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Numerical simulation of three-dimension stress field in double-sided double arc multipass welding process

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ABSTRACT

A new high-efficiency method for welding thick plates of low-alloy high-tensile steel which does not require back chipping – double-sided arc welding (DSAW) – is provided in this paper. Backing run adopts double-sided pulse gas tungsten arc welding, and other passes adopt double-sided gas metal arc welding. Three-dimensional numerical models of DSAW with 50 mm plates are developed to predict the stress distribution by using finite-element analysis, computer parallel processing technology and multiple jobs design, and are compared with single arc welding (SAW). The analysis of the interpass stresses indicates that the stresses of the back and cover pass are to be regarded as the key point in multipass welding. To verify the calculated results, the residual stresses and transient temperature of back run weld measured individually agree approximately with the calculated results, which illustrates that the backing run and residual stresses of DSAW are lower than those of SAW.

1. Introduction

Welding structure of thick plate of low-alloy high-tensile steel is widely used in high-pressure vessel, shipbuilding and so on. At present, the process of conventional welding technology for thick plate of low-alloy high-tensile steel is as follows: preheating, gas metal arc welding (GMAW) in one side, then back chipping by carbon arc air gouging, polishing, magnetic particle examination, preheating again, GMAW on the other side again, finally post-heating and so on. This production process is very complex and productivity is very low. There is a strong need to develop a new method to simplify the conventional welding process. A new high-efficiency technique which does not need back chipping – double independent power double-sided double arc welding (DSAW) – is provided in this paper. Backing run adopts double-sided pulse gas tungsten arc welding (GTAW), and other passes adopt double-sided GMAW. The production process is simplified and productivity is very high. At present, like this method has been applied to thin and medium plate welded structures in China [1,2]. But the stress distribution of thick plate for low-alloy high-tensile steel by the new method has not been clear. The thermal cycling effects of this new method on the microstructure and property had been investigated in our recent studies [3], which illustrated the new technology has high welding quality. So further investigation of this method is very significant.

It is well known that the welding structure of high-tensile steel thick plate is prone to generate high residual stresses which affect the fabrication, assembly, and service life of the structures [4,5]. Therefore, prediction of residual stresses to the new DSAW process is extremely important for the application of this method. Multipass welding is widely used for thick plate. Many welding experts in other countries studied the residual stress problem of multipass welding since the 1990s, but the above researches mainly aimed on the two dimensional problem [6–9]. In recent years, with the development of computer and software, the three-dimensional (3D) simulation of multipass welding can be achieved. Nowadays most studies concentrate on the special weld structure after conventional single arc welding (SAW) [10,11]. However for the new double-sided arc multipass welding, the stresses distribution is even less clear. Three-dimensional numerical models of the two methods with 50 mm plates are developed to predict the stress distribution by using the finite-element analysis method (FEM), computer parallel processing technology and multiple jobs design. The transient temperature and stresses of back run and residual stresses are fatherly compared and analyzed through comparing the interpass stress of DSAW. To verify the calculated results, the residual stresses and transient temperature of back run weld were measured individually.

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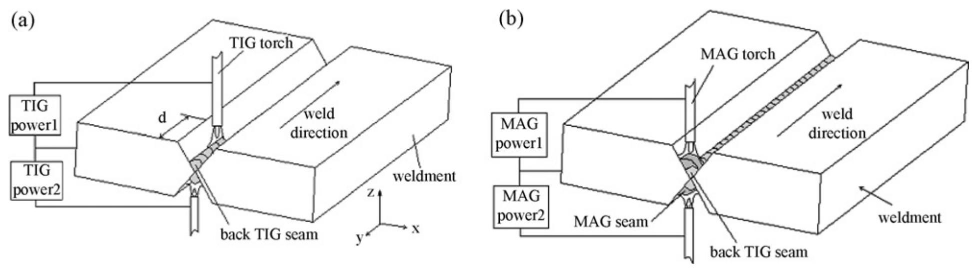

Fig. 1. Schematic diagram of DSAW. (a) Back welding by asymmetric GTAW. (b) Filler welding by symmetric GMAW.

