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ADHESIVE WEAR OF TOOL STEELS WITH FUNCTIONAL COATINGS

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Abstract: When processing metals by cutting, there are several materials prone to adhesion. This phenomenon leads to a change in the geometry of the cutter, cutting force and surface quality, technological dimensions of the detail. In this work, experimental studies of the processes of dry friction of tool steels with coatings were carried out to evaluate the effectiveness of reducing the process of adhesive bonding of materials. It was established that the nature of formation, destruction and size of adhesive areas depends on the chemical composition of the material and modes of friction. High-strength chromium-manganese steels are most prone to adhesion and microburring. It is shown that increasing the cutting speed cannot always be used to prevent adhesion. Along with this, adhesion reduction can be achieved using single-layer and multi-layer coatings with a defect-free structure and moderate friction modes. It has been experimentally proven that electrolytic single-layer nickel and chromium coatings contribute to the formation of growth on the studied materials and this phenomenon does not depend on friction modes. At the same time, electrochemical coatings, which have a defect-free structure, are almost not amenable to adhesion.

Keywords: adhesion, friction, wear, tool steels, chemical and electrolytic coatings

1. INTRODUCTION AND LITERATURE REVIEW

Under certain conditions of friction in air, in a vacuum and in environments that do not contain enough oxygen for the formation of secondary structures with its participation, wear of the contact surfaces is observed, which is associated with their direct destruction due to the development of the adhesion process. From the practice of cutting metals, it is known that there are several materials prone to growth. This phenomenon is undesirable, because in the process of metal cutting, it leads to a change in the geometry of the cutter, cutting forces and surface quality, and the final dimensions of the part. In closed systems (shaft-sleeve, piston-sleeve, etc.), this phenomenon causes jamming. In the practice of metal cutting, this phenomenon is overcome by changing the cutting modes, and in mechanical engineering, as a rule, they try not to use such materials. But such an approach is irrational, since materials that are likely to be prone to growth can exhibit quite attractive mechanical, physical, and tribological properties.

Therefore, in order to study the nature of this phenomenon, it became necessary to conduct a series of studies to identify materials that are prone to growth, study the nature of this phenomenon, and recommend prevention of growth. To identify the propensity of materials to build up, it is necessary to conduct a series of complex experimental studies.

Among the different types and mechanisms of wear, adhesive wear is very significant. Adhesion leads to an increase in the coefficient of friction, as well to the failure damage of the contacting surfaces. In extreme cases, adhesion can lead to complete cessation of sliding. Adhesive wear is one of the main causes of failure of most metal sliding contacts.

This article [1] discusses the mechanism of adhesive wear, including cuts, scratches, gouges, and gouges. Data on the results of research and tests in classic laboratory and standardized tests for the assessment of adhesive wear are presented. The article [2] discusses the hypothesis regarding the adhesion mechanism when cutting metal and its mechanical dynamics on the example of steel,

