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Microstructure and mechanical properties of 12 wt.% Cr ferritic stainless steel with Ti and Nb dual stabilization

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ABSTRACT

TCS stainless steel is a 12 wt.% Cr ferritic stainless steel with 0.040 wt.% Ti and 0.096 wt.% Nb dual stabilization. This paper investigated the microstructures and mechanical properties of TCS stainless steel heated at 600–1300 °C for 10 min and followed water quenching. Results show the increasing of both tensile strength and hardness meanwhile the ductility and toughness have experienced the decreasing due to formation of martensitic phase and grain coarsening. In the unheated and heated TCS stainless steel, there are mainly two kinds of particles: Ti-rich particles in size of 2–5 μm; Nb-rich particles in size of 20–50 nm.

1. Introduction

Ferritic stainless steels have been used in automotive exhaust systems, containers, railway vehicle and other functional applications owing to good fabrication at low cost and good resistance to chloride stress-corrosion cracking, atmospheric corrosion and also oxidation. Strong carbide (and nitride)-forming elements are usually added to eliminate the sensitization (defined as susceptibility to intergranular corrosion) and improve the mechanical properties of ferritic stainless steels [1–4]. Traditional ferritic stainless steels were usually stabilized using Ti-only additions. However, the resulting properties and surface quality of these ferritic stainless steels were not impressive. Compared with Ti-only stabilized grades, Ti and Nb dual stabilization (the combined addition of Ti and Nb to a ferritic stainless steel is called dual stabilization) has the following benefits: improved surface quality, improved formability and weldability, higher temperature strength (better creep resistance), superior thermal fatigue resistance, and better high temperature oxidation and aqueous corrosion resistance [5]. At the present time, it is believed that to achieve adequate full stabilization of ferritic stainless steels, a ratio of Nb to Ti equivalent to 2:1 is preferred [5].

A 12 wt.% Cr ferritic stainless steel with 0.040 wt.% Ti and 0.096 wt.% Nb dual stabilization was recently developed by Taiyuan Iron and Steel (Group) Company Limited to be specially used for production of railway vehicles, which was named as TCS stainless steel. TCS stainless steel is a cheap stainless steel with good corrosion resistance. The railway vehicles made of TCS stainless steel have the advantages such as weight saving, longer service lifetime, lower production and maintenance costs. Welding technique is extensively used in the manufacture of railway vehicles but is also the challenge to applications of ferritic stainless steels in the railway vehicles. The microstructures or mechanical properties of weld bead can be improved by the additions of alloy elements, the electromagnetic stirring and the liquid metal chilling [6]. But the mechanical properties or microstructures of heat affected zone (HAZ) are mainly related to the parent materials. Therefore, the mechanical properties of HAZ are a critical factor to its extensive use. However, during the welding process, the HAZ in a small width (<0.7 mm) would be suffered to the different temperature heat cycles below the melting temperature [7–8]. It is very hard to study the mechanical properties and microstructure of the HAZ due to its small width. To have a good insight to HAZ of welding process, this paper aims to study in details the microstructure and mechanical properties of TCS stainless steel which be subject to the different heating temperatures between 600 °C and 1300 °C. The study will lend itself to well understand the microstructures and mechanical properties of HAZ and contribute to improvement of its microstructures and mechanical properties.

2. Experimental

The 12 wt.% Cr ferritic stainless steel with 0.040 wt.% Ti and 0.096 wt.% Nb dual stabilization(named as TCS stainless steel) was supplied by Taiyuan Iron and Steel Company, which had been cold-rolled to 6mm thick sheets and annealed at about 700 °C. Table 1 shows its chemical composition. The examined specimens were

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Table 1
Composition of TCS stainless steel (wt.%)

C	Si	Mn	S	P	Cr	Ni	Nb	Ti	N	Fe
0.008	0.28	1.09	0.004	0.024	11.83	0.75	0.096	0.040	0.011	Balance

heated at 600–1300 °C for 10 min in a box-type resistance furnace, and followed by water quenching at about 20 °C (room temperature). The specimens for observation of Ti (or Nb-) rich particles was heated at 1300 °C for 10 min by using a Thermal Mechanical Simulator with type of Gleeble3800 and subsequently cooled at the rate of 100 K/s. The Charpy specimens for toughness measurement were in the dimensions of 5mm × 10mm × 55mm with V-type notch (GB/T229-1994 Chinese Standard). Test cross section of specimens for tensile strength was in the size of 6mm × 30mm (GB/T228-2002 Chinese Standard). The macrohardness and microhardness were measured by Brinell hardmeter under 750 kg load and Vickers hardmeter under 50 g load, respectively. Each test was carried out for three times, and the experimental data were average of three tests. Microstructures and fractograph were examined by using optical microscope, scanning electron microscopy(SEM, Cambridge S-360) coupled with energy dispersive spectrometry(EDS) and transmission electron microscopy (TEM, JEM-2000FX) coupled with EDS.

