RESEARCH ON WEAR BEHAVIOR OF ROTOR-STATOR COUPLE MATERIALS FOR SCREW/PROGRESSIVE CAVITY PUMPS

CERCETĂRI PRIVIND COMPORTAREA LA UZURĂ A CUPLEI DE MATERIALE PENTRU ROTOR-STATOR LA POMPELE CU ȘURUB/ CAVITATE PROGRESIVA

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Abstract: *The screw/progressive cavity pumps are ideal for handling highly viscosity fluid and those with separation or share tendencies, inclusive in petroleum industry to lift crude oil from wells, hydrocarbons, transportation, a.o. [6,7,12,13]. Their quality/technology have improved using synthetic rubber elastomers and soldering advancements, making these prevalent in petroleum industry and not only. The pumps has a screw-shaped rotor and helical stator.. The best results achieved when the rotors are made from steels hard crom plated, nitride or hardened with carbide spray process HVOF and the stators are made from rubber mixture materials or polyamide (elastomers) [6,7,12,13, a.o]. Manufactures use specific materials but ISO standards don't specify rotor metal/steels or stator elastomers. The present study evaluated the tribological behavior of some rubber mixtures, used or proposed for stator and hard chrome plated or not plated steel for rotor.*

Keywords: Screw /progressive cavity pumps, friction coefficients, rubber mixtures, wear.

Rezumat: *Pompele cu surub/cavitate progresiva sunt ideale pentru manevrarea/transportul fluidelor ca viscozitati mari, cu tendinte de separare sau de taiere inclusiv in industria petroliera pentru extractia titeiului din sonde, transportul titeiului si produselor petroliere (hidrocarburilor) s.a. [6,7,112,13]. Calitatea/tehnologia acestora s-a imbunatatit datorita folosirii cauciucului sintetic si tehnologiei de elaborare/sudare, fapt pentru care aceste pompe au devenit foarte folosite in industria de petrol si nu numai. Pompa are un rotor in forma de surub si un stator elicoidal. Cele mai bune rezultate s-au obtinut cand rotorul este facut din otel cromat dur, nitrurat sau incarcat cu*

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carburi dure cu procedeul HOVF, iar statorul este facut din amestecuri mixte de cauciuc sau poliamida (elastomeri) [6,7,12,13] s.a.Fabricantii acestor pompe folosesc materiale specifice deoarece standardele ISO nu indica anumite materiale pentru aceste pompe. Prezentrul studiu evalueaza comportarea tribologica a unor amestecuri mixte de cauciuc respectiv poliamide folosite sau propuse pentru stator si otel cromat dur sau netratat pentru rotor.

Cuvinte cheie: Pompă cu șurub/ cavitate progresiva, coeficienți de frecare, amestecuri de cauciucuri, uzură.

1. Introduction

For screw /progressive cavity pumps, the standards do not require materials for the construction of the shaft, impeller, screw and stator. For abrasive-corrosive environments, most manufacturers use hard chromium-plated steels for the impeller and screw, and plastic materials for the stator.

To determine the optimum combination of materials, manufacturers must characterize them, thus determining their mechanical and tribological characteristics.

The aim of the present study was to determine tribological behavior of the materials uses for active parts of screw /progressive cavity pumps. Pumps manufacturers largely high-strength AISI 4130 steel hard chrome plated and plastic materials for the stator. In the paper several types of plastics materials were studied, such as: Polychloroprene symbolized PC, polybutadiene symbolized RA6, butadiene symbolized SKN, Polyurethane Z13 and polyamide PA6.6.

The norms that specify the construction of screw pumps do not impose the types of materials to be used [1,2]. For this reason, the selection of these materials must be made according to their tribological behavior. For the tribological simulation between the rotor and the stator, for the rotor (screw) hard chromed plated AISI 4130 samples were made, these being presented in figures 1 and 2 [3].

2. Experimental research

For the determination of tribological characteristics, experimental determinations were made on two types of friction couplings using the Amsler tribometer for a third class friction couple, and the CSM micro-tribometer for a forth class friction couple.