Table 1
Welding parameters

Pass number	Weld method	Current (A)				Voltage (V)	Speed (cm min^{-1})
		Peak	Background	Frequency	Pulse width		
1	PGTAW	260	104	1	60%	13	150
9	PGTAW	249	75	1	50%	13	150
2, 10	GMAW	152				21	132
3, 4, 11, 12	GMAW	130				21	120
5, 6, 13, 14	GMAW	155				24	90
7, 8, 15, 16	GMAW	146				20	72

2. DSAW experiment

The new DSAW technology is a double, independent power type DSAW which is different from single-power DSAW presented by Zhang [12]. The basic principle of this new DSAW is presented in Fig. 1. Backing run adopts double-sided double pulse GTAW; two weld torches are laid on the upside and downside of the plate and supplied by weld power 1 and power 2 individually. Double-sided double Tungsten inert gas (TIG) torches keep an arc distance to realize asymmetric DSAW in the back pass. Other passes adopt double-sided double GMAW. Two metal active gas (MAG) torches are symmetrically laid on both sides of the plate and supplied by two independent weld powers individually. The direction of *Y* is the welding direction, *Z* is the thickness direction, and *X* is perpendicular to the welding direction (width direction).

In this study, welding experiments are carried to investigate the new DSAW and conventional SAW methods. Two methods adopt the same welding parameters as shown in Table 1. The conventional welding method adopts a single arc multipass welding. Welding sequences of SAW are shown in Fig. 2. The whole weld process consists of 16 passes all together, there are 8 passes in the upside and downside of plate individually. The preheating temperature and interpass temperature are 120–150 °C. The surrounding temperature is 25 °C. Low-alloy high-tensile steel plates are 50 mm thick, 120 mm in width and 300 mm in length, Lasea double-V symmetry groove (angle = 60 °C), and a root gap of 3 mm.

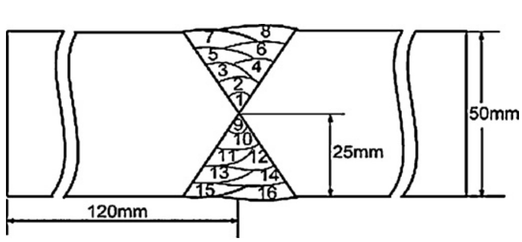

Fig. 2. Welding sequence of SAW.

3. Three-dimensional finite-element model

3.1. Numerical model establishment

Fig. 3 shows the mesh of the welded plate under investigation. 32,070 elements and 35,030 nodes are used in the 3D solid model established by using the simulation software MARC.MSC. Fine mesh is used around weld, but coarse mesh has to be used far from the weld. The initial condition is preheating temperature and all nodes are loaded except for fillers. The *X* axis is the plate width direction, the *Y* axis is the welding direction, and the *Z* direction is the plate thickness direction. The meshes of welding passes is designed according to macrograph of weld seam as shown in Fig. 3, the lattices of each pass are divided into independent unit, and it is defined as dead unit before welding. The units in weld zone are activated one by one during welding process. The double ellipsoid heat source model is applied to the base metal as the heat source model [13]. The welding speed of double arc is shown as in Table 1. The simulation process can keep in-step with the filling process. Since the unit numbers of model and increment steps are so large, we adopt the computer parallel processing technology to reach the aim. The working station is 18 nodal points of Morning Twilight Assembly, two AMD serial CPU is used in each nodal point. Six nodal points are used simultaneously. The whole calculation time of conventional SAW is about 8 days.

A low-alloy high-tensile steel was adopted in this paper. Its carbon content is 0.1%. At the situation of ambient temperature, the Poisson's ratio is 0.285, the density is 7.8 kg/m^3, the melting point is 1450 °C. Ref. [14] shows the thermodynamic property of material including the specific heat 434 J kg^{-1} K^{-1}, yield strength 850 MPa, heat conductivity 30.7 K^{-1} W m^{-1}, thermal expansion coefficient 1.06×10^{-5} K^{-1}, and Young's modulus 2.08×10^5 MPa under room temperature. The heat analysis near the weld molten pool zone mainly appears heat radiation. However the farther place mainly appears surface heat exchange. Considering the common effects of radiation and surface heat exchange, the formula of compound heat conduction coefficient as follows [15]:

$$h = \frac{\varepsilon_e \sigma_b (T^4 - T_a^4)}{(T - T_a)} + h_c \quad (1)$$