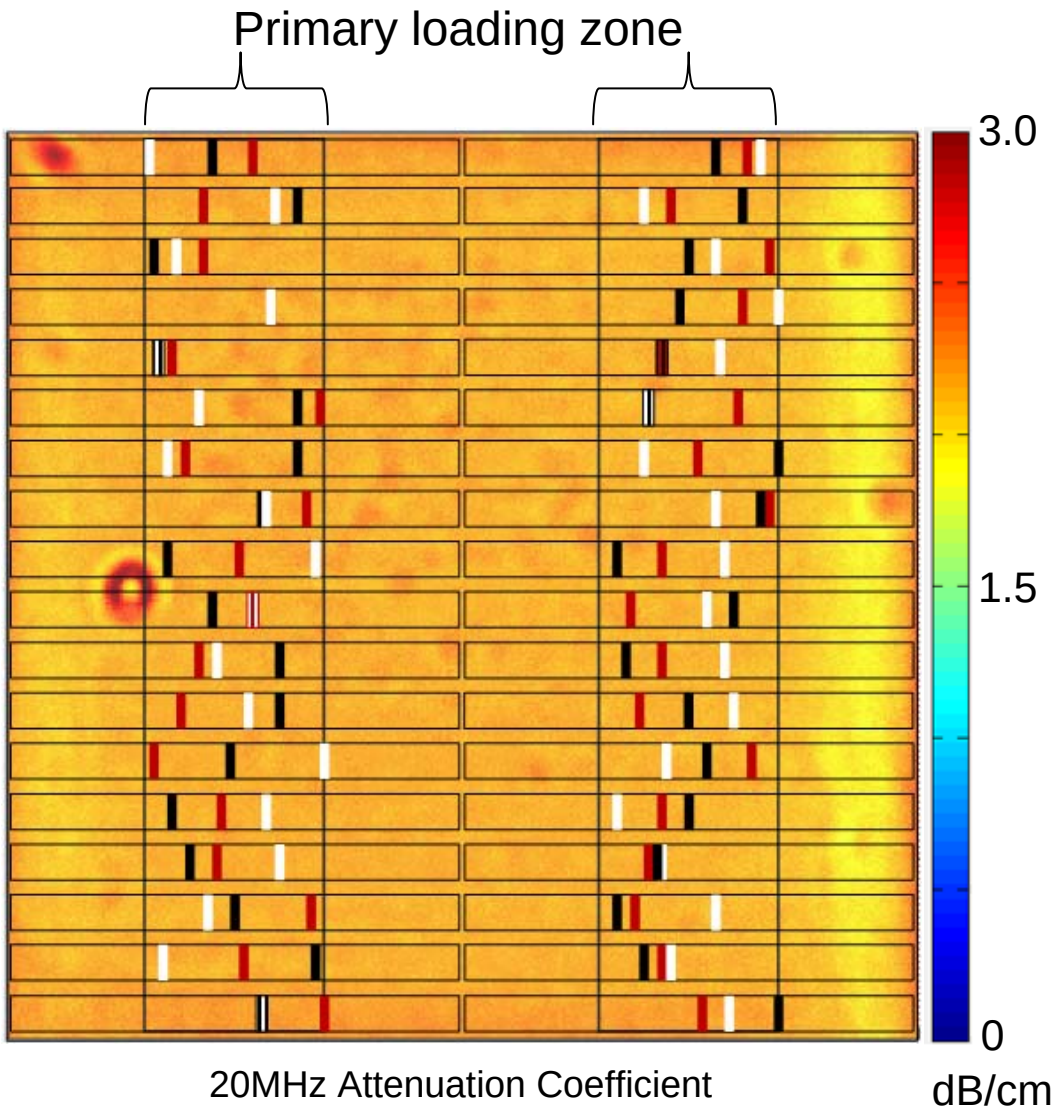






and





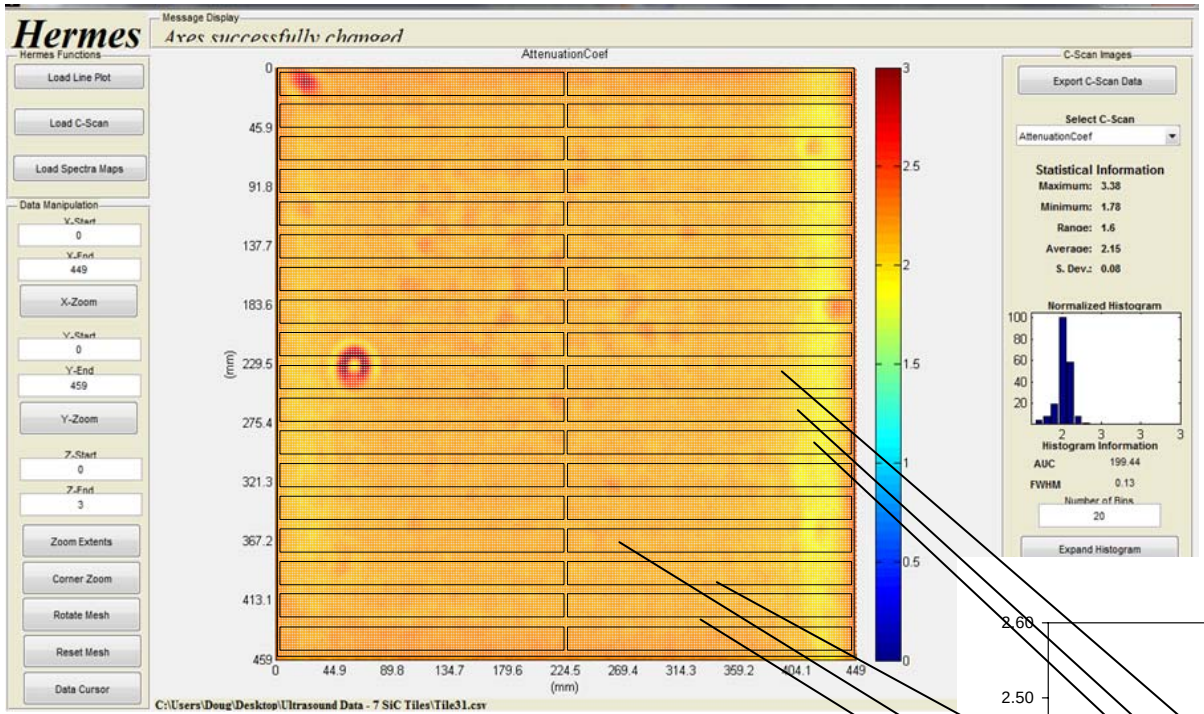
Fracture Position Indicators

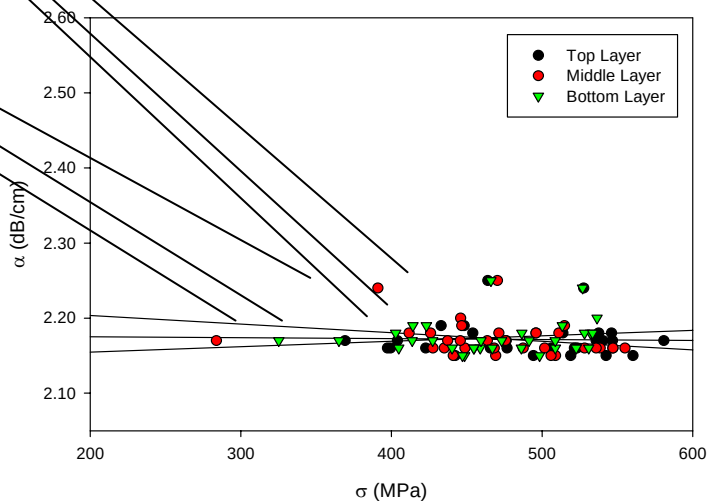
Top Layer - **Black**

Middle Layer - **Red**

Bottom Layer - **White**

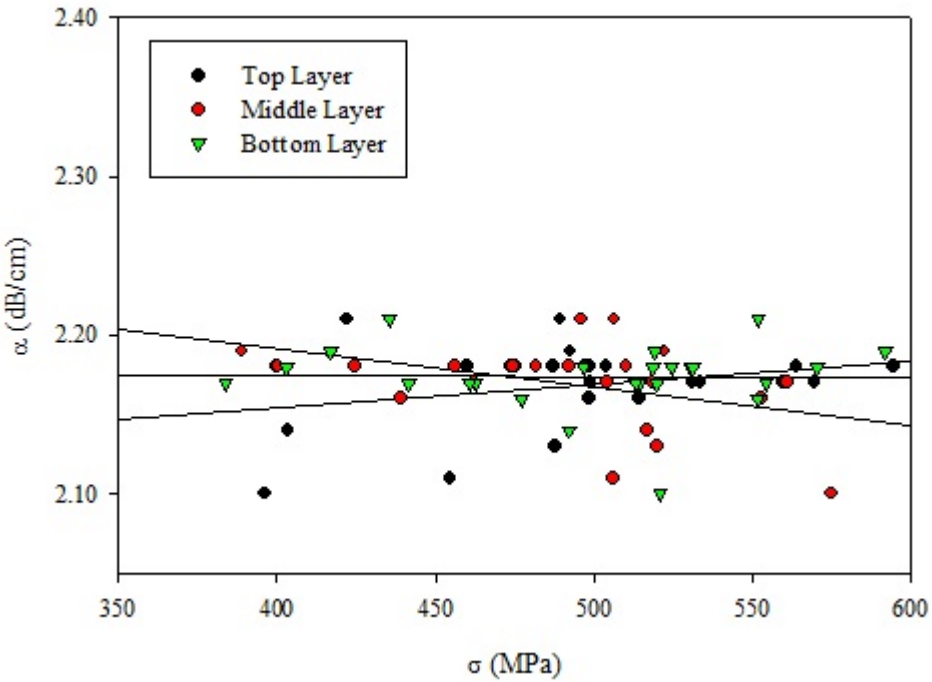
Attenuation coefficient (α) vs. MOR





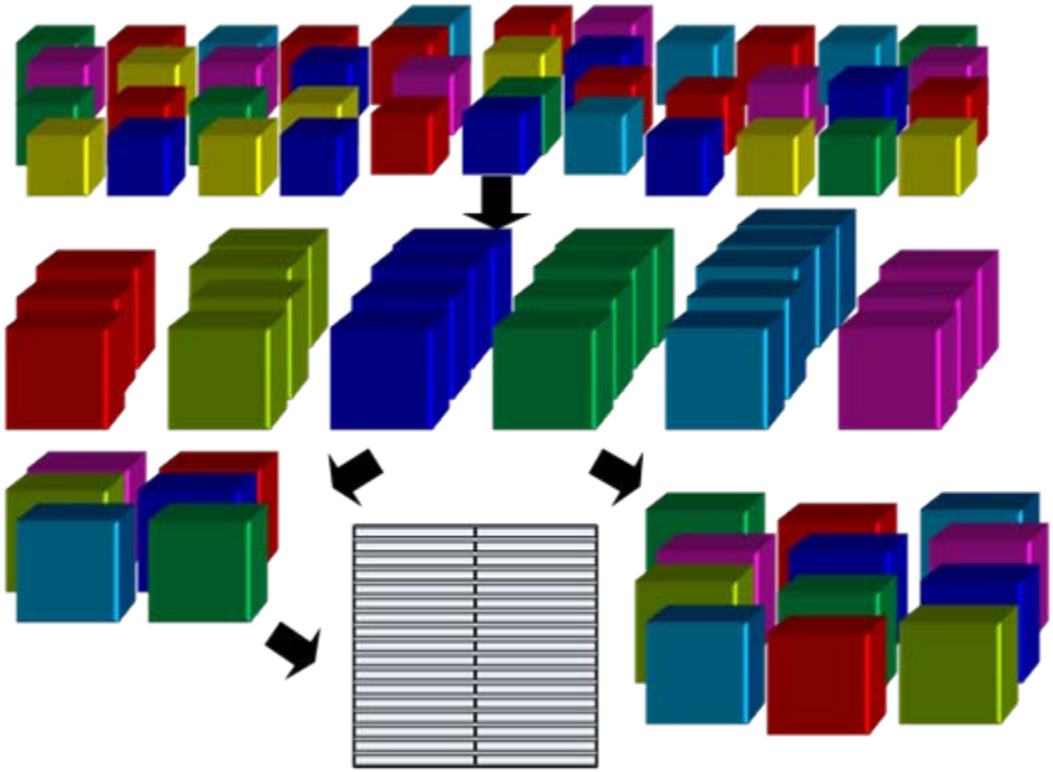
Attenuation coefficient (α) vs. MOR

Tile A



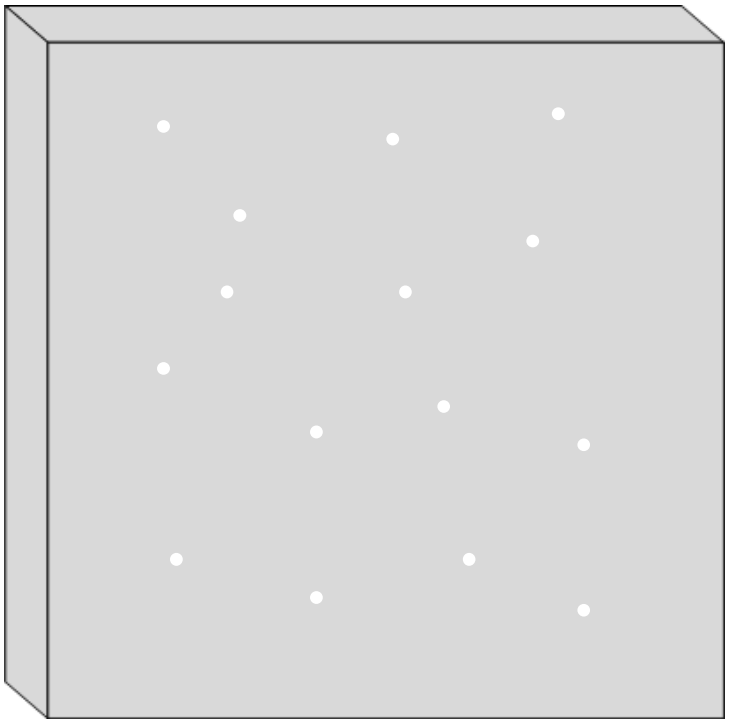
- Average value of attenuation coefficient $\longrightarrow$ 2.15 dB/cm
