EFFECT OF HEAT TREATMENTS ON PRECIPITATE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A CuCrZr ALLOY—D. J. Edwards (Pacific Northwest National Laboratory),* B. N. Singh (Risø National Laboratory, Denmark), and S. Tähtinen (VTT Industries, Finland)

EXTENDED ABSTRACT (presented at the 12th International Conference on Fusion Reactor Materials, Santa Barbara, California, December 4–9, 2005)

Experimental investigations have demonstrated that neutron irradiation of prime aged CuCrZr at temperatures below ~ 473K leads to a substantial increase in strength, formation of a tensile instability, and a severe loss of work hardening ability and uniform elongation [1, 2]. The precipitates in this alloy are unable to inhibit localized deformation via dislocation channeling in the irradiated materials, namely because the precipitates are small Guinier-Preston (G-P) zones too weak to effectively prevent or hinder dislocation motion once dislocations become mobile at stress concentrations. It was therefore decided to coarsen the precipitate microstructure by annealing the prime aged CuCrZr so that larger and hopefully stronger precipitates, albeit in lower density, might prove more effective at preventing the initiation of plastic flow localization by resisting dislocation motion. As a starting point, we hoped to achieve a precipitate microstructure in the over-aged CuCrZr that was coarsened to a level near that of the GlidCop Al25, that is, particles with an average size of ~ 7–8 nm with a density of ~ 10^{22} particles per m^{-3}.

A CuCrZr alloy (Cu-0.73%Cr-0.14%Zr) supplied by Outokumpu Oyj (Finland) was solution annealed at 1233K for 3 h, water quenched and then prime aged (PA) at 733K for 3 h. After prime ageing the specimens were given further heat treatments to modify the precipitate microstructure. In the first series, the prime aged specimens were annealed in vacuum at 873K for 1, 2, and 4 h. In the second series a number of prime aged specimens were annealed at 973K and 1123K for 4 h. All specimens were water quenched after final annealing at the various temperatures.

The microstructures of each heat treatment condition were characterized using a JEOL 2000FX transmission electron microscope (TEM). Specimen preparation and the imaging conditions used to characterize the microstructure of these samples have been described in previous work [1,2]. As expected, heat treatments after prime ageing led to significant coarsening of the prime aged precipitate microstructure. The annealing replaced the G-P zones with precipitates thought to be predominately incoherent Cr-rich particles, which are commonly observed in this alloy [3–6]. As the data presented in Table 1 shows, annealing for 1–2 hours at 873K produced a significant coarsening that was accelerated when the annealing time was increased to 4 hours. Increasing the annealing temperature to 973K for 4 hours produced an even lower density of larger precipitates, whereas annealing at 1123K appeared to solution anneal the material and remove all but the sub-micron Cr inclusions, which were probably present in the original solution annealed material.

Table 1. Measured size and densities of precipitates

Heat Treatment	Precipitate Size (nm)	Precipitate Density (x 10^{23} m^{-3})
Prime aged (PA)	2.2	2.6
PA + 873K/1 h	8.7	0.17
PA + 873K/2 h	9.4	0.18
PA + 873K/4 h	21.3	0.015
PA + 973K/4 h	46.4	0.007
PA + 1123K/4 h	Precipitates removed (effectively solution annealed)	----------

Because the over-aged condition of 873K at 1–4 hours yielded a reasonable density of larger, and presumably stronger, particles than found in the prime aged condition, samples given these two over-aging treatments were selected for inclusion in a neutron irradiation experiment. A number of tensile and fracture toughness specimens of the CuCrZr alloy in the prime aged condition and the 1 or 4 hour over-aging treatment were irradiated with fission neutrons in the BR-2 reactor at Mol (Belgium) at 373 and 573K to a displacement dose level of ~ 0.3 dpa (displacement per atom). The damage rate during irradiation was ~ 6 x 10^{-8} dpa s^{-1}.

The tensile and fracture toughness results shown in Figs. 1 through 4 demonstrate that the coarsening of the precipitates due to over-aging produced a significant decrease in the tensile strength and some increase in fracture toughness properties of the alloy. The irradiation at 333K to a dose level of ~ 0.3 dpa caused significant hardening both in the prime aged and over-aged specimens while severely reducing the ductility and work hardening. The tensile response and post-deformation microstructure of the irradiated alloy indicate that the lower density of larger particles produced by over-aging at 873K for one hour improved the plastic instability and led to some increase in the overall ductility. The over-aging heat treatment PA+873K/1 hr also improved the fracture toughness properties when compared to those of the prime aged CuCrZr alloy in irradiated conditions at 333 and 573K.

