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ARTICLE

Effect of Temperature on Corrosion Behavior of 304 Stainless Steel in Liquid Sn

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Abstract: Sn is a kind of low melting point metal and can be used as a liquid coolant due to its higher thermal conductivity. Compared with the currently used sodium liquid coolant, Sn is more chemically stable and unfeasible to fire or explore when contacting with air or water. The chemical reactions between Sn and 304 stainless steel that is widely used as primary circuit pipeline materials in fast reactor were researched, and the effect of temperature on the corrosion behavior between 304 stainless steel and liquid Sn was discussed. The results show that pitting happens when the temperature is lower than 823 K, and dissolution happens when the temperature is higher than 823 K.

Key words: Sn; 304 stainless steel; corrosion

As one of the next generation nuclear reactors, fast reactor is a technological step beyond conventional nuclear reactors and is one of the best choices in the design of future reactors [1-3]. The biggest advantage of the fast reactor is that it generates more fissile material than it consumes, and improves the utilization of natural uranium. As we know, 99.3% of natural uranium is uranium-238, and uranium-238 is not a fissile material. But by absorbing a fast neutron, uranium-238 can transform into plutonium-239, which is a fissile material [4, 5]. Thus the fast reactor, or fast neutron reactor, is more efficient than other reactors, and has received more and more attention recently. Furthermore, fast reactor has a high power density and often operates at 773~823 K, so it should be cooled rapidly. Liquid metal coolant has more advantages than water, such as higher thermal conductivity, higher heat capacity and no fast neutron absorption [6-8]. Among various liquid metals coolant, sodium is a common coolant used in fast reactors[9, 10]. However, it comes to the question of safety issue since sodium burns once contacts with air or water (sometimes explosively when contacts with water) and requires special precautions to prevent and suppress fires [11-13]. Besides sodium as a coolant, Sn, which has a low melting point and excellent thermal conductivity property, can also be considered as another choice [14, 15]. More importantly, Sn does not react with water or air, which implies the great advantage of safety used as a coolant.

304 stainless steel is widely used in primary circuit pipelines of fast reactors [16]. However, little is known about the corrosion interaction between liquid Sn and 304 stainless steel. Thus it is very necessary to carry out detailed researches on this respect. In this paper, we examined the chemical reactions between liquid Sn and 304 stainless steel and the effect of temperature on the corrosion behavior of 304 stainless steel in liquid Sn was also discussed.

1 Experiment

Commercial pure Sn bulk (purity > 99.9%) and 304 stainless steel mesh were used in this study. The purpose of applying of the stainless steel mesh is that it has larger specific surface area and can react with liquid Sn more sufficiently. For the corrosion test, the Sn and a piece of 304 stainless steel mesh were put into a small quartz tube, which was used as a crucible, and then the small quartz tube was put vertically into a chamber. After pumped to a

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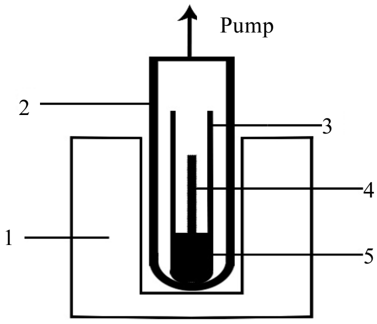
vacuum of 10^{-4} Pa, the chamber was heated to the temperatures of 573, 723, 823, 873, 923 and 1073 K for corrosion. The time for the corrosion was 2 h at each temperature. After corrosion the chamber was furnace cooled to room temperature. Fig.1 is the schematic drawing of the experimental equipment.



1-furnace, 2-chamber, 3-small quartz tube, 4-304 stainless steel mesh, 5-Sn

Fig.1 Schematic drawing of the experimental equipment

2 Results and Discussion

Fig.2 shows morphologies of samples corroded at the temperatures of 573, 723 and 823 K. It can be seen that the appearance of these 304 stainless steel meshes are almost kept the same, as it original be, see Fig.2a, 2c, 2e, but pitting corrosion takes place on the surface of these 304 stainless steel meshes. More and more small white dots are observed on the surface with the increase of temperature, see Fig.2b, 2d, 2f. By means of EDS analyses of sample at 823 K (see Fig.3), we can see that these small white dots contain Sn element, which implies that pitting corrosion occurs between liquid Sn and 304 stainless steel. According to the Fe-Sn binary phase diagram (as shown in Fig.4), it is supposed that these white dots may be the corrosion product of $FeSn_2$.

