COMPLETION OF THE FIRST TF COIL STRUCTURE OF ITER

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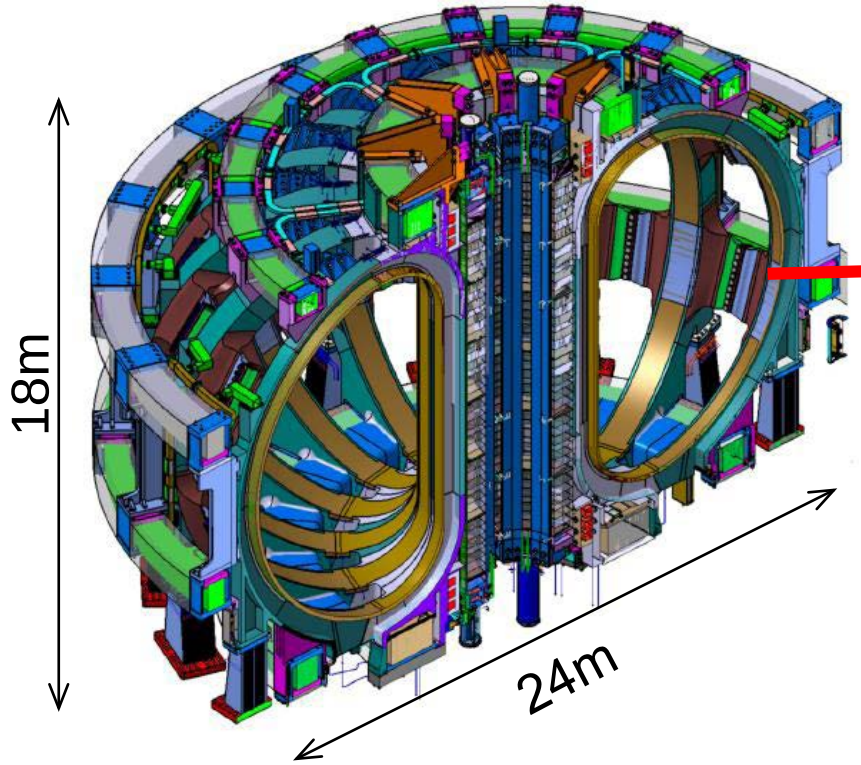
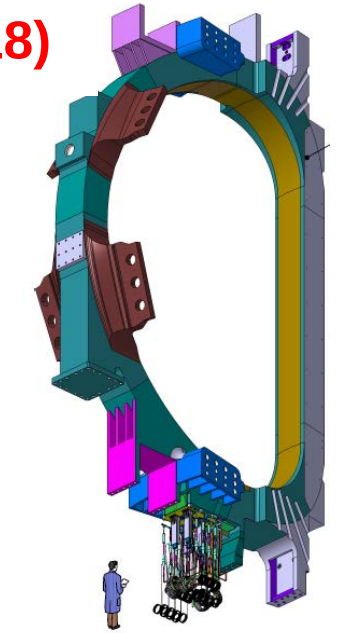
Ahmedabad, India

ITER Toroidal Field Coil



TF Coils (18)



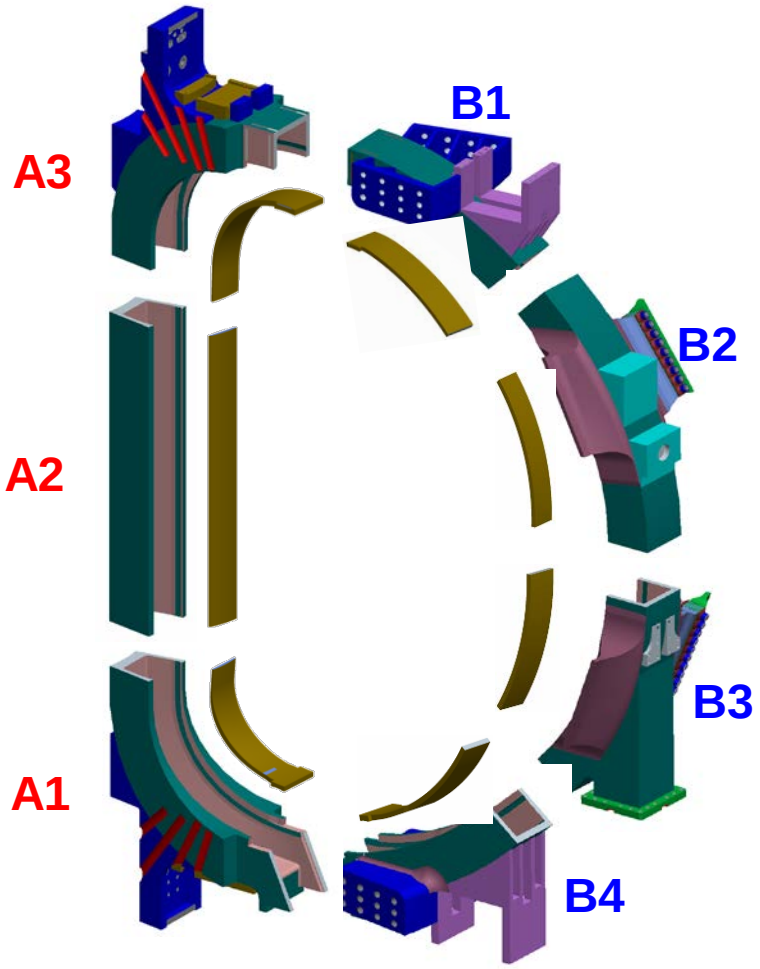
~300 ton

Great Stupa (**16m** high, Sanchi, India)

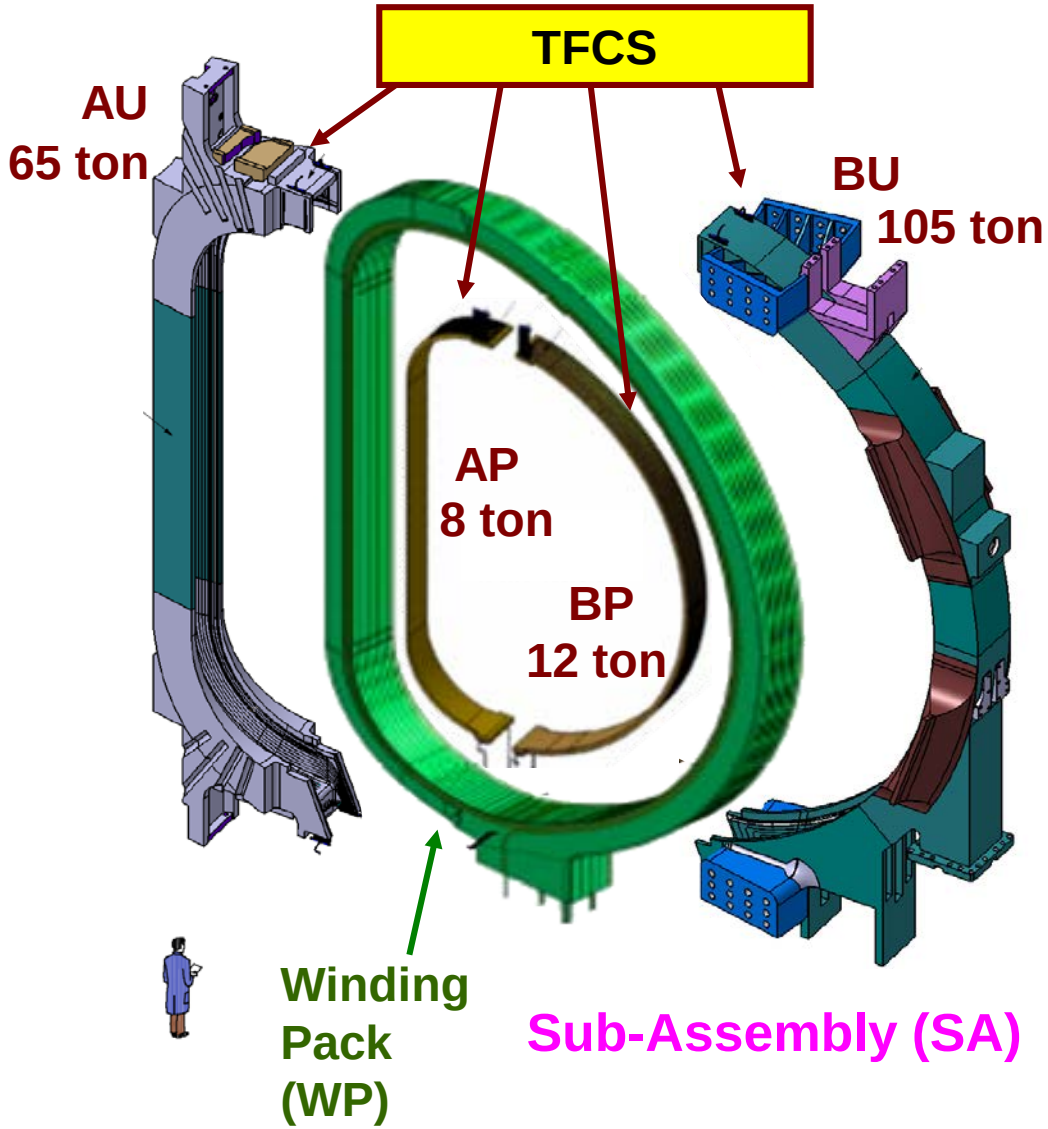
Water in 25mx12m pool (~300ton)

TF Coil Structure (TFCS)

- The biggest super conducting coil structures
- The procurement responsibility :100% Japan Domestic Agency (JADA).

