THERMAL ANNEALING OF WWER-440 NUCLEAR REACTOR PRESSURE VESSEL INTERNALS: PRESENT STATUS

Ondřej BURŠÍK [1], Barbora MAREŠOVÁ [1], Petra PETELOVÁ [1], Radim KOPŘIVA [1], Pavel PEŠEK [1]

[1]ÚJV Řež, a. s., Husinec - Řež, Czech Republic, EU
ondrej.bursik@ujv.cz

Abstract

Reactor pressure vessel (RPV) of light water reactor and its internals are the most important components of any nuclear power plant. RPV and its internals are exposed to high temperatures, pressures and intensive neutron flux during the operation. These conditions lead up to material degradation - especially radiation hardening and embrittlement.

Paper presents the annealing treatment as one of the possible solutions to provide and re-establish sufficient mechanical properties of RPV internals during the operation. The first part of the poster is dedicated to the description of equipment which is used for the annealing of unirradiated and irradiated materials at the UJV Rez hot cell facility. Following part shows selection of unirradiated material for definition of original mechanical properties. Next part is an overview of selected annealing regimes. The main section is focused on definition of mechanical properties (especially hardness) of original and annealed material of WWER 440 type reactor internals as well as on methods and analyses employed to study of mechanical properties changes.

The final part discusses the next planned steps in the solution of the research project TH02020565: "Assurance of Safe and Long Term Operation of Nuclear Reactor Pressure Vessel Internals" which is realized in the period from 2016 to 2020 with the support of Technology Agency of the Czech Republic.

Keywords: Austenitic stainless steel, reactor pressure vessel internals, annealing

1. INTRODUCTION

One of the possible solutions how to extend service life of Reactor Pressure Vessel (RPV) is its thermal annealing, which became a verified technology and its application in nuclear industry was prompted mainly due to an inability of RPV exchange [1]. A similar process, which would be focused on reactor internals, has not been realized yet. The internal parts are exposed to severe conditions during operation including high neutron flux and aggressive chemical environment of the coolant [2]. UJV Rez, a. s. is realizing a research program between years 2017 and 2020. The aim of this research is design, development and certification of a standard procedure for restoring the initial properties of WWER 440-type reactor internals by the thermal annealing method. Successful solution of this problem will contribute to long-term operational life of NPPs and could eventually lower radioactive waste production.

2. PROJECT OVERVIEW

Main task is to design several annealing regimes and proof their application to unirradiated materials (**Figure 1**). Evaluation of mechanical properties of unirradiated specimens before and after annealing treatment (hardness testing especially) is necessary. After that, a selection of one annealing regime and its application to irradiated material will be possible. In the next part, mechanical properties evaluation of irradiated specimens after annealing treatment - hardness testing, static fracture toughness (miniaturized compact test specimens), corrosion-mechanical testing (small strain rate testing) will follow. Thermal annealing process certification for RPV internals will be the final task in this experimental project.

3. MATERIAL

Irradiated material used in this research program has its origin in Greifswald nuclear power plant (WWER-440) which had been closed after 15 years of service. Blocks of materials are cut from Greifswald I RPV internals. Internals are made from corrosion resistant titanium stabilized austenitic steel 08Ch18N10T. Chemical composition is shown in **Table 1** below. Further, these blocks (**Figure 2**) will be cut into specimens for testing of mechanical properties and susceptibility to stress corrosion cracking after thermal annealing.

Table 1 Chemical composition of the 08Ch18N10T steel (atomic %) [3]

Material	C	Mn	S	P	Ni	Cr	Ti
08Ch18N10T	≤ 0.08	1.0 2.0	≤ 0.02	≤ 0.035	9.0 - 11.0	17.0 - 19.0	≥5C; ≤0.6

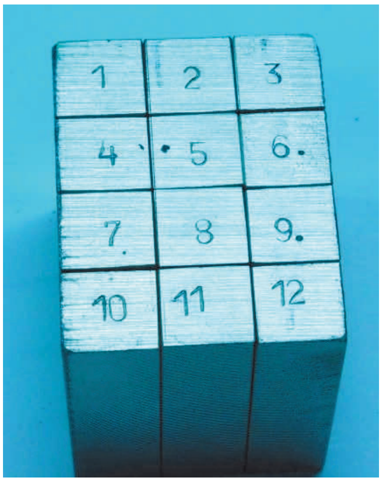

Figure 1 Unirradiated block of 08Ch18N10T material -picture after fabrication of 12 samples

