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ABRASIVE WEAR OF STEEL IN MOLDING EQUIPMENT

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Experimental studies of the wear resistance of steel 45 with a strengthened surface in the abrasive mass used as raw material for the porcelain-faience industry were conducted. The results of the studies can be used for selecting a method of strengthening of molding equipment.

Harsh working conditions in contact with moist abrasive mass are characteristic of the steel forming instrument used in the porcelain industry. The rapid wear of this instrument worsens the product quality and the necessity of changing it frequently causes the equipment to be shut down for a long time and decreases labor productivity. In this respect, the problem of increasing the abrasive resistance of the instrument for molding articles from a porcelain mass is very pressing. The strengthening technology should ensure approximately six-month operation of the equipment without replacement of the working organs before converting to other models or types of articles. It is necessary to have an idea of the kinetics and mechanisms of wear of steel in the specific medium of the crude porcelain mass for solving this problem.

The rate of abrasive wear, where mechanical loading of the surface layers of the metal predominates, should correlate with the surface properties of the worn instrument. The mechanism of failure is a function of the dynamics of contact of the abrasive particles with the surface.

The raw material used in the porcelain-faience industry is a free abrasive containing up to 70 vol. % solid oxide particles whose effect on the surface of metal with a different structure and hardness can be exercised according to different mechanisms of failure. The results of a study of the concrete conditions of surface wear of molding equipment are thus of both scientific and practical interest, since they will allow rationally selecting a strengthening method in the final analysis.

The kinetics of the relative wear of steel 45 used in the porcelain industry for fabrication of molding equipment were investigated with different methods of strengthening — bulk quenching, borating, and diffusion chrome plating. The studies were conducted on 10 × 100 mm cylindrical samples of steel 45. The thickness of the borated and chrome-plated layers was ~60 μm, the hardness was 14,000-16,000 MPa, and the hardness of the annealed and tempered samples was 2400 and 5900 MPa, respectively.

Wear was conducted according to a scheme of rotation in a container containing a porcelain mass with a 20-25% moisture content, and the rotation rate of the samples, close to the rotation rate of a molding roller and equal to 200-220 min^{-1}, was kept constant. The duration of the test was no less than 50 h for each type of sample. The wear was quantitatively estimated by the ratio of the weight loss of the sample after the next weighing to its initial weight. The error of measurement was $\pm$0.5 mg. The fracture surface and size and shape of the particles of the abrasive mass were investigated with an ISM-35C scanning electron microscope.

A typical photomicrograph of particles of the abrasive mass is shown in Fig. 1. Note that 0.5-30 μm particles are the basic structural elements of the abrasive, and most of the abrasive grains are coagulated into conglomerates of complex shape. The size of these conglomerates attains tens of micrometers, which is commensurate with the thickness of the strengthening diffusion layers.

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Fig. 1. Photomicrograph of abrasive particles in porcelain mass (×1600).

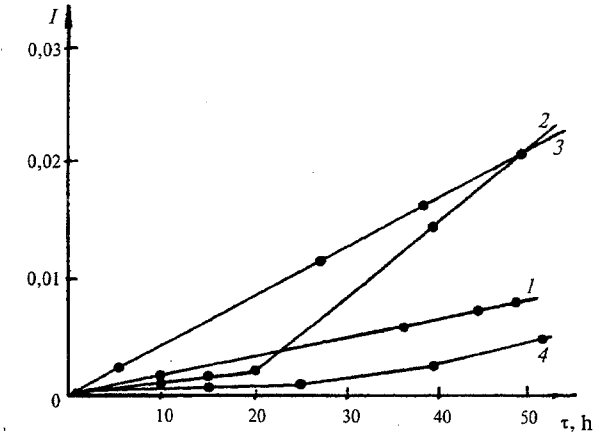


Fig. 2. Wear resistance of steel 45 under the effect of porcelain mass: 1) annealed; 2) tempered; 3) with borated layer; 4) with chrome-plated layer.

The kinetics of relative wear of the samples investigated are shown in Fig. 2, which indicates that the intensity of wear under the effect of the abrasive mass is inversely proportional to the surface hardness of the sample. The wear curves of borated and chrome-plated samples consist of two segments — regions with an insignificant increase in the degree of wear and regions with a pronounced tendency toward an increase in wear. This is probably due to the presence and absence of a strengthened diffusion layer and fracture of the borated layer is catastrophic after a certain period of time.

The study of the surface structure of worn samples showed that the mechanics of wear as a result of the effect of the abrasive mass are based on sliding of the abrasive particle over the surface of the sample and scratching of the surface by sharp edges. The character of the reaction of the particle and surface is determined by the shape and hardness of the particle and the physicomechanical properties of the surface of the steel.

