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HEDL-7534

NEUTRON-INDUCED SWELLING OF Fe-Cr-Mn TERNARY ALLOYS

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HANFORD ENGINEERING DEVELOPMENT LABORATORY — Operated by Westinghouse Hanford Company, P.O. Box 1970, Richland, WA, a Subsidiary of Westinghouse Electric Corporation. Prepared for the USDOE, Office of Energy Research, Office of Fusion Energy, under Contract No. DE-AC06-76FF02170, B&R No. AT-15-02-03-04.

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

1.0 Objective

The object of this effort is to determine those factors which control the swelling of alloy systems which have the potential for reduced activation.

2.0 Summary

It appears that the swelling of Fe-Cr-Mn alloys is remarkably insensitive to both irradiation temperature (420-600°C) and composition. The slight dependence of macroscopic swelling on manganese content is thought to be primarily the consequence of a composition-dependent densification, possibly associated with radiation-induced spinodal decomposition in the Fe-Cr-Mn Invar regime. The steady-state swelling rate of these alloys appears to be ∿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 Accomplishments and Status

5.1 Introduction

In a previous report[1] it was shown that the swelling of simple Fe-Mn binary and Fe-Mn-Cr ternary alloys in FFTF-MOTA at 520°C and ∿14 dpa is remarkably insensitive to the chromium level and only weakly dependent on the manganese level as shown in Figure 1a. Figure 1b shows that this behavior is quite different from that of Fe-Cr-Ni alloys which are strongly sensitive to both chromium and nickel for comparable irradiation conditions.

Additional immersion density data are now becoming available for this irradiation series. The portion of the data matrix that is now complete leads us to revise somewhat our earlier conception of the parametric dependency of swelling in the Fe-Cr-Mn system.

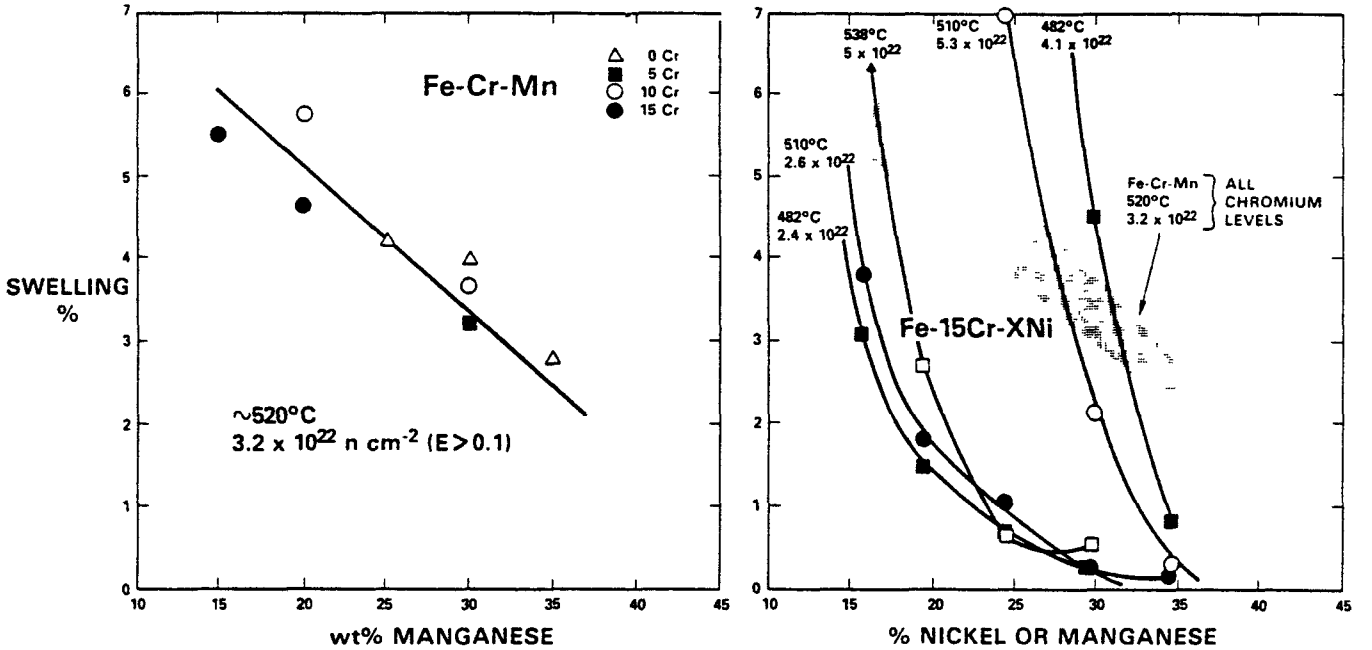

FIGURE 1. Comparison between neutron-induced swelling in Fe-Cr-Mn and Fe-Cr-Ni alloys.[1]

