

Developing Enhanced Strength and Texture in Titanium 6AL-4V Hollows and Shapes



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PURPOSE

- Demonstrate that enhanced long transverse, short transverse and hoop properties can be developed in alpha and alpha beta titanium alloys that are extruded in tapered dies.
- Concept has particular advantage in tubes



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Strength Preconceptions

- The longitudinal direction is the strongest and most ductile direction... i.e. the direction of elongation obtained when metal is hot worked
- Assuming alloy chemistry and microstructure is fixed the yield strength and ductility/toughness is a function of grain size



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Why

These perceptions exist because:

- 1) The most commonly used materials have crystal structures that are BCC or FCC – steels, copper, nickel based alloys
- 2) Most wrought metals are formed by rolling or forging which compresses grains in the axial direction elongating them in the direction of hot work



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Slip Systems in Metallic Crystals

Crystal	Slip Plane	Slip Direction	Slip Systems
FCC	{111} (4 planes)	<110> (3 per plane)	4x3=12
BCC	{110} (6 planes)	<111> (2 per plane)	6x2=12
HCP	{001} (1 plane)	<100> (3 per plane)	3x1=3

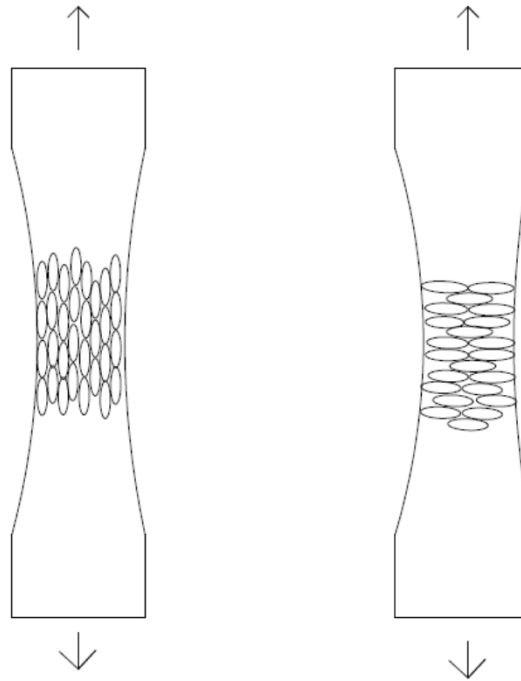


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Long and Trans Tensiles



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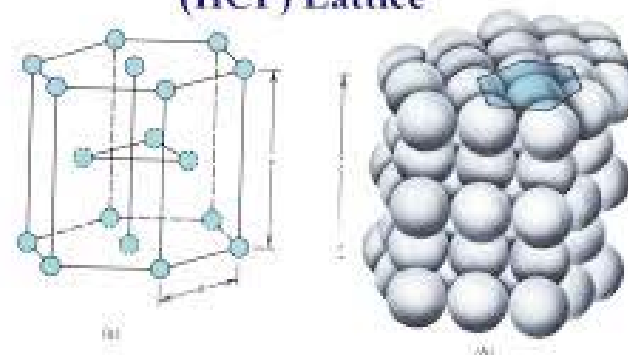
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Some HPC Metals

Metal	C/A Ratio
Zn	1.85
Co	1.63
Mg	1.62
Zr	1.593
Ti	1.588
Be	1.56

Hexagonal Close Packed (HCP) Lattice



The HCP lattice is not a Bravais lattice, because orientation of the environment of a point varies from layer to layer along the c-axis.



