A study of copper precipitation in the thermally aged FeCu alloy using SANS

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1. Introduction

The continued operation or lifetime extension of a number of nuclear power plant around the world requires an understanding of the damage imparted to the reactor pressure vessel (RPV) steel by radiation. Irradiation embrittlement of nuclear reactor pressure vessel steels results from a high number of nanometer sized Cu rich precipitates (CRPs) and sub-nanometer defect-solute clusters. The copper precipitation leads to a distortion of the crystal lattice surrounding the copper precipitates and yields an internal micro-stress [1]. In order to study the effect of copper precipitation on the steel embrittlement under neutron irradiation, the characteristics of nano size defects were investigated using small angle neutron scattering (SANS) in the thermal aged FeCu model alloys. The results on the precipitation composition, number density, size distribution and matrix composition obtained using a high resolution TEM and SANS are compared and contrasted

2. Method and Results

The steel used in this study were the Korea Atomic Energy Research Institute (KAERI) Laval model alloy with Cu as the major variant. The steels had nominal compositions (in weight percent) of Cu-1%. The steels were homogenizined in the temperature of 850C-5 hours for Cu over-dissolving followed by water quenched for Cu precipitation. The alloy were finally aged at a tmeperature of 500C for 5, 15, 30, 100 and 300 hours for Cu precipitation. The SANS experiment were performed in the research reactor HANARO. The specimens were measured in a strong magnetic field to separate the nuclear and magnetic scattering. The scattering from a well-collimated data beam of 0.43 nm wavelength neutrons was recorded on a position sensitive detector with a maximum q-range of about 1.5 nm. Small angle neutron scattering (SANS) measures the angular dependency of the scattering intensity. Indirect Fourier transformation is a widely used technique for the detection of instrumental broadening effects. Fourier transformation of the scattering intensity gives the correlation or the distance distribution function of the particles [2]. Indirect Fourier transformation (IFT) is a well established method in the field of small angle neutron scattering data evaluation.[3] In this study, the indirect Fourier transformation(IFT) is used to obtain the distribution of the thermal aged FeCu model alloys using GIFT(Generalized Fourier transformation) for a Windows program cooled at 228K with an applied potential of about 15V. The sizes of Cu precipitates were evaluated with the data of SANS and TEM analyses.

3. Results and discussion

Fig.1. shows the size distribution of Cu-precipitates. The diameter of the copper precipitates given by SANS varied from 3~10 nm, and increased continuously with the aging time. For the thermally aged alloy, the most notable results include the clear observation of copper-rich precipitates, evidence about the retention of a significant copper fraction in the solid solution at the peak of hardening, for a bimodal distribution of the particle sizes in the averaged condition. For the thermally aged Fe-Cu specimens, the neutron scattering intensity is no more linear in Guinier's representation with the whole studied q range.

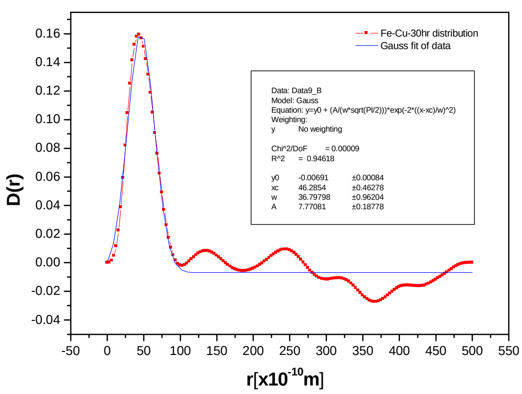

Fig.1. Calculated size distribution of precipitates for $FeCu_{1\%}$ thermally aged at 500 ℃ for 30 hours

In order to determine the precipitated volume fraction and the number density of clusters, we have calculated the A ratio which is defined as the ration between the nuclear and magnetic contrast. The A ratio in the as quenched specimen is nearly constant and almost equal to 1. But, the A ratio in the more aged specimens can be larger than 1. The size of Cu precipitates calculated from the SANS data of Fe-1.0%Cu specimen aged over 30 hours is about 5 nm which is well accord with that of HRTEM result in Fig.2. The micro-hardness increased with ageing time up to 30 hours, but decreased above the 300 hours.

Fig.2. HRTEM image of precipitates for $FeCu_{1\%}$ thermally aged at 500 ℃ for 30 hours.

References

[1] I. Altpeter et al., Nucl. Eng. Design, 206 (2001) 337-350

[2] J. Appl. Cryst. Otto Glatter. 14 (1981) 101-108

[3] J. Appl. Cryst. O. Glatter and K. Gruber 26. (1993) 512-518