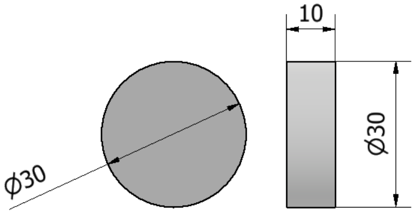

Figure 1. Disk-type sample drawing

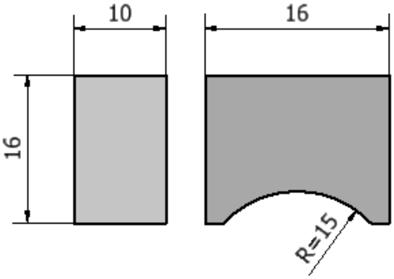

Figure 2. Shoe-type sample drawing

The elastomer test samples are shown in Figure 1 and 2 and AISI 4130 cube and roll-type test samples are shown in Figure 3 and 4. Due to the small size of the cubic test samples, hard chrome layer could not be obtained for the cubic test samples.

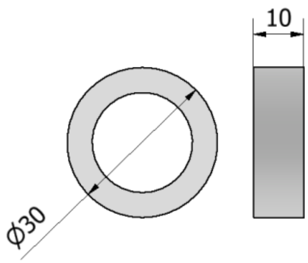

Figure 3. Sketch of the roll-type sample

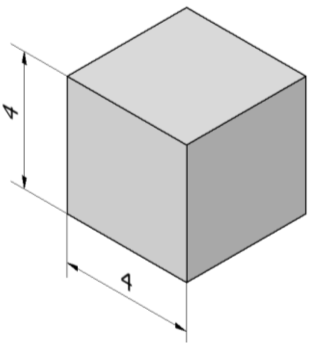

Figure 4. Sketch of the cube sample

The study was conducted in two directions: the determination of mechanical characteristics and wear tests, both sets of tests being explained in detail below.

3. Determination of mechanical characteristics

The materials used for determining the hardness are of ring rollers form. The determination of the hardness of the ring-type samples with and without hard chrome layer was performed on the DuraScan 20 (EMCO-TEST Prufmaschinen GmbH Austria) equipment at the Petroleum-University of Ploiești (see Figure 5).

The types of elastomers and their main mechanical properties are shown in Table 1. The elastomers RA6, SKN, Z13, PE(PC), PA6.6 were tested. The chemical composition and the mechanical characteristics of AISI 4130 steel are presented in Table 2 and Table 3.

Figure 5. EMCO-TEST Prufmaschinen GmbH

Table 1. **Material characteristics of elastomers**

Material characteristics	**Types of elastomers**				
	RA6	**PC**	**SKN**	**Z13**	**PA6.6**
Ultimate tensile strength, R_m [MPa] SR ISO 37:1997	20	10	16.01	21.5	90
Elongation at break, *A* [%] SR ISO 37:1997	250	400	258	167	>40
Hardness [Shore] SR ISO 7619:2001	77±5	55±5	75±5	80±5	160
Young's modules [MPa] SR ISO 37:1997	4.0	4.5	5.60	13.7	3.450

Table 2. **Chemical composition of AISI 4130 steel**

%	**C**	**Mn**	**Cr**	**Mo**	**Si**	**P**	**S**	**Ni**	**Cu**
Min	0.28	0.40	0.80	0.15	0.15	-	-	-	-
Max	0.33	0.60	1.10	0.25	0.35	0.025	0.025	0.35	0.35

Manufacturers of elastomers for the stator of screw pumps recommend Shore hardness values of minimum 73 units [4,5].

The experimental values obtained for the hardness tests can be seen in Figure 6.

Table 3. **Mechanical characteristics of AISI 4130 steel**

Material characteristics	
Ultimate tensile strength, R_m [MPa] ASTM E21-20	655
Ultimate tensile strength, R_m [MPa] ASTM E21-20	517
Elongation at break, *A* [%] ASTM E21-20	18

