Excellent Corrosion Resistance of Tungsten Materials in liquid Tin

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Liquid tin (Sn) is a promising coolant for liquid surface divertor of fusion reactors. However, material compatibility of liquid Sn with structural materials is one of the important issues. The purpose of the present study is to investigate the corrosion resistance of tungsten (W) materials such as pure W, W-5Re alloy and W based sintered alloy (HAC2) in liquid Sn. Static corrosion tests were performed at 773 K for 250 hours. Pure W and W-5Re revealed corrosion resistance in liquid Sn, though HAC2 corroded due to dissolution of sintering additives.

Keywords: liquid divertor, tungsten, liquid tin, compatibility

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Liquid metal has been proposed as plasma facing materials for fusion reactors [1, 2]. Liquid tin (Sn) surface divertor is a promising component of fusion reactors [3]. One of the important issues is the material compatibility of liquid Sn with structural materials. Al-rich steels revealed corrosion resistance in liquid Sn [4], while reduced-activation ferritic martensitic (RAFM) steels revealed poor compatibility [5]. The information on the corrosion-resistant materials in liquid Sn is still limited. Then, US/Japan joint research project FRONTIER [6] has started to overcome the material compatibility issues of liquid divertor concept.

Tungsten (W) is the most promising plasma facing material of solid divertors [7]. Its melting tolerance can mitigate the damage in the case of loss of coolant accident of the liquid divertor, when the surface of structural material is directly exposed to large heat load. W produces Rhenium (Re) by the nuclear transmutation of W under neutron irradiation. The Re concentration in W reaches approximately 3% in 5 years which is the expected lifetime of the divertor [8]. However, the corrosion resistance of W and W-Re alloy in liquid Sn was not made clear so far. The processability of W based sintered alloys is better than that of pure W, though their chemical compatibility in liquid Sn is also not made clear so far.

The purpose of the present study is to investigate the corrosion resistances of pure W, W-5Re alloy, and W based sintered alloy in liquid Sn.

The test materials were pure W, W based sintered alloy HAC2 (W-4Ni-2Cu), and W-5Re alloy. The rectangular specimen of these materials was installed in the crucible made of 316 L austenitic steel with liquid Sn of 3 cc. Table 1 presents the test materials and the corrosion test conditions. The ratio of liquid Sn volume to wetted surface of specimen and crucible was approximately 2.7×10^{-3} m [9]. The corrosion of the specimens after the tests was metallurgically analyzed by Electron Probe Micro Analyzer (EPMA). The weight losses of pure W (II) and W-5Re specimens were measured by an electro reading balance with an accuracy of 0.1 mg after the removal of Sn adhered on the specimens by means of the immersion of the specimens to liquid lithium [5]. The metal impurities dissolved in Sn were analyzed by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES).

Table 1 Specimens and corrosion test conditions.

Specimen	Size [mm^3]	Temp. [K]	Time [hr]
Pure W (I)	10×15×2.45	773	262
Pure W (II)	15×15×2.45	773	250
HAC2	10×15×2	773	262
W-5Re	10×7.5×1	773	250

Figure 1 shows the results of visual inspection on the specimens after the corrosion tests. They kept their initial shape, and large damage due to severe corrosion which was reported in Ref. [5] was not detected. Figure 2 shows the results of cross-sectional EPMA analysis on the surface of pure W (I) specimen. The diffusion of Sn into W matrix was not detected. Carbon (C) was enriched on the specimen surface, and the thickness of the carbon-rich layer was approximately 7 μm. The W specimen reacted with C dissolved in liquid Sn as it possibly formed tungsten carbide (WC). The Gibbs free energy for standard formation of WC at 773 K is −36.7 kJ. The C concentration in liquid Sn was approximately 100 wppm (or more) according to the assumption and the mass balance for the formation of WC on the specimen surface in liquid Sn.

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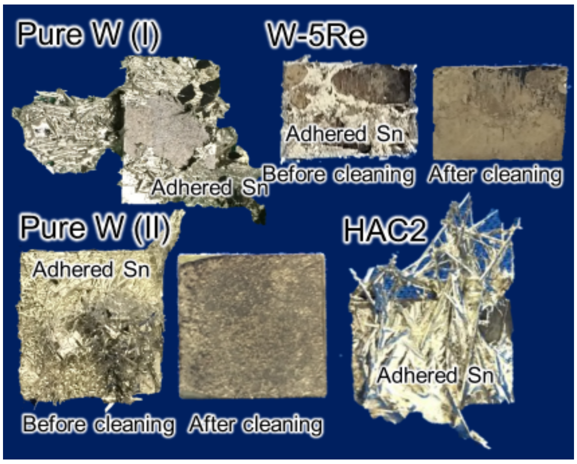

Fig. 1 Results of visual inspection on specimens after corrosion tests.

