THE IMPACT OF TRIBOCORROSION ON WEAR OF WORK PARTS OF THE SCREW PRESS

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Abstract: *In the production of oil in the oil mill parts of the equipment wear due to contact with seeds which contain microabrasive particles. This wear manifests itself by changing the dimensions and geometry of the screw press. The paper analyzes the influence of tribo-corrosive wear on the workpieces of the screw press. The appearance of wear is most likely due to the action of aggressive media, in this case the oilseeds. In the experimental part of this paper, on samples made of cast steel and austenistic stainless steel, following laboratory tests were performed: electrochemical testing, testing of chemical composition of the base material, wear analysis, microstructure recording and hardness testing. Based on the laboratory testing, conclusion was that the austenistic stainless steels 304L and 316L with nitrated surfaces exhibit better resistance to tribo-corrosion wear in relation to cast steel GS-42CrMo4.*

Keywords: *TRIBOCORROSION, ELECTROCHEMICAL TESTING, WEAR, SCREW PRESS*

1. Introduction

It is commonly known that corrosion processes can not completely stop, but they can also be slowed down and the damage caused by corrosion can be reduced, such as breaks, breakdowns and work related stoppages [1]. Corrosion also has a negative impact on raw materials, semi-products and products. Costs caused by corrosion can be classified into two main categories: direct and indirect costs. Direct costs include replacement of damaged parts and equipment caused by corrosion, stoppages in production due to protection of corrosion etc. Indirect costs, for example, are lower quality of the final product and lower efficiency of corrosion damaged equipment [2]. Screw presses represent a classic tribo system in which, when relative movement between the media and the metal surface occurs, metal parts wear. The oil seeds from which the oil is sown, above all the sunflower, contains in its structure microabrasive particles (SiO_2) whose effect on the working surface of the screw press can not be avoided. Therefore, one of the basic requirements for the material (protective layer) of the working parts of the screw press is in terms of raising wear resistance. Examination of the wear process should enable the operation of all these parts under the given conditions with known and acceptable friction and wear values [3]. In addition to the inevitable wear, damages are also noted caused by the agressive media (sour soups). These damages are best expressed in the tribocorosis of the gear parts which are in contact with the other parts. One of the ways to extend the life cycle of worn-out elements is replacement of worn-out stainless steel half-rings [4].

2. Visual examination of work parts of the screw press

The main supporting parts of the screw press are the power and movement gearboxes and the gear housing, the shaft of the screw press and the yarn colanders, but the working parts are the sledge segments and the knives of the colander buckle. The screw is made up of splinter segments and conical rings which are pinned to the shaft. The shaft is made in five stages with different diameters. The diameter on the gear box is the biggest and it is 160 mm, and the smallest diameter is on the shaft at the end of the screw press and it is 151,4 mm.. It should be noted that the shaft (total length 4355 mm) is mounted only at the gear unit so that the screw actually "floats" in the colander surrounded by mill. Colander buckle is formed by bunding the blades on the "yarn" brackets, which, after forming the paths, form a closed colander around the bushing. The knives are constructed so that, after stacking and forming the base of the basket, the respective gap remains between them (0,75 mm the entrance to the press, and to 0,17 mm at the end of the press).

Oil is dripping through these gaps. The gap size defines the so-called work fields of which this type of press has a total of 7. By using conical segments is achieved that the pressure increases from the inlet to the outlet of the press, and because of the gradual performance of the screw press, the press locally reaches the value of 450 to 500 bar. The first unusual wears on the screw press were observed three years after the installation, and the approach to the prolonged lifespan consisted, first, of welding the surfaces on the yarn colanders [5]. After 5 years of work with the welded yarmas, it was noticed that they were re-damaged. Conclusion was that by applying an additional material, hardness of about 400 HB, achieved a prolongation of the yarms for almost 70 %. The visual inspection showed that the functional breakdown of the screw presses occurred due to: damages on the gear housing, damages on the abutment surfaces and damages of the yarn.

