Materials and Design 32 (2011) 2206–2212

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of rare earth element yttrium addition on microstructures and properties of a 21Cr–11Ni austenitic heat-resistant stainless steel

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ARTICLE INFO

Article history:
Received 8 June 2010
Accepted 11 November 2010
Available online 16 November 2010

Keywords:
A. Ferrous metals and alloys
F. Microstructure
E. Mechanical

ABSTRACT

In this comparative study, the microstructure and the mechanical properties of a 21Cr–11Ni austenitic heat-resistant stainless steel with and without addition of rare earth (RE) element yttrium have been investigated. The results show that a number of fine spherical yttrium-rich oxide particles are not uniformly distributed in the matrix of steel with yttrium; instead, they are aligned along the rolling direction. The grains surrounding the alignment are nearly one order of magnitude smaller than those farther away from the alignment. The approximate calculation results indirectly show that the grain refinement may be mainly attributed to the stimulation for nucleation of recrystallization rather than to pinning by particles. Furthermore, the alignment has resulted in significant loss in transverse impact toughness and tensile elongation at room temperature. There is a trough in the hot ductility–temperature curve, which is located between 973 and 1173 K. The ductility trough of steel with yttrium becomes shallow within a certain temperature range, especially around 1073 K, indicating that improvement on hot ductility is achieved by yttrium addition. The results may be attributed to the increase of grain boundary cohesion indicated by the effective improvement on intergranular failure tendency, and the inhibitory effect of yttrium on sulfur segregation to grain boundaries is believed to be an important cause.

1. Introduction

Austenitic heat-resistant stainless steels play an important role in high temperature structural applications [1,2]. The type 21Cr–11Ni stainless steel is being developed due to its excellent oxidation resistance and good creep strength. It also provides potential replacement for more expensive heat-resistant alloys such as 309S and 310S stainless steels containing higher strategic elements like nickel and chromium. The addition of cerium to 21Cr–11Ni stainless steel identified as 253MA was considered many years ago. Earlier studies showed that the addition of cerium to the heat-resistant alloy resulted in improvements of high temperature properties. So far, many reports have focused on the applications of cerium and the effect of cerium on oxidation resistance and creep properties of 21Cr–11Ni stainless steel [3–8]. Yttrium, as another reactive element, not only exhibits some similarities to those of cerium, but also displays its own characteristics. However, there have been few studies made of this steel modified with yttrium, which can be viewed as a new alloy, especially in term of the microstructure changes and associated influence on mechanical properties.

In this paper, an attempt has been made to describe the effect of yttrium on microstructural characteristics and mechanical properties of 21Cr–11Ni austenitic stainless steel at room temperature and during thermo-mechanical processing in order to lay the basis for better understanding of the application of yttrium in steel.

2. Experimental

Two test alloys were prepared by vacuum induction melting in an argon atmosphere with nominal compositions listed in Table 1, in which Y_{sol} and Y_t are the Y solution content and the total Y content, respectively. Y_{sol} was measured by an OPTIMA 2000DV type ICP optical emission spectrometer. The 50 kg origin ingots were held in a furnace at 1423 K for 1 h and hot forged to a thickness of 30 mm and subsequently hot-rolled at 1373 K to a 13 mm thick plate and annealed at 1323 K for 1 h and water quenched immediately.

The samples for the examination of mechanical properties at room temperature were cut from transverse section of the hot rolled plate. Tensile tests were carried out using an MTS 810 machine. Round tension test samples of 5 mm diameter and 20 mm gauge length were subjected to tension with a crosshead speed of 5 mm/min, according to ASTM standard E8M [9]. Charpy V-notch samples for impact test were machined with dimensions

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doi:10.1016/j.matdes.2010.11.022