MECHANICAL TESTING OF IRRADIATED MATERIALS IN HOT CELLS IN ŘEŽ

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Abstract

Development and maintenance of materials for nuclear power plants and aerospace usage is an important area of the materials science. It includes the study of various aspects of materials damage as well as an improvement and development of new observation and testing techniques. New research facility for materials study in Rez allows perform mechanical testing and microstructural analysis using novel techniques specially developed for irradiated materials. New hot cells complex allows to operate with irradiated samples up to 300 TBq of 60Co. In this work, the instrumentation part and the operation procedure are described.

Keywords: Hot cells, mechanical testing, irradiated materials, radiation damage

1. INTRODUCTION

Maintenance and operation of nuclear power plants require a complex study of materials properties under a variety of conditions, such as radiation, mechanical, thermal and environmental treatment. In most of the cases those factors, resp. their combinations crucially affect the microstructure and thus, mechanical properties of the NPP's structural materials. Steels are widely used as a material for the NPP's components [1], [2]. During the operation, they are exposed to the high level of radiation, which leads to the progressive degradation of the structure. This process has been studied for a couple of decades and brings an important knowledge for the prolongation of the lifetime of the NPP's worldwide and development of new stable resistant materials []. Neutrons and gamma radiation can cause embrittlement in several materials [3] and hardening in steels and pure tungsten [4], [5]. Irradiation Assisted Stress Corrosion Cracking (IASCC) is a subject for a number of investigations since small intergranular cracks formed on the surface of reactor vessel internals due to the corrosion can result in the drastic damage of the component and limitation of the NPP's operation. It means that the materials should maintain the resistance to IASCC crack initiation and growth after neutron irradiation over a certain threshold dose, which is about 2-3 dpa in light water reactors Li-based (PWR) and KOH-based coolants (VVER) [6]. Thus, the development of techniques for investigation and in-situ monitoring of the internal parts of the nuclear reactor is required. There is a limited amount of facilities for the irradiated materials studies in the world. So-called "hot cells" facilities available in several countries enable a complex scientific overview on the mechanical properties and microstructure of irradiated samples and their comparison with non-irradiated materials. One of the newest hot cells complex was recently built in Czech Republic, near Prague, and consists of 8 gamma- and 2 alpha hot cells equipped with instrumentation for metallic samples preparation, various mechanical testing and microstructural observations. This paper describes the mechanical testing solutions for irradiated materials studies inside the hot cells.

2. INSTRUMENTATION

CVR hot cells facility is located in Czech Republic and contains "dry pool" for samples reception, ten hot cells with the maximum allowed activity of 300 TBq of ^{60}Co for samples preparation and mechanical testing and one "semi-hot" cell for microstructural studies and nanoindentation with a maximum activity of 250 GBq.

Transportation of radioactive samples between the cells is ensured by a special crane machine moving above the ceiling shielding. The material is transported in the container of a sufficient shielding for highly irradiated samples. Loading of the material into the hot cell is done through the hole in the upper part of each cell.

2.1. Dry pool and reception hot cell

Irradiated materials transported in a special shielded transportation cask (e.g. B(U) - type) are first received in a dry pool, where the cask is opened and the samples are transferred to the reception hot cell. There, each sample is labeled and registered into the internal datasheet with a unique number.

2.2. Samples preparation

CVR hot cells are designed for a production of a wide spectrum of specimen's types for mechanical testing and microstructural investigation using devices for cutting, machining, welding, grinding and polishing described below.

2.2.1. EDM

Automated electrical discharge machine (EDM) Eir-EMO 2cv (**Figure 1**) located inside a hot cell will be used for cutting and machining of testing specimens without heat treatment of the initial microstructure. It enables a 3D movement range of the sample table in x, y, z with the maximum values of X: 30 cm, Y: 39 cm, Z: 12 cm. Maximal workpiece weight corresponds to 5 kg.

Figure 1 EDM machine inside the CVR hot cells for cutting and machining of irradiated samples (left) and the distanced operation of the machine (right)

2.2.2. Machining and grinding

The combined Mikronex computer numerical control (CNC) machining center with four controlled axes equipped by lathe machine for round samples production is used e.g. for tensile samples preparation of various sizes (**Figure 2**, on the left). CNC grinding machine for surface grinding, which includes cycles for all conventional methods of surface grinding is also located inside the same hot cell. Round-shaped specimens, TPB, μTPB, CT, 0.5 CT, RCT, flat samples machining and a surface grinding, after e.g. the EDM machining, can be performed using these Mikronex CNC devices.

