Influence of compositions ABRO GT-409 and POLYTRON^{MTC} in transmission oil on tribological contact in material systems "CuCrNiZrTi - KCh50", "CuCrNiZrTi – 40X"

Influence of compositions ABRO GT-409 and POLYTRON^{MTC} in transmission oil on tribological contact in material systems "CuCrNiZrTi - KCh50", "CuCrNiZrTi – 40X"

V I Kubich[1], O G Cherneta[2] and V M Yurov[3]

[1]National University "Zaporizhzhya polytechnic", Zaporizhia, Ukraine, schmirung@gmail.com
[2]Dniprovsk State technical university, Kamenskoye, Ukraine, ocherneta@gmail.com
[3] Karaganda University named after E.A. Buketov, Karaganda, Republic of Kazakhstan, exciton@list.ru

Abstract. The work carried out definitive tribotechnical tests of the systems of materials "CuCrNiZrTi - 85W90 - 40X", "CuCrNiZrTi - 85W90 - KCh50" to assess the nature of the manifestation of the effect of additive compositions (AC) ABRO GT-409 and POLYTRON^{TMC} on adaptability to loading and lubrication modes parameters of adhesion properties when modeling shear on small samples. It was found that at the stage of running-in, the systems of materials operate stably with clearly pronounced tendencies to reduce the sliding resistance to a certain minimum, followed by its increase due to the influence of the AC components. ACs do not determine the effect of reducing the wear intensity in the investigated range of contact pressures, and a decrease in friction is caused by a decrease in shear resistance in the zones of contact interaction of protrusions and depressions of surface irregularities. A more significant effect on the decrease in the parameters of adhesion properties is exerted by the POLYTRON^{MTC} 10% AC components, which cause the formation of secondary lubricant formations with denser structures at the interface of adhesion with metal surfaces and reduced resistance to movement within the formed cohesive bonds between them.

1. Introduction

A decrease in the thermomechanical tension of the zones of contact interaction of surfaces operating during lubrication and transmitting motion is predetermined by a number of factors. One of them is the recommended use of additives compositions (AC), for example, in transmission oils for lubricating parts, for example, gears of automobile transmissions. The list of such ACs is quite wide, and each of the proposed compositions differs in the content and direction of manifestation of the implemented mechanisms for reducing friction and wear. These compositions currently include the process fluid POLYTRON^{MTC} [1] (Metal Treatment Concentrate - metal treatment concentrate [2]) on an oil base and the additive ABRO GT-409 [3], which includes Teflon (PTFE), which are recommended add to transmission oils in the amount of 10% of the capacity of the lubrication systems of units and mechanisms. However, the recommendations of the manufacturers of such compositions do not take into account the possible features of the manifestation of their tribological action when using new promising materials of friction and antifriction action in typical mechanisms, for example, in the same gear drives. Based on the above, the establishment of regularities in the manifestation of the parameters of tribological interaction in systems of structural metals with promising new compositions seems to be an urgent scientific and fundamental task considered in tribology.

2. Analysis of publications

In [4], the properties of the first synthesized high-entropy alloy (HEA) of the CrNiTiZrCu system by the method of mechanical alloying followed by heat treatment in vacuum under certain conditions are estimated. It was found that the microhardness of the coating of the CrNiTiZrCu system is not inferior and in most cases exceeds the hardness of high-entropy equiatomic alloys. Based on the results of tribotechnical tests in nitrogen and argon, the dynamic coefficients of friction were determined, which had values when interacting with copper 0.041 and 0.057, with aluminum 0.066 and 0.057, respectively. This indicates the manifestation of antifriction properties by the alloy. The wear resistance of the CrNiTiZrCu coating, determined on a calotester in contact with a steel ball, is $3 \cdot 10^{-4}$ g/min, which meets the wear resistance requirements of special steels. It follows from the above that the proposed material seems promising from the point of view of meeting the high requirements for reducing tension in the contact interaction zone and predetermines the need for obtaining statistical experimental information on the parameters of interaction with other structural materials.