2.1. Analysis of gear unit housing damages

After a visual inspection, conclusion was that damage of the working parts of the screw press came for several reasons. One of them was damage of the gear unit housing, which resulted in the unauthorized eccentric "swinging" of the colander and the appearance of tribo-corrosion on its parts, Figure 1.

Figure 1 *Appearance of damaged gearbox.*

Figure 2 shows the detail of the damaged half-ring on the contact surface of the gear unit housing. Half-rings are made of austenistic stainless steel AISI 304L and 316L, after which they are placed on the contact surface. Half-ring tightening is done by the appropriate screws made from the same stainless steel. By control with the portable spectrometric chemical analyzer it was determined that the gear housing was made of cast steel Cr-Mo, and with portable hardness measure device it was found that the hardness of its surface ranged from 210 to 235 HB. With detailed surface control, conclusion was that damage is most likely caused by the action of aggressive media (sour soups), and manifested it by the appearance of tribo-corrosion on the parts of the reducer which are in contact with the settling surfaces of the colander.

Figure 2 *Appearance of damaged reducers half-ring.*

Tribocorrosion can be defined as a process of degradation of the material due to the combined action of corrosion and wear [6]. Dimensional control indicated that the base material of the gearbox housing was locally damaged up to 8 mm (in diameter). Except for damages due to dismantling, no major damages have occurred on the reducers half-rings, Figure 3.

Figure 3 *Macrorecordings of reducers half-ring.*

Reason for the high wear of the base material caused by the corrosion is aggressive media which passes between half-rings and reducers housing. To solve this problem, silicon sealing compounds are mounted between the half-rings and the reducers housing. However, because of the high temperatures, these gaskets hardened during operation, allowing aggressive media to pass.

2.2. Analysis of screw press colander damages

Damages of the colander is the second reason for the end of the functional operation of the screw press. On the part of the colander located in the gasket with the gear housing, traces indicate damages due to eccentric motion in the contact area of the enclosure casing/colander, but also traces that can be attributed to tribocorosis. After disassembling the half-ring, there are also some damages visible on the base material of the screw press. These damages are most likely the effect of action of the agressive media (sour soups), Figure 4.

Figure 4 *Appearance of the damaged colanders half-ring.*

3. Experimental part

In the experimental part of the paper, electrochemical tests on samples made of cast steel and austenitic stainless steel were performed. These tests were performed to simulate conditions of agressive media These tests were conducted to simulate aggressive media conditions which largely contribute to the wearing of screw presses. Austenistic stainless steel chosen for this testing are 304L and 316L (Standard ASTM A240). By nitriding these steels, modified contact surface was obtained. Cast steel chosen for this testing is GS-42CrMo4 (EN-10083). In this steel, a modified contact surface was also obtained by the improvement process. After the electrochemical testing, further examinations were perfomed.

3.1. Electrochemical testing

In order to simulate the conditions of aggressive media for electrochemical testing, the following parameters were selected: the tests were performed in a solution of saturated water with CO_2, pH value was from 4,8 to 5 at 50 °C. The Tafel's extrapolation method was used to determine the corrosion rate (v_{kor}), while the diagram E-t was used to determine the corrosion potentional (E_{kor}). The recording of the polarization curves was used to determine the resistance of the material (R_p). The cyclic polarization method was used to determine the area of passivation and pitting potential (E_{pit}) on test samples. Samples for the tests were of the following dimensions: ϕ16x8 mm. The examined chemical composition of the steels selected for this test are shown in the Table 1.

