Characterization of Titanium Alloy Friction Stir Butt-Welds TIMET 54M, ATI 425 and BOATI Standard Grain

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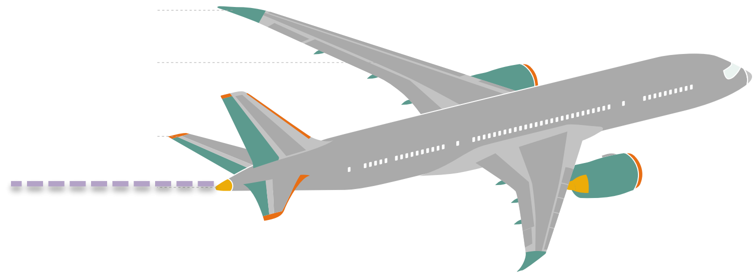
Outline

- Introduction
- Titanium Alloys
- Friction Stir Welding
- FSW : A brief Review
- Experiments
  - Microstructure
  - Hardness
  - Tensile Tests
  - Fatigue
- Results
- Conclusion

Introduction

- Aerospace industry: *Buy to fly* ratio extremely important
- Minimizing material wastage by adopting light-weight materials – *Titanium*
- Near net shapes
- Size Limitation (Titanium Sheets)
- Joining Techniques
  - Diffusion Bonding
  - Friction Stir Welding
- Titanium -High Strength to weight ratio, High Melting point, corrosion resistant, and low density
- Titanium use has been expanded on Boeing 787 to roughly 14 percent of the total airframe [1]



14% Titanium ***Boeing 787***

[1] Boeing QTR_0406 A quarterly Publication Boeing.Com/Commerical/Aeromagazine

Titanium Alloys

- **TIMETAL 54M** (Ti-5Al-4V-0.6Mo-0.4Fe)
  - New α-β Alloy
  - Superior machinability and strength
  - Produced by Vacuum Arc Remelt (VAR) or Electron Beam Single Melt (EBSM)
  - Take various forms bar, billet, plate and shapes.

- **ATI425** (Ti-4Al-2.5V-1.5Fe-0.25O)

➢ Originally developed by ATI for ballistic armor application Aerospace and defense.

➢ New α-β Alloy Fe and V as Beta stablizers and Al as alpha stablizers

➢ High Strength, high ductility, high corrosion resistance, superplastic formability

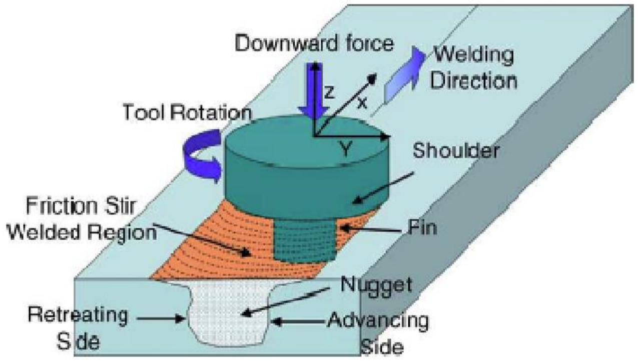
➢ Developed to improve upon overall production costs of Ti-6Al-4V while providing similar properties.

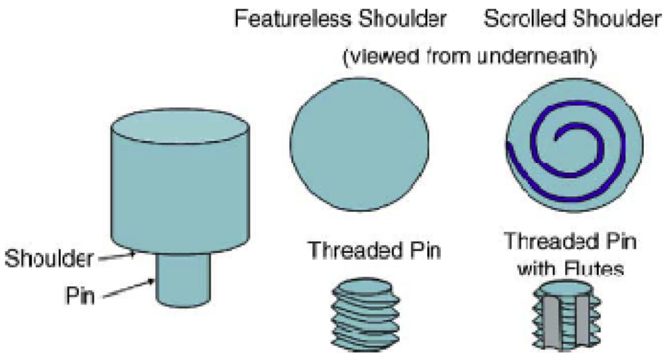
➢ Both Ti-54M and Ti-6Al-4V have similar properties, difference in microstructure to be reason for improved machinability (10-15%)

- Boati (NO INFORMATION GIVEN)

Friction Stir Welding

- Solid state Joining Invented in 1991
- Production of weld : Similar to base metal properties
- No fumes or splatter, less distortion and more energy efficient
- Non-consumable tool imparts severe plastic deformation
- Quality of weld depends on of spindle speed, traverse speed, tool geometry
- Have been validated by industry leaders. And production parts in aircraft \
- Critical part of certifying the joining process is establishing a high cycle fatigue limit





D. G. Sanders. M. Ramulu, P.D. Edwards, and A. Cantrell, "Effect on the Surface Texture, Superplastic Forming and Fatigue Performance of Titanium 6Al-4V Friction Stir Welds", Journal of Materials Engineering and Performance, Vol. 19, 2010, pp. 503-509

[1]

