

Quality Evaluation of Hot Melt Welding of Plastic Pipes

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Abstract: In this paper, aiming at the welding quality problems of plastic pipes, finite element analysis method was used to evaluate the quality of welded joints through temperature, melting layer and stress. The results showed that: the crystallization degree and heat transfer distance of the welded surface and its heat-affected zone were different, resulting in different properties of welded joints. Stress stabilization will increase polymer apparent viscosity and reduce melt flow capacity, thus reducing residual stress.

Keywords: Plastic pipe, Simulation analysis, Quality evaluation.

1. Introduction

In recent years, polymer plastic pipeline has become the most economical and environmentally friendly fluid transportation equipment because of its easy processing, corrosion resistance, environmental protection and other advantages. In pipe network construction, hot melt welding operation is simple and fast, economic and reliable, suitable for different specifications of PE pipeline.

Ziad Chebbo[1] analyzed the numerical simulation of polyethylene pipe welding process through experiments and 3D finite element software. NP Starostin[2, 3] analyzed the thermoelastic state of polyethylene pipeline under different ambient temperatures through experiments and analyzed the temperature field law by mathematical model. Xiao Zhao, Yafeng Lv, Yan Liu [4-6] analyzed the distribution law of temperature field and stress field of high density polyethylene gas pipeline by using Ansys software. Jae Hyun Yoo[7] analyzed heat transfer and fluid flow in the butt welding process through finite element simulation. In summary, the literature shows that a large number of studies evaluate the quality of welded joints by simulating the welding temperature field and stress field under standard environment, but do not explore the welding quality of welded joints under outdoor environment. The welding quality was evaluated by temperature, thickness of melting layer and stress stability.

2. Finite Element Simulation

In a general three-dimensional problem, the field variable of the instantaneous temperature field $\phi(x, y, z, t)$ has the differential equation satisfying in the cartesian coordinate system:

$$\rho c \frac{\partial \phi}{\partial t} - \frac{\partial}{\partial x} \left(k_x \frac{\partial \phi}{\partial x} \right) - \frac{\partial}{\partial y} \left(k_y \frac{\partial \phi}{\partial y} \right) - \frac{\partial}{\partial z} \left(k_z \frac{\partial \phi}{\partial z} \right) - \rho Q = 0 \quad (\text{In } \Omega) \quad (1)$$

The boundary conditions are:

$$\phi = \bar{\phi} \quad (\text{On the } \Gamma_1\text{-boundary}) \quad (2)$$

$$k_x \frac{\partial \phi}{\partial x} n_x + k_y \frac{\partial \phi}{\partial y} n_y + k_z \frac{\partial \phi}{\partial z} n_z = q \quad (\text{On the } \Gamma_2\text{-boundary}) \quad (3)$$

$$k_x \frac{\partial \phi}{\partial x} n_x + k_y \frac{\partial \phi}{\partial y} n_y + k_z \frac{\partial \phi}{\partial z} n_z = h(\phi_a - \phi) \quad (\text{On the } \Gamma_3\text{-boundary}) \quad (4)$$

ρ is the material density (Kg/m^3); c is Specific heat

capacity of material ($J/(kg \cdot K)$); t is time (s); k_x, k_y, k_z Is material objects along the three main direction (x, y, z direction) of the coefficient of thermal conductivity ($W/(m \cdot K)$); $Q = Q(x, y, z, t)$ It's the density of the heat source inside the object (W/kg); n_x, n_y, n_z is the direction cosine of the normal outside the boundary; $\bar{\phi} = \bar{\phi}(\Gamma, t)$ is the given temperature on the Γ_1 boundary; $q = q(\Gamma, t)$ Is the given heat flux at the Γ_2 boundary (W/m^2); h Is the convective heat transfer coefficient ($W/m^2 \cdot K$); $\phi_a = \phi_a(\Gamma, t)$, For Γ_3 boundary, under natural convection condition, ϕ_a Is the ambient temperature; Under forced convection conditions, ϕ_a Is the adiabatic wall temperature of the boundary layer.

3. Influencing Factors

(1) Temperature

Heating temperature is the key process parameter of hot melt welding of plastic pipe, which plays a key role in ensuring welding quality. TSG D2002-2006 Technical Rules for the Welding of Polyethylene Pipe for Gas Use requires that the heating temperature be controlled between 200 and 235°C. The research object in this paper is the plastic pipe of PE100, and the heating temperature is 225°C. In this paper, the uniformity of temperature distribution under different environmental conditions is simulated to evaluate the welded joint.

(2) Time

The time factor mainly refers to heating time, switching time and cooling time. Heating time refers to the time it takes for heating to reach the minimum flanging height. In this paper, it is SDR11. The wall thickness is 10mm and the minimum flanging height is 1.5mm, so the heating time is 100s. The switching time refers to the time from taking out the heating plate to closing the pipe to reaching the welding pressure, which is all less than 12s. The switching time in this paper is 3 seconds. Cooling time refers to the time to cool down to room temperature, without depressurizing or moving the pipe in the middle. In this paper, the heating time was improved and optimized based on the melting layer thickness, and the switching time and cooling time remained unchanged.

(3) Pressure

The pressure in the welding process includes heating pressure, welding pressure, holding pressure, etc.

Heating pressure and welding pressure ensure that the polymer intertwine and permeate fully, molecular chain recrystallization completely; Pressure holding pressure is the

pressure exerted to cool the welding joints to normal temperature, but in the cooling process, residual stress will be generated, affecting the welding quality. This paper will analyze the stability of the pressure in the welding process, so as to judge the quality of the welding joints.

In addition, the high-density PE pipeline is also affected by the environment and weather. This paper will explore the distribution of temperature and the thickness of the melting layer in different environments, as well as the stability of the distribution of welding pressure at different times, in order to fully understand the performance of the welded joint and optimize the welding process parameters.

4. Finite Element Analysis

The simulation analysis was carried out from three characterizing parameters: uniformity of temperature field distribution, thickness of melt layer and stability of plane stress.

The higher the uniformity of the temperature field, the higher the degree of crystallization of the welded surface and its heat-affected region, and the higher the welded joint is formed. In other words, it is necessary to explore the influence law of different environments on the plane temperature uniformity and determine the degree of temperature uniformity by comparing the size of the plane temperature uniformity.

The thickness of the melting layer will determine the depth of the entanglement and diffusion of macromolecular chains in the welding process, thus determining the strength of welded joints. The harsh environment will accelerate the heat loss and affect the energy transfer, resulting in the thickness of the melt layer is lower than that of the indoor standard process, which increases the welding quality risk, reduces the welding quality and reduces the service life of the pipeline. Therefore, it is very important to carry out research on the thickness of the melt layer.

As one of the welding process parameters, the variation degree of welding stress will affect the effect of intermolecular permeability. In the absence of external interference, the better the stress stability, the better the welding quality, but due to the internal and external surface cooling rate and material anisotropy, the thermal residual

stress can not be completely avoided, resulting in the decline of welding quality. Based on the results of temperature field, the stability of plane stress is analyzed to provide theoretical support for improving welding quality.

5. Conclusion

Because the ambient temperature and wind speed will lead to great changes in axial and radial temperatures in the cooling process of the pipeline, the crystallization degree and heat transfer distance of the welded surface and its heat-affected area are different, and finally the performance of the welded joint is different. In addition, stress stabilization will increase polymer apparent viscosity and reduce melt flow capacity, thus reducing residual stress.

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