Research on Improving the Reliability of Copper Alloys Parts by Polyester Coating

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Polyester coating of copper alloys is part of the technological procedures meant to improve the performances of metallic parts in order to reduce the rate of premature removal from operation. The paper highlights the positive influence that copper alloys coating with polyester impregnated with 5 - 10% graphite has on the main mechanical characteristics, especially the wear resistance. The effects on the wear, fragility and structural modifications have been determined on Amsler testing machine by means of roller-roller type couplings: polyester coated copper alloy – treated copper alloy; treated copper alloy - treated copper alloy. The comparison revealed the positive influence of the thin layer of polyester as lubricating agent, thermal barrier, electrical insulator, damping layer, and stress dissipation medium it also established the temperature limit up to which it is recommended to use the polyester coating in industrial applications.

Keywords: polyester, graphite, cooper alloys

Under the conditions of sustainable development, which imposes restrictive measures in terms of environmental protection, the researches on increasing the products life have been intensified. Particular attention is given to the increase of the resistance to wear meant to improve the service life [7, 8]. In this context, the researches on copper alloys coating with thin layers of polyester impregnated with graphite aim to improve the functional performances [11, 12]. Worldwide there are several methods to increase the functional performance of the metallic parts subject to friction: use of bimetallic parts and composite materials, multilayer parts, depositing of antifriction layers by electrical discharge in vacuum, depositing of layers by heat plating and lubricant spray resistant to high temperatures [9, 10]. On the national level, for increasing the resistance to wear, there were developed technologies based on the processing in inductive field and depositing of metallic and non-metallic superficial layers [2, 4]. In general it was found out that the companies' management became more responsive to innovation issues [5, 6]. Polyester depositing on copper alloys is a recent method and, in this respect, it is a novelty in terms of operation behavior study. The researches monitor the behavior and influence of the polyester layer throughout friction intensification process. Using the comparative analysis as analysis method we studied the behavior of roller type test specimens coated with polyester, establishing the temperature limit up to which the procedure is efficient. The results reveal that the moment of polyester layer influence slowdown is the moment of degradation processes onset.

Experimental part

The wear tests were performed on the Amsler testing machine of the mechanical testing laboratory, on roller-roller type couplings with the initial diameter d_1 = 50.01 mm and a thickness B=10 mm. The rollers made of copper alloys were covered by polyester resin in which graphite carbon was incorporated in the proportion of 5-10%. The values of polymerization treatment technological parameters are: $T_{heating}$ =200°C, $t_{maintaining}$ =20 min [1, 3].

The rollers made of copper alloy coated with polyester impregnated with 5-10% graphite were ground before the wear test. The average thickness of the polyester layer was 100 -200μm.

The experimental tests were aimed at studying the friction in couplings with linear and curved surface contact using Amsler machine with roller type test specimens [3].

The two roller type test specimens rotate in reverse; at their contact there is a pure rolling movement or a sliding rolling movement, depending on the diameters of the test specimens. The working rotational speeds of the two test specimens (roller type) are constant. If rollers have equal diameters, a sliding of about 10% is obtained.

The experiments were performed on the following types of roller – roller couplings: copper alloy coated with polyester- treated copper alloy; treated copper alloy - treated copper alloy.

Table 1 presents the results of the experiments regarding the dry friction on the rolling couplings roller-roller type.

The results of experiments are graphically shown in figure 1, highlighting the values of current wear intensity and cumulative wear intensity.

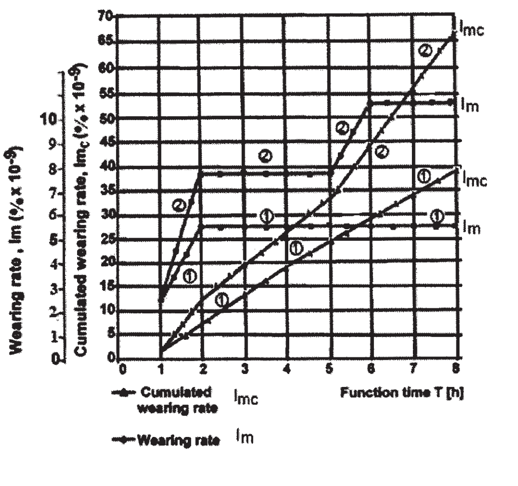

Fig. 1. Wear intensity and cumulative wear intensity (dry friction without relative sliding)

