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**Technical Specifications (In-Cash Procurement)**

# Technical Specification - Experimental Validation of Acceptance Criteria of CuZrZr-IG/316L(N)-IG Joint

Technical specification - Experimental Validation of Acceptance Criteria of CuZrZr-IG/316L(N)-IG Joint

Scope of work:

- Generate the drawing of test samples and prepare the test samples
- Perform cycling bending test and static bending test

# Table of Contents

# 1 Background

The ITER project aims to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes and to gain the knowledge necessary for the design of the next stage device, DEMO, or the DEMOnstration fusion power plant. ITER is a joint international research and development project for which initial construction activities have started.
The seven Members of the ITER Organization (IO) are the European Union (EU), Japan, the People's Republic of China, India, the Republic of Korea, the Russian Federation and the USA. ITER is being constructed in Europe, at St Paul Les Durance, in southern France, where the IO has its headquarters.
As illustrated in Figure 1, the machine consists of:

- The cryostat, which maintains the entire machine in a vacuum to thermally insulate the cryogenically cooled, superconducting magnets from the normal atmosphere,
- The thermal shields, which further thermally insulate the magnets;
- The assembly of 48 superconducting magnets, which confine and heat the plasma;
- The Vacuum Vessel, a doughnut shaped chamber located at the heart of the machine and containing the plasma under Ultra High Vacuum;
- The Blanket System, which faces the thermonuclear plasma and remove most of the heat loads and radiation coming from it;
- The Divertor, located at the bottom of the Vacuum Vessel where it faces thermonuclear plasma. During operations, the Divertor extracts impurities coming from the plasma.

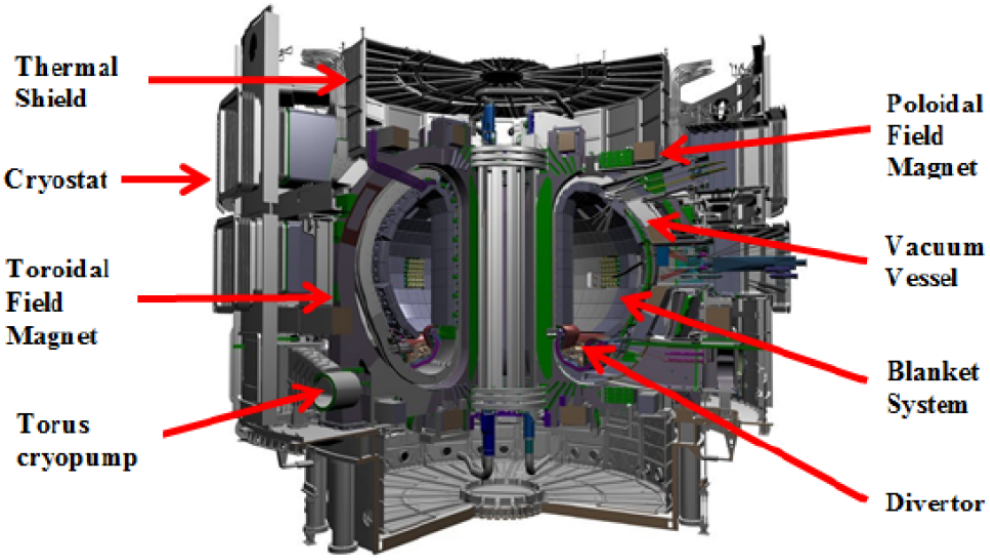


Figure 1: The ITER Machine and Major Components

The Blanket System and Divertor are two of the most technically challenging components of the ITER machine, needing to accommodate the high steady state heat fluxes and also large electromagnetic loads during off-normal events. The Blanket System consists of 440 Blanket Modules (BMs) covering ≈600 $m^2$ of the in-vessel surface. A BM consists of two main components: a plasma-facing first wall (FW) panel and a shield block. These components are actively cooled by water. Application of the steady-state heat fluxes led to the selection of two types of high heat flux (HHF) technology with the flat tile geometry: a "normal heat flux" technology (≤2 $MW/m^2$) and an "enhanced heat flux" (EHF) technology (≤ 4.7 $MW/m^2$).
The Divertor consists of 54 Divertor Cassettes covering ≈150 $m^2$ of in-vessel surface. The Divertor Cassette consists of three plasma-facing components (Inner and Outer Vertical Targets, and Dome) and Cassette Body. These components are actively cooled by water. The flat tile geometry was applied in the Dome plasma-facing unit (PFU).
The ITER EHF FW panels and Dome PFUs with the flat tile geometries utilize the hypervapotron heat sink design which contains the bimetallic joint of CuCrZr-IG and 316L(N)-IG. This bimetallic joints are