FSW : A brief Review

Alloy sheet thickness 5 mm

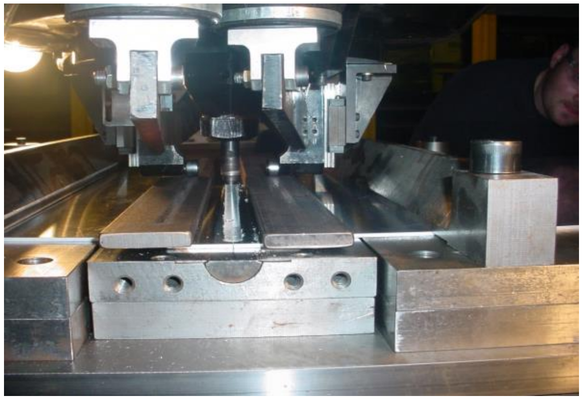
Processing Parameters : Rotation of the tool (rpm) and Feed rate (mm/min)

Solid state joining incorporated with severe plastic deformation

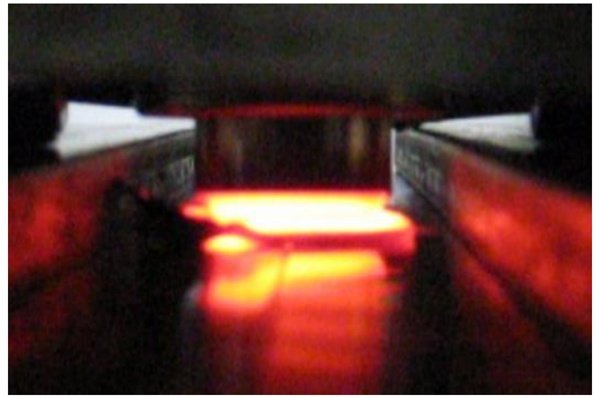
Importance of material on the retreating side

Commercial application of FSW; spliced with Super Plastic Forming (SPF)

