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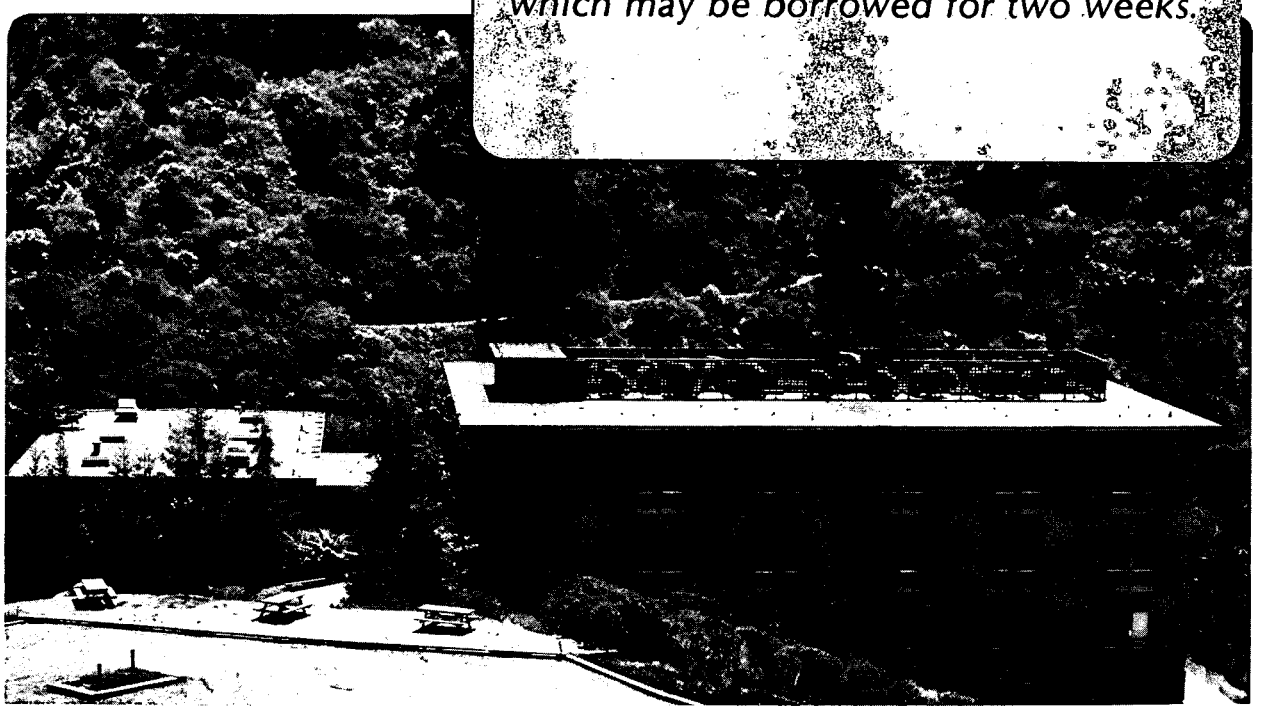

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CRYOGENIC MECHANICAL PROPERTIES OF HIGH-MANGANESE STEEL WELDMENTS

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ABSTRACT

The structural alloys used in fusion reactor magnets of the next generation are required to have a 4.2 K yield strength and fracture toughness combination superior to that of alloys used currently. An alloy of nominal composition 18Mn-5Ni-16Cr-0.22N after proper thermo-mechanical treatment approaches the JAERI projected requirements and exceeds the proposed U.S. requirements for 4.2 K yield strength and fracture toughness in the base metal. However, the properties in the welded condition are still uncertain. This work investigates the effect of autogenous GTAW on the cryogenic properties of this alloy. It was found that the 4.2 K yield strength of the weld can be increased through the addition of nitrogen to a 75% He/25% Ar shield gas; specifically, a yield strength comparable to that of the base metal was achieved for a 6 vol% nitrogen addition. Fracture toughness data are still preliminary; however, autogenous welds made on this alloy approach the U.S. requirements for both yield strength and K_{Ic}.

