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	JOB: GENERAL		CC:
	AREA: GENERAL		PROJECT: --
--	TITLE: ALTERNATIVE FLAW ACCEPTANCE CRITERIA OF SUBMARINE RIGID PIPELINE AND RISER WELDS		EDD/EDR --

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL ADAPTED FROM I-ET-0000.00-0000-210-PSQ-001 REV. 0

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1 INTRODUCTION

1.1 SCOPE

1.1.1 This document sets forth the technical requirements for Engineering Critical Assessment (ECA) of pipelines and risers in subsea installations (including equipment and components) to determine alternative flaw acceptance criteria in welds before installation. This specification is applicable to C-Mn and CRA. For CRA clad, lined and weld overlay material, additional requirements are given in APPENDIX A.

1.1.2 ECA shall be issued according to recognized industry practice and shall meet the requirements of the codes and standards referenced herein. The baseline methodology adopted to assess fatigue and fracture shall be according to the procedures defined in [A1] and [A2] as modified herein.

1.2 CONFLICT AND HIERARCHY OF DOCUMENTS

1.2.1 This technical specification provides additional requirements (AR) and modified requirements (MR) to [A1]. For the sake of clarity, the requirements specified herein shall be read in conjunction with the respective item in [A1] and they shall always prevail. CONTRACTOR shall submit an ECA philosophy/methodology before proceeding with analysis.

1.2.2 In the event of any conflict between this specification or any other applicable code, standard or regulation, this specification shall take precedence. Should CONTRACTOR's procedures deviate from this specification, a written report must be submitted to COMPANY highlighting the non-conformance, before proceeding with the work. COMPANY's approval of any deviation must be in written form.

1.2.3 The final ECA report shall be approved before starting any production weld. Installation premises (holding period versus sea state conditions) shall be included in both ECA Report and installation procedure. In no case it will be acceptable to consider post laid survey information for the purpose to reevaluate the welding criteria for a specific girth weld that exceed installation conditions.

2 CHANGES IN SECTION 1 OF DNV-RP-F108

2.1 GENERAL

2.1.1 *[Item 1.6 and Table 1-1]* (AR) The referred edition of the following codes, standards, and regulations, shall be used with this specification, unless the use of more recent edition is formal approved. COMPANY documents shall be used in the latest revision.

[A1]	DNV-RP-F108 (2021)	Assessment of Flaws in Pipeline and Riser Girth Welds
[A2]	BS 7910 (2019)	Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures.

[A3]	DNV-ST-F101 (2021)	Submarine Pipeline Systems
[A4]	I-ET-0000.00-0000-210-P9U-004	Welding and NDT of Submarine Rigid Pipeline, Risers, and Pipeline Components
[A5]	BS 8571 (2014)	Method of test for determination of fracture toughness in metallic materials using single edge notched tension (SENT) specimens
[A6]	ISO 12135 (2002)	Metallic materials — Unified method of test for the determination of quasistatic fracture toughness
[A7]	ISO 15653 (2010)	Metallic materials — Method of test for the determination of quasistatic fracture toughness of welds
[A8]	DNVGL 217-3114 (2018)	Guideline for Design and Construction of Lined and Clad Pipelines from JIP Lined and Clad Pipeline Materials
[A9]	NACE MR 0175/ISO 15156 (2015)	Materials for use in H_2S-containing environments in oil and gas production
[A10]	NACE TM 0177 (2016)	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments
[A11]	NACE TM 0284 (2003)	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking

2.2 VERBAL FORMS

2.2.1 *[Table 1-2]* (MR):

MAY	Verbal form used to indicate a course of action permissible within the limits of this specification requiring the formal COMPANY agreement.
SHOULD	Verbal form used to indicate that among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required. Other possibilities may be submitted to COMPANY approval under technical query form (TQF).

2.3 TERMS

2.3.1 *[Table 1-3]* (AR):

COMPANY	PETROBRAS
CONTRACTOR	The party responsible for the engineering design, procurement and/or construction, as applicable, of the respective contract.

