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Control of aluminium laser welding conditions with the help of numerical modelling

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ABSTRACT

Numerical modelling of laser welding in both conduction and keyhole modes is studied to highlight the influence of the main welding parameters on assembly performance.

Numerical simulation enables the thermal history of assembly weld joints to be described. A hot cracking criterion is proposed. The model predicts that (1) a deviation in the localization of the shielding gas does not affect instability and that (2) fluctuations of the absorbed laser beam power generate cooling speed deviations. The results also demonstrate that laser welding in keyhole mode, when compared to laser welding in conduction mode, is more likely to induce higher cooling speeds, greater risks of hot cracking but better sensitivity to post weld age hardening heat treatment.

1. Introduction

Laser welding has been widely used for several decades, particularly for the assembly of aluminium structures and has brought about technical developments in the aeronautical industry.

As for electron beams, the resulting weld bead can be very narrow, even for thick parts thanks to the formation of a keyhole as studied by Lee et al. (2002). According to this mode of welding, the so-called keyhole mode, the main difficulty is related to the stability of the welding conditions. Indeed, any instability of the narrow and deep keyhole geometry is likely to induce unacceptable porosity as specified by Tsushima et al. (2005).

Overcoming this difficulty can be achieved if the laser beam crosses the whole thickness which is impossible in very thick parts and it entails a significant waste of power. Otherwise, a slight defocusing of the laser beam prevents the formation of a deep keyhole. By contrast, the welding mode called the conduction mode (i) cannot be used for thick parts, (ii) as it leads to an extension in width on the weld bead, and (iii) induces other kinds of instability and wastes power as observed by Pastor et al. (1999).

Furthermore, depending on the welding mode used, the melting zone volume and the amount of metal filler to be incorporated are different, as illustrated in Fig. 1. Consequently, the composition of the melting zone is more or less likely to induce hot cracking and is more or less sensitive to additional heat treatment. Prinz et al. (2004) showed that the static and dynamic properties of welded joints can be improved by post heat treatment. Malarvizhi et al. (2008) found that post weld treatments are beneficial for improving the fatigue performance of welded joints. In addition, the welding speeds are not the same for the two welding modes, which means that the temperature distribution is also different; this gives rise to more or less significant heat gradients resulting in different levels of thermally induced residual stress as studied by Danis et al. (2010). All these differences in welding conditions are often considered in the literature through contributions focused on specific aspects related to either the interaction between the laser beam and the welded alloy or the influence of the filler on the mechanical performance of assemblies. Eibl et al. (2003) studied the effect of different filler material on the fatigue strength of welded joints. Braun (2006) has selected the most suitable filler metal to optimize the tensile properties of joints.

The present contribution aims to highlight the link between all the various parameters of laser welding with the help of numerical modelling and various partial experimental studies devoted to either the identification of the characteristics of the physical phenomena involved in the modelling or the validation of the

