



ATI Titan 23™ - A New High Strength Titanium Alloy with Improved Fatigue Life

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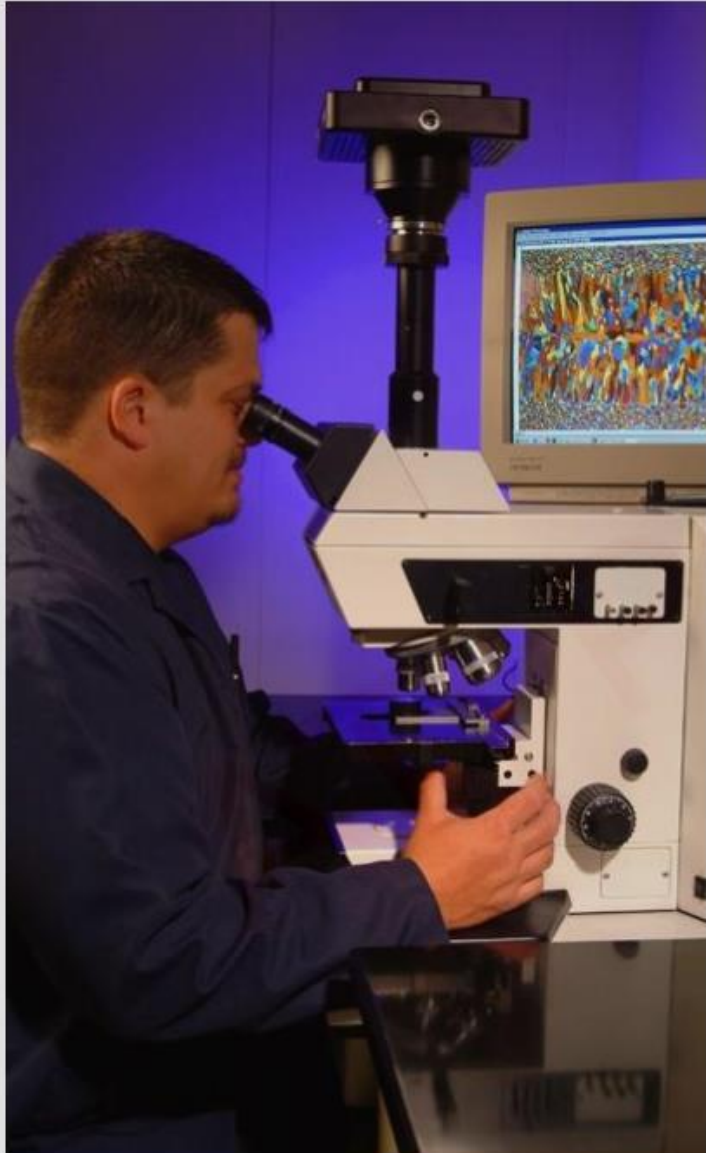
Relentless Innovation®

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ATI Proprietary

ATI Proprietary Data. These data are typical and should not be construed as maximum or minimum values for specification or for final design. Results from any particular piece of material may vary from those shown herein.

ATI Development of Advanced Titanium Alloys



Outline

- Aerospace future needs
- Background
- Experimental procedure
- Experimental results
- Summary

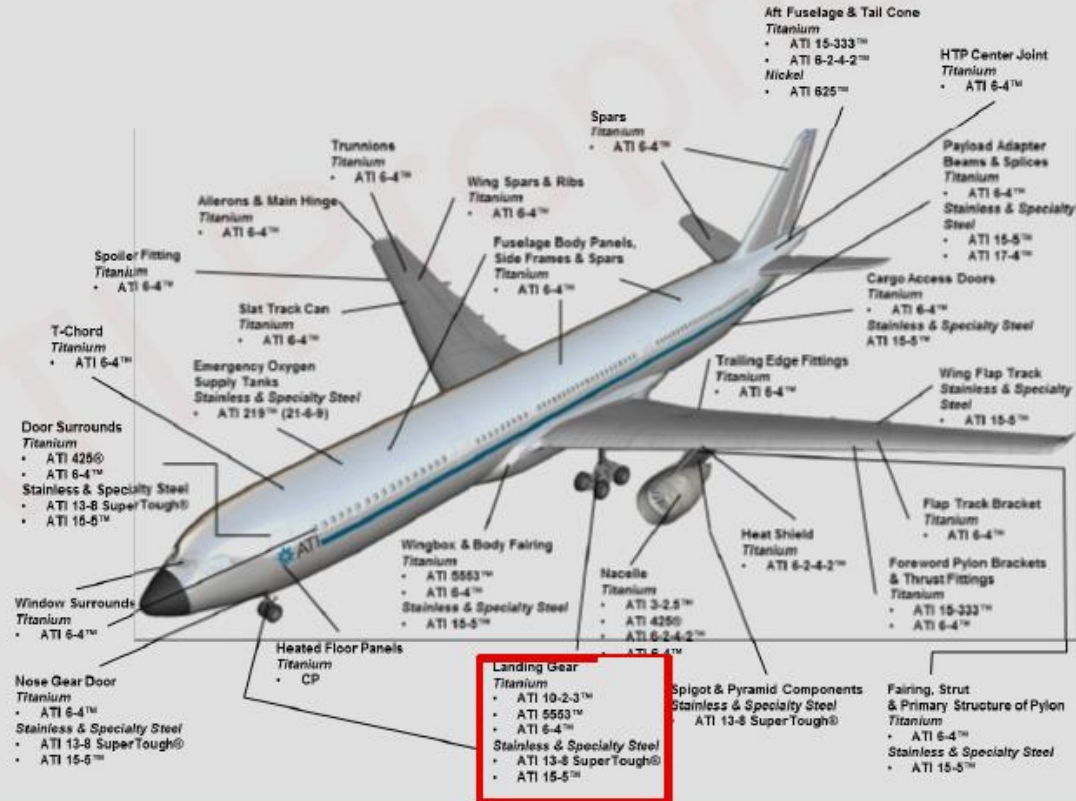
Airframe OEMs Needs for High Strength Ti Alloys