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34CrNiMo 6 coatings on a cutting tool. It is shown that the adhesive mechanism is a transient vibration as a cluster of waves with a stochastic duration, including a feedback system limited by plastic deformation. The study [3] presents the analysis of metrological and tribological aspects of machined surfaces obtained after turning using various methods of cooling and lubrication. The surface relief is measured, which is responsible for the tribological properties of the connected parts under the conditions of adhesive wear. In paper [4], to distinguish between adhesive and abrasive wear, a new approach is presented for testing metallic materials with different opposing parts and different sliding speeds in a wet slurry test. S355 steel and silicon carbide ceramics are used as counterbodies to differentiate the main wear mechanisms. The results show that it is possible to separate the wear behavior during tests under different conditions. In article [5], by programmatically changing the process parameters related to quenching, tempering and nitriding of vanadium steels, the aim of the study was to determine which of the parameters have a significant effect on its adhesive wear resistance. A significant influence of tempering temperature, number of temperings and thermochemical nitriding was revealed. The purpose of research [6] is to study the engineering application of chromium oxide scale on ferritic stainless steel. The destruction mechanisms of the oxide scale were investigated, which showed that the oxide scale adheres well to the steel substrate and is ductile. Pin-on-disk tribological tests show that chromium oxide scale on ferritic stainless steel causes adhesive wear of a high-cutting steel pin but increases the wear resistance of a ferritic stainless steel disk. In paper [7], the wear behavior of TiAlN coatings during turning of stainless steel 316L at low cutting speeds was investigated using scanning electron microscopy. It is shown that for low cutting speeds, the coatings are destroyed due to the adhesive wear mechanism. The difference in wear behavior is interpreted as a difference in the fracture toughness of the coatings. Study [8] investigates the effectiveness of PVD coating materials in steel sheet forming applications. The amount of adhered material was determined using 3D topographic analysis and the volume of accumulation was characterized, as well as the structure of the coating and growth in view of the diffusion coefficient of the elements. Research [9] is aimed at investigating the influence of the environment on friction and wear behavior of low-alloy wear-resistant steels and providing practical recommendations for their use. It was found that under dry friction conditions, the wear mechanism of NM500 is predominantly adhesive, fatigue and oxidative. In the case of wear testing in deionized water, the researchers characterized the dominant wear mechanism as adhesive wear combined with fatigue wear and abrasive wear.

2. RESEARCH METHODOLOGY

The research was carried out on a modernized universal friction machine UMT 2168 with data fixation and recording (linear wear, average temperature in the friction zone and friction moment) in automatic mode without stopping the friction process [10]. The samples were used with a spherical friction surface; the counterbody is made of AISI G51320 HRC 55 steel. Experiments were performed with a constant force of pressing the sample to the counterbody (from 20 to 60 N) in the range of speeds from 0.6 to 1.5 m/s. Since the shape of the surface of the sample is hemispherical with a radius of R=2.5 mm, according to Hertz's formula, high (1300-2000 MPa) contact stresses occur in the contact zone at the initial stage of friction.

The dependence of the size of the contact area on the stress is shown in Fig. 1.

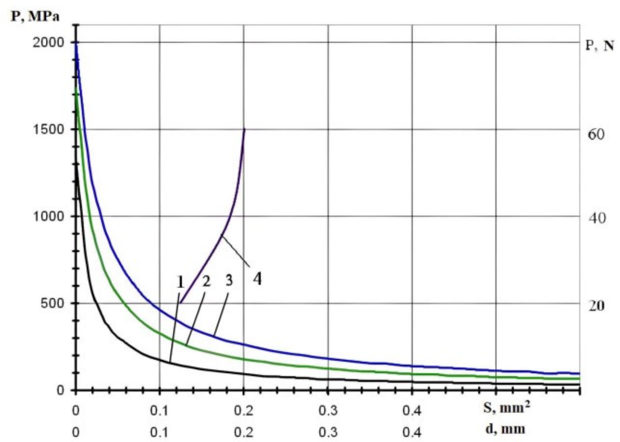

Figure 1. Dependence of the diameter of the contact spot on stress at different pressing forces (P) (1 – 20 N, 2 – 40 N, 3 – 60 N) of contacting bodies. Dependence of the size of the initial area ofthe contact spot (4) on the pressing force

Friction modes are given in table. 1, which were chosen from conditions close to the parameters that occur when cutting metals (in particular, stress) and from the requirements of mathematical planning.

Table 1. The modes of friction

Mode No	Friction parameters		
	Pressing force, N	Initial stress, MPa	Cutting speed, m/min
1	60	2000	80
2	20	1300	80
3	60	2000	40
4	20	1300	40

Tool alloy steels (AISI 9262, AISI T31507) and high-speed AISI M3 in the heat-hardened state were used as the object of the study, the mechanical characteristics of which are given in the table. 2.

