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Short communication

Effect of cold rolling on the oxidation resistance of T91 steel in oxygen-saturated stagnant liquid lead-bismuth eutectic at 450 °C and 550 °C

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ABSTRACT

The compatibility of T91 steels having different preparation processes with oxygen-saturated stagnant lead-bismuth eutectic have been investigated at 450 °C and 550 °C. It is found that cold rolling decreases the thickness of the oxide scale of T91 steel by forming a continuous enhanced Cr-rich belt in the inner oxide layer next to the internal oxidation zone, which is attributed to the rapid diffusion of Cr induced by numerous non-equilibrium grain boundaries and migrating dislocations.

1. Introduction

Lead-bismuth eutectic (LBE) has been a promising candidate material for the coolant in accelerator-driven system (ADS) and Lead-cooled fast reactor (LFR), as well as the spallation target in ADS. However, the liquid LBE is severely corrosive to structural materials at high temperature, which presents a critical challenge in the use of LBE in advanced nuclear systems [1]. Compared with austenitic steels, ferritic/martensitic (F/M) steels have a superior irradiation resistance [2] and lower Ni content that has a high solubility in LBE. Therefore, T91 martensitic steel has been selected as one of promising candidate structural materials in ADS and LFR.

Extensive investigations have been conducting to understand the oxidation behavior of T91 steel in liquid LBE [3–7]. Most of T91 samples in these literatures were forged rather than cold-rolled. However, some of the components, which directly contact with the high temperature liquid LBE in ADS and LFR, are produced by cold rolling. Therefore, it is of importance to investigate the effect of cold rolling on the oxidation resistance of T91 steel in LBE. In fact, several researches have shown the influence of cold rolling on the oxidation resistance of austenitic steels in LBE [8–10]. It has been reported that cold rolling improved the oxidation resistance of austenitic steel due to the formation of a protective oxide layer, which was caused by enhancing the Cr diffusion through structural transformation [8] or grain refinement [9]. Nevertheless, it has also been reported that cold rolling aggravated the oxidation resistance of austenitic steel because the increase in dislocation density induced by cold rolling accelerated the Cr and Ni dissolution into LBE [10]. The contrary conclusions for austenitic steels indicate the complex mechanism behind the experimental results. Compared with austenitic steel, the original density of dislocation in T91 steel is much higher [11], therefore, the effect of dislocations induced by cold rolling on oxidation resistance is uncertain. Additionally, there is no deformation-induced phase transformation during cold rolling in T91 steel. Therefore, although the oxidation behavior of cold-worked austenitic steel in LBE has been studied, the effect of cold rolling on oxidation resistance of ferritic-martensitic steel, such as T91 steel, in LBE remains unclear.

To address this concern, the compatibility of T91 steels having different preparation processes with liquid LBE have been investigated in this work. By comparing the oxidation resistance of different samples, the mechanism of cold rolling influencing the

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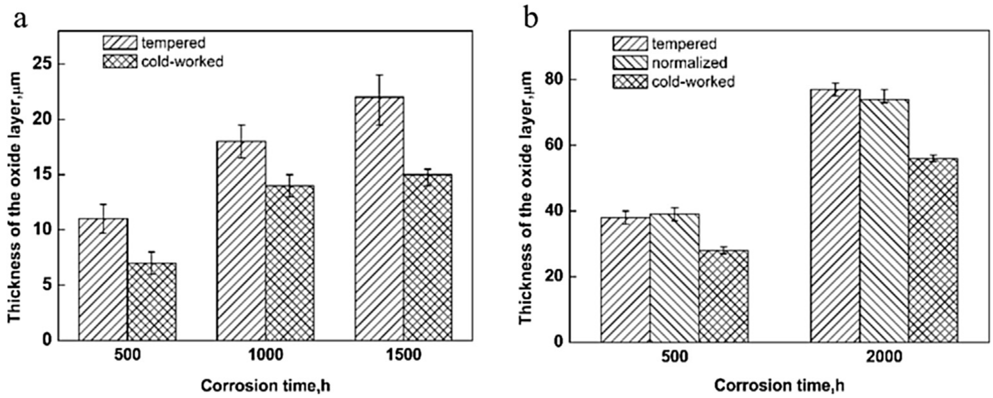

Fig. 1. The thickness of oxide layers after oxidation tests in oxygen-saturated stagnant LBE (a) at 450 °C, (b) at 550 °C.

oxidation resistance of T91 steel has been analyzed.