Figure 2 Mikronex CNC machining center inside the CVR hot cell

2.2.3. Metallographic preparation

Standard cutting, grinding and polishing of the samples for SEM analysis are performed in the metallographic hot cell equipped with Struers devices specially designed for irradiated materials (**Figure 3**). Thus, all the devices are shielded by steel and are simplified for the easy access and operation. Metallographic cutting saw is used for cutting samples with a diameter up to 70 mm or of maximum 165 x 50 mm size. Hot cell is also equipped with an ultrasonic cleaner for cleaning the specimens after each grinding/polishing step. It is possible to prepare Ø40 mm metallographic specimen.

Figure 3 Metallographic hot cell prepared for operation with active samples

2.2.4. Dimension measurements

Final specimen's dimensions will be quantified using Vertex 251 HM optical measuring device inside the hot cell (**Figure 4**). It is an automatic CNC controlled multisensor 3D measuring device equipped with CCD chip camera for determining the dimensions of test samples using video sensor and probe. The accuracy at maximum measuring range is at least 10 μm. The machine is also equipped with insulation against vibrations.

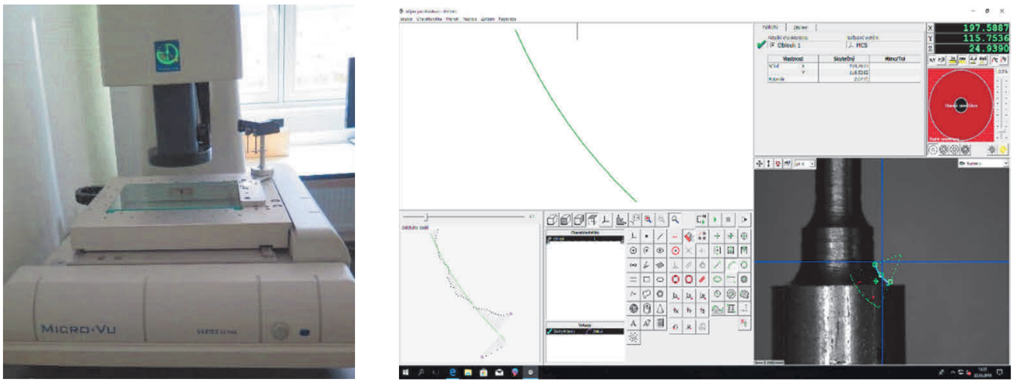

Figure 4 Vertex 251 HM optical precise measurement device

2.3. Autoclave system

Electrohydraulic autoclave system with a water loop, model AZS 01 - SUSEN, n. 2310 / 01 (**Figures 1- 3**) is used for the stress corrosion cracking testing. The autoclave body is located inside the hot cell and the water loop is in the operation room under the hot cell. System allows mechanical testing of test specimens to a maximum operating temperature of 350 °C and pressure of 16.6 MPa. The temperature measurement is performed by calibrated high-temperature sensors located inside the autoclave pressure vessel. The internal load build-up of the autoclave assures the unilateral or cyclic axial tensile loading of the specimen. Tensile stress control is performed using a hydraulic cylinder. The heating system of the autoclave consists of preheating furnace and primary heating circuit. The heating rate of the furnace cannot exceed 1 °C / min to exclude the possibility of an overheating. The total heating time of the system up to 350 °C can achieve 12 h. **Figure 5** shows the autoclave for active testing in the CVR hot cells.

Figure 5 Images of the autoclave body with a tightening system (left) and a water loop (right)

2.4. Tensile, Fatigue and Creep testing

Two servo-hydraulic testing machines allow perform tensile, compression and torsion experiments at a wide temperature range with various shapes of specimens. Universal servo-hydraulic testing machine INSTRON 8802 enables testing with a maximum load of 250 kN, e.g. tensile, compression and fatigue tests of round or quadrangular cross-sections samples with the possibility of testing in the temperature range from -193 °C (liquid nitrogen) up to 800 °C (air) or 1200 °C (argon). It is possible to perform low cycle fatigue test with controlled force (soft loading) or with controlled deformation (hard loading). Moreover, fracture toughness testing, i.e. measuring a crack propagation rate depending on the amplitude of the stress intensity factor for compact tension (CT) specimen can be done. Combined loading (tensile-compression, torsion) with the possibility of testing in the temperature range from -193 to at least 800 °C (air) is performed on a INSTRON 8874 servo-hydraulic machine with a maximum load capacity of 25 kN.

Electromagnetic resonance testing machine Zwick with the axial dynamic load strength of at least ± 25 kN, with the power capacity of at least ± 50 kN (± 10 %) and the maximum stroke amplitude of at least 2 mm and 250 Hz. It allows perform fatigue tests in a high cycle fatigue mode and creating a crack on a standard CT and three-point bending (TPB) specimens at the temperature range from RT to 600 °C.