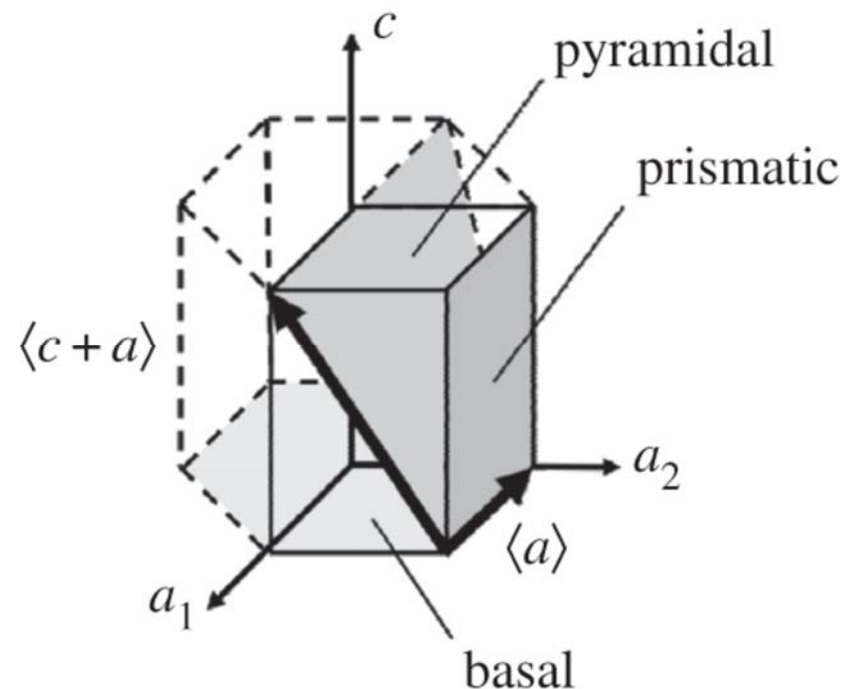
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Deformation (yielding) of HCP Metals

- HCP alloys normally only slip along the basal planes
- HCP will also slip along pyramidal planes but only at elevated temperature under high constraint and deformation (i.e. tapered die extrusion)



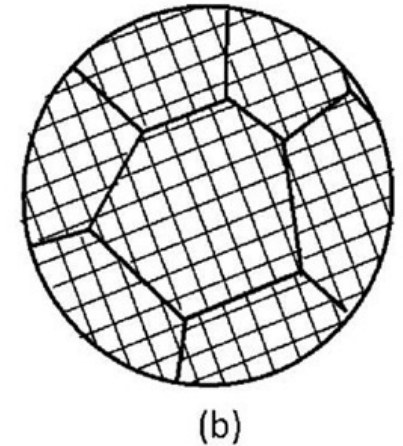
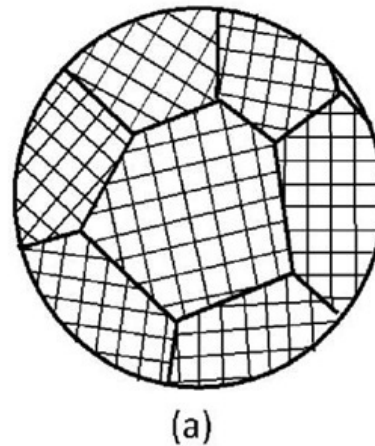
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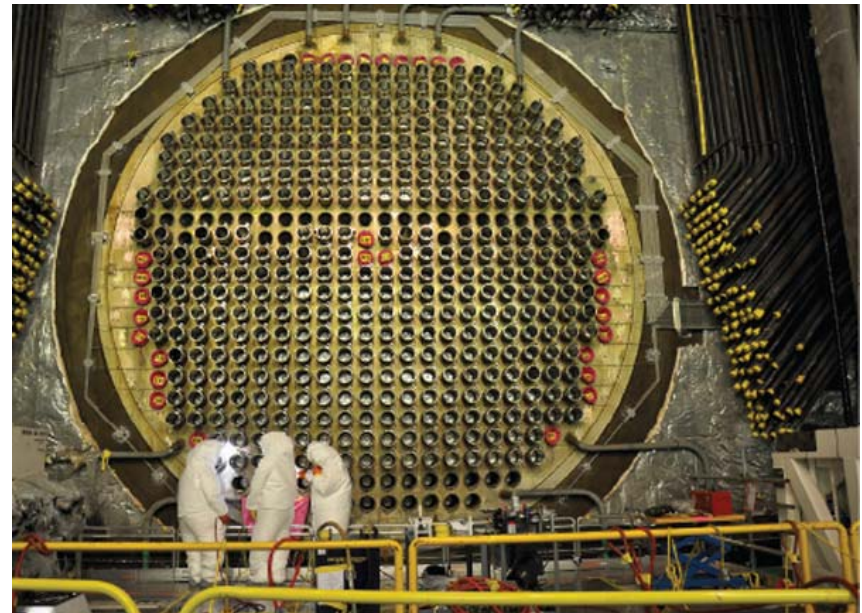
Texture

- Material A is random, B has Texture
- In HCP materials texture can influence strength far more than grain size can



Case Study: CANDU Reactor Core

- What if you could make a metal strong in exactly the direction you needed it
- The core of a CANDU reactor is made up of about 500 pressure tubes
- Nu-Tech has made these tubes for 50 years



