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Abrasive Properties of Modified Oxides for Finish Polishing of Steel

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Abstract. The study of modified chromium and aluminum oxides, demonstrates that finish polishing by modified hydroxocomplexes based on a solid solution of iron and aluminum oxides provide a surface nanoroughness of 0.02 to 0.005 µm for the hardened ShKh15 steel (American Standard AISI 52100).

INTRODUCTION

In precision engineering and instrument engineering there is the problem of obtaining metal surface roughness less than 0.005 µm with a 10 G degree of precision for parts produced (GOST 3722-81). For final polishing, abrasive nanodispersed highly hard materials are used, for instance, natural and synthesized nanodiamond powders, as well as boron and silicon carbides, cubic boron nitride; in addition, ultramicropowders based on aluminum oxide (corundum) and silicon dioxide are also used. As a rule, the final polishing of precision items is carried out in 3–5 cycles with a consequent decrease in the grain size of the abrasive material in the composition of pastes and suspensions, which are applied for procedures of primary, final, and fine polishing.

At the same time, among the most effective abrasive powders there are transition-metal and rare-earth oxides with medium hardness (5–7 on the Mohs Scale): CeO_2, ZrO_2, Cr_2O_3, Al_2O_3, Fe_2O_3. They are, however, not always capable of ensuring a sufficient abrasion rate or surface roughness class. Solid solutions of oxides, e.g. chromia and alumina, offer a higher abrasive performance [1–3]. Modification of chromium oxide with the formation of solid solutions with REE and calcium results in increased polishability while providing a surface roughness of less than Ra = 0.08 µm [4, 5].

Aluminum and iron oxides prepared from hydroxycarbonate complexes are known to possess high polishing performance for final polishing of the quenched ShKh15 steel with austenitic-martensitic structure and to provide a nanorough surface owing to their high tribochemical activity [6–8].

Various methods are known for producing a nanoparticle powder material based on aluminum oxide, e.g. by pulsed heating; however, using such a material for polishing is not recommended, since it does not have correct abrasive particles with a crystal structure [9, 10]. Methods based on the preparation of sol-gel transition metal hydroxide with subsequent igniting, fail to produce a tribochemical effect in polishing, since not only nanosized particles are of importance during tribochemical activation, but also some complexes obtained from oxides [11]. Obtaining of nanoparticles of abrasive material by self-propagating high-temperature synthesis (SHS) or by a mechanochemical method does not provide the entire set of properties necessary to achieve the highest surface finish quality [12-14].

One attractive approach to the preparation of nanoparticles is chemical modification of layered structures through the formation of $M^{2+}_{1-x}M^{3}_{x}(OH)_2\left(X^{n-}\right)_{x/n}\cdot mH_2O$. Selecting and developing new abrasive materials should be based on the knowledge of the processes of polishing.

The purpose of this study is to compare the abrasive properties of oxide-based powder materials for finish polishing of metals with obtaining a nanorough surface.

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METHODOLOGY

The abrasive properties of samples in the polishing process were assessed by standard procedures of measuring the variation of polishability and surface roughness (Ra), with a Wyko NT1100 optical profiler, to find the arithmetic mean of the roughness profile with a sampling length of 0.08 mm. The source samples were made of hardened steel with an austenitic-martensitic structure, the initial value of Ra being 0.2 to 0.3 μm. The process performance (polishability) of polishing was evaluated by the formula

$$P = \Delta M / (S \cdot t),$$

where ΔM is a change in the mass of the samples during polishing, mg; S is the size of the polished surface, cm^2; t is the duration of polishing, min.

Surface roughness, Ra, is the arithmetic mean of the absolute value deviations within the profile length, and it is determined as follows

$$R_a = 1/n \cdot \sum |y_i|$$

RESULTS AND DISCUSSION

Polishing with the use of abrasive micrograined powder materials can be represented as a set of processes; namely, mechanical, adsorption, adhesion, wetting and oxidation of the surface layer. Previously, it was found that finish polishing is a mechanochemical process in the subsurface layer of metals. To obtain a surface roughness of less than Ra = 0.02 μm, the abrasive material must be chemically active in the process of friction [7, 9, 15 and 16].

