Experimental study on corrosion and precipitation in non-isothermal Pb-17Li system for development of liquid breeder blanket of fusion reactor

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Abstract. The corrosion characteristics of RAFM steel JLF-1 in a non-isothermal Pb-17Li flowing system were investigated by means of the corrosion test using a non-isothermal mixing pot. The corrosion test was performed at 739K with a temperature gradient of 14K for 500 hours. The corrosion tests at a static and a flowing conditions in an isothermal Pb-17Li system were also performed at the same temperature for the same duration with the non-isothermal test. Then, the effect of mass transfer both by the flow and the temperature gradient on the corrosion behaviors was featured by the comparison of these results. The corrosion was caused by the dissolution of Fe and Cr from the steel surface into the flowing Pb-17Li. The specimen surface revealed a fine granular microstructure after the corrosion tests. A large number of pebble-shaped protrusions were observed on the specimen surface. This microstructure was different from the original martensite microstructure of the steel, and might be formed by the influence of the reaction with Li component in the alloy. The formation of the granular microstructure was accelerated by the flow and the temperature gradient. Some pebble-shaped protrusions had gaps at their bases. The removal of these pebble-shaped granules by the flowing Pb-17Li might cause a small-scale corrosion-erosion. The results of metallurgical analysis indicated that a large-scale corrosion-erosion was also caused by the destruction of the corroded layer on the surface. The non-isothermal mixing pot equipped a cold trap by a metal mesh in the low temperature region. The metal elements of Fe and Cr were recovered as they precipitated on the surface of the metal mesh. It was found that a Fe-Cr binary intermetallic compound was formed in the precipitation procedure. The overall mass transfer coefficient for the dissolution type corrosion in the non-isothermal system was much bigger than that in the isothermal system. This model evaluation indicated that the temperature gradient accelerated the corrosion.

1. Introduction
A liquid lead lithium alloy (Pb-17Li) is one of the candidate tritium breeders of fusion reactors \cite{1, 2} due to its excellent nuclear characteristics and thermodynamic stability. The experimental studies on
the fabrication of high-purity alloy [3], the control of non-metal impurities in the liquid alloys [4] and the thermophysical properties at high-temperature [5, 6] have been performed for the development of the fusion blanket.

A reduced activation ferritic martensitic (RAFM) steel is one of the candidate structural materials for the liquid breeder blanket. The corrosion of the RAFM steel in a flowing Pb-17Li is one of the important issues. The corrosion is caused by the dissolution of the steel components from the steel surface into the liquid Pb-17Li [7, 8]. The mechanism of this dissolution type corrosion is based on the mass transfer, which is created by the flow and the concentration gradient in the liquid metal system. Then, the flow may accelerate the dissolution of the steel elements from the steel surface [9]. The heavy density fluid flow may also cause a corrosion-erosion [10], in which the corroded surface is destructed by the flow. However, the information of the corrosion-erosion behavior is still limited.

The blanket system is a non-isothermal system, which consists of a high-temperature region and a low-temperature region. The corrosion is caused in the high-temperature region, and the dissolved elements transfer to the low temperature region on a flowing Pb-17Li. The solubility of the metal elements in the liquid alloy depends on the temperature, and it is larger at higher temperature. Therefore, the elements are precipitated in the low temperature region, when the concentration of the elements in the flowing Pb-17Li is higher than the solubility of the low temperature region. Then, the dissolution type corrosion is continuously caused in the high-temperature region without the saturation of the metal elements in the liquid metals. The previous articles reported about the precipitation of the metal elements in a flowing Pb-17Li [11] and a flowing Pb-Bi [12]. The information of the corrosion and the precipitation in these non-isothermal systems is still limited. The metal impurities dissolved in the flowing Pb-17Li should be recovered during the operation of the blanket system to suppress the loop plugging accident by the large precipitation in the low temperature region. The investigation on the effective way for the removal of the precipitates is also important issue.

