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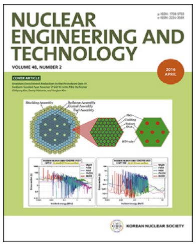

Original Article

Effect of Thermal Aging on Microstructure and Mechanical Properties of China Low-Activation Martensitic Steel at 550 °C

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ABSTRACT

The thermal aging effects on mechanical properties and microstructures in China low-activation martensitic steel have been tested by aging at 550 °C for 2,000 hours, 4,000 hours, and 10,000 hours. The microstructure was analyzed by scanning and transmission electron microscopy. The results showed that the grain size and martensitic lath increased by about 4 μm and 0.3 μm, respectively, after thermal exposure at 550 °C for 10,000 hours. MX type particles such as TaC precipitated on the matrix and Laves-phase was found on the martensitic lath boundary and grain boundary on aged specimens. The mechanical properties were investigated with tensile and Charpy impact tests. Tensile properties were not seriously affected by aging. Neither yield strength nor ultimate tensile strength changed significantly. However, the ductile—brittle transition temperature of China low-activation martensitic steel increased by 46 °C after aging for 10,000 hours due to precipitation and grain coarsening.

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1. Introduction

The reduced activation ferritic/martensitic (RAFM) steels have been developed using modified (8—12)CrMoVNb type ferritic—martensitic steels by replacing Nb, Mo, and Ni with W, Mn, and Ta to obtain low activation capability [1]. RAFM steels are considered the primary candidate structural materials for future fusion power reactors because of their good thermophysical properties, thermomechanical properties, and general industrial experience [2]. China low-activation martensitic (CLAM) steel is a RAFM steel that was developed at the Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences, Hefei, China with the collaboration of many domestic and international institutes and universities [3—6]. It has been chosen as the primary structural material in the designs of FDS series PbLi blankets for fusion reactors, the China test blanket module for ITER (ITER CN TBM), and the breeder blanket of China fusion engineering test reactor [7]. A series of studies of CLAM steel have been done by the FDS team, including property measurement [8—12], welding

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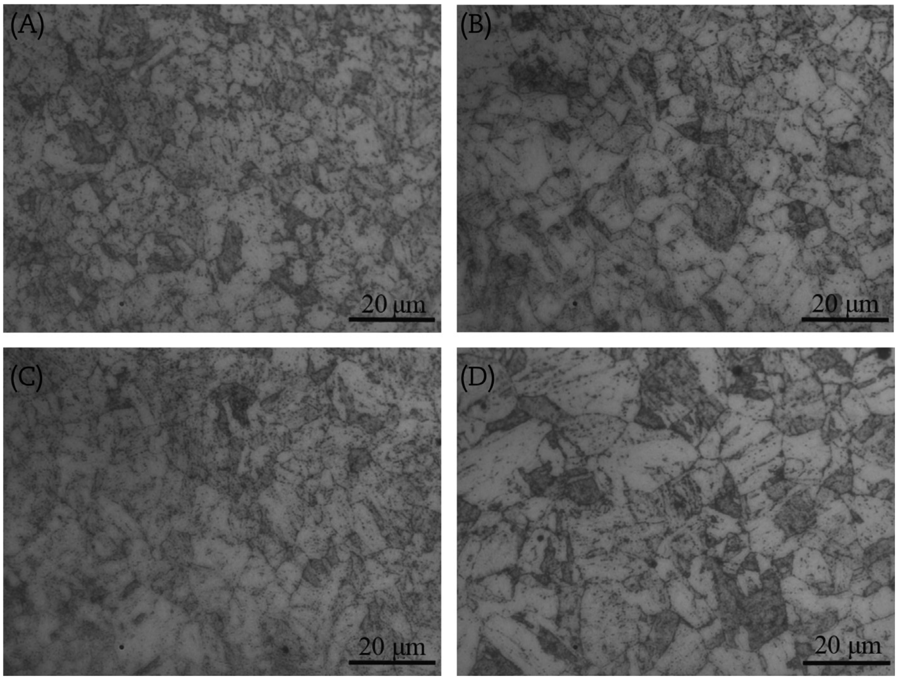

Fig. 1 – Optical micrographs of as-received and aged samples of China low-activation martensitic steel. (A) As-received; (B) 2,000 hours; (C) 4,000 hours; and (D) 10,000 hours.

techniques [13], post irradiation performance [14], and the research and development of TBM [15,16].

The upper limit temperature of the CLAM steel used in breeding blankets was proposed to be 550 °C. Hence, the thermal aging property is an important property to ensure the operation safety during exposure at the operating temperature. After long-term thermal exposure, the microstructure of RAFM steel will evolve, including precipitation and grain coarsening. This results in changes of mechanical properties. A number of thermal aging tests of other RAFM steels such as F82H and Eurofer have been conducted to characterize the microstructure evolution and properties change [17,18]. However, few studies were conducted on the aging effects of CLAM steel at 550 °C. The aim of the present work is to investigate the microstructure evolution and mechanical properties change of CLAM steel that has been aged at 550 °C up to 10,000 hours.

2. Materials and methods

The CLAM steel (HEAT 1005) used in this study was melted in a vacuum induction furnace and then electro-slag remelted into an ingot of 500 kg. The chemical composition of this material was 0.092% C, 8.9% Cr, 0.14% Ta, 0.15% V, 1.5% W, 0.05% Si, 0.49% Mn, 0.005% P, 0.002% S, and Fe in balance (in wt.%). The hot-rolled CLAM steel plate was heat treated with normalizing at 980 °C for 30 minutes and tempered at 760 °C for 90 minutes. Then, the tempered specimens were subjected to exposure at 550 °C for 2,000 hours, 4,000 hours, and 10,000 hours under air atmosphere in a tube furnace. The machining allowance of each specimen was more than 2 mm to eliminate the oxidation effects on the mechanical properties of the specimens.

The microstructure of the aged specimens was analyzed with optical micrographs (OM), a scanning electron microscope (SEM), and a transmission electron microscope (TEM). The surfaces of all the specimens used in OM were etched with ferric chloride solution, and the OM was used to observe the grains of CLAM steel samples. The grain size was measured with microimage analysis and process software using linear intercept measurement. The samples for the SEM images were produced by electrolytic polishing. The electrolyte was a solution of 20% perchloric acid and 80% alcohol, and the operating voltage was 20 V. The Ø3 mm discs used for TEM observation were polished down to a thickness below 0.1 mm. Then the discs were electropolished to their final thickness using a double jet electropolisher with a solution of 10% perchloric acid and 90% alcohol at −8 °C.

The mechanical properties after aging were measured by tensile and Charpy impact tests. Both the cylindrical tensile samples (Ø5 mm) and the Charpy-V-notch samples (10 mm × 10 mm × 55 mm) were machined parallel to the rolling direction of the plates. The tensile tests for as-tempered and as-aged samples were conducted at a strain rate of 5×10^{-3} Hz in air at room temperature and 550 °C. Each condition for the tensile tests used three samples. The ductile–brittle transition temperature (DBTT) of CLAM was obtained by the Charpy impact test. The testing temperatures ranged from −120 °C to room temperature (RT), and there were not less than two samples for each condition of the Charpy impact tests.

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