FIP1-1 / CN258

COMPLETION OF THE FIRST TF COIL STRUCTURE OF ITER

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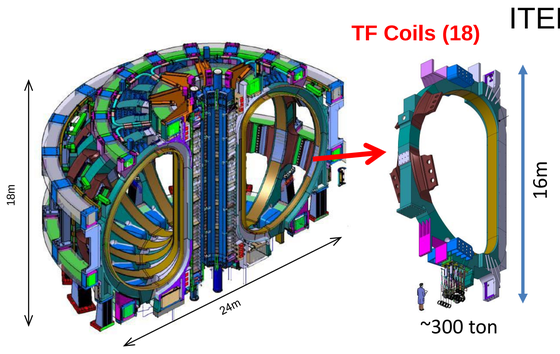
INTRODUCTION

ITER Toroidal Field Coil

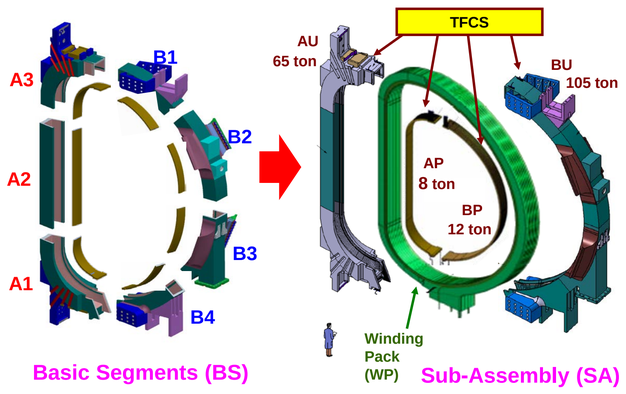


Great Stupa (**16m** high, Sanchi, India)

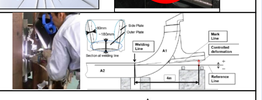
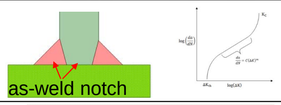
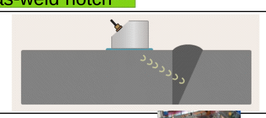
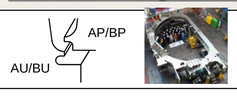
Water in 25mx12m pool (~300ton)

TF Coil Structure (TFCS)

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



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	

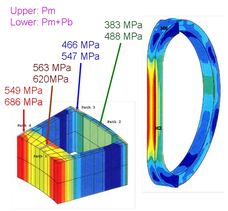
Conclusion

- 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

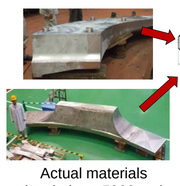
(i) Material

Control yield strength at 4K

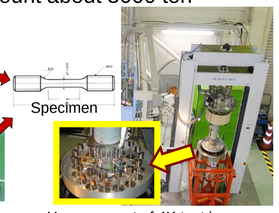
Special material is required with total amount about 5000 ton



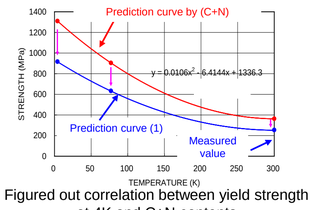
Ensure Huge magnetic force (Static analysis)



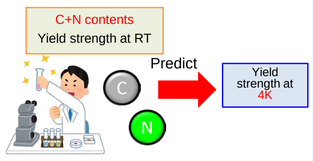
Actual materials (total about 5000 ton)



Huge amount of 4K test is needed



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



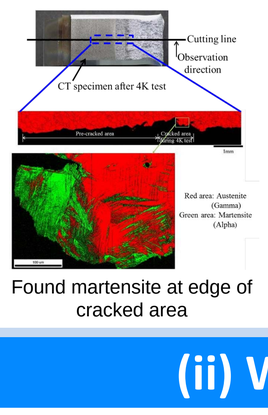
In beginning of 2018, material procurement for TFCS was completed.

