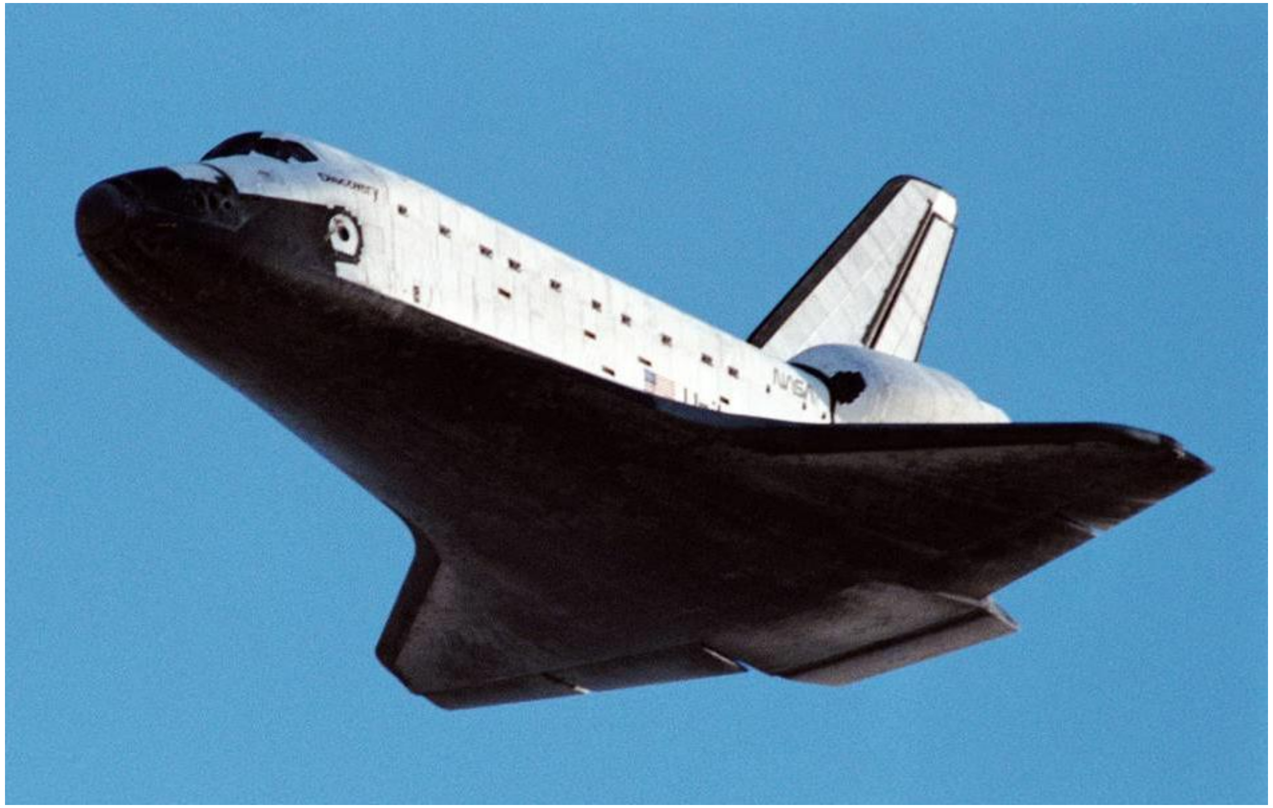
Modernization of Insulative Reusable Thermal Protection Systems (IRTPS)

Adam Caldwell[1]
Peter Marshall[1], Jay Feldman[1], Jose Chavez-garcia[2], Kyle Hendrickson[2]
Audrey Turcotte[2], Tiffany Alcantara[2], Chris Swaiss[2], Adam Bebak[2]
[1]NASA Ames
[2]Analytical Mechanics Associates
[3]Oak Ridge Associated Universities

Outline

- Reusable Thermal Protection Materials Background
- Motivation & Goals
- IRTPS Modernization
  - Initial Production
  - Process Investigation
  - Example Modifications
- Summary



Space Shuttle Discovery approaches for landing on a concrete runway at Edwards Air Force Base (1990)

Background

- The Space Shuttle Orbiter's thermal protection systems (TPS's) are the *flight proven starting point* for reusable entry systems
  - Used by the Orion capsule for its backshell but for fundamentally different reasons
  - The last decade has seen renewed interest in reusable TPS from the dramatic growth in commercial space
- Reusable, insulating TPS were developed extensively for Shuttle and some for the X-37B, but little else until recently
- Gap between the Shuttle efforts and now:
  - Loss of personnel, know-how, supply chains, and equipment
  - Reusable insulating TPS were produced using raw materials from lifetime purchases by NASA for the Shuttle Program in the 1990's - called "heritage"
  - This NASA stockpile will be depleted during planned Artemis Orion missions
- Modernization efforts are aligned with NASA's strategic objective to support the commercial space sector

Motivation & Goals

Motivation:

