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ANALYSIS OF CORROSION CAUSES OF THE CHROMIUM-NICKEL COATING APPLIED FOR PROTECTING THE ACTUATOR OF PISTON RODS

Key words: piston rod, chromium-nickel coating, cathode coating, anode protection, corrosion, damage in the operation.

Abstract: In the work, the results of testing the actuator piston rod that corroded in the operating conditions are presented. It was found that the direct cause of the corrosion were local damages of the Cr/Ni dual-layer coating. In locations of cracking, a brittle chromium coating and deterioration was observed with the character of the sub-coating corrosion intensified by the influence of chloride ions. In consequence, it led to losing its adhesion, and locally exposed the nickel coating, which is less resistant to mechanical impact. The corrosive or mechanical damages of the nickel sub-layer led to uncovering the steel substrate-constituting anode, which was the direct cause of the appearance of the corrosion pits observed macroscopically.

Analiza przyczyn korozji powłoki chromowo-niklowej zastosowanej do zabezpieczenia tłoczyska siłownika

Słowa kluczowe: tłoczysko, powłoka chromowo-niklowa, powłoka katodowa, ochrona anodowa, korozja, uszkodzenia eksploatacyjne.

Streszczenie: W pracy przedstawiono wyniki badań tłoczyska siłownika hydraulicznego, które uległo korozji w warunkach eksploatacyjnych. Stwierdzono, że bezpośrednią przyczyną korozji było występowanie lokalnych uszkodzeń dwuwarstwowej powłoki Cr/Ni. W miejscach spękań kruchej warstwy chromowej obserwowano niszczenie o charakterze korozji podpowłokowej, intensyfikowanej oddziaływaniem jonów chlorkowych. W konsekwencji doprowadziło to do utraty jej adhezji i miejscowego odsłonięcia mniej odpornej na oddziaływania mechaniczne powłoki niklowej. Uszkodzenia korozyjne lub mechaniczne podwarstwy niklu prowadziły do odsłonięcia podłoża stalowego stanowiącego anodę, co było bezpośrednią przyczyną powstania obserwowanych makroskopowo wżerów korozyjnych.

Introduction

Hydraulic actuators found wide application in drive systems of machines and equipment. One of the more important components in them is the piston rod, the movement of which should be steady and uninterrupted by external factors. It requires the application of materials providing the rods with high abrasive resistance and uninterrupted operation in positive and negative temperatures, frequently in an environment of high pollution and dust. For this reason, one of the basic methods of improving the quality of piston rod surfaces is applying chromium coatings.

The chromium coating, frequently electroplating deposits the layer of nickel or copper and nickel on steel, which is a common and successful method of tribological and corrosion protection of steel products. Protective properties of the coatings are essentially influenced by the quality of their manufacturing conditioned by the technology of surface preparation and the production of coatings [1–3]. Due to the harmful effects of frequently applied chromium VI in electroplating, more and more frequently trivalent chromium is used for chromium plating [2, 4]. In terms of corrosion, the chromium coatings are resistant to most of the aggressive environments; however, they corrode in hydrochloric acid [5].

The purpose of the work was to determine the causes and the mechanism of corrosion damage created on actuator piston rods.

1. Research material

The tests were performed on an actuator rod made of the S355J2 grade steel, which had premature failure due to corrosion. The general view and the character of corrosion changes present on surface of the tested component are shown in Figure 1. It was found that the defects show the nature of pitting corrosion. Traces indicating the occurrence of mechanical damages in the chromium coating were locally observed.

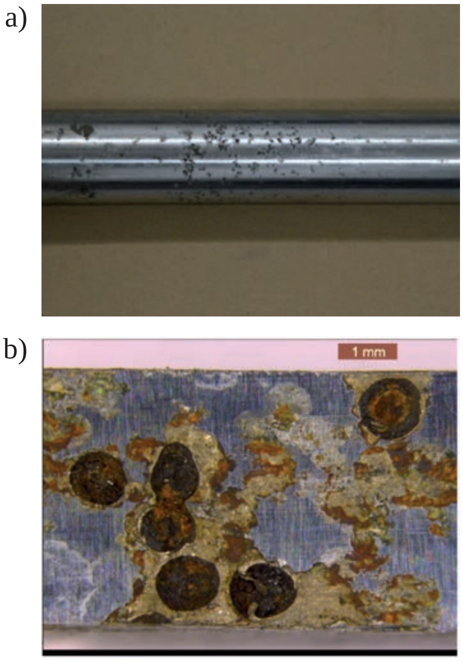

Fig. 1. General view of the tested rod (a) and a stereoscopic image obtained from the sample collected from its surface (b). Corrosion pitting is visible and the chromium coating is peeled off locally

2. Microscopic tests

The microscopic tests using light microscopy methods were performed with the use of a Leica CTR6000 microscope at the transverse section of the sample taken from the piston rod. It was found that the microstructure of the steel substrate material was characterised with the correct ferritic-pearlitic structure. The chromium coating of about 30 μm thickness deposited by electroplating was applied over the sublayer of nickel of the same thickness in order to increase its adhesion to the substrate. Microscopic mechanical defects of the external surface of the tested rod created as a result of the hard particles action were observed locally (Fig. 2).

