Marine Structures 46 (2016) 30–55

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

Influence of the welding sequence on residual stress and distortion of fillet welded structures

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ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form 3 December 2015
Accepted 3 December 2015
Available online 29 December 2015

Keywords:
Welding sequence
Fillet weld
Residual stress
Distortion

ABSTRACT

T-joints are one of the most common welded joints used in the construction of offshore structures, including ships and platforms. In the present study, a sequentially coupled thermo-mechanical finite element model that considers temperature-dependent material properties, high temperature effects and a moving volumetric heat source was used to investigate the effect of welding sequence on the residual stresses and distortions in T-joint welds. The parameters of Goldak's double ellipsoidal heat source model were predicted using a neural network. The numerical models were successfully validated by the experimental tests. The results show that the welding sequences have significant effects on the residual stresses and distortions, both in the magnitude and distribution mode. The optimization of the welding sequences should be investigated numerically or experimentally before the construction welded structure.

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1. Introduction

The demand for ships and offshore platforms in Brazil in the last ten years has motivated the opening of new shipyards and recovery of the shipbuilding industry. The competitiveness of this

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http://dx.doi.org/10.1016/j.marstruc.2015.12.001
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industry relies on the implementation of technological advances in the design and construction of large ocean structures. One of the challenges is to provide better interactions between the design and construction phases. From a structural point of view and considering that ocean structures are, in general, composed of welded stiffened plates, it is of paramount importance to better understand the effect of the welding process on distortions and residual stresses. These two fabrication factors are responsible for the decrease in the ultimate strength of the stiffened plates under compression loads [1–3], affecting the initial design, as well as generating geometric imperfections that can seriously delay the proper matching of the structural blocks during construction. The overwork in the shipyards caused by mismatching of structural components is responsible for the over-expenditure of manpower, which can jeopardize the competitiveness of the shipbuilding industry.

With the development of computational technology, experimentally validated numerical simulations have become an efficient tool in the investigation of welding related problems [4,5]. Wang et al. [6] carried out an finite element (FE) computation based on inherent deformation method to predict welding induced buckling by employing large deformation theory. The European Network on Neutron Techniques Standardization for Structural Integrity (NeT) supported a series of projects to investigate the residual stress mechanism and established an accurate numerical method to predict the residual stress in stainless steel welding [7–11].

The welding sequence is one of the factors that significantly influence the welding induced residual stresses and distortions [12,13]. Optimizing of the welding sequences is an important aspect that needs to be investigated experimentally or numerically before the structure's construction, because it has significative influence on the quality of the final product and may reduce the amount of re-work required to finalize the structure. The welding sequences significantly influence the welding induced residual stresses, and the final welding pass has the largest contribution to the final residual stress fields in the tube-block joint [13]. For welding induced distortions, the welding sequences influence both the magnitude and distribution mode in the tube-block joint. Fu et al. [14] conducted a 3D experimentally validated numerical model to investigate the effect of welding sequences on the residual stresses in an octagonal pipe-plate aluminum alloy structure. Nine welding sequences were performed using the numerical model. It was shown that the welding sequences significantly affect the longitudinal and transverse residual stresses in the octagonal pipe-plate structure. And the symmetric welding sequence was recommended by Fallahi et al. [15] and Fu et al. [14]. Gannon et al. [16] developed a 3D numerical model to investigate the effects of welding sequence on the residual stresses and distortions. Four different welding sequences were employed in the numerical simulation. It was found that the welding sequence did not influence the distribution of the longitudinal residual stresses, but it did affect the peak value of the residual stress. However, the distributions of the vertical and lateral deflections are different under different welding sequences. Guirao et al. [17,18] carried out different welding sequences simulations to investigate how welding sequences induce different welding distortions in large structures. Manurung et al. [19] investigated the effect of welding sequences on the welding distortions in a T-joint with two webs under clamped boundary conditions, and they concluded that the welding sequences have no significant influence on welding distortions.

Recently, several research programs have been conducted to investigate the influence of fabrication imperfection on ultimate strength of ships and offshore structures [4,20–24]. Considering that residual stresses and distortions are directly associated with the welding process, the present study aims to better understand these fabrication factors. A sequentially coupled thermo-mechanical finite element model considering temperature-dependent material properties, high temperature effects and a moving volumetric heat source was developed to investigate the effect of the welding sequence on the residual stresses and distortions in T-joint welds. The parameters of Goldak's double ellipsoidal heat source model were determined using a neural network [23]. The numerical models were successfully validated by the experimental measurements. The results indicated that the welding sequences have a significant effect on the residual stresses and distortions, both in magnitude and the distribution mode. By comparing the results under different welding sequences, it can be concluded that the optimized welding sequence which induces low welding residual stresses and distortions can be applied in a practical construction operation.

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