International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:3, 2014

Titanium-Aluminum Oxide Coating on Aluminized Steel

Fuyan Sun, Guang Wang, Xueyuan Nie

***Abstract*—**In this study, a plasma electrolytic oxidation (PEO) process was used to form titanium-aluminum oxide coating on aluminized steel. The present work was mainly to study the effects of treatment time of PEO process on properties of the titanium coating. A potentiodynamic polarization corrosion test was employed to investigate the corrosion resistance of the coating. The friction coefficient and wear resistance of the coating were studied by using pin-on-disc test. The thermal transfer behaviors of uncoated and PEO-coated aluminized steels were also studied. It could be seen that treatment time of PEO process significantly influenced the properties of the titanium oxide coating. Samples with a longer treatment time had a better performance for corrosion and wear protection. This paper demonstrated different treatment time could alter the surface behavior of the coating material.

***Keywords*—**Corrosion, plasma electrolytic oxidation, thermal property, titanium-aluminum oxide.

I. Introduction

ALUMINIZED steel using hot-dip aluminizing process is regarded as a fundamental material in the construction and transportation due to its high corrosion resistance [1], [2]. It has the strength of the steel substrate and the corrosion resistance of the aluminum. Aluminized steel is utilized widely for environmental superior corrosion, and its cheap production cost among other high alloy steels also makes it a preferred material for motorcycle exhaust gas systems and manufacturing auto mobiles.

The hotdip aluminum coating does provide long term galvanic protection against pitting corrosion and long term protection against cosmetic red rusting, coordinated with wear resistance to abrasion and friction. However, aluminized steel can pits gradually after exposure to moist salt after cycles of corrosion during elevated temperature applications. The property in wear resistance is also inferior. To improve the performance, the aluminized steel can be coated with titanium oxide. Titanium oxides have superior corrosion resistance in various corrosive environments [3]. So to obtain the high stability, adherent property and protection, a titanium-based oxide coating can be added to the top of aluminized steel.

Plasma electrolytic oxidation is the anodic polarization of metals or alloys, with the interaction between spark micro-discharges and film growth on the substrate surface. The process is constructed in an aqueous electrolyte solution [4]-[6]. The utilize of the low concentration alkaline solution and light metal of low cost makes the PEO process more environmentally friendly than traditional hard anodizing process which includes high concentrations of strong acids [7]. As a result, the PEO coating process attracts increasing attention to strengthen the wear, corrosion resistance and hardness of substrate materials. These high performance properties make the PEO coating treatment a promising technique for industrial applications, which contains biomedical, electronics, automotive, aerospace and manufacturing industrials [8], [9]. In this paper, a titanium-aluminum oxide coating was prepared on aluminized steel using the PEO coating method. The corrosion, wear and thermal properties of the PEO-coated samples were investigated.

Fuyan Sun and Guang Wang are with Department of Mechanical, Automotive and Materials Engineering in University of Windsor (e-mail: guniaosue@uwindsor.ca, wang1161@uwindsor.ca).

Xueyuan Nie is with Department of Mechanical, Automotive and Materials Engineering, University of Windsor (corresponding author to provide; phone: (519) 253-3000 ext. 4148; fax: (519) 973-7007;, e-mail: xnie@uwindsor.ca).

II. Experimental Details

A. Sample Preparation

An aluminized steel rectangular plate was cut into square pieces with the length of 25 millimeter each and used as the substrate materials. The irregular spurs along the cut edges of square pieces were eliminated by abrasive equipment. Then the square pieces were degreased in acetone and distilled water before dried in an ambient condition.

B. PEO Process of Titanium-aluminum Oxide Coating

All the samples were utilized as the anodes and a stainless steel plate was used as the cathode. 50-100g potassium-titanium oxalate, 5-13g citric acid, 5-15g potassium hydroxide and other additives were dissolved in 3 liters of distilled water. The pH of the solution was around 7. Sample A is named for an untreated aluminized steel, and the PEO process time of sample B and C was one minute and three minutes respectively where a pulsed unipolar power source was used. The aluminum layer on the aluminized steel was oxidized to an aluminum oxide incorporated with titanium oxide from the electrolyte solution during the plasma electrochemical oxidation process. The coating is comprised of titanium-aluminum oxides.