2.4 ABBREVIATIONS

2.4.1 *[Table 1-4]* (AR):

3D FEA	Finite Element Analysis with solid elements
AR	Additional Requirement
DR	Deleted Requirement
MR	Modified Requirement
PoD	Probability of Detection
PoR	Probability of Rejection

3 CHANGES IN SECTION 2 OF DNV-RP-F108

3.1 FATIGUE AND FRACTURE LIMIT STATE

3.1.1 *[Item 2.1]* COMPANY philosophy for fatigue and fracture limit state analysis is based on the assessment of flaw size and reliability of volumetric weld inspection to aid S-N approach. Whether the specification of a good workmanship or generic acceptance criteria is feasible for low-strained non-fatigue sensitive welds, it may become very onerous for critical applications such as rigid risers and sour service pipelines. Engineering Critical Assessment (ECA) is a more cost-efficient alternative to derive weld flaw acceptance criteria and assure that quality level is fit-for-purpose. (MR)

3.1.2 *[Table 2-1]* In addition to table 2-1, project documents may specify if ECA is mandatory. (AR)

3.1.3 *[Item 2.3]* If not specified in project documents, welds may be classified as "non-fatigue-sensitive" if: (a) sub-critical fatigue defect growth (da/dN), caused by cyclic loading in the operating phase, is limited to 0.2 mm depth in the ECA; or, alternatively: (b) The fatigue damage (S-N) caused by cyclic loadings in the operational phase, including the appropriate safety factors (Dfat x DFF), is limited to 2.5% of the capacity of the D curve to the outside and F1 to the inside. The limit described in (b) can be extended to 5% when less than 1% of the welds in the analyzed flowline section are exposed to damage greater than 2.5%. Welds not classified as "non-fatigue-sensitive" should be treated as "fatigue-sensitive". (MR)

3.1.4 *[Item 2.4 and Table 2-2]* If ECA is not required in project documents, weld quality requirements for assessment category I and II in Table 2-2, i.e., Tables E-1 and E-2 of [A3], shall be adopted for girth welds within a specific zone or for the entire pipeline (risers excluded). See [A4]. For risers, assessment categories III, IV and/or V shall be carried out at least to validate flaw sizes of Table E-2 [A3]. (MR)

3.1.5 *[Item 2.4 and Table 2-2]* For CRA clad, lined and weld overlay materials, additional requirements are given in APPENDIX A. For clad, lined or overlay materials other than alloy UNS N06625, additional requirement may apply, and COMPANY shall be formally consulted. *(AR)*

3.1.6 *[Item 2.4 and Table 2-2]* Project documents shall inform if the presence of H_2S, CO_2 or other aggressive environment promotes corrosion fatigue or any mechanical properties degradation which invalidates workmanship criteria according to assessment categories I and II in Table 2-2. Specific FCGR and applicable requirements for material fracture toughness in sour environment for assessment category V will be provided in project specific documents. (AR)

3.1.7 *[Item 2.4]* For quality purposes, AUT acceptance criteria for production welds shall not be higher than t/4 (but max 4 mm) in height and D/2 (but max 200mm) in length. The smallest acceptable flaw height in AUT acceptance criteria shall not be less than PoD 90%l95% or PoR 85%l95%. For CRA layer, the maximum defect height shall be limited to half of CRA thickness. (MR)

3.1.8 *[Item 2.4]* A minimum ligament of 3 mm shall be considered for embedded flaws in region B. Embedded flaws detected in regions A and C during inspection shall be re-characterized as surface breaking flaws according to [A4]. (MR)

4 CHANGES IN SECTION 3 OF DNV-RP-F108

4.1 GENERAL

4.1.1 *[Item 3.1.1]* The main purpose of this technical specification is to determine alternative flaw acceptance criteria of submarine rigid pipeline and riser welds. The same premises may not be suitable to perform fitness-for-service evaluations considering fracture limit state or to avoid PWHT for large wall thickness, where COMPANY shall be formally consulted. (MR)

4.1.2 *[Item 3.1.1]* It is not acceptable to conduct integrity assessments based on standards or procedures other than [A1], [A2] and this specification. BS 7910 option 1 shall not be used to derive acceptance criteria or sensitivity analysis. (AR)

4.1.3 *[Item 3.1.1]* If CONTRACTOR does not use Crackwise 5 software to perform calculation, the employed software with its license shall be provided for COMPANY for validation. The software shall be submitted to a Verification & Validation process, with DNV approval. Crackwise 5 and/or other input files shall be provided with ECA Report. This also includes finite element analysis input files, whenever it is adopted in the fracture mechanics analysis. (AR)

