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SWELLING OF COMMERCIAL COPPER ALLOYS AND NiBe IRRADIATED IN FFTF

H. R. Brager and F. A. Garner (Hanford Engineering Development Laboratory)

1.0 Objective

The object of this effort is to provide data on the swelling of high conductivity alloys in response to high fluence fast reactor irradiation and thereby predict their behavior in anticipated fusion environments.

2.0 Summary

The swelling of tensile specimens irradiated in the MOTA-1B experiment at ~450°C have been measured using immersion density. The majority of these specimens were constructed from various commercial copper alloys and exhibited density changes ranging from -0.66% to 16.6% swelling. The latter was obtained in a copper-0.1% silver specimen that reached 16 dpa, implying a swelling rate of at least 1%/dpa.

3.0 Program

Title: Irradiation Effects Analysis (AKJ)
Principal Investigator: D. G. Doran
Affiliation: Hanford Engineering Development Laboratory

4.0 Relevant DAFS Program Plan Task/Subtask

Subtask II.C.1, Effects of Material Parameters on Microstructure.

5.0 Status and Accomplishments

5.1 Introduction

In an earlier report(1) it was noted that nine copper-base alloys in thirteen material conditions had been inserted into the MOTA-1B experiment for irradiation in FFTF at ~450°C. Ni-1.9Be and AISI 316 were also included. The experiment involved both TEM disks and miniature tensile specimens. The tensile specimens do not include all of the alloy treatment conditions that are included in the TEM disks. The first discharge of MOTA-1B has occurred with the average fluence in the 450°C capsule at ~2.5 x 10^{22} n/cm^2 (E > 0.1 MeV). For stainless steel this exposure corresponds to ~12 dpa, but for copper, which has a lower displacement threshold energy, it corresponds to ~16 dpa. The tensile specimens have been measured for changes in density, using standard immersion density techniques.

5.2 Results

The measured changes in swelling of the miniature tensile specimens are given below:

TABLE I

SWELLING OF VARIOUS COMMERCIAL COPPER ALLOYS, Ni-1.9Be AND AISI 316 IN MOTA-1B AT ~450°C AND 2.5 x 10^{22} n/cm^2 (E > 0.1 MeV)

Alloy	Condition	% Swelling
Cu (99.999%)	Annealed	6.5
Cu-0.1 Ag	20% CW	16.6%
Cu-0.3 Ag-0.06 P-.08 Mg	20% CW	7.9
Cu-1.8 Ni-0.3 Be (A)	20% CW & Aged (1/2 HT)	1.70
Cu-1.8 Ni-0.3 Be (B)	Annealed & Aged (AT)	0.29
Cu-2.0 Be (A)	20% CW & Aged (1/2 HT)	-0.18
Cu-2.0 Be (B)	Annealed & Aged	-0.66
Cu-0.9 Cr-0.1 Zr-0.05 Mg	Aged & 90% CW	1.03
Cu-0.25 Al_2O_3	20% CW	0.13
Ni-1.9 Be	Annealed & Aged	-0.37
AISI 316 (lot CN-13)*	Annealed	-0.20

*Included as a standard reference material.

5.3 Discussion

The 16.6% swelling observed in the 20% cold-worked Cu-0.1 Ag alloy represents a swelling rate of at least 1%/dpa which is comparable to that observed in pure nickel and Fe-Ni-Cr simple ternary alloys.(2) Zone-refined copper in the annealed condition swelled only 6.5%, however, which is initially surprising since most solutes added to pure metals result in a reduction of swelling. The addition of silver to copper is known to be an exception, however. As shown in Figure 1, Makin found that the addition of 1% silver greatly suppresses the tendency of copper to saturate in swelling during electron irradiation at 250°C.(3) Barlow also studied copper with 0.1 and 1.0 wt.% silver using electron irradiation.(4) He found that the 0.1% alloy behaved like pure copper at all temperatures, but the 1% Ag alloy swelled at a higher rate than pure copper at 150-250°C. In the range 350-450°C the swelling rate of the electron irradiated pure copper and copper +1% silver were the same.

