Welding Metallurgy and Capstone Design Project

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Fundamentals

1. Parts are joined at contact surface by heat and/or pressure
2. Many welding types uses only heat (without pressure)
3. Sometimes filler metal are added

Why Welding is Important

1. Provides a permanent joint
2. Usually the most economical way to join parts
3. Mechanical fastening usually requires additional components (e.g., screws and nuts) – additional weights
4. Can be done "in the field" (portable)
5. Benefits for various industries: automotive, constructions, aerospace, etc ….

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Limitations and Drawbacks of Welding

a) Most welding are performed manually
b) Labour cost can be expensive
c) Needs high energy and may be dangerous
d) Disassembly can be difficult (permanent joint)
e) Can have defects that are difficult to detect

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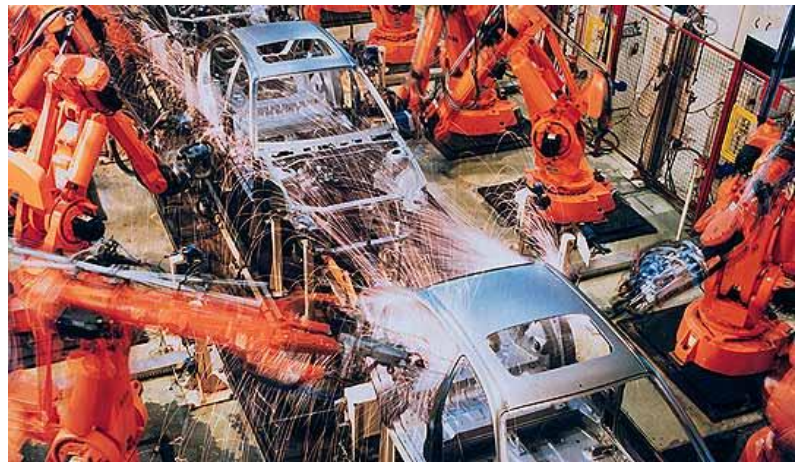
Welded Components

Bicycle

Bridges

4

Welded Components – cars (automotives)



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Types of Welding Processes

- American Welding Society: 50 types of welding
- Two big categories:
  - **Fusion welding:** **melts** the base metals
  - **Solid state welding:** does **not** melt the base metals

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Fusion Welding

Fusion welding: joining metals by **melting** joint surfaces and adjacent base metal

Fusion Welding Processes:

- Gas welding,
- Arc welding *(most common)*, and
- High-energy beam welding

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Fusion Welding

1. **Gas Welding**
   - Oxyacetylene Welding (OAW)
2. **Arc Welding:**

   a. Consumable electrodes
   - Shielded Metal Arc Welding (SMAW)
   - Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG)
   - Submerged Arc Welding (SAW)

   b. Non-consumable electrodes
   - Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG)
   - Plasma Arc Welding (PAW)
3. **Other Fusion Welding Processes (High Energy)**
   - Electron Beam Welding (EBW)
   - Laser Beam Welding (LBW)

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Heat Source in Fusion Welding

- Gas welding: gas flame
- Arc welding: electric arc
- High-energy welding: high-energy beam or laser

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Heat Distributions

A hair dryer:

- 1.5-2kW,
- Heat is spread over 50 mm in diameter: heat the metal but will **not** melt

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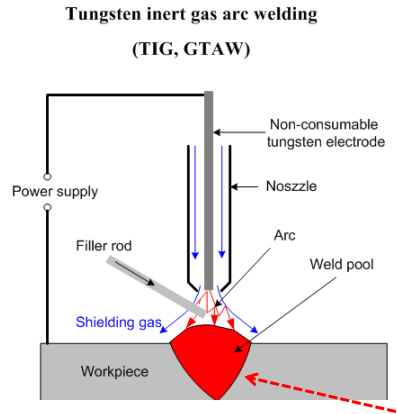
Heat Distributions



Melt and solidify

A simple/small arc welder:

- 1.5-2kW,
- Heat is spread only 6 mm in diameter: will melt the metal

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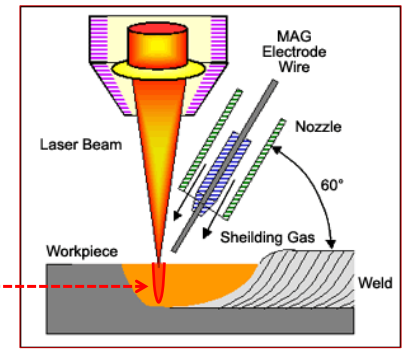
Heat Distributions



Melt and solidify

Laser/electron beam welder:

- Up to 16kW (thin sheets: 1-3kW),
- Heat is highly focused~ 0.3-0.8 mm:

could weld up to 13 mm thick plate in a single pass

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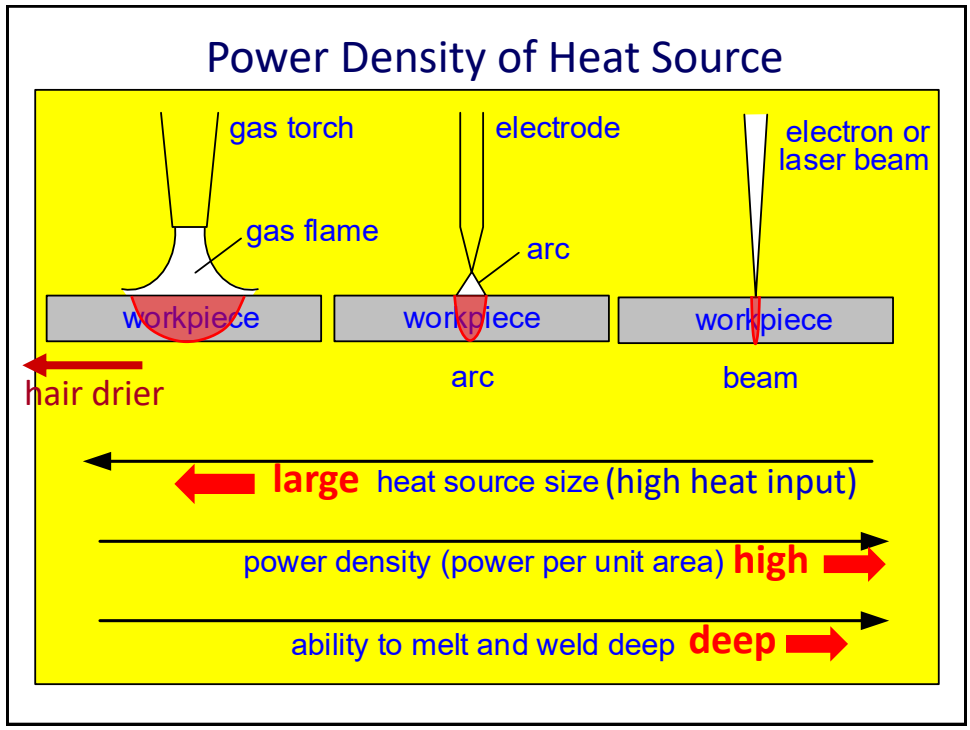
Power Density of Heat Source
gas torch
gas flame
electrode
arc
electron or
laser beam
workpiece
workpiece
workpiece
hair drier
arc
beam
large heat source size (high heat input)
power density (power per unit area) high
ability to melt and weld deep deep