Table 2. Mechanical characteristics of tool steels

Material	HRC	Endurance limit σB, MPa
AISI 9262	55	1760
AISI T31507	52	1850
AISI M3	60	1300

To increase the tribological parameters and prevent the formation of growth, chromium and nickel coatings were used, as well as composite coatings based on Ni and dispersed particles of Cu, Al2O3 (the thickness of the coating was 10...15 microns). At the same time, the coating technology was used [11].

3. RESEARCH RESULTS AND DISCUSSION

After conducting a number of test experiments on different steels AISI M3, AISI 9262, AISI T31507 and under different test conditions, it was found that the tendency of AISI T31507 and AISI 9262 steels to form growth, which manifested itself in an increase in the initial linear dimensions of the sample at the first stages of the experiment. Moreover, this phenomenon was observed only at the initial stages, and therefore our calculations will reflect the characteristics of friction and wear of the studied materials at the initial stage, that is, during a fairly short period of time of the study (for 200...300 m of the tested path). We will not provide data on changes in tribological parameters (moment of friction, temperature in the contact zone, intensity of wear) in this message.

As shown by the results (Fig. 2), at the first stage of research on AISI T31507 steel, at friction modes 2, 3, 4, the first wear zone is distinguished, where an increase in the linear size of the sample by 0.02-0.05 mm is observed when passing 25 m of the friction path and its gradual reduction to the initial dimensions at 150 m of the traveled friction section, intensive wear of the sample occurs in mode 1.

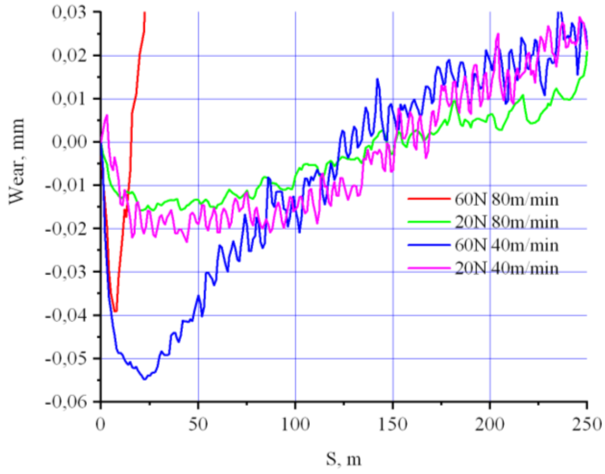

Figure 2. Effect of friction modes on linear wear of AISI T31507 steel

The increase in the linear size of the growth is accompanied by a rapid increase in temperature and friction moment and depends on the modes of friction - the amount of contact stress and the speed of sliding (larger growth sizes corresponded to higher contact stress). Moreover, only at the maximum contact stress and the maximum sliding speed (Fig. 2, curve 1) is there a chipping of the growth and a sharp change in the linear size of the sample under study, for all other modes (Fig. 2, curves 2, 3, 4.) - smooth monotonic reduction of growth. This is clearly shown on the graphs when the scale is increased along the ordinate axis (traveled path). By reducing the discreteness of the measurement of the amount of wear to 0.5 s, the nature of wear of the material is clearly marked on the wear curves and, as can be seen from fig. 2, the wear process takes place, in our opinion, by periodic seizure of contacting micro-areas, destruction of the bridge, removal of wear products from the contact zone. This is evidenced by the dust-like wear curves. To verify such assumptions, it is necessary to carry out fine studies of the friction surface, which will allow us to judge the mechanism of wear.

It is known that all materials can be divided into materials that are not prone to or prone to growth. Technological methods of applying wear-resistant coatings were used to prevent growth.

After testing the electrolytic nickel coating of Fig. 3 for friction and wear, it was established that under the same regime growth occurs again, and in general, the general pattern of wear has not changed, and in some cases the amount of wear has increased. The growth disappears after 100 m of the traveled path, while on the samples without coating the growth stops after 150 m of the traveled path. The wear process is carried out in the same way as the sample without coating.

