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Restoration of machine-components wear resistance

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Abstract. The research relevance is conditioned by the fact that wearing of friction surfaces is determines their limiting state. The content of the process of components wear resistance reduction due to the choice of material composition for restoring coatings, the subsequent mechanical and thermal treatment.

Key words: restoration, wear, wear resistance, coatings, treatment.

1. The necessity of property reduction

Component wear is the result wearing process. The main share of components (80-90%) in the conjunction with other components reaches limiting state due to wearing. As a result of this process material destruction and separation from the surface of the solid body and (or) deformation accumulation at friction take place. Wear is characterized by velocity and intensity. The mentioned effects leads to gradual change in dimensions and (or) shape of components. A part of wear-resistant layers of components is lost, and in conjunctions of wearing components closing dimensions (allowances) are changed.

Components life according to static capacity as a rule exceeds their capacity according to wear resistance and cyclic strength. At that, worn components weight to a little degree (1-3%) differs from new components weight. Such a condition presupposes the use of components remaining life by means of restoration of their dimensions and properties to the values specified in technical documents.

Typical varieties of components wear are abrasive (by solid particles getting in contact zone), adhesive, oxidizing, fatigue and fretting. Components running together are part of a mechanism. At their restoration it is reasonable to ensure wear resistance and working life equal to the working life of the aggregate where the components work. Strengthening of a component is supposed to ensure multiple increase of its working life as compared to a new component, which is a technically and economically difficult task.

2. The content of wear resistance restoration

For surface wear resistance restoration such methods as coating, cutting, thermal treatment and surface plastic deformation are applied. The objective of wear resistance restoration includes selection of coating material, application technique, type and mode of thermal, thermochemical, and mechanical treatment. These procedures ensure obtaining of required factors:

- chemical, phase and structural composition of coating material;
- hardness of coated surface;

- values and residual stress sign on working surfaces;
- microrelief and roughness of surface after its treatment.

At selection of coating material it should be taken in consideration that wear resistance depends not only on coating material properties, but also to a significant degree on operative conditions of a component. Operative conditions are so diversified that there are no universal wear resistant material. A coating resistant to wear in some conditions may rapidly fail in other conditions.

Continuous work of mating components requires material compatibility. By compatibility we shall understand properties of interacting surfaces materials to inhibit their setting at working without lubricating stuff or in conditions of continuity violation of oil layer [1]. In friction pairs the following materials are compatible: hard material with soft material (that has the temperature of recrystallisation lower than the average temperature of the friction surface during operation); and hard material with hard material (combination of pairs of nitrided, chromized, and hardened steel). Combination of soft material with soft material as well as pairs of same materials should be avoided.

Wear resistance of surface layer is determined by the composition of material and strengthening phases presence in it.

Coating material composition and structure. According to homogeneity of structure coating material can be homogeneous (single-phase) or heterogeneous (polyphase). Heterogeneous materials have higher tribotechnical characteristics. Phases of heterogeneous coating differ from each other in their chemical composition and properties and are divided by boundaries. Continuous phase according to the coating volume or its layer is a matrix (binder), and a phase of separate fragments is reinforcing or strengthening (filler). Coatings with structure of robust steel, nickel or cobalt matrix in form of a solid solution, holding particles of solid phase in form of carbides, borides, nitrites, oxides (Table.1) and intermetallic compounds.

Basic methods for obtaining heterogeneous coatings structure are:

- making compositions of eutectic and proeutectoid constituents. Such coatings are obtained at surfacing. They are most widely applied;
- obtaining of metastable supersaturated solid solutions by means of subsequent thermal treatment. Dispersion hardening (release of highly consistent secondary phases) additionally strengthens the surfaced coat;
- retention of initial composite structure of particles in coating due to their incomplete fusion, for example, at spraying. Possibilities for obtaining such coatings with different composition of strengthening and matrix phases are wider than in coatings obtained by crystallization from melt;
- insertion of dispersion strengthening phase to electrochemical coatings at their application.