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Extruded With Tapered Dies

Properties at 300° C

	Yield Strength (psi)	Ultimate Strength (psi)	Elongation %
Longitudinal	55,000	76,000	15
Transverse	77,000	81,000	18



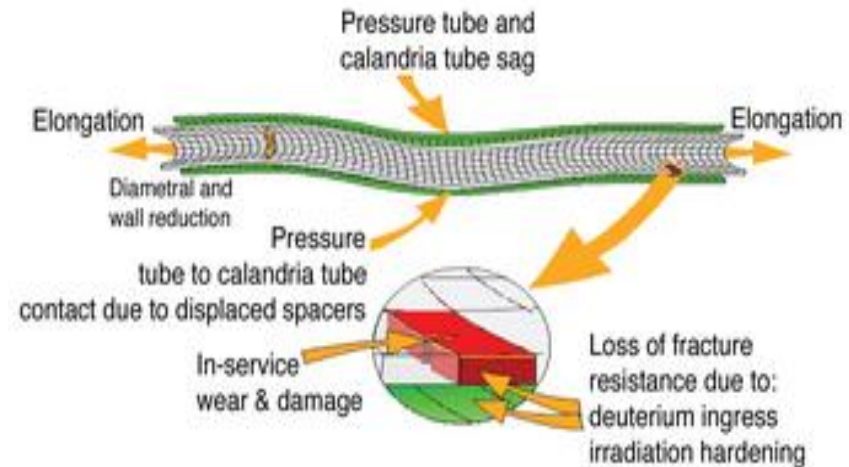
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Zr Nb Pressure Tubes

- $\alpha\beta$ Zr alloys tube that retains hot (350C), radioactive, pressurized (1500psig) water while being bombarded by radiation – tube growth and sagging limits life
- Planned life of 15 years, actual life of 30 years by fortunate luck that trans strength is 40% higher than long strength
- Savings is \$ 2 billion x 30 plus units



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If Zr Behaves This Way – Does Ti?

ARE THERE BENEFITS?



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Applications for $\alpha\beta$ Ti Tubes

Component Type	Characteristic - Principal Stress
Hydraulic Tubing	Pressure - Hoop (Transverse)
Piston Type Actuators (LG)	Pressure - Hoop (Transverse)
Torque Tube (Wing Flaps)	Torque - Hoop (Transverse)
Drive Shafts	Torque - Hoop (Transverse)
Shear Tubes (Engine)	Tension /Compression (Long/ Thru Wall)
Structural (Frame)	Tension/ Compression (Long/ Thru Wall)



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Texture Development

- Erich Tenckhoff, Deformation Mechanisms, Texture and Mechanical Anisotropy in Zirconium Alloys, 14th Symposium on Zirconium in the Nuclear Industry, ASTM 2005



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What The Theory Tells Us

- The basal poles line up where there is the greatest amount of hot work ... material is strongest in the direction where reduction is the greatest
- Hot reduction needs to be constrained (extrusion and plate rolling) and greater than 40% for texture to fully develop
- Large amounts of cold work (80%) will develop texture (pilgering)
- Heat treatment and moderate cold work does not alter the texture created in hot working



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Where the theory is wrong

We find the following also greatly influences the material flow during extrusion and thus texture:

- Lubrication
- Die angle
- Billet grain size and microstructure (for two or more phase alloys)

