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WELDING SUPERALLOY SHEET FOR SUPERCONDUCTING CABLE JACKETS

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JBK-75, an iron-based superalloy, has been selected for use as the cable jacket material for the Westinghouse magnet of the large coil project. Previous investigations of GTA welds of JBK-75 and its sister alloy, A-286, have shown that age-hardened weld metal has significantly lower yield and tensile strengths than comparable heat-treated base metal[1]. In this investigation of A-286 weldments the undermatching properties are shown to be the result of chemical segregation during weld pool solidification. This chemical segregation results in significant changes in the kinetics of precipitation of the gamma prime (γ') hardening phase.

A-286 is an iron-based precipitation hardening stainless steel. Hardening is achieved by the precipitation of an intermetallic $Ni_3(Ti,Al)$ phase during heat treatments at temperatures usually between 650 and 800°C[2,3]. The $Ni_3(Ti,Al)$ γ' phase is an ordered coherent FCC precipitate of the $L1_2$ type structure. The effects of chemical composition and heat treatment upon the aging response have been well characterized[4,5].

EXPERIMENTAL PROCEDURE

The material used was commercially available round stock of A-286 of the composition indicated in Table I. Cut sections of the round stock were hot rolled to plate form of 2.8 mm (110 mils) thickness and solutionized at 1100°C and water quenched. The plate surface was sand blasted to remove an oxide scale and received a final grinding with 80 grit emery papers prior to welding.

Table 1. Composition of A-286 Stainless Steel.

C	Mn	Si	Cr	Ni	Ti	Al	Mo	Fe
0.05	1.3	0.6	15.0	25.0	2.15	0.15	1.0	BAL

Autogenous gas tungsten arc bead on plate welds were produced using an automated welding torch. Welding was conducted at 110 Amps, 16VDC straight solarity. The electrode/work piece gap was maintained at 2.54 mm (0.1 in) and torch travel speed was set at 2.54 mm/sec (6 in/min). Total heat input was 690 J/mm. An argon shielding gas was utilized and supplied at 0.4 m^3/h (15 ft^3/h).

Tensile tests were conducted using flat tensile specimens. The specimens were manufactured and oriented so that the applied load was normal to the welding direction.

Specimens for metallographic and SEM analysis were prepared using standard procedures. Specimens for TEM and STEM analysis were prepared by mechanical grinding of thin sections followed by electrochemical jet polishing.

RESULTS AND DISCUSSION

The aging response of A-286 weld and base metal at 725°C is shown in Fig. 1. It is significant to note that the base metal hardens faster and to a greater degree than the GTA weld metal. The room temperature mechanical properties of both weld and base metal are shown in Fig. 2. Using the deviation from linearity, we obtain yield strengths of approximately 89 ksi and 110 ksi for aged weld and base metal, respectively. A dissimilarity in ultimate tensile strength is also observed, the weld metal showing an ultimate tensile strength of 133 ksi while that of the base metal being 165 ksi. Highly localized deformation in the weld zone was observed in the welded specimens.

Scanning electron micrographs of typical aged base and weld metal microstructures are shown in Figs. 3a and 3b, respectively. The base metal exhibits large equiaxed grains that exhibit few grain boundary precipites. Direct observation of the γ' hardening phase using TEM shows a uniform size and distribution of precipitates in the base metal. The weld metal, however, exhibits (Fig. 3b) large precipitate-free zones located along the dendrite cores. These zones have been determined to comprise approximately 40 v/o of the