INTRODUCTION

The next generation of fusion reactors will require high field superconducting magnets for plasma confinement. The low allowable strain limit for the winding material, service at liquid helium temperature and other design considerations impose stringent requirements on the cryogenic mechanical properties of the alloys used as structural materials for these magnets.

The projected requirements as proposed by JAERI[1] are 1200 MPa yield strength and a fracture toughness of 200 MPa√m for the base metal at 4.2 K and similar properties in the welded condition. The tentative U.S. requirements[2] are less stringent, calling for a yield strength of 1000 MPa and a fracture toughness of 200 MPa√m for the base metal with 1000 MPa yield strength and a K_{Ic} of 150 MPa√m at 4.2 K in the welded condition.

Previous research[3] indicates that with proper thermomechanical treatment a nitrogen-strengthened high-manganese austenitic alloy of nominal composition 18Mn-5Ni-16Cr-0.22N approaches the JAERI specifications and more than satisfies the U.S. requirements for the base plate. However, these properties were achieved in the as-rolled state; it is not certain that these properties can be retained in the welded condition.

The purpose of this work is to establish the effects of welding on the cryogenic mechanical properties of this alloy, and to examine how suitable process modifications can be used to obtain properties matching those of the base metal.

EXPERIMENTAL PROCEDURE

The composition and thermomechanical history of the alloy used in this work are given in Tables 1 and 2, respectively. The yield strength of the base alloy is 1140 MPa.[3] Autogenous GTA welds were made on the 8 mm thick plates using the parameters listed in Table 3. As shown in Figure 1, the weld centerline is in the transverse direction of the base plate. Shield gases of 75% He/25% Ar and a 75% He/25% Ar mixture plus nitrogen additions of 1, 3, and 6 vol% were used. Tensile and compact tension specimens were machined from the welded plates. Figure 1 illustrates the orientation of these specimens with respect to the weld. The tensile specimens were 25.4 mm gauge length flat composite specimens with the weld at the center of the gauge section, and the compact tension specimen dimensions were W=50.8 mm and B=6 mm. The mechanical testing was conducted at 4.2 K using an Instron model 1332 load frame. J_{Ic} values were obtained by the compliance method and the K_{Ic} values calculated from the J_{Ic} data according to ASTM E813-81. The fracture surfaces of the compact tension specimens were examined by scanning electron microscopy. Interstitial nitrogen contents were determined by a commercial laboratory from 1mm wide through-thickness slices removed from the welds.

RESULTS AND DISCUSSION

The autogenous welds made using the 75% He/25% Ar shield gas have a 4.2 K yield strength of 1040 MPa. This value is 100 MPa lower than the 4.2 K yield strength of the base metal. A profile of the interstitial nitrogen content across the weld bead is shown in Figure 2. The interstitial nitrogen content drops from 0.22 wt% in the base metal to 0.16 wt% across the fusion zone. Since the 4.2 K yield strength of this alloy is strongly dependent on its interstitial content,[4] part of the loss in strength can be attributed to the depletion of interstitial nitrogen from the weld fusion zone.

The addition of nitrogen to the shield gas changes the interstitial nitrogen profile by significantly raising the nitrogen content in the weld fusion zone. A profile of a weld made with 3 vol% nitrogen addition to the shield gas is shown in Figure 3. In this case, the concentration rises to above 0.25 wt% at the weld centerline as compared to 0.16 wt% across the fusion zone of the nitrogen free shield gas weld.

Figure 4 shows the change in the average interstitial nitrogen content of the fusion zone as a result of nitrogen additions to the shield gas. The average interstitial nitrogen level can be raised to above 0.25 wt%, slightly higher than the 0.22 wt% of the base metal, with the addition of 6 vol% nitrogen to the shield gas.

The increase in 4.2 K yield strength as a function of the average interstitial nitrogen content is shown in Figure 5. The yield strength increases with increasing average interstitial nitrogen content from a low of 1040 MPa for welds made with the nitrogen free shield gas to a high of 1130 MPa for welds made with a 6 vol% nitrogen addition to the shield gas. The latter value approaches the yield strength of the base metal.

