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H.J. Kim and J.W. Morris, Jr.

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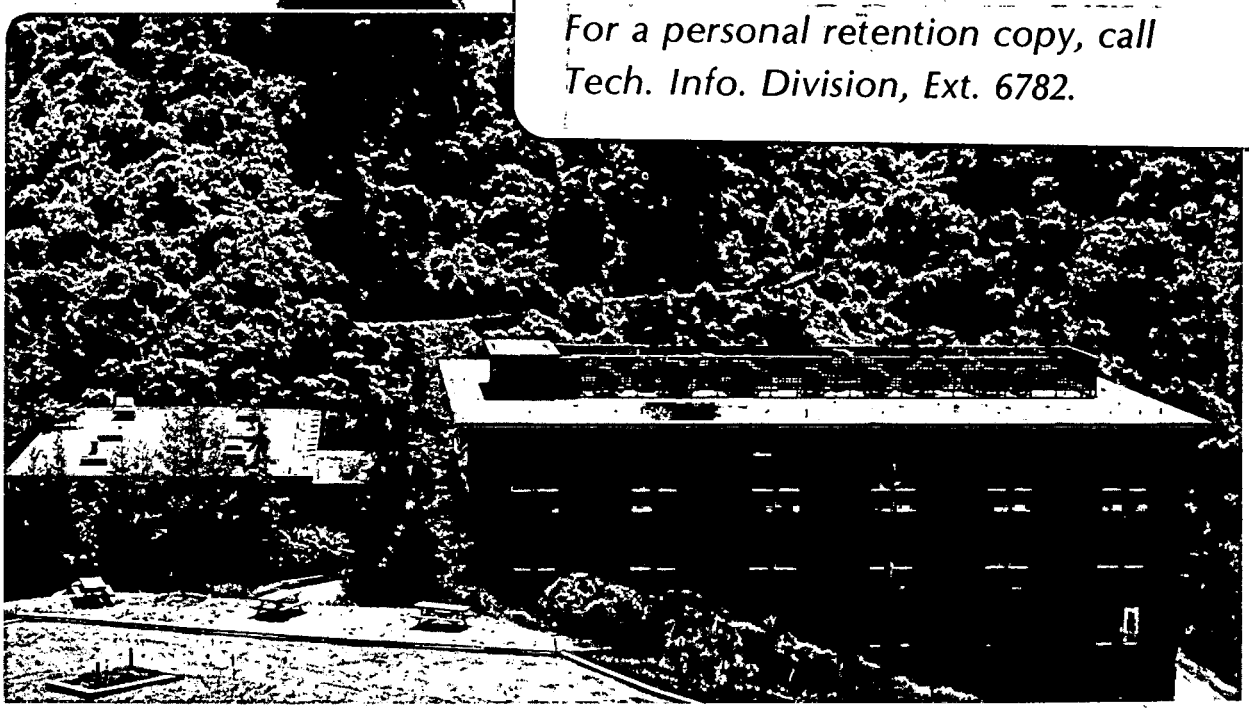

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WELDABILITY OF 2BT-TREATED 9NI STEEL WITH FERRITIC FILLER METAL

H. J. Kim and J. W. Morris, Jr.

Dept. of Materials Science and Mineral Eng. and
Lawrence Berkeley Laboratory,
University of California, Berkeley, CA 94720

INTRODUCTION

Previously, authors reported [1] the preliminary studies on ferritic GTA weldments of grain-rfined and tempered (2BT-treated) 9Ni steel. Those results demonstrated the absence of brittleness at 77K and good impact toughnesses even at 4.2K not only in the base metal but also in the welded region. However, the 77K fracture toughness values reported in the previous paper [1] were obtained using small size specimens (fatigue precracked Charpy specimens) and the 4.2K ones have not been measured.

Continuing the line of research, this paper presents to results of the testing and evaluation of 2BT-treated 9Ni steel and its ferritic weldment for liquid helium temperature (4.2K) service.

ALLOY PREPARATION AND EXPERIMENTAL PROCEDURES

The 9Ni steel used in this work was commercial grade provided by Nippon Kokan K.K. The materials were received in the form of 25.4mm (1.0 in) thick plates in quench-and-tempered (QT) condition. These plates were solution-annealed at 900°C for 2 hours and then given the 2BT heat treatment. The chemical composition of these plates and the heat treatment schedule are given in reference 1. After full heat treatment, the plates were machined into 60° double-V groove configuration and then manually welded using gas tungsten arc welding (GTAW) process. The ferritic filler rod of nominal composition Fe-14Ni-0.2Ti-0.003B was prepared from the cost ingot in this laboratory. The welding conditions were also given in reference 1.

