Evolution of Mechanical Properties during Aging of ErT_2 Target Films

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Motivation—The tritiated target films of neutron tubes are subject to aging problems because of the unavoidable decay of tritium into ^{3}He, forming bubbles which eventually limit the lifetime and performance of the tube. A detailed understanding of the effect of bubble growth on film properties was needed to help quantify tube reliability and margin to failure. We studied model ErT_2 films loaded with 100% tritium over a period of more than three years to measure the evolution of their properties as the He content grew through the entire range that production films might experience.

Accomplishment—The changing mechanical properties of the model films were monitored using ultra-low load nanoindentation, combined with finite-element modeling to separate the mechanical properties of the thin films from their substrates. The size of the growing ^{3}He bubbles was followed in parallel with transmission electron microscopy, while ion beam analysis was used to monitor total T and ^{3}He content.

The mechanical properties (yield strength, Young's modulus) of the films exhibited two behavior regimes, shown in Fig. 1: an initial period of increasing strength and approximately constant modulus followed by a period of decreasing modulus and slowly decreasing strength. The ^{3}He bubbles were observed in TEM micrographs to have a thin platelet morphology aligned with {111} planes in the matrix. Combining measurements of the platelet diameters with theoretical models of bubble growth, we deduced the density and thicknesses of the bubbles and showed that their growth also divided into two regimes which correspond to the observed changes in mechanical properties. First is an initial "Griffith-crack" nucleation and growth, where the ^{3}He forces apart {111} planes and forms the platelet-like bubbles. Once the bubbles are thick enough, they transition to a dislocation dipole mode, where circular dislocations form around each platelet, further increasing the thickness and lowering the pressure. The bubbles continue to grow in this mode until they overlap enough that the layer fractures.

A model of dispersion hardening was used to show that the increase in yield strength during the initial aging can be explained through binding of dislocations by the bubbles, resulting in strengthening much like that resulting from hard precipitates. As the bubbles transition to a dipole mode of growth, the lack of further strengthening is due to increasing bubble overlap combined with the large increase in available dislocations and a lowered pressure in the bubbles. The elastic behavior during aging was more difficult to model, but the general trend is the expected elastic softening due to the increasing fraction of ^{3}He in the material. The approximately constant Young's modulus during the initial aging may be partly due to the concurrent increase in yield strength. Some models predict a dependence on gas pressure in the bubbles which may be reflected in the data.

Significance—The new understanding of metal tritide film aging provided by this study is important as input to theoretical modeling of ^{3}He bubble growth and its effect on aging of neutron tube target films, helping to quantify margin to failure in present and future neutron tube designs. In particular, the previously unknown transition in properties at intermediate age may have unsuspected implications for film stability.

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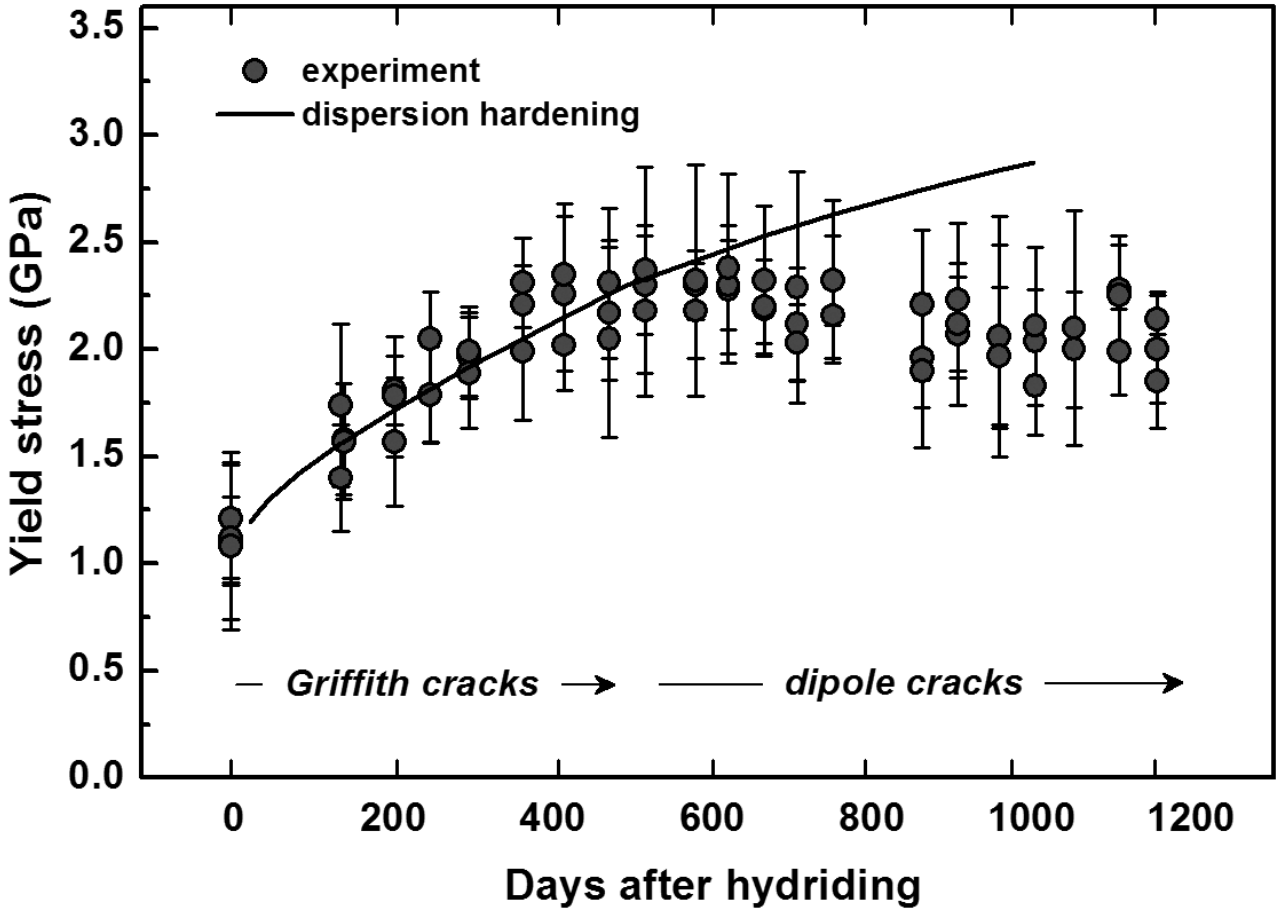

Figure 1. Yield strength of the tritiated films as a function of age, determined by nanoindentation. Two regimes are evident, associated with two different modes of bubble growth. The solid line is a prediction of strength from dispersion hardening theory.