CHARPY IMPACT TEST RESULTS OF FOUR LOW ACTIVATION FERRITIC ALLOYS IRRADIATED AT 370°C TO 15 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, primarily 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 low activation ferritic alloys have been impact tested following irradiation at 370°C to 15 dpa. Comparison of the results with those of control specimens indicates that degradation in the impact behavior occurs in each of these four alloys. The 9Cr-2W alloy referred to as GA3X and the similar alloy F82H with 7.8Cr-2W appear most promising for further consideration as candidate structural materials in fusion energy system applications. These two alloys exhibit a small DBTT shift to higher temperatures but show increased absorbed energy on the upper shelf.

PROGRESS AND STATUS

Introduction

Previous reports[1,2] described results of CVN tests on six low activation ferritic alloys which had been irradiated in the FFTF MOTA 1C through 1E experiments below core at 370°C to approximately 10 dpa and 30 dpa. This document reports results of CVN impact tests on identical specimens irradiated in FFTF in the MOTA 2A and 2B experiments, also below core, to ~15 dpa at a temperature of 370°C. The alloys under investigation are F82H (7.8Cr-2W), GA3X (9Cr-2W), GA4X (11Cr-2W), and HT9 (12Cr-1Mo-0.5W). 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 2 were obtained from specimens of an experimental heat obtained from General Atomics which had only 7.5Cr.

The HT9 alloy was included in this study for reference purposes since there are substantial data available on the alloy. However the HT9 alloy contains molybdenum and does not meet the criteria established for a low activation material, and it is not a candidate for fusion applications.

Experimental Procedure

The specimens utilized were about one third the size of the ASTM standard CVN specimen.[3] The specimens of three of the alloys 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 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.[4,5]

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

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Specimen temperature control was accomplished in a ceramic enclosure adjacent to the anvils.[6] A pneumatic ram moved the specimen from the temperature chamber to the test position. Elevated temperatures were achieved by passing low voltage electric current (AC) through the specimen. Temperatures below ambient were achieved by flowing nitrogen gas chilled to about -196°C over the specimen. The flow rate was adjusted to obtain different specimen temperatures. Specimens typically reach the test temperature in 10-20 minutes and are allowed to stabilize at temperature for three minutes prior to test initiation. Two seconds is the approximate time interval between the specimen exit from the chamber and impact. If positioning is not completed properly, or if the time interval exceeds three seconds, the impact test is not performed, the specimen is returned to the temperature chamber, and the heating/cooling cycle is repeated. The highest temperature at which tests were performed was 300°C due to limitations of the test system.

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 control data. 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. The two alloys with lower chromium content, GA3X and F82H, retained DBTTs below room temperature with only a 20-30°C DBTT increase. Both also exhibited higher USE values after irradiation. Thus only the GA3X and F82H alloys appear to warrant continued interest on the basis of DBTT, although the DBTT values obtained on these one-third size specimens can be expected to be lower than those that would be obtained on standard full size specimens.

Discussion

The GA3X and GA4X alloys have the same composition except for chromium content. The higher chromium in GA4X results in a two-phase microstructure. Since the GA4X specimens were not precracked, direct comparisons of the USE and DBTT values of the alloy to the corresponding values for the GA3X alloy are not valid. However, since the DBTT curves of precracked and notch-only specimens are qualitatively the same, the magnitude of the shift in the DBTT and the relative change in the USE of the two alloys can be compared. Given that a large shift in the DBTT is unacceptable and that reduction of the USE indicates loss of toughness, the 9Cr alloy, GA3X, is superior to the 11Cr alloy, GA4X.

In reference 2, the particular heat of GA3X investigated had only 7.5% chromium, which is approximately the same as was in the F82H alloy investigated here. In Figure 5, the reference 2 data on GA3X are reproduced with the data generated on the GA3X and F82H alloys of the current study. The DBTT curve of the irradiated F82H is approximately the same as the DBTT curves of the 7.5Cr GA3X irradiated to 10 and to 30 dpa. The DBTT value obtained is approximately the same for each of the three data sets, but the USE value for the F82H is ~15% greater. The DBTT curve of the irradiated 9Cr GA3X heat exhibits a DBTT value that is ~40°C lower than both the 7.5Cr GA3X heat and the F82H alloy. For the irradiated materials, the USE value of the 9Cr GA3X heat is about the same as that of the F82H alloy and, likewise, ~15% greater than the value obtained for the 7.5Cr GA3X heat. These results tend to indicate an advantage for a 9% chromium content in comparison to a 7.5% composition.

