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A study on port plug distortion caused by narrow gap combined GTAW & SMAW and Electron Beam Welding

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ABSTRACT

A study of port plug distortion resulting from narrow gap combined GTAW & SMAW and Electron Beam Welding was carried out. Thermomechanical finite element analysis of port plug becomes virtually impossible because of the requirement of huge number of nodes and elements. Hence an analysis method based on the concept of inherent strain was used in this work. The computational time required was about 40–50 min only in a Core (TM) 2 Duo, 2.66 GHz computer with 2 GB RAM, which otherwise was not possible with other conventional computation techniques. As was expected the overall distortion due to EB welding was found to be less compared to that of narrow gap GTAW & SMAW.

1. Introduction

The distortion in a welded structure results from the nonuniform expansion and contraction of the weld and surrounding base material, due to the heating and cooling cycle during welding process.

Thermal elastoplastic finite element method can be effectively used to predict welding residual stress and distortion for small or medium welded structures [1–5]. However this method is inapplicable to simulate the welding distortion for large welded structures because of the large amount of computational time.

For seeking practical methods to predict welding residual stress and residual distortion, many numerical simulation procedures [6–10] were developed in the past decades. Ueda and Yuan [6,7] studied the characteristic distributions of inherent strains in butt, T and I joints, and employed them to predict welding residual stress.

Michaleris and DeBiccari [8] developed a two-step numerical analysis procedure to predict welding induced deformation. In their method, a two-dimensional thermomechanical welding simulation was performed to determine the welding residual stresses. Then, the residual stresses were introduced to a three-dimensional structure for elastic analysis.

Jung and Tsai [9] developed a method named plasticity-based distortion analysis (PDA) and applied it to investigate the relationship between cumulative plastic strains and angular distortion in fillet welded T joint. In their research, the relationship between six cumulative plastic strain components and angular distortion was examined. They also studied the effect of external restraints and thermal management technique on the relationship between cumulative plastic strains and angular distortion using PDA procedure [10].

Experimental studies were carried out to investigate the thermal character and the effects of arc distance and welding parameters on the angular distortion in asymmetrical double-sided double arc welding [11] (ADSAW). An experimental study was carried out to investigate the characteristics of welding deformation of fillet joints [12]. Meanwhile, a 3-D thermal elastic plastic finite element model was developed to simulate welding deformation. The influence of the flange thickness on welding deformation was investigated. All these methods lacked into the capability of having large structures.

To ascertain the extent of deformation due to the thermal cycles caused by welding it calls for solving a complex thermal elastoplastic problem, which is non-linear and involves plastic deformation of the medium at high temperature varying in both time and space. Analytical solutions turned out to be inadequate [13]. At the same time conventional numerical techniques proved to be highly time

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consuming and thereby prohibitively expensive in real life situations.

To minimize computational time and cost, axi-symmetry modelling approach [21] is adopted widely for welding simulation, recent investigations have advocated in favor of three-dimensional solid modelling without considering the axi-symmetry for better prediction of distortions and residual stresses [14].

The increasing power and capability of computer systems mean that direct, detailed computational simulations are feasible to some extent. However, simplifications seem to be necessary in practice [15], as noted by Josefson et al. [16] and Lindgren [17], it is important to keep computational times within a reasonable industrial time frame.

In this work a comparative study of port plug distortion that may result from narrow gap combined GTAW & SMAW and Electron Beam Welding was carried out. The FE model based on inherent strain [18] generated due to welding was developed to predict the welding distortion of full scale upper port plug. The computational time required was about 40–50 min only in a Core (TM) 2 Duo, 2.66 GHz computer with 2 GB RAM, which otherwise would have been not possible with other conventional computation techniques. Though EBW is a low distortion welding process but the results herein strongly indicate that the proposed welding procedure using narrow gap GTAW & SMAW is also a good candidate for fabrication of port plugs. Apart from the cost factor of EBW, one should also consider the possibility of any welding defect coming into place while carrying out EBW. In such an event it will be a very expensive and difficult process to carryout such repairs. Whereas if any such thing happens using the combined GTAW & SMAW welding procedure, the repair techniques are simple and inexpensive.

2. Analysis methodology

The welding process being a transient phenomenon, thermo-mechanical finite element analysis of port plug becomes virtually impossible because of the requirement of huge number of nodes and elements. Hence an analysis method based on the experimentally verified concept of inherent strain [20,24] was used in this work.

