FURTHER CHARPY IMPACT TEST RESULTS OF LOW ACTIVATION FERRITIC ALLOYS, IRRADIATED AT 430°C TO 67 DPA - L. E. Schubert, M. L. Hamilton, and D. S. Gelles (Pacific Northwest National Laboratory)[a]

OBJECTIVE

The objective of this work is to evaluate the effects of neutron irradiation in low activation ferritic alloys, by examining the shift of the ductile to brittle transition temperature (DBTT) and the reduction of the upper shelf energy (USE) in miniature Charpy V-notch (CVN) specimens.

SUMMARY

Miniature CVN specimens of four ferritic alloys, GA3X, F82H, GA4X and HT9, have been impact tested following irradiation at 430°C to 67 dpa. Comparison of the results with those of the previously tested lower dose irradiation condition indicates that the GA3X and F82H alloys, two primary candidate low activation alloys, exhibit virtually identical behavior following irradiation at 430°C to ~67 dpa and at 370°C to ~15 dpa. Very little shift is observed in either DBTT or USE relative to the unirradiated condition. The shifts in DBTT and USE observed in both GA4X and HT9 were smaller after irradiation at 430°C to ~67 dpa than after irradiation at 370°C to ~15 dpa.

PROGRESS AND STATUS

Introduction

Two low activation ferritic steels have been identified for application as structural materials in a fusion reactor. These are F82H and GA3X, in the 7-9Cr range, strengthened by additions of W. This document reports results of CVN impact tests on miniature specimens of these alloys that had been irradiated in-core in the FFTF, in the MOTA 2A and 2B experiments to ~67 dpa at 430°C. Two additional alloys, HT9 and GA4X, were irradiated and tested for comparison. Nominal alloy compositions are 7.8Cr-2W for F82H, 9Cr-2W for GA3X, 11Cr-2W for GA4X, and 12Cr-1Mo-0.5W for HT9. Each alloy also contains 0.2-0.3V. Note that while GA3X was designed to be a 9Cr alloy, and that the current work reports results of tests conducted on a 9Cr heat of GA3X, the results reported in reference 1 were obtained from specimens of an experimental heat obtained from General Atomics which had only 7.5Cr. Previous irradiations were accomplished below core at 370°C to ~15 and ~30 dpa.

Experimental Procedure

Previous reports[1,2,3] on six low activation ferritic alloys described the experimental procedures. The specimens utilized were about one third the size of the ASTM standard CVN specimen.[4] Specimens of two of the alloys (GA3X and HT9) were fatigue precracked before irradiation. The GA4X was expected to exhibit a duplex microstructure; therefore precracking of the specimens of this alloy was not conducted. The F82H specimens were not precracked prior to irradiation. Impact tests were conducted inside a hot cell using a remotely operated vertical drop tower. The fracture energy was calculated from the load versus time record of each impact. The method of calculation and data analysis as well as the details of the system have been described previously.[3,5,6,7]

---

[a]Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

Specimen temperature control is described in the references cited and is estimated at an accuracy of ±3°C. This value should be doubled for temperatures below -100°C due to difficulties associated with the very cold equipment.

Results

Tests were conducted on each alloy over a range of temperatures in order to establish full DBTT curves. The data are plotted in Figures 1-4 with the data from control specimens and from the specimens tested after the previous irradiation at 370°C to ~15 dpa. Of these four alloys, the two higher chromium alloys, HT9 and GA4X, exhibited large increases in the DBTT and a significant drop in the USE when compared to the control data, but neither were as severe as was exhibited after irradiation at 370°C. For the two alloys with lower chromium content, the GA3X exhibited the same DBTT as after irradiation at 370°C to ~15 dpa, but a somewhat lower USE. The USE determined for the GA3X at the 15 dpa level was ~20% greater than the control data. The USE determined for the GA3X at the 67 dpa level had decreased ~10% from the 15 dpa USE value, but it was still about 10% above the USE value for the unirradiated control specimens. The results obtained on the F82H specimens were qualitatively the same for both irradiation conditions, but since the previously tested specimens were precracked and the current specimens were only notched, quantitative comparison is not possible. The results of the notch-only specimen tests indicate essentially the same behavior both for the unirradiated control specimens and for the specimens irradiated to 67 dpa.

