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EFFECT OF THE WELDING PARAMETERS ON RESIDUAL STRESSES IN PIPE WELD USING NUMERICAL SIMULATION

MAHMOOD ALHAFADHI[1]–GYÖRGY KRÁLLICS[2]

University of Miskolc, Faculty of Material Science and Engineering,
3515, Miskolc-Egyetemváros
mahmoodhs199@gmail.com

Abstract: The objective of this article is to predict the residual welding stress in a dissimilar pipe weld. The 2D model, instead of 3D was used to reduce the time and cost of the numerical calculation. The 2D numerical simulation MSC MARC code is used to predict the residual stress developed during pipe welding. The present model was validated using hardness measurement. Good agreement was found between the measurement and numerical simulation results. The effects of welding parameters on residual stress field on the outer and inner surface were assessed. The effect of welding parameter (welding current) is examined. The axial and hoop residual stresses in dissimilar pipe joints of different thickness for pipe weld were simulated in outer and inner surfaces. When the other parameters remain fixed, and the current has great effect on the weld shape and size, and then affects the residual stress level significantly.

Keywords: *Numerical Simulation, Welding Pipe, Residual stress.*

1. INTRODUCTION

Welding is a reliable and efficient metal joining process between two parts of dissimilar pipes. Arc welding joints are more extensively used in the fabrication industry, oil and gas pipeline, offshore structures, and pressure vessels. Welding residual stresses are caused by differential thermal expansion and contraction of the weld metal and dissimilar base metal. Further, these residual stresses can be of either tensile type or the compressive type, depending upon the location of the non-uniform volumetric change. Numerical simulation is used to predict residual stresses due to the complexity of the shape structure. Nowadays, it is possible to use numerical simulation techniques to predict the residual stresses in welded structures and it can be employed to simulate welding temperature field and welding deformation. [1–7]. In order to reduce the computational time and cost, most of the researchers choose the 2D model. Brickstad and Josefon [8] employed 2D model to simulate welding of stainless steel pipe in thermo-mechanical finite element analysis. Dean Deng et al. [9] presented a 2D FE model for simulating residual stresses during multipass welding of a pipe. The distribution of residual stress in welded pipe structures depends on several factors such as structural dimensions material properties, and heat input, etc. Siddique M. et al. [10] analysed the residual stress fields in circumferentially arc welded and studied the effect of two basic welding parameters including welding current and speed. However, there are minimal studies on effects of welding parameters on residual stresses in dissimilar welded pipe joints. In this study, the prediction of residual stresses in a dissimilar pipe weld joint made of E355K2 and P460NH_1 is studied by using 2D finite element method. This study also presents the 2D FE model of pipe joint to investigate the effect of welding current on residual stress distribution.

2. 2D AND 3D MODELLING PROCESS

A dissimilar pipe with outer diameter of 114.3 mm, with different thickness of 8 mm and 11, and a total length of 800 mm as shown in *Figure1* is considered for the analysis. The meshed model of pipe is shown in *Figure 1(b)*. The material used are, P460NH_1 steel, E355K2 steel and filler metal Böhler and its mechanical and thermal properties with varying temperature are shown in *Figure 2*.

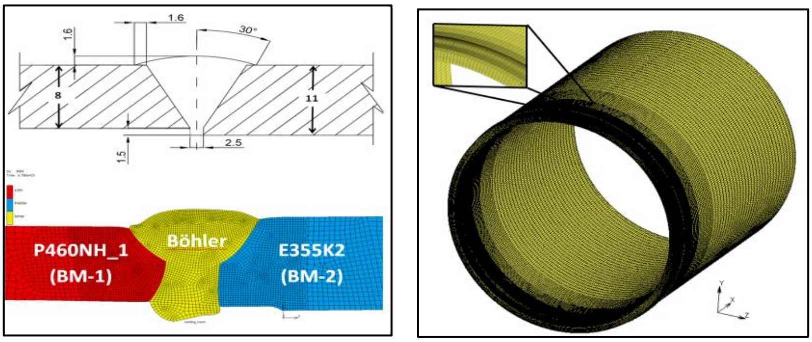

Figure 1. (a) 2D finite element model with dimension (mm)
(b) 3D finite element model of pipe

In this study, three pass welding with an inter-pass temperature of 50 ^{o}C is used. Chemical composition of the pipe used in this study is given in *Table 1*.