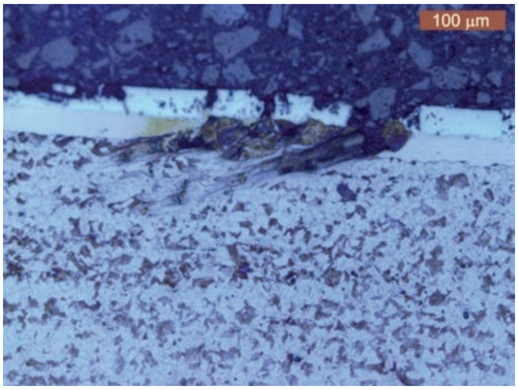

Fig. 2. The ferritic-pearlitic microstructure of the tested piston rod in the near surface area. Visible Cr/Ni coatings mechanically damaged by the action of the hard particles. Transverse section. Etched state. Light microscopy

The SEM microscopic observations were performed on the external surface of the component using a Phenom ProX microscope. It was found that, in the area of macroscopic corrosion, changes shown in Figure 1 b are the local mechanical damages of the chromium coating that appeared as a result of its cracking. The characteristic feature of brittle chromium coat is its cracking leading to a network of fine cracks (Fig. 3). Similar surface damages were observed by the authors of works [2, 6, 7]. It has been proved that their density is closely related to thickness of the chromium coating and the existing residual stresses [7]. As a consequence, in locations of their occurrence, as a result of reactions with galvanic corrosion mechanisms, intensified by the presence of slots, leading to differentiation in oxygen concentration at the component surface, the sublayer corrosion took place. The chromium coatings are cathodic relative to the nickel sublayer; therefore, in the case of the appearance of its discontinuity or damage, a corrosion of the nickel coating takes place. The corrosion of the nickel sublayer at the boundary of both coatings led to the loss in adhesion and local removal of the chromium coating from substrate resulting in uncovering the nickel.

In locations of corrosion in the areas of cracking, the preserved fragments of unseparated but dissolved chromium coating were locally observed. This indicates that electrochemical processes are also taking place in the case of chromium. The residues were situated exclusively in the areas of cracking, creating the characteristic morphology (Figs. 4, 5). Spectra of the characteristic X-ray radiation enabling identification of individual structural components are presented in Figures 6 and 7. The presence of reflexes coming from calcium, sodium, and chlorine in the spectrum obtained from the residues indicates the interaction of the corrosive environment containing calcium and sodium chlorides. In presence of water and the absorption of CO_2 from air, reactions (1) and (2) take place for those compounds leading to a lowering of the pH. Their product is hydrochloric acid leading to dissolving the chromium coating [5], which additionally contributed to loosing adhesion to the substrate.