The purpose of the present study is to make clear the corrosion characteristics of the RAFM steel and the precipitation behaviors of the metal elements in the non-isothermal system of the liquid Pb-17Li flow. The corrosion characteristics of RAFM steel JLF-1 in the non-isothermal system were investigated by means of the corrosion test using a non-isothermal mixing pot. The results were compared with those obtained from the isothermal corrosion tests to feature the effect of the temperature gradient on the corrosion characteristics.

2. Experimental apparatus and conditions

2.1 Static pot apparatus

Figure 1 (a) shows the schematic drawing of the isothermal static pot. The rectangular type specimen of JLF-1 steel steel [13] was installed in the crucible, which was also made of JLF-1 steel. The chemical compositions of JLF-1 (JOYO-HEAT) are summarized in Table 1. The crucible was filled with a liquid Pb-17Li (3cc). Then, the specimen was fixed to the crucible using Mo wire to suppress the floating of the specimen in a liquid Pb-17Li. The crucible was installed in the vessel made of SUS316 austenitic steel (Fe-18Cr-12Ni), which was filled with the cover gas of a high-purity Ar (99.999%). The vessel was heated by the heater installed on the outside of the vessel.

2.2 Isothermal mixing pot

Figure 1 (b) shows the schematic drawing of the isothermal mixing pot. The inventory of the liquid Pb-17Li in a crucible of this pot is 75cc. The crucible was made of Fe-12Cr steel. The cover gas was a high purity Ar (99.999%). Four cylindrical specimens were installed on the same circumferential position whose center was the shaft of the rotating impeller. The specimens were fixed to the specimen holder made of Fe-12Cr steel. The specimens were immersed to a rotational flow made by the co-rotating with the rotating impeller. The flow velocity around the specimens was roughly expressed by:

\[ v = \pi dn \]
where \( d \) is the diameter [m] of the circumferential layout of the specimens and \( n \) is the rotating speed [s\(^{-1}\)] of the impeller. Then, the Re number for mixing is expressed by:

\[
Re_{\text{mix}} = \frac{\rho n d^2}{\mu}
\]

(2),

where \( \rho \) and \( \mu \) are density [kg/m\(^3\)] and viscosity [Pa\cdot s] of liquid Pb-17Li, respectively. In the current work, \( d, n, \nu \) and \( Re_{\text{mix}} \) are 0.033 m, 50 rpm, 8.7x10\(^{-2}\) m/s and 8564, respectively.

2.3 Non-isothermal mixing pot

Figure 1 (c) shows the schematic drawing of the non-isothermal mixing pot. The inventory of the liquid Pb-17Li is 200 cm\(^3\). The sizes of the specimen and the specimen holder are the same with those of the isothermal mixing pot. Four cylindrical specimens of JLF-1 steel were installed in the high-temperature region as the same way with the isothermal mixing pot. As discussed in the previous study [7, 9], the size and the layout of the specimens in the test apparatus must influence on the test results. Therefore, the non-isothermal mixing pot was designed as it had a similar structure and a geometrical parameter with the isothermal pot apparatus. The geometrical parameter is the ratio of the liquid volume \( (V, [m^3]) \) to the total surface area \( (A, [m^2]) \) for corrosion \( (V/A, [m]) \). The values of this geometrical parameter for the apparatuses used in the current work were presented in Table 2.

The apparatus consists of the high-temperature region and the low temperature region. The high-temperature region was heated by some heaters and the low temperature region was cooled by a flowing air. The vessel was made of SS316 steel (Fe-18Cr-12Ni). The cylindrical partition, which was made of Fe-12Cr steel, was installed in the vessel. A rotational flow of the liquid Pb-17Li was made by the rotation of an impeller inside the partition. In the same time, a descending flow passed the outside of the partition. Then, one part of the descending flow passed the metal mesh, which was installed as a cold trap in the low temperature region. The metal mesh is made of Fe-12Cr steel. The diameter of the wire of the metal mesh and the mesh opening are 0.22mm and 0.4mm, respectively. The cover gas was a high purity Ar (99.999%).

