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LASER FORMING OF ALUMINIUM METAL FOAM PANELS

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ABSTRACT

Aluminium metal foam panels can be formed by laser bending without collapse of the cell structure and with relatively large bending angles. A diode laser having the power set to 100 W and three scan rates (4, 6, and 8 mm/s) were used in the experiments. The maximum number of passes was 150 and a flow protective gas was provided on the processed zone of two panels different in density. In the paper are investigated the obtained values of the bending angles, the microstructure in the deformation zone of the AlSiMg metallic foam panels deformed by laser bending.

KEYWORDS: laser forming, metal foams, diode laser, non-conventional bending

1. INTRODUCTION

Cellular metals are heterogeneous materials formed by a 3D metallic matrix with pore occupying more then 70% vol. (figure 1). The expression “metal foams” is used to describe the solid product. Their relative density is less than 0.3. The cellular metals can be differentiated by their structural features: the geometric form of the solid (skeleton) in the individual cells and their 3D arrangement, the variation of that geometry within the part, the microstructure of the solid and its surface.

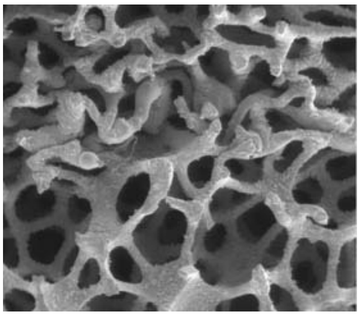

Fig. 1. *Metal foam structure*

The cellular architecture of the foams could be described using several structural parameters such as number, size-pore distribution, average size, shape and geometry of the pores, thickness, intersections and defects in the cell-walls and thickness, defects and cracks of the external dense surface for describing [1]. The most attractive material feature is that, by changing its density, the properties can be easily tailored, within large limits. Even the structure of 3D metallic foams is often non-uniform; this could be used for obtaining acceptable and reproducible properties.

Among the metal foams, the Al-alloy ones are commercially the most exploited due to their low density, high ductility, high thermal conductivity, and metal competitive cost.

In this paper, a laser forming characterization is made and a microstructural analysis of open-cell AlSi7Mg foam panels bended by laser forming is presented.

2. LASER FORMING CHARACTERIZATION

The laser bending process requires shallow depth of phase change at the surface. From the heating point of view, the radiated surface undergoes solid heating and melting following the rapid solidification for the forming process. The high cooling rates which resulted during the solidification of the melted regions causes attainment of high temperature gradients across the radiated zone while increasing the thermal strain in this region [2]. The residual stress generated could be compressive or tensile and so the bending of the irradiated substrate takes place towards or opposite to the radiated surface of the part.

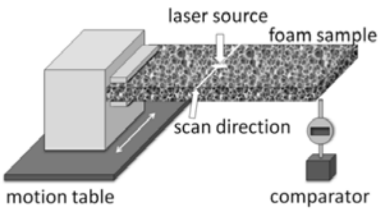

Fig. 2. *Laser bending process [3]*

The most important physical mechanisms responsible for laser forming are: the temperature gradient mechanism, the buckling mechanism, and the upsetting mechanism [3]. Some of these mechanisms can act together, or switch from one mechanism to another.

The temperature gradient mechanism [4] is present when the spot diameter is on the order of the sheet metal thickness. The temperature gradient produces a non-uniform thermal expansion through the thickness [5]. The constraining effect of the non-heated surrounding material determines the presence of an elastic stress. At high temperatures the material yield stress decreases and the pure elastic strains are converted into plastic ones. During cooling, the difference in thermal contraction between the upper and lower sheet layers generates a bending angle toward the laser beam source [6].

The buckling mechanism [7] appears when the laser beam diameter is much larger than the sheet thickness. The diameter of the heated area is ten times the sheet thickness. There is no steep temperature gradient through the sheet thickness. Due to heating, thermal compressive stresses develop in the sheet which results in a large amount of thermo-elastic strain which in turn results in local thermo-elasto-plastic buckling of the material. The part can be made to bend in either the positive or the negative directions depending on a number of factors including the process parameters, the sheet bending orientation, the existing residual stresses.