Hardness values | Samples | Hardness value

Roll-type sample
AISI 4130 hard chrome plated
462 HV0.5

Roll-type sample
AISI 4130 Not chromed
352 HV0.5

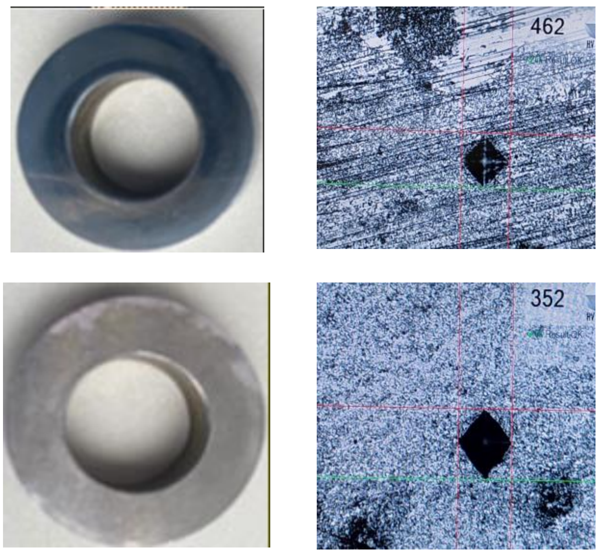

Figure 6. Hardness values for the Roll-type samples

Numerous pump manufacturers seek guidance regarding the selection of elastomers for pump construction. Currently, there is no established standard governing the utilization of elastomers in this context. The ISO sub-committee responsible for the review of ISO 15136-1 [1], which comprises specialist and pump manufacturer representatives, does not endorse any specific elastomers. Therefore, pump manufacturers must conduct testing to determine the optimal elastomer material for a particular application.

4. Wear tests

4.1. Tribological test on the micro-tribometer CSM

The tests were carried out on a friction coupling of class IV with plane friction contact. AISI 4130 static cube-type test sample and elastomer disc-type mobile samples: made of polychloroprene symbolized PC, symbolized rubber mixtures RA6, SKN, Z13 and polypropylene symbolized PA6.6. The tests were carried out in dry air conditions with the following working parameters: Working load 2 N, sliding speed 0.314 m/s at radius of 10 mm^2, working environment: air temperature 20°C, relative air humidity RH=44% pill 3.97X3.97=15.76 mm^2. The preparation of the test samples consisted of degreasing all surfaces by immersion in methyl-ethyl-ketone (MEC), followed by air drying [6,8,11]. The graphs obtained after the tests can be seen in Figure 7.

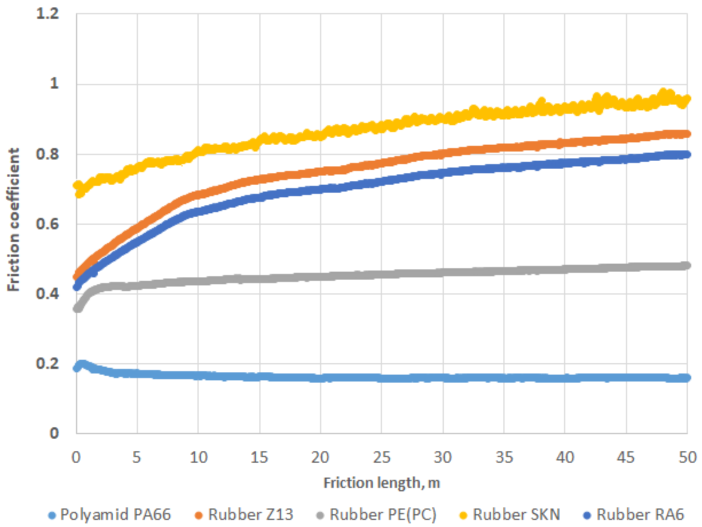

Figure 7. Values of friction coefficients in time/friction length

In terms of friction coefficients, the lowest values were on samples made of PA6.6 followed by PC, RA6, Z13 and SKN. In Figure 8 are presented the image of Instrument X software obtained for rubber SKN.

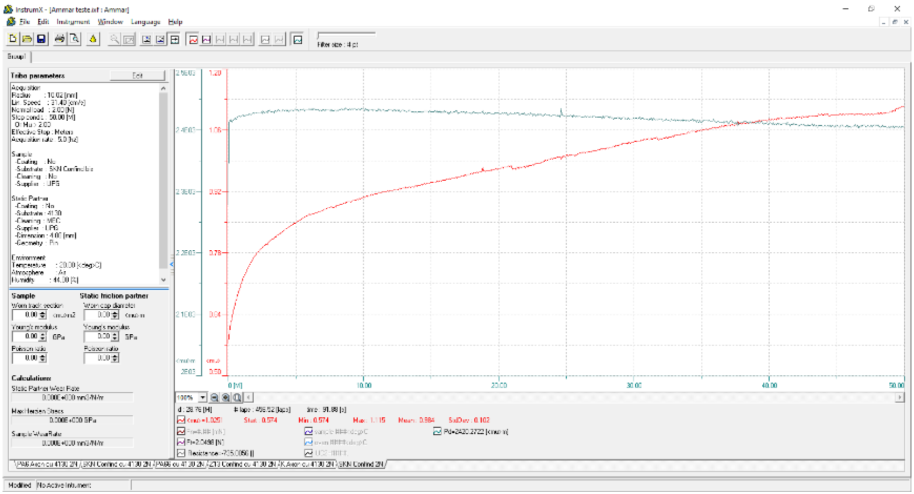

Figure 8. Image of Instrument X software obtained for disk of rubber SKN and AISI 4130 cube

