Vacuum 111 (2015) 110–113

Contents lists available at ScienceDirect

Vacuum

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

Rapid communication

A study of the influence of plasma post-oxidizing on the corrosion resistance

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ARTICLE INFO

Article history:
Received 28 August 2014
Received in revised form
27 September 2014
Accepted 27 September 2014
Available online 7 October 2014

Keywords:
Plasma post-oxidation
Plain air
Gibbs free energy
Corrosion resistance
AISI 4140 steel

ABSTRACT

AISI 4140 steel was selected as the material and plasma post-oxidation by plain air in the same nitriding system just after plasma nitriding was investigated primarily. The results show that a thin oxide layer composed of Fe_3O_4 and Fe_2O_3 is formed, and the ratio of Fe_3O_4 to Fe_2O_3 is closely related to the plasma post-oxidizing temperature and time. The highest ratio of Fe_3O_4 to Fe_2O_3 is obtained while post-oxidizing at 673 K for 60 min due to lower standard Gibbs free energy and appropriate forming rate for the formation of Fe_3O_4 at this condition. The thin oxide layer brings out significant improvement of corrosion resistance, especially at higher ratio of Fe_3O_4 to Fe_2O_3. Surface images of the corroded specimens after polarization test shows that there exists no corrosion pit for the specimen post-oxidized at 673 K for 60 min, though some corrosion pits exist for those treated under other conditions.

AISI 4140 steel is widely used for gears due to its excellent combined properties. Meanwhile, in order to meet the design criteria of gears, surface modification is essential to improve their fatigue strength, wear and corrosion resistance. Plasma nitriding is one of the most widely used surface modifications to improve surface hardness and wear resistance for AISI 4140 steel [1–4], which involves the introduction of nitrogen atoms into the component surface to produce the modified layer on the surface of materials. Unfortunately, the modified layer formed during plasma nitriding can not offer good corrosion resistance, thus restricts the applications of this technique in some environments. Plasma post-oxidation done immediately after plasma nitriding can produce a thin chemically resistant protective oxide layer [5–7], mainly composed of Fe_3O_4 on top of the nitrided layer, which can cover and seal micropores in the compound layer and significantly improve the corrosion resistance of the nitrided AISI 4140 steel [8–11].

Plasma post-oxidizing is usually performed using a mixture of hydrogen and oxygen gases [12–14]. To make the process more convenient and effective, plain air is primarily used as oxygen bearing gas for post-oxidation in this study. In plasma oxidizing, the high-energy oxidizing ions [15,16] bombarding the surface simultaneously and a dense oxide layer without any stress forms and grows. And the effect of plasma post-oxidizing temperature and time on the corrosion resistance for plasma nitrided AISI 4140 steel is investigated systematically.

The material used for this investigation was AISI 4140 steel with the following chemical compositions (in wt. %): C, 0.41; Cr, 0.91; Mo, 0.18; Mn, 0.83; Si, 0.21; P, 0.014; S, 0.011 and Fe, balance. Specimens with the size of 10 mm × 10 mm × 5 mm were cut from a used gear. Samples were austenised at 1133 K for 10 min, oil quenched, tempered at 893 K for 20 min, and air cooled. This process led to the homogenization of the micro-structures of the samples. All the surfaces of samples were grounded and polished by using chromic oxide slurry to achieve a fine finish and ultrasonically cleaned in anhydrous ethanol prior to nitriding.

Both plasma nitriding and plasma post-oxidation were performed in the same 20 KW pulsed DC plasma nitriding equipment. All samples were nitrided at 823 K for 4 h in a mixture gas of nitrogen and hydrogen with a ratio of 1/3 at a gas pressure of 180 Pa. After nitriding process, the samples were cooled in the chamber with nitrogen supply, and nitrogen was substituted by plain air with a flow rate of 4L/min at a gas pressure of 100 Pa to run plasma post-oxidation process once the designed temperature was reached, and three temperatures (623 K, 673 K and 723 K) and three holding duration (30 min, 60 min and 90 min) were applied in this study. Finally, the vacuum chamber was pumped to 10 Pa and the samples were cooled down to room temperature in the furnace. For comparison, samples annealing in vacuum at identical time and temperature as those in post-oxidizing was performed and analyzed as a reference.