The upsetting mechanism [8, 9] is present when the dimension of the heated area is much smaller compared to the sheet thickness. Due to nearly homogeneous heating of the sheet and the restrictions in thermal expansion from the surrounding material, the sheet is compressed with an almost constant strain along the thickness, causing a shortening of the sheet and an increase in thickness. With the upsetting mechanism the thickness of the work piece at the area irradiated by the laser beam can only thicken.

3. EXPERIMENTAL WORK

For laser forming, a 1.5 kW CW mode diode laser with 940 nm wavelength and an early rectangular spot (Rofin-Sinar, DL 015) was used. The spot was 3.8 mm in length and 1.2 mm in width.

Open-cell AlSi7Mg foam panels (by m-pore GmbH) with different pore size were used in the experiments. Rectangular specimens were cut from panels with the size of 100×35×10 mm^3. Figure 3 shows the structure of the acquired foam panels: the panel on the left (namely "low density" foam) had an apparent density of 0.21g/cm^3; the panel on the right (namely "high density" foam) had an apparent density of 0.25g/cm^3 [3]. The measured average dimensions of the pores are presented in next section.

Fig. 3. *Foam panels*

The metal foam structure consists of ligaments forming a network of interconnected dodecahedral cells [3]. The foam structure is not rigorously homogeneous in terms of cell structure and several cells with different size or number of ligaments can be observed see also next section.

For bending tests, the foam sample was fixed on a CNC motion table and the laser beam was focused on the upper side of the specimen. The specimens were laser scanned by moving them in a single direction under the motionless laser source. Each laser scan was 10 mm longer than the specimen width to avoid the ramp effect at laser turn-on. During laser scanning, a flow of protective gas (nitrogen) was provided on the processed zone [3].

The laser power was of 100 W and three scan velocities values (4, 6, and 8 mm/s) were applied. Each specimen was bent with a sum of 150 laser passes which were divided in sets of 10 consecutive passes. After each set, the specimen was cooled in air for 2 min. At the end of the test, the bending angle was measured and the laser bent samples were prepared for the microstructural analysis.

4. RESULTS AND DISCUSSIONS

Figure 4 presents results of the laser bending samples in terms of bending angle as a function of the laser speed (scan velocity) for both foams.

By increasing the scan velocity, the bending angle will decrease. At small scan velocities, the heat penetrates into the specimen more deeply, so the thermal induced stresses are higher, which increases the amount of the laser processed material and finally increases the bending angle.

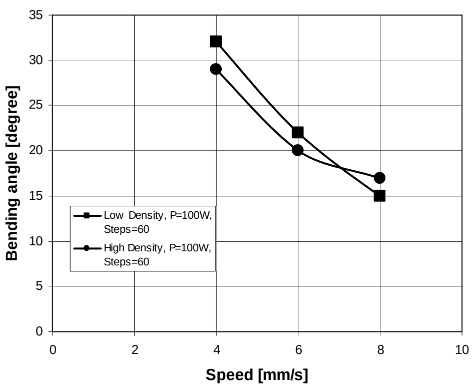

Fig. 4. *Laser bending angle as function of the laser speed*

Also, at the same laser power and scan velocity, higher bending angles were obtained for the low density foam. Due to the higher porosity of the low density foam, the laser deeply penetrates into the specimen, increasing the amount of the laser processed material and finally increasing the bending angle.

Figures 5 and 6 present images of the bent foams.

Fig. 5. *Laser bent foams of lower density*

The heat affected zone (HAZ) is present at all samples and is more visible at samples of high density.

Fig. 6. *Laser bent foams of higher density*

Using the EDX method, a chemical composition analysis was performed. One of the results is presented in Figure 7.

The EDX qualitative analysis identified the components Al, Si, Mg traces and oxide compounds of these elements mainly in the inner zone where the action of the laser was present.

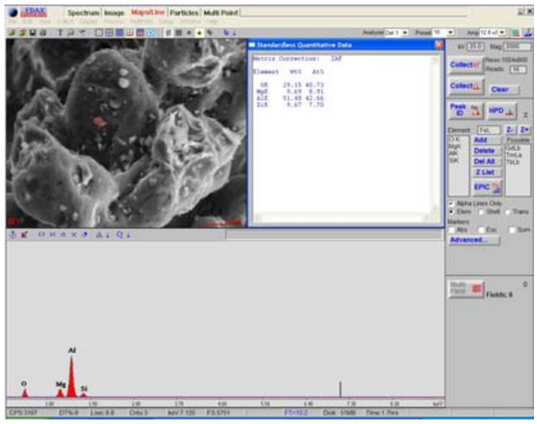

Fig. 7. *EDX analysis of a high density foam sample, 8 mm/s scan velocity (interior zone)*

A microstructural analysis was performed to evaluate the effect of the laser processing on the foams structure. For this, a Quanta 200 (FEI, Olanda) SEM was used, with a accelerating voltage of 25 kV (figure 8).