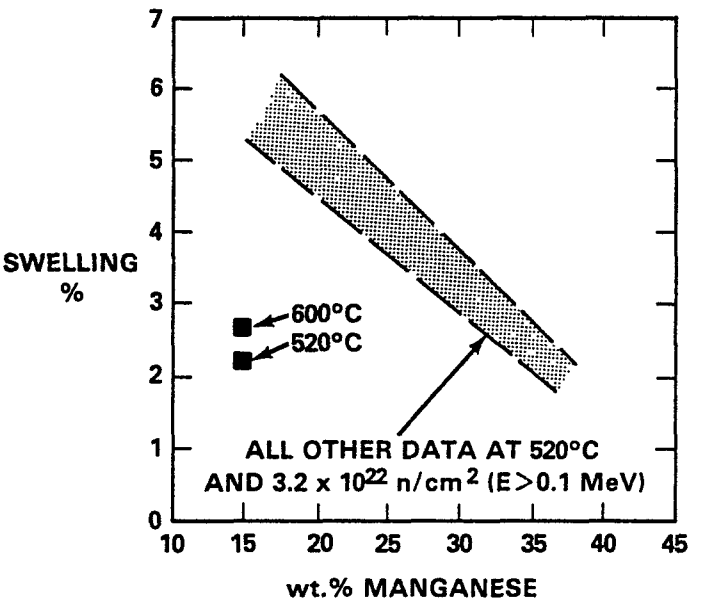

FIGURE 2. Comparison of new data on swelling of Fe-5Cr-15Mn at 14 dpa and the trend of previously published data for other Fe-Cr-Mn alloys at 520°C and 14 dpa.

5.2 New Data

Figure 2 shows that the swelling data of one alloy, Fe-5Cr-15Mn, does not fit the behavior typical of the other previously reported alloys irradiated at 520°C and 14 dpa. At 600°C and 14 dpa essentially the same swelling is observed for this alloy, however, which leads us to speculate that irradiation above 500°C has caused some relatively temperature-independent phase evolution for this alloy that is different from that of the others. Figure 3 shows that, with the exception of Fe-5Cr-15Mn, all other alloys exhibit after irradiation at 600°C and 14 dpa essentially the same swelling as observed at 520°C and 14 dpa. This implies that there is little or no dependence of swelling on temperature in the range 520-600°C. It is

desired to check whether the independence of temperature extends as low as 420°C but unfortunately the data at 420°C exist only at 9 dpa, as is also shown in Figure 3. Note that at 420°C most of the specimens densify but that rather large densifications are exhibited at the higher manganese levels.

At this point we can borrow from our experience on Fe-Cr-Ni alloys and remember that at low temperature there is usually no temperature dependence of swelling and thus we can plot the data ignoring the temperature.[2,3] Note in Figure 4 that we can draw lines between (420°C, 9 dpa) data and (520°C, 14 dpa) data for each alloy and that each line exhibits a slope of ~1%/dpa. This apparent swelling rate is identical to that observed for all other austenitic alloys in the post-transient regime.[2]

The densification shown in Figures 3 and 4 tends to imply that much of the previously observed composition dependence of post-irradiation density change is a reflection of a process other than void swelling. Therefore the composition dependence of swelling in the Fe-Cr-Mn system appears to be even less than previously reported.[1]

