Materials and Design 29 (2008) 1533–1539

Contents lists available at ScienceDirect

Materials and Design

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

Comparisons of 30Cr2Ni4MoV rotor steel with different treatments on corrosion resistance in high temperature water

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ARTICLE INFO

Article history:
Received 2 September 2007
Accepted 14 February 2008
Available online 29 February 2008

Keywords:
Heat treatments
Deep cryogenic treatment
Laser surface melting
High temperature water corrosion

ABSTRACT

Three different treatments, including the heat treatment, deep cryogenic treatment and laser surface melting, were carried out on the 30Cr2Ni4MoV rotor steel. Electrochemical polarization curve and stress corrosion test at the high temperature autoclave were employed to evaluate the corrosion resistance of treated specimens in high temperature water. Results indicate that the conventional heat treatment will increase the value of K_{IH} for specimens with the lower yield strength, and hence reduce the susceptivity of stress corrosion cracking. However, for the deep cryogenic treated specimen, no apparent improvement was observed on the hardness and corrosion resistance due to the limited carbon precipitate and austenite transformation. In comparison, the best corrosion resistance of laser treated specimens was gained among the three-method-treated specimens according to results of the electrochemical polarization tests at temperature of 90 °C. Nevertheless, some micro-cracks produced on the tensioned surface during the fabrication of self-loaded U-bend specimen due to the large deformation, and thus lead to a decreased stress corrosion cracking resistance in the environment of high temperature water.

1. Introduction

At the IAEA conference of Moscow, it was declared that 130 new nuclear reactors would be built in the coming 15 years and then the total nuclear power capacity would rise to about 427–430 GW. As a key equipment of nuclear power station, the steam turbine has suffered many problems for several decades, e.g., erosion, pitting, environment assisted cracking (EAC), deposit build up and the associated loss of efficiency, which are related to the impurities of steam [1]. The guidelines for chemical element control of boiler feed water and steam have been included in many corresponding standards and codes. However, controlling of chemical impurities during operation is an extremely difficult issue because of the deficiency of water treatment, leakage of the condenser and transients during the startup and shutdown periods. Nevertheless, it has been realized that decreasing the strength grade of rotor steel can significantly improve the stress corrosion cracking resistance [2,3]. The lower strength will be inevitable to face with the increasing possibility of mechanical failure and thus produce a limit in practice.

Deep cryogenic treatment (DCT) of materials is an extension of cooling process for the standard heat treatment. Generally, the treatment temperature of DCT is set in the range of −130 °C and −196 °C. As a result of residual austenite transformation and dispersion strengthened by microstructure refinement, DCT can improve the mechanical properties of material including intensity, hardness, toughness, fatigue resistance and wear resistance [4,5]. In addition, it is believed that DCT could reduce the magnitude of internal stresses and steady the dislocation structure of steel, which should result in the decreasing free energy of atom and the better corrosion resistance of steel [6].

Recently, laser surface melting (LSM) was introduced in the material treatment because it can improve surface properties of material without significantly effects on the bulk properties. It have been generally accepted that LSM can be used for improving the corrosion resistance of metallic alloys through the homogenization/refinement of microstructure, dissolution/redistribution of precipitates or inclusions and phase transformation [7]. LSM was also used to improve the SCC resistance of metallic alloys [8–11].

To provide an appropriate treatment method for 30Cr2Ni4MoV rotor steel in practice, this paper focused on the comparison of corrosion behaviors through three kinds of treatment, including conventional heat treatment (HT), deep cryogenic treatment (DCT) and laser surface melting (LSM). Electrochemical polarization curve and high temperature autoclave stress corrosion experiment were employed to evaluate the corrosion resistance of treated specimens.

2. Experimental method

30Cr2Ni4MoV is the widely used middle alloy as the turbine rotor and disk materials of the nuclear power generation. The

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doi:10.1016/j.matdes.2008.02.003

chemical composition of 30Cr2Ni4MoV is (wt.%): C 0.28, Cr 1.85, Ni 3.35, Mo 0.42, V 0.089, Mn 0.22, Si 0.06, P 0.004, S 0.002, Al 0.007, Cu 0.06, Sn 0.004, As 0.0044, Sb 0.0009.

Specimens were cut off from the low pressure steam turbine rotor and then treated under the condition of 850 °C/12 h quenching + 620 °C/17 h tempering +560 °C/14 h anneal for stress relieving. As a result, the yield strength of 30Cr2Ni4MoV is 827 MPa. In comparison, tempering conditions of 640 °C/17 h and 670 °C/17 h were also assigned which led to the yield strength of 753 MPa and 661 MPa, respectively.

Deep cryogenic treatment was completed in the liquid nitrogen environment (about −196 °C). The prepared specimens were put into a box imbued with the liquid nitrogen, then taken out after 24 h holding time and tempered at 200 °C with 2 h holding time. On the other hand, a 7 kW multifunctional CO_2 laser was used for surface treatment with a scanning rate 1 m/min at beam power of 1.4 kW and 1.6 kW. The finial beam at the focal point was 9 mm × 2 mm. In consideration of the width of specimen being 15 mm, 2 mm width folded zone produced at the surface middle of specimen.

