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FRACTURE TOUGHNESS OF FERRITIC ALLOYS IRRADIATED AT FFTF

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7.8 FRACTURE TOUGHNESS OF FERRITIC ALLOYS IRRADIATED IN FFTF - F. H. Huang (Westinghouse Hanford Company)

7.8.1 ADIP Task

7.8.2 Objective

The objective of this work is to evaluate the effects of neutron irradiation on the fracture behavior of HT-9 and 9Cr-1Mo, which are candidate materials for fusion first wall applications.

7.8.3 Summary

Ferritic compact tension specimens loaded in the Material Open Test Assembly (MOTA) for irradiation during FFTF Cycle 4 were tested at temperatures ranging from room temperature to 428°C. The electrical potential single specimen method was used to measure the fracture toughness of the specimens. Results showed that the fracture toughness of both HT-9 and 9Cr-1Mo decreases with increasing test temperature and that the toughness of HT-9 was about 30% higher than that of 9Cr-1Mo. In addition, increasing irradiation temperature resulted in an increase in tearing modulus for both alloys.

7.8.4 Introduction

Irradiations of ferritic alloys in support of the ADIP program have been carried out in the Experimental Breeder Reactor (EBR) II and the Fast Flux Test Facility (FFTF). During irradiation in FFTF, the specimens were placed in the Materials Open Test Assembly (MOTA) which was capable of monitoring and controlling the temperatures of the canisters containing the specimens. Irradiation effect data on fusion reactor alloys must be obtained from experiments conducted in the existing irradiation facilities since the fusion reactor environment is still lacking.

Small specimens were used to economize on the available irradiation space. The single specimens electric potential technique was used for the same reason. Specimens were fabricated from HT-9 and 9Cr-1Mo. Previous fracture toughness results from control tests on these alloys have been reported.[1,2] This report compares the baseline data with the post-irradiation results to describe the effect of irradiation on the fracture behavior of the materials. In addition, comparisons are made between the fracture responses of HT-9 and 9Cr-1Mo.

7.8.5 Progress and Status

7.8.5.1 Experimental Procedures

Compact tension specimens were fabricated from 3.175 mm thick plate. HT-9 specimens were given a prefabrication heat treatment of 1050°C/0.5 hr/AC+760°C/2.5 hr/AC, while 9Cr-1Mo specimens were given a prefabrication heat treatment of 1038°C/0.5hr/AC+760°C/0.5hr/AC. Reference 2 provides the configuration of the 2.54 mm thick disk-shaped compact tension specimens and the test procedures for fracture toughness using the electric potential technique to monitor the precrack length. After each test was completed, the specimen was heat tinted to reveal the crack extension. An empirical calibration curve was established by relating the crack extension and the electric potential output. Continuous crack extensions and J versus Δa curves were obtained from this calibration curve. Since the specimen was small, the results were analyzed using the J-integral approach. The procedure given in ASTM Standard E813 was followed to measure the fracture toughness of the irradiated material, with some precautions taken with respect to the size of the data exclusion zone.

7.8.5.2 Results and Discussion

Figures 1 and 2 show typical load and potential output versus displacement records for HT-9 and 9Cr-1Mo, respectively. These records were used to calculate the J values and continuous crack extensions using the electric potential calibration curve. Figure 3 shows the continuous J versus Δa curves for both ferritic alloys. The initial portion of J-Δa was fitted to the blunting line to determine the value of J_{Ic}. Fracture toughness results are compiled in Table 1. Where the tearing modulus (T), test and irradiation conditions are also listed.

Figures 4 and 5 show the range of toughness data available for HT-9 and 9Cr-1Mo. since there are only two specimen per irradiation condition, the temperature dependence of fracture properties cannot be established in detail. Figure 4 shows that increasing test temperature results in a decrease in toughness for both irradiated HT-9 and 9Cr-1Mo. It also shows that the fracture toughness of HT-9 is ~30% higher than that of 9Cr-1Mo. The temperature dependence of the tearing modulus is shown in Figure 5. In general, the tearing modulus of HT-9 decreases while that of 9Cr-1Mo increases as the test temperature is increased.