It was determined in [5] that a high-entropy alloy of the CuCrNiZrTi system upon contact interaction with steels 40X, 12X2H4 and cast iron KCh50 in an environment of TAD-17I 85W90 (hereinafter 85W90) transmission oil is satisfactorily running-in, and also exhibits antifriction properties with a dynamic coefficient of friction $\mu = 0{,}13$ with cast iron KCh50. It has been established that the strength of the adhesive bond in the 85W90 transmission oil medium is higher than in dry contact, taking into account the increase in the shear rate. To a greater extent, this increase is determined in contact with KCH50 cast iron and 40Kh steel, which can affect the frictional fatigue of the near-surface structures of metals, as well as the formed secondary lubricant formations that screen these layers. The high hardness of the alloy of the CuCrNiZrTi 890 HV system and the manifestation of antifriction properties by it predetermines the possibility of manufacturing from it, for example, such parts as gears and thrust washers, for example, in the designs of gears working in tandem with steel 40X 229 HV, cast iron KCh50 200 HV. From which it follows that the assessment of the effect of the above mentioned additive compositions seems to be important and significant. The lack of such information predetermines the need for appropriate research.

Since for the system of materials "CuCrNiZrTi - 85W90 - 12X2H4" the calculated value of the energy intensity of wear was determined to be the highest in comparison with the systems "CuCrNiZrTi - 85W90 - 40X", "CuCrNiZrTi - 85W90 - KCh50" with an average value of the dynamic coefficient of friction, the technical interest in this system in this work is relegated to the background.

The purpose of the work is to conduct definitive tribotechnical tests of the systems of materials "CuCrNiZrTi - 85W90 - 40X", "CuCrNiZrTi - 85W90 - KCh50" to assess the nature of the manifestation in them of the action of AC ABRO GT-409 and POLYTRON^{TMC} on adaptability to loading modes and lubrication properties and the manifestation of parameters when simulating shear on small-sized samples. Based on the above, this work seems to be a continuation of the complex of studies begun in works [4-6].

3. Research methods

Tribotechnical tests were carried out on a friction machine SMTs-2 in two stages on small-sized samples according to the friction scheme "movable disk - fixed block" in accordance with the method described in [5, 6]. At the same time, the nature of the change in the dynamic coefficient of sliding friction (hereinafter referred to as the coefficient of friction) from normal step loading at the stage of running-in and at the stage of operation without lubricant supply was assessed in accordance with the methodology described in [4]. The normal force in the friction zone of the surfaces of the samples ranged from 22 N; 45 H; 90 N, 140 N, 180 N, 230 N. The rotational speed of the disk was constant and amounted to 300 min-1. The nominal friction area at the end of the tests was $S_1 = 7.6 \pm 0.5$ mm^2 for the "CuCrNiZrTi - 40X" system and $S_2 = 6.5 \pm 0.5$ mm^2 for the "CuCrNiZrTi - KCh50" system. The parameters of the adhesive bond were evaluated using an SMTs-2 friction machine with additional equipment in accordance with the procedure described in [7]. The pressure in the contact zone of the samples of the "CuCrNiZrTi - 40X" system was 5.92 MPa; 18.42 MPa; 30.26 MPa, 42.1 MPa; for the system "CuCrNiZrTi - KCh50" 6.94 MPa; 21.6 MPa; 35.5 MPa, 49.4 MPa, respectively.

Transmission oil 85W90 with dynamic viscosity μ = 0.106 Pa·s at 50 ºC and AC POLYTRON^{MTC} [1,2], AC ABRO GT-409 [3] were used as a lubricant, which were introduced into the composition in the amount of 10% of the prepared volume for research.

Samples - disks d = 50 mm, b = 12 mm were made of the following materials:

- steel 40X, 229 HV;
- cast iron KCh50, 200 HV.

Samples - pads 9x15x3 were made of AISI-201 steel coated with a high-entropy CuCrNiZrTi alloy (890 HV). The assessment of the wear of the pads was carried out according to the energy intensity of wear Im (mg·J^{-1}), taking into account the determination of the work of friction forces at each of the stages of tribotechnical tests in accordance with the procedure described in [7]. In the case of obvious jumps in the resistance to rotation, at the second stage of the research, it was supposed to subject the systems of materials to repeated running-in with low load values of 45 N and 90 N with a holding time on each of them for 2 minutes.