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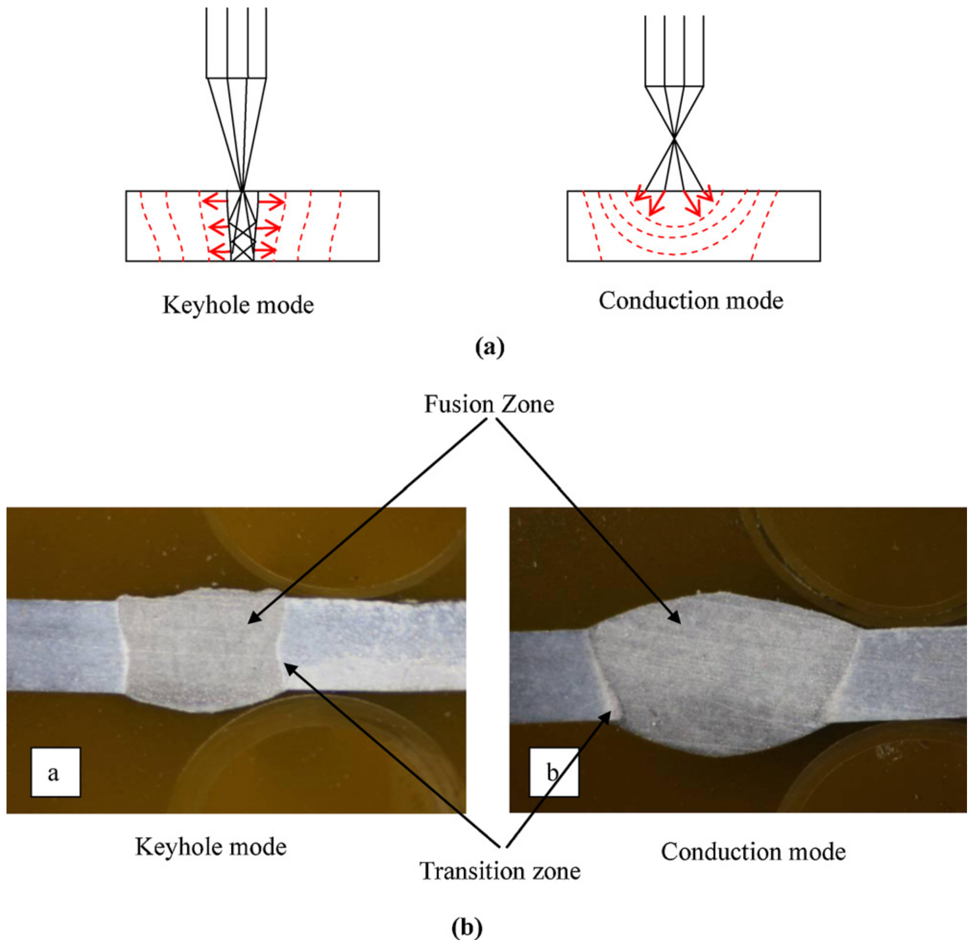

Fig. 1. Keyhole and conduction modes of laser welding. (a) Schematics of isotherms and (b) bead section micrographs.

numerical simulation. Thus, parameters such as the proportion of laser power effectively absorbed by the assembly, the effect of the protective gas, the thermal conductivity of liquid and solid aluminium, the welding and filler speeds, the compositions of the base alloy and metal filler as well as the assembly size and the conditions of restraint were taken into account to show the influence of the processing conditions on the occurrence of defects such as hot cracking or insufficient resistance and ductility of assemblies.

2. Numerical modelling

2.1. Representation of the welding conditions

The laser welding equipment involved in the present study was a 3 kW Nd-YAG continuous wave laser with a 0.45 mm spot diameter, the fibre of which is directed to the top surface of the work piece vertically. The rectitude of the beam, that is to say, the parallelism of the laser beam is characterized as proposed by Okon et al. (2002) by a quality factor M given by:

$$M^2 = \frac{\pi D r_0}{2F\lambda} \quad (1)$$

where D is the diameter of the non focused beam at the lens, F is the lens focal distance, λ is the laser beam wave length and r_0 is the radius of the beam when it is focused.

However, the laser beam was considered as cylindrical for the modelling but the defect of rectitude was taken into account in the modelling through the actual laser spot radius which is dependent on M as specified by Okon et al. (2002):

$$r_i = r_0\left(1 + \frac{\lambda z M}{\pi r_0^2}\right) \quad (2)$$

where z is the distance from the welded plate surface.

The amount of energy Q brought to the work piece through the conduction mode was approached by the following commonly equation used by Zhao and Debroy (2001):

$$Q = \frac{2\eta P}{\pi r_l^2} e^{(-2((x^2+y^2)/\pi r_l^2))} \quad (3)$$

where P is the laser power, η is an efficiency factor, and x, y are the coordinates from the centre of the laser spot perpendicular to the weld line and in the direction of the weld line respectively.

For the keyhole mode, Cho and Na (2006) have represented the amount of energy by:

$$Q = \frac{2\eta P}{\pi r_l h} e^{(-2((x^2+y^2)/\pi r_l^2))} \quad (4)$$

where h is the welded plate thickness.

The main parameter which remains unknown in the previous equations is the efficiency factor η the identification of which will be considered later.

The protection of the work piece against oxidation and the control of the plasma formed by the laser/matter interaction was ensured by a flow of helium which created an 30° angle with the work piece surface, in front of the advancing laser beam and the flow q of which is about 20 l/min. The related cooling effect on