The compact tension specimens for fracture toughness tests were machined from the as-welded plates and tested at 77K and 4.2K using th single-specimen J-integral technique. Because of the limit in thickness of the base plates (25.4 mm) and in the quantity of welded plate, the thickness of the specimens vary from 8.9 mm (0.35 in) to 22.9 mm (0.9 in). Precracks were produced at 77K at a minimum to maximum load ratio, R, of 0.1 and 10 Hz.

RESULTS AND DISCUSSION

The load vs. load-point displacement curves obtained in the J_{IC} test at 77K are drawn in Fig. 1 (unloading curves are ommitted during drawing). As shown in these curves, the weld metal specimen is immune to catastrophic crack propagation but the base metal and HAZ specimens display unstable propagation after passing maximum load. Since the first crack advance points, where the fracture toughness (J_{IC}) is determined, were monitored near the maximum load points in all the specimens tested at 77K J_{IC} value itself was not affected by the unstable crack propagation. Each unstable propagation shown in the load vs. load-point displacement curve (Fig. 1) corresponds to a series of thumb nail marks which are visible to the naked eye on the fracture surface, as shown in Fig. 2. Another thing to note in Fig. 2 is that the HAZ specimen has the abnormal shape of a fatigue crack front resulting in a non-valid toughness value. Since this specimen is from a double-V weld joint, the center part of the specimen lies far inside the base metal region and the edge part is close to the fusion line. So the fatigue properties of the center of the HAZ specimen are different from that of the outer edges.

The plane strain fracture toughness values, $K_{IC}(J)$, converted from J_{IC} are listed in Table 1. Based on 77K data, the weld and HAZ fracture toughness values compare favorable with that of the base metal: 292 MPa m (265 ksi in) in HAZ and 365 MPa m (332 ksi in) in the weld metal as compared with 323 MPa m (294 ksi in) for 2BT-treated 9Ni steel.

Table 1. Mechanical Properties of 9Ni Weldment

Specimen	Yield Strength MPa(ksi)		Fracture Toughness $K_{IC}(J)$ MPa m (ksi in)	
	77K	4.2K	77K	4.2K
9Ni Steel (QT-treated)	989(143)	1312(190)	-	73(66)*
9Ni Steel (2BT-treated)	1007(146)	1312(190)	323(294)	110(100)
Heat-affected zone	-	-	292(265)	90(82)
Weld Metal	-	-	365(332)	145(132)

* R.L. Tobler: Fracture, 3:893, 1977.

As the temperature decreases further down below 77K, the 9Ni weldment, particularly the base metal and HAZ, tend to become brittle and eventually give jagged load vs. load-point displacement curves at 4.2K. Also, as shown in Fig. 3, the crack grows slowly and steadily with very small amplitude serrations up to the maximum laod, which is substantially low compared with that at 77K, and with rather larger load-drops afterwards. All the resistance curves constructed in this study clearly demonstrated that the first crack advance occurs at the first serration and the crack advances step by step with the subsequent load-drops. It indicates that these continuous serrations are due to the successive minute pop-in type propagations. This kind of crack propagation results in a brittle characteristic in the fracture surface as shown in Fig. 4a. Consequently, all the 4K toughness values reported in table 1 are the ones calculated based on the critical J values at the first serration marked by arrows on each of the curves.

One thing to note in Fig. 3 is the load difference between the first serration and maximum load point. The maximum load on the base metal specimen was reached right after the first serration but that of the weld metal specimen was reached after substantial amounts of deformation. As a result, the maximum load on the weld metal specimen is almost twice as large as that at the first serration. Considering the thickness difference (base metal is 17.8mm (0.7 in) thick and the weld metal specimen is 8.9mm (0.35 in) thick), itd is expected that the load carrying capacity of the weld metal is almost two times higher than that of the base metal.