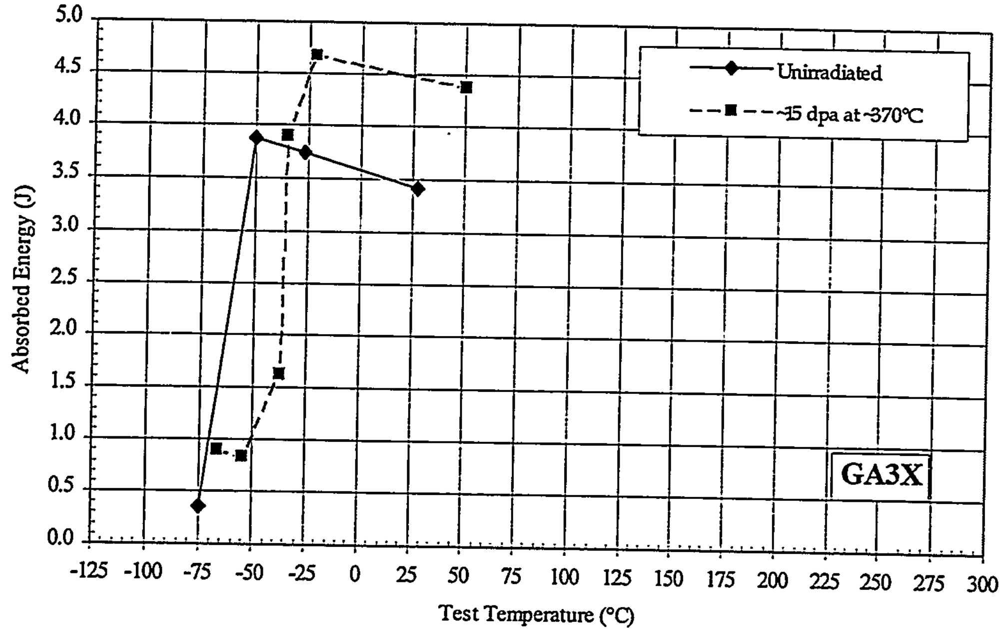

Figure 1. Test results of impact tests of precracked, miniature CVN specimens of alloy GA3X, Fe-0.15C-9.0Cr-2.0W-0.3V (no Mn).

