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Hydride formation and effects of hydrogen on the mechanical properties of Zirconium-rich alloys

K. R. F. Silva(1)*, V. Meyer(1), D. S. Dos Santos(1), L. H. Almeida(1)

1PEMM-COPPE/UFRJ, P.O. Box 68505, 21941-972 Rio de Janeiro, RJ, Brazil

email: karla@metalmat.ufrj.br

* Corresponding author.

Abstract – Three zirconium-rich alloys used in the nuclear industry were hydrided and studied by means of optical microscopy, scanning electron microscopy and thermal desorption spectrometry. The hydriding performed led to the reduction of ductility of the tubes and hydrides were formed in all the alloys. The morphology and orientation of the hydrides were found to have a strong effect on their mechanical properties. Furthermore, the binding energy of hydrogen was calculated for some alloys.

Rich-Zirconium alloys, or more frequently called Zircaloys, are used in nuclear technology as cladding materials due to their high corrosion resistance, low neutron absorption and good mechanical properties at high temperatures.

Zircaloys absorb hydrogen through various sources during service, such as moisture present in pellets. However, the main source of hydrogen is related to the reaction of zirconium with the coolant water.

During service, these alloys are submitted to high pressure (160 atm) and high temperature (600K). In these conditions, the tubes may suffer corrosion such as: $Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$, and the resulting hydrogen may diffuse through the oxide layer and may be absorbed by the alloy.

The operational performance of Zircaloy tubes is largely restricted by problems associated with hydrogen absorption because of the formation of brittle zirconium hydrides. Not only the hydride concentration is important to evaluate the loss of ductility but also its morphology and orientation. The detrimental effects of hydrides in causing premature fracture of in service tubes have been documented [1].

The aim of this work is to study the hydrogen effects on the microstructure and mechanical properties of three zirconium-rich alloys used in the nuclear industry: Zr-1Nb, Zr–1Nb–1Sn–0.1Fe and Duplex.

The tubes were hydrided for different periods and then submitted to tensile tests. The hydride observation near the fracture zone allowed us to evaluate the effect of its morphology and orientation on the fracture mode and a fractographic investigation was also conducted. For the Thermal Desorption Spectrometry (TDS) some samples were taken from cold rolled sheets of the tubes, and then recrystallized and hydrided. The hydrided samples were submitted to a desorption test in order to find out the binding energy of hydrogen in each microstructure and the values obtained were compared.

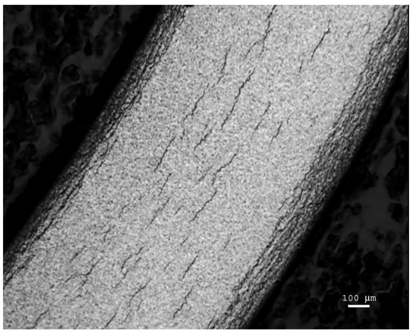

Figure 1: Optical micrograph showing a compact layer of hydride in the surface of the Zr–1Nb–1Sn–0.1Fe alloy.

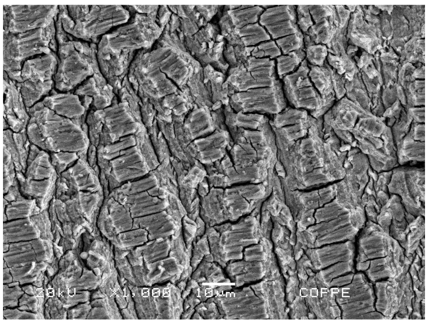

Figure 2: Fractographic investigation of the Zr–1Nb–1Sn–0.1Fe alloy hydrided for 96h.

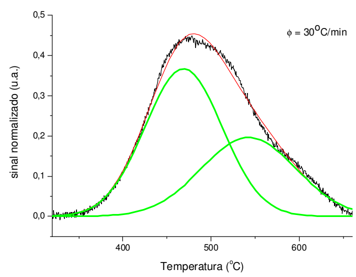

Figure 3: Hydrogen desorption spectra for Zr-1Nb alloy with a 30°C/min heating rate

References

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