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ScienceDirect

Surface & Coatings Technology 202 (2007) 993–997

SURFACE & COATINGS TECHNOLOGY

www.elsevier.com/locate/surfcoat

Improvement of the slurry erosion resistance of an austenitic stainless steel with combinations of surface treatments: Nitriding and TiN coating

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Available online 11 August 2007

Abstract

The combination of different surface treatments for improving the erosion resistance of an AISI 304 stainless steel was studied. Six kinds of sample conditions were tested in a slurry composed of distilled water and SiC particles: High temperature gas nitriding (HTGN), low temperature plasma nitriding (expanded austenite), high temperature gas nitriding followed by a PVD-TiN coating, low temperature plasma nitriding followed by a PVD-TiN coating as well as PVD-TiN coated and uncoated samples in the solubilized condition. The erosion tests were performed during 6 h in a jet-like device with a normal angle of incidence and an impact velocity of 8.0 m/s.

Wear rates were assessed by accumulated mass loss measurements and through analysis of scanning electron microscopy images of the worn surfaces. The results were related to the microstructure and hardness of the surface to establish a ranking of the different surface treatments. After the first few minutes of testing cutting of the surface occurred in the solubilized, in the HTGN and in the low temperature plasma nitrided AISI 304 samples, whereas TiN coated samples did not show any cutting marks, although some indentation marks could be observed. The TiN coated samples showed wear resistances one order of magnitude greater than the solubilized, HTGN and low plasma nitrided samples.

Keywords: Slurry erosion; TiN coatings; High temperature gas nitriding; Low temperature plasma nitriding; Expanded austenite

1. Introduction

Austenitic stainless steels have been used in a lot of industrial applications owing to their good corrosion resistance. However this steel suffers from poor wear resistance in comparison to other stainless steels, leading to premature failure of engineering parts. Many of these failures in marine, food, chemical, and energy industries are related with erosion wear, due to impact of high velocity particles entrained in fluid streams. During the last years, different surface treatments using nitrogen have been developed for improving the wear resistance of this material without loss of its corrosion resistance. These treatments include high temperature gas nitriding HTGN [1] low temperature plasma nitriding [2,6], and TiN coatings deposition [4]. In this work the potential of these surface treatments for reducing erosive wear behavior of an AISI 304 stainless steel is assessed.

During a HTGN process, a sample is annealed in a nitrogen rich atmosphere, between 1273 and 1473 K. In this range of temperatures, nitrogen diffuses through the surface forming a layer with nitrogen in solid solution. HTGN has been successfully used to improve the erosion resistance of different stainless steels [1,5]. On the other hand, low temperature plasma nitriding forms a layer of a metastable fcc solid solution supersaturated in nitrogen, sometimes called 'expanded austenite'. This phase is very hard and improves the load bearing capacity and the wear resistance while maintaining the corrosion resistance of austenitic stainless steels [2,3,7]. The formation of this layer may not be enough to avoid wear under severe testing conditions. The deposition of an additional hard coating on a nitrided substrate improves the adherence of the layer to the substrate and avoids the abrupt change of mechanical properties between the TiN layer and the substrate. An abrupt variation of hardness and elastic modulus leads to failure of the coating due to a low load bearing capacity of the substrate [3]. When the duplex treatment is composed by a pulsed plasma nitriding treatment followed by a PVD-TiN

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0257-8972/$ - see front matter
doi:10.1016/j.surfcoat.2007.07.078

Table 1
Plasma nitriding, PVD-TiN coating and duplex treatments parameters

Treatments	Pressure	$H:N_2$	Time (min)	$Ar:N_2$	Current (A)	Potential (V)	Temperature (^{0}C)
Ion nitriding	6.0 Torr	1:3	1200.0	–	0.75	550	400
TiN layer deposition	3.0 mTorr	–	140.0	20:3	3.0	330	320

coating and both processes are carried out in the same chamber the treatment is called a hybrid treatment.

In this work, the combination of different surface treatments using nitrogen, for improving the erosion resistance of an AISI 304 stainless steel, was studied.

2. Experimental procedure

2.1. Specimens and treatments

Solubilized (solution annealed) samples of AISI 304 stainless steel were used as base material for the different treatments. The surface of the samples was manually polished with diamond paste until 1.0 µm, washed in acetone and hot dried. The chemical analysis of the concentrations of the elements gave in wt.% Cr 18.9, Ni 7.2, Mn 1.5, Mo 0.22, C 0.04, S 0.004, Fe bal.

