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Experimental study on hollow structural component by explosive welding

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HIGHLIGHTS

- This paper relates to a study on a thin double-layers hollow structural component by using an explosive welding technology.
- This thin double-layer hollow structural component is an indispensable component required for certain core equipment of thermonuclear experimental reactor.
- An adjusted explosive welding technology for manufacturing an inconel625 hollow structural component was developed which cannot be made by common technology.
- The result shows that a metallurgical bonding was realized by the ribs and slabs of the hollow sheet.
- The shearing strength of bonding interface exceeds that of the parent metal.

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ABSTRACT

A large thin-walled hollow structural component with sealed channels is required for the vacuum chamber of a thermonuclear experimental reactor, with inconel625 as its fabrication material. This hollow structural component is rarely manufactured by normal machining method, and its manufacture is also problematic in the field of explosive welding. With this in mind, we developed an adjusted explosive welding technology which involves a two-step design, setting and annealing technology. The joints were evaluated using optical microscope and scanning electron microscope, and a mechanical experiment was conducted, involving micro-hardness test, cold helium leak test and hydraulic pressure test. The results showed that a metallurgical bonding was realized by the ribs and slabs, and the shearing strength of the bonding interface exceeded that of the parent metal. Hence, the hollow structural component has a good comprehensive mechanical performance and sealing property.

1. Introduction

A large thin-walled hollow structural component with sealed channels is required for the vacuum chamber of a thermonuclear experimental reactor constructed in China. The hollow structural component is composed of internal and external slabs and multiple rib pieces, with the dimension of internal and external slabs all being 600 mm × 350 mm × 6 mm, the rib dimension being 600 mm × 12 mm × 18 mm, and the material being inconel625. Multiple sealed channels are formed between the ribs and the slabs to transport the cooling liquid for heat dissipation. This hollow structural component is a main pressure-bearing structural member in the vacuum chamber [1], whose maximal load may reach 42-times atmospheric pressure [2]. The maximum service temperature of the hollow structural component may be over 600 °C. Therefore, the fabrication of this hollow structural component is one of the critical processes in vacuum chamber construction.

The explosive welding is a type of processing technology where the explosive provides the energy so that more than two kinds of similar or inhomogeneous metallic elements can reach solid-phase connection [3].

A multi-layer plate with AA5083/AA1050 (interlayer) aluminum alloys/SS41 steel sequence was manufactured by the explosive welding method, and the variations of the interface morphology and the shear properties with thickness of the AA1050 aluminum alloy interlayer were investigated by Han and colleagues [4]. 304 L

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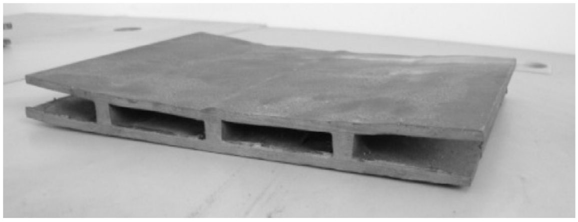

Fig. 1. Actual product photo of explosive welding hollow structural component.

(ASTM A312) stainless steel tubes and 51CrV4 spring steel rods were cladding together by Mendes et al. [5]. The bonding properties of the interface in Fe/Al clad tube prepared by explosive welding were investigated by Sun and colleagues [6]. However, research on explosive welding application mainly focuses on multi-layer composite plate, metallic composite tube and rod, while there are few studies on explosive welding for structural components with complex form [7].

Compared with welding of other types of elements, the welding of the hollow structural component is recognized as problematic in the field of explosive welding [8–10,11–17]. Since there are multiple cavities separated by ribs inside the hollow structural component, it is very difficult to prevent the explosion destroying the thin slabs of the structural component. This line of research has been pursued by Holtzman and Rundershausen (1981), Lines (1971) and others, but the experimental details and the experimental condition for good bonding have not been reported [18].

