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Investigation of microstructure and mechanical properties of explosively welded ITER-grade 316L(N)/CuCrZr hollow structural member

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HIGHLIGHTS

- Develop a new explosive welding method to fabricate the hollow structural member.
- Effects of solution annealing on microstructure of welding interface researched.
- Influence of heat treatments on hardness evolution in welding interface studied.
- The ultimate strength and elongation were increased after solution annealing.
- The interface of samples was exhibited ductile fracture after solution annealing.

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ABSTRACT

In this study, a new explosive welding method furnished an effective way for manufacturing ITER-grade 316L(N) stainless steel/CuCrZr alloy hollow structural member. In order to recover some hardening effects, caused by plastic deformation during explosion welding in the materials bonding interface region, the welded samples were subject to the solution annealing (SA) treatment at 970 °C for 30 min. The SA heat-treated samples were then aged at 580 °C for 2 h. Optical microscopy (OM) and electron microscopy (SEM) were used to analyze the microstructure of bonding interface. Energy dispersive spectroscopy (EDS) analysis was performed to investigate the diffusion zone formed in the interface region after the solution annealing (SA) treatment. Moreover, the mechanical properties of the welded samples were evaluated through microhardness test and tensile strength test.

Microstructural analysis showed that the welded sample had a wavy interface, and there was no melting zone and intermetallic layer formed in the interface. The result of microhardness test revealed an increase in hardness for both sides near to the bonding interface; this is due to more severe plastic deformation in these regions during the explosive welding. After the tensile test, obvious necking was observed in the fracture cross section of samples. SEM observation indicated that the samples with the post solution annealing treatment exhibited a ductile fracture with dimple features after tensile test.

1. Introduction

In the structural design of the International Thermonuclear Experimental Reactor (ITER), the first wall (FW) module is designed with the super evaporator cooling channel structure, irregular three-dimensional surface, super constraint assembly of multiple "finger" and center beam, etc. [1–4]. The super evaporator cooling channel is composed of 316L(N) stainless steel cover plate and CuCrZr cooling trough in hollow structure. The cooling trough includes base, trough body and channel cavity, as shown in Fig. 1. It is welded with the 316L(N) stainless steel cover plate to constitute a complete cooling channel member, as shown in Fig. 2.

Currently, the welding of this kind hollow structure metal part mainly uses brazing, friction stir welding and fusion welding. A brazing solder with low melting point is required on the welding surface, leading to poor thermal resistance and lower joint strength. Friction stir weld joints between CuCrZr and stainless steel showed

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Table 1
The chemical composition (wt%) of 316L(N)–IG stainless steel and CuCrZr–IG alloy.

	Elements (% weight)										
	C	Ni	Cr	Zr	Mn	Si	Nb	N	Ta	Fe	Cu
316L(N)–IG	<0.03	13.8	16.6	–	<2.0	<0.75	–	0.16	–	Balanced	–
CuCrZr–IG	–	–	0.64	0.082	–	–	<0.1	–	<0.01	–	Balanced

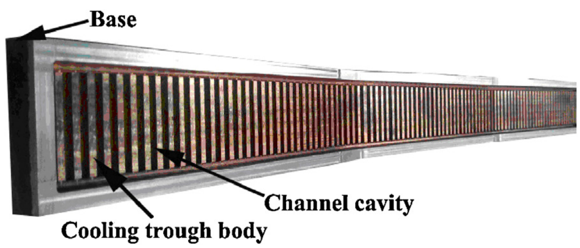

Fig. 1. Cooling trough appearance.

best results when performed in an over-aged state [5]. But, the joint strength was also relatively low. The performance for 316L(N) stainless steel and CuCrZr alloy has a big difference both in the melting point and thermal conductivity, leading to the poor weldability, and making it hard to use fusion welding method to complete the high quality welding.

Explosive welding is a solid-state welding technique, which utilizes detonation pressure to drive a cladding plate towards a base plate to create a crash (see Fig. 3); the high velocity of oblique impact in the crash generates a jet which contains the materials of the surfaces, and brings them together to create a metallurgical bond.

