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Underwater explosive welding of tungsten to reduced-activation ferritic steel F82H

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HIGHLIGHTS

- The underwater explosive welding was successfully applied in the joining of tungsten to F82H reduced activation ferritic steel.
- Microstructure of the interface showed the formation of a wave-like interface with a thin mixed layer of tungsten and F82H.
- Nanoindentation hardness results exhibited a gradual change away from the welded interface without hardened layer.
- Small punch tests on the welded specimens resulted in the cracking at a center of tungsten followed by the interfacial cracking.

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ABSTRACT

The present study reports the underwater explosive welding of commercially pure tungsten onto the surface of a reduced-activation ferritic steel F82H plate. Cross-sectional observation revealed the formation of a wave-like interface, consisting of a thin mixed layer of W and F82H. The results of nanoindentation hardness testing identified a gradual progressive change in the interface, with no hardened or brittle layer being observed. Small punch tests on the welded specimens resulted in cracking at the center of the tungsten, followed by crack propagation toward both the tungsten surface and the tungsten/steel interface.

1. Introduction

Plasma facing components based on tungsten-coated reduced-activation ferritic (RAF) steels are a key aspect to the realization of fusion-based nuclear reactors; as such, these components are able to withstand the severe environment created by energetic particle irradiation at high temperatures [1]. Various coating/welding technologies have therefore been examined, including: diffusion bonding [2], spark plasma sintering [3], and vacuum plasma spraying [4]. However, there are still concerns that the mechanical properties in the vicinity of the bonding interface may deteriorate during processing or operation, due to the thermal stress induced by the difference in the coefficients of thermal expansion (CTE) of tungsten and RAF steels at high temperatures.

Explosive welding is a well-known solid-state welding technique that uses the controlled energy of a detonating explosive directed onto the material surface [5]. This process is generally performed in atmosphere by placing an explosive charge on the surface of a flyer plate, which is located well away from the base plate in order to achieve the desired velocity during collision of the two plates. However, as shown in Fig. 1, such a method has been found to be unsuitable for the fusing of tungsten to ferritic steels (SUS430), due to the brittle nature of tungsten.

The underwater explosive welding process developed by one of the authors has been successfully applied to the joining of a number of similar and dissimilar materials, including tungsten foil to a copper base plate [6–8]. The shock wave generated underwater offers the advantage of allowing the uniform acceleration of a thin flyer plate. The present study examines the application of underwater

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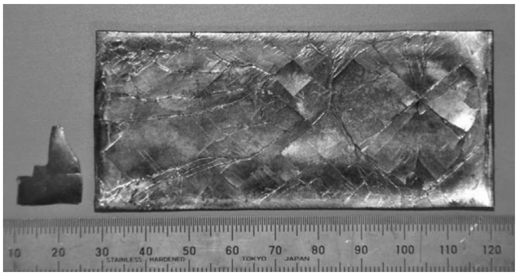

Fig. 1. Photograph of a tungsten coating on commercial ferritic steel (SUS430) obtained by conventional in-air explosive welding.

explosive welding to the fabrication of tungsten coated RAF steel for first-wall fusion reactor components. The microstructure of the resulting interface is investigated by field emission type electron microprobe analyzer (FE-EPMA), and the mechanical performance of the weld is evaluated by nanoindentation hardness and small punch (SP) testing.

2. Experimental method

2.1. Underwater explosive welding

All underwater explosive welding was carried out at the Shock Wave and Condensed Matter Research Center of Kumamoto University. Fig. 2 shows the experimental set-up used for the underwater explosive welding of tungsten and F82H. For the base plate, a 50 mm square sheet, 3 mm in thickness, of F82H-IEA (Fe–8Cr–2W–V–Ta–0.1C) was used; while the flyer plate was a 0.2 mm thick, 50 mm square tungsten foil that was purchased from Nilaco Co. A cover plate consisting of 0.2 mm thick stainless steel sheets was positioned 0.1 mm away from the tungsten flyer plate, so that the flyer plate achieves the required velocity conducive to welding. The entire set-up was then water-sealed and placed on an