This paper describes how the inconel625 hollow structural component was successfully manufactured by utilizing an adjusted explosive welding method, as shown in Fig. 1. It also discusses in detail the morphology and properties of the interface of the hollow structural component.

2. Experimental details

2.1. Material and its preparation

Inconel625 alloy is an Austenite nickel-based alloy [19]. It contains Cr ~ 23.0 at%, Mo ~ 10.0 at%, Fe ~ 5.0 at%, Mn ~ 0.5 at%, Si ~ 0.5 at%, Al ~ 0.4 at%, and is balanced with Ni.

Inconel625 (UNS6625) rolling slabs provided by a research institute of the China National Nuclear Corporation are used as slabs and ribs.

The inconel625 slab is endowed with severe cold hardening characteristics and always adheres to the cutting tool. During the machining operation, deformation and warping can easily occur due to the influence of hot machining. In order to reduce deformation of the workpiece, a water cutter is used to cut and convert the inconel625 cold-rolling slab with thickness of 6 mm and 12 mm into slabs and ribs, respectively.

The surface of the workpiece is ground by a handheld fine wheel and then further polished until the surface roughness reaches Ra < 6 μm.

2.2. Two-step explosive welding method and its development

There is a significant difference between explosive welding technology of hollow structure and that of conventional multi-plates.

If no supporting mold is used to fill the existing large cavity between the ribs or if an unsuitable supporting mold is used, explosive welding tends to damage the slabs. To prevent this damage, a suitable filling mold is essential.

Because the structure of the hollow structural component is special, welding should be completed in two stages. The first stage is welding the internal slab and ribs together. The second stage is welding the external slab and the internal (ribbed) slab together.

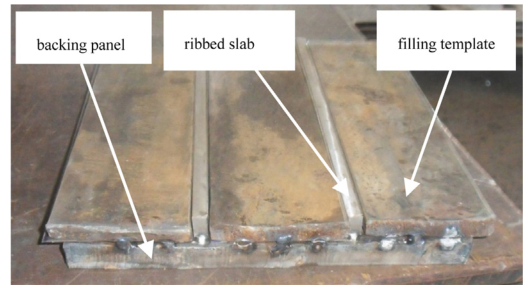

Fig. 2. Assembly picture of filling template in the first stage.

2.2.1. Welding experiment: first stage

The filling molds in the two stages are different. The filling mold in the first stage mainly provides a bearing platform for the internal slab, to prevent impact damage to the slab from the ribs. Therefore, the mechanical property of this material should be as close as possible to that of inconel625. Several common steels are compared in Table 1.

By comparing mechanical properties of the steels in Table 1 and that of inconel625, the mechanical property of 45 medium carbon steel was found to be closest to that of inconel625. Therefore, 45 medium carbon steel was used to make filling templates, and in order to facilitate the installation of ribs and supporting templates, a steel shim with a thickness of 20 mm was first placed on the anvil, as shown in Fig. 2.

The results of the welding experiment in the first stage are shown in Fig. 3: the internal slab and ribs welded together, and filling molds are demolded easily.

2.2.2. Welding experiment: second stage

Demolding of the inside filling template in the second stage is more complicated than in the first stage. The two slabs and ribs have gathered together, and the filling template has been clamped by two slabs and ribs on both sides, so the filling template can be taken out only from the ends of the inside channel, as shown in Fig. 4.

If a steel filling template is used in filling, as in the first stage, the steel template will be clamped in a narrow channel of the component and it will be hard to demold by manual or mechanical force, as shown in Fig. 5. Hence, material that is easy to demold should be used to make the filling mold in the second stage. The following experiments were carried out.

2.2.2.1. Low melting point alloy filling experiment. The American Denver Research Institute has made a Ti-6V-4 V ribbed strengthened structural component, using a low melting point alloy as the

Fig. 3. Welded ribbed single slab after explosive welding in the first stage.