- Standard deviation of attenuation coefficient $\longrightarrow$ 0.05 dB/cm
- Detectable variation within attenuation coefficient measurement $\longrightarrow$ 0.05 dB/cm

	b_1	R^2
Top Layer	4.00E-06	7.00E-05
Middle Layer	-2.00E-05	1.40E-03
Bottom Layer	2.00E-04	1.11E-01



- Study performed on ‘good’ commercially available tiles
- Expected to determine corresponding difference in mechanical properties and NDE results

- NDE results show that there was not enough detectable variation amongst the tiles used in the study
- Need to manufacture/alter samples such that there was a difference - Targeted Samples



Route I
Reduced-Density SiC tiles

- Stage I tiles were fully-dense commerical samples
- Inclusion of additional porosity
  → detrimental affect on strength and increased acoustic attenuation

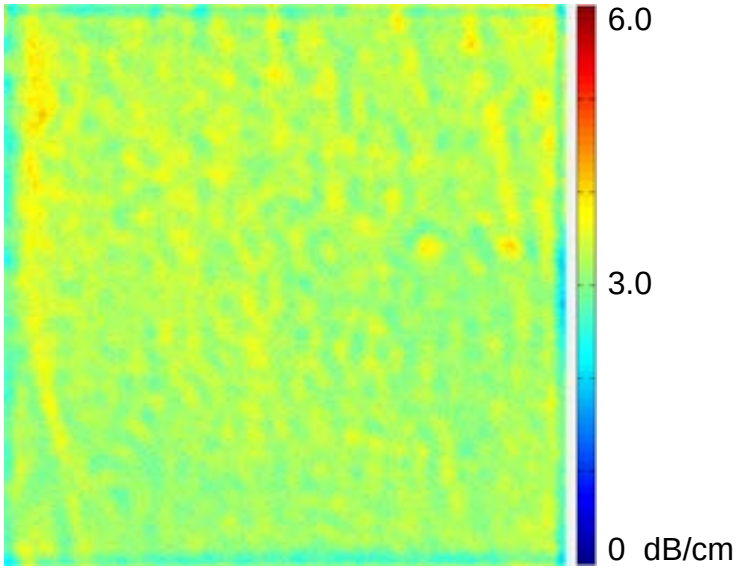
- Tiles pressed to a lower green density
- Standard firing cycle
- Intent → tile with increased porosity

