

TECHNIQUE OF SCC TESTS OF ZIRCONIUM TUBE SPECIMENS UNDER INTERNAL PRESSURE

МЕТОДИКА ИССЛЕДОВАНИЯ КРН ТРУБЧАТЫХ ОБРАЗЦОВ ЦИРКОНИЕВЫХ СПЛАВОВ ПОД ВНУТРЕННИМ ДАВЛЕНИЕМ

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Abstract: In the work method of SCC test of zirconium cladding tube specimens has been developed. The influence of corrosion damages on the mechanical properties and stability of the tube during loading by internal pressure has been investigated. Mechanisms of corrosion damage in zirconium alloys after SCC-tests were analyzed.

KEYWORDS: ZIRCONIUM ALLOYS, STRESS CORROSION CRACKING, MECHANISM AND KINETICS OF FRACTURE

1. Introduction

One of the processes that can limit the life time of fuel rods in nuclear reactors is stress corrosion cracking (SCC) of fuel claddings. This type of corrosion leads to the formation of cracks in the claddings with subsequent possible depressurization. Cracking occurs because of contemporary action of stresses (appearing because of the nuclear fuel growth) and active corrosion agents - the fuel fission products (mainly iodine). Fracture of the cladding by the mechanism of SCC may occur during a power ramps after a sufficiently high fuel burn up [1, 2].

Formation and development of SCC defects can essentially change durability and mechanical rigidity of claddings in places of concentration of corrosion defects [2].

The aim of work is to develop SCC-test method to study the mechanisms and kinetics of accumulation of defects during SCC and their influence on the mechanical properties of zirconium alloys.

2. Material and method

SCC-tests have been carried out on tubular specimens of 20 mm long with a diameter of 9, 13 mm and wall thickness of 0.7 mm of E110 and E635 alloys having different structure and strength.

Method includes: flooding of tube specimen by liquid tin, preloading of tube specimen by tin compression on the tensile testing machine Instron for creation of tensile stresses of 35 MPa in specimen, exposure in the corrosive solution of 1% methanol-iodine from 2 to 12 hours and additional mechanical loading of tin by compression to formation of a through-wall crack.

Compression of specimens was carried out on a universal testing machine INSTRON 150 LX with a strain rate of 1mm/min with the registration of diagram "load-displacement". The diameter of the specimen was measured with an accuracy of a digital micrometer (0.001 mm).

Pre-loaded specimens were completely immersed in a corrosive solution of 1% iodine in methanol solution and exposed for 2, 4, 6, 8 and 12 h (3-5 specimens of each alloy per a point).

Qualitative and quantitative analysis of surface corrosion defects was carried out after exposure in the corrosive solution on the scanning electron microscope JEOL JSM-6380 and an optical microscope Nikon Eclipse MA200. Quantity, size (diameter) and square of pits in the entire area of the outer surface of the cylindrical sample were measured at each specimen.

There is the formation of defects in the process of exposure in the corrosive solution at the outer surface of the specimens occurs. Typical defects - pits and intergranular fracture areas are shown in Figures 1 and 2.

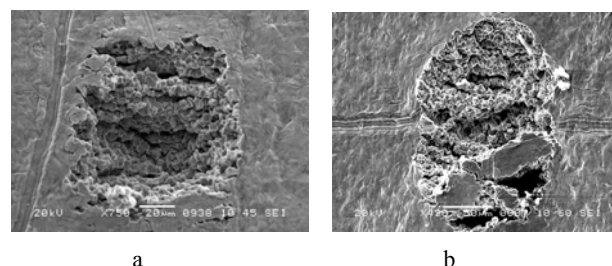


Figure 1. Pits on the surface of specimens of E110 (a) and E635 (b) alloy after exposure in the corrosive solution for 3 hours and additional mechanical loading

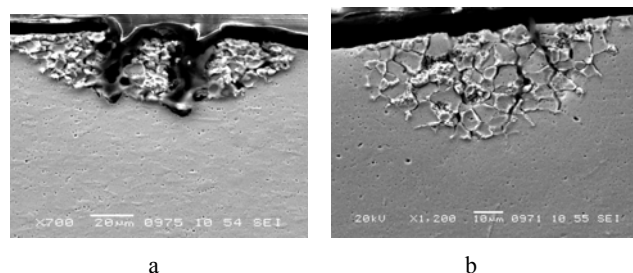
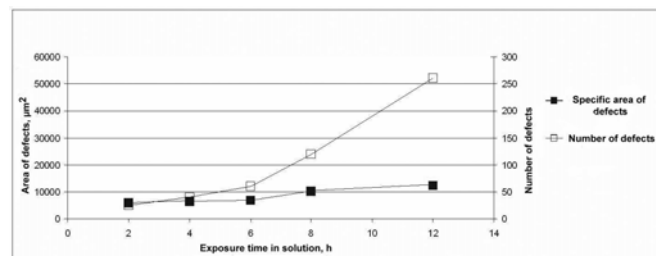
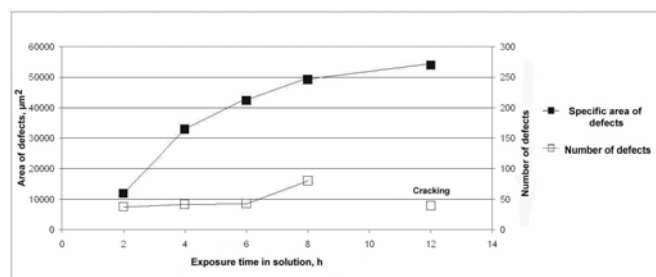