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Roller-roller type rolling couplings		Dry friction without relative sliding		*Roller no.1: polyester coated copper alloy* / *Roller no.2: copper alloy- treated by solution + ageing hardening*							
Friction time (h)	d_1 (mm)	d_2 (mm)	S (%)	Q (N)	ΔT (s)	L_f (x10^6) (mm)	G_f (mm)	Im (x10^{-9})	I_{mc} (x10^{-9})	Um (%)	Umc (%)
0	50.01	52.64	-	-	-	-	-	-	-	-	-
1	50.00	52.62	5.24	60	3600	1.8840	0.005	2.6539	2.6539	0.02	0.02
2	49.98	52.58	5.20	60	3600	1.8832	0.01	5.3101	7.9640	0.04	0.06
3	49.96	52.54	5.16	60	3600	1.8824	0.01	5.3123	13.2763	0.04	0.10
4	49.94	52.50	5.12	60	3600	1.8817	0.01	5.3143	18.5906	0.04	0.14
5	49.92	52.46	5.08	60	3600	1.8809	0.01	5.3166	23.9072	0.04	0.18
6	49.90	52.42	5.05	60	3600	1.8802	0.01	5.3185	29.2257	0.04	0.22
7	49.88	52.38	5.01	60	3600	1.8794	0.01	5.3208	34.5465	0.04	0.26
8	49.86	52.34	4.97	60	3600	1.8787	0.01	5.3228	˙39.8693	0.04	0.30
Roller-roller type rolling couplings		Dry friction without relative sliding		*Roller no.1: copper alloy- treated by solution + ageing hardening* / *Roller no.2: copper alloy- treated by solution + ageing hardening*							
Friction time (h)	d_1 (mm)	d_2 (mm)	S (%)	Q (N)	ΔT (s)	L_f (x10^6) (mm)	G_f (mm)	Im (x10^{-9})	I_{mc} (x10^{-9})	Um (%)	Umc (%)
0	50.01	52.64	-	-	-	-	-	-	-	-	-
1	50.00	52.62	5.24	60	3600	1.8840	0.005	2.6539	2.6539	0.02	0.02
2	49.97	52.59	5.24	60	3600	1.8828	0.015	7.9668	10.6207	0.06	0.08
3	49.94	52.56	5.24	60	3600	1.8817	0.015	7.9715	18.5922	0.06	0.14
4	49.91	52.52	5.22	60	3600	1.8806	0.015	7.9761	26.5683	0.06	0.20
5	49.88	52.48	5.21	60	3600	1.8794	0.015	7.9812	34.5495	0.06	0.26
6	49.84	52.44	5.21	60	3600	1.8779	0.02	10.6501	45.1996	0.08	0.34
7	49.80	52.40	5.22	60	3600	1.8764	0.02	10.6587	55.8583	0.08	0.42
8	49.76	52.36	5.22	60	3600	1.8749	0.02	10.6672	66.5255	0.08	0.50

d_1 = diameter of roller no. 1; d_2 = diameter of roller no. 2;
B= 10 mm – width of contact between rollers;
n_1 = 200 rpm – speed of roller 1; n_2 = 200 rpm - speed of roller 2;
$S = \frac{n_2 \cdot d_2 - n_1 \cdot d_1}{n_1 \cdot d_1} \cdot 100$ - sliding; Q = 60 N –normal load on rollers;
T – friction time; ΔT = 3600 s –time between two measurements;
$L_f = \frac{\pi d_1 n_1 \Delta T}{60}$ - friction length;
$G_f = \frac{d_{1,i} - d_{1,i+1}}{2}$ – thickness of worn layer;
$Im = \frac{Gf}{Lf}$ intensity of wear;
$I_{mc} = \sum_1^n I_m$ - intensity of cumulative wear;
$U_m = \frac{2G_{f,i}}{d_{1,i}} \cdot 100$ –current wear;
$U_{mc} = \sum_1^n U_m$ –current cumulative wear.

