FRACTURE TOUGHNESS VARIABILITY IN F82H - D. S. Gelles (Pacific Northwest National Laboratory)*, and Mikhail A. Sokolov (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this effort is to better understand the fracture toughness response of low activation ferritic steel F82H.

SUMMARY

The fracture toughness database for F82H displays some anomalous behavior. Metallographic examination reveals banding in the center of 25 mm thick F82H plate, which is more evident in transverse section. The banding is shown to arise because some grains are etched on a very fine scale whereas the remainder is etched more strongly and better delineates the martensite lath structure. However, the banding found does not provide explanation for the anomalous fracture toughness behavior.

PROGRESS AND STATUS

Introduction

Fracture toughness measurements of 25 mm F82H plate [1] are showing indications of non-uniform behavior as a function of thickness. The point was most clearly made by Wallin and colleagues [2] based on small specimen testing reported in the 4th ASTM symposium on Small Specimen Test Techniques. They found larger than normal scatter for master curve analysis of their F82H data, and because they had kept track of the plate location of each tested specimen, they were able to show degraded behavior for some of the specimens coming from a region 12-17 mm from the plate upper surface, (and less so for specimens adjacent to the upper surface.) Also, cleavage initiation site examination of compact tension specimens of full thickness geometries showed initiation had consistently occurred in the 12-17 mm layer. Therefore, a lower toughness zone was indicated for the mid thickness of the plate, and small specimens fabricated away from this central zone showed higher toughness. However, this behavior can be identified in ORNL and JAERI measurements as well, [3] as will be shown. The purpose of the present effort is to identify the microstructure features that may be responsible for this fracture toughness degradation.

Experimental Procedure

A piece of the grip area of a tested full thickness compact tension specimen was selected for optical metallography. Longitudinal- and cross-rolling directions were maintained. Sections parallel to the plate rolling direction (longitudinal) and perpendicular to the rolling direction (transverse) were prepared for metallographic analysis using standard procedures, and were then etched using Kellers etch (1% hydrofluoric acid, 1.5% hydrochloric acid, and 2.5% nitric acid in water) as a dip. Microscopy was performed using a JEM-840 Scanning Electron Microscope (SEM) operating at 20 KeV equipped with a backscatter detector. Images were stored digitally.

Results

Metallography

Both etched samples of the full plate thickness revealed a difference in microstructural contrast towards the center. Examples are given in Figures 1 and 2 showing a mosaic for the full thickness of the

