UDC 621.893

Increase of Mining and Smelting Equipment Life on the Way of Tribological Barrier Overcoming

R. P. Didyk[1], P. B. Aratskiy[2]

[1]*National Mining University*
19 Karls Marks Ave., Dnipropetrovsk, 49027, Ukraine
[2]*JSC "ROSTEKHremont"*

Serpentine decomposition products that form a protective metal-ceramic layer on the metal surface have been identified for the first time based on the fundamental structural investigations. The results of commercial tests confirming high efficiency of using natural minerals as modificators of machine element surfaces are presented.

Keywords: GEOMODIFICATOR, SERPENTINE, MECHANICAL ACTIVATION OF SURFACE, METAL-CERAMIC LAYER, FRICTION

Introduction

The increase of service life of basic kinds of mining machinery and equipment, reduction in metal consumption and quantity of workers occupied in repair works, increase of productivity and mining equipment safety are closely related to solving tribological problems including that of friction, wear, lubrication and new technologies of processing and modification of machine detail working surfaces. High workloads, extreme speeds and wide range of temperature changes, aggressive environment determine the new requirements to tribological unit operation and exploitation. Maintenance of proper operation for gear set, rolling and sliding bearings, cam gearing, directional and compacting elements, joints, latching, docking devices requires creation of special self-lubricating materials, coverings, tribological unit modifiers, means of their processing, wear-resistant lubricating coverings with high chemical activity.

Results and Discussion

Mechanochemical effect of tribotechnical powder compositions – friction geomodifiers (FGM) with high adsorptive potential on machine detail working surfaces is a new trend in solving this problem. The friction geomodifiers represent a set of crushed natural materials containing minerals of ultrabasic rocks, occurring on tectonic platforms joints and used by the nature as the materials for triboprocesses [1]. The chemichal composition of serpentine including Ukrainian deposits (Novomoskovskiy region and Priazovye) is given in **Table 1**.

The problem of achievement of FGM high-adsorptive potential, which serves as a measure of mechanoactivation, was solved by crushing the serpentine via vibroimpact method [2]. This crushing method compared to others enabled to obtain the total adsorptive potential 2.5 times higher than that obtained during serpentine crushing by grinding balls in a drum mill (compare: in first case $\Delta\mu_{\Sigma} = 1.52$ kJ/mol, in second case – $\Delta\mu_{\Sigma} = 0.6$).

The result of obtained mechanoactivation effect (**Table 2**) revealed at following stages of technological process of friction geomodifier manufacturing. Fine-dispersed powders (size 2.0-2.5 μm) having been reduced in vibroimpact mills and having passed the mechanoactivation stage, being brought in friction zone with the lubricant, apply structural changes in friction surface, which are able to modify it in profitable way for tribotechnics. Tribotechnical indices of activated serpentine are given in **Table 3**.

