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Microstructure and mechanical properties of laser welded beads realized for joining CuZn open cellular foams

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ABSTRACT

Porous materials as well as cellular metallic foams intrinsically combine thermo-physical, functional and structural characteristics. This mix of different properties makes these materials very attractive for the development of new applications in biomedical, electronic, chemical and structural engineering fields. A requirement for the diffusion of applications based on metal foams is the study of the joining processes, which could result a suitable route for processing metallic foams integrated devices. In this work, microstructure and mechanical properties of the laser welding beads were investigated. The melted zones and the heat affected zones of lap joints were characterized by optical microscopy and micro-hardness profiles. Shear strength of plate/foam and plate/bulk lap joints was compared.

1. Introduction

Cellular materials represent a stimulating class of materials, able to offer an almost unique mix of morphological and functional performance [1]. The combination of physical, chemical and mechanical properties can make these materials very attractive for different potential applications in ship building, aerospace industry and civil engineering, for light-weight constructions, energy absorption and acoustic and thermal control [2].

Depending on the chemical composition, several methods are used to prepare metallic cellular materials with different porosity. One of these methods is based on the liquid infiltration of leachable solid particles [1–4]. Liquid infiltration was performed for foaming Al and Cu alloys [4–6]. Because of the industrial diffusion of these alloys [7], the processing of metallic foam structures represents an important achievement for the manufacturing of new devices. In this regard, laser beam is considered a possible tool for processing metallic foams. A few works based on laser technology were published on this topic, namely: foaming process [8], bending [9], cutting [10] and welding of sandwich Al panels [11]. All these works deal with micro-sized pores and close cellular structures. Laser weldability of CuZn open cell foams was also approached [12,13] and some processing issues were highlighted.

In this work, $Cu_{65}Zn_{35}$ [wt%] open cell foams with large pore size were lap joined with brass plates by laser beam welding. The microstructural and mechanical properties of the welded beads were investigated. Cross sections of the welded beads were analyzed by optical microscopy and micro-hardness profiles were also performed across the joints. Finally, the strength of the laser welded plate/foam lap joints were tested and compared to the plate/bulk reference ones.

2. Experimental methods

$Cu_{65}Zn_{35}$ [wt%] brass foams were produced with pore size in the range of 3.5 mm $\pm$ 0.5 mm. Details of the foaming method are reported elsewhere [5,6]. The welding experiments were executed in lap joint configuration using a continuous wave fiber laser (YLR 1000 model from IPG Photonics). CuZn plates, of 1 mm in thickness, were placed on the top of the CuZn foam samples. The list of the main process parameters used in the experiments are collected in Table 1.

Cross and longitudinal sections of the weld beads were analyzed by optical microscope (OM). Vickers micro-hardness was measured across the welded beads in both the plate and the foam with a load of 100 g.

The mechanical properties of the plate/foam welded beads were compared to those of the reference material realized in the plate/bulk lap joint. Tensile tests were done with a MTS Alliance RT/100 setting a constant crosshead speed of 10 mm/min, at room temperature. The specimens used for mechanical tests (see Fig. 1) were designed according to the E8/E8M – 13a ASTM standard specifications [14,15].

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Table 1.
Process parameters used in the welding.

Process speed	5 mm/s
Power	1000 W
Laser spot	0.54 mm
Assist gas	Argon
Gas pressure	5 bar
Gas flow	40 l/min
Inclination of the laser beam	10°
Collimation/focusing length	100/200 mm
Focal position	+3 mm

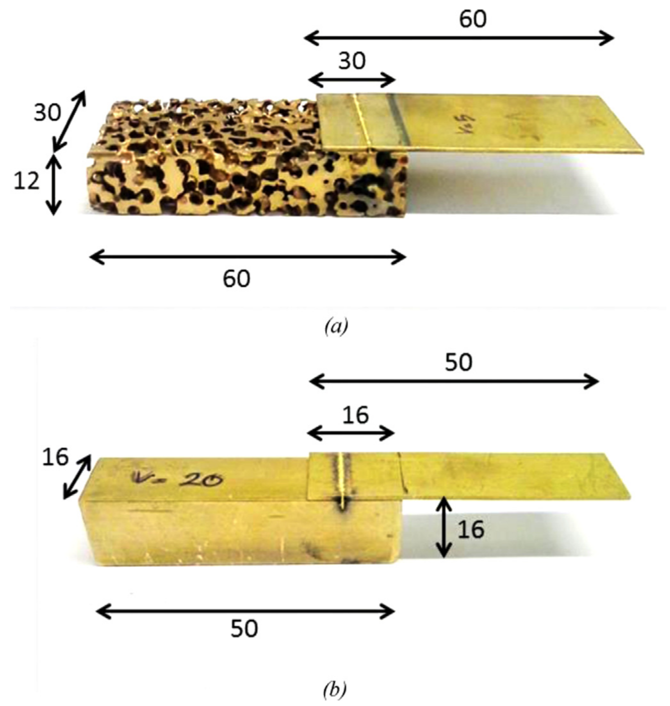

Fig. 1. Samples welded for the mechanical testing in (a) plate/foam and (b) plate/bulk lap joint.