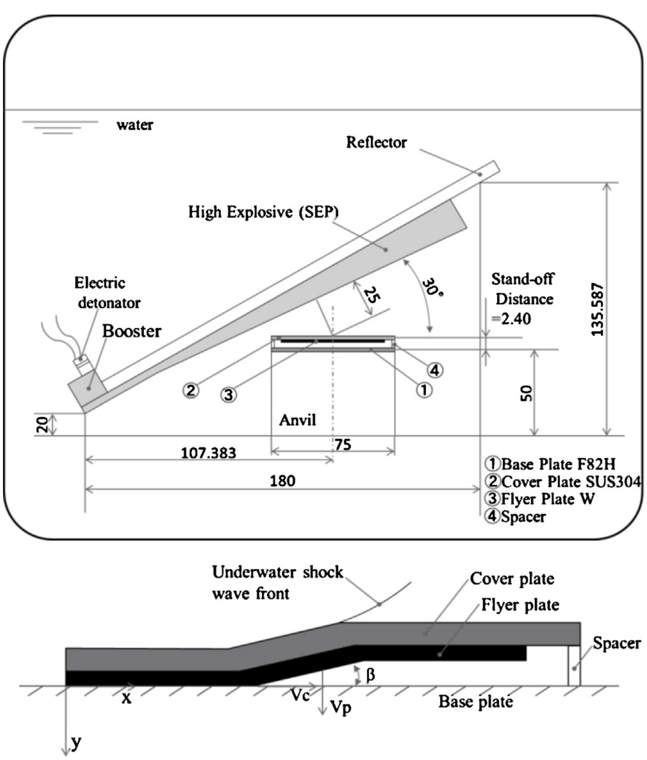

Fig. 2. Schematic drawing of underwater explosive welding.

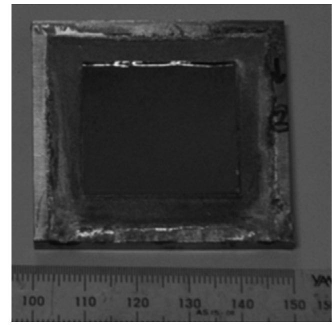

Fig. 3. Photograph of the tungsten coating on F82H RAF steel obtained by underwater explosive welding.

anvil. A plastic explosive, SEP, with a detonation velocity 7000 m/s and a density of 1310 kg/m^3, was supplied by Kayaku Japan Co. Ltd., Japan and used for all explosion experiments. The plastic explosive was suitably molded on a PMMA plate, and then placed at preset angle of 30° with an electric detonator for initiating the explosion. The stand-off distance between the center of the sample and the explosive was fixed at 25 mm for all experiments.

2.2. Material characterizations

Longitudinal cross-sections of the welded samples along the detonation direction were fabricated by electric discharge wire-cutting and mechanical polishing. Microstructural observation and chemical map analysis was performed using a JEOL JXA-8500F FE-EPMA.

The cross-sectional hardness distribution was measured using an Agilent Technologies NanoIndenter G200. Continuous stiffness measurements were used for the nanoindentation hardness evaluation [9].

SP tests [10] were carried out at room temperature with a crosshead speed of 0.2 mm/min. Disk specimens of 3 mm diameter were cut from the welded sample, and were mechanically polished to reduce the thickness of the F82H to 0.2 mm. A 1 mm diameter hardened steel ball was then loaded onto the F82H side of the disk specimen. The resulting fracture surface was then observed by a JEOL JSM-6010LA scanning electron microscope (SEM).

3. Results and discussion

Fig. 3 shows a photograph of the tungsten layer formed on F82H after underwater explosive welding. Although some peeling was evident at the starting point of welding, the present conditions

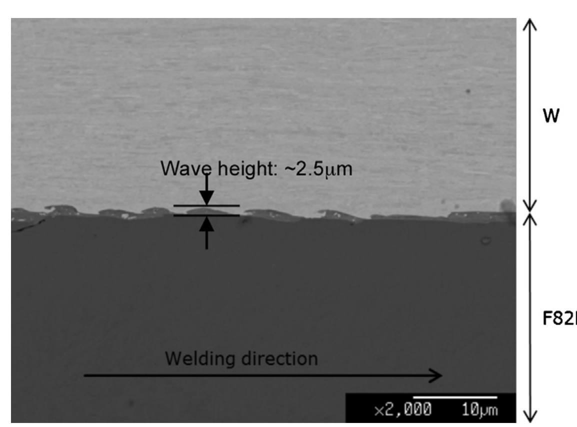

Fig. 4. Longitudinal cross-section in the welding direction, showing the microstructure at the center of the sample.