

Wear resistance of a metal surface modified with minerals

S V Kislov¹, V G Kislov¹, P V Balasch², A V Skazochkin^{3,5}, G G Bondarenko⁴ and A N Tikhonov⁴

¹ Research and Production Association “Geoenergetika”, Kaluga, Russia

² Scientific and Production Center “Mico-Tech” Limited Liability Company, Moscow, Russia

³ Kaluga branch of the Russian Presidential Academy of National Economy and Public Administration, Kaluga, Russia

⁴ National Research University “Higher School of Economics”, Moscow, Russia

^{1,2} E-mail: geoen@mail.ru

^{3,5} E-mail: avskaz@rambler.ru

⁴ E-mail: gbondarenko@hse.ru

Abstract. The article describes the advantages of the new technology of mineral coating of metal products for the friction pair of mechanical systems. It presents the research results of the wear rate of the samples made of 12X13 steel (X12Cr13) with mineral layers, in the experiments with a piston ring sliding inside a cylinder liner with grease. The wear rate of the samples with mineral layers is lower almost by two factors than that of the samples made of grey foundry iron and untreated samples. As the result of slip/rolling abrasion tests of parts with mineral layers under conditions of high contact pressure, a suggestion was made concerning probable mechanics of surface wear.

Introduction

The core indicators of the quality of machine’s parts, assemblies and mechanisms are reliability and lifespan, which are greatly defined by the properties of the surface layers of parts and junctions: wear resistance, corrosion resistance, friction rate, contact rigidity, seating stability, connection tightness. The reason for a short lifespan of parts and other structural components may be significantly associated with tear-and-wear and corrosive deterioration of their surface layers. To eliminate or slow down the processes taking place on the border between metal and environment, which have a negative effect on the operability of materials, various types of surface treatment are used.

Besides multiple methods involving coatings, films and protective layers, there is a rapidly developing modern technology of changing physical and chemical properties of surface layers of metal parts by means of modification. In particular, industrial application of natural minerals for hardening surface layers of structural materials is finding its niche, due to the effects, combination of which leads to enhanced wear resistance, anti-friction, anti-corrosion and other specific properties of a friction pair.

The basis for a new original technology of creating mineral layers enhancing wear resistance of metal parts was created in Russia in 2009-2013 [1]. The mineral layers protect parts of all-purpose mechanical systems from wearing off, extend their lifespan and reduce energy consumption due to significant elimination of mechanical losses in machines and mechanisms [2]. The properties of mineral layers created by RPA “Geoenergetika”, have been confirmed by experiments and field tests

⁵ To whom any correspondence should be addressed.



conducted by partners from the Federal Institute for Materials Research and Testing, BAM, Germany [3].

The technology of creating mineral layers was introduced to the Russian and European markets in 2012-2015 and has already found application in various industries: metallurgy, machine building, power engineering, ship construction.

The mineral layers created enhance wear resistance of friction pairs from 3 to 10 times, feature unique tribotechnical parameters and can be applied to water lubricated metal parts, in environments with abrasive particles, and under conditions of unlubricated friction [2, 4, 5].

The created layers have unique properties, because parts coated by mineral layers of RPA “Geoenergetika”, demonstrate great performance:

- in seawater, salt mist, hydrogen sulphide, increased humidity, abrasive dust and other aggressive environments;

- under thermal cyclic loads in a wide temperature range.

Technology of mineral layers’ creation:

- does not require special basins, furnaces, vacuum chambers or specific conditions;

- has no fundamental limitations of mass and dimensional properties;

- does not change the geometry of the treated parts, does not require alteration of designs;

- is environment-friendly, has no harmful effect on human health and environment.

The present work investigates the wear rate of the samples before and after application of mineral coatings, as well as in comparison with some other samples.

Experiment details, results and their discussion

The technological process of mineral layers’ creation consists in embedding nanocomposite mineral powders into the crystal lattice of the treated metal by means of ultrasound and electrospark treatment, as well as ball and roller knurling. The details of the technological process of mineral layers’ creation, as well as structural changes on the surface and subsurface layers of metal samples (chromium steels, titanium alloys) are described in the work [4]. As the result of the combination of technological procedures changing the surface, microhardness of the surface layers is increased. Microstructural researches have demonstrated that a modified layer is observed, with granular structure, clearly different from the remaining mass [4]. The enhancement of hardness and strength properties is conditioned by the reduction of grain size.

This work investigates deterioration of samples with mineral layers and without special treatment, by means of an experiment including sliding of a piston ring in a cylinder liner lubricated with machine oil (the methodology is described in works [6, 7]) and an experiment of slip/rolling under conditions of high contact pressure (a thorough description of the method can be found in work [8]).

For all the experiments modified mineral layers according to NPO “Geoenergetika” technology were created on the surface of metal samples produced by lathe turning from 12X13 steel (Russian equivalent of EU X12Cr13 steel) rods in the shape of piston rings [1]. The thickness of the mineral layers created varied from 5 to 20 micron.