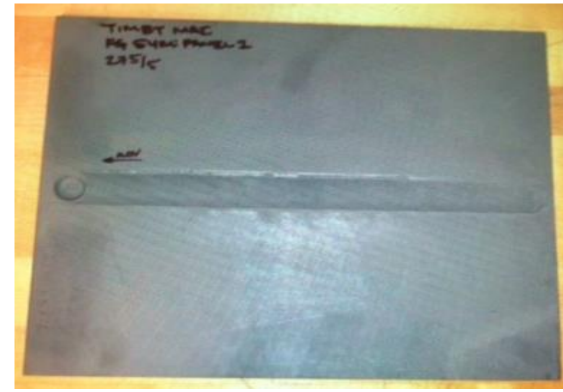
FSW : A brief Review Contd…



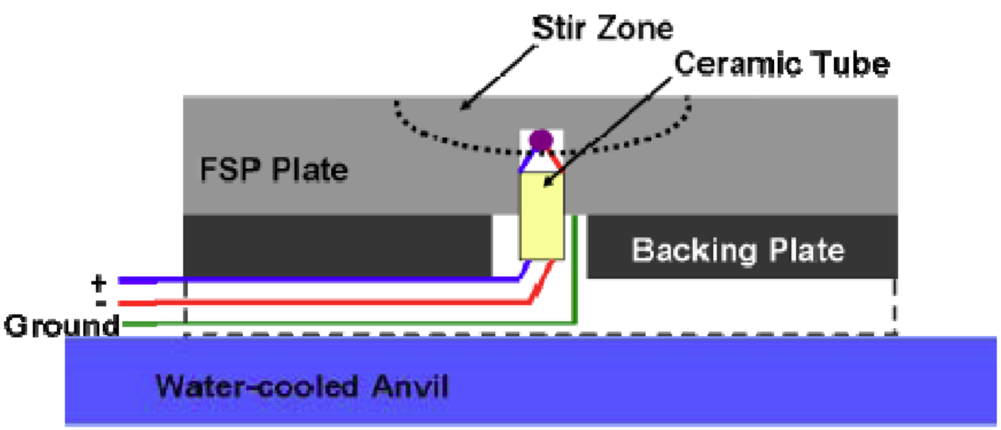
FSW Process

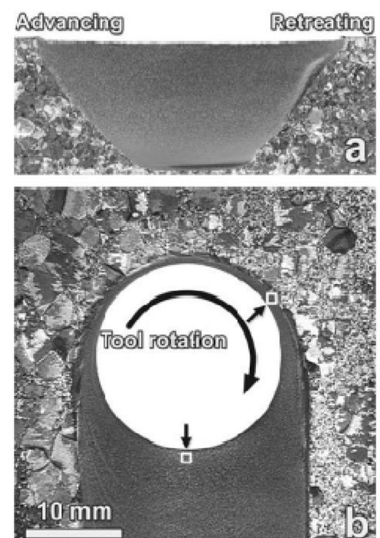


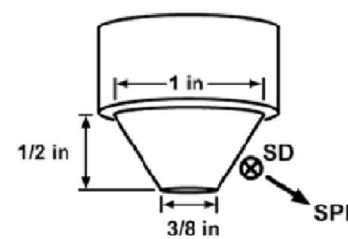
FSW Experiment



Ti-Alloy FSW

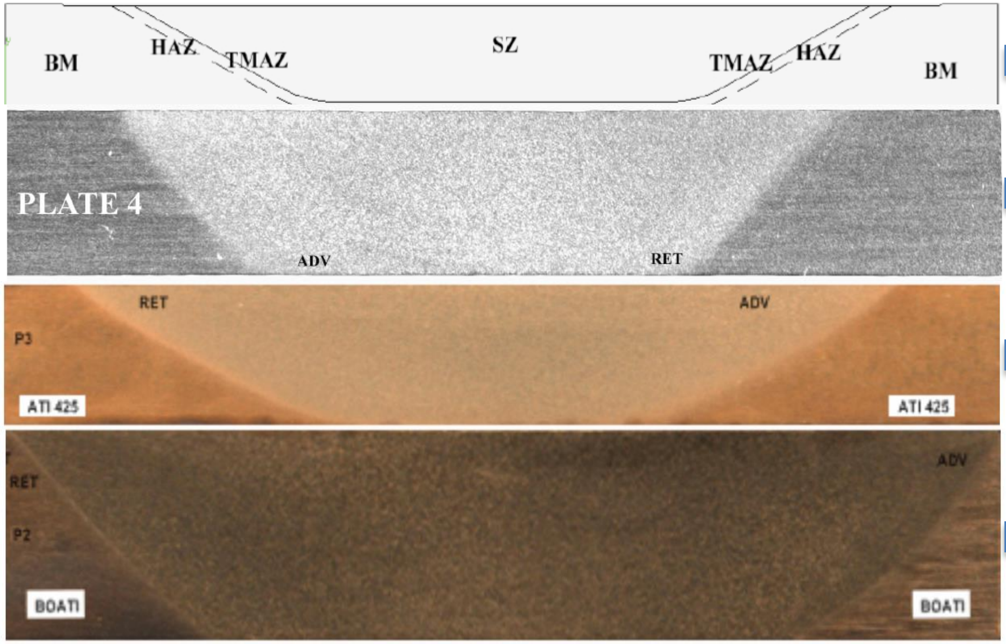






Friction Stir welding in Ti-Alloys

- BM = Base Material (Unaffected by the welding process)
- HAZ = Change in the materials properties; due to heat induced by welding
- TMAZ* = Thermo-mechanical affected zone
- SZ = Stir Zone (or Weld Nugget)



Weld Profile Macro

TIMET 54M

ATI425

BOATI

No inclusions or voids in the stir zone; i.e. 'good' welding quality

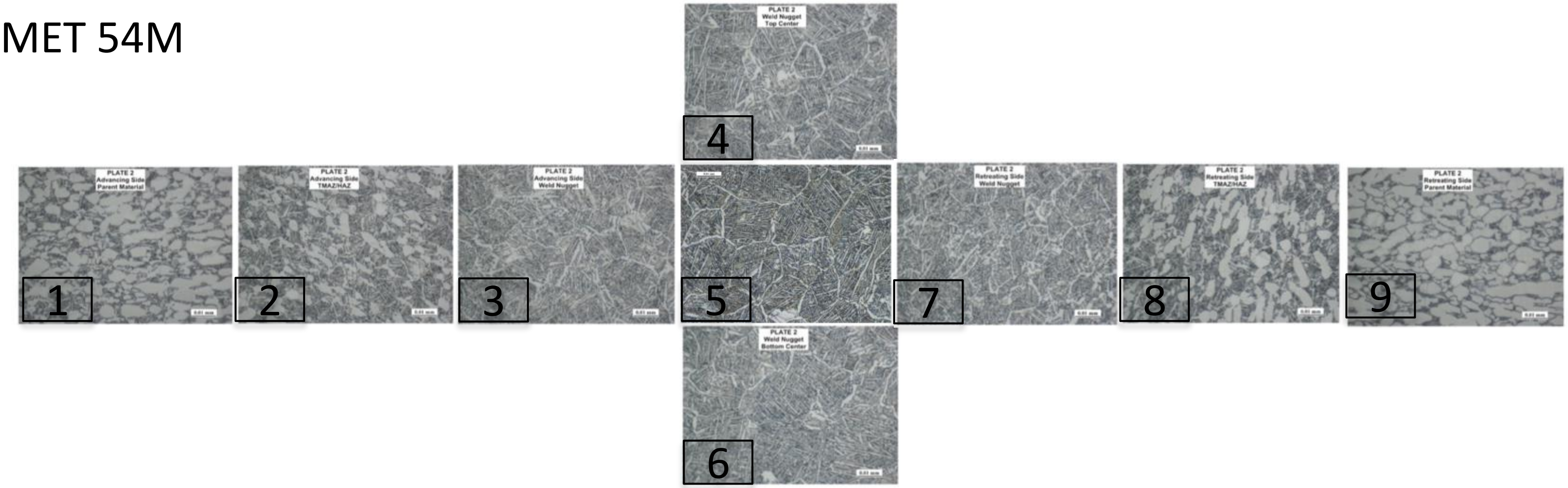
* Negligible TMAZ in Ti-alloys due to low conductivity of Titanium