4.1.4 *[Item 3.1.1]* Manual ultrasonic testing shall not be used for flaw detection and sizing when ECA is used to derive flaw acceptance criteria. AUT, according to Appendix E of [A3], shall be used for reliable flaw detection and sizing. (MR)

4.1.5 *[Item 3.1.2]* Minimum fracture toughness shall be J=150 N/mm for single fracture toughness parameter and $J_{0.5}$=150 N/mm and $J_{1.0}$=200 N/mm for fracture toughness resistance curve if not specified anywhere else. Only fracture toughness results in terms of J_m or J_u are acceptable. J_c results are not acceptable. For the assessment of pop-in in fracture toughness testing, COMPANY shall be consulted. (AR)

4.2 WELD STRENGTH MISMATCH

4.2.1 *[Item 3.2.1]* For C-Mn and low alloy material, weld metal strength shall be equal to or higher than the parent material for all strain levels. The strength mismatch procedure described in [A2] shall not be used to increase weld flaw acceptance criteria. (AR)

4.2.2 *[Item 3.2.2]* Full under-match of CRA girth welds are not permitted. Girth welds shall be considered “full under-matched” when all-weld metal stress-strain curves are lower than the stress-strain curve of the parent pipe for strain levels equal or higher than 5%. (AR)

5 CHANGES IN SECTION 4 OF DNV-RP-F108

5.1 ECA CATEGORY III

5.1.1 *[Item 4.1.1.a. and 4.2.1]* Generic ECA is not acceptable. (MR)

5.1.2 *[Item 4.1.2]* All static loads adopted in ECA shall be fully traceable with other design documents (e.g., installation analysis). It means that ECA report shall mention which document they are based on, and the design documents shall mention which loading will be considered in ECA. (AR)

5.2 SPECIFIC ENGINEERING CRITICAL ASSESSMENT (ECA)

5.2.1 *[Item 4.3.1]* For ductile tearing analysis, the accumulated tearing for all installation strain cycles shall be limited to 1.5 mm or 10% of the wall thickness (whichever is lower). When ductile tearing assessment is performed for analysis of pipelines installed by J-Lay or S-lay, accumulated tearing shall not exceed 0.5 mm. (MR)

5.2.2 *[Item 4.3.3]* Non-uniform solutions for residual stresses are not acceptable. Residual stress simulation is only permitted when CDF are obtained from 3D FEA described in section 6. The model shall be validated experimentally. The analysis shall be fully documented and reproducible. (AR)

5.2.3 *[Item 4.3.4]* It is acceptable to define actual wall thickness (t_c) based on measurements after manufacturing, but the mean value minus two standard deviations shall be considered. The minimum of at least eight measures around the circumference in each pipe end shall be taken for the statistics. (MR)

5.2.4 *[Item 4.3.5]* For double sided welds, SCF for internal surface flaw shall be calculated from equations 4.7, however values of the internal surface shall be considered for "ROOT" and values of the external surface shall be considered for "CAP". The maximum internal and external misalignment accounted in SCF calculation shall be achieved during production. The detailed procedures for internal and external misalignment control shall comply with [A4]. (MR)

5.2.5 *[Item 4.3.6]* For the purposes of defining $L_{r,max}$, specified minimum tensile properties shall not be used. (MR)

5.2.6 *[Item 4.3.7]* If hydrogen charged specimens are not specified for EOL fracture limit state verification in project documentation, fracture toughness may be derived from installation J-R curve (SENT specimens) at a crack extension of 0.2 mm ($J_{0.2}$) to guarantee that no further tearing occurs. For operational scenarios where $\varepsilon_{l,nom}$ exceeds 0.4%, COMPANY shall be formally consulted. (AR)

5.3 INTERNAL OVER-PRESSURE

5.3.1 *[Item 4.4.2]* Regarding internal over-pressure, the biaxial effect in longitudinal stress shall be included in the applied stress. Uniaxial yield stress shall not be corrected according to Eq. 4.9 to determine the value of Lr. Maximum defect height at end-of-life shall not exceed half the thickness. (MR)

5.3.2 *[Item 4.4.2]* It is not acceptable to adjust CDF by changing other inputs, such as the reference stress solution or the relative flaw height, to compensate the biaxial effect in the applied stress. (MR)