Explosive welding technology applies to a wide range of metal combination. The metals with big difference of melting point and thermal expansion coefficient can be used for explosive welding [6]. Compared with other welding methods, the explosive welding can form a good metallurgical bonding, having high bonding strength. The characteristics of the explosive welding are very suitable for such 316L(N)/CuCrZr dissimilar bulk metals joining.

But, the application research of explosive welding mainly emphasizes on the welding of planar metal composite panels, metal composite tubes and rods [7–9]. There are few studies on the explosive welding of metal parts in hollow structure. Compared with the plane or curve structure members, the explosive welding of structural members in hollow structure faces a lot of challenges to be solved. First, for welding, since the cavity of cooling trough has no bearing capacity, the convex part of trough may form strong shearing action to the cover plate, and then leading to the cover plate rupture. Second, if the pressure bearing module is set in the cavity, after welding, the extending deformation of trough part may clamp the module, making it difficult to release from the cavity. Finally, after the completion of welding, the cover plate and trough form an airtight structure, which is difficult to correct the welding deformation.

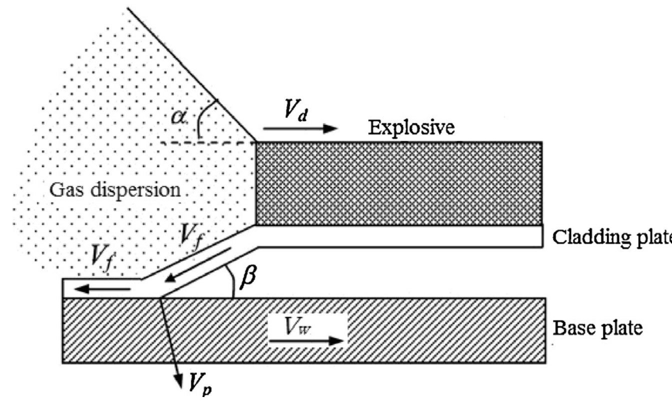

Fig. 3. Schematic diagram of explosive welding.

The goal of this study is to explore a new explosive welding technology for 316L(N)/CuCrZr double metal hollow structural member, and to evaluate the performance of the explosively welded sample.

2. Materials and methods

2.1. Material

The test materials use ITER certified CuCrZr–IG alloy and 316L(N)–IG stainless steel. The chemical composition of the age hardened CuCrZr–IG alloy and 316L(N)–IG stainless steel are given in Table 1.

The 316L(N) and CuCrZr raw materials were machined respectively into a cover plate and the cooling groove based on the size shown in Fig. 2. The surfaces of raw materials were ground by a handheld fine wheel and then further polished until the surface roughness reached $Ra < 5\ \mu m$.

A powdery emulsion explosive (ammonium nitrate 92% and fuel-oil 8%), known as ANFO, was chosen as explosive material. Its detonation velocity was 2300–2500 m/s and its density 0.8 g/cm^3.

2.2. Experimental procedure

The experimental process is shown in Fig. 4. A three-step explosive welding method modified by the explosive welding method of flat plate, was developed:

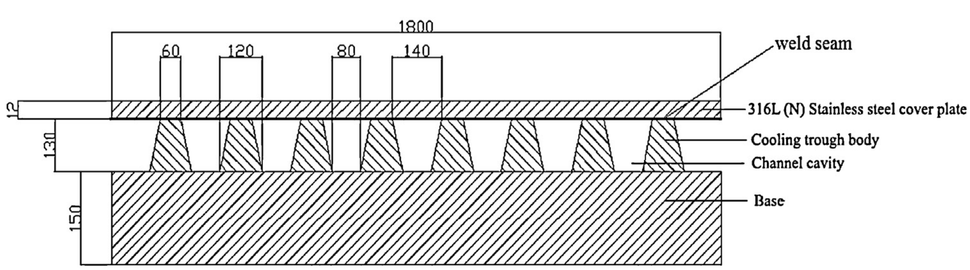

Fig. 2. Cooling channel sketch.