Figure 2. Intergranular fracture areas on the surface of specimens of E110 (a) and E635 (b) alloy after SCC-tests for 3 hours

Figure 3 shows that continuous increase in the number of defects is typical for the E110 alloy specimens with exposure in the corrosive solution from 2 to 6 hours. However, their size and the area remains unchanged. In contrast, there is growth of the specific area of defects in the specimens of E635 alloy, while their number remains almost unchanged. Thus, when the exposure in the solution is 4 hours the number of defects in alloys is the same, but the specific area of defects in specimens of E635 alloy is 2 times higher. When exposure in solution takes from 6 to 12 hours in specimens of E110 alloy there is a further increase in the number of surface defects with a slight change in their area. In E635 alloy an increase of not quantity, but area of defects was observed and as a result the formation of through-wall cracks on these defects was determined. Such cracks are detected at an early stage of loading of specimens during compression testing. At the same time of exposure in the corrosive solution there are no cracks in the specimens of E110 alloy. Number of defects in specimens of E110 alloy is 1.5 times higher, and the specific area of the defect is 5 times lower compared to specimens of the E635 alloy after exposure for 8 hours.



a



b

Figure 3. Dependence of the parameters of defects on the surface of the tube specimens of the exposure in the solution for E110 (a) and E635 (b) alloy

Thus, SCC for E110 alloy is characterized by gradual accumulation of small pits, and E635 alloy characterized by fracture through increasing defect size and area.

There was diagram "stress-strain" curves compared which were averaged over five specimens for each alloy obtained under compression of tube specimens after SCC. It was made to assess the effect of corrosion defects on the mechanical properties of specimens E110 alloy and E635 alloy.

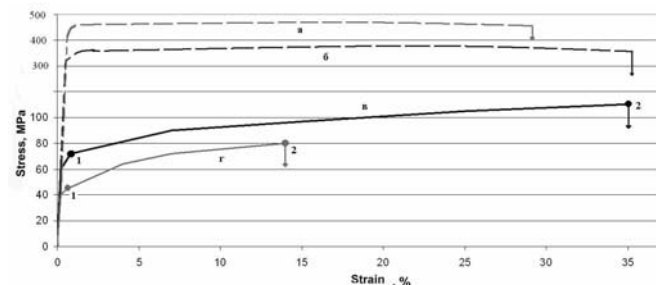


Figure 4. Diagrams "stress-strain" after compression of specimens of E110 (a, d) and E635 (b,c) alloy before and after SCC-tests for 3 hours

1 – Beginning of "blowing up"; 2 – Fracture of specimen

Formation of corrosive damages leads to a significant change in the mechanical properties of tube specimens. The strength and ductility after exposure in the corrosive solution decreases compared with specimens in the initial state (not corroded specimens).

It is known that the strength of zirconium alloys affects the mechanisms of SCC tubes [3]. Pitting and intergranular fracture is gradually suppressed by formation and rapid development of individual big surface cracks with increasing strength of alloys.

There is formation of surface cracks for specimens of E635 alloy that develop and lead to the final fracture at the strain $\varepsilon_2 = 13-14\%$ that is lower compared with the initial state ($\varepsilon_2 = 28-30\%$). It is characterised at an early stage of loading. The stress of "blowing up" falls 8-9 times compared with the initial state.

Failure of the specimens before and after the SCC tests for the E110 alloy is the same. While the stress of "blowing up" is reduced by 4-5 times, and the stress of fracture is reduced by 3.5 times compared to baseline.

Thus, the mechanical properties of specimens after SCC tests are associated with accumulation and development of defects.

3. Conclusion

Formation and accumulation of corrosion damage in SCC leads to changes in mechanical properties of the tube specimens.

The degree of change in mechanical properties of tubes depends on the amount of corrosion damage and the strength of the alloy in the initial state. For a stronger E635 alloy even a small amount of defects can become critical and lead to a significant decrease in mechanical strength and "rigidity" of tubular specimens.

4. References

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