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Technical Specifications (In-Cash Procurement)

Technical Summary of Qualification and Production of the Inconel 718 tie-rod

This document provides summary of technical requirement of Qualification and Production of the Inconel 718 tie-rod

Reference: Technical Specifications for PCCF threaded rods (A54WAC v1.5),

Table of Contents

1 Preamble

This document provides technical summary of Qualification and Production of the Inconel 718 tie-rod, which is a part of ITER Pre-compression system.

2 Overview of ITER Pre-compression system

ITER Tokamak magnet system has 18 Toroidal Field Coils (TFCs) that are arranged as a torus. Figure 2-1 shows two TFCs with the Pre-Compression rings (PCR) and the TF Inter-coil Structures, such as IIS, OIS, and IOIS.

In the inboard curved region of each TFC, the overall radial expansion of the TFCs during energization results in the opening of toroidal gaps between adjacent TFCs. The radial movement would be sufficient to create a toroidal gap of approximately 0.3 mm between the poloidal shear key and the key slot at Upper and Lower IIS in Figure 2-1. During plasma operation, the shear loads acting on the Upper and Lower IIS keys increase this gap to more than 1mm. In order to suppress this undesirable "breathing" effect and ensure that the keys do not become loose in their slots, each TFC is put under a centripetal load of approximately 47.8 MN (23.9 MN at the top and bottom curved regions) at operating conditions by two sets of pre-compression rings (PCR, x 6 in total). The TF Pre-Compression substantially reduces the toroidal loads in the intermediate Inter-coil connections (Upper/Lower OIS and Upper/Lower IOIS in Figure 2-1), thus increasing the machine fatigue life significantly beyond the 60000 design cycles with an allowable defect size of 100 mm^2 in the bulk material.

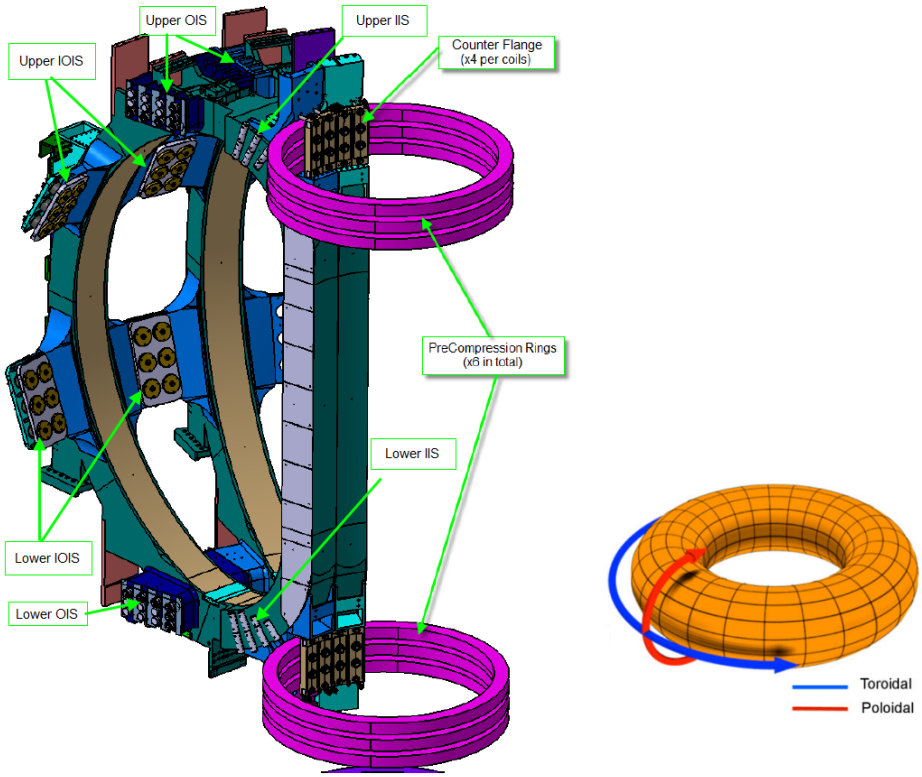


Figure 2-1: TF Coils Sector, Pre-Compression Rings and the Inter-coil Structures

Once all the 18 TF Coils are assembled, the PCR and PCCFs are placed in front of TF Pre-Compression Flanges (TFC PCFs). Component names of Pre-compression system are shown in Figure 2-2