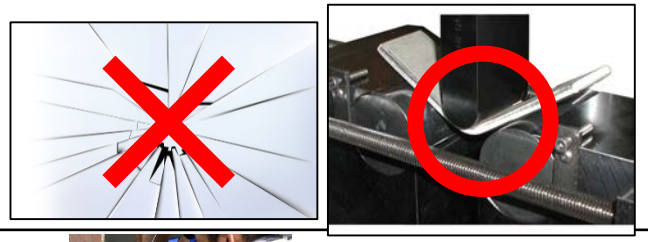
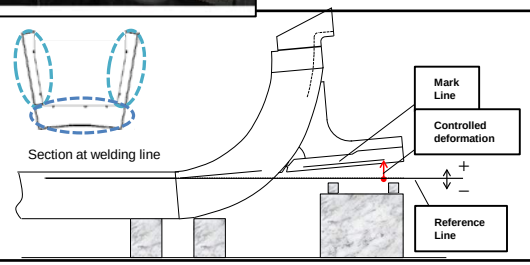
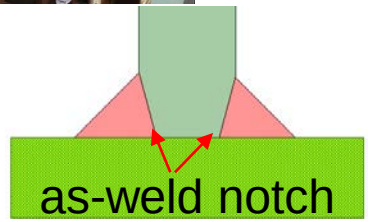
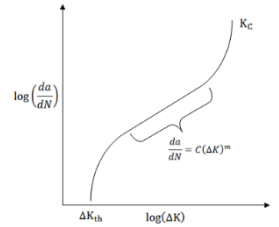
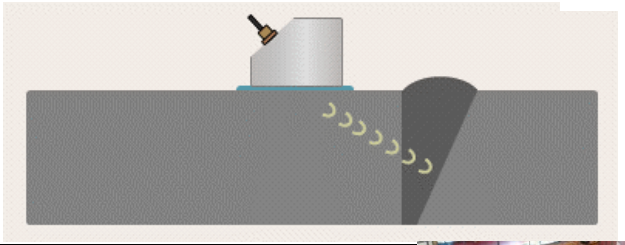
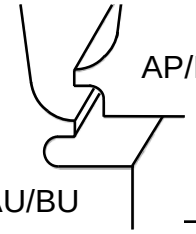


Basic Segments (BS)



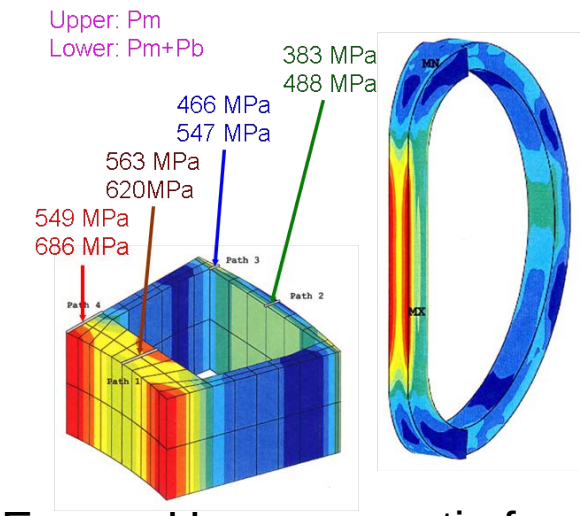
Sub-Assembly (SA)

Challenges

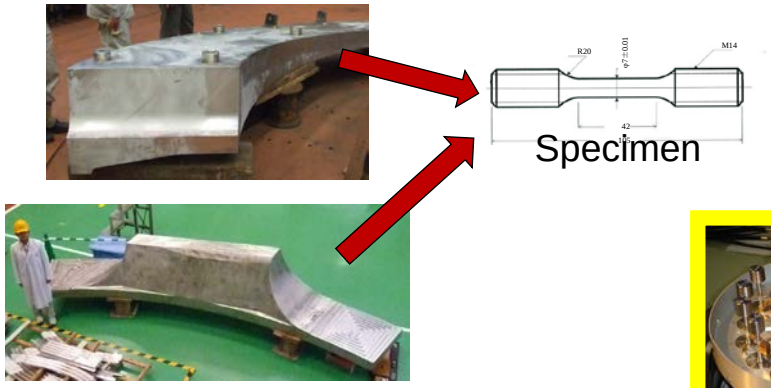
(i) Material: Control yield strength at 4K Control fracture toughness at 4K	
(ii) Welding deformation Control welding deformation Control segments welding	 
(iii) Partial Penetration Welding (PPW) PPW crack initiation PPW crack growth	 
(iv) Ultrasonic testing (UT) Attenuation compensation method Attenuation compensation factor UT for PPW	
(v) Fitting test Fitting test for AU-AP and BU-BP Fitting test for AU-BU	 

Challenge (i) Control yield strength at 4K

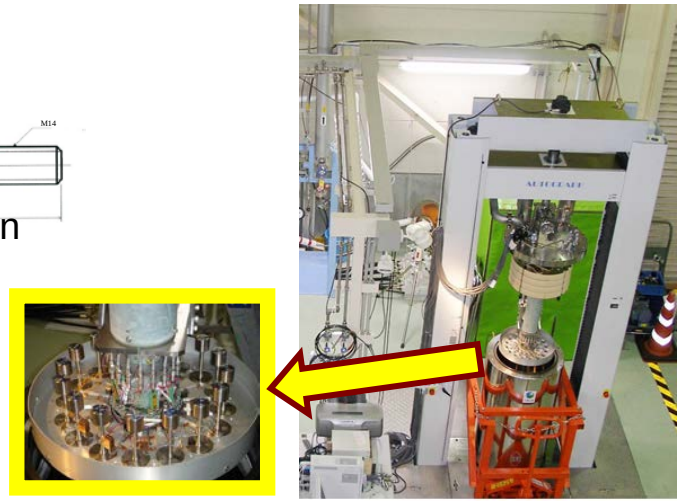
Special material is required with total amount about 5000 ton



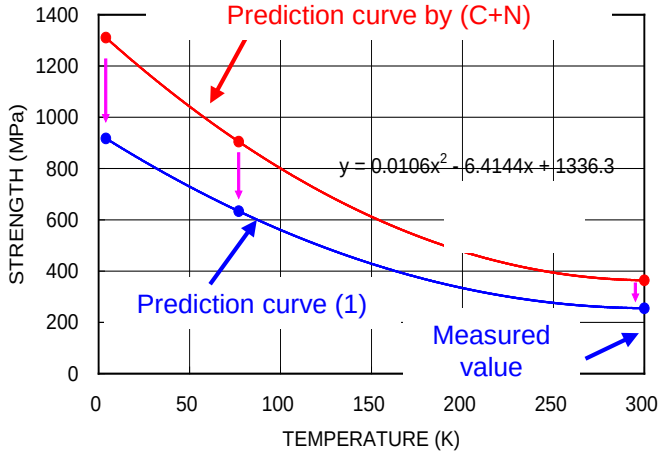
Ensure Huge magnetic force (Static analysis)



Actual materials (total about 5000 ton)



Huge amount of 4K test is needed



Figured out correlation between yield strength at 4K and C+N contents

C+N contents
Yield strength at RT

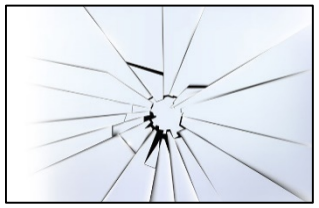
Predict

Yield strength at 4K

In beginning of 2018, material procurement for TFCS was completed.