Table 1
Chemical composition (wt%)

Materials	C	S	P	Mn	Si	V	Cr	Cu
Base material P460NH_1	0.2	0.001	0.02	1.49	0.33	0.2	0.01	0.03
Base material E355K2	0.13	0.01	0.86	0.86	0.01	0.058	0.02	0.02
Filler metal Böhler	0.1	–	0.02	0.4	0.14	–	0.1	0.17

Thermal cycles at the weld zone of the pipe are shown in *Figure 2*. All region in and around the weld of pipe have a maximum temperature of 620 ºC. It can see the sudden drop of temperature in minimum time intervals.

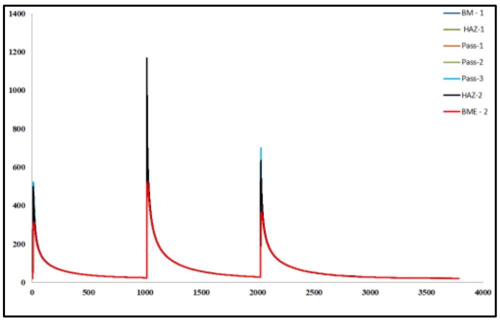

Figure 2. Thermal cycle all region in the weld

3. THERMAL AND MECHANICAL ANALYSIS

Analysis is done for a V-grooved weld since the pipe is unsymmetrical, the pipe is modeled. By using appropriate mesh optimization technique, relatively fine mesh is created in and around the weld centreline and coarse mesh is in areas away from weld line as shown in *Figure 1(a)*. Four nodes and 86,642 thermal and mechanical elements are used for the analysis. The equations are used for transient heat transfer and heat source with a double ellipsoidal distribution proposed by Goldak et al. during welding is given by [1]

$$pc\frac{\partial T}{\partial t(x,y,z,t)} = -\nabla q(x,y,z,t) + Q(x,y,z,) \tag{1}$$

$$Q(x,y,z,t) = \frac{6\sqrt{3}\, f_i \eta IV}{abc_f \pi\sqrt{\pi}} e^{-3\left(\frac{x-vt}{a}\right)^2} e^{-3\left(\frac{y}{b}\right)^2} e^{-3\left(\frac{z}{c}\right)^2} \tag{2}$$

Where p is the density of the materials, c is the specific heat capacity, q is the heat flux vector, T is the temperature, Q is the inside heat rate, x, y and z are the coordinates in the system, t is time and ∇ is the spatial gradient operator. The various weld parameters in a double ellipsoidal distribution proposed by Goldak et al. [11] (see *Figure 3)*. Where x, y, and z are the coordinates of the Goldak double ellipsoid model, π is the fraction of heat deposited in the weld region, the heat input rate Q = ηVI is calculated by welding operational parameters current (I), voltage (V) and η is the arc efficiency for the welding process, *v* is the speed of torch travel in mm/s, and t is the time in seconds. The factors f_f and f_r refer to the fraction of the heat deposited in the front and rear quadrant respectively, which are set up to attain the restriction $f_f + f_r = 2$. The parameters a, b and c are related to the characteristics of the welding heat source. The parameters of the heat source are chosen according to the welding conditions. The same element mesh is used in the thermal analysis and the mechanical analysis. During the welding process, the solid-state phase transfor-mation occurs in the base metal and the weld metal. Therefore the total strain rate can be expressed as follows:

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon_e} + \boldsymbol{\varepsilon_p} + \boldsymbol{\varepsilon_{th}} \tag{3}$$

Where the elastic strain is $\boldsymbol{\varepsilon_e}$, the plastic strain $\boldsymbol{\varepsilon_p}$ and $\boldsymbol{\varepsilon_{th}}$ is the thermal strain.

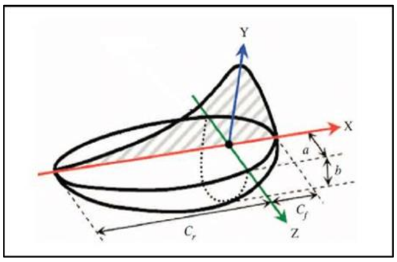

Figure 3. Double-ellipsoidal volumetric heat source model

4. VALIDATION 2D PIPE MODEL

The Cross-sectional views of the hardness test shown in *Figure 4* and the 2D model is validated using hardness measurement. The predicted simulation results are in good agreement with the measurement results, as shown in *Figure 4*.