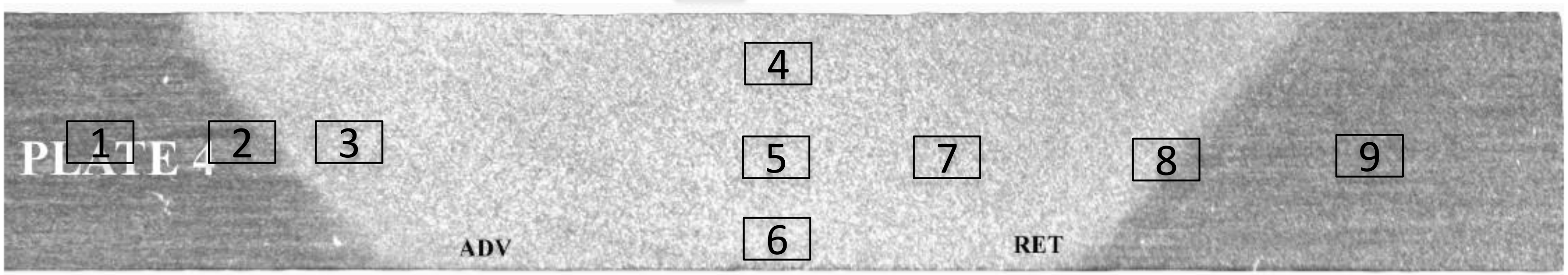
Experiments

Microstructure Analysis

- Each specimen was sectioned, mounted, and polished in accordance with ASTM E3-01.
- Etching: 2% HF etchant per ASTM E407- 07.
- The microstructure analysis : Nikon Eclipse LV150 microscope/camera and NIS image analysis software system.

- TIMET 54M

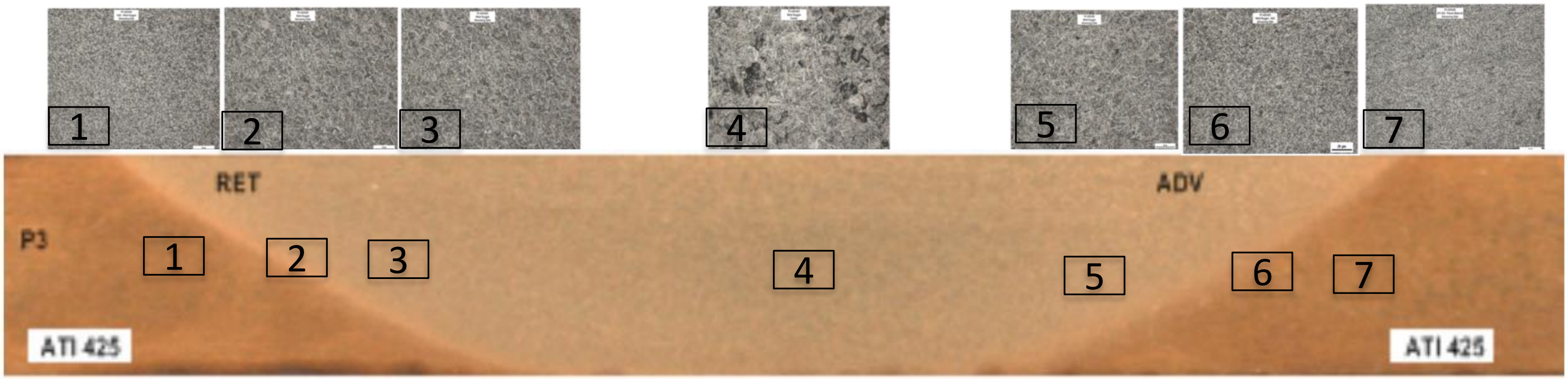




- Base material : α/β phase*
- HAZ and TMAZ : Transition of primary α with a matrix of β into distorted grains with smaller portions of plate like α intermixed.
- WN (or SZ) : Refined and distorted grains of α in a matrix of transformed β containing acicular α
- Microstructure in the welded region in the center is almost same along the weld centerline.

*β is dark and α is light as visually observed in optical microscopy

- ATI 425



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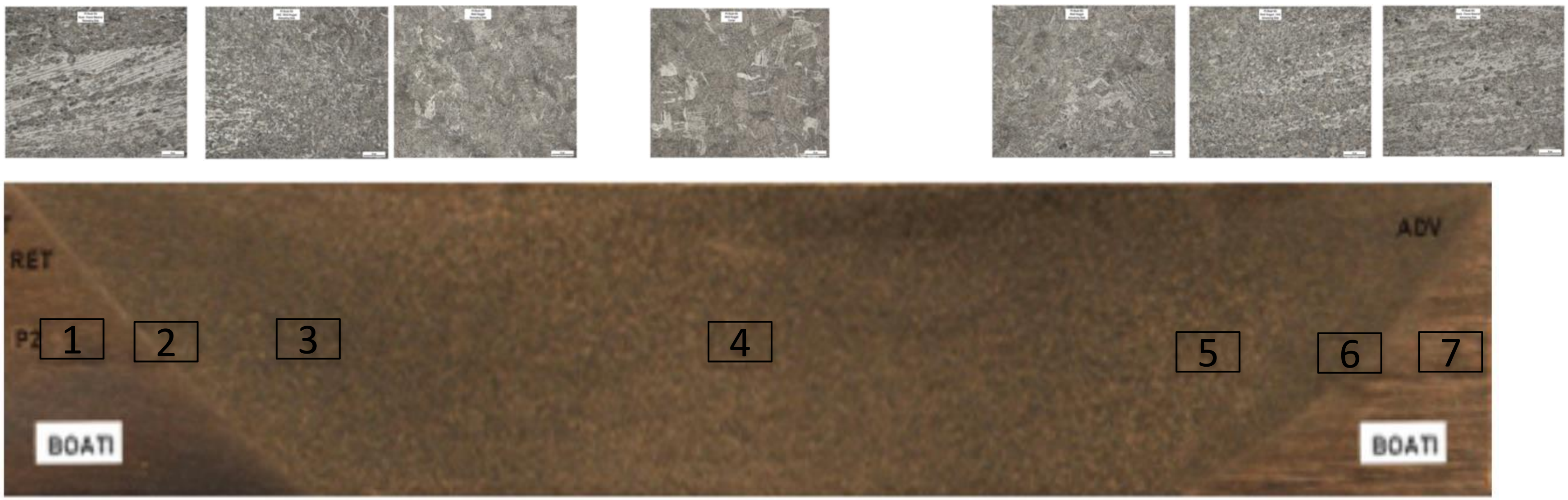
➢ BOATI Standard Grain (SG)