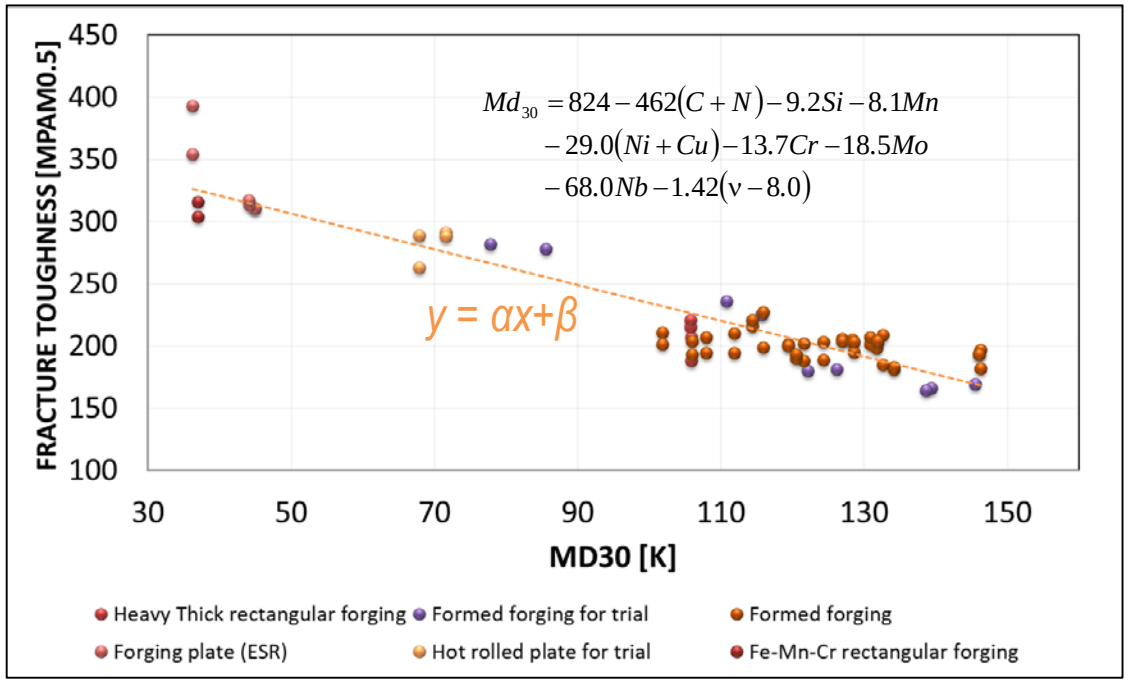
Challenge (i) Control fracture toughness at 4K

In the work to improve control fracture toughness, JADA discovered the strong correlation between Md30 and fracture toughness at 4K.

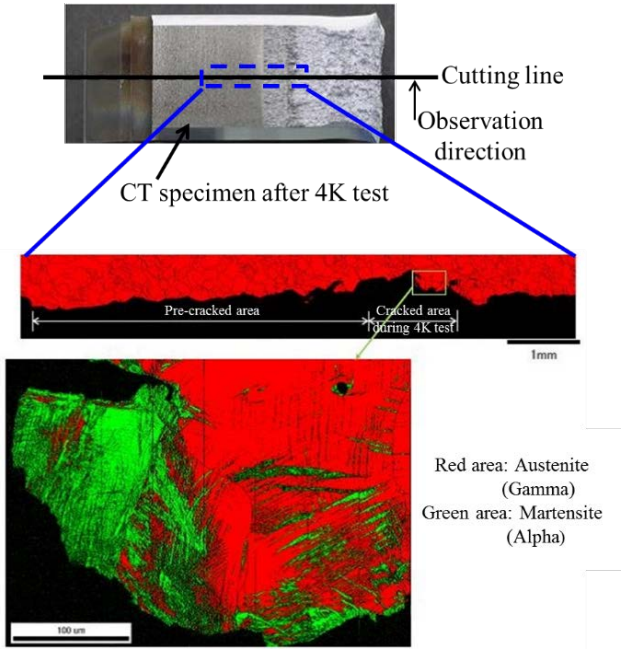


Low fracture toughness
(ex. Glass: Hard but fragile)

High fracture toughness
(ex. Metals)



Figured out correlation between fracture toughness at 4K and Md30



Found martensite at edge of cracked area

Chemical contents (9 elements)
Grain size

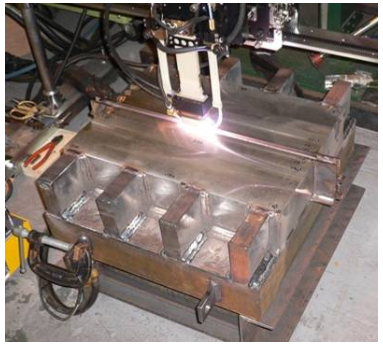
Predict

Fracture toughness at 4K

The Md30 has improved the quality of fracture toughness.

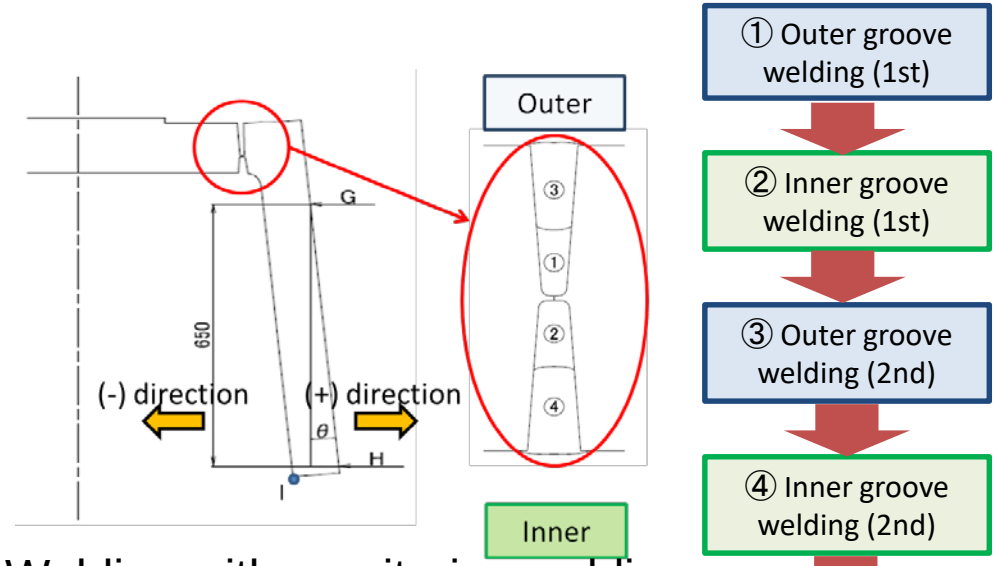
Challenge (ii) Control weld deformation

JADA performed 1) welding qualification using mock-ups, Mechanical properties of welding joints were confirmed, 2) Basic segment mock-ups. Control method of welding deformation was improved.



Welding qualification

B3 segment mock-up



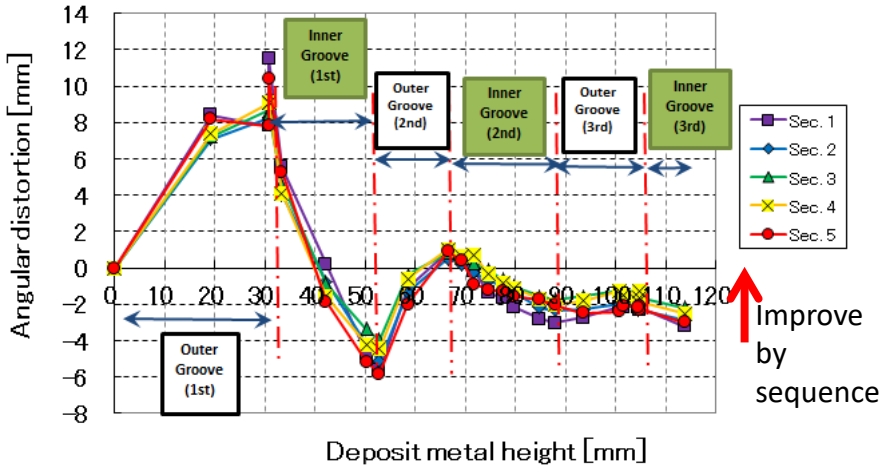
① Outer groove welding (1st)

② Inner groove welding (1st)

③ Outer groove welding (2nd)

④ Inner groove welding (2nd)

Welding with monitoring welding deformation (Balance welding)

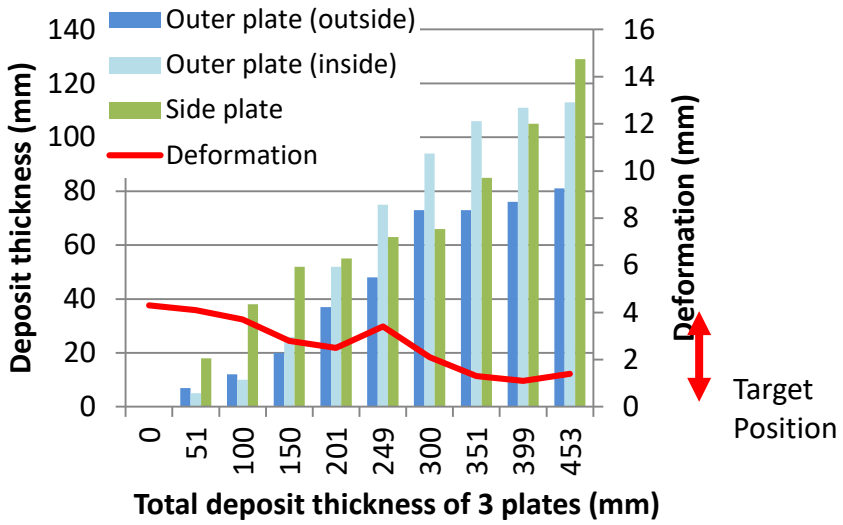


The deformation converges to 0mm.