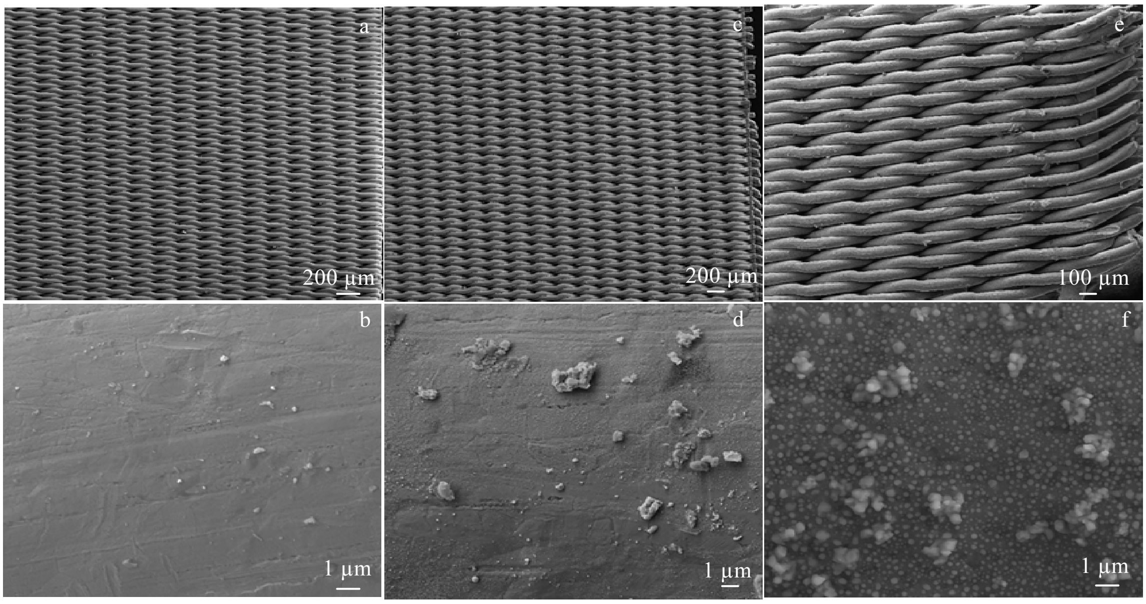


Fig.2 Morphologies of samples corroded at different temperatures: (a, b) 573 K, (c, d) 723 K, and (e, f) 823 K

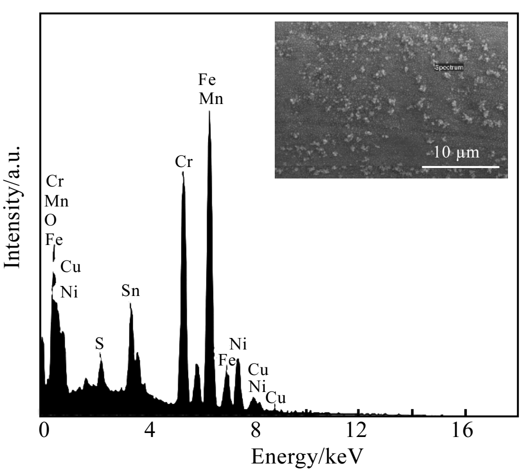


Fig.3 EDS analysis of small white dots containing Sn element for the sample at 823 K

Fig.5 shows morphologies of samples corroded at the temperatures of 873, 923 and 1073 K. It can be seen from Fig.5a, 5c, 5e that 304 stainless steel meshes are dissolved, and with the increase of temperature the extent of dissolution becomes more and more heavy, from a partial dissolution at 873 K to the full-scale dissolution along interface between 304 stainless steel meshes and liquid Sn at 1073 K. It is also found that a layer covers the surface of 304 stainless steel meshes, see Fig.5b, 5d, 5f. In order to analyze the surface layer on the 304 stainless steel meshes, the EDS mapping was carried out on the cross section of the sample of 1073 K. The result is shown in Fig. 6 and Fig. 7. It can be seen that the wire is surrounded by the thick layer. This thick layer is indentified to be Sn element, while the wire is indentified to be 304 stainless steel which contains Fe, Cr and Ni elements. By considering the Fe-Sn binary phase diagram, it can be concluded that the 304 stainless steel meshes is indeed dissolved into liquid Sn without the formation of Fe-Sn compounds. Since there is not a composition gradation at the interface between Sn and 304 stainless steel, it is further approved of the dissolution mechanism between 304 stainless steel and liquid Sn; as shown the EDS line scan in Fig. 8.