- Future Performance Targets

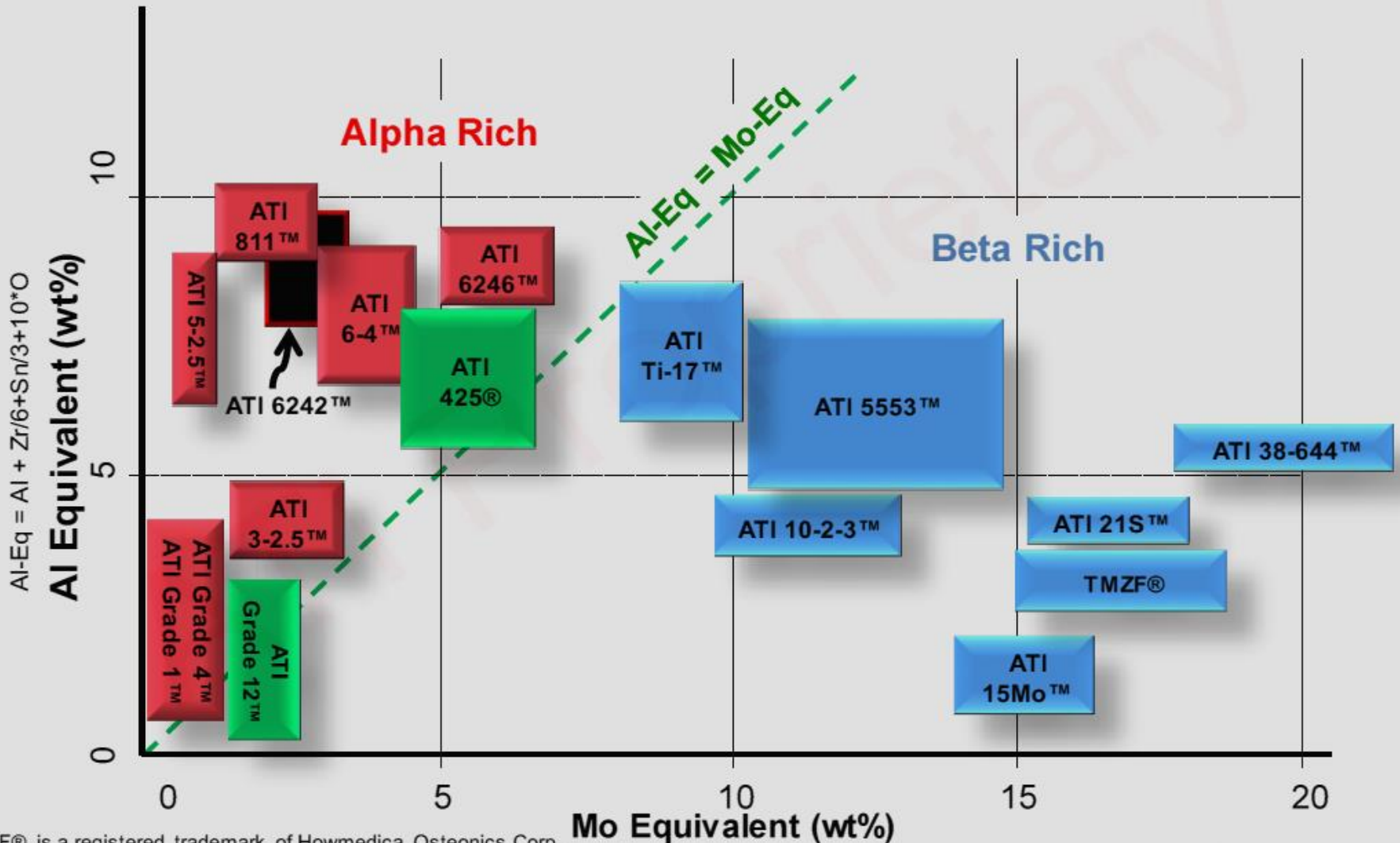
- UTS > 180 ksi
- $K_{IC} > 55 \text{ ksi} \sqrt{\text{in}}$
- Thick section hardenability > 6 in
- Maintain mid-temperature tensile properties

- Manufacturability

- Near net shape forgeability
- Heat treatment with air cool vs. water quench, age hardenable
- Inspectability/sonicability



Titanium Alloys by Chemical Equivalency



TMZF® is a registered trademark of Howmedica Osteonics Corp.
 Formula reference: Titanium Alloys, R.Boyer ed., ASM, 1994.

Mo-Eq = Mo+Ta/5+Nb/3.6+W/2.5+V/1.5+1.25*(Cr+Ni)+1.7*Mn+2.5*Fe



For ATI Alloys, ™/® trademarks of ATI Properties LLC

Baseline High Strength β -Titanium Alloy

Legacy Alloy ATI 10-2-3™ (10V-2Fe-3Al-0.13 O)

- ATI 10-2-3™ Alloy (UNS R56410) is a near beta alpha-beta alloy developed by TIMET in the 1970s as a high strength, high toughness deep hardening alloy for airframe structural components
- Typical properties (ksi): 180 UTS / 170 YS / 8%el and 50 ksi- $\sqrt{\text{in}}$ toughness for cross-sections up to 3in. thick
 - Density $\sim 0.168 \text{ lb./in.}^3$ and Beta Transus $\sim 1475^\circ\text{F}$

Improved High Strength β -Titanium Alloy

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 - Density ~0.168 lb./in.³ and Beta Transus ~1475°F

ATI Titan 23™ Alloy (9V-3.5Al-5Sn-3Zr-2.5Mo-0.2O)

- A new alloy with increased alpha and beta stabilizer content to improve room temperature strength, thick section hardenability and fatigue life
 - Density ~0.175 lb./in.³ and Beta Transus ~1525°F

References: Materials Properties Handbook: Titanium, R.Boyer/G.Welsch/E.W.Collings ed., ASM Int. 1994, pp.453-463.
Beta Titanium Alloys in the 1980s, R.Boyer/H.W.Rosenberg ed., TMS AIME, 1984, PP239-254, 433-439.

