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Temperature and stress field measurement at friction-stir welding of an aluminum alloy probe

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Abstract. The presented work is devoted to an experimental determination of a non-stationary temperature field during friction-stir welding using a thermo camera and thermocouples respectively. The aim of the measurements was to tune up the heat source originating from friction between the rotating tool and a stationary probe by finding appropriate parameters of an employed mathematical model. After having identified the parameters, the friction-stir welding simulation has been carried out using an aluminium alloy probe. Strain measurements at the probe selected locations were also performed during welding. The experimentally determined results have been compared with the results of the numerical simulations.

Introduction

Friction stir welding (FSW) is a relatively new joining technology which was developed and patented in 1991 by The Welding Institute (TWI), United Kingdom [1]. This is a solid-state welding process providing good quality of butt and lap joints. The FSW process has been proved to be ideal for creating high quality welds in a number of materials including those that are extremely difficult to weld by conventional fusion welding. There is the scheme of the friction-stir welding process in Fig. 1.

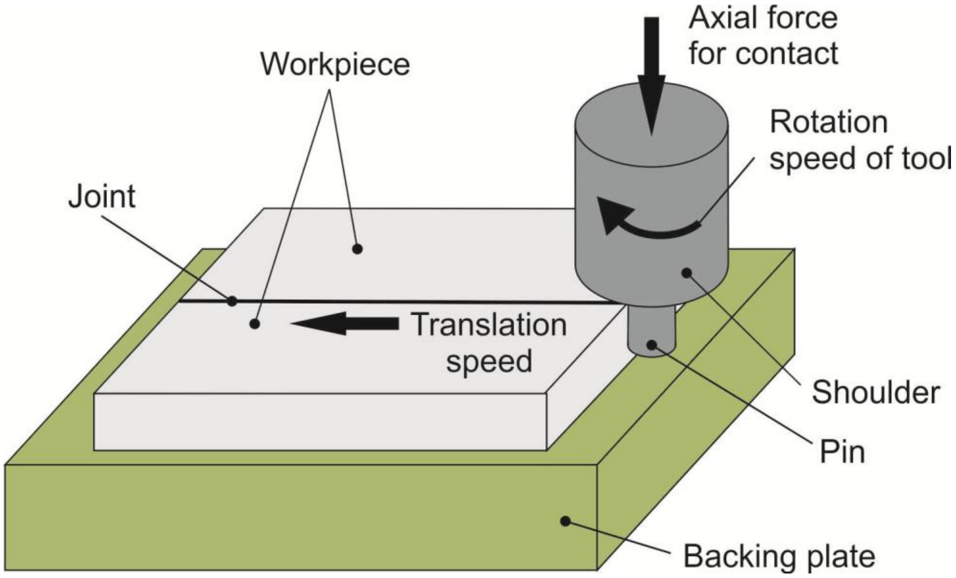

Fig. 1 Schematic diagram of FSW

The welding zone is completely isolated from the atmosphere during welding process. Advantages of this type of welding are minimized formations of voids in the welding zone, so that the welding defect and large distortion commonly associated with fusion welding are minimized or avoided. This welding technique is extensively applied to aerospace, automobile and shipbuilding industries.

Basic parameters of welding and model geometry

The intensity of the heat source during friction-stir welding is a function of several variables, the identification of which requires experimental measurements, that mostly involves non-stationary temperature field measurement at carefully chosen locations or areas of the probe. The parameters of the model are chosen in such a way that the best fit between the experimentally and the numerically determined temperature time history curves corresponding to the same location is reached. In our experiment two flat aluminium alloy AlMg4, 5Mn0,7 (EN AW 5083) plates, dimensions 125 x 300 mm were welded. The basic characteristics of the welding were: 600 rpm angular velocity of the tool, 60 mm/min velocity of the advancing tool respectively. There was a 19 W/(m.K) heat transfer coefficient considered on the upper surfaces and on the sides of the plates, while ideal contact was considered on the bottom surfaces of the plates. A few measurements have been carried out using various setups of thermocouples and tenzometers. Fig. 2 depicts the location of the thermocouples within the most appropriate setup. The initial temperature of the aluminium alloy plates was 19 °C. The plates were fixed on their sides along the direction of welding as well as in the perpendicular direction at their ends using steel plates that were screwed to the backing plate. The perpendicular plate near the beginning position of the friction-stir welding tool was not fixed. During welding the tool did the rotary movement, while the table of the friction-stir welding machine was carrying out the translational movement, where the backing plate and the welded probes were fixed. The thermo camera was also fixed to the table and was moving along with the probe.

