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V/HTR vessel materials testing programme -
Specification of Vessel materials PIE tests and progress

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Specification of Vessel materials PIE tests and progress

Abstract

The development of the Very High Temperature Reactor (VHTR) requires material data and an understanding of the material behaviour under reactor operating conditions and environment. Specific work on the development of Mod 9Cr 1 Mo steel as a Reactor Pressure Vessel (RPV) material is being carried out within RAPHAEL focusing on the invetsigation of effects of irradiation on material behaviour. In this report the test-matrix specification of Vessel materials PIE test programme and progress are summarised. It was also concluded that further investigations are required for creep- fatigue interactions and temper embrittlement and the specifications of these tests are also reported.

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V/HTR vessel materials testing programme in the frame of the RAPHEAL-IP

Deliverable D-ML1.1: Specification of Vessel materials PIE tests and progress

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This document provides an initial statement of the planned experiments on pre-irradiated specimens which will be reviewed and updated at the second Progress Meeting prior to implementation.

1 Introduction

The development of Advanced High Temperature Reactor (HTR) and very high temperature reactor concepts requires material data and an understanding of the material behaviour under reactor operating conditions and environment. For components important to the safety and feasibility of designs, such as the main steel structures (vessel, internal structures, turbine) and the graphite structures (core), investigation of the behaviour of the different materials in the reactor environment is a necessary requirement. In this work, in the frame of the Raphael project, mainly focuses on the Reactor Pressure Vessel (RPV) for the V/HTR.

The reactor pressure vessel in the high temperature reactor will be irradiated with neutrons, which cause damage within the material and will result in a change in mechanical behaviour of these materials. Depending on the operating conditions of the HTR and V/HTR, this irradiation takes place at temperatures between 120°C and 450°C, where 120°C is the lower temperature of the "cold-vessel" option, 375°C the lower temperature for the 'hot-vessel' option and 450°C the upper end of the temperature operating window of the hot-vessel. Where both options may be applicable for the HTR, the V/HTR may require the 'hot-vessel'.
In the 5th framework programme, the work on the RPV materials concentrated on the 'hot-vessel' option[1][3]. A mod. 9Cr 1Mo was selected for the irradiation programme. It was concluded that mainly the irradiation behaviour of the welded joints should be addressed. Therefore Framatome ANP produced a thick welded joint for a reference and irradiation-testing programme. The test matrix was optimised for the HTR "hot vessel" option and tailored to deliver complementary data to the RCC-MR and ASME design code. In the 5th framework programme the test-matrix comprised tensile tests, impact properties, fracture toughness and creep (at off-normal temperatures, i.e. 550°).
During the 5th framework HTR-M programme it was identified that for V/HTR, i.e. the hot vessel option, the operation temperature of the vessel (~450°C) might be close to the negligible creep temperature. Therefore a number of test specimens produced and irradiated in the 5th framework programme, were saved for testing in the Raphael project in order to determine the negligible creep temperature.
In this report the test-matrix specification of Vessel materials PIE test programme and progress are summarised. It was also concluded that further investigations are required for creep- fatigue interactions and temper embrittlement. The specifications of these tests are also reported.

2 Specification of the creep tests

2.1 specimen geometry and locations

Specimens for mechanical testing were selected from a welded joint produced by Framatome ANP. The weldment was produced by narrow gap TIG welding on modified 9% Chromium steel (P91). The plate is 150 mm thick and the weldment has a length of approximately 1 m. In order to study the mechanical behaviour of such a weldment the following assessment was made: The heat affected zone (HAZ) and the weld metal are identified as critical zones, i.e. those regions are most susceptible to crack initiation and growth.
Four material conditions have been selected for the creep testing: plate material, in parallel L and in perpendicular direction T with respect to the rolling direction, cross weld specimens XW to include the heat affected zone (HAZ) and the full weld metal WM. For each specimen type a detailed description on the orientation and the test conditions is given in [1]. The specimen geometry for reference testing and for post irradiation examination has been the same for all the specimen types to enhance the comparison between the EOL condition and reference condition, see figure 1.

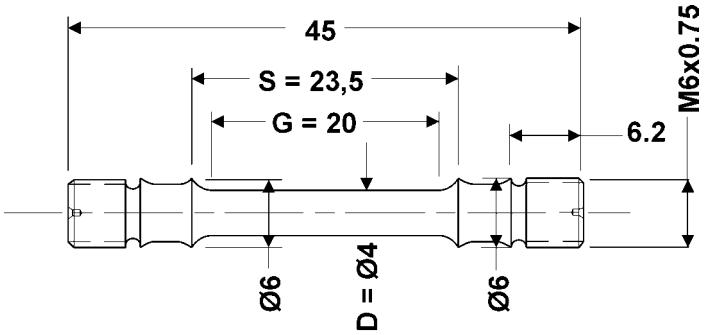

figure 1 Geometry of the tensile and creep test specimen (in mm)