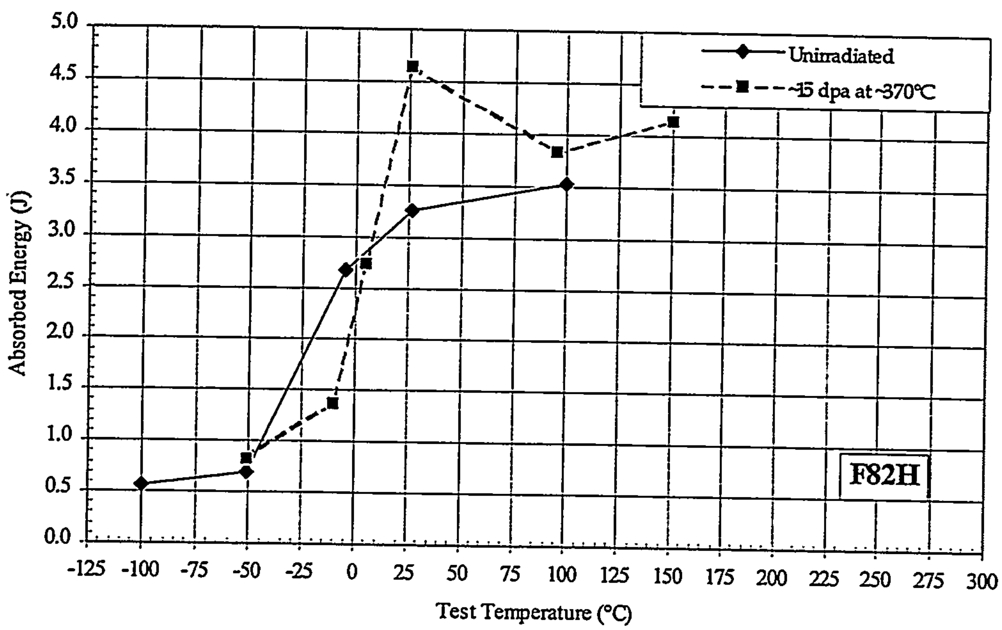

Figure 2. Test results of impact tests of precracked, miniature CVN specimens of alloy F82H, Fe-0.10C-7.8Cr-2.0W-0.5Mn-0.2V.

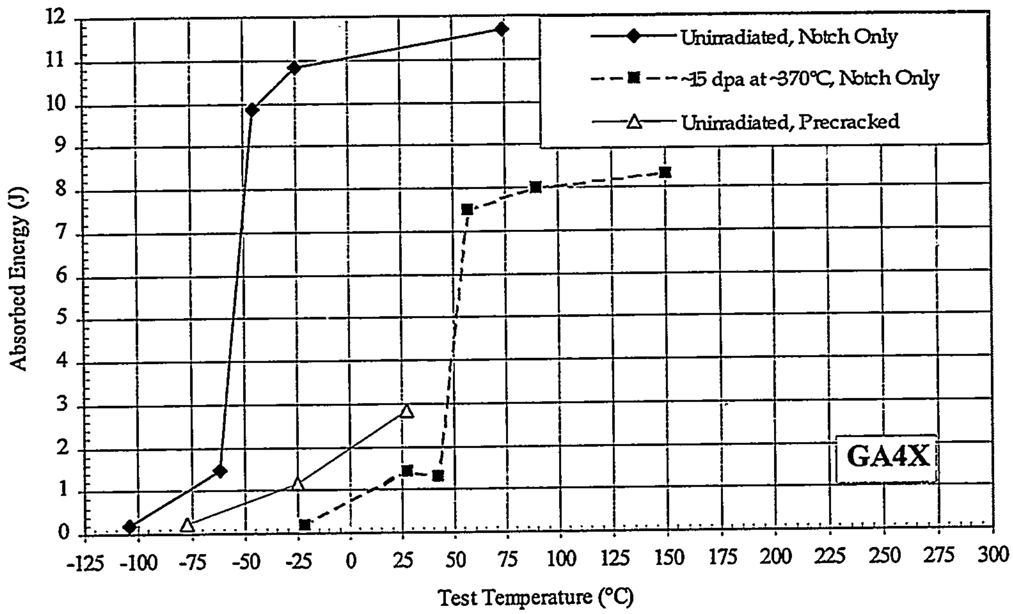

Figure 3. Test results of impact tests of miniature CVN specimens of alloy GA4X, Fe-0.14C-11.0Cr-2.0W-0.3V (no Mn).

