Materials Science & Engineering A 640 (2015) 180–189

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Some studies on mechanical properties and microstructural characterization of automated TIG welding of thin commercially pure titanium sheets

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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form
20 May 2015
Accepted 21 May 2015
Available online 3 June 2015

Keywords:
GTAW
C.P Titanium
Welding parameters
Gas shielding
SEM

ABSTRACT

Gas Tungsten Arc Welding (GTAW) is a commonly used welding process for welding Titanium materials. Welding of titanium and its alloys poses several intricacies to the designer as they are prone to oxidation phenomenon. To overcome this contamination, a relatively new type of shielding arrangement is experimented. The proposed design and arrangement have been employed for joining commercially pure titanium sheets with variations in the GTAW process parameters namely the welding current and travel speed. Bead on plate (BoP) trials were conducted on thin sheets of 2 mm thickness by varying the process parameters. Subsequently, the macro structure images were captured. Based on these results, the process parameters are chosen for carrying out full penetration butt joints on 1.6 mm and 2 mm thick titanium sheets. The influences of these parameters of GTAW on the microstructure, mechanical properties and surface morphology at the fractured locations of the welded joints are examined. The microstructural properties of base metal, heat affected zone and fusion zone are analyzed through optical microscopy. The welded joints showed an ultimate tensile strength of about 383 MPa with 15.7% elongation. The hardness value at fusion zone and base metal are typically observed to be 191 and 153 HV-0.5, respectively. X-ray diffraction study is conducted to examine the chemical composition in the parent metal and fusion zone of the weld. Fractured surface is examined using Scanning Electron Microscopy which revealed dimple kind of rupture present at the fractured surfaces owing to insufficient or excessive heat with slight impurities that prevents the accomplishment of stronger micro-level weld integrity.

1. Introduction

Commercially Pure (C.P) titanium has good corrosion resistance, bio-compatibility and excellent weldability. This promotes the use of titanium in fabrication of airframe, aircraft engine parts, marine, orthopedic and dental implants, chemical parts and condenser tubing [1,2]. However, titanium material is highly reactive when the processing temperature exceeds 500 °C. The surface of titanium can easily absorb the gases such as oxygen, nitrogen and hydrogen from atmosphere. The colorization of titanium due to the absorption of gases results in increasing brittleness and hardness. Hence in order to minimize these issues an appropriate shielding medium must be introduced to cover the localized weld area [3–5].

Commercially pure Titanium are welded by conventional arc welding processes, although the chemical reactivity of titanium material requires special attention/precautions to avoid contamination in the fusion zone (FZ) and reduce the length of the HAZ. Fusion welding of titanium is carried in an inert gas atmosphere, while there are other alternate welding processes which have been developed, such as electron beam, diffusion bonding which requires the high vacuum chamber to shield the hot metal from atmospheric contamination [6].

Few researchers have been working in the area of TIG or GTA welding of titanium sheets and investigated the microstructural studies and fractography analysis of the welded region compared with the parent metal and the development of specific device for top and back side shielding to protect the titanium weld metal from oxidation. Aleksander implemented a multi nozzle system to protect the molten pool and heated surface of the titanium joint [6]. But this nozzle type of arrangement is inadequate to provide sufficient shielding gas to the joints. A combined study was carried out by Krishnanunni et al. [7] for selecting shielding gas flow level and number of passes for titanium welding. It is reported that increased shielding gas flow rate reduced the hardness value at

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http://dx.doi.org/10.1016/j.msea.2015.05.056
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the fusion zone.

Gao et al. reported that the edge preparations and filler metals are not required for welding thin sheets. In GTAW, instantaneous molten pool is covered by shielding medium from torch head. The disadvantage of this process is that it will generate huge amount of heat which causes distortion and formation of coarse grain in the welded material [8]. A study was conducted by Winco et al. on welded joints to identify the parameters affecting tensile properties of titanium materials and concluded that the Cooling rate, Grain size and formation of new structure are the major factors influencing the quality of the joints. It was found that faster the cooling rate, smaller the grains formed resulting in maximum ductility in the welded joints [9]. Cemal Meran discussed the selection of major parameters for GTAW namely welding current, travel speed and arc length. Welding current affect the weld geometry and travel speed has the influence of controlling molten pool shape and size [10]. Wu et al. investigated the electron beam welding of α-β titanium alloy by using X-ray diffraction (XRD) and conducted microstructure evaluations in the fusion zone [11]. Guoqing et al. studied the welded region of Ti–43Al–9V to identify the presence of new phases by using XRD. By using lattice strain calculation, the residual stress was measured using XRD in the weld surface [12]. Based on the literature survey, it is observed that only limited amount of research work has been reported in the area of experimental and characterization studies on Automated TIG welding of thin sheets of commercially pure Titanium. Hence, an attempt is made in this research work to improve the previous studies on autogenous TIG welding of thin C.P titanium sheets. For this purpose, a C.P Titanium sheet is welded by autogenous TIG welding process and the microstructural analysis, variation in micro hardness and fractography of the welded materials are investigated and compared with the parent/base metal. The experimental trials are conducted by varying the TIG welding input process parameters such as welding current and travel speed. Furthermore, a specific device is developed for providing a proper shielding at the top and back side of the weld during titanium welding in order to protect the molten pool from oxidation and to obtain sound butt joints.

2. Experimental work

Commercially pure titanium sheets of 1.6 mm and 2 mm are used in this study. The chemical composition of C.P titanium is listed in Table 1. A little amount of oxygen (α-stabilizer) is present in addition to impurities like Fe, C, N and H within the matrix.

The welding of C.P titanium are conducted using GTA welding machine with water cooled torch head, (FRONIUS MAGIC WAVE 400) as indicated in Fig. 1. Numerical control unit is used for controlling the travel speed. Based on the literature and weld experience, it is inferred that among all of the possible GTAW process input parameters, welding current and travel speed are the primary factors which determines the energy input to the workpiece. Hence, it is decided to conduct the experimental trials by varying the welding current and the travel speed as presented in Table 2. A 3-level experimental plan with the welding current and the travel speed has been selected in a Full-Factorial scheme (3^2 Design – Two independent variables with three levels each). The input process parameters are selected to conduct the bead on plate trials with an aim of producing full penetration followed by thorough investigations to determine the influence of process parameters on weld bead geometry. For all the experimental trials electrode diameter of 2.4 mm and arc length of 3 mm are kept as constant.

Table 1
Chemical composition (Wt%) of the commercially pure titanium.

N	C	H	Fe	O	Ti
0.02	0.08	0.007	0.18	0.15	balance

Fig. 1. Experimental setup.

Table 2
TIG welding process parameters.

Welding current (A)	75-90-105
Travel speed (mms^{-1})	250–275–300
Shielding medium	Industrial pure Argon (99.99%)

Tadayuki suggested a shielding arrangement for welding titanium successfully. In this arrangement GTAW torch was placed at an advanced angle of 40° [13]. To attain good weld quality in titanium, primary, secondary and bottom purging are needed. Hence, for the present experimentation a shielding arrangement has been designed to address the above three areas and ascertain successful implementation.

Primary shielding gas flowing from nozzle head covers the initial and instantaneous molten pool of the weld. To prevent the weld region and adjacent base metal from contamination, secondary and bottom purging is used. The secondary shielding is provided by the box type arrangement as indicated in Fig. 2. The box has LASER drilled holes in the bottom side to distribute the shielding medium steadily and the bottom shielding arrangement is provided with a copper insert with gas distribution holes [14]. Earlierto welding, flow of inert gas has been initiated both in secondary and bottom arrangements. The top and bottom plate