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Laser welding of stainless steel capsules

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This paper presents the results of the experimental research regarding laser microwelding parameters for sealed stainless steel capsules used for radioactive sources. The investigations took into consideration the metal loss, penetration of the radiation, geometric size of the welding area, and the relation between these measured parameters and laser parameters.

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1. Introduction

The use of small enclosed nuclear radiation sources has raised a large interest lately in many fields of activity such as: physics, mechatronics, medicine and industry. The radioactive capsules are used as gamma radiation sources for non destructive testing of welded joints or measurement applications based on absorption of gamma radiation when passing through a material.

One of the main requirement of radioprotection states that the enclosed nuclear radiation sources, namely the capsules in which the radioactive material is placed should be perfectly sealed through all their usage time.

The technical specifications and testing methods of the sealed capsules are established by SR ISO 9978 standard "Radioprotection. Enclosed sources of radiation" and the mechanical tests are established by ISO EN 15614-1 standard.

Laser- Beam Welding (LBW) uses a moving high-density (10^5 to 10^7 W/ cm^2, or 6 x 10^5 to 6 x 10^7 W/in.^{2}) coherent optical energy source called a laser as the source of heat. Lasers have been promoted as potentially useful welding tools for a variety of applications. A variety of laser systems had been developed for making microwelds in electronic circuit boards, inside vacuum tubes, and in other specialized applications where conventional technology was unable to provide reliable joining. The availability of high-power continuous-wave (CW) carbon dioxide (CO_2) and neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers and the limitations of current welding technology have promoted interest in deep-penetration welding in the past 20 years using these devices [1].

Microwelding with Pulsed Lasers, like pulsed ruby lasers and pulsed Nd:YAG lasers is credited with some of the earliest successful applications of laser welding, including laser welding of thermocouple gages in the Apollo lunar probes. Numerous experiments have shown that the laser produces precision welded joints of high quality in ferrous alloys, nickel alloys, and titanium alloys that is rivalled only by those made by Electron Beam Welding (EBW). However, though EBW is used by radioactive capsules producers, the EBW installation is far more expansive than a laser welding installation and it needs a sealed vacuum chamber to perform the welding. LBW on the other hand doesn't need a vacuum chamber, thus offering a simple, cost effective tool for microwelding with comparable performances to EBW - speed, automation, precision and quality of welded assemblies.

A great deal of laser welding research has been conducted on ferrous alloys. Most of the initial parametric studies were carried out on stainless steel. Stainless steel was investigated because of its importance in the power plant and chemical industries.

Nd:YAG lasers are extensively used in manufacturing for cutting and welding stainless steel and super alloys. Laser welding has shown many advantages over traditional welding methods in the low thickness applications like capsules for radioactive sources. Owing to the precise power source and high welding speed, the heat input to the work piece is small and distortions are minimal [2, 3,4].

The very rapid cooling rates associated with LBW can produce marked departures from the expected solidification mode and ferrite content. Nevertheless, the minimum 4 FN convention has been a very successful guideline in normal welded fabrication of normally austenitic stainless steels.

Arc welding heats the base metal adjacent to the weld deposit, which can produce undesirable metallurgical reactions. In austenitic stainless steels, a principal concern is grain-boundary carbide precipitation. Whatever carbides were initially present before welding can be dissolved at temperatures above approximately 1000 °C.

Then, subsequent slow cooling through the temperature range from approximately 950 °C down to approximately 500 °C can cause chromium carbides to precipitate again, usually on austenite grain boundaries. This precipitation can leave the metal adjacent to the grain boundaries depleted in chromium and, therefore, susceptible to inter granular corrosion. The steel is said to be "sensitized". Improper heat treatment can do this to an entire base metal [5].

2. Experimental procedure

2.1 The materials

The study is concerned to analyze the welding behaviour of stainless steel capsules for gammagraphy applications (fig. 1). The enclosed capsules for nuclear radiation used in non destructive testing or measuring applications require a good sealing during the working period. The capsule assembly contains two pieces, the capsule body and the cover, which needs to be joined together by circular welding made on the capsule's top. In order to obtain a good quality sealing, laser welding process was applied to join the cover to the capsule's body without filler metal.

The capsules are made of 304 type stainless steel 10TiNiCr180 with a balanced austenitic structure (chemical formula Fe, <0.08% C, 17.5-20% Cr, 8-11% Ni, <2% Mn, <1% Si, <0.045% P, <0.03% S).

Fig. 1. Stainless steel microcapsules.

The dimensions of a capsule are: 5mm in diameter and 8mm in length.

The radioactive material is Sr-Ir tablet.

2.2 The equipment

The investigations were carried out using a ROFIN STARWELD PERFORMANCE SWP 6002 (fig. 2.) laser installation, a Nd:YAG pulsed laser, and a SEM INSPECT S microscope for measurements of the geometrical size of the welded zone in order to correlate the penetration and width for the different values of welding parameters. Also the metal loss during welding process was measured using a KERN electronic balance type ABJ 220-4M, as well as a microhardness measurements using a Shimadzu HMV 2T microhardness tester, in order to measure the metal hardness variation after laser welding.

To avoid the weld contamination with impurities on the material, the capsules and the capsule's cover were ultrasonic cleaned using UCI50 ultrasonic cleaner.

The tests were not performed with radioactive material in the capsules due to radioactive contamination that might occur. An industrial installation for welding the capsules would have to be specially designed for this purpose.

Fig. 2. ROFIN STARWELD laser installation

2.3 Welding parameters

The depth of laser welding penetration is directly related to the power density of the laser beam and it is a function of incident beam power and beam diameter. For a constant beam power diameter, penetration typically increases as the beam power is increased. The Laser-Beam diameter is one of the most important because it determines the power density.