C. Potentiodynamic Polarization Corrosion Test

In this technique a three electrode corrosion probe was used to polarize the electrode that serves as the sensing element. The current of potential response was measured as the potential or current was shifted away from the free corrosion potential. The test was operated in a NaCl solution with 3.5% mass percentage. The use of this test was to investigate the corrosion resistance of Samples A, B and C, to see whether corrosion or pitting is a problem.

D. Pin-on-Disc (POD) Tribotest

The test was carried out using a steel ball pin (SAE 51200 steel) as the counterface material in the ambient condition under a 1N load for 200m sliding distance. The diameter of the circle of the wear track was 4mm and the sliding speed was 0.05m/s. The ball was fixed and the sample was rotated to obtain the wear track. The coefficient of friction was recorded with the increase of the sliding distance.

E. Roughness Measurement

A Mitutoyo surface profiler SJ201p was utilized to measure the average roughness Ra and skewness Rsk on the surfaces of coatings of untreated sample and 3-min treated sample. The significance of the above values considering the tribological properties has been reported. If Rsk< 0, the surface is featured with holes and if Rsk> 0 the surface is flat one with peaks.

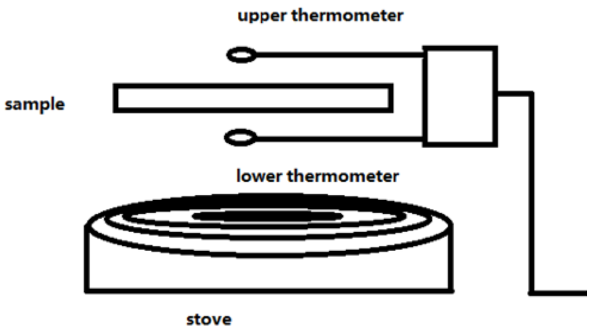

Fig. 1 Setup illustration of roughness measurement

F. Thermal Transfer Test

The uncoated sample and 3-min coated sample are respectively fixed above a stove and placed between two thermometers. The thermometers were 3mm away from the sample surface, Fig. 1. The temperatures of four locations (stove, lower thermometer, upper thermometer and sample) were recorded every minute in a process of 20 minutes.

III. Results and Discussion

A. Wear Behaviors of PEO-Coated Sample and Uncoated Sample

As-prepared PEO coatings were tested by POD under a 1N normal load for a 200m sliding distance in an ambient condition. The coefficient of friction (COF) vs. sliding distances of Sample A, Sample B and Sample C are shown in Fig. 2. The COF value of coated sample with 3-minute treatment time (in a range of 0.2-0.5) is lower than the value of coated sample with 1-minute treatment time (in a range of 0.5-0.8) and uncoated sample (in a range of 05-0.8). The fluctuation of COF values in the curve of 3-min coated sample indicates change in the contact area. In the coated sample prepared with a longer treatment time, the coating layer may consist of two parts: titanium-aluminum oxide top layer and aluminum oxide intermediate layer. The COF of titanium oxide is lower than the alumina [5]. Due to this, the unstable curve with increasing value of COF was recorded for Sample C while the intermediate alumina layer was gradually involved with the proceeding of the sliding wear test. The overlapping part of the curve of uncoated sample and 1-min coated sample indicates that Sample B had a thin oxide coating layer on the substrate owing to a shorter coating treatment time, which may explains the treatment time has a significant effect on the wear resistance.

According to the Fig. 3 where the roughness of surface of coatings are recorded by Mitutoyo surface profiler SJ201p, the average roughness Ra of uncoated sample and coated sample are Ra= 2.40 and Ra=2.50 respectively. The surfaces of coating on both sample are not so smooth but similar. The surface roughness should not contribute the COF difference between two PEO-coated samples.