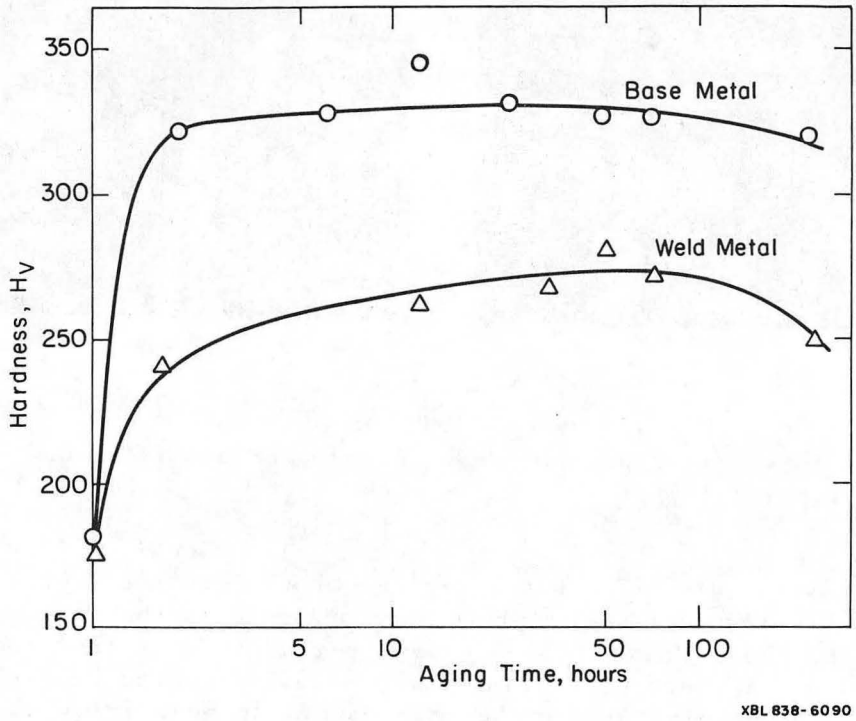


Fig. 1. Aging response of base and weld metal for heat treatment at 725°C.

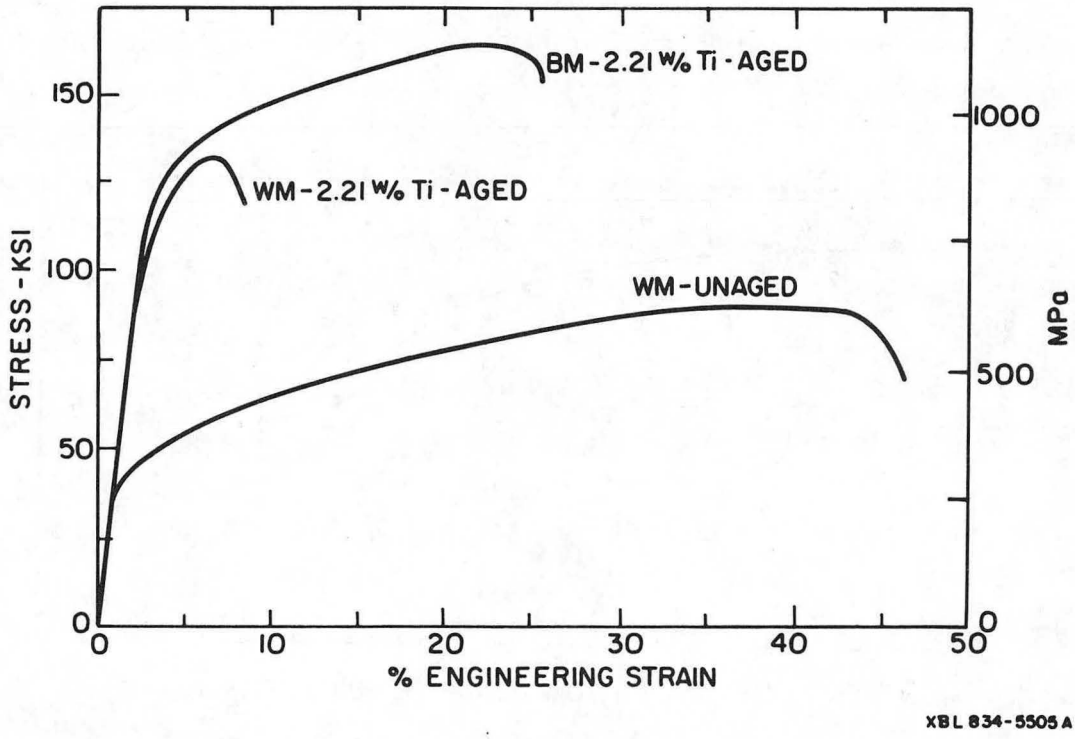
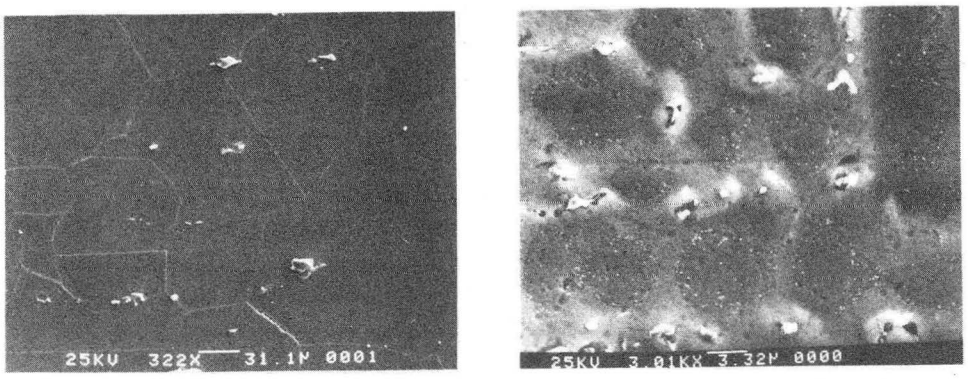


Fig. 2. Room temperature mechanical properties of base and weld metal aged at 725°C for 48 hours.



