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Experimental Research of Back Effect for Mechano-Sliding Fatigue of the 0.45% Carbon Steel–Siluminum Active System*

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Экспериментальные исследования обратного эффекта при трибоусталостных испытаниях стали 45 с использованием силуминовой активной трибосистемы

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Экспериментально исследовано накопление повреждений в зоне трения скольжения металл–металл при трибоусталостных испытаниях с использованием активной трибосистемы. Описана экспериментальная методика. Получены экспериментальные значения характеристик сопротивления металла трибоусталости в исследуемом узле трения. Проанализированы полученные результаты и приведены новые данные по обратному эффекту при трибоусталостных испытаниях стали 45 с использованием силуминовой активной трибосистемы.

Ключевые слова: трибоусталость, трение скольжения, обратный эффект.

Introduction. The back effect is defined as change of a friction and wear process characteristics due to repeated stresses effect [1]. The experiment including two stages has been planned:

sliding friction (sliding fatigue) test;

wear-fatigue (mechano-sliding fatigue) test.

At the first stage of tests it is necessary to find the regularities of wear processes for the next it comparison with the test results on the second stage.

1. **Methods of Research**.

1.1. ***Sliding Fatigue Tests***. The model of an active system for sliding fatigue tests is shown in Fig. 1. The specimen *1* made of a 0.45% carbon steel with a test portion diameter of 10 mm is cantilever fixed in a spindle *2* of a testing machine UKI-6000-2 and rotate with frequency of 3000 $\min^{-1}$. The counterspecimen *3* with a width of 4 mm, made of siluminum is pressed to dangerous cross section of the specimen *1* with the force F_N which magnitude is supported a stationary value during the tests of each friction pair the specimen/counterspecimen. The lubricant – universal all-weather engine oil SuperLuxoil SAE 15W-40 is brought in a friction region by the dropwise method. The measuring of magnitude of the

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cumulative linear wear i of friction pair with the precision of 2 μm in the local points *1–8* uniformly proportioned on ambit of dangerous cross section of the specimen is made periodically (Fig. 1b).

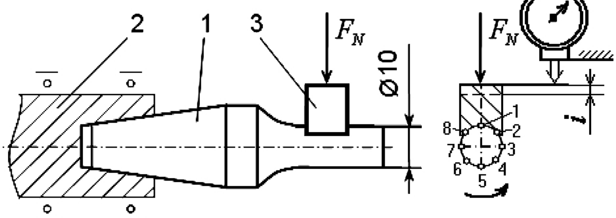

Fig. 1. Scheme of sliding fatigue tests (a) and scheme of the wear i measuring (b).

The cumulative wear of a friction pair specimen/counterspecimen i_f^{lim} = 100 μm has been accepted as the limiting state. We used 10^7 cycles as the base of tests according to the state standard of Belarus STB 1448-2004 [2]. Let's consider some results of tests of the examined frictional pair at a contact loading $F_N = 280$ N as example. The circle diagram of wear i, μm, for each of 8 points uniformly proportioned on ambit of dangerous cross section of the specimen is shown in Fig. 2. Values i in these local points at the given number of cycles N of loading we connected by direct lines. It is visible, that wear process occurs nonuniformly on ambit of the specimen, and the greatest irregularity is observed at the initial stage (diagram *a* in Fig. 2). Irregularity decreases with the growth of number of cycles. The greatest wear occurred at $N = 6.5 \cdot 10^6$ cycles for the local points *5* and *6* (101 and 103 μm).

Irregularity of the wear process is caused primarily by difference of physics-and-mechanical properties of the surface blanket of metal.

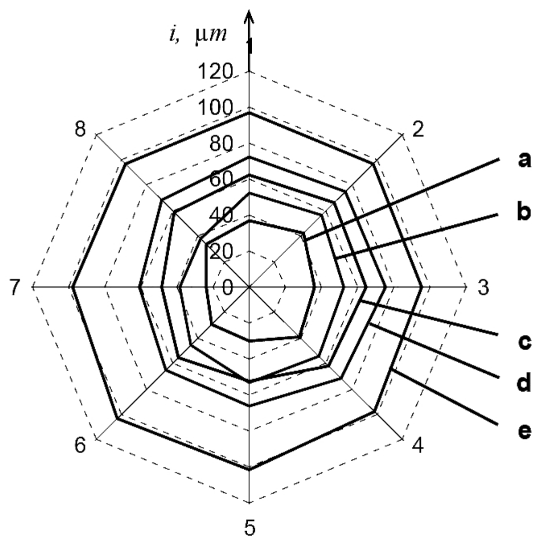

Fig. 2. The circle diagram of wear at contact load $F_N = 280$ N for number of cycles: (a) $0.2 \cdot 10^6$; (b) $0.51 \cdot 10^6$; (c) $1.0 \cdot 10^6$; (d) $2.2 \cdot 10^6$; (e) $6.5 \cdot 10^6$.

