CHARPY IMPACT TEST RESULTS FOR LOW ACTIVATION FERRITIC ALLOYS IRRADIATED TO 30 DPA

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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 specimens of six low activation ferritic alloys have been impact tested following irradiation at 370°C to 30 dpa. Comparison of the results with those of control specimens and specimens irradiated to 10 dpa indicates that degradation in the impact behavior appears to have saturated by ~10 dpa in at least four of these alloys. The 7.5Cr-2W alloy referred to as GA3X appears most promising for further consideration as a candidate structural material in fusion reactor applications, although the 9Cr-1V alloy may also warrant further investigation.

PROGRESS AND STATUS

Introduction

A previous report[1] described results of post-irradiation CVN tests on six low activation ferritic alloys which were irradiated in the FFTF MOTA 1C experiment at 370°C to approximately 10 dpa. This document reports results of CVN impact tests on identical specimens irradiated in FFTF through the MOTA 1E experiment to ~30 dpa at a temperature of 370°C. The alloys under investigation have been designated as series L0 (7.5Cr-2W), L3 (2Cr-1V), L5 (9Cr-1V), L7 (12Cr-6Mn-1V), L8 (9Cr-1W), and L9 (12Cr-6Mn-1W). The 7.5Cr-2W alloy (L0) is referred to as GA3X.

Experimental Procedure

The specimens utilized were about one third the size of the ASTM standard CVN specimen.[2] The specimens were fatigue precracked before irradiation. The impact tests were conducted inside a hot cell using a remotely operated vertical drop tower.[3] The drop assembly included an 8.9 kN load cell fitted with a modified striking tup. The tip radius was 4 mm, half of that used for standard size specimen tests. The tup was also relatively long and narrow to allow for passage of the tup and the specimen pieces through the 18 mm gap between the support anvils without binding. The 1 mm radius at the tip of each anvil results in a 20 mm unsupported span before impact. A rigid, opaque flag, mounted to the drop assembly, passed through an infrared detector immediately prior to impact. Precisely measuring the time of passage of the flag allowed the velocity, and thus the kinetic energy, to be precisely calculated for each test; the velocity at impact was ~2.1 m/sec^2 for these tests.

Specimen temperature control was accomplished in a ceramic enclosure adjacent to the anvils.[4] 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 ~-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. The time interval from the specimen exit from the chamber to impact is approximately two seconds. 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.

Static load cell calibration was accomplished with NIST-traceable calibrated dead weights in a static, compressive load configuration. To verify the validity of the calibration, specimens of the strain rate insensitive aluminum alloy 6061-T651 were tested in a static loading configuration as well as in the impact loading configuration.

The signal from the load cell was recorded with a digital oscilloscope during each test. Typical test resolution was 2 μs and 50 μV with the impact and fracture event comprising ~2500 points. The millivolt versus time values were saved to floppy disk and transferred to a desk top computer for analysis, where these data were converted to load versus displacement utilizing the established calibration factor and the velocity at impact calculated for each test. The area under the load/displacement trace is the apparent energy, E_a, which is calculated by numerical integration and subsequently corrected for deceleration during the impact loading. The corrected fracture energy is E_d, determined as $E_d = E_a(1 - E_a/4E_o)$ where E_o is the kinetic energy at impact;[5] this determination of E_d is exact.

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 1-6 with the data obtained earlier at 10 dpa. Virtually no additional shift in the DBTT curve was observed between 10 and 30 dpa for the L0 (7.5Cr-2W), L3 (2Cr-1V), L8 (9Cr-1W) and L9 (12Cr-6Mn-1W) alloys. The shift in DBTT with irradiation for these alloys had evidently saturated by 10 dpa. Of these four alloys, the only one that retained a DBTT below room temperature was L0 (7.5Cr-2W), for which alloy the DBTT of the unirradiated material was also very close to that of the material irradiated to 10 dpa and to 30 dpa. The L3 (2Cr-1V), L8 (9Cr-1W), and L9 (12Cr-6Mn-1W) alloys exhibited DBTTs well above room temperature as well as large irradiation-induced shifts in DBTT. The DBTT increased ~30°C between 10 and 30 dpa for the L7 (12Cr-6Mn-1V) alloy, and actually appeared to decrease by ~30°C between 10 and 30 dpa for the L5 (9Cr-1V) alloy. Thus L0 (7.5Cr-2W) and L5 (9Cr-1V) are the only alloys that appear to warrant continued interest on the basis of DBTT, although the DBTT values obtained on these one-third size specimens are most likely lower than those that would be obtained on full size specimens.