As shown in Figure 3, the tests were stopped before a reached 0.55 mm. Crack growth would be under a mixture of plane stress and plane strain conditions if Δa were too long. The 1.5 mm data exclusion zone size recommended in ASTM E813 is for specimens one inch or larger in thickness, although it is not specified in the standard. For small specimens, the maximum a must be smaller than 1.5 mm to ensure that J-controlled conditions are satisfied.[3] Both the thickness criterion and J-controlled conditions were satisfied and the J_{Ic} values obtained were therefore valid.

In general, the fracture toughness of HT-9 is not significantly degraded after irradiation. Results showed that the value of J_{Ic} at 205°C in fact increased as the fluence was increased from zero to x 3 10^{22} n/cm^2. According to the fracture toughness guideline given in Reference 4, the fracture toughness of HT-9 irradiated to 3 x 10^{22} n/cm^2 is well above the minimum toughness of about 15kJ/m^2 required for a structure of thickness 3 mm and a crack depth of 1.5 mm with a sufficient margin of safety.

Table 1. Fracture Toughness of Ferritic Alloys Irradiated in FFTF

Alloy	Irradiation Temperature (°C)	Fluence (10^{22} n/cm^2)	Test Temperature (°C)	J_{Ic} (kJ/m^2)	Tearing Modulus
HT-9	420	2.2	208	95.4	66.5
	420	2.2	428	61.6	48.9
	520	3.2	37	107.4	131.8
9Cr-1Mo	420	1.8	41	57.2	65.5
	420	1.8	427	43.4	82.7
	520	3.1	202	76.5	81.2
	520	3.1	316	49.2	86.2

7.8.5.3 Conclusions

The major conclusions are:

1. The fracture toughness of both HT-9 and 9Cr-1Mo decreases with increasing test temperature and the toughness of HT-9 was higher than that of 9Cr-1Mo.
2. The tearing modulus of HT-9 decreased but that of 9Cr-1Mo increased as a function of test temperature.
3. Increasing irradiation temperature resulted in an increase in fracture toughness for both alloys.
4. HT-9 showed adequate upper shelf fracture properties after irradiation.

7.8.5.4 References

1. F. H. Huang and G. L. Wire, "Fracture Toughness Testing on Ferritic Alloys Using Electropotential Techniques," Journal of Nuclear Materials, Vol. 104, pp. 1511-1516, 1982.
2. F. H. Huang, "J_{Ic} Measurements on Single Subsized Specimens of Ferritic Alloys," Journal of Testing and Evaluation, Vol. 13, No. 4, pp. 257-264, 1985.
3. J. W. Hutchinson and P. C. Paris, "Stability Analysis of J-Controlled Crack Growth," ASTM STP 668, American Society for Testing and Materials, pp. 37-64, 1979.
4. F. H. Huang, "Fracture Toughness of Irradiated HT-9 for Structural Application," Nuclear Engineering and Design 90, pp. 13-23, 1985.