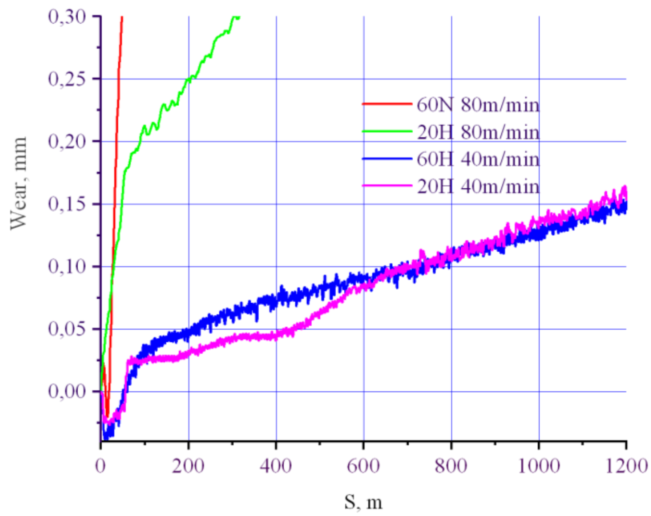

Figure 3. Linear wear of AISI T31507 nickel-plated steel

Electrolytic coatings have a significant number of defects in the form of microcracks. The voltage in the contact zone exceeds the yield point of electrolytic nickel. Thus, it can be assumed that the presence of such defects contributes to the seizure of nickel electrolytic coatings. In addition, it was established that such chemical elements as nickel, chromium, copper, aluminum, under certain test conditions, create conditions for the seizure of contacting bodies, and, in our opinion, at high contact stresses and sliding speeds, in conditions close to the conditions of chip formation during the processing of metals by cutting, which is accompanied by the continuous formation of new juvenile surfaces, conditions are created for growth formation, it should be noted that when cutting metals, the stresses are about 600 MPa. To test the proposed hypotheses, a study of the behavior of a two-layer coating (copper-nickel) under conditions of friction and wear was conducted. Analysis of the above studies of the tribo-behavior of AISI T31507 steel with a two-layer coating (sublayer of copper (Cu) and nickel (Ni)), which is presented in Fig. 4, indicates that the conditions for growth formation are created on the surface of this coating. A growth was formed, but the linear size of the growth was insignificant, the maximum size was equal to 0.035 mm. Moreover, this value was obtained according to test mode 4. In other research modes, growth formation was not observed. In addition, after wear to a certain limit, there is a sharp decrease in the moment of friction, which, in our opinion, is a manifestation of the effect of copper on the change in the coefficient of friction.

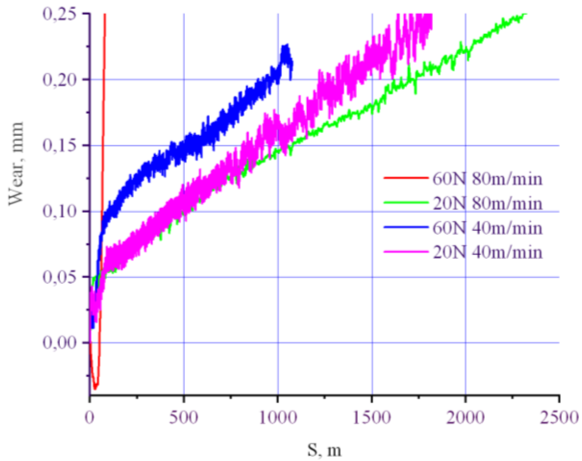

Figure 4. Linear wear of steel AISI T31507 with two-layer copper-nickel coating

After a relatively successful attempt to solve the problem of build-up formation by applying a two-layer copper-nickel coating, the modes of build-up formation of a combined coating based on nickel (Ni) with particles of corundum (Al2O3) were determined, fig. 5, which was applied to the surface of AISI T31507 steel according to the technology proposed by the authors [11].