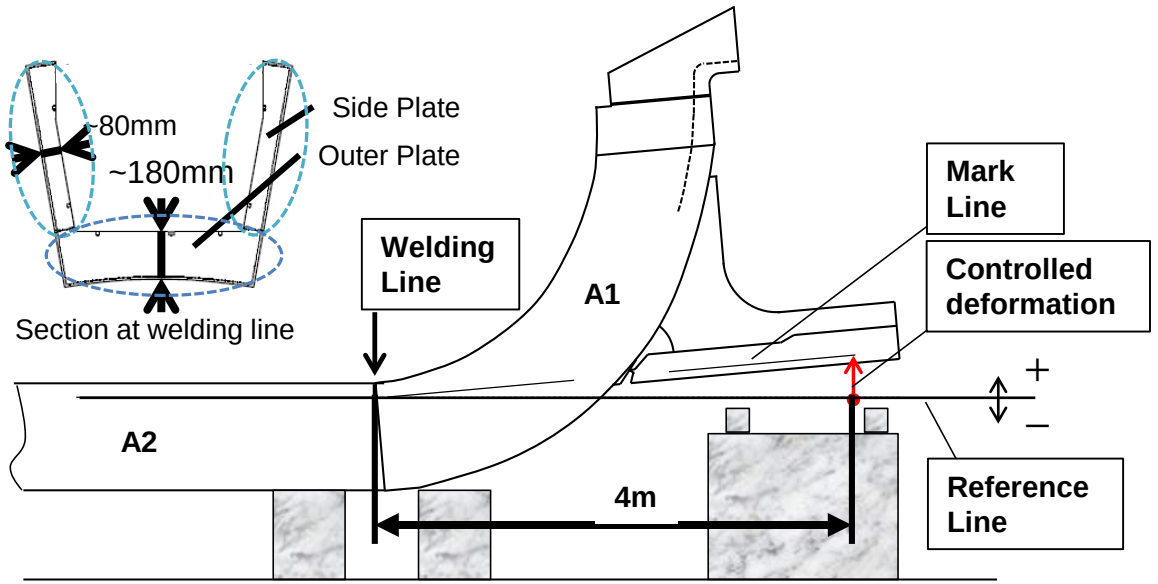
Challenge (ii) Control segments welding

Segments welding is the most difficult to control. Through trial, amount of deformation and tendency are figured out to implement to actual manufacturing.

Welding trial (A1+A2(3m))



Example of welding deformation control



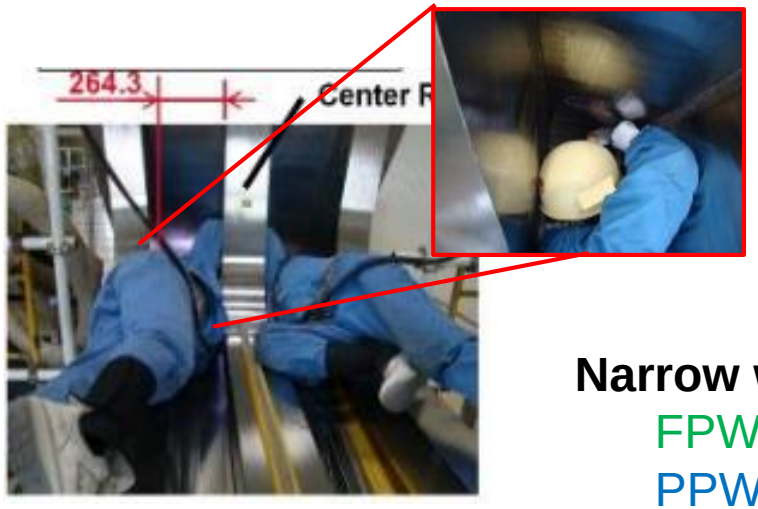
Segment-to-segment welding (A1+A2)

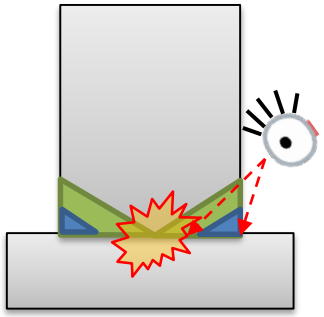
Welded Sub-assemblies (AU)

The actual manufacturing, deformation is well controlled

Challenge (iii) Partial Penetration Welding (PPW)

Full Penetration welding (FPW) is better. But…





Narrow work space

FPW: Invisible welding

PPW: Visible welding

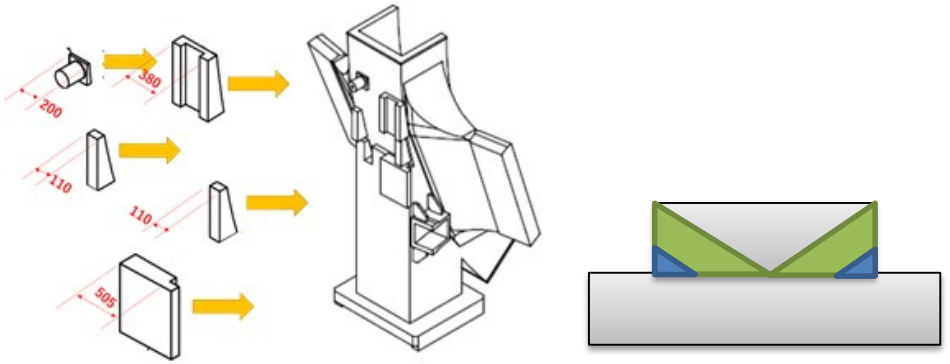
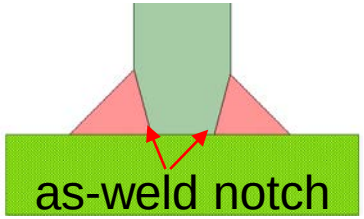


