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Numerical simulation of the laser welding process for the prediction of temperature distribution on welded aluminium aircraft components

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ABSTRACT

The present investigation is focused to the modelling of the temperature field in aluminium aircraft components welded by a CO_2 laser. A three-dimensional finite element model has been developed to simulate the laser welding process and predict the temperature distribution in T-joint laser welded plates with fillet material. The simulation of the laser beam welding process was performed using a nonlinear heat transfer analysis, based on a keyhole formation model analysis. The model employs the technique of element "birth and death" in order to simulate the weld fillet. Various phenomena associated with welding like temperature dependent material properties and heat losses through convection and radiation were accounted for in the model. The materials considered were 6056-T78 and 6013-T4 aluminium alloys, commonly used for aircraft components. The temperature distribution during laser welding process has been calculated numerically and validated by experimental measurements on different locations of the welded structure. The numerical results are in good agreement with the experimental measurements.

1. Introduction

Laser welding technology is used widely in many industrial fields. The process of laser welding offers a great potential for new product design [1–3]. Compared to other welding processes (arc welding, solid-state welding, induction welding, etc.) less heat is coupled into the work piece, resulting in a small heat affected zone (HAZ).

Aluminium alloys are widely used in the automotive, aerospace and other industries because of their high strength/weight ratio. A large number of aerospace components have complex shapes and are manufactured in several steps, often using fusion joining (particularly low heat input LB welding) and solid state joining operations, i.e. friction stir welding (FSW) which is widely used to join Al-alloys [4–11].

During laser welding, complicated phenomena such as temperature dependency of material properties phase transition, (i.e. melting and evaporation), laser light absorption and reflection in a plasma occur in a very short time. In deep penetration laser welding, when a laser beam with high intensity irradiates the workpiece, a keyhole is formed in the workpiece, which enables the laser beam to penetrate deeply into the workpiece; while in conductive laser welding, the laser energy is absorbed on the surface of the workpiece.

Studies on the thermal cycles and temperature distribution during welding are very important, as the thermal cycle data form the input for many other analysis like the prediction of the microstructures in weld and HAZ and susceptibility of the weld for cracking. Traditional trial and error approaches based on welding experiments have encountered many difficulties to optimise the laser welding process and avoid the crack initiation. In order to extend the industrial applications of laser welding and make the process more reliable, it is necessary to develop appropriate control techniques based mainly on numerical simulation. After the advent of high steed computers, numerical techniques like FEM have acquired importance as they have capability to model different material types, heat sources, boundary conditions and structures.

Numerical simulation of the welding process has been one of the major topics in welding research for several years as presented in [12–14]. The results of simulations can be used to explain the physical essence of some complex phenomena in the welding process explicitly and can be also used as the basis for optimising the welding parameters. Simulation of the laser welding process enables estimation of the temperature distribution during welding. In order to determine the thermal field, an accurate description of the heat source should be provided. The keyhole phenomenon is the principal contribution to the non-homogeneous heating along the thickness. In deep penetration welding the keyhole shape its nearly conic and its vertex angle decreases as keyhole depth increases.

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Several approaches to the mathematical modelling of keyhole formation in laser welding can be found in the literature. A number of researchers have developed mathematical models for the shape and location of the weld pool and the keyhole, by setting appropriate energy and pressure balances [15–19]. Other authors for similar purposes used alternative heat source approaches

A number of analytical and numerical local models of welding processes have been developed to evaluate temperature distribution during the welding process of structural components [20–27]. In the above 3D models, the investigations on aluminium alloys components are limited [28–31]. However, to the author's knowledge, no investigations about new aircraft aluminium alloys such as 6056 and 6013 have been presented until today.

In the present investigation, a local three-dimensional finite element model for the laser welding simulation, using the finite element software SYSWELD, was developed. The model considers a Gaussian distribution of heat flux using a moving heat source with a conical shape as evaluated by the keyhole formation model. A non-linear thermal analysis was performed using temperature dependent thermal material properties. The developed model has been applied on aircraft components building on 6056-T78 and 6013-T4 aluminium alloys. The applications of the model were verified with experimental investigations.

