Numerical simulation of laser-arc hybrid welding of high strength steel

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Abstract. The numerical simulation of high-strength low-alloy steel in the welding temperature field is carried out. The SYSWELD special welding analysis software is used to establish the geometry model of the butt joint of the flat Y-shaped groove. The temperature field of single-layer and multi-layers welding of 12 mm high-strength low-alloy steel provides a theoretical basis for the welding process and has engineering practical value.

1. Introduction
The combined heat source welding mode formed by combining the laser heat source and the arc heat source is called laser-arc hybrid welding. The advantages of laser welding and arc welding are combined to give full play to the high speed of laser welding and the high bridge of arc welding Ability [1-7]. Metal inert gas welding / metal active gas welding has the advantages of higher welding speed, less heat input, good weld bridging ability, and strong penetration ability. Laser arc hybrid welding has been a scientific researcher at home and abroad in recent years One of the researched welding methods [8-13]. During the welding process, the welding heat source is concentrated on the welding joint, so that the weldment has a temperature gradient and forms an uneven temperature field. For thick plate joint with a large number of weld passes, the prediction accuracy is difficult to be guaranteed. Finite element numerical simulation technology has been increasingly applied to the prediction of residual stress and deformation of welded members [14,15]. This paper uses SYSWELD software to study the temperature field of high-strength steel plate butt welding.

2. Finite element model of laser-arc hybrid welding

2.1. Geometric models and groove design.
Two pieces of high strength steel workpiece with size of 100 × 50 × 12 mm are welded in the form of plate butt joint. The geometric model is shown in Fig. 1. The experimental design of two layers of weld is carried out, and the blunt edge height of Y groove is 6 mm. The same parameters are selected for welding. ER316L wire is used for welding wire, and the diameter of welding wire is 1.2 mm.
2.2. Establishment of finite element grid model

The simulation experiment adopts the method of dividing the grid into regions. Higher precision calculation results can be obtained by using fine mesh division near weld and its heat affected area. The large grid is used to divide the position far from the weld on the specimen, which can solve the problem that the calculation time of the computer is too long and improve the operation speed. The statistics of the divided model show that the maximum 2 mm, of the grid element obtains a total of 146829 nodes and 138350 entities. It is assumed that the weld metal has the same thermal physical and mechanical properties as the base metal. The high temperature thermophysical and mechanical properties of base metal and welding wire are reviewed in reference [16].

2.3. Check of action mode of welding heat source

In the experiment, double ellipsoid moving heat source is used to simulate and analyze. The double ellipsoid (double ellipsoid, DE) heat source model proposed by Golak et al. [17] holds that the distribution of heat source power density of welding arc heating spot is described by double ellipsoid moving heat source model, and the body heat source acting on the workpiece is divided along the axis. The distribution of heat flux in the ellipsoid along the front and back half of the y axis is as follows:

\[ q_r(x, y, z) = \frac{6\sqrt{3}(f_rQ)}{ab\pi\sqrt{a}} \exp\left(-\frac{3x^2}{a^2} - \frac{3y^2}{b^2} - \frac{3z^2}{c^2}\right) \quad y \geq 0 \quad (1) \]

\[ q_f(x, y, z) = \frac{6\sqrt{3}(f_fQ)}{ab\pi\sqrt{a}} \exp\left(-\frac{3x^2}{a^2} - \frac{3y^2}{b^2} - \frac{3z^2}{c^2}\right) \quad y < 0 \quad (2) \]

Effective heat input: \[ Q = \eta(UI + P) \] (I is Welding current, U is arc voltage, P is laser power, \( \eta \) is welding thermal efficiency): \( f_1 \) and \( f_2 \) are the energy distribution coefficients of the total heat input power before and after the molten pool, respectively. \( f_1 + f_2 = 2 \), \( f_f = \frac{b_1}{b_1 + b_2} \), \( f_r = \frac{b_2}{b_1 + b_2} \); \( a, b_1, b_2, c \) are the shape parameter of double ellipsoid heat source, respectively (fig. 2).
In general, when welding simulation is performed, in order to save calculation time and resources and ensure the accuracy of simulation calculation, some unimportant factors in the simulation process need to be simplified or even not considered. The following assumptions need to be made:

1) The initial temperature of the test piece is set to 20 °C at room temperature. [18,19]
2) Ignore the impact of droplets and chemical reactions, agitation and convection in the molten pool.
3) It is assumed that all the outer boundaries of the test piece only undergo convective heat transfer with air.
4) The heat source moves along the welding line at a constant speed, and the energy density obeys the Gaussian distribution.
5) The material of the alloy to be welded is isotropic, that is, the thermal physical properties of the material have nothing to do with the spatial position inside the material, but it changes with temperature and has a piecewise linear relationship with temperature.
6) Ignore the residual height generated in the actual welding process, and assume that the surface of the molten pool is flat.