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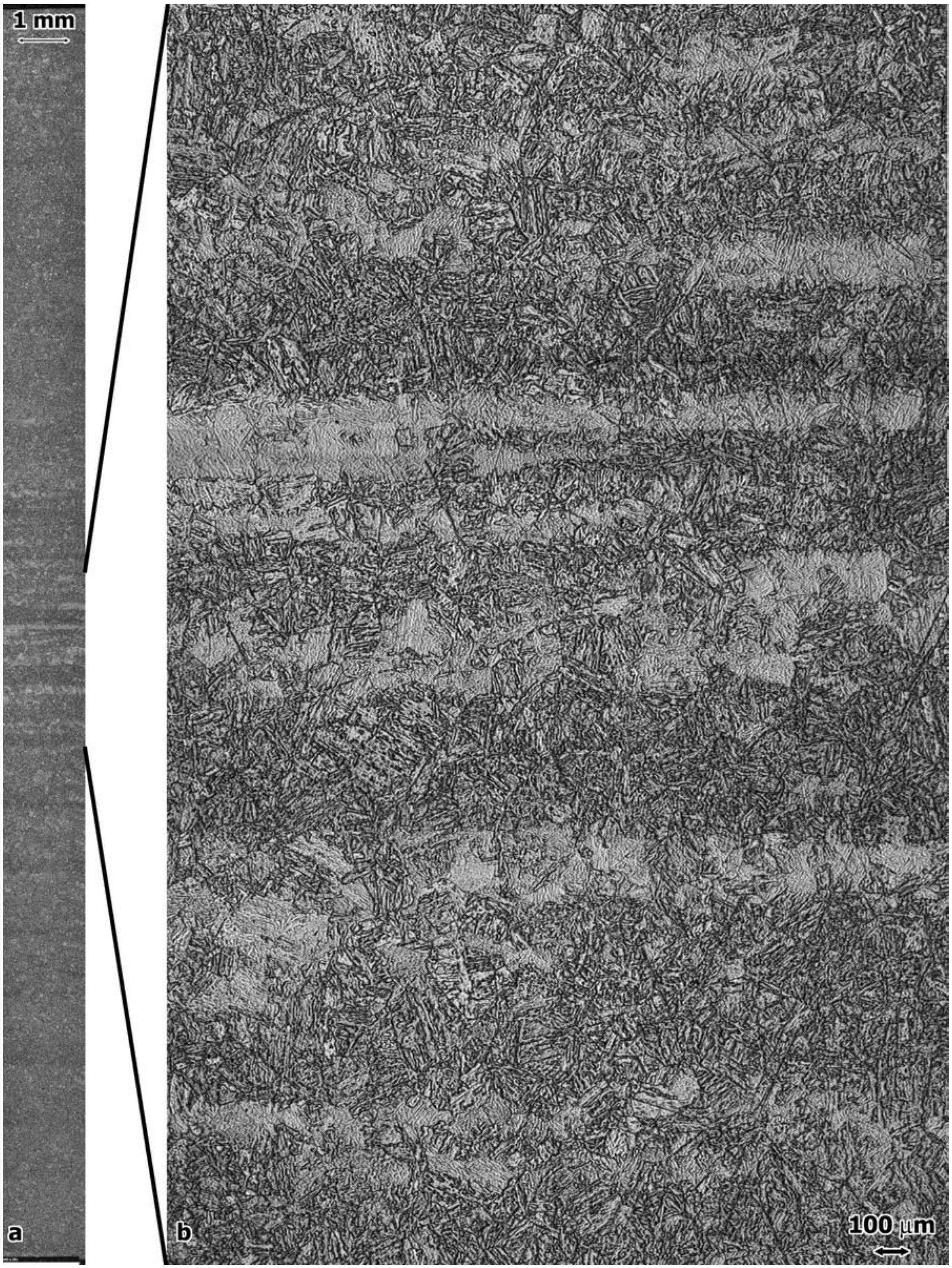

Figure 1. Transverse section etched microstructure of F82H plate showing in a) a mosaic of the microstructure across the full width of the 25 mm plate and in b) the central region at higher magnification.