The early stage of serration and the very high maximum load in the weld metal specimen seems to be based on the microstructural effect of the weld deposits. Examination of whole fracture surfaces illustrated that the fracture mode of the 9Ni base metal, which has a uniform microstructure, is quasi-cleavage throughout the fracture surface as shown in Fig. 4a, but that of the weld metal specimen is a mixture of typical dimple-rupture and a small amount (about 20%) of quasi-cleavage. These two modes are usually divided with very clean straight boundaries as shown in Fig. 4b. Therefore, it is reasonable to expect that the early stage of serration is attributable to brittle crack initiation occurring in some localized areas which were not fully refined by the subsequent weld passes. On the other hand, well-refined regions carry the bulk of the applied load through a ductile failure mode. As a result, the abnormal features in the load-COD curve of the weld metal specimen is attributable to the non-uniform grain size in the multipass weld deposit. This implies that a uniformly refined microstructure is an important factor in increasing the toughness value of the ferritic weld deposit.

In the case of the base metal, the 2BT heat treatment increases the 4K toughness of the 9Ni steel from 73 MPa m in the QT condition [2] to 110 MPa m, as shown in table 1, but this improvement is not enough to change the fracture mode from brittle to ductile at 4.2K. However, it

should be noted that this improvement in toughness is obtained without sacrificing the strength of the steel, i.e., the yield strengths of both conditions are at the same level of 1312 MPa (190 ksi), and are obtained only by the microstructural control. This kind of trend, also observed in other ferritic steels [3,4], is quite a contrast to that known in the austenitic steel grade, which has inverse relationship between yield strength and fracture toughness [5]. Moreover, the strength, and consequently the toughness, of the austenitic steel is mainly a function of the chemical composition, particularily the content of carbon and nitrogen, rather than the microstructure [5]. TLherefore, the effort in alloy development for ferritic steel has to be different from that for austenitic steel, i.e., it should be focused on the mechanism of microstructural refinement during heat treatment and the ductile-brittle transition behavior with the variation of microstructures.

ACKNOWLEDGEMENTS

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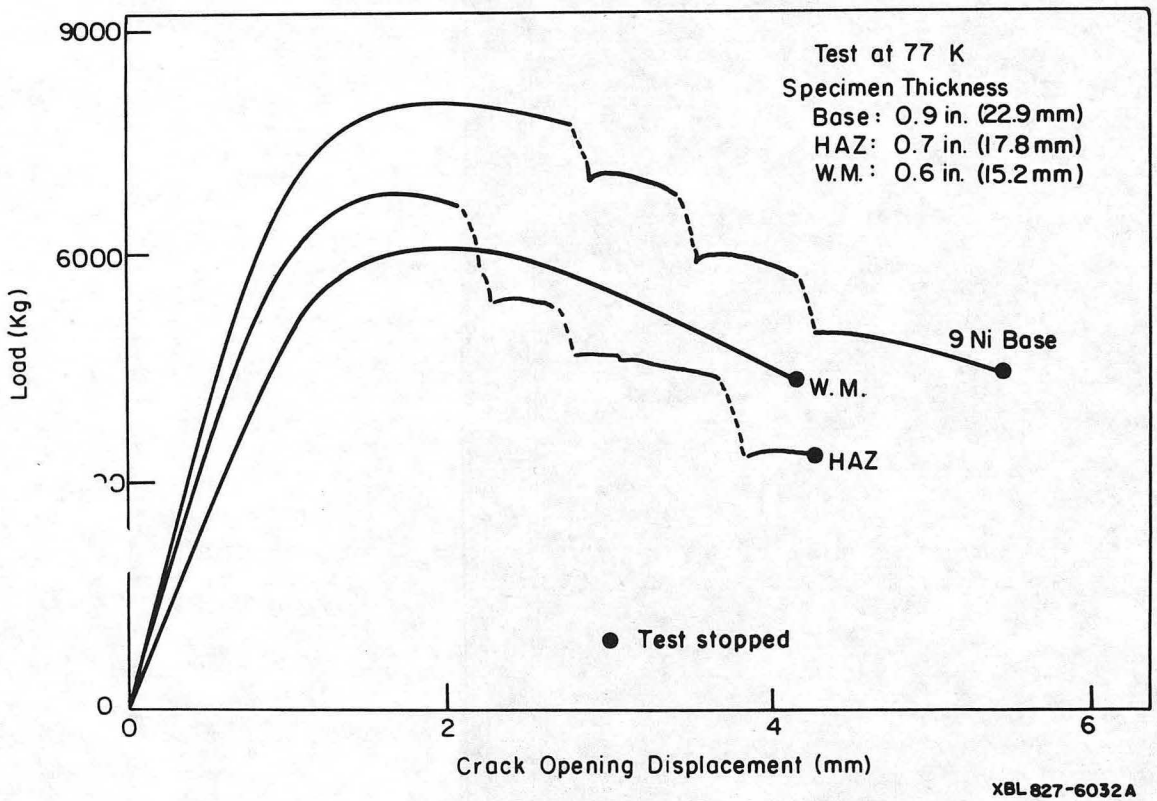

Fig. 1 Load vs. load-line displacement curves at 77K.