Route I
Reduced-Density SiC tiles

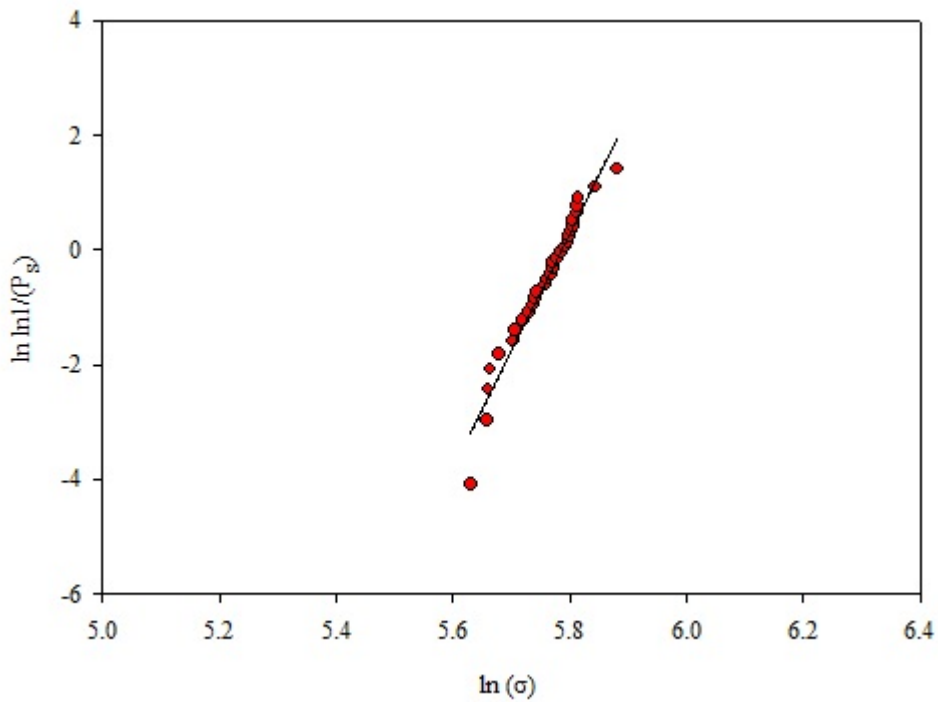
- 3 tiles were produced
- 60 x 60 x 6 mm

	Tile 1	Tile 2	Tile 3
Bulk Density (g/cm^3)	3.08	3.09	3.09

- Average of original lot of 41 tiles 3.16 g/cm^3



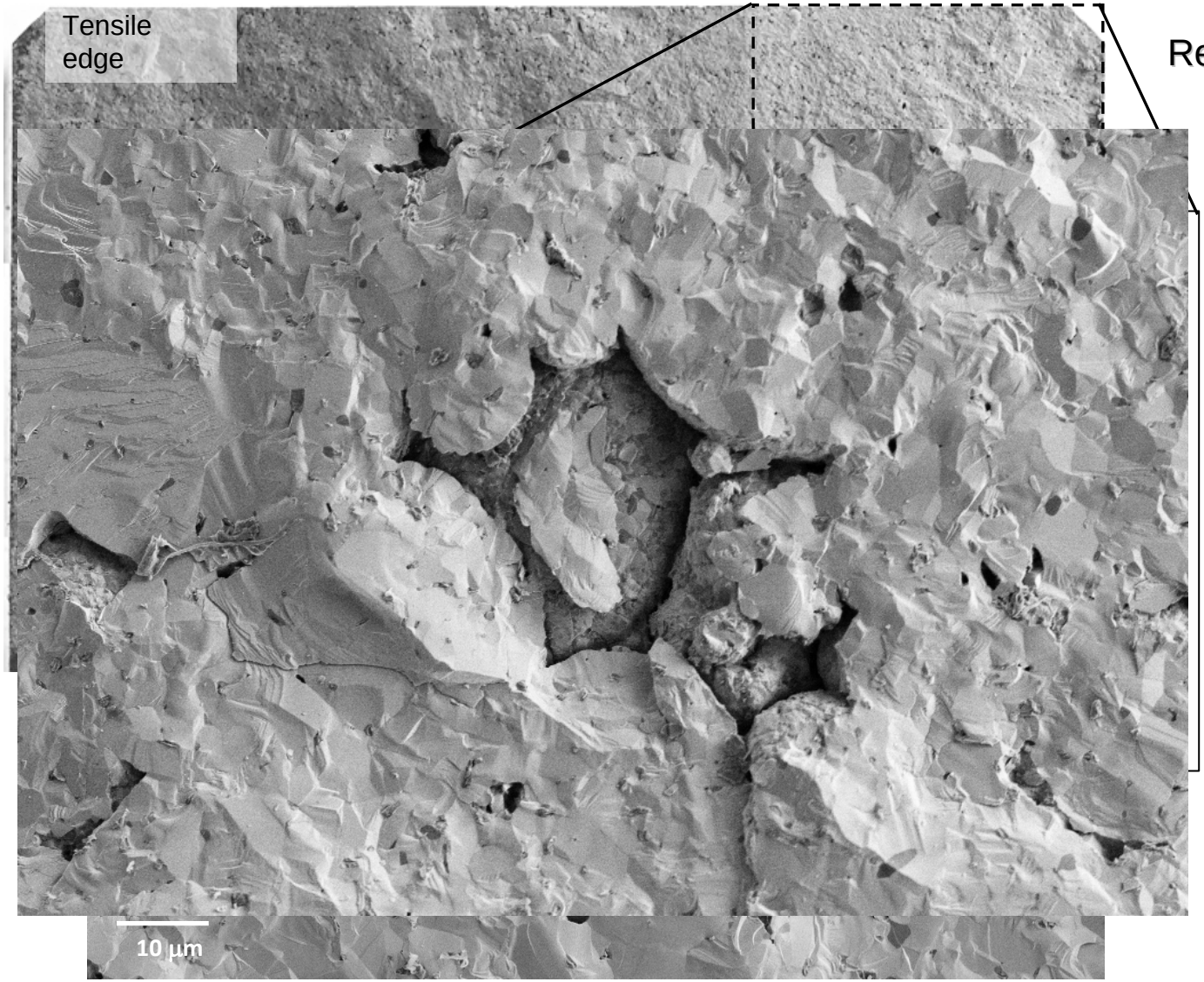
20MHz Attenuation Coefficient
Avg - 3.26 dB/cm



	Avg (MPa)	Std dev (MPa)	m
Tile 1	306	17	-
Tile 2	324	18	-
Tile 3	322	18	-
Three Tiles	317	19	20.4

