IRREVERSIBLE HYDROGEN TRAPPING IN WELDED BETA-21S TITANIUM ALLOY

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β-21S titanium alloy is ranked among the most important advanced materials for a variety of technological applications, due to its combination of a high strength/weight ratio, good corrosion behavior and oxidation resistance. However, in many of these technological applications, this alloy is exposed to environments which can act as sources of hydrogen, and consequently, hydrogen-induced cracking and property degradation, hydrogen-induced ductile-to-brittle transition associated with a change in the fracture mode from ductile, micro-void coalescence to brittle, cleavage have to be considered[1-4]. In the aged β-21S alloy, the susceptibility to hydrogen induced cracking and the decrease in the alloy's strength has been attributed to the β-phase precipitated during the aging and the hydrogen-induced stabilization of the β-phase[1, 2, 5]. Hydrogen-induced intergranular cracking in the cathodically pre-charged β-21S alloy was significantly influenced by the preferential α precipitation at β grain boundaries[5]. Even without hydriding, the α-β interfaces could provide trapping sites and the accumulation of hydrogen at these interfaces could result in fracture. Pound[6] revealed that in aged β-Ti alloys the relationships among the trapping constants, resistance to hydrogen embrittlement and grain boundary are critical in determining the role of trapping in hydrogen embrittlement of these alloys.

Very few data are available in literature for intrinsic hydrogen effects in welded β-Ti alloys and almost no reports on trapping characteristics. Thus, in this work hydrogen was introduced to the alloy via the arc shielding gas (argon with pre-mixed amount of hydrogen (5% H_2) at a flow rate of 20 L/mi), using a GTA welding process for full penetration, bead-on-plate welds on β-21S plate. GTAW allowed us to investigate the hydrogen evolution phenomenon from the welded β-21S alloy and, in particular, to determine whether the trapping characteristics can change in correlation with the unique morphology induced in the alloy's microstructure by the welding process. NDT analyses exposed no porosity or any other volumetric defects in the welds. The amount of hydrogen inside the welded specimens, measured by Leco, was 455 ± 29 wt. ppm, in comparison to 56 ± 6 wt. ppm in the as-received material. SEM microstructure investigations showed quite clearly the boundary between the dendritic microstructure in the fusion zone and the equiaxed grain microstructure in the HAZ with coarser quenched grains in comparison to the base metal. The microstructure developed in the weld metal varied noticeably from the edge to the centerline of the weld. EDS analysis revealed that enrichment of Mo and depletion of Ti takes place in the interdendritic regions.

Hydrogen desorption and trapping characteristics were determined by means of thermal desorption spectroscopy (TDS) and were supported by other experimental techniques, such as LECO hydrogen determinator, XRD and SEM microstructure investigations. Detailed technical descriptions of the Leco and TDS system, as well as the quantification of several trapping parameters are given elsewhere[7]. TDS analyses are conducted on the welded β-21S titanium specimens using different temperature ramps of 3, 5 and 7 ºC/min. The results were summarized in Table 1.

TABLE 1. Summary of TDS parameters for GTA welded -21S alloy.

Heating Rate / °C/min	Temp. at desorption peak / °C	Half height peak width / °C	Maximal desorption rate / $\times 10^{15}$ H-atoms·gr-alloy^{-1}·sec^{-1}	Calculated total desorbed hydrogen / ppm wt.
3	623	27	2.68×10^{2}	203
5	650	20	2.45×10^{2}	170
7	670	25	2.16×10^{2}	130

The TDS plots were characterized by only one desorption peak, which occurs at very high temperatures (623-670ºC). The calculated energy for hydrogen desorption was found to be approximately 111 kJmole^{-1}. This is a very high value, indicating that the residual hydrogen induced to the material from the gas shield during the welding process, is probably trapped at an irreversible, strong trapping site. Furthermore, even at a slow rate of 3 ºC/min, less than half of the absorbed amount of hydrogen is desorbed. XRD patterns of the weld metal revealed the existence of α -phase in addition to the β-phase. Therefore, similar to aged β-Ti alloys, irreversible trapping might take place at the α -β interface[8], resulting from possible misfit strain, or some other cause. Another assumption could be that the dendritic arms spacing might act as a possible irreversible trap site, for hydrogen accumulation at the interface might occur due to the high residual stresses induced by the welding process. Since hydrogen evolution and trapping can be affected by several factors, i.e., the unique microstructure; the shape, morphology and size of the dendrites, elements segregation and the change in the chemical composition, phase transitions that might occur, residual stresses induced by the welding process, the reasons for such deep trapping associated with welding have to be investigated further.

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