Discussion

Impact tests have also been performed on other low activation ferritic alloys being studied; a comparison is shown in Figure 5 with data obtained on a similar 9Cr-2WVTa alloy irradiated in the same reactor at ~365°C to ~15 dpa.[8] Note that these data were obtained on notched specimens rather than precracked specimens. The figure shows that while the impact behavior of the alloys was virtually identical in the unirradiated condition, the 9Cr-2WVTa alloy exhibited a DBTT shift of ~30°C (using notched specimens) while the F82H exhibited virtually no shift (using precracked specimens). The major difference between these two alloys is the presence of tantalum in the 9Cr-2WVTa, thus there appears to be reason to speculate that the larger DBTT shift in the 9Cr-2WVTa alloy might result from the presence of the tantalum.

CONCLUSION

Impact tests were performed on four ferritic alloys irradiated at 430°C to ~67 dpa in order to determine behavior in reduced activation alloys. Impact property degradation was no different in the 7-9Cr alloys than had been observed after irradiation at 370°C to ~15 dpa, and was minimal. Degradation in the 11-12Cr alloys was more significant, but less was observed than after irradiation at 370°C to ~15 dpa. The results support the earlier conclusions that the impact behavior of the GA3X and F82H alloys is superior to that of the GA4X and HT9 alloys, that on the basis of the impact data, both the GA3X and F82H alloys appear to warrant further consideration as potential structural materials in fusion reactors, and that chromium content of about 9% appears to be optimum for Fe-Cr-W/V ferritic alloys.

FUTURE WORK

Scanning electron microscopy will be performed on fracture surfaces from the specimens tested in this work to determine the fracture mode.

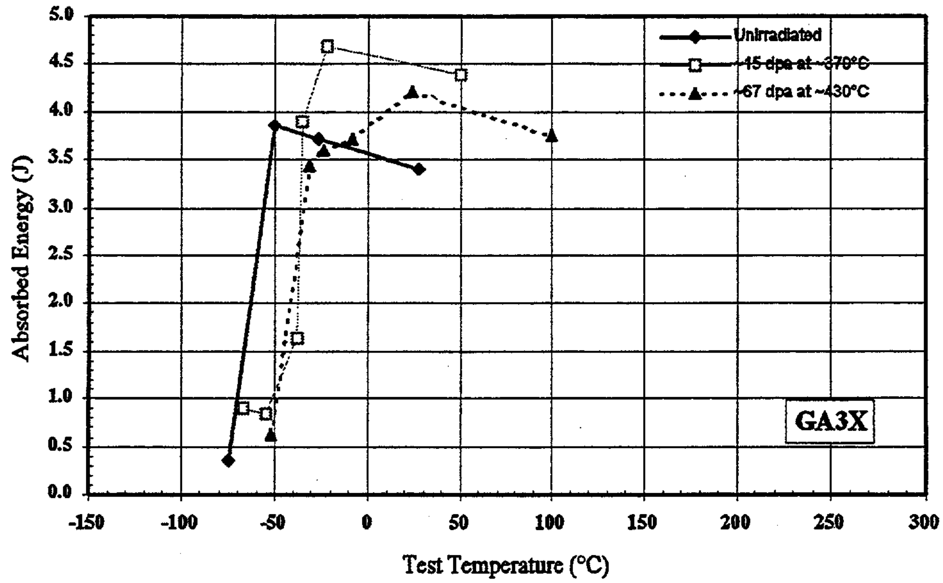

Figure 1. Test results of impact tests of precracked, miniature CVN specimens of alloy GA3X, Fe-0.15C-9.0Cr-2.0W-0.3V.

