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Pulsed Nd:YAG laser seam welding of AISI 316L stainless steel thin foils

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ABSTRACT

Experimental investigations were carried out using a pulsed neodymium:yttrium aluminum garnet laser weld to examine the influence of the pulse energy in the characteristics of the weld fillet. The pulse energy was varied from 1.0 to 2.25 J at increments of 0.25 J with a 4 ms pulse duration. The base material used for this study was AISI 316L stainless steel foil with 100 μm thickness. The welds were analyzed by optical microscopy, tensile shear tests and microhardness. The results indicate that pulse energy control is of considerable importance to thin foil weld quality because it can generate good mechanical properties and reduce discontinuities in weld joints. The ultimate tensile strength of the welded joints increased at first and then decreased as the pulse energy increased. The process appeared to be very sensitive to the gap between couples.

1. Introduction

In general, one important problem in the experimental measurements performed at elevated temperatures or in a corrosive environment is selecting a material that is resistant to chemical attack and is easily formed into the desired shape. For this purpose, industrial product parts and components are covered with stainless steel thin foils or other corrosion-resistant material such as tantalum and Ni alloys. The significance of microtechnology has increased dramatically over the last years, and this has created a growing need for microwelding of thin foils. Furthermore, Nd:YAG pulsed laser welding is expected to be the method of choice because it allows more precise heat control compared with others processes and it reduces the heat-affected zone (HAZ), residual stress and the presence of discontinuities.

Materials play an important role in manufactured goods. Materials must possess both acceptable properties for their intended applications and manufacturability. These criteria hold true for micromanufacturing, in which parts have overall dimensions of less than 1 mm. The wide range of materials that can be processed by lasers includes materials for micro-electronics, hard materials such as tungsten carbide for tool technology and very weak and soft materials, such as polymers for medical products. Even ceramics, glass and diamonds can be processed with laser technology to an accuracy better than 10 μm. In comparison with classical technologies, laser processes are generally used for small and medium lot sizes but with strongly increased material and geometric variability (Gillner et al., 2005).

Industrial product parts and components are being made smaller to reduce energy consumption and save space, which creates a growing need for microwelding of thin foil less than 100 μm thick. For this purpose, laser processing is expected to be the method of choice because it allows more precise heat control compared with arc and plasma processing (Abe et al., 2005).

There is a trend toward increased steel microwelding applications in the medical device manufacturing industry; these require spot sizes down to 25 μm and even smaller. Applications include sensors with very thin membranes (where no thermal deformation is allowed), microbonded wires with diameters of about 15 μm and welding of markers on to stents. As medical devices become smaller in size, new challenges will appear that laser welding will have to address (Tolinski, 2008).

Welding with a pulsed Nd:YAG laser system is characterized by periodic heating of the weld pool by an incident high peak power density pulsed laser beam that allow melting and solidification to take place consecutively. The welding speed is defined by the overlap, the pulse repetition rate and the focus diameter. However, due to the very high peak power density involved in pulsed laser welding, the solidification time is shorter than that using a continuous laser or conventional welds. A combination of process parameters such as pulse energy (E_p), pulse duration (t_p), repetition rate (R_r), beam spot size (Φ_b) and welding speed (v) determines the welding mode, i.e., conduction or keyhole (Ion, 2005; Duley, 1999; Steen, 2005).

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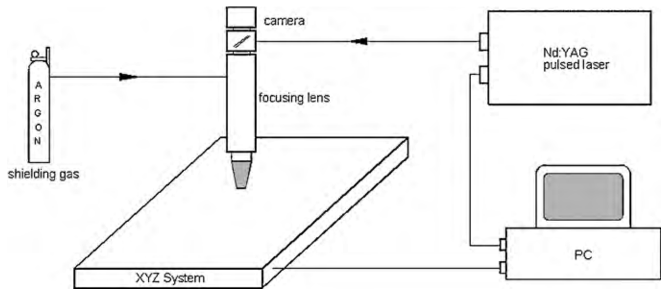

Fig. 1. Schematic of typical pulsed Nd:YAG laser welding system.

Research examining the Nd:YAG laser for continuous welding, pulsed welding, dissimilar sheet welding and coated sheet welding has been published. Kim et al. (2001) reported successful welding of Inconel 600 tubular components of nuclear power plant using a pulsed Nd:YAG laser. Berretta et al. (2007) using a home-made Nd:YAG pulsed laser system studied dissimilar welding of austenitic AISI 304 and martensitic AISI 420 stainless steel. Ping and Molian (2008) utilized a nanosecond pulsed Nd:YAG laser system to weld 60 μm of thin AISI 304 stainless steel foil.

This paper investigates the use of an Nd:YAG laser operating in pulsed mode for welding a 100 μm thick AISI 316L stainless steel thin foil. The effect of pulse energy on weld joint characteristics is studied, and a discontinuity-free welding structure with good mechanical properties is proposed.

2. Experimental apparatus and procedures

This study used a pulsed Nd:YAG laser system. The experimental setup of the laser system is shown in Fig. 1.

