Short communication

Effect of irradiation temperature on void swelling of China Low Activation Martensitic steel (CLAM)

Fei Zhao[a], Jiansheng Qiao[a], Yina Huang[a], Farong Wan[a,b,*], Soumei Ohnuki[c]

[a]School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China
[b]Beijing Key Lab of New Energy and Technology, Beijing 100083, China
[c]Faculty of Engineering, Hokkaido University, Sapporo 060, Japan

ARTICLE DATA

Article history:
Received 14 January 2007
Accepted 23 January 2007

Keywords:
Irradiation damage
CLAM
High voltage electron microscope
Void swelling

ABSTRACT

CLAM is one composition of a Reduced Activation Ferritic/Martensitic steel (RAFM), which is being studied in a number of institutes and universities in China. The effect of electron-beam irradiation temperature on irradiation swelling of CLAM was investigated by using a 1250 kV High Voltage Electron Microscope (HVEM). In-situ microstructural observations indicated that voids formed at each experimental temperature – 723 K, 773 K and 823 K. The size and number density of voids increased with increasing irradiation dose at each temperature. The results show that CLAM has good swelling resistance. The maximum void swelling was produced at 723 K; the swelling was about 0.3% when the irradiation damage was 13.8 dpa.

1. Introduction

Fusion is one of the most attractive long-term energy options. There is an essentially unlimited fuel supply: deuterium from the ocean and tritium from transmutation of lithium using neutrons produced in the D–T fusion reaction. Fusion does not produce CO_2 or SO_2 and thus will not contribute to global warming or acid rain [1]. For this reason, more and more institutes and laboratories in the world are working in this field, including complementary research on both plasma physics and materials. The performance of materials is one of the decisive factors that control the economic, safety and environmental acceptability of fusion power. First wall/blanket assemblies are an important component of the fusion reactor; these provide the primary heat recovery and tritium breeding systems, so the materials must have good mechanical properties, compatibility with coolants and breeder materials, and good irradiation damage resistance [2].

Ferritic/Martensitic steels, with chromium contents ranging between 9 and 12 wt%, were introduced into fusion material programs about 30 years ago, when it became evident from research in fast reactor programs that they possessed better swelling resistance and excellent thermal properties compared to austenitic stainless steels [3]. Currently, RAFM are considered as promising candidates for first wall/blanket materials in Demonstration Fusion Power Plant (DEMO) [4]. Several kinds of RAFM have been produced and tested; these include F82H, JLF-1, ORNL-9Cr2WVTa and EUROFER 97 [5–8]. In China, the focus is on the CLAM, which will be considered for a test blanket module in ITER and as a first wall/blanket materials for the DEMO.

The aim of this study was to investigate the effect of electron-beam irradiation temperature on irradiation swelling

* *Corresponding author*. School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China. Tel.: +86 10 62334807; fax: +86 10 62333724.
E-mail address: wanfr@mater.ustb.edu.cn (F. Wan).

1044-5803/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.matchar.2007.01.014