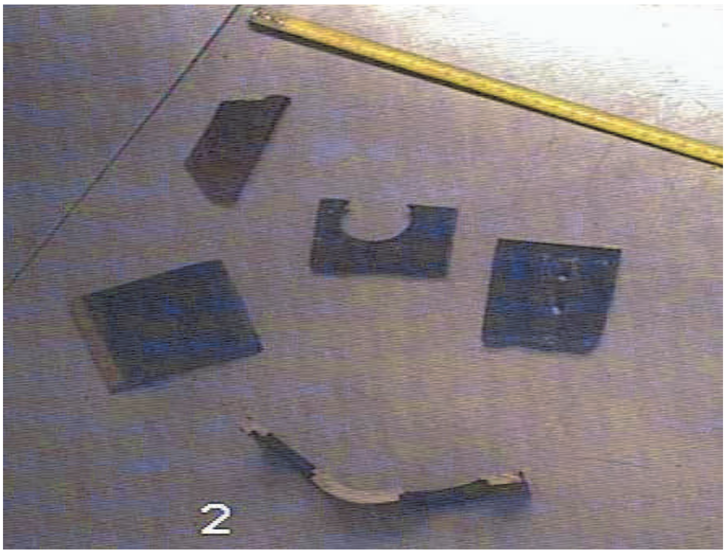

Figure 2 Irradiated samples from Greifswald WWER 440 NPP

4. SPECIMEN PREPARATION

Mechanical clamping device for precise manufacturing of miniaturized test specimens from irradiated material was developed, see (**Figure 3**). Positional clamping device enables precise remote-controlled manufacturing of irradiated miniaturized compact test pieces with dimensions 10 x 10 x 4 mm. These specimens will be used for fracture toughness testing of irradiated and annealed material.

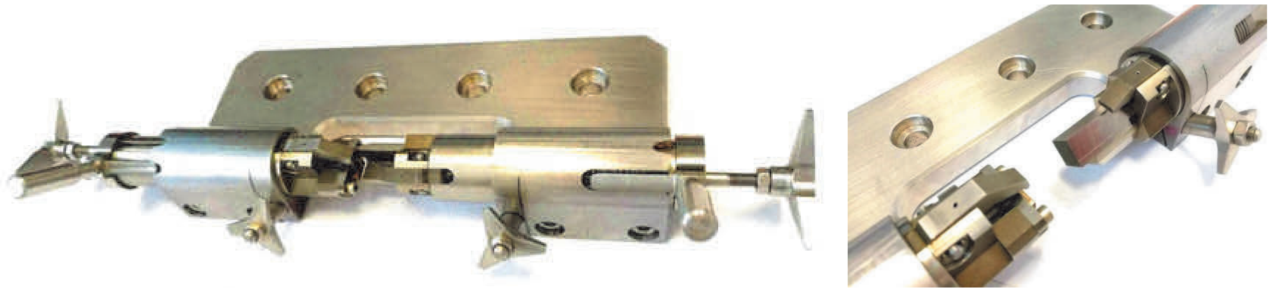

Figure 3 Holding device for miniaturized compact test samples fabrication (detail on the right side)

5. ANNEALING DEVICE

Laboratory of Mechanical Testing Department is equipped with furnace (**Figure 4**), which is used for annealing of metallic materials in protective atmosphere at high temperatures. Temperature is controlled with three independent thermocouples and regulated by temperature regulator Clare 4.0. The moving mechanisms are driven by compressed air. Outer surfaces are cooled by water as a coolant with forced circulation and water-air passive heat exchanger. Annealing experiments are controlled by PC which is also used for data recording. Before the annealing process starts, the furnace inner environment is cleaned using a vacuum pump and a repetitive flushing of the furnace chamber and the sample with an inert gas. Annealing experiments could be controlled using integrated GSM module.

Figure 4 Annealing furnace

6. ANNEALING REGIMES

For unirradiated specimens, several annealing regimes were selected - temperatures: 550, 600, 700, 800 and 900 °C as could be seen in **Figure 5**. Other parameters of process will be following: heating rate (10 °C / min), holding time (6 hours), cooling (inside the furnace to room temp.), experiment duration (approx. 24 hours), environment (air or argon, 2 litres per minute flow), specimen load (either one or several pieces),the end of experiment (50 °C or lower temperature).