2. Investigation cases

The simulation of the laser beam welding process of a skin-clip aircraft component has been succuded in order to predict the temperature distribution during process. The F.E. results have been compared with experimental measurements presented by research centre Helmholtz-Zentrum Geesthacht (formerly GKSS Research Center) in the frame of the programme "Development of short distance WELding concepts for AIRframes" (WEL-AIR).

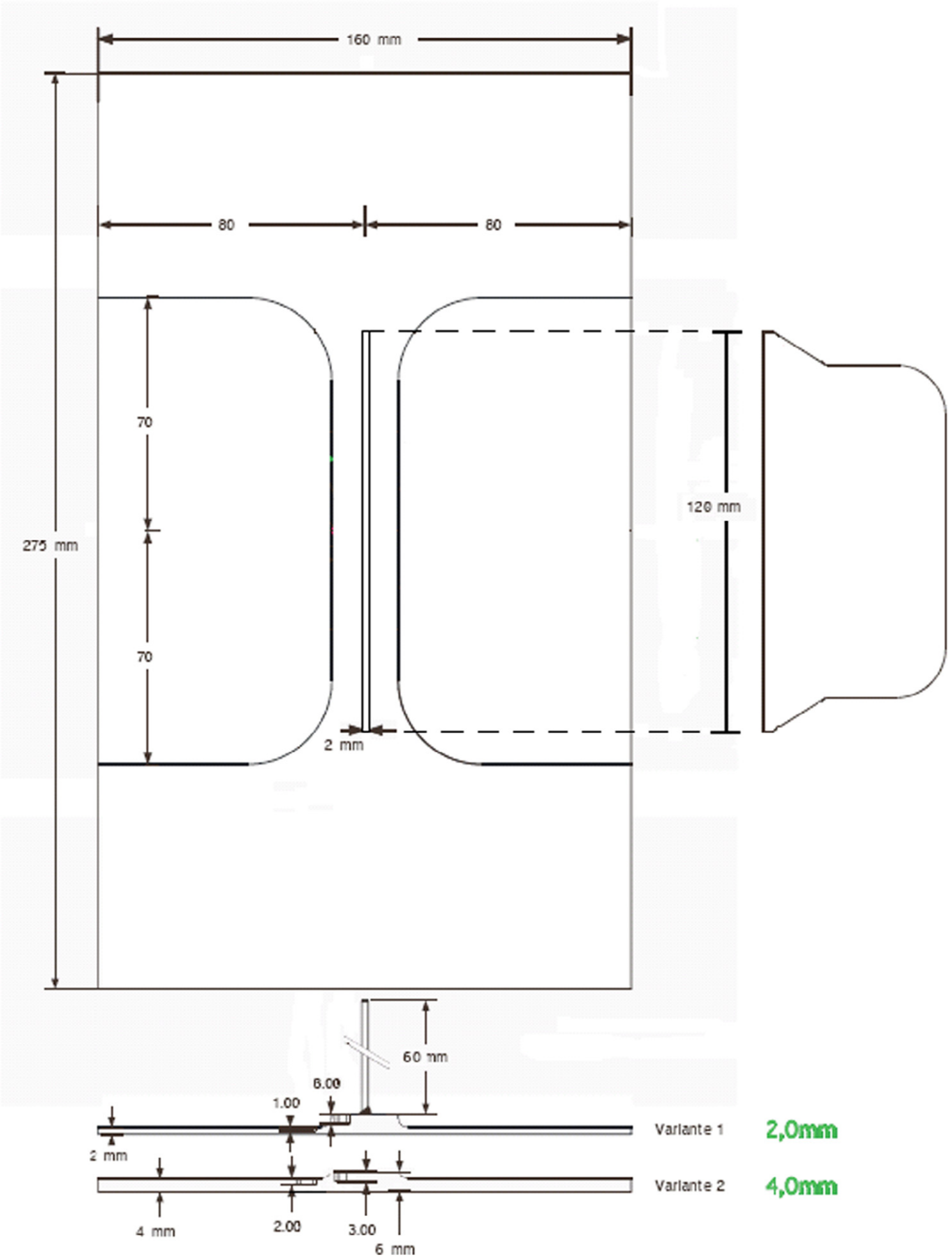

Fig. 1. Geometry of the skin-clip specimen.