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Prediction of laser welding induced deformation in thin sheets by efficient numerical modeling

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ABSTRACT

A local solid model and a global shell model were employed for fast prediction of deformation in laser welded thin sheets based on inherent strain theory. Transient thermo-elastic-plastic analysis was performed on the local three-dimensional solid model to obtain inherent strain for the global shell model. To ensure solution accuracy, the characteristics of the laser welding heat source were considered in determination of the mesh size and time increment. The penetration shape of laser welded joint was well reproduced compared with the results by experimental observation. By applying inherent strain into shell element model, the out-of-plane welding deformation was predicted within a few minutes using elastic FEM. The predicted deformation mode and magnitude agreed with the measured ones for laser welded joints of different dimensions. By considering geometrical imperfection in the numerical model, it was reproduced that the laser welding induced deformation in thin sheets generally has the same mode as initial shape of the sheet.

1. Introduction

Engineering structures fabricated by laser welding have been increasing owing to the high energy density and lower heat input. Thin sheets such as stainless steel (Liao and Yu, 2007) can be effectively joined by laser welding. Hybrid laser-TIG welding has also been developed to weld thin sheet in the past decade (Arias et al., 2005). Compared with conventional arc welding methods, the laser welding induced deformation in thin sheets such as angular distortion is generally smaller due to the high welding speed and small fusion zone. Based on the optical characteristic of laser beam, the setup of welding pieces has high requirement in positioning accuracy. Comparing with the thick plate, the welding deformation of thin sheets has greater uncertainty. Therefore, it is very important to understand and control the welding deformation of thin sheet quantitatively for a high welding quality.

In previous works, extensive attention has been focused on the deep penetration welding for plates with more than 3 mm thickness. For instance, Mackwood and Crafer (2005) reviewed the thermal modeling with keyhole formation, and Cao et al. (2006) discussed about some important processing parameters and the effects on weld quality in laser welding of magnesium alloy. Ma et al. (2015) analyzed residual stresses in butt joints of 6 mm thick plates induced by laser-arc hybrid welding with different energy ratios. Due to the small bending stiffness, the welding deformation in thin sheets usually has quite large out-of-plane deformation compared with welded thick plate. Brockmann et al. (2003) calculated the temperature field in a thin sheet heated with laser beam, for which the Gauss function is employed to describe the power density distribution. The problem was simplified into two-dimensional by averaging temperature over plate thickness. Tsirkas et al. (2003) predicted the panel distortions generated by laser welding process using a 3D finite element model based on Sysweld. Analysis on welded specimens was carried out in a coupled transient thermo-mechanical mode. Darcourt et al. (2004) presented the finite element simulation of the laser beam welding process for aeronautical stiffened panels in aluminum alloys. Semi-coupled thermo-mechanical analyses have been performed to evaluate the distribution of welding residual stresses by MSC. Zain-ul-Abdein et al. (2009) calculated the laser beam welding induced residual stresses and distortions in small specimens made of 6056T4 aluminum alloy. The effects of thermal and mechanical boundary and loading conditions on welding distortions and stresses were investigated in their study.

It can be noted that the above simulation work about laser welding induced deformation is based on the direct thermo-mechanical

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approaches, which generally takes long computation time even for a small size specimen (Ueda et al., 2012). Because the focused laser spot size on the surface of specimen is usually less than 1 mm, a highly dense mesh should be made along the welding line to accurately model the heat source and to capture the steep temperature gradient. Accordingly, the time increment should be given a very small value to get a smooth temperature field. The determination of these parameters mainly depends on experience, simple estimation of the proper values is necessary to reduce the error and calibration time in a simulation.

In this study, an elastic FEM based on inherent strain theory was employed to predict the laser welding-induced deformation within short terms. Laser welding experiments on stainless steel SUS301 sheets were carried out under different welding speeds. Simulation of welding deformation in shell element models of several specimens was performed by elastic FEM. Firstly, a local solid model was built to conduct a 3D transient thermo-elastic-plastic analysis for each welding condition. Penetration shape calculated from numerical analysis was compared with experimental macrographs to validate the thermal model. Secondly, the inherent deformation was integrated from the residual plastic strains, and then used as the equivalent load in the elastic analysis on the models with different dimensions. The welding deformation predicted from simulation was compared quantitatively with experimental measurements. Furthermore, the effect of geometrical imperfection on final welding deformation has also been investigated by numerical simulation.

