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Long Pulse Laser Micro Welding of Commercially Pure Titanium Thin Sheets

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Abstract

The paper deals with the application of a long pulse, lamp pumped Nd:YAG laser source in welding thin sheets of commercially pure titanium. An experimental campaign was designed and planned by means of the Response Surface Method (RSM) in order to assess the effect of the main process parameters on the weld bead penetration depth, width and general morphology. In particular the role of pulse duration, pulse peak power and pulse frequency was determined by means of optical observations and statistical analyses. Weld bead penetration depth, width and overall geometry were measured and related to the process parameters, in order to assess optimized operating process windows. The results point out, in particular, that pulse peak power is responsible for weld bead penetration depth. Pulse duration, on the other hand dominates weld bead width: by means of an in-depth analysis of these results it was pointed out that sound weld beads, characterized by the proper morphology, can only be achieved by means of a proper balance between these two parameters. A too high peak power, in fact, easily leads to the right penetration depth, but it tends to produce spatters, porosities and drop-through in the weld bead, while acting on the pulse duration the right morphology of the weld bead can be achieved.

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Keywords: Pulsed Laser Welding; Nd:YAG; Titanium; Design of Experiment

1. Introduction

Laser welding has become an established practice by the industrial point of view and since the mid-60s, a few years after the construction of the first laser by Theodore Maiman, many researchers had already identified the great potential of this technology [1], both on small [2, 3] and on large thicknesses [4] and in the most diversified production environments, such as packaging [5] and biomedical [6].

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Nomenclature

P_p	Pulse peak power [%]
P_d	Pulse duration [ms]
f	Pulse frequency [Hz]
P_e	Pulse energy [J]
P_o	Pulse overlap
P_m	Average power [W]
D_s	Spot diameter [mm]
v	Welding speed [mm/s]
P	Weld bead penetration depth [μm]
W	Weld bead width [μm]

From the early 70s to the late 80s the study of laser welding had an extraordinary impulse and the validity of the technology was demonstrated and assessed in many industrial sectors and on different materials: dentistry [7], sheet-metal [8], energy production [9], process modeling [10], electronics [11], difficult-to-weld materials [12], light alloys [13] and stainless steel [14]. The 90s were characterized by a strong diversification of the studied topic related to the application of laser welding, because, being assessed all the basic features of this technology, the researchers focused on more specific aspects, such as physical phenomena involved, process monitoring, modeling and microstructural aspects of the welded materials. The high power density and the low thermal load characteristic of laser processes, especially if compared with those typical of arc welding technologies, on one hand favor many positive aspects, such as reduced heat affected zones, high penetration depths, reduced thermal distortions but, on the other hand they tend to favor severe thermal cycles which may lead to crack formation, as shown by Yoo et al. [15]. Regarding the welding of low thickness components, in the first half of the 2000s several studies assessed the undoubted validity of LASER even in this field [16]: in particular studies were carried out on MEMS [17], wires [18] and micro-manufacturing [19]. In this case the use of low average power pulsed laser sources turned out to be very profitable, since the control of pulse-related parameters (duration, energy, peak power and frequency) allows an accurate tuning of the heat input in the workpiece during the process, determining the right conditions for the achievement of sound, crack-free and properly shaped weld beads on many different metallic materials. In particular, the first studies on the possibility of applying pulsed laser welding on thin sheets date back to the mid-90s, when Olsen et al. [20] presented good results on welding AISI 316 stainless steel with a Nd:YAG millisecond pulsed laser source, demonstrating the importance of controlling the energy transfer given by the pulsed regime when the thickness to be welded is below 1 mm. Glasmacher et al. [21], using similar sources, proved the possibility of extending this technology to electronics, demonstrating the feasibility of soldering 100 mm thick Fe-Ni and Cu-Ni alloys. The first half of the 2000s was by far the most profitable in terms of studies and innovations in this field. Schmidt et al. [22], exploiting a Nd:YAG millisecond pulsed source, focused on the welding of 50mm thick stainless steel micro-filaments. Szymanski et al. [23] studied the effect of pulse modulation as a mean of process stabilization in welding of thin sheets. Klages et al. [24] proposed a special technique called SHADOW©: the weld seam is achieved exploiting the energy of a single pulse (20ms long) "smeared" on the welding line by means of a very fast welding speed. Semak et al. [25], demonstrated that deep keyhole welding of thin sheets can be achieved also with short-pulse sources. Chmelickova et al. [26] studied long pulse Nd:YAG laser welding of 0:5mm thick aluminum alloy, steel and stainless steel. Mys et al. [27] focused on dissimilar welding of copper and aluminum, while Kawahito et al. [28] studied the possibility to weld titanium thin sheets underlining the role of adaptive controls during the process to compensate the negative effect of the variability of the welding gap. Okamoto et al. [29] evaluated the possibility to exploit galvanometric beam displacement in laser welding of 25mmthick stainless steel. P'ng et al. [30] proposed a study in which a nanosecond pulsed source was used in welding 60mum thick stainless steel sheets. The article highlights the benefits of using low average power and high peak power sources in joining very thin components. The possibility of exploiting nanosecond pulsed laser sources was then further demonstrated by Fortunato et al. [31] and Ascari et al. [32] even on difficult-to-weld materials such as high carbon steels.