K_{Ic} values were obtained for a single set of welds. However, there was significant scatter in the raw data, and, since fracture toughness measurements of weldments are generally subject to large scatter,[5,6] these data must be considered preliminary. The 4.2 K K_{Ic} fracture toughness of the weld made with 75% He/25% Ar shield gas is 140 MPa√m. The fracture toughnesses of the welds made with 3 and 6 vol% nitrogen addition to the shield gas are approximately 70 and 110 MPa√m respectively. All specimens fractured in the ductile dimple mode. If the toughness values reported here prove to be representative, it seems likely that further process modifications or the use of a different composition filler wire will enable the alloy to meet the U.S. requirements in the welded condition.

CONCLUSIONS

The 4.2 K yield strength of the 18Mn-5Ni-16Cr-0.22N alloy after autogenous pulsed current GTAW using a 75% He/25% Ar shield gas is approximately 100 MPa below the strength of the base metal. The addition of nitrogen to the shield gas causes an increase in the nitrogen concentration in the weld fusion zone and a concommitant increase in the 4.2 K yield strength of the alloy. The yield strength of the weld and base metal are comparable when a 6 vol% addition of nitrogen is made to the shield gas.

Although the fracture toughness data are still preliminary, autogenous welds made on this alloy approach the U.S. requirements for 4.2 K yield strength and fracture toughness.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1. Specimen orientations. Darkened area indicates weld metal region.

Fig. 2. Interstitial nitrogen profile for a weld made using 75% He/25% Ar shield gas.

Fig. 3. Interstitial nitrogen profile for a weld made using 75% He/25% Ar mix + 3 vol% N_2.

Fig. 4. Average interstitial nitrogen content in the weld as a function of nitrogen content of the shield gas.

Fig. 5. Dependence of 4.2 K yield strength on average interstitial nitrogen content.

Table 1. Alloy Composition

Table 2. Processing

Table 3. Welding Parameters

Table 1. Alloy Composition

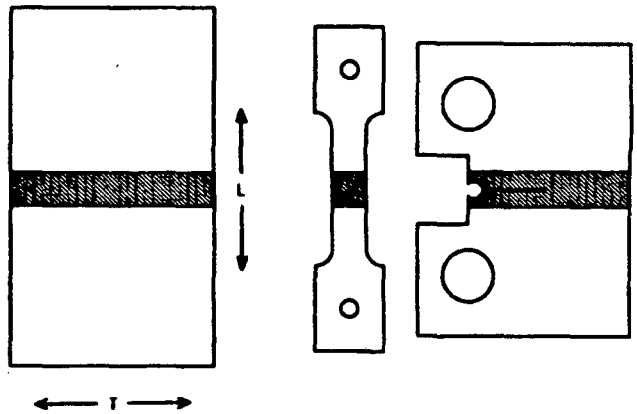
Mn	Ni	Cr	N	C	Si	S	P
17.98	4.96	16.26	0.216	0.024	0.53	0.010	0.004

Table 2. Processing

VACUUM INDUCTION MELTING
HOT-FORGED TO 80 mm
SOAKED AT 1250°C FOR 1 HOUR
HOT-ROLLED TO 30 mm
MACHINED TO 8 mm THICKNESS
AUTOGENOUS GTAW

Table 3. Welding Parameters

SHIELDING GASES	75% He / 25% Ar 75/25 MIXTURE + 1% N_2 3% N_2 6% N_2
BACKGROUND CURRENT	80-100A
PULSE CURRENT	150-165A
DUTY CYCLE	75%
ELECTRODE	2.38 mm diameter, 60° truncated tip
STICKOUT	4.76 mm
TRAVEL SPEED	50.8 mm/min
BACKING GAS	100% Ar