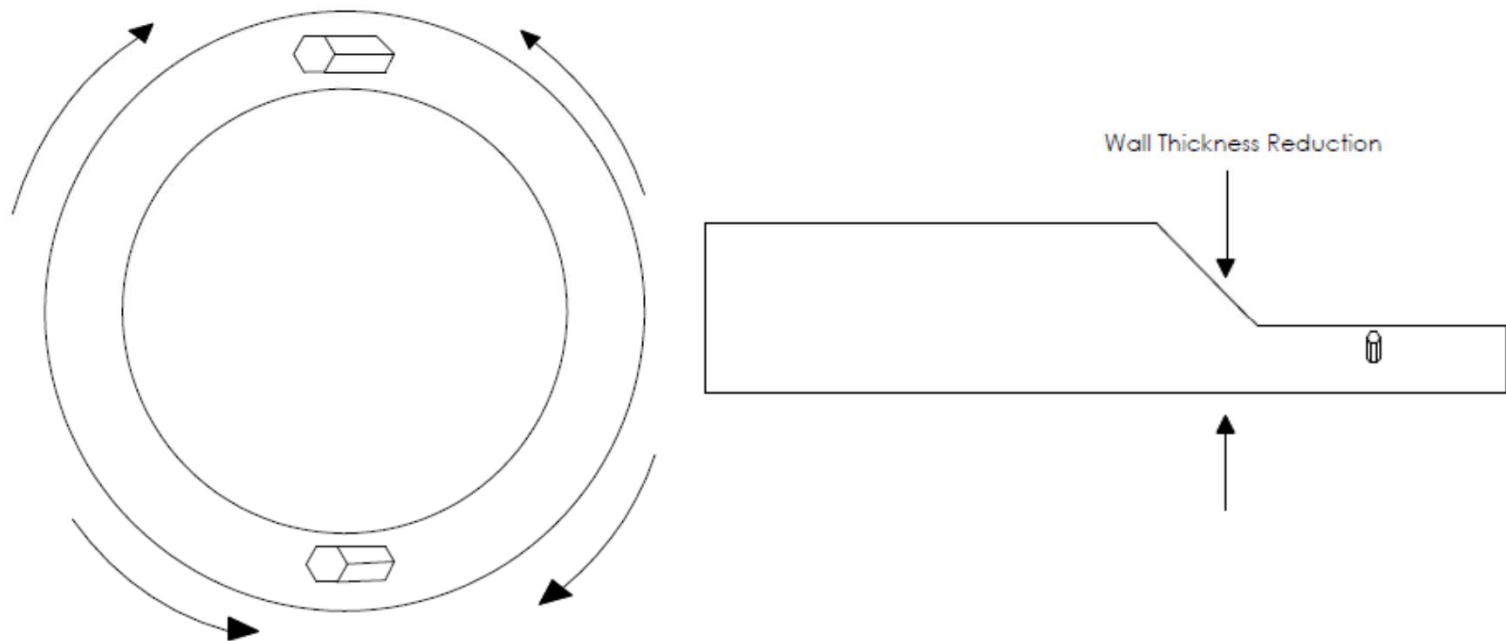


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Hot Deformation and Texture in Hollows Made in Tapered Dies



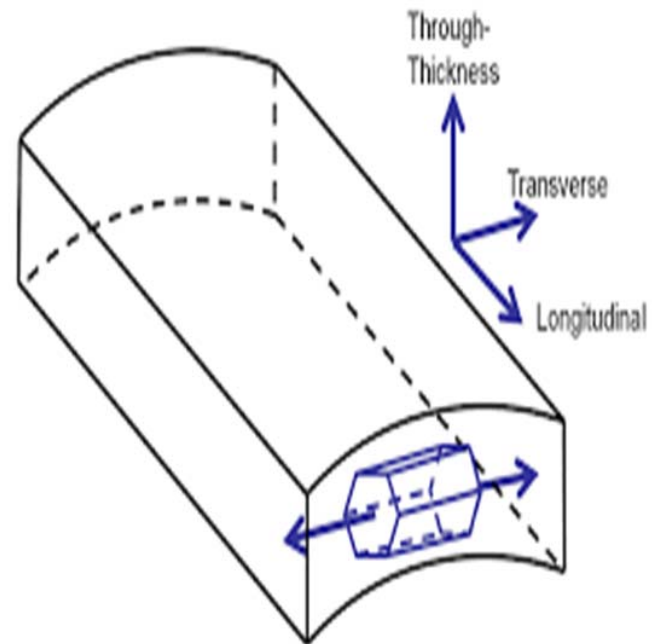
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Extrusion of Grade 2 (100% α)

- 10" OD x 5.9" ID x 29" Billet
- 6.675" OF x 5.8 ID x 15 ft
- $R_w = 4.6$, $R_d = 1.5$,
- $R_w/R_d = 3$
- $ER = 6$ to 1
- Preferred texture will be thru wall but also significant component transverse (shown)



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Grade 2 Ti 6" SCH 80 Annealed

	Yield Strength (psi)	Ultimate Strength(psi)	Elongation %
ASTM B 861	40,000	50,000	24%
Tube (Longitudinal)	51,000	85,500	29%
Tube (Transverse)	70,000	94,000	25%