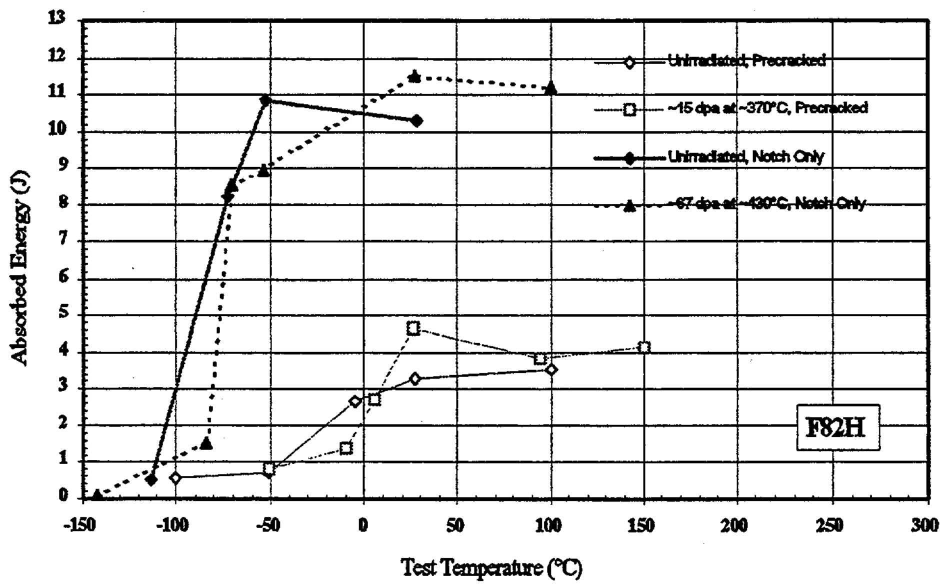

Figure 2. Test results of impact tests of precracked and notch-only, miniature CVN specimens of alloy F82H, Fe-0.10C-7.8Cr-2.0W-0.5Mn-0.2V.

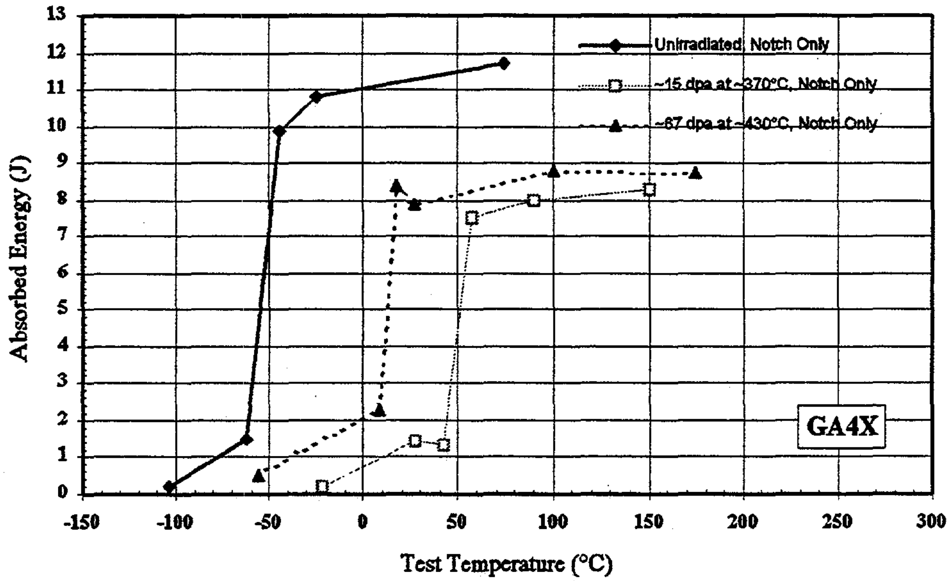

Figure 3. Test results of impact tests of miniature CVN specimens of alloy GA4X, Fe-0.14C-11.0Cr-2.0W-0.3V.

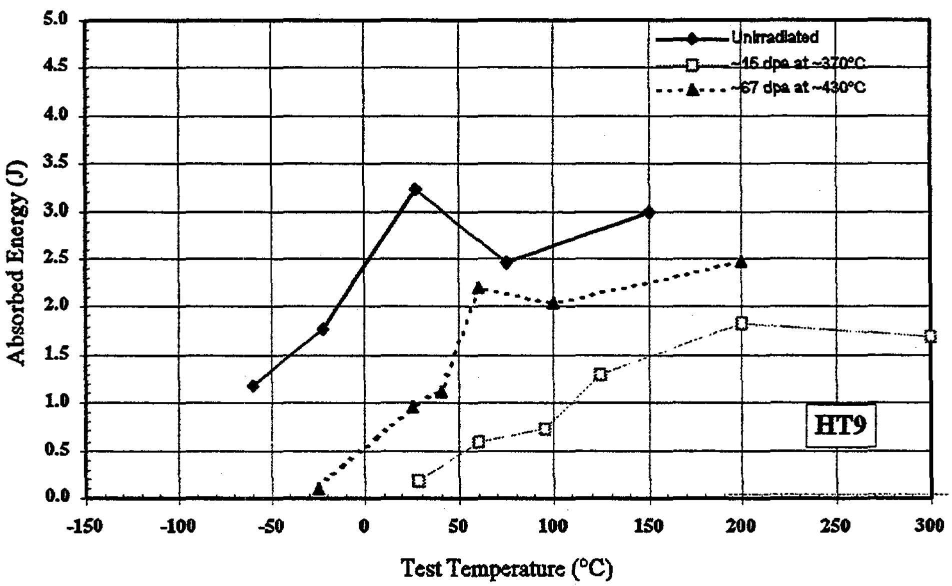

Figure 4. Test results of impact tests of precracked, miniature CVN specimens of alloy HT9, Fe-0.20C-12.1Cr-1.0Mo-0.6Mn-0.5Ni-0.5W-0.3V.

