INVESTIGATION OF DELAYED HYDRIDE CRACKING IN THE Zr-2,5% Nb ALLOY

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Introduction

Zirconium alloys are used as a constructional material for manufacturing of cladding of fuel assemblies and fuel channels of RBMK, as well as CANDU type reactors [1]. Zirconium alloy (Zr+2,5% Nb) absorbs hydrogen during operation as a consequence of the corrosion reaction with water. Hydrogen has very limited solubility in zirconium alloys; when the thermal solid solubility (TSS) [2] is exceeded in a component such as pressure tube that is highly stressed for long periods of time, delayed hydride cracking (DHC) failures may occur. DHC is a phenomenon where a crack can propagate in stepwise fashion as a result of hydrogen redistribution ahead of the crack tip under a stress level below the yield stress. If stress levels are sufficiently high the local hydrogen concentration can exceed the TSS, and the hydride platelets precipitate in the primary cracking direction. When a platelet reaches a critical length, it cannot support the local stress and it ruptures. The crack advances this distance and it arrests in the fracture resistant zirconium matrix. Repetition of this process causes continued cracking. This incremental growth of the crack forms a striation on the fracture surface. There is an incubation period between each crack growth increment while a new hydride zone is formed at the crack tip [3]. DHC has been recognized as the potential cause of failure of pressure tubes in both CANDU [4] and RBMK reactors [5].

Results and discussions

Sections of the pressure tube were hydrided to produce required hydrogen concentration using an electrolytic method and diffusion annealing treatment. Hydrogen homogeneity was controlled by metallographic examination. Metallography of hydride structure on radial-axial and radial-transverse sections shows a uniform hydride distribution with hydrides elongated in the longitudinal direction (Fig. 1). From the hydrided pressure tube material curved compact toughness (CTT) specimens were machined. Except for the thickness and the curvature of the tube, the in-plane dimensions of specimens were in proportion described for compact specimen in ASTM standard test method (E-399).

The CCT specimens have been fatigue pre-cracked at room temperature to produce an initial crack length about 1.7 mm. Then specimen has been loaded to give K_I values at range of 14 MPa·m^{½} to15 MPa·m^{½}. Test ended after estimated crack length has reached about 1.5 mm

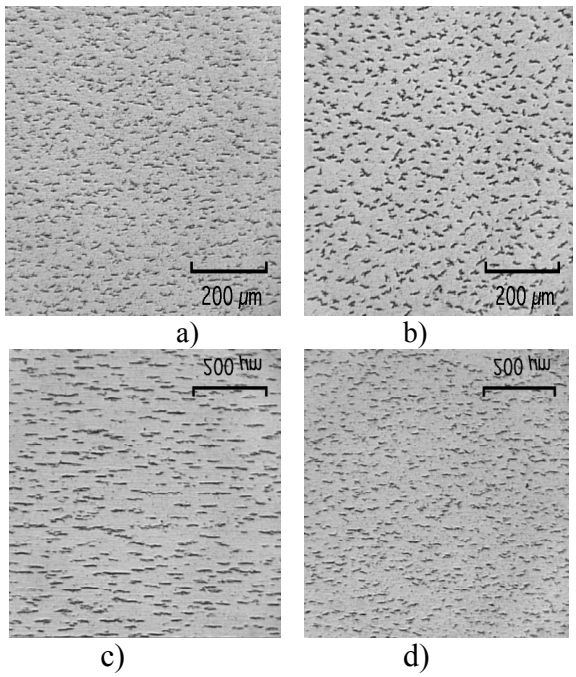


Fig. 1. Hydride microstructure of CANDU(a, c) and RBMK (b, d) pressure tube material in radial-transverse (a, b) and radial-axial(c, d) sections. Hydrogen concentration 76-79 ppm.

After completion of DHC test specimen has been unloaded and cooled down in the furnace to the room temperature. Specimen then has been subjected to cyclic loading to outline the DHC crack and then fractured. After completion of DHC test actual crack length was measured from fractographs (Fig. 2).

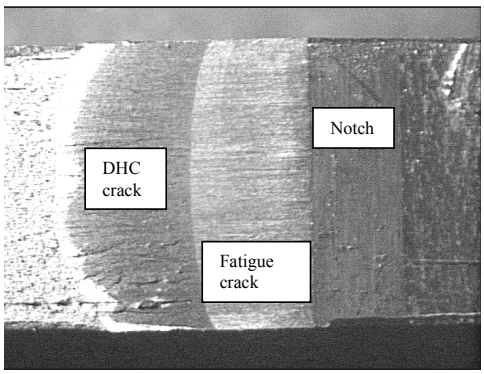
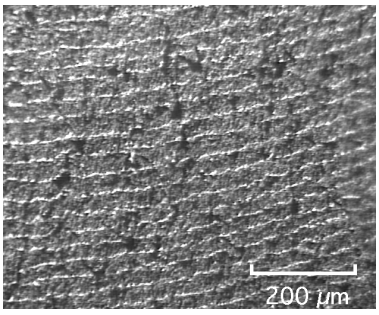
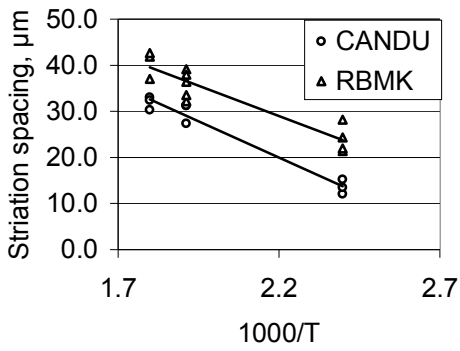


Fig. 2. Fractured surface of CCT specimen.

The propagation of a crack creates lines on the fracture surface, which lie parallel to the crack front, perpendicular to the direction of crack growth [6]. Each incremental advance of the crack front results in the formation of a striation on the fracture surface (Fig. 3, a).



a)



b)

Fig. 3. Striations on the DHC fracture surface (a); relationship between inter-striation spacing and temperature (b).

Conclusions

Crack growth in RBMK pressure tube material occurs at larger increments of the crack front. Striation spacing increases with increase in test temperature and appear to be larger in the specimens of the RBMK material than in the CANDU material.

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