![Figure 1. Schematic drawings of corrosion test apparatuses](image)

(a) Static pot (Pb-17Li: 3cc)  (b) Isothermal mixing pot (Pb-17Li: 75cc)  (c) Non-isothermal mixing pot (Pb-17Li: 200cc)
3. Experimental conditions
The conditions of the corrosion tests are summarized in Table 2. The test duration and the temperature for the tests at a static and an isothermal conditions were 500 hours and 773K, respectively. This temperature corresponds to the outlet temperature of a liquid Pb-17Li in fusion blanket systems. In the non-isothermal flowing test, the temperature of the high-temperature region was 739K. This temperature was slightly lower than the other tests, because the space for the heater installation was limited in the high-temperature region, and then the heater power was smaller than the other apparatuses. The temperature gradient in the system was approximately 14K. Re number for mixing in the corrosion test section was 8567. The flow velocity in the cold trap was estimated approximately 1mm/s from the heat balance of the system.

After the corrosion tests, the specimens were taken out from the liquid Pb-17Li. Some specimens were cleaned in a liquid Li at 350°C to remove an adhered Pb-17Li from the specimen surfaces. After the immersion to the liquid Li, an adhered Li on the specimens was removed by the immersion to ethanol. Then, the weight changes of the specimens by the corrosion were measured, and the surface microstructure was observed by field emission type scanning electron microscope/energy dispersive X-ray spectrometry (FE-SEM/EDX). The surface cross sections of the specimens without the removal of adhered Pb-Li were metallurgically analyzed by FE-SEM/EDX and electron probe micro analyzer (EPMA).

Table 1. Chemical compositions of RAFM steel JLF-1 (JOYO-HEAT) (wt%) [13]

|     | Cr  | W   | C   | Mn  | Other | Fe    |
|-----|-----|-----|-----|-----|-------|-------|
| JLF-1| 9   | 1.94| 0.09| 0.49| V:0.2 | Balance |

Table 2. Experimental conditions

| Conditions | Temperature | ΔT | Time | ReMIX | V/A |
|------------|-------------|-----|------|-------|-----|
| Static test | T_high = 773K, T_low = - | - | 500 | - | 2.1x10⁻³ |
| Isothermal flowing test | 773 | - | 500 | 8.7x10⁻² | 8567 | 8.1x10⁻³ |
| Non-isothermal flowing test | 739 | 725 | 14 | 500 | 8.7x10⁻² | 8567 | 4.6x10⁻³ |

4. Results and Discussions
4.1 Corrosion behavior of JLF-1 steel in static Pb-17Li at 773K
Figure 2 (a-1) shows the SEM image of the specimen surface after the test. The result of the EDX analysis for the specimen surface is presented in Table 3. The concentrations of Cr and W on the corroded surface was larger than that before the corrosion test. The Fe concentration was lower than that before the test. These results indicated that the corrosion was mainly caused by the dissolution of Fe. Though Cr and W were also dissolved by the corrosion, the dissolution of these elements were smaller than that of Fe. The specimen surface revealed small granular microstructure. The size of the granules is approximately 0.2µm. Some large-size granules having a diameter of approximately 0.5µm were observed on the surface. These large-size granules might be formed as the small granules are combined and coarsened.

Figure 2 (a-2) shows the tilt view of the corroded surface by FE-SEM. Small pebble-shaped protrusions were observed on the surface. The size of the protrusions was approximately 0.2µm, and almost the same with that of granules observed in the plan-view image by SEM (Figure 2 (a-2). This microstructure is different from the original martensite microstructure of the steel. However, this microstructure is similar to that observed after the immersion to a liquid Li [14, 15]. The pebble-shaped protrusions were formed in the liquid Li by the progress of the selective corrosion along the boundary of grains and sub-grains. Therefore, this microstructure might be formed by the influence of
the reaction between the Li component in the alloy and the steel surface. Some gaps are observed at the base of the protrusions.