3. Results and discussion

TCS stainless steel has better plasticity and formability compared to other high-chromium or low-chromium ferritic stainless steels due to low-carbon (0.008 wt.%) and low-nitrogen content (0.011 wt.%) [7–9]. Moreover, due to Ti and Nb dual stabilization, it eliminates or alleviates intergranular corrosion generally associated with the precipitation of chromium carbides, nitrides and carbonitrides at the grain boundaries. The mechanical properties of TCS stainless steel are shown in Table 2.

3.1. Effects of heating temperature on mechanical properties

Fig. 1 shows the hardness of TCS stainless steel heated at 600–1300 °C for 10 min. Results indicate that when the heating temperature is below 900 °C, it does not affect the hardness of TCS stainless steel. But when the heating temperature is 1000 °C and 1100 °C, its hardness sharply increases from about 140 kg/mm^2 to 244 kg/mm^2 to 2668 kg/mm^2. However as the heating temperature is 1200 °C and 1300 °C, its hardness begins to decrease again from 266 kg/mm^2 to 246 kg/mm^2 to 215 kg/mm^2. But hardness is still greater than that of unheated samples.

Table 2
Mechanical properties of TCS ferritic stainless steel

Hardness HB	143 kg/mm^2
Yield strength $R_{p\ 0.2}$	345 MPa
Tensile strength R_m	460 MPa
Elongation percentage	33%
Impact energy (room temperature)	72.6 J
Impact energy (−40 °C)	31.0 J

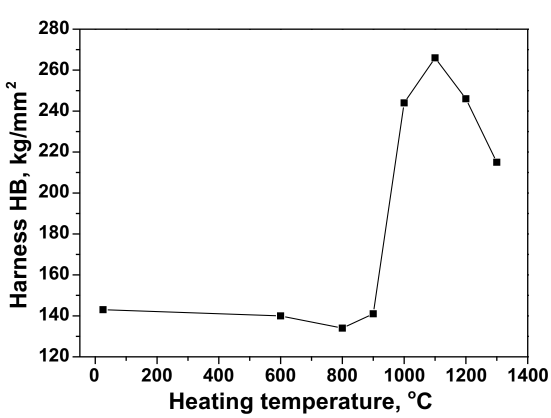

Fig. 1. Hardness of TCS stainless steel heated at 600–1300 °C for 10 min.

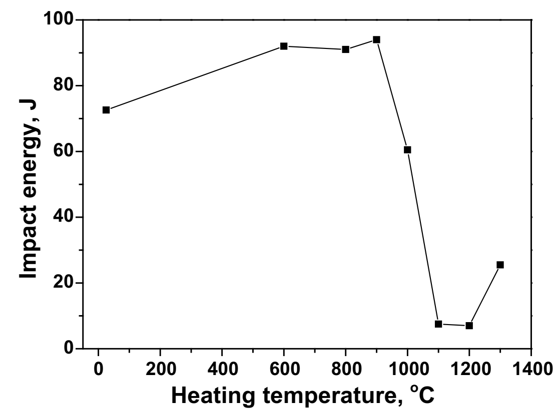

Fig. 2. Impact properties of TCS stainless steel heated at 600–1300 °C for 10 min.

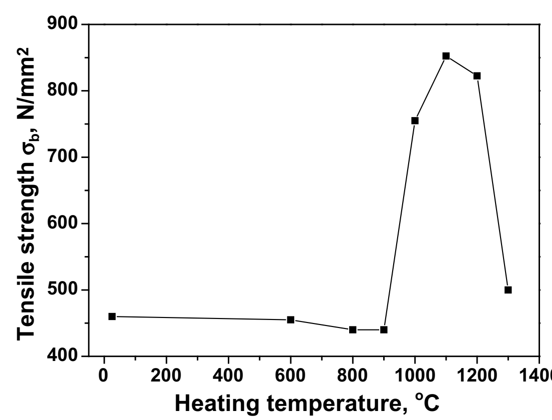

Fig. 3. Tensile strength of TCS stainless steel heated at 600–1300 °C for 10 min.

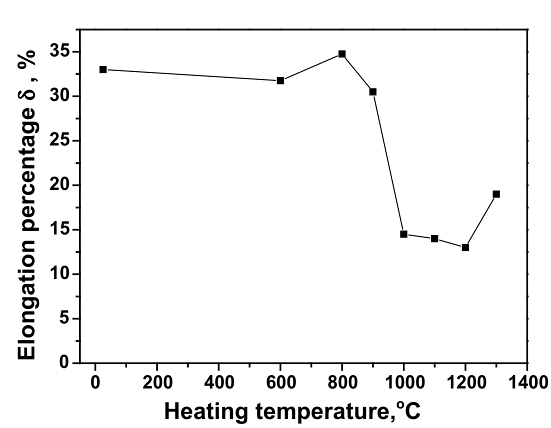

Fig. 4. Elongation percentage of TCS stainless steel heated at 600–1300 °C for 10 min.