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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　陳 思維

学 位 論 文 題 名

Helium Effect on Irradiation Hardening and Anneal Hardening in Iron and its Alloys
(鉄及びその合金における照射硬化及びアニール硬化に対するヘリウムの影響)

Fusion is an option for safe and sustainable energy supply which is placed to meet the energy requirements for the growing population. The effect of He on the microstructural stability and properties of materials used in the first wall blanket and diverter regions is a major focus of fusion materials research and development.

This dissertation contains work attempting to solve the problems about helium irradiation hardening (RH) and irradiation anneal hardening (RAH) in BCC iron and ferritic/martensitic steels. Materials were irradiated by helium ions at RT and nano-hardness is measured by a berkovich nanoindenter based on the Nix-Gao model. Nano-hardening as a function of helium concentration was obtained. Post-annealing was employed to investigate nano-hardness change as a function of temperature. To evaluate the helium effect on dislocation motion, pop-in phenomenon was analyzed and activation volume was extracted from experiment.

In Chapter 2, the range of irradiation hardening for pure iron is 3 - 4 GPa with the helium concentration from 500 to 2000 appm at RT. The irradiation hardening increases as a function of helium concentration. Helium induced hardening is saturated by a helium concentration at about 1000 appm. The saturation of irradiation hardening suggests that the formation of the irradiation damage structures which cause the irradiation hardening are balanced by the flow of the point defects in and out of the structures. In the post- annealing, 200 - 600 °C, pure Fe with helium concentration of 500 and 1000 appm shows a recovery behavior at temperature of 200 - 600 °C. The great recovery appears above 500 °C. For pure Fe with 2000 appm helium concentration, additional hardening (1GPa) was observed at the temperature of 300 °C. That is the first finding of the additional hardening in ion irradiation. The reason is the mobile helium atom and helium atom clusters can diffuse to defects and dislocation lines to pin the slip dislocation motion.The recovery behavior appears above 300 °C.

In Chapter 3, the range of irradiation hardening for F82H-IEA is 1 - 2.5 GPa with the helium concentration from 500 to 2000 appm at RT. The irradiation hardening increased with increasing in helium concentration, without a saturation tendency. In the post-annealing, specimens with/without helium were annealed at temperature 200 - 600 °C. Irradiation anneal hardening is independent as a function of temperature, indicating a stability of induced defects. The reason is that F82H-IEA steel is provided with high number density of dislocations. Helium atoms are trapped by dislocations and vacancies. There are no mobile helium atoms and clusters in those range of temperature. The obvious recovery behavior is expected to appear above 600 °C.

In Chapter 4, the range of irradiation hardening for F82H-ODS is 0.5 - 1.8 GPa with the helium concentration from 500 to 2000 appm at RT. The irradiation hardening increased with increasing in

helium concentration, without a saturation tendency. In the post-annealing, 200 - 600 °C, no additional hardening was observed in F82H-ODS and the induced defects are stable at temperature 200 - 600 °C. The reason is that F82H-ODS steel possesses a medium level of dislocation density and a high number density ($10^{23}m^{-3}$) of nano-sized oxide particles (4 nm). Helium atoms are trapped by dislocation, oxide particle-matrix interface and vacancy. There is no mobile helium atoms and clusters in those range of temperature. The obvious recovery behavior is expected to appear above 600 °C.

To understand the helium effect on dislocation motion, pop-in behavior during nanoindentation was investigated and activation volume of Fe, F82H and F82H-ODS with/without helium was extracted from experiment by a statistical thermal activation model in Chapter 5. The activation volume is decreased after helium irradiation, that means helium induced defects can act as barriers of slip dislocation motion. The change value depends on the nature of materials.

Chapter 6 is the conclusions of the whole work. Models on helium mechanisms of both pure iron and ferritic/matensitic steels have been given.