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Surface preparation of Ti–3Al–2.5V alloy tubes for welding using a fiber laser

Aniruddha Kumar [1], Mool C. Gupta *

Charles L. Brown Department of Electrical and Computer Engineering, University Of Virginia, Charlottesville, Virginia 22904, USA

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ABSTRACT

Ti–3Al–2.5V tubes are widely used in aircraft hydraulic systems. Meticulous surface preparation before welding is necessary to obtain a sound weld involving these alloy tubes. Conventionally this is done by cleaning with environmentally malign toxic chemicals, such as, hydrofluoric acid and nitric acid. This paper describes the laser-cleaning process of the surface of these tubes with a fiber laser as a preparation for pulsed gas tungsten arc welding and results obtained. A simple one-dimensional heat equation has been solved to evaluate the temperature profile of the irradiated surface. It is shown that surface preparation by laser cleaning can be an environmentally friendly alternative process by producing acceptable welds with laser-processed tubes.

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1. Introduction

Titanium alloys are used extensively in aerospace applications mainly due to their superior strength to weight ratio, corrosion resistance and good weldability by standard welding processes. Different grades of titanium alloys are used for different applications. The alloy Ti–3Al–2.5V (ASTM grade 9) is used to make seamless tubes for hydraulic and fuel-transmission systems in aircrafts due to its excellent cold formability. Welding of these tubes with other components is indispensable for installing hydraulic systems. Production of high-quality welds in titanium alloys require meticulous pre-weld cleaning of the work-pieces. Conventionally such cleaning procedures are chemically based, where the entire component is cleaned by chemical etching with hydrofluoric and nitric acid. This process removes some material from the surface along with the contaminants, exposing fresh material for joining purposes. However, these chemicals are hazardous and environmentally malign. Handling of these chemicals, disposal as well as other safety aspects are also of concern. Furthermore, the footprint of these cleaning systems is very large.

Lasers are being recognized as attractive cleaning tools in many fields, for example semiconductor industry [1,2], nuclear industry [3–7] and in art restoration work [8,9], for its dry nature of cleaning and its ability to remove a controlled volume of material without affecting the property of the bulk. Although, laser cleaning of Ti–6Al–4V alloy components for welding [10,11] and thermal spray [12] preparation has been reported, reports on cleaning of components made from another highly valuable alloy, Ti–3Al–2.5V is not available in literature. Most of the reported results on Ti–6Al–4V alloy are based on experiments performed with samples of planer geometry and utilize either Nd–YAG [10,12] or CO_2 [11] laser beam for cleaning. In this work, we report surface preparation of Ti–3Al–2.5V tubes with nominal outer diameter of 9.5 mm having nominal wall thickness of 0.83 mm by fiber laser cleaning. A thin adhered surface oxide layer, with a thickness of several tens of nanometers and residual contaminants are removed from the as-received tube with a pulsed fiber laser as a preparation for pulsed gas tungsten arc welding (PGTAW). Such surface preparation is achieved without any damage to the parent metal. Unlike other solid-state lasers and gas lasers, normally used in cleaning processes, the size of a fiber laser is much smaller and with the absence of any additional chilling system makes it easier to install and operate in space-constrained industrial environments. In this cleaning process, a focused laser beam scans the external as well as the internal surface area near the edge of the tube. The cleaned surface has been evaluated by optical microscopy, profilometry, SEM, EDX and X-ray photoelectron spectroscopy (XPS). A simple one-dimensional heat equation has been solved to evaluate the temperature profile of the irradiated surface. The laser-cleaned tubes are then used to make welds with end fittings by the PGTAW technique in an orbital welding machine. Welds have been evaluated by X-ray radiography and metallography. Consistently good quality of welds has been obtained.

* Corresponding author. Tel.: +1 757 325 6850; fax: +1 757 325 6701.
E-mail address: mgupta@virginia.edu (M.C. Gupta).
[1] Permanent address: Advanced Fuel Fabrication Facility, Bhabha Atomic Research Centre, Tarapur Complex, Thane, Maharashtra 401504, India.

