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Effect of cerium addition on the corrosion behaviour of carbon-alloyed iron aluminides

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Abstract

The effect of Ce addition on the microstructure and corrosion behavior of carbon-alloyed iron aluminides Fe–20.0Al–2.0C, Fe–18.5Al–3.6C and Fe–19.2Al–3.3C–0.07Ce (in at.%) has been studied. The potentiodynamic polarization behaviour of the alloys was evaluated in freely aerated 0.25 mol/l H_2SO_4. A 0.05% C steel was used for comparison purposes. All the alloys exhibited active–passive behaviour in the acidic solution. The addition of Ce destroyed passivity as indicated by lower breakdown potentials in polarization studies. This has been related to the finer distribution of the carbides in the microstructure. Corrosion rates were evaluated by immersion testing. The iron aluminide with Ce addition exhibited a lower corrosion rate compared to the aluminides without Ce addition. This has been attributed to modifications in surface film with Ce addition. Scanning electron microscopy of corroded surfaces indicated that the carbon-alloyed intermetallics were susceptible to localized galvanic corrosion due to the presence of carbides in the microstructure.
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Keywords: Corrosion; Iron aluminide; Fe_3Al; Carbon alloying; Cerium addition; Potentiodynamic polarization; Corrosion rate; Galvanic corrosion

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1. Introduction

Iron aluminides, based around the stoichiometric compositions of Fe_3Al and FeAl, offer excellent resistance to oxidation and sulphidation at high temperatures, with low material cost and density than austenitic and ferritic stainless steels [1,2]. They contain enough aluminium to form a thin film of aluminium oxide (in oxidizing environments) that is often compact and protective. They possess relatively high specific strengths and suitable mechanical properties at elevated temperatures. They have, therefore, undergone extensive development, in the recent past, exclusively for high temperature applications. However, their potential use as structural materials at elevated temperatures has been hindered by limited ductility at room temperature and sharp drop in strength above 600 °C. It is well established that the poor room temperature ductility of iron aluminides is due to hydrogen embrittlement [3,4], with the hydrogen causing embrittlement arising out of the interaction of atmospheric moisture with Al as per $2Al + 3H_2O \rightarrow Al_2O_3 + 6H$ [5]. Considerable efforts have been devoted to understand and improve their mechanical properties. Addition of passivity-inducing alloying elements has been one of the methods suggested to improve ductility of iron aluminides [6–8]. These alloying additions modify surface condition such that hydrogen diffusion into the material is hindered, thereby reducing the propensity to hydrogen embrittlement. Hydrogen pick-up can also be minimized by surface coatings [9]. Microstructural control leads to further enhancement in ductility. These include refinement of grain structure, enhancement of grain boundary cohesion, control of grain shape and adjusting the recrystallization condition [10–12].

Several passivity-inducing elements (Ti, Zr, Nb, Ta, Cr, Mo, W, Si, and Ni) were alloyed to base Fe_3Al intermetallic to produce Fe_3Al–5M intermetallics and their mechanical and electrochemical behaviour was evaluated in 0.05 mol/l H_2SO_4 [13]. The most promising additions were Cr and Ti. The effect of rare-earth elements on the mechanical behaviour of Cr and Ti-alloyed iron aluminides has also been evaluated [14]. It has also been shown that carbon additions may be beneficial in improving the room temperature ductility of iron aluminides [15,16]. The main benefit of carbon-alloyed iron aluminide is their cheap cost (by using steel scrap) and their robust processing by the electroslag remelting (ESR) process. The addition of carbon, even in small amounts, however, drastically modifies the microstructure because carbon results in the precipitation of $Fe_3Al_xC_y$ carbides in the microstructure [15,16]. The size, shape and distribution of these carbides are influenced by alloy composition and thermomechanical processing conditions [17]. It has been suggested that carbon additions lowered the degree of hydrogen embrittlement by hindering hydrogen diffusion by the precipitated carbide [18] and by interstitial carbon [19]. Lower hydrogen diffusivities have, in fact, been measured in carbon-alloyed iron aluminides [20].

Yangshan et al. [21] reported that small additions of Ce to Fe_3Al-based alloys resulted in enhancement of ductility and strength of Cr-alloyed iron aluminides at ambient temperature. Moreover, they also observed improvements in tensile properties and creep resistance at 600 °C [21]. Improvements were also observed in the case

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