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NDT&E International 39 (2006) 272–276

NDT&E international

www.elsevier.com/locate/ndteint

Temperature control in laser brazing of a steel/aluminium assembly using thermographic measurements

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Received 1 April 2005; revised 12 April 2005; accepted 17 August 2005
Available online 27 September 2005

Abstract

One way of making car bodies lighter is to introduce some aluminium parts in place of steel. Steel and aluminium can be joined by laser braze welding. As in other types of thermal joining, inter-metallic phases may weaken the joint. In laser braze welding, these appear as a thin layer of brittle compounds at the steel/seam interface. Their formation is related to temperature. It has been shown that, if the layer is less than 10 μm thick, the joint is not compromised [Kreimeyer M., Sepold G. Laser steel joined aluminium-Hybrid structures, Proceedings of ICALEO'02, Jacksonville, USA; 2002]. Not only can temperature gradient be calculated by numerical simulation, but it is also possible to measure the surface temperature by thermography. We show here how thermography may be used to control temperature during laser braze welding.

Keywords: Laser welding; Laser brazing; Thermography; Process control; Thermal modelling

1. Introduction

Laws to reduce pollution and save energy will require lower overall fuel consumption. Other things being equal, the lighter a car is the less fuel it uses. One way to make car bodies lighter would be to introduce some aluminium parts [9,10]. For both mechanical and economic reasons, it can be advantageous to use mixed structures, which may be joined by brazing or by soldering [3]. One source of energy that can be used for joining these types of materials is the laser. Some advantages of laser processes are that they allow not only localized fusion with limitation of the 'heat affected zones' (HAZ), but also the possibility of automation and perfect control of the quality of the joints [11,1,2].

The problem to resolve in joining aluminium to steel is the formation of brittle phases at the steel/seam interface. Kreimeyer [4] has shown that, if the layer is less than 10 μm thick, the joint will be mechanically sound. Since the formation of these phases is related to the thermal conditions at the steel/seam interface, the process could be optimized if the temperature were known. In laser processes, however, surface temperature measurements are difficult to make. Not only are temporal temperature gradients significant, but spatial ones as well. The temporal temperature gradient can be of the order of twenty thousand degrees per second (20,000 °C/s), and the spatial gradient of the order of one thousand degrees per millimetre (1000 °C/mm). These factors, therefore, preclude measurements involving contact. Thermography, then, is the only way to control the surface temperature of the assembly during laser processing. The infrared signal cannot be converted into a temperature, however, unless the emissivity of the viewed surface is also known. Unfortunately, that is the most difficult parameter to ascertain, depending as it does on many others, such as temperature, wavelength, and condition of the surface [5]. If the various influences are taken carefully into account, infrared thermography may be used as a surface temperature-mapping device. We have found only a few papers on thermographic control of laser processing. For instance, Brüggemann et al. have used thermography to record the temperature field in the laser welding of steel and of aluminium alloy [1]. There, a measured surface temperature field is used to determine the dimensions of the melt pool and the cooling down time, from 850 to 500 °C, (called t8/5), which has an essential influence on the properties of the weld. Our intention is quite different from that: it is to access, from a surface temperature field measurement, the temperature field inside

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doi:10.1016/j.ndteint.2005.08.005

the assembly and, particularly, at the interface. This paper presents the method for measuring, by an infrared camera, the temperatures of the surface of an assembly, comparing that with temperatures calculated by a finite element method.

2. Experimental procedure

2.1. Materials

The aluminium sheet material (thickness 1.2 mm) is a heat-treated T4 and naturally aged 6016 alloy. The other part of the assembly is a ferritic low carbon steel sheet (thickness 0.77 mm). Both sides of the steel sheet are zinc coated to a thickness of about 10 μm. This coating is obtained by hot dip galvanization.

The filler material is a zinc alloy (85% Zn, 15% Al, melting point near 430 °C). This was chosen because of the solubility of zinc and aluminium and for its low melting point. These properties are important for the quality of the joints.

2.2. Laser processing

The laser source is a continuous wave Nd: YAG from TRUMPF©(HL 3006D) pumped by lamps, with a maximum power of 3 kW.

The beam is carried to the target surface through a 600 μm diameter fibre-optic cable. The laser spot exhibits a circular shape with a near-uniform intensity profile deriving from a classical optical arrangement. A collimating lens is used together with a focusing lens of 200 mm focal length. The shielding gas, a helium-based mixture (ARCAL37©, 70% Helium, 30% Argon), is emitted from a 10 mm diameter tube with a flow rate of around 20 L/min [6,7,12]. The wire speed is the same as the work-piece feed. The diameter of the wire is 1.6 mm.

The moving of the pieces is carried out with a numerically controlled 4-axis displacement machine. The assembling configuration is an angle joint geometry (Fig. 1).

2.3. Thermographic measurements

The camera was a FLIR Thermacam S40 imaging system. It has a 240×320 pixels focal-plane-array uncooled microbolometer detector, which is sensitive within a wavelength range of 7.5–13 μm. Imaging and storage was made at a frequency rate of 60 Hz. We chose to observe a part of the steel that was not directly illuminated by the laser beam. For that, we created an aperture in the clamping device (Fig. 2).

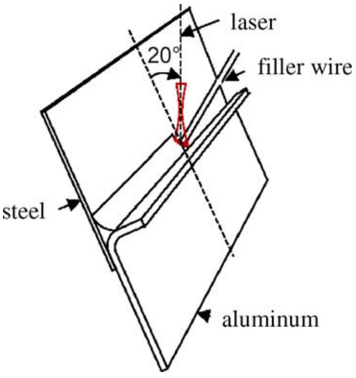

Fig. 1. Assembly configuration.

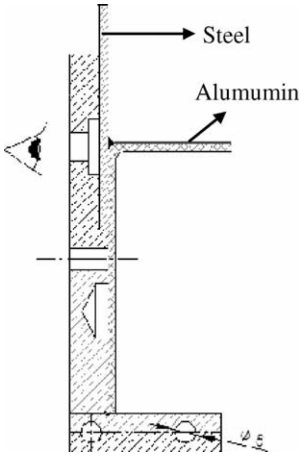

Fig. 2. Experimental set-up for temperature field measurement.

The infrared camera was fixed at the clamping device, so that it was possible to observe the effect of the passage of the laser beam on to the surface of the steel. A 100 close-up lens was used, which let us reach a spatial resolution of one hundred micrometers.

3. Thermal simulation

The aim of the numerical simulation was to obtain the thermal field around the seam/steel interface during laser irradiation.

In steel/aluminium braze welding, filler material is melted by the laser beam and wets the steel surface. The geometry of the welded joints depends on the properties of the filler material and on those of the base materials, as well as parameters such as laser power, braze welding speed and filler wire speed. Here, in order to simplify the model, we consider that the geometry of the joint is fixed before laser irradiation.

Laser irradiation is considered as a surface flux in the model. The efficiency of the interaction between laser and materials is estimated by taking into account emissivity measurements with a pyrometric device. Thus, we consider that 40% of the incident laser power is absorbed.

The distribution of energy in the molten pool is difficult to quantify, owing to convection transfer phenomena, which induce turbulent movements. To take them into account, without using the Navier–Stokes equations, we use the simple method of artificially increasing the conductivity of the molten matter.

The model is based on a finite element approach [13]. It solves the thermal equations with advection deriving from the relative speed between the laser and the piece (1). It also takes