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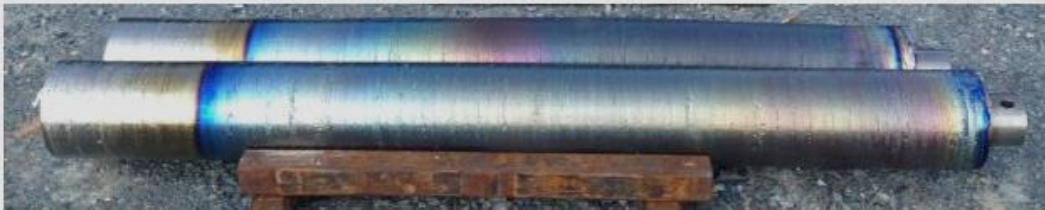
ATI Titanium Alloy Development Process



- 70 lb. Pilot-scale Single Melt
- 450 lb. Pilot-scale Double Melt Ingot
 - Plasma Arc (PAM) Primary Melt
 - Vacuum Arc Remelt (VAR)
 - 10" diameter ingot
- Pilot-Scale Conversion
 - In-house forging, rolling, heat treatment, ultrasonic inspection, surface conditioning
 - 1000 Ton hydraulic press
 - Equivalent microstructure to full-scale production billet

Pilot Scale Trials: Melting and Conversion

- PAM Melted 9" + VAR 10" (R&D pilot plant)
- Upset and forged to 3" Rd billet
- Pancake forgings and heat treat study



