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Friction and wear resistance of Al_2O_3 $40TiO_2$ (AMDRY 6250) coating of a pump shaft sleeve bearing

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Abstract. The equipment of wastewater treatment plants is continuously subjected to different kinds of wear, as corrosion, abrasion, cavitation, erosion etc. The most affected components are those of slurry pumps, the slurry producing intense abrasive wear. The service life of pumps (wear rings, sealing, bearings, impellers, and casings) can considerably be extended by proper coating. Before the implementation of a new coating in equipment, its friction and wear behaviour must be determined beside corrosion resistance. This paper presents the results of friction tests carried out on AMSLER machine. The tribological pair was composed by Al_2O_3 $40TiO_2$ (AMDRY 6250) coating deposited on substrate of a pump shaft sleeve running against a rolling bearing steel disk in dry lubrication conditions. The experimental results are compared against those obtained for uncoated steel.

1. Introduction

Wastewater treatment stations are key points in modern life of urban society, assuring the wellbeing of the people and also the requirements for a healthy and ecological life. The flaws of such systems are pipelines and pumping stations, but especially the machine parts of pumps themselves: impellers, rolling and journal bearings, seals, bushes and sleeves. Slurry pumps and irrigation pumps are usually subjected to various kind of wear as abrasion, corrosion, erosion, and cavitation. The vertical irrigation pumps are usually lubricated by the circulating agent (water). Regarding the latest issue, Paleu et al. [1] investigated wear behaviour of aluminium oxide coated steel for both dry and water lubrication. Water lubrication of Al_2O_3 coated steel reduced the friction coefficient about 45%. The aluminium oxide is known for its corrosion resistance [2], being mostly used as coating for pipes of sewage systems. The latest of them (bushes and sleeves) can be easily reconditioned by proper choose of wear resistant coating material and deposition method. The deposited coatings can change impeller and casing interstitial gap, so the thickness of the coating must be carefully chosen to avoid cavitation phenomena [3-4].

Al_2O_3-$40TiO_2$ powder is also known as AMDRY6250 being recommended by manufacturer for atmospheric plasma spray (APS) deposition on pump components. Recent research [5-12] investigated aspects related to the influence of aluminium titanate (Al_2TiO_5) in Al_2O_3-TiO_2 thermal spray coatings, the structure of Al_2O_3–$40TiO_2$ for different deposition methods, corrosion and erosion resistance, tribological performances, and emissivity. The microstructure of TiO2, Al_2O_3+$40TiO_2$ and Al_2O_3+$13TiO_2$ at plasma spraying and laser engraving were investigated in [11]. According to results, Al_2O_3+$40TiO_2$ is the best of three, possessing low porosity (1.9%) and good hardness (HV0.3=1083).

Moreover Al_2O_3–$40TiO_2$ has corrosion resistance over Cr_3C_2–20NiCr, both coatings demonstrating good resistance to wear.

The shaft and bushes of modern vertical pumps are made of AISI 303 (EN 1.4305) and AISI 316 (EN 1.4401), and their impellers, casings and sleeves of AISI 304 (EN 1.4301) and AISI 316 L (EN 1.4404), but these materials are expensive and usually supposed to failure due to abrasion, erosion, corrosion and cavitation wear.

This paper investigates dry friction behaviour of steel samples coated by multiple layers of Al_2O_3+$40TiO_2$. An AMSLER machine is used as tribometer and scanning electron microscopy (SEM) and EDAX analysis are employed to inspect the worn surfaces of tested samples.

2. Experimental procedure

2.1. AMSLER machine

AMSLER machine is a tribometer used to perform tests in dry and lubricated conditions for different configurations of the contacts: disk on disk, roller on disk orthogonally disposed, brake block on disk, and fixed pad on rotating disk. A general view of AMSLER machine and testing pad-on-disk arrangement are presented in figures 1 and 2, respectively. The testing arrangement is presented in figure 2.

Figure 1. General view of testing machine.

