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Development of benchmark reduced activation ferritic/martensitic steels for fusion energy applications

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Abstract
Reduced-activation ferritic/martensitic (RAFM) steel is the benchmark structural material for in-vessel components of fusion reactor. The current status of RAFM developments and evaluations is reviewed based on two leading RAFM steels, F82H and EUROFER-97. The applicability of various joining technologies for fabrication of fusion first wall and blanket structures, such as weld or diffusion bonding, is overviewed as well. The technical challenges and potential risks of utilizing RAFM steels as the structural material of in-vessel components are discussed, and possible mitigation methodology is introduced. The discussion suggests that deuterium–tritium fusion neutron irradiation effects currently need to be treated as an ambiguity factor which could be incorporated within the safety factor. The safety factor will be defined by the engineering design criteria which are not yet developed with regard to irradiation effects and some high temperature process, and the operating time condition of the in-vessel component will be defined by the condition at which those ambiguities due to neutron irradiation become too large to be acceptable, or by the critical condition at which 14 MeV fusion neutron irradiation effects is expected to become different from fission neutron irradiation effects.

Keywords: reduced activation ferritic/martenssitic steel, joining technologies, irradiation effects, 14 MeV neutron irradiation effects, mitigation methodology

(Some figures may appear in colour only in the online journal)

1. Introduction

The fusion blanket structural materials will be subjected to high heat loads and high flux 14 MeV fusion neutrons, and will experience internal pressure loads, thermal stresses, substantial magnetic forces in case of plasma disruptions, and high pressure loads in the case of a coolant ingress. An effort to develop low-activation materials for fusion reactor application was initiated in the early 1980s, because it was regarded as an important issue related to the public acceptance of fusion energy [1]. The concept of reduced-activation ferritic/martensitic (RAFM) steels was proposed in 1982 based on the composition of high Cr heat resistant steels, Mod9Cr–1Mo (Grade91, ASME Section II), by replacing Mo with W and Nb with Ta to meet the shallow land burial limitation [2]. RAFM steels are advantageous compared to austenitic stainless steels (such as 316LN) as they exhibit lower radio activation levels (no Ni), better thermal conductivity (less Cr), lower thermal expansion ratio, and superior swelling resistance [3]. Several variations of steels were investigated to develop RAFM steels