PAM 9" electrode



VAR 10" ingot



Pancakes

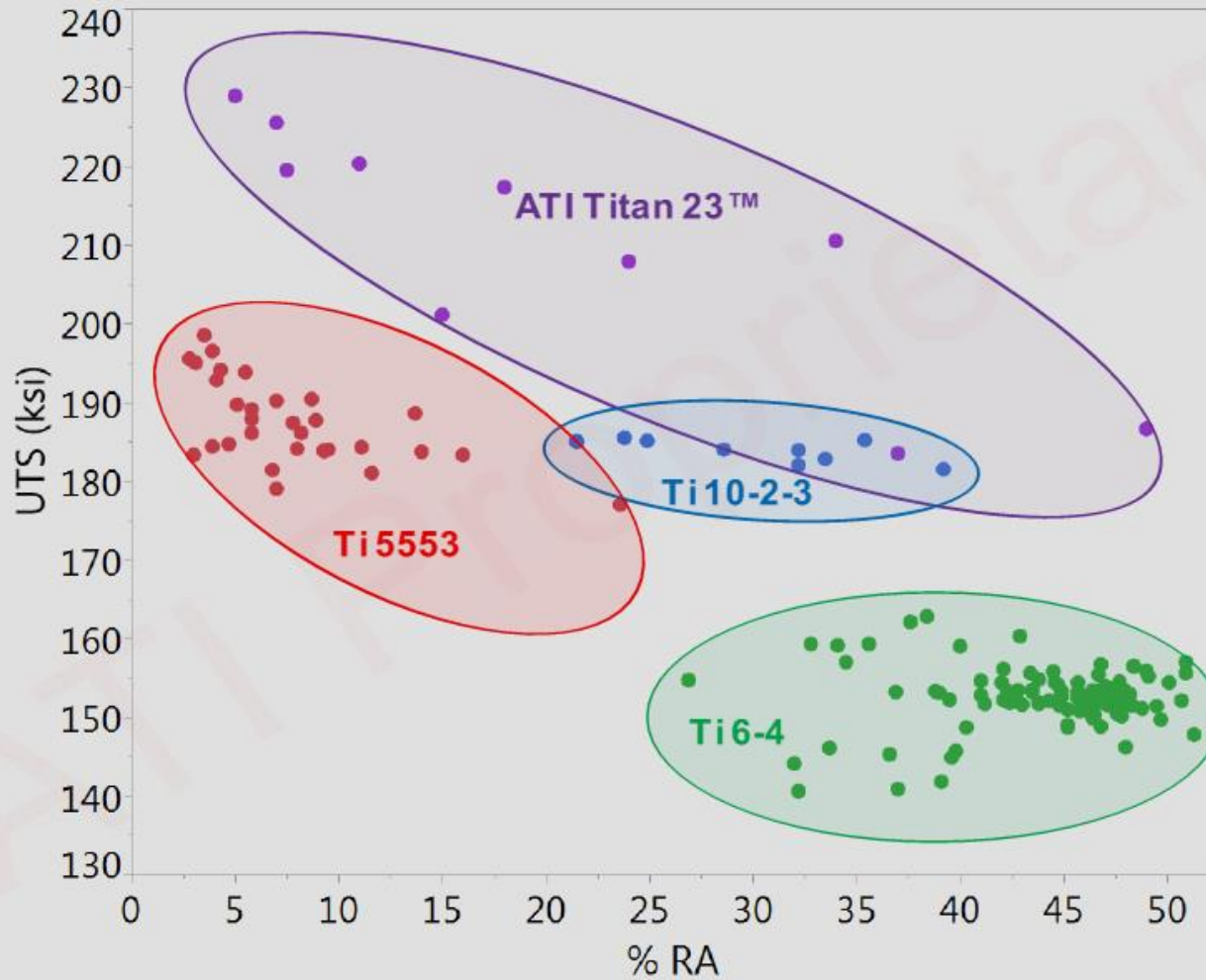


3" billet macro



Intermediate press forged to 7" Rd

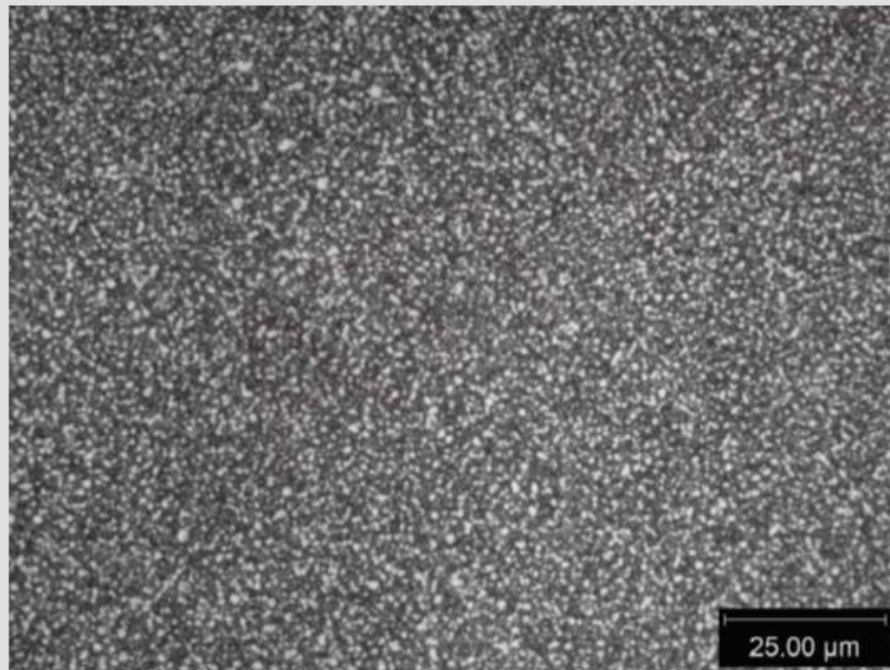
ATI Titan 23™ Tensile Strength Capability



ATI Titan 23™ Conventional vs. All-Beta Forging

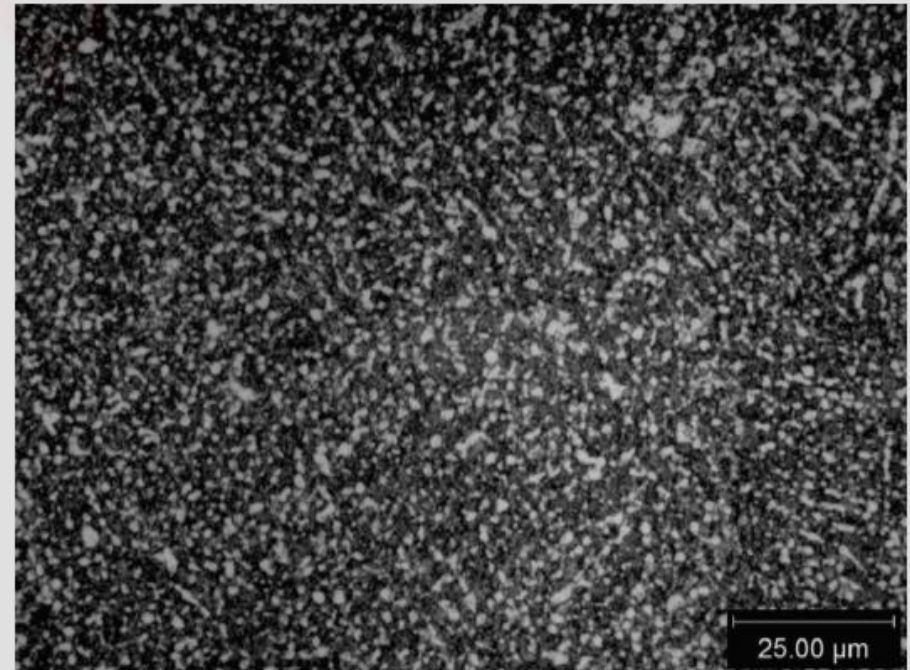
Trial 1: Conventional

STA : 1400°F/2hr/AC
+1000°F/8hr/AC
178ksi/183ksi/13/37
(YS/UTS/%EI/%RA)



Trial 2: All Beta

STA: 1400°F/2hr/AC
+1000°F/8hr/AC
180ksi/187ksi/12/49
(YS/UTS/%EI/%RA)



ATI Titan 23™ Full Scale Production

- PAM-VAR melt 30" ingot x 70" long – 8300 lb.
- Forge 30" diameter ingot to 11" billet