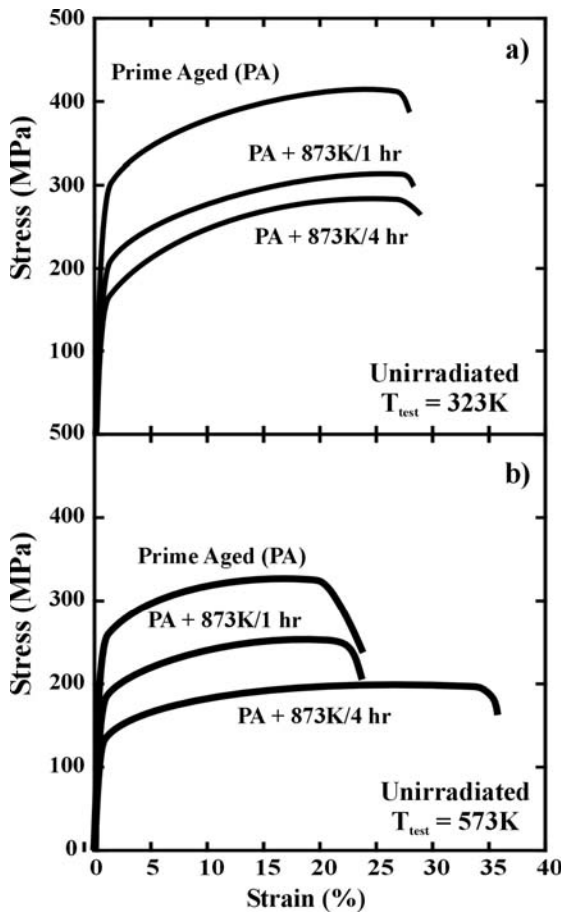

Fig. 1. Stress-strain curves for CuCrZr alloy in the prime-aged condition and after annealing at 873K for 1 and 4 hours and tensile tested at (a) 323K and (b) 573K.

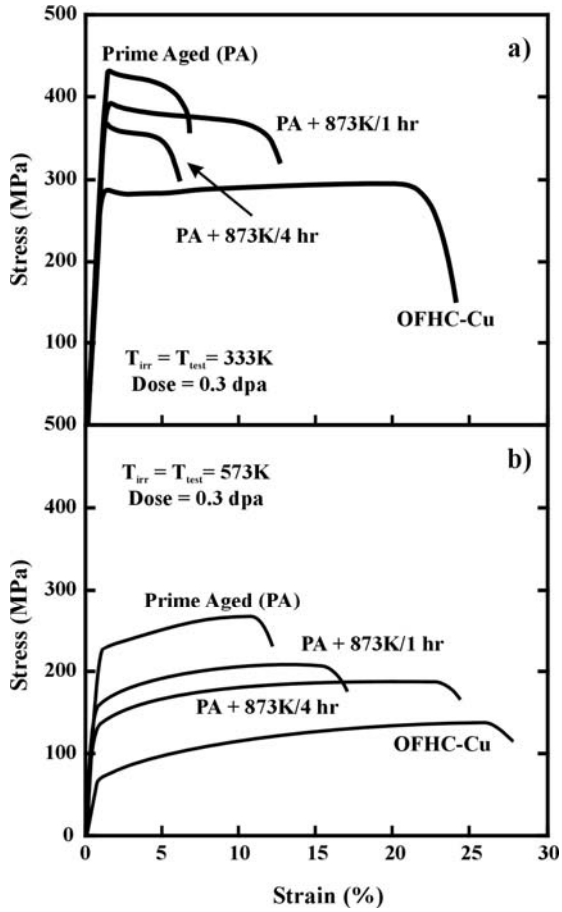

Fig. 2. Stress-strain curves for CuCrZr alloy irradiated to a dose level of ~ 0.3 dpa in the prime aged and over-aged at 873K for 1 h and 4 h conditions and tensile tested at (a) 333K and (b) 573K.