Fig. 8. *SEM Quanta 200*

The specimens were analysed in three zones: 1-exterior (E), 2-middle (M) and 3-interior (I), in the bent regions (figure 9).

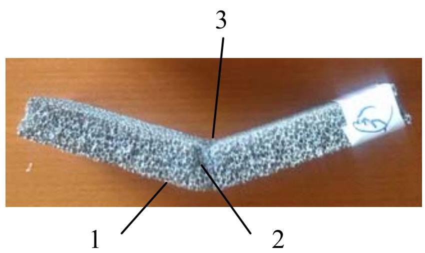

Fig. 9. *Investigation zones in the bent foam*

From the SEM analysis, as it was presented in [3], the melting occurrence was so limited as not to affect the bending efficiency. The analysis shows a disordered microstructure with a wide dispersion of cell size and shape (figures 10 and 11). In the cell walls crack or holes are present.

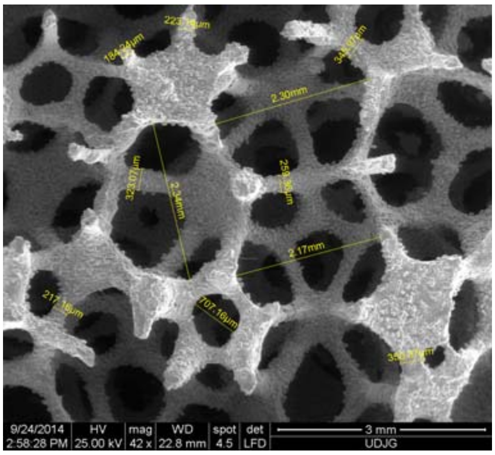

Fig. 10. *SEM images of Al foams of lower density, laser bent with velocity of 8 mm/s*

Table 1 presents the pore dimension and the average thickness of the cell walls, on the interior part of the samples.

Table 1. *Characteristics of the foam structure on the interior part of samples*

AlSi7Mg Foam	Low-density (interior zone)		High-density (interior zone)		
Scan velocity (mm/s)	6	8	4	6	8
Average pore diameter (mm)	-	1.012	0.767	0.787	0.679
The average thickness of the cell walls (μm)	209.45	176.41	198.64	150.93	255.11

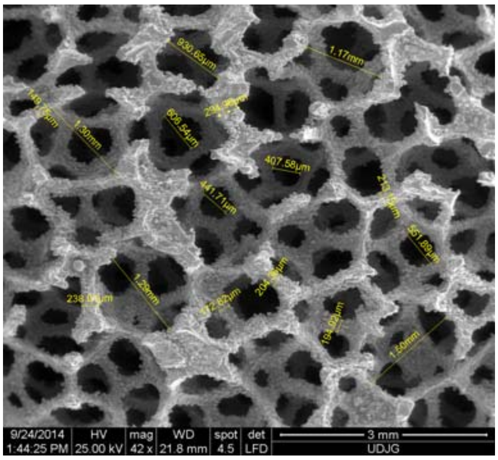

Fig. 11. *SEM images of Al foams of higher density, laser bent with velocitiy 8 mm/s*

In the exterior region of the samples the laser action does not exist. The foams have a typical eutectic structure of the aluminium alloy, characterized by a coarse grain size probably due to the foam production. In the middle, the structure is the same as in the exterior part. In the interior region of the samples, where the laser acts, the structure is modified and contains fine and homogeneous eutectic phase because of the fast cooling after laser heating.

5. CONCLUSIONS

The paper presents the particularities of the diode laser forming applied to aluminium foams using as analysis criterion the microstructure of deformed samples.

The laser affects mainly the microstructure of the material directly exposed to the laser source, interior region, without affecting the bending capacity of the foam material. The initial microstructure contains cells with different size and shape and the cell structure displays many imperfections. After laser bending, the microstructure in the exterior and interior regions remains the same.

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