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ScienceDirect
Journal of Nuclear Materials 373 (2008) 212–216
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Effect of re-irradiation by neutrons on mechanical properties of un-irradiated/irradiated SS316LN weldments

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Received 19 February 2007; accepted 21 May 2007

Abstract

Stainless steel of type SS316LN-IG (ITER Grade) is used for the branch pipeline connecting of the module coolant system and for other structures of ITER. One of the most important requirements for the branch pipeline connection is to recover various defects by welding. In the present study, characteristics of irradiated weldments were evaluated. SS316LN-IG specimens irradiated to helium contents of 3 and 10 appm He were prepared by the first neutron irradiation. Thereafter, the SS316LN-IG specimens with three different combinations of un-irradiation and irradiation were welded by a tungsten inert-gas (TIG) welding method. These weldments were re-irradiated at 150 °C up to a fast neutron fluence of about 7.5×10^{24} n/m^2 ($E > 1$ MeV). Tensile tests of the weldments and the base material were carried out at 20 and 150 °C after the re-irradiation. The results of the comparison before and after the re-irradiation showed that tensile properties of all weldment specimens with the different combinations were almost the same as those of the base materials.

1. Introduction

Austenitic stainless steel of type SS316LN-IG (IG means ITER grade) is a candidate material for structural materials for ITER (International Thermonuclear Experimental Reactor) [1]. Rewelding of irradiated materials has a large impact on the design and the maintenance scheme of in-vessel components of ITER [2].

Recently, joining technology of irradiated structural materials has been developed using the methods of tungsten inert-gas (TIG) welding [3,4], laser welding [5–7] and electron beam (EB) welding [8]. Helium atoms are one of the most prominent transmutation products to be generated in austenitic stainless steels because of a considerably large cross-section of Ni for (n, α) reaction by high-energy neutrons in a fusion reactor [9].

For neutron irradiation of stainless steels, it is thermodynamically favorable for entrapped helium to precipitate as bubbles at relatively low temperatures below about 400 °C. Formation of bubbles at grain boundaries could ultimately lead to drastic changes of macroscopic properties, including severe embrittlement at elevated temperatures. At high temperatures (above ~600 °C), these bubbles will grow under the influence of stress and temperature [9–11]. Welding processes produce internal stresses and temperature rise.

In the present study, un-irradiated and irradiated SS316LN-IG weldments were irradiated in the Japan Materials Testing Reactor (JMTR), and the effects of re-irradiation of neutrons on mechanical properties of the weldments were evaluated.

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doi:10.1016/j.jnucmat.2007.05.046

2. Experimental

A flow chart of the re-weldability test and the re-irradiation test in this study is given in Fig. 1. Two kinds of SS316LN-IG specimens were used. One was SS316LN-IG (JA: Japan) of the Japanese Industrial Standard (JIS) grade, which was fabricated by the Japan Steel Works, LTD. The other was SS316LN-IG (EU: European Union), which was fabricated by an EU company. Chemical compositions and mechanical properties of SS316LN-IG(JA) and SS316LN-IG(EU) are shown in Table 1 [12]. These specimens were irradiated in JMTR (as the first neutron irradiation test) for preparation of irradiated materials for weldments. Dimensions of samples for the first neutron irradiation are shown in Fig. 2. The fast neutron and thermal neutron fluences were about 2.0×10^{24} and 5.0×10^{24} n/m^2, respectively. The irradiation temperature was about 150 °C. The detail irradiation conditions in the first irradiation were already described in Ref. [12].

A TIG welding procedure with remote operation was adapted for preparation of weldment specimens in the JMTR hot cell. Procedures of the TIG welding were also described in Ref. [12]. The TIG welding with different heat inputs was carried out on both sides of the SS316LN-IG samples.

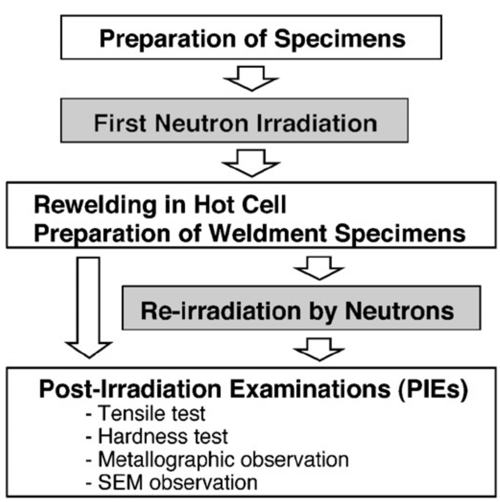

Fig. 1. Flow chart of re-weldability test and re-irradiation test.

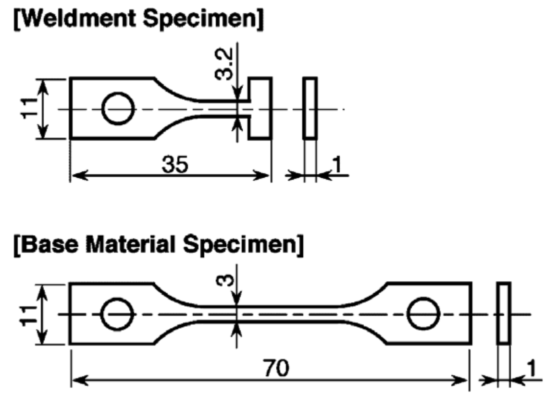

Fig. 2. Dimensions of SS316LN samples for the first neutron irradiation.

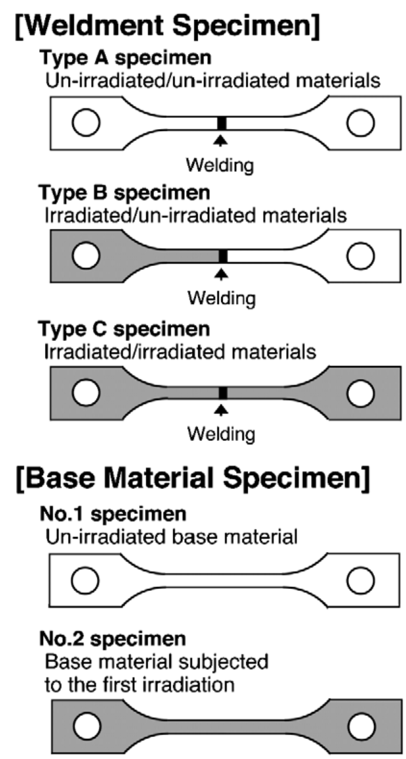

Fig. 3. Configuration of irradiation specimens for the re-irradiation.

Three kinds of weldment and base material specimens (see Fig. 3) were irradiated in JMTR for the re-irradiation of neutrons. Irradiation temperatures were calculated by

Table 1
Chemical compositions and mechanical properties of SS316LN-IG [12]

	Ultimate tensile strength (UTS) (MPa, 20 °C)			0.2% Yield strength (0.2%YS) (MPa, 20 °C)			Total elongation (TEL) (%, 20 °C)		
Mechanical properties									
SS316LN-IG(JA)	583			269			46		
SS316LN-IG(EU)	590			300			54		
Chemical composition (wt% except for B)									
	Cr	Ni	Fe	Mo	Mn	C	Co	N	B (ppm)
SS316LN-IG(JA)	17.45	12.24	Bal.	2.66	1.64	0.023	0.02	0.075	3.4
SS316LN-IG(EU)	17.15	12.19	Bal.	2.38	1.75	0.020	0.079	0.077	11.8