Table 1: *Examined chemical composition of steel.*

Chemical composition, %						
Sample	C	Mn	Si	Cr	Ni	Mo
304L	0,030	2,0	0,75	17,00	11,00	2,51
316L	0,048	1,224	0,438	16,71	10,08	2,124
GS-42CrMo4	0,400	0,60	0,40	1,00	-	0,25

Electrochemical corrosion tests were performed according to the standard ASTM G5-94 on the test device Potentiostat / Galvanostat Model 273A EG & E with program SoftCorr III in the Laboratory for the material protection in the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. Measurements were performed in comparison with the reference saturated calomel electrode (SCE) known potential + 0,242 V according to a standard hydrogen electrode. General corrosion parameters were defined: corrosion potential (E_{kor}), corrosion power density (j_{kor}), corrosion speed (v_{kor}), resistance to polarization (R_p), pitting potential (E_{pit}) and potential for protection (E_{zpit}). Corrosion potential (E_{kor}) was defined by measuring the potential change in the period of 1000 sec. The final measured value is used as a corrosion potential. Corrosion potential is also called the potential of an open circuit E_{ok}, because the circuit is open during the measurement, ie the electrochemical reaction is not performed on the working electrode. By applying an external source, the working electrode is polarized to the potential of ± 250 mV compared to the potential of corrosion and measuring the power response. Tafel diagram, which shows the dependence of the power in the logarithmic scale on the applied potential, is obtained by measurement. Extrapolation of linear anode parts (+ 250 mV in relation to E_{kor}) and cathode (250 mV in relation to E_{kor}) polarization curves and corrosion potential E_{kor} result in a logarithm of corrosion power density j_{kor}. Polarization resistance of the material R_p is determined from the Tafel polarization diagram for the area ± 20 mV compared with corrosion potential. The results of the electrochemical tests are shown in the Table 2.

Table 2: *Results of the electrochemical testing of samples.*

Sample	$\beta_{A,}$ V/dek	$\beta_{K,}$ V/dek	$j_{kor,}$ μA/cm^2	$v_{kor,}$ mm/god	$R_{p,}$ Ωcm^2
AISI 304L, nitrided	0,078	0,103	6,62	0,067	3282
AISI 316L, nitrided	0,988	0,039	6,71	0,069	5254
GS-42CrMo4, improved	0,088	0,598	86,62	1,003	250

After conducting polarization measurements, macrostructure recording was performed. Figures 5, 6 and 7 show cyclic polarization schemes and images of recorded macrostructure patterns.

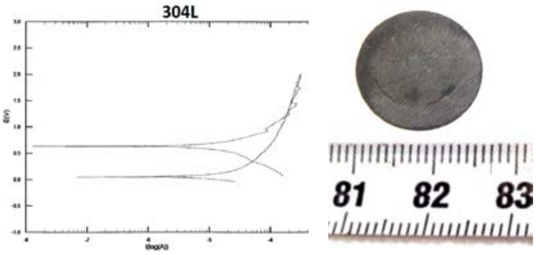


Figure 5 *Cyclic polarization diagram and macro recording of sample 304L.*

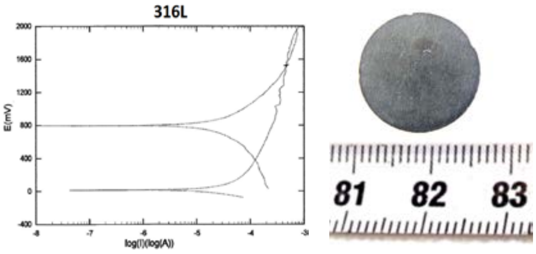


Figure 6 *Cyclic polarization diagram and macro recording of sample 316L.*

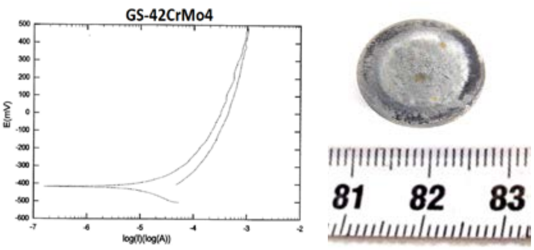
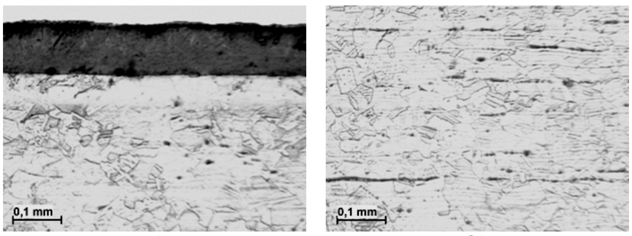


