FRACTURE TOUGHNESS OF THE IEA HEAT OF F82H FERRITIC/MARTENSITIC STAINLESS STEEL AS A FUNCTION OF LOADING MODE - Huaxin Li, D. S. Gelles (Pacific Northwest Laboratories)[a] J. P. Hirth (Washington State University--Pullman) and R. H. Jones (Pacific Northwest Laboratories)[a]

OBJECTIVE

The purpose of this research is to compare mixed mode fracture toughness response on the IEA heat of F82H with previous measurements on a small heat given a different heat treatment.

SUMMARY

Mode I and mixed-mode I/III fracture toughness tests were performed for the IEA heat of the reduced activation ferritic/martensitic stainless steel F82H at ambient temperature in order to provide comparison with previous measurements on a small heat given a different heat treatment. The results showed that heat to heat variations and heat treatment had negligible consequences on Mode I fracture toughness, but behavior during mixed-mode testing showed unexpected instabilities.

PROGRESS AND STATUS

Introduction

We have reported previously on mode I, mode III and mixed-mode I/III fracture toughness for heat #8033 from Nippon Kokkan Corporation (NKK).[1-3] That work was based on material given a laboratory heat treatment optimized for strength and designed for martensitic steels that were not given progressive hot deformation treatments [1000°C/20h/AC + 1100°C/7min/AC + 700°C/2h/AC]. Therefore, the results obtained did not apply directly to the large IEA heats of F82H made available for international testing.[4,5] The present effort is intended to extent these earlier results by duplicating the mode I and mixed-mode tests to the IEA heat in the standard as-received heat treatment conditions [1040°C/40min/AC + 750°C/1h/AC].

Experimental Procedures

Specimens were prepared from 15 mm plate of F82H received directly from Dr. A. Hishinuma of JAERI. This plate was from lot 1, heat 9741, plate RB802-3-14. Details for this material have been published previously.[4,6] Only specimen crack angles of 0° (mode I) and 35° (mixed-mode I/III) were used, and the heat treatment condition was as-received. Specimens were 12.7 mm thick and therefore, specimens for this study were almost the thickness of those from heat #8033 which were 14 mm thick. Both specimen geometries meet the plane strain condition as specified in ASTM E399. Specimen testing followed standard procedures.[1]

Results

Two tests were performed on the IEA F82H heat in mode I (crack angle 0°) and two tests were

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

performed in mixed mode I/III (crack angle 35°), all at room temperature. The results of the mode I test are provided in Table 1, with the value obtained for the small heat tested previously provided for comparison. Tests in mixed mode produced unstable crack propagation, making measurements of fracture toughness and tearing modulus impossible. Comparison of the results in Table 1 between the IEA heat and the small NKK heat shows that both materials behave similarly, with values from the small heat intermediate between the measurements made on the large heat both for fracture toughness and tearing modulus. This is shown more clearly in Figure 1 which provides data for mode I and mixed mode I/III toughness as a function of crack angle.

Table 1. Results of fracture toughness and tearing modulus for Mode I specimens of the IEA heat of F82H.

Specimen ID	J (KJ/m^2)	T ($KJ/m^2/mm$)
IEA-1	273	264
IEA-2	328	248
Heat 8033	284	263

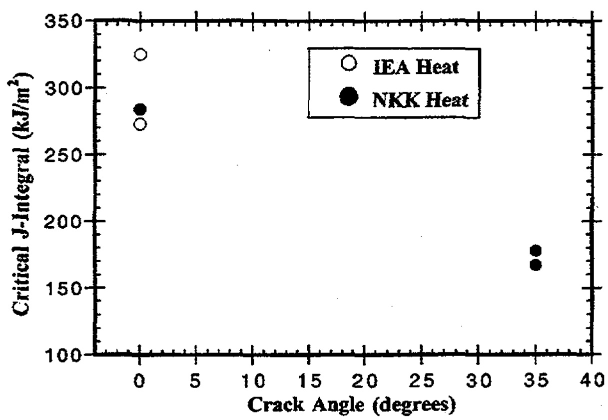

Figure 1 Fracture toughness for F82H as a function of crack angle

The cause of unstable crack propagation during mixed-mode testing is not yet understood. A test trace is shown in Figure 2 for specimen IEA-9, and reveals that testing proceeded normally until after the 28th compliance unloading step, needed to quantify crack propagation, when the crack advanced suddenly to failure.