The kinetics of wear for the local points *1*, *2*, *5*, and *6* is presented in Fig. 3. It is fixed, that the experimental points are well featured by degree dependence of a type $i = aN^b + c$. Values of coefficients a, b, and c and a coefficient of correlation k are determined with the help of the MathCAD system and reduced in Table 1.

T a b l e 1
The Characteristics of the Equations of Regression of the Wear for the Local Points

Coefficients	Number of point							
	1	2	3	4	5	6	7	8
a	1.995	2.945	2.030	1.851	0.522	0.444	0.218	0.985
b	0.251	0.228	0.252	0.257	0.337	0.348	0.390	0.295
c	−4.307	−5.107	−5.150	−3.882	−2.468	−1.695	−2.231	−3.328
k	0.986	0.985	0.986	0.986	0.978	0.976	0.969	0.983

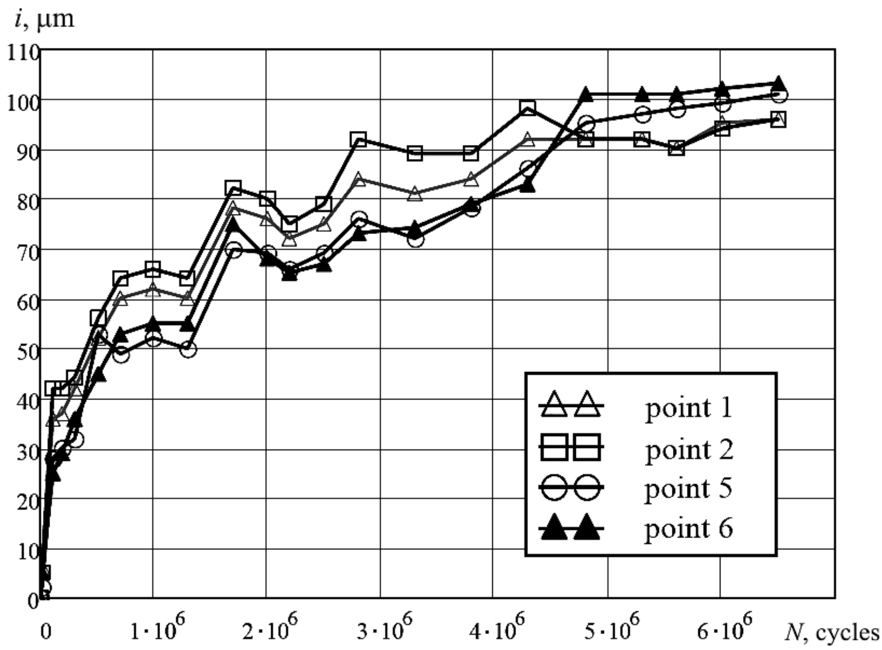

Fig. 3. The kinetic curves of wear in local points *1*, *2*, *5*, and *6* at $F_N = 280$ N.

Figure 3 visually displays the most intensive wear process occurs at the given contact load during the first 700–800 thousand cycles of loading. This period is term as a running-in stage. It is caused by cutting of microprotuberances of a surface. As a result the area of contact of friction surfaces and the linear wear intensity decrease (curves in Fig. 3 after 800 thousand cycles of a loading become more gently sloping).

It is fixed that regularities of wear process are saved at other values of a contact load, and its magnitude makes major impact on wear intensity.

1.2. ***Mechano-Sliding Fatigue Tests***. The model of an active system for the mechano-sliding fatigue tests is shown in Fig. 4. The bending load Q is affixed to free end of specimen *1*. It provides the amplitude of the cyclic bending stresses σ_a for a dangerous section of specimen. Other test specifications remained invariable.