Optimal type of structure for a metallic substrate depends on operative conditions of a material: at low specific pressure martensite structure is preferable, because its hardness is close to that of carbides, while at high pressure and impact occurrence austenitic structure is preferable. At that austenite depending on the degree of stability at wearing can undergo martensite transformation. In such a case it is not the soft austenite that resists wear but hard and robust martensite.

Table 1. Physical-mechanical properties of highly consistent phases, applied in materials for components restoration

Phase	Microhardness, hPa	Melting temperature, °C	Density, g/sm^3	Modulus of elongation, hPa
Cr_7C_3	13,7–24,0	1655	6,92	360
$Cr_{23}C_6$	12,3–22,8	1550	6,97	380
Cr_3C_2	13,5–18,0	1660	6,68	280
VC	30	2810	5,36	270–430
TiC	24–32	3150	4,93	460
ZrC	28	3420	6,57	350–420
WC	17,4–22,0	2720	15,6	610–720
CrB_2	20,6–21,0	2200	5,2	220
VB_2	21,0–27,4	2400	5,28	270
TiB	32–33	2980	4,45	455–540
W_4B	37	2800	15,3	790
ZrB	22,5–34,0	3040	6,17	220–350
CrN	11	1500	6,1	330
VN	15	2180	6,1	267
TiN	19,0–20,5	2950	5,43	340–616
ZrN	15	2950	7,1	400
Al_2O_3	20,0–25,4	2050	3,9	410
SiO_2	11,5	1720	2,65	73
Cr_2O_3	29,4	2300	5,21	405
B_4C	35,6–49,5	2350	3,2	460

The best metallic substrate at impact abrasive, cavitational and mechanochamical wear fracture is an admixture of austenite and martensite. Correlation of these components depends on the intensity of impact load: the more the impact load, the more the content of austenite in the alloy should be. In such a case martensite should be low-carbon due to fixation of carbide-forming elements. The quantity and type of carbides or other solid components also have an effect on the wear resistance of the surface coating. At the absence of an abrasive in mating pairs wear resistance can be ensured by the presence of martensite in the structure or martensite with some quantity of carbide fines.

Examples of selection of phase and chemical composition of surfaced coats for components working in different operative conditions are as follows. Rolling of metal on metal: phase composition of coatings – 90% martensite and 10% carbide; chemical composition: C≤1, Cr ≤ 15, Ni, Mo, W. At manual arc fusing in Co_2 it is possible to apply electrodes PP-AH 103 (200X12M). Friction of metal on metal with lubricating material: phase composition of coatings – C ≤ 0,5, Cr ≤ 5, Mn ≤ 3, Ni. At manual arc fusing in Co_2 it is possible to apply electrodes ЭН-60М (70Х3 СМТ), wires PP-25Х5ФМС and PP-AH122 (30Х5Г2СМ). Composition operation in conditions of boundary lubrication (wear type – contact fatigue): phase composition of coatings – 90-100% martensite, 0-10% carbides or 70-80% ferrite and 20-30% carbides; chemical composition C ≤ 0,5, Cr, Mn (for martensite matrix), C≤ 1,2, Cr, Mn. Electrodes HP-70 (30Г2ХМ) and ОЗИ-3 (90Х4М4ВФ) and wire PP-AH126 (20Х2Г2СТ).

3. Values of coatings mechanical properties

Values of coatings mechanical properties must grow in the direction from the surface to the depth of metal. This requirement ensures low velocity of component wear and is expressed by the rule of positive gradient of mechanical properties of material according to its depth [2]

$$d\tau / dz > 0, \text{Н·м}^{-3},$$

where τ is breaking shear stress, Pa; z –values of coordinate directed to the depth of material perpendicular to friction surface, m.

If the inverse takes place, the generated surface ties are stronger than the depth ones and setting of the friction surface takes occurs. For instance, soft constituent of austenitic steels does not allow obtaining high quality of components working surfaces from such materials.