Modification of chromium oxide with the formation of solid solutions with rare-earth elements and calcium has the effect of enhancing the polishing ability while providing a surface roughness of 0.07 to 0.08 μm. The use of chromium oxide modified by CaO and ZrO_2 improves the quality of polishing and increases the output of high-precision products made of the hardened ShKh15 steel by 80-82%.

The abrasive material produced by thermal treatment of ammonium, aluminum and iron hydroxycarbonate has high abrasive properties. The total reaction of hydroxycarbonate deposition can be presented as follows:

$$FeSO_4 + Al_2(SO_4)_3 + 9NH_4HCO_3 = NH_4Al_2Fe(OH)_5(CO_3)_2 \downarrow + 4(NH_4)_2SO_4 + 2H_2O + 7CO_2 \uparrow \quad (1)$$

As a result of thermal influence on ammonium hydroxycarbonate, solid solutions on the basis of hematite and corundum are formed,

$$\begin{aligned} &NH_4Al_{2-x}Fe_x(OH)_5(CO_3)_2 \cdot H_2O \xrightarrow{220\text{–}250^0 C} Al_{2-x}Fe_x(OH)_2O_2 \xrightarrow{300\text{–}340^0 C} Al_{2-x}Fe_xO_3 \xrightarrow{425\text{–}450^0 C} \\ &\xrightarrow{425\text{–}450^0 C} Al_2O_{3amorph} + \alpha - Fe_2O_3 \xrightarrow{950\text{–}1150^0 C} \alpha - Al_{2-x}Fe_xO_{3cryst} + \alpha - Fe_{2-y}O_{3cryst} \end{aligned} \quad (2)$$

To obtain the lowest surface roughness Ra = 0.002 μm, solid solution containing iron oxide in the range of 0.156 to 0.125 mol% must be used. This is due to the formation of solid solution phases based on corundum and hematite with nanosized particles. Extreme polishing ability is observed for samples based on the solid solution of aluminum and iron oxides (Fig. 1).

Figure 2 presents a dependence of surface roughness after polishing with a solid solution of iron and aluminum oxides (curve 1), with chromium oxide modified by CaO and ZrO_2 (curve 2) and with boron carbide B_4C (curve 3) on the polishing process time.

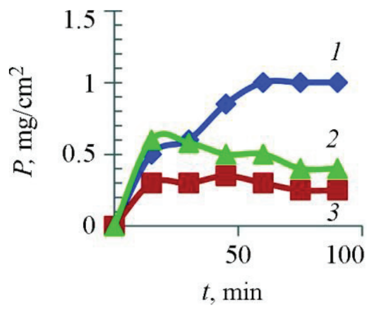

FIGURE 1. Abrasion ability *P* as a function of polishing time (Steel ShKh15): solid solution based on an aluminum-iron oxide (1), chromium oxide modified by CaO and ZrO_2 (2) and boron carbide (3)

The lowest roughness is demonstrated by the samples made of steel treated with a solid solution of aluminum and iron oxides (Ra = 0.002 to 0.005 µm). Polishing with boron carbide fails to provide surface nanoroughness. The data on deposition and the results of electron microscopy have shown that the samples based on the solid solution of aluminum-iron oxide (Fe_2O_3 0.12 to 0.156 mol%) contain nanoparticles with sizes up to 10 nm in the range of 4-5%.

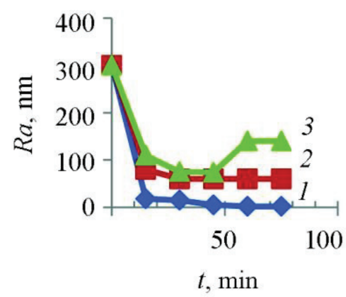

FIGURE 2. Surface roughness Ra as a function of polishing time: solid solution of aluminum-iron oxide (1); chromium oxide modified by CaO and ZrO_2 (2); boron carbide (3)

CONCLUSION

The study has revealed that the lowest surface roughness (Ra = 0.005 to 0.002 µm) of the finish-polished ShKh15 steel (American Standard AISI 52100) is obtained with the abrasive material based on a solid solution of aluminum-iron oxide. Polishing by currently used boron carbide and modified chromium oxide fails to provide a nanorough surface.

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