Wear 319 (2014) 150–159

Contents lists available at ScienceDirect

Wear

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

Cavitation erosion of thermomechanically processed 13/4 martensitic stainless steel

Brij Kishor, G.P. Chaudhari *, S.K. Nath

Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India

ARTICLE INFO

Article history:
Received 10 April 2014
Received in revised form
29 July 2014
Accepted 30 July 2014
Available online 9 August 2014

Keywords:
Power generation
Cavitation erosion
Optical microscopy
Steel
Hardness

ABSTRACT

This investigation is concerned the cavitation erosion resistance of 13/4 martensitic stainless steel that was processed in a Gleeble® 3800 simulator using thermomechanical treatments at two different temperatures (1000 °C and 1100 °C) and with two strain rates (0.01 s^{-1} and 0.1 s^{-1}). Microstructures of the as-received and thermomechanically processed 13/4 martensitic stainless steel specimens were documented by light optical microscopy, and worn surfaces were examined using scanning electron microscopy. The erosion behavior was quantified using cumulative volume loss, volume loss rate, and roughness parameters plotted as a function of exposure time. The erosion characteristics were correlated with microstructure and mechanical properties. The best cavitation erosion resistance was exhibited by the specimen that was thermomechanically processed at 1000 °C using a strain rate of 0.1 s^{-1}. This result is attributed to microstructural refinement and higher hardness that led to a longer incubation period.

1. Introduction

Low carbon 13Cr4Ni martensitic stainless steel (13/4 MSS) is used in the fabrication of hydro turbine underwater parts. In spite of its excellent corrosion resistance, high strength, and good low temperature ductility and toughness [1–4], it suffers erosion in service. Erosion of steels by shock waves and silt in a fluid stream cause heavy damage to underwater parts of hydro-turbines. This erosion refers to the loss of material from surfaces that are in relative motion with liquid in the area of implosion of vapor bubbles contained in the fluid [5]. Formation of bubbles and their sudden implosion create characteristic cavitational noise, makes turbine vibrate which can considerably damage a machine and material is eroded [6–7].

An alternative of 13/4 MSS is nitrogenated stainless steel which however is expensive [8–9]. Therefore, several researchers tried to improve the cavitation erosion resistance of 13/4 MSS by heat treatment and by applying the different coatings [10–13]. Thermochemical surface modification process like plasma nitriding is used for improving the erosion resistance of 13/4 MSS and promising cavitation erosion resistance is reported [1,14]. In addition, laser cladding technique is shown to improve the cavitation and corrosion-erosion resistance of AISI 420 MSS [15–16]. However, these are surface modification techniques and the effect is limited to modified thickness. An alternative way to improve the cavitation erosion resistance of 13/4 MSS throughout the cross-section can be thermomechanical processing (TMP). Thermomechanical processing (TMP) of metals using different strain rates and temperature conditions alters the microstructure from processes such as work hardening, dynamic recovery, and dynamic recrystallization [17]. These can refine the grain size; alter the final microstructure and mechanical properties, which can influence the cavitation erosion resistance. In addition to microstructural modification, the surface finish also influences cavitation erosion resistance greatly.

The present study is an attempt to enhance the cavitation erosion resistance of 13/4 MSS by different TMP schedules employed in Gleeble® 3800 simulator. TMP is carried out at two different temperatures of 1000 °C and 1100 °C and at strain rates of 0.01 s^{-1} and 0.1 s^{-1} in order to produce a refined microstructure. Cavitation erosion resistance of as received (ASR) and TMP 13/4 MSS specimens is evaluated in order to study the relationship among microstructure, surface roughness, and cavitation erosion resistance. It is observed that the actual degradation mechanism and the mass-loss behavior of the specimens is related to various roughness parameters [18,19]. Hence, the incubation time and roughness induced by cavitation erosion is studied and correlated with microstructures and erosion behavior.

2. Experimental procedure

2.1. Materials and thermomechanical treatments

ASTM A 743 grade CA6NM 13/4 MSS investigated in the present study was procured from M/s. Vaishnav Steel Pvt. Ltd., India. The

* Corresponding author. Tel.: +91 1332 285524; fax: +91 1332 285243.
E-mail address: chaudfmt@iitr.ernet.in (G.P. Chaudhari).

http://dx.doi.org/10.1016/j.wear.2014.07.024
0043-1648/

chemical composition as determined from Thermo Jarrell–Ash spark emission spectroscope is shown in Table 1. Cylindrical specimens of 15 mm height and 10 mm diameter were prepared from the ASR 13/4 MSS ingot for hot compression tests, according to ASTM E209 standard.

The hot compression experiments were performed in thermo-mechanical simulator Gleeble® 3800. Thermocouples were welded in the center of the specimen in order to monitor the actual temperature during the testing. Tantalum foil was used between specimen surface and the anvil to prevent sticking during hot deformation. A schematic representation of the designed TMP schedules is shown in Fig. 1(a) and (b). Before the deformation, all the specimens were heated to 1100 °C using heating rate of 5 °C/s and were held at this temperature for 120 s for homogenization. The specimens were cooled from 1100 °C to the deformation temperature at 1 °C/s. Specimens were continuously hot compressed at 1000 °C and 1100 °C using strain rates ranging from 0.01–0.1 s^{-1}, with holding time of 30 s before deformation in order to eliminate the thermal gradients.