manufactured by Hot Isostatic Pressing (HIP) and/or by explosion bonding and inspected by ultrasonic test. The acceptance criterion for ultrasonic test is defined that no defect size shall be equal or larger than Flat Bottom Hole (FBH) 2 mm at the joint interface.

This work aims to validate the IO-defined acceptance criterion for the defects (FBH 2mm) in the bimetallic CuCrZr-IG/316L(N)-IG joint through the cycling mechanical tests of bimetallic test samples with the different notch depths, as well to examine the fracture behaviour under static loads at elevated temperatures.

# 2 List of abbreviations

| | | | |
|---|---|---|---|
| BM: | Blanket Module | HHF: | High Heat Flux |
| EHF: | Enhanced Heat Flux | IO: | ITER Organization |
| FBH: | Flat Bottom Hole | PFU: | Plasma-Facing Unit |
| FW: | First Wall | HIP: | Hot Isostatic Pressing |

**[I]** All items in this specification prefaced with **[I]** indicate that they are for information, while all items prefaced with **[R]** indicate an item that is a requirement.

# 3 Complimentary Applicable Standards

EN ISO 6892-2: 2011 Metallic materials Tensile testing Part 2: Method of test at elevated temperature

ISO 7438:2016 Metallic materials — Bend test

ISO 12110-1:2013 Metallic materials - Fatigue testing - Variable amplitude fatigue testing - Part 1: General principles, test method and reporting requirements

ASTM E21 Test for Elevated Temperature Tension Tests of Metallic Materials

ASTM E290-14 Standard Test Methods for Bend Testing of Material for Ductility

ASTM E606/E606M-21 Standard Test Method for Strain-Controlled Fatigue Testing

# 4 Scope

**[I]** The scope of work of the contract includes:
- Generation of the drawing of test samples and fabricate the test samples
- Performance of cycling and static mechanical tests

**[I]** The contract consists of two part (1) obligatory part, i.e. Fabrication of test samples, fatigue and statistic mechanical test with materials from Chinese and EU suppliers; (2) optional part, i.e. Fabrication of test samples, fatigue and statistic mechanical test with materials from Russian supplier.

**[I]** The bimetallic joint blocks will be provided as free-issue-item. The information of base material blocks and bimetallic joint blocks will be provided. Procurement of these materials are outside scope of this Contract.

**[I]** The sizes of bimetallic joint materials (HIP and explosion bonding) from Chinese supplier are 30 (steel part 16 mm, CuCrZr part 14 mm) x 35 x 35 $mm^3$ and 23 (steel part 10 mm, CuCrZr part 13 mm) x 35 x 35 $mm^3$, respectively. The sizes of bimetallic joint materials from EU supplier are 197 (steel part 99 mm, CuCrZr part 98 mm) x 97 x 155 $mm^3$. The sizes of bimetallic joint materials from Russian suppliers will be informed when available.

**[I]** The bimetallic joint block from EU supplier has a large enough dimension and will be used for the base material samples.

# 5 Work description

## 5.1 Fabrication of test samples, mechanical cycling and statistic test-materials from China and EU

### *5.1.1 Fabrication of test samples - materials from China and EU*

**[R]** The Contractor shall fabricate the test samples from the provided blocks. The samples cut out from bimetallic joint shall have 5 x 5 $mm^2$ cross section at the joints in gauge area, and the sample cut out from base materials shall have the same geometry.

**[R]** The Contractor shall propose test sample geometries based on their experiences and the available test facility.

**[R]** The notch shall be located at the joint for bimetallic joint samples. The samples from base materials shall be the same configuration as bimetallic joint samples.