In fusion welding processes a structure undergoes locally a large thermal cycle. The thermal expansion of the weld metal and nearby areas is restricted by the surrounding cold metal. This leads to formation of residual plastic strains in the weld metal and nearby area. These plastic strains are referred to as inherent strains. These strains are considered to be responsible for causing welding deformations. Once the relation between the welding heat input and the inherent strain distribution is established, the residual stress and the deformation can be calculated by elastic analysis using inherent strain as initial strain.

These strains can be divided as longitudinal inherent strain and transverse inherent strain. Let the volume subjected to longitudinal and transverse inherent strains per unit length be expressed as V_x and V_y respectively. It is assumed that V_x and V_y are related to rate of heat input q as shown in Eqs. (1) and (2) respectively:

$$V_x = Kq \tag{1}$$

$$V_y = \beta q \tag{2}$$

The range of coefficients K and β are given in Eqs. (3) and (4) respectively:

$$K = (0.255\text{–}0.335)\frac{\alpha}{c\rho}\,(\text{m}^3/\text{J}) \tag{3}$$

$$\beta = (0.255\text{–}1.0)\frac{\alpha}{c\rho}\,(\text{m}^3/\text{J}) \tag{4}$$

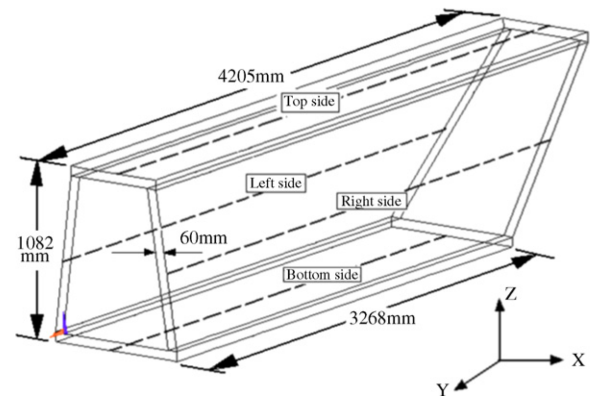

Fig. 1. Detail dimensions of upper port plug.

where α is the thermal expansion coefficient; c is the thermal capacity; ρ is the density. Here the coefficients are taken as [6]: $K = 8.6 \times 10^{-7}$ cm^3/J, $\beta = 2.8 \times 10^{-6}$ cm^3/J.

Longitudinal inherent strain ε_L and transverse inherent strain ε_T are defined as follows:

$$\varepsilon_L = \frac{V_x}{A_i} \text{ and } \varepsilon_T = \frac{V_y}{A_i} \tag{5}$$

A_i is the zone area where V_x and V_y are distributed. For predicting welding deformation, using different area in a certain region has no effect on deformation analysis if the total volume of inherent strains and the location of its center do not change [19,21].

The rate of heat input q was calculated based on welding current, welding voltage, welding speed and number of weld passes as given below,

$$q = \sum_{i=1}^{n} \frac{\eta V_i I_i}{(ws)_i}\,(\text{J/m}) \tag{6}$$

where q is the heat input per unit length (J/m), n is the number of weld pass, η is the welding efficiency, V is the welding voltage (volt), I is the welding current (amp) and ws is the welding speed (m/s).

3. Welding procedure and parameters

The GTAW with argon shielding is one of the most suitable methods for welding of various grades of stainless steels. However one major limitation of the GTAW is its low deposition rate. Therefore GTAW in conjunction with SMAW was considered for fabrication of the port plug. The dimensions of upper port plug are shown in Fig. 1. The details of joint configuration and edge preparation are given in Ref. [24].

GTAW with argon shielding and DCEN polarity was taken for root pass. After root pass a finishing weld pass to be carried out above the root pass weld deposit. The welding parameters for root pass and finishing pass are shown in Table 1.

Filler runs to be carried out using SMAW. The 1st two filler passes to be carried out using 2.5 mm diameter electrode and the remaining welding to be done using 4 mm diameter electrode. Total number of 22 filler runs was considered. The welding parameter to be used in different passes of SMAW are given in Table 2.

4. Co-ordinate system

The co-ordinate system adopted for the analysis of upper port plug is shown in Fig. 2. The fixed reference point was represented as (0, 0, 0), as shown in Fig. 2. The Z-coordinate was considered along the length of upper port plug.