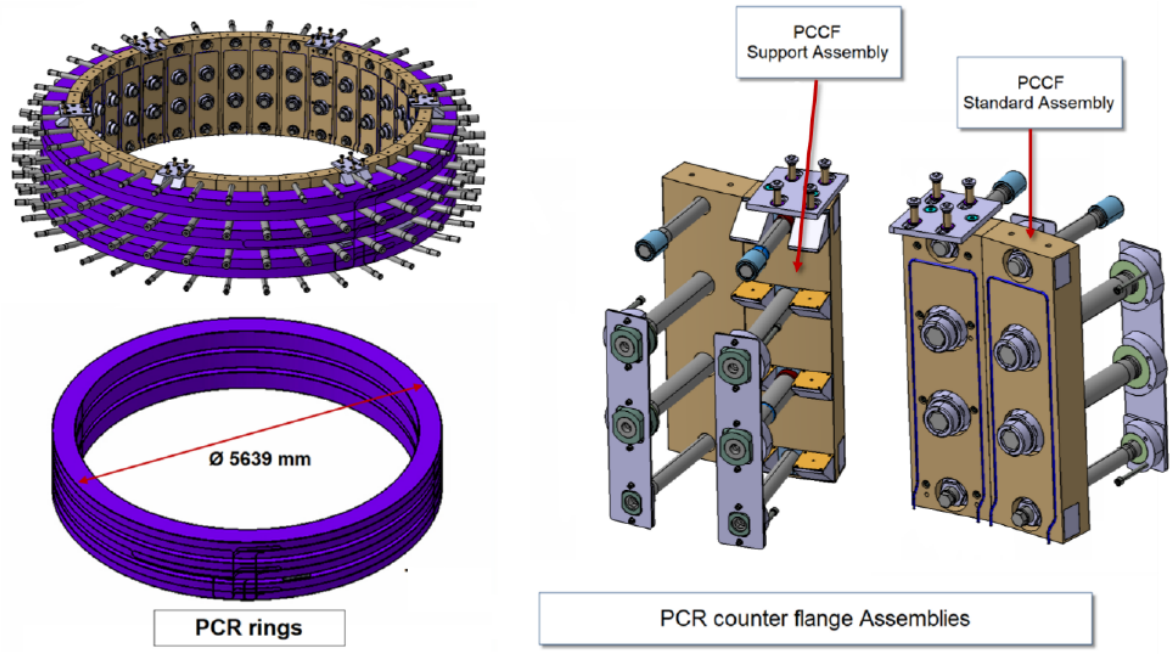


Figure 2-2 Components of TF Pre-Compression System

The TF Pre-Compression process is progressive stretching of the PCR via PCCFs using hydraulic tensioners as shown in Figure 2-3. The tie-rods are shown in Figure 2-3, which connect TFC PCFs and PCCFs and bear high axial loads for 20 years.

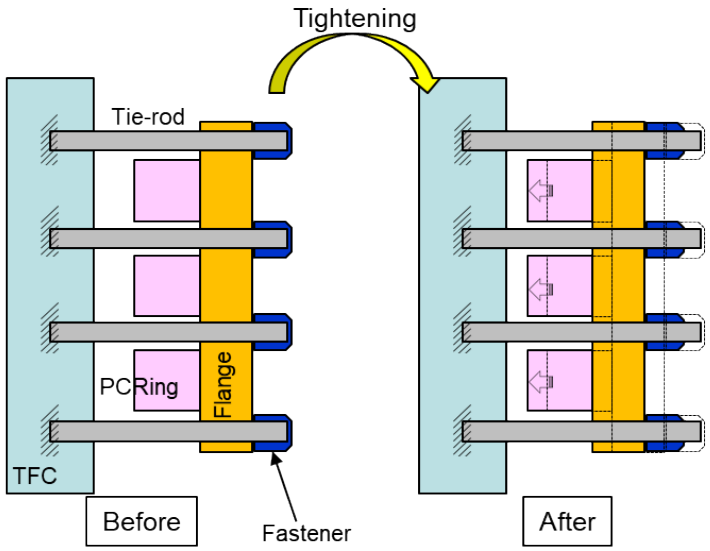


Figure 2-3 TF Pre-Compression Mechanism

3 Scope of Supply

3.1 Scope of Supply

Based on the IO design, the Contractor shall perform the:

- Production of PCCF Tie-rods
- Delivery to the IO site: ITER Organization Warehouse zone 2, Route de Vinon-sur-Verdon - CS 90 046 – 13067 St Paul Lez Durance Cedex France

3.1.1 Technical Requirements

The design of tie-rods is detailed in Appendix 1. The Contractor shall manufacture the items listed in Table 3.1.