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Grade 2 Ti 6" SCH 80 Pipe

- Grade 2 transverse properties meet the requirements for Grade 9 (3 - 2 ½) but with higher ductility!
- Pipe selected randomly from past production – extruded at 1540°F (840 C)
- No emphasis placed on optimizing grain size which could be done by lowering extrusion temperature or optimizing billet structure



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α - β Extrusion of 6Al -4V

- 11" OD x 5.4" ID x L Billet extruded to 6.5 OD x 5.3 ID x L tube – selected randomly, past production
- $R_w = 5$ $R_d = 1.7$ $R_w/R_d = 2.9$
- $ER = 6.5$ to 1
- Billet Heating Temperature 1750°F (approx. 70°F below transus), billet at about 1700 when deformation begins
- Annealed 1300°F



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6.5" OD x 5.3" ID 6Al-4V

	Yield strength (psi)	Ultimate Strength (psi)	Elongation
AMS 4928	125,000	135,000	10%
Longitudinal	139,000	153,000	16%
Transverse	153,000	162,000	16%



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7.2" OD x 6.0" ID 6Al-4V

	Yield Strength (psi)	Ultimate Strength (psi)	Elongation
AMS 4928	125,000	135,000	10
Longitudinal	131,000	154,000	13
Transverse	141,000	155,000	16



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**No special effort made to optimize properties
but transverse yield strength is 20% higher than
the requirements of AMS 4928.**



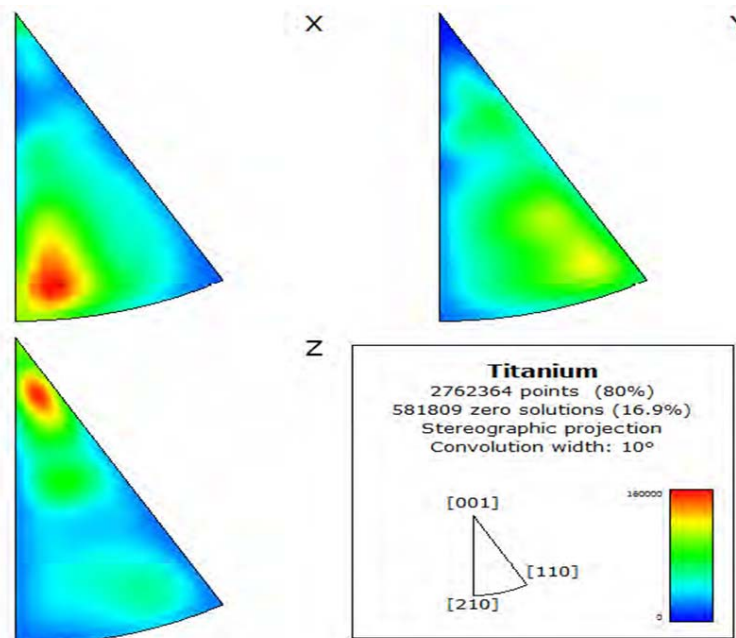
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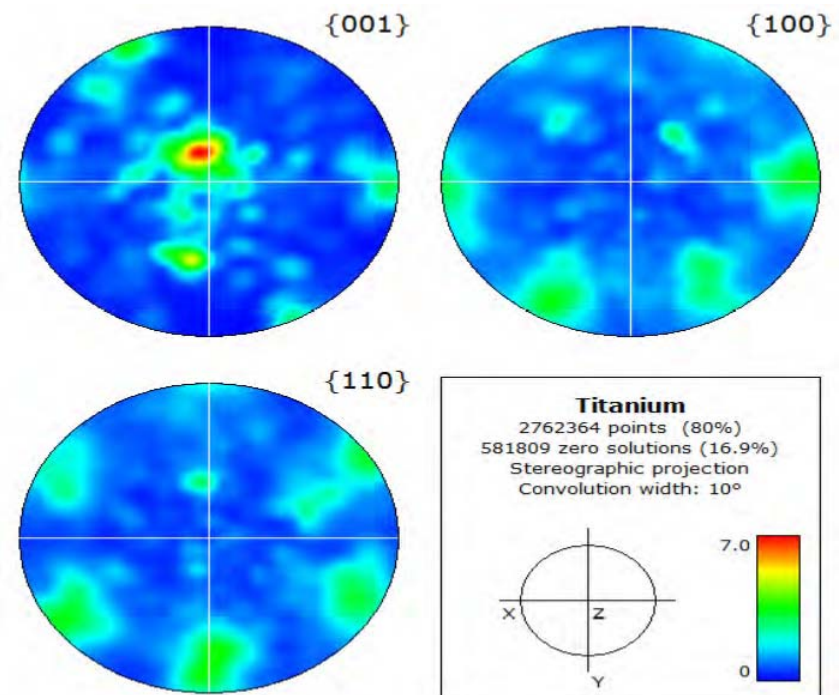
Strong texture in transverse direction with some radial rotation