Control fracture toughness at 4K

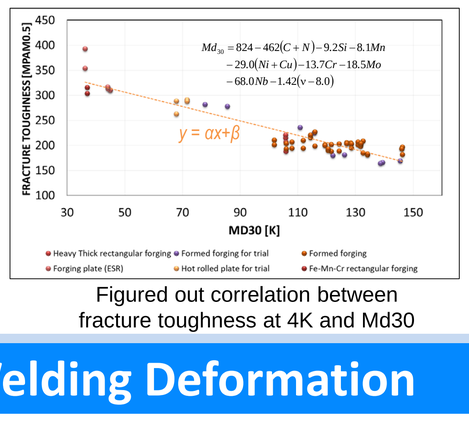
In the additional work to improve control fracture toughness, JADA discovered the strong correlation between Md30 and fracture toughness at 4K.

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

High fracture toughness (ex. Metals)



Found martensite at edge of cracked area



Figured out correlation between fracture toughness at 4K and Md30

Chemical contents (9 elements) Grain size → Predict → Fracture toughness at 4K

The Md30 has improved the quality of fracture toughness.

Note: Md30 is defined as the temperature which 50% martensitic transformation occurs when 0.3 strain is applied. Originally, it's tendency of martensitic transformation.

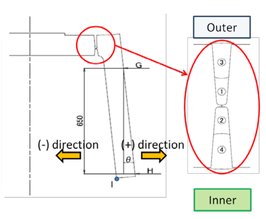
(ii) Welding Deformation

Control weld deformation

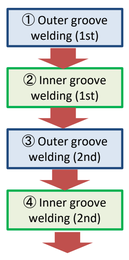
JADA performed 1) welding qualification using mock-ups, Mechanical properties of welding joints were confirmed, 2) Basic segment mock-ups. Control method of welding deformation was improved.

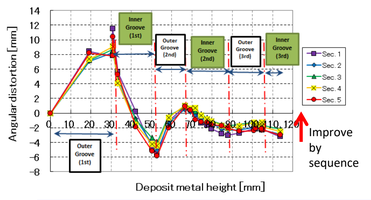
Welding qualification

B3 segment mock-up



Welding with monitoring welding deformation (Balance welding)



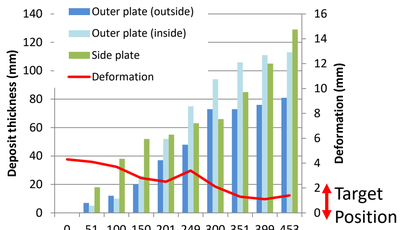


The deformation converges to 0mm.

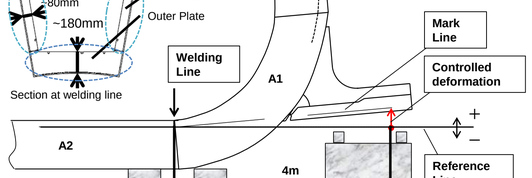
Control segments welding

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))



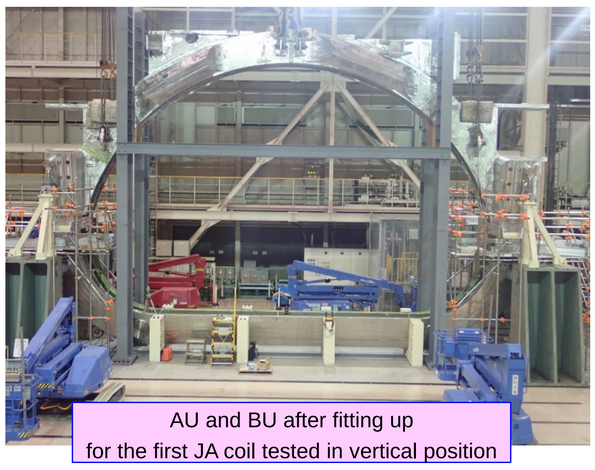
Example of welding deformation control



Segment-to-segment welding (A1+A2)

Welded Sub-assemblies (AU)

