EFFECT OF LOW DOSE NEUTRON IRRADIATION ON TENSILE BEHAVIOR OF HT-9 STEEL AT ROOM TEMPERATURE

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Keywords: Neutron irradiation, X-ray diffraction, tensile test

Abstract

HT-9 steel samples have been irradiated with fast neutrons [E>0.1 MeV] to a low dose (1.2×10^3 dpa). Microstructure of the unirradiated and irradiated samples has been characterized by X-ray Diffraction Line Profile Analysis using different model-based approaches. The domain size and density of dislocations of the irradiated steel have been estimated. Different types of tensile tests have been carried out at room temperature to assess the changes in mechanical properties of HT-9 steel due to neutron irradiation.

Introduction

Materials degradation due to radiation damage in nuclear reactor core components has been investigated for more than four decades [1-3]. It is a continuing effort to understand how the degradation occurs under irradiation in order to provide guidance in the development of new and more resistant alloys and to optimize the performance of the existing alloys. Consequently, the materials development community continues to rely on developing a fundamental understanding of the various processes that are involved in radiation effects of materials, particularly primary damage production, microstructural evolution, and the changes in mechanical, physical and chemical properties [4-6]. This understanding definitely helped to provide a superior methodology for interpreting and applying available data to the prediction of the property and the other microstructural changes for the structural materials of the reactor of interest.

Ferritic/martensitic (F/M) steels are considered to be potential candidate materials for the core structural materials of fast reactors (FRs), and also for the blanket and first wall materials of fusion reactors because of their superior swelling resistance [7-12]. HT-9 is a typical F/M steel which has been investigated extensively considering its prospective use in the nuclear industry [13-16]. HT-9 is also called a 12Cr-1MoVW steel. It has high chromium (Cr) content of about 12% and thus HT-9 is also called a high-chromium F/M steel. Presence of increased Cr content in this steel provides excellent resistance to atmospheric corrosion and resistance to degradation in many organic media. The presence of molybdenum (Mo) enhances the localized corrosion resistance in environments containing deleterious species by preventing the breakdown of protective oxide films. HT-9 steel has a body-centered-cubic (BCC) structure which gives better swelling resistant property in comparison with austenitic stainless steels. In reactor applications, this steel remains in high neutron irradiation environment and thus pronounced changes in the
microstructural behavior occur in F/M steels as a function of irradiation dose and temperature. In spite of several irradiation studies performed on F/M steels over the past 25 years, there is still lack of low fluence data for this alloy [17-22]. Keeping in view of the importance of these studies, an attempt has been made to understand the evolution of defects and mechanical properties in HT-9 steel at low dose and at low temperature, which has been described as a transient regime before attaining the steady state of the microstructural components [23]. The objective of this study is to characterize the change in microstructure of HT-9 steel sample after low neutron irradiation and investigate its effect on the tensile properties of the steel.

Materials and experimental procedures

Material
Material used in this study was received as cast and rolled plates. The chemical composition of HT-9 steel is shown in Table 1.

| Table 1 Chemical composition of HT-9 steel |
|-----------------|---|---|---|---|---|---|---|---|
| Fe | Cr | Ni | W | Mo | Mn | Si | V | C |
| 84.36 | 11.94 | 0.62 | 0.48 | 1.03 | 0.6 | 0.30 | 0.30 | 0.21 |

Tensile specimens of 10 mm gauge length and 0.5 mm thickness were machined along the rolling direction from the rolled plate.

Neutron irradiation
A number of tensile specimens and some flat strips were exposed to neutron radiation in the PULSTAR reactor at North Carolina State University at a fast [>0.1 MeV] flux of $3 \times 10^{12}$ n/sec.cm$^2$ at the reactor operating temperature of ~ 50°C to an accumulated fast fluence of ~ $2 \times 10^{18}$ n/cm$^2$. The flux measurements were made using high purity nickel wires which were also inserted in the radiation capsule along with the samples. NaI detector was used to measure the 811 keV gamma rays emitted by the radioactive decay of $^{58}$Co from the threshold reaction $^{58}$Ni(n,p)$^{58}$Co. The specimens were left in lead containers till the accumulated radioactivity decayed to levels low enough to be able to perform the mechanical tests without any special remote arrangements. The neutron damage generated in HT-9 sample is calculated using the SPECTER code [24]. In this case, the maximum damage value amounts to $1.2 \times 10^3$ dpa.

X-ray diffraction
The X-ray diffraction (XRD) patterns were recorded from the unirradiated and irradiated samples by a Rigaku SmartLab diffractometer using Cu $K_a$ radiation. All the diffraction profiles were obtained by varying $2\theta$ from 40° to 120° in a step scan mode. The data were recorded in a $2\theta$ interval of 0.02°. Time spent per step was 4 seconds.

Tensile Testing
The tensile tests were performed on the unirradiated and irradiated samples using a closed loop Instron machine. Three types of tests were carried out: (i) straight tensile tests at a nominal strain rate of $1.0 \times 10^{-3}$ s$^{-1}$ to determine the mechanical properties (ii) strain rate change (from $10^{-3}$ s$^{-1}$ to $10^{-4}$ s$^{-1}$ and again to $10^{-3}$ s$^{-1}$) tests at different strains to determine the strain rate sensitivity and (iii) stress relaxation (for 300 sec) tests at different stress to determine the activation volume.