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Corrosion Science 44 (2002) 2013–2026

CORROSION SCIENCE

www.elsevier.com/locate/corsci

The corrosion behavior of Fe-based shape memory alloys

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Received 27 April 2001; accepted 18 December 2001

Abstract

Fe–30Mn–6Si, Fe–30Mn–6Si–5Cr and Fe–13Mn–5Si–12Cr–5Ni shape memory alloys were prepared by a VIM technique. The various corrosion tests were conducted to investigate the corrosion behaviors of these alloys. Experimental results show that in 3.5% NaCl solution, the Fe–13Mn–5Si–12Cr–5Ni alloy had the best chemical corrosion resistance, whereas the Fe–30Mn–6Si–5Cr alloy was locally attacked, forming many corrosion pits after immersion test. In addition, the detachment of the corrosion product covering the Fe–30Mn–6Si alloy caused an abrupt increase in the weight loss. After 2 h of heat treatment at 1000 °C, the corrosion potential of the Fe–30Mn–6Si alloy increased due to the formation of α-ferrite, while the Fe–30Mn–6Si–5Cr alloy became more active. In the stress-corrosion cracking test, the Fe–13Mn–5Si–12Cr–5Ni alloy, having the highest fracture stress in the atmosphere among these alloys, exhibited the largest decrease in fracture stress in the saturated H_2S solution due to the existence of α-martensite.

Keywords: Fe-based shape memory alloys; Chemical corrosion; Electrochemical corrosion; C. Stress corrosion

1. Introduction

In light of their low cost and excellent workability, the Fe-based shape memory alloys, which are composed of Fe–Mn–Si compositions, have attracted much attention recently. For example, the Fe–Mn–Si alloys, which contain 28–34 wt.% Mn and 4–6.5 wt.% Si, exhibit a nearly perfect shape memory effect (SME) [1–4]. The

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0010-938X/02/$ - see front matter
PII: S0010-938X(02)00027-6

addition of Cr and Ni improve their SME and corrosion resistance [5,6,21]. In contrast to the TiNi and Cu-based shape memory alloys, the Fe–Mn–Si alloys exhibit a non-thermoelastic martensitic transformation. Their SME arises from the reverse transformation of stress-induced ε-martensite (HCP structure) into γ parent austenite (FCC structure) upon heating [1]. In the past decade, extensive studies for the Fe–Mn–Si alloys were made focusing on the transformation behaviors [1,7–9], physical properties [7–10] and composition dependence of SME [1,5,11,12,21,22]. More recently, the thermo-mechanical training was demonstrated to effectively improve the SME of the Fe–Mn–Si alloys [13–15,22]. That is, the alloys are treated by the repetition of small amounts of tensile deformation at room temperature, followed by a subsequent annealing at 500–600 °C. There is also an effort to increase the use of these materials, especially the "heat-to-shrink" pipe coupling [16].

The pipes for conveying water, acid and alkaline fluids are susceptible to various chemical and electrochemical corrosions because of the existence of Cl^- and OH^- ions. Thus, the pitting and crevice corrosions are frequently observed on the pipes. Furthermore, the existence of H_2S in the petrochemical industry can cause hydrogen embrittlement [17,18]. Meanwhile, the constrained stress introduced during the heat-to-shrink pipe coupling can cause stress corrosion. The above-mentioned corrosion phenomena would reduce the running life of the fitting pipes and hence impede their applications. Consequently, the corrosion behaviors of the Fe-based shape memory alloys must be thoroughly investigated to extend their applications. Therefore, the corrosion behaviors of the Fe-based shape memory alloys are investigated in the present study including the chemical-immersion, electrochemical and stress-corrosion cracking (SCC) tests.

2. Experimental procedure

2.1. Specimen preparation

A vacuum melting technique was employed to prepare the Fe–30Mn–6Si, Fe–30Mn–6Si–5Cr and Fe–13Mn–5Si–12Cr–5Ni (wt.%) alloys. The as-cast ingots were homogenized at 1100 °C for 24 h and then hot-rolled into 6-mm-thick plates by a two-high hot-rolling mill. The specimens for various corrosion tests were carefully cut from the hot-rolled plates. Prior to corrosion tests, some specimens were annealed at 1000 °C for 2 h to annihilate the effect of hot rolling.

2.2. Immersion test

Immersion tests of the various Fe-based shape memory alloys were conducted at 25 °C in a 3.5 wt.% NaCl solution for 2–20 days. Following this, the specimens were removed and cleaned in ethyl alcohol using an ultrasonic cleaner. The weight loss of the specimen during immersion test was calculated by subtracting the weight of the specimen before test from that after immersion test. The specimen weight was measured by a precise electronic balance to 0.01 mg accuracy.