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Studies on weldability of Ti–5Ta–1.8Nb alloy

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Abstract

The welding, qualification and characterization of welds of Ti–5Ta–1.8Nb alloy, which is being developed for high corrosion resistant performance, are reported. Based on the studies performed as per the ASME Section IX standards, welding procedure specification and procedure qualification record have been formulated. The heterogeneous microstructures of the weldment are rationalized, based on phase transformation in the alloy system and differences in the thermal cycles of various microscopic regions.

1. Introduction

The electrolytic dissolver used for dissolution of spent fuel in the Nuclear Fuel Reprocessing Plant is exposed to an aggressive chemical and radiation environment. Pure unalloyed titanium exhibits good corrosion resistance [1]. However, studies on the influence of various alloying elements on corrosion in concentrated nitric acid by Takumara et al. [2] show that the corrosion rates could further be reduced with the addition of tantalum and niobium. Hence, an alloy of nominal composition Ti–5Ta–1.8Nb is being developed. It has also been shown that formability of the alloy is improved by the addition of Ta and Nb, by enlarging the $\alpha + \beta$ phase i.e., providing a larger temperature window for the hot working. An important criterion besides corrosion resistance and workability, for considering the alloy for the intended application, is its weldability. This paper presents the results of the assessment of weldability characteristics of the Ti–5Ta–1.8Nb alloy and the qualification of the weldment to meet the design criteria.

2. Experimental details

Wet chemical analysis of the alloy has shown that Ta and Nb contents are 4.39 and 1.94 wt%, respectively. The impurity content (in ppm), of Fe, O, N, C and H have been found to be 263.0, 501.5, 47.0, 125.0 and 9.0, respectively.

The alloy plates of dimension $150\,mm \times 90\,mm \times 3\,mm$ were prepared. They were machined along the width direction to obtain Single-V groove. Manual GTAW welding process was employed for welding using filler wires of 1.6 mm ϕ with a composition same as that of the base metal. Welding was carried out in a clean room with continuous purging of ultra-pure (99.995% purity) argon gas, providing the shielding, trailing and backing actions. Using DCEN

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polarity with a Thoriated Tungsten welding torch, the weld joint was obtained in a single pass along the face side followed by a root pass. Distortion and residual stress in the material were reduced by the use of high energy density to achieve a full penetration single pass weld rather than a multipass weld.

The welding and qualification tests were carried out as per ASME Section IX codes dealing with the 'Qualification Standards for Welding and Brazing Procedure'. The qualification tests included X-ray radiography, bend tests and tensile test on the weld joints.

Characterization of the base metal, weld and heat affected zone (HAZ) were carried out using optical microscope (Leica MEF4A), scanning electron microscope (SEM – Philips XL30 ESEM) and transmission electron microscope (TEM – Philips CM200). Specimens for the above were prepared from width–thickness (W–T) sections by standard metallographic techniques, reported elsewhere [3].

3. Results and discussion

Results on weldability of the developmental Ti–Ta–Nb alloy and the various qualification tests necessary to arrive at the welding procedure specification (WPS) and procedure qualification record (PQR) is discussed initially. This is followed by a discussion of the microstructures in the base metal, weld and HAZ.

The welding procedure and parameters were chosen based on the experiences from the commercial welding of pure Ti. The parameters employed were current of 50–80 A, voltage of 12–14 V, torch speed of 60–80 mm/min and gas flow of 35 l/min of argon (shielding, trailing and backing). A uniform weld bead was obtained which exhibited a bright luster finish. The quality of the weld joint was assessed without any additional post weld heat treatment. The joint was found to be satisfactory from the radiography and 180° U-bend (both face and root bend configurations) tests. Tensile test of the joint showed an UTS value above 524 MPa and the fracture occurred by ductile mode outside the joint. The above tests show that the weld joint possesses adequate strength. Preliminary tests on corrosion behavior of the weld joint in boiling 11.5 M nitric acid show that the corrosion rate is comparable to that of base metal (~0.3 mpy in liquid phase). Thus, the above results confirm that the selected welding process and parameters ensure sound welds in the Ti–5Ta–1.8Nb alloy based on which PQR and WPS for the new alloy were prepared.