Fractographic examinations revealed the expected dimple rupture response in specimen IEA-2 tested in mode I, but unexpected response in specimen IEA-8, tested in mixed mode. This unexpected response was in two forms. Areas of the fracture surface were found to have failed by brittle transgranular cleavage, and, in large dimples created on other parts of the fracture surface, features as large as several microns could be identified. Examples are provided in Figures 3 through 5. Figure 3 shows the area of the specimen adjacent to the fatigue crack at low magnification, with the fatigue crack at the bottom, a region adjacent that failed by dimple rupture, and the upper region which failed by cleavage fracture. The cleavage fracture response is shown in greater detail in Figure 4. Figure 5 provides an example of large features found in a large dimple that can be expected to have been the

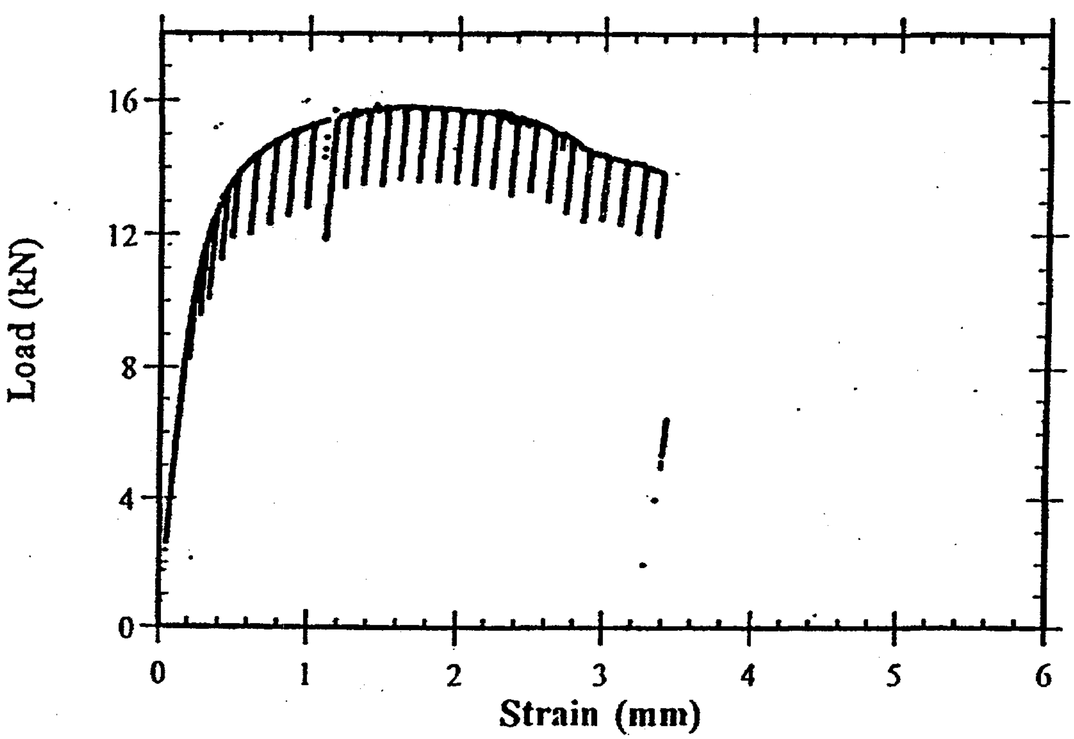

Figure 2 Test trace for mixed-mode specimen IEA-9.

cause of cavitation.

Discussion

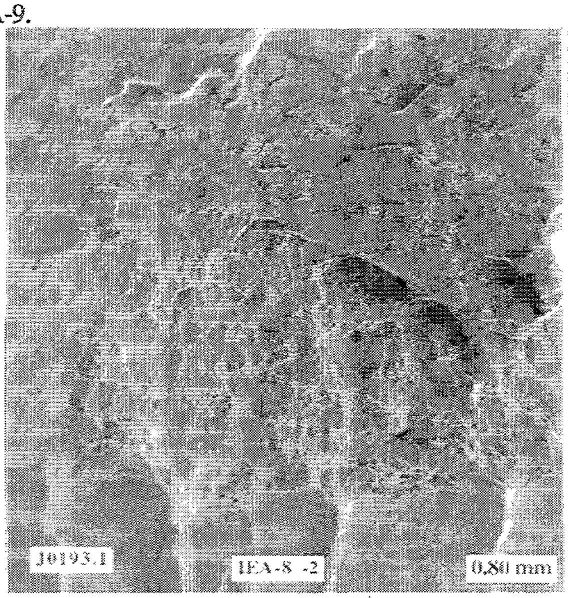

Figure 3 Fracture Surface of Specimen IEA-8 Showing the Fatigue Surface at the Bottom.