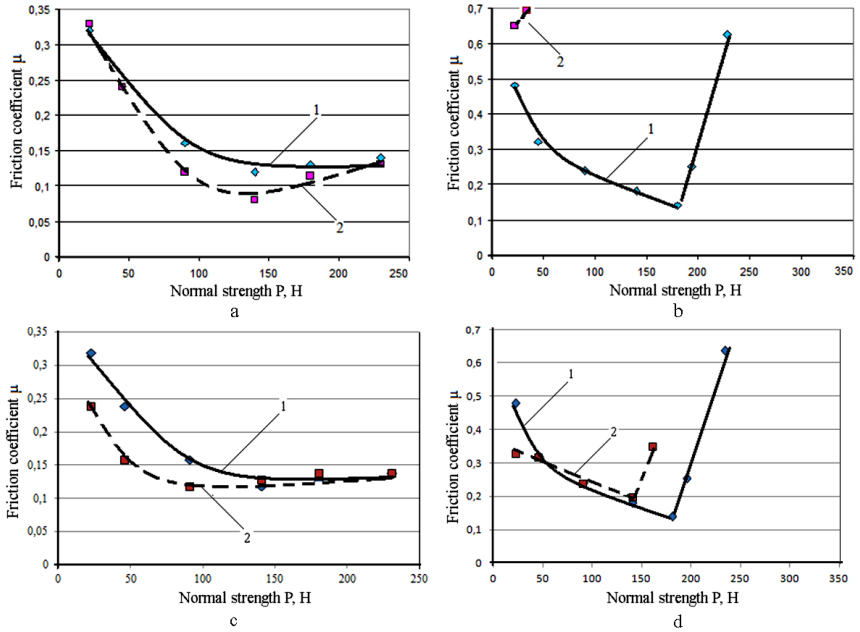
4. Research results and their discussion

The results of tribotechnical tests of the studied systems of materials are given in the form of the constructed regularities of changes in the dynamic coefficient of friction from the normal force in the contact zone, Figures 1, 2. At the running-in stage, both systems of materials worked stably with clearly pronounced tendencies of a decrease in slip resistance to a certain minimum, followed by its increase due to the influence of AC components. At the same time, a more significant effect of DC on the formation of tribological structures on metal surfaces was manifested in the "CuCrNiZrTi - 40X" system (Figures 2 a, c), for which:

– in the first 6 minutes of running-in, the friction coefficient decreased 2.6 times with ABRO 10% AC, 2 times with POLYTRON^{MTC} 10% AC;

– the maximum reduction in the coefficient of friction at steady-state friction for ABRO10 DC was 2.3 times, for POLYTRON^{MTC} 10% AC - 1.8 times, respectively;

– adaptability to normal loads was provided by ABRO10% AC in the range from 45 N to 65 N for 2.5 - 3 minutes, POLYTRON^{MTC} 10% AC in the range from 65 N to 115 N for 5.5-6 minutes.



a, b - 85W90 with ABRO 10% AC (a – 1st stage, running-in; b – 2nd stage, friction on residual lubricating formations); c, d – 85W90 with POLYTRON^{MTC} AC 10% (c – 1st stage, running-in; d – 2nd stage, friction on residual lubricating formations); 1 – without AC; 2 – with AK

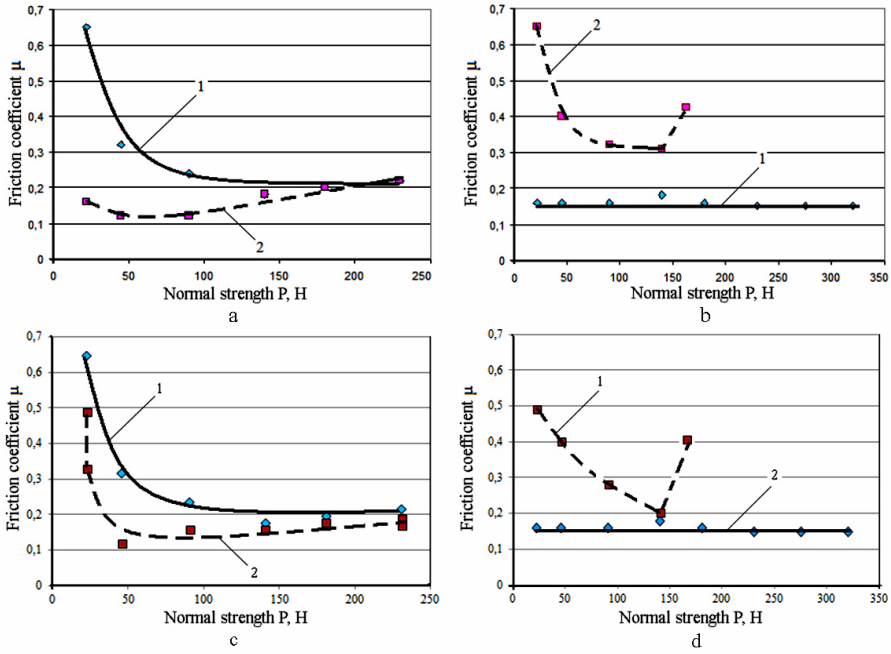
Figure 1. Dependence of the dynamic coefficient of friction on the normal force in the system of materials "CuCrNiZrTi - KCh50":