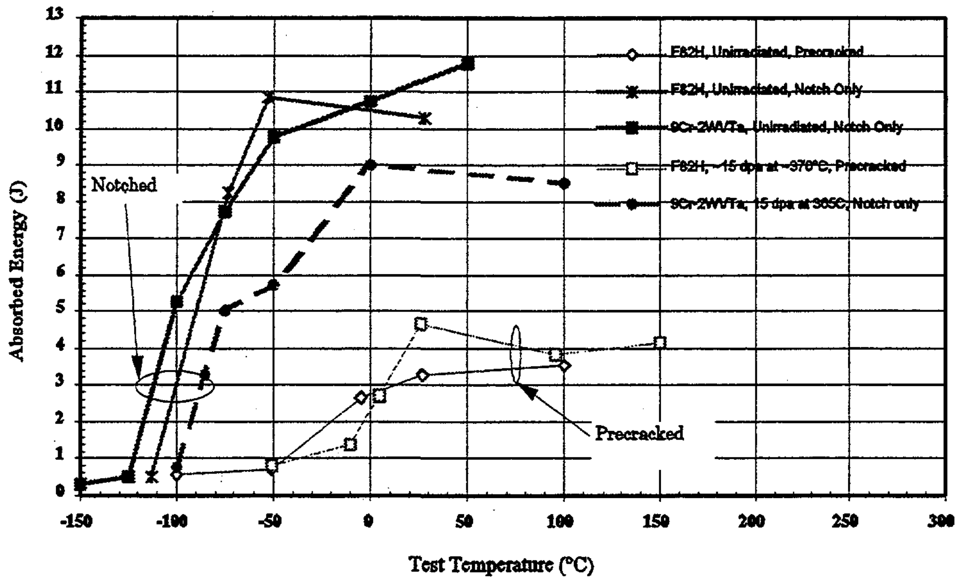

Figure 5. Comparison between impact data from F82H and 9Cr-2WVTa.

REFERENCES

1. L. E. Schubert, M. L. Hamilton, D. S. Gelles, "Charpy Impact Test Results for Low Activation Ferritic Alloys Irradiated to 30 dpa," Fusion Reactor Materials Semiannual Progress Report for the Period Ending December 31, 1995, DOE/ER-0313/19, p. 133.

2. N. S. Cannon, W. L. Hu, and D. S. Gelles, "Charpy Impact Test Results for Low Activation Ferritic Alloys," Fusion Reactor Materials Semiannual Progress Report for the Period Ending March 31, 1987, DOE/ER-0313/2, p. 119.

3. L. E. Schubert, M. L. Hamilton, D. S. Gelles, "Charpy Impact Test Results of Four Low Activation Ferritic Alloys Irradiated at 370°C to 15 dpa," Fusion Reactor Materials Semiannual Progress Report for the Period Ending June 30, 1996, DOE/ER-0313/20, p. 171.

4. "Standard Test Method for Notched Bar Impact Testing of Metallic Materials," Designation: E 23, The American Society for Testing and Materials.

5. W. L. Hu and N. F. Panayotou, "Miniature Charpy Specimen Test Device Development and Impact Test Results for the Ferritic Alloy HT9," Alloy Development for Irradiation Performance Semiannual Progress Report for the Period Ending September 30, 1981, DOE/ER-0045/7, p. 235.

6. L. E. Schubert, "Effects of Specimen Size Reduction on the Transition Curve of the Charpy V-Notch Impact Test," M.Sc. Thesis, Nuclear Engineering, A. S. Kumar--Advisor, UMR, May 1995.

7. W. L. Hu, "Miniature Charpy Impact Test Results for Irradiated Ferritic Alloys," Alloy Development for Irradiation Performance Semiannual Progress Report for the Period Ending September 30, 1982, DOE/ER-0045/9, p. 255.

8. R. L. Klueh and D. J. Alexander, Journal of Nuclear Materials 233-237 (1996) 336-341.