Figure 3 (a-1) shows the result of SEM observation and EDX analysis for the cross section of specimen surface. The solid arrow in Figure 3 (a-1) indicated the protrusions observed on the corroded surface in Figure 2 (a-2). From the results of EDX analysis shown in Figure 3 (a-1), the surface layer can be classified into four layers marked as (I) – (IV) in the Figure. The layer (I) is located in the Pb-Li alloy adhered on the specimen surface. The thickness of this layer is approximately 3µm. Fe and Cr are enriched in this layer. This enrichment was due to dissolution of Fe and Cr from the steel surface and their diffusion in a static Pb-17Li. The layer (II) is the Pb diffusion layer in the steel matrix. The thickness of the layer (II) is approximately 1.5µm. The layer (III) is the Fe depleted layer due to the dissolution of Fe into a static Pb-17Li, and its depth is approximately 3.5µm. The Pb concentration in the layer (IV) was higher than the other part of the JLF-1 matrix. This high concentration of Pb was possibly due to the Pb diffusion at the dent part of the surface as illustrated in Fig. 3 (a-2). This result indicated that the gaps, which were observed at the bases of the protrusions (Fig. 2(a-2)), might be formed by the removal of Pb by the cleaning procedure of the specimen.

Figure 2. Plan-view and tilt-view SEM images of specimen surfaces, (a-1) & (a-2) surface after static test, (b-1) & (b-2) surface after isothermal flowing test, (c-1) & (c-2) surface after non-isothermal flowing test.
Table 3. Composition ratio of Fe, Cr and W of specimen surface after corrosion test by EDX (wt %)

|                  | Fe   | Cr   | W    | Total |
|------------------|------|------|------|-------|
| Static test      | 88.33| 9.52 | 2.15 | 99.97 |
| Isothermal flowing test | 88.74| 7.82 | 3.43 | 100   |
| Non-isothermal flowing test | 87.24| 10.40| 2.36 | 100   |

4.2 Acceleration of corrosion by flow in isothermal system

Figure 2 (b-1) shows the SEM image of the specimen surface after the test. The surface revealed the granular microstructure having some crevasses and gaps. The crevasses and the gaps were formed along the boundaries of grains and sub-grains of the martensitic microstructure. Figure 2 (b-2) shows the tilt-view for the corroded surface by FE-SEM. The specimen surface was fully covered by the pebble-shaped protrusions. The number of the protrusions on the specimen surface was larger than that observed after the static test. The corroded surface had a flattened shape in several places, as the corroded surface was made flat by the shaving and/or the removal of the granules in the flowing Pb-17Li. The diameter of the protrusions is approximately 0.4µm. This size is twice larger than that observed after the static test. These results indicated that the protrusions were combined and coarsened by the corrosion under the flowing conditions. The results of EDX analysis for the corroded surface indicated that the depletion of Cr from the steel surface into Pb-Li alloy.

4.3 Corrosion and precipitation in non-isothermal Pb-17Li system

The corroded surface revealed a fine granular surface (Figure 2 (c-1)). The diameter of granules is approximately 0.1µm. Some crevasses and gaps are observed on the surface. The size of the gaps was larger than the diameter of the granules. Therefore, these gaps were possibly made by the removal of the granules in flowing Pb-17Li. The results of the EDX analysis on the corroded surface indicated the dissolution of Fe from the steel surface into Pb-17Li. Figure 2 (c-2) shows the tilt view for the surface. The surface was fully covered by the pebble-shaped protrusions. Some large size protrusions, which had a diameter of 0.5-1µm, were dotted on the surface.

Figure 3 (b-3) shows the result of FE-SEM/EDX analysis on the cross sections of the large-size protrusions. The size of the protrusions are approximately 2.6µm. The concentrations of Fe and Cr in the protrusions are lower than the steel matrix (L-1 and L-3 in Fig.3 (b-3)). This result indicated that the protrusions might be formed by the corrosion in flowing Pb-17Li. The depletion of Fe was also detected on the surface of steel matrix (L-1, L-2 and L-3 in Fig.3 (b-3)). There was the gap between the protrusions and the steel matrix, and Pb was detected in the gap. These results indicated that the protrusions were not firmly fixed on the steel surface, and these could be removed from the surface by flowing Pb-17Li. Then, the removal of the pebble-shaped protrusions may cause a small-scale corrosion-erosion.