3. Results and discussion

Although the high reflectivity of Cu based alloys [16], a typical keyhole bead was realized on the bulk material, as shown in Fig. 2. The process parameters reported in Table 1 produced a penetration depth and a bead width of 4 mm and of 0.4 mm, respectively. No cracks were found in the melted zone (MZ) nor in the heat affected zone (HAZ), which is highlighted with a red dash line in Fig. 2. This shows the effectiveness of the joint performed on an alloy that is considered hard to be welded [17].

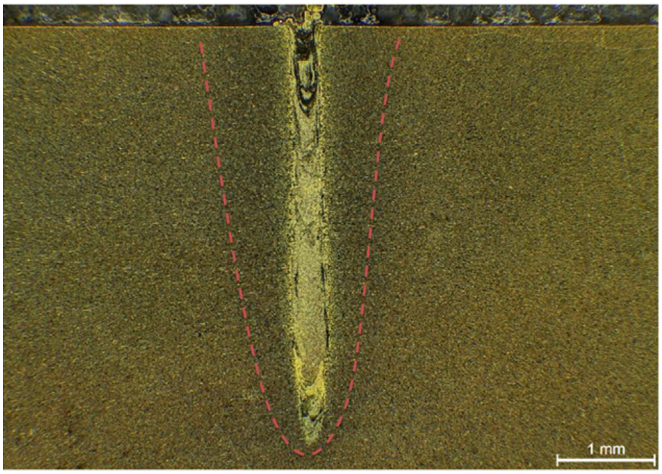

Fig. 2. Cross section of the welded bead realized in bead on plate configuration.(For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

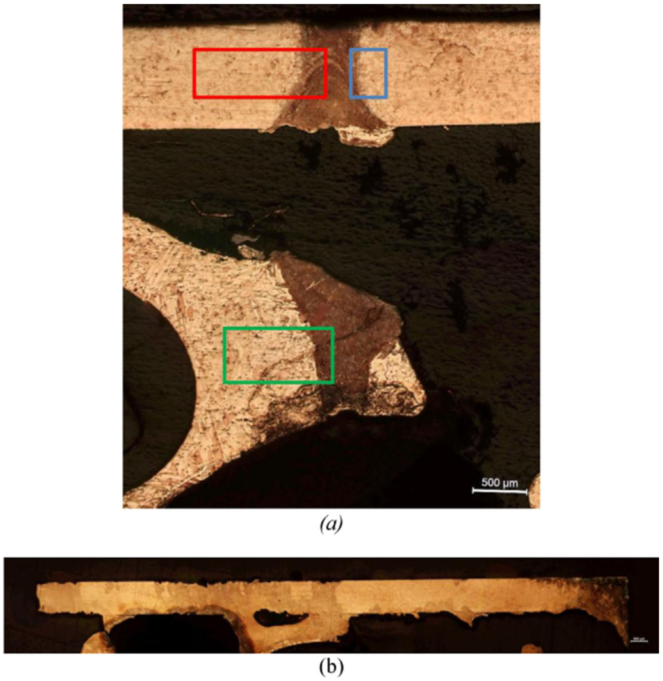

Fig. 3. (a) Cross and (b) longitudinal sections of the welded bead realized in lap joint on foam (both markers have a length of 0.5 mm).

A previous work showed that a laser spot, smaller than pore size, leads to unsuccessful bead on foam welding because of a negligible amount of melted material for void filling [11]. Therefore the welding of brass foam was approached in lap joint configuration to allow the molten material coming from the upper plate to fill pores and to bridge adjacent ligaments (see Fig. 3a). As expected, the penetration of the welded bead in the foam was irregular, due to the plate/foam surface contact. In Fig. 3b the micrograph of the longitudinal section of the joint is depicted, in which some top/foam bridges can be observed.

Fig. 4 depicts a higher magnification micrograph of the characteristic regions of a joint highlighted by rectangles in the micrograph of Fig. 3a. The evolution of the microstructure from the MZ to the base material (BM) of a plate/plate joint is reported in Fig. 4a and b. A fine dendritic structure is visible in the MZ: it is the result of a rapid solidification process. Next to the HAZ, about one hundred microns wide, the BM shows an equiaxed grain structure with twins. Fig. 4c reports the magnification of the welded part in the foam. The MZ exhibits again a fine dendritic microstructure, due to the melting and the rapid cooling typical of laser processing. On the contrary, the HAZ of the foam shows a significant difference with respect to the plate: the microstructure of the HAZ is characterized by a mix of fine and coarse dendritic structures: the former is due to the high cooling rate induced by laser processing, the latter is distinctive of the low cooling rate of the casting process of the foam.

Mechanical properties were evaluated through micro-hardness and tensile tests. A representative profile of micro-hardness is shown in Fig. 5a, in which the plate and foam bead profiles are shown. Because of rapid solidification the center of the welded bead (x=0 mm) was characterized by the highest hardness values (125 HV and 135 HV for the plate and foam, respectively). A softening effect was identified in the HAZ of the plate