Table 3.1 PCCF components to be manufactured

ITEM	TAG NUMBER PART NUMBER (PNI)	NAME	MATERIAL	Quantity
602	1101CA_000551_--J_602 PNI: 2ZKMTT	THREADED ROD M80x745 (specified in Appendix 1)	INCONEL718 (specified in Appendix 2)	4
702	1101CA_000551_--J_702 PNI: 2ZKM3P	THREADED ROD M80x940 (specified in Appendix 1)	INCONEL718 (specified in Appendix 2)	9
802	1101CA_000551_--J_802 PNI: 2ZK732	THREADED ROD M110x1010 (specified in Appendix 1)	INCONEL718 (specified in Appendix 2)	9

The Contractor shall perform FAT and submit FAT reports, including material acceptance inspection, Inspection before silver-coating (Liquid penetrant examination on threaded portion, dimension, gage check of thread), visual examination after silver-coating and cleaning.

3.1.2 Material requirements

Alloy 718 specification is shown in Appendix 2.

Material certification shall be included in the FAT reports.

3.1.3 Cleaning, Packing & shipping

During cleaning, particular attention shall be given to the removal of weld spatter, debris and other foreign matter. Final cleaning shall ensure effective cleaning without damage to the surface finish, material properties or metallurgical structure of the materials. The Contractor shall include cleaning procedure in MP.

The Contractor shall design and supply appropriate packaging, adequate to prevent damage during shipping lifting and handling operations.

3.1.4 Delivery Time

The maximum expected duration from the contract signature to the supply of the scope of work is 24 months, considering long lead time for a small amount of raw material procurement.

The contractor allows to deliver the tie-rods earlier than 24 months, to terminate the contract.

4 IO Documents & IO Free issue items

4.1 IO Documents:

Under this scope of work, IO will deliver the following documents by the stated date:

Ref	Title	Doc ID	Version
[i]	1101CA_000551K - Pre-compression Counter Flange	000551	K

4.2 Free issue items:

No free issue item is expected from IO.