Table 1
EXPERIMENTS ON DRY FRICTION OF ROLLER-ROLLER TYPE ROLLING COUPLINGS

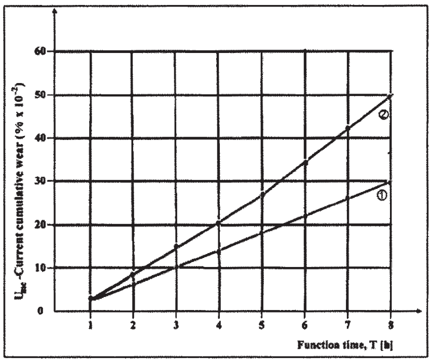

Fig. 2. Percentage values of current wear and current cumulative wear

The percentage values of current wear and current cumulative wear resulting from the 8 h of dry friction without relative sliding tests are shown in figure 2.

The presence of polyester layer contributes to the decrease of the cumulative current wear by 40.07% related to the wear of the treated rollers. The layer of polyester impregnated with 5-10% graphite reduces the wear value by its cumulated effects of: lubricating agent; insulating thermal barrier; dampening layer, medium of uniform distribution of stresses and medium of dissipation and mutual extinction of stresses.

Results and discussions

The wear tests are dry friction without relative sliding. The dry wear tests on rolling couplings performed on Amsler machine lasted 8 h. The time between two measurements was one hour. The rated load on contact surface is 60 N.

Measurements made on diameters before and after the tests reveal the depth of the worn layer and the wear intensity. Contact pressure causes an elastic deformation of the alloy; the polyester layer is consistent with this deformation and does not allow the alloy-alloy contact. The comparison highlighted the positive influence of the thin layer of polyester.

The experimental results showed that test specimens made of copper alloy coated with polyester impregnated with 5-10% graphite have a higher wear resistance compared to the treated alloy test specimens. Thus, the cumulative wear intensity recorded after 8 hours of testing in the case of the test specimens made of polyester coated alloys is by 40.07% lower than for the specimens made of alloy treated by solution + ageing hardening. The impregnation of polyester with graphite under dry powder form improves the lubrication, due to its lamellar structure. A percentage of 5-10% graphite gives a better lubrication and, moreover, a thermal barrier by alloy insulation.

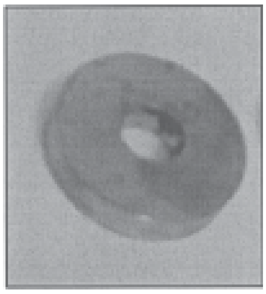

Fig. 3. Roller type test specimen made of copper alloy coated with polyester

Table 2
STUDY OF LAYERS FRAGILITY –SPECIMEN OF POLYESTER COATED COPPER ALLOY

No.	T (s)	g_i (μm)	g_f (μm)	F_f (daN)	Analysis of imprint
1	28800	100	10	15.0	No cracks or tears appear on the contour of the imprinted marks
2	28800	100	10	28.0	No cracks or tears appear on the contour of the imprinted marks
3	28800	100	10	44.8	No cracks start from the contour of indenter mark
4	28800	100	10	68.1	There is a fine network of cracks, some of which start from the indenter mark contour

T – friction time (time for dry wear tests on rolling couplings);
g_i – initial average thickness of the polyester layer impregnated with 5-10% graphite;
g_f - final average thickness (after dry wear tests) of the polyester layer;
F_f – pressing force during fragility test.

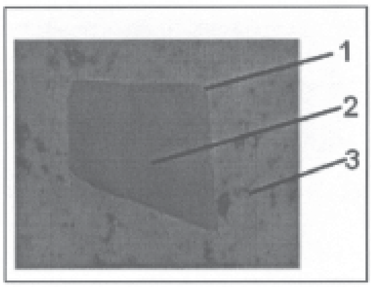

Fig.4. Study of fragility – roller no.1 made of copper alloy coated with polyester impregnated with 5-10% graphite carbon; F_f = 68.1 daN; (1000:1)

Practically, the polyester layer contributes to decreasing the cumulative current wear from 0.50 to 0.30%. After 8 h of tests of dry friction without relative sliding, the polyester layer contributes to the decrease by 40.07% of the cumulative current wear of the rollers.