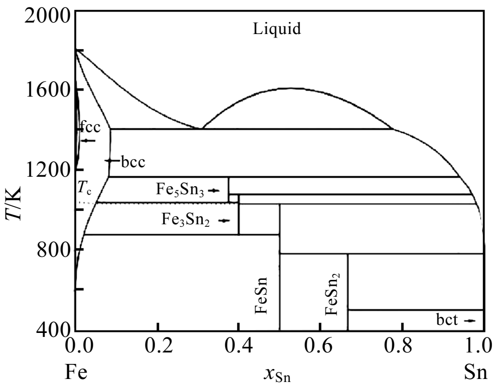


Fig. 4 Fe-Sn binary phase diagram

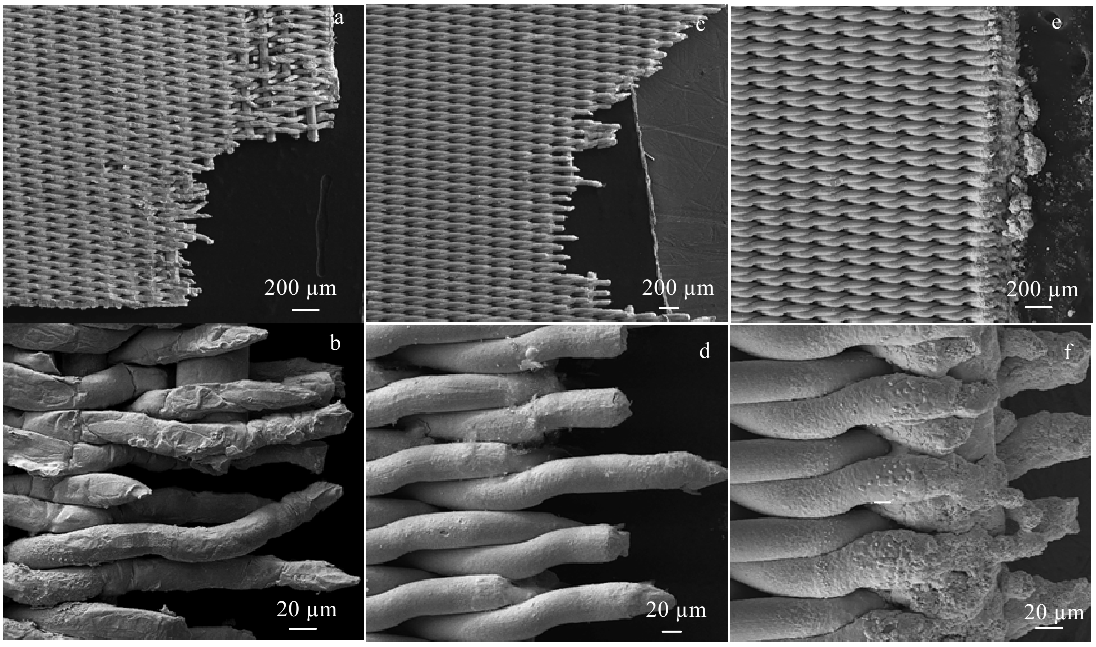


Fig.5 Morphologies of samples corroded at different temperatures: (a, b) 873 K, (c, d) 923 K, and (e, f) 1073 K