In the system of materials "CuCrNiZrTi - KCh50" (Figure 1 a, c), the tribological structures formed under the influence of both ACs caused a less significant effect on slip resistance and adaptability of metal surfaces to loading conditions. In this case, the following took place:

– the intensity of the decrease in the friction coefficient was practically equal to the intensity of its decrease without the use of AC, however, the difference in the values themselves when using AC ABRO10 was 1.25-1.5 times, when using DC POLYTRON^{MTC} 10% 1.7 times, respectively;

– adaptability to normal loads was provided by ABRO 10% DC in the range from 115 N to 175 N for 2.5 - 3 minutes, POLYTRON 10% AC in the range from 90 MPa to 150 MPa for 5.5-6 minutes.

Based on the obtained graphical dependencies shown in Figures 1 a, c and 2 a, c, it follows that POLYTRON 10% AC is capable of providing adaptability to the loading mode in a larger range of time and load values than ABRO 10% AC. It can also be stated that the running-in of the studied systems of materials is more efficient when using POLYTRON^{MTC} 10% AC. This is confirmed by the flatter right branch of the graphical dependence μ = f(p). However, it is not advisable to talk about a decrease in the friction coefficient at the end of running-in when using both ACs.



a, b – 85W90 with ABRO 10% AC (a – 1st stage, running-in; b – 2nd stage, friction on residual lubricating formations); c, d – 85W90 with 10% POLYTRON^{MTC} AC (c – 1st stage, running-in; d – 2nd stage, friction on residual lubricating formations); 1 – without AC; 2 – with AK

Figure 2. Dependence of the dynamic coefficient of friction on the normal force in the system of materials "CuCrNiZrTi - 40X".

In general, at the running-in stage, the coefficient of friction that appeared in certain sections was:

– for the system "CuCrNiZrTi - 40X" with AC ABRO10 μ=0.12, with AC POLYTRON^{MTC} 10% μ=0.13;

– for the "CuCrNiZrTi - KCh50" system with ABRO10 AC μ=0.08, with POLYTRON^{MTC} AC 10% μ=0.11.

At the stage of testing on residual lubricant formations, the effectiveness of the action was manifested only for POLYTRON^{MTC} AC 10% in the system of materials "CuCrNiZrTi - KCh50" and then only in a narrow range of load and interaction time:

– the pressure in the contact zone was from 22 N to 40 N;

– the interaction time was 2.5 minutes;

– the decrease in the coefficient of friction in the first 0.5 min of interaction was 1.5 times, while the rate of its decrease also decreased by 24 times, i.e. from 0.028 N^{-1} without AC to 0.00086 N^{-1} with AC.

This effect was manifested due to the compatibility of the interaction of free carbon in CN50 and the hydrocarbon base of POLYTRON 10% AC on metal surfaces at the running-in stage was found to be insufficient. AC ABRO10% does not provide the formation of stable tribological structures from the components of the interaction medium to ensure boundary friction on residual lubricant formations in the system of materials "CuCrNiZrTi - KCh50". In the system "CuCrNiZrTi - 40X" AK ABRO10% showed the possibility of influencing the friction reduction mechanism. However, this mechanism could be caused not by the creation of additional screening of the profile by lubricating formations of PTFE molecules, but by their destruction due to the adsorption decrease in the strength of the surface structures of metals. At the same time, a section of steady-state friction with a friction coefficient of 0.31 was observed for 2.5-3 minutes, which exceeded its value by 1.9 times without the use of DC throughout the test period. As a result of processing the tribograms and evaluating the weight loss of the samples-pads, the values of the energy intensity of wear Im were calculated, the data are given in Table 1.

Table 1. Energy intensity of wear of the alloy of the CuCrNiZrTi system.