While the L5 (9Cr-1V) alloy exhibits some shift in DBTT with irradiation, the USE appears to remain unchanged and at a moderately high level (for precracked, one-third size specimens). The USE of the L0 (7.5Cr-2W) alloy decreased ~40% with irradiation to 10 dpa, but the drop has apparently saturated by then since no additional decrease was observed with continued irradiation to 30 dpa. The USE of both alloys is comparable in the irradiated condition. Thus both the L0 (7.5Cr-2W) and L5 (9Cr-1V) alloys appear to warrant further consideration, although the L0 (7.5Cr-2W) alloy is the only one with a DBTT that remains below room temperature.

Discussion

A few comments are in order about the earlier data obtained on both unirradiated controls and

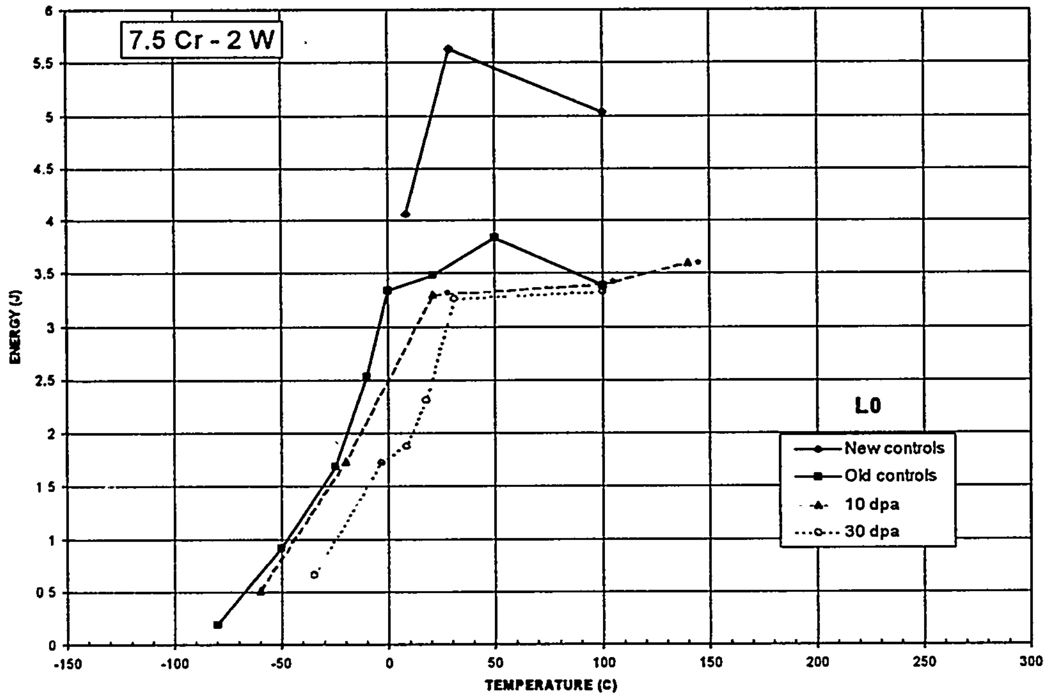

Figure 1. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy GA3X (7.5Cr-2W) [series L0]. Asterisked points indicate reevaluated oscilloscope traces, as described in text.

