INVESTIGATION OF CORROSION EFFECTS OF EUROFER STEEL IN Pb-17Li STATIONARY FLOW IN THE MAGNETIC FIELD

I. Bucenieks[1], *R. Krishbergs*[1], *E. Platacis*[1], *G. Lipsbergs*[1], *A. Shishko*[1], *A Zik*[1], *F Muktupāvela*[2]

[1] *Institute of Physics, University of Latvia, 32 Miera str., LV-2169 Salaspils, Latvia (imants@sal.lv)*
[2] *Institute of Solid State Physics, University of Latvia, 8 Kengaraga str., LV-1063, Riga, Latvia, (famuk@latnet.lv)*

Introduction. Due to rapid progress in last two decades, a specific Pb-17Li loop has been designed and fabricated at the IPUL for long-run experiments for assessment of constant magnetic field effects on corrosion of EUROFER steel (the candidate material to be used for fusion in the blanket construction) in an eutectic Pb-17Li stationary flow. Corrosion of EUROFER steel in the Pb-17Li flow without magnetic field was investigated in [1, 2]. Main parameters of the experimental facility are the following: the operating temperature in the test section 550°C, the intensity of the steady magnetic field 1.7 Tesla. The first 2000 hours' session of experiments was carried out at the mean velocity of Pb-17Li melt 5 cm/s in the test section and first results of investigation of the magnetic field influence on corrosion processes were reported. The next 2000 hours' session is planned at running with a twice smaller mean flowrate velocity.

1. Experimental facility. The experimental Pb-17Li loop was designed and fabricated for a specific task – for long-run experiments for assessment of magnetic field effects on EUROFER corrosion in Pb-17Li in a magnetic field. Main operating parameters of the experimental facility are the following: the operating temperature in the test section 550°C with an adjustable mean flow rate velocity of Pb-17Li melt in test section, the maximal intensity of the magnetic field in the region of test section layout is 1.7 Tesla.

In Fig. 1 the principal schematic of the liquid metal facility is represented. Main components of the facility are the following: a loop assembly, an electromagnet, an EM induction pump with permanent magnets, an EM conductive flowmeter, a heat exchanger, a cold trap, an expansion tank, a supply container, a test section and heaters. The loop consists of two parts – a cold part and a hot part. In the cold part of the loop (after the heat exchanger, at the inlet of the cold trap, in the EM flowmeter and in the pump) the temperature is kept in the range of about 350–400°C. The cold part of the loop is made of stainless steel 316 L. The hot part of the loop (the heater and the part of the loop up to the heat exchanger) has been made of chrome steel 12X1M. All parts of the loop are welded together except the flange connections used only in the test section as it must be removable.

The electromagnet has an adjustable gap between the poles and allows to vary the magnetic field strength from 2.0 Tesla and lower values depending on the width of the gap and the feeding current. Pole shoes of the electromagnet are made rectangular to fit the dimensions of the test section.

Design concept of the EM induction pump used in the loop is based on generating of a traveling alternating magnetic field by a system of rotating permanent

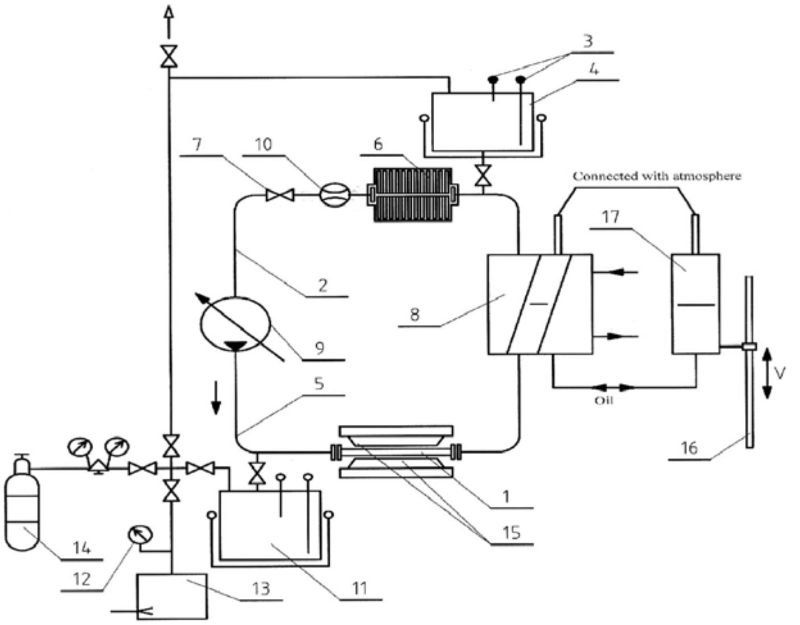

Fig. 1. Principle scheme of the Pb-17Li loop for EUROFER corrosion experiments in a magnetic field. 1 – test section; 2 – liquid metal loop; 3 –level meter; 4 – expansion tank; 5 – heater; 6 – cold trap, 7 – flow adjusting valve; 8 – heat exchanger; 9 – EM induction pump; 10 – EM flowmeter; 11 – vacuum pump; 12 – vacuum meter; 13 – vacuum pump; 14 – argon balloon; 15 – magnet pole shoes; 16 – device for adjusting oil level in the heat exchanger; 17 – oil supply tank.

magnets [3].