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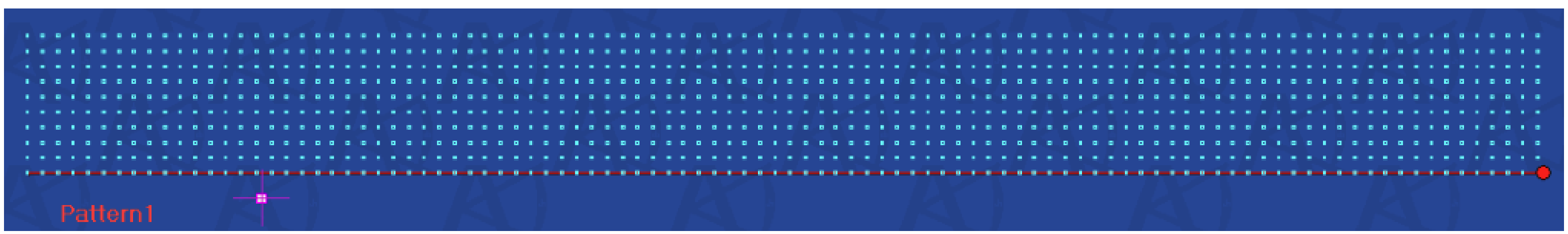
Micro hardness Analysis

- Each specimen was sectioned, mounted, and polished in accordance with ASTM E3-01.
- All micro hardness indents have spacing of 254 microns.
- All the hardness traverses were conducted with a LECO AMH 43.
- Vickers Hardness (Hv) with a 500g load and dwell time 13s.
- Hardness was conducted in accordance with ASTM E384-06
- Recorded data from Left to right