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Figs. 3. Microstructure of age hardened base metal (a) and weld metal (b).

age microstructure. The outer regions of the dendritic structure shows γ distributions similar to that observed in the base metal during TEM observation. The boundary region between the precipitate-free and precipitate-containing regions is delineated by highly coarsened γ′ precipitates. The interdendritic boundaries have been observed to be decorated by large titanium-rich precipitates. These have been identified as TiC using TEM diffraction analysis.

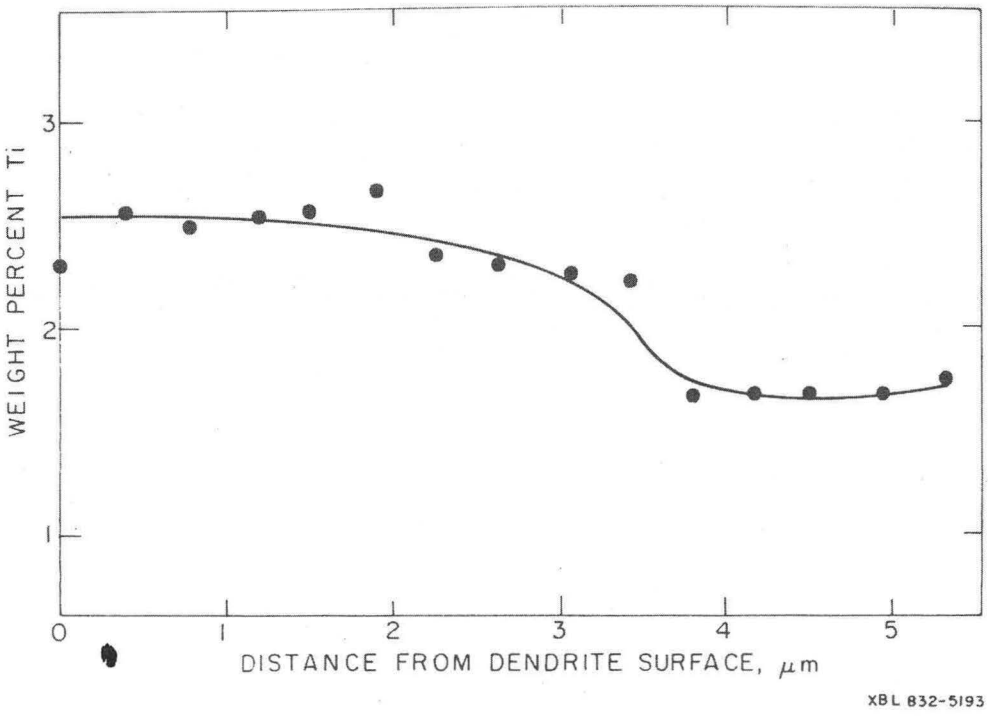

Fig. 4. STEM microanalysis of weld metal titanium microsegregation.

The observed mechanical properties of A-286 weldments are the direct result of the formation of the precipitate-free regions. These regions provide easy pathways for localized deformation resulting in the characteristic delineation of the weld microstructure that is observed in tensile specimens. The interdendritic TiC carbides have a large diameter and interparticle spacing and, thus, exert little influence on weld metal mechanical properties.

A STEM microanalysis was employed to determine the extent of chemical segregation during weld pool solidification. A slight partitioning of the major alloying elements Ni, Cr, and Fe was observed. However, a significant partitioning of Ti was detected. Titanium strongly segregates to the interdendritic regions, leaving the dendrite cores depleted of titanium (see Fig. 4). The formation of the precipitate-free zones is found to coincide with a titanium concentration of approximately 1.75 w/o, thus indicating a minimum concentration for γ' nucleation. This critical concentration is consistent with the observations of previous researchers[6].

CONCLUSIONS

Autogenous gas tungsten arc welds produced in A-286 exhibit significantly lower yield and ultimate tensile strengths than comparably heat-treated base metal. Deformation in the aged weld metal is highly localized and delineates the dendritic microstructure. The observed mechanical properties are caused by the formation of precipitate-free regions located at the dendrite cores. These regions form as the result of titanium segregation during weld pool solidification which yields dendrite cores sufficiently lean in titanium as to prevent nucleation of the hardening phase.

ACKNOWLEDGMENTS

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