NEUTRON-INDUCED CHANGES IN DENSITY OF
COPPER ALLOYS

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NEUTRON-INDUCED CHANGES IN DENSITY OF COPPER ALLOYS - F. A. Garner, Pacific Northwest Laboratory,^(a) and H. R. Brager, Westinghouse Hanford Company

OBJECTIVE

The objective of this effort is to identify those copper alloys which offer promise as high heat flux materials for fusion applications.

SUMMARY

Density change measurements have been completed on the Generation 2.0 copper alloy experiment at 411°C after reaching 100 dpa. The Glidcop alloy CuAl25 continues to exhibit excellent resistance to void swelling. Welding and high oxygen levels both degrade the swelling resistance of oxide dispersion-strengthened alloys. The alloy Cu-2.0Be also resists swelling and appears to be densifying in response to the continued formation of the transmutant nickel.

PROGRESS AND STATUS

Introduction

In an earlier report, the neutron-induced swelling was reported for a number of copper alloys included in a first generation exploratory program designed to assess the suitability of such alloys for high heat flux diverter applications.¹ These alloys reached 16, 47, 63 and 98 dpa in FFTF/MOTA at a reported temperature of 450°C. This temperature assignment included an upper bound estimate of 30°C gamma heating above the ambient coolant temperature of 420°C. More recent calculations now yield 8-10°C gamma heating such that 430°C is a better temperature assignment for that experiment.

As documented in a separate report, the earlier results of the first generation experiment led to two successively more focused experiments, designated Generation 1.5 and 2.0.² These experiments involved the irradiation of some but not all of the Generation 1.0 alloys, but also included a wider variety of alloys hardened either by dispersed oxides of various types or by spinodal decomposition. While Generation 1.5 reached 34 dpa at 414°C and 32 dpa at 529°C, Generation 2.0 has reached 50 and 100 dpa at 411°C and is still being irradiated. The last specimens of Generation 2.0 alloys at 400°C and 150 dpa will be discharged from the current MOTA cycle.

An earlier report presented the results of density change measurements for the Generation 1.5 and 2.0 alloys for displacement levels of 50 dpa or lower.³ Measurements are now complete for the Generation 2.0 specimens at 411°C and 100 dpa. A list of the alloys and their processing conditions is presented in Table 1.

Results

Figures 1 and 2 present the accumulated swelling data for all fluences and temperatures measured in Generations 1.5 and 2.0. While some alloys have yet to show swelling at 100 dpa, others have reached levels of 50 to 70%. The highest swelling levels were reached by a group of oxide dispersion-strengthened (ODS) alloys known to have high oxygen levels, while the lowest swelling alloy is the dispersion-strengthened Glidcop alloy CuAl25, which has a relatively low level of oxygen.

Figure 3 compares the swelling observed in pure copper and Cu-5Ni in five separate irradiation tests conducted in three different reactors at 400°C. Adding the most recent datum for pure copper at 100 dpa confirms the reproducibility of the swelling phenomenon at 400°C. Both Cu and Cu-5Ni swell at a rate of 0.5%/dpa.

As shown in Figure 4, the swelling of Glidcop alloys depends on the oxide content and possibly on the cold work level. These alloys are designated by their aluminum content. CuAl25 contains 0.25 wt.% of aluminum in the form of Al₂O₃ and CuAl15+B contains 0.15 wt.% aluminum and ~100 appm boron. The progressive densification observed in CuAl25 may represent the influence of accumulating transmutants, primarily nickel and zinc. Laser welding was found to completely destroy the swelling resistance of the Glidcop alloy and accelerate the swelling of the ODS alloy. The behavior of the welded Glidcop alloy is shown in Figure 5. Several other ODS alloys prepared by mechanical alloying (CuCr and CuHf) were found to swell at levels intermediate to those of the Glidcop and ODS alloys, as shown in Figure 6. The post-irradiation microstructures of all the dispersion-strengthened alloys are discussed in reference 4.

