NEW TECHNOLOGY FOR HARDENING READY-MADE TOOLS IN AQUAEOUS DISPERSED MEDIA

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Abstract
The new method for hardening ready-made steels, hard alloys and diamond tools is developed: low-temperature process for producing thin-film solid lubricant coatings by hydro chemical treatment in specially prepared aqueous media of nanosized hard refractory compounds and subsequent tempering. The main advantages of the method over known processes are presented. The principles for dispersion of refractory materials are formulated. The structure and properties of the obtained coatings are examined. The fields of high compression strains (180-470 MPa) are created in tool materials subjected to hydro chemical treatment. The new process permits decreasing the friction coefficient of tools surface in 3.8-12.1 and increasing the service life of steel, carbide and diamond tools by the factor of 1.5-8 as compared with untreated materials.

Keywords: nanotechnology, tools, solid lubricant coatings, the friction coefficient

1 Introduction
Technologies of chemical or physical deposition of coatings on machine parts and tools are very close to the proposed method. However the known methods are rather power consumable; require application of vacuum equipment and coating deposition is executed at high temperature. The known methods are characterized by the following disadvantages: they do not meet requirements pertaining to ecology and environmental protection. In addition to this it is necessary to point out the fact that chemical and physical methods make it possible to deposit protective coatings only on external surfaces of parts having a simple configuration, without internal cavities and sometimes parts with complicated profile have zones which are impossible to process. However treatment process in accordance with the proposed technology is carried out at low temperature and an initial structure and an initial configuration of parts are unchangeable. At the same time formation of even and uniform nano-structurized coating of super-hard or refractory (high-melting/heat-resistant) coating occurs along/across the whole part’s surface (including concealed cavities).
In connection with the above, the main purpose of this work is the development of simple and inexpensive method to increase service life of ready-made tools by low-temperature processing in aqueous dispersed media on the basis of nano-scale strengthening phase: oxides, diamond, graphite, carbides and other refractory compounds.

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2 Methods

The proposed low-temperature process with thermo-hydro-chemical treatment (THCT) does not have any disadvantages of the known strengthening methods [1]. Thermo-hydro-chemical treatment consists of two stages: (1) hydro-chemical treatment of items in specially prepared aqueous media, containing nano-clusters of oxides, diamond, carbides and other wear-resistant materials; (2) subsequent thermal treatment using isothermal soaking at temperature which is lower than temperature of structural transformations and does not lead to changes in initial structure, size and shape of tools (for example, at temperature 150-180 °C – for carbon steel; at 300-1000 °C – for hard alloys etc.);

Advantages of the proposed method in comparison with the known strengthening methods:

- simplicity in application, standard equipment is used, vacuum or protective atmosphere are not required;
- high thermal resistance and nano-structure reliability (up to 1050 °C);
- preservation of properties and size of products due to low THCT temperature (up to 180 °C);
- low energy consumption because the process does not require current supply to the surface;
- high productivity because the process permits quickly (not more 60 minutes) and numerously to make treatment of products having various shape and size;
- high universality because the process may be applied for various types of tools and machine parts manufactured of various steel, hard alloys and diamond-containing materials;
- small expenditure of chemical nano-components (up to 1-5 %);

Low-temperature simple and high-performance method dispersing refractory and raw materials to produce aqueous media for thermo-hydro-chemical treatment is developed in this research work. The dispersion process can be explained within the Rebinder effect owing to wedging action of polar molecules of surface-active substances in a microcrack of any solids including refractory and raw materials. Dispersing materials is based on pressure gradient **Δ P**, temperature gradient **Δ T**, chemical gradient **Δ C** and other gradients **Δ** $\mathbf{X_i}$ which are created within materials and outside. The radius of dispersed particle **r** is mathematically dependent on the following parameters:

$$\mathbf{r} = f\,(\sigma_s \cdot \tau \cdot n \;/\; \Delta P \cdot \Delta T \cdot \Delta C \cdot \Delta X_i) \qquad (1.)$$

where: σ_s - surface tension

n - number of cycles

τ - duration of change of the gradient

As seen from the formula minimal radius of particle r is provided if (2.):

$$\sigma_s,\ \tau \rightarrow \min;\ \ \Delta P,\ \Delta T,\ \Delta C,\ \Delta X_i \rightarrow \max;\ \ n \geq 1 \qquad (2.)$$

An aqueous suspension of refractory and raw materials is dispersed by special technology. Maximum process temperature does not exceed 350 °C and the minimum temperature - 0 °C. Varying the regimes (temperature, duration, concentration, etc.) on a specially developed device for dispersing materials and composition of aqueous media, we can reduce the particle size up to 30-500 nm.

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3 Results and Discussion

Structure Investigations

Thermo-hydro-chemical treatment has double character of material strengthening: (1) nano-structural coating is formed on the surface; (2) fields of high compression strains are created in the material.