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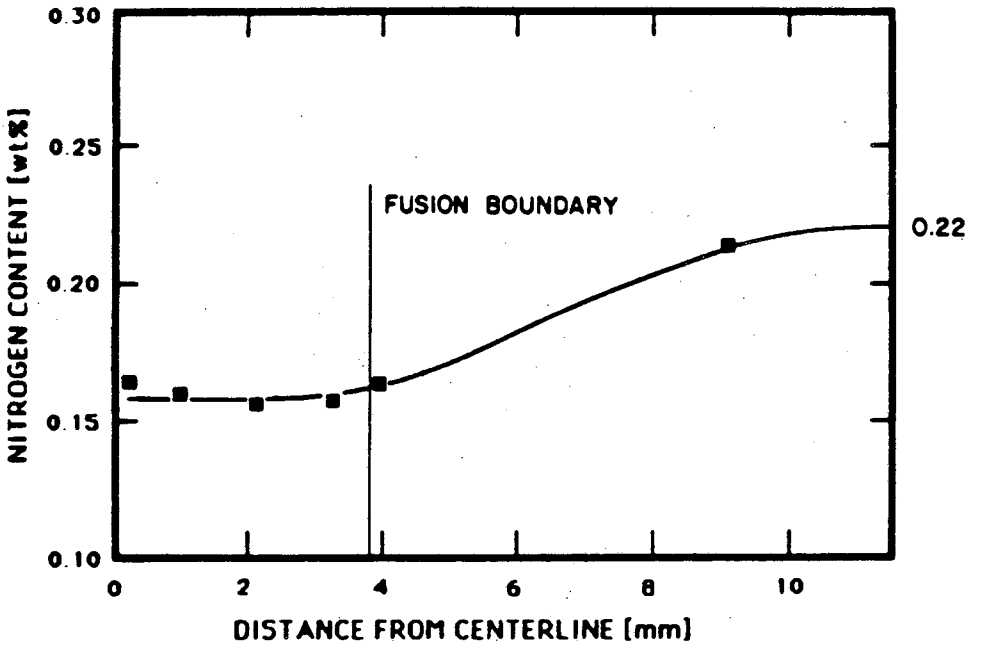

Fig. 2. Interstitial nitrogen profile for a weld made using 75% He/25% Ar shield gas.

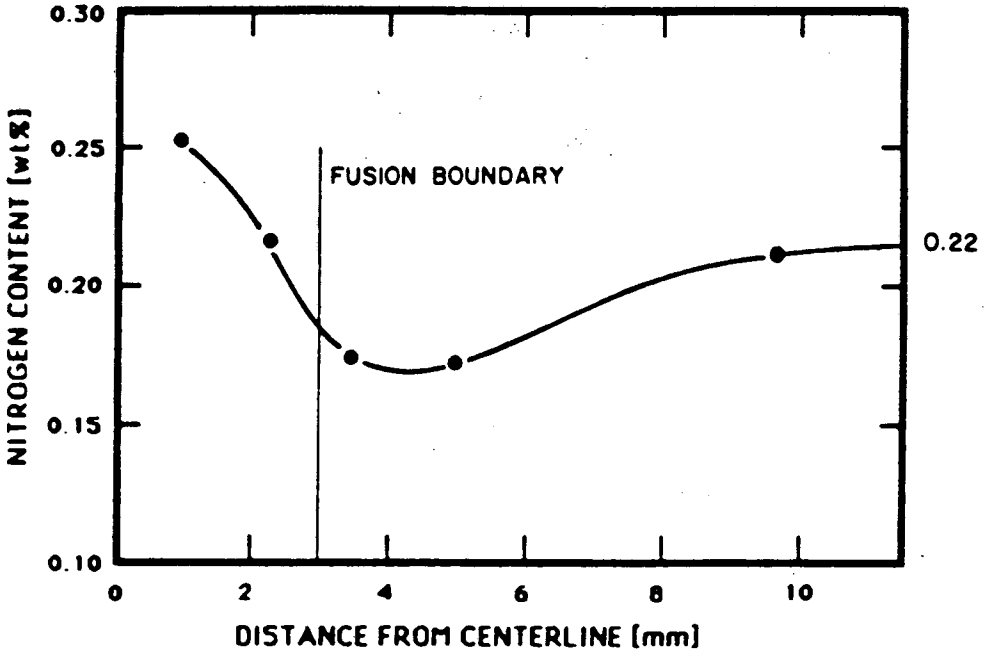

Fig. 3. Interstitial nitrogen profile for a weld made using 75% He/25% Ar mix + 3 vol% N_2.