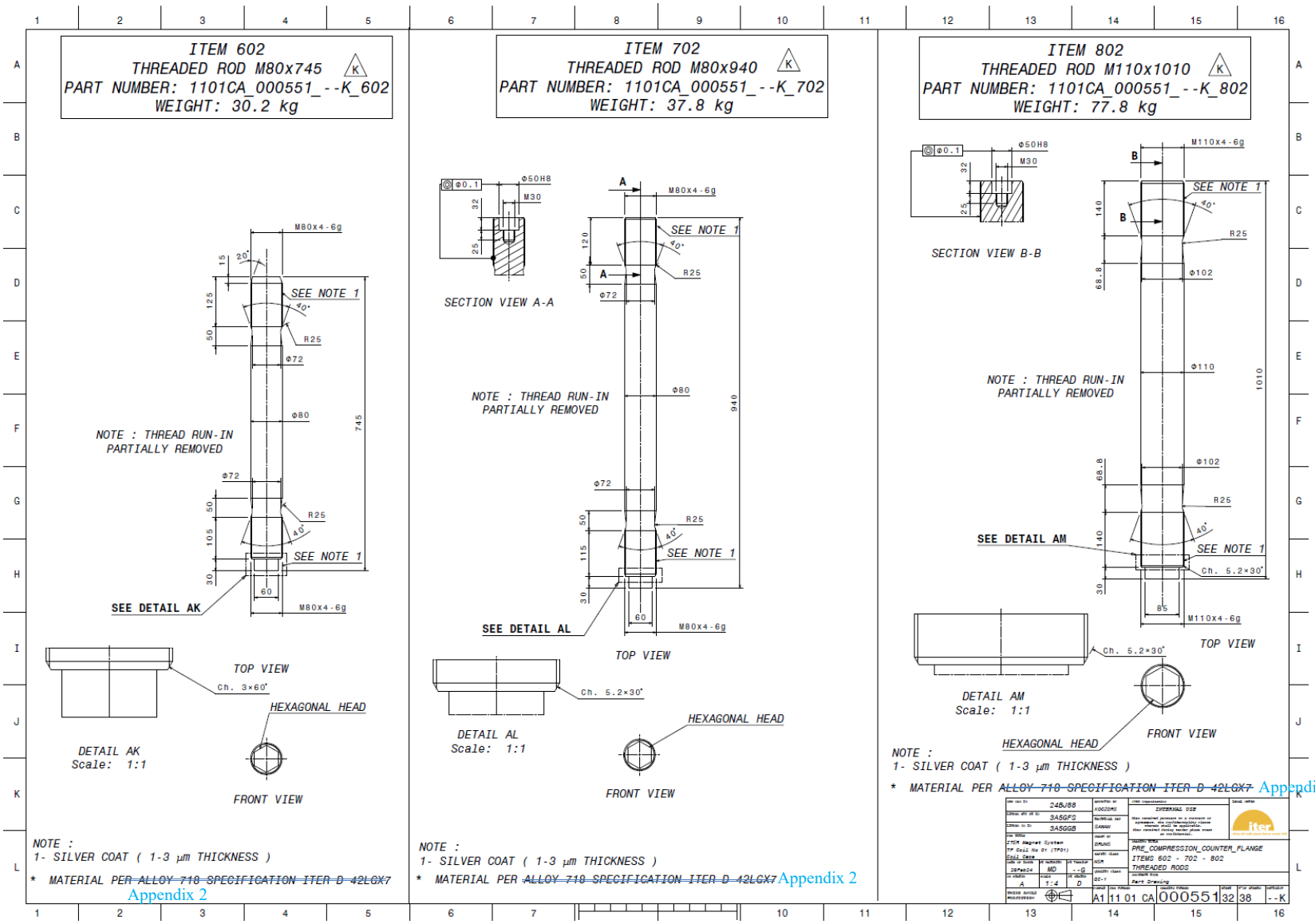
5 List of deliverables

The Contractor shall provide IO with the documents and products listed in below.

Deliverable #	Deliverable description	Due date (Months)
D1	Contract management documents including “Quality Plan”, “Contract Schedule”, “Minutes of Meeting of Kick-off meeting”, and “Subcontracting prior approval”, approved by IO	T0 + 1
D2	Other documents including “Material procurement document”, “Manufacturing and Inspection Plan” (MIP), and Manufacturing documents, such as “MP”, “MD”, and Specific procedures, approved by IO	T0 + 3
D3	INCONEL718 Bars & Discs, FAT report, material certificates, approved by IO	T0 + 20
D4	Delivery of threaded rods, procurement report, shipping or logistics record including Manufacturing dossier, Release Note, Delivery Report and Storage & Preservation requirement, accepted by IO	T0 + 24

T0 = Commencement Date of the contract ; X in months.

Appendix 1 Tie-rods drawing



Appendix 2 Alloy 718 Specification

1 General

This appendix defines requirements and procedures for the procurement of rods of precipitation hardened nickel - base alloy 718 (UNS N07718), also known under the trade name Inconel 718, to be used for the manufacture of fasteners for the PreCompression Counter Flange (PCCF) Assembly.

2 Referenced Documents

The applicable version is the latest released version as of 1 Jan 2007, unless agreed otherwise by the IO and the Contractor.

- ASTM B637 'Standard Specification for Precipitation-Hardening Nickel Alloy Bars, Forgings and Forgings Stock for High-Temperature Service'
- ASTM A962 / A962M, 'Standard Specification for Common Requirements for Steel Fasteners or Fastener Materials, or Both, Intended for Use at Any Temperature from Cryogenic to the Creep Range'
- ASTM A1014 / A1014M, 'Standard Specification for Precipitation-Hardening Bolting Material (UNS N07718) for High Temperature Service'
- ASTM E1473, 'Test Methods for Chemical Analysis of Nickel, Cobalt and High-Temperature Alloys'
- ASTM B880, 'Standard Specification for General Requirements for Chemical Check Analysis Limits for Nickel, Nickel Alloys and Cobalt Alloys'
- ASTM E112-96 (2004)e1, 'Standard method for determining average grain size'
- ASTM E45-05, 'Standard practice for determining the inclusion content of steel'
- ASTM A370, 'Test Methods and Definitions for Mechanical Testing of Steel Products'
- ASTM E1450, 'Standard Test Method for Tension Testing of Structural Alloys in Liquid Helium'
- ASTM E1820, 'Test Method for Measurement of Fracture Toughness'
- JIS Z 2284, 'Method of elastic-plastic fracture toughness J_{Ic} testing for metallic materials in liquid helium'
- ASME Section III, NB-2000
- ASME Section V, Article 6 Liquid Penetrant Examination
- ASME Section V, Article 5 Ultrasonic Examination Methods for Materials and Fabrication
- ISO 9712, 'Non-destructive Testing – Qualification and Certification of Personnel'
- ASTM A700, 'Standard Practices for Packing, marking, and Loading Methods for Steel Products for Domestic Shipment'