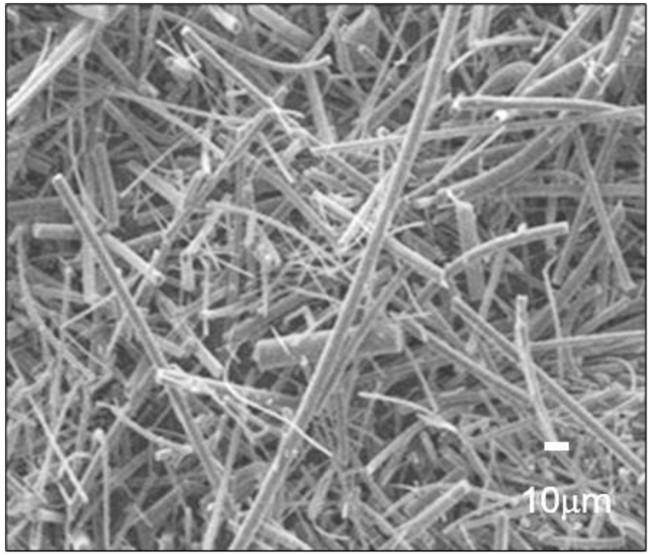
- Early work at TPSF (tile production facility at KSC) and ARC showed that AETB tile produced using modern raw materials vs heritage has reduced material properties, primarily mechanical
- Work is needed to transition to using "modern" raw materials produced today for continued use of AETB by NASA and commercial space

Goals:

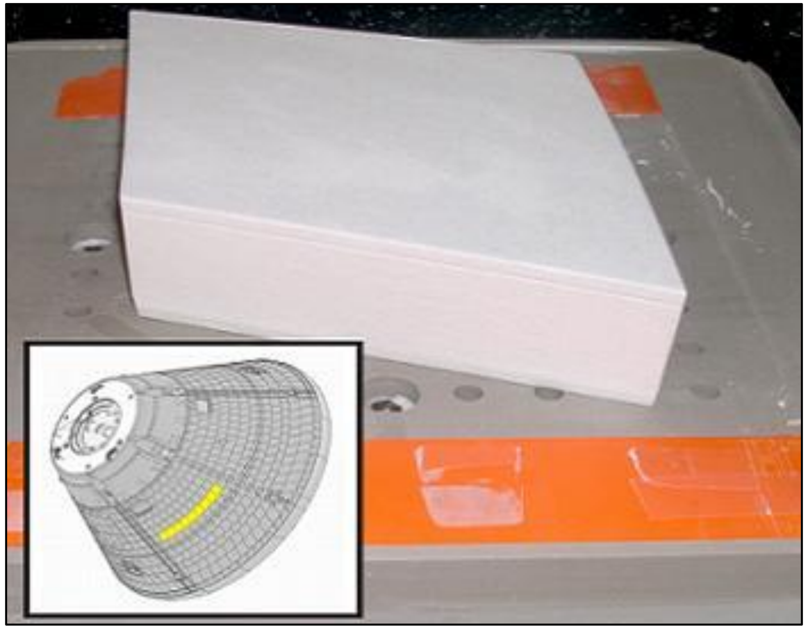
- Implement modern fiber constituents without degraded material properties
- Gain better understanding of the tile casting process/property dependencies to aid the agency and partners

Alumina Enhanced Thermal Barrier (AETB)

- AETB-8, -12, -17, -20 (pcf)
  - Density ranges from 0.13 to 0.32 g/cc
- Consists of:
  - Aluminoborsilicate fibers (Nextel-312)
  - Alumina fibers (Saffil)
  - Silica fibers (Q-fiber)
  - Silicon carbide
- Thermally insulative with ~95% porosity
- Lower thermally induced shrinkage than earlier tile generations (LI- and FRCI)
- <u>Used up to 1537ºC (2800ºF)</u>



