
	Manufacturing, testing and supply of vacuum vessels for HNB3 (Beam Line Vessel and Beam Source Vessel) and DNB <i>Annexure-4F: Materials_Rolled or forged bars and semi-finished products for HNB3 Vessel</i>	INDUS Ref No
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1. Scope

This specification covers all rolled or forged bars and semi-finished products made from weldable (1.4404 / X2CrNiMo17-12-2 / SS 316L-N) forgings (RCC-MR 2007, Section-2, RM 3324) controlled nitrogen austenitic stainless steel, with a diameter or a thickness less than 250 mm.

2. Reference

RCC-MR 2007; Section-2; RM 3324 Product procurement specification: class 1, 2 and 3 austenitic stainless steel forgings

Chemical composition and impurity requirements for materials (REYV5V_v2_3)

3. Melting process


The steel shall be made using an electric furnace or by any other technically equivalent process. Melting of the steel should be completed by a suitable secondary refining processes like Argon oxygen decarburization (AOD) or Vacuum oxygen decarbonized (VOD).

4. Chemical requirements

Chemical composition, as determined by product analyses per heat of metal, shall comply with the following requirements (Table 1). The Steelmaker shall also supply a ladle analysis certified by the Mill Manager or his duly accredited representative. This analysis may be performed on metal discards taken from mechanical test specimens. These analyses shall be performed in accordance with RMC 1000

Table 1: Chemical composition requirement

Chemical composition,	Content in Wt. %
X2CrNiMo17-12-2 controlled nitrogen	
<i>Elements</i>	<i>Range or Max</i>
Fe	balance
C	0.030
Mn	1.60 - 2.00
Si	0.50
P	0.030
S	0.015

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Cr	17.00 - 18.00
Ni	12.00 – 12.50
Mo	2.30 – 2.70
N	0.060-0.080
Cu	1.00
B	0.0020
Additional ITER specific requirements [6] and [93]:	
Co	0.05
Nb	0.01
Ta	0.01
Ti	0.10

Control of Co, Nb and Ta is identified as Protection Important Activity (PIA). Therefore, the compliance with above requirements have to be closely monitored.


5. Intergranular Corrosion test

- 5.1 It shall be performed in accordance with **RMC 1310**, on a test ingot made at the time of casting. In case this is not possible, one test shall be performed per heat of metal.
- 5.2 The sensitizing heat treatment shall be performed with treatment B at the heating temperature of $725^{\circ}\text{C} \pm 10^{\circ}\text{C}$.
- 5.3 The corrosion test result shall be considered satisfactory if (1) during sound testing the test specimen gives a clear metallic sound, and (2) provided no cracks or tears are detected during the bend tests. Should any doubt remain, the absence of intergranular corrosion shall be confirmed by micrographic examination.

6. Ferritic Content

The ferrite content evaluated using the Schaeffler diagram modified by Pryce and Andrews (Fig. RMC 1341.2, placed at the end of this annexure) and measured on a solution heat treated product must be less than 1%.

The ferrite content shall be measured on the surface of one bar per lot.

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7. Structure

- 7.1 A micrographic examination, with photographs, shall be performed parallel to the main direction of extension.
- 7.2 The structure must be homogeneous and the grain size number as determined in accordance with RMC 1000 / EN ISO 643: Steels- Micrographic determination of the apparent grain size, shall not be less than 2. The grain size homogeneity shall be ± 1 around the true average value.
- 7.3 This grain size is determined on a test sample taken close to the mechanical test specimens.
- 7.4 Non-metallic inclusions amount and definition shall meet standard ASTM E45-05.
- 7.5 Micro inclusions (indigenous inclusions detectable by Micro Examination methods): Method D is applicable. Severity level number shall be at most 2 for types A, B, C and D. The tolerance for acceptance may be a half-class above the set limit to the extent of 2% of the fields counted.
- 7.6 Macro inclusions (exogenous inclusions from entrapped slag or refractories): they are strictly forbidden and are cause of rejection.

8. Manufacture and manufacturing programme

The overall ratio of reduction calculated in accordance with RM 0380, should not, as a general rule, be lower than 3.


Prior to commencement of manufacturing operations, the Foundry shall draw up a manufacturing programme. This shall include the following:

- a) Identification of melting process
- b) Ingot weight and type,
- c) Top and bottom end discard percentages,
- d) As-treated and as-delivered bar diameters,
- e) Conditions for intermediate heat treatments and for final heat treatment for mechanical properties,
- f) Dimensional drawing with position of test specimens on samples

For bars of diameter ≤ 80 mm points b) and c) of the manufacturing programme are not required.