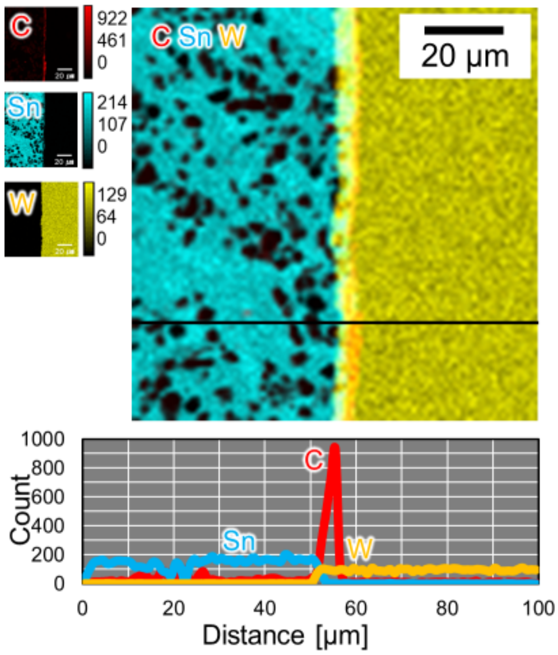

Fig. 2 Results of surface cross-sectional EPMA analysis on pure W (I) specimen.

The HAC2 specimen corroded by the depletion of Ni and Cu from its matrix, which were contained as sintering additives (Fig. 3). The dissolved Ni was detected in solidified Sn. The penetration of Sn into the sintering boundary where Ni and Cu initially existed was detected. The depletion of Ni and Cu was promoted by the penetration of liquid Sn into the sintering boundary. Needle-like substances were observed in the Sn adhered on the HAC2 specimen as shown in Fig. 1. The C concentration was high on the specimen surface and the thickness was approximately 6 μm.

The results of ICP-AES analysis indicated the W concentration in the Sn after the test with pure W (I) specimen was 0.5 wppm. The W concentration in the Sn after the test with HAC2 specimen was lower than the mini-

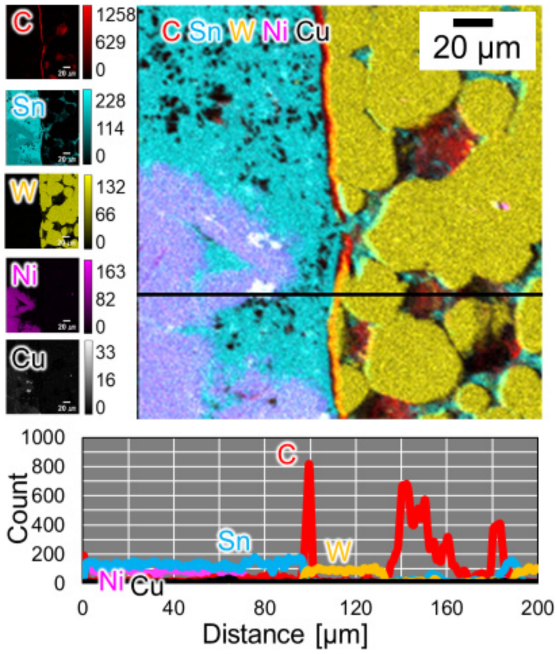

Fig. 3 Results of surface cross-sectional EPMA analysis on HAC2 specimen.

mum limit of determination, while those of Ni and Cu were 1.7×10^3 wppm and 4.2×10^3 wppm, respectively. The weight change of W-5Re specimen due to the corrosion was negligibly small.

Major conclusions are follows;

1. Pure W revealed corrosion resistance in liquid Sn. The surface was carbonized possibly due to the chemical reaction with C dissolved in liquid Sn.
2. W-5Re revealed corrosion resistance in liquid Sn.
3. W based sintered alloy HAC2 (W-4Ni-2Cu) corroded in liquid Sn due to the depletion of Cu and Ni from the matrix.

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[1] R.E. Nygren and F.L. Tabares, Nucl. Mater. Energy **9**, 6 (2016).
[2] F.L. Tabares, Plasma Phys. Control. Fusion **58**, 014014 (2016).
[3] J. Miyazawa *et al.*, Fusion Eng. Des. **125**, 227 (2017).
[4] M. Kondo *et al.*, Fusion Eng. Des. **146**, 2450 (2019).
[5] M. Kondo *et al.*, Fusion Eng. Des. **98**, 2003 (2015).
[6] Y. Hatano *et al.*, J. Plasma Fusion Res. **96**, 3, 145 (2020).
[7] V. Philipps, J. Nucl. Mater. **415**, S2 (2013).
[8] H. Bolt *et al.*, J. Nucl. Mater. **43**, 307 (2002).
[9] M. Kondo *et al.*, Fusion. Eng. Des. **86**, 2500 (2011).