Journal of Nuclear Materials 377 (2008) 232–242

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Corrosion rate of parent and weld materials of F82H and JPCA steels under LBE flow with active oxygen control at 450 and 500 °C

Kenji Kikuchi [a,*], Kinya Kamata [b], Mikinori Ono [b], Teruaki Kitano [b], Kenichi Hayashi [b], Hiroyuki Oigawa [a]

[a] Japan Atomic Energy Agency, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan
[b] Mitsui Engineering and Ship-building Co., Ltd., 5-6-4 Tsukiji, Chuo-ku, Tokyo 104-8439, Japan

A B S T R A C T

Corrosion behavior of parent and weld materials of F82H and JPCA was studied in the circulating LBE loop under impinging flow. These are candidate materials for Japanese Accelerator Driven System (ADS) beam windows. Maximum temperatures were kept to 450 and 500 °C with 100 °C constant temperature difference. Main flow velocity was 0.4–0.6 m/s in every case. Oxygen concentration was controlled to 2–4 × 10^{-5} mass% although there was one exception. Testing time durations were 500–3000 h. Round bar type specimens were put in the circular tube of the loop. An electron beam weld in the middle of specimens was also studied. Optical microscopy, electron microscopy, X-ray element analyses and X-ray diffraction were used to investigate corrosion in these materials. Consequently corrosion depth and stability of those oxide layers were characterized based on the analyses. For a long-term behavior a linear law is recommended to predict corrosion in the ADS target design.

1. Introduction

Lead bismuth eutectic (LBE) is to be used as a spallation target and reactor coolant in an accelerator driven nuclear transmutation system (ADS). In order to realize ADS, one of the main issues is to determine corrosion properties of materials under flowing LBE. In the Japanese ADS design proposed by Japan Atomic Energy Agency (JAEA) [1], candidate materials to be utilized for a beam window are ferritic–martensitic steel, F82H, and austenitic stainless steel, JPCA [2,3]. Hitherto, investigations of materials corrosion under flowing LBE condition were done by using martensitic steels and austenitic stainless steels [14–18]. The corrosion tests were carried in the parallel flow condition where specimens were set up in the flowing channel parallel to the LBE flow. So far modified F82H, which replaces elements producing long-lived isotopes such as Mo and Nb by W, was investigated in the loop but oxygen concentration in the melt eutectic was not measured [16]. F82H was investigated at higher temperature, 550 °C, under active oxygen control but at lower oxygen concentration of 2 × 10^{-9} wt% and under parallel flow condition [18]. However, the proton beam window is to be submerged in the reactor vessel under impinging LBE flow condition in the ADS design. The position is thought to be the most severe part where incident proton penetrates the plate under LBE flow cooling [4]. Thus studies are needed on JPCA corrosion in the flowing LBE. We have done corrosion tests of candidate materials, F82H and JPCA, under impinging flow condition at temperatures of 450 and 500 °C. Temperature difference in the corrosion test loop was decided to be 100 °C in every case with a reference design of 800 MWth power design. The objective of this study is to evaluate corrosion rate of not only the parent materials but also electron beam welded materials applicable to join a thin plate without distortions due to excess heat.

2. Experiment

2.1. Test loop

The LBE loop at MES, Mitsui Engineering & Ship-building Co., Ltd., was used for corrosion tests, which consists of test section, heater, economizer, electro-magnetic flow meter, electro-magnetic pump, filter, expansion tank, cooler, circulating pipe and dump tank as shown in Fig. 1 [5]. Oxygen concentration was controlled by adding hydrogen and/or moisture with argon carrier gas, and monitored by Bi/Bi_2O_3 type oxygen sensor.

2.2. Materials

Materials tested are ferritic–martensitic steel F82H [2], austenitic stainless steel JPCA [3] and the electron beam welding of those materials. Chemical compositions of the materials are listed in Table 1. Welded materials are prepared from bead-on-plate with 15 mm in depth of melting. F82H steel was welded after pre-heating at 300 °C, heat-treated at 300 °C in 2 h, and then annealed at 750 °C for 2 h for stress relieving. No heat-treatment was done after welding the JPCA material.

* Corresponding author. Tel.: +81 29 282 5058; fax: +81 29 282 6489.
E-mail address: kikuchi.kenji21@jaea.go.jp (K. Kikuchi).