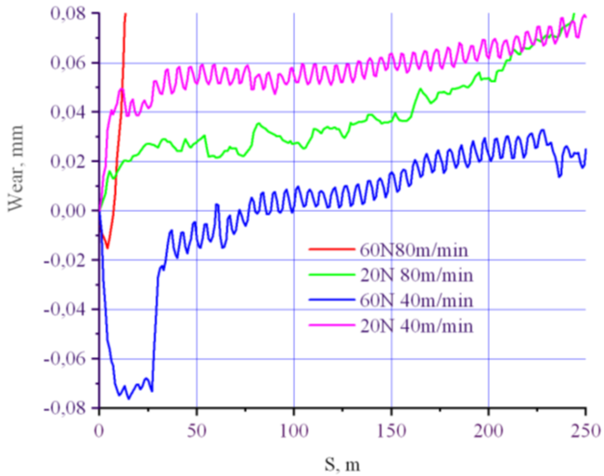

Figure 5. Linear wear of T31507 steel with combined Al2O3-Ni coating

It was established that the growth process does not occur at all during experimental studies in modes 2, 4, but at the same time, an increase in the moment of friction, temperature, and more intense wear compared to the original material is noted.

Since nickel coatings, complex coatings based on nickel, copper and corundum on AISI T31507 steel are insufficiently effective against scale formation, the aim was to test the influence of chromium on the process of scale formation. For this, electrochemical and chemical chromium coatings were used, differing among themselves in the defectiveness of the surface layer. When a coating was applied to the base by chemical deposition of chromium and during the further study of tribological characteristics on a friction machine, no build-up was recorded (Fig. 7) in any mode, and the friction moment and average temperature in the friction zone also decreased.

For comparison, a chrome coating was applied using the electrolytic method. During tribological studies, intensive growth was established on friction modes 1, 2, 3; the intensity of growth formation depended on the modes of friction (Fig. 6).

From our observations and as a result of the analysis, it was established that the greater the force of clamping the sample, the greater the linear size of the growth.

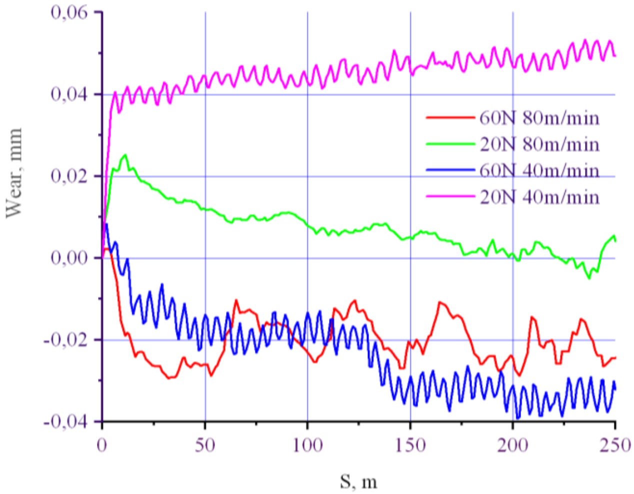

Figure 6. Linear wear of AISI T31507 steel with electrochemical chromium coating

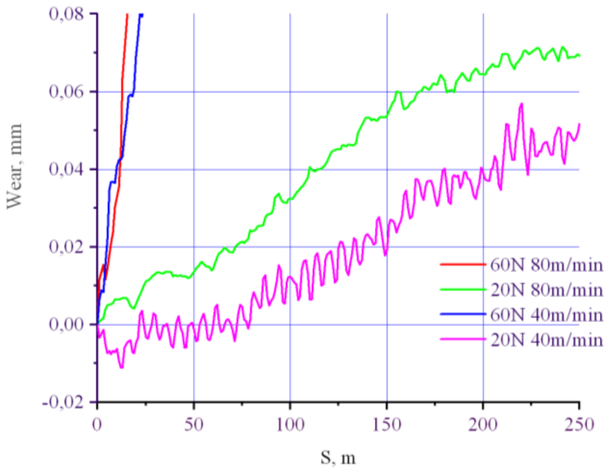

Figure 7. Linear wear of steel AISI T31507 with chemical chromium coating

Since the active formation of growth with chromium coating applied by the electrolytic method and its almost absence on samples with chemically deposited chromium was detected, we decided to investigate its behavior on siliceous spring steels with different structural states of the matrix (steel AISI 9262, tempering temperature 200, 300, 400 ºC), high-speed steel AISI M3.