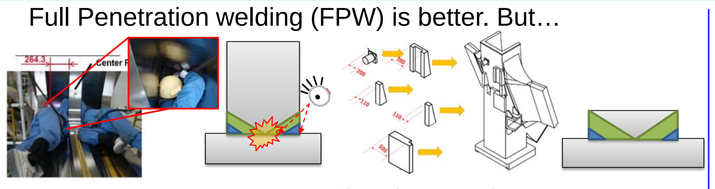
The actual manufacturing, deformation is well controlled



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

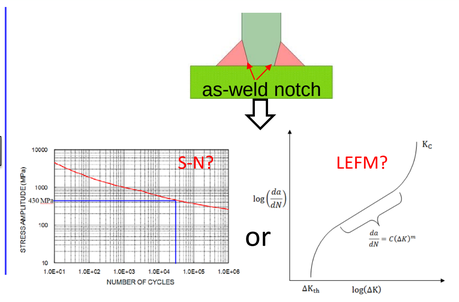
(iii) Partial Penetration Welding (PPW)

Full Penetration welding (FPW) is better. But…

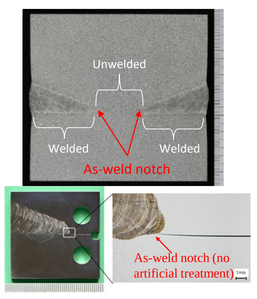


Narrow work space
FPW: Invisible welding
PPW: Visible welding

Plate shape attachments
FPW: Impractical weld joint design
PPW: Practical weld joint design

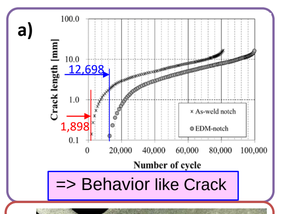


⇨ Application of PPW is necessary

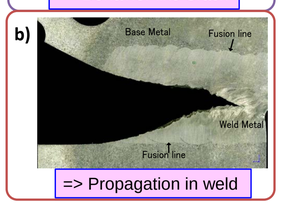


CT specimen (As-weld notch)

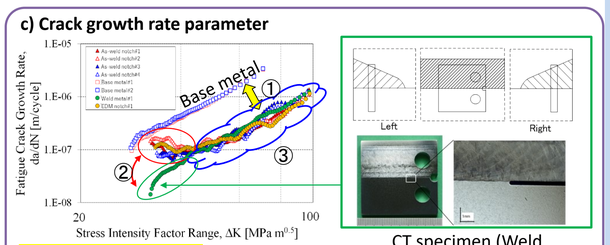
Base: 316LN (N~0.21%)
Weld: JJ1 (12Cr-12Ni-10Mn-5Mo-0.13N)
Method: TIG weld



=> Behavior like Crack

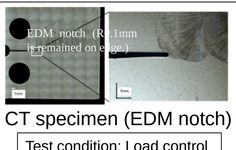


=> Propagation in weld



① Slow crack growth
②Stress redistribution when sampling
③Application of common region to assessment

CT specimen (Weld metal/EDM notch)



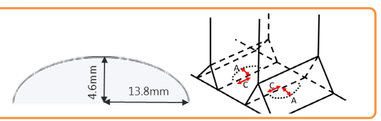
CT specimen (EDM notch)

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

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

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

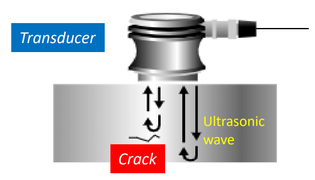
=>**100mm²** of semi-elliptical at root



Method of "Design by analysis" for PPW was successfully established!

(iv) Ultrasonic Testing (UT)

Principle of Ultrasonic Testing



Attenuation of weld metal was evaluated.

UT attenuation compensate method

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

*: DAC curves (Distance Amplitude Characteristic curves)

The difference were quantified.

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

Weld metal attenuation of TFCS was Properly corrected.

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.

(v) Fitting Test

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

AU and AP after fit-up

Jigs used to fit up AP to AU

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