5 - 7 A Comparative Study of Proton Irradiation Responses of Three Candidate Materials for Proton Beam Windows: T91, SIMP Steel and Ti-6Al-4V

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Some typical ferritic-martensitic (F/M) steels (such as T91, SIMP) and dual-phase (α+β) Ti-6Al-4V alloys have been considered as candidate materials for high-intensity proton accelerator beam/target windows in the Spallation Neutron Source (SNS) and Accelerator-Driven Systems (ADS), owing to their excellent comprehensive properties, such as high strength, high thermal conductivity, and excellent radiation resistance. The material behaviors under high irradiation load by protons and neutrons is one of the key factors for the assessment of window lifetime. As a preferred material for beam window in the MEGAPIE project, the mechanical performance response of T91 to high irradiation exposure and LBE corrosion has been investigated. It is shown that an increase in the ductile-to-brittle transition temperature (DBTT) under irradiation is a critical limitation to the lifetime of the T91 beam window. In essence, the increase of DBTT is associated with the formation and evolution of radiation defects at high temperatures. In view of the hardness/embrittlement occurring at lower temperatures as well as high temperature creep and He embrittlement, the operational temperature range for T91 window was recommended to be 450∼550 ℃. Taking as a reference T91 and other (9% -12%Cr) F/M steels, a novel low-activation martensitic steel named SIMP steel has been cooperatively developed by Institute of Modern Physics (IMP) and Institute of Metal Research, Chinese Academy of Sciences (CAS). Both the composition and preparation procedures were optimized to offer the steel low activation characteristics and improve its resistance to radiation, oxidation and LBE corrosion. In the past studies, considerable efforts have been devoted to evaluating these properties and revealing the underlying micro mechanisms. In addition, it has been reported that titanium alloys seem more suitable than the steels as structural material for an industrial ADS beam window based on an integral analysis and calculations of spallation sources. However, so far, there is a lack of comparative experimental study on the proton radiation response of these three materials.

In the present study, proton radiation responses of T91, SIMP, and Ti-6Al-4V, three candidate materials for proton beam windows, were investigated by a 700 keV H^+ irradiation experiment at 460 ℃. Their radiation swelling and hardening were estimated by transmission electron microscope (TEM) and nanoindentation, respectively. As shown in Fig. 1, SIMP steel shows the lower radiation swelling and hardening as compared to T91 due to a higher Si content. No cavities were observed in Ti-6Al-4V by TEM, which may be attributed to high-density precipitates. Therefore, Ti-6Al-4V exhibits the best resistance to radiation swelling among these three materials. However, its radiation hardening rate is relatively higher due to precipitation strengthening. The combination of high-density bubbles and ¡100¿ loops is responsible for the radiation hardening of T91, while the radiation hardening of SIMP is resulted from a higher density of black dots and dislocation segments (Fig. 2). A more systematic study is underway.

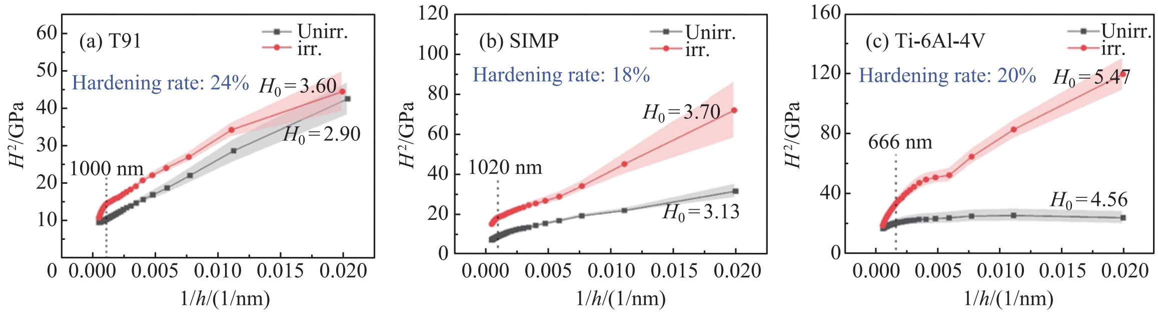

Fig. 1 (color online) The plots of H^2 vs. $1/h$ for irradiated and un-irradiated samples: (a) T91, (b) SIMP, and (c) Ti-6Al-4V.