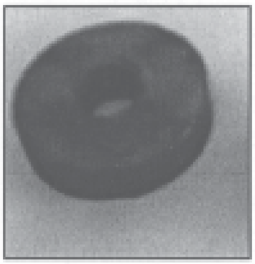

Fig.5. Roller type test specimen made of treated copper alloy

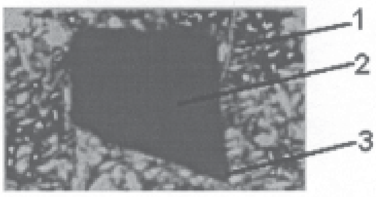

Fig. 6. Study of fragility – roller no.1 made of copper alloy – treated by solution + ageing hardening; F_f = 44.8 daN; (1000:1)

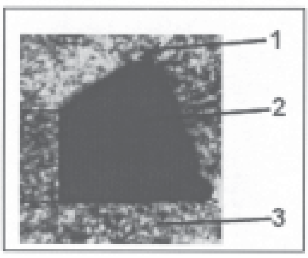

Fig. 7. Study of fragility – roller no.1 made of copper alloy – treated by solution + ageing hardening; F_f = 68.1 daN; (1000:1)

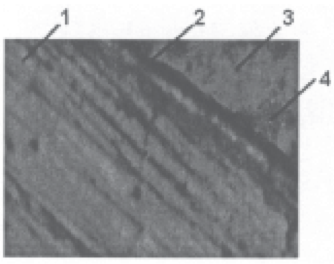

Fig. 8. Microstructure of copper alloy coated with polyester (100X)

Analysis of layer fragility

Researches on the fragility were performed after the wear tests. The flat surfaces of the polyester coated rollers were submitted to increasing pressure forces by means of the indenter with diamond pyramidal tip (the indenter is an integral part of the apparatus that determines fragility). The trapezoidal marks left on test specimens surface were analyzed on an optic microscope at magnification of 1000:1. The results of the researches on fragility are shown in figure 3, 4 and table 2.

The results of researches on fragility in case of the roller type test specimens made of treated copper alloy, uncoated with polyester, are listed in figures 5-7 and table 3.

By its cumulative effects, the polyester layer influences the layers fragility:

-the good adhesion of surfaces leads to a negligible fragility;

-in the case of polyester coated rollers, the cracks network is visible to sizes of 1000:1, at pressing forces of 68.1 daN (which is a very high value for the copper alloys);

-in the case of the treated rollers, one can observe cracks starting from the contour of the mark left by the pressing force of 44.8 daN.

The combined effects of the polyester layer on the rollers contribute to the diminution by 34.21% of the pressing force that entails fragility. The percentage by which decreases the wear (40.07%) is close to the percentage by which the resistance to fragility increases (34.21%). The effect of the polyester layer applied to rollers is positive. The technological procedure is likely to be promoted to industrial scale too.

Structural analysis of layer

The rollers made of copper alloy coated with polyester impregnated with 5-10% graphite have a surface layer deposited by polymerization of 100-200 μm. Figure 8 shows the microstructure of the copper alloy coated with polyester.

After the tests of dry friction without relative sliding, the test specimens coated with polyester were microscopically analyzed by means of the scanning electronic microscope Quanta Inspect F type –manufactured by FEI-Philips. The microscopic study was performed after a friction time of 6, 7 and 8 h. Figure 9 shows the micro-

Table 3
STUDY ON LAYERS FRAGILITY – TEST SPECIMEN MADE OF TREATED COPPER ALLOY (SOLUTION + AGEING HARDENING)

No.	T (s)	g_i (μm)	g_f (μm)	F_f (daN)	Analysis of imprint
1	28800	0	0	15.0	No cracks or tears appear on the contour of the imprinted marks
2	28800	0	0	28.0	No cracks or tears appear on the contour of the imprinted marks
3	28800	0	0	44.8	Fine cracks at the corners of indenter mark contour
4	28800	0	0	68.1	Fine network of cracks, some of which start from the indenter mark contour