AISI 316L was selected as the base metal for welding experiment with the following composition (wt.%): C – 0.03, Cr – 17.28, Ni – 13.0, Mn – 0.80, Si – 0.75, P – 0.045, S – 0.003, and Mo – 2.3. The base material used for this study was thin foil with a thickness of 100 μm. It was cut to a size of 20 mm × 44.5 mm. The experimental results were analyzed on the basis of the relationships between pulse energy and weld bead geometry, the presence of discontinuities and mechanical properties. The specimens were prepared and cleaned to ensure that all samples presented the same surface conditions with a homogeneous finish.

To evaluate the influence of the pulse energy, welding was performed using specimens positioned as lap joints. They were welded with a beam spot size (Φ_b) and beam angle (A_b) of 0.2 mm and 90°, respectively. The focus point was fixed on the surface of the workpiece. The welding speed (v) and repetition rate (R_r) were fixed at 525 mm/min and 39 Hz, respectively. The pulse energy (E_p) varied from 1.0 to 2.25 J at increments of 0.25 J with a 4 ms pulse duration (t_p). Thus, there was one controlled parameter in this process: the pulse energy. The specimens were held firmly using a jig, as shown in Fig. 2, to fixture and prevent absence of contact and excessive distortion. Fixturing is extremely important for thin-section laser welding. Tolerances were held closely to maintain joint fitups without allowing either mismatch or gaps.

The specimens were laser-welded in an argon atmosphere at a flow rate (F_r) of 10 l/min. Back shielding of the joint was not necessary because AISI 316L is not an oxidizable metal like Al and Ti. None of the specimens were subjected to any subsequent form of heat treatment or machining. After welding, the specimens were cut for the tensile shear tests, as shown in Fig. 3. Finally, part of the cut surfaces was prepared for metallographic inspection by polishing and etching to display a bead shape and microstructure. Metallographic samples were prepared by electrolytic etching (2.2 V, 20 s) with a solution of 50% nitric acid. The bead shape measurements were made using an optical microscope with an image analysis system. Fig. 4 shows a schematic illustration of the transverse joint section with the analyzed geometric parameters.

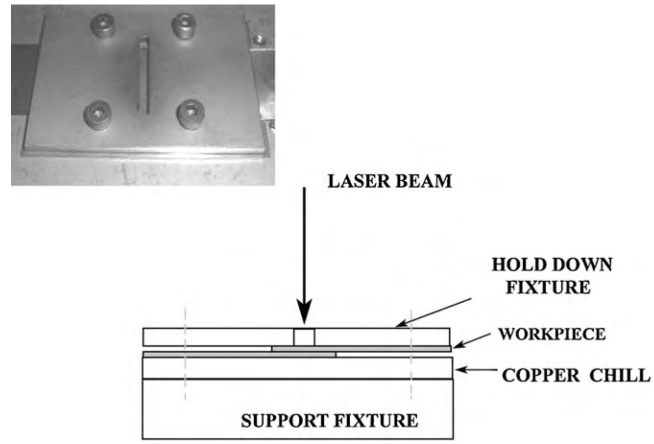

Fig. 2. Schematic of the hold-down fixture developed to hold firmly the thin foils of austenitic stainless steel AISI 316L.

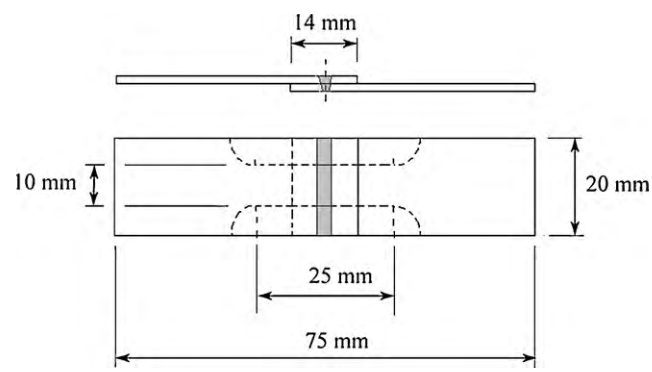

Fig. 3. Lap joint configuration of AISI 316L thin foil and schematic diagram of tensile test specimen design (mm).

The strength of the welds was evaluated using Vickers microhardness and tensile shear strength tests. Microhardness (HV10) tests were performed on a transverse section of the weld bead, parallel to the surface of the thin foils, in the region next to the connection line of the top foil. Microhardness tests identify possible effects of microstructural heterogeneities in the fusion zone and in the base metal. The reported data were the average of five individual results. For the tensile shear test, specimens were extracted from welded samples, and the width of the samples was reduced to 10 mm to lower the load required to fracture them.

3. Results and discussion

The optimum performance of the seam welded joint for chemical seals employed in corrosive environment applications was

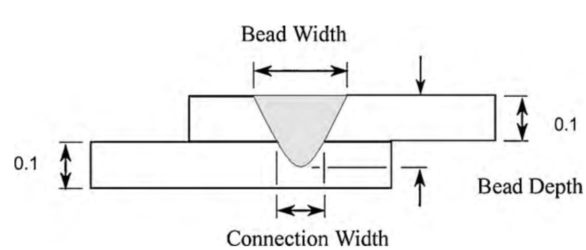

Fig. 4. Schematic of the joint transversal section showing the analyzed geometric parameters (mm).