SEM image of AETB-8



AETB-8 fabricated for Orion backshell

Tile Manufacturing Overview

Fibers, Water, and Additives

V-Blender

Casting Tower

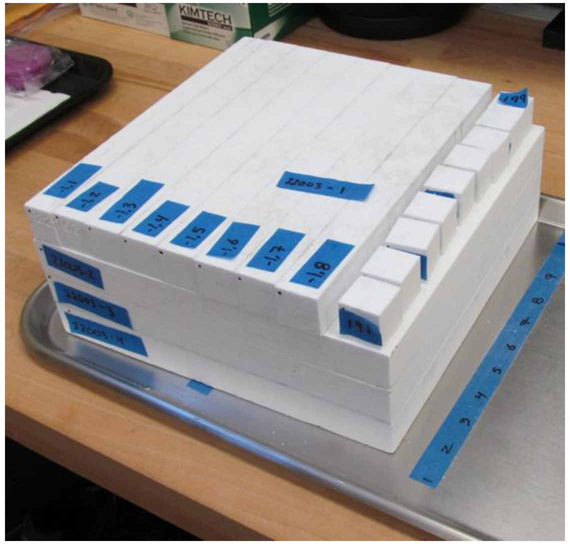
12-inch casting tower

Drying Oven

Furnace

Up to 2400 °F

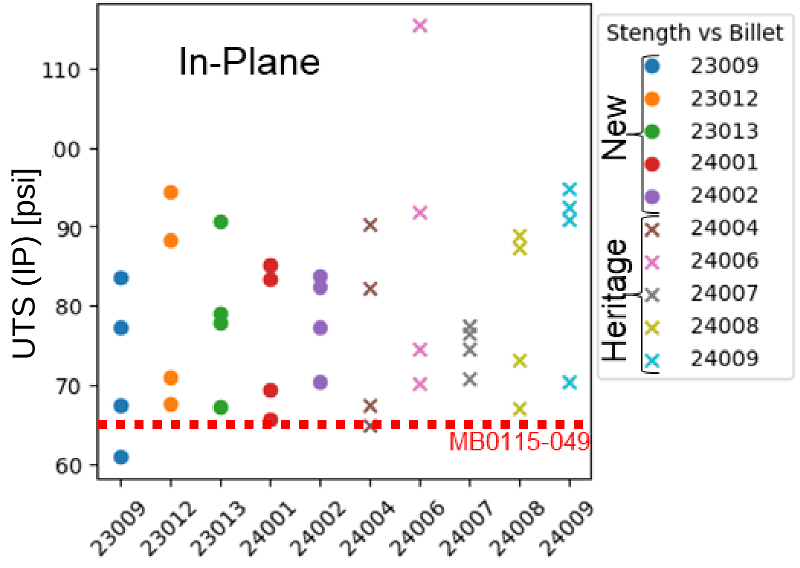
AETB Billet

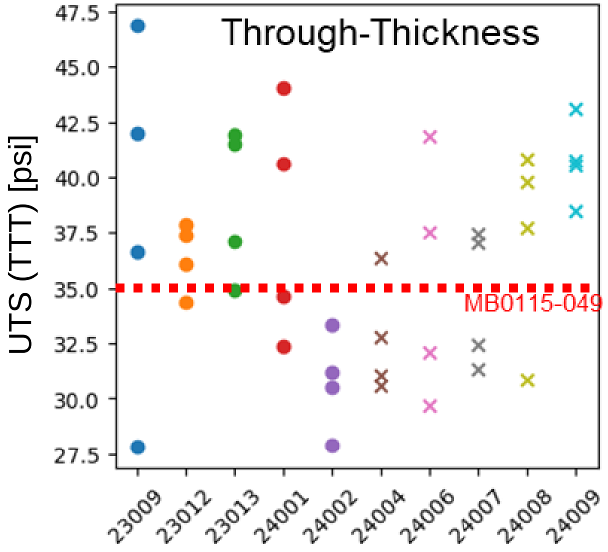


Initial Production Using Heritage vs Modern Fibers

- Observed significant difference in the processing (mixing/casting) from one set/lot of modern to heritage fiber
  - Higher pH and lower cake height (equivalent chop time) for heritage fibers
  - Limited changes to the fibers, per manufactures and in-house characterization
  - No difference in XRD patterns of fired billets
  - Minor processing modifications to accommodate fiber differences (e.g. longer chop time)
- Tensile strengths were statistically equivalent with a 95% C.I.
- Further process investigation is needed to achieve strengths that meet material specs

Fiber Type	Density (pcf)	Direction	UTS (psi)	Sample Count	Shuttle Boeing Spec UTS (psi)
Modern Fibers	7.9 ± 0.1	IP	63.9 ± 5.8	46	All ≥ 65
		TTT	30.7 ± 2.7	75	All ≥ 35
Heritage Fibers	7.8 ± 0.1	IP	63.4 ± 17.0	9	All ≥ 65
		TTT	34.9 ± 6.6	8	All ≥ 35



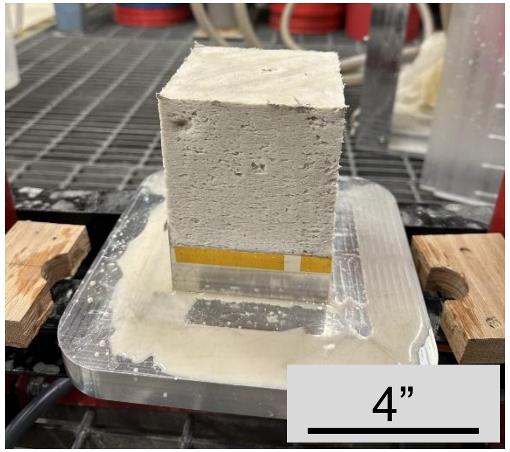


Initial work achieved similar tile properties between heritage and modern fibers, but improvements must be made

Tile Casting Process Investigation

- Explored broad set of process variables to determine impact on properties
- Process variables include:
  - Raw materials (fibers + additives)
  - Blending/chopping
  - Casting compression
  - Firing process (e.g. temperature and duration)
  - Chemistry (pH, surfactants…)
- Evaluated using tensile strength and texture for first order comparison