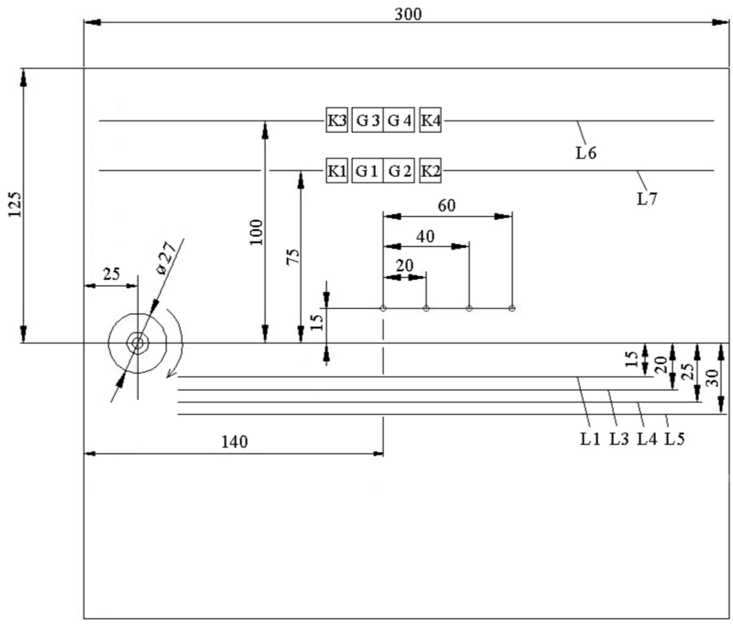

Fig. 2 The set-up of thermocouples T1 T2 T3 and T4 during welding

Temperature field and strain measurement

Some of the measurement results, such as temperature measurement at various distances from the weld are depicted in Fig. 3, at an instant when the welding tool was in the distance corresponding to time t = 200 s from the beginning of the welding. The temperature field measurement was carried out with a thermo camera, make FLIR® SC660 [4]. The surfaces of the welded plates were coated with a thin film of FLIR® SC660 paint to increase emissivity, ε = 0,96.

The disadvantage of using the thermo camera for temperature field determination is the fact that flying chips and pieces of the probe during friction-stir welding distort the image and thus decrease the accuracy of the measurement, which needs to be compensated by filtering out the corresponding data.

In the next series of experiments the temperature measurement was carried out by thermocouples T1 up to T4, the locations of which are depicted in Fig. 2. The corresponding temperature time history curves from 0 s to 500 s, including the onset of welding with no translational movement of the tool until the welding temperature is reached up to the end of the welding process and the subsequent cooling is shown in Fig. 4.

Comparing the thermo camera measurements with the measurements of the thermo couples, it can be stated that both methods produce similar results, but the advantage of the thermo camera is, that it tells us more, as its images represent the temperature field time histories over the measured area, however both methods are appropriate to tune up the heat source for numerical simulation of friction-stir welding. The animations of the temperature time history curves also show that maximum temperatures that correspond to each curve change insignificantly during the welding process.

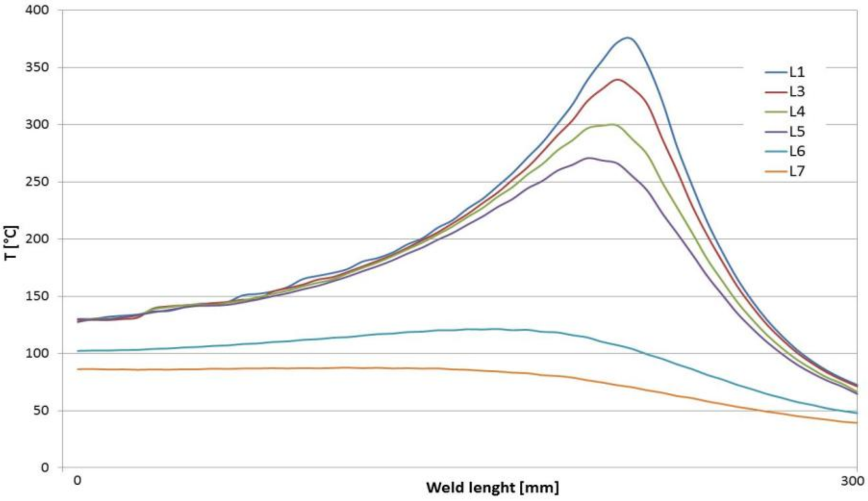

Fig. 3 Temperature time history curves determined by the thermo camera at various distances from the weld at time t = 200 s