Figure 4 shows the results of EPMA analysis on the cross sections of the metal mesh installed as the cold trap in the low temperature region. The black portions, which are dotted in Pb-17Li (Figure 4 (a-1)), are abrasive powders used for the polishing procedure of the cross section. The surface of the wire was fully covered by the metal elements of Fe and Cr as shown in Figures 4 (a-2) and (a-3). These metal elements were dissolved from the surface of the specimen and the wall of the vessel in the high-temperature region of the pot. These elements were transferred to the low temperature region.
by flowing Pb-17Li, and then they precipitated on the wire surface since their solubility in the low temperature region was lower than the concentration in flowing Pb-17Li.

The precipitates of Fe and Cr were observed as they formed a double layer on the wire surface. In the layer (I), Fe and Cr were precipitated in a solidified Pb-Li. The thickness of the layer (I) was approximately 10µm. The positions of the Cr precipitates overlapped with those of Fe as shown in Figures 4 (b-2) and (b-3). These trends indicated that Fe-Cr alloy was formed in the precipitation procedure. In the layer (II), the particulate precipitates of Fe and Cr were observed. However, some Fe precipitates in the layer (II) did not contained the element of Cr. The solubility of Fe in Pb-17Li and its temperature dependence were larger than those of Cr [16-18]. Therefore, the precipitation of Fe was larger than that of Cr. The metal element of Ni was not detected in the precipitates. The solubility of Ni in Pb-17Li is much larger than those of Fe and Cr [18]. Then, Ni was not precipitated since the Ni concentration in Pb-17Li did not reach the solubility at the temperature of the cold trap during the test duration.

Figure 3. Results of FE-SEM/EDX analysis, (a-1) surface cross section of specimen exposed to static condition, (a-2) schematic drawing of corrosion and Pb diffusion around pebble-shaped protrusion, (b-1) surface exposed to non-isothermal system (low magnification), (b-2) schematic drawing of large scall corrosion-erosion, (b-3) surface cross section of specimen exposed to non-isothermal system (high magnification).
Figure 4 Results of EPMA analysis for cross section of metal mesh installed in cold trap. (a-1), (a-2), (a-3) and (a-4): BEI image and mapping analysis for Fe, Cr and Pb with low magnification, (b-1), (b-2), (b-3) and (b-4): BEI image and mapping analysis for Fe, Cr and Pb with high magnification.

4.4 Corrosion evaluation by mass transfer model in non-isothermal Pb-17Li system

The mass flux for the dissolution type corrosion on the specimen surface ($J_{\text{corrosion}}$ [g/m$^2$s]) is expressed by:

$$J_{\text{corrosion}} = h \rho (C_s - C)$$  \hspace{1cm} (3),

where $h$, $C$ and $C_s$ are the overall mass transfer coefficient [m/s], the metal concentration and the metal solubility in flowing Pb-17Li, respectively. The solubility is the function of the temperature.

The mass flux for the metal precipitation in the low temperature region of the non-isothermal mixing pot ($J_{\text{precipitation}}$ [g/m$^2$s]) is given by:

$$J_{\text{precipitation}} = k \rho (C - C_s^*)$$  \hspace{1cm} (4),

where $k$ is the effective rate constant [m/s] for the precipitation including the trap of the precipitation on the surface of the cold trap. $C_s^*$ is the solubility of metal elements at the temperature of the cold trap. At the balance point [11] in the non-isothermal system, the mass fluxes for the corrosion and the precipitation are equal expressed as:

$$J_{\text{corrosion}} = J_{\text{precipitation}} = 0$$  \hspace{1cm} (5).