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2. Experimental

Ti–3Al–2.5V tubes with 9.5 mm outer diameter and 0.83 mm wall thickness are chosen for the experiments. Due to the high affinity of titanium alloys to atmospheric gases at high temperature, the tubes are processed inside a stainless steel chamber (100 mm × 100 mm × 100 mm), which is purged with industrial argon gas and maintains a continuous flow of 2–3 liters per minute (lpm) throughout the cleaning process. The schematic of the cleaning system is shown in Fig. 1. In this scheme, the laser beam is kept stationary and the tube is rotated and moved across the beam to scan the necessary area. Unlike chemical methods, cleaning is done only near the edge of the tube, which gets fused during welding. The beam from a fiber laser (IPG: YLP-RA-1/50/30/30) emitting at 1064 nm wavelength is incident on the tube through a quartz window mounted on the chamber. The beam incident angle is kept around 45° with the normal to the tube, so that the beam can be easily focussed on the inner surface of the tube without any hindrance. The tube is mounted on a motorized rotational stage (Newport: SR50PP) and is positioned inside the chamber through an opening provided on the flange of the chamber. The rotational stage in turn is mounted on an *X–Y–Z* translational stage (Newport: MFACC). Movement in *X*-axis provides the required linear scan along the length of the tube. The tube surface is brought under the focused beam by moving the *Y* translational stage. Vertical positioning of the tube with respect to the incoming beam is achieved by controlling the *Z*-axis. Once a tube is positioned perfectly with respect to the focused beam, the *X*-axis and the rotational stage are required to be operated for scanning. A programmable motion controller (Newport: ESP 300) is used to control the *X* translational and rotational motion of the tube. The entire setup with the laser, focussing optics and the cleaning chamber is suitably enclosed to reduce reflected and scattered radiation during processing in the working place. We have scanned the surface of the tube across a rectangular focused beam, to obtain better efficiency of cleaning [13]. A rectangular focal spot is obtained by using cylindrical lenses. Combination of two cylindrical lenses (focal length: 100 mm) is used as shown in Fig. 1, to vary the focal spot size on the tube by varying the distance between them. Initially, the outer surface of the tube is cleaned. The tube is scanned across the beam in the following manner (Fig. 2). The scan starts from the edge of the tube (position 1). Linear motion in the *X*-direction (axial) brings the laser spot to position 2. Now rotation of the tube brings the spot to position 3. Again, a linear scan in the opposite direction brings the spot to position 4. A further rotation of the tube brings the spot to position 5. The axial scanning is restricted to 2 mm from the edge of the tube considering the requirement of welding. The scanning continues for a full rotation (360°) of the tube. In Fig. 2, movement of the beam spot is shown, the tube actually moves in the opposite direction as the laser beam is stationary. For clarity the overlap between successive cleaned areas is not shown in the figure. Throughout the experiment the velocities of the motorized *X*-axis translational stage and rotational stage have been kept at their maximum specified values to reduce the cleaning time. The velocity of linear motion and rotational motion has been kept at 2.5 mm/s and 4°/s, respectively. The angle of rotation followed after each translational motion is chosen to provide at least 30–40% overlap with successive scanned area. It has been observed, for an optimum beam size of 430 μm × 100 μm, a rotation of 2.75–3.00° provides the required overlap. After cleaning the outer surface, the *Y* stage is moved to bring the inner surface at the laser focus. The relative position of the tube with respect to the laser beam while cleaning outer and inner surfaces is shown in Fig. 3a and b. The inner surface is cleaned in the same way as is done for the outer surface. Fig. 4 shows few laser-cleaned tube inner and outer edges. Experiments have been performed with different laser fluences at different repetition rates to obtain the cleaning and damage threshold parameters. Cleaned surface has been evaluated by optical microscopy, profilometry, SEM, EDX and XPS. The cleaned tubes are then used to make weld with tube fittings in an orbital welding machine by the pulsed gas tungsten arc welding technique. High-purity argon gas is flown in the chamber and also through the inner side of the tube during the welding process. Several welds have been carried out to obtain the optimum welding parameters. The welds have been characterized by X-ray radiography and metallography.

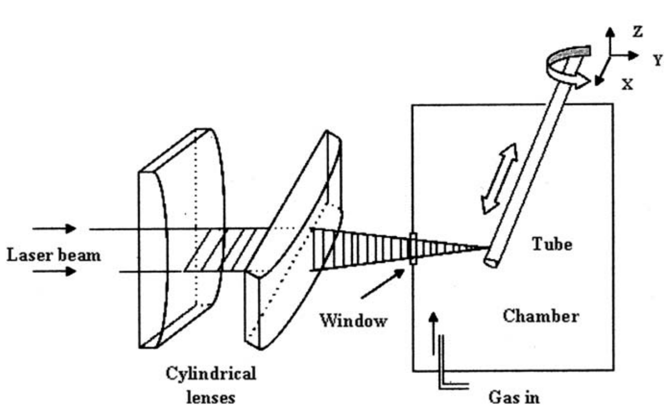

Fig. 1. Schematic of the fiber laser cleaning system.

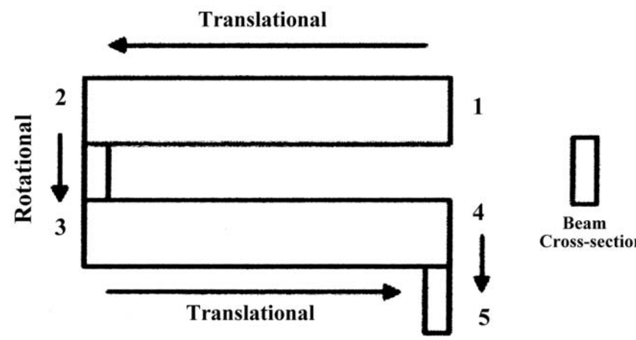

Fig. 2. Schematic of the scanning sequence.

3. Results and discussion

Titanium is a highly active material and readily oxidizes in atmosphere. When fresh titanium material is exposed to ambient atmosphere, a passive oxide film is spontaneously formed on its surface. The characteristics of the oxide film depend on chemical composition, structure, morphology and mechanical condition of the material and other conditions such as temperature, oxygen partial pressure. To obtain a sound weld with these alloys, the oxide layer and other contaminants need to be removed thoroughly. Fig. 5 shows a SEM image indicating presence of the oxide layer on the tube surface. The laser-cleaning threshold and material damage threshold parameters have been evaluated visually and also by optical microscopy.

Laser-cleaning experiments have been performed at repetition rates from 30 to 80 kHz with different fluences keeping linear and rotational scanning speed constant. The laser fluence has been varied systematically aiming to find the optimum condition for the removal of the oxide layer without damaging the bulk. Figs. 6a and b show the variation in depth of material removal with

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