2.2. Microstructural characterization

Microstructures of ASR 13/4 MSS and TMP specimens were analyzed by using a Leica DMI 5000 M light optical microscope (LOM). Deformed specimens were cut along the compression axis and the surfaces were polished with 0.02 μm grade alumina powder. The polished surfaces of 13/4 MSS and TMP specimens were electro-etched using 60% nitric acid + 40% water solution for microstructural examination. The average prior austenite grain size was revealed by using Villela's reagent (1 g picric acid + 5 ml HCl + 100 ml ethyl alcohol) and was measured using the linear intercept method according to ASTM E112-10. X-ray diffraction (XRD) was performed with the help of Rigaku SmartLab X-Ray Diffractometer using Cu-Kα radiation. The amount of ferrite in ASR 13/4 MSS and TMP specimens was measured using systematic manual point count method as per ASTM E562-02. In order to identify the main erosion mechanisms, eroded surfaces were studied using scanning electron microscope (SEM). Hardness measurements were carried out on polished surface using a FIE VM50 Vickers hardness tester with 10 kg load and dwell time of 15 s. Average of 10 readings obtained at different locations is reported. Thermo-Calc® software was used to estimate the amount of different phases present in the stainless steel composition used in the present work as a function of temperature.

Table 1
Chemical composition (wt%) of 13/4 MSS.

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V	Al
0.065	0.62	0.73	0.027	0.008	12.30	3.78	0.45	0.22	0.04	0.005

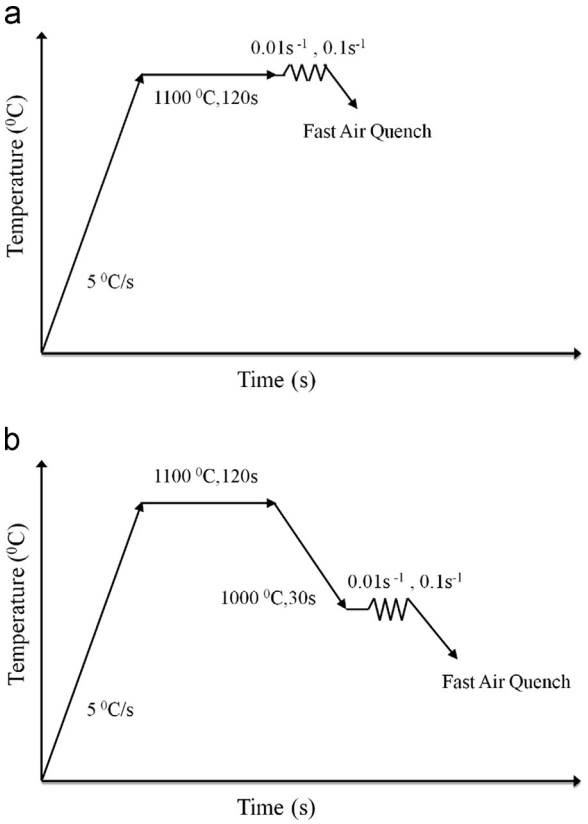

Fig. 1. Thermomechanical processing schedule of 13/4 MSS hot compressed at (a) 1100 °C and (b) 1000 °C.

2.3. Cavitation erosion tests

Fig. 2 shows a schematic diagram of the cavitation-erosion experiment setup. It consists of a VCX 1500® (Sonics and Materials, USA) ultrasonic transducer operating at a frequency of 20 kHz with peak-to-peak displacement amplitude of 50 μm. The specimens for cavitation tests were prepared in the form of discs of 14.8 mm in diameter. Prior to testing, all the specimens were polished to obtain the roughness profile ordinate, R_q, value smaller than 1 μm. The polished specimen was immersed in 500 ml glass beaker filled with distilled water and placed below the tip of the probe at a distance of 0.5 mm. The diameter of the probe/horn was 19 mm. In order to maintain the water temperature at 25 ± 2 °C, the glass beaker was placed inside a circulating thermostatic water bath. The test was conducted for 11 h and the weight loss was measured every 1 h by a Mettler electronic balance having an accuracy of 0.1 mg. Prior to weighing and surface roughness measurement, specimens were cleaned with acetone and dried.

2.4. Surface topography measurements

A Mitutoyo SJ-400 surface stylus profilometer with 2 μm tip radius and 0.01 μm resolution power measured the surface roughness of all the samples before and after the cavitation test, between every 1 h cycle. According to ISO 4288 standard, a cut-off length of $L = 0.8$ mm is used to obtain a total traversing length

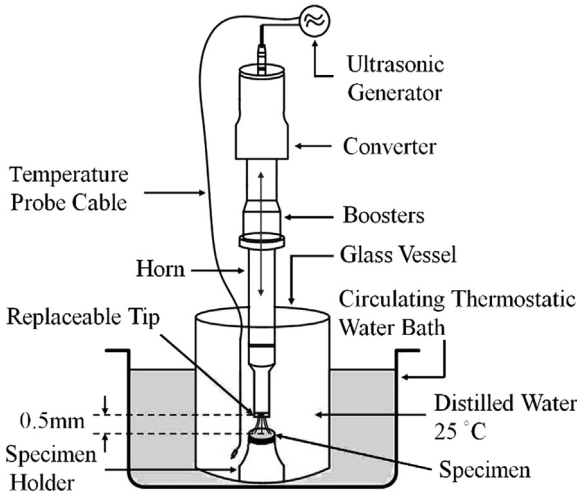

Fig. 2. Schematic of the experimental setup for cavitation erosion tests.