30" dia. VAR Ingot

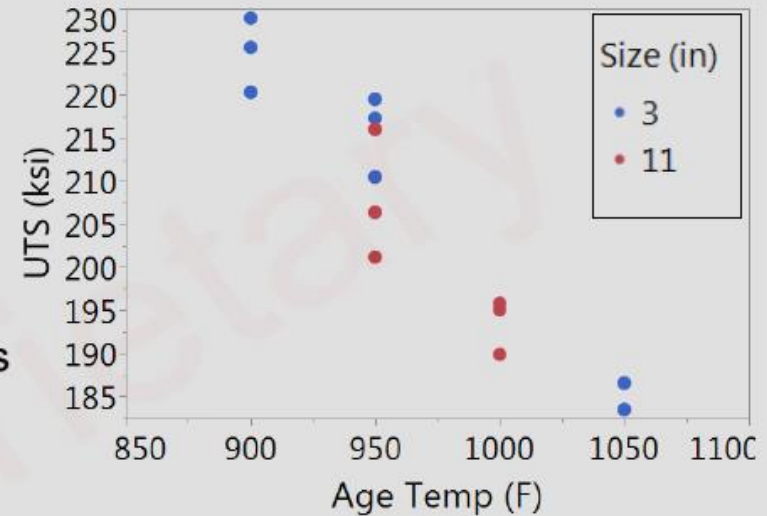


Billet at 14" dia. prior to GFM

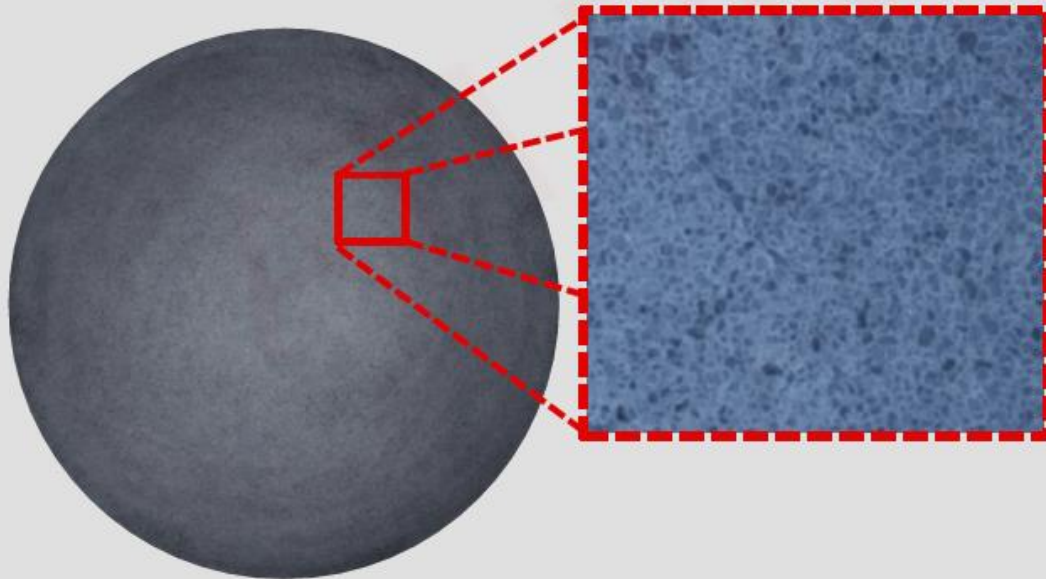


ATI Titan 23™ Full Size Billet Results

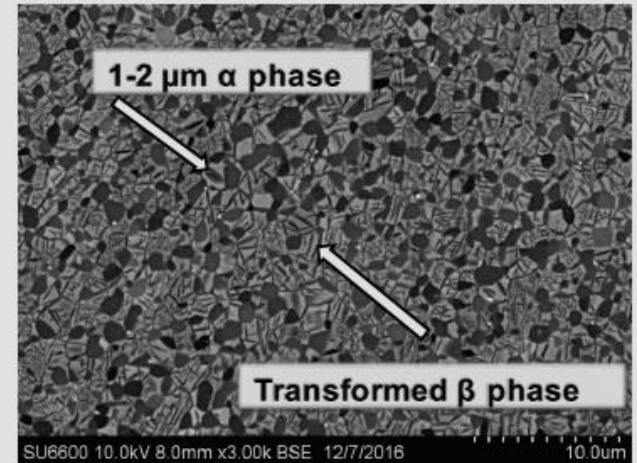
- No issues with segregation or melt-related defects
- No surface cracking issues on billet
- Flow stress similar to ATI 10-2-3™ alloy
- Uniform macrostructure
- Sonic inspectability consistent with other billet products
- Mechanical properties in line with pilot scale trials



11" Billet Macrostructure



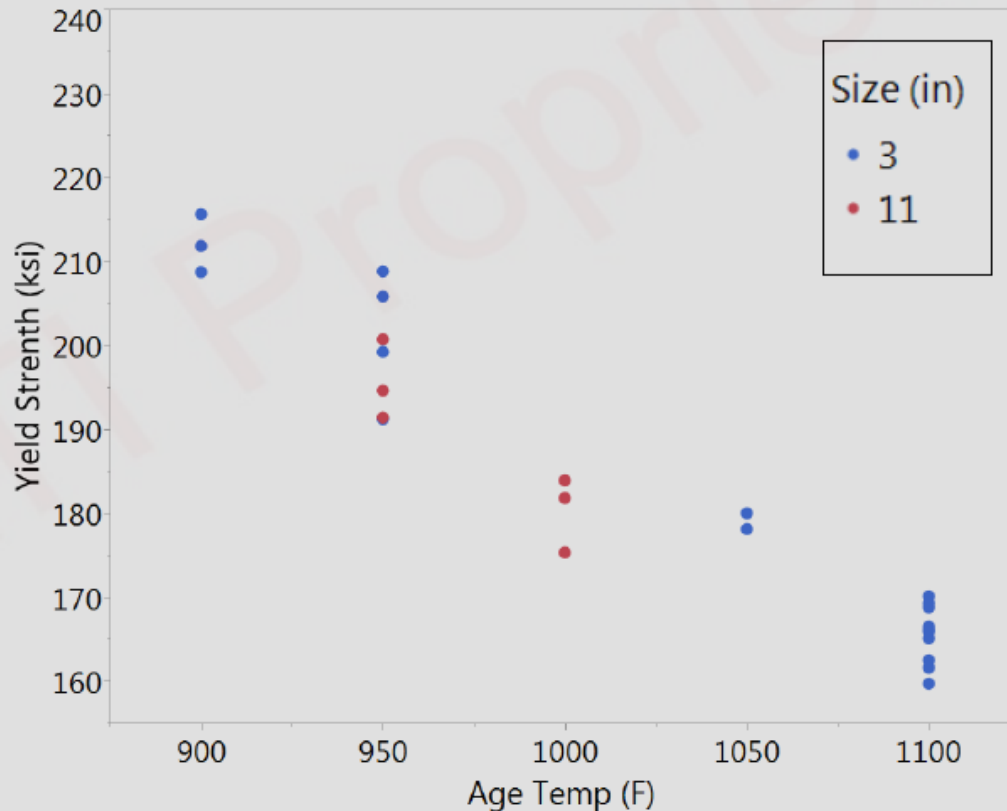
Ultra Fine Grain Microstructure



180ksi/187ksi/12/49
(YS/UTS/%EI/%RA)