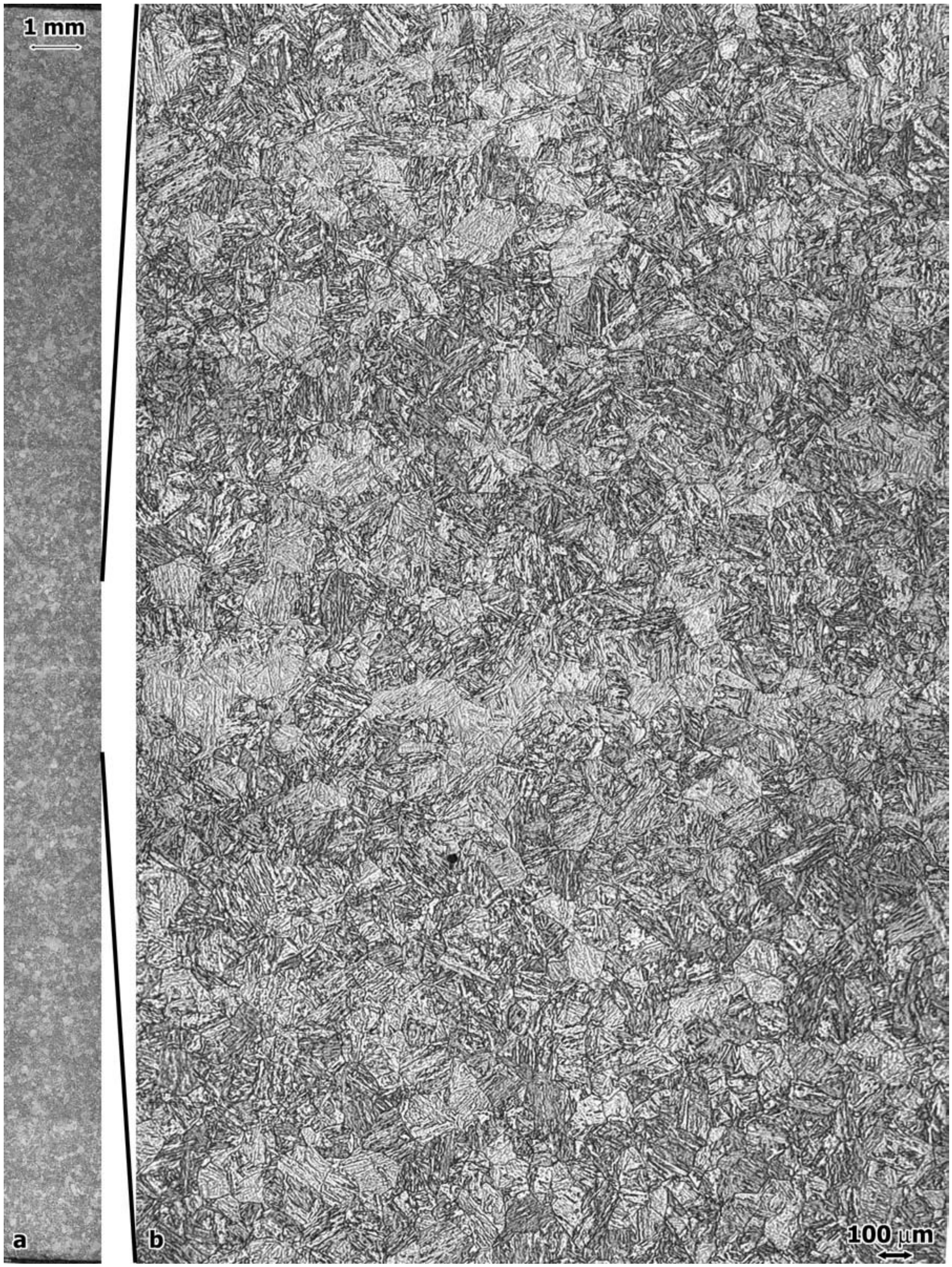

Figure 2. Longitudinal section etched microstructure of F82H plate showing in a) a mosaic of the microstructure across the full width of the 25 mm plate and in b) the central region at higher magnification.

transverse section in a) and the central region of the sample in b) for transverse and longitudinal sections, respectively. Bands can be identified that appear lighter and contain less structure. The difference in contrast appears to be due to the fact that these bands are less heavily etched than are neighboring bands or other regions away from the center. The distribution of grains showing less etching is different for the transverse and longitudinal section, indicating that the bands appear more often in the transverse direction and are concentrated at the center of the plate.

Scanning Electron Microscopy

SEM verified that the central bands showing less contrast were less affected by the etchant. Examples are provided in Figure 3, showing six views, the first four using a backscatter detector so that carbide particles show up brightly. Figure 3a) shows an area at low magnification containing both structures, with the area towards the upper left corresponding to the structure showing less etching. Note the two large carbide particles probably on prior-austenite grain boundaries at the upper left. Figure 3b) provides the central area at higher magnification, revealing evidence for lath structure within the less etched region. Figures 3c) and d) show comparison of the etch variations at higher magnification. The less etched region in Figure 3c) is found to contain very fine structure whereas the strongly etched region actually contains two types of features, one deeply etched and the second showing very little structure. The final two examples are similar, but at slightly lower magnification and without the backscatter detector. Therefore, the effect of etching is to produce bands of grains that are very finely etched within the remaining grains that etch non-uniformly, and better reveal the martensite lath structure.