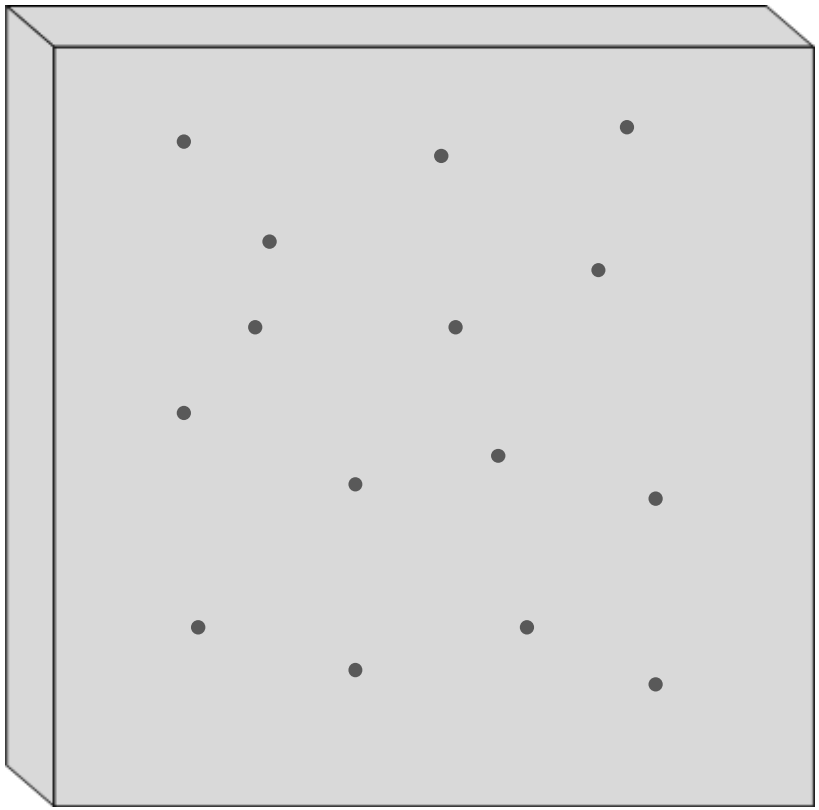
Route I
Reduced-Density SiC tiles

Route I
Reduced-Density SiC tiles



- Increased residual porosity
- Partially compacted spray dried granule relic

σ_f - 287 MPa



Route II
Enhanced Boron Content SiC tiles

- Flexure bar fracture → agglomerates of boron carbide sintering aid

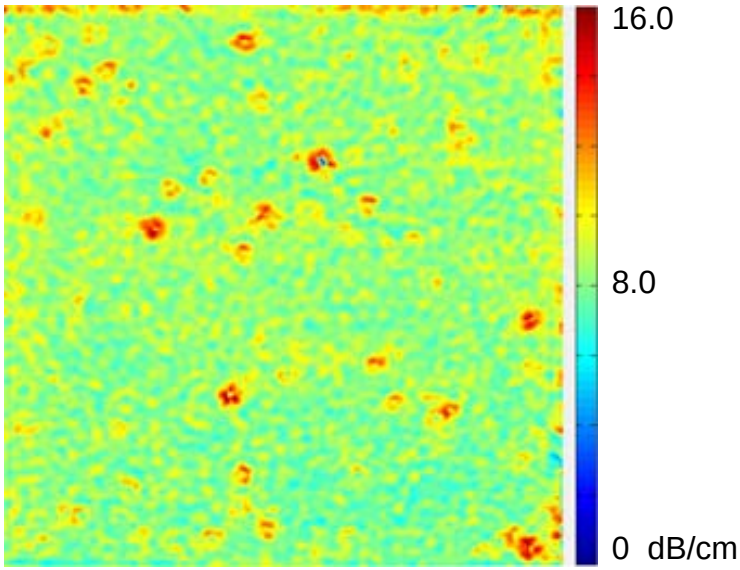
- Spray-dried boron carbide fines added to batch
- Tiles undergo standard firing cycle

Route II
Enhanced Boron Content SiC tiles

- 2 tiles were produced
- 101 x 101 x 6 mm
- 3.0% boron content
  (0.6% for commercial tiles)

	Tile 1	Tile 2
Bulk Density (g/cm^3)	3.14	3.14

- Average of original lot of 41 tiles 3.16 g/cm^3

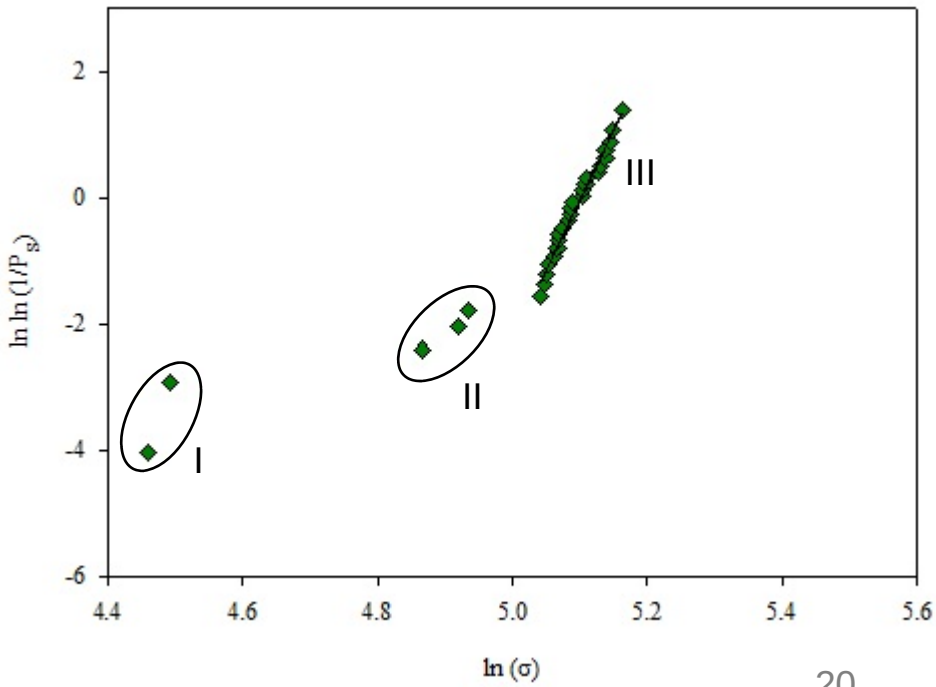


20MHz Attenuation Coefficient
Avg – 8.85 dB/cm

Route II
Enhanced Boron Content SiC tiles

$\sigma_f < 100$	Region I
$100 \leq \sigma_f < 140$	Region II
$140 \leq \sigma_f \leq 175$	Region III