(1) Hydro-chemical treatment (HCT) in aqueous dispersed media makes it possible to form coatings on steels, hard alloys and diamond-containing materials consisting of nano-particles on the basis of refractory (heat-resisting/high-melting) compounds having size of 15-30 nm with high (up to 1050 °C) thermal resistance. Due to mechanism of intercrystallite sliding the coatings formed with the help of nano-particles are characterized by solid lubrication properties, when friction coefficient of a material without lubrication is significantly decreasing (up to 4-12-fold decrease). In materials at a depth of 0.5 mm; a zone of compression stress (180–470 MPa) is formed on steels, hard alloys (**Table 1**) and diamond-containing materials (**Table 2**). Strengthening-phase nanoclusters can penetrate in material depth along grain boundaries, mosaic blocks and imperfect structure areas and create meta-stable stressed sub-structure. The subsequent local or volumetric heating is necessary for obtaining more uniform distribution of nanoclusters in the material, strengthening of adhesion binding at a "coating-base" boundary zone. Fields of compression strains are formed under the coating which increase design volume strength.

Table 1 Results of X-ray diffraction analysis of steel and hard alloys

Material	Schedule of treatment	Phase (line)	$2\theta_{\perp}$, degree	$2\theta_0$, degree	$d_{\perp}$, nm	d_0, nm	σ, MPa	Dislocation density, 10^9 sm^{-2}
Steel У8	Trad.	α-Fe (220) [06-0696]	98,889	98,945	1,01379	1,0134	-270	2,77943
	THCT		98,865	98,945	1,01408	1,0134	-470	2,77711
Hard alloy Т15К6	Trad.	WC (211) [25-1047]	117,30	117,29	0,90206	0,9020	-120	1,84246
	THCT		117,26	117,29	0,90212	0,9020	-235	2,47587
Hard alloy ВК6	Trad.	WC (211) [25-1047]	117,30	117,29	0,90203	0,9020	-71	1,96186
	THCT		117,25	117,29	0,90209	0,9020	-210	1,97629

Table 2 Results of X-ray diffraction analysis of diamond-containing material

Schedule of treatment	Phase	$2\theta_{\psi}^{(311)}$, degree	$2\theta_0^{(311)}$, degree	$d_{\psi}^{(311)}$, nm	$d_0^{(311)}$, nm	$\sin^2 \psi$	σ, MPa
Without treatment	Ni	114,7	114,68	1,0631	1,0632	0,4132	-50
	C (diamond)	112,57	112,5	1,0761	1,0765	0,4132	≈-700
THCT	Ni	114,75	114,68	1,0627	1,0632	0,4132	-180
	C (diamond)	112,5	112,5	1,0765	1,0765	0,4132	0

Investigation of wearing-out processes

It is rather important for the tool having eventually changeable contact area with the treated part (running-in process is not going on in one point) to have not only minimum, but unchangeable values of friction coefficient; nanostructurized THC coatings fully meet these requirements. They have a number of advantages in comparison with PVD diamond and other types of solid lubricant

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coatings which initially have rather high friction coefficient and then it is slowly reducing according to running-in process of a coating with a counter body and with high oscillation amplitude.
New hardening treatment permits decreasing the friction coefficient of the tool steel surface in 12,1 and hard alloy surface in 3,8 as compared with untreated.

Tools testing
While considering tool wear problems a great significance is paid to state of its cutting edge. Its difference is vividly observed in steel slugger punches prior and after THCT. Cutting edge wear of THC-strengthened punch is uniform and 2.5-fold less in comparison with non-treated it and wear of such punch is of local character.
As result of investigations a great number of diamond grains with plain wear site is detected on the surface of diamond grinding point being THCT strengthened. Such phenomena is not observed on the surface of non-strengthened tool. Diamond points worked out for 120 minutes while continuously machining BK8-hard alloy. In this case average diamond expenditure of strengthened points was equal to 11.55 g/cm² and an index of non-strengthened ones was 16.74 g/ cm², in other words by 50% lower.
Test results showed that after thermo-hydro-chemical treatment the operational resistance of steel, hard alloy and diamond tools has been increased by the factor of 1.5-8.0 in comparison with the standards.

Application of technology
The developed THCT technology shall permit, **Table 3**:

- to reduce friction coefficient of steel without lubrication from 0.70 up to 0.07; hard alloy from 0.45 up to 0.10;
- to preserve unchangeable structure, size and shape of products;
- to improve service life of tools by 1.5-8-fold;
- to increase heat- and corrosion resistance of tools by 2-5-fold;
- to increase cutting modes for cutting tools by 30%;
- to preserve initial resistance of a strengthened tool up to 80-100 % after re-sharpening

The technology and nano-compositions are presently considered as a completed research development for tool strengthening and they can be introduced in any production process. The nano-compositions and THCT technology do not have analogues in world practice.
Unit for chemical treatment ensures deposition of nanostructure coatings with thickness up to 0.5 μm during 60 minutes on tools of weight up to 1000 kg without supply of electric current to products' surface. Standard equipment is applied for the treatment. Single technological process combines all operations of chemical treatment such as cleaning, etching, heating in aqueous nanocluster medium, flushing, drying and also thermal treatment in oxidizing or protective medium.

