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► **To cite this version:**

M. P. Puls. The role of hydride size, matrix strength and stress state on fracture initiation at hydride precipitates in zirconium alloys. *Revue de Physique Appliquée*, 1988, 23 (4), pp.718-718. 10.1051/rphysap:01988002304071800 . jpa-00245873

HAL Id: jpa-00245873

<https://hal.science/jpa-00245873>

Submitted on 4 Feb 2008

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THE ROLE OF HYDRIDE SIZE, MATRIX STRENGTH AND STRESS STATE
ON FRACTURE INITIATION AT HYDRIDE PRECIPITATES IN ZIRCONIUM ALLOYS

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In hydride-forming metals, the presence of hydrides can sometimes lead to brittle fracture. Zirconium is a hydride-forming metal that forms the basis of a number of alloys used in CANDU^R nuclear reactors. Under certain circumstances, zirconium alloys are susceptible to a process of slow crack propagation called delayed hydride cracking (DHC). Experiments have shown that DHC crack velocity is approximately independent of the mode I stress intensity factor, K_I , up to values approaching those of the fracture toughness of the bulk material, whilst at low K_I -values, a sharp drop-off occurs in crack velocity, suggesting a critical value, K_{IH} , for DHC (1,2).

Although a theoretical description of the DHC process (2,3) has provided an explanation for many significant features of the observed cracking behaviour, such as the dependence of the crack velocity on temperature and K_I , it cannot predict the critical value, K_{IH} . In order to develop a theoretical understanding of K_{IH} , a criterion for the initiation of fracture at hydride platelets would appear to be needed. Previous studies showed that the critical stress and strain to fracture hydrides could be quite different, depending on the uniaxial yield stress and on the stress state prevalent in the material tested (3). The conditions for fracture initiation at hydrides are, therefore, complex, requiring information on the internal stress and strains near the hydride at the time of fracture. A promising new technique to investigate this process involves the use of acoustic emission (AE) (4). The AE associated with hydride fracture can be correlated with the load-deflection curve and, when combined with finite element calculations, used to determine the stress and strain state at the onset of microcracking in the hydride particles.

The present work describes the results of such an approach to determine crack initiation in hydrides in Zircaloy-2, Zr-2.5 wt% Nb and Excel (the latter is an experimental alloy). These alloys cover a range of matrix strengths. The effect of matrix strength (yield stress) on hydride fracture and alloy ductility has been studied as a function of stress state, hydride content, hydride size and precipitation stress. Uniaxial and triaxial states of stress were investigated by using smooth and notched tensile specimens, respectively, containing 0.18 or 0.90 at.% H with the longest hydride platelet dimension varying from 5 to 400 μm . The majority of the hydrides in the

specimens had their plate normals oriented parallel to the tensile axis direction. Crack initiation at hydrides was monitored using acoustic emission, finite element calculations were employed to determine the stresses and strains in the notched specimens and metallographic and fractographic analyses were carried out to determine the state of fractured hydrides/voids near and on the fracture surface. These techniques showed that up to a hydride platelet length of ~50 to 100 μm and regardless of the stress state, a critical plastic strain, independent of matrix strength, controls the initiation of fracture in hydrides. The amount of plastic strain needed to fracture hydrides decreases as (a) the average hydride size increases and (b) the axiality of stress increases. The equivalent plastic strain to fracture small hydrides is ~1% under a triaxial as opposed to ~5% under a uniaxial state of stress. When the average hydride platelet lengths are bigger than ~50-100 μm , negligible plastic deformation is required to fracture hydrides. A critical applied stress then is the governing factor in all three materials, ranging from 750 to 850 MPa, depending on the stress state.

The experimental results have been rationalized semi-quantitatively on the basis of a model that assumes that hydride fracture requires a critical internal stress. This stress arises, in part, from the inhomogeneity of strain between the ductile matrix and the less ductile hydride. This stress can be calculated using a modified version of Eshelby's theory of inclusions (5,6).

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