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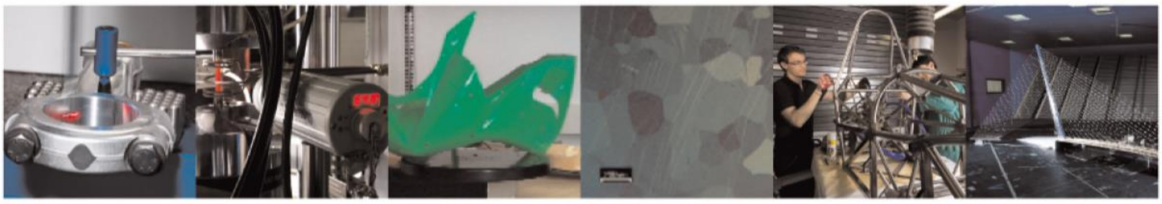

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Microstructure and mechanical properties of laser welded beads realized for joining CuZn open cellular foams

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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.

Keywords: Cu alloys, foams, laser welding, mechanical properties.

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 shear strength of the laser welded plate/foam lap joints were tested and compared to the plate/bulk reference ones.

Experimental Methods

$Cu_{65}Zn_{35}$ [wt. %] brass foams were produced with pore size in the range of 3.5 mm ± 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.

Table 1: Process parameters used in the welding

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 Figure 1) were designed according to the E8/E8M − 13a ASTM standard specifications [14-15].

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

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 Figure 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 Figure 2. This shows the effectiveness of the joint performed on an alloy that is considered hard to be welded [17].
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 Figure 3a). As expected, the penetration of the welded bead in the foam was irregular, due to the plate/foam surface contact. In Figure 3b the micrograph of the longitudinal section of the joint is depicted, in which some top/foam bridges can be observed.

Figure 2: Cross section of the welded bead realized in bead on plate configuration

Figure 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)

Figure 4 depicts a higher magnification micrograph of the characteristic regions of a joint highlighted by rectangles in the micrograph of Figure 3a. The evolution of the microstructure from the MZ to the base material (BM) of a plate/plate joint is reported in Figure 4a and 4b. 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. Figure 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.

Figure 4: Magnification of some representative areas in the lap joint on plate/foam: microstructure evolution from the MZ to the BM (a) and transition from MZ to HAZ (b) in the plate; microstructure evolution from the MZ to the BM in the foam.

Mechanical properties were evaluated through micro-hardness and tensile tests. A representative profile of micro-hardness is shown in Figure 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 (approximately 85 HV); this is quite common in Cu alloys after thermal processing [17].

Vice versa, the softening effect was less evident in the HAZ of the foam, which is characterized by microhardness scattering correlated to the bimodal dendritic structure of HAZ foam. The extent of the HAZ was evaluated to be about 2 mm, including both microstructural modification and softened area, on both plate and foam.

The strength of the welded beads, evaluated in tensile shear configuration, was investigated. The stress/strain results of the plate/foam and plate/bulk lap joint samples are reported in Figure 5b. Upon loading, the plate/bulk curve shows an almost continuous increase in stress up to the failure (about 170 MPa); the stress/strain results are in good agreement with the literature [18]. As expected, the plate/foam lap joint showed reduced mechanical performances. A maximum stress values of 83 MPa, about 50% less than the plate/bulk sample, was measured. The strength reduction is related to foam porosity while the stress fluctuation of the tensile curve for plate/bulk is due to irregular bead penetration.

Figure 5: Microhardness profiles across the welded bead (a); shear stress/ strain curves of the lap joints realized in two configurations: plate/foam and plate/bulk (b).

Conclusions:

In this work, the effect of laser welding on the microstructure and the mechanical properties of CuZn open cell foams was studied. The joining was carried out in lap joint configuration and the welded bead was successfully realized without filler material. The upper plate, once melted by the laser beam, filled the foam pores close to the top. Fine dendritic microstructure was observed in the MZ while the HAZ, one hundred of microns in width, showed a bimodal microstructure made up of fine and course dendritic structure. On the other hand, microhardness profile indicated a softened area of approximately 2 mm in the plate, not in the foam. Tensile shear tests showed that the plate joined to the foam can offer a maximum shear stress equal to half of the value offered by the plate lap joined to the bulk alloy. This effect is certainly related to the foam porosity and to the discontinuous bead along the welding trajectory. Laser weldability of open cell foams was successfully demonstrated, showing reasonable mechanical properties and crack free welded bead.