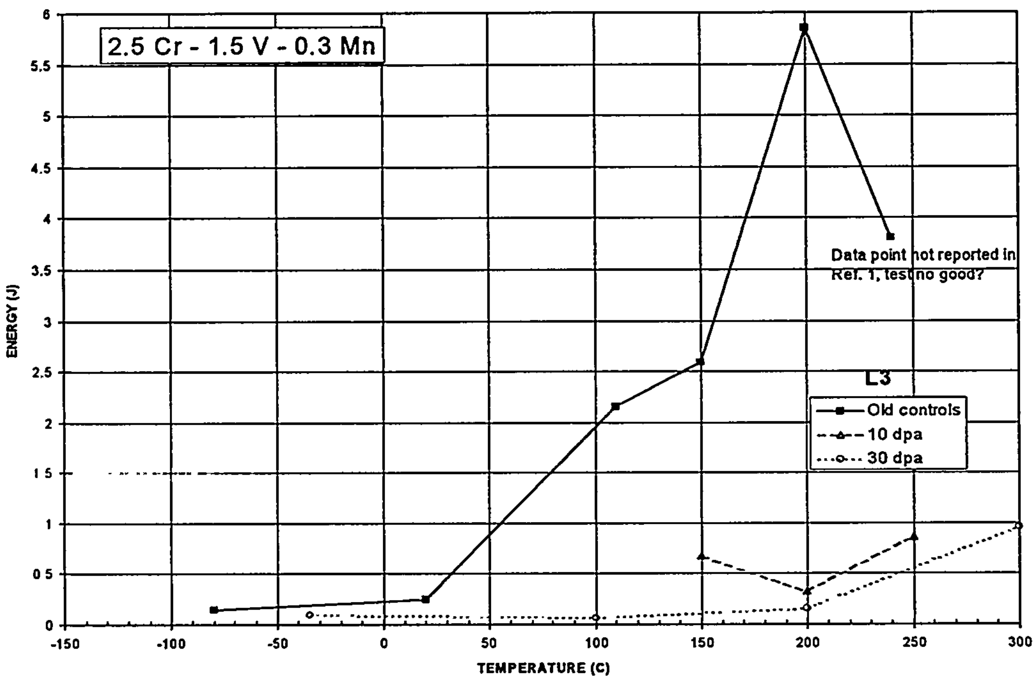

Figure 2. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy 2Cr-1V [series L3].

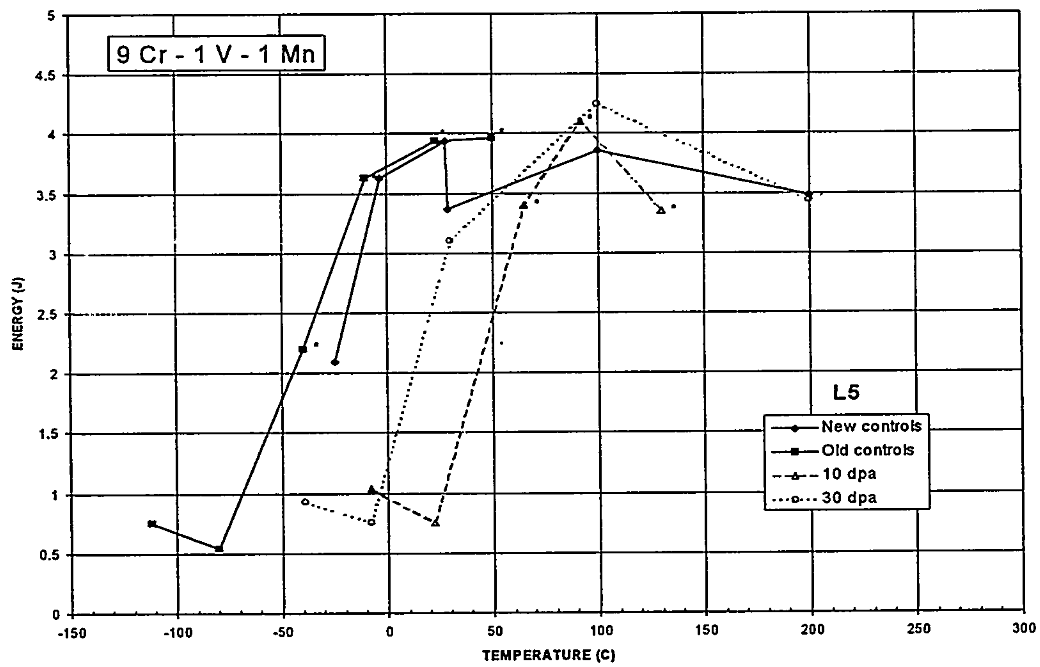

Figure 3. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy 9Cr-1V [series L5]. Asterisked points indicate reevaluated oscilloscope traces, as described in text.