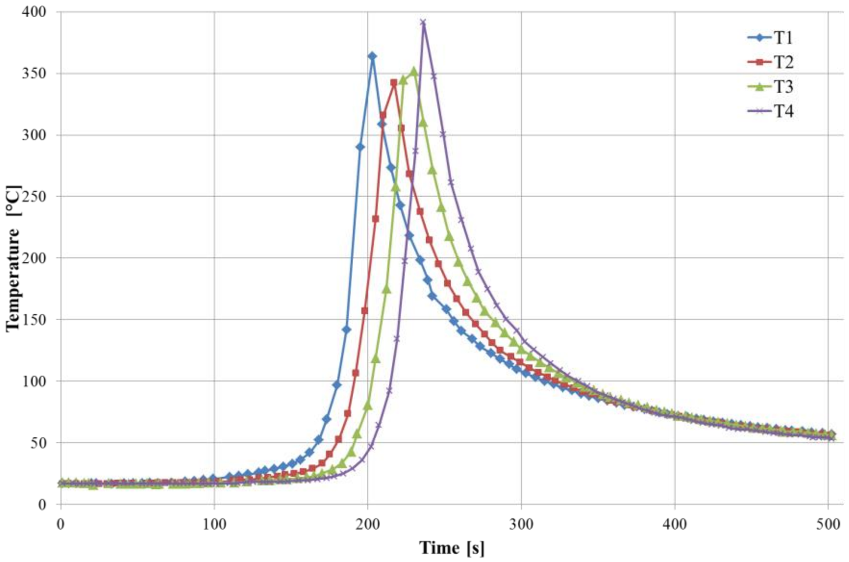

Fig. 4 Temperature time histories determined by thermocouples T1 up to T4

Tensometers, make 1-LY11-6/120 from HBM and a special glue, X 280, both capable of working at elevated temperatures were used for strain measurements. The sensors were connected into a half bridge circuit using temperature compensation [7]. Tensometers G1 and G3 measured the strains in perpendicular direction to the weld and tensometers G2 and G4 in parallel direction to the weld. Each tensometer was supplemented with a compensating one (K1 through K4), which were applied in the close vicinity of the measuring tensometer. The compensating tensometers were glued to aluminium plates, thickness 0.5 mm, which were placed near the location of the measurement, and their contact with the welded plate was improved by a thin oil film to improve heat transfer. The set-up of the tensometers is depicted in Fig. 2. The measured strain time histories are shown in Fig. 5.

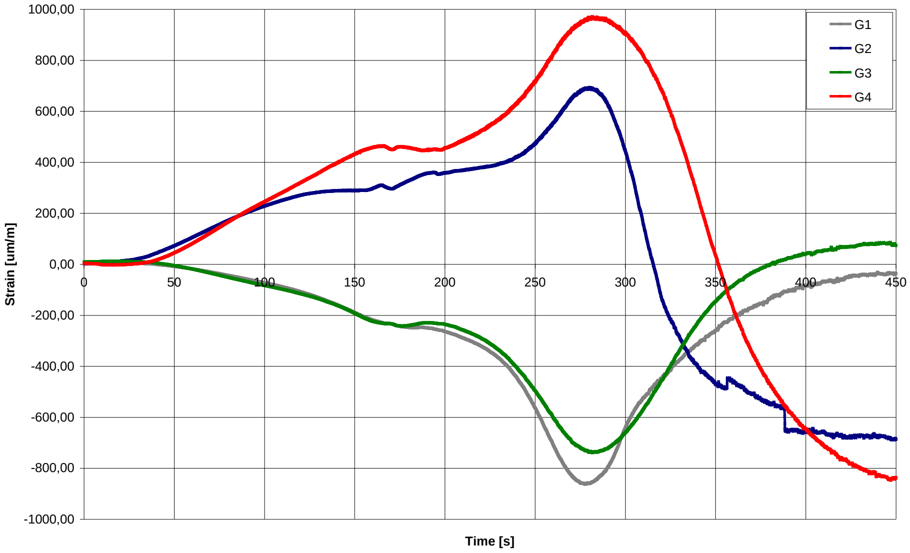

Fig. 5 Strain time histories

The strain time history curves show that in the period, approximately from 150 s through 200 s deformations of the plates took place, which might have originated from geometric imperfections of the supporting frame, allowances between the screws of the screw joints that fixed the frame, or irreversible deformations due to reaching the shear limit of the joint due to friction, etc. [2]. Such circumstances are very difficult to capture in numerical simulations, as they might necessitate to use very stiff supports to fix the probe during welding or flexible supports in combination with deformation measurements and subsequent adjustment of the stiffness of supports of the probe in numerical simulations, as far as a good agreement between experimental and numerical results is reached.

Numerical simulation of temperature and stress field

Some details of the numerical simulation of the friction-stir welding using the finite element method, such as mesh refinement have been published in [3]. Fig. 6 depicts the temperature field of the plate during welding at 1,67 mm/s welding velocity and 400 rpm of the tool using f = 0,33 friction coefficient. The lines drawn on the plate and the corresponding nodes are the ones depicted in Fig. 2.