Discussion

The variations in fracture toughness for 25 mm thick F82H plate obtained by Wallin and colleagues [2] at VTT Manufacturing Technology, Finland are best demonstrated in the figures reproduced from their work in Figure 4 showing behavior in 5 x 5 x 27 mm notched bend bars. Similar behavior can be identified in smaller 3 x 4 x 7 mm bend bars but the trends are not as clear. Figure 4a) shows master curve analysis of the data with many points clearly below the 95% confidence limits. Figure 4b) compares the results as a function of position in the 25 mm plate. It is clear that the solid triangles for samples prepared from the 12-17 mm layer are distributed into two groups, some within the master curve response but the remainder falling below the curve (and the remainder of the low points are for specimens taken from the 1.6-6.6 mm layer.) Therefore, it can be anticipated that there are features within the 12-17 mm layer that can reduce fracture toughness in the 25 mm F82H plate.

Similar behavior can be shown in results from ORNL and JAERI. Figure 5 provides a compilation of fracture toughness from these data bases [3]. It should be noted that JAERI testing was done at –40 and –60ºC, fitting the trend along with several other measurements below 100 MPa $m^{1/2}$ and above –100ºC. Therefore, fracture toughness behavior in the 25 mm thick plate of F82H can show response below expected master curve prediction and this behavior has been demonstrated worldwide.

It may be worth noting that unexpected response has been found both in Japan and Europe regarding fatigue crack propagation in F82H [4-5]. Fatigue generally results in transgranular crack propagation, but these tests on F82H showed intergranular cracking. The behavior was confirmed during recent studies of crack tip microstructures in F82H [6]. The cause is not yet understood.

Anomalous fracture toughness and fatigue cracking response can generally be attributed to either grain boundary weakening due to segregation or enhancement of sites promoting crack nucleation. As the most prominent crack nucleation sites are large carbides, and the largest carbides in martensitic steels such as F82H are generally on prior austenite grain boundaries, it is reasonable to expect that large carbides exist in the center of the F82H plate and are responsible. Note that fractography of the F82H specimens showing anomalously low toughness does not show intergranular fracture, and therefore grain boundary weakening due to segregation is unlikely to be relevant. Therefore, evidence of sites for

