1.2.24. ELECTROMAGNETIC EVALUATION OF THE CONCENTRATION OF HYDROGEN DIFFUSED IN ZIRCONIUM ALLOY USED IN PHWR

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Pressurized Heavy Water Reactors (PHWR) contains a horizontal cylindrical vessel, named Calandria vessel, filled with D_2O used as neutrons moderator. The normal temperature of the moderator is 70°C. The ends of the vessel have holes in which fuel channels are inserted. One fuel channel is made from two concentrically tubes:

– internal tube named pressure tube is made from Zr 2.5% Nb with 6.3 m length, 105 mm inner diameter and 4.15 mm wall thickness;
– external tube named calandria tube is made from Zircalloy 2.

Inside of the pressure tube the fuel bundle are inserted and between them D_2O circulates as coolant fluid with the maximum temperature of 270°C. The concentricity of the tubes is assured by 4 garter springs.

Two mechanisms of deuterium (hydrogen) apparition are possible:

– radiolysis of heavy water: $2D_2O \rightarrow 2D_2 + O_2$;
– corrosion of Zr 2.5 % Nb alloy: $D_2O \rightarrow Zr \rightarrow ZrO + D_2$ deuterium appeared may diffuse in the pressure tube's wall from the "hot" intemal surface (270°C) and the "cold" (~100°C) external surface.

If the deuterium concentration exceeds a certain threshold, the deuterium chemical combines with Zr: $Zr + D_2 \rightarrow ZrD_2$, resulting zirconium hydrides.

For determination of $D_2(H_2)$ content for Zr 2.5% Nb alloy, an electromagnetic method has been proposed. This method determines the conductivity of Zr alloys with different quantities of absorbed hydrogen, the correlation between the electrical conductivity and hydrogen concentration being experimentally established.

For a circular coil with rectangular cross section, closed form solution for the impedances are given in [1]. The ohmic resistance of the coil will be neglected.

If Z_{air} is the reactance of the coil in air and Z is the reactance of the same coil placed at height h over an amagnetic conductive plate with H thickness and having local conductivity $\sigma(x_0, y)$

$$\delta Z(k) = (\sigma - \sigma_0) \frac{\partial \theta(x_0, y_0, k)}{\partial \sigma}\bigg|_{\sigma=\sigma_0}, \tag{1}$$

where $\delta Z(k)$ the Fourier transform of the variation of the impedance.

$$\theta(x_0, y_0, k) = \frac{\left(\gamma^2(x_0, y_0) - k^2\right)\left(1 - e^{-2\gamma(x_0, y_0)H}\right)}{\left(\gamma^2(x_0, y_0) + k^2\right)\left(1 - e^{-2\gamma(x_0, y_0)H}\right) - 2k\gamma\left((x_0, y_0)\right)\left(1 + e^{2\gamma(x_0, y_0)H}\right)}. \tag{2}$$

Take inverse Fourier transform of (1), we can write

$$\delta z = U\delta\sigma. \tag{3}$$

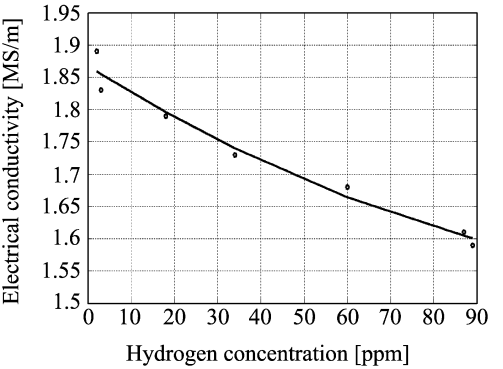

Fig. 1. The electrical conductivity v.s. hydrogen concentration

By inversion of (3) we can determine the local modification of the electric conductivity of material. 10 coupons from pressure tubes with $28 \times 28 \times 4.18$ mm^3 have been taken into study with hydrogen content between 2 and 89 ppm. In fig. 1 is presented the electrical conductivity of samples in function of hydrogen content.

When $\sigma \leq 1.68$ Ms/m, the development of the Zr hydrides oriented after a circumferential direction of pressure tube wall is possible.

When $\sigma \leq 1.61$ Ms/m, the Zr hydride start to change orientation after radial direction. In this situation blisters and hydrogen cracking is possible to appear.

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Reference:

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