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Hot cracking in Al–Mg–Si alloy laser welding – operating parameters and their effects

E. Cicală[a], G. Duffet[b,*], H. Andrzejewski[b], D. Grevey[b], S. Ignat[a,b]

[a] *Polytechnic University, Mechanical Faculty, 1 blv. Mihai Viteazu, 300222 Timisoara, Romania*
[b] *Université de Bourgogne, Laboratoire Laser et Traitements des Materiaux (LTm), 12 rue de la Fonderie, 71200 Le Creusot, France*

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Abstract

Hot cracking is a phenomenon that frequently occurs in the laser welding of some "special" alloys, such as the aluminium–magnesium–silicon type. Each occurrence of this phenomenon needs to be studied in itself, taking into account not only the individual, but also the interactive, influences of the various parameters. The advantage of using laser beams in welding processes lies in the speeds that can be reached. The disadvantage, however, is that, owing to the high cooling rates characteristic of the interaction between the laser beam and the material, the welding speed itself becomes a cause of hot cracking. The aim of this paper is to see how this disadvantage may be eliminated. We consider what the most important parameters may be, relating to tensile strength and the quantity of cracks produced, that might influence the presence or absence of hot cracking. The most influential factors in avoiding hot cracking are the welding speed and wire parameters. Also important is welding stability, as instability generates cracks. We can then determine a technological window, useful for industrial applications, which takes into account the values of these influential factors and stability.

Keywords: Laser welding; Aluminium welding; Hot cracking

1. Introduction

Owing to their low density and good mechanical properties, aluminium alloys are increasingly employed in many important manufacturing areas, such as the automobile industry, aeronautics and the military. Using aluminium alloys implies the development of assembly processes, especially in welding, where conventional techniques have shown their limitations. Laser welding, therefore, has progressively attracted the attention of scientists during the last decade [1,2].

In the laser welding of some aluminium alloys, many types of defects have been revealed, such as porosity, cavities and hot cracking [3,4].

Hot cracking is a defect manifesting itself as a surface crack during the solidification of a metallic alloy. Metallic alloys do not have a good deforming capacity during the solidification stage of a calorific process, and hot cracking takes place during the final stage of solidification [5,6], when the alloy is semi-solid. This cracking phenomenon occurs at a high percentage rate (85–95%).

In the case of aluminium alloys, the cracks that appear during welding are produced by the direct interaction of many factors [7,8], such as: solidification shrinking and thermal tensions, which generate tensions and deformations; wide range of solidification; temperature and time-cycle of solidification speed; chemical composition of the alloy (a hot cracking domain) (Fig. 1) [9]); fastening system of the welding components, which can limit contraction.

Current techniques for reducing hot cracking in the laser welding of aluminium alloys usually relate to the above factors [10–15].

In a recent review, Eskin et al. [16] presented results from the last 50 years on hot tearing of aluminium alloys. They conclude that a generic quantitative criterion that will predict hot cracking under varying conditions is still not available.

* Corresponding author. Tel.: +33 3 85 42 43 17; fax: +33 3 85 42 43 29.
E-mail address: g.duffet@u-bourgogne.fr (G. Duffet).

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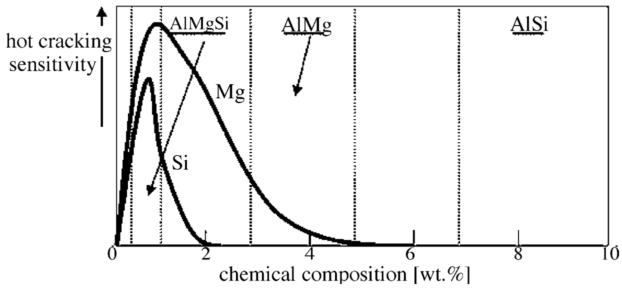

Fig. 1. Hot cracking sensitivity of aluminium alloys dependent on the Si and Mg content.