Table 1. Geoactivator chemistry of different geological tests, %

Chemical element	Grade of powder				
	NIOD-5, Russia	NIOD-2, Russia	Serpentinite SW, Germany	Geoactivator No. 1 (Novomoskovsk), Ukraine	Geoactivator No. 2 (Priazovye), Ukraine
SiO_2	38.6	36.0	39.05	33.4	44.5
Al_2O_3	1.5	2.4	0.66	2.5	3.2
Fe_2O_3	4.7	4.7	7.4	4.0	6.6
FeO	3.0	11.0	-	2.6	3.3
TiO_2	0.035	0.87	0.016	0.03	0.12
P_2O_5	0.03	0.1	-	>0.1	0.10
MnO	0.07	0.16	0.083	0.04	0.15
CaO	0.09	1.2	0.18	0.15	9.4
MgO	38.2	30.4	38.5	38.0	25.6
Na_2O+K_2O	0.11	0.12	0.0013	>0.1	>0.2
$SO_{3sul.}$	-	0.40	-	-	-
$SO_{3simple}$	0.27	2.47	-	0.025	0.022
nnn	12.3	12.2	13.6	20.0	7.6
Cu	>0.001	0.058	0.0007	>0.001	>0.001
Ni	0.21	0.28	0.225	0.21	0.17
Pb	n/d	n/d	n/d	n/d	n/d
Zn	0.0018	0.007	0.0008	n/d	n/d
Co	0.013	0.015	0.01	0.013	0.01
Cr	0.66	0.18	0.254	0.16	0.40
V	>0.02	>0.02	0.0019	n/d	-
ΣTR_2O_3	0.061	0.080	n/d	n/d	-
Si	18.1	16.8	39.05	15.6	20.8
Al	0.79	1.23	0.66	1.3	1.7
Fe^{3+}	3.3	3.3	-	2.8	4.6
Fe^{2+}	2.3	8.5	-	2.0	7.7
Ti	0.02	0.52	0.016	0.018	0.072
P	0.0130	0.044	-	>0.05	>0.1
Mn	0.054	0.12	0.083	0.03	0.12
Ca	0.64	0.86	0.18	0.11	6.7
Mg	23.0	18.2	38.5	22.8	15.4
K+Na	>0.1	>0.1	0.013	>0.07	>0.1
$SO_{3sul.}$	-	0.16	-	-	-
S_{simple}	0.11	0.99	-	0.01	-

Table 2. Results of crushed serpentine investigation

No.	Mill type	Trunnion	Vibratory	
			horizontal	vertical
1	Crushing time, hr	10	1.5	1.5
2	d_{av}, μm	3.4	2.7	2.4
3	Σn_{10}, %	60	75	79
4	d_{max}, μm	2	32	32
5	$S_{уд}$, cm^2/g	12833	15960	16564
6	$\Delta\mu_{\Sigma}$, kJ/mol	0.6	1.41	1.52

Table 3. Tribotechnical indices of activated serpentine

Sample number	Crushing in drum mill	Crushing in vibroimpact mill
Speed of sample wear, mg/h	0.35	0.22
Friction ratio	0.010	0.0055
Area of contact patch, mm^2	4	4
Limit load before impact line occurrence at ω = 1600 RPM	700	830
Running time after oil draining, min	60	85
Coefficient of wear rate increase	1.37	1.25

Defective metal layer is formed on the friction surfaces during manufacture and further operation of tribological unit. FGM particles, put into friction zone and having abrasive properties, remove this layer. Further, the surface is micro cold worked in the process of friction. At this stage, micrometallurgical processes take place in the points of physical contact. The mechanism of conversion zone forming is connected with diffusion processes into surface material layers, structure formation as a metal-ceramic layer featured by high wear-resistant characteristics and consisting of initial tribological unit material and fine-dispersed natural mineral material (**Figure 1**). Al and Fe included in the powder composition are catalysts of pyrolytic carbon formation along the grain boundaries to undersurface layer. And the main composition of FGM modifies the boundary film with a high degree of available bonds that attach “lost” material from the disperse environment.

Herein FGM diffusion into more solid surface is slower which leads to complete leveling of microhardness of contacting details surface layers.