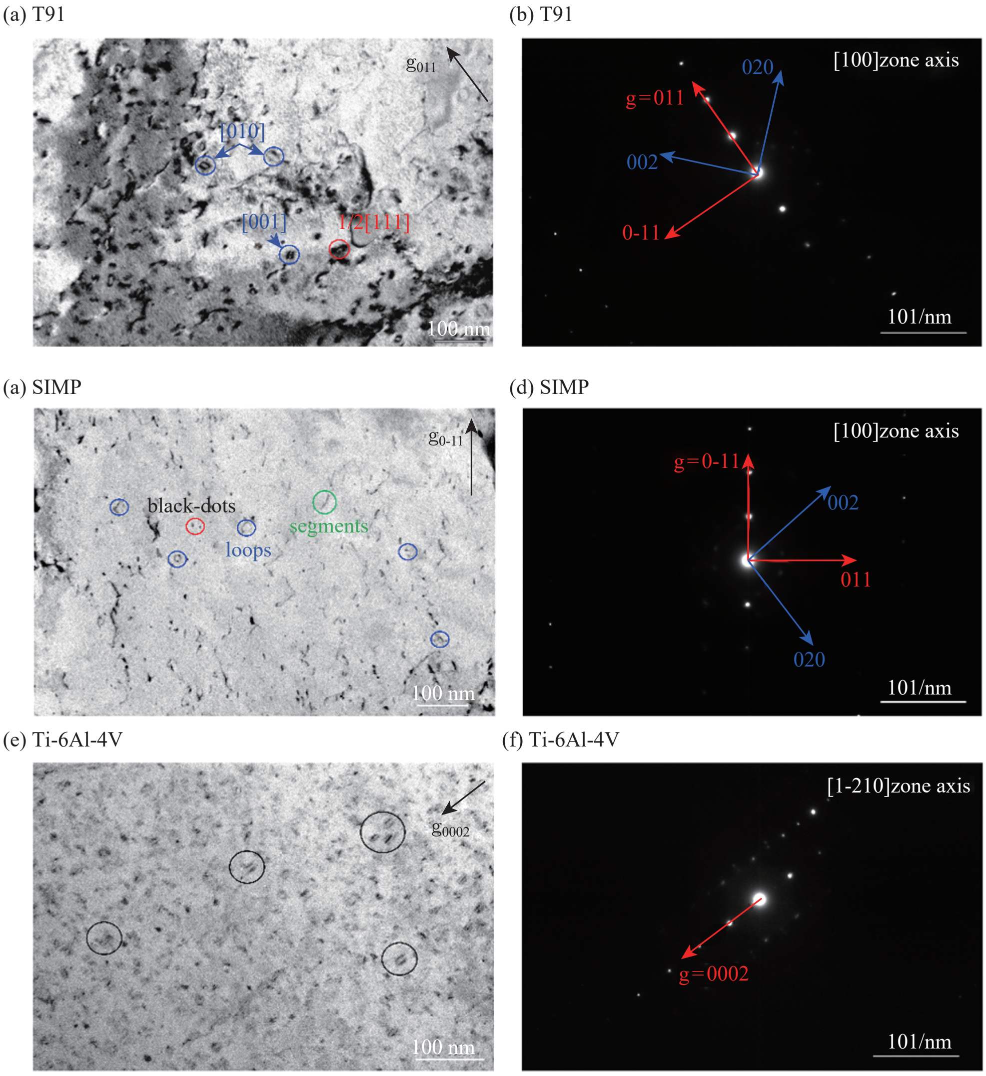

Fig. 2 (color online) The dislocation morphology near the peak damage region and corresponding diffraction pattern for T91(a, b), SIMP (c, d), and Ti-6Al-4V (e, f). For T91 and SIMP, the TEM bright-field images were taken near the zone axis [100] with g=<011>. <100> loops, 1/2 <111> loops (or black dots), and dislocation segments were marked by blue, red, and green circles, respectively.