**[I]** In the tests, the notch depth is considered to correspond to the diameter of FBH. The notch depth varies as a parameter. The notch width is typically 0.2 mm.

**[R]** The Contractor shall design the test sample to be sufficient to perform test and re-test with the materials provided.

**[R]** The Contractor shall detail the method of creation and control of the notch. The description of test sample preparation process including the sample drawings shall be approved by the IO prior to the preparation of the test samples. This represents a Hold Point.

### *5.1.2 Mechanical cycling test - materials from Chinese and EU suppliers*

**[R]** The test protocol for mechanical cycling test shall be approved by the IO prior to the test. This represents a Hold Point.

**[R]** The mechanical cycling test shall be performed in strain-control condition, asymmetric cyclic test (0..load) under the given stresses.

**[R]** Depending on the test configuration, the Contractor shall select either combined stress for Tensile configuration or bending configuration (see **Table 5-1**).

**[R]** Mechanical cycling test shall be performed <1 Hz at 150 ±5 °C.

**[R]** Mechanical cycling test shall be performed until failure but limited to 15 000 cycles except maximum 6 samples, extension to 30 000 cycles.

**[I]** The loads might be reduced along the test campaigns upon the request from the IO.

**[R] Table 5-2** shows the test matrix for the cycling test. The test shall be performed accordingly. Number of test samples is 48 in total.

**[R]** The test report of mechanical cycling test shall be approved by the IO. The test report shall include as minimum:

(1) Cycling mechanical tests and cycling mechanical test results;
(2) Visual examination results of the test samples before and after the test;
(3) Dimension examination results (including notch depth and width) of the test samples before the test;
(4) Traceability documents of the test equipment.

**Table 5-1**: combined stresses for asymmetric mechanical cycling test (0..load).

| | | Tensile configuration | Bending configuration | No. of cycles |
|---|---|---|---|---|
| 1 | Samples of bimetallic joints from **Chinese supplier** | 69 MPa | 278 MPa | 15 000 |
| 2 | Samples of bimetallic joints from **EU supplier** | 37 MPa | 150 MPa | 15 000 |
| 3 | Samples of base materials (CuCrZr and 316L(N)-IG) from **EU supplier** | 69 MPa | 278 MPa | 15 000 |

**Table 5-2**: Test matrix for cycling mechanical test.

| | Sample material | Notch depth | Number of test samples |
|---|---|---|---|
| 1 | Bimetallic joint - HIP by Chinese supplier | 0 mm, 1 mm, 2 mm, 3 mm | 4 x3[a] |
| 2 | Bimetallic joint – explosion bonding by Chinese supplier | | 4 x3[a] |
| 3 | Bimetallic joint – HIP by EU supplier | | 4 x3[a] |
| 4 | CuCrZr-IG by EU supplier | | 6[b] |
| 5 | 316L(N)-IG by EU supplier | | 6[b] |

[a] Minimum three samples /test condition shall be tested.

[b] Sample distribution in the different test conditions shall be agreed with the IO.

### *5.1.3 Static mechanical test - materials from China and EU*

**[R]** The test protocol for static mechanical test shall be approved by the IO prior to the test. This represents a Hold Point.

**[R]** The static mechanical test shall be performed at three test temperatures, 150 ±5 C, 250 ±5 C, 350 ±5 C.

**[R]** The notch depth shall be 0 mm or 2 mm.

**[R]** The test report of mechanical static test shall be approved by the IO.

**[R]** **Table 5-3** shows the test matrix for the static test. The test shall be performed accordingly. Number of test samples is maximum 48 in total.

**[R]** The static mechanical test report shall include as minimum:

(1) The static mechanical test and the test results;
(2) The visual examination results of the test samples before and after the test;
(3) The dimension examination results (including notch depth and width) of the test samples before the test;
(4) The traceability documents of the equipment.

