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Performance Test of a Diffusion Bonded Waveguide Sensor for Under-Sodium Visualization

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1. Introduction

In a Generation IV sodium-cooled fast reactor (SFR), liquid sodium is used as a coolant due to its good heat capacity and thermal conduction properties. However, visual inspection of reactor internals, which is quite important for the safety, is very difficult because liquid sodium is optically opaque. Thus, the ultrasonic inspection technique has been employed for in-service inspection of reactor internals thus far from the early development of an SFR and two types of ultrasonic sensors (immersion [1, 2] and waveguide sensors [3, 4]) have been mainly developed. A waveguide sensor installs an ultrasonic sensor in a cold region outside the reactor whereas an immersion sensor is directly immersed in hot liquid sodium. Therefore, the waveguide sensor can be efficiently applied to long-term inspection in hot liquid sodium even though it provides lower resolution images than those obtained by the immersion sensor owing to the frequency limitation caused by the long propagation distance.

In relation to the waveguide sensor technology, a method to coat thin beryllium (Be) and nickel (Ni) layers on the radiation surfaces of the sensor using the brazing technique has been recently proposed to improve the radiation efficiency of the ultrasonic wave into liquid sodium [5]. However, this brazing technique can decrease the signal sensitivity because it uses a filler metal which acts as an obstacle to the ultrasonic wave propagation. To overcome this problem, the diffusion bonding technique is newly proposed and employed to coat thin beryllium and nickel layers on the radiation surfaces of the sensor in this work. And the under-sodium test of the diffusion bonded waveguide sensor was also carried out to demonstrate the performance improvement.

2. Diffusion Bonded Waveguide Sensor

Thin beryllium and mirror-like polished nickel layers are coated on the radiation surfaces of the waveguide sensor to improve the ultrasonic radiation ability and the sodium wetting property in a sodium environment, respectively as shown in Fig. 1. In a newly developed waveguide sensor, 0.25 mm thick beryllium and 0.1 mm thick nickel layers were coated by the diffusion bonding technique which uses a diffusion phenomenon between contact surfaces generated in a high pressure and temperature condition in a vacuum environment. Because the diffusion bonding technique does not need a filler metal unlike the brazing technique, the ultrasonic wave can propagate without any additional effects caused by the filler metal and this can enhance the signal sensitivity of the ultrasonic wave.

Fig. 1 also shows the ultrasonic C-scan result of the diffusion bonded radiation end section of the waveguide sensor. The C-scan was performed in water and an immersion ultrasonic sensor centered at 20 MHz was used. From the results, one can see that beryllium and nickel layers are uniformly bonded on the radiation surfaces by the diffusion bonding technique.

The whole feature of the diffusion bonded waveguide sensor is shown in Fig. 2. It consists of a 10 m long SS304 plate, an acoustic shielding tube and a bellows. The thickness and width of the SS304 plate are 1.5 mm and 15 mm, respectively. The shielding tube with 1.5 m in length and 19 mm in outer diameter is employed to protect from energy leakage into surrounding liquid sodium during the ultrasonic wave propagation through the SS304 plate. In addition, argon (Ar) gas inlet and outlet are installed on the top of the shielding tube to prevent the air from inflowing into inside the shielding tube.

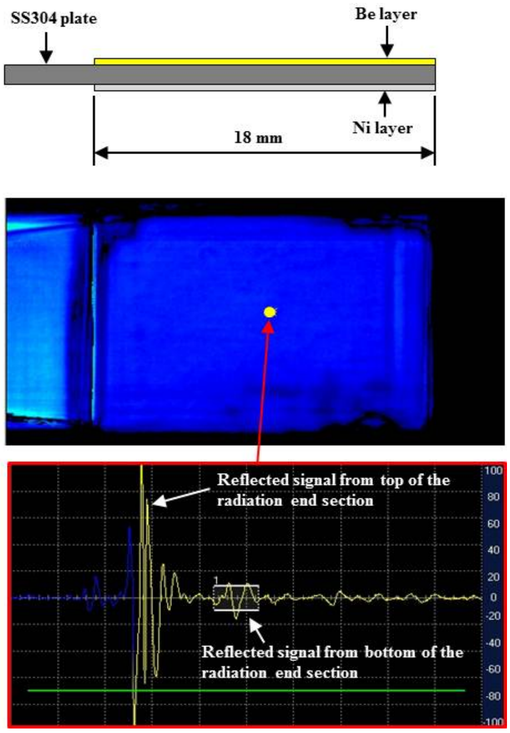

Fig. 1. Diffusion bonded radiation end section of the waveguide sensor and its C-scan result.