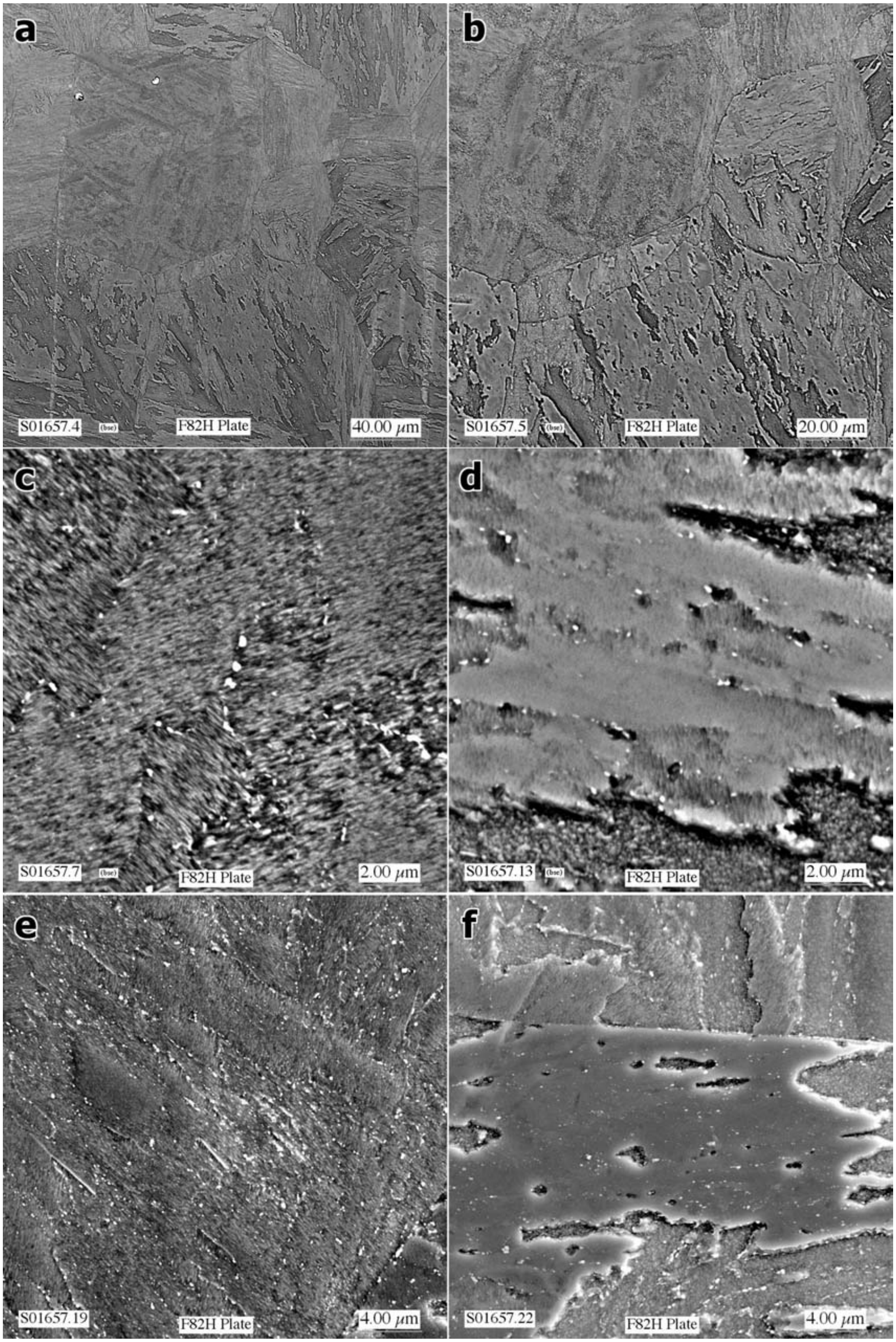

Figure 3. SEM images of the center of the transverse etched section.

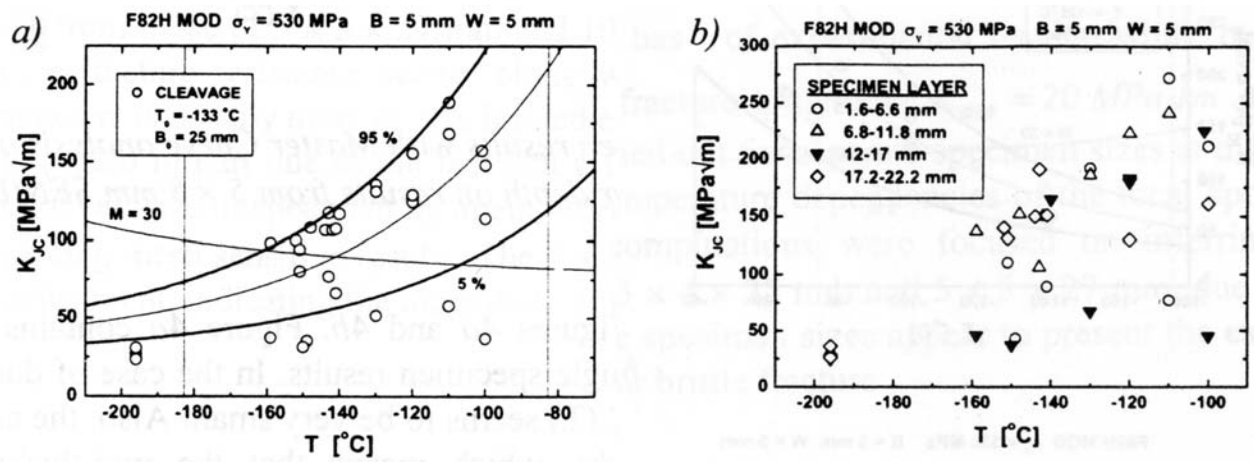

Figure 4. Fracture toughness of 5 x 5 x 27 mm bend bar specimens from reference [2].

enhanced crack nucleation in the plate center in the form of large carbide particles is most likely to explain the observed behavior.

