Mechanical properties of ITER CICC jacket in China

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### Background

The ITER magnet system is made up of four main sub-systems: The 18 Toroidal Field coils (TF), the Central Solenoid (CS), the 6 Poloidal Field coils (PF), and the Correction Coils (CC). The Feeder system with its Main Busbar (MB) and Correction Coil Busbar (CB) represents one of the main magnetic components as well. All coils and busbars with different dimensions used Cable-in-Conduit Conductors (CICC). China needs to provide 6 different types of conductors. The ITER CICCs consist of a cable made of Nb or Nb3Sn or Nb-Ti strands inserted in a stainless steel tube (called jacket or conduit). Depending on the coil type, the jacket material is either made of a low carbon AISI 316LN (for Toroidal Field coil) and AISI 316L grade stainless steels (for Poloidal Field and correction coils). Mechanical properties of base material need to be tested at room and/or cryogenic temperature under predefined mechanical deformation and heat treatment conditions. This paper will introduce the mechanical properties, including tensile and fatigue testing.

### Jacket types and parameters

<table>
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<tr>
<th>Item</th>
<th>Material Type</th>
<th>OD (mm)</th>
<th>ID (mm)</th>
<th>OD (mm)</th>
<th>ID (mm)</th>
</tr>
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<tbody>
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<td>TF</td>
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<td>43.2</td>
<td>43.7</td>
<td>39.7</td>
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<td>PF 2-4</td>
<td>316L</td>
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<td>38.0</td>
<td>51.9 x 51.9</td>
<td>35.3</td>
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<td>PF 5</td>
<td>316L</td>
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<td>38.0</td>
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<tr>
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<td>23.2</td>
<td>18.8</td>
<td>19.2 x 19.2</td>
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<tr>
<td>MB</td>
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<td>44</td>
<td>40</td>
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<tr>
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<td>23.9</td>
<td>20.1</td>
<td>22</td>
<td>18</td>
</tr>
</tbody>
</table>

Fig. 1. Cross section of ITER conductors produced in China.

### TF Jacket Mechanical performance

- TF jacket (CSD.015SN.35316LN) sample preparation:
  - Compaction with 3.5% cold working
  - Stretching by 2.5% to monitor coil winding
  - Heat treated at 650°C for 200 hours.

- Tensile properties of TF jacket in cold worked and aged condition at cryogenic temperature (4.2K):
  - Yield Strength (YS): 1050 MPa - 1500 MPa
  - Ultimate Tensile Strength (UTS): 810 MPa
  - Elongation (EL): 30% - 40%

- Tensile and fatigue properties of TF jacket (35316LN) under representative conditions: compacted (5% cold working) + bending (8º-4º) straightening.

### PF Jacket Mechanical performance

- Mean values of YS, EL and UTS at 4.2K for PF jacket under representative conditions are about 810 MPa, 48% and 1510 MPa respectively. Mean fracture toughness 380 MPa m\(^{1/2}\).

### Conclusion

All required TF, CC, CB and MB conductors have been finished manufacturing in China, and PF conductors will finish manufacturing in 2018. Mechanical performance of ITER CICC jackets manufactured in China have been tested for samples randomly selected from each heat lot. Conclusions can be summarized as follows:

- Even undergo 6% cold working and aging treatment at 650°C for 200 hours, TF jacket showed the combined high strength and good ductility at cryogenic temperature. Elongation for all samples were higher than 30%.
- Tensile properties, FCGR and fracture toughness of PF jacket under representative operation conditions of conductor compacted and coil bended states were tested at cryogenic temperature. Results showed the tested tensile and fatigue properties satisfy the ITER requirements.
- Yield strength, ultimate tensile strength and elongation of CC and feeder busbar jackets were higher than the required values of 700 MPa, 1000 MPa and 30% at 4.2K, respectively.

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