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INFLUENCE OF COLD-WORK ON THE
NEUTRON-INDUCED SWELLING
OF Fe-Ni-Cr TERNARY ALLOYS

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INFLUENCE OF COLD-WORK ON THE NEUTRON-INDUCED SWELLING OF SIMPLE Fe-Ni-Cr TERNARY ALLOYS

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

1.0 Objective

The object of this effort is to determine the origins of the sensitivity of void swelling in irradiated metals to environmental and material variables.

2.0 Summary

The swelling of simple Fe-Ni-Cr ternary alloys in EBR-II appears to be sensitive to both irradiation temperature and cold-work. It is suggested that cold-work interacts with the tendency of Fe-Ni-Cr alloys to order during irradiation and thereby affects swelling.

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 earlier reports it was shown that cold-working of solute-bearing austenitic alloys affects their phase evolution, thereby controlling the composition of the alloy matrix and the onset of void swelling.⁽¹⁻³⁾ In the absence of solutes such as carbon and silicon, there is very little tendency to form precipitate phases. It was therefore proposed that cold-work might exert no influence on swelling of f.c.c. metals and alloys in the absence of such solutes.⁽³⁾ This suggestion was supported by observations that low fluence neutron irradiations of pure aluminum, copper and nickel produced either small increases in swelling with cold-work or no change.⁽⁴⁾ Holmes⁽⁵⁾ also showed that 50% cold-working did not influence the swelling of pure nickel over the range 399-455°C, as shown in Figure 1. To test this hypothesis the swelling of both annealed and 20% cold-worked specimens of "pure 316" (Fe-17Cr-16.7Ni-2.5Mo) designated as alloy P-7 was measured after irradiation in the Oak Ridge Research (ORR) reactor at several temperatures.⁽⁶⁾ No effect of 20% cold-work on swelling was observed. It now appears that this result may not have been a fair test of the hypothesis, however.

It was later learned that this alloy contained in excess of 1000 appm oxygen and it appears that void nucleation was dominated by this anomalous aspect of the alloy. One possible indication of this supposition is that the swelling behavior of P-7 in the High Flux Isotope Reactor (HFIR) was completely atypical of that observed in other heats of AISI 316 as well as other Fe-Ni-Cr alloys irradiated in both HFIR and EBR-II. Whereas all Fe-Cr-Ni alloys irradiated to date have exhibited a minimum transient regime of ~10 dpa and a post-transient swelling rate of ~1%/dpa, the P-7 alloy in HFIR had no measurable transient regime and a temperature-independent swelling rate of 0.5%/dpa.⁽⁷⁾

Although many simple Fe-Ni-Cr ternary alloys have been irradiated in EBR-II and reported in the DAFS Quarterly Progress Report series,⁽⁸⁻¹⁰⁾ all of these alloys were irradiated in the solution-annealed condition. In the AA-XI experiment, however, both annealed and 30% cold-worked conditions of alloy E20 were irradiated side-by-side in EBR-II at 425 and 540°C to fluences of 3.7 and 4.9×10^{22} n/cm² ($E > 0.1$ MeV) respectively. These exposures correspond to 18.5 and 24.5 dpa. Alloy E20 is Fe-24.4Ni-14.9Cr with very low levels of the usual solutes.⁽⁸⁾

5.2 Results

The swelling was determined by immersion density measurements and is shown in Table 1.

TABLE 1
SWELLING OBSERVED IN ALLOY E20 IN THE AA-XI EXPERIMENT

Temperature °C	Displacement Level (dpa)	Alloy Condition	Swelling %
425	18.5	Annealed	12.8*
425	18.5	30% CW	3.8*
540	24.5	Annealed	1.14*
540	24.5	30% CW	4.81**
			3.61**

*Average swelling of four identical specimens exhibiting very small differences in density.

**Separate measurements on two nominally identical specimens.

5.3 Discussion

Contrary to our previous expectations, it appears that cold-working can indeed affect the swelling of solute-free ternary alloys although the results above indicate that swelling can be either increased or decreased, depending on the irradiation temperature. Note in Figure 2 that the swelling of solution-annealed specimens in this study agrees reasonably well with the behavior observed in the same alloy in the AA-VII experiment. This is consistent with the similarity observed between specimens irradiated in the AA-VII and AD-1 experiments.⁽¹⁰⁾

With some caution, one can make another observation. Note that when the irradiation was performed in the temperature-insensitive regime (400-510°C), cold-working led to decreased swelling. When the irradiation was performed above the order-disorder transition temperature (which lies somewhere in the range $510 < T < 538^\circ\text{C}$) the effect of cold-work was to increase the swelling. While it is too early to draw definitive conclusions, it appears that this unexpected result may be due to the influence of cold-working in destroying the tendency of the alloys to exhibit short-range order. Ordering processes have recently been implicated in controlling of the swelling behavior of Fe-Ni-Cr alloys.⁽¹¹⁻¹³⁾

6.0 References

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FIGURE 1. Effect of Cold-Work and Impurities on Swelling of Various Nickel Alloys in EBR-II Over the Range 379 to 455°C.(5)

FIGURE 2. Swelling of Alloy E20 (Fe-25Ni-15Cr) in Two Separate Experiments Conducted in EBR-II. The influence of cold-work on swelling can be seen in (b) and (c).

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7.0 Future Work

This effort will continue, focusing on the examination of these and other Fe-Ni-Cr ternary specimens using electron microscopy and x-ray analysis.

8.0 Publications

None.