The boundary conditions can be divided into three main types:

The first type of boundary condition is known boundary temperature value.

$$ T_s = T_s(x,y,z,t) $$

The second type of boundary condition is known boundary heat flux density distribution.

$$ k_n \frac{\partial T}{\partial n} = q_s(x,y,z,t) $$

The third type of boundary conditions, known heat exchange between boundary objects and surrounding media

$$ k_n \frac{\partial T}{\partial n} = h(T_a - T_s) $$

$$ k_n \frac{\partial T}{\partial n} = \kappa(T_r - T_s) $$

Adiabatic boundary conditions, that is, no heat exchange between boundaries:

$$ \frac{\partial T}{\partial n} = 0 $$

In the above formulas, $n$ is the direction of the normal outside the boundary surface, $k$ is the thermal conductivity in the direction of the boundary normal, and $q_s$ is the external input heat flow.
per unit area, \( h \) is the convective heat transfer coefficient, \( T_a \) is the temperature of the surrounding medium, \( \kappa \) is the radiation coefficient, \( T_r \) is the temperature of the radiating object, and \( T_s \) is the temperature on the known boundary.

When solving a nonlinear transient problem, there should be an initial condition, which is the temperature distribution of the entire region at the beginning of the process.

\[
T|_{t=0} = T_0 \\
T|_{t=0} = \varphi(x, y, z)
\]

3. Calculation results and analysis of temperature field

3.1. Distribution characteristics of temperature field

By using the heat source checking tool provided by SYSWELD software, through the input of welding process parameters and thermal physical parameters of metal materials, the actual shape and size of weld pool area and weld pool area of workpiece are observed, the parameter setting is constantly modified, and the heat source is checked in order to determine the best heat source mode. The welding section obtained by the experiment is compared with the section checked by the heat source. The overall outline is similar, which indicates that the heat source mode selected by the software can be checked successfully and can be used(Fig.3(a)(b)).

Fig. 4 shows the distribution of temperature field at a certain time from the beginning of welding to the end of welding. The welding process is divided into two processes: the welding and cooling process of the first weld and the welding and cooling process of the second weld of the filling layer. Figure 4 (a), figure 4 (b) shows the temperature field distribution of the weld seam of the blunt edge layer and the filling layer, respectively. It can be seen from figure 4 that the maximum temperature of the first layer weld reaches 2250°C, that is, it has exceeded the melting point of the high strength steel, and the base metal begins to melt, indicating that in the welding, the absorption of laser-arc heat is completed instantly, the temperature of the ordinary arc welding reaches the melting point of the metal material from room temperature to the melting point of the metal material, and there is a stage of unpenetration in the initial stage of laser-arc hybrid welding. On the whole, with the movement of heat source, the temperature field of welding specimen has been in the process of dynamic change, which can be divided into two processes: heating and cooling, and the temperature of welding parts varies with time.

(a) Temperature field distribution of the first layer welding parts (b) temperature field distribution of second-layer weldments

Fig.3 The area division of weld surface.
3.2. Characteristic curve of welding thermal cycle

Select a feature point on a line parallel to the upper surface of the first layer weld and extract the temperature-time curve, as shown in Fig.5. The peak temperature is 2250°C, the laser-arc hybrid welding thermal efficiency is high, the peak temperature of the thermal cycle is high, the second filling welding peak temperature is 1650°C, and when the second layer is welded, since the extracted points are on the upper surface of the blunted edge layer, away from the welding area, while the heat of the first layer has been lost, the heating of the point is small, so the temperature is low.

4. Conclusion

Based on the simulation of laser-arc hybrid welding multi-layer single-pass welding of high strength steel 12mm thick plate, the following conclusions are drawn in this paper. The main results are as follows:

1) The transient temperature field distribution of butt welding of high strength steel plate is obtained by numerical simulation with SYSWELD software, and the temperature change and distribution of workpiece in welding process are understood.

2) The distribution of temperature field in laser-arc hybrid welding can be mastered by finite element simulation, and the software simulation analysis can provide theoretical support and basis for the selection of welding methods in engineering practice.
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