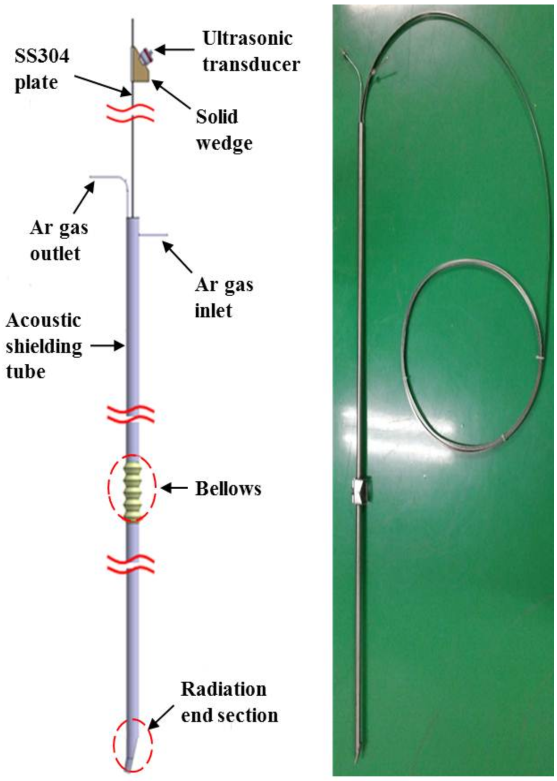

Fig. 2. Diffusion bonded waveguide sensor.

Once the ultrasonic wave is generated by the ultrasonic transducer, it is converted into A_0 mode Lamb wave in the SS304 plate. Then, it propagates through the plate and is radiated into liquid sodium at the radiation end section of the sensor. The angle of the radiation end section is 20° to the vertical direction of the sensor to vertically radiate the ultrasonic wave into liquid sodium. And the fine adjustment of the radiation angle can be controlled by the bellows installed in the middle of the shielding tube.

3. Under-Sodium Performance Test

3.1 Sodium Test Facility

The under-sodium performance test of the diffusion bonded waveguide sensor was carried out using the sodium test facility as shown in Fig. 3. The test facility consists of a sodium storage tank, an open-type sodium test chamber, a glove box, an argon purification system and a main control box. Three sodium pipes were installed between the sodium storage tank and the test chamber for sodium feeding, drain and over flowing. An XYZ scanner is installed inside the glove box to control the position of a test specimen. The waveguide sensor is installed through the roof of the glove box with a flange and only the radiation end section is immersed in liquid sodium. The temperature of each part of the facility is controlled by the main control box.

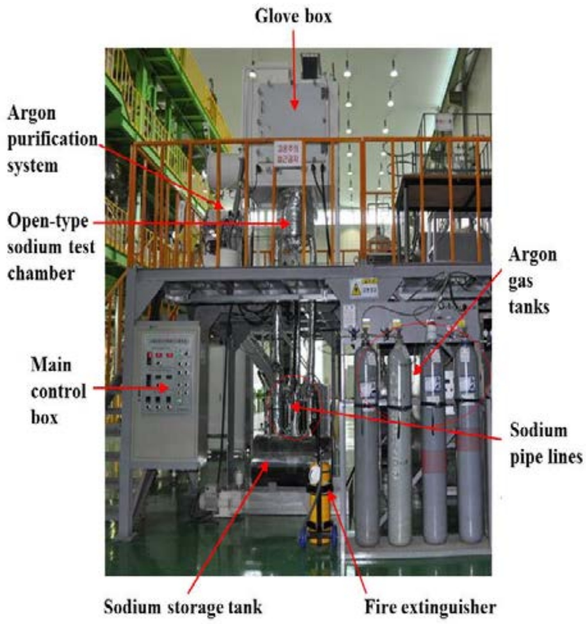

Fig. 3. Sodium test facility

3.2 A-scan test

To evaluate the signal sensitivity of the diffusion bonded waveguide sensor, the A-scan test was carried out using a square block reflector. When a 4-cycle sine pulse is generated by a function generator (Agilent 33521A), it is amplified by a power amplifier (Ritec GA 2500) and input to an ultrasonic transducer installed 10 m away from the radiation end section. Then, ultrasonic wave propagates along the 10 m long waveguide and is radiated to the reflector at the radiation end section. The distance between the reflector and the radiation end section of the sensor was 30 mm, and the signal sensitivity was evaluated using the measured reflected signal from the reflector. Fig. 4 shows the measured reflected signal by the diffusion bonded waveguide sensor in 200°C liquid sodium. From the figure, one can calculate that the signal-to-noise ratio of the 10 m long diffusion bonded waveguide sensor is almost 16 dB.