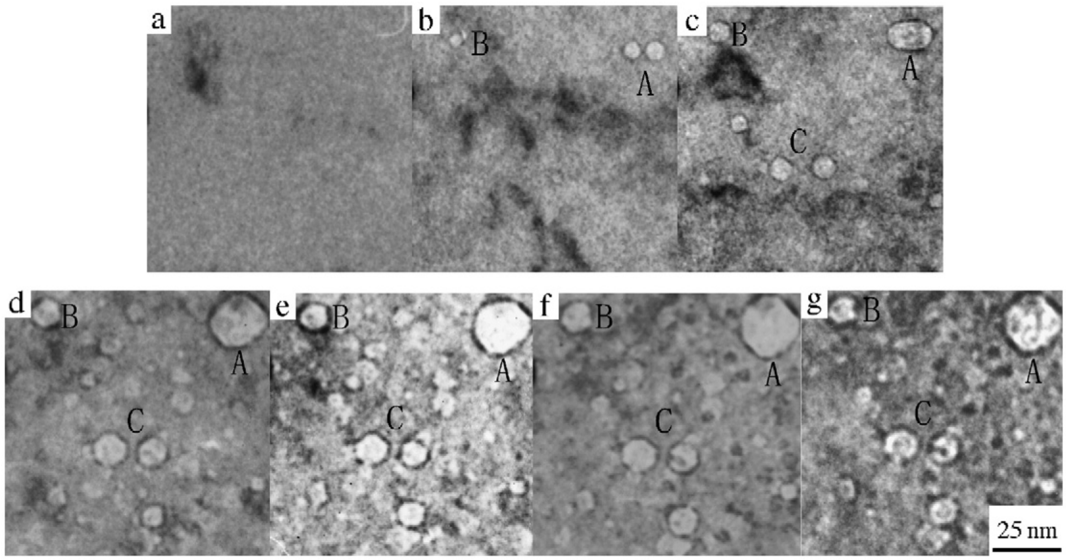

Fig. 1 – Microstructure of CLAM after irradiation at 723 K. a — 0 dpa, b — 1.4 dpa, c — 3.6 dpa, d — 10 dpa, e — 11.5 dpa, f — 13.2 dpa, g — 13.8 dpa.

of CLAM by using HVEM to simulate the reactor damage processes.

2. Experimental Procedure

Specimens of CLAM, containing (in wt%) 8.8 chromium, 0.13 carbon, 1.49 tungsten, 0.20 vanadium, 0.06 tantalum, 0.68 manganese and the balance iron were used. The steel was heat-treated by normalizing at 1253 K for 30 min and was fully martensitic after water quenching at room temperature. The tempering was conducted at 1023 K for 90 min. The prior austenite grain size was about 30 μm. The specimens for electron irradiation were TEM specimens. Disk specimens with 3 mm diameter were punched out from a 0.1 mm thick strip which was prepared from a thick plate of CLAM by spark cutting and milling to final thickness. The final TEM specimens were polished by twin-jet electro-polisher, using a 5% $HClO_4$–95%C_2H_5OH polishing solution.

The electron-beam irradiation was carried out with a damage rate of about 2×10^{-3} dpa/s at 723, 773 and 823 K up to a dose of 13.8 dpa in a 1250 kV HVEM (JEM-ARM 1300), located in Hokkaido University, Japan. The specimen thickness of irradiation area was selected about 500 nm to avoid surface effect on the formation of irradiation point defects. A low index crystal plane (100) was chosen for electron-beam irradiation. The microstructure was observed in-situ at various stages during the electron irradiation process.

3. Experimental Results and Discussion

3.1. *Void Swelling at 723 K*

Fig. 1 shows the microstructure of CLAM irradiated at 723 K. In-situ microstructural observations indicated that very small, approximately 6 nm diameter, voids were present after irradiation to 1.4 dpa. The number density was about 0.8×10^{21} m^{-3}. The size increased with the damage dose; when irradiated to 3.6 dpa, the maximum size of voids increased to 14 nm. It was observed that two nearby voids can grow to a larger one, for example void A in Fig. 1c. When the damage increased to 10 dpa (Fig. 1d), the size of void A was 22 nm. After further irradiation to as high as 13.8 dpa, the diameter of void A remained 22 nm, indicating little further coarsening.

Fig. 2 shows the void number density as a function of irradiation dose in CLAM; these are for the specimens irradiated at 723 K. The number density increased monotonically with increasing irradiation dose. The number density was only 0.8×10^{21} m^{-3} when irradiated to 1.4 dpa, while it reached 10.6×10^{21} m^{-3} when irradiated to 13.8 dpa. This indicates that the void nucleation and growth process is occurring continuously under irradiation.

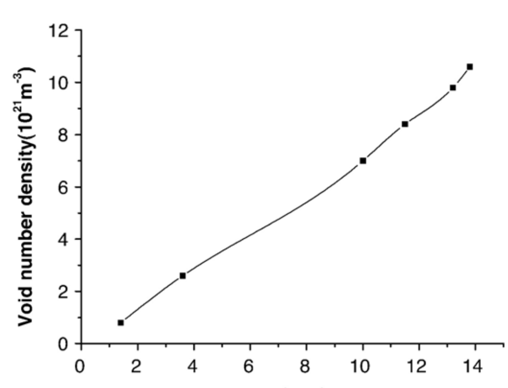

Fig. 2 – Dose dependence of void number density up to 13.8 dpa for irradiation at 723 K.