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Radiation Hardening Mechanism of Fe-Cu

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1. Introduction

Generally radiation hardening has been explained with the mechanism of matrix damage and precipitation damage. When Fe-Cu alloys are irradiated with energetic particles, the increase of hardness cannot be explained simply with those mechanisms. To study the effect of copper precipitates, the hardness increase of Fe-Cu alloys and pure Fe were checked through changing ageing time at 500°C and irradiating with Fe ion. From the experimental results, over-saturated Cu was proved as a major factor of the hardness increase. And the number density and the motion of clusters were measured with HVEM. The density in Fe-1.0%Cu showed one order higher than that in pure Fe. This means Cu atoms affect the formation of clusters and the clusters could do the role of Cottrell atmosphere when dislocations pass through the clusters.

2. Methods and Results

2.1 Experimental

The starting material for this study was a binary Fe-Cu alloys made in our laboratory and Fe single crystal (99.98% Fe) supplied by Goodfellow. After Fe-Cu samples were solution-treated at 1,123K for 5 hrs in the vacuum condition, they were water-quenched. Samples were isothermally aged at 773K.

Vickers hardness was measured on the polished surface after aging for checking the effect of Cu precipitates growth. To measure the size and its distribution of precipitates, methods of SANS and TEM were selected. For examination in electron microscope, discs of diameter 3 mm were punched from aged samples. Thin areas were obtained by electropolishing in a Struers twin-jet electropolisher using a solution of 5% perchloric acid in methanol cooled at 228K with an applied potential of about 15V. . Some TEM samples were observed with 1.25 MeV HVEM in KBSI.

2.2 Mechanical Properties (Hardness)

The increase in hardness of Fe-1.0%Cu as a function of aging time at 773K is shown in Fig. 1. It shows a hardness increase by precipitation of 65 HV, after approximately 30 hours. After a comparatively short time (5 hours), the hardness has increased to a substantial amount (about 74% of maximum increase). The precipitates responsible for this initial stage must be very small since they are not detected in TEM analysis.

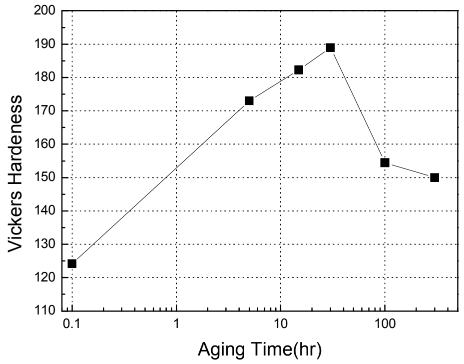

Fig.1. Change of microhardness in Fe-1.0%Cu during aging at 773K.

After 30 hours, a decrease in hardness shows over-aging. The analysis of the hardness change in FeCu alloys is usually explained by using of Russel and Brown model[1].

After 8 MeV Fe ion irradiation with the fluence of 1.9 x 10^{16} Fe^{+4}/cm^2, the hardness of Fe-1.0%Cu and Fe-0.1%Cu is shown in Fig.2.

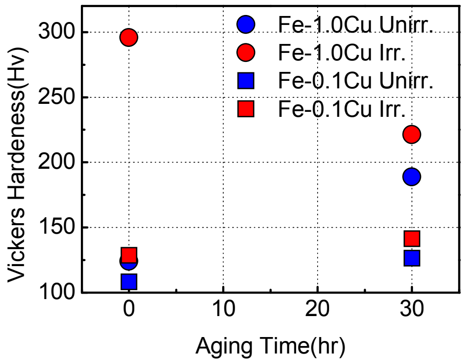

Fig. 2. Change of hardness after irradiation of Fe ion to Fe-1.0%Cu and Fe-0.1%Cu.

Fe-1.0%Cu shows severe increase of hardness in quenched specimens which have over-saturated Cu atoms. The samples aged 30 hrs and irradiated show a little increase of hardness, but the amount is smaller than that of quenched sample. The increase of aged samples can be explained with the effect of matrix damage.

2.3 Size of Cu Precipitates

The size of Cu precipitates in aged Fe-1.0%Cu is shown as Table 1. . After a comparatively short time (5 hours), the hardness has increased to a substantial amount (about 74% of maximum increase). The precipitates responsible for this initial stage must be very small since they are not detected in TEM analysis. Through SANS methods, the size of precipitates was measured as 2 nm. Therefore very small size precipitates can be considered as the major factor of hardness increase. But the increase of quenched samples cannot be explained with only the effect of precipitates.

Table 1. Size of Cu precipitates calculated from SANS and TEM measurements.

Aging Time(hr)	Size of Cu ppts (SANS), nm	Size of Cu ppts (TEM), nm
5	2	-
15	4	2(p1) 4(p2)
30	4.5	3(p1) 5(p2)
100	7	8(p1) 10(p2)
300	8	10(p1) 16(p2)

* P1and P2 means peaks at the bimodal distribution of precipitate size.

2.4 HVEM observation

The density of clusters was measured in Fe-1.0%Cu and pure Fe during the electron irradiation with HVEM.
Fig. 3 shows that the density in Fe-1.0%Cu was one order higher than that in pure Fe.

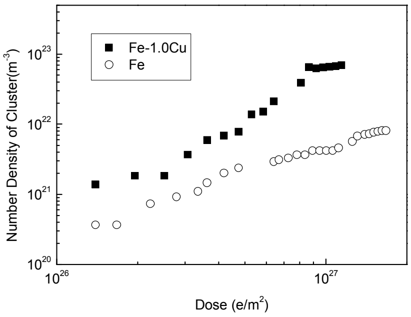

Fig. 3. Defect cluster density increase of Fe and Fe-1.0%Cu irradiated with electrons.

The density increased with the electron dose almost linearly. This means the formation of interstitial defects build up continuously without any reaction with sinks. The cluster density was well consistent with the data of Arakawa's[2] under similar irradiation condition. When this result is compared with the data of Fe-1.0%Cu alloy, the cluster density of pure Fe is about 3 order less than that of Fe-Cu under the similar irradiation condition. This phenomenon can be explained as the effect of Cu atoms which trap the vacancies.
In Fe-1.0%Cu, clusters showed higher frequency of one dimensional motion compared with that in pure Fe.

3. Conclusion

The Cu effect on radiation hardening was reviewed in Fe irradiated with energetic particles. Quenched Fe-1.0%Cu showed more hardness increase than aged sample did. From the cluster density data and cluster motion observation, the radiation hardening mechanism in Fe-1.0%Cu can be explained with the effect of vacancy trap in Cu atoms and the role of clusters as the Cottrell atmosphere. This work has been carried out as a part of Nuclear R&D program supported by Ministry of Science and Technology, Kore. And we thank the Korea basic Science Institute for the use of HVEM.

REFERENCES

[1] K. C. Russel. L. M. Brown, Acta Metall., Vol. 20, p. 969, 1972.

[2] K. Arakawa, M. Hatanaka, H. Mori and K. Ono, Effect of Chromium on the One-dimensional Motion of Interstitial-type Dislocation Loops in Iron, J. Nucl. Mater., Vol. 329-333, p. 1194, 2004.