The microstructural heterogeneity in the weldment was studied by analyzing the microstructures in the base metal, weld and HAZ. The base plate was obtained by cold rolling and a final stress relieving treatment. The TEM micrograph of the base metal is shown in Fig. 1.

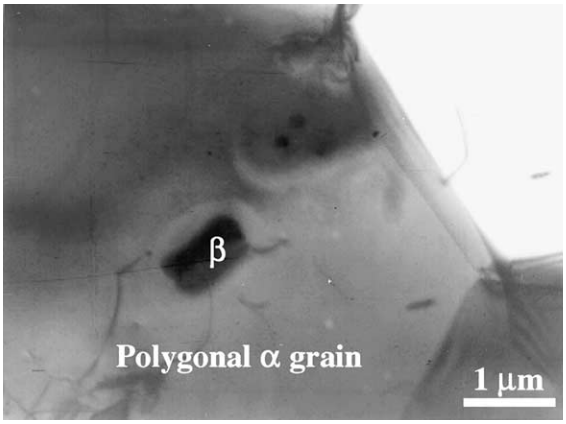

Fig. 1. TEM micrograph showing the precipitate of nodular β in equiaxed α grain.

Equiaxed grain with a fine nodular second phase dispersed both along the grain boundaries and within the grain is seen. Energy dispersive X-ray (EDS) spectroscopy has revealed that the second phase is enriched with the solute elements Ta and Nb in comparison to the matrix. The nodules were identified as the β since both Nb and Ta are strong β stabilizers and have a tendency to repartition into β phase. The above microstructure is in agreement with the structure expected in Ti alloys subjected to thermo-mechanical followed by stress relieving treatments [4]. A microstructure consisting of a polygonal α matrix with randomly distributed β, has been shown to be a structure desirable for improved corrosion resistance [4].

The optical micrograph of the weld region in macro-etched condition is shown in Fig. 2(a). Columnar grains (~2 mm long) with a substructure are observed. The observed microstructure is a product of liquid $\rightarrow \beta \rightarrow \alpha + \beta$ transformation. Formation of such coarse grains during solidification, has been reported in several Ti alloys [5].

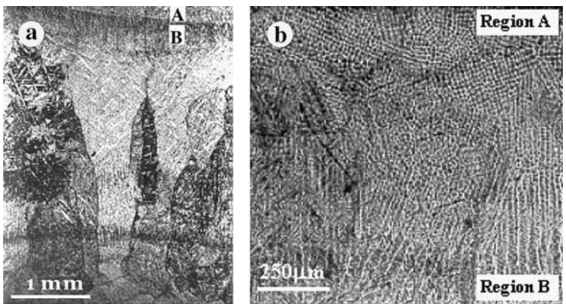

Fig. 2. (a) Optical micrograph of weld region in macro-etched condition showing the growth of columnar grains. The cellular-dendritic structures near the face and root surface is seen, (b) magnified view of the cellular-dendritic structures at the face side.

A wide variation in the width of the columnar grain is observed, which arises due to the combined effect of the solidification processes during the face and root passes. The direction of growth of columnar grains during solidification is expected to be along the steepest temperature gradients. The substructure within the columnar grains reveals a uniform lamellar transformed β structure. The transformed β, consisting of alternate lamellae of α and β, obtained by Widmanstätten transformation of β, has been established in our earlier studies [3].

