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Effect of heat input on microstructure and strength of welds in tantalum and niobium alloys

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Abstract

Welding of niobium and tantalum materials is currently conducted in vacuum or inert gas chambers, which limits the size of the equipment to be produced. The objective of this study is to investigate the means to make TIG welding on these materials in atmospheric environment and analyse the effect of heat input on the properties of welds. It was found that it is possible to make TIG welds on these materials in atmospheric environment, provided that adequate protection is ensured on the face and root sides of welds. The increase of weld heat input coarsens the microstructure in melted and heat affected zones of both materials; increases also hardness in melted zones and tensile strength of welds, and there is not an obvious loss of ductility in heat affected zones.

Keywords: Weld heat-input; tantalum; niobium; microstructure; tensile strength.

1. Introduction

Refractory metals, such as tantalum (Ta) and niobium (Nb), are increasingly applied in a variety of industries, such as chemical process industry, nuclear or even in medical device industry [1]. Niobium and tantalum have very high melting temperature and excellent corrosion resistance, but are very sensitive to oxidation at temperatures just above 300ºC, which limits their use to moderate temperature applications or high temperature applications in non-oxidizing atmospheres. Welding of those materials presents several difficulties due to their great affinity to oxygen and nitrogen at elevated temperature [2]. Therefore, the welding of these materials should be conducted in vacuum or inert gas chambers in order to prevent the formation of brittle structures, using processes such as laser, electron beam or TIG, welding [3]. A significant grain coarsening was reported in the heat affected zone (HAZ) as well as porosity in melted zone (MZ) of welds on commercially pure tantalum as the heat input increases in welds carried out with a CW Nd:YAG laser of 2.2 kW, using argon as shielding gas [4]. Significant grain coarsening in MZ and HAZ have already been observed in a previous study in TIG welds in tantalum and columbium (niobium) as well as porosity in MZ of Ta welds [5]. Pulsed Nd:YAG laser was used recently to weld pure niobium to Ti-6Al-4V with success but the study concentrates mainly on the effect of pulse current characteristics on penetration depth and tensile strength of the welds [6]. Electron Beam Welding (EBW) has been used for assembling single-cell and multi-cell cavities made of Nb; however, for small complicated parts of thin wall thickness, TIG welding can be advantageous [7].
However, when large equipment needs to be welded, it is not possible to weld in chamber; so, it is necessary to optimize the welding conditions outside the chamber. The purpose of this research is to optimize the manual TIG welding conditions in order to achieve

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similar microstructural and mechanical properties in welds on these materials performed into and out of the chamber. The results presented in this article refer only to welds performed in air using local shielding systems developed for the purpose in the company ARSOPI S.A., which is specialized in manufacturing equipment for chemical, petrochemical and nuclear industries.

2. Experimental Procedure

Similar welds were performed between plates of 250x80x2 mm size, in commercial Ta alloy R05200 – ASTM B 708-05 and Nb alloy R04210 – ASTM B 393-99, by manual gas-tungsten arc welding, using thoriated tungsten electrodes type EWTh2 and filler wire of similar chemical composition. The chemical composition and mechanical properties of the plates are shown in Tables 1 and 2. In fact they are made of tantalum and niobium commercially pure. Welds were done in air and shielded from the root and face sides with high-purity argon (99.996% Ar). Argon was supplied by specific diffusers developed for maintaining protection for the weld to cool to temperature below 200ºC. Direct current connected for straight polarity, without any pulse, was used. Different heat inputs were used for each alloy, 1 and 1.7 kJ/mm for Nb and 1.3 and 2.5 kJ/mm for Ta, because of their different physical properties; for example, melting temperatures are very different (2468ºC for Nb and 3017ºC for Ta). The welds were radiographed to detect porosity or other defects and specimens for metallographic analysis, tensile and bend testing were removed transversely to welding direction. Metallographic specimens were polished according to conventional procedures but final polishing should be done using colloidal silica. Etching of Nb and Ta specimens was done in two similar steps: 25 mL lactic acid - 15 mL HNO_3 - 5 mL HF (48%) was used for 120s for the first step and 10 mL HNO_3 - 10 mL HF - 30 mL H_2SO_4, for 5 to 15s, for the second step. Vickers hardness tests were made at 0.5 kg for 15s on metallographic specimens. Tensile testing was done in specimens extracted transversely to the welding direction, with a cross section of 10x2 mm^2, and the weld reinforcement was removed.
Tests were done in an Instron 4206 testing machine and an optical extensometer (ARAMIS) with digital image correlation (DIC) was used too.

Table 1. Chemical composition of niobium and tantalum plates.

Niobium R04210 (ppm)											
C	N	O	H	Zr	Ta	Fe	Si	Ni	Hf	Ti	Nb
39	34	83	3	<5	120	20	50	<5	<20	7	Rem.

Tantalum R05200 (ppm)									
C	O	N	H	Mo	Nb	Ni	Si	W	Ta
7	32	18	2	<10	133	3	10	63	Rem.

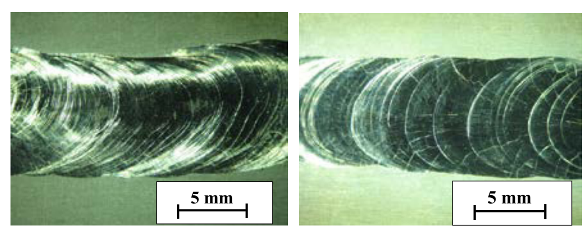
Table 2. Mechanical properties of niobium and tantalum plates.

Metal	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
Nb	225	127	54
Ta	245	161	59

3. Results and Discussion

3.1. Microstructure

All welds showed glossy appearance, revealing that protection was effective, but the morphology of the weld face is different between materials, as shown in Fig. 1.



a) b)

Fig. 1. Morphology of surface of welds on alloy: a) Nb (1 kJ/mm) and b) Ta (1.3 kJ/mm).

There was no internal porosity, or other defects in welds on both materials; however, there was substantial grain growth, both in MZ and HAZ of the welds, as illustrated in Fig. 2.
Although macrographs do not exhibit the same quality level because the polishing and etching of these materials is very difficult, it appears that the grain growth is more distinct in the MZ than in the HAZ. In the HAZ, the grain size decreases with increasing distance to the molten zone. Furthermore, it is apparent that the grain increases with increasing heat input (HI). The welds performed with higher HI exhibit some grains occupying the entire thickness of the weld (2000 μm), in contrast to welds performed with lower energy, which have in general at least two grains through plate thickness. Fig. 3 illustrates the