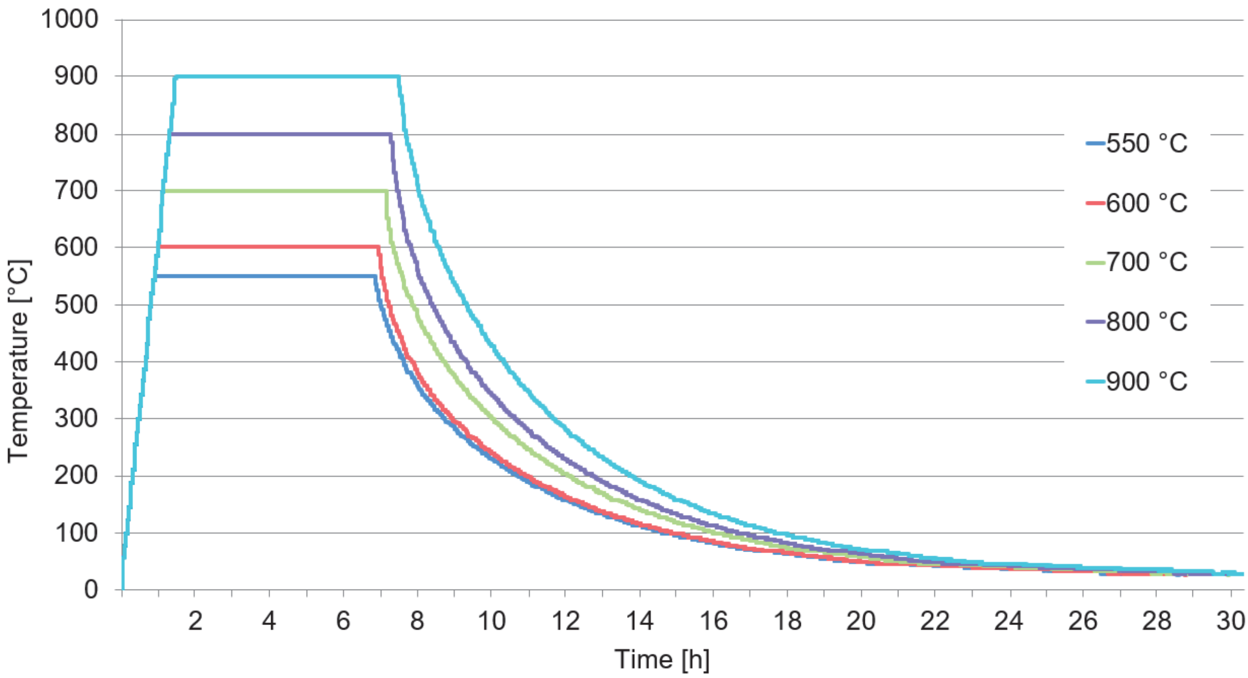

Figure 5 An overview of 5 selected annealing regimes

7. NEXT STEPS

First goal is to measure initial hardness of unirradiated 08Ch18N10T sample without any mechanical or heat treatment. Annealing treatment will be applied on 5 specimens - one for each temperature level. Hardness will be measured after annealing treatment as well. Another six specimens will be first subjected to work hardening before annealing treatment. Original thickness of 6 block specimens - 12 x 12 x 60 mm will be reduced by 10 % (one half of specimens) or 20 % (second half of specimens). Six work-hardened specimens will be annealed according to 3 preselected regimes and hardness measurement will follow. After these experiments further tests will be performed with changed time duration of thermal annealing procedure.

8. CONCLUSIONS AND DISCUSSION

Annealing of unirradiated specimens and following mechanical testing will lead up to selection of one annealing regime and its application to irradiated specimens. The final mechanical and corrosion-mechanical testing of irradiated specimens will help to confirm the proper annealing regime for WWER-440 internals material. Following certification of the thermal annealing methodology of the internal components of RPV is one step in possible restoration of the mechanical properties of the highly irradiated materials. That will contribute to the long-term and safe operation of NPPs. Certification of the methodology will allow introduce this methodology into industrial practice.

ACKNOWLEDGEMENTS

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