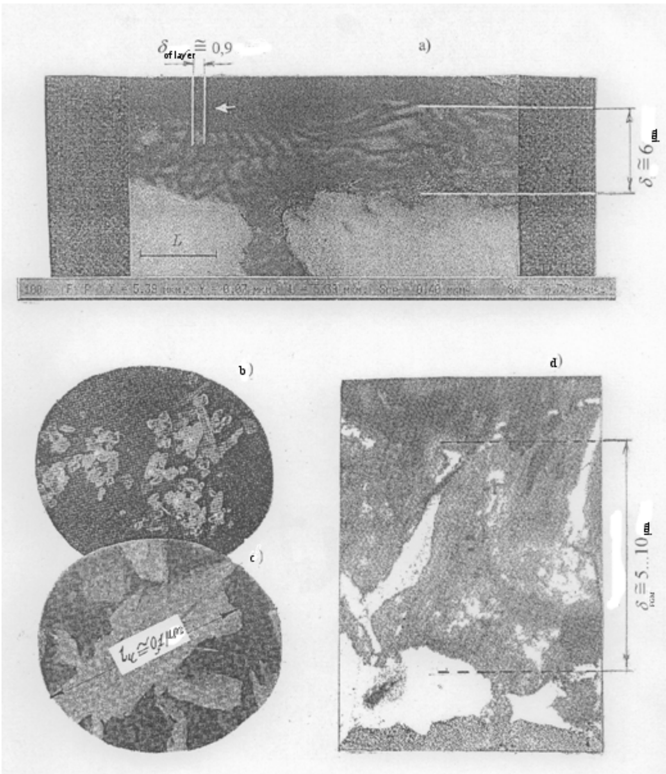


Figure 1. Thickness, structure and microstructure of protective metal-ceramic layer on metal surface: *a* – multilayer structure of protective layer ~ 6 µm; *b* – products of serpentine destruction and decomposition as α-quartz (SiO_2) particles and round-shaped olivines; *c* – nanoparticles of dispersed layered magnesium silicate hydrate as petals 100 nm long and 1.0 nm thick; *d* – heterogeneous microstructure of protective metal-ceramic layer. Images are taken on scanning electronic microscope

Simultaneously the process of connected surfaces micropolishing occurs, that leads to essential reduction of their roughness. A typical grain-oriented microrelief is formed on the friction surface. This microrelief has microcavities good in holding oil.

Equal microhardness combined with low surface roughness leads to unique antifriction effect. The results of comparative tests carried out on the friction machine SMTs-2 under the scheme roller-to-roller (one – movable, other – fixed) at rotation frequency 500 RPM and load change from 0 to 300 kgf/cm^2 with 5-hours working cycle and 1% FGM concentrated oil illustrate decrease of medium-carbon twain friction coefficient in 2 and more times. The analysis of the whole test cycle, including tribological unit temperature measuring, revealed an essential improvement of tribological characteristics when using FGM which is indicative of high efficiency of their application.

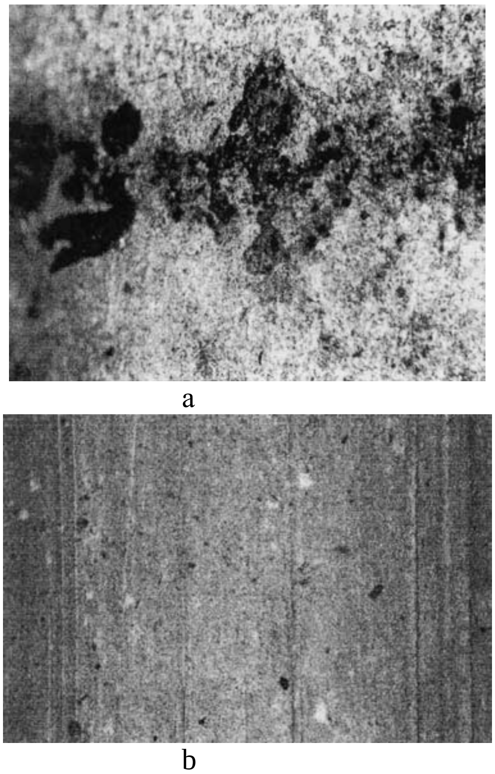
The efficiency on friction surface reconditioning due to using geoactivators is proved by following examples. The rollers of rolling mill 150-1 were treated by geoactivators at JSC “Iron & Steel Integrated Works “Krivorizhstal”. The amount of metal rolled increased by 30-35 %. The comparative analysis showed that service life of bearings increased in 2-5 times after using geoactivators (**Figure 2**).

