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Residual stress field and distortions resulting from welding processes: numerical modelling using Sysweld

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Abstract

This paper concerns the study of residual stresses and distortions in fusion butt joint welding, using the computational modelling software ESI Sysweld. Thermal gradients across the part will introduce geometrical variations that cause residual stress and distortions; their study and prediction are critical to ensure a sound welding.
To foresee the welding behaviour is a complex task because there are many physical-chemical phenomena involved in the welding processes. Using Sysweld - a finite element method based software - it is possible to integrate all the physical-chemical phenomena and elaborate computational models for most welding cases.
A real case consisting of three sets of aluminium plates welded by laser will be studied in this paper. A finite element model is realized for each case and the results are analysed using Sysweld capabilities.

Keywords: Finite element method (FEM); residual stress; distortion; Sysweld; welding simulation.

1. Introduction

Welding is an effective joining process for a wide range of applications, allowing to join parts permanently in a fast and economic way and, at the same time, with adequate mechanical properties.
However, the uneven heating resulting from welding processes combined with mechanical restrictions from clamping systems leads to significant stresses in the weldment area and distortions in the work piece [1]. These distortions are interrelated to the residual stresses and occur in the presence of some kind of restraint condition. It is not possible to separate both phenomena; there is an interrelationship between them, shown in Fig. 1. Many efforts are made to predict and correct these phenomena, like varying the welding sequence and clamping conditions [3].

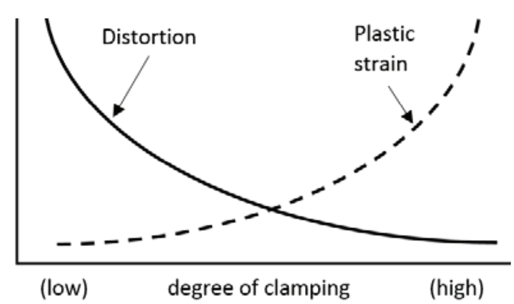

Fig. 1. Relationship between distortions and plastic strains as a function of degree of clamping. Adapted from [2].

1.1. Welding computational simulation

Computational modelling, based on finite element method theory, enables the virtual examination of the distortion and can verify the influence of the welding sequence, direction and boundary conditions effects, supporting a faster process development and improved welding parameters [3].

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Sysweld simulates the physical phenomena occurring in the welding process. The thermal analysis is based on transient thermal conduction model. The heat source is the main difference between different welding processes. Heat sources, like double ellipsoid, are typical for welding processes such electric arc, MIG and TIG. High power welding processes use beam sources, characterized by a Gaussian temperature distribution [2].
This paper presents a case study of simulation of residual stresses in a simple butt laser beam weldment, using a numerical tool dedicated to welding processes modelling.

1.2. Residual stress distribution

In a 2D planar case, the static equilibrium condition implies that the tensile residual stress area needs to be equal to the compressive residual stress area. The usual schematic diagram for butt joint residual stress distribution is presented *e.g.* by K. Masubuchi [4] and it is schematically shown in Fig. 2.

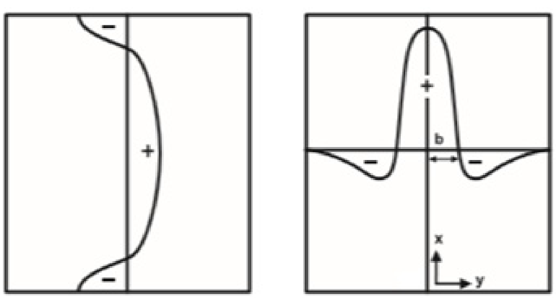

Fig. 2. Transversal residual stress (a) and longitudinal residual stress (b) [4,5].

Using simulations tools, as Sysweld, it is possible to predict residual stress field for different welding processes and for complex geometries, allowing a better decision about the best suitable process for a given purpose, as presented in the study of Zaeh and Roeren [6], comparing a Nd:YAG-laser with a high power diode laser (HPDL) for an aluminium profile welding.

2. Case Study

The numerical study is based on an experimental work of laser beam welding in thin aluminium alloy sheets, using a fiber laser Nd:YAG of 400W [7].
The sample dimensions and Al alloys used are listed in Table 1. Fig. 3 presents the samples after welding. These samples were measured and characterized to provide inputs for the computational analysis using Sysweld.

Table 1. Welded samples characteristics.

Test name	Welding type	Material	Dimensions (width x length x thickness) (mm)
Set I	Laser	AA5083	2x(20x123x1)
Set VII	Laser	AA6082	2x(20x123x1)
Set VIII	Laser	AA5083 and AA6082	(20x123x1)+(20x123x0.8)

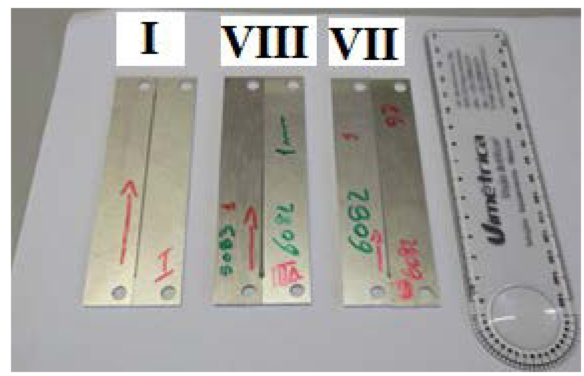

Fig. 3. Aluminium alloy welded samples.

2.1. Boundary conditions

Fig. 4 shows the welding set-up, in particular the two rectangular cross section tubes used for clamping. These tubes are of sufficient stiffness to be considered rigid.
In the finite element model, the nodes were restrained in the vertical direction due to the grip system adopted, as shown in Fig. 4. Therefore, it is assumed that the vertical movement of the plates during the process, in the grip region, can be neglected.
The contact conditions and external forces were also neglected since they originate a numerical complex problem during the transient state and their effect on the residual stress is minor. A two phase clamping condition was adopted in the simulation. The first phase considers the time during the welding process (Fig. 5) and the second phase refers to the cooling stage (Fig. 6). For each phase a time period of 30s was adopted.
The already mentioned tubes were fixed in the working table; so, the top surface clamping condition consists in two columns of nodes where all directions were fixed (Fig. 4).