So, knowledge of the influence of the operating parameters on hot cracking during laser welding is an important step in establishing a criterion for prediction.

The method most often employed to prevent the phenomenon of hot cracking consists in chemical modifications to the molten pool. Some alloys have a chemical composition within the range that presents a high risk of cracking [17].

To reduce this risk, wires having adequate alloying elements are added during the welding process. Nevertheless, welding may still be made difficult, or even impossible, unless a good correlation is achieved between the welding parameters [18,19]. The optimum correlation is hard to find, as the optimum zone, that is to say, the one in which no cracks are present, is very narrow [6].

Initially, butt-welding of plates was carried out, so that the operating parameters that influence hot cracking could be placed in order of importance. This process is fully described in this paper. Later, T-joint welding was carried out using two laser heads. The results of this process will be presented in a future paper.

2. Experimental strategy

To clarify the phenomenon under review, any general approach should be designed with the aim of establishing from the outset the appropriate response functions and contributory factors. In our case, the “product”, that is, the final result of welding is the weld, which is the direct result of the solidification of the molten pool (Fig. 2). The characteristics of the weld can be appreciated from different points of view: technological, aesthetic, economic, etc. As for laser welding, the factors influencing the response functions that characterise the weld can be put into two categories, namely, phenomenological factors and operating factors (Fig. 2).

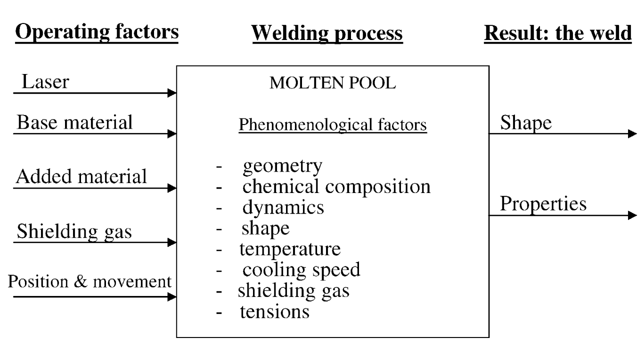

Fig. 2. Functional design of laser welding processes.

The phenomenological factors relating to the molten pool are: size, solidification speed, chemical composition, external tensions, gas shielding system, dynamics.

The operating factors are: welding speed, laser power, nature of the shielding gas, focal point position, gap, gas flow.

The operating factors are the welding setup parameters. Their values and interactions induce the phenomenological factors, which can be considered, in this context, as intermediate response functions (Fig. 2). From that, the phenomenological factors give the final result, namely, the weld. In order to control any phenomenon relating to laser welding and, in particular, hot cracking of aluminium alloys, the influence of the phenomenological factors needs to be understood.

Among the operating factors influencing the shape and properties of the molten pool, and, consequently, the properties of the weld, we can identify absolute factors and relative factors. The absolute factors relate to the following:

– The laser beam: its wavelength, power, power distribution, operating mode, spot size.
– The welded materials: their chemical composition, properties, microstructure, geometry.
– The shielding gas: its composition, flow rate, flow configuration.
– The added material: its chemical composition, properties, geometry, shape.

The relative factors are the following:

– The position of the laser beam relative to the welded materials, to the shielding gas stream and to the added material.
– The angle and distance relative to the welded materials.
– The movement between the laser beam and weld material (welding speed).
– The movement between the added material and the laser beam (feed rate of added material).

We must emphasize here that, as in all phenomena relating to laser welding, and in particular the phenomenon of hot cracking, there are many parameters that also present internal interactions.

When the parameters do not have precise levels, which are generally numerical, that will be a general example of the problem under review. When they have precise values and, consequently, an experiment takes place that will be an example of a particular case of the general problem. For every experiment, a value from the response area is obtained, which is specific to the studied phenomenon. In other words, the general case can be solved using experimental methods and data processing, usually based on statistical methods [20]. Therefore, using as parameters the influences on the phenomenon of hot cracking in the laser welding of aluminium alloys, a