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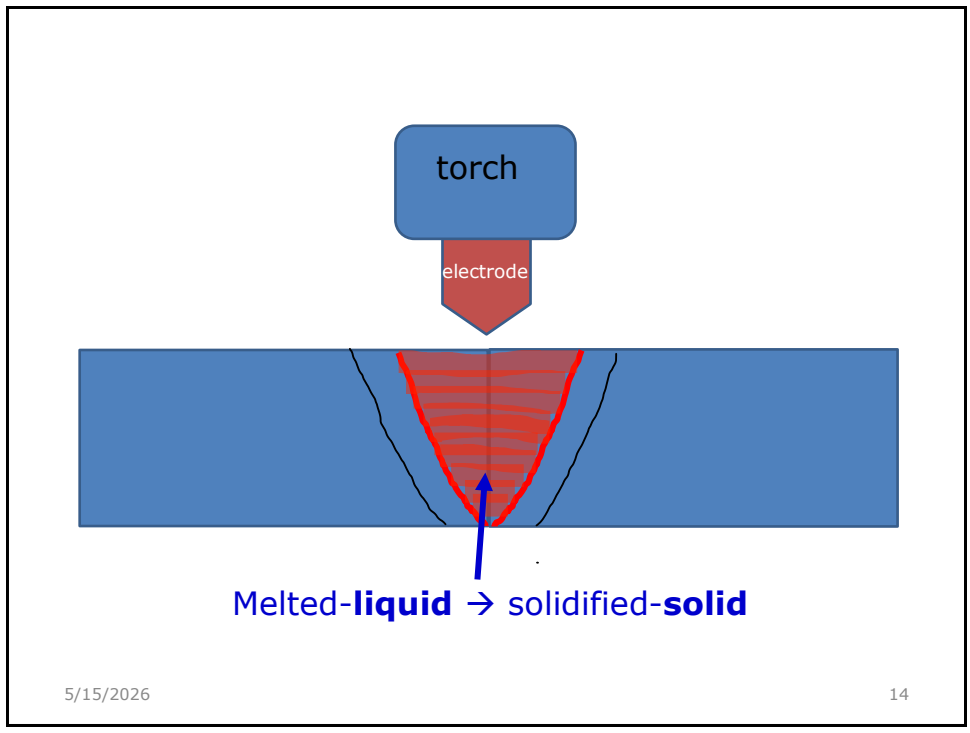
torch
electrode
Melted-liquid → solidified-solid
5/15/2026
14

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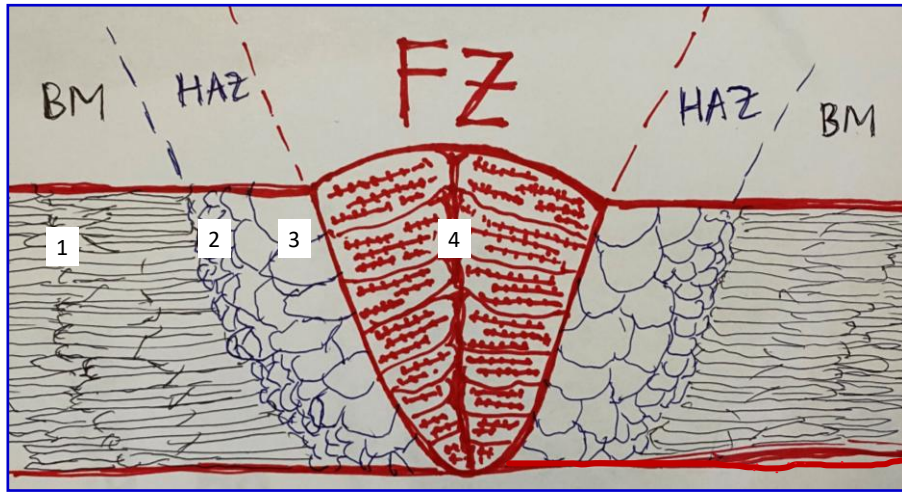

1. Base metal (BM): unaffected by the heat
2. Heat affected zone (HAZ) or Far HAZ: affected slightly by the heat: grains are small
3. Heat affected zone (HAZ) or Near HAZ: affected significantly by the heat: grains are big
4. Fusion zone (FZ): large columnar grains with dendritic structure *(and weld centreline)*

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Capstone Design

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Welding of titanium and titanium alloys

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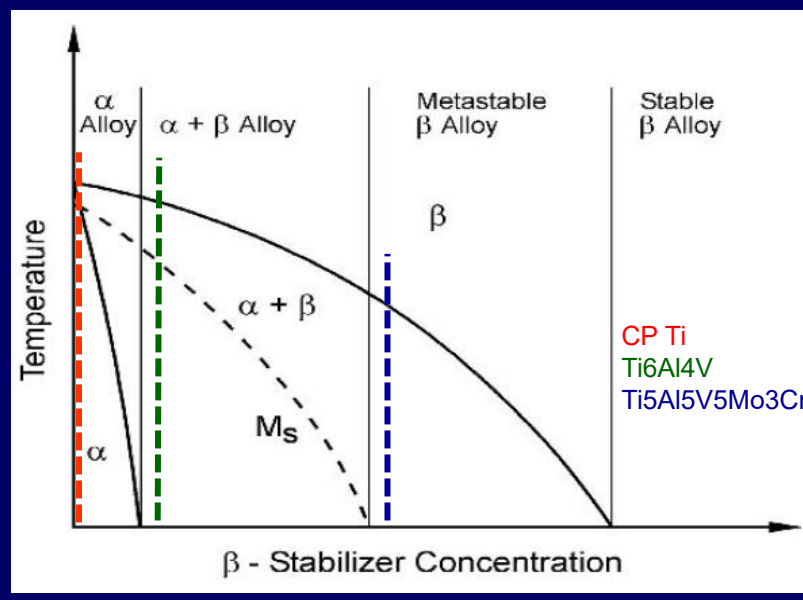

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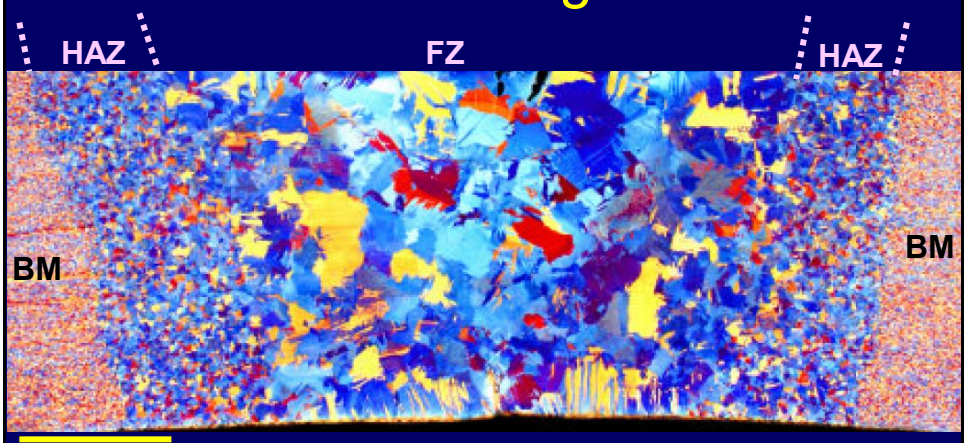
Fusion Welding Profile