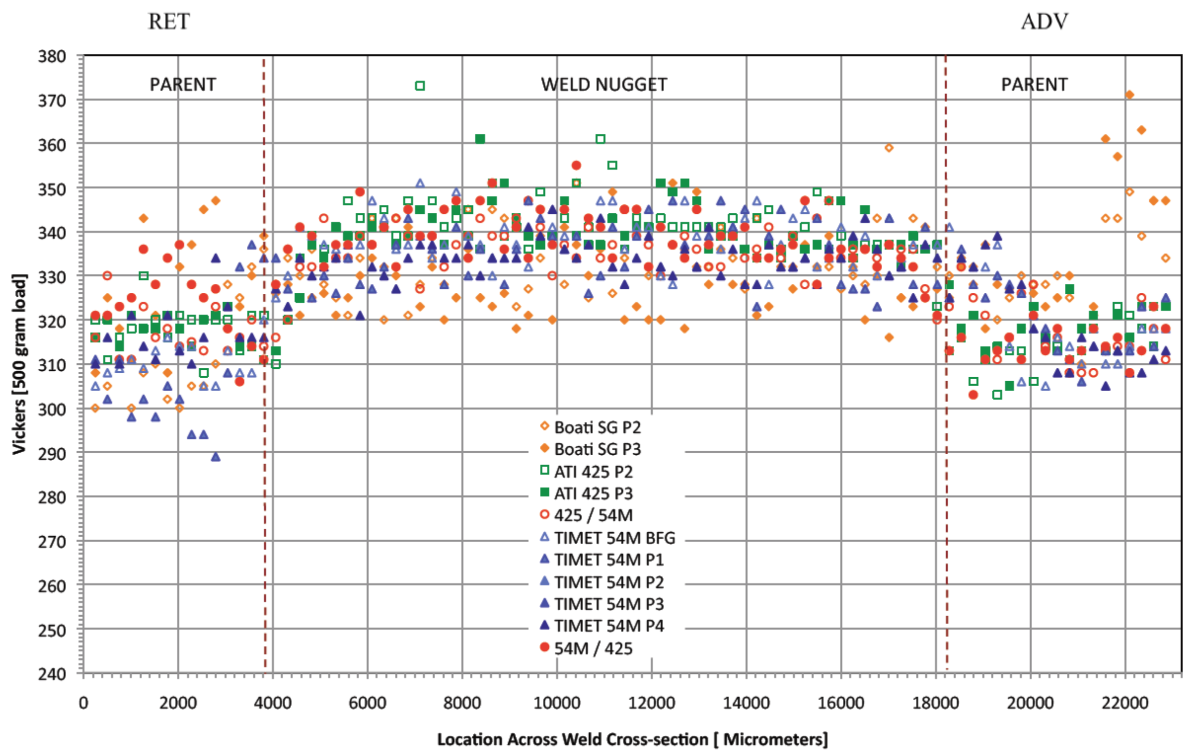
Magnification : 12.5X

254µm

Magnification : 700X

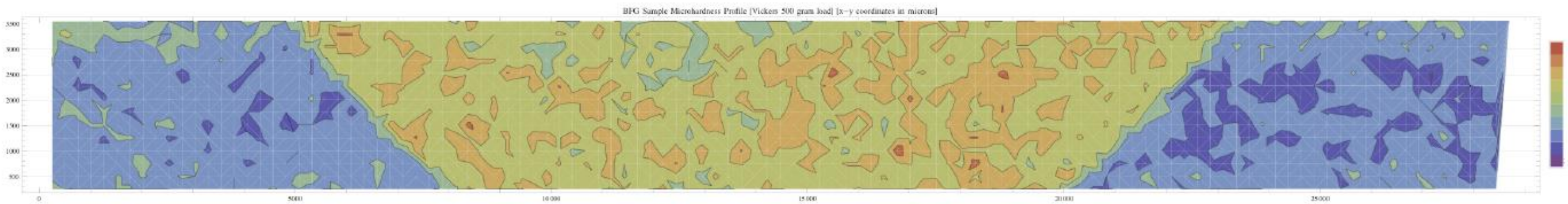
Micro hardness results

Materials		Microhardness Profile						Weld Nugget Center		Parent Material	
		Vickers 500 gm load, indent spacing 254 µm						3 indent average off centerline 1200 micrometers		3 indent average from ends of traverses	
Advance	Retreat	Number of indents	Length	Height	Max	Min	Ave	Above	Below	Above	Below
TIMET 54M		96	22860	2400	363	300	331	329	333	329	333
ATI 425		96	22860	2400	373	303	332	339	346	339	346
BOATI SG		1859	28194	4066	357	295	325	331	336	331	336

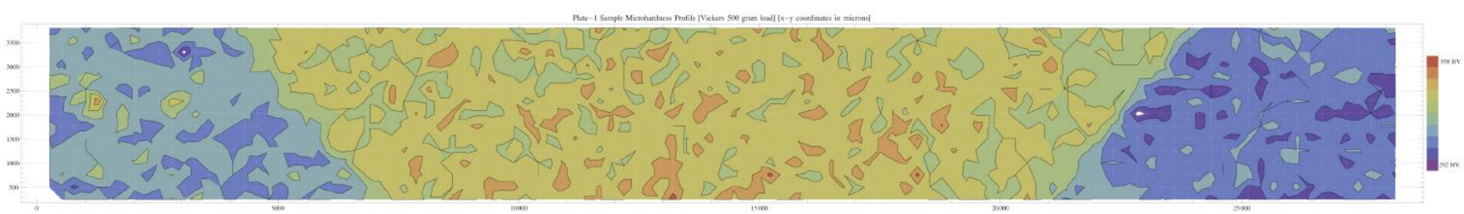


Micro hardness contours TIMET 54 (ONLY)

Color contour plots were generated using Mathematica 7.0 software package from the hardness measurements of each alloy weld cross- section.



TIMET BFG Hardness Profile



TIMET Hardness profile- Plate 1

Micro hardness contours TIMET 54 (ONLY)