9. Delivery condition

Forged parts shall be delivered in the solution heat treated condition and machined to the as-delivered profile.

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10. Solution heat treatment

Solution heat treatment shall consist of holding at a temperature between 1050°C and 1150°C followed by water cooling. The thermal cycles involved in the heat treatment shall be recorded and the records kept at the disposal of the Surveillance Agents.

11. Machining - Surface condition

11.1 The bar shall be machined to its as-delivered profile. The surface condition evaluated shall be in accordance with **RMC 7200**. Further, the requirements of the various non-destructive examinations shall be fulfilled.

11.2 Unless specified otherwise, maximum average surface roughness (defined in accordance with ISO 4278:2000) shall be 6.3 µm Ra for all metallic components. The measurement shall be performed by a stylus probe type instrument.

12. Mechanical properties

12.1 Sampling:

12.1.1 Test samples shall be cut after the bar or semi-finished product has undergone solution heat treatment. They shall be appropriately marked.

12.1.2 The size of the test samples shall be such that they can provide enough test specimens for all tests and retests.

12.1.3 Sampling procedures are defined in **§10.5.2 of the standard NF EN 10272 (figures 1 and 2)**.

12.2 Testing in the solution heat treated condition

Tests shall be performed on test specimens which were not subjected to heat treatment after sampling.

12.3 Definition of a lot


A lot shall comprise parts of similar shape, cross-section and diameter, as defined below:

$$\frac{\varnothing_{\max}}{\varnothing_{\min}} \leq 1,1 ; \frac{e_{\max}}{e_{\min}} \leq 1,1 \text{ et } \frac{S_{\max}}{S_{\min}} \leq 1,25$$

∅: Diameter; e= Thickness; S= Stress

These parts are produced from the same heat, have been subjected to the same manufacturing cycle and form part of the same furnace charge or the same heat treatment cycle. A lot shall be restricted to 3000 kg.

12.4 Number and content of tests

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12.4.1 One series of tests shall be performed per lot for parts weighing 500 kg or less.

12.4.2 Two series of tests shall be performed for parts weighing more than 500 kg.

12.4.3 A tests series shall comprise:

- (i) one tension testing at room temperature
- (ii) one tension testing (only Yield Strength) at 200 C

12.5 Tension testing at room temperature

12.5.1 Test specimen:

Test specimens shall have a circular section. Their normal diameter shall be 10 mm and their dimensions as specified in **RMC 1211**.

12.5.2 Test method:

The tension test shall be performed in compliance with **RMC 1211**. The following values shall be recorded:

- (i) Yield strength at 0.2% offset, in MPa,
- (ii) Yield strength at 1% offset, in MPa,
- (iii) Ultimate tensile strength, in MPa,
- (iv) Percentage elongation after fracture,
- (v) Percentage reduction of area after fracture.


12.5.3 Results

Results obtained shall meet the requirements given in **Table-2** Below.

Table-2: Tensile properties at Room temperature

Yield strength at 0.2% offset, in MPa, $R_{p0.2}$	220
Yield strength at 1% offset, in MPa, R_{p1}	To be recorded For Information
Ultimate tensile strength, in MPa, R_m	525-700
Percentage elongation after fracture, A% (5d)	45 (Longitudinal) 40 (Transverse)
Percentage reduction of area after fracture	To be recorded For Information

12.5.4 If the requirements of clause **12.5.3** are not fulfilled, and the test specimen has a physical defect (which does not affect the usefulness of the product) or if unsatisfactory test results are due to incorrect mounting of the specimen or a testing

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machine malfunction, the test shall be repeated using another specimen. If the results of the second test are satisfactory, the part and/or the lot shall be accepted; if not, the following paragraph shall apply.

Where unsatisfactory results cannot be attributed to any of the above-mentioned causes, two retests may be performed for each unsatisfactory result obtained. The second set of test specimens shall be taken close to those which were defective. If the results of the retests are satisfactory, the lot shall be accepted; if not, it shall be rejected (clause 12.7).

12.6 Tension testing at high temperature (200 C)

12.6.1 Test specimen:

The nominal diameter shall be 10 mm and their dimensions as specified in RMC 1212.

12.6.2 Test method:

The tensile test is performed in compliance with RMC 1212.

12.6.3 Results:

Yield strength at 0.2% offset, MPa, $R_{p0.2}^t$:	144
Yield strength at 1% offset ($R_{p1\%}$)	To be recorded for information
tensile strength (R_m)	To be recorded for information

12.6.4 If the requirements of clause 12.6.3 are not fulfilled, then follow clause 12.5.4.


12.7 Retreatment

12.7.1 Lots rejected on the basis of unsatisfactory results for one or more mechanical tests may be retreated (solution heat treatment).