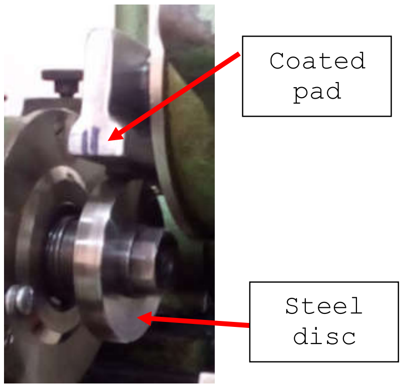

Figure 2. Testing arrangement.

The AMSLER machine was upgraded with data acquisition system based on half-bridge strain gauges disposed for bending beam arrangement, a Vishay P3 compact module data acquisition system with 4 channels, and LabVIEW interface allowing the display of friction torque, friction coefficient, and statistical parameters of data acquisition (arithmetic mean, standard deviation, signal-to-noise ratio SNR, Kurtosis and Skewness etc.). Also, the mean values of friction torque T_f and coefficient of friction μ are automatically computed for all acquired samples and displayed. An image of data acquisition and signal processing software interface is given in figure 3.

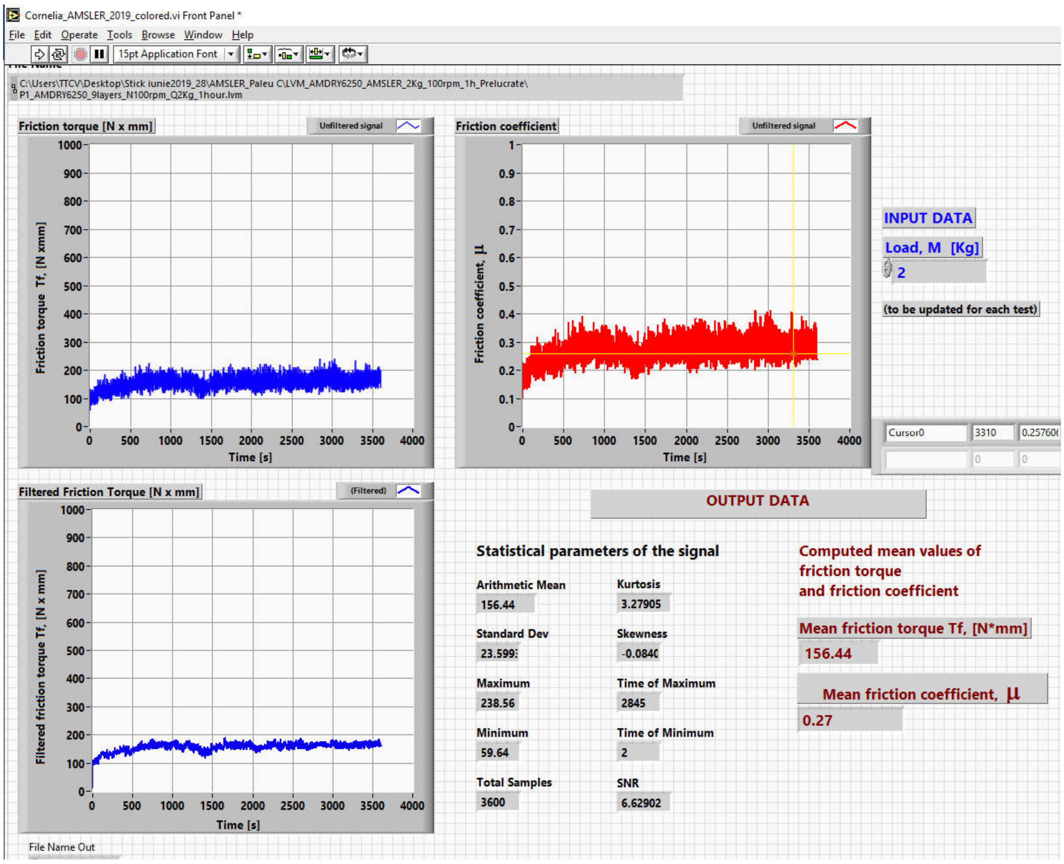

Figure 3. LabVIEW data acquisition and signal processing interface (test P1-9L).