- 4-inch casting tower was developed and used to accelerate process investigation
  - Only used 14% of material used in 12-inch casting
  - Mini v-blender was also utilized to mix fibers and additional components
  - Designed a 3D printed press-plate to compress the billet to its desired density



4” x 4" x 4" As-Cast AETB Billet

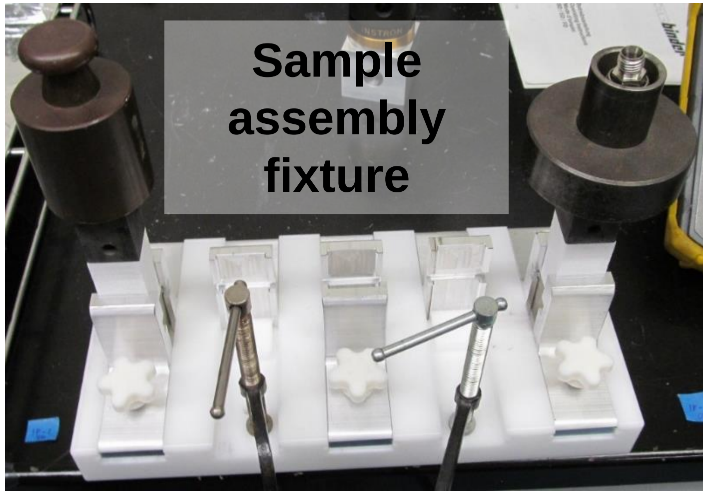
4-inch casting tower

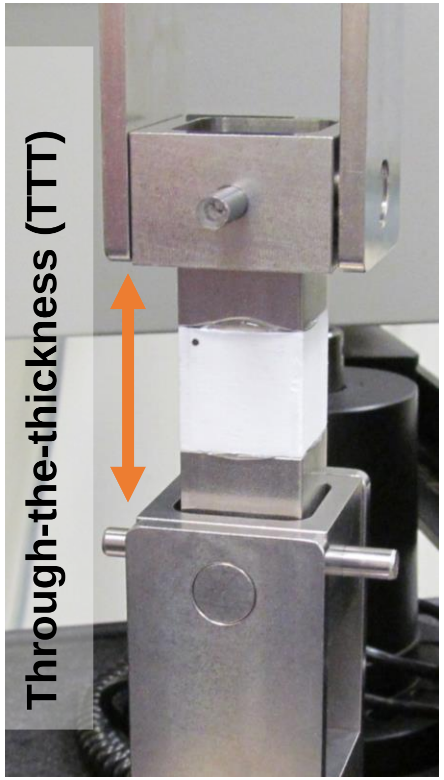
Mechanical Testing

- Developed and refined tensile testing procedure following ASTM D 1623
  - New sample assembly fixture for repeatable high tolerance alignment of the test blocks
  - Utilizing a new thermoplastic bonding adhesive (Crystalbond) to <u>greatly speed up testing process cycles</u>
  - Tested sample geometries of (1” x 1” x 1”) and (1” x 1” x 2”) were evaluated