Figure 6a) alpha Inverse Pole figure
Z --> transverse, Y --> radial, X --> axial

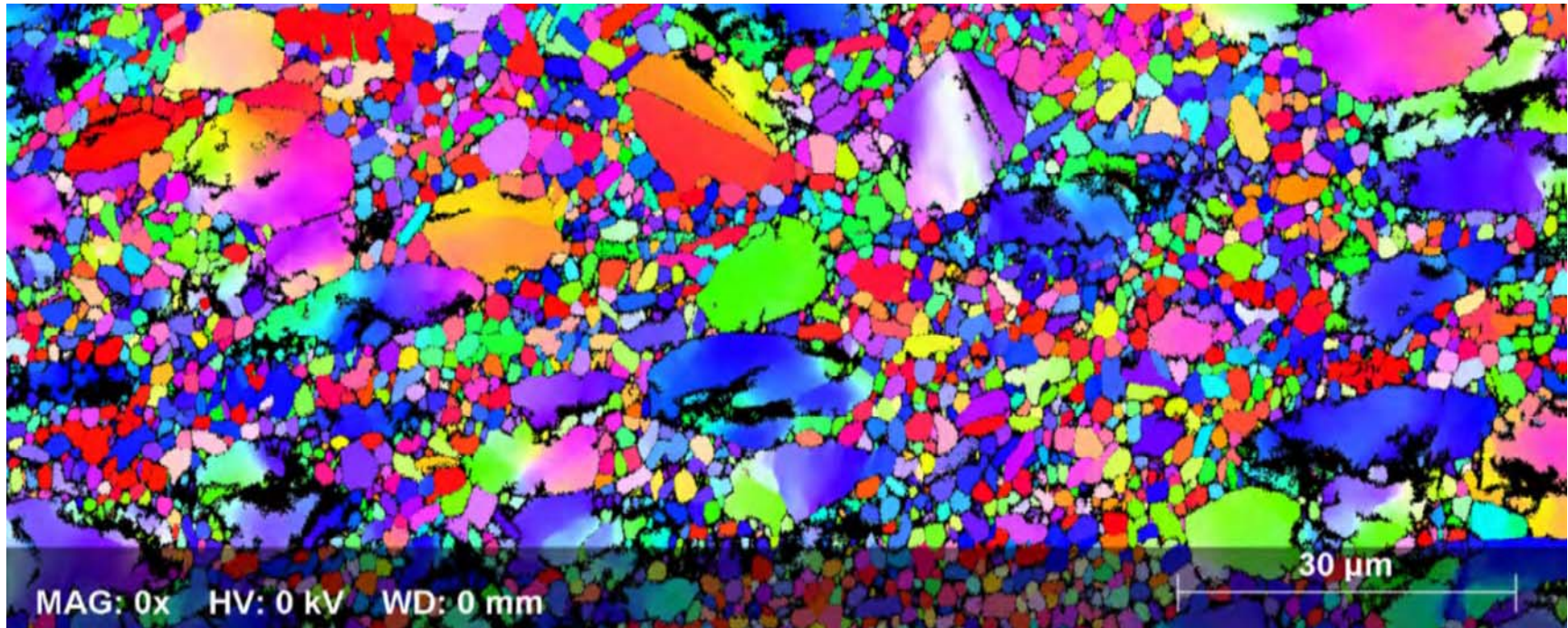


Texture is strongly transverse

Figure 6b) alpha Pole figure
Z --> transverse, Y --> radial, X --> axial



Microstructure

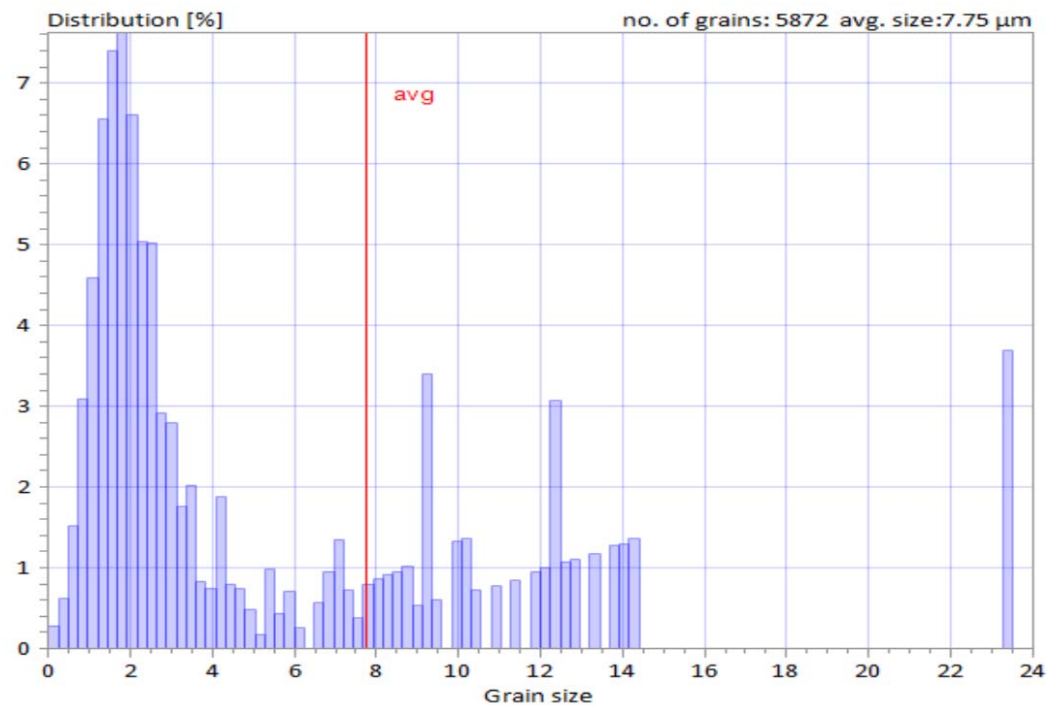


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Transformed α – ASTM 14+ Primary α – ASTM 8 to 10



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Further Strength Enhancement

Our work with zirconium would suggest Ti 6-4 transverse and radial properties can be further increased by:

