Journal of Alloys and Compounds 704 (2017) 649–658

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Effect of Ag doping and isothermal aging on phase transformation in 2205 duplex stainless steel

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ARTICLE INFO

Article history:
Received 7 December 2016
Accepted 7 February 2017
Available online 10 February 2017

Keywords:
Precipitation
Diffusion
Phase transitions
Secondary γ-austenite
Grain boundaries

ABSTRACT

In this study, 0.2 wt% Ag-doped 2205 duplex stainless steel (DSS) was adopted to investigate the relationship between secondary precipitates and aging temperature. Before aging, 2205-0.2Ag samples were homogenized at 1200 °C for 12 h to resolve other secondary phases. The eutectoid reaction of $\alpha \rightarrow \gamma_2 + \sigma$ and the formation of intergranular γ_2 at the α/γ interfaces were observed after aging at 900 °C for 2 h. Notable quantities of α-ferrite transferred to the γ_2, χ, σ, and Cr_2N phases, resulting in decreases of α-ferrite content during 900 °C aging. Because of decomposition of α-ferrite under 800 °C aging, the considerable Cr_{eq}/Ni_{eq} ratio difference between α-ferrite/γ-austenite facilitated the formation of the γ'_2 phase and its growth at the α-ferrite/γ-austenite interface. This also indicated that doping DSS with silver can benefit the precipitation of γ_2 phases from α-ferrite. Furthermore, α-ferrite transferred to γ-austenite and the merger of primary austenitic grains facilitated the stabilization of phase constitution. Because the mutual solubility of silver and iron is very low, liquid silver solidified and caused silver particles to distribute at the α phase, γ phase, and α/γ interface. Furthermore, the solubility of silver in α, γ, and γ_2 phases decreased progressively as the aging temperature decreased. Moreover, the behavior of secondary precipitates was not affected by silver doping in 2205 DSS.

1. Introduction

Duplex stainless steel (DSS) consists of approximately equal proportions of an austenite phase and a ferrite phase; DSS is widely used in the pulp and paper industry, cargo tanks for ships and trucks, food processing equipment, and biofuel plants, because its phase constitution provides excellent properties of hardness, toughness, and localized corrosion resistance [1–4]. To enhance DSS with antibacterial properties for high-performance applications, Yang et al. doped 2205 DSS with silver through melting. The results showed that the bacteria-inhibition rate of silver-doped 2205 DSS against *E. coli* and *S. aureus* were 100% and 99.5%, respectively [5].

Even though 0.2 wt% Ag alloyed 2205 DSS was developed to function with excellent bacteria-inhibiting effects in aggressive environments, a multitude of alloy elements (including Cr, Ni, Mo, and W) in DSS readily promote the precipitation of secondary phases under isothermal aging. Materials such as chromium carbides, nitrides, the χ phase, and the σ phase inevitably precipitate when this type of steel is heated to temperatures ranging from 600 to 1000 °C [6–10]. Preventing the formation of intermetallic compounds is critical in the annealing process, but relatively few published articles have discussed applications of silver-containing DSS. Therefore, the purpose of this study was to investigate the effect of aging temperature and isothermal aging on the microstructure and precipitation behavior of DSS by doping a 2205 DSS matrix with silver through melting; experiments are reported herein that established the relationship between secondary phases and aging treatment.

2. Experimental

2.1. Material preparation

Samples of 2205 DSS with a 0.2 wt% silver content (called 2205-0.2Ag) were adopted for this work; the chemical composition of the steel is described in Table 1. The material was prepared in a high-frequency induction furnace under a nitrogen atmosphere and homogenized at 1120 °C for 2 h to eliminate microsegregation after

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http://dx.doi.org/10.1016/j.jallcom.2017.02.060
0925-8388/

Table 1
Chemical composition of 2205-0.2Ag DSS.

Specimen	C	Si	Mn	P	S	Cr	Ni	Mo	Ag	N	Fe
2205-0.2Ag	0.02	0.38	0.81	0.024	0.003	22.8	6.5	2.97	0.19	0.26	Bal.

Unit: wt.%.

casting. This sample was subsequently cut into specimens measuring 10 mm × 10 mm × 5 mm to investigate the effects of aging treatment on the microstructural transformations of 2205-0.2Ag DSS.

2.2. Aging treatment and continuous observation of secondary phases

To obtain an initial microstructure with only ferritic and austenitic phases, 2205-0.2Ag samples were homogenized at 1200 °C for 12 h to resolve other secondary phases before aging. After that initial homogenization, aging treatments were performed for an aging time of 2 h at temperatures of 800–1100 °C, after which samples were cooled to room temperature through water quenching to retain the microstructure. In addition, continuous examination of secondary phase transformations was carried out at 800 °C for aging times ranging from 10 to 120 min. During continuous examination of microstructures, each observational location was marked by an indention impressed with a Vickers hardness tester to ensure microstructural transformation.