Figure 7 *Cyclic polarization diagram and macro recording of sample GS-42CrMo4.*

3.2. Recording and analysis of microstructure

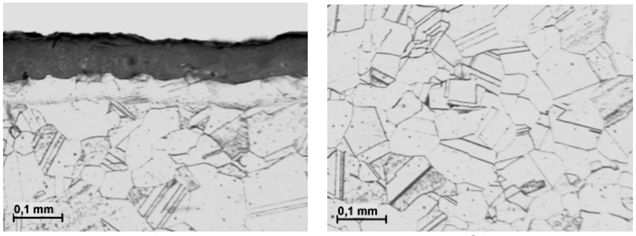
Metalographic and hardness test give the complete information about the material before and after the nitration process. The microstructure of test samples was analyzed at their edges and in the core. Samples made of stainless steel were wiped in glycerin, while the sample made of cast steel was wiped in nital (2 %). The characteristic microstructure of the edge of the sample 304L is shown in the Figure 8.a., while the characteristic microstructure of the core is shown in the Figure 8.b.



a) b)

Figure 8 *Characteristic microstructure of test sample 304L. a) edge; b) core*

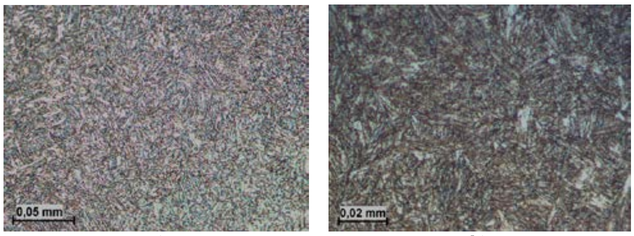
Characteristic microstructure of the edge of test sample 316L is shown in the Figure 9.a., while the characteristic microstructure of the core is shown in the Figure 9.b.



a) b)

Figure 9 *Characteristic microstructure of test sample 316L. a) edge; b) core*

Characteristic microstructure of test sample GS-42CrMo4 is shown in the Figure 10.



a) b)

Figure 10 *Characteristic microstructure of test sample GS-42CrMo4.*

3.3. Hardness testing

Microhardness measurement was performed on the device Durimet Leitz, with method Vickers HV 0,5 (load of 5 N). Results of measured microhardnesses of test samples 304L and 316L are shown in Tables 3 and 4.

Table 3: *Results of hardness testing of sample 304L.*

Distance from edge, mm	Hardness HV 0,5
0,03	1180
0,04	1172
0,05	1168
0,07	817
0,08	435
0,16	221
0,22	227
0,32	208
0,50	230
0,75	182
1,00	205
1,25	202

Table 4: *Results of hardness testing of sample 316L.*

Distance from edge, mm	Hardness HV 0,5
0,03	1184
0,04	1200
0,05	1176
0,07	819
0,08	403
0,16	223
0,22	225
0,32	204
0,50	215
0,75	210
1,00	203
1,25	201

Measured vaules of hardness of impoved sample made of cast steel GS-42CrMo4 are from 230 to 280 HV 0,5.