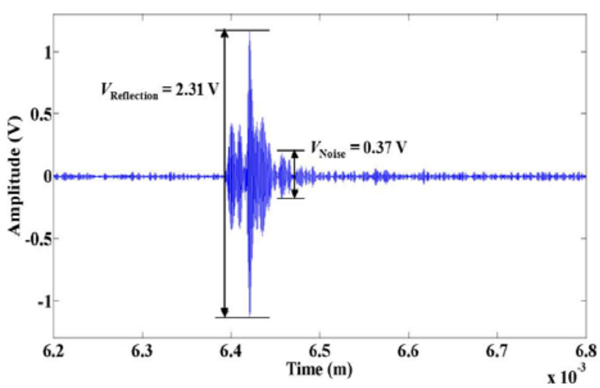

Fig. 4. The measured reflected signal by the diffusion bonded waveguide senor in 200°C liquid sodium.

3.3 C-scan test

The C-scan test was also conducted to evaluate the detectability of the diffusion bonded waveguide sensor using a test specimen made of stainless steel as shown in Fig. 5(a). The length, width and thickness of the test specimen are 85 mm, 50 mm, and 10 mm, respectively, and it has four 2 mm thick slits whose widths are 2 mm, 1 mm, 0.8 mm, and 0.5 mm, respectively. In this C-scan test, the distance between the specimen and the radiation end section of the sensor was 30 mm, and the specimen was moved by the XYZ scanner to the pre-determined positions. The obtained C-scan image is shown in Fig. 5(b). From the image, one can see that the diffusion bonded waveguide sensor can well detect all slits including a slit whose width is 0.5 mm.

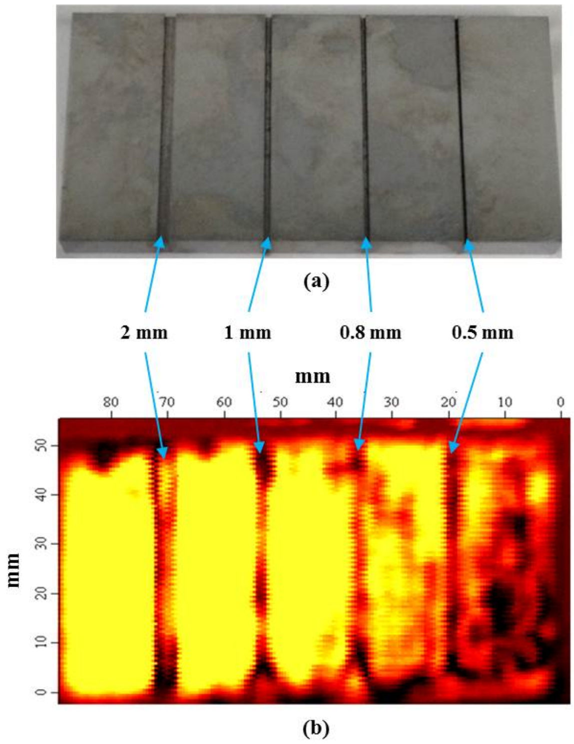

Fig. 5. (a) Test specimen for the C-scan test. (b) C-scan image obtained by the diffusion bonded waveguide sensor in 200°C liquid sodium.

4. Conclusions

In this work, a 10 m long diffusion bonded waveguide sensor was newly developed and its performance test was carried out in 200°C liquid sodium. Since the diffusion bonding technique does not use a filler metal which is required for the brazing technique, the ultrasonic wave can propagate without any additional effects caused by the filler metal. And this can improve the radiation efficiency of the sensor. The performance improvement of the sensor was clearly demonstrated through under sodium experiments. The signal-to-noise ratio was almost 16 dB and a 0.5 mm width slit was clearly detected in 200°C liquid sodium.

Acknowledgement

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