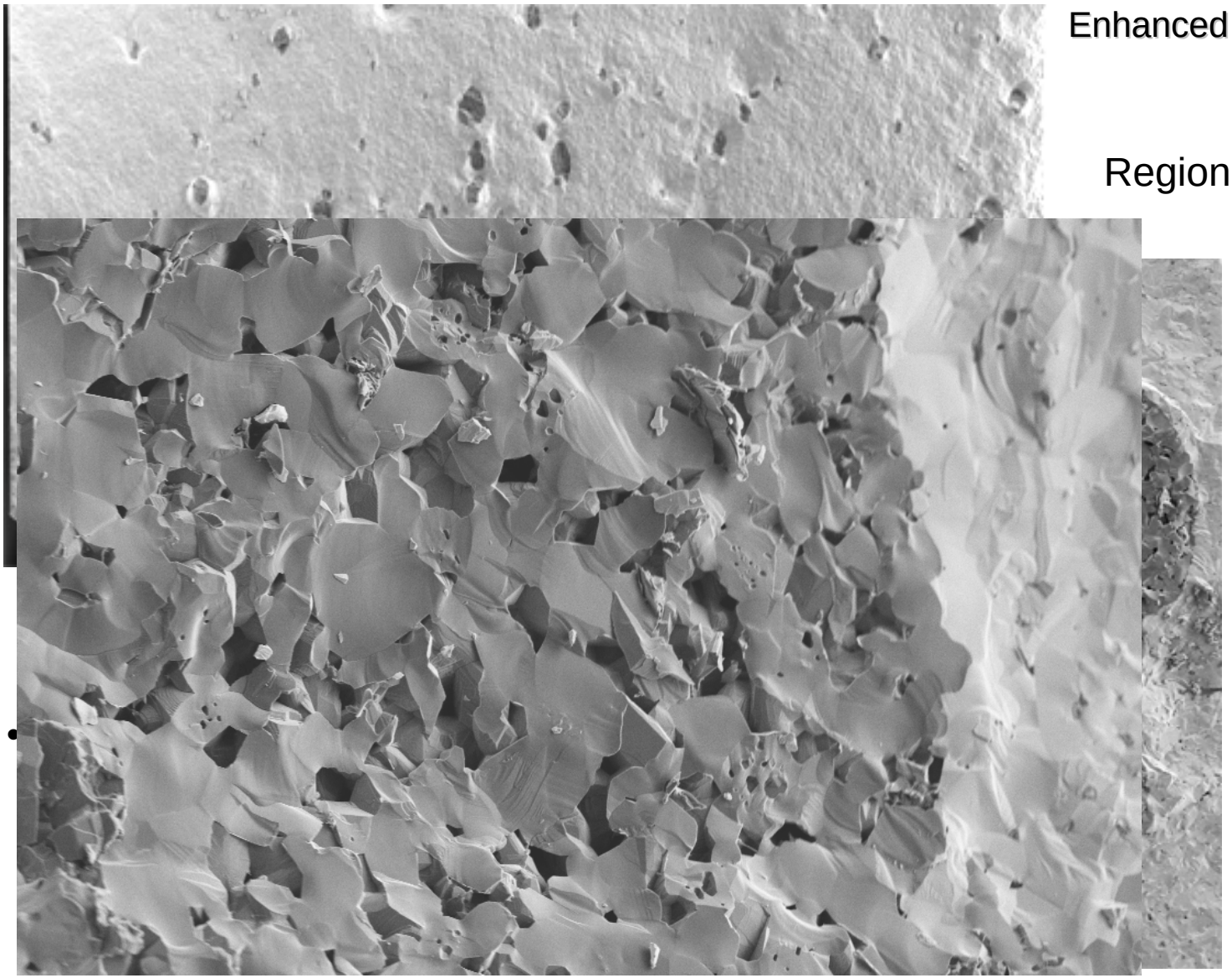
	Avg (MPa)	Std dev (MPa)	m
Tile 1	152	22	-
Tile 2	159	21	-
Three Tiles	155	21	22.2