Plate shape attachments

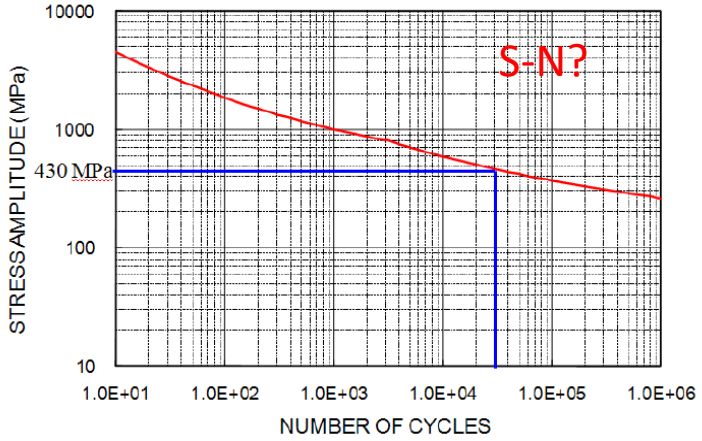
FPW: Impractical weld joint design

PPW: Practical weld joint design

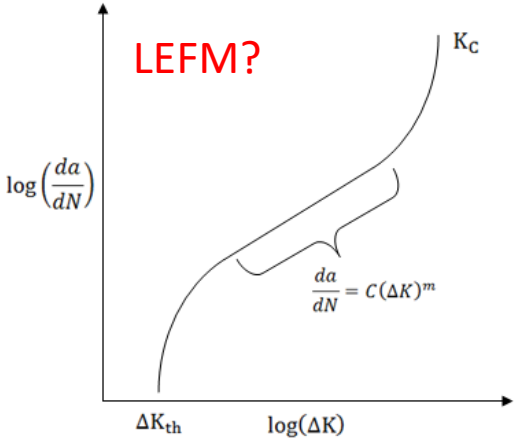
⇨ Application of PPW is necessary



⇨

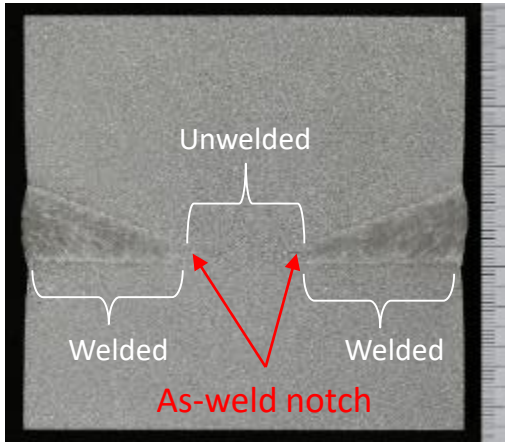


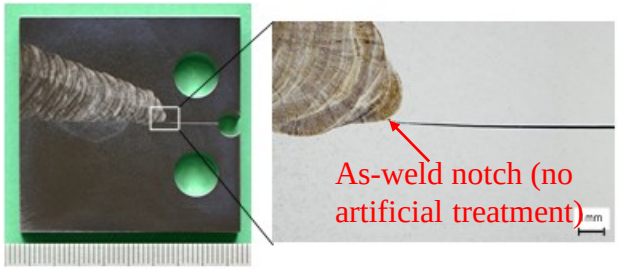
or



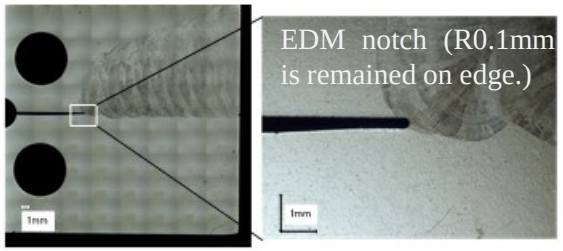
Challenge (iii) PPW crack initiation

1: Confirmation of crack initiation behavior





CT specimen (As-weld notch)

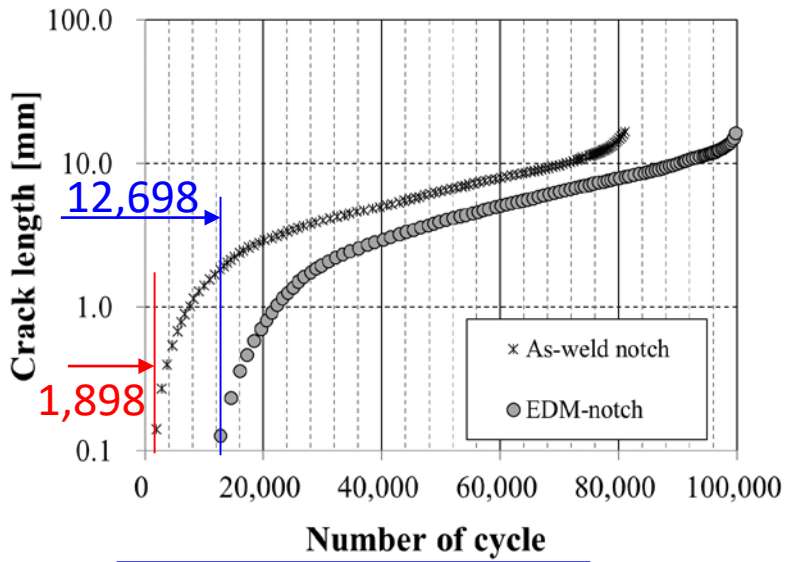


CT specimen (EDM notch)

Base: 316LN (N~0.21%)
Weld: JJ1 (12Cr-12Ni-10Mn-5Mo-0.13N)
Method: TIG weld

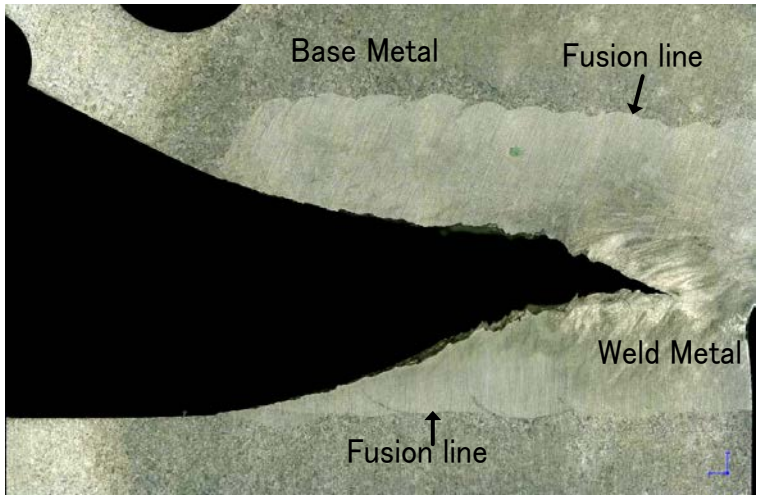
Test condition: Load control
Frequency: 10Hz
Stress ratio: 0.1

a)



=> Behavior like Crack

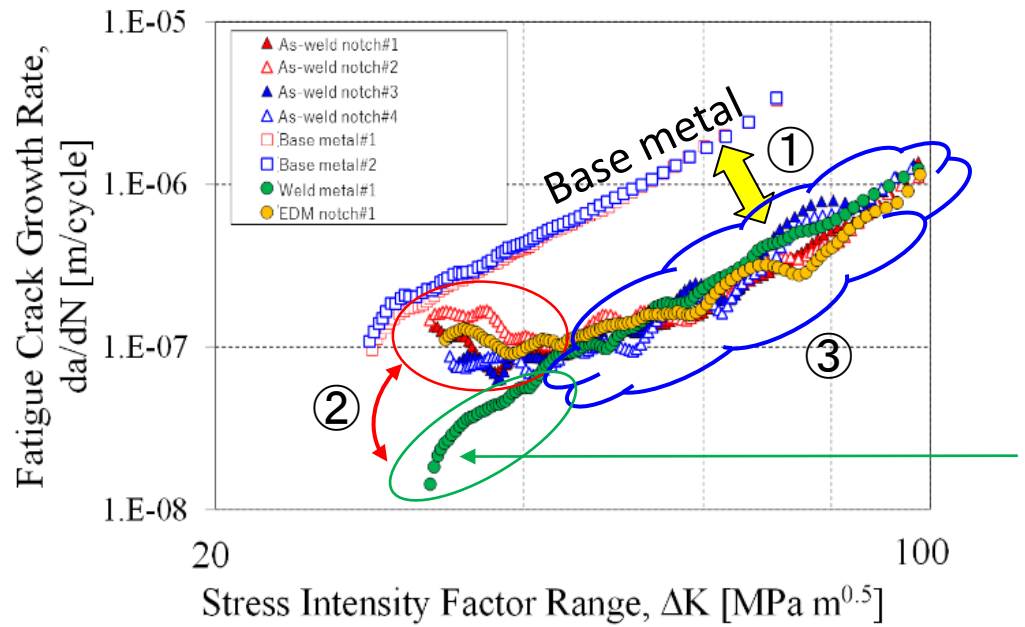
b)

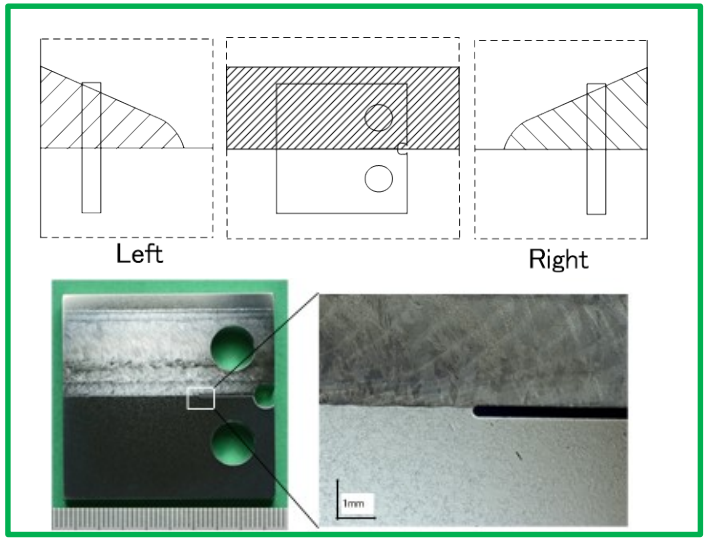


=> Propagation in weld

Challenge (iii) PPW crack growth

c) Crack growth rate parameter





CT specimen (Weld metal/EDM notch)

