APPROACHES TO ASSESSING THE FAILURE RESISTANCE OF FUSION REACTOR FIRST WALLS

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In-service mechanical property degradation and microstructural instabilities leading to failures of fusion first wall structures pose serious obstacles to commercial fusion power. Therefore, a national program to develop "radiation resistant" alloys for fusion applications has been initiated by the U.S. Department of Energy through the Office of Fusion Energy Materials and Radiation Effects Branch with technical planning and coordination provided by an Alloy Development for Irradiation Performance (ADIP) Task Group. The scientific basis for this program will be described.

Alloy development and fusion design efforts are confronted by at least three major problems including:

1. There is no completely proper test environment in terms of appropriate combinations of spectrum, flux, volume, and time history of temperature, flux and stress, which simulate the fusion environment.

2. The most proper high flux test environments will have small irradiation volumes (< 1000 cm$^3$ for $\phi > 10^{14}$n/cm$^2$-sec and < 10 cm$^3$ for $\phi > 10^{15}$n/cm$^2$-sec).

3. There are a large number of potential structural failure modes ranging from creep rupture to catastrophic fracture.

In order to relate the data obtained in test environments to conditions in fusion reactors, a second Task Group on Damage Analysis and Fundamental Studies (DAFS) complements the ADIP efforts. Its charge is to develop a proper correlation methodology which rests on a firm physical understanding
of the radiation effects and on structural failure modes. The major efforts can be divided into three categories:

1. Extract useful mechanical property information from very small sample volumes;
2. Relate microstructure to properties;
3. Establish the connection between properties and design criteria.

With regard to the first one, microtensile experiments, instrumented hardness tests, and bulge/punch tests are discussed.

As examples of the second category, we describe the relationship between yield stress and ductility and the development of cavities, loops, and dislocation structure. The extension of this approach to failure related properties is then outlined and demonstrated with models to predict \( K_{IC} \) for irradiated and unirradiated stainless steels from flow properties and microstructural data. The approach looks promising when comparison is made with the limited amount of experimental data. The extension to other failure modes, such as creep rupture and crack growth is briefly indicated. Finally, unique properties of highly irradiated materials, such as flow localization and channel fracture are discussed. An important component of this effort will be the development of coupled microstructure/flow/fracture maps.

As examples of the third category, we analyze the likely flaw sizes, their configurations, and the stresses in a first wall. Comparison is made with the test conditions for various standard fracture specimens, and it is shown that valid \( K_{IC} \) measurements are not always appropriate measures of the fracture resistance of the first wall. Some fracture specimen geometries consistent with the limited test volume and the first wall environment are explored.