Danielson, Adv. Mat & Processes, Feb 2003

FZ: Fusion Zone

HAZ: Heat Affected Zone

BM: Base Metal

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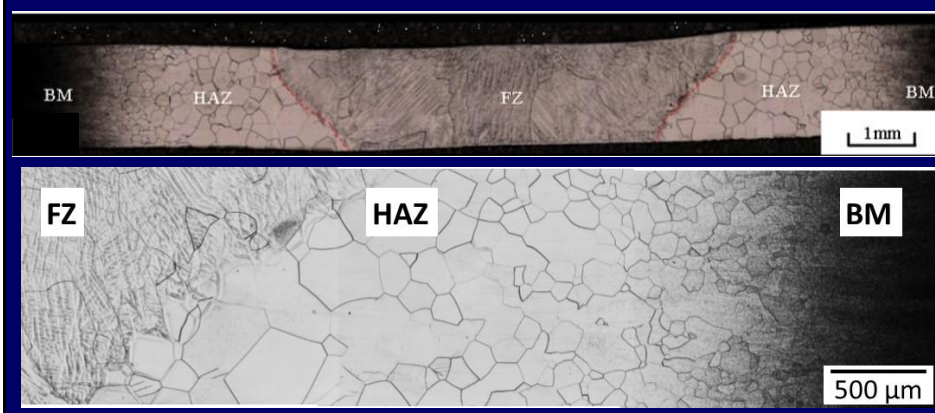
Ti5553-Ti5553_GTAW



Ti5553 = Ti-5Al-5V-5Mo-3Cr

- Microstructure?

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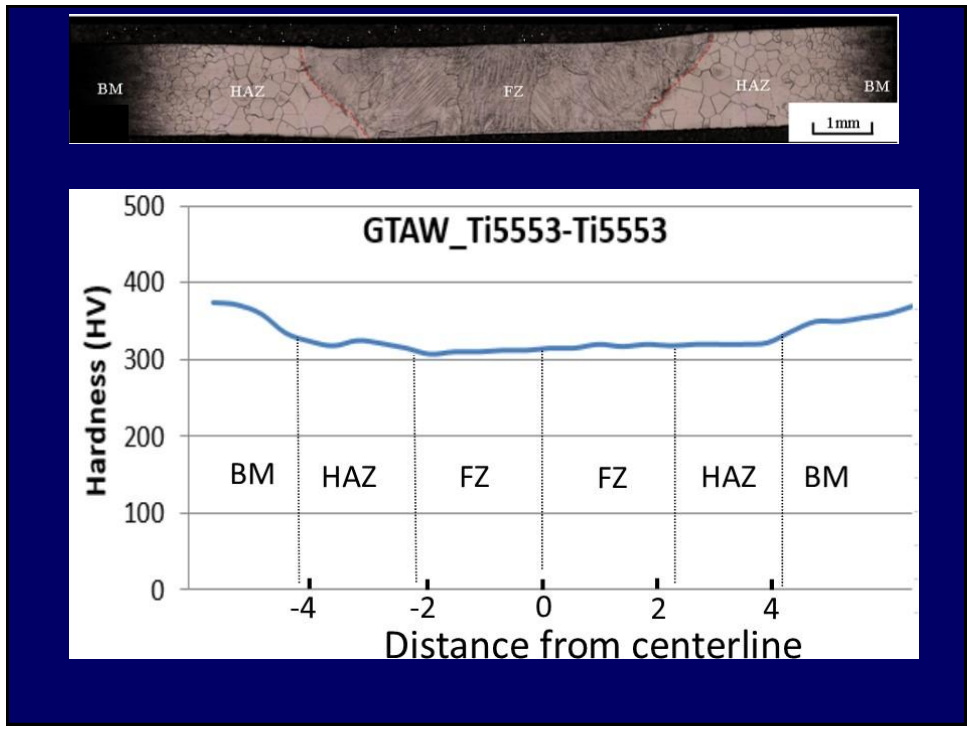
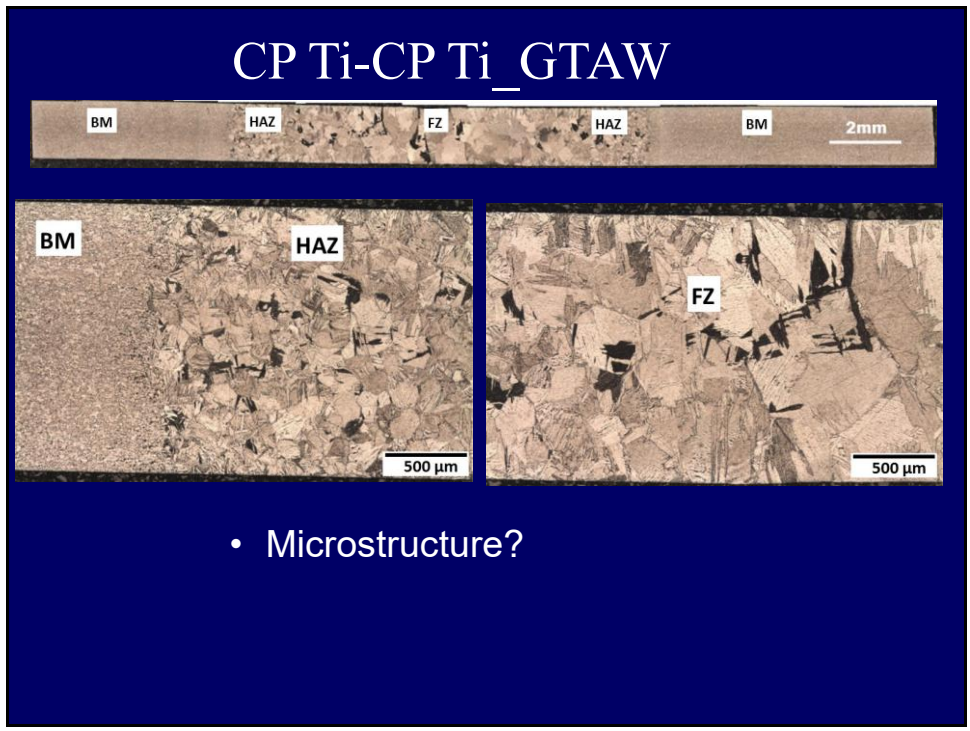

BM
HAZ
FZ
HAZ
BM
1mm
GTAW_Ti5553-Ti5553
Hardness (HV)
500
400
300
200
100
0
BM
HAZ
FZ
FZ
HAZ
BM
-4
-2
0
2
4
Distance from centerline

21


CP Ti-CP Ti_GTAW
BM
HAZ
FZ
HAZ
BM
2mm
BM
HAZ
500 µm
FZ
500 µm
• Microstructure?