2.3. Phase identification and microstructure examination

The 2205-0.2Ag DSS samples were ground using SiC abrasive papers (up to #2000 grade) and then were polished with Al_2O_3 suspensions (with particle sizes of 1.0 μm and 0.3 μm). Subsequently, LB1 reagent solution (0.5 g of $K_2S_2O_5$ + 20 g of NH_4HF_2 + 100 mL of H_2O) was used for the α, γ, γ_2, χ, and σ phases. In addition, optical microscopy and field-emission scanning electron microscopy (FE-SEM, Hitachi S-4800) with an energy-dispersive spectrum (EDS) system were adopted to observe and analyze the microstructures. An electron probe X-ray microanalyzer (JEOL JXA-8200) was also employed to examine the silver content by using wavelength-dispersive spectroscopy (WDS). The δ-ferrite content variation after aging was measured using the Fischer Feritscope FMP30.

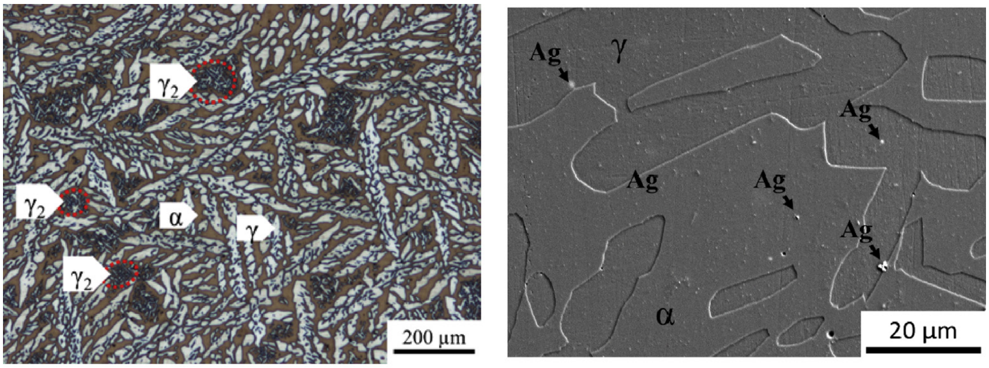
3. Results and discussion

3.1. Effect of silver doping on the microstructure in 2205 DSS

The 2205-0.2Ag DSS exhibited the typical microstructure of α-ferrite, primary γ-austenite (γ_1), and secondary γ-austenite (γ_2), as shown in Fig. 1(a). A solid solution transformation produced γ_2-austenite from the ferrite phase, and ferrite decomposed through a eutectoid solid-state reaction ($\alpha \rightarrow \sigma + \gamma_2$) [2,11]. Because 2205–0.2 Ag specimens were solute treated and then subjected to rapid quenching, γ_2 formed from the ferrite phase without σ phase precipitation; this indicates that the γ_2-austenite decomposed into the ferrite phase. Yang et al. reported that the grain size of γ_2 in 2205–0.2 Ag DSS was smaller than that in 2205 DSS, and the amount of nuclei was large [5]. Results showed that 2205–0.2 Ag DSS possessed a higher nitrogen content in γ_2-austenite compared with α-ferrite and primary γ-austenite, causing an overall decrease in the Cr_{eq}/Ni_{eq} ratio in 2205–0.2 Ag DSS. This suggests that doping silver lowered the Cr_{eq}/Ni_{eq} ratio of ferrite and promoted the rapid nucleation of γ_2-austenite from ferrite, with fine grains in 2205–0.2 Ag DSS [5].

Swartzendruber [12] reported that the mutual solubility of Ag and Fe is very low in both the solid and liquid states. The solubility of Ag in solid Fe reaches a maximum of approximately 0.022 at.% at 1398 °C in the γ phase. This indicates that silver particles tend to solidify at interdendritic spaces because of secondary inclusions with low melting points. Fig. 1(b) shows that silver particles were located at the ferrite phase, the austenite phase, and the ferrite/austenite interface. A quantitative method was used to measure the positions of silver particles in a 10-mm^2 area. The results showed that the quantities of silver particles in α, γ, α/γ, and γ_2 were 137, 101, 382, and 49, respectively. This indicated that the probability of silver particles forming at the ferrite/austenite interface was higher than the probabilities at other locations.

The silver solidified at the end of the casting process, resulting in a reaction between the silver and other alloys that formed an Ag-rich compound through diffusion. The SEM mapping of a silver particle in as-received 2205-0.2Ag DSS (after homogenization)



(a) (b)

Fig. 1. (a) Microstructure and (b) silver distribution of 2205-0.2Ag DSS in the as-received condition.