2. Experiments

The investigated T91 steel with the composition of Fe-0.09C-0.48Si-0.53Mn-8.94Cr-0.93Mo-0.19V-0.09Nb-0.04 N (wt%) was prepared by vacuum induction melting. After forging at 1150–850 °C three kinds of samples with different processing technology were prepared. The first sample was normalized at 1050 °C for 1 h and tempered at 760 °C for 1 h (called tempered sample), which is similar to the heat-treatment used in industry and other literatures. The second sample was only normalized at 1050 °C for 1 h (called normalized sample). The third sample was used to simulate the fabrication process of thin-wall tubes [12,13] (called cold-rolled sample). It was first hot rolled at 1150 °C, resulting in a 67% reduction in thickness. Then, the hot-rolled plate was cold rolled in three passes to fabricate cold-rolled sheet from 5 mm to 1.2 mm in thickness. Moreover, the intermediate heat

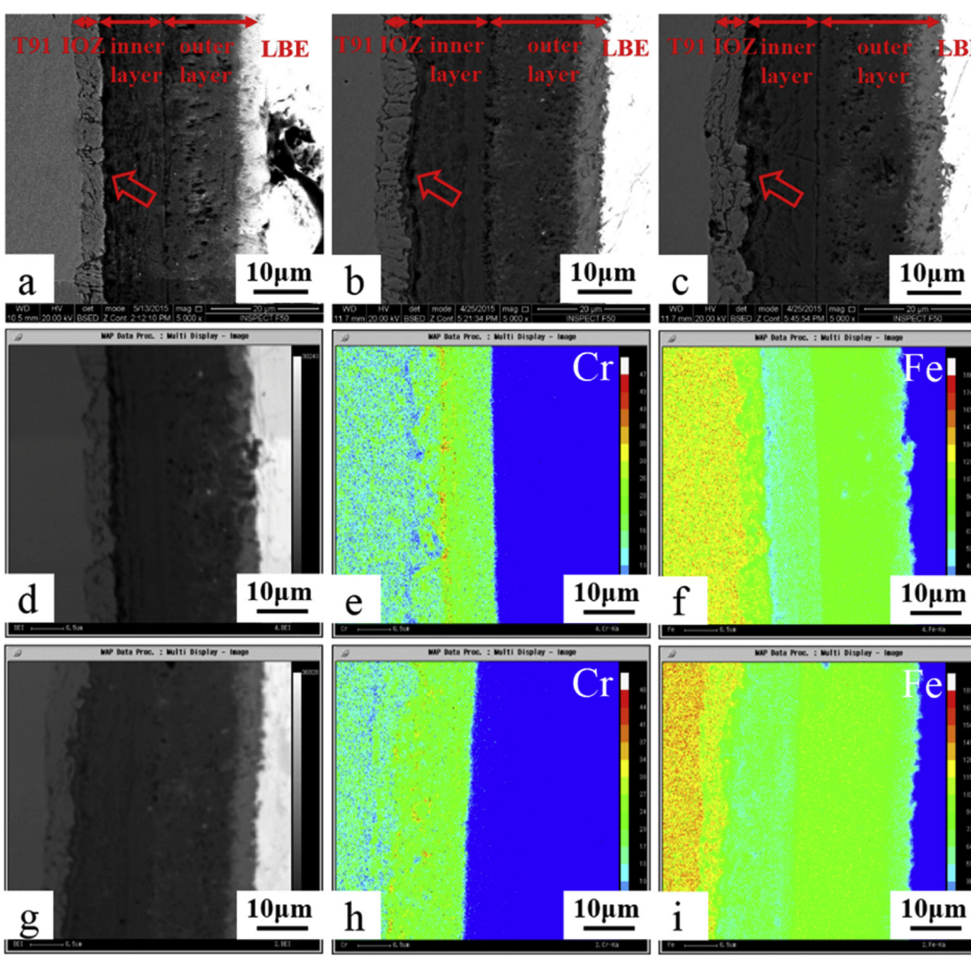

Fig. 2. SEM-BSE and EPMA images of oxide layers after exposure in oxygen-saturated stagnant LBE at 550 °C for 500 h (a) SEM image of cold-worked sample, (b) SEM image of tempered sample, (c) SEM image of normalized sample, (d–f) EPMA image of cold-worked sample, (g–i) EPMA image of tempered sample.