If the surface is tough, as in annealed steel 45, the particles penetrate deeply, so-called "charging" of the surface. In this case, the brittle particle can be covered by the soft structural constituent and be exposed to a relatively significant mass of metal (Fig. 3a). Tempered samples are basically scratched by the sharp edges of the particle, the depth of penetration is low, the particles are separated from the wear surface by sliding, and the area of separation is different and sometimes very significant.

The borated surface has the highest hardness and is subject to brittle fracture; many cracks are formed as a result of the effect of the solid particles, the surface peels, separates, and sections of the layer are removed (Fig. 3b).

The chrome-plated layer does not crack, and the abrasive particles scratch the layer but do not cause important fractures (Fig. 3c). This is probably due to the specific features of the structure of the layer, which consists of a plastic α-Fe layer strengthened by finely disperse carbide particles, which withstands the impact effect of the solid abrasive particles.

According to some data [1, 2], the chrome-plated diffusion layer has a zonal structure: 1) a composition zone or a zone of carbides and a solid solution of chromium in α-iron; 2) a homogeneous zone or a zone of a solid solution of chromium in

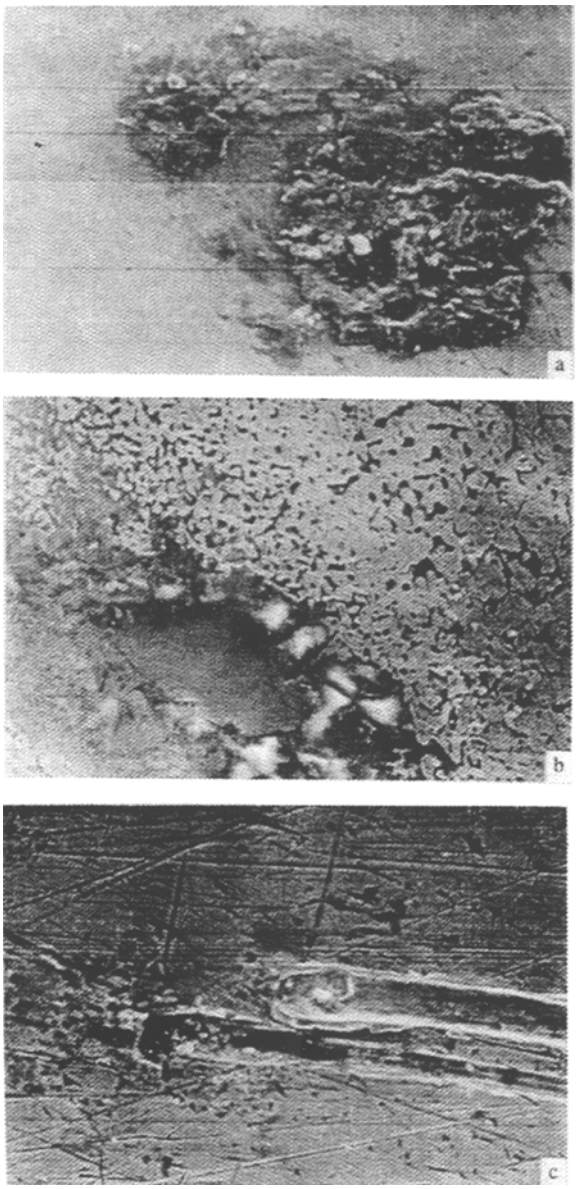


Fig. 3. Surface structure of wear of steel 45: a) annealed (×200); b) with a borated layer (×540); c) with a chrome-plated layer (×600).

α-iron; 3) an intermediate, hypothetically eutectoid, zone. Zone 1 has a high level of toughness which makes it possible to withstand high contact loads. Relaxation of deformation stresses in the solid solution in zone 1 and partially in zone 2 preserve the carbide grains and consequently also the high wear resistance of the layer. The diffusion layer is also preserved because the carbide grains do not chip due to the adhesive strength with the solid solution.

There are data on the possibility of increasing the wear resistance of chrome-plated diffusion layers due to incorporation of additional alloying components in the saturating mixture, carbon-containing organic compounds in particular [3]. The rate of wear is decreased in this case by changing the stoichiometric composition of the carbides toward formation of chromium carbide, Cr_7C_3, which has elevated microhardness in comparison to other carbides. However, the industrial use of this method is difficult due to the ecological requirements regulated by the possibility of escape of active gas into the air of the production premises. The search for available and ecologically clean methods of additionally increasing the wear resistance of chrome-plated diffusion layers in abrasive wear is thus pressing.

The experimental data reported suggest the necessity of comparing not only the hardness values but also the structure of the layer obtained with different strengthening mechanisms in studying wear resistance. The porcelain mass could be a good model material in studying the mechanism of abrasive wear.

A promising direction in the search for methods of decreasing the intensity of wear of molding equipment in the porcelain-faience industry is deposition of wear-resistant chrome-plated layers on the surface. The search for saturating mixture compositions which ensure the formation of optimum structures of a layer with the necessary set of physicomechanical properties is an important factor in the development of technology for fabricating such layers.

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