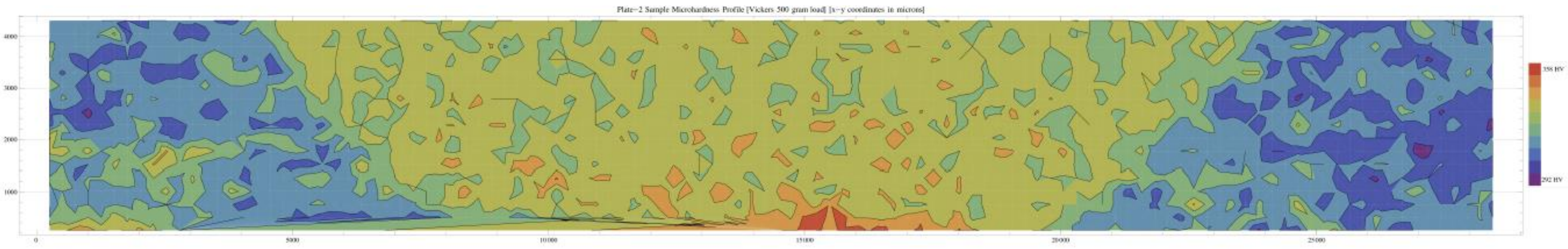


Plate 2

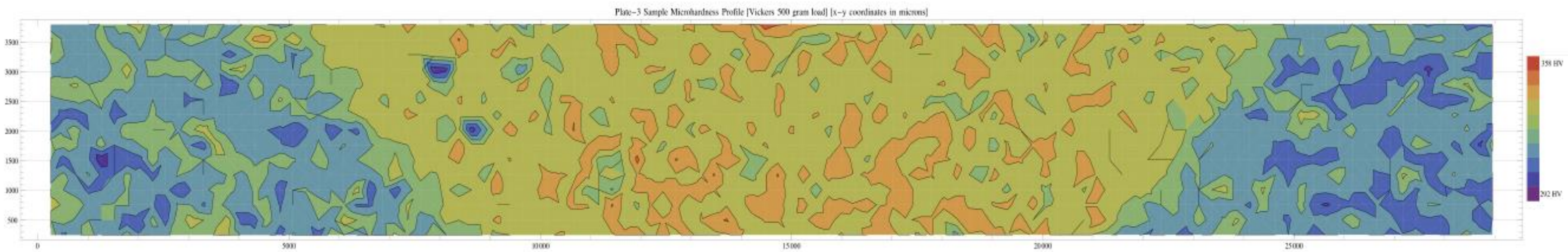


Plate 3

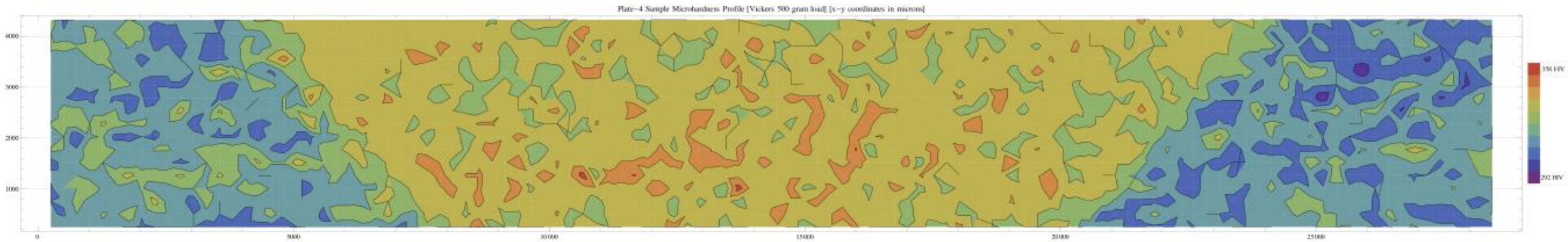


Plate 4

In some cases high values of hardness have been observed in the bottom of the weld nugget which could be attributed to the higher penetration depth of the tool.

Tensile tests

- ❑ Each specimen was sectioned, mounted, and polished in accordance with ASTM E8M.
- ❑ All tensile tests were completed on an Instron/Compression test frame
- ❑ The testing was completed in displace extensometer.
- ❑ The strain rate ($\dot{\varepsilon}$) was in accordance with AMS-T-9046B until specimen fracture

Material		YS (in ksi)	UTS (in ksi)	Elongation (%)	Fracture Location
ADV	RET				
TIMET 54M		136	141	8.2	Parent RET/(or)ADV
ATI425		149	156	3.8	Weld
Boati		121	145	8.8	Weld RET