As observed linear wear (cumulative for disk and cube samples) indicates the best behavior for Z13 followed by PA 6.6. The maximum dilation is found at RA6, which is much higher than the wear. PC shows the highest linear wear values. Above these values of linear wear (cumulative penetration, but metal test has not worn out what is actually linear wear of non-metallic test samples) should be taken into account and dilation, so in reality the wear will be even greater.

Testing under conditions similar to in-service conditions as specified in ISO standards 15136.1 & 2 [1,2] shall be required.

4.2. Tribological test on Amsler type A135 machine

The tests were carried out on samples in the form of Amsler friction couplers (roller-shoe). Roller type samples made of hard chrome plated AISI 4130 steel were used for the tests, and the shoe test samples were made of different materials such as: rubber RA6, PC, Z13, SKN and also polyamide PA 6.6. The friction coefficient was determined in pure rolling conditions, pure sliding and rolling gliding at a load of 500 N and a sliding speed of 0.314 m/s.

Temperature as a friction-related effect changes the properties of friction surfaces, so is important to observe the influence of temperature. For the research conducted in the study, the temperature was measured using a professional type APPA 105 sensor multi-meter and a K type thermocouple. Figure 10 shows the temperature variation over time related to the friction surfaces.

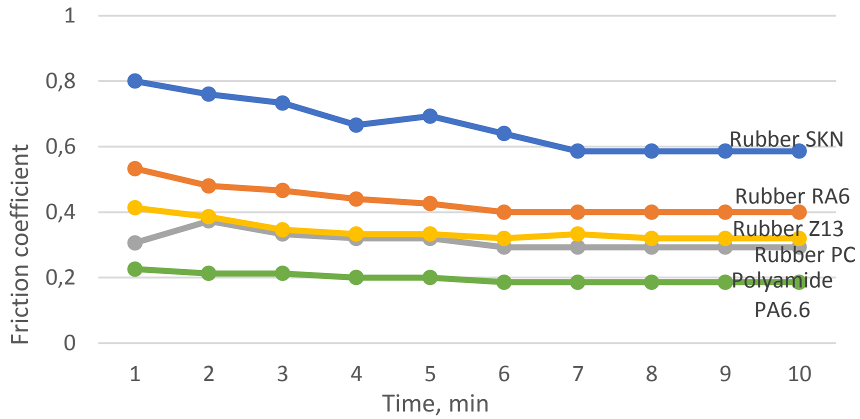

Figure 9. shows the variation of friction coefficients over time for the hard chrome plated 4130 steel roller - rubber shoes material couples (RA6, PC, Z13, SKN and polyamide PA 6.6.)

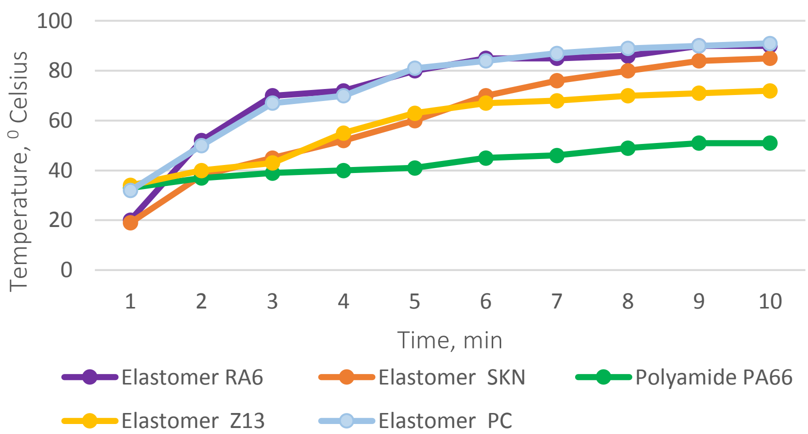

Figure 10. Temperature variation over time for material couple chrome-rubber, roller - shoes RA6, PC, Z13, SKN & polyamide PA 6.6.