6 CHANGES IN SECTION 5 OF DNV-RP-F108

6.1 ECA CATEGORY IV

6.1.1 *[Item 5.1.1]* For the calculation of maximum acceptable flaw size before installation, every crack growth promoted by installation and operational loads shall be considered, step-by-step. ECA Report shall provide a table with the detailed crack growth and critical flaw size at each step (e.g., installation, hydrotest, operation, etc.) for the initial crack sizes considered in the acceptance criteria. (AR)

6.1.2 *[Item 5.1.3]* All static and cyclic loads adopted in ECA shall be fully traceable with other design documents. It means that ECA report shall mention which document they come from, and the design documents shall mention which loading will be considered in ECA. (AR)

6.1.3 *[Item 5.1.4]* When it is expected that the pipeline or riser will have some parts submitted to more critical operational fatigue than the rest, a specific ECA should be carried out for these parts. For instance, important riser locations such as touchdown zone or top should be analyzed separately. Other specific project requirements may be applicable. (AR)

6.1.4 *[Item 5.2.3]* Regardless of maximum longitudinal stress, unstable fracture assessment (category III) and fracture toughness testing shall always be carried out for both installation (overbend and sagbend) and operational phase (EOL). Critical flaw sizes shall be reported. (AR)

6.2 FATIGUE CRACK GROWTH ANALYSIS

6.2.1 *[Item 5.3.1]* Fatigue crack growth analysis shall be based in fracture mechanics according to [A2]. Fatigue input loads for installation and operation phase of the ECA shall come from respective fatigue report documents issued according to contractual requirements and approved by Company. (AR)

6.2.2 *[Item 5.3.1]* All macro images from welding procedure qualification record shall be evaluated in the report to derive the most critical values of attachment length (L) to be considered in Mk and SCF calculation. (AR)

6.2.3 *[Item 5.3.2 and Table 5-2]* If FCGR is not specified in project documents for each environment, BS-7910 mean plus two standard deviation FCG curves for “marine environment with CP 1100mV” shall be used for external surface flaw and for “air” shall be used for embedded and internal surface flaw with $R \geq 0.5$. For installation fatigue, BS-7910 mean plus two standard deviation FCG curves for “air” may be used for external surface flaw. (AR)

6.2.4 *[Item 5.3.3]* Fatigue crack growth analysis shall consider a safety factor in life (number of cycles or blocks) not less than half the $DFF_{S\text{-}N}$ specified in Table 5-11 of section 5 of [A3], unless clearly specified in other project documents. (MR)

6.2.5 *[Item 5.3.4]* It is acceptable to define actual wall thickness based on measurements after manufacturing, but the mean value minus two standard deviations shall be considered. The minimum of at least eight measures around the circumference in each pipe end shall be taken for the statistics. (MR)

6.2.6 *[Item 5.3.5]* Fatigue crack growth analysis shall also consider low cycle loading (e.g., shut-in/shutdown). For operational scenarios where $\varepsilon_{l,nom}$ exceeds 0.4%, COMPANY shall be formally consulted. (AR)

6.2.7 *[Item 5.3]* A sensitivity analysis shall be included for the most critical flaws with $DFF_{ECA} = 1.5$ for installation, operation and decommissioning. The same fatigue histogram used for installation shall be used for decommissioning (AR)

7 CHANGES IN SECTION 6 OF DNV-RP-F108

7.1 FINITE ELEMENT FRACTURE MECHANICS ANALYSIS

7.1.1 *[Item 6.1.1]* The analysis shall be fully documented and reproducible by a 3rd party. A methodology statement shall be submitted for Company approval before analysis are performed. Reports shall include J integral path independency verification, mesh convergence studies and sensibility analysis for input data. All input files shall be provided with report for Company analysis. (AR)

7.1.2 *[Item 6.1.1]* When assessing maximum allowable flaw sizes, safety margin shall be demonstrated to ensure that target safety class requirements are satisfied. This can be achieved by structural reliability analysis or appropriate safety factors. (MR)

7.1.3 *[Item 6.1.2]* In order to demonstrate that CDF calculated by FEA is lower than BS-7910 solutions, a full circumferential flaw representing PoD/PoR at the threshold level shall be included in validation. (AR)