$$CaCl_2 + H_2O + CO_2 = CaCO_3 + 2HCl \qquad (1)$$

$$2NaCl + H_2O + CO_2 = Na_2CO_3 + 2HCl \qquad (2)$$

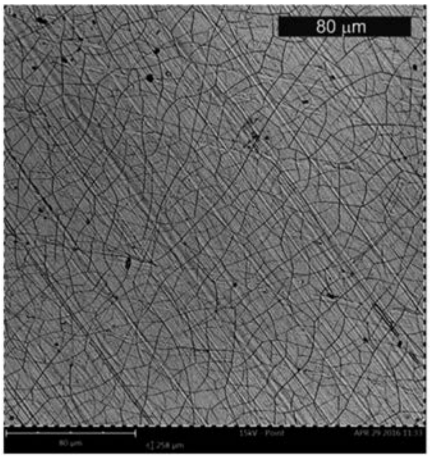

Fig. 3. General view of the cracked chromium coating. SEM

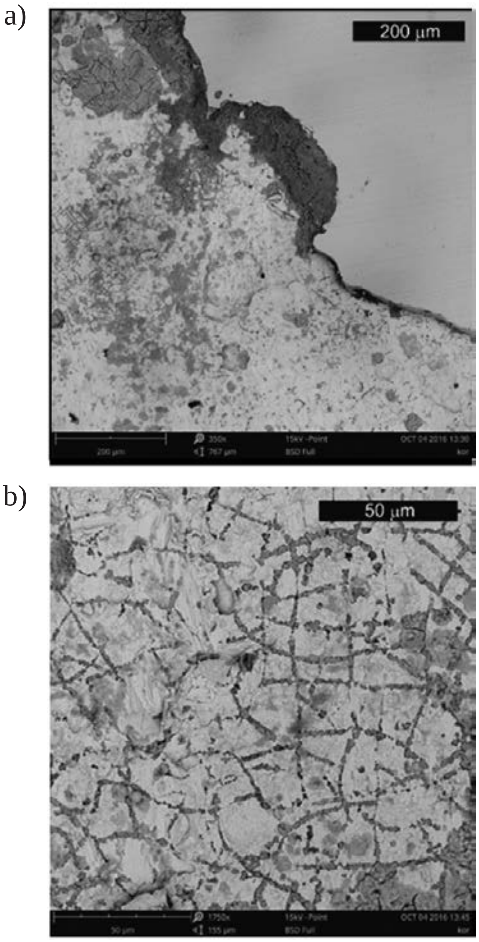

Fig. 4. The nature of chromium coating damages (a). At larger magnifications, the characteristic surface morphology is visible in locations with the chromium coating peeled off (b). SEM

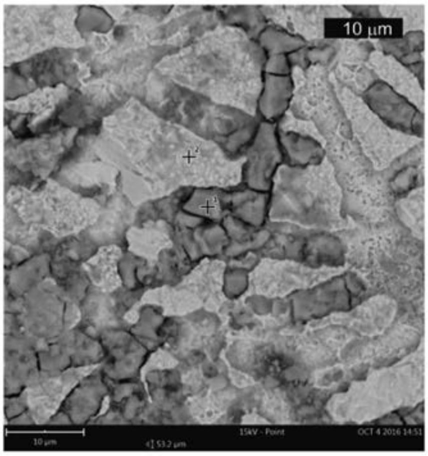

Fig. 5. The magnified fragment of the area from Figure 4. Visible residues of the oxidised chromium coating (dark areas) on the surface of the nickel coating (bright areas). Numbers 1 and 2 mark the locations of the microanalysis of the chemical composition using the EDX method. SEM

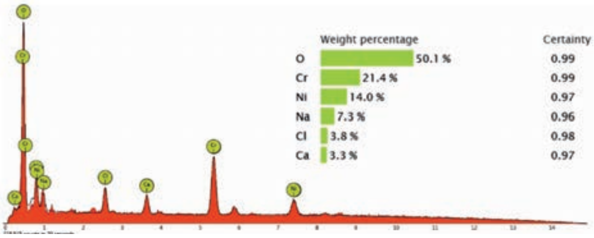

Fig. 6. The spectrum of characteristic X-ray radiation and the results obtained from microanalyses performed for location 1 shown in Figure 5. In the location of the oxidation of chromium and nickel coatings, the presence of chlorine, sodium, and calcium was observed

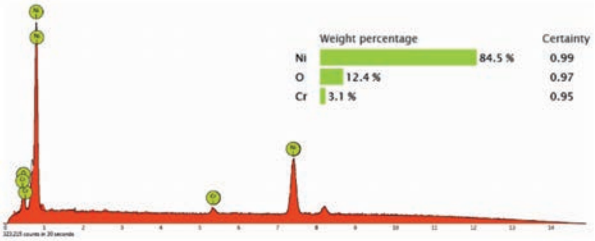

Fig. 7. The spectrum of characteristic X-ray radiation and the results obtained from microanalyses performed for location 2 shown in Figure 5, in the place of the nickel coating's appearance

As a result of corrosion or mechanical damage of the impaired nickel coating, the steel substrate was uncovered locally. Both coatings, i.e. chromium and nickel, are cathodic in relation to steel, and losing their density leads to intensive corrosion of steel. Where the steel substrate is revealed, the corrosion pitting happened. The high intensity of the processes is observed in this case, since the unfavourable phenomenon of large cathodic and small anodic surfaces appear here. This leads to a high density of anodic currents, and it means high rate of the local corrosion in practice. The exemplary microscopic image obtained at the transverse section running through a corrosion pit is shown in Figure 8, and the spectra obtained with the EDX method is shown in Figures 9 to 11. The carbon content in the obtained analyses is overstated due to the application of the conducting graphite resin in the preparation. In order to better illustrate the course of corrosion damages, it is schematically presented in Figure 12.