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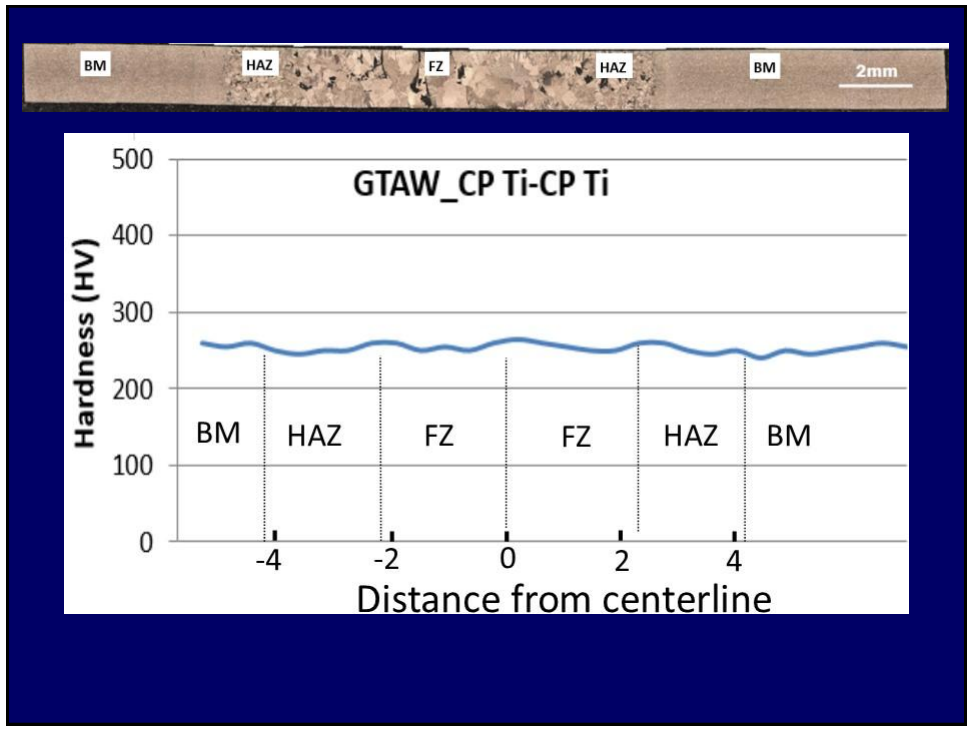

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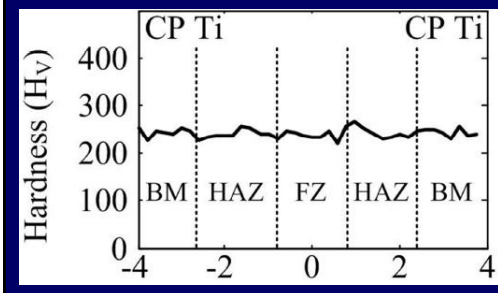
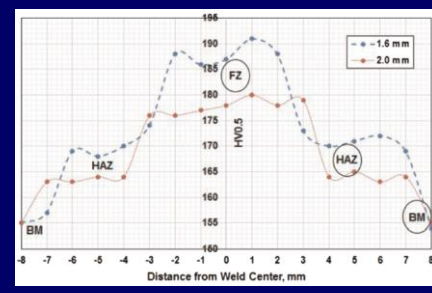
Welding of CP Ti and α Alloys





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Advanced Materials Research Vol. 275 (2011) pp 81-84
Online available since 2011/Jul/04 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.275.81

Characteristics of Electron Beam Welded Ti & Ti alloys

Ryan Mitchell [1, a], Andrew Short [2,b], Timotius Pasang [1,c] and Guy Littlefair [1,d]

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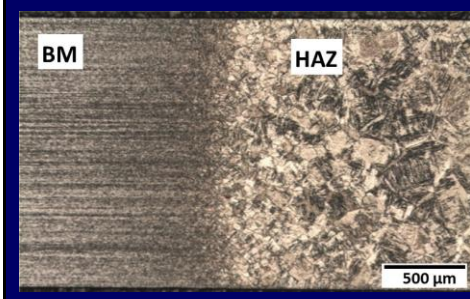
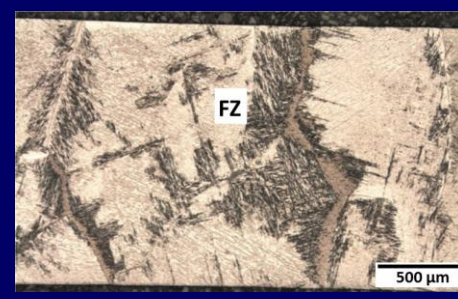
Ti64-Ti64_GTAW

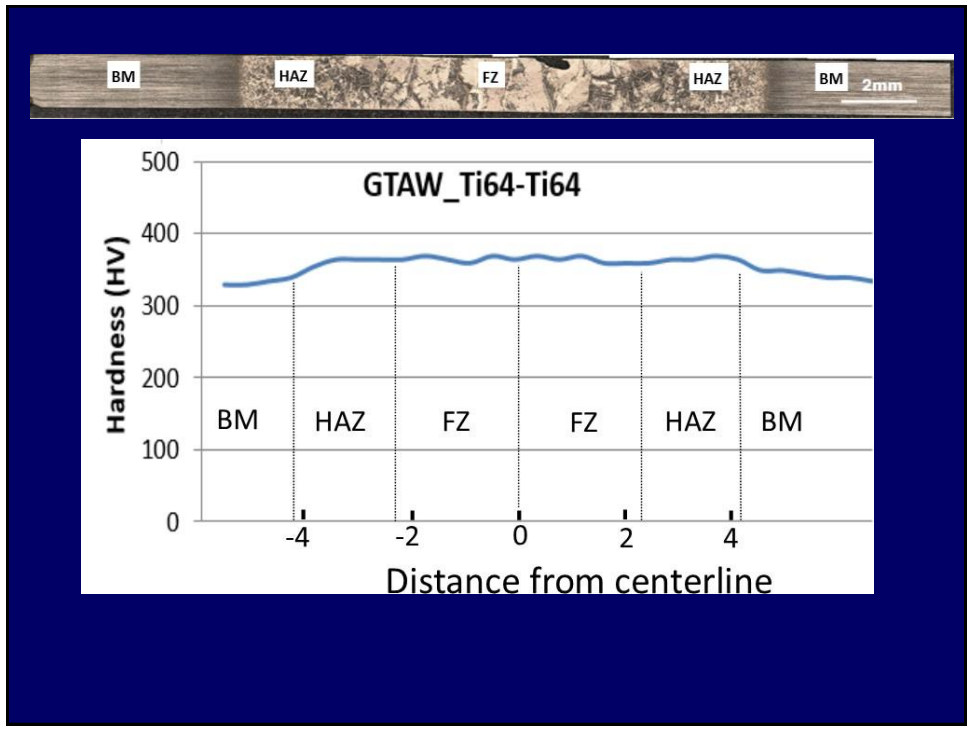




Ti64 = Ti-6Al-4V

- Microstructure?

26



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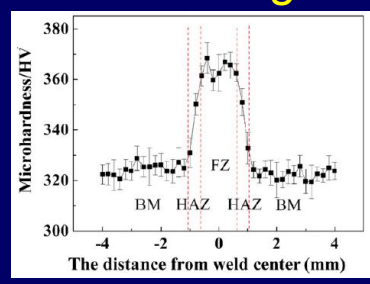
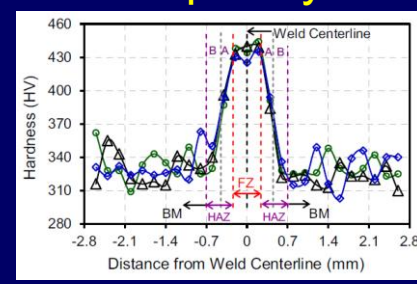
Welding of Titanium α/β alloys



Ti6Al4V (Ti64)



Ti6Al2Sn4Zr2Mo (Ti6242)