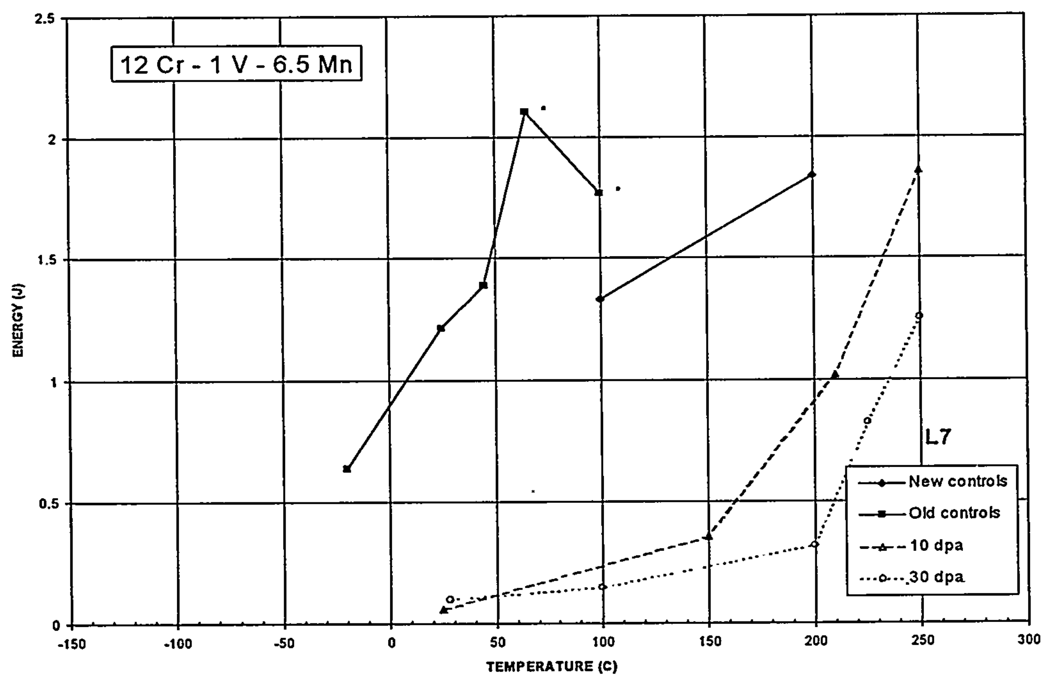

Figure 4. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy 12Cr-6Mn-1V [series L7]. Asterisked points indicate reevaluated oscilloscope traces, as described in text.

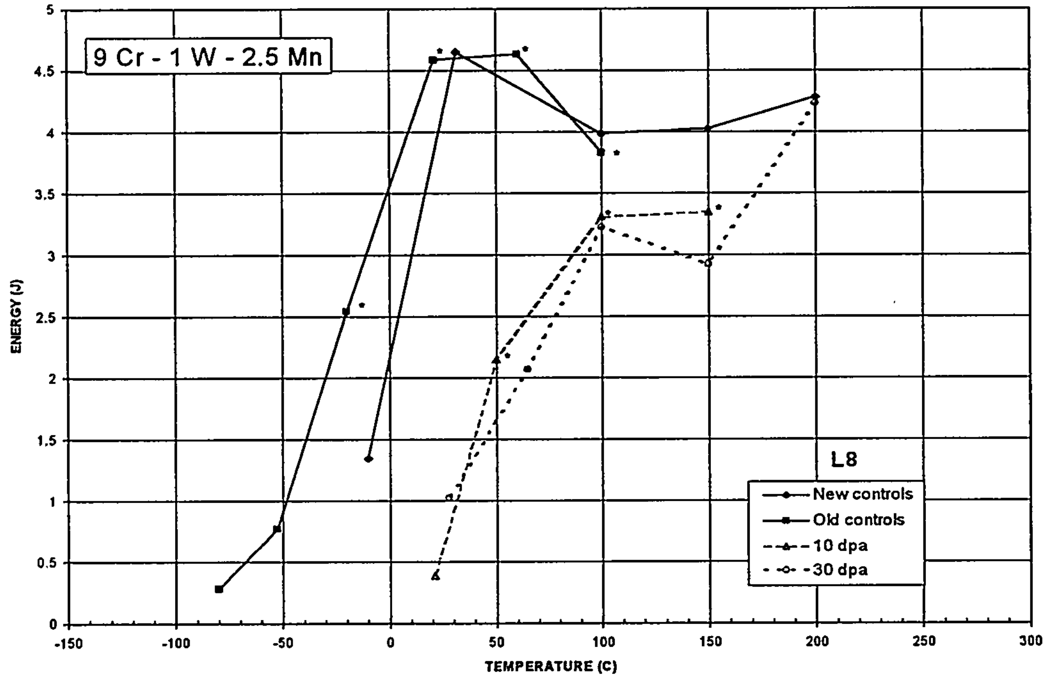

Figure 5. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy 9Cr-1W [series L8]. Asterisked points indicate reevaluated oscilloscope traces, as described in text.