As can be observed from statistical results, signal-to-noise ratio SNR=6.6 is high, skewness is almost nil and kurtosis factor is near to 3, indicating good quality of data acquisition and Gaussian form of diminished noise. The presence of Gaussian noise means that all the factors influencing data acquisition process were aleatory, probably generated by small vibrations noise presented due to vibrations of metallic leaf with strain gauges brazed on it, produced by variable dry friction forces between the tested rough samples and by kinematics chain of gears, no systematic errors being present.

2.2. Testing conditions
Each coated sample was tested at 2 KgF (20 N) normal load. The lower disk turned at constant speed of N=100 rpm, the span of each test being of 3600 s. Before tests the samples were cleaned with acetone and dried, all the tests being carried out in dry conditions (no lubricant).

2.3. Materials
Three sample pads of steel were coated by atmospheric plasma spay APS method (on equipment made Sulzer Metco 9MB) with 5 layers, 7 layers, and 9 layers of of Al_2O_3 – 40 TiO_2 coating, denoted as P1 – 5L, P1-7L, and P1-9L, respectively. Supplementary information on parameters of APS process are given in [13]. Samples P00 and P01 were obtained by removing the chrome layer of original sleeve taken from a damaged pump. P00 was finished by grinding and P01 was machined by milling, having different roughness (see table 1). The turning disk used in tribological tests was made of AISI52100 steel, hardness 62-64 HRC.

2.4. Profilometry

Taylor-Hobson profilometer was used to measure the roughness of the tested samples. Table 1 indicates the roughness values of tested samples on transversal (axial) and longitudinal (rolling) directions.

Table 1. Roughness of the tested samples.

Sample	P1-5L	P1-7L	P1-9L	P00	P01	Disc AISI 52100
Longitudinal roughness, Ra [μm]	5.401	6.722	7.464	0.085	1.231	0.9 – 1.0
Transversal roughness, Ra [μm]	3.382	7.729	7.285	0.065	0.334	1.1 - 1.3

It can be observed that the roughness of coating on P1-5L sample is better than the others (P1-7L and P1-9L). After each test the rotating disc of AISI 52100 steel was polished by grinding, the obtained mean roughness being also indicated in table 1.

3. Results

3.1. Friction tests

Results of friction tests consist in mean friction torque and mean friction coefficients for each test. As can be observed from figure 4 and figure 5, the least friction coefficient and friction torque are obtained for P1-7L (7 layers of AMDRY6250 coating). These are preliminary results; future tests must concentrate also on oil and water lubrication of coated samples.

One can remark that even the roughness of uncoated samples P00 and P01 was 5 times better than of coated samples, mean dry friction torque and coefficient are lower for P1-7L probe. Friction results must be correlated with SEM and EDAX analysis, which are presented in the following section.

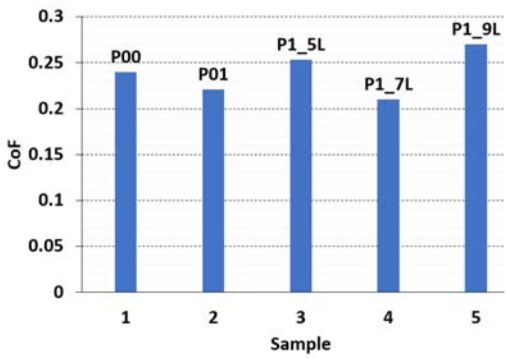

Figure 4. Mean friction coefficient for different samples.