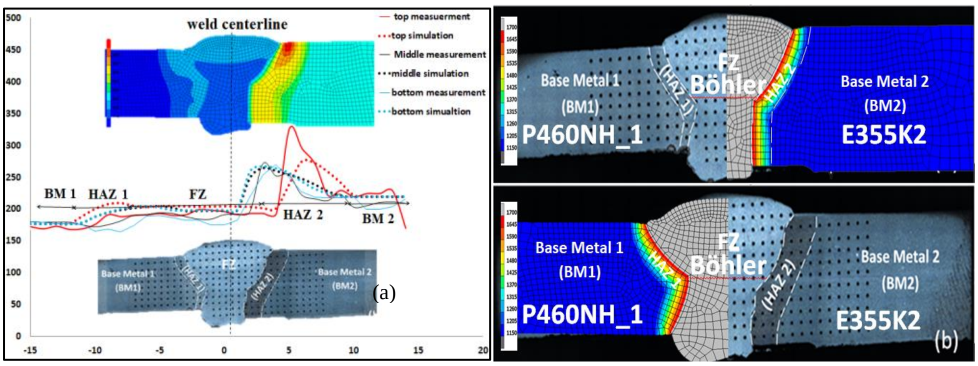

Figure 4. (a) Comparison between the predicted hardness simulation and the hardness measurement (b) Simulated temperature distributions in the cross-section

Figure 4 (b) shows the peak temperature experienced during welding enveloped over all three passes. The resulting final fusion zone is indicated by the region with the temperature above 1,650 °C. Heat affective zone (HAZ-1) and (HAZ-2) are outlined approximately by the temperature interval between about 1,000 °C and 1,600 °C

5. Results and discussion

5.1. Axial, radial and hoop residual stress on the outer and inner surface

Residual stresses predicted from 2D model simulation results on the outer and the inner surfaces, as shown in *Figure 5*. Maximum tensile axial stresses in the weld region were on the inner surface approximately 340 MPa located near HAZ-1 of the base metal (P460NH_1). Axial compressive stresses of roughly 350 MPa in the outer surface and radial stresses up to around 200 MPa was observed in the inner surface weld region. Hoop stresses up to ~ 100 MPa were found in the inner surface pipe weld and 85 in the outer surface, but it can see that the high values in the middle of weld region.