Roller material	Friction force work A_{tr}, J			Wear rate $I_m \cdot 10^{-8}$, mg•J^{-1}		
	Without AC	With AC ABRO	Without AC POLYTRON	Without AC	With AC ABRO	With AC POLYTRON
40X	41184.4	25860.3	22766.2	7.7	17	17.6
KCh50	23380.4	17742.7	18055.3	21.3	41.7	60.9

Analysis of the data in Table 1 indicates the following:

– the work of friction forces when using AC is reduced in the system of materials "CuCrNiZrTi - 40X" 1.6-1.8 times, which is 23% and 38% more than in the system of materials "CuCrNiZrTi - KCh50";

– there is a slight decrease in the work of friction forces in the system "CuCrNiZrTi - 40X" when using AC POLYTRON^{MTC} 10%., which is 12% with practically unchanged in the system "CuCrNiZrTi - KCh50";

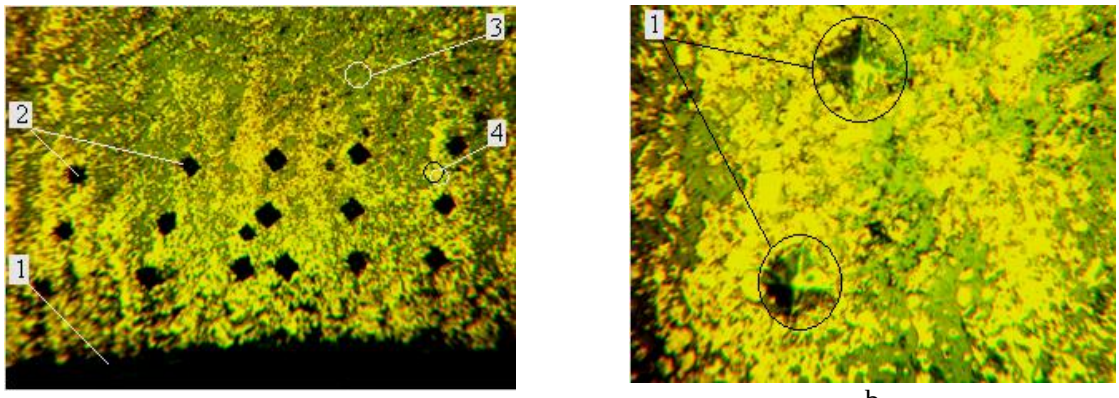
– an increase in the wear rate of CuCrNiZrTi in both systems of materials by an average of 2 times when using ABRO10% AC, and 2.8 times when using POLYTRON 10% AC. in the system of materials "CuCrNiZrTi - KCh50";

– almost equal wear rates of CuCrNiZrTi in the system of materials "CuCrNiZrTi - 40X" when using the investigated ACs.

Such a manifestation of the wear parameters of the CuCrNiZrTi system can be explained as follows. The components of the ACs under study have an ambiguous effect on the initiation and course of wear mechanisms of the surface structure of the CuCrNiZrTi HES, which is represented by five phases: $Cu_{1.5}ZrNi_{3.5}$ - 10%; Cu - 7.8%; $Zr_{0.02}Ni_{0.98}$ - 19.8%; $TiCr_2$ - 29.5%; NiTi - 33%. Also, the distribution of microhardness HV10 at a load of 100 g on an area of S = 0.009 mm^2, which also includes five groups of values 792 ± 13 MPA, was preliminarily determined; 1075 ± 17 MPa; 1374 ± 51 MPa; 939 ± 7 MPa; 2982 ± 63 MPa, Figure 3.

The destruction of both the phases themselves and the interphase bonds is presumably due to a decrease in their strength due to the manifestation of the adsorption effect of the molecules of the lubricant composition in the zones of the contoured contact areas, reinforced by high contact pressures. In this case, less solid phases are destroyed to a greater extent, which forms the parameters of the topography of the friction surface. Since carbon in 40X is all bound, carbon comes out into the composition of the lubricating medium only from CN50, enriching it energetically, which has a greater effect on the softening of the adhesive bonds between the phases of the HES CuCrNiZrTi, leading to a greater loss of sample masses. In this case, there is a lower mechanical stress of the contact on the surface of the KCh50 disk with a greater

wear of the surface of the pad made of CuCrNiZrTi, which is evidenced by the lower total work of friction forces for the two test stages. It would seem that free carbon should reduce friction and thus wear. However, no, free carbon supplementing POLYTRON^{MTC} 10% AC enhances the destructive effect of its action. In general, it becomes clear that the investigated ACs do not cause the effect of decreasing the wear intensity in the investigated range of contact pressures, and a decrease in friction is caused by a decrease in shear resistance in the zones of contact interaction of protrusions and depressions of surface irregularities.



a b

a – a fragment of a transverse thin section: 1 – working surface of the coating; 2 – imprint of the indenter; 3,4 – chromaticity phases; b – fragment of coverage in the measurement area: 1 – indentation print

Figure 3. Metallography of a transverse section of a CuCrNiZrTi WES coating.