0022-3115/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2008.02.047

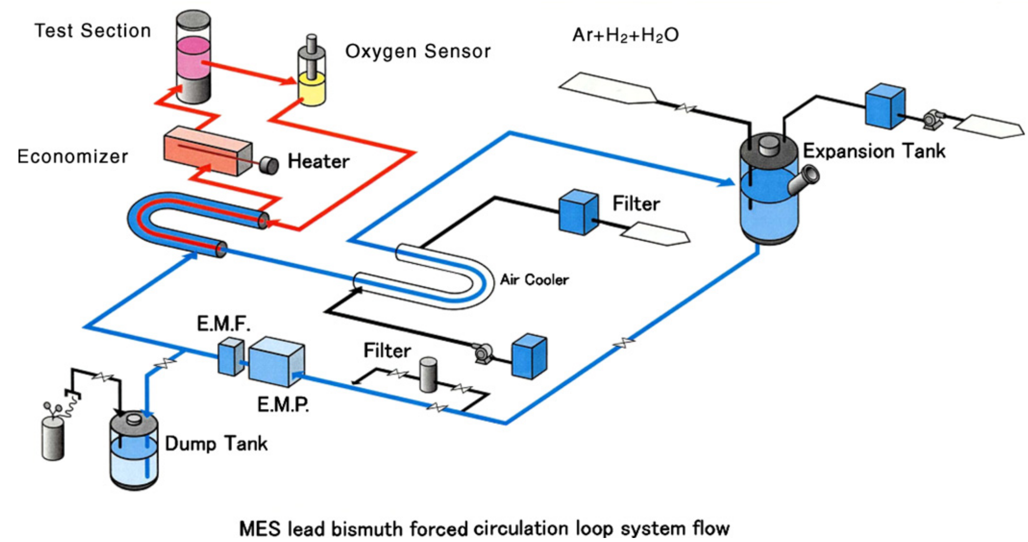

Fig. 1. Flow diagram of MES loop.

Table 1
Chemical compositions of F82H and JPCA (wt%)

	Cr	Ni	Mo	Ti	W	V	Ta	C	Fe
F82H	8	–	–	–	2	0.2	0.04	0.1	Bal
JPCA	15	15	2	0.25	–	–	–	0.06	Bal

Table 2
Test conditions

	Temperature (°C)	Time (h)
Case-1	450	1000
Case-2	450	3000
Case-3	500	1000

2.3. Specimen preparation

Specimen is a bar shape at a size of 8 mm in diameter and 130 mm in length. Surface preparation was done by buffing finally after mechanical shaping. Maximum surface roughness was 1.6 μm in F82H and 1 μm in JPCA, respectively, in the measurement of laser microscope. One end of specimen bar has a hemispherical shape setup in the upstream and other end was fixed to test holder in the downstream. The test holder includes two parallel flow channels with a round cross section of 12 mm in diameter. Specimens were setup in the channel. LBE flows in the main channel, impinges on the hemispherical edge of specimens and then passes through an annular flow channels. LBE velocity of the main duct is 0.5 m/s and 0.9 m/s in the annular channels, respectively, as shown in Fig. 2.

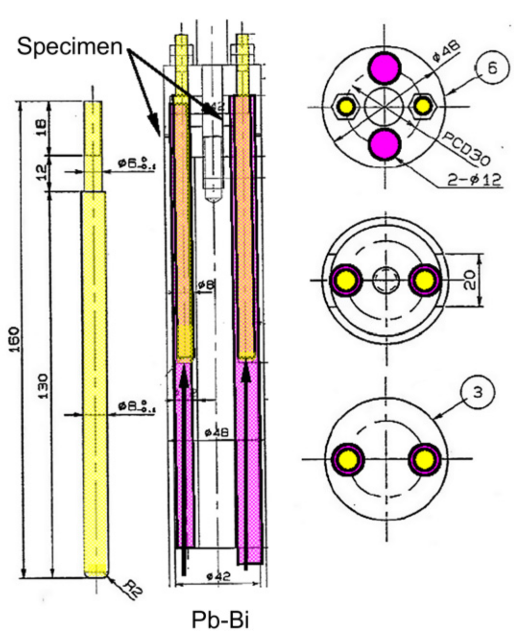

Fig. 2. Specimen in the test holder. The left figure is a detailed sketch of a specimen.

2.4. Test conditions

The conditions of corrosion tests are listed in Table 2. The described temperature means the scheduled values at the specimen position and time means the test duration. LBE velocity in the main channel is 0.5 m/s. Oxygen concentration is controlled to 2–4 $\times$ 10^{-5} mass% by adding hydrogen and/or moisture with argon career gas, and monitored by Bi/Bi_2O_3 type oxygen sensor. Our study was done under known condition. Saturated oxygen concentration, C_s, in LBE is described by the next equation [19]:

$$\text{Log } C_s = 1.2 - 3400/T, \qquad (1)$$

where T is absolute temperature in K. In the experiment C/C_s is about 0.2, where C is the oxygen concentration in LBE. This is a regime where iron oxide can be formed in LBE. The temperature difference between hot and cold region is 100 °C due to the ADS design [4].

3. Results

3.1. Optical microscopy

Fig. 3 shows micro and macro structures of specimens for F82H. Figs. 3(a) and (b) show the cross section at the middle part and the edge part of specimen, respectively. It is found that there was a welded zone with 1 mm in width accompanied by heat affected zone at the middle of the specimen. LBE collides with the round tip in the flow channel. Figs. 3(c) and (d) show the micro structure at welded part and tip region, respectively, after tests in Case-1