Electromechanical creep testing machine with a 50 kN load, equipped with high-temperature air furnace, system for measuring the deformation of samples and recording measured data is located in the separated hot cell. Two extensometers (video and laser) are available for precise in-situ deformation determination. The creep facility includes clamping adapters for a number of test specimens, accessories and can be used for testing up to 800 °C using software for controlling basic tests and evaluation. The equipment allows to perform tensile and bending creep tests to fracture according to ASTM E139, E292, crack growth in creep according to E1457 - 13, tensile and bending creep tests with a cyclic loading, release stress test at constant deformation

2.5. SEM

After metallographic preparation of active samples is done the specimen is transferred to the semi-hot cell for SEM analysis. The microstructural characterization of the material can be performed using field emission gun (FEG) scanning electron microscope (SEM) TESCAN MIRA3 equipped with SE (secondary electrons), BSE (back scattered electrons) including in-lens detectors, in-beam SE, EDX (energy-dispersive X-ray) and WDX (Wavelength-dispersive X-ray) detectors. The overview of SEM facility in the CVR hot cells is shown in **Figure 6**. FEG enables accelerating voltage in a range of 0.05 - 30 kV, resolution better than 1.2 nm. WDX and EDX detector components are used for chemical microanalysis. Using MIRA3 SEM it is also possible to display electrons absorbed by the material in electron-beam-induced current (EBIC) mode. The system is also equipped with plasma decontaminator and detectors shielding for operation with irradiated samples. All detectors are protected against radiation by special steel shielding as is shown in **Figure 6**, on the right.

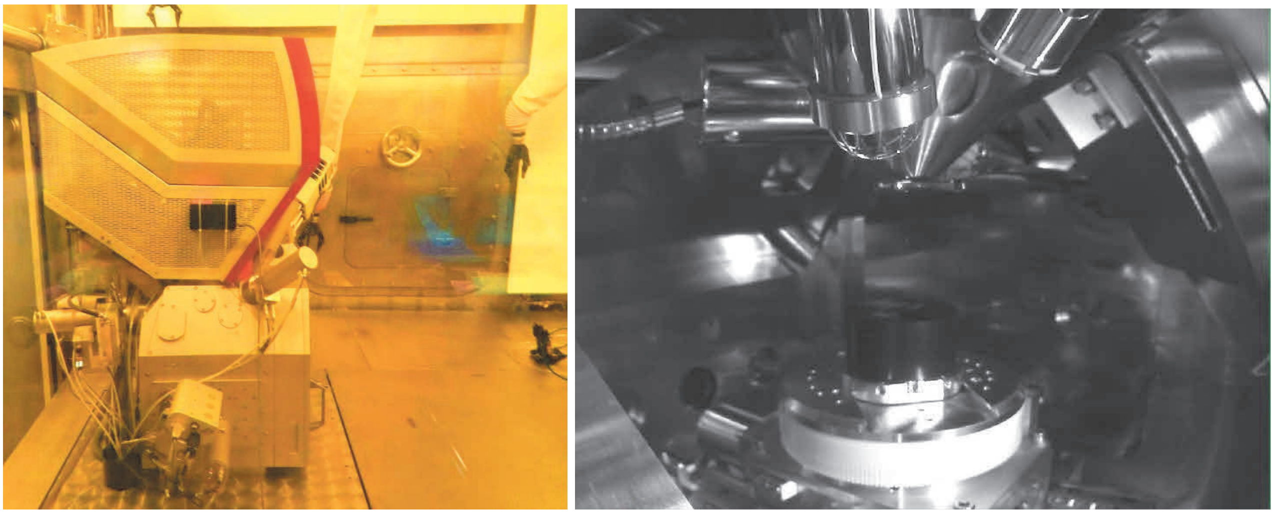

Figure 6 The overview of TESCAN MIRA3 FEG-SEM inside the CVR semi-hot cell (left) and operational room (right)

3. CONCLUSION

This paper describes the operation of the CVR hot cells facility. Active testing starts from the receiving of irradiated material in the transportation cask following by registration and labeling of pre-machined samples and manufacturing of the specimens from the irradiated semi-finished products. Several devices for cutting, machining, grinding, polishing and metallographic preparation are used to produce the irradiated specimens for mechanical testing and microstructural characterization in the CVR. Thus, the full range of testing can be performed for the research and industrial purposes to fulfill the aims of development of new advanced materials for primary and secondary circuit components of Gen III and IV nuclear power plants usage and to prolong the lifetime of the existing power plants.

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