The first indications that the presence of oxygen in the friction zone may affect the character of friction and wear phenomena were observed in the investigations of Tomlinson (1929), Rozenberg (1931) and Fink (1932). Further studies in this field enabled the mechanism of oxidation of metal surface layers in friction to be elucidated, the foundations of the theory of oxidation-induced wear of metals to be laid [1-14].

More often than not oxidation-induced wear is suffered by machine parts in service. This type of wear was studied under conditions of dry [2, 3, 5, 7] and boundary-lubricated [1, 6, 8] sliding friction, as well as under rolling friction conditions [9, 12-14]. These investigations were carried out both on machine parts in service [1, 8, 9] and on various metal and alloy specimens under laboratory conditions [2, 3, 7, 8, 14].

The main cause of wear in both rolling and sliding friction under normal service conditions is periodic flaking off of secondary structures which are formed in the rubbing surface layers as a result of oxidation [10, 12]. Investigations of rolling friction revealed the duplex character of the part played in this process by oxygen [12, 14], enabled the oxygen concentration limits in the friction zone to be determined and methods of controlling the degree of surface oxidation in rolling friction to be suggested [13, 14].

The duplex role of oxygen in oxidation-induced wear of various metals in sliding friction was attributed to differences in chemical and mechanical properties of their secondary structures (oxides) [10, 11]. The existence of an inversion effect was established in studies of the influence of oxygen on friction and wear; this made it possible to classify various metals and alloys according to their wear-resistance in various ambient media [11].

Analysis of the results of studies of the effect of oxygen upon friction and wear (with particular reference to the laws governing the oxidation-induced type of wear) leads to a conclusion that the normal concentration of oxygen dissolved in lubricants (which, under normal service conditions, is determined by the oxygen concentration in atmospheric air) is not the optimum concentration from the point of view of friction and wear. Further studies are therefore necessary to elucidate the effect of oxygen concentration in the contact zone upon friction and wear, to determine the optimum oxygen concentration under various friction conditions and to develop methods of controlling the degree of surface oxidation so as to reduce to a minimum the degree of wear.

Fig. 1. Degree of wear of quench-hardened steel 45 plotted against ambient air pressure for specimens tested under a normal pressure of 10/kgf/cm² at the following sliding speeds: 1) 0.377 m/sec; 2) 0.18 m/sec; 3) 0.06 m/sec.

Fig. 2. Degree of wear of quench-hardened steel 45 plotted against ambient air pressure for specimens tested at a sliding speed of 0.06 m/sec under the following normal pressures: 1) 20 kgf/cm²; 2) 10 kgf/cm²; 3) 5 kgf/cm².
Hence the present investigation, in which friction and wear of carbon steels at various oxygen concentrations in the ambient atmosphere was studied.

Experimental Method

The tests were carried out under dry sliding friction conditions on steel 45, 80 and U10 tube specimens (6 mm long, 45 mm o. d., 36 mm. i. d.), the end faces of which were used as the rubbing surfaces. The specimens were heat treated to specified hardness values.

To attain the objectives of the investigation it was necessary to study the following:

(i) effect of air pressure in the $10^{-5}$ - 760 mm Hg range (i.e., the quantity of oxygen in the contact zone) upon the qualitative and quantitative characteristics (i.e., the form and intensity of wear;

(ii) effect of sliding speed and normal pressure upon friction and wear of steel in air at $10^{-5}$ mm Hg;

(iii) effect of mechanical properties (hardness) of the rubbing surfaces upon friction and wear of steel in air at $10^{-5}$ mm Hg.

Investigation of the Effect of Quantity of Oxygen Present Upon Friction and Wear of Steel

In this series of tests quench-hardened steel 45 specimens (HRC = 58) were used; the tests were carried out at sliding speeds of 0.06, 0.18 and 0.377 m/sec and normal pressures of 5, 10 and 20 kgf/cm². The quantity of oxygen in the contact zone was varied by changing the air pressure in the working chamber of a special friction testing machine between $10^{-5}$ and 760 mm Hg.

The results reproduced in Figs. 1, 2 and 3 show that both the character and intensity of wear of steel in air at low pressures are strongly dependent upon the sliding speed and normal pressure. Oxidation-induced wear, which takes place in air at relatively high pressures, changes to wear caused by seizure when the air pressure is sufficiently low. Both the position of the transition point and the intensity of wear depend mainly upon the normal pressure (Figs. 1 and 2). At a pressure of 5 kgf/cm² the intensity of oxidation-induced wear differs little from that of wear caused by seizure (Fig. 2, curve 3) because plastic deformation under these conditions does not develop to a sufficient degree.

Analysis of data in Fig. 1 and profilographs 3a and 3b show that oxidation-induced wear of steel takes place in air at 760-$10^{-3}$ mm Hg, the wear intensity reaching its minimum at pressures of 1-10 mm Hg. When the air pressure is reduced below $10^{-4}$ mm Hg, there is a sharp transition to wear caused by seizing; this is accompanied by an increase in the intensity of wear which, however, remains practically constant when the air pressure is further reduced (below $10^{-5}$ mm Hg).

A typical profilograph of specimens tested in air at very low pressures is shown in Fig. 3c.