USE OF EPOXY-MODIFIED FLUX SYSTEMS FOR UNDERWATER SUBMERGED ARC WELDING

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This study investigated the synergistic mechanism of the epoxy-modified flux system in underwater submerged arc welding (USAW). Quantitative analysis showed that adding 40 wt % epoxy resin to HJ350 flux could reduce the cooling rate (V_{500}) to 19.57 °C/s and the porosity to 0.35%. X-ray tomography determined that the main droplet transport mode was indirect repulsion transfer (81.8 %), and the droplet diameter was reduced by 31.3% compared with conventional wet welding.

Keywords: underwater welding, submerged arc welding, epoxy flux, cooling rate control, pore suppression

Introduction. Underwater welding technology is the core process of marine engineering (such as submarine pipeline repair and drilling platform maintenance), but there is a fundamental contradiction between the water environment and the welding process. Traditional wet welding faces two core challenges: uncontrolled cooling rate and a surge in hydrogen-induced defects.

In a water environment, the high heat capacity characteristics will cause the welding thermal cycle to accelerate sharply, and the measured cooling rate is extremely high (43.02 °C/s V_{500}), generating brittle structure; water decomposition and diffusion of hydrogen (44.12 ml/100g) increase the risk of pores and hydrogen embrittlement.

Epoxy resin modified flux (40 wt.%) provides triple synergy:
1) Forming a ≥ 25 mm pre-sealing layer, forming a sealing slag skin (25±3μm) to block water;
2) Reducing the cooling rate to 19.57 °C/s (54.5% reduction) and extending the high temperature time ($t_{8/5}$ up to 16.47 s), optimizing the microstructure;
3) Decomposing and producing diluent gas (11.24 vol% C_nH_m), significantly reducing the diffusible hydrogen content. This cooling-metallurgical synergistic regulation method provides a new direction for deep-sea welding.

This material system contains three main components:1) The function of HJ350 flux is to promote the formation of slag, and its main amount is added to 60 wt. %; 2) The epoxy resin is responsible for achieving the function of waterproofing, and the effective content range confirmed by experiments is 30~50 wt. %; 3) Nano-SiO_2 can significantly improve the permeability of slag by adding a small amount, and the recommended addition amount is controlled at 0~5 wt. %.

Research methodology. The experiment used Q345B steel plate with a thickness of 15 mm as the base material. The welding parameters were set as current 280±15 A and voltage 32±2 V. Welding was carried out at a depth of 0.5 m using flux-cored wire under a layer of HJ350 flux with epoxy resin.

Results of experiments and their discussion. Experimental results show that the epoxy-modified flux system significantly extends the thermal cycle time and encourages the control of the cooling rate. When the epoxy content reaches 40 wt.%, the V_{500} cooling rate decreases from 43.02 °C/s to 19.57 °C/s, and the high-temperature holding time $t_{8/5}$ increases from 7.74 s to 16.47 s. This thermal buffering effect transforms the coarse ferrite (grain size is 12.65 μm) into an acicular ferrite group; under the microstructure, the coarse-grained zone of the USAW weld forms an interwoven mesh structure of acicular ferrite (AF) and proeutectoid ferrite (PF), which greatly refines the grains and optimizes the mechanical properties [2,3].

During the solidification process of the weld pool, the epoxy resin decomposes to form 11.24 vol. % CnHm gas. Slag analysis confirmed (Fig. 1[1]) that 40 wt. % epoxy resin forms a continuous FeO-SiO_2-Al_2O_3 slag layer (25±3 μm thick), which completely blocks water penetration. The content of diffusible hydrogen is significantly reduced. Excess epoxy resin (>50 wt.%) causes macrocracks due to gas entrapment [4].

Compared with the traditional process, three key process parameters with 40% epoxy flux showed significant changes: the cooling rate (V_{500}) decreased from 43.02°C/s to 19.57°C/s, an optimization of 54.5%; the porosity decreased from 0.75% to 0.35%, a decrease of 53.3%; the droplet diameter increased from 2.2 mm to 3.2 mm, an increase of 31.3%.

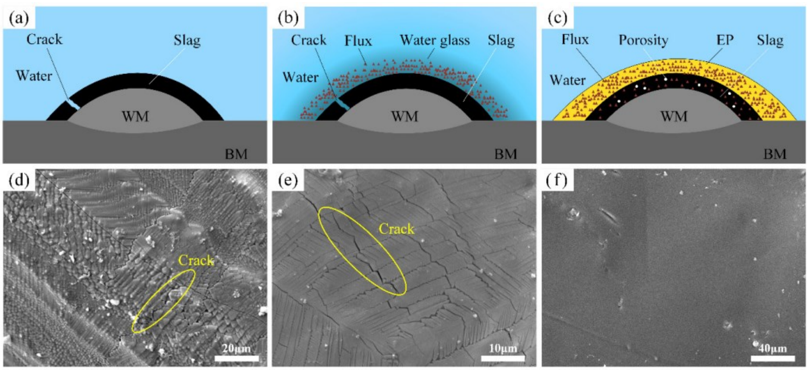

Fig. 1. a, b, c – Schematic diagram of the macrostructure of UWW, waterglass-USAW, and epoxy-USAW slag; d, e, f – SEM results of the corresponding processes.

X-rays confirmed that there are three modes of droplet migration in epoxy submerged arc welding: front wall transition (47.65%), rear wall transition (45.29%), and repulsive transition (7.06%). The slag wall guidance mode (front wall + rear wall) accounts for 92.94%. In this mode, not only can the size of the droplet be optimized, but it is also a key physical barrier to prevent hydrogen penetration [5].

Mechanical tests have shown that the strengthening synergistic effect significantly improves the plasticity. The USAW joint achieves full plastic deformation (180° without cracking) in the flexural test, which is significantly better than UWW (62.5° failure).

The USAW sample has no cracks on the surface, while the UWW sample cracks early. This ductile failure is due to:1) The interlaced structure of acicular ferrite prevents crack propagation due to mechanical bite; 2) The fine grain strengthening improves the resistance to grain boundary sliding.

Current limitations include insufficient experimental validation for thick plates (>16 mm), because existing studies used base materials with a thickness of 8–16 mm thickness [1,2,3]. Laboratory trials with optimized parameters (flux: HJ350 + 40% epoxy resin; current: 280±15A; voltage: 32±2V) achieved leak-free joints under 30 MPa hydrostatic pressure at a depth of 0.3 m water depth, with 100% RT certification demonstrating consistent performance in simulated deep-sea environments [2].

Conclusions. Thanks to the joint cooling and metallurgical control strategy and coordinated optimization, the microstructure optimization conditions are created and the diffusible hydrogen content is significantly reduced. Further research should be aimed at: Thickness limitation (current maximum: 20 mm); Development of bioresins to replace epoxy resins.

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