Tensile Properties Pilot Scale and Full Size

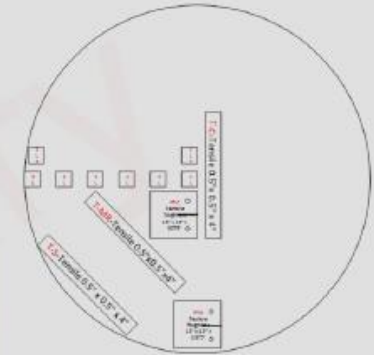
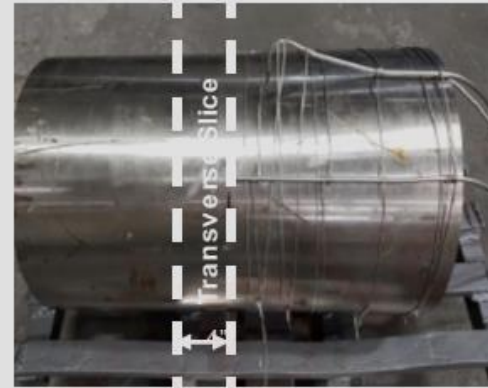
- Solution treated and aged material (STA)
- Mechanical properties in line with pilot scale trials
 - Slightly lower Oxygen in 11" billet resulted in slightly lower strength



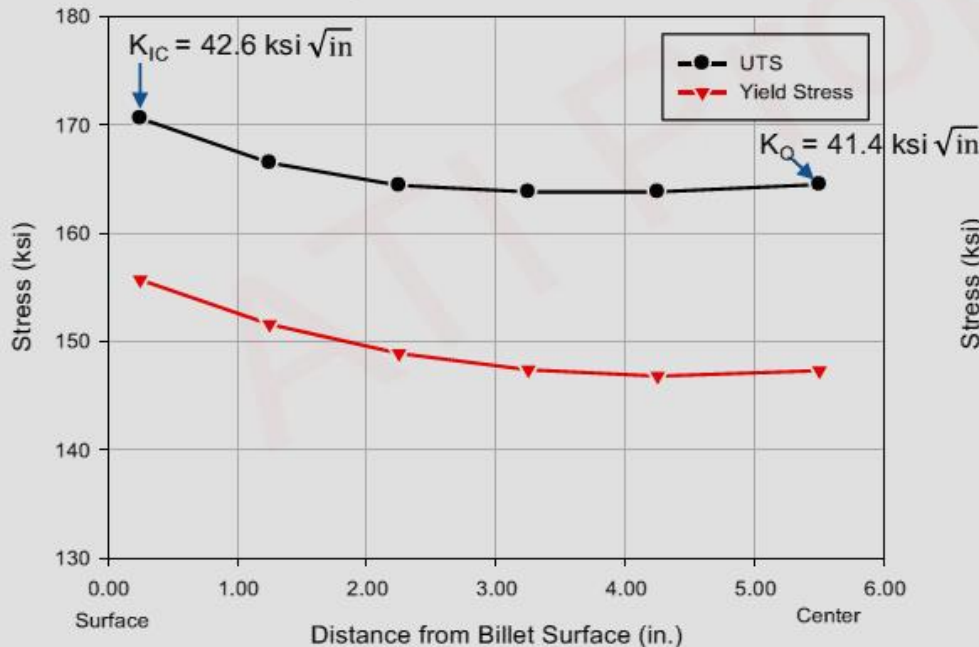
ATI Titan 23™ Thick Section Hardenability

Experiment:

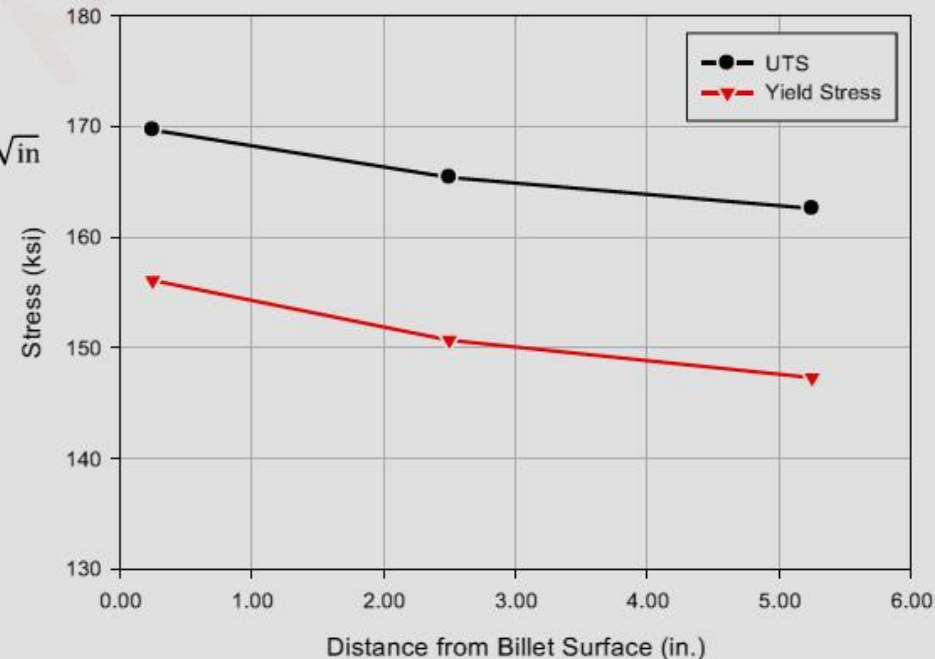
- 11" diameter beta forged billet
- Solution treated, aged and air cooled
- 4" thick transverse slice from mid-length
- Surface to center mechanical properties