2.2 creep test matrix

Next to the test-matrix for the 5th framework HTR-M programme, 16 additional specimens have been machined for reference creep testing and another 16 creep specimens have been irradiated in the LYRA-08 irradiation. The original full test-matrix is summarised in table 1. In order to determine the negligible creep temperature, which is close to the maximum operating temperature of the pressure vessel, the creep specimens will be performed at 450°C. The target rupture times are 1khrs, 2 khrs, 5 khrs and 10 khrs, i.e. for each material condition and target time one specimen will be used, see figure 2. Since four creep machines will be used in parallel, the four material conditions L, T, XW and WM will run in parallel starting with a target of 2000 hrs. The list of specimen numbers and initial target rupture times are presented in appendix A. The reference testing will be carried out by JRC.IE while the irradiated specimens will be tested by NRG in the HotCell facilities. A similar procedure as described in [4] will be used to determine the stress levels.

table 1 HTR-m test matrix for reference and irradiation testing

Specimen type	#	condition s	Temp.	**sub-total**	6th FP	irr/ref	**total**
Small size Charpy (KLST)	15	4		**85**		irr & ref	**170***[1]
Tensile	2	4	4	**32**		irr & ref	**64**
Creep	4	4	1	**16**	16*[2]	irr & ref	**32 (32*[2])**
Fracture toughness (CT10)	5	4	2	**20**		irr & ref	**40***[3]
full-size Charpy	11	3		**25**	25	irr & ref	**50***[4]

*1 15 Specimens in each plate direction L-T and T-L, 15 specimens in the weld metal, 40 specimens in the Heat Affected Zone (HAZ).

* 2 16 specimens have been irradiated for the 6th framework RAPHAEL IP programme, also 16 additional creep specimens for reference testing in RAPHAEL IP.

*3 four additional CT specimens of commercial T91 have been irradiated for comparison

*4 25 additional full-size Charpy specimens have been included in the irradiation rig (for 6th FP bending or impact testing in Eastern Europe through JRC.IE) and 25 specimens for reference testing, hence 12 specimens of base material in T-L orientation, 11 specimens with the notch in the weld metal and 2 specimens with the notch in the HAZ for both irradiation and reference testing

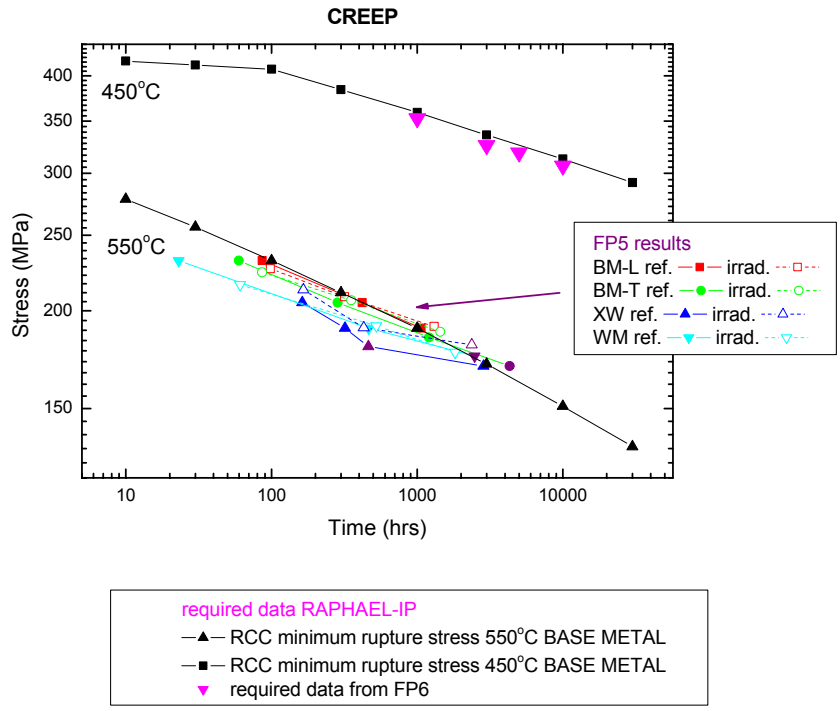

figure 2 Target creep rupture times at 450°C for reference and irradiated mod. 9Cr steel

2.3 Irradiation condition of the specimens

The irradiation programme was carried out in the frame of the HTR-M programme. The LYRA irradiation was performed in the Pool Side Facility (PSF) i.e. outside the reactor core of the High Flux Reactor, Petten. The average temperature in the entire capsule during irradiation was 370°C with a standard deviation of 13°C. The distribution of the thermocouples is shown in figure 3. The maximum temperature observed was 389°C. The average fluence of the HTR-m specimens is 9.44·1022 m-2 (with E>0.1MeV) and for E>1.0MeV the average fluence is 3.85·1022 m-2, which gives a dose level for mod. 9Cr steel of 5.84 mdpa. Actual specimen fluences corrected for flux buckling and self-shielding will be reported with the experimental results.

