RESEARCH AND DEVELOPMENT ON VANADIUM ALLOYS FOR FUSION APPLICATIONS* — S. J. Zinkle (ORNL), H. Matsui (Tohoku Univ.), D. L. Smith (Argonne National Laboratory), A. F. Rowcliffe (ORNL), E. van Osch (NERF-Petten), K. Abe (Tohoku Univ.), and V.A. Kazakov (RIAR-Dimitrovgrad)

Extended Abstract

The current status of research and development on unirradiated and irradiated V-Cr-Ti alloys intended for fusion reactor structural applications is reviewed, with particular emphasis on the flow and fracture behavior of neutron-irradiated vanadium alloys. Recent progress on fabrication, joining, oxidation behavior, and the development of insulator coatings is also summarized. Fabrication of large (>500 kg) heats of V-4Cr-4Ti with properties similar to previous small laboratory heats has now been demonstrated. Impressive advances in the joining of thick sections of vanadium alloys using GTA and electron beam welds have been achieved in the past two years, although further improvements are still needed.

Pronounced flow localization and loss of strain hardening capacity with uniform elongations <1% generally occurs in vanadium alloys for irradiation temperatures below ~400°C (0.31 T_M). These changes in tensile properties for T_{irr}<400°C are generally accompanied by large increases in the ductile-to-brittle transition temperature measured under both dynamic and quasi-static loading conditions. The irradiated mechanical properties at temperatures between 430 and 650°C are acceptable for most structural applications. Further work is needed to determine how far the allowable lower and upper operating temperature limits can be expanded beyond the 430-650°C range. The poor work hardening behavior of vanadium alloys at irradiation temperatures below 400°C is due to small defect clusters which can be easily sheared by dislocations during deformation. The concomitant poor fracture properties of vanadium alloys at these low irradiation temperatures is attributable to matrix hardening effects. Microstructural alterations which would improve the tensile elongations of irradiated vanadium alloys (e.g., introduction of nonshearable precipitates) would not necessarily produce any improvement in the fracture properties. Tensile test ductility and toughness often provide misleading information about the temperature-dependent fracture toughness obtained from Charpy impact or compact tension specimens.

In order to build upon the present state of knowledge for vanadium alloys, additional work is needed on several different topics. Regarding unirradiated properties, additional work expanding upon the recent advances in joining technology are needed. The ultimate goal of these studies is to develop techniques for joining thick sections of vanadium alloys which do not require post-weld heat treatments. An expanded investigation of alternative alloys (controlled matrix interstitial solute contents; dispersion or precipitation hardened alloys, etc.) would be useful to see if alloys with unirradiated and irradiated properties superior to V-4Cr-4Ti are possible. Further work is also needed to develop adherent self-healing insulator coatings which are compatible with vanadium-liquid metal coolant systems. A key issue regarding radiation effects is to determine the minimum and maximum allowable operating temperatures. Further irradiation studies at 350 to 450°C to doses of 1-10 dpa are needed to evaluate the radiation hardening, ductility, and fracture toughness properties. The possible impact of fusion-relevant levels of helium on radiation hardening at higher doses should also be considered. It would also be useful to perform some fundamental studies to determine whether flow localization (dislocation channeling) modifies the relationship between fracture properties and matrix hardening. Creep rupture studies on unirradiated and irradiated specimens (with and without helium) at test temperatures ≥650°C are needed in order to help establish maximum allowable operating temperatures. Additional work is also needed to determine the magnitude of radiation creep in vanadium alloys.

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