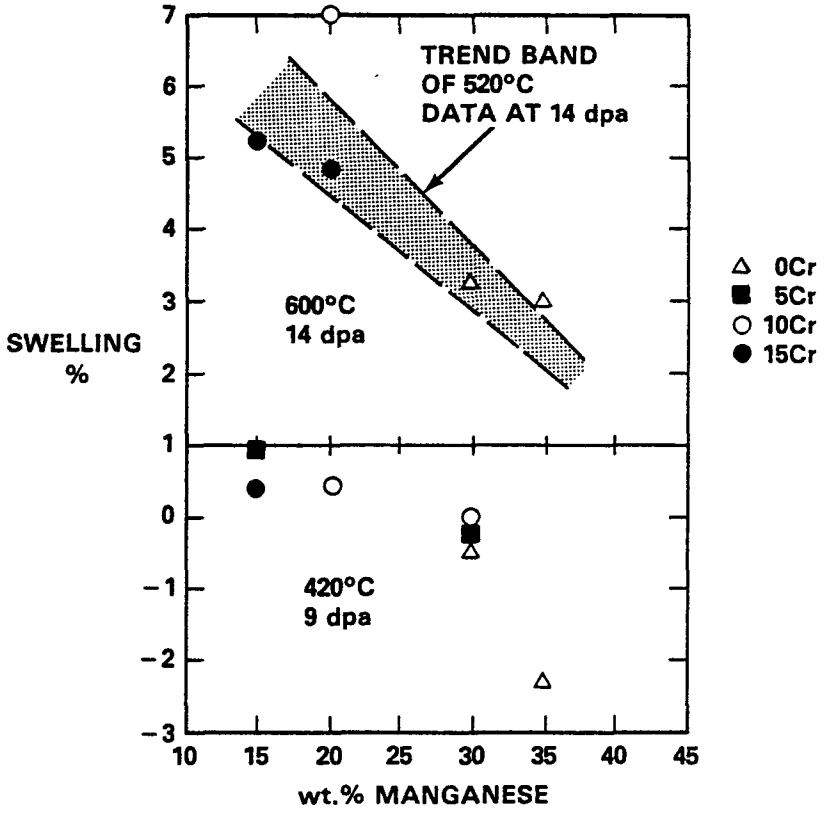

FIGURE 3. New data showing swelling of Fe-Cr-Mn alloys and 420°C and 600°C. Some alloys densify at 420°C.

5.3 Discussion

The alloys irradiated in this experiment were selected to explore the possibility that a correlation exists between anomalous Invar properties and swelling resistance.[4] Since the Fe-Cr-Mn system also exhibits Invar behavior in the range around 35% Mn[5,6,7] it was thought that there might be some advantage to developing low activation austenitic alloys which contain manganese levels of this magnitude.

Just as radiation-induced spinodaling is a consequence of the same metastability that produces anomalous properties in the Fe-Cr-Ni Invar regime, it is suggested that spinodaling also occurs in the Fe-Cr-Mn Invar regime. In order to quickly and almost completely destroy the compositional and temperature dependence of swelling, however, spinodal decomposition in the Fe-Cr-Mn system must occur faster than it does in the Fe-Cr-Ni system. The densification of 2.2% observed in Fe-35Mn is much larger than the 0.9% that occurs in the Fe-Ni-Cr system.[8] This implies a much larger driving force in the Fe-Cr-Mn

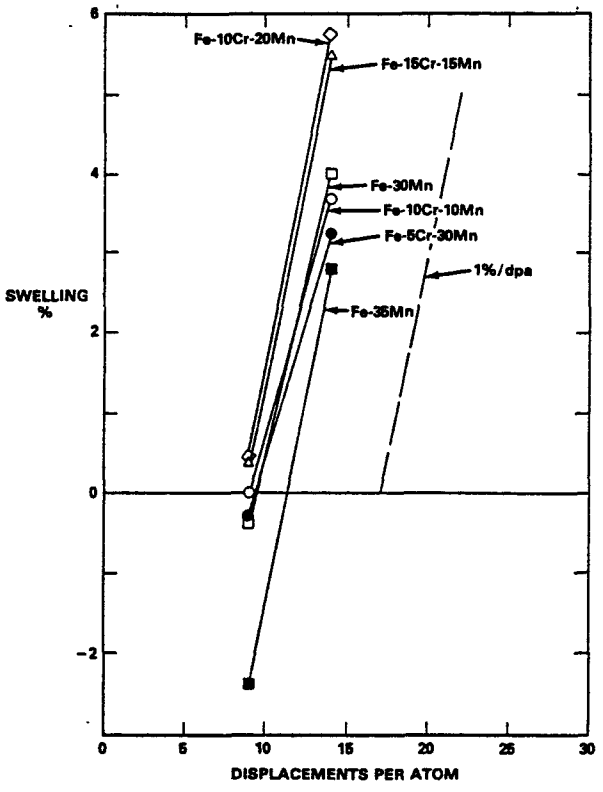

FIGURE 4. Plot of Fe-Cr-Mn swelling data assuming independence of swelling on temperature between temperatures of 420 and 520°C.

