Modeling of Residual Stresses in a Butt-welded Joint with Experimental Validation

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Abstract

Marine structures are constructed by joining many assemblies or sub-assemblies by numerous welding operations using medium to high thickness HSLA steel plates. Fatigue behaviour of welded structures is critically dependent on the type (tensile or compressive) and magnitudes of in-situ residual stresses as well as their variations with thickness of the weld joints. Dependence of fatigue behaviour on the residual stresses has been studied in butt joint [1] and T-joint [1, 2] weld configurations. However, fatigue analysis requires the prior information of the magnitudes of the residual stresses measured in-situ by experimental techniques (destructive or non-destructive). In-situ measurements of residual stresses are not always feasible or accurate enough, given the limitations of the experimental techniques. Hence, it is of paramount significance that the weld joints are modelled to conduct FEM simulation of the arc welding process for predicting the in-situ residual stresses existing in these joints. Since, arc welding is a complex process consisting of thermal / structural /mass transport / metallurgical / magnetic interactions, COMSOL Multiphysics® being a multi-physical simulation platform, can be utilized efficiently to simulate arc welding [3] and predict the residual stresses with adequate accuracy. In this study, 2D simulation of butt-welded joint of HSLA steel was conducted to predict residual stresses distribution primarily across the thickness of the weld joint. Two HSLA steel plates (1 and 2) of dimensions (500 mm x 500 mm x 40 mm) each were weld simulated as per schematic drawing in Figure 1. Weld simulation parameters were:- Plate Geometry : 500 mm x 500 mm x 40 mm; Steel Properties : HSLA Structural Steel; Weld Process: GMAW; Weld Joint : Butt-joint; Weld Pre-Heat/ Interpass Temperature : 150 oC (423 oK); Weld Heat Input : 15 KJ/cm. Surface Heat Flux was calculated at the contact surface between weld-electrode and base steel plates from weld heat input and the resultant heat source was modelled as a Gaussian pulse. Figure 2 shows the screenshot of the temperature evolution in the fusion zone at an intermittent time step as the simulated welding proceeds. Thermal behaviour was coupled with structural mechanics with appropriate initial and boundary conditions to evaluate the strains and Von Mises stresses during simulated welding in the absence of any external loads or stresses. Steady-state solution achieved after suitable number of time steps described the residual stresses evolved in the studied butt-welded joint. Predicted Residual stresses distribution across the thickness-oriented plane in the form of iso-stress contours is shown in Figure 3. In order to validate this COMSOL Multiphysics model, X-Ray Diffraction (XRD) method was used to experimentally measure residual stresses present in the weld zone of a physically butt-welded HSLA steel with the identical welding parameters as the simulation. Table 1 shows the comparative validation between

COMSOL predicted and XRD measured residual stresses with percentage deviations. It can be observed that there is close agreement (within 15 %) between the simulated and experimental values of in-situ residual stresses validating the accuracy of COMSOL Multiphysics simulated FEM model of the studied butt-weld joint.

Reference

[1] Barsoum Z, Barsoum I, Residual stress effects on fatigue life of welded structures using LEFM, Eng Fail Anal (2008), doi:10.1016/j.engfailanal.2008.06.017.

[2] T. Mann et al, Fatigue of Welded Aluminium T-Joints, European Conference of Fatigue 2015 (ECF15).

[3] F. Roger and A. Traidia, Modeling Residual Stresses in Arc Welding, Excerpt from the Proceedings of the COMSOL 2010 Boston.

Figures used in the abstract

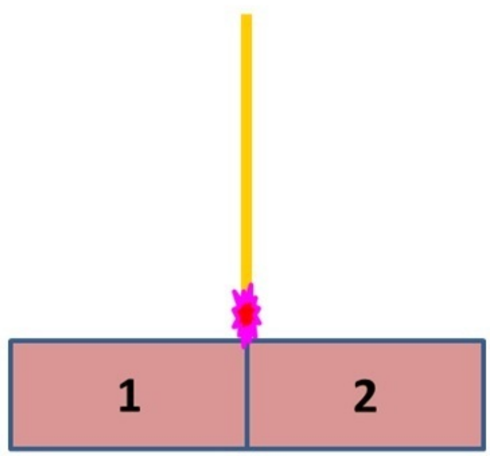

Figure 1: Figure 1: Schematic Geometry of Butt-Weld Joint used for this study.

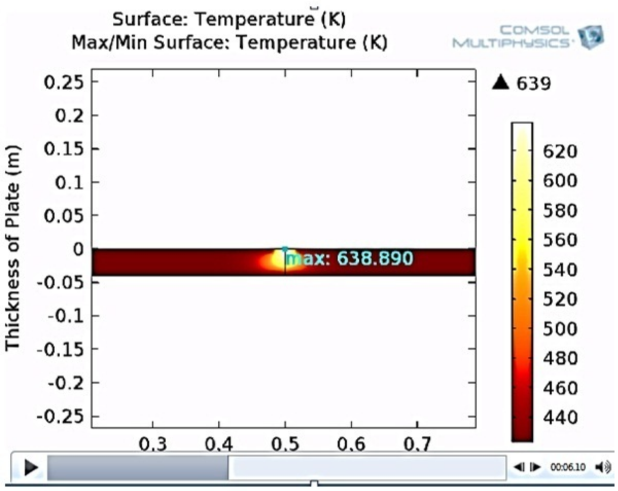

Figure 2: Figure 2: Screenshot of Temperature Evolution in Fusion Zone during Simulated Welding.

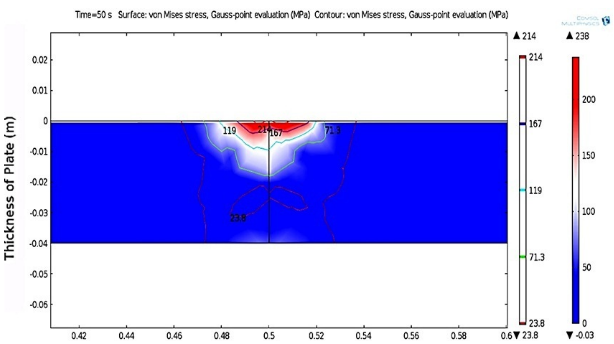

Figure 3: Figure 3: Residual Stress distribution across thickness-oriented plane showing iso-stress contours after Weld Simulation.

Depth (mm)	Residual Stress - Simulation (MPa)	Residual Stress – Experimental (XRD method) (MPa)	% Deviation
10	**116.1**	**100.8**	**15.2**
20	**65.3**	**73.5**	**11.2**
30	**32.1**	**34**	**5.6**

Figure 4: Table 1: Comparative validation between COMSOL predicted and XRD measured residual stresses with percentage deviations.