Conclusion

1. A new low-temperature process of the thermo-hydro-chemical treatment for hardening ready-made steels, hard alloys and diamond tools is developed;
2. For the first time the double character for strengthening tool materials at the thermo-hydro-chemical treatment was discovered: (1) nano-structural solid lubricant coatings are

formed on the surface; (2) fields of high compression strains (180-470 MPa) are created in the materials;

3. Developed treatment with optimal regime permits decreasing the friction coefficient of tools surface in 3.8-12.1 and increasing the wear resistance of steel, carbide and diamond tools by the factor of 1.5-8 as compared with untreated materials.

Table 3 Results of industrial tests and application of THCT technology

Type of Tool	Material of Tool or Item/Product	Material to Be Treated	Resistance Increase, K_w	Industrial Application
PA Minsk Tractor Works (MAZ)				Reduced in practice in 1995
Taps	P6M5 Steel	Tool steel	1.7-4.8	
PA Belarusian Automobile Plant (BelAZ)				Reduced in practice in 2000 with economic impact - 70,000 US $
Taps	P6M5 Steel	40X Steel (up to HB220)	2.0-3.0	
		40Л Steel (HB217)	>2.5	
Cutting plates for finish turning	T15K6 Hard alloy	40X Steel (HB217)	>2.0	
Diamond bowl-shaped discs	Diamond material	45 Steel (up to HRC 60)	1.6-2.2	
Blanking die punch	У10 Steel	08КП Steel	2.0-3.0	
"BelAZ" suspension bush	45 Steel	Abrasive sand	1.5-2.0	
"InToGor" Subsidiary Enterprise of Minsk "Horizont" Holding Company				
Drawing dies	У10 Steel	Tool steel	2.0	
RUE Borisov Plant of Automotive and Tractor Electrical Equipment (BATE)				
Drills	P6M5 Steel	10, 15 Steel	2.0-2.3	
Taps	P6M5 Steel	15 Steel	2.0-3.0	
Reamers	P6M5 Steel	20XH2M Steel	3.0-3.5	
RUE "Heavy Die Forging Plant" (KZTSh)				
Cutting plates for finish turning	T15K6 Hard alloy	20 Steel	1.8-1.9	
RUE "Minsk Factory Calibre"				Reduced in practice in 2005
Diamond bowl-shaped discs	Diamond material	45 Steel (up to HRC 60)	2.0-2.7	
Joint Institute of Mechanical Engineering NAS Belarus				Reduced in practice in 2008-2009
Diamond trepanning drills	Diamond material	Glass	3.3	
JSC "Minsk Bearing Plant" (MPZ)				
Diamond bowl-shaped discs	Diamond material	Hard Alloys	1.9	
Interlocking face milling cutters	T15K6 Hard alloy	Structural and tool steel	2.1	
Filleting tools		Structural and tool steel	2.0	
OJSC Minsk Motorcycle and Bicycle Plant (MVZ or Motovelo)				Reduced in practice in 1994-2004 with economic impact - 57 millions BYR
Taps	P6M5 Steel	08КП Steel (HB143)	2.2-3.0	
		20 Steel	2.1	
		35 Steel	4.0	
		45 Steel	1.5-2.2	
		15X Steel	2.8-3.1	
Twist drills		35 Steel	4.2	
Reamers		35 Steel	2.0-4.0	
Disc milling cutter		45 Steel	2.0-8.0	
"Povazske Strojarne" (Slovakia)				
Drills	19824 Steel	Structural steel (HB 280)	2.4-2.9	
ZVL-LSA Skalica" (Slovakia)				
Heading discs	19732 Steel	14109 Bearing steel	1.8-2.0	
"Skloplast Trnava" Company (Slovakia)				
Knives/Blades	19824 Steel	Glass fibre	1.9-2.2	
"Daewoo Motor Polska" Company (Poland)				
Taps	SW7m Steel	30HM (HB 190)	3.0	
		20J (HB 145)	2.0	
"VUHZ" Company (Czechia)				
Drills	S6-5-2 Steel	Tool steels	2.0-2.5	
Bandsaws, Taps, Cutters	S6-5-2 Steel		2.5-3.0	
BNTU – "Stock" Company (Germany)				
Drills for deep drilling	HSS S6-5-2	45 Steel (HB180)	1.8	

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