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Corrosion experiments on IN-RAFM steel in flowing lead-lithium for Indian LLCB TBM

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ABSTRACT

Corrosion experiments were carried out in a pump driven loop, exposing IN-RAFM (India specific Reduced Activation Ferritic Martensitic) steel samples to lead-lithium, Pb-16Li. In this loop, flat and tensile samples, made of IN-RAFM steel were exposed to lead-lithium, flowing at ~10 cm/s velocity and maintained at (465 ± 3)°C temperature. Three experiments were carried out, for different time durations, 1000 h, 2500 h and 5000 h. Samples were removed after each experiment and metallurgical investigations were carried out using SEM and SEM/EDX. Tensile strength and hardness measurements were also carried out and the results are discussed in this paper. Corrosion rate estimated from weight loss measurements was ~44 μm/year up to 2500 h and it reduced to ~31 μm/year after 5000 h exposure. Iron and chromium were found leaching from the samples. Hardness reduction was observed up to 40 μm after exposing to liquid metal for 5000 h. There is no significant reduction in tensile strength and % elongation after exposing the samples up to 5000 h to liquid metal.

1. Introduction

Lead-lithium (Pb-16Li) eutectic is used as coolant and tritium breeder in Indian LLCB (Lead Lithium Ceramic Breeder) TBM (Test Blanket Module) [1–3] to be tested in equatorial port No. 2 in ITER. Here after Pb-16Li will be referred to as Pb-Li. For Indian LLCB TBM, IN-RAFM (India specific reduced activation ferritic martensitic) steel [4] is considered as the structural material. LLCB blanket mainly consists of U shaped first wall, lithium titanate ceramic pebbles packed in the form of pebble bed, with liquid metal lead-lithium flowing around them as shown in Fig. 1. The liquid metal extracts volumetric heat generated in TBM and transfers it to helium coolant. Compatibility of the structural material with the liquid metal is one of the factors, which decides the operation temperature of blanket [5–7]. It is one of the prime concerns for the successful operation of TBM in ITER. Therefore compatibility of the structural material with liquid metal needs to be studied at relevant flow and temperature conditions, corresponding to TBM operation in ITER. During normal operation of TBM, inlet and outlet temperatures of Pb-Li are 300 °C and 460 °C [3] respectively and it is flowing at ~10 cm/s velocity inside TBM. The present experiment was carried out at 465 °C and ~10 cm/s flow velocity. Slightly higher temperature is chosen to estimate worst case corrosion rate and also to take into account the temperature variation during long experimental durations.

Corrosion and compatibility studies of different ferritic martensitic steels with lead-lithium [5–23] have been carried out worldwide in static and flowing conditions. Different types of coatings over the structural material, such as hot dip aluminizing and electrochemical coating [24–27] have been undertaken worldwide to reduce corrosion as well as tritium permeation.

2. Experimental set up

The corrosion experiments were carried out in a pump driven loop in TBM lab, at IPR (Institute for Plasma Research), India.

Schematic of the pump driven loop setup is shown in Fig. 2. In this loop, liquid metal Pb-Li was driven with electromagnetic induction pump (EMIP) based on rotating permanent magnets. The path of the liquid metal is as follows- EMIP– heating section- flow meter- heating section- test section- heat exchanger section- EMIP. Main components of the loop are dump tank, expansion tank, EMIP, flow meter, test section and heat exchanger. The whole loop is made of stainless steel 316 L.

In the test section, flat and tensile (miniature) samples, made of IN-RAFM steel were exposed to flowing lead-lithium. Inside the test

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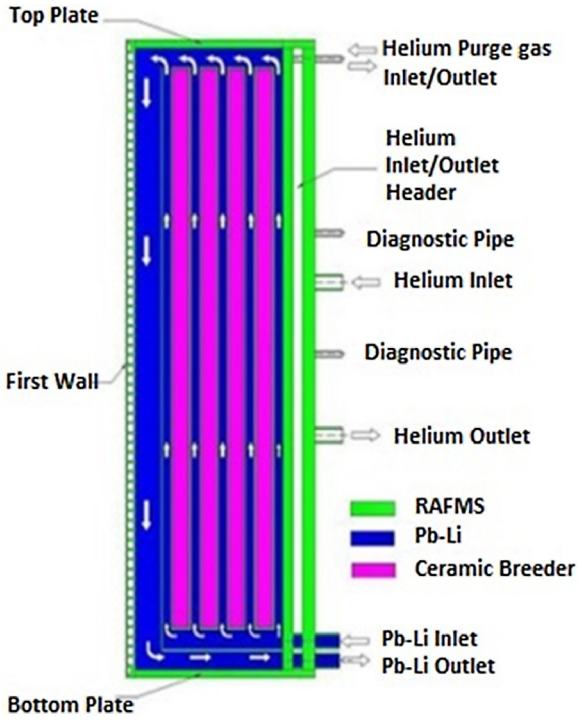

Fig. 1. Pb-Li flow configuration in Indian LLCB TBM.