7.8.5.5 Figures

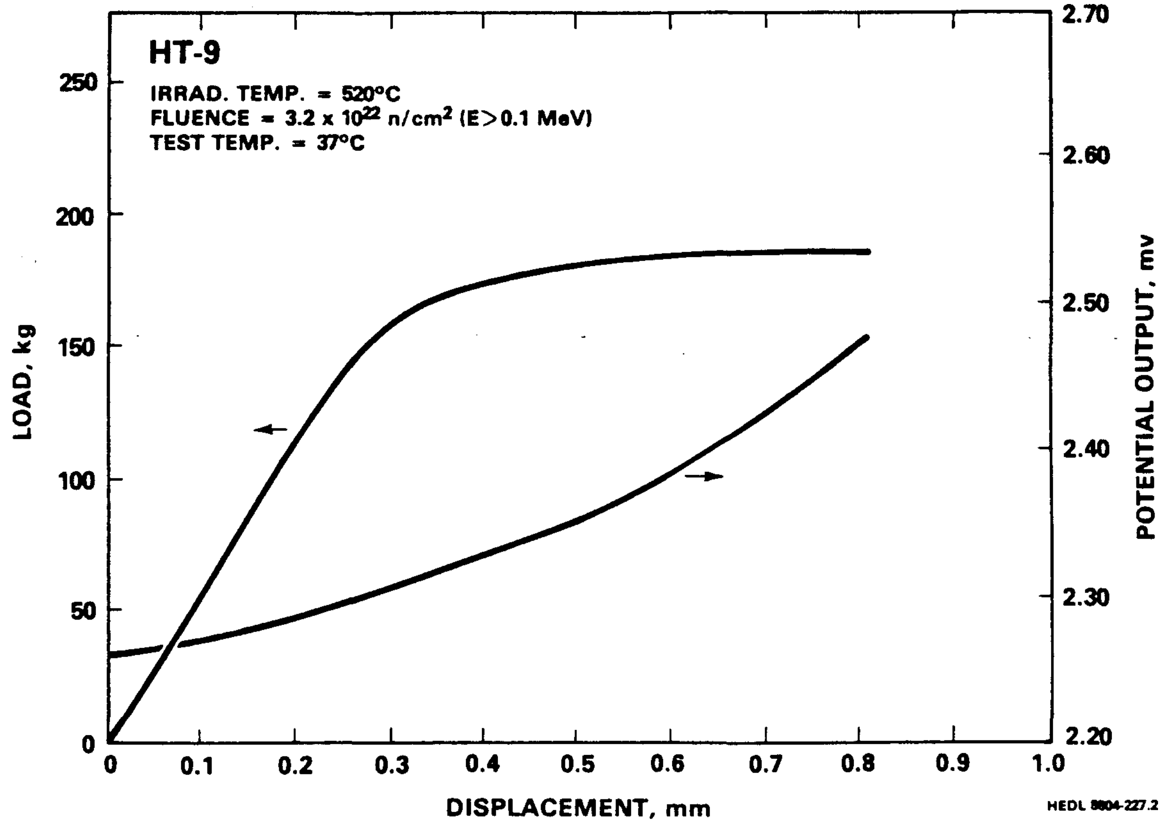

Figure 1. Potential Output and Load Versus Load-Line Displacement for HT-9 Irradiated at 520°C

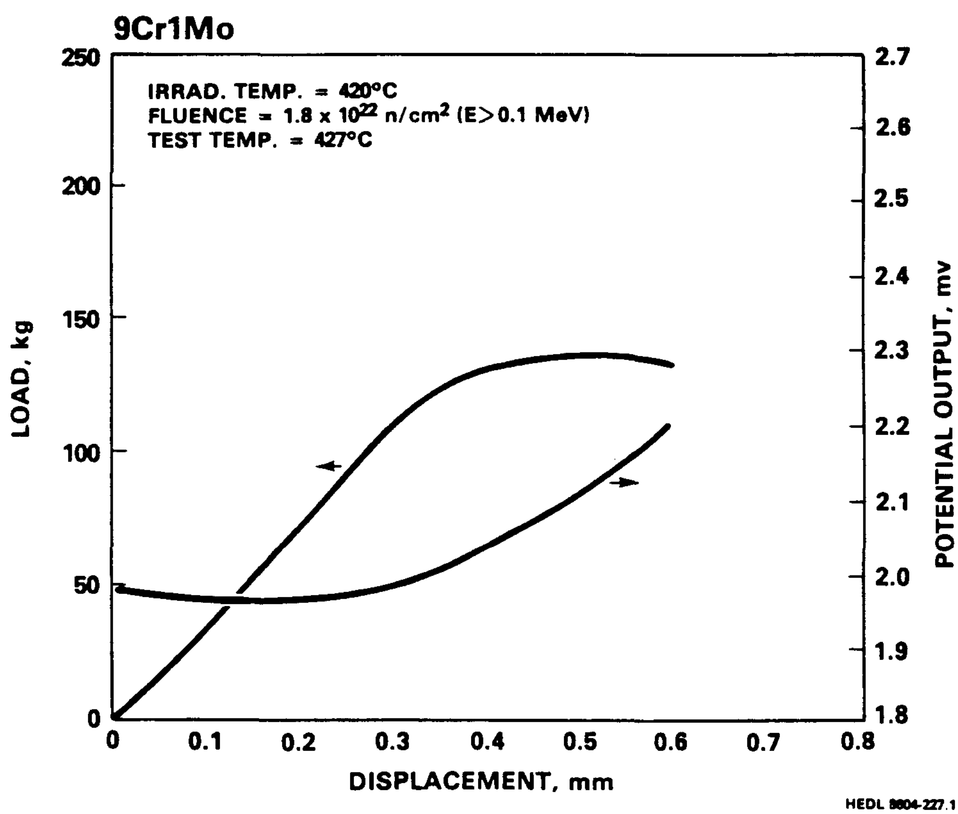

Figure 2. Potential Output and Load Versus Load-Line Displacement for 9Cr-1Mo Irradiated at 420°C