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Figure
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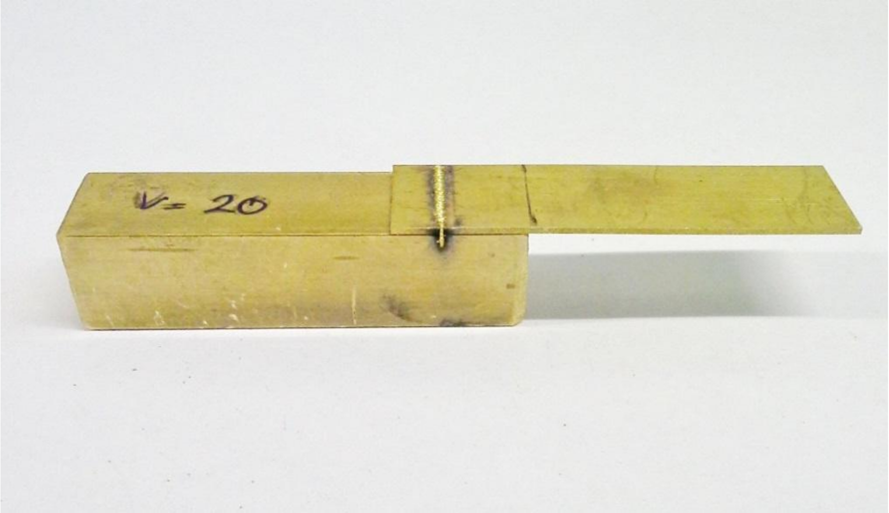
Figures:

(a)



(b)

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

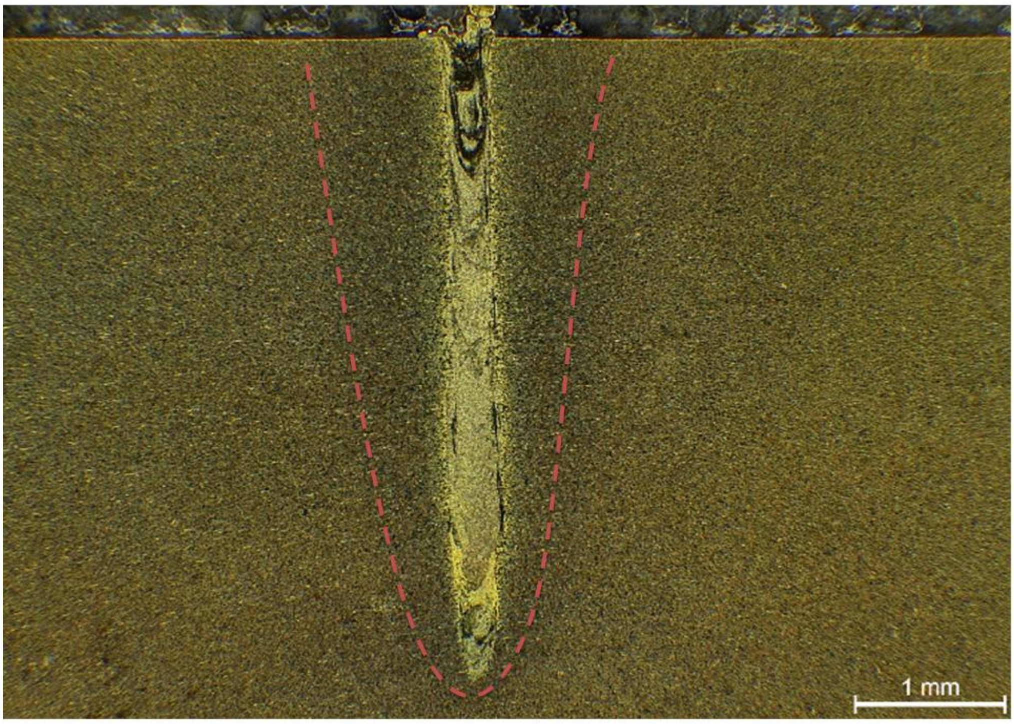
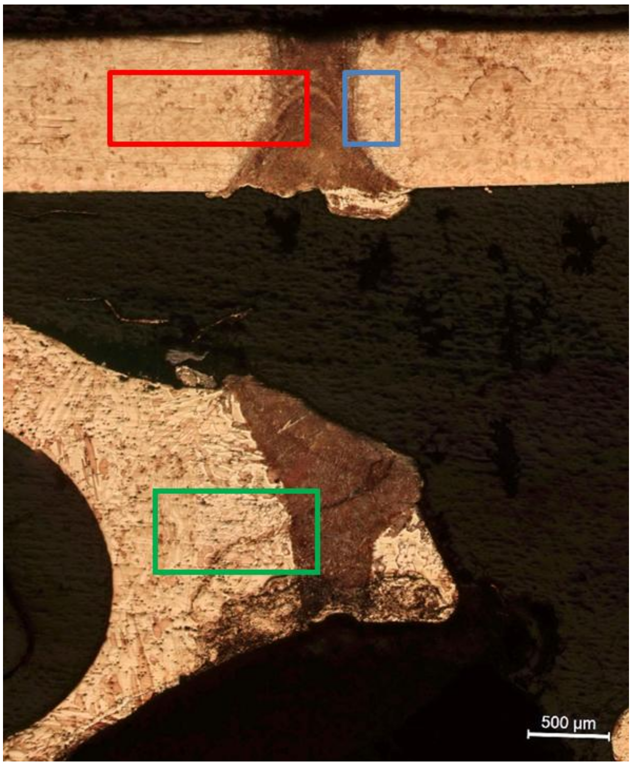


