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Original Article

Non-contact sheet forming using lasers applied to a high strength aluminum alloy

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ABSTRACT

Laser beam forming (LBF) is a contactless mechanical process accomplished by the introduction of thermal stresses on the surface of a material using a laser in order to induce plastic deformation. In this work, LBF was performed on 1.6 mm thick sheets of a high strength aluminum alloy, AA6013-T4 class by using a defocused continuous Yb-fiber laser beam of 0.6 mm in diameter on the sheet top surface. The laser power and process speed were varied from 200 W to 2000 W and from 3 to 30 mm/s, respectively. For these experimental conditions, the bending angle of the sheet ranged from 0.1° to 2.5° per run. In the highest bending angle condition, 1000 W and 30 mm/s, the depth of remelted pool was 0.6 mm and the microstructure near the plate bottom surface remained unaltered. For the whole set of experimental conditions, the hardness remained constant at approximately 100 HV, which is similar to the base material. In order to verify the applicability of the method, some previously T-welded sheets were straightened. The method was efficient in correcting the distortion of the sheets with a bending angle up to 5°.

1. Introduction

Due to the high level of automation and the process speed, laser beam welding (LBW) has been used by the general industry. Another advantage of LBW is the low heat input, which results in a small heat-affected zone and reduced distortion of the welded assemblies. Typically, the distortion of the metal sheet in keyhole welding is much smaller than in arc welding, even with high thickness sheets as those observed in the shipbuilding industry [1].

It has been observed that conduction welds carried out using low laser beam intensities produces an effect of permanent deformation of the sheets. The phenomenon involved is usually called temperature gradient mechanism (TGM) [2], which is shown schematically in Fig. 1 [3]. Moving a defocused

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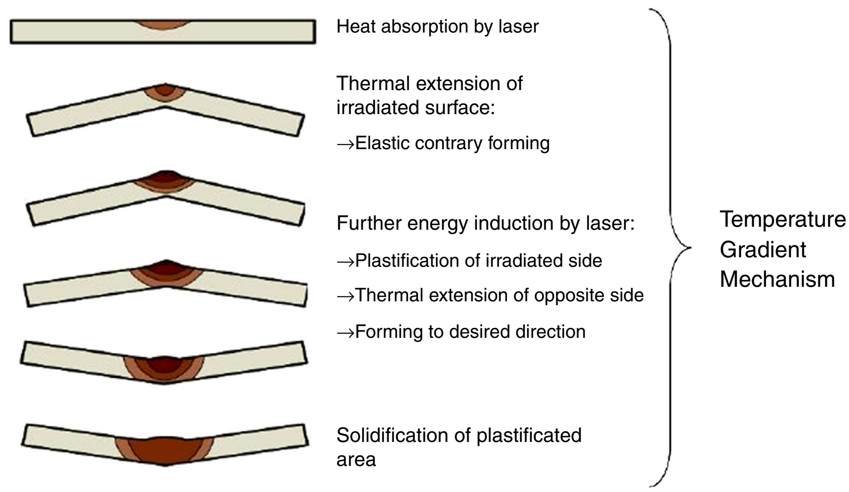

Fig. 1 – The bending mechanisms of a metal sheet according to MGT [3].

laser beam over the metal sheet surface generates a steep thermal gradient between the surface exposed to the laser and the lower surface. At the beginning of the process, when the plate is being heated, the central part of the sheet near the laser beam moving line is "raised", leading to a bending in the direction opposite to the surface normal. This folding is limited by the appearance of the liquid, which does not offer more tensile force on the sheet. When the beam has passed through the solidification point on the sheet surface, two phenomena occur: (a) cooling contraction and (b) compressive shrinkage forces. The end result is a V-shaped bend with a thin line mark on the surface of the sheets [4].

The process is relevant for ductile materials like steels [5], aluminum [6] and titanium [6] and is proven to be feasible on a laboratory scale for the forming of composite laminates such as glass-fiber aluminum [7].

A particularly interesting feature of the laser forming process is the possibility to combine it with conventional laser welding. For example, an aircraft panel can be formed at a given angle by the small residual heat of the welding process, directly producing the necessary curvature [8]. Alternatively, one can use a defocused laser beam to produce the required curvature, after the welding process [9].

Watkins et al. [6] found that the bending angle of an AA2024 aluminum sheet with 0.8 mm thickness was between 0.3° and 6° per scan using a CO_2 laser. The authors used a laser power ranging from 250 to 1300 W and a speed between 10 and 140 mm/s for a beam diameter of 10 mm, and applied graphite to the surface of the aluminum to increase the absorptivity. The authors also noted the possibility of increasing the bending angle by increasing the number of the laser runs over the same track. Edwardson et al. [10] showed that increasing the number of runs to increase the angle reaches limit efficiency due to the loss of the absorber layer, the local deformation hardening, and loss of the initial geometry of the part, blocking the action of the laser.

The modeling of laser forming process is quite complex, having been initially performed by the finite element method by Ji and Wu [11]. Vollertsen and Shen [12] conducted a review of the laser beam forming from the point of view of analytical and numerical methods and empirical observations. The use of modern computational tools, such as the finite element analysis software Sysweld® [13], allows estimating the temperatures, stresses and deformations that the material undergoes during the LBF process. This software was used in this work.

The purpose of this work is to study the laser beam forming process using a laser fiber without the need for an absorbing layer. This laser allows joint welding operations and forming of the welded panels such as those used in a commercial aircraft. Thus, the step of forming the panels before welding, which causes problems in setup and delay the work of welding robots, could be eliminated. The choice of an Al–Mg–Mn–Si–Cu–Fe alloy, AA6013 under T4 condition, reflects the future demands of aerospace and general transportation sectors. Finally, the usefulness of the technique was tested by using LBF to straighten a T-joint laser welded panel.

2. Materials and methods

The material used was a grade AA6013 alloy (Al–0.94Mg–0.27Mn–0.62Si–0.82Cu–0.20Fe, wt.%) aged at ambient temperature (T4) in the form of sheets with 1.6 mm thickness. The coupons dimensions were 100 mm (L) × 50 mm (W). Firstly, the samples were used as flat sheets and then T-joint laser welds were performed to test the efficiency of the process. Some selected thermal and mechanical properties of the aluminum sheet are summarized in Table 1 [13]. In the table, K is the thermal conductivity, Cp is the specific heat, α is the thermal expansion coefficient, E is the Young's modulus and σ_y is the yield strength. The number between parentheses refers to the T4 aluminum condition (1) and the as-welded (2) condition. LS means liquid state, where mechanical strength does not apply – N/A.

The laser was an Yb-fiber laser, model YLR-2000 of IPG Photonics, with maximum power of 2 kW. The minimum beam diameter was 0.1 mm, which corresponds to the diameter of the optical fiber itself. The material displacement was performed by a three-axis CNC table, and a vertical Z axis focused