Summary of Tensile Testing

Billet		Total Test Completed	
Size	No. Cast	TTT	IP
12"	52	173	265
4"	38	179	177

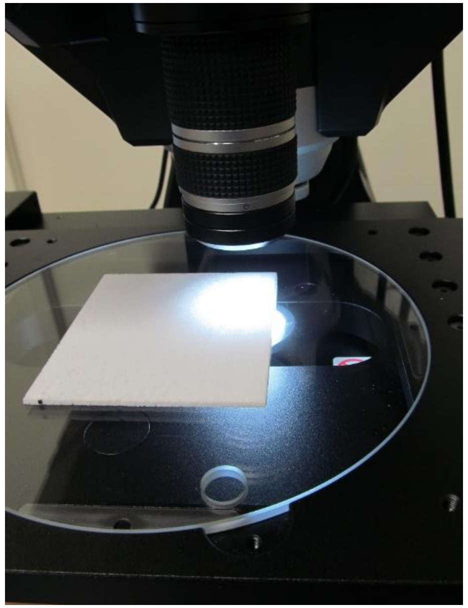




In-Plane

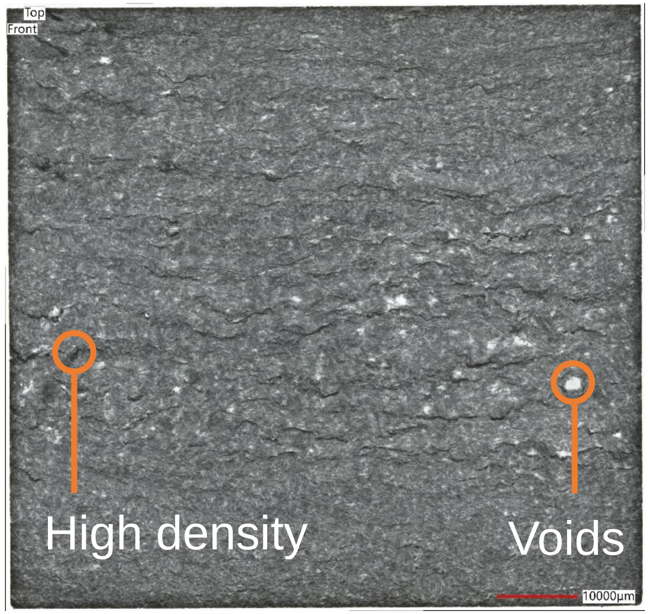
Optical Characterization

- Observable differences in “texture” of billet throughout process investigation
  - Thermomechanical and optical properties are structure dependent
- Transmitted light microscopy method used to better evaluate meso-structure
  - Imaged 2 mm thick panel in through-the-thickness direction
  - High density regions are shown dark, while void regions are bright
  - Enables quantification of defects and segregation



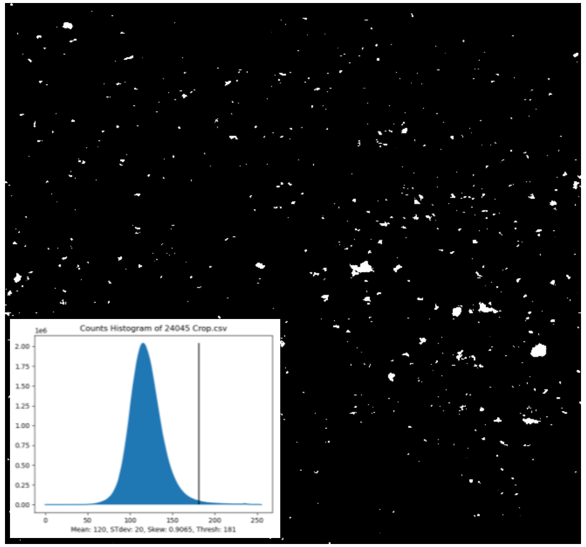
Full Area Transmission Optical Microscopy