The magnitude σ_a supported on a fixed level ($\sigma_a = 160$ MPa) for the first series of wear-fatigue tests.

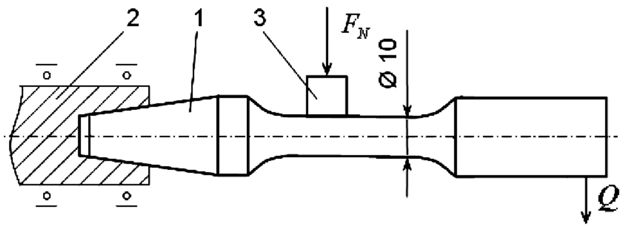

Fig. 4. Scheme of the mechano-sliding fatigue tests.

Tests result at contact load $F_N = 300$ N and at amplitude of the cyclic stresses $\sigma_a = 160$ MPa is displayed in the circle diagram of wear (Fig. 5) and in the kinetic curves of wear in local points (Fig. 6). Wear process occurs nonuniformly on ambit of the specimen as well as in other cases.

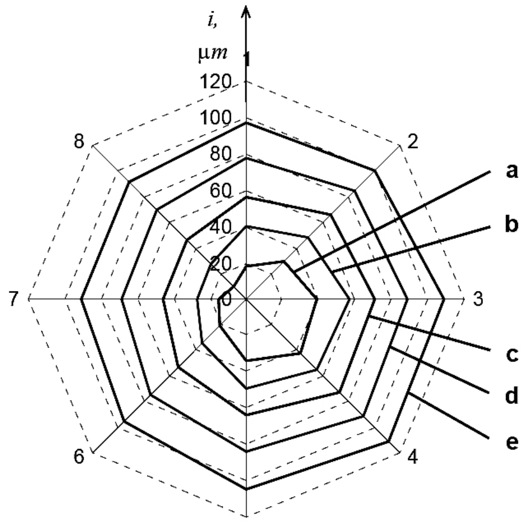

Fig. 5. The circle diagrams of wear at $F_N = 300$ N and $\sigma_a = 160$ for number of cycles: (a) $0.4 \cdot 10^5$; (b) $1.3 \cdot 10^5$; (c) $2.8 \cdot 10^5$; (d) $5.2 \cdot 10^5$; (e) $7.7 \cdot 10^5$.

From the Fig. 6 it is visible, that the active system has the greatest wear intensity during the first 80–90 thousand of cycles. The wear-fatigue tests for an active system has been realized at $\sigma_a = 256$ MPa (next series) also. Character of irregularity and wear intensity is saved.

2. **Results of Experiments and Discussion**. Comparison of the some tests results is introduced in Fig. 7. Wear intensity decreases at $F_N = 410$ N if the amplitude of the cyclic bending stresses for a specimen critical section increases.

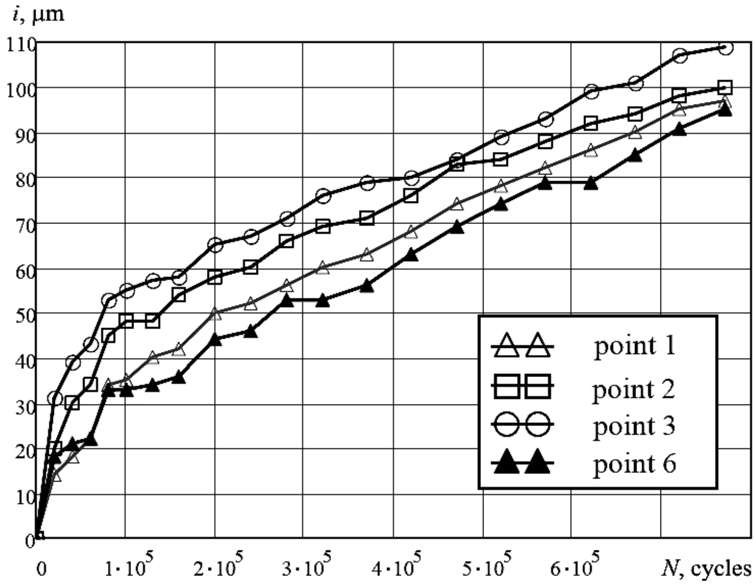

Fig. 6. The kinetic curves of wear in local points *1*, *2*, *3*, and *6* at $F_N = 300$ N and $\sigma_a = 160$ MPa.

