Marine Structures 56 (2017) 69–84

Contents lists available at ScienceDirect

Marine Structures

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

A benchmark study of uncertainness in welding simulation☆

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ARTICLE INFO

Article history:
Received 31 October 2016
Received in revised form 28 April 2017
Accepted 7 July 2017

Keywords:
Welding
Welding residual stress
Welding distortion
Computation welding mechanics
Finite element method

ABSTRACT

Steel stiffened panels assembled by fusion welding are widely used in the design of marine structures. Although the numerical model calibrated via experimental measurements is becoming a common solution, certain unrealistic result from numerical welding simulation are commonly observed due to the use of different software and modeler practices. Each selected parameter such as mesh size, material modelling, heat input, boundary conditions play an important role in the finite element model, and directly impact the final results. Therefore, key challenges must be addressed in order to analyse in what extent modeler practice and software influence the reliability and accuracy of the results. This paper propose a benchmark study to understand the influence of the modeler's practice and FEM codes on the welding simulation results. The welding residual stress and distortion of a "T-joint" weld are analyzed numerically under various material models, boundary conditions and heat inputs. Then, results of various 3D thermo- mechanical simulation models are confronted to a well reported experimental results. The findings show that the difference of modeler practice may have considerable effects on welding residual stresses, i.e. $\gtrsim$20% difference whereas welding distortions are less sensitive to the user decisions i.e. $\lesssim$12% difference. Finally we suggest that the sensitive parameters of welding simulation such as equivalent heat source and material modelling need a general guide in order to evolve from a reproduction tool to a prediction method for any welding procedures.

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1. Introduction

Steel stiffened panels are widely used in the design of marine structures. They are important design elements of hull structures, due to the excellent relation between their weight and their load capacity under tension and compression. The buckling of stiffened panels has a close relation with geometric imperfections caused, among other reasons, by welding

☆ Paper prepared in conjunction with the ISSC Committee work 2012–2015. Edited in cooperation with Professor Carlos Guedes Soares, Chairman of ISSC2015 Conference.

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http://dx.doi.org/10.1016/j.marstruc.2017.07.005
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distortions. Moreover, knowledge of welding residual stress characteristics is essential for structural integrity assessment containing weld components.

The exponential growth in computer performance combined with equally rapid developments in numerical methods and geometric modelling have enabled welding simulations to reach the stage where it can solve an increasing number of problems that interest the shipbuilding and offshore industry. The nature of the welding simulation process is complex because it is a multiphase simulation with heating, melting and solidification, with phase transition between solid and fluid states. Many researchers have worked on thermo-elasto-plastic finite element methods using computation welding mechanics (CWM) coupled to experimental tests to cover this concern [1–6].

Numerical simulations have been used to assess the effect of different boundary conditions [7], welding processes [8], and welding sequences [9,10], on the final distortion and residual stress distribution of stiffened plates. Other factors related to material behavior has also been investigated. For instance, [11] developed a novel material constitutive model to investigate the effects of the material model on the residual stress and distortion in welding process for multi-pass welding process. The effect of material models under different phase transformation assumptions has also been investigated recently [12]. Researchers have modeled these processes by a moving heat source, according to the weld bead shape and heat flux distribution. By this means it is possible to determine the temperature field distribution over the base material as well as the residual stress and distortion [1,13].

To decrease the number of costly prototypes and to reduce the lead time of the design of complex structures, a large number of CWM tools to simulate transient welding phenomena are becoming available. Recently published CWM standards [14] indicates that welding simulation is in the progress to become an established and mature engineering process in the field of residual stresses and distortion predictions [15]. It also indicates that CWM analyses can be used as a fairly reliable tool at the assessment of welding procedure specifications and proposed weld process parameters at the manufacturing engineering stage.

Until now, a limited number of benchmark and round robin activities have been undertaken in order to better understand simulation technique to predict welding distortion and residual stresses [16,17]. Most of that developments are developed based on a finite length weld bead laid on a AISI 316L austenitic steel plate. Important discrepancies of numerical simulation results and residual stress measurement are often observed even for the most comprehensively characterised welding benchmark yet produced undertook by the European Network on Neutron Techniques Standardization for Structural Integrity (NeT) [18]. In this peculiar case, a round robin activity involving 14 independent sets of residual stress measurements and five different techniques shows a variance of $\simeq$30% of the measured residual stresses. In all cases, uncertainties on measurements, equivalent heat source modelling and material modelling are mentioned to be amongst the most sensitive parameters. Therefore, it becomes evident that the effect of decision of the modelers may strongly impact the numerical simulation results. To the knowledge of the authors, up to now there is no extensive benchmark available devoted to ”T-joint” weld for marine structures.

Although, the numerical model calibrated via experimental measurements is a becoming a common solution, certain unrealistic results are commonly observed due to the use of different software and modeller practices. Each selected parameter play an important role in the finite element model, and directly impact the final results. Some inputs arise directly from those applied in the experiment data, but others, like heat source selection, needs special formulation to the finite elements language, and requires special attention. In the worst case oversimplifications of the model may lead to misinterpretation of the numerical results. Therefore, key challenges must be addressed in order to analyse in what extent modeller practice and software influence the reliability and accuracy of the results. Having comprehensive and systematic experiments is also considered as of a great importance in this study. Finally, the study of the robustness of local 3D welding simulation models is considered as an important prerequisite to further studies of large and complex welded marine structures using local/global approaches.

In this paper a benchmark study is proposed to understand the influence of the modeller practice on the simulation results. Both the experimental test and numerical simulation were performed. The welding residual stress and distortion of a ”T-joint” weld are analyzed under various material model and heat inputs by the use of various FEM software. Then, results of various thermo- mechanical simulation models are confronted to the experimental results.

2. Welding experiment

The conditions of the experimental welding tests performed for this study are described below. This gives the reference point for further comparisons with numerical simulations.

2.1. Experimental setup

Geometry – The specimen considered is a welded ”T-joint”, Fig. 1, also called fillet weld assembly, typically used for almost all stiffened panels in ships and offshore structures. It is made up of two parts: a base plate and a stiffener. The stiffener with a web height of 300 *mm* and a thickness of 12 *mm* is welded perpendicularly on the middle of the base plate that has a length of 500 *mm*, a width of 500 *mm* and a plate thickness of 12 *mm*. Neither a bevel neither a chamfer have been considered on the root of the stiffener.

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