Stitch full panel into single image



Transmission Optical Image of (4” x 4”) AETB-8

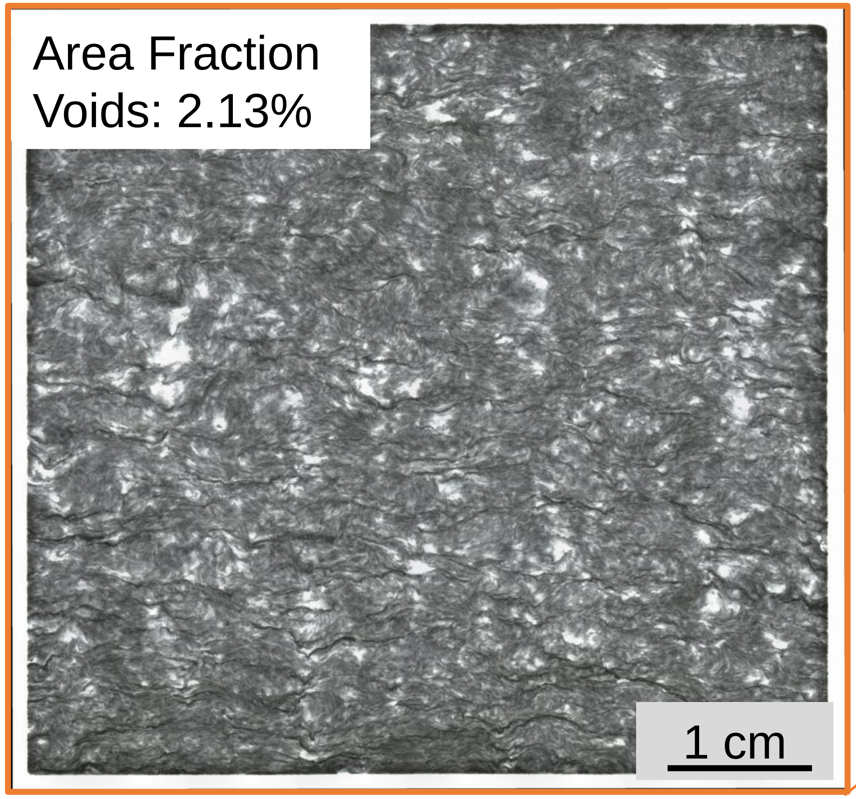
Threshold Image for quantification



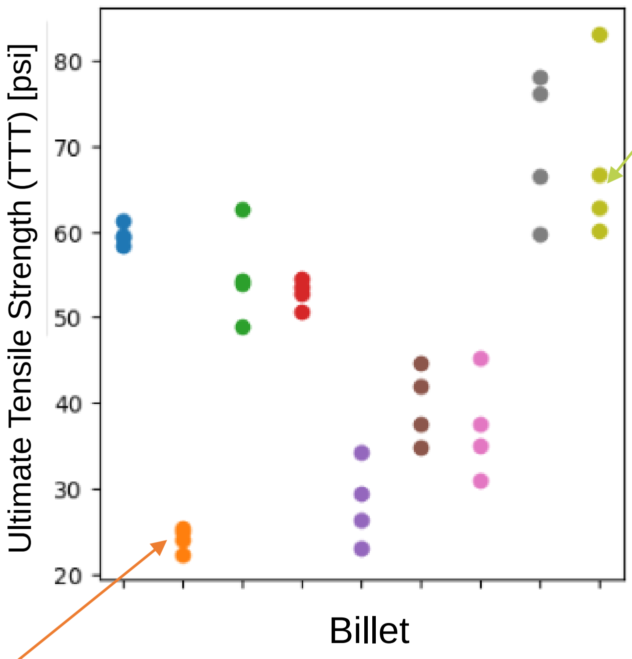
Thresholded Image of (4” x 4”) AETB-8

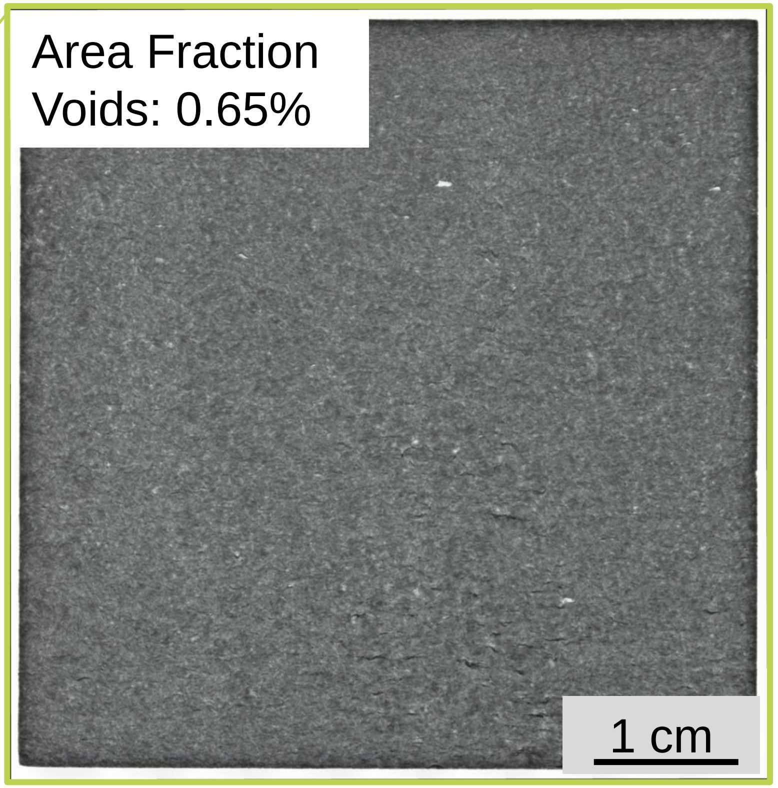
Billet Texture - Role of Nextel-312

- Nextel-312 is thermally pre-treated prior to use in tile production
  - Remove sizing and promotes crystallization
  - Reported to effect distribution within slurry
  - A variety of pre-treating profiles have been used historically
- AETB cast using Nextel-312 with <u>different pre-treatments show dramatically different texture</u>
  - Correlates to tensile strength in the TTT orientation



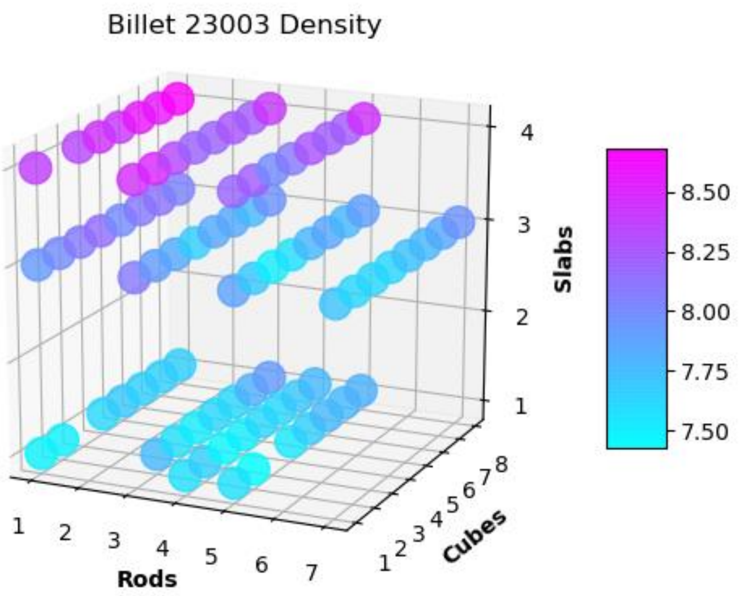
AETB-8 made with Nextel-312
pre-fired at <u>700C</u>