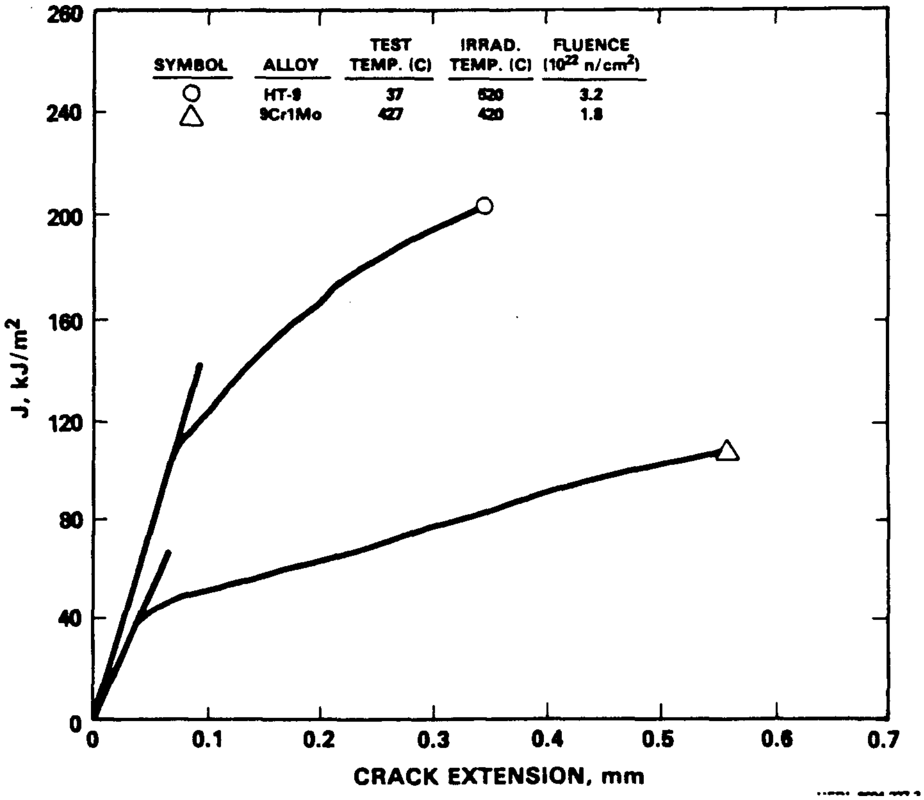

Figure 3. J Versus Δa Cuves via an Electric Calibration Curve for Irradiated HT-9 and 9Cr-1Mo.

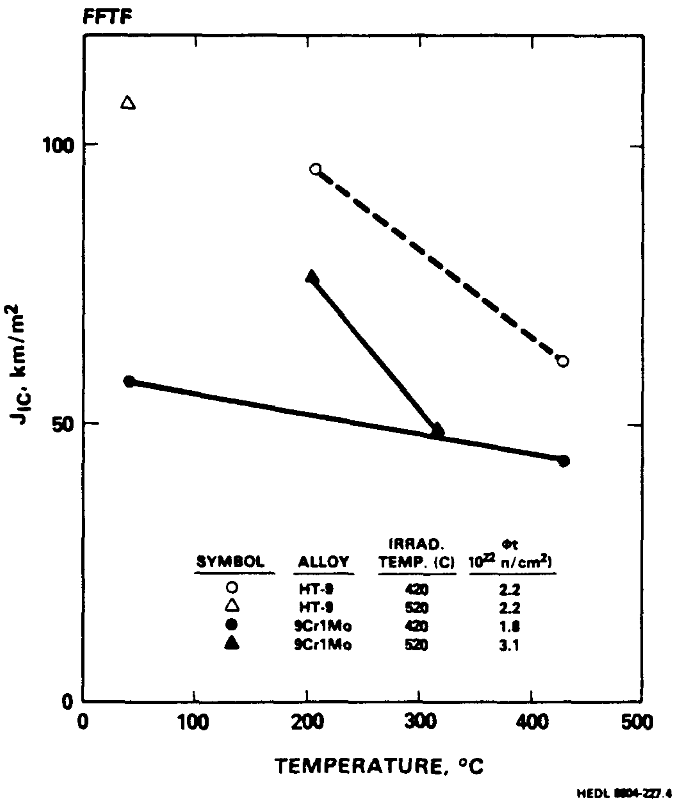

Figure 4. Temperature Dependence of Fracture Toughness for Irradiated HT-9 and 9Cr-1Mo.