system. Figure 5 indeed shows that the rate of change with manganese content of pre-irradiation density of Fe-Cr-Mn alloys below 35% manganese is very large. If the density again rises steeply above 35% manganese, spinodal decomposition could indeed lead to a very substantial densification and a large driving force.

5.4 Conclusions

There does not appear to be any advantage to be gained at higher (>20%) manganese contents in terms of the intrinsic swelling resistance of simple Fe-Cr-Mn alloys. However, this conclusion may not apply to the solute-modified Fe-Cr-Mn alloys which have not yet been examined. If radiation-induced spinodal decomposition is causing both large densifications and the destruction of the swelling resistance, then the study of the differences between Fe-Cr-Mn and Fe-Cr-Ni Invar alloys may lead to clues as to how to suppress the spinodal process and extend the incubation period of swelling. Therefore examination of the Fe-Cr-Mn Invar alloys will continue despite the initially unsuccessful application of the Invar-swelling resistance correlation to the simple Fe-Cr-Mn system.

6.0 References

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7.0 Future Work

Density change data will continue to be accumulated on ternary and solute-modified Fe-Cr-Mn alloys. A series of Fe-Cr-Mn-Ni alloys is also being prepared for irradiation in FFTF-MOTA.

8.0 Publications

None.

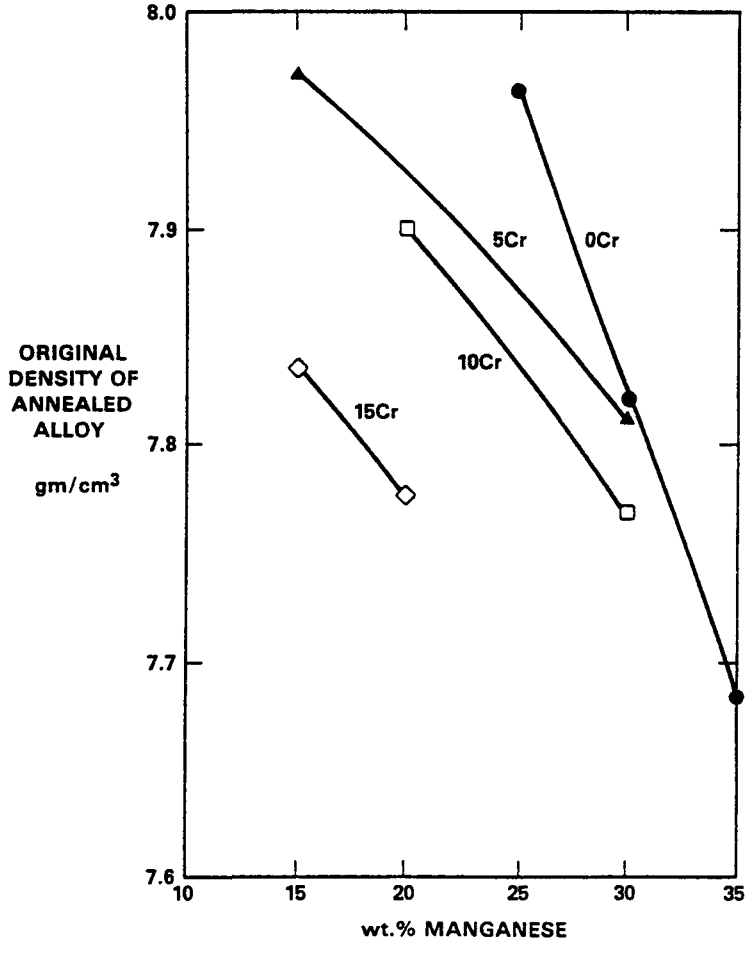

FIGURE 5. Dependence of pre-irradiation density on composition for annealed Fe-Cr-Mn alloys.