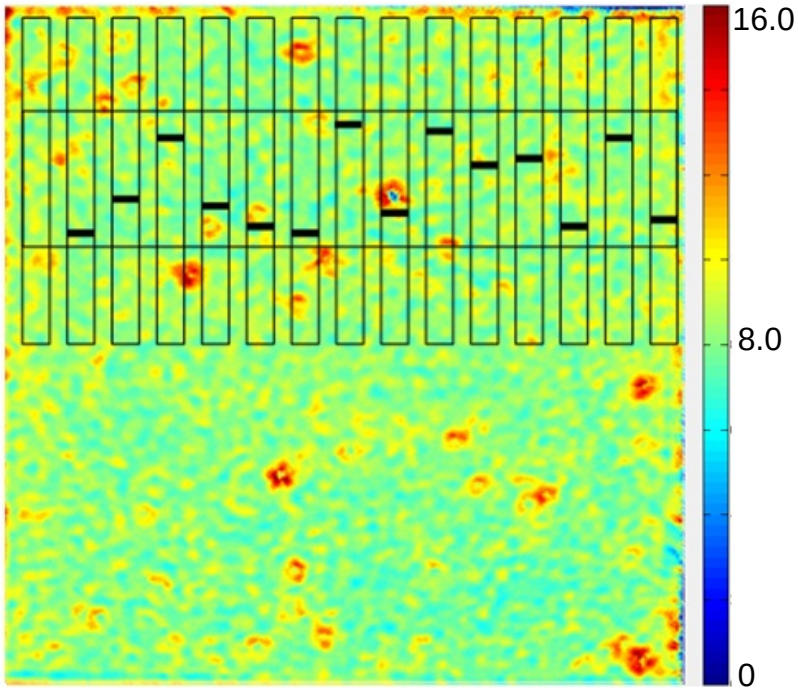
Route II

Enhanced Boron Content SiC tiles

Region II flexure bar

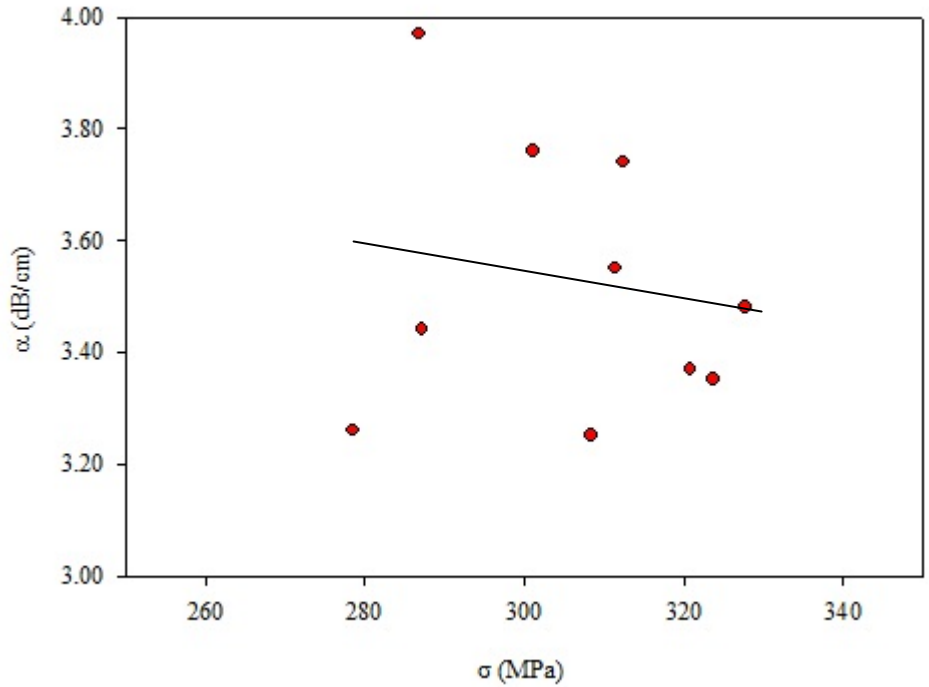


σ_f - 130 MPa



Enhanced Boron Content Tile B

	b_1	R^2
Reduced Density	-2.60E-03	3.24E-02
Enhanced Boron Content	-1.00E-05	2.00E-06



Reduced Density Tile B

Qualitative and Quantitative NDE Analysis

Summary and Conclusions

	σ_f (MPa)	$\alpha_{20\ MHz}$ (dB/cm)	ρ (g/cm^3)
Commercial samples	485	2.20	3.16
Reduced Density	317	3.25	3.08
Enhanced Boron Content	155	8.65	3.14

- The contributions of individual strength limiting features were not resolved in the ultrasound scan maps
- However, variations in bulk microstructure corresponding to the three sample sets were represented in the attenuation coefficient values

Acknowledgements

- We would like to thank the NSF/IUCRC - Ceramic, Composite, and Optical Materials Center (CCOMC) as well as the US Army Research Laboratory - Materials Center of Excellence (MCOE) for funding this research
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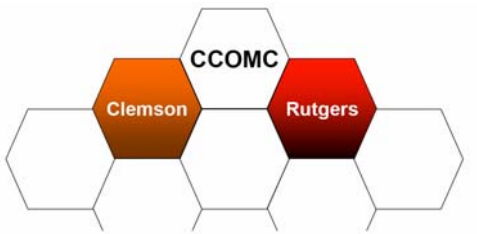
- The author wishes to thank Nikolas Ninos for preparation of samples