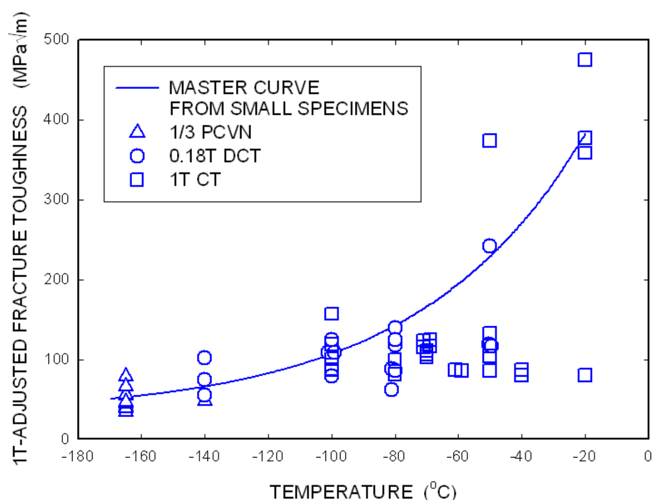

Figure 5. 1TCT fracture toughness data for 25 mm F82H plate from ORNL and JAERI.

It was noted that Figure 3a) contained two large carbide particles probably on prior austenite grain boundaries. Unfortunately, this evidence is insufficient to demonstrate the source of anomalous fracture toughness behavior because larger carbides do exist elsewhere in the plate, and a more complete statistical distribution of these large carbides is required. Also, the metallographic observation of bands in the center of the plate (shown in Figures 1 and 2) cannot be used to explain reduced toughness because no mechanism for enhanced fracture can be envisioned based on the structural differences of these bands. For example, the prior austenite grain size is similar not only for the lighter bands found metallographically and nearby darker grains, but also throughout the thickness. (A larger prior austenite grain size would enhance levels of carbide forming elements at boundaries and produce larger carbide particles.) Therefore, the present effort does not appear to provide sufficient information to explain anomalous fracture toughness response in F82H 25 mm plate.

It is likely that the problem is to envision a simple mechanism that creates larger carbides in the center of the plate and not elsewhere. Larger carbides may arise during casting because the center of the heat cools more slowly. The center is therefore the last to solidify and remains at higher temperatures longer, allowing more coarsening of particles that do not dissolve during heat treatment. After processing, the center of the billet would normally become the center of the plate. However, the 25 mm F82H plate was made from heat 9753 which was split into two parts to create 15 mm and 25 mm plate, and the 25 mm plate came from the ingot bottom [1]. The procedure whereby the plate was made from the bottom of the ingot is unclear, and so the center of the plate may not be directly traceable to the center of the ingot.

Conclusions

Fracture toughness measurements on 25 mm plate of F82H show anomalous response outside the Master Curve 95% confidence limits for specimens prepared from the center of the plate. Metallographic examination shows bands in the center of the plate that appear lighter and contain less structure. The difference in contrast appears to be due to the fact that these bands are less heavily etched than are neighboring bands or other regions away from the center. The distribution of grains showing less etching is different for the transverse and longitudinal section, indicating that the bands extend more often in the transverse direction and are concentrated at the center of the plate. SEM verified that the central bands showing less contrast were less affected by the etchant but the effect of etching is to produce bands of grains that are very finely etched within the remaining grains which are etched non-uniformly, and therefore better reveal the martensite lath structure. However, these results do not explain the anomalous toughness response.

Future Work

The effort will be continued as opportunities become available.

References

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