Wear rate was compared individually for a piston ring with untreated surface and a piston ring with modified surface. Synthetic oil based on polybutyleneglycol (GLYMOT PBG B20) and machine oil were used in the experiments. The mode involving machine oil lubrication was chosen because lube is typically present in most practical situations.

“PU”, “PV”, “PW” and “PT” samples in figure 1 designate various combinations of surface treatment conditions and metal from which the samples are produced.

Wear rates of the rotating disks were compared with wear rates of GGL20HCN European brand grey foundry iron disks with high carbon content (3.7 weight percent of carbon and 2.0 weight percent of silicon) which is normally used for production of cylinder liners and brake disks. The curly bracket and “X12Cr13” title in figure 1 denote the results acquired for a 12X13 (X12Cr13) steel piston ring without any treatment.

Abrasion slip-rolling experiments were conducted under conditions of high contact pressure $P = 2.25$ GPa. Experiments involving sliding with machine oil were conducted under much lower contact pressure, of about 100 MPa.

Figure 1 presents wear rates of the surface of PT series rings (PT-502, PT-503, PT-504 and PT-201, PT-202, PT-203) made of 12X13 steel with mineral layers which were compared with wear rates of the surface of untreated rings made of 12X13 steel, 20X13 steel and grey foundry iron.

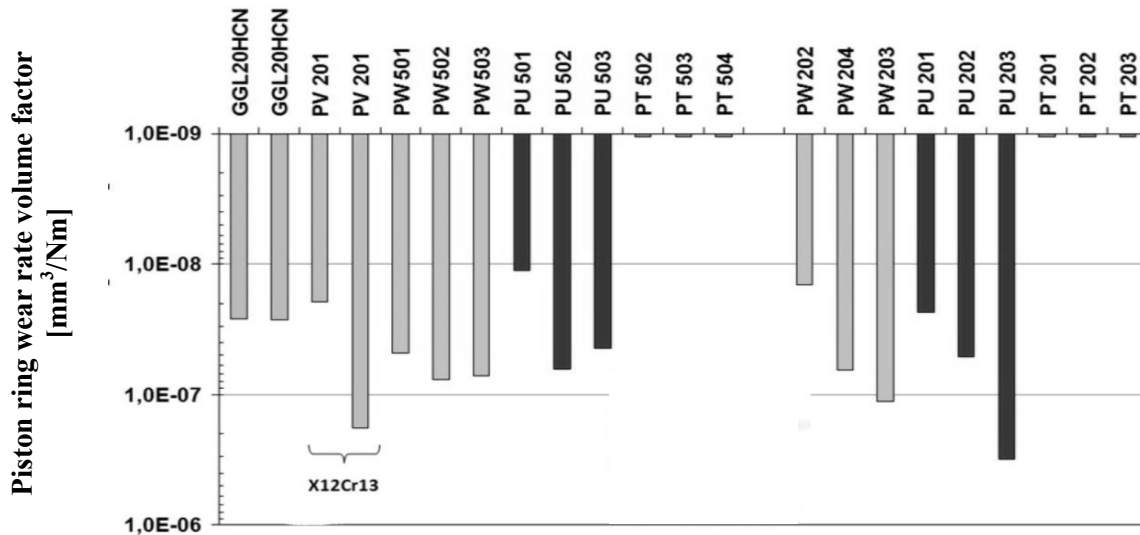


Figure 1. Wear rate volume factors for piston rings sliding under mixed lubrication conditions over cast iron and 12X13 steel treated by RPA “Geoenergetika” in machine oil ($F_N=50$ H; $v=0,3$ m/s; $T_{oil}=170^\circ\text{C}$; $s=24$ km)

Evidently, creating mineral layers on the surface of PT series rings provided wear rate which is by two factors lower than that of standard samples made of grey foundry iron and untreated 12X13 and 20X13 steel rings.

Figures 2 and 3 clearly demonstrate that after 10 million cycles of slip-rolling abrasion test the surfaces with mineral coating, exposed to friction, became smoother. It is possible that the technology of creating a thin modified layer on a metal surface, leading to its local strengthening and enhanced hardness [4], preconditioned good slip-rolling friction resistance of the samples made of 12X13 and 11X15 (Russian equivalent of 102Cr6 German steel) steels, which was probably defined by general residual compression stresses.



Figure 2. The picture of a wear track on a treated 12X13 steel surface performed by means of an optical microscope ($T=120^\circ\text{C}$, $P=1.5$ GPa, 10 million cycles, slip-rolling).