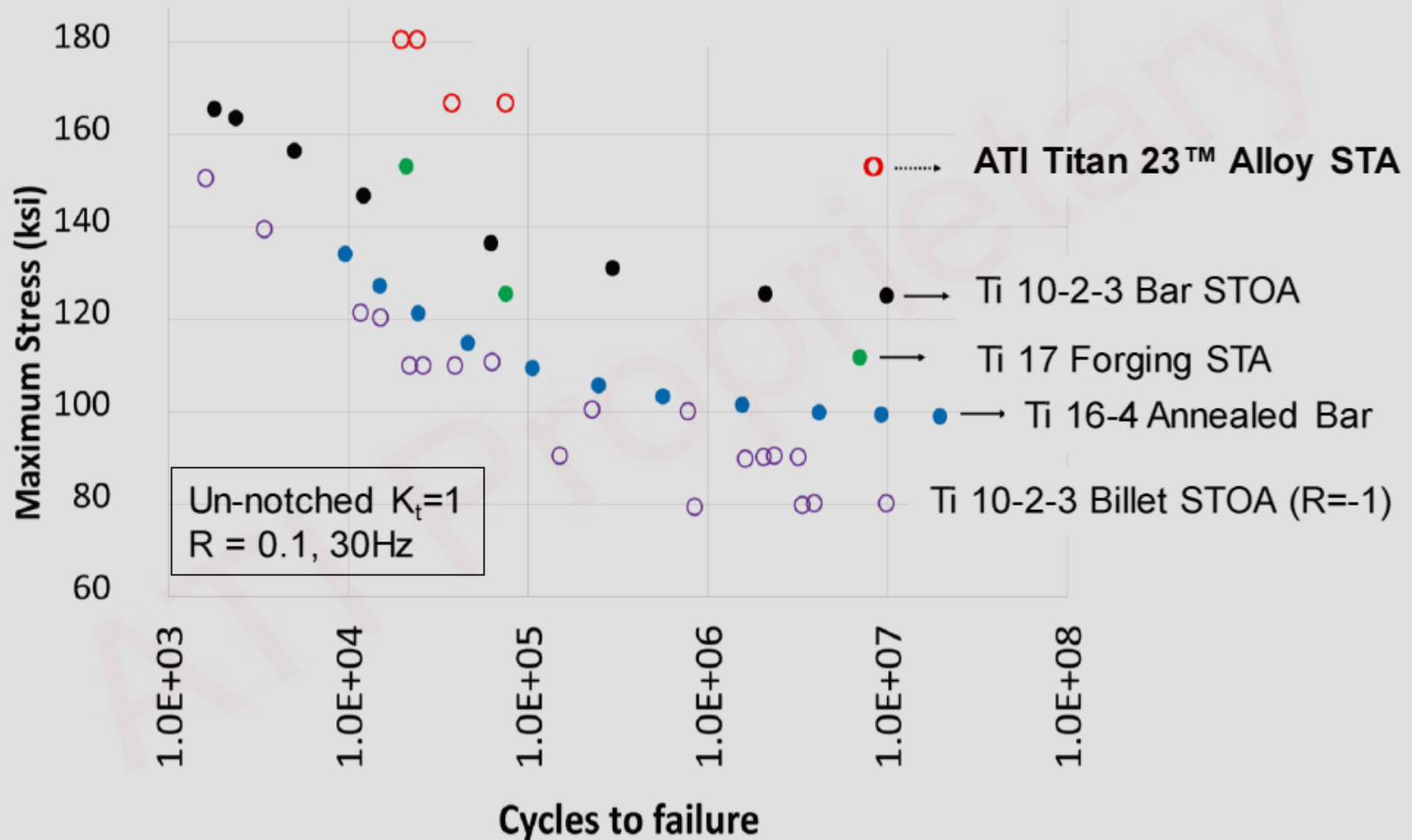
Longitudinal Tensile Results



Transverse Tensile Results



ATI Titan 23™ Fatigue Behavior

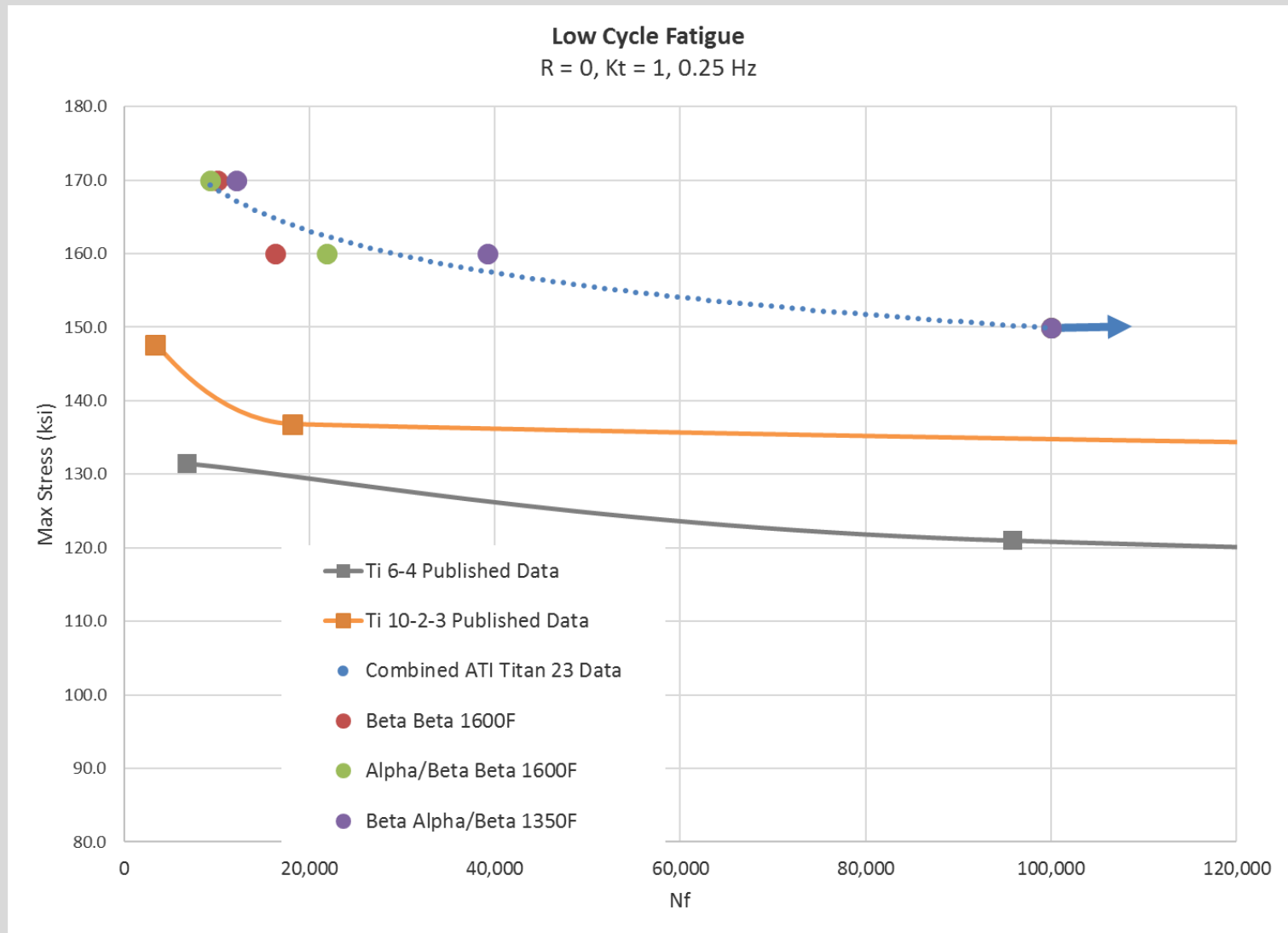


Typical properties from [Materials Properties Handbook: Titanium](#), R. Boyer, G. Welsch, E.W. Collings, ed., ASM Int. 1994.

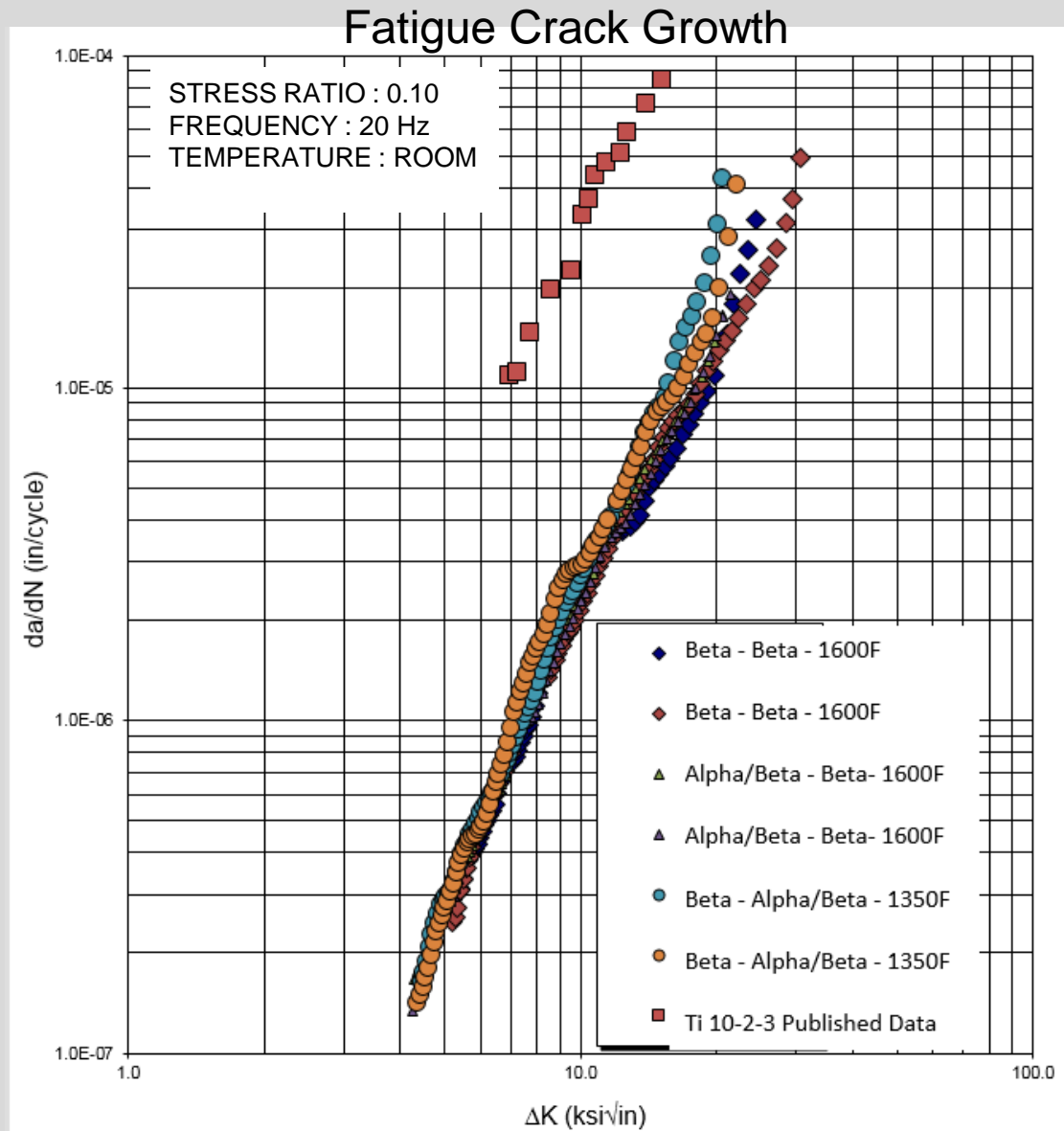


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ATI Titan 23™ Fatigue Behavior



ATI Titan 23™ Crack Growth Behavior



Development ATI Titan 23™ Alloy

Summary

- ATI experimental alloys are exceeding performance targets
 - Increased strength: 180-220 ksi achieved with improved ductility and $K_{IC} > 55 \text{ ksi } \sqrt{\text{in}}$
 - Thick section hardenability up to 12" diameter
 - No water quench needed
 - Improved forgeability → UFG microstructure → superior HCF properties
 - High-temperature strength up to 800°F
- Scale-up results
 - Full size melted and converted to 11" billet with consistent properties to pilot scale
 - ATI has filed patent applications for a new titanium alloy
 - Working with OEMs on production scale assessment
- Future
 - AMS specification development – 3 full size heats required
 - Development of design allowables (10 heats / multiple sizes and product forms)

Discussion

- ATI Titan 23™ Vertical Lift “Case Study”
- How do we accelerate material solutions to enable RAM?
- ATI Titan 23™ for FVL