The typical solidification structure of the weldment on the face side is shown in Fig. 2(b). There is an apparent difference in the solidification growth pattern of β-grains between region A (near the plate surface) and region B (away from the plate surface). In region A, the grains contain an array of cells with a typical cell spacing of ∼10 μm. The direction of cell growth is seen to be parallel to the welding direction, suggesting that the temperature gradient was the highest in this direction. Region B, on the other hand shows prior-β grain to consist of parallel arms of primary dendrites, which are pointing normal to the plate surface. The direction of dendrite growth is in agreement with the expected direction of maximum heat flow in this region. The weld is thus seen to solidify by cellular-dendritic mode and the structures seen in regions A and B are only different sectional views of the cellular-dendritic. However, the dendritic spacing in region B is seen to be large (15 μm) compared to region A, which is attributed to the relatively lower temperature gradients at region B [6].

Microstructure of HAZ was not uniform and depended crucially on the distance of the region from the heat source. Fig. 3 shows the typical structure of a region in the HAZ close to the weld. Coarse prior β grains (∼40 μm) with its boundaries decorated with α, called the grain boundary α (gb-α) are observed. The uniform microstructure and β grain sizes suggest that the temperature was sufficiently above the β transus temperature of the alloy (∼1140 K [7]). The formation of transformed β showed that the cooling rate was low favoring the Widmanstätten transformation of the high temperature β. This transformation can be summarized as:

$$\text{Equiaxed } \alpha + \beta \text{ nodules} \xrightarrow{\text{heating}} \beta \xrightarrow{\text{cooling}} \text{grain boundary } \alpha + \text{Acicular } (\alpha + \beta)$$

A detailed study on variation of microstructure with distance from heat source and the possible thermal cycles is in progress.

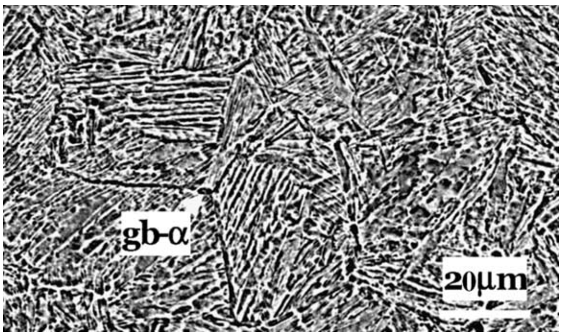

Fig. 3. SEM micrographs of HAZ in Ti–5Ta–1.8Nb weldment, showing the transformed β and gb-α.

4. Conclusion

The Ti–5Ta–1.8Nb weldment has been fabricated using a manual GTAW process. The test welding and weld qualification tests were performed as per the ASME section IX standards. The PQR and WPS could be established for this alloy based on these results. Microstructures of the base metal, weld and HAZ have been studied. The microstructures in the weld and HAZ have been understood in terms of the possible solidification and phase transformation mechanisms.

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References

[1] J.D. Destefani, 10th Ed.Metals Handbook, 2, ASM Intl., 1990, p. 586.
[2] A. Takamura, K. Arakawa, Y. Moriguchi, in: R.I. Jaffee, N.E. Promisel (Eds.), Proceedings of the International Conference on Science, Technology and Applications of Titanium, Pergamon, 1970, p. 209.
[3] T. Karthikeyan, A. Dasgupta, S. Saroja, M. Vijayalakshmi, A.J. Khan, D. Bhattacharjee, V.S. Raghunathan, Mater. Sci. Eng. A, submitted.
[4] R. Mythili, S. Saroja, M. Vijayalakshmi, V.S. Raghunathan, in: B. Raj, K.B.S. Rao, P. Shankar, N. Murali, (Eds.), Proc. Conf. on Mater. and Technol. for Nucl. Fuel Cycle, 15–16 December 2003, Chennai, India, p. C24.
[5] S. Sundaresan, G.D. Janaki Ram, G. Madhusudhan Reddy, Mater. Sci. Eng. A 262 (1999) 88.
[6] K. Easterling, Introduction to the Physical Metallurgy of Welding, 2nd Ed., Butterworth-Heinemann, Oxford, UK, 1992.
[7] R. Mythili, S. Saroja, M. Vijayalakshmi, V.S. Raghunathan, Mater. Sci. Eng. A, in press.