Figure 2: Cross section of the welded bead realized in bead on plate configuration



(a)

(b)

Figure 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)

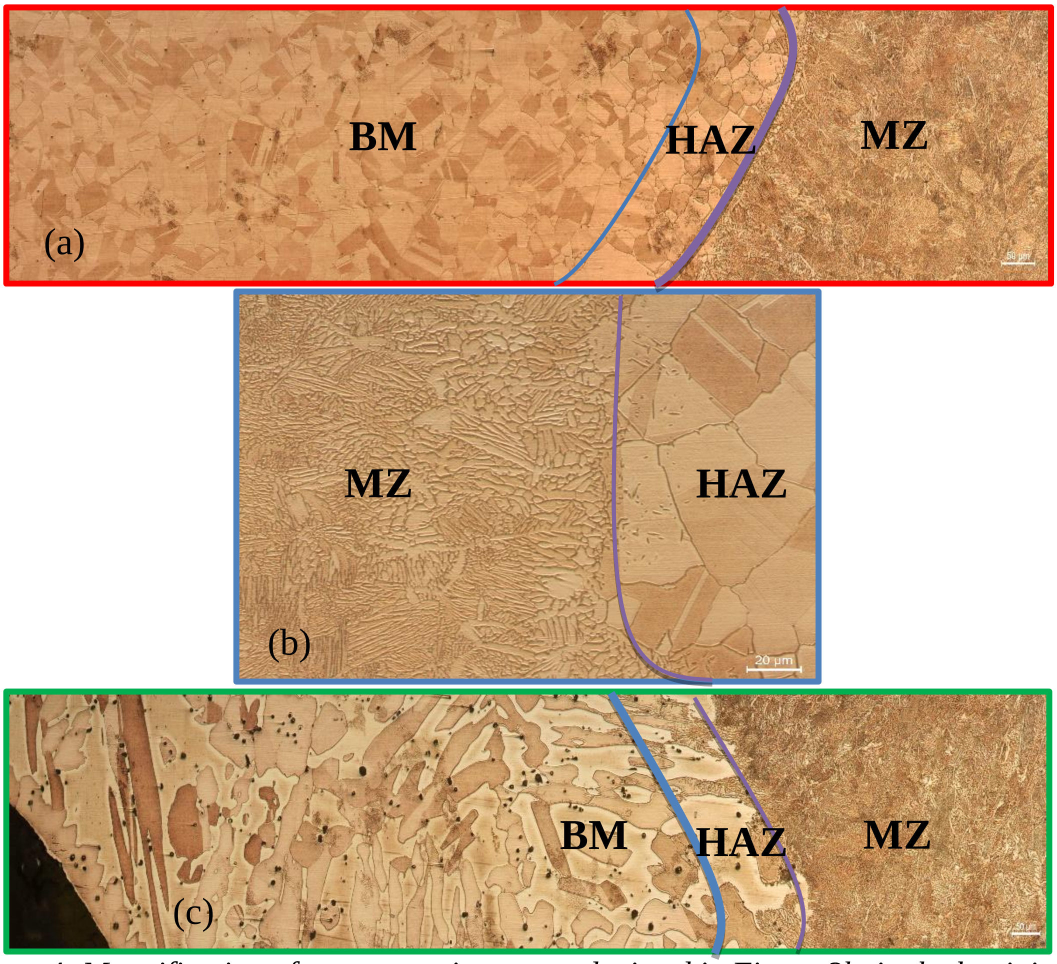
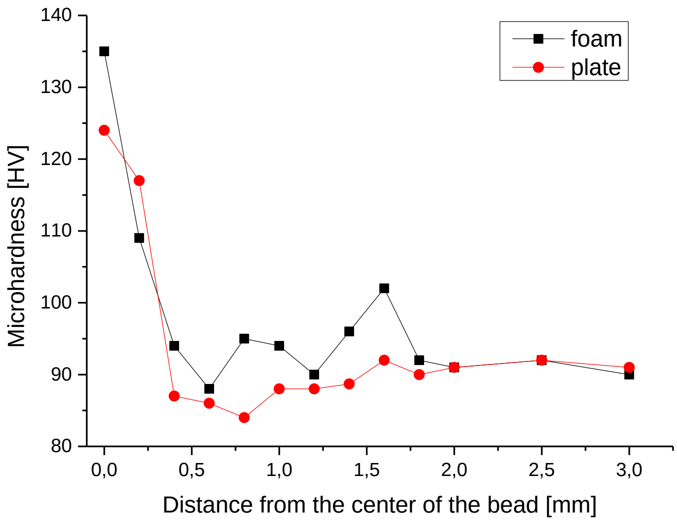
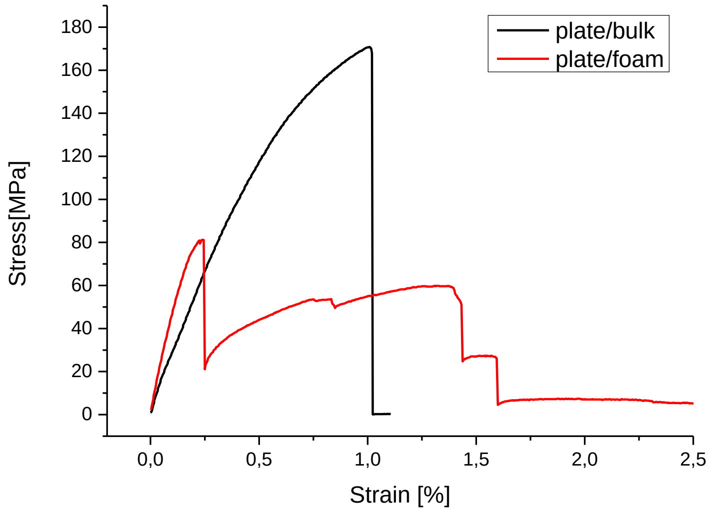


Figure 4: Magnification of representative areas, depicted in Figure 3b, in the lap joint on plate/foam:(a) microstructure evolution from the MZ to the BM and (b) transition from MZ to HAZ in the plate; microstructure evolution from the MZ to the BM in the foam.



(a)



(b)

Figure 5: Microhardness profiles across the welded bead (a); shear stress/strain curves of the lap joints realized in two configurations: plate/foam and plate/bulk (b).

Table

Table:

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

Table 1: Process parameters used in the welding