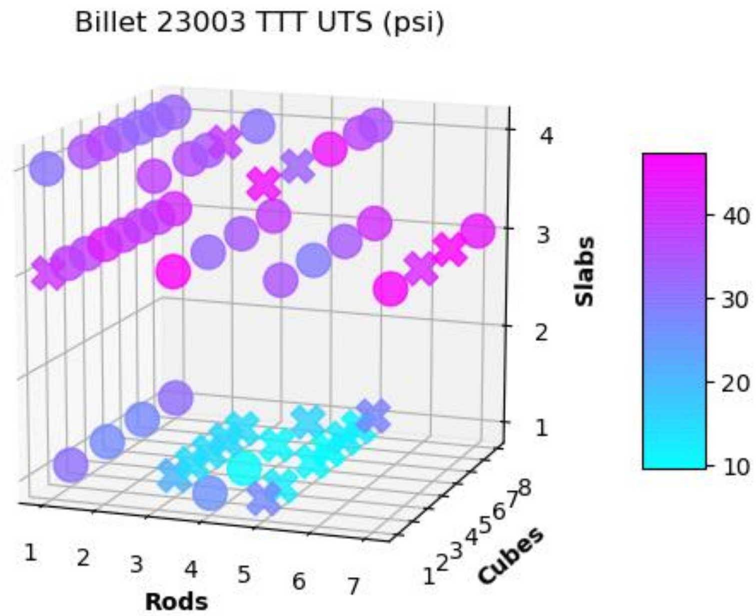


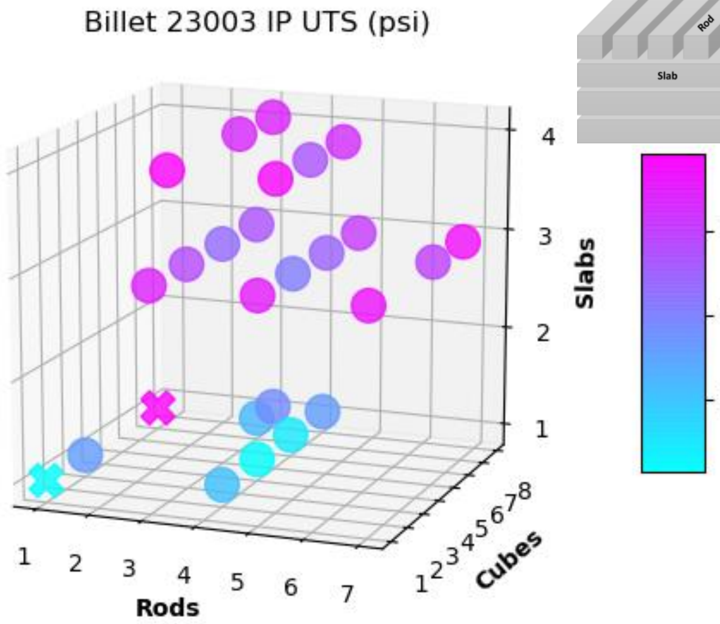


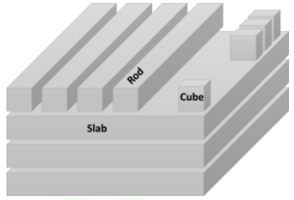
AETB-8 made with Nextel-312
pre-fired at <u>1204C</u>

Property Variation Within Billet





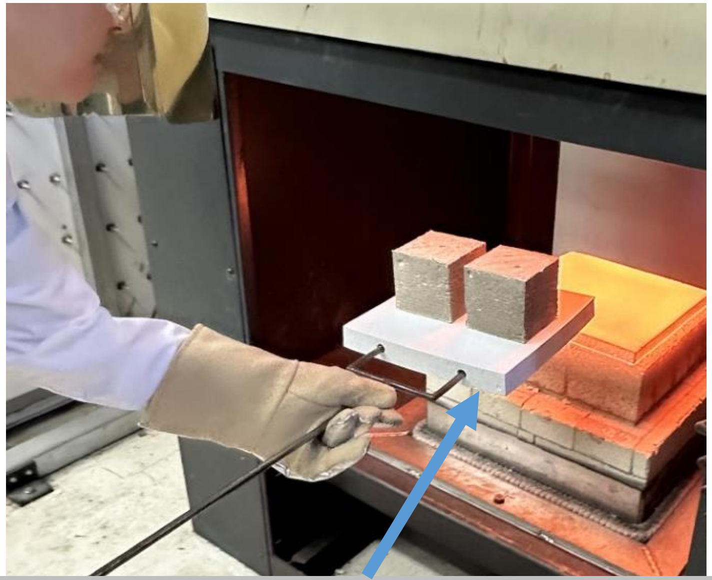




- Measured density and ultimate tensile strength (UTS) in the in-plane (IP) and through-the-thickness (TTT) orientations
  - Early billet produced using modern fibers with minor process updates
  - Specimens are 1” cubes. “X” are tests which failed near the bond.
- Largest variation observed near bottom (as-fired)