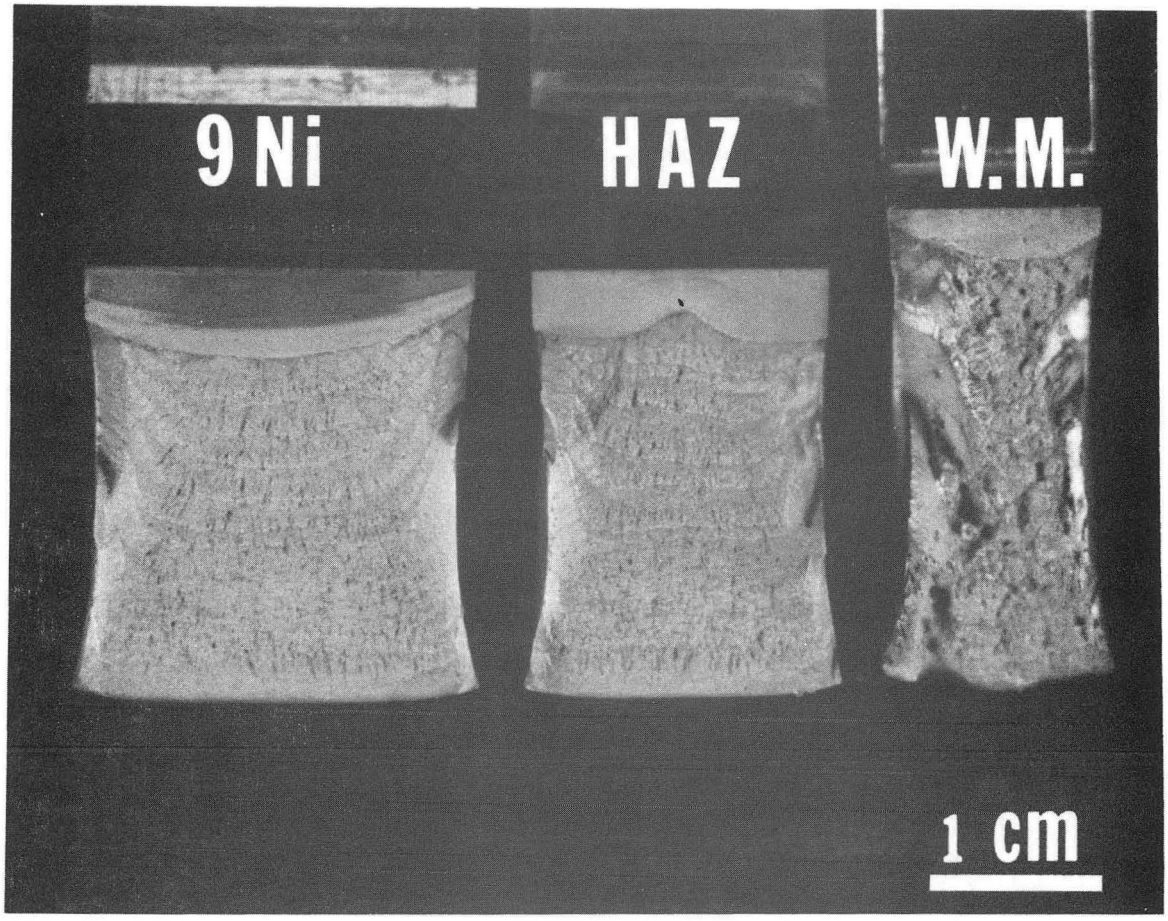

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Fig. 2 Macroscopic fracture surfaces after testing at 77K.