Allows of new generation – fractal materials with broken long-range order, are highly efficient. Amorphous alloys represent a specimen of such materials. They have universal physicochemical properties, nevertheless their application in engineering is limited due to the fact that obtaining of coatings of them requires more system non-equilibrium than it is required at ultraspeed cooling. The future of fractal materials is associated with the development of two areas – development of chemical composition and techniques that would allow obtaining of massive amorphous alloys, and development of nano- and microcrystalline materials.

4. Impact of material hardness and internal stress

There is no univocal connection between wear resistance and hardness. The intensity of abrasive wear depends on the correlation of hardness of the material base and the ingrained abrasive material [3]. This peculiarity, conditionally called the effect of ultra wear resistance, opens new possibilities for improving components working life. The effect is that the linear dependence between wear resistance and hardness is broken, and wear resistance at some types of wear is dramatically increased. Correlation of material hardness and abrasive particles with respect to shaft necks subject to abrasive wear, must be not less that 0,7. The increase in surface wear resistance, for instance, is ensured by welding of a steel band with a width of 0,3-0,5 mm. with carbon content no more that 0,5% with particles of hard alloys of ВК and ТК groups, and of wolframfree alloys of КХТ and ПТЖ types with the size of 0,3-0,5 mm. Sound connection of particles with the steel band ensures heating of the sub-electrode lotto the temperature of 1350°C and the pressure of at least 33 MPa. Wear resistance of coatings is 10 to 15 times higher than that of hardened steel 45 and 2,6 times more than that of coatings of self-fluxing alloys. Coatings are applied with the help of condenser seam machines for contact welding, for instance МШЛ-2002 (К-421 М) or with the help of special equipment developed by National Research and Production Association "Remdetal" operating on alternating current. Restored shaft necks are polished with a diamond wheel АПП 300x27x127x5 АСВ 100/80 МВ1 on a metallic bond. On samples with composite coatings predominately compressive residual stresses are created on the surface layer. Fatigue resistance limits of the samples is 8% lower than that of reference samples of steel 45 with surface hardening to hardness 52 HRC.

An important component of physicochemical state of a surface layer is the value and sign of residual stresses in the surface layer. It is necessary to strive for obtaining compressive stresses in a coating.

The value and the sign of residual stresses in a material depend on the following factors:

- correlation of volume expansion coefficients of coating and base materials. For decreasing the tension stress it is necessary to ensure that the coefficient of volume expansion of a coating is less than the base metal;

- final mechanical treatment modes. For decreasing tension stresses it is necessary to ensure minimal heating of a component at final mechanical treatment. In such a case strengthening from cutting load in the surface layer forms compressive stress in the coating surface layer;
- Usage of surface plastic deformation (SPD). Cold working of a surface at SPD ensures formation of compressive stress in a surface layer. The higher the hardness the higher the effect of SPD treatment. For example, for a component surface made of steel 45 at running-in force of 2250 MPa compressive stress of 400-500MPa is achieved in the depth up to 1.0 mm.

5. Microgeometry of friction surface

Geometric state of the coating surface layer is determined by roughness and presence of surface oil pockets. Coating pores or dimension cavities on the surface can serve as oil pockets or reservoirs.

Wear resistance of coatings can be controlled by changing their porosity. Pores act as reservoirs for lubricating material that is extruded from its volume in the course of wearing and gets in the friction zone, contributing to restoration of boundary lubrication. Obtaining of porous coatings by means of gas-thermal spraying is the most efficient. Such coatings are also saturated in lubricating materials for improvement of wear resistance.

In a number of cases discreet or continuous cavities on a friction surface obtained by knurling can also serve as oil reservoirs. An example is treatment of piston surfaces of aluminum alloy running together with the surface of steel or cast-iron cylinder.

