§12. Irradiation Effect of 14 MeV Neutron on A-15 Superconducting Wires

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According to the progress on design of fusion devices where D-D or D-T reaction will take place, neutron streaming from NBI ports and neutron penetration through shielding blankets has been clarified. The analytical researches show that some amount of neuron will reach superconducting magnets and activate the materials in the magnets. It is very hard to shield the neutron perfectly, so designers must know the protection of the superconducting magnets and the irradiation effect of fast neutron on the superconducting magnet materials. The irradiation has to be recognized as an unavoidable matter in the fusion system.

From 2002, the research on the effect of the neutron irradiation on the superconducting magnet materials has started. To investigate the effect of irradiation temperature, a cryogenic target system was designed and installed at Fusion Neutron Sources (FNS) in Japan Atomic Energy Agency (JAEA) at 2003. This was the first trial to irradiate 14 MeV neutron on the superconducting materials in Japan. The irradiation tests were carried out in 2004, 2005 and 2006. In parallel with the irradiation experiments, reviewing was performed to clarify the mechanism of change in superconducting property. Regarding the superconducting properties, the critical current, the critical temperature and the critical magnetic field are concerned and the experimental facts and the mechanism on the critical current are focused in this report.

Some important investigations on the neutron irradiation effect on superconducting materials were carried out in 1970s and 1980s using fission reactors (Brookhaven High Flux Beam Reactor, Kyoto University Reactor, etc.), a 14 MeV fusion neutron source (RTNS-II in LLNL) and an intense pulsed neutron source (IPNS in ANL. Nuclear spallation device). The effect of neutron irradiation on critical current is summarized and shown in Fig. 1 [1-4]. Three sets of irradiation experimental data are plotted in one figure. The results describe the following issues.

(1) By the irradiation, the critical current increases once and then decreases. This phenomenon is explained by knock-on effect and strengthening of pinning sites. As the critical current is related to the status of the pinning sites, it is considered that the neutron irradiation would strengthen the pinning sites and induce the new pinning sites of interstitials clusters.

(2) The Nb3Sn wires with the third element such as Ti and Ta show smaller increase of the critical current. This will be caused by a sort of saturation of the pinning sites.

(3) The test results at higher magnetic field give a larger increase of the critical current. Since the absolute critical current at higher magnetic field is smaller than that at lower magnetic field, the increment of the current is related to the phenomenon.

(4) The bronze process gives better change in the critical current than the other processes such as In-situ and Nb-tube methods. It means that the grain size and the long range ordering of the crystal will affect the superconducting behavior after neutron irradiation.

(5) The irradiation in fission reactor contains neutron spectrum and gamma ray, and the fusion neutron source provides pure 14 MeV neutron and no gamma ray. Therefore, there will be some effect of the neutron spectrum and the gamma ray, but no clear data has been reported.

(6) The total neutron fluence of 10^{22} n/m^2 will be available for the design of the superconducting magnet for fusion application, for no degradation of the critical current has not been observed in the region up to 10^{22} n/m^2.

As mentioned above, the knock-on phenomenon is one of key issues to explain the irradiation effect, i.e. changes in the critical current and the critical temperature. When fusion neutron hits an atom, the atom changes its position. Variable of dpa, displacement per atom, shows the fraction of the position change per one atom. Since the knock-on means the position change of the atom, a parameter of dpa will be a better variable to express the damage by neutron than the neutron fluence. Based on this consideration, conversion factors from neutron fluence to dpa were estimated for fission reactor and the fusion neutron source focusing on resistivity of pure copper [5]. The factors are as follows; 3.06 dpa/1.0 x 10^{26} n/m^2 for fission, and 3.67 dpa/1.0 x 10^{25} n/m^2 for fusion. It must be noted that there is one order difference in both factors. Therefore, it is easy to imagine that the KUR data in Fig. 1 will come near to the RTNS-II data, when the horizontal axis is converted from fluence to dpa. The critical current increases once and decreases, and a peak position exists around at a certain dpa. It represents that the pinning sites are in the most strengthened at that dpa.

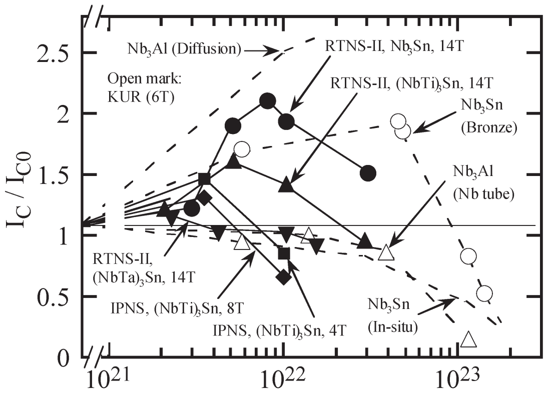

Fig.1 Change in critical current of Nb3Sn and Nb3Alwires as a function of neutron fluence.

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