The overall mass transfer coefficient for the dissolution type corrosion is derived from the Sherwood number, which is the non-dimensional number for mass transfer in fluids [9]. The coefficient increases with the Reynolds number. On the contrary, the effective rate constant for the precipitation decreases with the flow rate.
The weight losses per unit area of the specimens obtained by the corrosion experiments are summarized in Table 4. The total weight loss of the specimens and the crucible by the dissolution type corrosion in the isothermal system ($\Delta m_{\text{all(isothermal)}} [\text{g}]$) is derived as:

$$\Delta m_{\text{all(isothermal)}} = \rho V C_s (1 - \exp(-\frac{h(A_{\text{crucible}}+A_{\text{specimens}}) t}{V}))$$

(6),

where $V$ and $t$ are the inventory of liquid Pb-17Li [m$^3$] and the exposure time [s], respectively. $A_{\text{crucible}}$ and $A_{\text{specimens}}$ are the fluid contact area of the crucible and the specimens, respectively. The material of the crucible had similar chemical compositions with the specimen. The flowing condition near the vessel wall was also similar to that on around the specimen. Here, the corrosion on the wall of the crucible is assumed as the same with the specimens in the current work. Then, $\Delta m_{\text{all(isothermal)}}$ is also given by the total weight loss of the specimens exposed to the liquid Pb-17Li ($\Delta m_{\text{specimens(isothermal)}} [\text{g}]$) in the corrosion test. This relation is expressed as:

$$\Delta m_{\text{all(isothermal)}} = \frac{A_{\text{crucible}}+A_{\text{specimens}}}{A_{\text{specimens}}} \Delta m_{\text{specimens(isothermal)}}$$

(7).

The solubilities of Fe and Cr in liquid Pb-17Li at the temperature of 773K are assumed as 47wppm and 10wppm, respectively [17]. Then, the maximum weight loss of the specimens from these solubilities in the isothermal system is given by:

$$\Delta m_{\text{specimens(isothermal),max}} = \rho V C_s$$

(8).

The overall mass transfer coefficients in the isothermal system are obtained from the weight loss of the specimens by eqs. (6) and (7). The results of the model evaluation are summarized in Table 4. The weight losses of the specimens obtained by the corrosion tests were smaller than the values given by eq. (8). It was indicated that liquid Pb-17Li was not saturated with the metal elements during the corrosion tests. The overall mass transfer coefficient at the flowing conditions are approximately 10 times larger than that at the static condition. These results indicated that the mass transfer on the corrosion was accelerated by the flow. However, it must be carefully considered that the occurrence of the corrosion-erosion is not separately evaluated in the current model evaluation.

In the non-isothermal Pb-17Li system, the concentration of the metal impurities in the fluid at the inlet of the high-temperature region can be the same with the solubility in the low temperature region due to the cold trap after the operation of a certain period. Then, the concentration of metal impurities at the inlet is constant. The mass flux for the corrosion in the high-temperature region of the non-isothermal system under the steady state condition is expressed by:

$$J_{\text{corrosion}}^* = h \rho (C_v - C_v^*)$$

(9).

The weight gain in the cold trap by the precipitations of the dissolved metal elements in total is expressed by:

$$\Delta m_{\text{precipitation}} = J_{\text{precipitation}} A_{\text{precipitation}} t$$

(10),

where $A_{\text{precipitation}}$ is the effective surface area for the precipitation in the cold trap [m$^2$]. Based on the mass balance between the corrosion in the high-temperature region and the precipitation in the low temperature region, the total weight loss of the specimens and the vessel in the non-isothermal system is expressed:
\[ \Delta m_{\text{all}(\text{non-isothermal})} = \frac{A_{\text{vessel}} + A_{\text{specimens}}}{A_{\text{specimens}}} \Delta m_{\text{specimens (non-isothermal)}} \]  

(11).

The weight loss of the specimens after the exposure for a certain period is expressed as:

\[ \Delta m_{\text{specimens (non-isothermal)}} = J_{\text{corrosion}} A_{\text{specimen}} t \]  

(12).

The overall mass transfer coefficient for the corrosion in non-isothermal system under the steady state condition is derived from eqs. (9) and (12) as:

\[ h = \frac{\Delta m_{\text{specimens (non-isothermal)}}}{\rho A_{\text{specimen}} (C_s - C_s^*)} \]  

(13).