At Nikopolskiy ferroalloy plant, reducing gears of crushing-machines are processed by geoactivators. As a result, noise during reducing gear operation is essentially decreased, current load dropped by 12 %, contact patch increased from 60 to 90%, pitting on teeth surface disappeared, bearing heating temperature dropped from 45 to 34 °C.

The practice showed that geoactivators established a good reputation in the processing of different constructions of power drives; mining machinery and excavator transmissions; rolling and sliding bearings; travelling crane runaways; pinion and axial-piston gear oil pumps and etc.

Further gradual decrease of friction coefficient in time is observed at long-run tests of tribological units processed with geoactivator. It can be explained by lasting surface structure formation after processing. The total increase of geoactivator-processed tribological units life makes 1.5-5 times.

The occurring changes lead to essential increase of detail linear sizes. Putter open gearing transmission of walking excavator ЭШ-15/90 was processed at Basanskiy open-pit mine. Teeth measuring in 2 months after processing showed increase of teeth thickness by 0.14 mm (from 31.64 to 31.78 mm), while 2-month wear of non-processed teeth was equal to 0.04 mm.



a

b

Figure 2. Macrosurface of roller bearing of rolling mill 150-1: *a* – no processing; *b* – after geoactivator processing

The process of linear size increase is self-regulated as it lasts until existing gaps are chosen. Self-regulation ability gives wide opportunities in geomodificator application. Their usage allows recovering worn gearings, rolling and sliding bearings, pump elements. High antifriction properties of the surfaces formed give the opportunity for essential reduction of power consumption, efficiency increase of machinery and mechanisms.

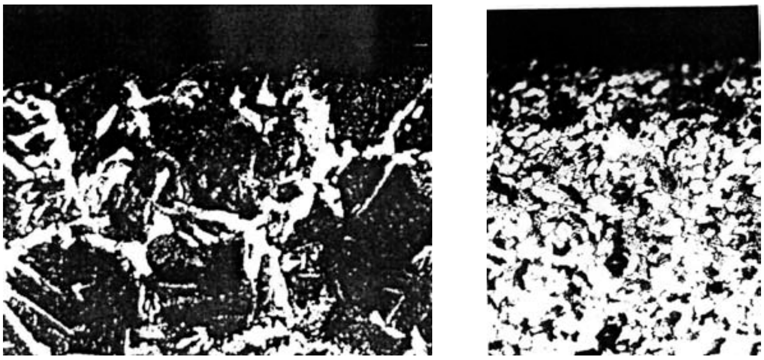
The surface modification for roughness decrease and significant enhancement of operational characteristics of machine details is achieved by joint using high-energy dimensional ultrasonic detail processing with simultaneous application of friction geomodificator in surface metal layers [3].

The surface and friction geomodificator particles, which are in microroughness cavities of processed surface, strengthen in the process of ultrasound processing [4]. Acoustic energy, transmitted by the system of alternating pressure and expansive waves, creates a favorable field of residual stress in the surface layers of detail material. Conglomerate is partially decomposed at cold work hardening of solid geomodificator ingredients on the serpentine basis. As a result of conglomerate decomposition, fine parts of new structural compounds are formed and block fracture propagation. The latter leads to essential increase of dislocation density, grain distortion, increase of cold work hardening degree and, as a result, substantial increase of surface hardness. The structural changes, which take place in near-surface layers, lead to essential rise of such operation characteristics as contact persistence, wear resistance.

Test results are illustrated on the example of combined processing of steel 45 shaft with 50 mm in diameter at the initial value of surface hardness 180 HV and roughness Ra = 3.7 μm. The initial structure of surface layer consists of coarse-grained ferrite-perlite grains (**Figure 3a**). The shaft surface is preliminary FMG coated after the final pass of acoustic head. The microhardness of processed shaft section increased doubly and more as compared to initial microhardness and was equal to 450 HV.

The structure analysis (**Figure 3b**) after processing showed that the grains in the surface layer became finer and underwent multiple shape distortion.

