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The influence of process parameters on porosity formation in hybrid LASER-GMA welding of AA6082 aluminum alloy

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ABSTRACT

This paper deals with an experimental campaign carried out on AA6082 8 mm thick plates in order to investigate the role of process parameters on porosity formation in hybrid LASER-GMA welding. Bead on plate weldments were obtained on the above mentioned aluminum alloy considering the variation of the following process parameters: GMAW current (120 and 180 A for short-arc mode, 90 and 130 A for pulsed-arc mode), arc transfer mode (short-arc and pulsed-arc) and mutual distance between arc and LASER sources (0, 3 and 6 mm). Porosities occurring in the fused zone were observed by means of X-ray inspection and measured exploiting an image analysis software. In order to understand the possible correlation between process parameters and porosity formation an analysis of variance statistical approach was exploited. The obtained results pointed out that GMAW current is significant on porosity formation, while the distance between the sources do not affect this aspect.

1. Introduction

Hybrid LASER-GMA welding techniques are receiving a growing industrial attention due to the synergic effect achieved by coupling two technologically different welding methods together. The presence, in fact, of a high energy density source, such as the LASER one and of an arc source with a filler material, such as the GMA one, allows to set up a well defined process, characterized by its own peculiar characteristics. These characteristics are the result of the complementarity of the two coupled techniques and derive from the fact that in hybrid processes the main positive aspects of one involved technology allow to override the main drawbacks of the other and vice versa. In particular the most relevant benefits of hybrid LASER-GMA welding technique are high process speed, very good bridging ability, high bead penetration, possibility to modify the bead metallurgy and possibility to deal with variable gaps, misalignments and chamfers. Typical applications of hybrid LASER-GMA welding concern shipbuilding, automotive, pipeline constructions and, more in general, but joints with high thickness sheets [1] where the main difficulty is to deal with variable gaps between the sheets and to achieve single pass and high speed weldings in order to maximize productivity. On the other hand, considering the availability of modern high beam quality and fiber-deliverable LASER sources, such as Nd:YAG disk and fiber ones, the application of hybrid LASER-GMA welding also on low thickness sheets is becoming very common in many industrial applications [2]. According to the above mentioned considerations, the combination of two technologically different energy sources leads to several undoubted advantages, but, on the other hand, it also determines the occurrence of several technological problems which have to be faced. Some of these problems concern the stability and the repeatability of the process, mainly related to the shielding gas flux and composition [3–8], drops deposition [9,10], arc current [11,12] sources position and mutual interaction [13–15] and porosity formation [16]. In particular, mechanisms and physical phenomena related to the porosity formation are not fully understood yet even if they drastically influence the mechanical resistance especially in aluminum welding. In [16] it was first observed and described the phenomena of bubble formation in AISI 304 stainless steel and AA5052 aluminum alloy for hybrid GTA-YAG and GMA-YAG LASER welding under different process conditions and it was pointed out that arc current is the main factor in bubble formation. According to the previous assumptions, this paper investigates the influence of arc welding parameters such as arc current and transfer mode and of the mutual distance between arc andLASER sources on the number and on the extension of the porosity generated during the hybrid welding process. The experiments were carried out on a AA6082 aluminum alloy exploiting a CO_2 hybrid LASER-GMA welding technique. The test specimens were analyzed by means of X-ray inspection and the porosities were counted and measured exploiting computer image analysis. The porosity related

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parameters were then analyzed by means of analysis of variance (ANOVA) statistical techniques in order to understand the actual correlation between process parameters and output ones and to find eventual mathematical models expressing their relationships.

2. Experimental setup

The experimental equipment exploited in this campaign consisted of an El.En. FAF 3 kW continuous wave CO_2 LASER source, equipped by a three axes CNC cell, and by a Selco 380 A synergic pulsed GMAW generator. The LASER beam was focused by means of a copper parabolic mirror with a focal length of 200 mm which allowed a minimum spot diameter of 500 μm. The sources were coupled together by means of a Binzel automatic torch fixed on the vertical (*Z*) axis of the CNC cell. The welding direction was set to LASER leading as presented in Fig. 1.

