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Development of remote handling technology of liquid lithium target and replaceable back plate with lip seal in IFMIF-EVEDA

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ABSTRACT

The IFMIF is an accelerator-based intense neutron source for testing candidate fusion materials. Intense neutrons equivalent to neutron irradiation damage of about 50 dPa/y are emitted inside the Li flow through a back plate. Around the back plate, a lip seal made of 316 L is welded by laser-welding system for replacement by remote handling. The back plate will be designed for replacement at least every year. According to material tests of the lip seal weld joint (316 L/316 L) at room temperature, significant deterioration was not observed. Further investigation of the welding process of the lip seal such as a welding direction and a welding joint shape is in progress. Remote handling procedure of the back plate is examined. At first, three lip seal joints of connection piping will be cut by the laser cutting/welding device and then the target assembly with the back plate will be moved to a hot cell. The back plate lip seal will be cut by the laser arm in the hot cell. After machining and Li cleaning of the lip seal, a new back plate will be welded and moved to test cell/target room.

1. Introduction

The International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based D-Li neutron source aimed at to producing an intense high-energy neutron flux (2 MW/m^2) for testing candidate materials and components to be used in ITER and the fusion DEMO reactor [1].

The major function of the Li target system assembly is to provide a stable Li jet with a wave amplitude less than 1 mm at up to a speed of 20 m/s. Intense neutrons are emitted inside the Li flowing on through a thin back plate attached to the target assembly. Since the back plate is operating under a severe neutron irradiation condition (50 dPa/y), the back plate needs to be designed as a removable component to be replaced by a remote handling system [2,3].

For the back plate replacement, two design options of JA-option (Lip seal type) [4] and EU-option (Bayonet type) [5] are under investigation. In lip seal type, target assembly is connected by flanges designed as lip sealing structures to the main Li pipe, quench tank, and accelerator vacuum duct.

In this paper, material characteristics of the lip seal made of 316 L, a lip seal cutting/welding equipment for remote handling and the remote handling procedure are described.

2. Lithium target system and replaceable backwall

The Li target system consists of the target assembly with the back plate and the Li loop. A three dimensional view of the target assembly is shown in Fig. 1(a). The target assembly is made of 316 L stainless steel, and the back plate is made of Reduced-Activation Ferritic/Martensitic (RAFM) steel such as F82H. The back plate is connected to the target assembly by a welded lip seal and a mechanical clamp at the circumference. Major specifications of the Li target back plate are shown in Table 1.The back plate is designed for replacement less than every 11 months. For the replacement, it is required to exchange by the remote handling system with high setting accuracy. As a reference concept, the back plate is removed with the target assembly, carried to the hot cell, and the back plate is exchanged in hot cell. In addition, alternative concept of in situ replacement in test cell room is considered.

3. Lip seal welding and cutting by laser system

In previous design study for the IFMIF target, thermal-stress analysis of the back plate was carried out considering nuclear heating in normal operation [6]. In addition, butt joint specimens simulating thicknesses of the welds in the back plate and at the lip seal part were tested [7].

There are four lip seal joints as shown in Fig. 1(a). One is a joint between target assembly and the back plate. The other joints are those between target assembly and each of quench tank, inlet pipe, and beam duct. The lip seal joint is of 2-mm in thickness,

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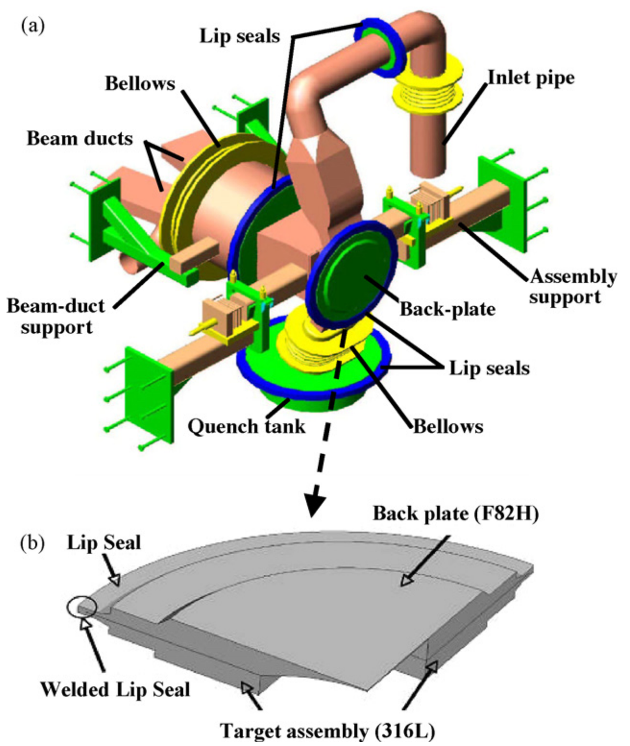

Fig. 1. Overview of Li target assembly (a) and a quarter of the back plate with lip seal (b).

corresponds to the lip-weld (316 L/316 L). The shape of the lip seal in connected part of the back plate and the target assembly is shown Fig. 1(b).