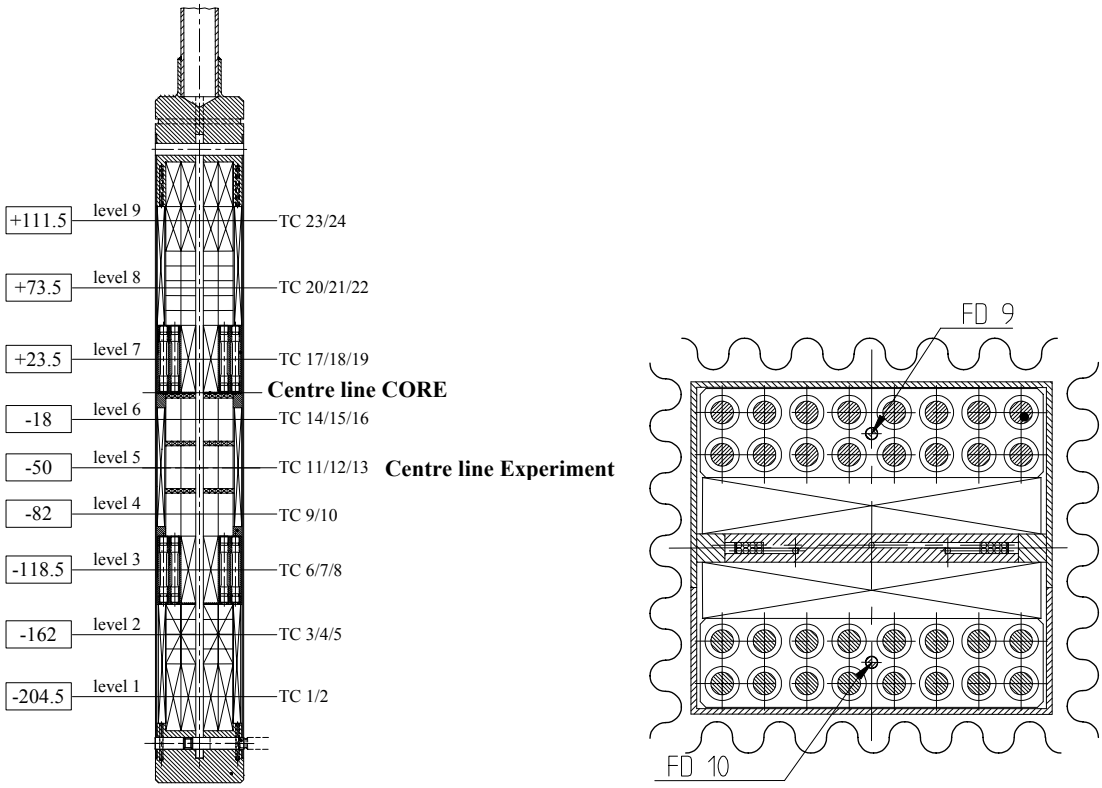

figure 3 Vertical distribution of the thermocouples with respect to the centreline of the HFR core and typical cross-section of the irradiation capsule

2.4 Planning and progress report

The planning for the testing covering the definition of the test matrix for the vesel creep experiments have been reviewed. The indicated duration of the creep test programme may change if the response of the mod. 9Cr under creep loading is faster or slower than expected compared to the ASME and RCC-MR curve, especially for the long-term creep tests, i.e. 10khrs.

3 Concluding Remarks

The activities in RAPHAEL IP are performed with financial support from the European Commission and the Netherlands Ministry of Economic Affairs. They are being considered within the EU contribution to the Generation-4 International Forum.

This document provides an initial statement of the planned experiments on pre-irradiated vessel Mod 9Cr 1 Mo steel welded specimens which will be reviewed and updated at the second Progress Meeting prior to implementation.

Literature

[1] J.B.J. Hegeman, J.H. Rantala, *HTR Vessel Materials, Specification of the sample selection, irradiation and PIE of mod. 9Cr steel*, NRG report 20585/03.52037/P, January 2003, HTR-M-03/02-D-1.4.63

[2] J.B.J. Hegeman, *Loading report LYRA-08 (304-08)*, *irradiation in the frame of HTR-m*, NRG Report 20585/03.56740/P, December 2003

[3] RPV results

[4] R.D.W. Bestwick, *Proposed creep rupture test conditions for the HTR-M irradiation experiment on a modified 9Cr-1Mo steel weld*, HTR-M 03/08-D-1 4 78, August 2003

[5] ECCC Recommendations 1999, Creep Data Validation and Assessment Procedures, European Creep Collaborative Committee (ECCC) 1999

appendix A

table 2 Specimen numbers for creep testing

	Direction L		Direction T	
rupture time	reference	Irradiated	reference	Irradiated
2000	L194	L224	L231	L188
1000	L407	L230	L189	L195
5000	L287	L286	L270	L271
10000	L292	L293	L277	L276

	Direction WM		Direction XW	
rupture time	reference	Irradiated	reference	Irradiated
2000	L168	L224	L254	L188
1000	L172	L230	L179	L195
5000	L236	L286	L258	L271
10000	L243	L293	L261	L276