B. OM Observations on POD Wear Tracks

The optical micrographs (OM) taken form wear tracks on the coatings are shown in Fig. 4. Sample A is the uncoated (within a PEO coating) sample and B is the PEO-coated sample with 3-minute treatment time. The Sample B has less damage than Sample A on the wear track of the circle after the POD tests. This indicates the PEO-coated sample has a better wear resistance. The wear track of a deeper and larger range of damage on the surface of the uncoated sample indicated partial elimination of the hot-dip aluminum layer. On the wear track of coated sample, the track was shallow owing to the coating wear protection provided from the titanium-aluminum oxide layer, on the steel, prepared by the PEO process.

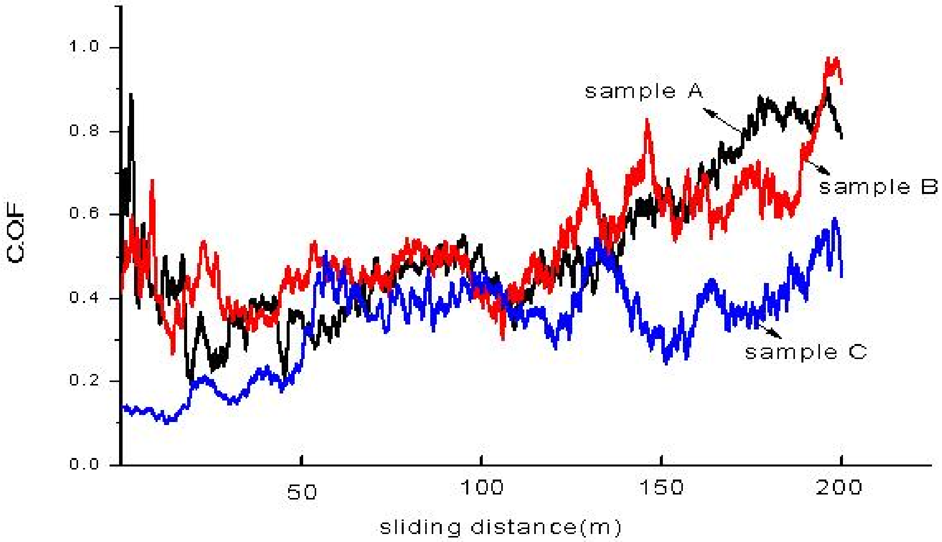

Fig. 2 COF vs. sliding distance in POD wear tests at 1N load, 200m sliding distance for Sample A(a), B(b) and C(c)

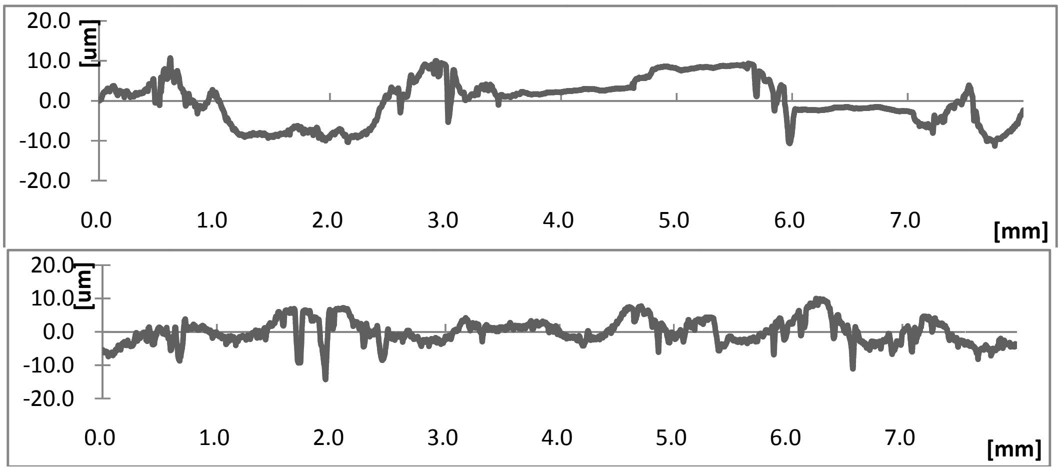

Fig. 3 Schematic of surface of uncoated sample and 3-minute coated sample with a negative skewnessRsk