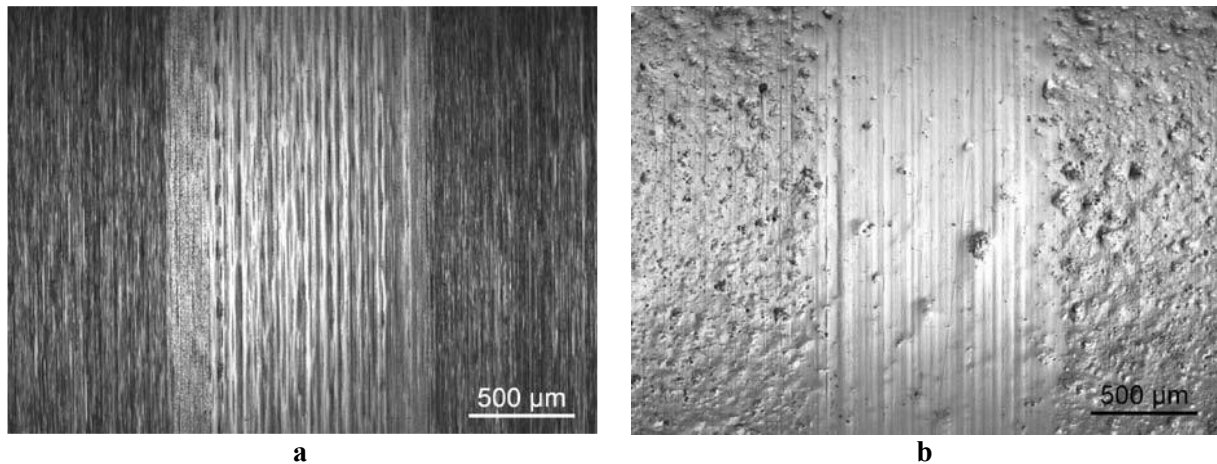


Figure 3. The picture of a wear track after slip-rolling performed by means of an optical microscope (a - surface of the sample made of IIIX15 steel without mineral coating; b - cylindrical sample made of IIIX15 steel with mineral coating; $T = 120\text{ }^{\circ}\text{C}$, $P = 1.5\text{ GPa}$, 10 million cycles, slip-rolling).

The thin layer of the hardened surface of steel samples modified by minerals has demonstrated good resistance to slip-rolling procedure [7, 8] after ten million cycles at the temperature of $120\text{ }^{\circ}\text{C}$ and pressure $P = 1.5\text{ GPa}$. Under such conditions the effective thickness of the oil film h_{\min} at $120\text{ }^{\circ}\text{C}$ was $0.027\text{ }\mu\text{m}$ [8] which is the evidence of boundary lubrication mode, so the wear of the surfaces is mainly conditioned by physical and chemical interaction taking place at the spots of actual surface contact. Besides, the pictures in figure 2 show microcavities randomly scattered over the working surface of the sample. It is due to these created microcavities that the oil is detained when lubrication is suspended, which may be listed among the advantages of the technology [4] because performance capabilities and equipment safety are enhanced during start-and-stop operations, e.g. spindle bearings in case of insufficient lubrication.

Conclusions

1. The mineral layers created on the surface of the samples presented by 12X13 steel rings provided wear rate which is almost by two factors lower than that of the samples made of grey foundry iron and untreated 12X13 and 20X13 steel samples during experiments involving piston ring sliding in a cylinder liner with machine oil lubrication.
2. When testing slip-rolling abrasion of parts with mineral layers under high contact pressure conditions, boundary lubrication mode is possible. That is why the surface wear is only conditioned by physical and chemical interaction at the spots of actual surface contact.

Acknowledgements

The authors are grateful to Dr. Mathias Woydt, head of Tribology and Wear protection division of Federal Institute for Materials Research and Testing, BAM, Germany, for performing sample measuring operations and consulting.

References

- [1] Kislov S V, Kislov V G and Lazarev S Yu 2011 Creation method of combined mineral surface layer for metal products protecting it from action of aggressive medium and with designated tribotechnical parameters *Patent on invention №2421548 from 20.06.2011, patent application 2009142259/02 from 18.11.2009*
- [2] Elagina O Yu, Gantimirov B M, Tomskij K O, Mazurkevich AN and Kislov S V 2013 Research of tribotechnical parameters of coat by metal to metal friction without oil *Perspective materials* **7** 56-60
- [3] Kislov S, Kislov V, Ostrovsky P and Woydt M 2012 Localized hardening and structuring of steel by a simple process. *53 Tribologie Fachtagung «Reibung, Schmierung und Verschleiß» der GfT Göttingen, Herstellung: Druckservice Zillekens* **2** 49/1-7

- [4] Kislov S V, Kislov V G, Skazochkin A V, Bondarenko G G and Tihonov A N 2015 Effective mineral coats for surface hardening of metal products *Metals* **4** 56-63
- [5] Polovinkin V N 2009 *Nanotechnology in ship construction* Academician A.N. Krylov Reserch institute St-Peterburg 132
- [6] Woydt M and Kelling N 2003 Testing the tribological properties of lubricants and materials for the system “piston ring/ cylinder liner” outside of engines *Industrial Lubrication&Tribology* **55 5** 213-222
- [7] Löffelbein B, Woydt M and Habig K-H 1993 Sliding friction and wear of ceramics in neutral, acid and basic aqueous solutions *WEAR* **162-164** 220-228
- [8] Scholz C, Spaltmann D and Woydt M 2011 Slip-rolling resistance of thin films and high toughness steel substrates under high Hertzian contact pressures *WEAR* **270 7-8** 506-514