12.7.2 Retreatment conditions shall be described in the test report.

12.7.3 In such cases, test samples and specimens shall be taken in the same conditions as specified in clause 12.1 and clause 12.2. The tests performed shall be the same as those described in clause 12.3 to 12.6.

12.7.4 No more than one retreatment shall be allowed.


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13. Surface examination - Surface defects

- 13.1 Surfaces shall be thoroughly examined during all phases of production and machining to check the soundness of the metal. The part shall be sound and free of scale, strings, tears, nicks or other injurious defects.
- 13.2 A visual examination shall be performed on all parts and this may be followed by a liquid penetrant examination in accordance with **RMC 4000**.
- 13.3 The following recordable conditions and examination criteria shall be applied for liquid penetrant examination:
- 13.3.1 Except in the particular case described below:
- Any defect with one dimension of 1 mm or more shall be considered a recordable condition
- 13.3.2 The following indications shall be unacceptable:
- (i) linear indications,
 - (ii) rounded indications with one dimension greater than 3 mm,
 - (iii) 3 or more indications aligned less than 3 mm apart edge to edge.
 - (iv) 5 or more grouped indications within a rectangular area of 100 cm², whose greater dimension shall not exceed 20 cm, taken in the most unfavorable location relative to the indications being evaluated.

14. Volumetric examination

- 14.1 An ultrasonic volumetric examination shall be performed.
- 14.2 Degree and time of examination: This examination shall be performed after heat treatment and machining to delivery dimensions.
- 14.3 Procedures
- 14.3.1 Ultrasonic examination procedures are specified in paragraphs **RMC 2310**
- Probe frequency shall normally be 2 MHz
- 14.5 Evaluation of indications
- Indications shall be evaluated in accordance with the requirements of **RMC 2310**
- 14.6 Recordable conditions and examination criteria

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The ranges considered and the acceptance criteria which depend on the thickness of the parts examined, shall be those defined by the standard **NF EN 10228-4** for normal probe. The quality **class 2** shall be adopted.

For thickness above or equal to 75 mm, concerning the loss of back echo, the recordable attenuation range is $R \leq 0.12$ with no acceptability limit.

15. Removal of unacceptable areas

- 15.1 The forging mill may eliminate surface defects by grinding, provided that the dimensional tolerances of the part in the as-delivered condition are respected.
- 15.2 After grinding, a liquid penetrant examination shall be performed in accordance with **RMC 4000**. Examination criteria shall be those defined in **clause 13.3** above.
- 15.3 No repairs by welding by the forging mill shall be permissible.

16. Dimensional check

- 16.1 The dimensions shall be checked in accordance with the requirements of the procurement drawings.
- 16.2 The main dimensions shall be recorded.
- 16.3 The values obtained shall be within the tolerances given on the drawing.
- 16.4 In the case of drop forgings, this examination shall be performed by representative sampling.

17. Marking


- 17.1 The Supplier shall specify the identification and marking methods used, in compliance with **RC 1300**.

18. Cleanliness - Packaging – Transportation

- 18.1 Requirements shall be specified in the purchase order, taking particular account of the requirements of **Annexure 13**.

19. Test reports

- 19.1 In addition to the inspection certificate type 3.1 in accordance with NF EN 10204, the following reports shall be drawn up by the Supplier after each individual test and, in any case, prior to delivery of the part:
 - 19.1.1 Ladle and product analyses
 - 19.1.2 Micrographic examination, grain size

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19.1.3 Intergranular corrosion test

19.1.4 Ferrite content

19.1.5 Record of all the heat treatment

19.1.6 Mechanical tests

19.1.7 Non-destructive examinations

19.1.8 Dimensional check

19.2 These reports shall also include:

19.2.1 Heat number and part reference number

19.2.2 Supplier's particulars

19.2.3 Purchase order number

19.2.4 Name of the inspection agency, where applicable

19.2.5 Test and retest results together with required values


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Figure RMC 1341.2: Schaeffler diagram, modified Pryce and Andrews – determination of the δ ferrite content

Nickel equivalent: $Ni\ eq. = Ni + 21\ C + 11.5\ N + 0.5\ Mn$

Chromium equivalent: $Mo < 2\ %: Cr\ eq. = Cr + Mo + 3\ Si$

$Mo \geq 2\ %: Cr\ eq. = Cr + 2\ Mo + 3\ Si$