An efficient way for increasing wear resistance of components in a friction pair is changing physicochemical state of a layer due to final antifriction nonabrasive treatment (FANT). The essence of such treatment is that the surface of components friction is coated with a fine brass, bronze or copper layer. The work surface is degreased, and prior to coating deposition it is covered with glycerol or glycerol-base solution. Coating deposition process is friction rubbing of a copper alloy to a steel surface (Table 2). Rubbing is carried out both by iron cores and hogs and by loose spherical and cylindrical rollers. The thickness of antifriction layer of brass on the base of steel at FANT is 2-3 micron, bronze and copper – 1-2 micron. Roughness of the original layer must be about Ra 2,5 micron. As a rule, FANT slightly reduces the surface roughness. At small parameters of the surface roughness (Ra 0,63-0,08 micron) FANT does not change their values.

Coatings deposited with FANT ensure positive gradient of mechanical properties (soft film covers hard surface), increase the area of real contact of surfaces and reduces friction force, and plasticizes friction surface. All the above mentioned contributes to better conformability and higher wear resistance of restored components.

Table 2. Parameters of the technique for coatings deposition by means of FANT

Component material	Operating fluid	Core material	treatment parameters				Examples of application
			Appli-cation pressure, MPa	Component surface velocity, m/s	Length feed, mm/vol.	Number of strokes	
Steel 30ХГСА	Glycerol	Brass Л62	120–150	0,15–0,20	0,1-0,2	1-2	Non-mobile heavy loaded components
Steel 45	Glycerol	Copper, Bronze БрОЦС 6-63; brass Л62	80–100 60–80 40–70	0,15 0,20 0,20	0,2 0,2 0,2	3-4 3-4 3-4	Crankshafts and cam shafts
Steel 12Х18Н9Т	10 ml ortophosphoric acid + 10 ml anilin + 50 ml glycerol	Brass	70	0,10	0,08	–	Shafts
Steel 35 (nirmalization)	***Glycerol***	Brass	70	0,2	0,2	2	Press fit of screw propellers
Steels 30ХГСА, Х12М, ХВГ, 12Х18Н9Т	33 % glycerol + 67 % of 10% solution HCl	Brass Л62, bronze БрОФ-10-1	50–70	0,10–0,20	0,1-0,2	2-3	Spool-and-sleeves and pump elements of fuel engine equipment
Steel 38Х2МЮА nitrated; steel with surfaced coat	40 % glycerol + 60 % of 10%solution HCl	Brass Л63	80–120	0,50–0,60	0,22	–	Components of piston-cylinder engines
Steel 35 (normalization)	Glycerol with additive HCl	Brass Л63	120	0,06	–	1-2	Thread connections
High-alloy steels, grey cast iron	Glycerol	Brass Л58	230–690	0,05–0,2	0,1-0,4	–	Internal combustion engine cylinder sleeves
Steels 45, 40Х, 65Г	Glycerol	Copper, brass	80 100	0,20	–	2–3	Shafts, hydraulic cylinder rods
Grey cast iron	Glycerol	Brass Л63	270	0,14	0,15	4	Engine shafts
Perlitic cast iron	Glycerol + activator	Brass	70	0,30	0,2	–	Diesel generators cylinder sleeves
Grey cast iron	Glycerol	Brass Л63	64–95	0,30–0,50	0,3–0,6	4	Engine cylinder sleeves

6. Conclusion

Conditions ensuring standard wear resistance of restored components surfaces are come to obtaining heterogeneous structure of coating material with presence of hard fine-dispersed inclusions mainly carbides and nitrates. Conditions for obtaining such structure are presented. Positive gradient rule for mechanical properties of coating material to the depth of its surface layers are ensured at usage of final antifriction nonabrasive treatment.

References

[1] D.N. Garkounov, *Tribotechnics: Textbook for higher educational establishments.*/D.N. Garkounov. 2nd edition, amended and supplemented. M. Machine-building, 1989, 328 p.

[2] P.N. Bogdanovich, *Friction and wear in machines: textbook* / P.N. Bogdanovich, V.Y. Proushak. – Minsk.: Higher school, 1999, 374 p.

[3] M.M. Tenebaum, *Resistance to abrasive wear* / M.M. Tenebaum. – M.: Machine-building, 1976, 271 p.