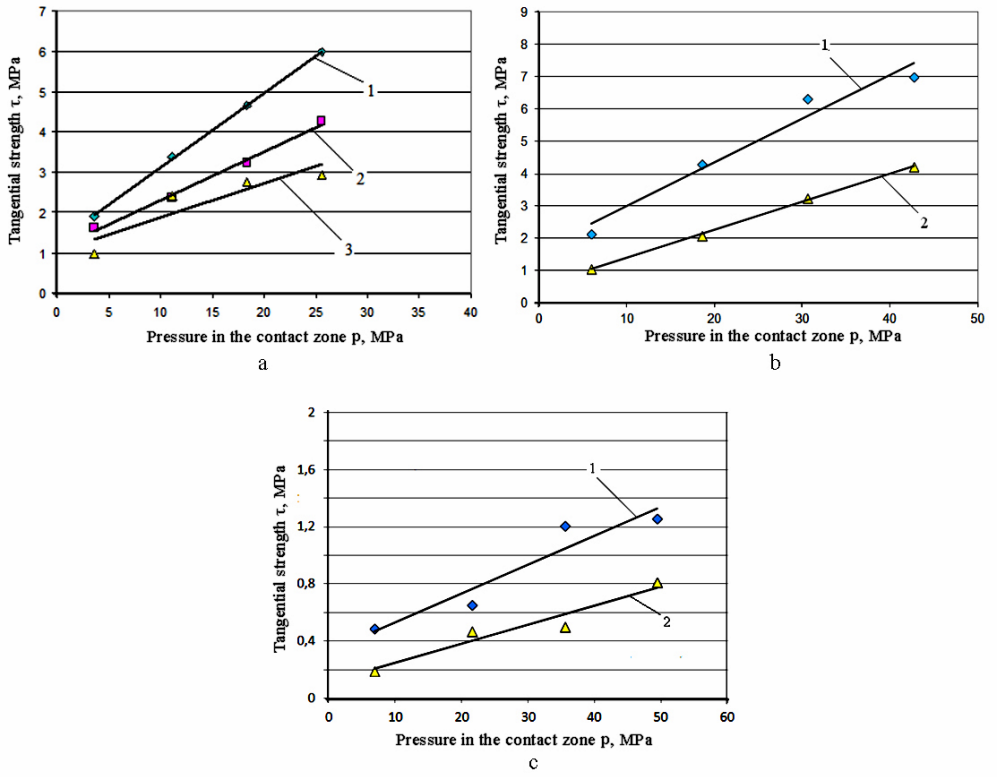
The repeated running-in showed the following results:

– for the "CuCrNiZrTi - KCh50" system, the friction coefficient decreased from 0.16 to 0.12 at a load of 45 N, and was constant 0.1 at a load of 90 N;

– for the "CuCrNiZrTi - 40X" system, the friction coefficient decreased from 0.32 to 0.24 at a load of 45 N, and was constant 0.2 at a load of 90 N.

These results confirmed the similar tendencies towards decreasing friction observed during the first running-in. Based on the results of modeling the shear of surfaces, a graphical approximation of the averaged data of changes in the tangential strength of their frictional bond in a limited area with a multiple distributed contact of microroughnesses in the form of linear dependences was performed, Figure 4, 5. The surface microrelief was previously formed by contact interaction during friction at the second stage of tribotechnical tests. At the same time, according to the parameters of the trend lines in the Excel program, their equations and the reliability of the approximation R^2 were determined, the results are shown in Table 2, 3. The results obtained indicate the following. First, the high values of the reliability of the approximation of the experimental data results confirm the correctness of the graphical expression of the described processes, and indicates once again the binomial nature of the law of molecular friction in the studied systems of materials. Second, the components of the investigated ACs have an ambiguous effect on the parameters of adhesion properties.

