A Radiation Hardening Model of 9Cr-Martensitic Steels Including Dpa and Helium

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Low activation ferritic/martensitic steels are receiving a high priority in the European long term materials research. Although extensively investigated, the available experimental data do not cover all required parameter ranges and cannot unambiguously be used to produce hardening/embrittlement trend curves. Therefore, the main objective of this work is to provide a physically-based engineering model offering a rational to experimental observations. From the literature, experimental data were selected to establish a database that mainly consists of 8 to 9Cr-steels irradiated in the range of 50 to 600°C up to 30 dpa and with a He-content up to 5000 appm. The database includes neutron and proton irradiations, He-implanted as well as B- and Ni-doped steels.

Because of the difficulty of interpretation inherent to the Charpy impact test, only tensile data were considered. The difficulty stems from the large range of specimen sizes that are used, the arbitrary definition of the ductile-to-brittle transition temperature (DBTT) and more important its inadequacy to monitor embrittlement when plastic flow localization occurs.

The test temperature varies from one material to another and usually tests were performed at room temperature and/or at the irradiation temperature. Therefore, to be consistent (test temperature independent), assuming that irradiation affects mainly the athermal part of the yield strength, the latter was modified to take the variation of the Young’s modulus into account.

This database was first used to extract general tendencies in terms of hardening behavior as a function of dpa, irradiation temperature and helium content. In a second step, the database was rearranged to allow investigation of a single parameter. The effect of material composition (9Cr-1MoVNb, 9Cr-1WVTa ...) was found negligible except when nickel is added to promote helium generation and simulate fusion environment. The effect of irradiation temperature was rationalized using both irradiation and annealing experiments. A simple comprehensive engineering model will be presented and discussed in terms of its performances.

Number of words in abstract: 311

Keywords:
Technical area: 31. Developing fusion materials Ferritic/martensitic and ODS steels
Special session: Not specified
Presentation: No preference
Special equipment: No special equipment