① Slow crack growth

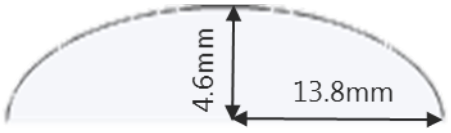
②Stress redistribution when sampling

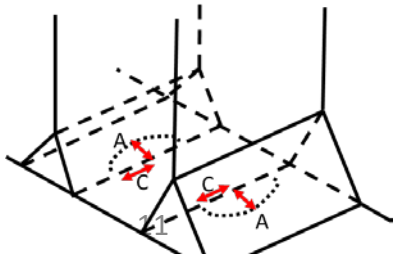
③Application of common region to assessment

d)FEM analysis and assessment allowable weld joint and maximum initial defect size

- FEM analysis (total 133 weld joints)
- Allowable maximum initial defect size

=>**100mm²** of semi-elliptical at root

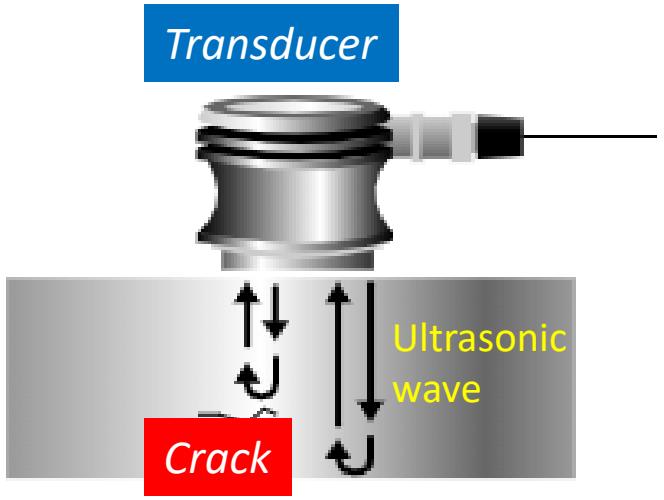


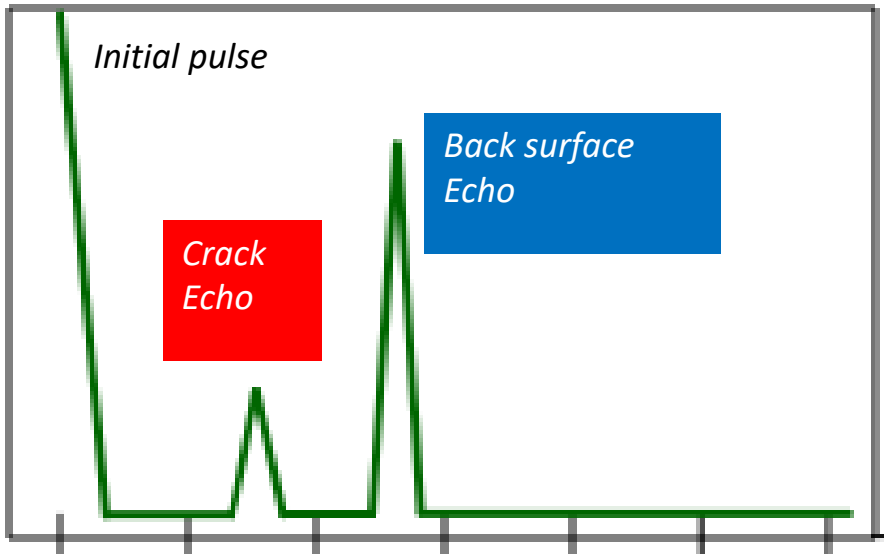


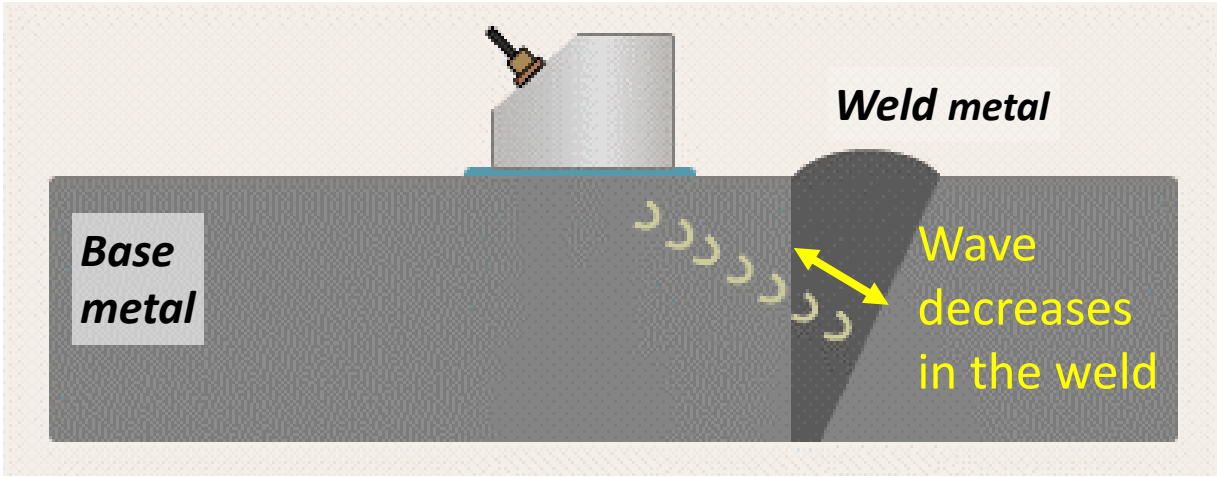
Method of “Design by analysis” for PPW was successfully established!

Challenge (iv) Ultrasonic Testing (UT)

- Principle of Ultrasonic Testing



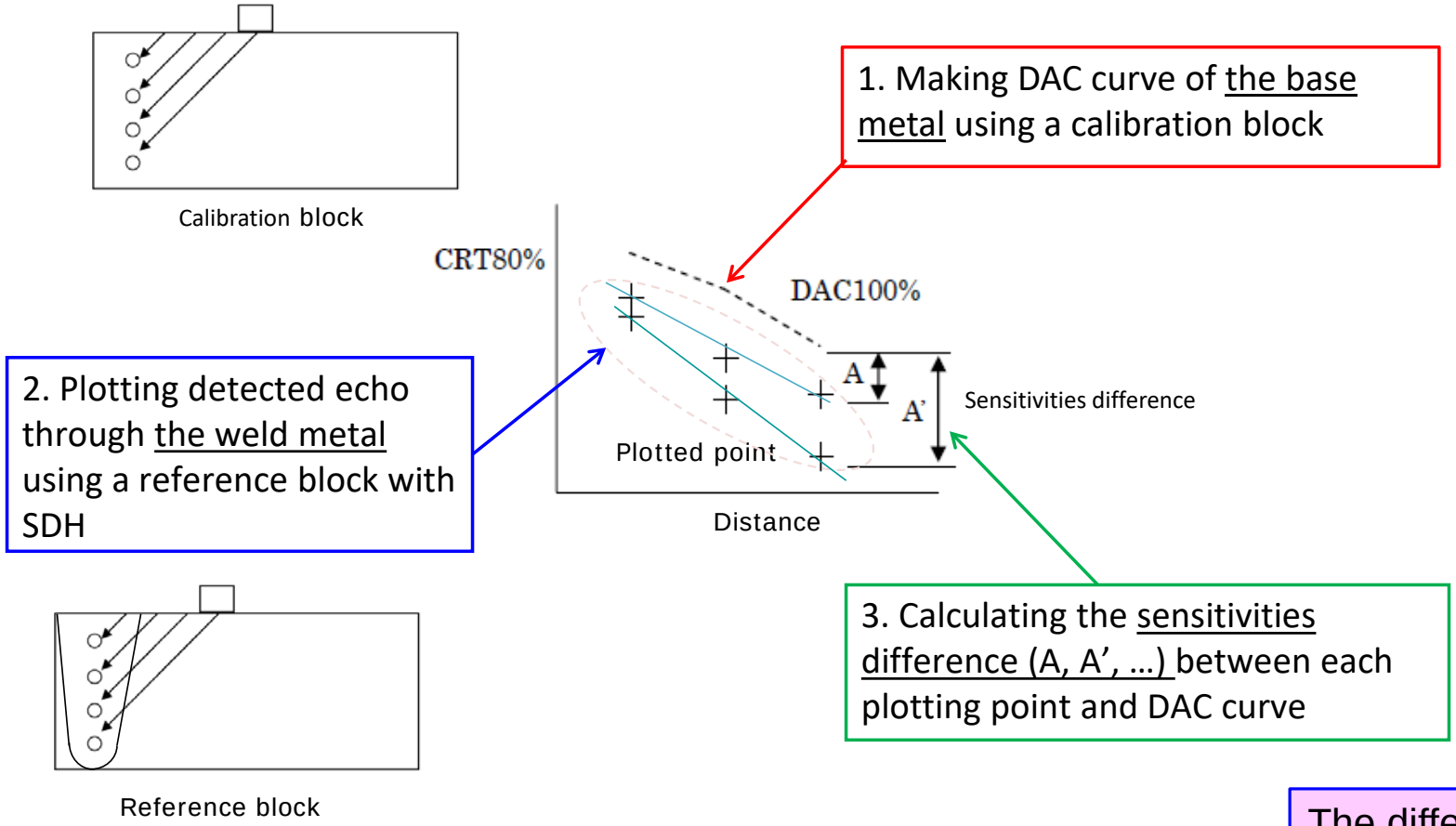




Attenuation of weld metal was evaluated.