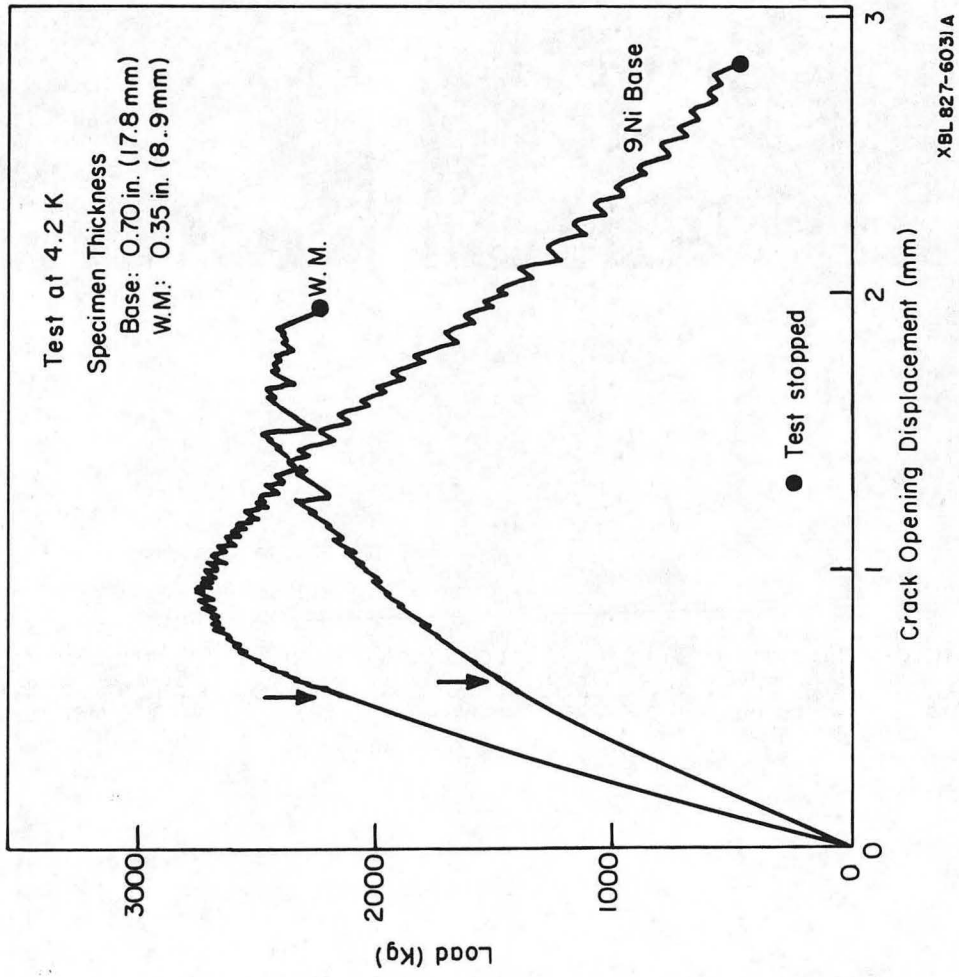

Fig. 3 Load vs. load-line displacement curves at 4.2K.

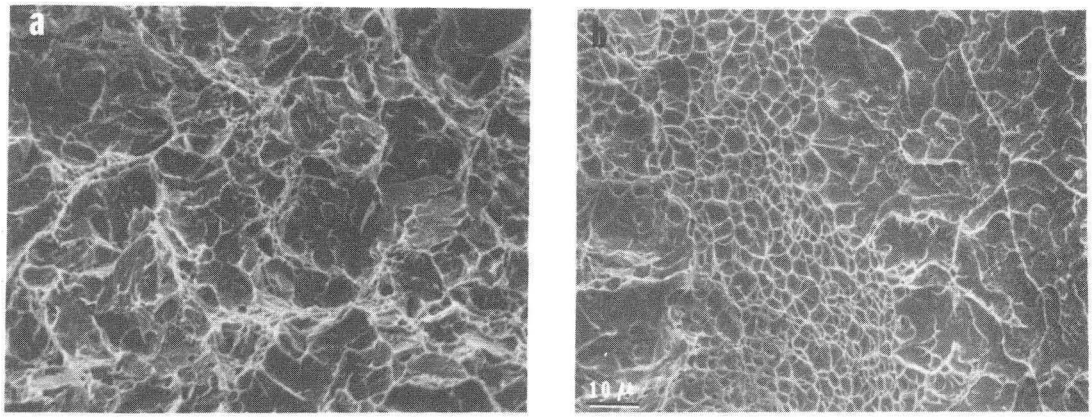

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Fig. 4 Scanning electron micrographs taken from fracture surfaces of (a) 2BT-treated 9Ni steel and (b) wled metal specimen tested at 4.2K.

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