The overall mass transfer coefficient was obtained as 3.8 × 10^{-9} m/s by eqs. (9) and (12), when C_s^* was assumed as a half of C_s due to the small temperature difference in the current system. The coefficient was obtained as 8.3 × 10^{-11} m/s by eqs. (6) and (7) under the assumption as the steady state condition was not achieved during the current corrosion test. This value is also approximately 8 times larger than that in the isothermal flowing condition. These results indicated that the temperature gradient might strongly accelerate the corrosion in liquid metal flowing system.

| Table 4 Weight losses of specimens and mass transfer coefficient |
|---------------------------------------------------------------|
| Weight loss of specimens per unit area by experiment [g/m²] | Maximum weight loss of specimens per unit area by eq. (8) [g/m²] | Mass transfer coefficient [m/s] |
| \( \Delta m_{\text{specimens(isothermal or non-isothermal)}} \) | \( \Delta m_{\text{specimens(isothermal), max.}} \) | \( \rho A_{\text{specimens}} \) |
|-----------------|-----------------|------------------|
| Static test     | 7.62 × 10^{-1}  | 1.24             | 1.0 × 10^{-11} by eq. (6) |
| Isothermal      | 1.23            | 4.81             | 1.1 × 10^{-11} by eq. (6) |
| flowing test    |                 |                  |                               |
| Non-isothermal  | 2.03            | (2.77)           | 3.8 × 10^{-9} by eq. (13)    |
| flowing test    |                 |                  | (8.3 × 10^{-11} by eq. (6))  |

5. Conclusion

The corrosion characteristics of RAFM steel JLF-1 in the non-isothermal Pb-17Li system were investigated by means of the corrosion test using the non-isothermal mixing pot. The corrosion test was performed at 739K with the temperature gradient of 14K for 500 hours. The corrosion tests in the isothermal Pb-17Li system were performed at the same temperature for the same duration with the non-isothermal test to feature the effect of mass transfer in the non-isothermal system on the corrosion behaviors. Major conclusions are follows;

(1) The corrosion was mainly caused by the dissolution of Fe and Cr from the steel surface into the Pb-17Li regardless of the flowing condition and the temperature gradient. The corroded surface of the specimens revealed the slight enrichment of Cr and W, and this behavior indicated that the dissolution ratios of Cr and W were smaller than that of Fe in Pb-17Li.

(2) The specimen surface revealed the granular microstructure after the corrosion test. The pebble-shaped protrusions were observed on the corroded surface. The size of the protrusions was 0.2µm - 1µm. The size of the protrusions, which were formed in the flowing Pb-17Li with the temperature gradient, was larger than that formed in the isothermal conditions. This microstructure was not based on the original martensite microstructure of the steel, and might be formed by the influence of the reaction with Li component in the alloy. The formation was accelerated by the flow and the temperature gradient. Some pebble-shaped protrusions had gaps...
around their bases. This unstable structure indicated the protrusions could be removed by the flowing Pb-17Li.

(3) The trace of the large-scale corrosion-erosion was observed on the corroded surface after the exposure to the liquid Pb-17Li flow at the isothermal condition. The width and the depth of the trace was approximately 50µm and 15µm, respectively. The Fe-Cr-Pb layer was formed on the surface. The thickness of the layer on the eroded part was much thinner than that in the other part. These results indicated that the large-scale corrosion-erosion was caused on the surface by the partial destruction of the corroded layer.

(4) The metal elements of Fe and Cr were dissolved by the corrosion in the non-isothermal Pb-17Li system. These elements were precipitated on the surface of the metal mesh of the cold trap installed in the low temperature region of the pot. These elements precipitated as they formed Fe-Cr alloy on the surface of the wire.

(5) The overall mass transfer coefficient for the dissolution type corrosion in non-isothermal Pb-17Li system was larger than that in the isothermal system. This model evaluation indicated that the temperature gradient strongly accelerated the corrosion.

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