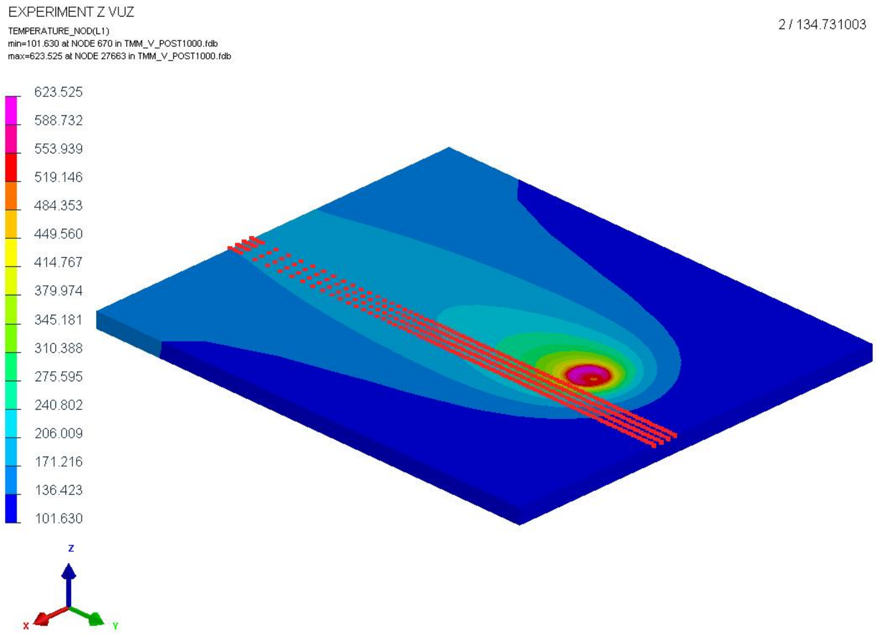

Fig. 6 Temperature field of the welded plate at time 138 s

In the Fig. 7 is depicted the temperature profiles along the lines L1, L3, L4 and L5 in Fig. 2 at time t = 138 s.

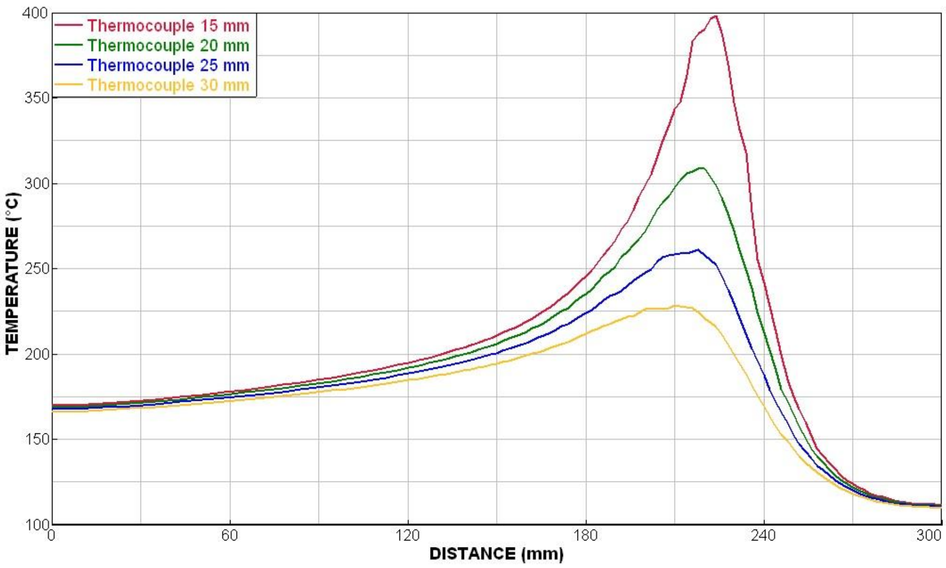

Fig. 7 Temperature profiles along the weld at various distances from its centreline

Summary

In this work we present a few experimental results on a temperature field measurement using a thermo camera and strain measurements in mutually perpendicular directions at two locations of a welded probe. The experiments have been carried out in collaboration with the Welding Research Institute in Bratislava. The results show that the temperature time history curves coming from the thermo camera allow us to determine the parameters of the heat source accurately for numerical simulation of friction-stir welding. Evaluating the results of the numerical analyses, such as deformations, strains, stresses resulted from high temperatures, temperature gradients; it will be necessary to consider the stiffnesses of the supports of the welded probe.

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