TECHNICAL SCIENCES
Abbrev.: Techn. Sc., No 16(2), Y 2013

TRIBOCORROSION OF A CHROMOSILICONIZED LAYER

***Iwona Bauer*[1*], *Andrzej Baryga*[2]**

[1] Chair of Materials and Machinery Technology
University of Warmia and Mazury in Olsztyn
[2] Institute of Agricultural and Food Biotechnology
Department of Sugar in Leszno

Received 3 February 2013; Accepted 17 April 2013; Avilable on line 15 July 2013

Key words: chromosiliconizing, tribocorrosion, sugar slurry.

Abstract

The paper presents the results of an experiment investigating the tribocorrosion of C45 steel samples which were chromosiliconized by the powder-pack method.

The technological process was carried out at 1000°C for 6 hours. The layer was produced with the use of ferrochromium powder combined with SiC, kaolin and ammonium chloride. Analytical samples were placed in boxes containing the powder mix, and the boxes were sealed with vitreous enamel. The frictional resistance of a chromosiliconized layer was investigated under exposure to a corrosive medium of sugar slurry. Corrosion damage was examined with the use of a three-cylinder and cone wear tester.

The structure of the analyzed layers was evaluated by light and scanning microscopy, X-ray diffraction and glow discharge optical emission spectroscopy (GDOES). The thickness, surface roughness and hardness of samples were determined. Chromosiliconizing of C45 steel samples extended the life of friction elements in a sugar slurry environment.

Introduction

The design of machine elements requires solutions that improve operational efficiency. Various technologies for producing surface coatings are developed (BI 2009, KASPRZYCKA 2006, MŁYNARCZAK 2011, PERTEK 2003, ROHR 2005, WIERZCHOŃ 2010). On a highly competitive market, there is a demand for low-cost methods that guarantee the achievement of satisfactory operating parameters, including resistance to wear caused by friction and corrosion.

* Corespondence: Iwona Bauer, Katedra Technologii Materiałów i Maszyn, Uniwersytet Warmińsko-Mazurski, ul. Oczapowskiego 1, 10-736 Olsztyn, e-mail: iwona.bauer@uwm.edu.pl

Chromosiliconizing is a method that fulfills the above requirements. This process has been discussed at length by (AGARWAL 2007, HONCHI 2002, IGNATENKO 1991, NISHIMOTO 2003, NAKONIECZNY 2006). It is a relatively inexpensive technique for improving the working parameters of tools and machine parts. The attributes of chromosiliconized layers produced by gas and powder methods are enhanced through the selection of optimal mixture components, process parameters and carbon concentrations in steel.

Damage to machine components caused by tribocorrosion, corrosion or both processes poses a significant problem in many industries. This study analyzes the tribocorrosion of chromosiliconized layers, which remains poorly investigated (BAUER 2008, WEI 2000).

A sugar factory can increase its productive capacity by optimizing its technological processes, reducing its consumption of raw materials and energy, increasing its productive efficiency and maximizing the reliability of process lines. Sugar production machines are made of various materials, including those characterized by high resistance to wear and consequently, high cost which affects overall economic effectiveness. In modern sugar plants, machines are designed based on the latest technological solutions. Drum vacuum filters are replaced with membrane-chamber filter presses, and honeycomb steam chambers are introduced. In the sugar industry, many machines become damaged under exposure to corrosive media, mechanical load and friction, as discussed by (BURSTEIN 2000, BUCHANAN 2007, ZHENG 2000).

The aim of the work

The aim of this study was to investigate the frictional resistance of chromosiliconized steel samples under exposure to a corrosive medium of sugar slurry.

The object and methodology of the study

Samples of C45 steel were chromosiliconized by the powder-pack method. The chemical composition of steel given in the product's certificate is presented in Table 1. The process was carried out in a Labotherm LH15/14 furnace at 1000°C for 6 hours. The applied powder mix had the following composition: 70% ferrochromium powder enriched with SiC, 29.5% kaolin and 0.5% ammonium chloride (NH_4Cl). Samples of C45 steel were placed in the powder mix in special boxes made of X6CrNiTi18-10 steel. To prevent sample oxidation, the boxes were covered with lids and sealed with vitreous enamel which melts at temperatures higher than 600°C. The boxes were placed in a furnace heated to process temperature. After the chromosiliconizing process, the first group of steel samples for tribocorrosion analysis was quenched in oil at 840°C and tempered at 500°C for 2 hours. The second group of steel samples was not subjected to heat treatment.