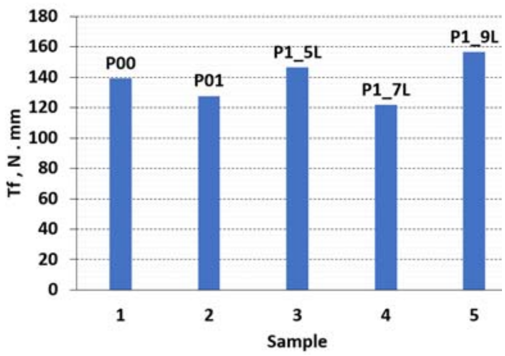

Figure 5. Values of mean friction torque for various test.

3.2. SEM analysis

SEM analysis revealed the wear modes of tested samples (figures 6-11). It seems that in some cases the coated samples present scratches (P1-5L). At magnification of 200x, the wear product seems transferred on the coated sample, the results of EDAX analysis confirming this assumption. A protective layer of aluminium oxide seems beneficial for friction decrease, but in certain limits (P1-7L

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and P1-9L samples, see Table 2 – EDAX analysis). In figure 11 the glassy nature of aluminium oxide formed on sample P17-L was highlighted at higher magnification (200 x).

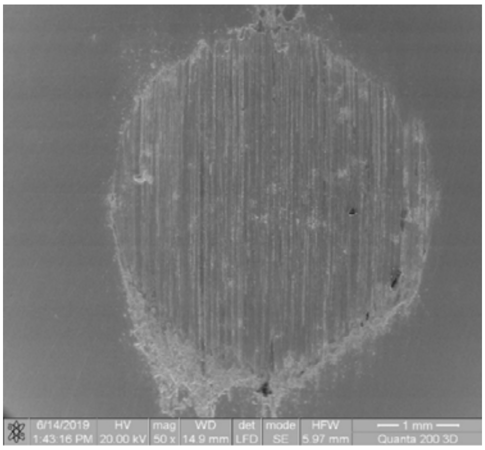

Figure 6. SEM image of P01 (50x).

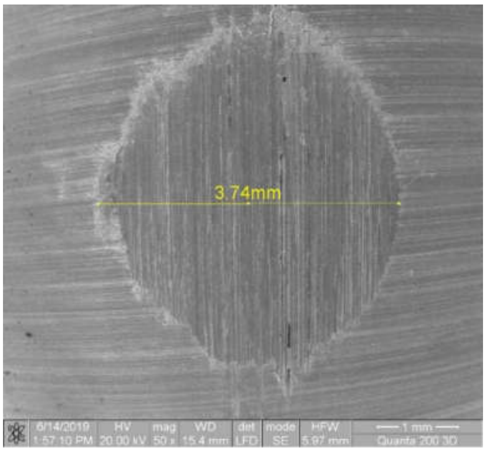

Figure 7. SEM image of P02 (50x).

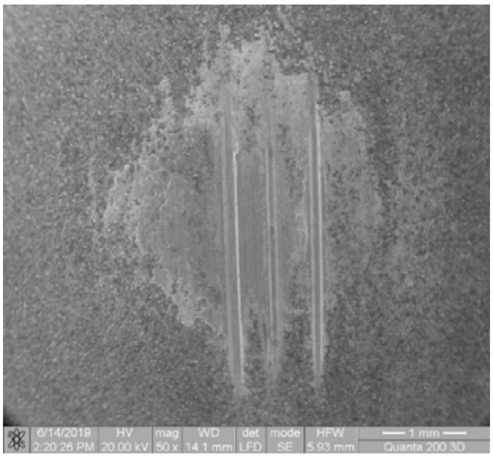

Figure 8. SEM image of P1-5L (50x).