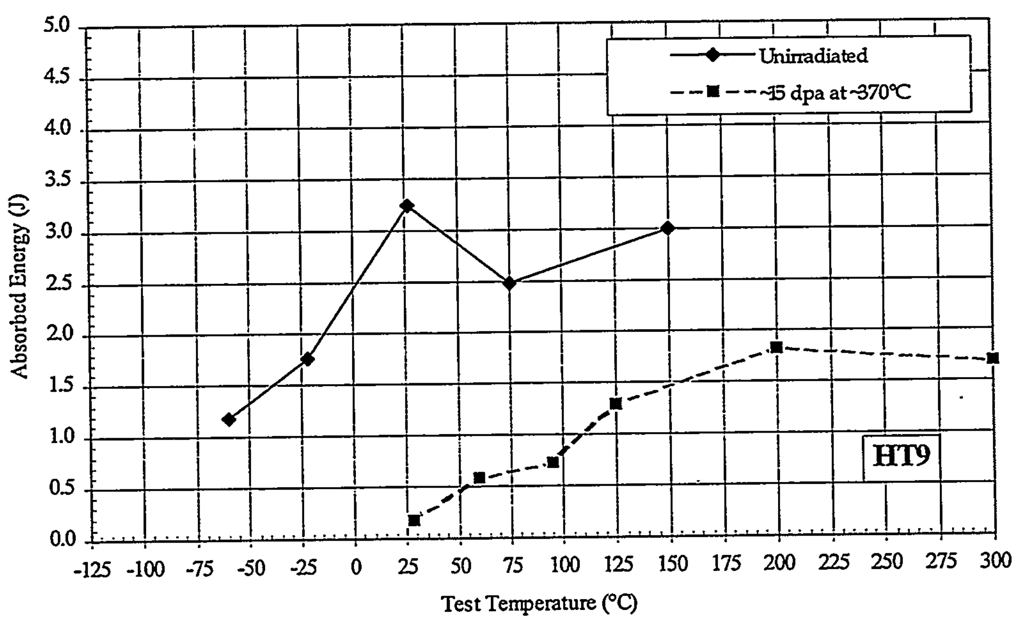

Figure 4. Test results of impact tests of precracked, miniature CVN specimens of alloy HT9, Fe-0.20C-12.1Cr-1.0Mo-0.6Mn-0.5Ni-0.5W-0.3V.

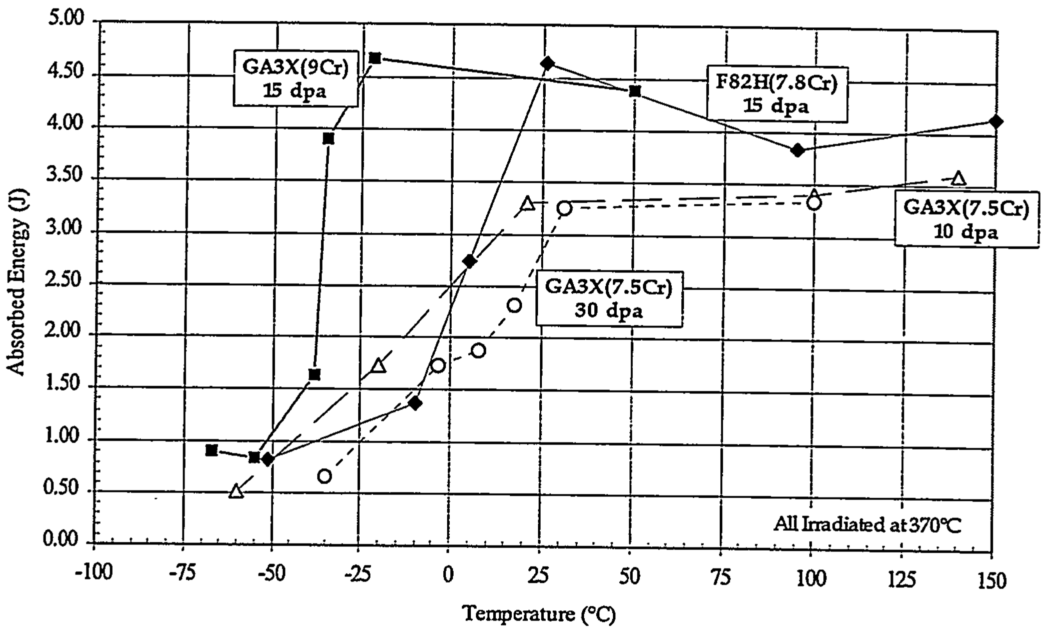

Figure 5. The DBTT curve for 9Cr GA3X in comparison with those of the 7.5Cr GA3X heat and the 7.8Cr F82H alloy. Specimens were irradiated below core in FFTF MOTA at 370°C.

CONCLUSION

Impact tests were performed on four ferritic alloys irradiated at 370°C to 15 dpa in order to determine behavior in reduced activation alloys. The impact behavior of the GA3X and F82H alloys is clearly superior to that of the GA4X and HT9 alloys. 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 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. Additional impact testing will be performed on similar one-third size specimens irradiated in core in FFTF MOTA at ~430°C to ~67 dpa.

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

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

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

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

5. L. E. Schubert, "Effects of Specimen Size Reduction on the Transition Curve of the Charpy V-Notch Impact Test," Master of Science Thesis, Nuclear Engineering, A. S. Kumar--Advisor, University of Missouri-Rolla, May 1995

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