3.1. Material test of 316 L/316 L welding joint

Mechanical properties of the lip seal welding joint welded by Yttrium Alumina Garnet (YAG) laser was investigated. Chemical compositions of the 316 L used to test are, Cr: 17.39%, Ni: 12.19%, Mo: 2.07%, Mn: 1.19%, Si: 0.002%, C: 0.011%, in wt.%.

Table 1
Major specifications of Li target back plate.

Items	Values
Neutron irradiation	50 dPa/y at center 0.1 dPa/y at lip seal
Nuclear heating rate	25 W/cm^3 at center
Averaged heat flux	1 GW/m^2
Liquid Li temperature	250–300 °C
Materials	RAF (back plate), 316 L (lip seal)
Replacement	Less than 11 month
Replacement method	Cutting and welding by laser torch

Welding conditions of the YAG laser-welding methods are, a specimen thickness of 2 mm, a joint geometry of I-Groove (without gap), an assist gas of Ar, a power of 3 kW, a welding speed of 2000 mm/min, a number of pass of 1.

In this welding, filler wire is not used, and heat-treatment is not performed. Specimens for the metallurgical and mechanical tests were sampled from the weld joints. Vickers Hardness distribution at the welds was measured with a testing load of 9.8 N and a holding time of 10 s. Cross section of a specimen and measured location are shown in Fig. 2(a). The tensile test is performed at room temperature with strain rates of 0.05 mm/min before elastic limit, and 30 mm/min after elastic limit. The tensile specimen has the parallel part with the dimension of 72 mm-long, 6 mm-wide and 2 mm-thick. The weld part is located at the center of the parallel part.

Fig. 2(b) shows microscopic views of 316 L/316 L welds. Micro-crack was not observed around the bond among the welded metal (WM), the base metal (BM) and heat affected zone (HAZ).

Vickers hardness distribution is shown in Fig. 2(c). The maximum hardness is about 190 HVs at the bonds. The hardness in a region of about 8 mm away from the center of the weld is about 170 HVs.

Result of tensile test is summarized in Fig. 3. 0.2% yield strength and ultimate tensile stress of the welding joint test piece were almost equal to those of 316 L base metal. Total elongation has decreased by about 16% because of the weld metal. These values exceed the value indicated in the ISO standard. And, the allowable stress for the lip seal is evaluated from these values. The allowable stress for the lip seal is defined as the 3Sm value because of secondary stress. According to the ASME code, Sm is defined as the

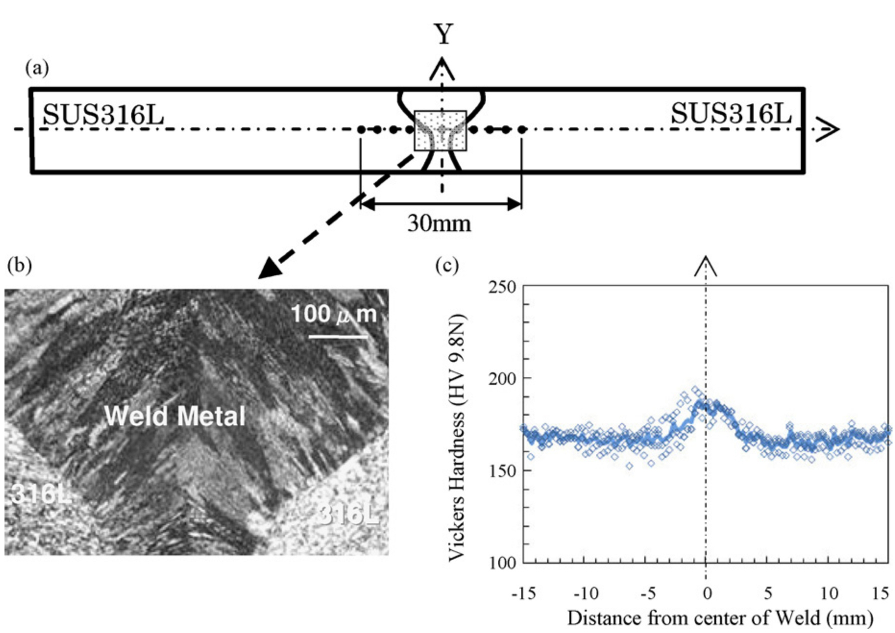

Fig. 2. Hardness distribution and cross-sectional macrostructure of weld joint.