Every experimental trial was carried out in a bead on plate configuration on AA6082 8 mm thick plates fixed on the X–Y table of the CNC cell. The obtained weld beads were straight linear ones characterized by a length equal to 100 mm. The LASER beam focal position was constantly kept on the upper surface of the workpiece. During the experimental campaign the parameters given in Table 1 were kept constant while arc current and distance between the two energy sources were varied in accordance to Table 2.

The distance between the heat sources and the inclination of the torch were defined as shown in Fig. 2. In particular two levels for the arc current, combined with three levels for the sources distance, were investigated for both pulsed and short-arc GMAW configuration. Finally, three repetitions were performed for every welding configuration in order to evaluate the repeatability of the process. The gas mixture composition reported in Table 1 represents a good trade off between arc stability and plasma formation during welding as reported in [5]. The shielding gas was supplied through the GMA torch. According to the previous descriptions the whole experiment consisted of 36 experimental trials: (2 levels for the arc current), (3 levels for the distance between the heat sources), (3 repetitions for every trial)=18 samples for short-arc mode and other 18 samples for pulsed-arc mode.

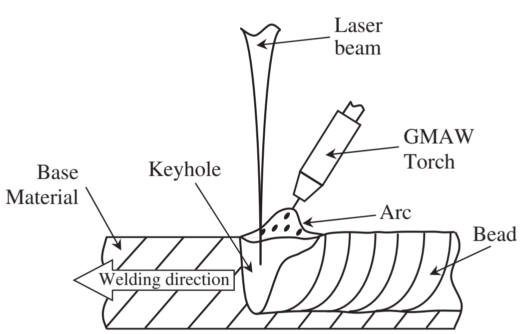

Fig. 1. Hybrid welding setup.

Table 1
Constant parameters.

LASER power	3 kW
Gas mixture	60% He, 37% Ar and 3% O_2
Gas flow	17 l/min
Torch inclination	65°
Welding speed	0.6 m/min
Wire type	Al–Mg ER5356
Wire diameter	1.2 mm

Table 2
Variable parameters.

Current – short-arc	120 and 180 A
Current – pulsed-arc	90 and 130 A
Distance (*D*)	0, 3 and 6 mm

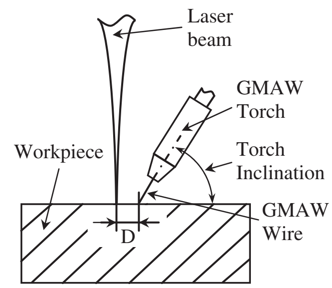

Fig. 2. Definition of *D* (distance between the heat sources) and torch inclination.

Table 3
X-ray inspection parameters.

Focal distance	Power	Current	Exposure
700 mm	55 kW	3 mA	60 s

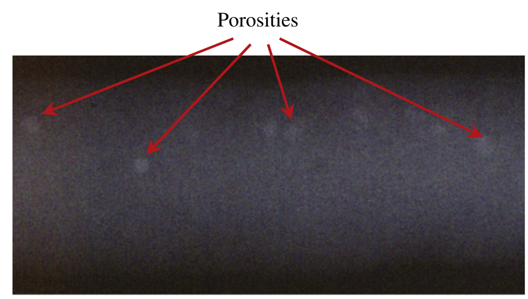

Fig. 3. Radiography showing a bead affected by a large number of porosities.

3. Experimental results

The specimens obtained during the experimental phase were radiographed by means of a General Electric ERESCO 42MF portable equipment. The parameters used during this inspection are summarized in Table 3. Every X-ray plate was then digitally acquired by means of a double face scanning equipment in order to allow a computerized image analysis. Figs. 3 and 4 show two examples of digitized X-ray plates. By means of the image analysis software MediaCybernetics ImagePro Plus 6.0 the bubbles could be detected, counted and measured in order to characterize the porosities of the obtained welding specimens. The mentioned software, in fact, can be conveniently tuned in order to apply a so-called "segmentation" on the picture which allows to separate single objects (bubbles in this case) from the background of the image and to subsequently count and measure them in terms of absolute number and total area. Fig. 5 shows the objects detection phase in the mentioned software: the green objects (indicated by the arrow) were classified as porosities, while the red and white ones are classified as dust, granulometry and imperfections of the X-ray plates according to the thresholds set in the segmentation phase. Every specimen was radiographed