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Author(s)	李, 聡
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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　　博士（工学）　　氏名　Li Cong

学 位 論 文 題 名

The Effects of Cr, Nb and Ti Additions on the Oxidation Behavior of Al_2O_3-Forming Ferritic Stainless Steels

(Al_2O_3 スケール形成フェライト系ステンレス鋼の酸化挙動に及ぼす Cr、Nb および Ti 添加の影響)

Ferritic stainless steels (FSSs) are widely used in industry as engineering materials because of their superior corrosion and oxidation resistance over a wide temperature range, from room temperature to above 1000 ℃. FSSs used in high-temperature oxidation environments form either a Cr_2O_3 or an Al_2O_3 scale, which acts as a barrier against aggressive environments and protects the metallic alloy substrate. However, a Cr_2O_3 scales exhibit lower oxidation resistance at higher temperatures due to evaporation caused by the formation of CrO_3 and the formation of volatile chromium hydroxide in atmospheres containing water vapor. In contrast, steels that form a continuous Al_2O_3 scale are expected to show better high-temperature oxidation and corrosion performance in more aggressive environments because Al_2O_3 has excellent oxidation and corrosion resistance. To form a continuous Al_2O_3 scale on FSSs, approximately 2 wt% Al is generally required. The critical Al content necessary for the formation of a protective Al_2O_3 scale is strongly influenced by alloying elements such as Cr and Si. Recently, Nb has been reported to promote the Al_2O_3 formation in FSSs with lower Al content; however, the effect of Nb on the long-term oxidation behavior of Al_2O_3-forming FSSs remains unclear. In this study, the effects of Cr, Nb and Ti on the oxidation behavior of Al_2O_3-forming FSSs were investigated. This thesis consists of five chapters in total.

Chapter 1 presented an overview of stainless steels, including their classification and applications. This chapter also introduced Cr_2O_3-forming and Al_2O_3-forming heat-resistant stainless steels and reviewed the current understanding of roles of alloying elements in improving high-temperature oxidation resistance of steels. The chapter concluded with the motivation and objective of the present study.

Chapter 2 investigated the effect of Cr content on oxidation behavior of Al_2O_3 scale on Fe-(10, 15, 20, 25) Cr-1Al-0.35Nb alloys. The oxidation mass gain was found to increase with decreasing Cr content. The oxide scale exhibited a duplex structure. The thickness of outer layer increased as the Cr content decreased, whereas that of the inner Al_2O_3 layer increased with increasing Cr content. The higher oxidation mass gain in the low-Cr content was attributed to their larger mass gain during the initial oxidation stage. Laves phase precipitates were confirmed at the scale/alloy interface, and their interfacial volume fraction increased with decreasing Cr content. The growth rate of the inner Al_2O_3 layer was low on the Laves phase which reduced the oxidation kinetics of low Cr alloy during prolonged oxidation.

Chapter 3 investigated the effect of Nb on growth behavior of Al_2O_3 scale on Fe-10Cr-(1, 3, 5) Al-(0, 0.35, 0.7) Nb alloys. The oxidation mass gain was confirmed to increase with increasing Nb content. This Nb effect was apparent in alloys with lower Al content, but no Nb effect was confirmed in 5Al alloys. STEM observations demonstrated that higher oxidation mass gain in higher-Nb alloys was attributed to the higher growth rate of the inner Al_2O_3 layer. Nb segregation at grain boundaries was proposed to be responsible for the enhanced growth of the inner Al_2O_3 layer.

Chapter 4 investigated the effect of Ti on the growth of oxide scale formed by Fe-10Cr-(1, 3) Al-(0.35, 0.7) Nb-(0, 0.35) Ti alloys. Ti addition consistently increased the oxidation mass gain in the 1Al alloys, irrespective of Nb content. STEM-EDS analysis showed that Ti appeared together with Nb as oxides and that $Cr(Nb, Ti)O_4$ formed beneath the Cr-rich transient oxide scale during the initial oxidation stage. Because Nb was consumed in formed Ti-containing oxides, the beneficial effect of Nb-namely, promoting Al_2O_3 scale through the formation of a $Cr(Nb, Ti)O_4$ layer was suppressed by Ti addition. This Nb consumption by Ti oxide formation diminished the ability of low Al alloys to form a protective Al_2O_3 scale, since sufficient Nb is necessary to develop a continuous Al_2O_3 scale. In addition, Ti increased the growth rate of the inner Al_2O_3 layer during long-term oxidation through the formation of Ti-rich oxides within the inner Al_2O_3 layer.

In Chapter 5, the main conclusion of this study was presented.