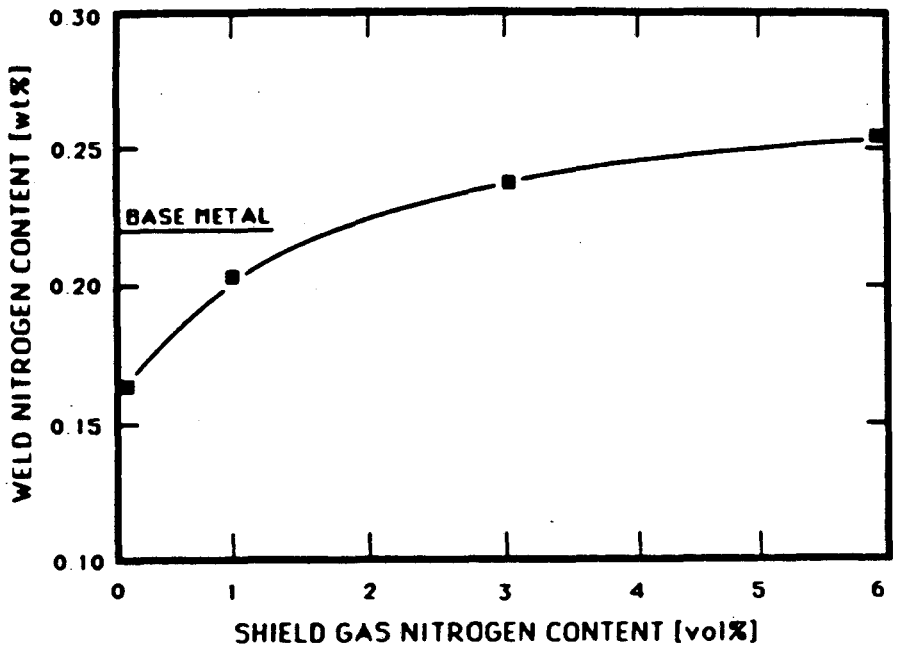

Fig. 4. Average interstitial nitrogen content in the weld as a function of nitrogen content of the shield gas.

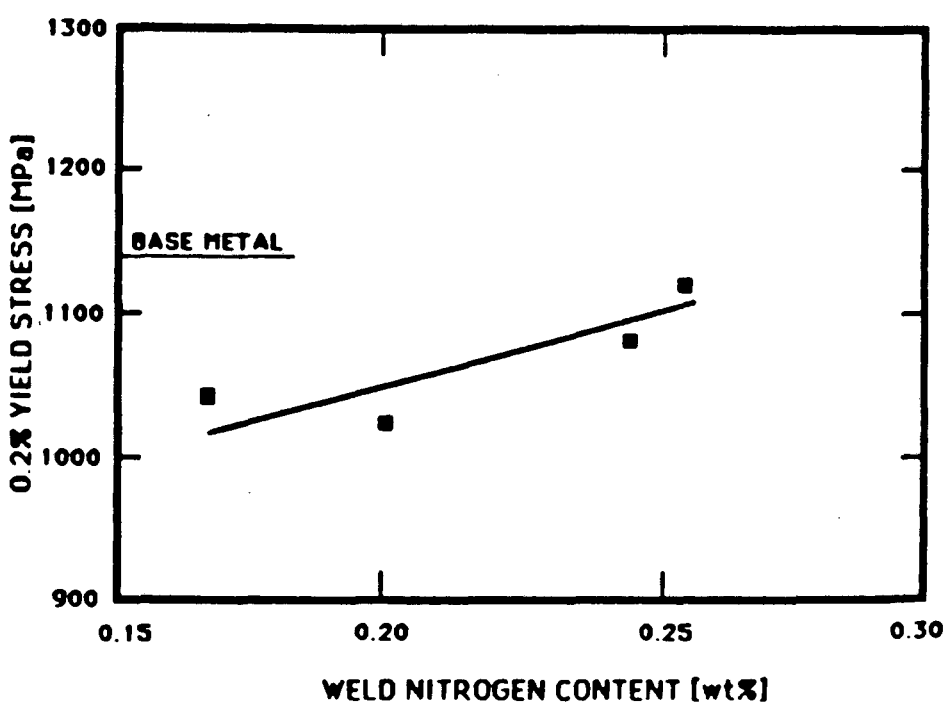

Fig. 5. Dependence of 4.2 K yield strength on average interstitial nitrogen content.

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