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http://dx.doi.org/10.1016/j.vacuum.2014.09.021
0042-207X/

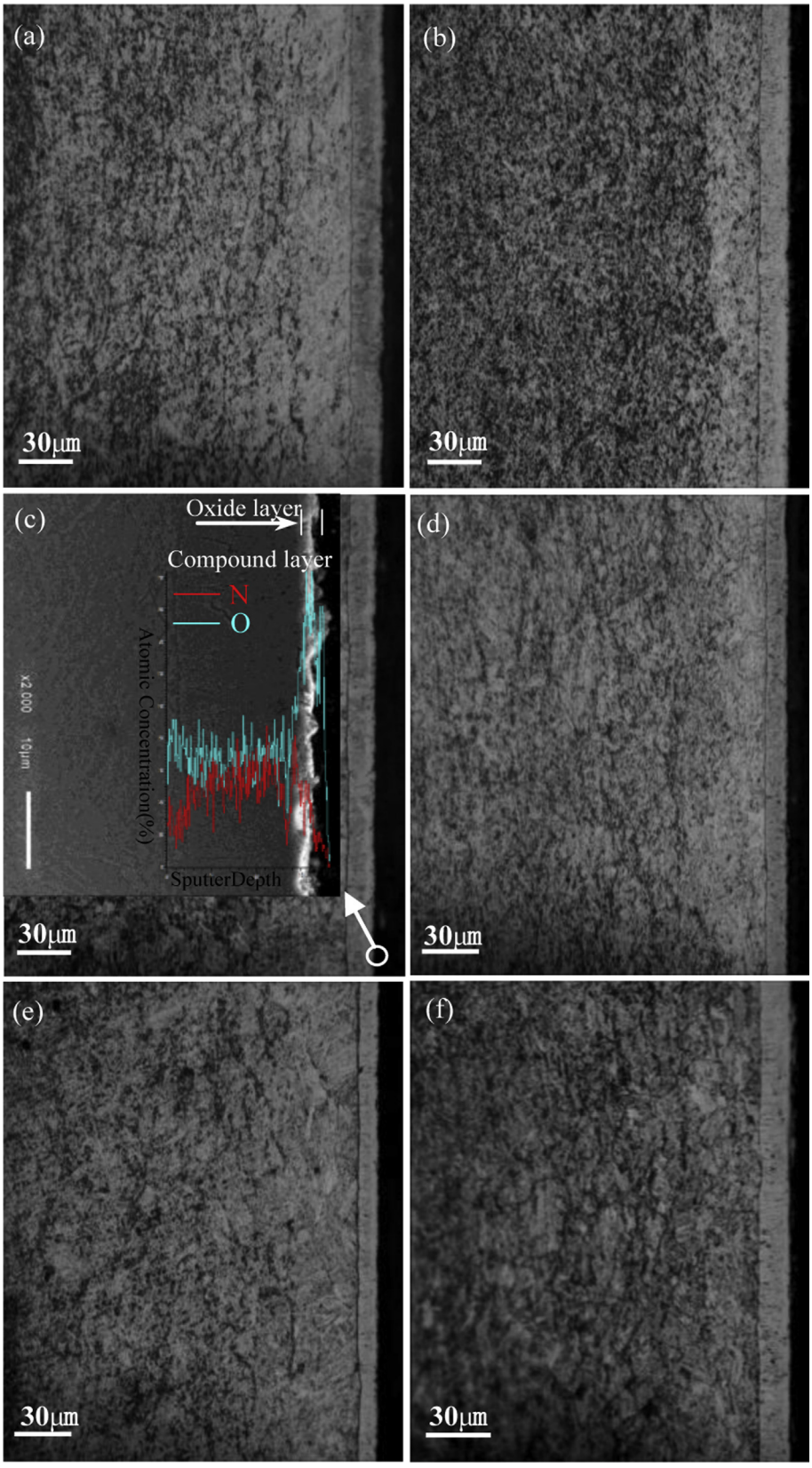

Fig. 1. The cross-sectional microstructure of AISI 4140 steel plasma nitrided and post-oxidized at different conditions (a) without post-oxidation (b) 673 K, 30 min (c) 673 K, 60 min (d) 673 K, 90 min (e) 723 K, 60 min (f) 623 K, 60 min.