Stress corrosion test in high temperature water was employed to evaluate the stress corrosion cracking susceptivity of the treated specimens with conventional heat treatment, deep cryogenic treatment and laser surface melting. The test environment was designed as 3.5% NaCl solution at 270 °C and a self-loaded type specimen with U-bend shape was selected and shown in Fig. 1. The dimension of specimen was 2 mm × 15 mm × 75 mm and fabricated to U-shape with the special mould.

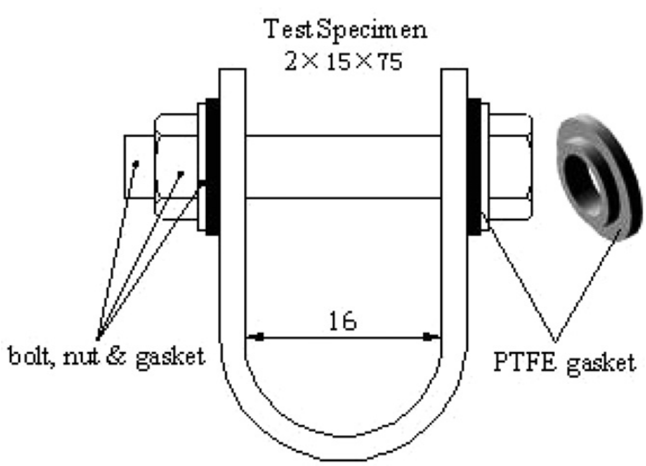

Fig. 1. U-bend specimen for SCC test.

To simulate the impurity concentrations of condensate under the abnormal condition, electrochemical polarization tests were carried out in the solution of 10 ppm NaCl + 10 ppm Na_2SO_4 and 5.38 ppm O_2 at temperature of 80 °C. The conductivity of the deionized water was less than 0.056 μS/cm (18 MΩ cm) and the chloride concentration was 1.106 ppm calibrated through the ionic chromatography analyzer. The arrangement of electrochemical polarization test was shown in Fig. 2. Tri-electrode measuring system was adopted including a working electrode, a reference electrode of Ag/AgCl and an auxiliary elect of Pt rode. The scan rate of 0.5 mV/s in the potential range of −1000 mV and −600 mV was selected in polarization curve tests. The corrosion potential and the corrosion current were calculated using the self-developed software program according to Stern–Geary equation.

3. Results and discussion

3.1. Microstructure and hardness

For 30Cr2Ni4MoV steel with yield strength of 753 MPa, microstructures of non-cryogenic-treated and cryogenic-treated specimens are shown in Fig. 3. It is clear that, compared with the non-cryogenic-treated specimen, a large number of fine particles coupled with fine carbides produced in the cryogenic-treated specimen. Moreover, austenite transformation was also observed, as shown in Fig. 3b. For austenite stainless steel with DCT, higher hardness is achieved due to the transformation of residual austenite to martensite and the precipitation of fine carbides [6]. However, non significant increase of hardness was observed for the 30Cr2Ni4MoV steel after DCT. For example, only 5 HV increment was detected for the specimen with the yield strength of 753 MPa and hardness of 259 HV after DCT.

For LSM treated 30Cr2Ni4MoV steel, three different regions were observed on the cross-section microstructures, including Zone I (matrix metal), Zone II (heat-affected area of 250–300 μm) and Zone III (laser melting area of 10–20 μm), which are shown in Fig. 4a–c. Nevertheless, it is worth noting that no significant discrepancy was observed on the optical cross-section microstructure with different yield strength.

Microhardness measurement was performed for LSM treated specimens by a microhardness digital tester with the load of 1.96 N and holding time of 15 s, as show in Fig. 5a and b. Results indicated that significant increase of microhardness in the melted layer was obtained than that of bulk metal. And then, hardness decreased gradually from the laser melting zone to the matrix. This was attributed to the finer grain of martensite and higher dislocation density of phase transformation zone due to the rapid heating and cooling rate of laser treatment process. However, no significant effects of different yield strength on the hardness of laser melting

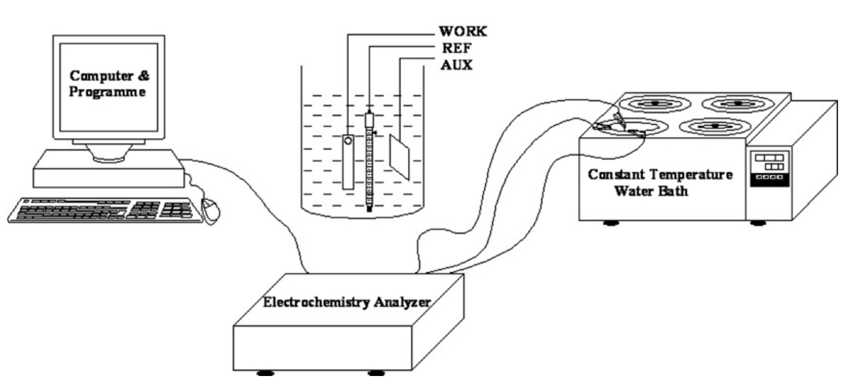

Fig. 2. Principle of the electrochemical polarization test and the corresponding instrument.