Measuring the surface microprofile on profile testing instrument "TAYSURE-5" gave following results: the roughness of shaft section reduced in 3.5 times after ultrasonic processing and in 6 times after ultrasonic-geomodificator processing (**Table 4**). Comparative tests are carried out on the friction machine SMTs-2 on steel 45 samples (roller to shoe) showed the increase of wear resistance in 3.5-5 times compared to other kinds of preliminary processing (**Figure 4**).



x400 a

x400 b

Figure 3. Initial structure of steel 45 (*a*) and structure after combined action of ultrasound and FGM (*b*)

Table 4. The results of investigation of 30ХГСА steel spindles in different treatment types

Treatment No.	Treatment type	Surface roughness, μm
555	Lathe machining	3.7
777	Ultrasonic treatment	0.97
333	Ultrasonic treatmentcombined with friction geomodificator	0.6

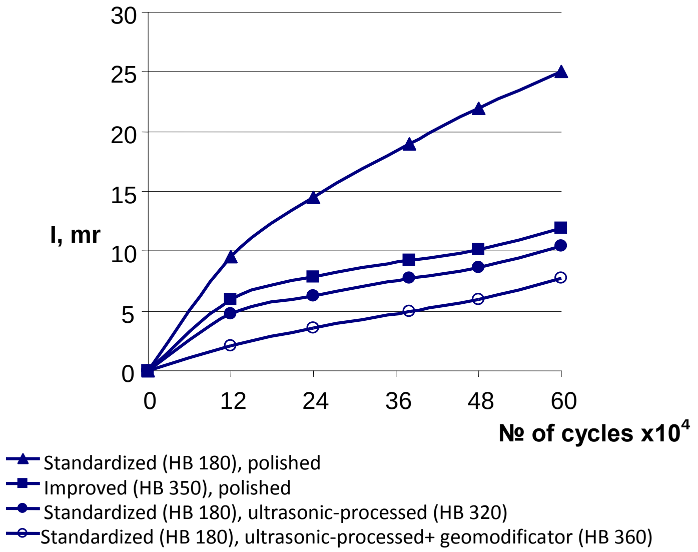


Figure 4. Comparative characteristic of wear indices for different methods of 40X steel sample processing

Conclusions

Usage of FGM as the compositions for depreciated tribological units recovery, without a shutdown of operating equipment, enables to reduce significantly maintenance costs related to machinery and equipment repair; to reduce power consumption and increase service life of machinery and mechanisms.

As a result of specific surface structure formation, worn-in tribological units have higher oil-holding property, wear-resistance, load ability and low friction coefficient.

Combined dimensional final processing with the use of strong sources of ultrasound as well as simultaneous adding of friction geomodificators to processed surface allow modification of working surface with high operational characteristics on local detail areas importantly.

References

1. R.P. Didyk. *Collected scientific papers*, Kyiv, NAS of Ukraine, 2003, pp. 23-27.*

2. O. V. Antsyferov, R. P. Didyk, A. B. Zavaliy, *Ukraine Patent* 56546 A (decl. July 18, 2002, publ. May 15, 2002). *

3. R. P. Didyk, D. V. Loskutov, P. B. Aratskiy, A. B. Zavaliy, *Ukraine Patent* 51394 A (decl. December 20, 2001; publ. November 15, 2002). *

4. Yu. I. Babey. *Phizicheskie Osnovy Impulsnogo Uprochneniya Stali i Chuguna*, Kyiv, Naukova dumka, 1988, 240 p.*

* Published in Russian

Received October 11, 2010

Увеличение ресурса горно-металлургического оборудования на пути преодоления трибологического барьера

Дидык Р.П. , Аратский П.Б.

Впервые на основании фундаментальных структурных исследований идентифицированы продукты разложения серпентина, образующие защитный металлокерамический слой на металлической поверхности. Приведены результаты промышленных испытаний, подтверждающие высокую эффективность применения природных минералов в качестве модификаторов поверхностей деталей машин.