**Table 5-3**: Test matrix for static mechanical test.

| | Sample material | T_test | Notch depth | Number of test samples |
|---|---|---|---|---|
| 1 | Bimetallic joint - HIP by Chinese supplier | 150 ±5 C, 250 ±5 C, 350 ±5 C | 0 mm, 2 mm | 12 [a] |
| 2 | Bimetallic joint – explosion bonding by Chinese supplier | | | 12 [a] |
| 3 | Bimetallic joint – HIP by EU supplier | | | 12 [a] |
| 4 | CuCrZr-IG by EU supplier | | | 6 [a] |
| 5 | 316L(N)-IG by EU supplier | | | 6 [a] |

[a] Sample distribution in the different test conditions shall be agreed with the IO.

## 5.2 Fabrication of test samples, mechanical cycling and statistic test-materials from Russia (Optional)

### *5.2.1 Fabrication of test samples - materials from Russia*

**[R]** See the section 5.1.1.

### *5.2.2 Mechanical Cycling test– materials from Russia*

**[R]** The test protocol for mechanical cycling test shall be approved by the IO prior to the test. This represents a Hold Point.

**[R]** The mechanical cycling test shall be performed in strain-control condition, asymmetric cyclic test (0..load) under the given stresses (see **Table 5-4**).

**[R]** Depending on the test configuration, the Contractor shall select either combined stress for tensile configuration or bending configuration (see **Table 5-5**).

**[R]** Mechanical cycling test shall be performed <1 Hz at 150 ±5 °C.

**[R]** Mechanical cycling test shall be performed until failure but limited to 15 000 cycles except maximum 6 samples, extension to 30 000 cycles.

**[I]** The loads might be reduced along the test campaigns upon the request from the IO.

**[R] Table 5-5** shows the test matrix for the cycling test. The test shall be performed accordingly. Number of test samples is 24 in total.

**[R]** The test report of mechanical cycling test shall be approved by the IO. The test report shall include as minimum:

(1) Cycling mechanical tests and cycling mechanical test results;
(2) Visual examination results of the test samples before and after the test;
(3) Dimension examination results (including notch depth and width) of the test samples before the test;
(4) Traceability documents of the equipment.

**Table 5-4**: combined stresses for asymmetric mechanical cycling test (0…load).

| | | Tensile configuration | Bending configuration | No. of cycles |
|---|---|---|---|---|
| 1 | Samples of HIP bimetallic joints from **Russian supplier1** | 61.4 MPa | 249 MPa | 15 000 |
| 2 | Samples of explosion bonding bimetallic joints from **Russian supplier2** | 77.3 MPa | 313.5 MPa | First 300 cycles |
| | | 39.3 MPa | 159.2 MPa | 15 000 after the first 300 cycles |

**Table 5-5**: Test matrix for mechanical cycling test.

| | | | |
|---|---|---|---|
| | Sample material | Notch depth | Number of test samples |
| 1 | Bimetallic joint - HIP by Russian supplier | 0 mm, 1 mm, 2 mm, 3 mm | 4 x3 [a] |
| 2 | Bimetallic joint – explosion bonding by Russian supplier | | 4 x3 [a] |

[a] Minimum three samples /test condition shall be tested.

### *5.2.3 Static mechanical test– materials from Russia*

**[R]** The test protocol for static mechanical test shall be approved by the IO prior to the test. This represents a Hold Point.

**[R]** The static mechanical test shall be performed at three test temperatures, 150 ±5 C, 250 ±5 C, 350 ±5 C.

**[R]** The notch depth shall be 0 mm or 2 mm.

**[R]** The static mechanical test report of mechanical static test shall be approved by the IO.

**[R]** **Table 5-6** shows the test matrix for the static test. The test shall be performed accordingly. Number of test samples is maximum 24 in total.

**[R]** The static mechanical test report shall include as minimum:

(1) The mechanical static test and the test results;
(2) The visual examination results of the test samples before and after the test;
(3) The dimension examination results (including notch depth and width) of the test samples before the test;
(4) The traceability documents of the equipment.