In order to ensure the needed stable temperature of the Pb-17Li melt in the loop, a heat exchanger is installed behind the test section. The heat exchanger consists of three parts: a liquid metal part, an intermediate oil part (high temperature oil type Ursa-40 is used) and a final water-cooled part. The heat exchanger can remove power up to 12 kW at its inlet temperature 550°C and outlet temperature about 450°C. A cold trap is installed in the loop to accumulate dissolved in liquid metal corrosion products, which solodify at lower temperatures. The outer cooler of the cold trap is made of Cu having a high thermal conductivity and cooled by air convection of forced air blowing. The expansion container of 3.0 L volume is used to compensate the volume of Pb-17Li melt at thermal fluctuations.

To investigate the strong magnetic field ($B = 1.7$ T) influence on the process of corrosion of steel EUROFER-97 in the Pb-17Li flow, a special Test Section (TS) has been developed and fabricated (Fig. 2), which is a part of the high temperature section of the experimental loop and partly is located between the poles of the magnetic system. The high temperature section was made of special steel 12X1Φ having corrosion features, which provide the most appropriate conditions in investigating EUROFER-97 samples placed inside the TS [1].

The TS includes a removable part as long as 600 mm with samples mounted inside it and an input section 500 mm long for getting a developed flow of the melt. The inner rectangular cross-section along the whole length of the TS is uniform and 10×27 mm^2. The outer frame of the TS, also having the rectangular cross-section, is formed by pressing a round tube (of stainless steel AISI 316L) with the inner inlet diameter $D = 27.3$ mm and wall thickness 1.5 mm. The height of the channel (inner dimension in the direction of the magnetic field) was chosen 13 mm.

The removable part of the TS is divided into three zones. In the first and third

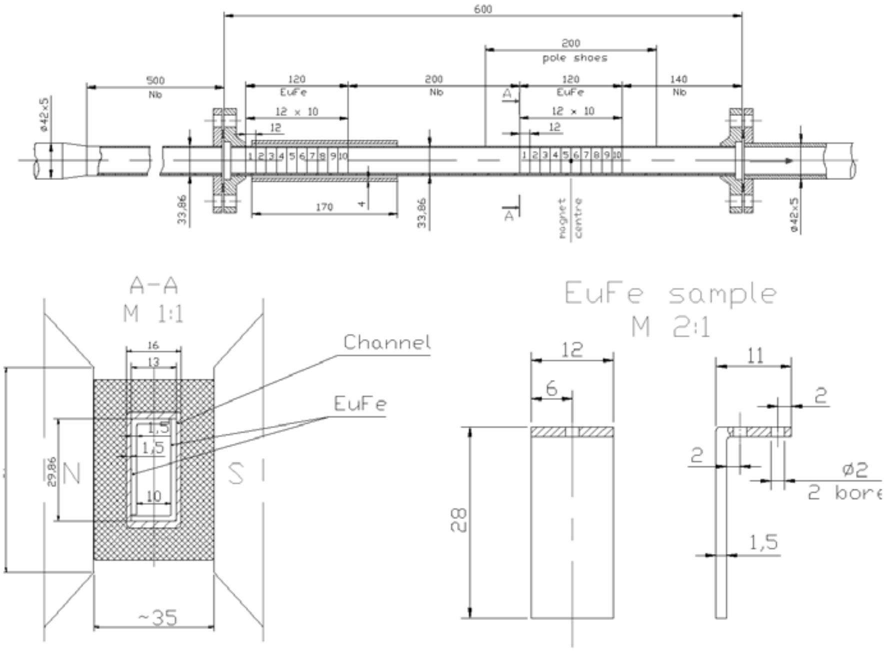

Fig. 2. Test section to investigate the corrosion of EUROFER samples in a magnetic field.

zones the entire inner surface of the channel is plated with EUROFER samples as thick as 1.5 mm. The first zone 120 mm long is located at a maximal distance from the magnet poles in the region of a scattered magnetic field. To remove the influence of this relatively weak scattered field on the flow, this zone has a ferromagnetic screen.

The third zone 120 mm long is located in the gap between the magnetic poles and starts an inside gap at the distance about one width of the channel in the region, where the magnetic field is already uniform.