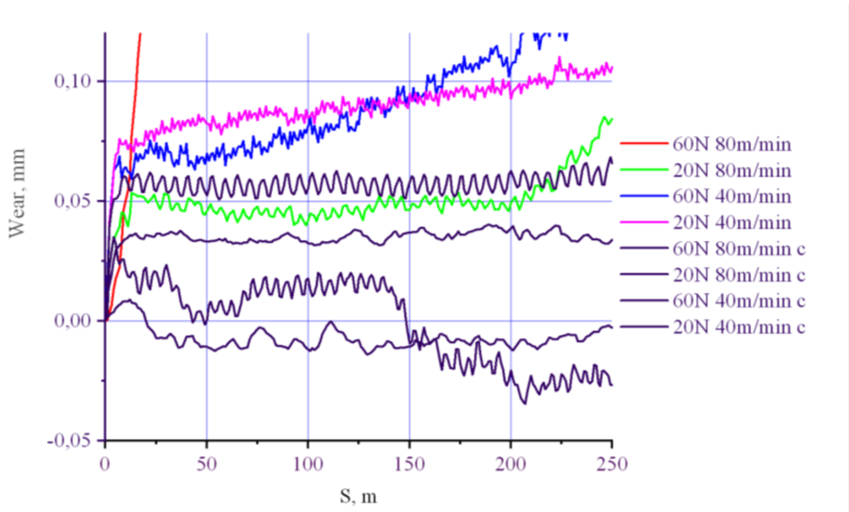

Figure 8. Linear wear of steel AISI9262, tempering temperature 200 ºC.

During experimental studies, it was established that on the surface of a sample of AISI 9262 steel with a tempering temperature of 200 ºC and a chrome electrolytic coating, growth was not formed only on the fourth mode of friction (Fig. 8) curve 4. It should be noted that on friction modes 2, 4 wear curves 6, 8 was 0.05 mm per 2,000 m of travel, while, using a clean sample, the wear was already 0.4 mm after 200 m of travel.

Chromium electrolytic coating on AISI 9262 steel with a tempering temperature of up to 300 ºC (martensite structure of tempering) behaved in a completely different way - at the same time, growth formation was observed in all modes of friction; moments and temperature jumps, which are interrelated, but with intense friction modes, the wear line fluctuates in the range of 5...6 µm, at 2000 m of the traveled path, while the wear of the uncoated sample when reaching 200 m was 0.2 mm (Fig. 9, mode 3, curve 3).

When using AISI 9262 steel with a tempering troostite structure (tempering temperature 400 ºC) for electrolytic chromium coating, growth formation is observed in all modes of friction, but wear decreased by 3-5 times, depending on the mode of friction when using this coating (Fig. 10).

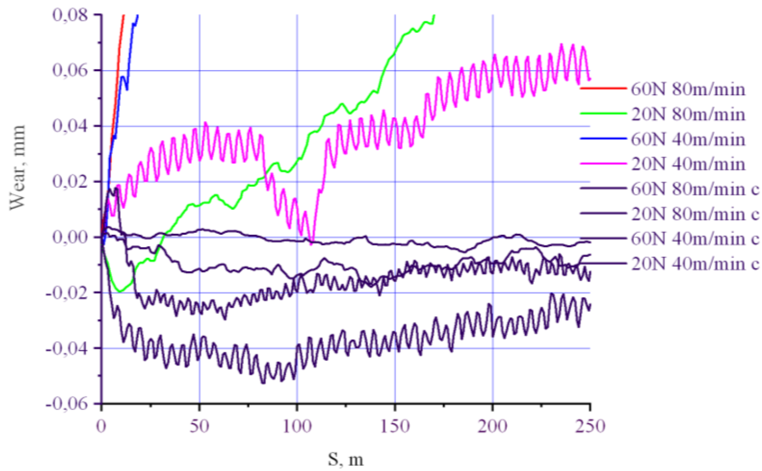

Figure 9. Linear wear of steel AISI9262, tempering temperature 300 ºC, modes 1-4 material without coating; modes 1-4 with chrome electrolytic coating