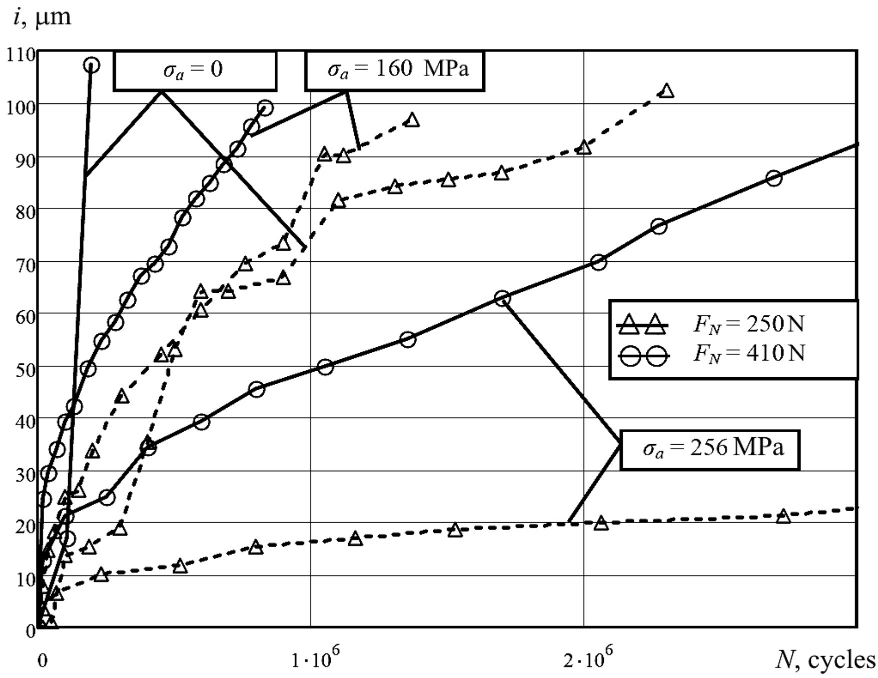

Fig. 7. The kinetic curves of wear (mean values).

However, at constant contact load $F_N = 250$ N wear intensity increases when the amplitude of the cyclic bending stresses σ_a for a specimen critical section increases from 0 to 160 MPa, and wear intensity decreases sharply if the amplitude of the cyclic stresses σ_a grows to 256 MPa.

The 16 active systems are tested at various contact loads over the range from 140 to 450 N in total.

The sliding fatigue curve (curve *1* in Fig. 8) is built in half-logarithmic coordinates contact load F_N – long time N defined as the logarithm of number of cycles before reaching of wear magnitude i_f^{lim} on tests results. The similar curves built by sliding fatigue tests results of the other materials are given in [1, 2].