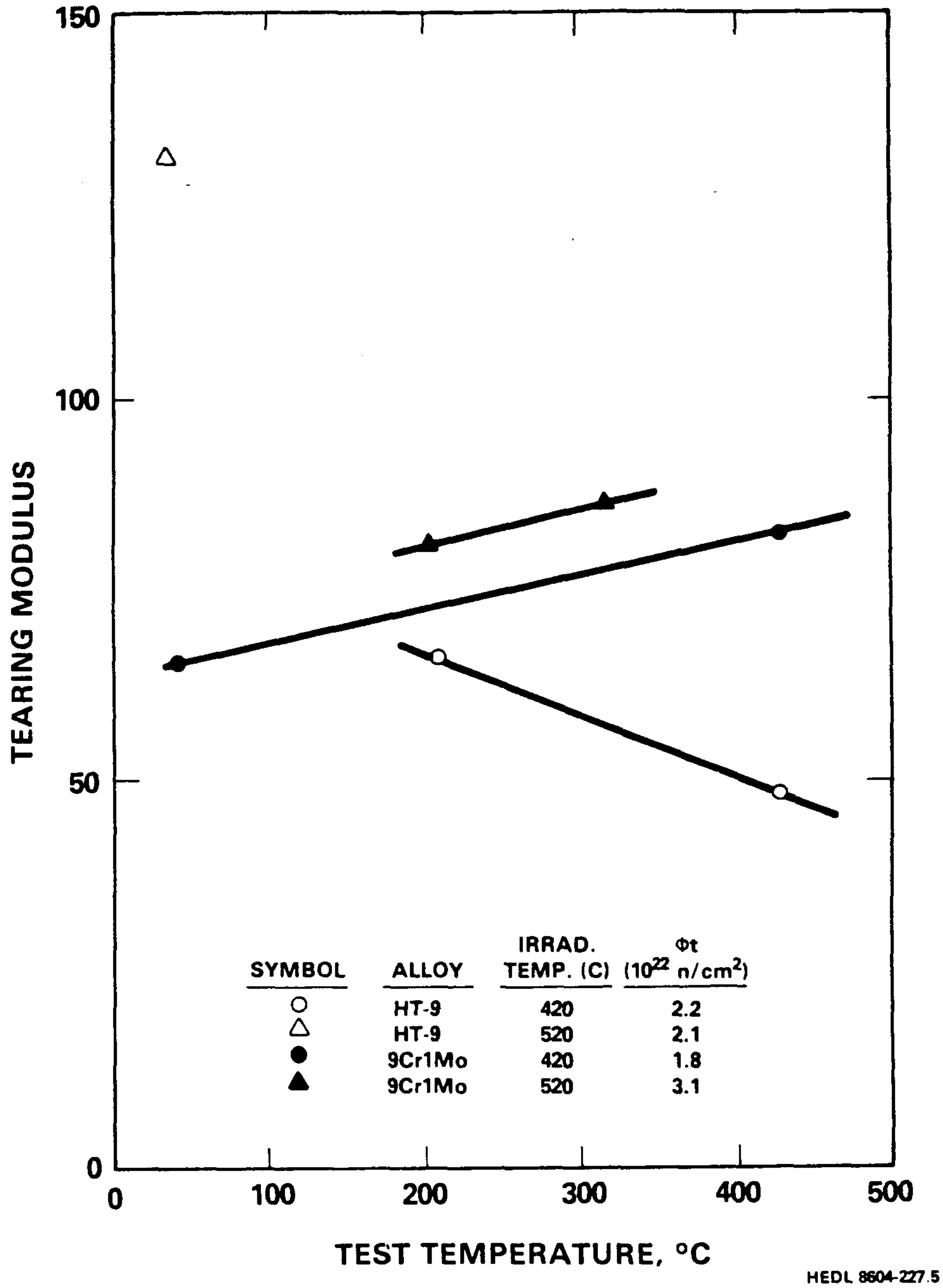

Figure 5. Temperature Dependence of Tearing Modulus for Irradiated HT-9 and 9Cr-1Mo.