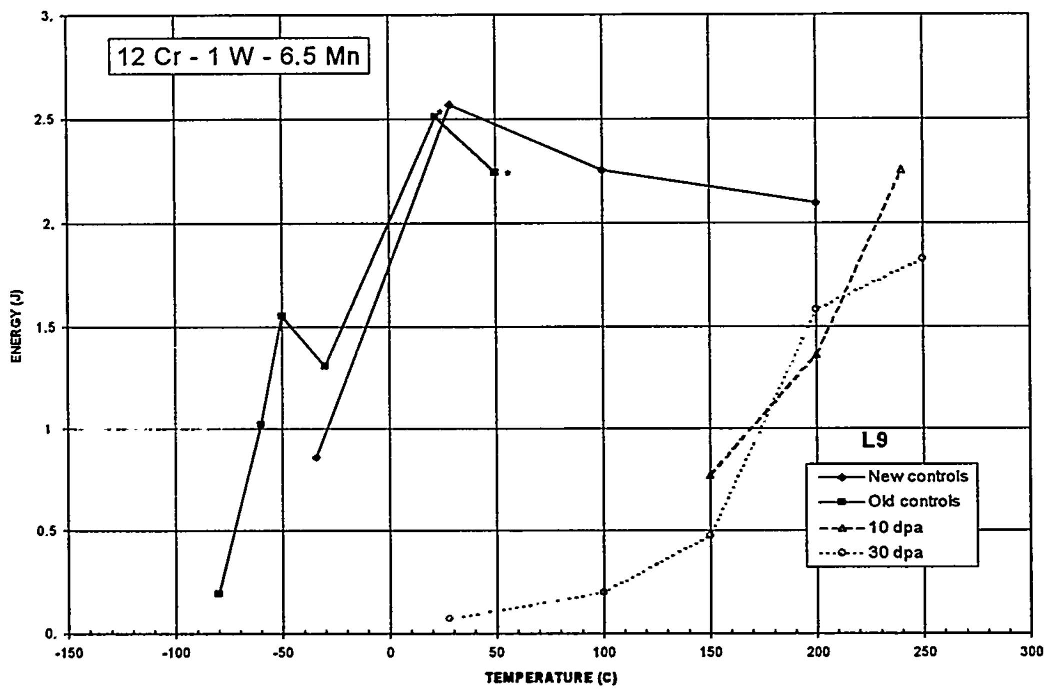

Figure 6. Charpy impact data obtained on precracked, one-third size specimens of the ferritic alloy 12Cr-6Mn-1W [series L9]. Asterisked points indicate reevaluated oscilloscope traces, as described in text.

specimens irradiated to 10 dpa. Both the earlier control data and the data obtained at 10 dpa that are shown in these figures have been reevaluated to reflect the fact that for temperatures at or above the DBTT, full oscilloscope traces were not obtained. A number of new control tests were performed to support the reevaluation. The reevaluation of the incomplete traces generated for the earlier controls was accomplished using a desktop computer by overlaying the traces from the old and new control tests, calculating what fraction of the total energy had been expended in the new test at the point where the old trace ended, and increasing the energy obtained from the old trace by the inverse of that fraction. Despite the fact that ~10 years elapsed between the times the old and new control data were obtained, it is believed that this technique is reasonable due to the incredible similarity in the traces that were overlaid (see Figure 7). None of the floppy disks containing the traces for the earlier L0 (7.5Cr-2W) control specimens were located, and no new control tests were performed on the L3 (2Cr-1V) alloy because no precracked control specimens were available; the energies of the old L3 and L0 control tests were therefore corrected by the average correction factor from the other unirradiated tests. Fairly good agreement between the old and new control data are evident in the majority of the plots, with the exception of alloys L0 (7.5Cr-2W), where the subjective correction factor was clearly too small, and L3 (2Cr-1V), where no new control data were available.