The Contractor may use other standards if it submits a Deviation Request demonstrating the equivalence to the IO reference documents.

3 Definitions

A heat is a single melt of material used to cast one or several ingots.

A remelt ingot is an ingot that has been produced using VAR or ESR process.

A lot for product analysis and other tests shall be in accordance with section 3.1.8 of ASTM A962 / A962 M.

4 Technical Specifications

4.1 Manufacturing process

The alloy shall be produced by vacuum induction melting and then refined using vacuum arc remelting process. In order to meet the required properties specified in this appendix, the alloy can be further refined using VAR or ESR methods. The rods shall be hot wrought and subsequently ground to their final dimensions.

The material supplier shall report the production process in the Inspection Certificate defined in section 4.12 of this appendix.

4.2 Heat treatment

The material to be used for fasteners manufacture shall be supplied in the solution treated state, suitable for subsequent precipitation hardening treatment. The material to be used for qualification and quality control tests as defined in this Appendix shall be supplied in the solution treated and precipitation hardened state.

The material shall be heat treated according to the requirements defined in ASTM A1014 / A1014M:

- Solution treatment: heat the material to a temperature of 924 to 1010°C, hold at the selected temperature for a time commensurate with cross-sectional thickness, air cool or faster
- Precipitation hardening treatment: heat the material to a temperature of 720±8°C, hold 8 h, furnace cool to 620±8°C and hold at this temperature so the total precipitation treatment time is 18 hours, then air cool to room temperature

The heat treatment conditions such as temperature and holding time shall be recorded and reported in the Inspection Certificate defined in section 4.12 of this appendix. The material supplier shall also inform the IO and the Contractor how to determine the solution-treated temperate and time. The solution treatment temperature shall be controlled in the range of ±14°C.

4.3 Chemical composition

The chemical analysis of representative material shall be performed in accordance with ASTM E1473. One sample per remelt ingot shall be selected for chemical analysis.

The material shall conform to the requirements prescribed in Table 1 (ASTM A1014 / A1014M, except the requirement for cobalt and tantalum contents).

The permitted variations of compositions for product analysis relative to the specified chemical requirements of Table 1 are defined in ASTM B880.

Table 1: Chemical composition

Element	Composition limits, (weight %)
C	0.08 max.
Mn	0.35 max.
Si	0.35 max.
P	0.015 max.
S	0.015 max.
Cr	17.0-21.0
Co	**0.3 max.[1]**
Mo	2.80-3.30
Nb+Ta	4.75-5.50 [2]
Ti	0.65-1.15
Al	0.20-0.80
B	0.006 max.
Fe	Remainder
Cu	0.30 max.
Ni	50.0-55.0

Notes:

- Co has been limited to 0.3% maximum.
- Ta has been limited to 0.05% maximum.

4.4 Microstructure

The microstructure shall be free of freckles, white spots and Laves phases.

The micro structural examination to determine grain size shall be in accordance with ASTM E112-96 (2004)e1. The grain size measured shall be equal or finer than No.5 and that the average grain size shall be homogeneous within the range of ±1 equivalent grain size number around the true average value.

4.5 Inclusions

The amount and definition of inclusions per lot shall follow method D of ASTM E45-05.

- Micro inclusions (indigenous inclusions detectable by microscopic test methods): method D is applicable. Severity level number shall be at most 2 for types A, B, C and D.
- Macro inclusions (exogenous inclusions from entrapped slag or refractories) are not permitted.

4.6 Mechanical properties

4.6.1 Tensile properties

Tensile tests shall be performed at room temperature according to ASTM A370 and at 4K according to ASTM E1450. The material shall be in the solution treated and precipitation hardened state. The following values shall be recorded:

- Yield Strength at 0.2% offset, in MPa
- Ultimate Tensile Strength , in MPa
- Total Elongation after fracture, %
- Reduction of Area, %

Test shall be performed in the direction of fabrication. The material shall conform to the tensile properties shown in Table 2. One test per lot is required.