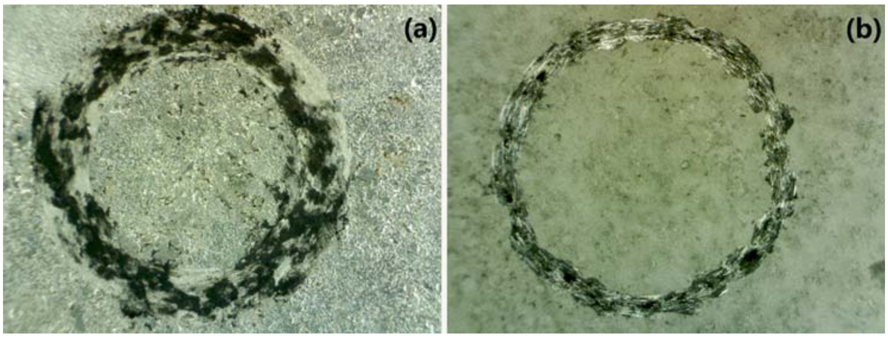

Fig. 4 OM micrographs on POD wear tracks under 1 N, 200 m condition, (a) uncoated sample,(b) three-minute coating

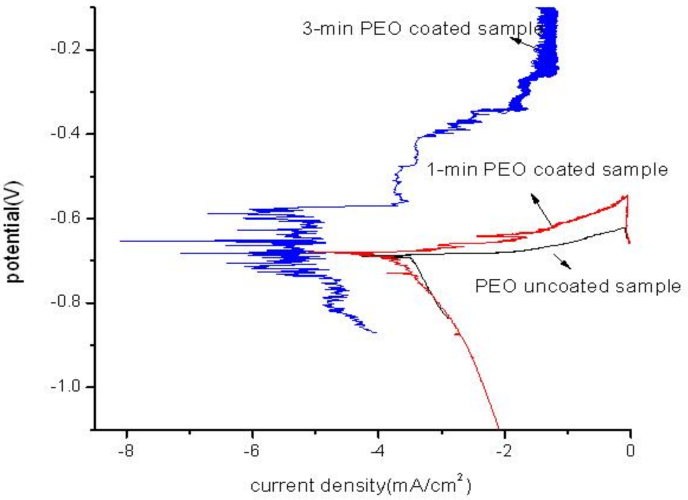

Fig. 5 Potentiodynamic polarization curve of uncoated sample, 1-min coated sample and 3-min coated sample

C. Potentiodynamic Polarization Test

Fig. 5 shows the corrosion polarization curves of uncoated sample, coated sample with one-minute treatment time and coated sample with 3-minute treatment time. The corrosion current and corrosion potential are recorded in Table I. According to the curve of potentiodynamic corrosion and the values of corrosion current density and corrosion potential in Table I, the coated sample with 3 treatment time have a lower corrosion current density compared to uncoated sampleand one-min coated sample.The relationship between Rp and icorr is equation Rp=ΔE/ΔIapp=ΔE/2.3Icorr [10], according to this, 3-min coated sample has the highest corrosion resistance (Rp=26kΩ/cm2). The coating of 3-min coated sample is thicker, and this ceramic titanium-aluminum oxide coating has a better corrosion protection compared to the metallic material, thus the coating with a longer treatment time has a higher corrosion resistance.

TABLE I
RESULTS OF ELECTROCHEMICAL CORROSION TESTS AT 37 °C

Testsamples	I_{corr} (μA/cm2)	E_{corr}(V)	Rp(KΩ/cm^2)
Uncoated sample	0.0631	-0.68	0.412
1-min coated sample	0.0627	-0.70	0.414
3-min coated sample	0.0001	-0.69	26