The same type of technique was applied to the incomplete traces generated at 10 dpa, although more judgement was necessary since no additional specimens at 10 dpa were available for testing. The

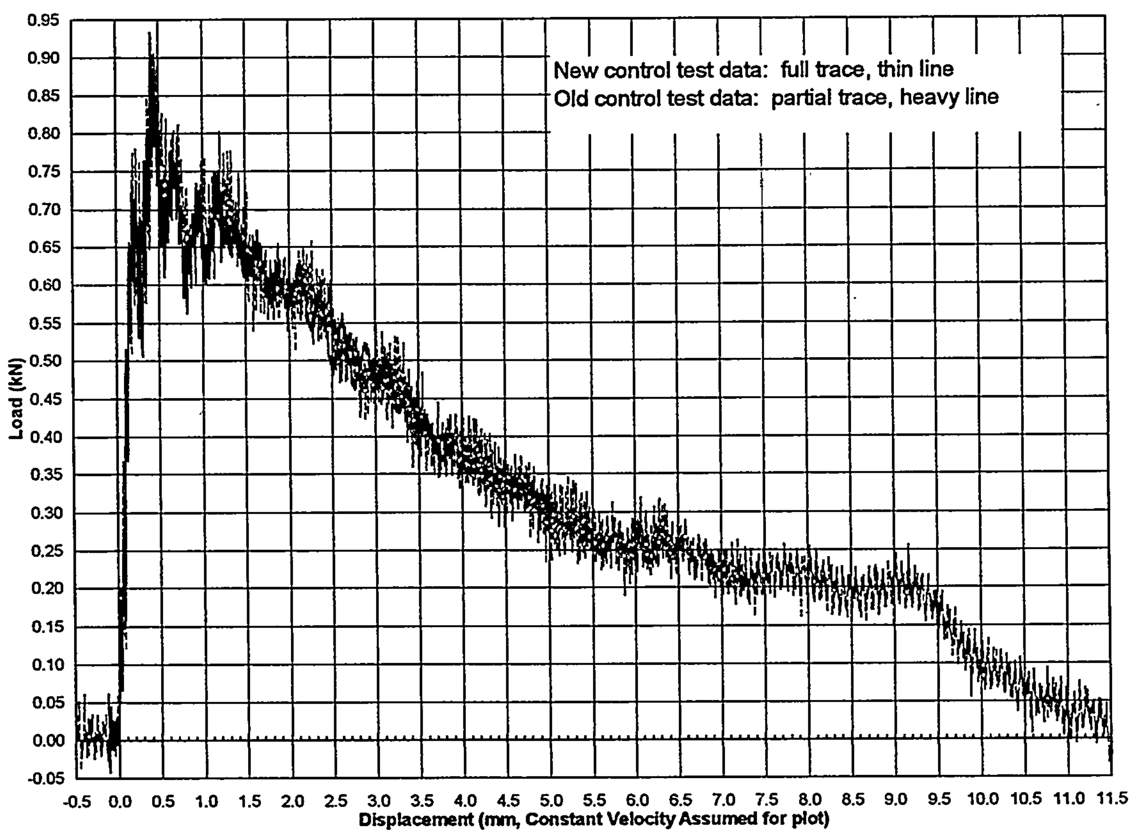

Figure 7. Comparison of oscilloscope traces for an old and a new test performed on unirradiated control specimens of alloy series L5 (9Cr-1V) at ~-10°C, illustrating the similarity in the traces.

oscilloscope traces from the specimens at 10 dpa were typically compared to traces produced at 30 dpa to determine the fraction by which they should be increased, although the 30 dpa was not necessarily obtained at the same temperature as the 10 dpa trace.

Conclusion

Impact tests were performed on a number of ferritic alloys irradiated at 370°C to 30 dpa. The impact behavior of the L0 (7.5Cr-2W) alloy (GA3X) is clearly superior to that of the others, although that of the L5 (9Cr-1V) alloy was also fairly good. On the basis of the impact data, both alloys appear to warrant further consideration as potential structural materials in fusion reactors.

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 under different conditions of temperature and neutron exposure.

REFERENCES

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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.