Wear was determined gravimetrically [6,7,12]. In Figure 11 the gravimetric wear curves for the hard chrome plated 4130 steel roller - rubber shoes material couples (RA6, PC, Z13, SKN and polyamide PA 6.6.) can be seen.

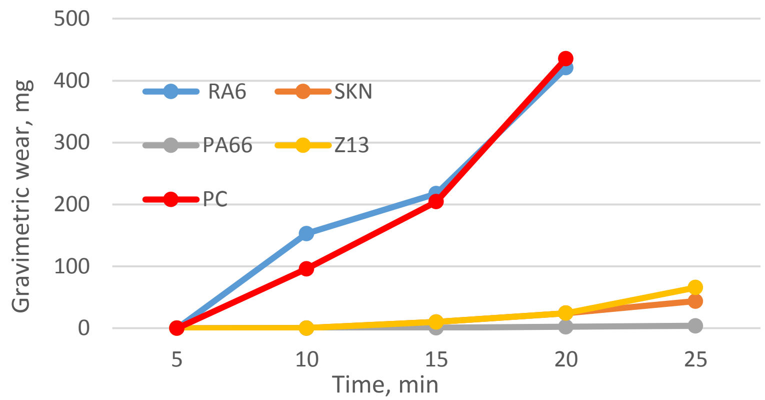

Figure 11. Gravimetric wear curves for hard chrome plated 4130 steel roller - rubber shoes material couples (RA6, PC, Z13, SKN and polyamide PA 6.6.)

5. Conclusions

This study examined five materials commonly used in the construction of screw pumps, and the experimental results indicate that PA 6.6 exhibits the lowest friction coefficients. Under the test conditions of coupled friction with 3rd class surface contact in air, there was no wear on the roll-type samples made of hard chromed steel due to the significant difference in hardness between this material and the conjugate parts made of rubber shoes (RA6, SKN, Z13, PC, and PA 6.6).

In terms of friction coefficients, the lowest values were shown by PA 6.6 followed by SKN, Z13, PA6 and SKN.

The linear wear shows the best behaviour for Z13 followed by PA 6.6. The negative values are explained by the expansion of the plastic material disc, and the maximum expansion is found for RA6, which is much higher than the wear. SKN shows the highest linear wear values. Above these linear wear values (cumulative wear, but the metal specimens have not worn which is actually linear wear of the non-metal specimens) the expansion should also be taken into account, so in reality the wear will be even higher.

The friction coefficients indicated that the lowest values were observed for the material couplings of shoes made of polyamide-hard chrome roller, which stabilized at 0.186. The rubber shoes displayed friction coefficient values more than twice as high, ranging from 0.293 to 0.586, depending on the type of rubber. The high friction coefficients of RA6, PC Z13, and SKN lead to the highest friction losses, low efficiency, pronounced heating, increased adhesion, increased load-by-expansion, and rubber degradation. These observations are applicable to dry friction (in air).

Regarding the temperature trend, polyamide PA6.6 exhibited the best performance, with a temperature of 51 degrees after 10 minutes, while RA6 and SKN had the weakest performance, with a temperature of 90 degrees. By assigning scores, polyamide received a score of 5, Z13 received 4, PC received 3, RA6 received 1, and SKN received 1.

For wear tests, similar to friction coefficients, a score is assigned between 5 and 1, where materials with the lowest shoe wear values receive a score of 5 because the rollers have not worn, and those with the highest values receive a score of 1. Polyamide received a score of 5, PC received 4, Z13 received 3, RA6 received 2, and SKN received 1. Thus, the greatest wear is observed in SKN rubber shoes. Adding up the scores from the friction coefficients, temperature, and wear allocation, we obtain polyamide with 15 points, PC rubber with 11 points, Z13 with 10 points, RA6 with 5 points, and SKN rubber with 3 points.

In real working conditions of progressive cavity pumps, the erosive-corrosive action of the working fluid will also lead to wear of the metal liner, reduce the values of friction coefficients, temperature in the rotor-stator coupling, and thus change the degradation mode of the non-metallic stator [9,10].

The performed tribological analysis showed that the worst performance was observed in SKN rubber, while the best performance in dry friction was observed in polyamide, followed by PC and Z13 rubbers.

The obtained results are in good agreement with expreminets/results presented in other papers/works. [6, 7, 8, 10, 12, 13, a.o.]

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