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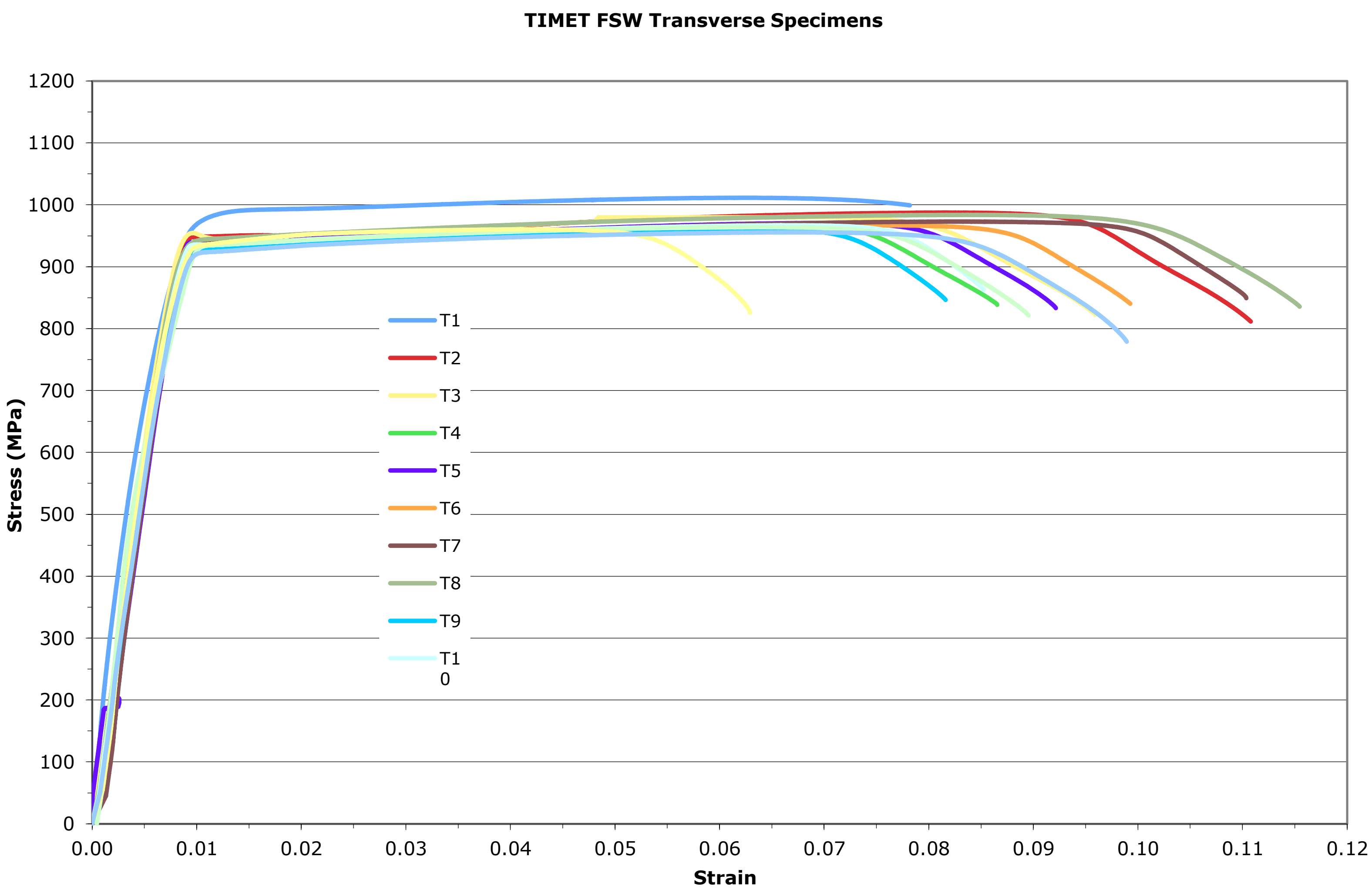
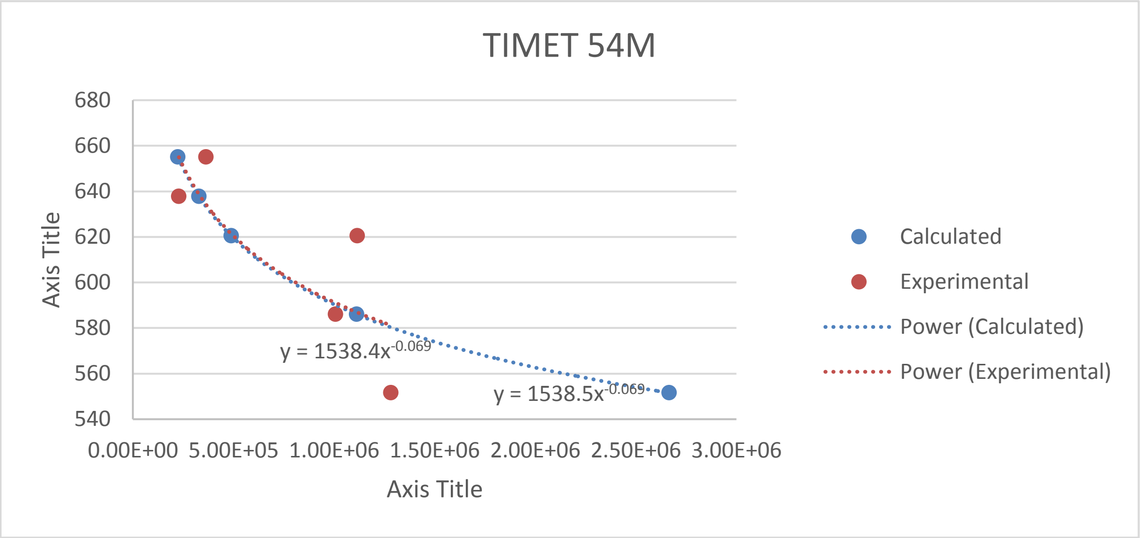
Tensile tests (TIMET 54, ONLY)



Fatigue tests



Conclusions

- Each macro specimen evaluated, showed good quality friction stir weld for each material condition of this study.
- No inclusion, or voids are seen in any of the FSWed cross section evaluated.
- A completely penetrated friction-stir butt-welded Titanium plates was verified in each examined case.

	Base Material	HAZ/TMAZ	WZ
TIMET 54M	Primary alpha with transformed beta	Refinement of alpha grains in an increasing amount of transformed beta matrix	Prior beta grains (Basket weave morphoology) defined by intergranular alpha plates
ATI 425	Primary alpha with infused intergranular beta	Refinement of alpha grains in an increasing amount of transformed beta matrix	Accicular alpha plates with basket weave morphoology
Boati	Large elongated alpha particles. Primary alpha with intergranular beta	Refinement of alpha grains in an increasing amount of transformed beta matrix. TMAZ is the termination of large elongated alpha stringers	Basket weave morphology with no observed prior beta boundary

Conclusions

- Hardness change of 5-20 has been observed from Base material to weld nugget
- A sudden inscrease in the hardness of Boati BM is due to weld joint being perpendicular to the original materials rolling direction.
- Hardness slightly increased from top to bottom in all weld due to refinement of weld microstructure.

- TIMET 54M has consistent yield. Most specimens failed in the parent material
- TIMET yield and UTS findings matched with the TIMET corporation data.

- ATI425 failed in the weld region weaker than than the base material
- All the properties were lower than than the values reported by Allegheny Technologies for parent material

- BAOTI has the largest % elongation.
- BAOTI has the lowest yield strength among the titanium alloys tested
-

Acknowledgements

- We sincerely thank The Boeing Company for financial support of Titanium Component Manufacturing Research Project at UW.
- Thanks are extended to Dr. Edwards, Senior Manager, The Boeing Company for support & encouragement

THANK YOU !