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Application of welding simulation to block joints in shipbuilding and assessment of welding-induced residual stresses and distortions

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ABSTRACT: *During ship design, welding-induced distortions are roughly estimated as a function of the size of the component as well as the welding process and residual stresses are assumed to be locally in the range of the yield stress. Existing welding simulation methods are very complex and time-consuming and therefore not applicable to large structures like ships. Simplified methods for the estimation of welding effects were and still are subject of several research projects, but mostly concerning smaller structures. The main goal of this paper is the application of a multi-layer welding simulation to the block joint of a ship structure. When welding block joints, high constraints occur due to the ship structure which are assumed to result in accordingly high residual stresses. Constraints measured during construction were realized in a test plant for small-scale welding specimens in order to investigate their and other effects on the residual stresses. Associated welding simulations were successfully performed with fine-mesh finite element models. Further analyses showed that a courser mesh was also able to reproduce the welding-induced reaction forces and hence the residual stresses after some calibration. Based on the coarse modeling it was possible to perform the welding simulation at a block joint in order to investigate the influence of the resulting residual stresses on the behavior of the real structure, showing quite interesting stress distributions. Finally it is discussed whether smaller and idealized models of definite areas of the block joint can be used to achieve the same results offering possibilities to consider residual stresses in the design process.*

KEY WORDS: Ship structure; Block joint; Welding-induced residual stress; Distortion; Numerical welding simulation.

INTRODUCTION

The welding simulation is today a wide-spread method to predict the welding-induced distortions and residual stresses. Not the process is modelled here, but the heat-input into the weld.

First attempts to explain the effects of the weld process in a scientific way started with the development of heat conduction models. Already in 1941, Rosenthal (1941) published a set of formulae for the calculation of the temperature field due to a moving heat source. 1952 appeared one of the detailed books by Rykalin (1952) for the calculation of the temperature development during welding. In the 1980's, these theories were further developed by Lancaster (1986). Different partial pheno-

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mena such as the formation of the arc with plasma flux, the vaporization at the surface of the molten weld pool, the melting and dropping of the electrode as well as the forming of the weld bead surface were increasingly included in the investigations (Karlsson and Lindgren, 1990; Lowke et al., 1992; Choo and Szekely, 1994; Hoffmeister, 1986; Ruyter, 1993; Böllinghaus, 1995). Up to then the individual models were only partially combined to models for engineering purposes (Haibach, 2002; Radaj, 2003; Rörup, 2003; Radaj et al., 2006). The accuracy of the simulations was determined in the past mainly by the limited computer capacity. With the increasing development in this area, new possibilities exist to increase the accuracy of the models.

Generally, different levels of accuracy of such simulations exist, starting from the modelling, followed by the implementation of the temperature-dependent material data until the consideration of the phase transformation. The more parameters are considered in the computation, the larger will be the time required for the solution. For this reason, the considered geometry is far idealized in many cases, however, it has been seldom verified up to now if the original geometry behaves in the same way, i.e. the results are comparable and transferable. Therefore, the main objective of the investigation presented here is to develop a method which allows the computation of relatively large geometries. A block joint in the forward part of a RO/RO vessel is considered. Local regions, idealized with small models, are compared with the results of the original geometry (block joint) so that conclusions regarding the comparability and transferability of the results from small models can be drawn and the simplified models can be used during fatigue design. All computations were performed with the finite element program ANSYS.

PROCEDURE

In addition to the computing time mentioned above, another problem exists during the investigation of large structures: The validation of the results is frequently impossible. Therefore it is very important to verify the algorithm chosen. The application of the welding simulation to the block joint considered requires simplifications because otherwise computation times of several months would have to be expected. A stepwise reduction of the mesh density is performed, starting point for the calibration of the different mesh density is a reference model which was thoroughly investigated and validated in an extensive research project (Zacke and Fricke, 2011). As shown in Fig. 1, a comparison model is calibrated against this reference model, the former containing the necessary simplifications in order to transfer the process to the block joint (original geometry).

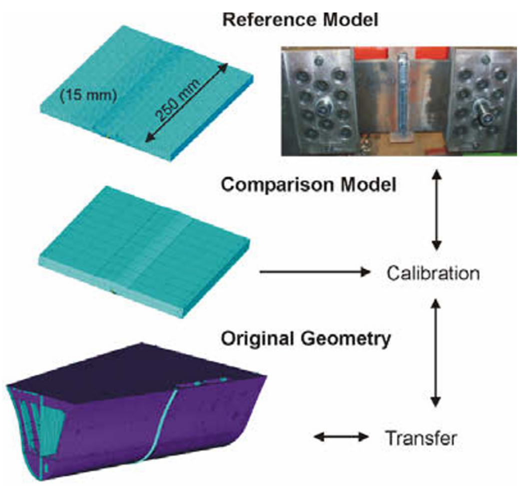

Fig. 1 Procedure chosen.

Higher-tensile ship structural steel D36 was used as material, which can be welded well using a rutile flux-cored wire. The welding process was an automatic metal-active gas (MAG) process, The temperature dependent material data required for the welding simulation were taken from Wichers (2006) assuming no effects from steel grade.

REFERENCE MODEL

The reference model consists of a plate with a 250*mm* long butt-weld. The plate thickness of 15*mm* corresponds to a typical thickness for a shell plate.