Since the influence of the solute silver was shown in HVEM studies to be dependent on its concentration, it is not surprising that the Cu-0.3 Ag-0.06 P-0.08 Mg alloy swelled in MOTA to a level intermediate to that of pure copper and Cu-0.1% Ag. The phosphorus and magnesium probably also played a role. No data are available for phosphorus, but the addition of 0.7% magnesium at ~500°C led to a slight reduction in the swelling of copper irradiated with 150 KeV Cu^+ ions.(5)

The data in Table 1 show that beryllium is an effective suppressor of swelling in copper, particularly at the 2% level. Makin also showed in his electron irradiation studies that the addition of 1% beryllium at 250°C resulted in a total suppression of swelling to 100 dpa.(3) One clue to beryllium's effectiveness in suppressing swelling lies in the large densification observed in the Cu-2% Be alloy. Such changes in density are usually associated with segregation and/or formation of ordered phases, particularly when substantial solute-solvent misfit is involved. Indeed, beryllium has a large negative misfit of -26% and forms CuBe precipitates during ion irradiation of Cu-1.35 at % Be in the range of 300-700°K.(6,7) Beryllium additions were also shown to strongly enhance diffusion in copper during irradiation.(7)

Nickel has a smaller misfit (-8%) and diffuses slower than does copper in Cu-Ni alloys.(7) Void formation was found to be inhibited by nickel additions during 46.5 MeV Ni^+ irradiation at 400°C.(8) In electron irradiations of various copper-nickel alloys, Barlow(4) and Leffers and coworkers(9) showed that nickel additions could both increase or decrease swelling, depending on the irradiation temperature and nickel level. In the MOTA experiment, the combined effect of 1.8% nickel and small (0.3%) beryllium additions led to a reduction but not total suppression of swelling.

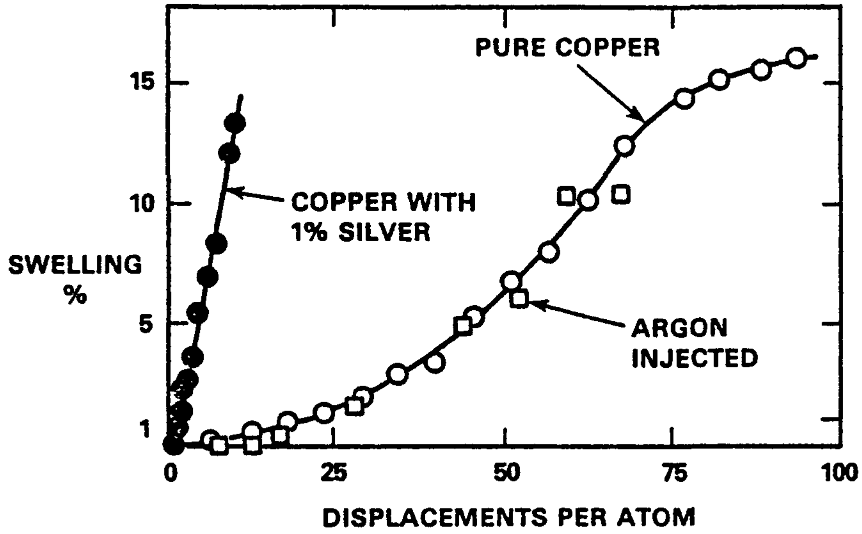

FIGURE 1. Swelling of Pure Copper and Copper +1% Silver During Irradiation With 1.0 MeV Electrons at 250°C.[3]

The most interesting swelling response in the MOTA experiment was that of Cu-0.25 Al_2O_3. Alumina additions should be inert at this temperature and yet the swelling was reduced from the 6.5% level of pure copper to only 0.13%.

Since the tensile specimens do not include the entire range of alloy conditions covered by the TEM disks, we cannot at this time make definitive statements about the effect of cold-work on swelling. Such conclusions must await the measurement of density changes in the TEM disks.

Table I also shows that a substantial densification occurred in the strong and moderately conductive Ni-1.9 Be alloy irradiated in MOTA at 450°C. The suppression of swelling in ion-irradiated nickel with beryllium additions has been demonstrated by several authors.[10,11] Ordered precipitates of NiBe were also found to develop during irradiation.[11] The swelling of pure nickel during fast neutron irradiation is covered in another report.[12]

5.4 Conclusions

Copper alloys have the potential for swelling at a rate of about 1%/dpa during neutron irradiation at 450°C. Zone-refined copper tends to swell to lower levels, however, and may be saturating at levels of swelling which are at least as large as 8%. Additions of various alloying elements can delay or suppress swelling, but the addition of silver tends to increase swelling, apparently by precluding the possibility of saturation. The data developed in this report show that the response of various copper alloys to either charged particle or neutron irradiation is quite similar.

6.0 References

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7.0 Future Work

Density change data will continue to be generated on the TEM disks. Tensile, resistivity measurements and electron microscopy examination will also be performed.

8.0 Publications

None