7.1.4 *[Item 6.2.1]* FE analysis simulating crack growth (e.g., Gurson-Tvergaard-Needleman formulation) are not permitted to assess ductile tearing and maximum allowable flaw sizes. Only solid 3D FE analyses with structured mesh are acceptable for fracture mechanics. A blunted notch shall be adopted for high plastic strain analysis ($\varepsilon_{l,nom}$>0.4%). Whenever HAZ softening is a concern, specific material stress-strain properties shall be defined for HAZ region in the finite element model. Use of other dedicated software is not permitted (e.g., LinkPipe, FlawPRO, etc.). (MR)

7.1.5 *[Item 6.2.3]* For ECA with internal over-pressure, the appropriate load history shall be considered. (AR)

8 CHANGES IN SECTION 7 OF DNV-RP-F108

8.1 TESTING REQUIREMENTS

8.1.1 *[item 7.3]* Temperatures for fracture toughness and tensile tests shall be according to table 7-2 of [A1]. Temperature for installation fracture toughness tests shall be not greater than minimum installation design temperature. Temperatures for “in service” assessment fracture toughness tests shall be according to table 7-2 of [A1] and $T_{ass,min}$ referred in this table shall be according to the specific project documents, considering also transient temperatures. The temperature that provides the more stringent fracture toughness results may be applied for all loading conditions, except when hydrogen charged specimens are required. (AR)

8.1.2 *[Item 7.4]* Fracture toughness properties shall be established from all relevant weld procedures, including repairs. Both weld metal and FL/HAZ microstructure shall tested. If different welding processes are used, fracture toughness testing shall sample each process which deposited thickness exceeds 20% of nominal wall thickness. If different thicknesses are qualified, the thickest one shall be considered for fracture toughness testing. It is not acceptable to estimate fracture toughness from Charpy V-notch test data. Other fracture toughness test methods and specimen geometries are not permitted. (AR)

8.1.3 *[Item 7.6]* If tearing initiation is not clear in SEM using ISO 12135 approach, the complete R-curve shall be used for all cycles in low cycle fatigue analysis. (MR)

8.1.4 *[Item 7.11]* The characteristic stress-strain curve shall not be solely based on SMYS and SMTS. Whenever there are not enough tests results to be used in conjunction with table 7-6 of [A1], a lower bound curve may be constructed using SMYS defined as Rt0.5 and the same strain hardening behavior observed in the tensile tests. (MR)

8.1.5 *[item 7.12]* If applicable, reeling strain cycles shall be established by CONTRACTOR regarding a “case by case” basis. ECA report data shall be according to the installation loads specified. In case of occurrence of any ramp angle modification able to cause the re-ingress of any pipe string into reel or aligner, an extra cycle shall be considered in the ECA. (AR)

8.1.6 *[item 7.13]* Specific FCGR and applicable requirements for material fracture toughness testing in sour environment for assessment category V will be provided in project specific documents. (MR)

9 CHANGES IN APPENDIX C OF DNV-RP-F108

9.1 ECA CATEGORY V

9.1.1 Appendix C of [A1] shall be disregarded. Specific FCGR and applicable requirements for material fracture toughness testing in sour environment for assessment category V will be provided in project specific documents. Whenever required, hydrogen charged fracture toughness specimens shall be prepared and tested according to APPENDIX B of this specification (MR).

10 CHANGES IN APPENDIX B OF DNV-ST-F101

10.1 FRACTURE TOUGHNESS TESTING

10.1.1 *[Item B.2.8]* For the use with [A2], fracture toughness testing results shall be reported in terms of J. Fracture toughness may be expressed in terms of CTOD when 3D FEA are used to derive CDF. In this case, fracture toughness derived from the double clip gauge arrangement according to [A5] shall be adjusted to consider potential non-conservativeness. Fracture toughness testing procedure shall be submitted for Company approval. (AR)

10.1.2 *[item B.2.8.2]* It is recommended to have three additional samples prepared for each position of HAZ to get at least three valid results for single value fracture toughness and at least six valid results for fracture toughness resistance curves. (AR)

10.1.3 *[item B.2.8.3]* In addition to the information required in [A5], [A6] and/or [A7], fracture toughness tests reports shall include: (AR)

a) Welding procedure specification number.
b) Test coupon identification.
c) All measured test data to calculate fracture toughness value.
d) Pictures of the post-test metallography validation.
e) Load versus CMOD graphs.
f) Characterization of single value fracture toughness parameter (J_u, J_m and J_c).
g) Pop-in assessment, if applicable.
h) J-R/CTOD-R curve fit, if required.