2. Experimental study

Test specimens of stainless steel SUS301 with 1.33 mm thickness were investigated in the present study. The specimens have a rectangular shape, and single pass laser welding was performed along the central line of the plate. A CO_2 laser beam with maximum power of 3000 W was used. And an inertial gas of 99.99% argon with a 25 l/min flowing rate was introduced during the laser welding processes. The dimensions and welding conditions of each specimen are summarized in Table 1. Two levels of welding speed were

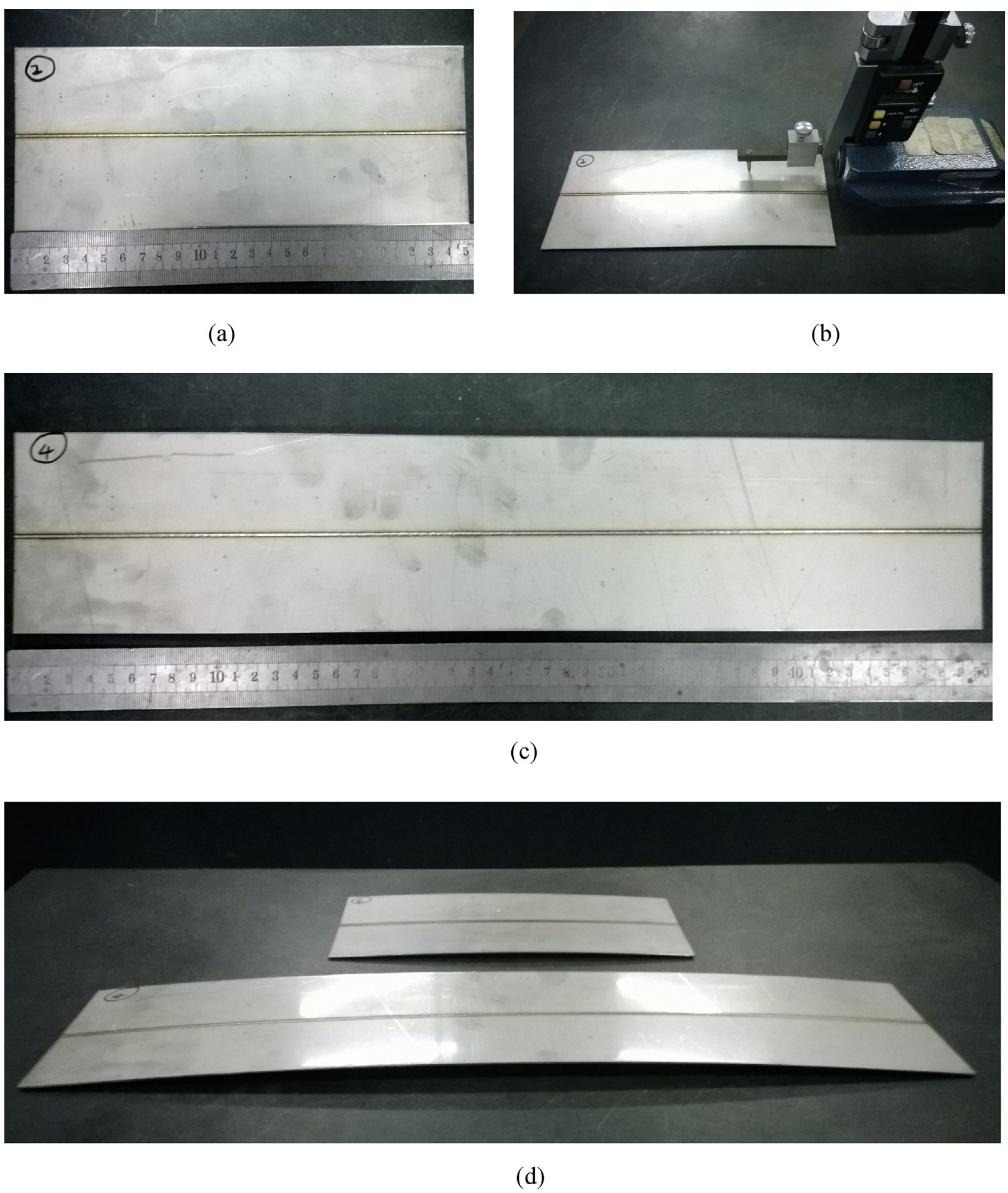

Fig. 1. Laser welded specimens: (a) Specimen-2, (b) measurement of coordinates by altimeter, (c) Specimen-4, and (d) deformation view of test specimens with different lengths.