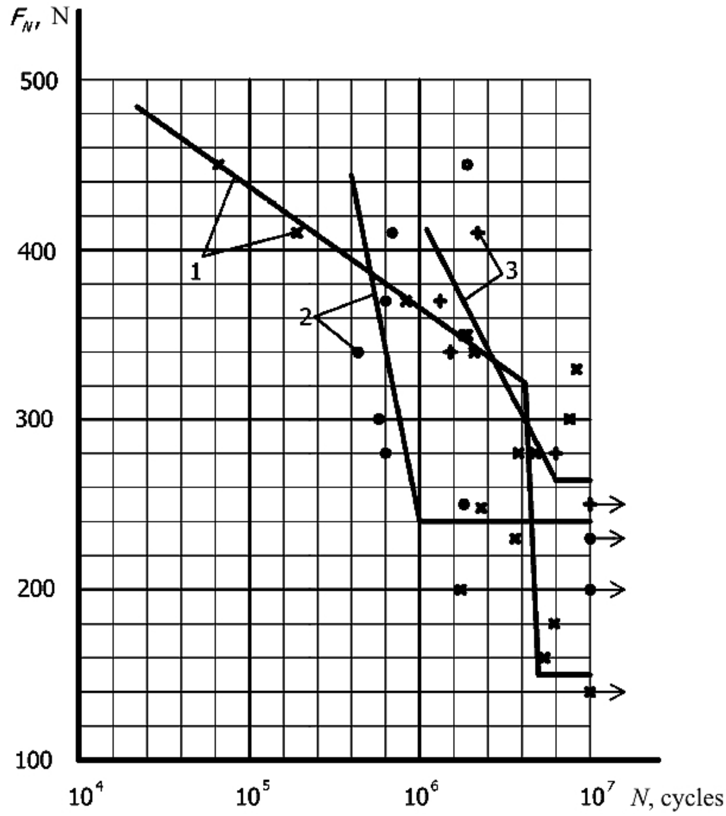

Fig. 8. The experimental sliding (*1*) and mechano-sliding (*2*, *3*) fatigue curves for the 0.45% carbon steel–siluminum pairs of friction and active systems.

It has appeared that the curve *1* has three characteristic sections: (I) the field of quasistatic fracture (approximately to $N = 4.2 \cdot 10^6$ cycles at region of contact loads $F_N = 320$–450 N), (II) and (III) the fields of low-cyclic and multicyclic fracture ($F_N = 150$–320 N), respectively. The boundary between fields II and III isn't determined, therefore the experimental points are approximated by one line. It is visible from Fig. 8 the sliding fatigue curve *1* has two branches: left with the big inclination and right which is situated almost vertically. The contact load corresponding to a sliding fatigue limit for the investigated pair of a friction is $F_f = 150$ N.

Mechano-sliding fatigue curves (curves *2* and *3* in Fig. 8) are built analogously.

The values of sliding and mechano-sliding fatigue characteristics for the 0,45% carbon steel–siluminum active systems are introduced in Table 2. They correspond to [2].

As we can see from Fig. 8 and Table 2 the mechano-sliding fatigue curve *2* is built on tests results at contact loads over the range from 200 to 450 N and at the

T a b l e 2

The Sliding and Mechano-Sliding Fatigue Characteristics for the 0.45% Carbon Steel–Siluminum Active Systems

Characteristics	Characteristic's value		
	sliding fatigue curve	mechano-sliding fatigue curve	
	$N(F_N)$	$N(F_N, \sigma_a = 160 \text{ MPa})$	$N(F_N, \sigma_a = 256 \text{ MPa})$
Fatigue limit, N	$F_f = 150$	$F_{f\sigma} = 240$	$F_{f\sigma} = 260$
Turning point of fatigue curve, cycles	$N_{FG} = 5.0 \cdot 10^6$	$N_{F\sigma G} = 1.0 \cdot 10^6$	$N_{F\sigma G} = 6.3 \cdot 10^6$
Fatigue curve exponent	$m_F = 0.05$	$m_{F\sigma} = 0.19$	$m_{F\sigma} = 0.51$

amplitude of the cyclic bending stresses for a critical section of specimen 160 MPa, the mechano-sliding fatigue curve *3* is built on tests results at contact loads at $F_N = 250$–410 N and at the amplitude of the cyclic stresses $\sigma_a = 256$ MPa.

The contact load corresponding to a mechano-sliding fatigue limit for the examined active system is compounded $F_{f\sigma} = 240$ N (at $\sigma_a = 160$ MPa) and $F_{f\sigma} = 260$ N (at $\sigma_a = 256$ MPa) that is accordingly in 1.6 and 1.7 times exceeds value of the contact load corresponding to a sliding fatigue limit $F_f = 150$ N.

The field of quasistatic fracture is detected only on a sliding fatigue curve *1* (Fig. 8). Probably this field for curves *2* and *3* is located above the peak value of a contact load ($F_N = 450$ N) accepted for these tests.

The increasing of fatigue curve exponents m_F and $m_{F\sigma}$ in the fields of low-cyclic and multicyclic fracture with increasing of the amplitude of the cyclic bending stresses σ_a is observed.

Thus, new regularities of a back effect for mechano-sliding fatigue of the 0.45% carbon steel–siluminum active systems are found.

Р е з ю м е

Експериментально досліджено накопичення пошкоджень у зоні тертя ковзання метал–метал при трибовтомних випробуваннях із використанням активної трибосистеми. Описано експериментальну методику. Отримано експериментальні значення характеристик опору металу трибовтомі в досліджуваному вузлі тертя. Проаналізовано отримані результати та приведено нові дані щодо зворотного ефекту при трибовтомних випробуваннях сталі 45 з використанням силумінової активної трибосистеми.

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