So, in both systems of materials there is a tendency to a decrease in the parameter τ_0, in the system "CuCrNiZrTi - 40X" this is more pronounced, table 3. At a shear rate of mm/s, the decrease is 2.5 times under the action of PTFE molecules in the composition of the formed lubricating formations, and 14 times with the action of POLYTRON^{MTC} carbon compounds. With an increase in the shear rate by 2.5 times, the decrease is 6 times under the action of PTFE molecules, and does not manifest itself at all under the action of POLYTRON^{MTC} carbon compounds. Wherein. the increase in the strength of the adhesive bond under the action of PTFE molecules is 3 times greater, and 1.4 times less under the action of POLYTRON^{MTC} carbon compounds with practically the same tendency to decrease with an increase in the shear rate.



a – in the environment of transmission oil 85W90 [5]: 1 – mm/s; 2 – mm/s; 3 – mm/s; b – 85W90 with 10% ABRO AC; c – 85W90 with POLYTRON^{MTC} 10% AC; 1 – mm/s; 2 – mm / s

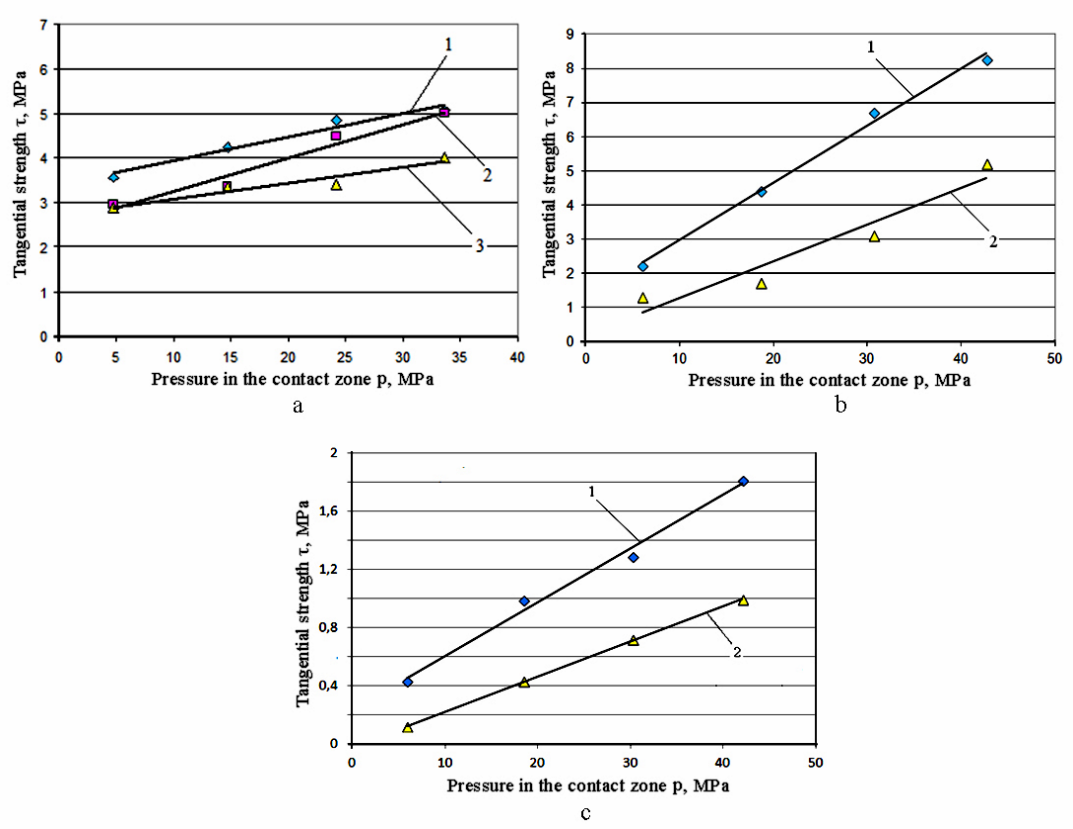
Figure 4. Tangential strength of adhesive bond in contact of materials "CuCrNiZrTi - KCh50".

Table 2. Parameters of approximation of experimental data for the tribological system of materials "CuCrNiZrTi - KCh50".

Parameter	In the environment 85W90, [5]			In the environment 85W90 with AK ABRO$_{10\%}$		In the environment 85W90 with AK POLYTRON$_{10\%}$	
	υ_1	υ_2	υ_3	υ_1	υ_3	υ_1	υ_3
Approximation reliability R^2	0.99	0.99	0.82	0.95	0.99	0.90	0.93
Piezo coefficient β	0.185	0.12	0.085	0.135	0.083	0.02	0.013
Tangential strength τ_0, MPa	1.26	1.09	1.02	1.63	0.53	0.33	0.11