Challenge (iv) UT attenuation compensate method

- DAC curves* were prepared by
  - Calibration block using base metal
  - Reference block including weld metal



1. Making DAC curve of the base metal using a calibration block

2. Plotting detected echo through the weld metal using a reference block with SDH

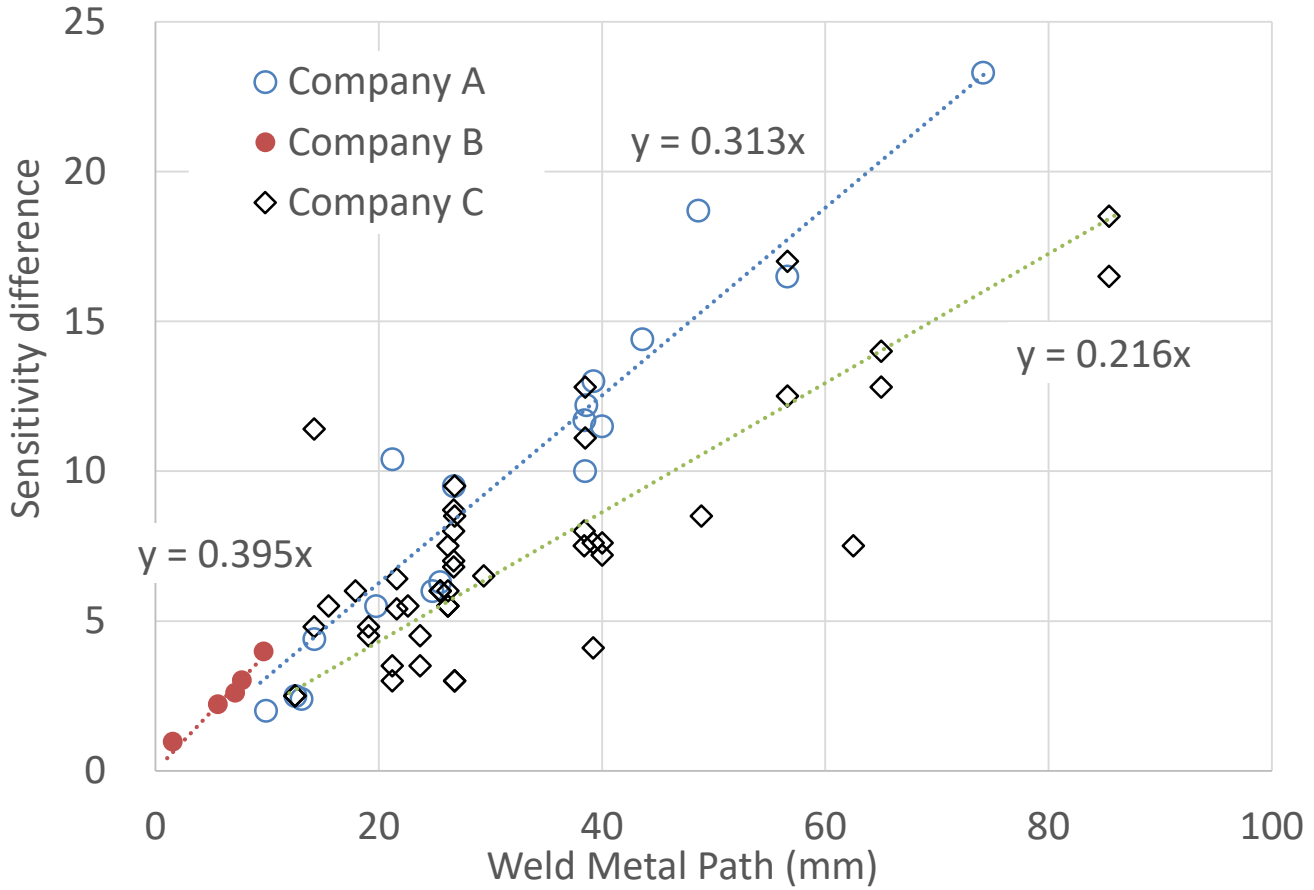
3. Calculating the sensitivities difference (A, A', …) between each plotting point and DAC curve

The difference were quantified.

***: DAC curves (Distance Amplitude Characteristic curves)**

Challenge (iv) UT attenuation compensation factor

- Ultrasonic attenuation (dB) vs. Weld metal path(mm)
  “y = ax” (a: 0.2 ~ 0.4)



Weld metal attenuation of TFCS was Properly corrected.

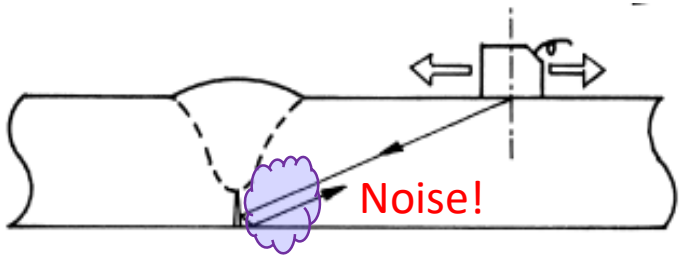
Challenge (iv) UT for PPW

Establishment inspection method for PPW

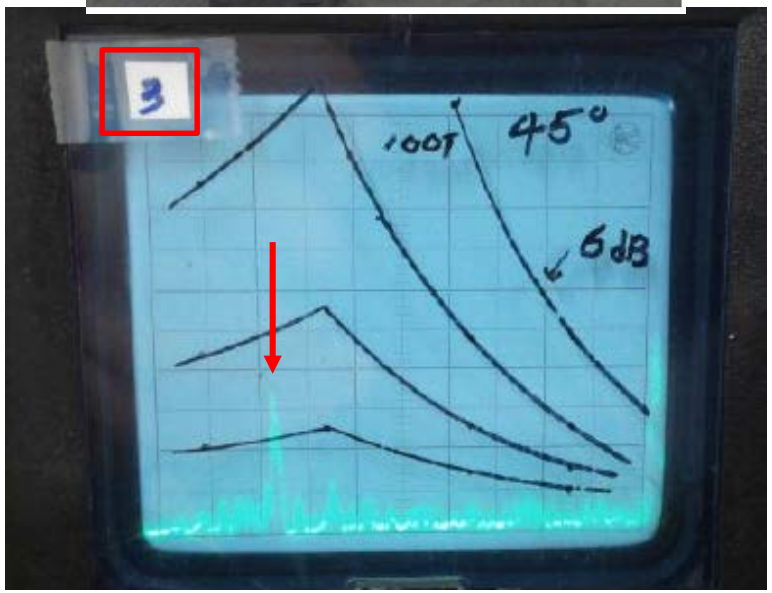
- High quality weld joint ← Inside defect inspection
- Weld depth& initial crack size ← weld depth Confirmation

⇨ Ultrasonic Testing (UT) method

- Noise near root → Low accuracy on depth measuring?
- Verification test by actual size PPW mock up.



⇨ **+/-1mm** accuracy for depth measuring.

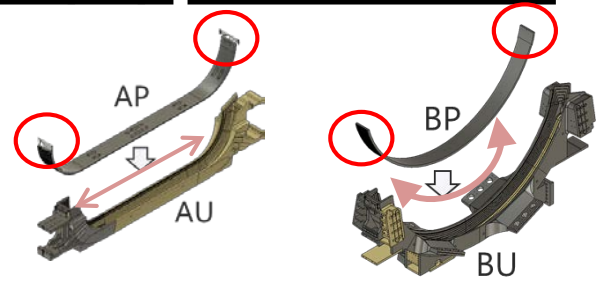


UT procedure was defined.