The efficiency of LBW depends on the absorption of light energy by the work piece. Any heat transfer calculation for laser processing is based on the energy absorbed by the work piece.

The infrared absorption of metals largely depends on the conductive absorption by free electrons. Therefore, absorptivity is a function of the electrical resistivity of the substrate material.

Measuring the absorptivity of polished surfaces of various materials it is concluded that absorptivity is proportional to the square root of the electrical resistivity.

This agrees closely with:

$$A = 112.2\sqrt{\rho_r}$$

where A is the absorptivity and ρ_r is the electrical resistivity [1]. The laser beam welding was performed circular and the welding parameters values, including metal loss during evaporation, are presented in the table 1.

The metal loss is significant for the welding regime of P2 sample, were the voltage and the welding pulse time has the maximum values. The metal loss values are similar with those reported in technical literature [3].

Table 1. Welding parameters for the test pieces.

Sample	Voltage, [V]	Pulse time, [ms]	Beam energy, J/cm^2	Pulse frequency, [Hz]	Average penetration, [µm]	Metal loss, [%]	Spot, mm
P1	233	2.3	1275	2.6	337.54	0.36	0.775
P2	245	3.1	1895	2.3	577.72	1.28	0.775
P3	230	3.0	1249	2.0	413.22	0.39	0.95

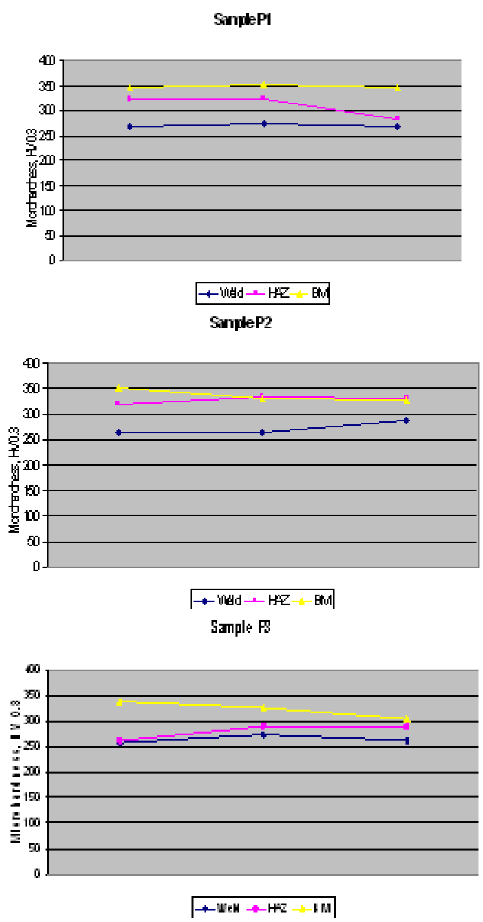

Fig. 3. Microhardness values measured in base material, HAZ and weld zone.

3. Results

3.1 Microhardness

Microhardness test was performed using the Shimatzu HMV 2T device with a weight of 300g. The test points were located every 0.1 mm from the fusion line, in the weld, HAZ and basic material. Microhardness profiles (Fig. 3) showed a significant softening of the weld.

3.2 Metalographic analysis

Macrostructure of the P2 assembly are given in Fig. 3. The voltage decreasing has determinate the weld width decreasing at the same values of frequency and spot dimension, while the decrease of pulse time has generate the increasing of weld width for the same values of the voltage and frequency.

The high increase of spot dimension has generated non-uniformity of the weld width, splashing (Fig. 4b), cracks (Fig. 4a) and pores (Fig. 4a). Using welding parameters on P1, the welding was performed correctly (Fig. 4c).

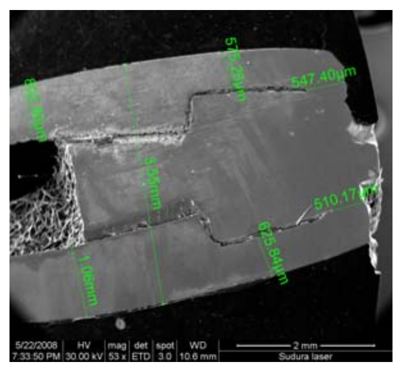

Fig. 4 a

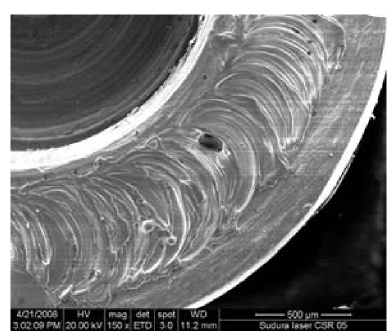

Fig. 4b

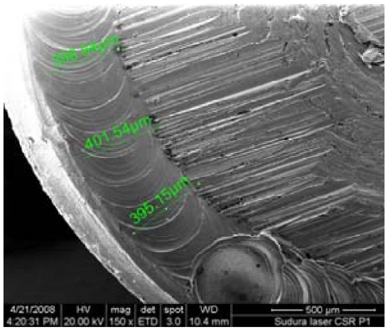

Fig. 4c

4. Conclusions

This research work showed that Nd: YAG laser process is a potential welding method to achieve good penetration of the stainless steel made capsule for medical application.

At the higher laser power value (sample P2) the microhardness values, metal loss by vaporisation and the penetration have got the maximum amplitude.

The increase of the spot dimension has generated non-uniformity of the weld width, splashing, cracks and pores.

For all samples the weld microhardness decrease comparatively with the base material due to cooling condition and low volume of melted material.

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