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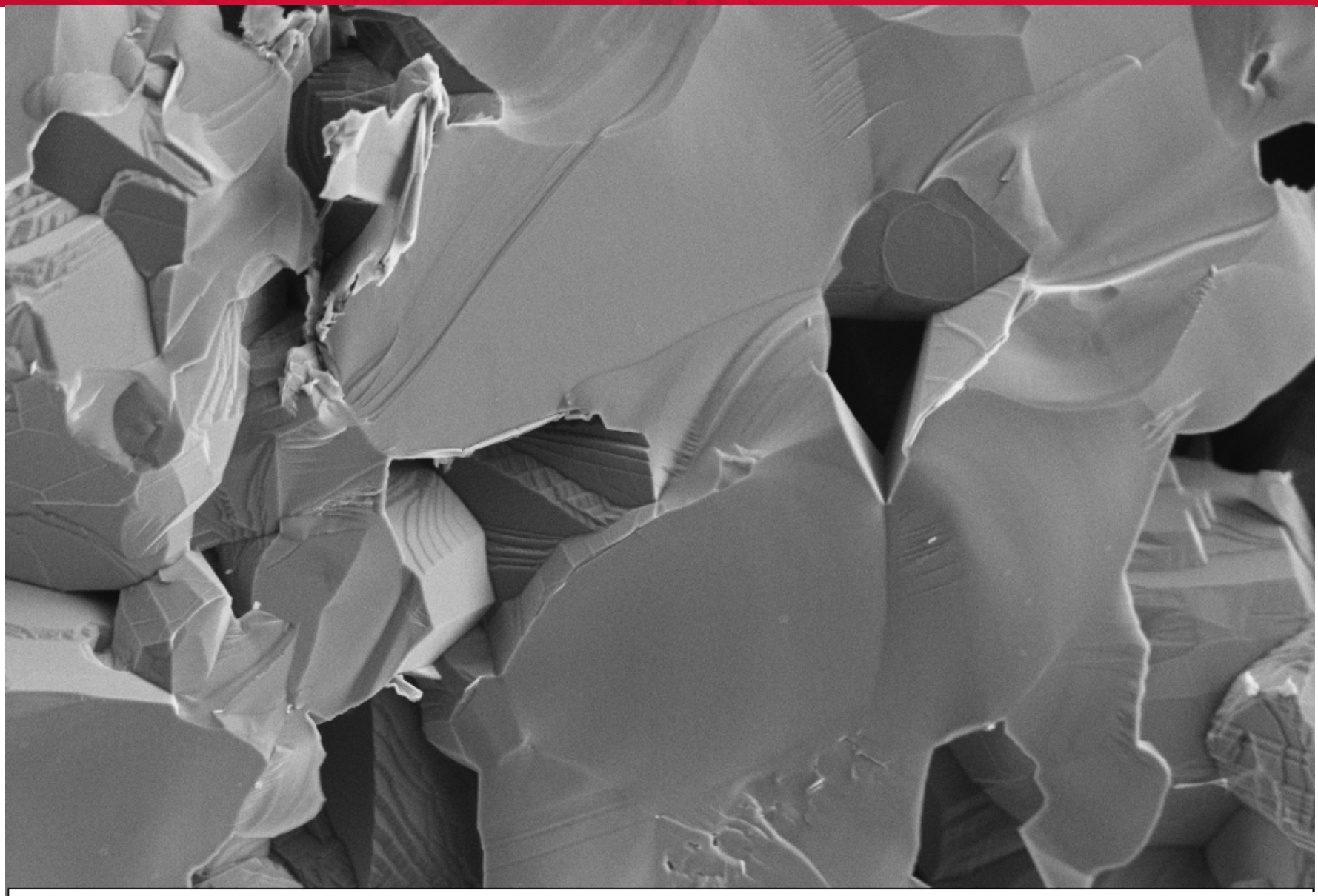
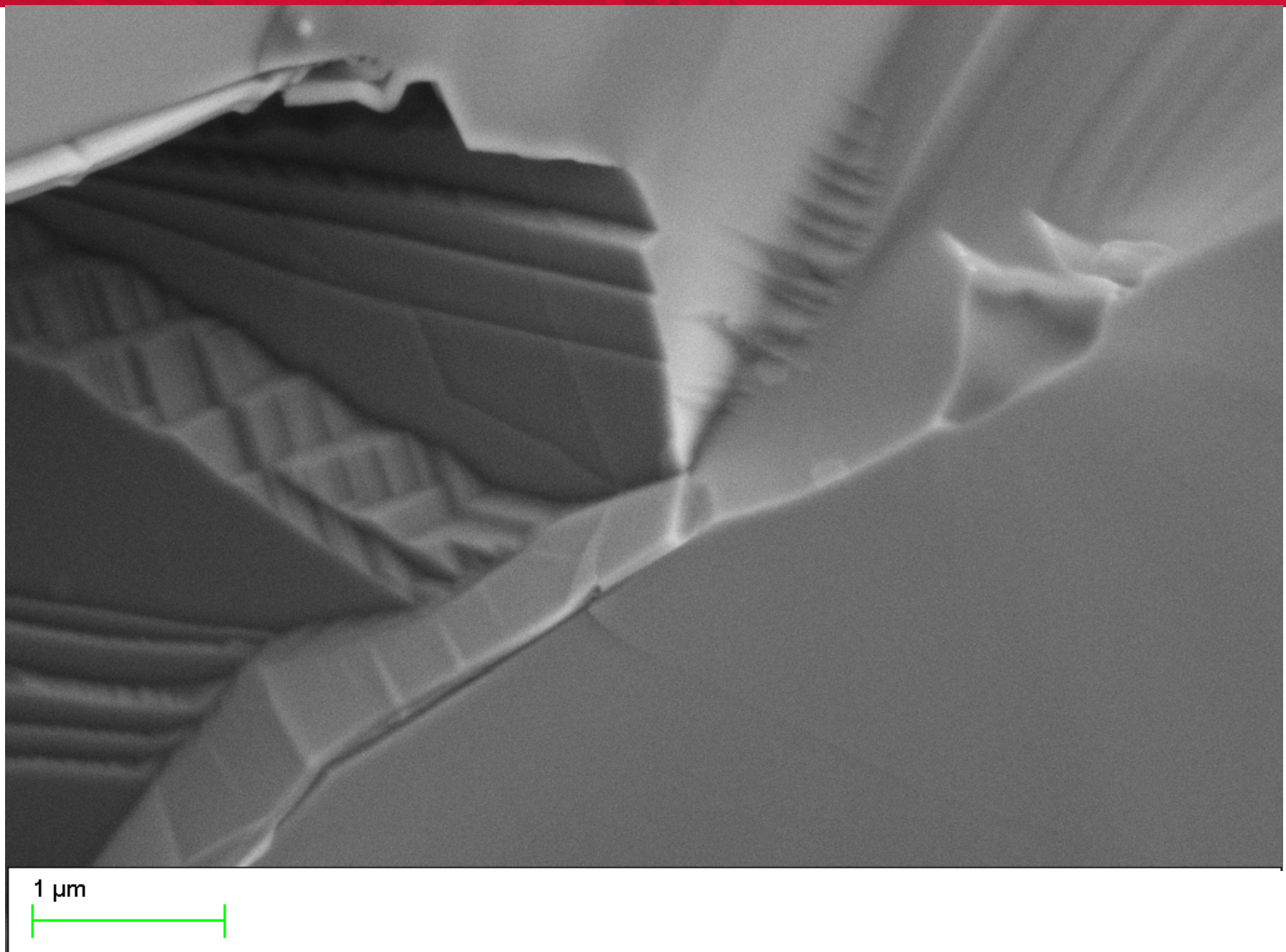
Questions?


1 µm


1 µm