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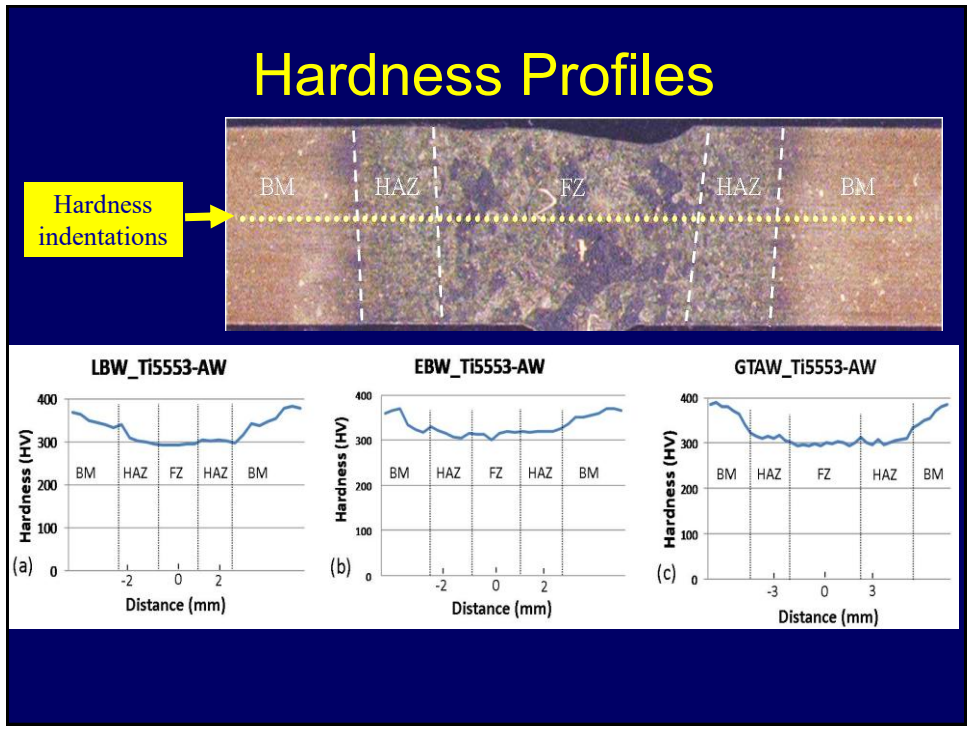
Hardness Profiles
Hardness indentations
BM
HAZ
FZ
HAZ
BM
LBW_Ti5553-AW
EBW_Ti5553-AW
GTAW_Ti5553-AW
Hardness (HV)
Distance (mm)
(a)
(b)
(c)

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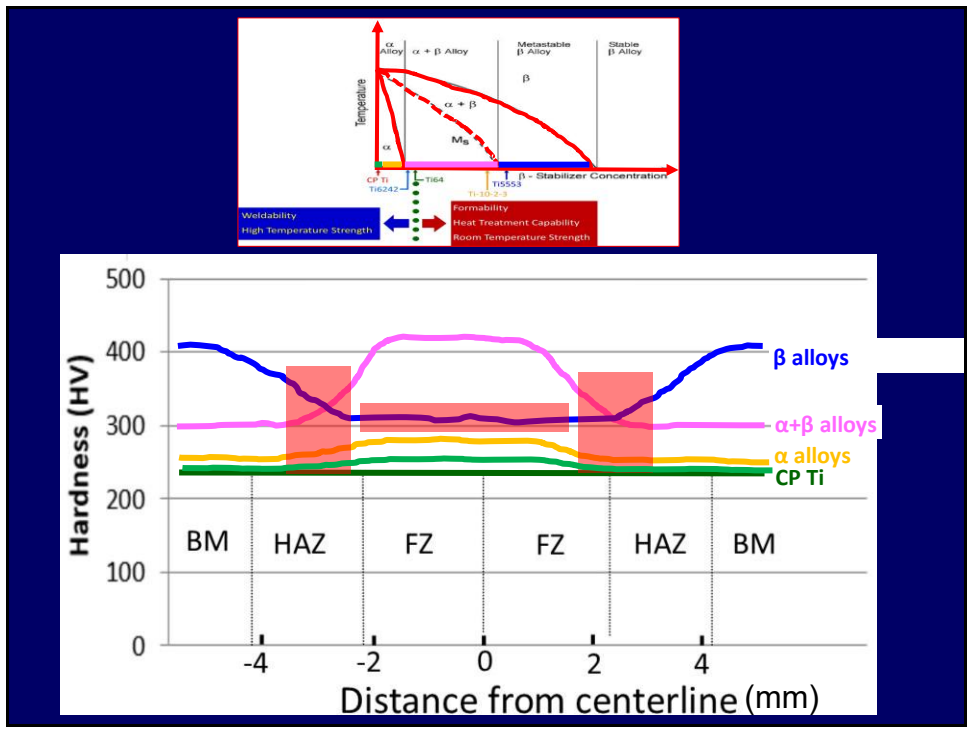
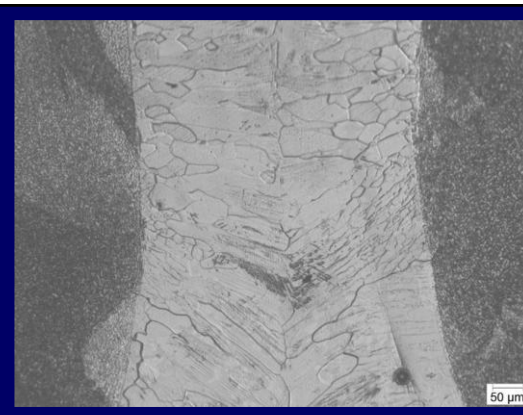

α Alloy
α + β Alloy
Metastable β Alloy
Stable β Alloy
Temperature
β
α + β
α
Ms
CP Ti
Ti6242
Ti64
Ti5553
β - Stabilizer Concentration
Weldability
High Temperature Strength
Formability
Heat Treatment Capability
Room Temperature Strength
Hardness (HV)
β alloys
α+β alloys
α alloys
CP Ti
BM
HAZ
FZ
FZ
HAZ
BM
Distance from centerline (mm)

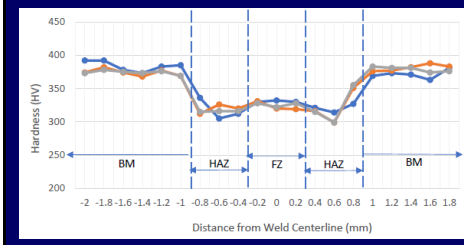
30

LBW of Ti10-2-3

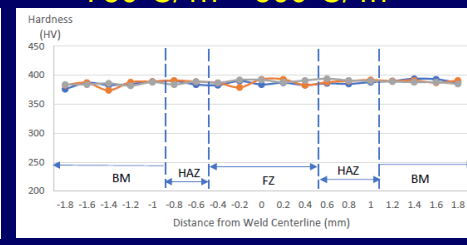
Meng Fu – PhD, Lehigh
Advisors:
Prof. Misiolek (Lehigh)
A/Prof. Tim Pasang (AUT)



As-welded



750°C/1h + 500°C/4h



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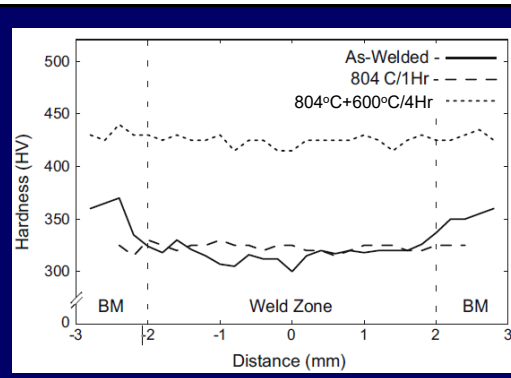
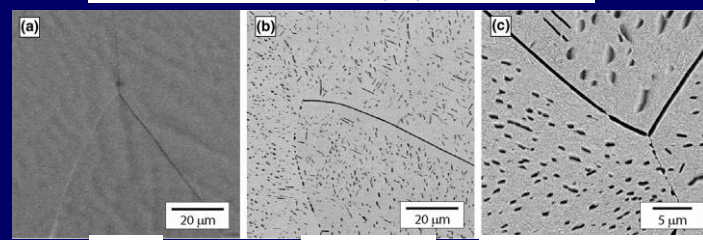
JC Sabol
PhD thesis -
Lehigh Univ.