10.1.4 *[item B.2.8.8]* SENB specimens with reduced notch length according with Annex E of [A7] are not acceptable. (MR)

10.1.5 *[item B.2.8.14 and B.2.8.17]* SENT specimens shall be designed with surface notch (NQ) and rectangular section (B≥W), for both weld metal and FL/HAZ. SENB specimens shall be designed with through thickness notch (NP) and square section (B=W) for weld metal and with surface notch (NQ) and square sections (B=W) for the FL/HAZ. (MR)

APPENDIX A – REQUIREMENTS FOR ECA IN CLAD, LINED AND WELD OVERLAY PIPES

A.1. ECA of CRA girth weld and weld overlay in clad and lined materials shall not differ significantly from the premises outlined for carbon steel, but a more intensive use of Finite Element (FE) Fracture Mechanics Analyses is expected. The requirements described in the main body of this specification also applies to CRA and shall be complied with.

A.2. ECA of CRA girth weld and weld overlay in clad and lined materials shall also comply with requirements of [A1] and the latest revision of [A8]. Whenever there is a recommended approach in the guideline, it shall be considered mandatory unless a better approach is technically justified. Additional and modified requirement are given below.

A.2.1. Fracture mechanics approach shall be performed for all weld regions and any level of longitudinal strain in addition to SN approach for assessing the fatigue and fracture limit state of CRA girth welds and derive flaw acceptance criteria. The rupture of CRA layer and exposure of C-Mn parent material to the environment shall be considered as failure. This also includes flaws at triple point in lined pipes.

A.2.2. Whenever ECA is mandatory for weld overlay sections and the maximum pass height are higher than the critical full circumferential flaw, NDT requirement shall consist in 100% volumetric inspection to detect lack of fusion and other planar flaws. The NDT detection performance shall be documented to be adequate to reliably reject the smallest critical flaw sizes in the applicable acceptance criteria. For the CRA layer, the 85%|95% PoR shall be the applied method for detection performance evaluation.

A.2.3. Stress intensity factor solutions for triple point shall be validated by 3D FEA.

A.2.4. For testing of internal surface flaw according to Figure 7-2 of [A1], the crack tip constraint shall be evaluated. Machined SENT specimens with deep notch ($a/t \geq 0.5$) are preferred. The crack tip constraint of SENT specimen shall be higher than the pipeline. For triple point assessment, the testing procedure shall be submitted for Company approval.

A.2.5. For fracture toughness testing of weld overlay, two sets of specimens shall be sampled at fusion line. The specimens shall be NQ oriented, according to [A7], with one set with notch from CS and one set with notch from weld overlay.

APPENDIX B – HIDROGEN CHARGED FRACTURE TOUGHNESS TESTS

Whenever required, hydrogen charged fracture toughness specimens shall be prepared and tested with the additional requirements described in this appendix if no further guidance is provided.

B.1. After the fatigue pre-crack preparation, the crack tip shall be protected from the environment with a thin strip of tape, mastic, or other suitable material to avoid any corrosion crack tip blunting.

B.2. The bath pH, H2S and CO2 content to be used for fracture toughness hydrogen charging specimens will be provided in project specific documents depending on region of [A9]. Solution preparation, specimens pre-cleaning and storing shall be according to [A10] and [A11].

B.3. Total soak time shall be long enough to reach the steady state at 100 kPa. For C-Mn specimen with 25 mm wall thickness or less, at least a week is required to guarantee that maximum level of hydrogen charging is obtained when diffused from the outside surface to the crack tip.

B.4. The specimens shall be washed after been taken out of the bath and immediately chilled and stored within a recipient filled with liquid nitrogen to prevent hydrogen diffusion prior to testing. If the specimens are charged and tested in the same place, fracture toughness testing may be performed straight from the bath.

B.5. Test temperature shall be the same required for the operational case, as described in item 8.1.1, with a tolerance of 2ºC. Test shall begin as soon as test temperature is reached and stabilized.

B.6. Specimens shall be loaded at a very slow rate to allow the hydrogen to diffuse to the crack tip during the test. The strain rate shall be at least one order of magnitude lower than that normally used in fracture mechanics tests and limited to 0.008 mm/min or 0.1 Nmm-3/2/s, whichever is lower.