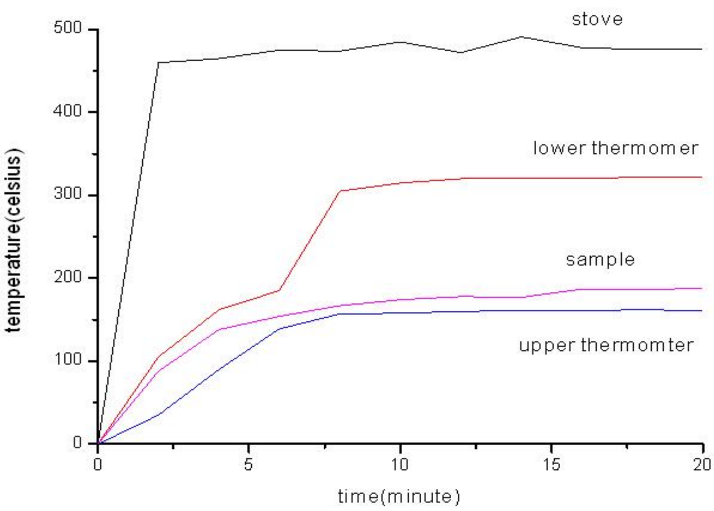

Fig. 6 Temperature vs. heating time of different locations of uncoated sample

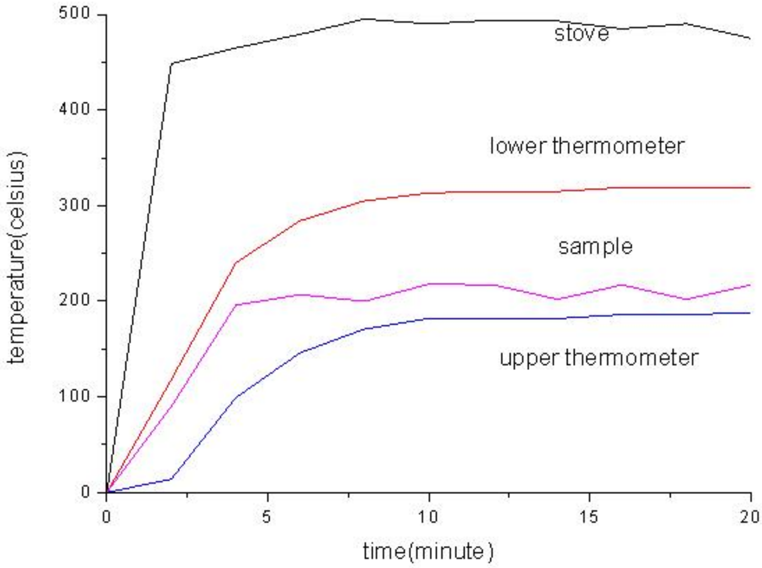

Fig. 7 Temperature vs. heating time of different locations of coated sample with 3-min treatment time

D. Thermal Transfer Behavior Test

Plots of temperature vs. heating time at different locations for cases of uncoated sample and 3-min coated sample are shown in Figs. 6 and 7 respectively. This test was conducted in the ambient condition. The trends of stove temperature of both samples are nearly the same which confirmed the same heating-up process of the stove. The surface temperature of uncoated sample (in range of 170-180^{0}C when stable) is lower than that of coated sample with 3-min treatment time (in range of 200-205^{0}C). The temperature of upper thermometer for the uncoated sample case (in range of 150-160^{o}C) is lower than that of the 3-min coated sample case (in the range of 160-170^{o}C). The temperature of lower thermometer of uncoated sample (in the range of 300-310^{0}C) is nearly the same as 3-min coated sample (in the range of 300-310^{o}C). These temperature differences indicate that the coated sample has better thermal absorption and emissivity properties.

IV. Conclusion

The PEO process in an aqueous electrolyte of a titanium-based compound using a unipolar power source was applied to make titanium-aluminum oxide coating on aluminized steel. Pin-on-disc tribotest was used to study the wear resistance and COF of titanium-aluminum coating of uncoated sample and coated sample with different treatment time. The sample with longer treatment time (3-minute) has a better wear performance than both the uncoated sample and 1-min coated sample. The PEO treatment didn’t change much of surface roughness of the samples.

The potentiodynamic polarization corrosion test was utilized to study corrosion resistance of the coating surface. Compared to the uncoated sample and coated sample with shorter treatment time, the 3-min coated sample has a lower corrosion current density and higher corrosion resistance (Rp). This indicates the better corrosion resistance of the titanium-aluminum oxide coating can be prepared at the longer (3 min) treatment time.

The temperature difference between the surfaces of the tested samples indicates that the PEO-coated sample has better thermal absorption and emissivity properties.

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