Tests to determine mixed-mode I/III fracture toughness of the IEA heat of F82H have provided unexpected response. Mixed-mode tests on the small NKK heat of F82H had given stable cracking response, whereas tests on the large heat did not. Also, brittle fracture appearance was very different for the two heats. The IEA heat is found to fail during mixed mode testing by transgranular cleavage at room temperature. It had been shown in the laboratory heat that mixed-mode (Heat 8033) response at low temperature (-90°C) produced an intergranular brittle fracture appearance which differed from that of mode I behavior, which was transgranular.[3] It was assumed from that work that the brittle response for mixed-mode I/III testing would always develop a tendency for intergranular failure. Therefore, both the unstable cracking and transgranular cleavage during unstable crack propagation were unexpected.

The cause of this unexpected response is not yet understood. The possibility of flawed material or incorrect heat treatment can be discounted because mode I testing was successful, providing similar results for both heats of material. Also, the observation of crack nucleation sites that were larger than expected in the IEA heat of F82H is in agreement with material characterization studies from Europe which showed that inhomogeneities were limited and generally ≤10 μm, but with some complex oxides of Al, Ta, Ti and/or Zr as large as 60 μm.[7]

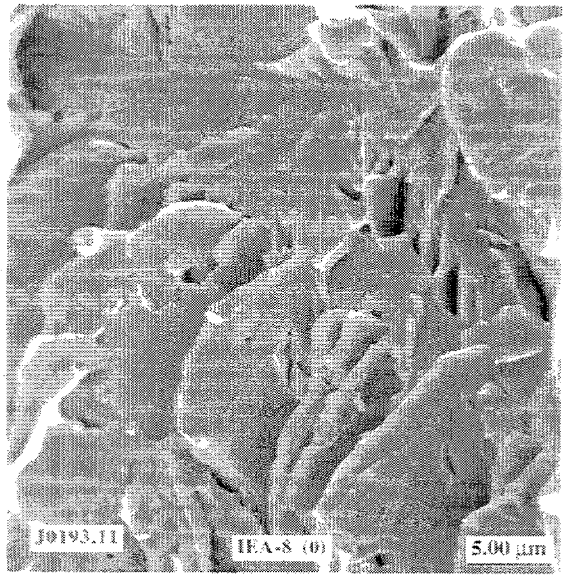

Figure 4 Example of Intergranular Brittle Cleavage in Specimen IEA-8.

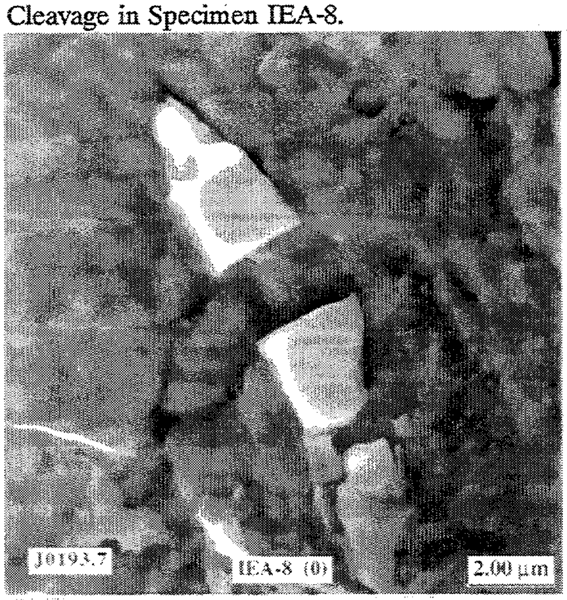

Figure 5 Example of Particles in a Large Dimple that were Possible Responsible for Cavitation.

CONCLUSION

The effect of heat-to-heat and heat treatment variations has been studied by performing critical J integral tests in mode I (J_{IC}), and in mixed-mode I/III (J_{MC}) at ambient temperature, for the IEA heat of the reduced activation ferritic/martensitic stainless steel F82H in a standard heat treatment, and by comparing with previous measurements on a small heat given a different heat treatment. The results showed that heat-to-heat variations and heat treatment had negligible consequences on mode I behavior, but behavior during mixed-mode testing showed unexpected instabilities.

FUTURE WORK

This work will be continued within the limits of available funding.

ACKNOWLEDGEMENTS

The material was supplied by Dr. A. Hishinuma of JAERI whose help is gratefully acknowledged. This research was supported by the Office of Fusion Energy of the U. S. Department of Energy under Contract DE-AC06-76RLO 1830 with Battelle Memorial Institute.

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