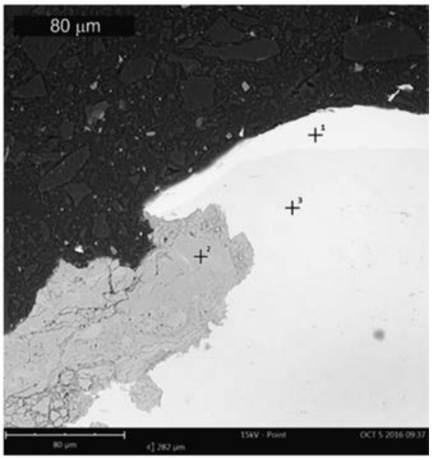

Fig. 8. Visible exposure of the nickel coating and the products of steel corrosion created as a result of its damage. Numbers 1 and 2 indicate locations of the microanalysis of chemical composition. Transverse section. SEM

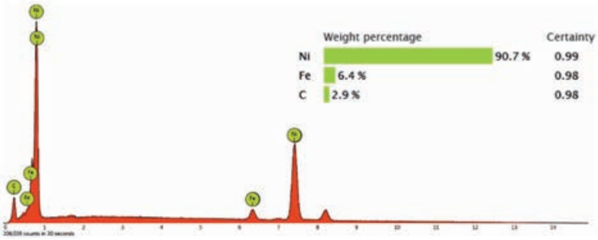

Fig. 9. The spectrum of characteristic X-ray radiation obtained from location 1, shown in Figure 8, indicating for presence of the nickel coating

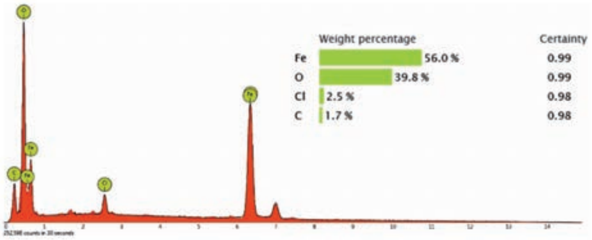

Fig. 10. The spectrum of characteristic X-ray radiation obtained from location 2, shown in Figure 8, in the area of the appearance of steel corrosion products. The presence of chlorine was observed, indicating for its participation in the corrosion process

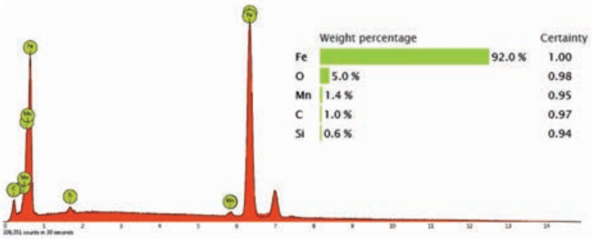

Fig. 11. The spectrum of characteristic X-ray radiation obtained from location 3, shown in Figure 8, in the area of the substrate material

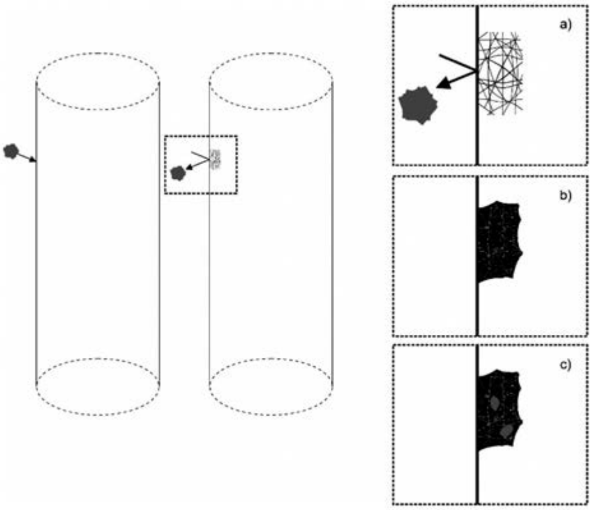

Fig. 12. Schematic diagram of creating damages to the chromium coating surface. (a) Network of fine cracks, (b) loss of the chromium adhesion, and (c) corrosion of the steel substrate

Conclusions

In this work, the results of tests on an actuator piston rod have been presented, which was damaged by corrosion as a result of mechanical damages of the chromium coating caused by the impact of hard particles. The first step of the chromium coat damage was cracking, which lead to anodic corrosion in relation to the chromium of the nickel sublayer. The corrosion was intensified by mechanisms of the subcoating corrosion and the presence of chloride ions in the corrosion environment. As a consequence, it led to the creation of the characteristic morphology of the surface in the area of its appearance.

The created damages led to exposing the nickel coating. In consequence, locally, as a result of corrosion or mechanical interactions, the steel substrate was uncovered, which constitutes an anode both for nickel and chromium, which was the direct cause of creating the observed macroscopically corrosion pits.

Due to the nature of the machine work and the environmental conditions of its operation, the effective protection against corrosion is the constructional shielding of the piston rod fragment, which is exposed to mechanical and corrosive impact of the environment. Consideration is justified of applying superficial layers that will show higher resistance to mechanical damage and corrosion will extend the life of actuators.

Example of coatings that could be alternatives are those based on chromium manufactured with thermal spray technologies, especially high-velocity oxy-fuel (HVOF). These indicate better resistance to corrosion, especially in an environment containing ions of chlorides and proper mechanical properties [8–10].

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