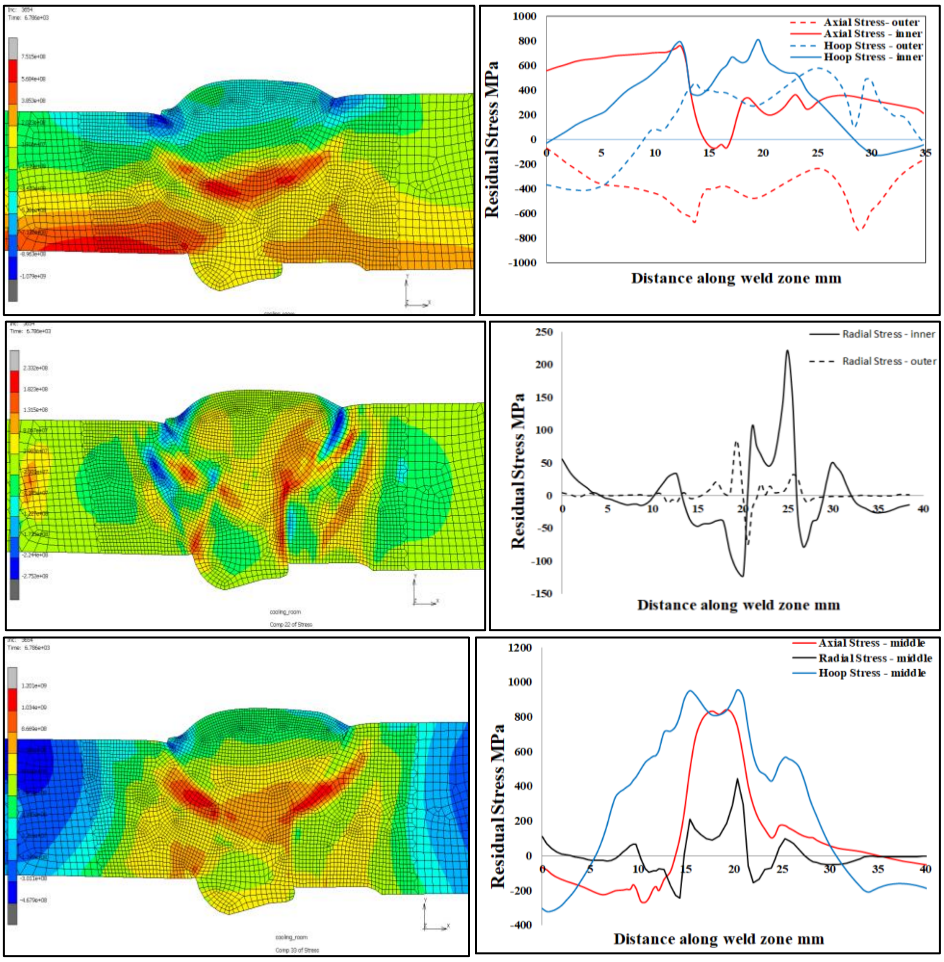

Figure 5. variation of axial, radial and hoop residual stress in the inner, outer and middle weld region

5.2. Effect of welding parameters

The residual stress calculation of weld pipe as a function of distance for current (70, 80 and 100 A) is shown in *Table 2*. From *Figure 6*, we can observe that the range of stress becomes wider with increasing welding currents. To clarify the welding current change influences on welding residual stress, Welding residual stresses at the outer and inner surfaces from the weld start point for different welding current combinations in three pass welding. Three main regions on inner weld surface (HAZ, FZ and BM) of the axial residual stress in the weld are shown in the *Figure (a)*: compressive stress (regions BM-1, BM-2, HAZ-1, HAZ-2 and FZ) and tensile stress (region FZ) in case B. It means that for welding currents (case A) with current 70 A the limit of stress are about 455 MPa in tension and 213 MPa in compression on outer and inner weld surface. But for the 100 A the maximum stress range is 800 MPa and in tension and 650 MPa in compression. The same is true for the stress plot of inner surface of pipe show in *Figure (b)*.

Table 2

Welding parameter cases and welding pool

Cases	Current (A)	Voltage (V)	Speed mm/s	Welding pool parameters			
				a (mm)	b (mm)	c_f (mm)	c_r (mm)
Case A	70	9	2	4	3	5	8
Case B	80	9	2	4	3	5	8
Case C	100	9	2	4	3	5	8

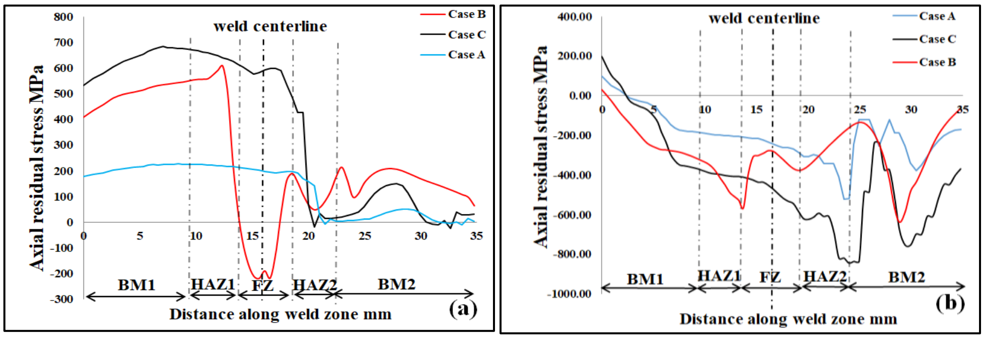

Figure 6. variation of axial residual stress with welding current (a) inner surface (b) Outer surface

6. SUMMARY

From the simulated finite element model, the 2D model was validated using the temperature distribution and hardness test measurement and shows the acceptable agreement. The 2D model for circumferential welding of the pipe is developed and the residual stresses for outer and inner surfaces are predicted. Axial residual stress changes from tensile to compressive from inner to the outer surface after the welding and the high value found in near and around (HAZ-2) for base metal (P460NH_1). Hoop residual stress changes from tensile to compressive in the outer surface and the high value found in near and around (FZ). The magnitude of residual stress distribution became wider when welding current increases.

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