Herewith, in each zone one of Hartman walls and the adjacent side wall of the channel are plated with a continuous L-shaped EUROFER-97 plate. The second Hartman wall and the side wall are plated with EUROFER-97 L-shaped samples each having width of 12 mm. It is supposed that the samples in the TS will be adjusted close each to other so allowing minimal penetration of the melt between them and that the main corrosion processes will take place only on the inner surface of the samples.

In the second transitional zone as long as 200 mm and located between the first and third zones in the region of a non-uniform magnetic field the walls of the channel are plated with two L-shaped continuous niobium plates as thick as 1.5 mm. It is supposed that at the given nominal parameters $B = 1.5$ Tesla, $U = 5$ cm/s, $T = 550°$C the MHD processes due to longitudinal end effects practically will be located in this second zone. Really, at the hydraulic diameter of the channel $d = 16$ mm, Ha $= 640$ and Re $= 7240$ the value of the MHD interaction parameter will be $N = 56,5 \gg 1$ and we can consider the flow in third zone be close to a fully-developed flow.

2. First 2000 hours' experimental session. The first experimental 2000 hours long session to investigate the magnetic field influence on the corrosion of EUROFER steel in the flow of Pb-17Li has been completed successfully. During the whole session at the experimental facility the following conditions were maintained: the minimal temperature in the cold part of the loop $T_{\min} = (350 \pm 20)°C$; the temperature in the test section was $T_{\mathrm{TS}} = (550 \pm 10)°C$; the mean flowrate velocity in the test section was $U_{\mathrm{mean}} = (5 \pm 0.5)$ cm/s; the magnetic field strength $B = 1.7$ Tesla.

Upon completion of the experiment and draining of the liquid metal from the loop, the curve of metal cooling in the main container was measured. Comparison of this curve with the initial curve (measured before experiments) demonstrates that the temperature of phase transition for the Pb-17Li melt practically has not change that shows that stoichiometry of the melt used in experiments is the same.

Visual observations of the test samples removed from the test section after experiments showed a sufficient distinction of corrosion processes between the samples located in the zone outside the magnetic field ($B = 0$) and those located in zone with the magnetic field ($B = 1.7$ T). For the samples located in the zone $B = 0$ all inner surfaces of the samples being subjected to the Pb-17Li flow were maintained sufficiently smooth, then in the zone with the magnetic field ($B = 1.7$ T) all Hartman surfaces (perpendicular to the magnetic field direction) of the samples were covered with a grooved structure oriented in the flow direction of the melt. Moreover, the side walls (parallel to the magnetic field direction) of these samples remained rather smooth.

Odd numbered samples from each zone ($B = 0$ and $B = 1.7$ T) were washed in a pure Li melt at the temperature 400°C, then the loss of mass for each sample was measured. These measurements showed that mass losses for corroded samples located in the zone with the magnetic field are approximately $1.5 \div 2$ times greater if compared to those located in the zone outside the magnetic field.

Using optical microscopy, visual investigations of microstructures of washed surfaces of the corroded samples were carried out. The optical method demonstrated a good correlation with the above-mentioned measurements of mass losses.

Metallographic investigations have shown that after 2000 h exposure to the flowing liquid Pb-17Li alloy on the surface of the samples located outside the magnetic field both the layers of alloy and of Pb oxides were present. On the surface of the samples in the magnetic field, small number traces of wetting of EUROFER with Pb-17Li were observed that is related to fast development of the stage of detachment of a corrosion layer in this case. Grain boundaries in the samples without a magnetic field are bright and strongly etched, the hardness of these samples has changed (frpm 205 HB up to 138 HB) in comparison with the samples in a magnetic field, whose hardness remained constant after tests in the flowing liquid Pb-17Li alloy. The obtained metallographic results will be coordinated with the measurements of losses in weight and thickness of these two series samples and testify to distinctions in mechanisms of corrosion in samples with a magnetic field and without it.

REFERENCES

1. G. Benamati, G. Fazio, C. Ricapito. Mechanical and corrosion behaviour of EUROFER 97 steel exposed to Pb-17Li. *Journal of Nuclear Materials*(2002), pp. 1391–1395.

2. J. Konys, H. Glasbrenner, W. Krauss, Z. Voss, O. Wedemeyer. Corrosion behavior of ferritic-martensitic steels and Al-based tritium permeation barriers in flowing Pb-17Li. In *2004-ENEA* (September 27-29, Brasimone, Italy, 2004).

3. I. Bucenieks. Perspectives of using rotating permanent magnets for electromagnetic induction pump design. *Magnetohydrodynamics*, vol. 36 (2000), no. 2, pp. 151–156.