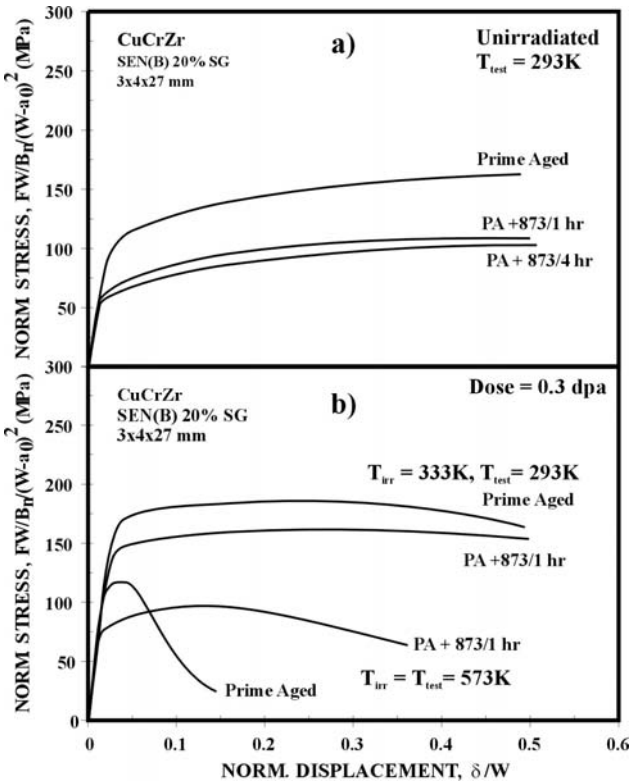

Fig. 3. Normalised load-displacement curves for CuCrZr alloy (a) in unirradiated and prime aged and over-aged (at 873K for 1 h and 4 h) conditions at 293K and (b) irradiated at 333K and 573K and tested at 293K and 573K, respectively, to a dose level of ~ 0.3 dpa in the prime aged and over-aged (at 873K for 1 h) conditions.

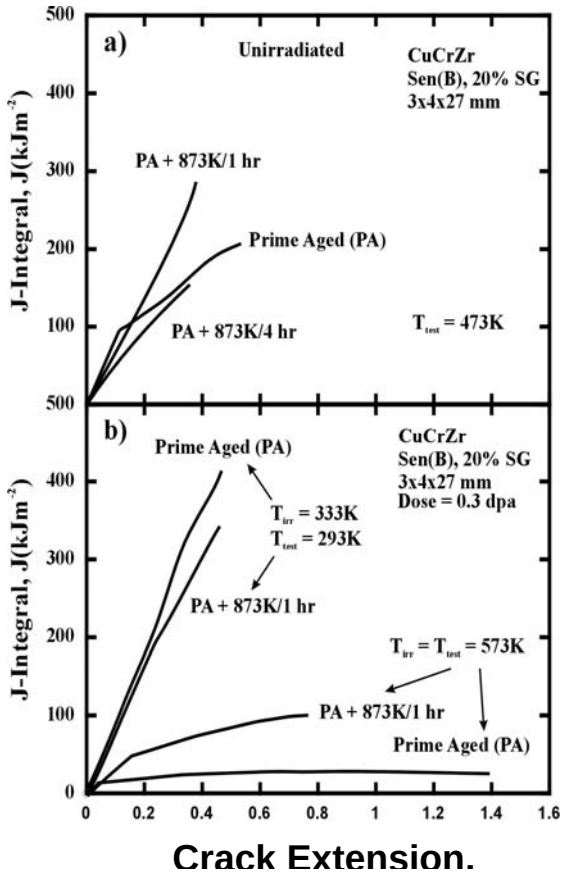

Fig. 4. Fracture resistance curves for CuCrZr alloy (a) in unirradiated and prime aged and over-aged (at 873K for 1 h and 4 h) conditions at 473K and (b) irradiated at 333K and 573K and tested at 293K and 573K, respectively, to a dose level of ~ 0.3 dpa in the prime aged and over-aged (at 873K for 1 h) conditions.

Despite these positive changes in the mechanical response, microstructurally the material was found to deform by a dislocation channeling in all of the conditions studied. These results suggest that some improvement in the mechanical response of irradiated CuCrZr can be realized if care is taken to alter the final thermomechanical treatment to introduce a precipitate dispersion that is coarser than that produced by prime ageing while still maintaining a sufficient precipitate structure to inhibit the motion of dislocations within the channels.

Acknowledgements

The present work was partly funded by the European Fusion Technology Programme. The authors wish to thank B. F. Olsen for his technical assistance. D. J. Edwards would like to thank Risø National Laboratory for the support and assistance during his visit. His work was partly supported by the U.S. Department of Energy under contract DE-AC06-76RLO 1830 with the Battelle Memorial Institute at the Pacific Northwest National Laboratory.

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