Investigating the Bifurcation Phenomenon in Plate Welding

A look at this buckling evolution process using an integrated experimental and numerical approach

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ABSTRACT. The evolution of the buckling phenomenon starts during the weld cooling cycle caused by an onset inelastic strain incompatibility condition. This initial bifurcation phenomenon may continue to grow until the completion of the cooling cycle, which results in the final buckling distortion of the plate. With lower heat input and/or smaller plate dimensions, this initial instability may stop during the cooling cycle due to diminishing strain incompatibility and recovering of the plate rigidity. The buckling evolution process is complex due to the highly nonlinear nature of the welding problem. This paper studies this buckling evolution process using an integrated experimental and numerical approach. Bead-on-plate welds of AH36 steel were experimentally studied. The welding process was numerically simulated and analyzed using a 3D large deformation thermal-elastic-plastic (3D EP) model. The phenomenon of the onset of bifurcation and instability was investigated by monitoring the transient stress and displacement. It was found the longitudinal shrinkage strain distribution can be uniquely determined by the maximum peak temperature profile characterized by "nil-plasticity peak temperature," which is influenced by welding heat input and plate size. The eigenvalue analysis using the longitudinal inherent shrinkage strain distribution and 3D EP analysis predicted the same critical welding conditions.

KEYWORDS

Buckling
Bifurcation
Plasticity
Welding Distortion
Longitudinal Inherent Shrinkage Strain
Finite Element Analysis

Introduction

Buckling is one of the most prevalent types of welding-induced distortion in fabricating thin plate panel structures. This distortion problem is of a particular concern when dealing with higher strength materials, which design tends to use thinner plates while the welding-induced compressive stress in the plate is also higher. The common engineering approach to this problem has been to apply the eigenvalue analysis to the compressive residual stress in the plate resulting from welding (Refs. 1–5). This compressive residual stress is dependent upon material, joint configuration, and welding parameters.

Once the characteristic residual stress is obtained for the given welding conditions, the critical dimensions (width and length) can be estimated using eigenvalue analysis from the design of experiments, or the stability of the specific dimensions under the given welding condition can be checked. This approach postulating the buckling instability under the residual stress state may inaccurately estimate the buckling strength of the panel due to the observation in this study of incipient bifurcation in the weldment during the weld cooling cycle. If this phenomenon continues until completion of the weld cooling cycle, the panel would buckle at lower threshold stress values than that predicted by the stress-based eigenvalue solution.

In this study, an integrated experimental and numerical approach was used to investigate the mechanics of welding-induced buckling phenomenon. In the experimental study, bead-on-plate welding was performed along the middle line of AH36 steel plates using the submerged arc welding process. The effect of welding heat input on distortion was evaluated with heat input ranging between 560 and 1280 J/mm. The plate size effect was also studied for a constant heat input (1097 J/mm). The purpose of this experimental study was to establish the baseline data for calibration and comparison with the numerical analysis.

In the numerical studies, three-dimensional, thermoelastic-plastic, large deformation analyses were performed on the weld experimental models to understand the distortion process observed in the experiments. The distorted shape and the magnitude of vertical displacements obtained from the numerical analyses were compared with those obtained from experiments. The numerical models were extended to analyze the transient evolution of the bifurcation phenomenon during welding and after completion of the weld thermal cycle for the buckling criterion.

Experimental Study

Figure 1 shows the test specimen configuration. All the specimens were square shaped of various sizes, made of 6-mm-thick AH36 (i.e., 345 MPa yield stress) steel plates. The submerged arc welding process and welding consumables in accordance with AWS A5.17 (F7A4-EL8) were used for welding. End tabs of 120 × 160 mm were attached to both ends of the specimen to ensure a continuous bead cross section in the ends of the weld plate. The electrode extension of 25 mm and direct current electrode positive (DCEP) arc polarity were used in all welding procedures.

Experimental Setup

Table 1 summarizes three plate sizes (300, 400, and 1000 mm) and welding parameters for the ten weld models investigated. The welding heat input varied from 558 to 1280 J/mm by setting the proper combinations of wire diameter, current, arc voltage, and travel speed. All experiments were carried out at an ambient temperature (25.8°C). The specimens were

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