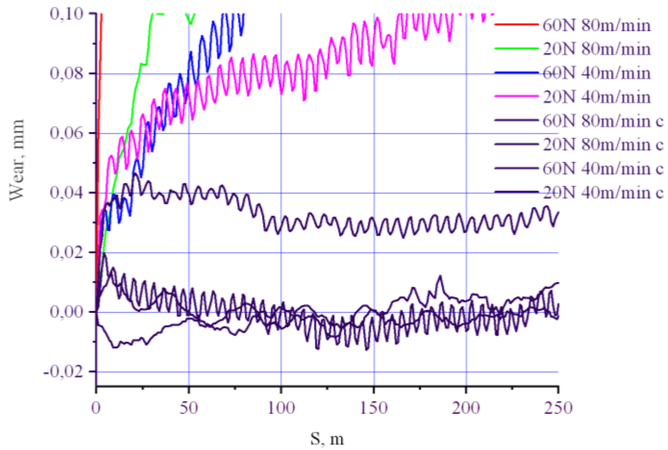

Figure 10. Linear wear of steel AISI9262, tempering temperature 400 ^{0}C, modes 1-4 material without coating; modes 1-4 with chrome electrolytic coating

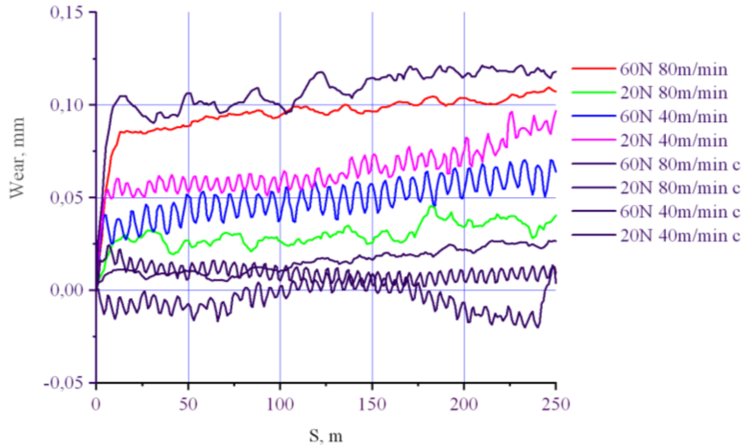

Figure 11. Linear wear of M3 steel, wear lines 1, 2, 3, 4 - material without coating, 5, 6, 7, 8 - with chrome electrolytic coating

Research on the wear resistance of AISI M3 steel (Fig. 11) showed that on the regimes (1-4 wear curves 5 - 8) growth formation is observed, but the wear of AISI M3 steel decreased by 2...3 times.

3. CONCLUSIONS

The technique of continuous, automatic recording of tribological characteristics allows us to detect not only the tendency of materials to form adhesive growth, but also the microseizure of surfaces during the tests.

The nature of formation, destruction, and adhesive growth size of materials prone to growth depends on the chemical composition of the material and friction modes. High-strength chromium-manganese steels are most prone to growth and microseizures.

To prevent adhesion, it is not always possible to use the well-known recommendation - to increase the speed, but to achieve it by using single-layer and multi-layer coatings with a defect-free structure and moderate modes of friction.

It was found that electrolytic single-layer nickel and chromium coatings contribute to the formation of adhesive growth on the studied materials and this phenomenon does not depend on the modes of friction, while the same chemical coatings, which have an almost defect-free structure, are almost not prone to adhesive growth formation.

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