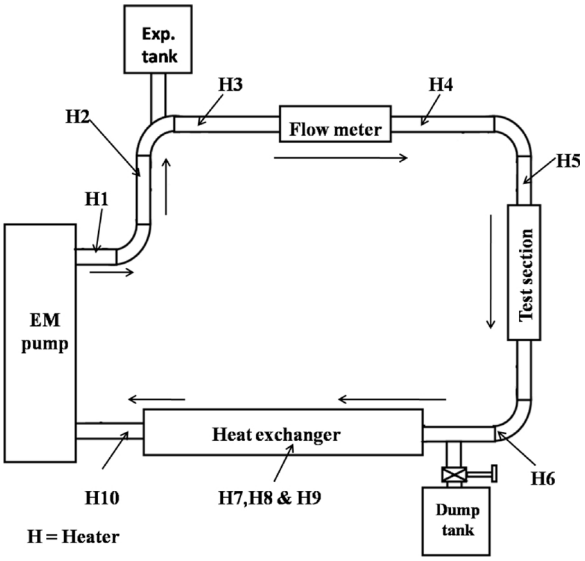

Fig. 2. Schematic of the pump driven loop.

section, Pb-Li temperature and flow velocity were maintained at (465 ± 3)°C and (10 ± 0.5) cm/s, respectively. IN-RAFM steel was normalized at 980 °C for 30 min and cooled in air, followed by tempering at 760 °C for 90 min and cooled in air. Chemical compositions of IN-RAFM steel and Pb-Li are given in Table 1 and 2 respectively.

Table 2
Chemical composition of Pb-Li.

Element	Li	Al	Cd	Cr	Cu	Fe
ppm	6375	11	3.8	< 2	< 2	12
Element	Ni	Mn	Mo	Co	Sn	Pb
ppm	< 2	< 2	< 2	< 2	17	Balance

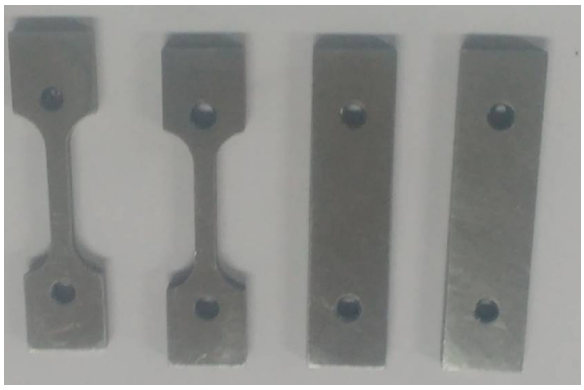

Fig. 3. Flat and tensile samples.

Overall size of the samples is 35 mm x 8.75 mm x 2.8 mm. Gauge length and width of the tensile sample are 9.98 mm and 2.19 mm, respectively. IN-RAFM steel samples are shown in Fig. 3. The samples were initially cleaned with petroleum ether in ultrasonic cleaner. A sample chain consisting of 6 flat and 6 tensile samples was prepared and cleaned with petroleum ether before mounting it in the test section. Length of the test section is 1 m and its internal diameter is ~41 mm. The sample chain was located in the central zone of the test section.

There are 13 heating zones in the whole loop. Temperature of each of the heating zones was maintained and controlled by a dedicated PID temperature controller and thyristor power controller. Temperature of eight important locations (H4 and H5, test section, EMIP inlet − H10, EMIP channel, dump tank, connecting section (loop section between dump tank and the main loop) and expansion tank) in the loop were logged using PXIe data acquisition system with an application developed in LabVIEW. Temperature data was logged every 5 min. Data were updated every second in GUI (Graphical User Interface). Separate thermo couples were used for logging and controlling the temperature. GUI has been developed using graphical programming in LabVIEW-2012 platform.

2.1. Preparation of the loop for the experiment

Pb-Li chunks were loaded in the dump tank. The dump tank was evacuated to 10^{-3} mbar at room temperature first. Then raising the temperature of the dump tank along with the chunks up to 200 °C, evacuation was continued till 10^{-3} mbar vacuum was achieved. Vacuum system was then disconnected and positive pressure of high purity Argon gas had been maintained in the dump tank. Temperature was slowly increased in steps up to 400 °C. Dump tank was maintained at 400 °C for more than 16 h to make sure that the whole liquid metal

Table 1
Chemical composition of IN-RAFMS.

Element	Cr	C	Mn	V	W	Ta	N	O	S	P
wt%	9.15	0.08	0.53	0.24	1.37	0.08	0.02	0.0022	0.002	< 0.002
Element	B	Ti	Nb	Mo	Ni	Cu	Al	Si	Co	Fe
wt%	< 0.001	< 0.002	< 0.001	< 0.002	0.004	< 0.002	0.004	0.026	0.003	Balance