Six kinds of specimens were analyzed: solubilized, high temperature gas nitrided (HTGN), pulsed plasma nitrided (expanded austenite), solubilized with a PVD-TiN layer deposition, HTGN with a PVD-TiN layer deposition and pulsed plasma nitrided plus PVD-TiN layer deposition.

The solubilizing treatments were performed with the aim of dissolving carbides present in the microstructure, and were carried out in an Ar atmosphere inside a tubular furnace described elsewhere [1]; the samples were heated up to 1373 K for 1 h and quenched in water. High temperature gas nitriding was carried out in the same equipment at 1473 K for 6 h under 0.15 MPa N_2 pressure. After nitriding the samples were directly quenched in water.

The pulsed plasma nitriding and the PVD-TiN layer deposition were carried out in a hybrid reactor. The TiN layer was deposited by Triode Cathode Magnetron Sputtering [4]. The hybrid process allows coating the pre-nitrided sample with a TiN layer without exposing the specimen to atmospheric pressure, avoiding cleaning operations of the surface between depositions. Table 1 shows the parameters used in both treatments.

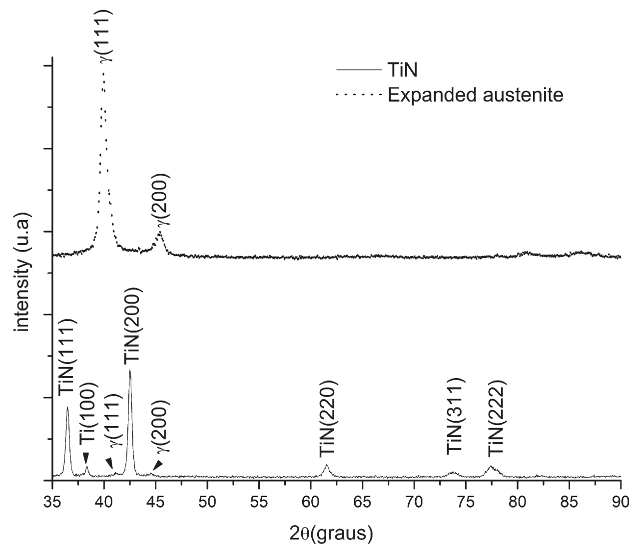

Fig. 2. XRD patterns for TiN and expanded austenite.

2.2. Test conditions

Slurry erosion wear tests were performed in a jet-like device described elsewhere [8]. The test was carried out with slurry composed by 900 ml of distilled water and 100 g of angular-shaped silicon carbide particles. The size of the particles was between 212 and 300 µm. The SiC abrasive particles with 26 GPa hardness are shown in Fig. 1. The impact angle was fixed in 90^o and the velocity of the jet was 8.0 m/s.

The samples were cleaned with distilled water for 10 min, dried in hot air, and weighed in a *Shimadzu* AUW 220D scale with a precision of 0.01 mg. Thereafter, the samples were eroded and then weighed again.

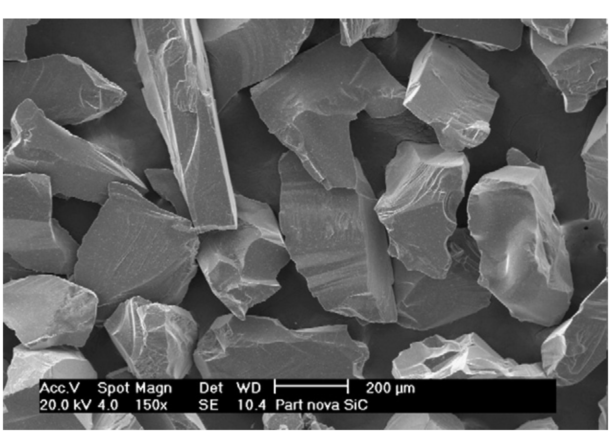

Fig. 1. Morphology of SiC particles used in slurry tests.

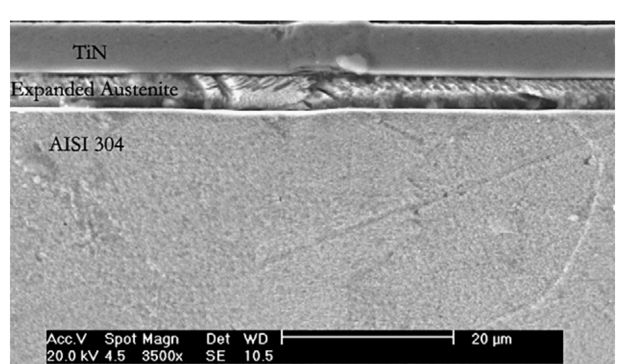

Fig. 3. Cross section of a duplex treated sample: TiN plus expanded austenite.