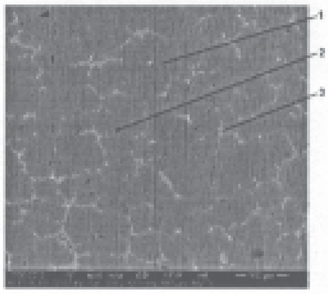

Fig. 9. Image of scanning electronic microscopy (SEM) at a magnification of 500X
Microstructure of copper alloy (Cu 92%, Ni 2%, Al 4%, Si 2%) initially coated with polyester (friction time = 6 h)

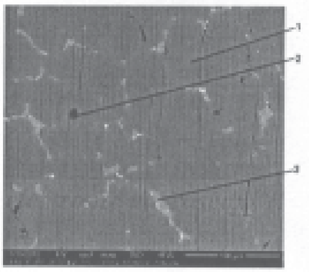

Fig. 10. Image of scanning electronic microscopy (SEM) at a magnification of 1000X

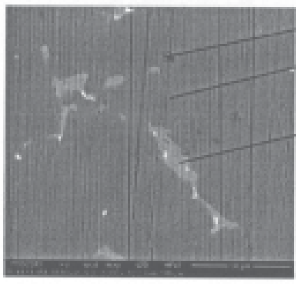

Fig. 11. Image of scanning electronic microscopy (SEM) at a magnification of 2000X

structure of the copper alloy after 6 h of dry friction without relative sliding.

After 6 h of dry friction there is induced a change in the mobility of the polymeric chains of the polyester layer. Layer degradation occurs. In figure 10 is shown the microstructure of the polyester coated copper alloy after 7 h of tests of dry friction without relative sliding.

Microstructure of copper alloy initially coated with polyester (friction time = 7 h)

After 7 h of dry friction tests there is an accentuation of the heating process. Drastic changes occur in the surface layer properties because of the thermal degradation onset. The chemical bonds are modified with a tendency to break the polymer chains. Figure 11 presents the microstructure of the copper alloy coated with polyester after 8 h of dry friction tests.

Microstructure of copper alloy initially coated with polyester (friction time = 8 h)

Intensifying friction led to increasing temperature. The process of thermal degradation results in the transformation of the layer into isolated traces of polyester and graphite carbon. There is no configuration of detection of layer hyperfine structure. The positive effect of the polyester layer in the friction process is kept up to the temperature of 200 – 250°C when the thermal degradation process is accelerated. Structural analysis reveals these phenomena, emphasizing the gradual transformation of the polyester layer into isolated traces of polyester and graphite carbon.

Conclusions

After conducting experimental researches and comparative analysis performed on roller type test specimens, the following aspects are highlighted:

- the polyester layer deposited by polymerization treatment had a positive influence on the copper alloys as it was found out a diminution of the wear by 40.07%. Simultaneously it was also observed an increase of the resistance to fragility by 34.21%. This fact shows that the percentage by which the wear decreases is close to the percentage by which resistance to fragility is improved;
- by taking over the elastic deformations that occur during operation, the polyester impregnated with graphite contributed to the improvement of the resistance to wear by ensuring a proper lubrication with effect on the reduction of friction. It was found out that the deposited polyester layer provides good adhesion and a negligible fragility, taking over a part of the stresses generated by the shock and contact stresses during the operation of the parts;
- in the polyester layer, during the first phase the friction induces little effect of crystallization. As the temperature increases, there is a change of mobility of the polymer chains. The absorption of energy by heating in the deposited layer causes reversible and irreversible phenomena that lead to the modification of physical-mechanical parameters. During the friction, there is an accentuation of the heating process because of the atmosphere oxygen, which entails changes in the chemical properties too. There was not noticed the apparition of a hyperfine structure;
- intensification of friction, due to temperature increase, triggers the process of thermal degradation that is accompanied by changes of the chemical bonds. Tendency is to break the polymer chains, particularly at temperatures over 250°C. Structural analysis highlighted the gradual degradation of the polyester layer along with the intensification of friction process. It is required that the temperature limit up to which the use of polyester coating is recommended has the value of 250 °C.

Polyester layer improves the resistance to wear and the resistance to fragility by its cumulative effect as: lubricating agent; insulating thermal barrier; damping layer; medium of tensions dissipation. The qualitative effect induced by the use of polyester layer imposes the extension of technology to industrial scale production conditions.

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