Table 2: Requirements for tensile properties

Temperature (K)	Minimum Tensile Strength (MPa)	Minimum Yield Strength at 0.2% (MPa)	Minimum Elongation in 4D (%)	Minimum Reduction of Area (%)
300	1275	1035	12	15
4	**1600**	**1350**	**8**	**-**

4.6.2 Fracture toughness

Fracture toughness tests shall be performed at a temperature of 4K according to ASTM E1820 and JIS Z 2284. The material shall be in the solution treated and precipitation hardened state.

Three compact tension (CT) specimens per lot shall be tested and cut in LR orientation (load applied along the longitudinal direction and crack propagates along the radial direction). The material shall conform to the value shown in Table 3.

Table 3: Requirements for fracture toughness

Temperature (K)	Fracture Toughness K_{Ic} ($MPa.m^{1/2}$)
4	75

4.6.3 Hardness

The test shall be performed in according to ASTM A370. The material shall be in the solution treated and precipitation hardened state.

The material shall conform to the room temperature hardness requirements prescribed in Table 4. One test per lot is required.

Table 4: Requirements for hardness

Brinell Hardness Number	Approximate Rockwell Hardness
331 - 444	35 - 48 HRC

4.7 Dimensions and permissible variations

The material shall conform to the permissible tolerances defined in section 7 of ASTM B637 and to the dimensions specified on the material order.

4.8 Non-destructive examination

All NDE can be carried out by Level 1 or 2 qualified personnel as per ISO 9712 but the coordination and reports shall be responsibility of a Level 3 NDE expert. The period of validity of the NDE level certification of the personnel shall not exceed 5 years.

4.8.1 Liquid penetrant examination

All external surfaces of the rods shall be examined by a liquid penetrant test in accordance with ASME Section V, Article 6. The acceptance criteria shall be in accordance with ASME Section III, ND-2546.

4.8.2 Ultrasonic examination

All rods shall be examined by the ultrasonic method in accordance with ASME Section V, Article 5. The examination procedure and acceptance standard shall be in accordance with ASME Section III, NB-2542.

4.9 Qualification of material supplier

The material for qualification shall be produced according to this appendix. The material supplier shall make all specimens. All tests listed in Table 5 shall be performed either by the material supplier or a qualified testing organisation, under the supervision of the Contractor.

Table 5: Qualification and quality control tests

Test Items	Test frequency
Chemical analysis	1 per remelt ingot
Tensile test at RT	1 per lot
Tensile test at 4K	1 per lot
Fracture Toughness at 4K	3 per lot
Hardness	1 per lot
Grain size	1 per lot
Microstructure	1 per lot
Inclusion content	1 per lot
Liquid penetrant examination	Each rod
Ultrasonic examination	Each rod

4.10 Quality control

Once a supplier has been qualified and chosen by the Contractor for the procurement of the material, quality control tests shall be performed throughout the production of the rods. The material supplier shall make all specimens. All tests listed in Table 5 shall be performed either by the material supplier or a qualified testing organisation, under the supervision of the Contractor.

4.11 Acceptance

Inspection Certificates as defined in section 4.13 of this Appendix have to be provided to the purchaser prior to delivery. Material and certification shall be in compliance with this specification. Material cannot be accepted if it does not comply with this specification.

4.12 Marking

Each batch shall be legibly identified with the following information:

- manufacturer name or symbol
- purchaser’s name
- order number
- grade of material
- heat number
- type of finish
- nominal diameter and length
- bar number or unique identification number related to quality history - date of manufacture

4.13 Documentation

The supplier shall provide the Inspection Certificate type 3.1 in accordance with EN 10204, which include at least the following information:

- material designation and marking
- the heat number and definition of product
- identification of supplier
- identification of order
- melting process method
- mill product manufacturing method
- record of heat treatment
- result of chemical analysis
- records of microstructure examination and grain size
- results of mechanical property tests
- results of all analysis and inspections that shall be done according this appendix
- records of non-destructive examinations
- packaging data

All documents shall be in the English language and all measures shall be given in the metric system SI. Each document shall be provided as an electronic file in PDF format.

4.14 Packaging

Packaging, marking, and loading for shipment shall be in accordance with ASTM A700.