AW | 804°C/1h | 804°C/1h+600°C/4h

Strength and Elongation increased by 25%

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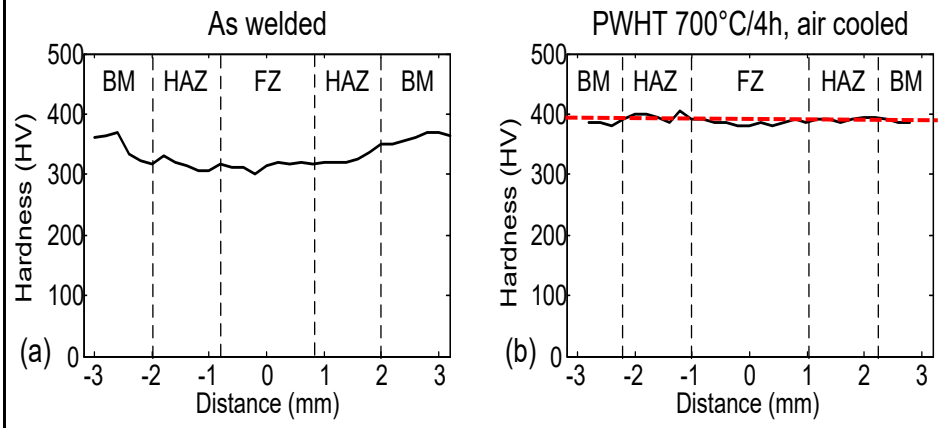
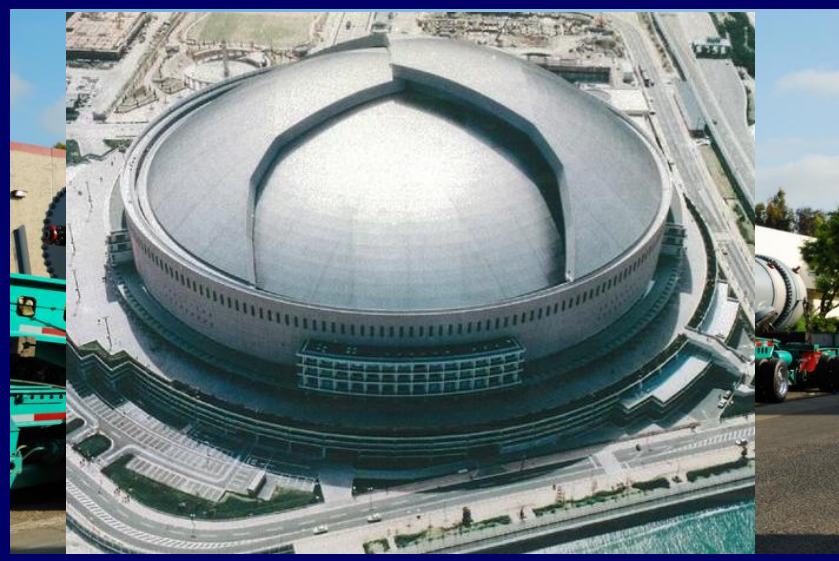
Hardness Profiles:

before vs. **after** Post Weld Heat Treatment



33



Post welding heat treatment??

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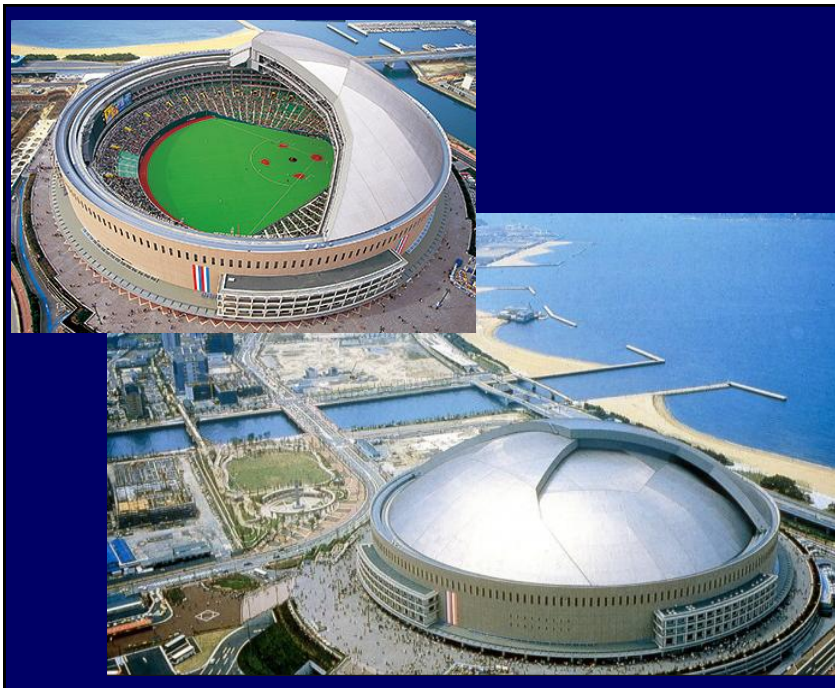

Fukuoka Dome, built 1993

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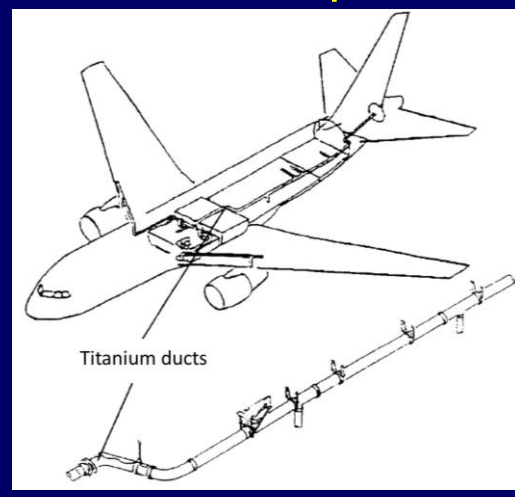
Aerospace



Ducts: to supply air on the plane (air conditioning)