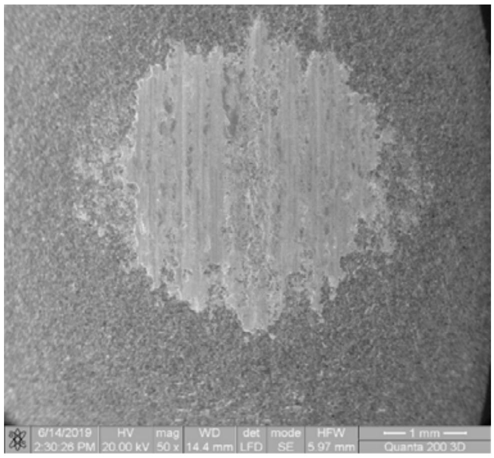

Figure 9. SEM image of P1-9L (50x).

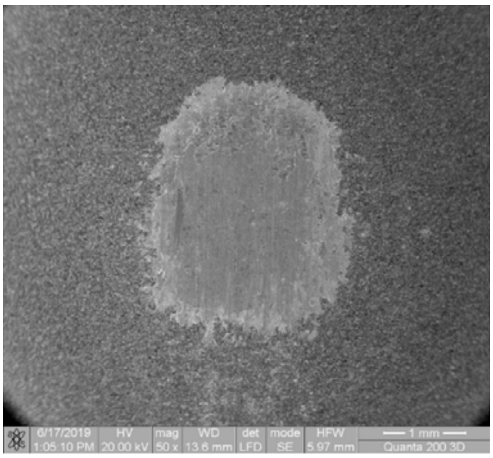

Figure 10. SEM image of P1-7L (50x).

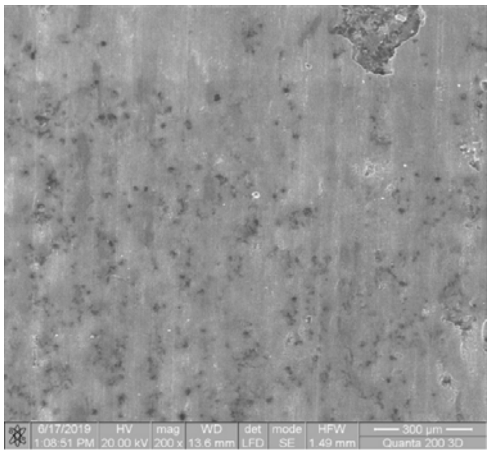

Figure 11. SEM image of P1-7L (200 x).

3.3. EDAX analysis

EDAX analysis results from the wear spots are presented in table 2.

Table 2. EDAX results of tested samples.

Element,	P00		P01		P1-5L		P1-7L		P1-9L	
Wt %	new	worn	new	worn	new	worn	new	worn	new	worn
OK	0.00	5.96	0.43	5.91	35.06	13.64	35.11	26.41	36.08	28.01
CrK	0.65	0.26	0.43	0.43	-	0.61	0.34	1.41	-	1.12
FeK	99.35	93.78	99.14	93.65	8.55	80.32	6.33	62.95	6.49	48.87
TiK	-	-	-	-	11.99	0.68	13.24	1.63	12.10	3.60
AlK	-	-	-	-	44.4-	4.75	44.97	7.6	45.33	18.4

According to EDAX results, higher friction of 5 layers sample is due to coating removal, proved by the abundant iron found on worn surface. In comparison with P1-7L, the 9 layers coated sample had higher friction because of abundant aluminium which was identified in augmented proportion on the wear scar at the end of the test.

4. Conclusions

Al_2O_3-40TiO_2 powder is also known as AMDRY6250, being recommended by manufacturer for atmospheric plasma spray (APS) deposition. Various layers of coating (5, 7 and 9) were deposited on steel samples. Preliminary dry tests were carried out on AMSLER machine at constant load and constant speed. The lowest values of friction torque and friction coefficient were obtained for the sample coated with 7 layers of AMDRY6250. SEM and EDAX analysis revealed that higher friction of 5 layers sample is due to coating removal from abrasive wear, proved by the abundant iron found on worn surface. In comparison with P1-7L, the 9 layers coated sample had higher friction because of abundant aluminium, which was identified in augmented proportion on the wear scar at the end of the test. Future tests must concentrate on oil and water lubricated coatings.

5. References

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