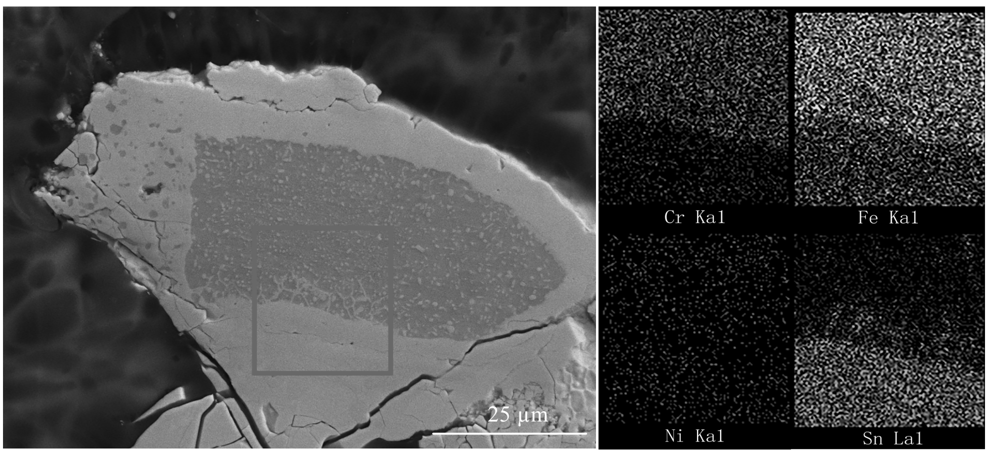


Fig. 6 Micro area EDS mapping on the cross section of the sample at 1073 K

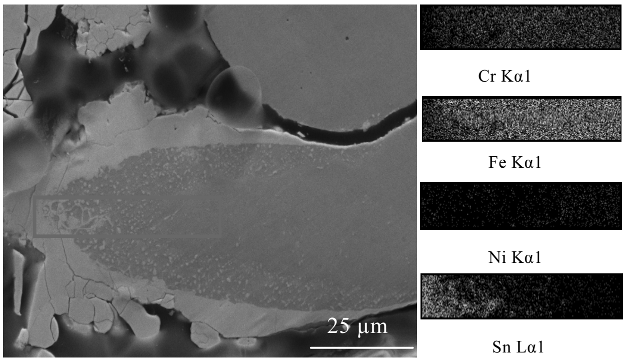


Fig. 7 Micro area EDS mapping on the cross section of the sample at 1073 K

For the dissolution process, there should exist two routes. One is the direct interface dissolution, the other is the grain boundary dissolution, i.e. dissolution can occur through the channels induced by the grain boundaries or defect inside the 304 stainless steel. This is illuminated by the morphology observation at the interface, which is shown in Fig.6 and Fig.7. The multiple dissolution processes may also accelerate the dissolution rate between 304 stainless steel and liquid Sn.

It should be mentioned that the time for the interaction between the 304 stainless steel meshes and liquid Sn is only 2 h, so the effect of time on the corrosion rate should be discussed further. Because the 304 stainless steel meshes may have different properties from the 304 stainless steel plate, the conclusion above should be verified when considering the situation with 304 stainless steel plate.

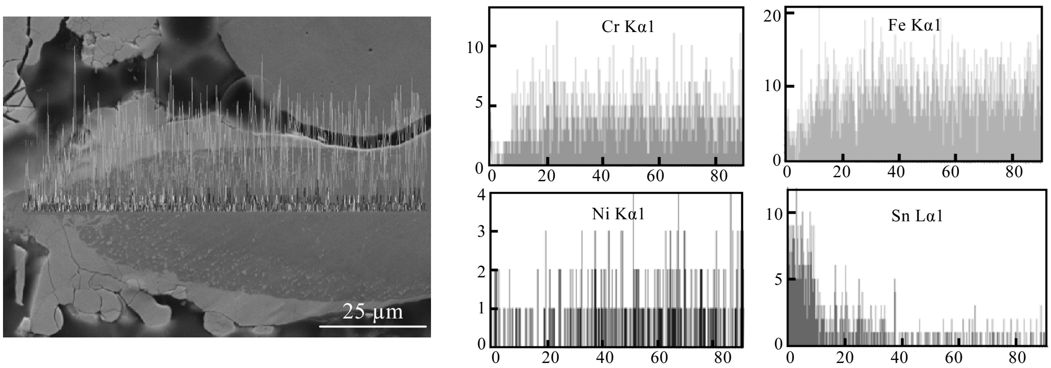


Fig. 8 EDS line scanning on the cross section of the sample at 1073 K

3 Conclusions

1) The corrosion behavior between liquid Sn and 304 stainless steel indicates that pitting happens when the temperature is lower than 823 K, and dissolution happens when the temperature is higher than 823 K.

2) Liquid Sn as a coolant can work below 823 K, which accommodate the working temperature for fast reactor. But the pitting is a serious problem and should be paid more attention to during long-term operation.

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温度对 304 不锈钢在液态 Sn 中腐蚀行为的影响

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摘 要：Sn 是一种低熔点金属，其导热性高可用作快中子反应堆中的液体冷却剂。与目前所使用的液态钠冷却剂相比，Sn 具有更好的化学稳定性及遇水或空气不易燃烧的特点。在快中子反应堆中，不锈钢是应用广泛的主回路管道，本工作研究了 Sn 与 304 不锈钢的化学反应，讨论了温度对 304 不锈钢在液态 Sn 中腐蚀行为的影响。结果表明，当温度低于 823 K 时，发生点蚀，当温度高于 823 K 时，发生溶解。

关键词：Sn；304不锈钢；腐蚀

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