Table 1

Chemical composition of C45 steel (wt. %)

Steel grade	C	Si	Mn	S	P	Cr	Ni	Cu	Mo
C45	0.44	0.1	0.64	0.018	0.015	0.05	0.10	0.27	0.023

Microstructural analyses and thickness measurements of a chromosiliconized layer were carried out under the Olympus IX 70 metallographic microscope. Nital-etched microsections perpendicular to the surface of the sample were examined. The phase composition of a chromosiliconized layer was evaluated using a Philips X'Pert diffractometer with CuKα radiation and monochromatization of diffracted beams.

Chemical composition was determined by SEM with X-ray microanalysis and glow discharge optical emission spectroscopy (GDOES).

Surface roughness was measured with a Hommel Tester T1000. The following values were registered: R_a – arithmetic mean roughness devation, R_z – height at ten roughness profile peaks, S_m – mean spacing of roughness profile peaks. Vickers hardness tests HV 0.05 were preformed on transverse microsections using Reichert REF-2 and Zwick hardness testers.

The tribological properties of two groups of steel samples exposed to a corrosive medium were analyzed with the use of the I-47-K-54 wear tester consisting of three cylinders and a cone. A conical counter sample of C45 steel was enhanced to hardness level 48HRC. Linear wear was measured for 100 minutes (which corresponds to a distance of s = 3470 m) at friction velocity of 0.58 m/s and cone rotational speed of 576 rpm under the pressure of 50 MPa, 100 MPa, 200 MPa and 300 MPa. The corrosive medium was sugar slurry with pH = 11.7 and the following composition: 66.5% $CaCO_3$, 3.5% $MgCO_3$, 0.06% Na and 0.12% K. Sugar slurry was administered in the amount of 30 drops/minute.

Results and discussion

Chromosiliconizing resulted in gray and somewhat glossy surface. SEM image of the surface is presented in Figure 1.

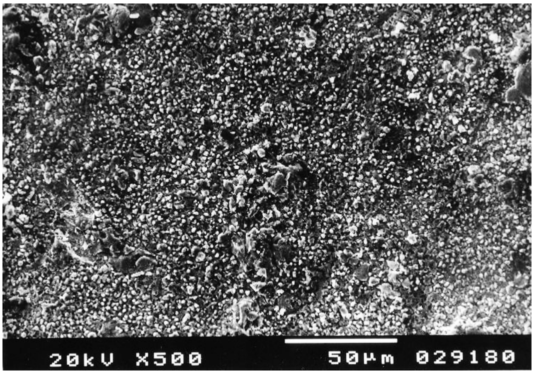

Fig. 1. Surface of C45 steel samples after chromosiliconizing, SEM, magnification 500×

Chromosiliconized layers on samples of C45 steel were characterized by higher surface roughness than uncoated steel. Roughness height was smaller than layer thickness. The results of surface roughness measurements are given in Table 2 and Figure 2.

Table 2
Stereometric parameters characterizing the surface topography of C45 steel samples with and without a chromosiliconized layer

Steel grade	R_a [µm]	R_z [µm]	S_m [µm]
C45 without surface layer	0.28	3.81	66.66
C45 after chromosiliconizing	0.58	4.34	100.0

The microstructure of a chromosiliconized layer on C45 steel was analyzed under a light microscope on transverse nital-etched microsections. A bright, non-etched layer with an estimated thickness of 16 µm was observed, and it was clearly separated from the steel substrate (Fig. 3).

X-ray diffraction of chromosiliconized layers revealed the presence of $(Cr,Fe)_7C_3$ carbide and $Cr_2(N,C)$ carbonitride. The estimated chemical composition of the layers determined by analysis was as follows: by weight 78% Cr, 12% Fe and 0.1% Si.

Vickers hardness tests (HV 0.05) (PN-EN ISO 6507-1:1999) performed on transverse microsections revealed a six-fold increase in hardness values to 1430 HV0.05 after chromosiliconizing. Hardness values are presented in Figure 4.

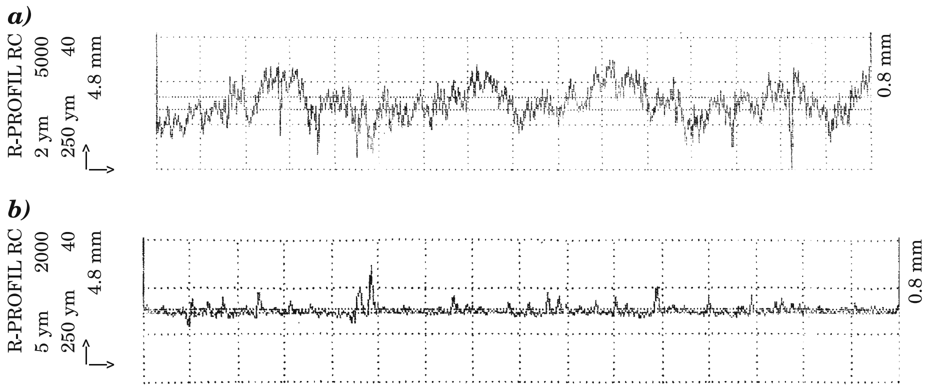

Fig. 2. The profilogram of the surface roughness of C45 steel samples with (*b*) and without (*a*) a chromosiliconized layer