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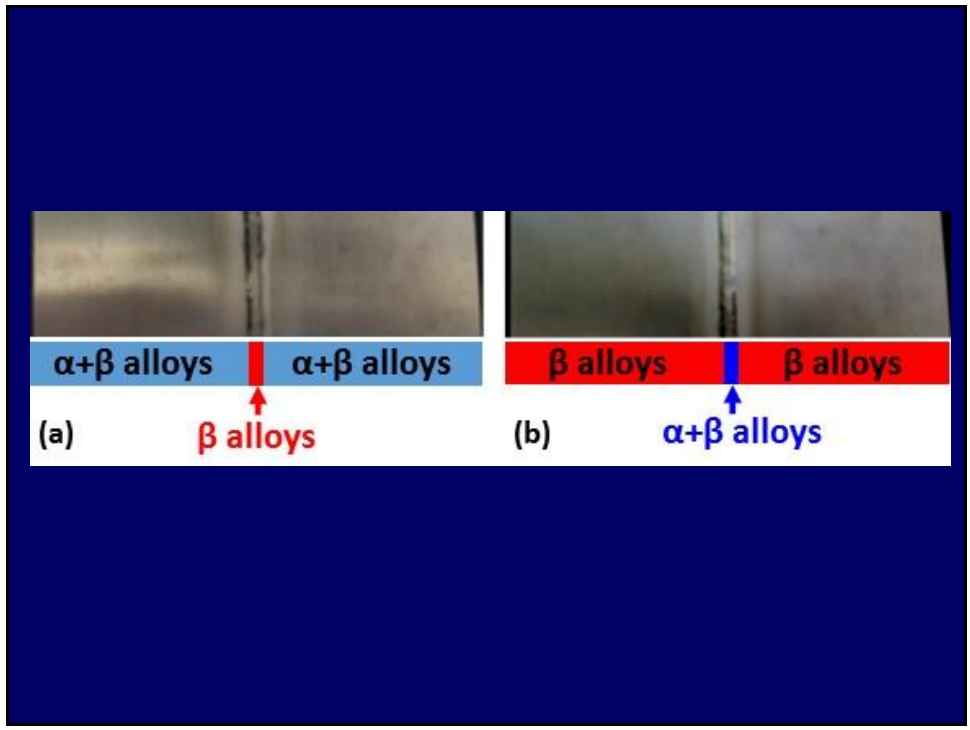

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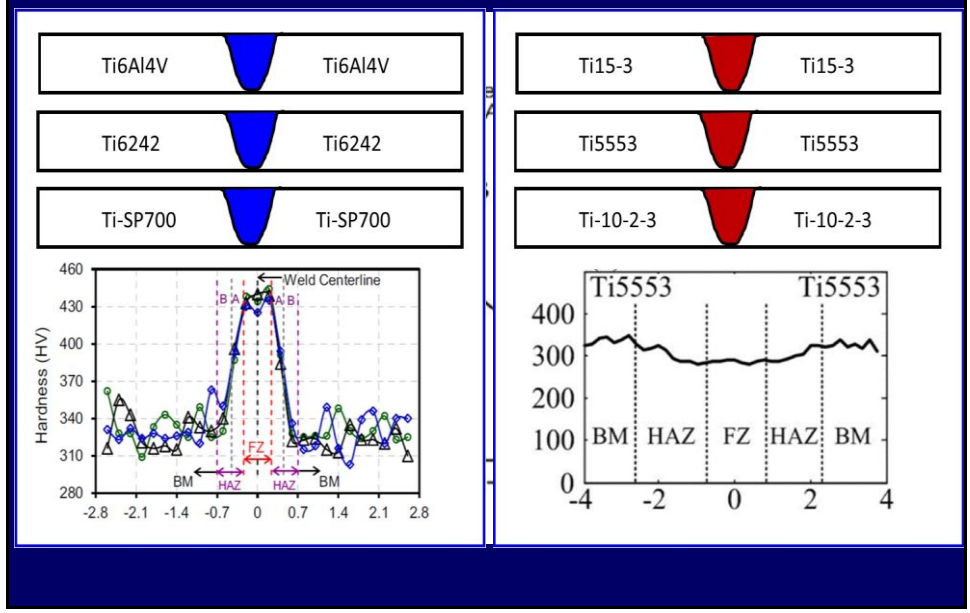
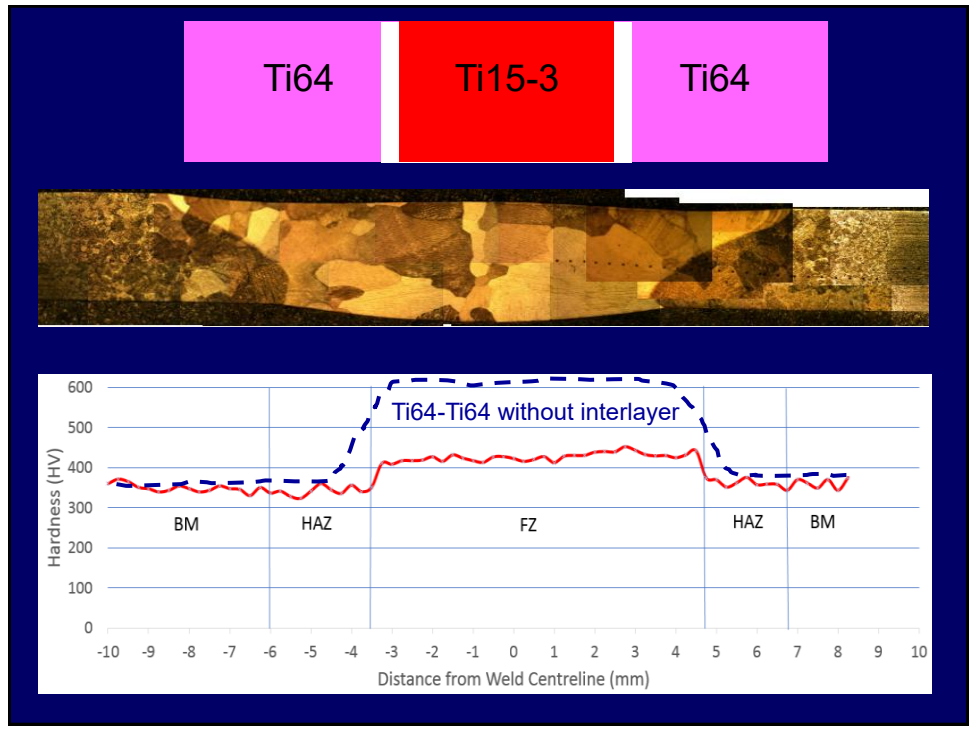
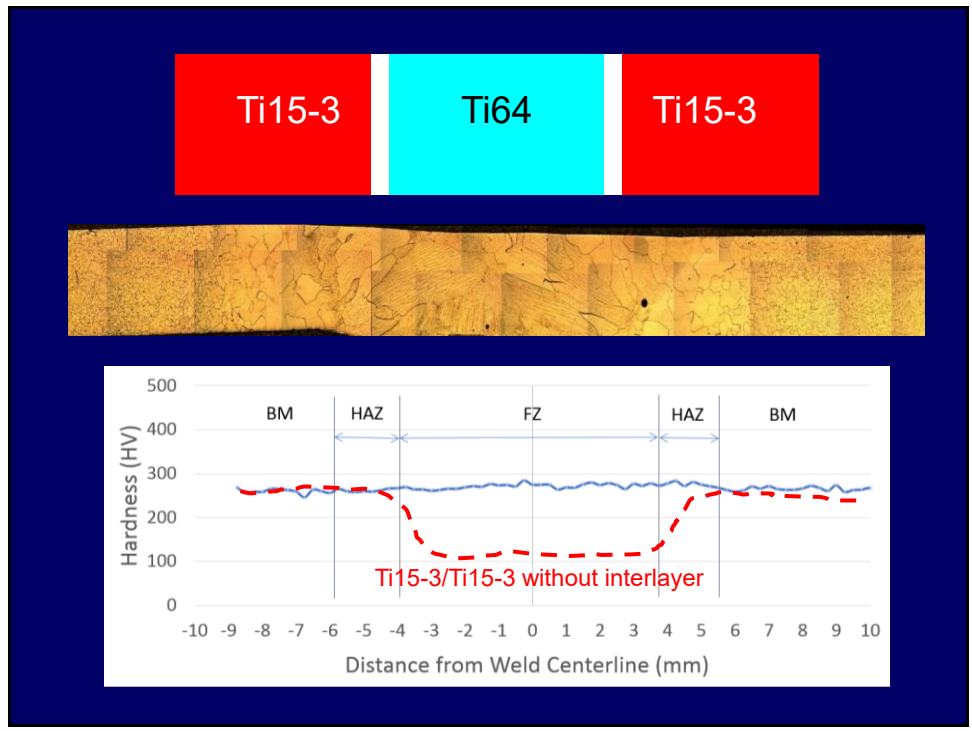
Welding using different interlayer