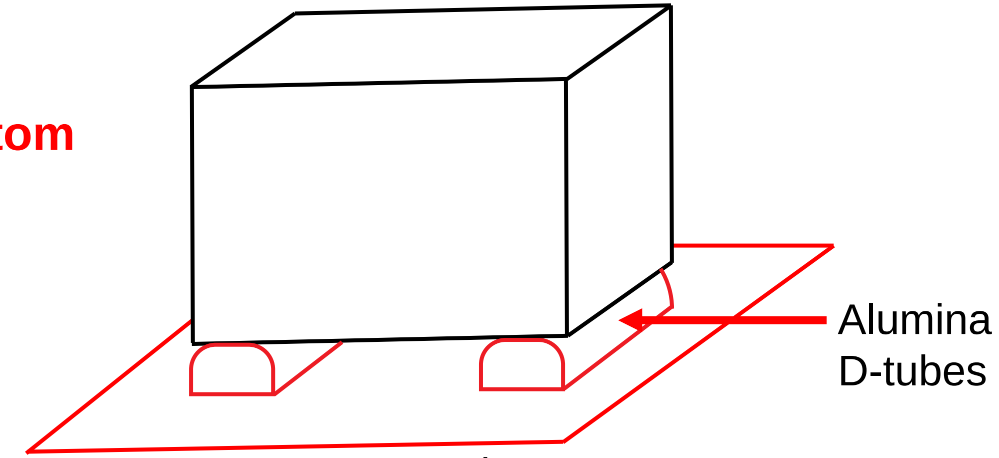
Firing Process

- Assuming the property gradient near the bottom of the as-fired billet results from thermal gradient due to hot loading billet firing process
- Modified billet sintering process:
    - Standard ARC firing protocol hot loads the billet into the furnace on a cold insulating setter plate (LI-2220)
    - Updated to load billet direction onto D-tubes
- The test billet was raised, exposing bottom surface to furnace environment



Room temperature LI-2200 setter plate

Firing set-up
Cold-bottom vs. **Hot-bottom**



Firing Process

- Top of billet as-fired was similar between both firing methods

	Cold Setter Plate		Hot Setter Plate	
Billet Location As-Fired	Bottom	Top	Bottom	Top
Density (pcf)	7.6±0.06	8.4±0.1	8.8±0.07	8.31±0.17
TTT UTS (psi)	20±4.7	37±2	33±7.2	34±3.9
IP UTS (psi)	56±5.1	86.4±7.8	56±14.4	88±7.7

*comparisons made using T-test with 95% confidence interval

Firing Process

- Top of billet as-fired was similar between both firing methods
- Cold setter plate - **Decreased** density and TTT UTS of bottom vs top of billet
- Hot setter plate - **Increased** density of bottom vs top of billet

	Cold Setter Plate		Hot Setter Plate	
Billet Location As-Fired	Bottom	Top	Bottom	Top
Density (pcf)	7.6±0.06	8.4±0.1	8.8±0.07	8.31±0.17
TTT UTS (psi)	20±4.7	37±2	33±7.2	34±3.9
IP UTS (psi)	56±5.1	86.4±7.8	56±14.4	88±7.7

*comparisons made using T-test with 95% confidence interval

Firing Process

- Top of billet as-fired was similar between both firing methods
- Cold setter plate - Decreased density and TTT UTS of bottom vs top of billet
- Hot setter plate - Increased density of bottom vs top of billet
- Similar IP UTS both
  - <u>TTT UTS is more sensitive to firing process than IP UTS</u>

	Cold Setter Plate		Hot Setter Plate	
Billet Location As-Fired	Bottom	Top	Bottom	Top
Density (pcf)	7.6±0.06	8.4±0.1	8.8±0.07	8.31±0.17
TTT UTS (psi)	20±4.7	37±2	33±7.2	34±3.9
IP UTS (psi)	56±5.1	86.4±7.8	56±14.4	88±7.7

*comparisons made using T-test with 95% confidence interval

Summary

- Added processing and material characterization capabilities
  - Created small scale (4”) tile caster and updated tensile testing method for rapid and efficient exploration of process dependencies
  - Optical transmission technique for texture/defect evaluation
- Investigated process/property relationships
  - Demonstrated role of Nextel-312 pre-firing on billet texture and mechanical properties
  - Identified and mitigated firing induced property gradient
- Evaluated heritage and modern fibers for AETB-8 production
  - Initial production achieved similar tile properties between heritage and modern fibers with low TTT tensile strength
  - Preliminary implementation of <u>process improvements</u> have resulted in significantly improved TTT tensile strength <u>achieving heritage specifications</u>

Next Steps

- Finalize modernization efforts:
  - Apply trends and observations from process investigation to large scale billet production
  - Characterize verification billets
  - Update process specifications incorporating modern raw materials
- Results are being leveraged to support:
  - Reusable Space Act Agreements (RSAAs) and Announcement of Collaboration Opportunities (ACOs) with Stratolaunch and Canopy Aerospace
  - HLS Project with Space X
  - Development of next generation reusable thermal protection systems that offer advantages in performance that include:
    - Increased use-temperature, duration, and cycles
    - Decreased cost, integration complexity, and maintenance

Thank you for your time!

Questions?

National Aeronautics and Space Administration

Ames Research Center
Entry Systems and Technology Division