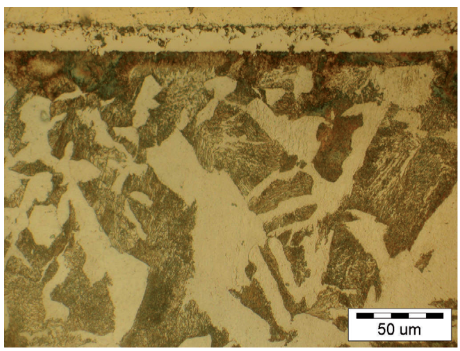

Fig. 3. Microstructure of C45 steel with a chromosiliconized layer. Light microscope, 500x magnification. Etched with nital

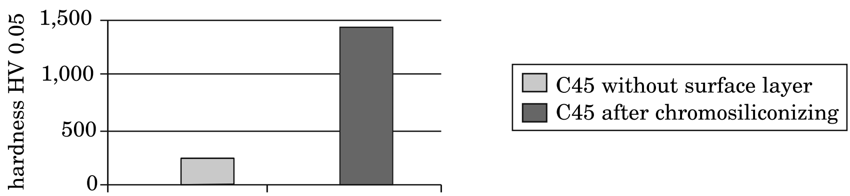

Fig. 4. Hardness of C45 steel samples

In frictional resistance tests under exposure to sugar slurry, chromosiliconized layers that had not been subjected to heat treatment at the first stage of the procedure (30 min) were characterized by loss of luster, and no signs of corrosion were observed. The examined layers underwent uniform wear at successive stages of the test under the pressure of 50 MPa, 100 MPa, 200 MPa. A pressure increase to 300 MPa led to accelerated wear, surface cracking and individual symptoms of uniform corrosion after 40 minutes of operation. Signs of non-uniform corrosion and frictional seizure were observed after 60 minutes. Linear wear was determined at 3.25÷15.48 μm during 10–100 minute tests carried out under the pressure of 50-200 MPa (Fig. 5).

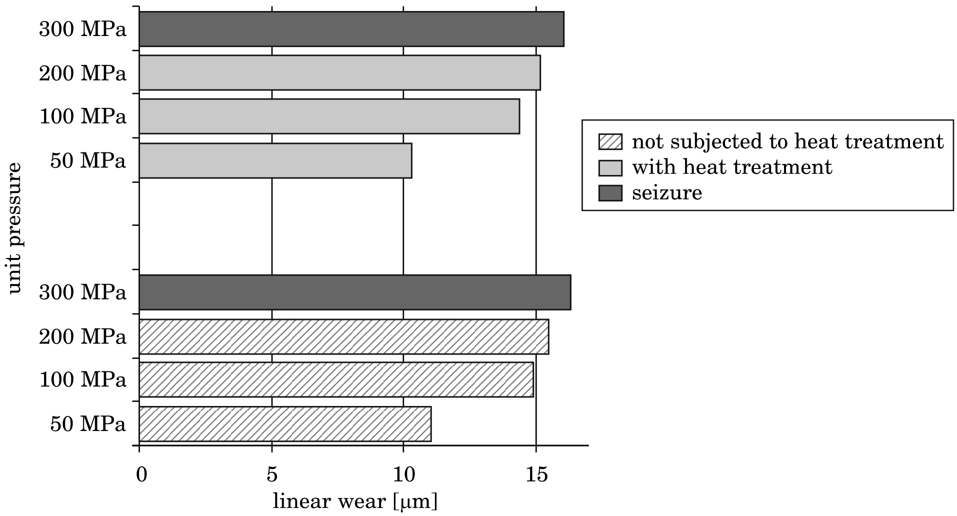

Fig. 5. Linear wear of C45 steel samples with chromosiliconized layers, at different unit pressure values in a sugar slurry environment

After 30 minutes of the friction test under exposure to sugar slurry, heat-treated chromosiliconized layers showed loss of luster but no signs of corrosion. No signs of accelerated wear were observed under the pressure of 50–200 MPa (linear wear 1.78÷15.19 μm). Intensified wear was reported after 80 minutes of operation under the pressure of 300 MPa when surface cracking and uniform corrosion were noted. Surface pits were reported after 100 minutes. Under the pressure of 300 MPa wear depth exceeded layer thickness which led to frictional seizure. Linear wear was determined at 16.05 μm (Fig. 5).