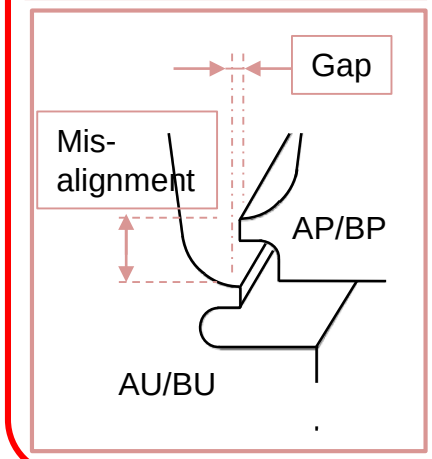
Challenge (v) Fitting Test

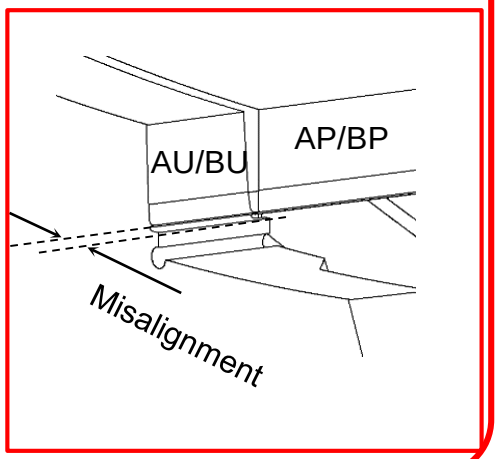
- Strict alignment accuracy requested on welding groove to assure welding quality
- Actual AU, AP, BU, BP were tested

Req. 1): AU-AP, BU-BP

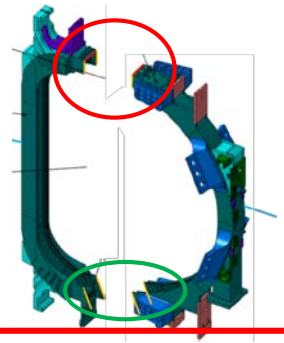


Req. groove tolerances (inner)	Req. groove tolerances (outer)
Gap: 0.5±0.25mm Misalignment:±0.3mm	Misalignment: ±1.3mm

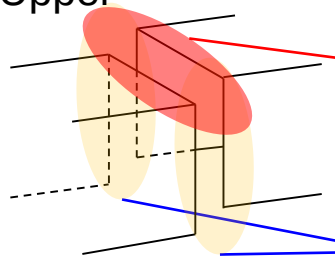




Req. 2): AU-BU



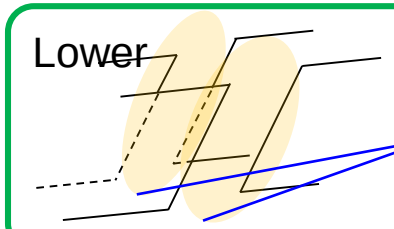
Upper



Back plate
Gap: 0.5±0.25mm
Misalignment:±0.7mm

Side plate
Gap: 0.5±0.25mm
Misalignment:±0.3mm

Lower

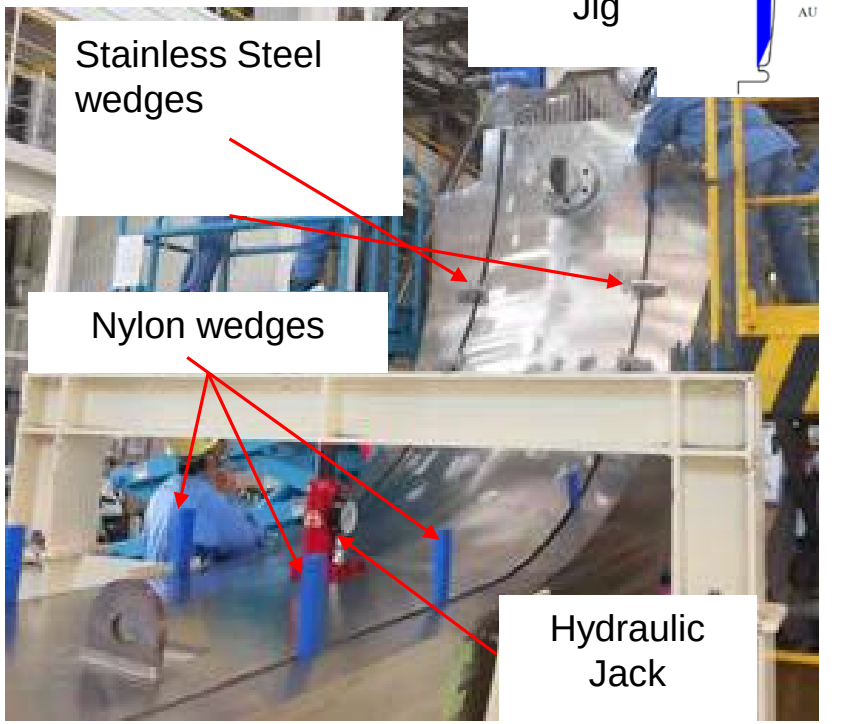


Side plate
Gap: 0.5±0.25mm
Misalignment:±0.3mm

Challenge (v) Fitting Test for AU-AP/BU-BP

- Difficulty: To control the precise position of AP and BP.
  To control the flexibility of AP and BP shape.
- Solution: Several types of guide jigs to adjust their position.
  Lever hoist to control their axial flexibility
- Result: Tests were successfully completed.

AU and AP after fit-up



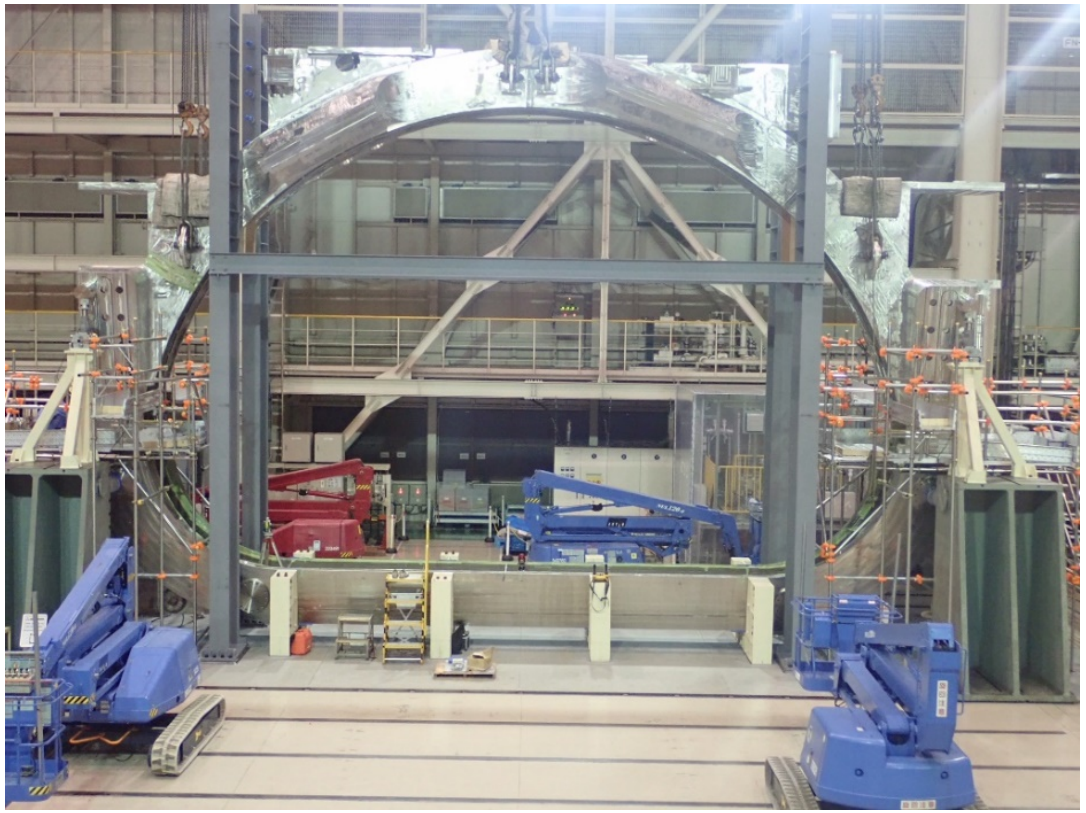
Jigs used to fit up AP to AU

Challenge (v) Fitting Test for AU-BU

- Difficulty: To find the exact position of actual AU and BU to achieve the target criteria
- Solution: Virtual fitting based on the dimension survey data by laser tracker
  Find the optimum position of AU and BU
- Result: Tests were successfully completed utilizing the above

AU and BU after fitting up for the first EU products tested in horizontal position

Aligned grooves



AU and BU after fitting up
for the first JA coil tested in vertical position

CONCLUSION

- **Solving the difficult challenges, TFCS became feasible.**
- **Two TFCSs has been completed in 2018, and another one will be completed soon.**
- **The first Japan-manufacturing TF coil will be assembled TFCS and WP from the fourth quarter of 2018 as the very first TF Coil of ITER**
- **All the TF coils will be delivered to ITER in 2021**

आपका ध्यान के लिए धन्यवाद