- Reducing the extrusion temperature (increases volume fraction of primary alpha)
- Reducing billet soak times- decreasing prior alpha grain size
- Reducing billet grain size



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Structural Shapes



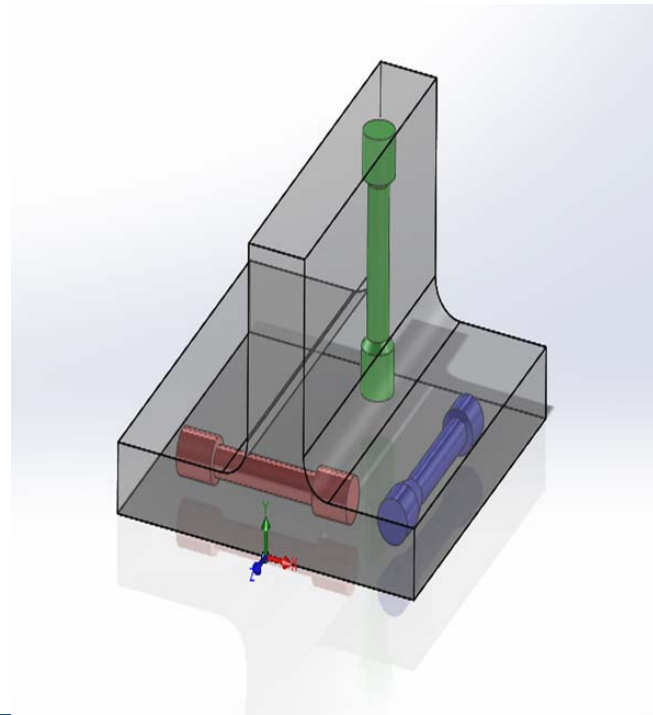
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Mechanical Properties – Annealed (Mid Extrusion) 1" x 7" x 7" Tee

	YS	UTS	El%	RA
Spec	125	135	10	25/20
Blue	131	146	15	30
Red	136	150	17	48
Grn	135	149	19	35