Conclusions

The study presents the results of an experiment investigating the tribocorrosion of chromosiliconized layers exposed to sugar slurry. Samples of C45 steel were chromosiliconized by the powder-pack method to produced a diffusion layer with the thickness of 16 μm, containing mostly $(Cr, Fe)_7C_3$ carbide and $Cr_2(N,C)$ carbonitride.

Chromosiliconized steel samples were characterized by higher surface roughness than uncoated samples. The hardness of chromosiliconized samples increased six-fold, to 1430 HV0.05. In comparison with chromosiliconized layers that had not been subjected to heat treatment (linear wear 3.25÷15,48 μm) and heat-treated chromosiliconized layers on C45 steel samples, extended the life of friction elements in a sugar slurry environment under the pressure of 50–200 MPa (linear wear 1.78÷15.19 μm).

Under the pressure of 300 MPa, wear depth exceeded layer thickness which led to frictional seizure.

Translated by Aleksandra Poprawska

References

Agarwal S., Jain A., Lal C., Ganesan V., Jain I.P. 2007. *Surface morphology and phase formation at Cr/Si system.* Applied Surface Science, 253(10): 4721–4726.

Bi Q., Liu W., Ma J., Yang J., Pu Y., Xue Q. 2009. *Tribocorrosion behavior of Ni-17.5Si-29.3 Cr alloy in sulfuric acid solution.* Tribology International, 42(7): 1081–1087.

Bauer I. 2008. *The effect of microstructure on the tribocorrosive properties of chromosiliconized layers.* Physico-Chemical Mechanics of Materials, 7: 293–295.

Buchanan V.E., Shipway P.H., Mc Cartney D.G. 2007. *Microstructure and abrasive wear behaviour of shielded metal arc welding hardfacings used in the sugarcane industry*. Wear, 263(1–6): 99–110.

Burstein G.T., Sasaki K. 2000: *Effect of impact angle on the slurry erosion-corrosion of 304L stainless steel.* Wear, 240: 80–94.

Honchi M, Yamazaki T. 2002. *Chromium/silicon composite pack cementation agent and treatment using the same.* Patent JP 2002129304.

Ignatenko P.I., Kudelin Yu.V., Goncharov A.A., Muza M.A. 1991. *The influence of nitrogen content and resistive chromosilicon films thickness on their corrosion resistance*. Fizyko-Chimiczeskaja Mechanika Materialov, 27(5): 102–103.

Kasprzycka E., Senatorski J. 2006. *Structure and tribological properties of carbide layers produced in vacuum chromizing process.* Tribologia, 3: 87–93.

Młynarczak A., Piasecki A. 2011. *Dyfuzyjne manganowanie żelaza.* Inżynieria Materiałowa, 4: 597–599.

Nakonieczny A., Bauer I. 2006. *Factors affecting corrosion resistance of chromium-silicon diffusion layers.* Conference "Balttechmasz", Kaliningrad (Russia), p. 420–424.

Nishimoto A., Akamatsu K., Nakao K., Ichni K., Ike K. 2003. *High temperature properties of chromosiliconized stainless steels.* International Surface Engineering Congress-proceedings of the 1 st Congress, Colombus, p. 246–249.

Pertek A., Kulka M. 2003. *Microstructure and properties of composite (B+C) diffusion layers on low-carbon steel.* Journal of Materials Science, 38: 269–273.

Rohr V., Donchev A., Sch7tze M., Milewska A., Perez F.J. 2005. *Diffusion coatings for high temperature corrosion protection of 9–12% Cr steels.* Corrosion Engineering Science and Technology, 40(3): 226–232.

Wierzchoń T., Szawłowski J. 2010. *Inżynieria powierzchni a potrzeby materiałowe przemysłu.* Materiały XIII Seminarium Grupy SECO/WARWICK, Świebodzin, p. 5–15.

WIERZCHOŃ T., ULBIN-POKORSKA I., SIKORSKI K. 2000. *Corrosion resistance of chromium nitride and oxynitride layers produced under glow discharge conditions*. Surface and Coatings Technology, 130(2–3): 274–279.

WEI P., WAN X.R. 2000. *The effect of coating heat treatment on Cr-Si and heat treatment on mechanical properties of Cr17Ni2 stainless steel*. Surface and Coating Technology, 132: 137–142.

ZHENG Y.G., YAO Z.M., KE W. 2000. *Errosion-corrosion resistant alloy development for aggressive slurry flows*. Materials Letters, 46: 362–368.

PN-EN ISO 6507-1:1999. *Metallic materials-Vickers hardness test*. Part 1: *Test method.*

PN-H-04302:1983. *The strength tests of metals. The friction test in 3 rollers-cone system.*