

Mechanical properties of weldments using irradiated stainless steel welded by the laser method for ITER blanket replacement

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Abstract

In the case of a blanket module replacement in the ITER, cooling water pipe will be joined to irradiated pipe by the laser welding method. On the cooling water piping of the ITER blanket, various loads (the vibration of coolant flow, plasma disruption or deadweight of blanket) will be applied to the joint. Therefore, an evaluation of the mechanical properties of weldments using irradiated material is necessary for replacement of the cooling water piping of the ITER blanket. In this study, the bending strength of weldments on irradiated material using the laser welding method was evaluated. This study made clear that the bending strength of weldments using irradiated material with 3.3 appm He by the laser welding method was similar to that of weldments of un-irradiated material to un-irradiated material. On the weldments using irradiated material, small bubbles were observed at the grain boundaries in heat-affected zone because the coagulation of helium generated in irradiated material was accelerated by heat input from laser welding. However, small bubbles did not have a bad influence on the bending strength up to at least 300 °C.

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1. Introduction

For replacement of the blanket of the International Thermonuclear Experimental Reactor (ITER), the cooling water pipe of the blanket must

be joined to irradiated cooling water pipe by the laser welding method. As for the joining technology of irradiated material, a tungsten inert gas (TIG) welding method and a laser welding method were investigated [1–3]. In welding irradiated material, the helium present in irradiated material affects the validity of the laser welding method and mechanical properties of weldments. At the cooling pipe of the ITER blanket, various loads (the vibration of cooling water flow, plasma disruption and so on) would be present at the joint during the operation of

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ITER. Therefore, the estimation of mechanical properties of weldments is an important consideration. For the study of laser welding using irradiated material, the laser welding method was found effective to weld irradiated material without defects and the tensile strength of weldments was about the same as that of un-irradiated material [4]. However, there are few studies of bending properties using irradiated ITER candidate material.

In this study, weldments using irradiated material and un-irradiated material were fabricated by the laser welding method, and the bending properties of weldments using irradiated material were evaluated.

2. Experiment

2.1. Material

In this study, SS316LN-IG was used as the stainless steel because this is a candidate material for ITER cooling pipe. The chemical composition of SS316LN-IG is shown in Table 1. For the preparation of irradiated material, irradiation was performed at the JMTR (Japan Materials Test Reactor) of JAERI (Japan Atomic Energy Research Institute). The fast neutron fluence was determined by fluence monitors (Fe wire), and its maximum value was about 1.6×10^{24} n/m² ($E > 1$ MeV), corresponding to a displacement dose of approximately 0.2 dpa (displacement per atom). The thermal neutron fluence was determined by fluence monitors (Al–Co wire), and its maximum value was about 4.0×10^{20} n/cm² ($E < 0.68$ eV). The irradiation temperature of the specimens was calculated by the ABAQUS code, and it was about 200 °C. After the

neutron irradiation, the helium content in the irradiated materials was measured by melting the actual irradiated material, and it was found to be 3.3 appm.

2.2. Fabrication of specimens

In this study, three types specimens made from weldments and two types of specimens of base material were prepared. As the three types of weldment specimens, Type-A was a combination of an un-irradiated material and an un-irradiated material, Type-B was the combination of an irradiated material and an un-irradiated material, and Type-C was the combination of an irradiated material and an irradiated material. For the two types of specimens of base material, un-irradiated base material specimens and irradiated base material specimens were prepared as reference for the weldments. Weldments were fabricated by a YAG laser welding machine (LAY-659F, Toshiba Co.) without filler metal. As the welding parameters for the laser welding were as follows: laser power was 1 kW (pulse laser), welding speed was 0.5 m/min and the welding heat input was about 1.2 kJ/cm. During welding, materials were supported with no load at the butt position to prevent residual stresses from the heat input was of the welding process. Liquid dye penetration testing at room temperature was performed in order to confirm the macro-integrity of weldment specimens, and the penetration period and development period were both 15 min. It was confirmed that all weldment specimens were intact without cracks. Figures of the bending specimens are shown in Fig. 1.

2.3. Test procedure

Three-point bending tests were performed using the procedure shown in Fig. 2. The loading speed was 0.5 mm/min. In this study, face bend tests and root bend tests were performed on each of the weldments for evaluation of the influence of the directions of the bending load and the heat input.

Bending strength was calculated by the following equation:

$$S = \frac{3P_y L}{2wt^2} \quad (1)$$

S : bending strength (kN/mm²);

P_y : maximum load (kN);

L : distance of support point (=20 mm);

w : width of specimen (=4 mm);

t : thickness of specimen (=3 mm).

Table 1
The chemical composition of SS316LN-IG

Elements	Content	Unit
Fe	Balance	
C	0.029	
Mn	1.64	
Si	0.44	
P	0.012	
S	0.009	
Cr	17.48	wt%
Ni	12.11	
Mo	2.56	
Nb	0.067	
Cu	0.07	
Co	0.02	
N	0.067	
B	3	ppm

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