If we assume that the value of the parameter τ0 = 1.12 ± 0.14 MPa in the system of materials "CuCrNiZrTi - KCh50" is relatively unchanged when modeling the shear with the considered rates, then PTFE contributes to its increase by 1.4 times, and the POLYTRON^{MTC} components - to its decrease by 3, 4 times, table 2. At the same time, the tendency of a decrease in the strengthening of the adhesive bond strength with an increase in the shear rate remains. In general, it is obvious that a more significant effect on the decrease in the parameters of adhesion properties is exerted by the POLYTRON^{MTC} 10% AC components, which cause the formation of secondary lubricant formations with denser structures at the interface of adhesion with metal surfaces and reduced resistance to

movement within the formed cohesive bonds between them. This mechanism of action can be explained by the adsorption effect of the molecules of the lubricating compositions, which are concentrated in certain orders on the friction-activated micro-areas of metal surfaces, as well as by their molar mass. The latter will determine the different density of secondary lubricant formations, and their cohesive bond is shear resistance. This is exactly what takes place under the action of PTFE in both systems of materials, in which the values of τ_0 differ within 20%.



a – in the environment of transmission oil 85W90 [5]: 1 – mm/s; 2 – mm/s; 3 – mm/s; b – 85W90 with AC $ABRO_{10\%;}$ c – 85W90 with $POLYTRON^{MTC}$ AC 10%; 1 – mm/s; 2 – mm/s

Figure 5. Tangential strength of adhesive bond in contact of materials "CuCrNiZrTi - 40X".

Table 3. Parameters of approximation of experimental data for the tribological system of materials "CuCrNiZrTi - 40X".

Parameter	In the environment 85W90, [5]			In the environment 85W90 with AK $ABRO_{10\%}$		In the environment 85W90 with AK $POLYTRON_{10\%}$	
	υ_1	υ_2	υ_3	υ_1	υ_3	υ_1	υ_3
Approximation reliability R^2	0.96	0.95	0.93	0.99	0.91	0.98	0.99
Piezo coefficient β	0.053	0.075	0.036	0.166	0.106	0.037	0.024
Tangential strength τ_0, MPa	3.39	2.48	2.71	1.32	0.22	0.24	>0 at p≈2MPa

5. Conclusion.

The results obtained in this work revealed the features of the manifestation of friction and wear of the HEA of the CuCrNiZrTi system during contact interaction with structural materials - alloy steel 40X and cast iron KCh50 with the addition of AC $ABRO_{10\%}$ and $POLYTRON^{MTC}$ 10% in gear oil 85W90, as well as the parameters of adhesion properties when modeling shear on small-sized samples.

It was found that under conditions of drip lubrication, the surfaces of the samples of the studied materials appear to be compatible and are satisfactorily run-in. In this case, the parameters of high-speed and force loading determine the manifestation of boundary lubrication. The CuCrNiZrTi system demonstrated the best antifriction properties during lubrication when interacting with KCh50 cast iron. At the same time, the lowest energy intensity of wear was observed when working with steel 40X.

The character of manifestation of the adhesive properties of the CuCrNiZrTi system in contact with 40Kh steel and KM50 cast iron with a change in shear rates has been established. It was determined that the parameter τ_0 manifests itself in the entire simulated pressure range with a tendency to decrease with an increase in the shear rate, while the parameter β manifests itself ambiguously when the considered ACs are added.

New information on the numerical values of the dynamic coefficient of friction and the parameters of the adhesion properties of the HES of the CuCrNiZrTi system expands the information on alloys of this kind. At the same time, it is recommended to use it in the selection of materials for joint work with it in friction pairs of mechanical engineering objects, as well as in the performance of analytical calculations for the predictive assessment of the effect of the adhesive friction component on the state of the tribological contact of the surfaces of parts, taking into account their loading conditions and operating conditions.

References

[1] Politron Ukraine. Lubricating materials. https://latifundist.com/kompanii/936-politron-ukraina
[2] Today’s Most Technologically Advanced Lubricants. http://www.polytron-lubes.com/
[3] Transmission oil additive Abro GT-409. https://drossel.ua/content/16544-abro-gt-409-prisadka-v-transmissionnoe-maslo-207ml
[4] Eremin E N, Yurov V M and Guchenko S A 2020 *Eurasian Physical Technical Journal* 17(1) 13
[5] Kubich V I, Cherneta O G and Yurov V M 2021 *Proceedings of the International Scientific and Practical Conference* (Karaganda: KTU Publishing House) p 1448
[6] Kubich V I, Cherneta O G and Yurov V M 2019 *Eurasian Physical Technical Journal* 16(2) 78
[7] Boguslaev V O, Greshta V L, Kubich V I, Tkach D V, …Fasol Ye. O, Lekhovitser V O Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2020, (6) p 41