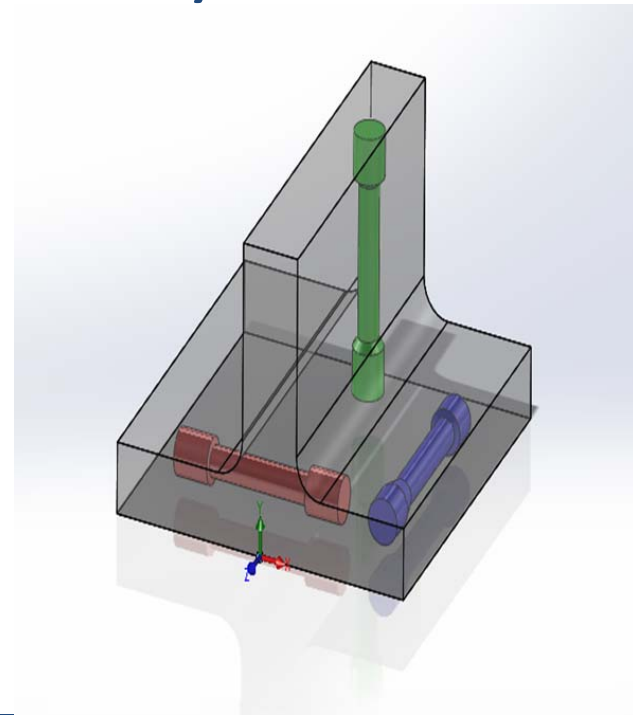
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Mechanical Properties – STA (Mid Extrusion)

	YS	UTS	El%	RA
Spec	130	150	6	12
Blue	137	159	12	53
Red	140	162	15	51
Grn	135	158	20	51



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Beta Extrusions



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Beta Extrusion

- 10" OD x 6.65 ID x L Billet Extruded to 7.5 OD x 6.5 ID x L Hollow
- 1900°F Heating Temperature
- $R_w = 3.3$ $R_d = 1.33$ $R_w/R_t = 2.5$
- $ER = 4$ to 1



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7.5" OD x 6.5" ID 6Al-4V Beta

	Yield Strength (psi)	Ultimate Strength (psi)	Elongation %
AMS 4935	120,000	130,000	10 L 8 T
Longitudinal	133,000	153,000	14
Transverse	130,000	148,000	14



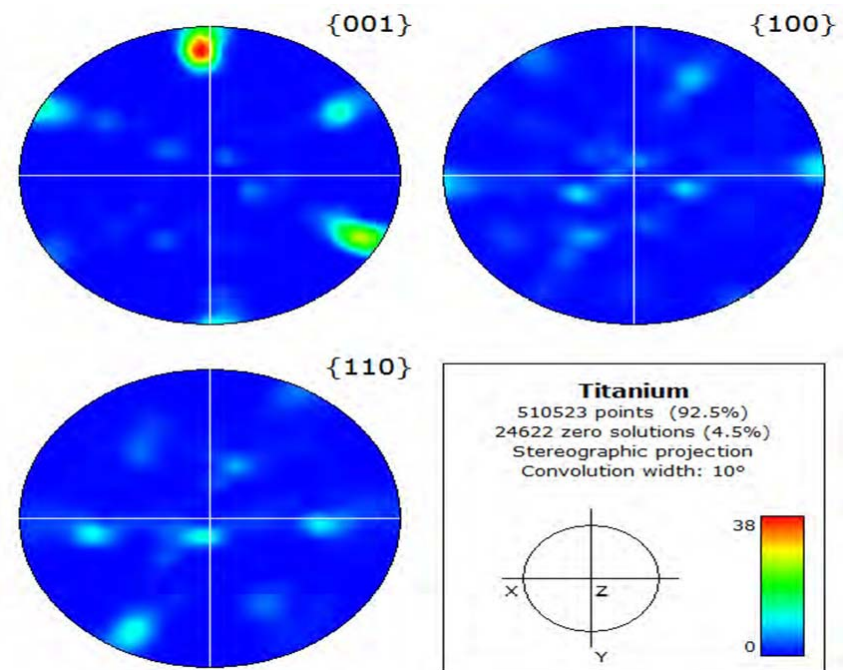
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Texture is strongly radial (through wall)

6a) Alpha phase pole figure
Z --> transverse, Y --> radial, X --> axial



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Summary

- α and $\alpha\beta$ titanium alloys when extruded with tapered dies develop transverse textures and thus enhanced transverse strength
- Properties presented were from past production and thus further optimization can be achieved by enhancing billet microstructure, modifying extrusion dies, extrusion temperatures and soak times



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