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Table 1
Composition and Final Processing Conditions of Copper Alloys

Alloy	Composition (wt%)	Final Processing Condition
Marz Cu	99.99 Cu	Annealed
Cu-5Ni	Cu - 5% Ni	Annealed
Cu-Be	Cu - 2% Be	Annealed, Aged 2 hr 320°C
CuNiBe	Cu-1.8% Ni-0.3% Be	Annealed, Aged 3 hr 482°C
CuNiBe	Cu-1.8% Ni-0.3% Be	20% CW, Aged 3 hr 482°C
CuNiBe	Cu-1.8% Ni-0.3% Be	20% CW, Aged 9 hr 540°C
MZC	Cu-0.9% Cr-0.1% Zr-0.05% Mg	90% CW, Aged 1/2 hr 475°C
MZC	Cu-0.9% Cr-0.1% Zr-0.05% Mg	90% CW, Aged 1 hr 500°C
MZC (MIT #2)	Cu-0.9% Cr-0.1% Zr-0.05% Mg	50% CW, Aged 1 hr 500°C
MZC (MIT #3)	Cu-0.9% Cr-0.1% Zr-0.05% Mg	Annealed, Aged 1 hr 500°C
CuAl25	0.25% Al as Alumina	50% CW
CuAl25	0.25% Al as Alumina	50% CW + welded
CuAl20	0.20% Al as Alumina	20% CW
CuAl15+B	0.15% Al as Alumina <200 ppm Boron	Annealed
CuCr	3.5% Cr as Cr Oxide	20% CW, 1/2 hr 450°C
CuHf	1.1% Hf as Hf Oxide	20% CW, 1/2 hr 450°C
ODS-1	0.25% Mg, 1% Alumina	40% CW
ODS-1	0.25% Mg, 1% Alumina	40% CW + welded
ODS-2	0.25% Mg, 1% Alumina	40% CW
ODS-3	0.5% Mg, 1% Zr Oxide	40% CW
ODS-4	0.5% Mg, 1% Alumina	40% CW
CuNiTi (VK)	Cu-5.0% Ni-2.5% Ti (MIT #3)	Solutionized and Aged
CuNiTi (VL)	Cu-5.0% Ni-2.5% Ti (LASL)	Solutionized and Aged

Figure 6 also shows the swelling behavior for those alloys involving solute modification and precipitation-strengthening. Note in some precipitation strengthened alloys that cold working prior to irradiation actually increases swelling. This behavior was also observed in the Generation 1.0 study and reflects the influence of cold work on precipitation.¹ Densification of Cu-2.0Be at higher fluence probably reflects additional precipitation of Be from solution as nickel is formed via transmutation. The phenomenon was also observed in the Generation 1.0 experiment.⁵

CONCLUSIONS

Density change measurements at 411°C and 100 dpa confirm the superiority of the Glidcop alloys for resistance to void swelling. Welding or lowering of the oxide dispersoid level leads to higher swelling in the Glidcop alloys. There may also be some influence of the cold work level.

FUTURE WORK

This work will continue, focusing on measurements of radiation-induced microstructure, changes in electrical resistivity, and changes in tensile properties and fracture mode.

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Figure 1. Swelling observed in various copper alloys irradiated in Generations 1.5 and 2.0.

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Figure 2. Swelling observed in various copper alloys irradiated in Generations 1.5 and 2.0.

Figure 3. Comparison of swelling behavior at 385-430°C of pure copper and Cu-5 wt% Ni in various irradiation experiments.

Figure 4. Dependence of swelling of Glidcop alloys at 411-414°C on Al_2O_3 content and starting condition.

Figure 5. Loss of swelling resistance in CuAl25 upon laser welding prior to irradiation. MOTA-IE refers to the Generation 2.0 experiment. The swelling at 100 dpa of the welded alloy was rather variable, ranging from 19 to 43% while the unwelded alloy densified, as shown in Figure 4.

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Figure 6. Swelling observed in various copper alloys irradiated in the Generation 1.5 and 2.0 experiments.

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