**Table 5-6**: Test matrix for static mechanical test.

| | | | | |
|---|---|---|---|---|
| | Sample material | T_test | Notch depth | Number of test samples |
| 1 | Bimetallic joint - HIP by Russian supplier | 150 ±5 C, 250 ±5 C, 350 ±5 C | 0 mm, 2 mm | 12 [a] |
| 2 | Bimetallic joint – explosion bonding by Russian supplier | | | 12 [a] |

[a] Sample distribution in the different test conditions shall be agreed with the IO.

## 5.3 Final report

**[R]** The Final Report shall be delivered in two parts – Final Report-1: obligatory part, i.e. with materials from Chines and EU suppliers; Final Report-2: optional part, i.e. with materials from Russian suppliers.

**[R]** The Final Report shall include as minimum the following information:

- Contractual information;
- List of all applicable documents;
- List of generated documents including the Deviation Requests and Non-Conformance Reports if any;
- Photos of test samples before and after tests;
- Summary of test results and recommendations/conclusions.

# 6 List of Deliverables, Control Points and Schedule

**Table 6-1**: Deliverables, Control Points and schedule.

| Deliverables | Description | Control point | Due date |
|---|---|---|---|
| D1 | Quality Plan | Hold Point | T0+1 month |
| D2 | Report of preparatory activity, drawings and procedure documents - materials from China and EU<br>- Description of Test Sample preparation process including sample drawing<br>- Test Protocol for mechanical cycling test<br>- Test Protocol for static mechanical test | Hold Point | T0+3 months |

| | | | |
|---|---|---|---|
| D3 | Reports - Fabrication of test samples, cycling and statistic mechanical test- materials from Chinese and EU suppliers<br>- Test Report of mechanical cycling test of materials from Chinese and EU suppliers<br>- Test Report of static mechanical test of materials from China and EU suppliers | | T0+11 months |
| D4 | Final Report-1 | | T0+12 months |
| D5 (Optional) | Report of preparatory activity, drawings and procedure documents - materials from Russian suppliers<br>- Description of Test Sample preparation process including sample drawing<br>- Test Protocol for mechanical cycling test<br>- Test Protocol for static mechanical test | Hold Point | T1+2 months |
| D6 (Optional) | Reports - Fabrication of test samples, cycling and statistic mechanical test- materials from Russia<br>- Test Report of mechanical cycling test of materials from Russian suppliers<br>- Test Report of static mechanical test of materials from Russian suppliers | | T1+9 months |
| D7 (optional) | Final Report-2 | | T1+10 months |

T0: The Contract signature day

T1: The delivery date of materials from Russia; T1 shall be within T0+24 months.

# 7 Communication, Monitoring, Right of Access

**[R]** The official language of the Contract is English. All reports delivered under this Contract shall be written in English and will be considered as the only official version.

**[R]** In order to ensure and to monitor the correct performance of work, regular meetings shall be organized by the IO upon mutual agreement between parties.

**[R]** In order to ensure and to monitor the correct performance of work, IO shall be entitled to witness the execution of tasks planned in the frame of the Contract. Schedule for the witnessing at the Contractor's premises shall be arranged upon mutual agreement between parties.

**[R]** The tested samples and remaining materials shall be returned to the IO.

# 8 Quality Assurance Requirements

**[R]** The organization conducting these activities shall have an ITER approved QA Program or an ISO 9001 accredited quality system.

**[R]** The Contractor shall ensure the quality of services meet the requirements of this QA program. The general requirements are detailed in ITER document ITER Procurement Quality Requirements (22MFG4).

**[R]** Prior to commencement of the task, a Quality Plan (22MFMW) shall be submitted for IO approval giving evidence of the above and describing the organization for this task; the skill of workers involved in the Contract execution; any anticipated sub-contractors; and giving details of who will be the independent checker of the activities.

**[R]** Manufacturing and Inspection Plan (or Inspection Plan) shall be implemented to monitor quality control and acceptance test. The Contractor are subject to Requirements for Producing an Inspection Plan (22MDZD).

**[R]** Deviations and Non-conformities shall follow the procedure detailed in IO documents - Procedure for the management of Deviation Request (2LZJHB) and Procedure for management of Non-conformities (22F53X).

**[R]** Documentation developed as the result of this task shall be retained by the Contractor for a minimum of 5 years and then may be discarded at the direction of the IO.