4. Analysis of results

Results of electrochemical testing (shown in Table 2) show that materials AISI 304L and AISI 316L have significantly higher values of polarization resistance R_p in relation to the material GS-42CrMo4, which has a twenty times lower polarization resistance value. The corrosion rate values for austenitic stainless steel are fairly similar, but for cast steel GS-42CrMo4 are 14 times bigger in relation to the austenistic stainless steels. Cyclic polarization diagram (Figures 5 and 6) show that nitrated samples of austenitic stainless steel 304L and 316L are not tended to pitting corrosion, while the material GS-42CrMo4 (Figure 7) shows tendency to the pitting corrosion. This confirms the image of the macrostructure of the surface after the test (Figure 7) with highlighted pitting. Metalographics analysis of test samples show that samples made of material 304L and 316L (Figures 8 and 9) have austenitic structure with recognizable double crystals that have finely divided the various precipitates. In addition to the sample boundary, there is a specific nitric layer followed by the austenitic structure of the base material. Cores of both samples also have austenistic microstructure. Microstructure values on the cross section of samples 304L and 316L are measured from the edge to the core (Tables 3 and 4) show that the microhardness of the samples is the same and adequate for the applied method of surface modification by nitrating.

5. Conclusion

Even today, application of corrosion protection procedures in the economy lags behind theoretical knowledge, largely due to the rapid progress of corrosion protection technology. Numerous studies have shown that with a single dollar invested in corrosion protection can reach $ 3 to $ 6 in terms of longer life span and greater reliability of the equipment [1]. Given the working conditions of process equipment in the oil industry (whose parts are exposed to the effects of tribo-corrosion), their life span shortens and this results in the malfunctions. Material losses and maintenance costs are also increased. There is a possibility of a sudden cancellation of the plant elements, which would lead to a halt in production. When replacing parts, special attention should be paid to the resistance of the materials used to make them in relation to the medium in which they are used. It is necessary to know the mechanical and tribological resistances in the phase of material selection during design. Material resistance is based on the use of appropriate layers by extending the life of the press during the long lasting part exploitation [7]. Based on the performed tests and the results analysis conclusion is that the test samples 304L and 316L have the same depth of nitrite layer. Hardness values on the cross section of the edge of both samples are equal and they are in range from 800 ÷ 1200 HV 0,5 which are good requirements for the application in the tribosystem of the screw press. Material 316L has a slightly higher resistance to corrosion, but from an economic point of view, taking into account the price of the basic material, 304L is to 45 % cheaper compared to the 316L. Suggestion is that material 304L is used for the work conditions in tribocorrosion conditions which are present in the screw presses during the vegetable oil extraction.

6. References

[1] Esih, I.: *Osnove površinske zaštite*, Fakultet strojarstva i brodogradnje, Zagreb, 2010.

[2] Zgaga, R.: *Tribologija u cementnoj i srodnim industrijama*, Zbornik savjetovanja o tribološkoj problematici u cementnoj i srodnim industrijama, Split, 1987., 1-5.

[3] Grilec, K.; Jakovljević, S.; Marić, G.: *Tribologija u strojarstvu*, Fakultet strojarstva i brodogradnje, Zagreb, 2015.

[4] Ivušić, V.; Marušić, V.; Grilec, K.: *Abrasion resistance of surface layers*, VTT Symposium 180 & COST 516 Tribology Symposium: Proceedings, Ronkainen, H.; Holmberg, K.,(ur.), VTT Technical Researche Centre of Finland, 1998., 201-210.

[5] Rozing, G.; Katinić, M.; Marušić,V.: *Neke specifičnosti utjecaja dominatnog mehanizma trošenja na pristup održavanju pužnih preša*, 16. Međunarodno savjetovanje ODRŽAVANJE 2010 Zagreb, HDO Hrvatsko-društvo održavatelja, 2010., 120-126.

[6] Priya, R.; Ningshen, S.; Thyagarajan, K.; Vasudevan, M.; Mallika, C.; Kamachi, U.: *Wear and tribocorrosion behaviour of 304L stainless steel welds*, Tribology – Materials, Surfaces & Interfaces 9 (2015) 4, 181-189.

[7] Landolt, D.; Mischler, S.: *Tribocorrosion of passive metals and coatings*, Woodhead Publishing Limited, Cambridge, 2011.