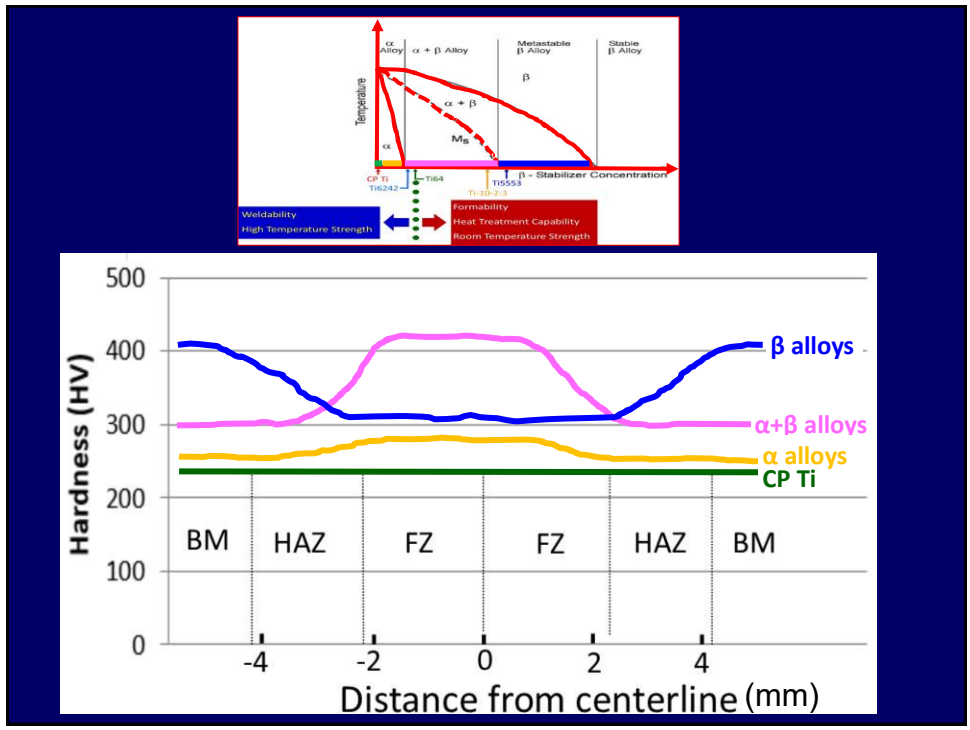
38


Ti64
Ti15-3
Ti64
Ti64-Ti64 without interlayer
Hardness (HV)
600
500
400
300
200
100
0
BM
HAZ
FZ
HAZ
BM
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Distance from Weld Centreline (mm)

39


Ti15-3
Ti64
Ti15-3
Hardness (HV)
500
400
300
200
100
0
BM
HAZ
FZ
HAZ
BM
Ti15-3/Ti15-3 without interlayer
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
Distance from Weld Centerline (mm)

40



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From Titanium Welding Project:

- 10-12 undergraduate thesis
- 1 Master thesis
- 3 PhD (Doctor) dissertation
  - JC Sabol – Lehigh University, USA
  - Meng Fu – Lehigh University, USA
  - Yuan Tao – AUT, New Zealand
- More than 10 journal publications

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Blue Diode Laser Welding Technology

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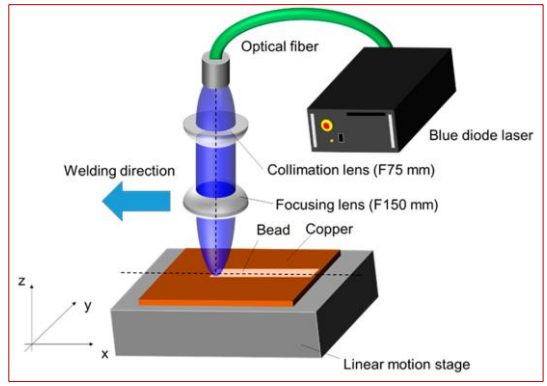

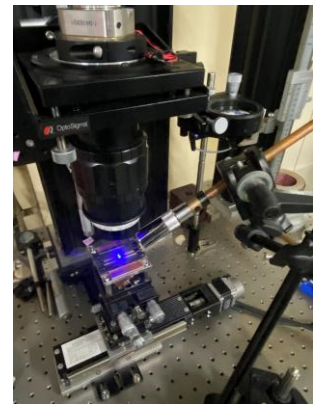

Why Cu? Electric Vehicle/Mobil Listrik!

Superior **electrical conductivity**, allowing efficient energy transfer from batteries to motors

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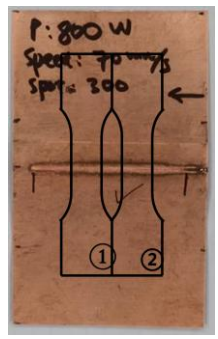
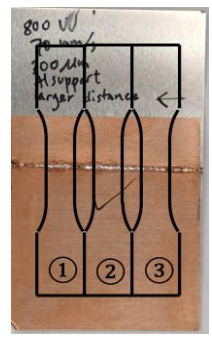
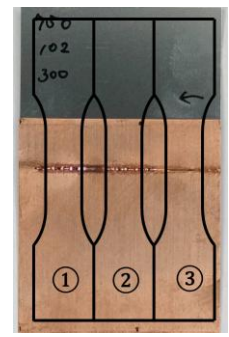


Cu-Cu



Al-Cu



SS-Cu

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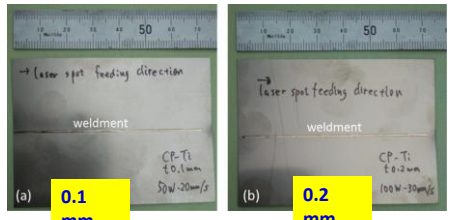

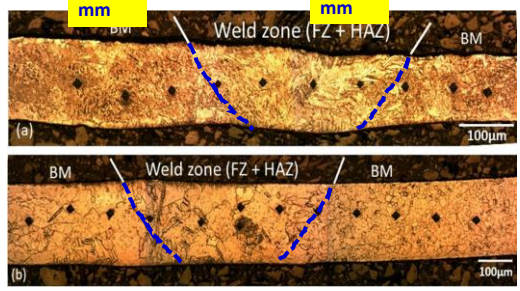

Hair dryer < 1000W

Thickness = 0.1 mm
Power = 50 W
Speed = 20mm/s

Thickness = 0.2 mm
Power = 100 W
Speed = 30mm/s

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Thank you

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