Results are presented from experiments confirming the possibility of spontaneous deflagration of compact samples of five types of titanium alloy in oxygen flows. The minimum (critical) total oxygen pressures at the site where the flow acts on the surface leading to ignition of the material are determined. It is proposed that deflagration of the titanium alloys is initiated by discharges of static electricity in the flow owing to electrization of droplets and particles of water and other impurities contained in the oxygen.

The ability of titanium and its alloys to burn at normal temperatures in oxygen is well known and shows up in the destruction of titanium structures when the oxygen pressure exceeds a certain critical level \( P_{cr} \) [1-5]. This paper presents results from some experiments confirming the possibility of spontaneous deflagration of samples of titanium alloys in oxygen flows without special damage.

The subjects of the experiments were samples (13 × 13 × 1.5-4.5 mm) of VT 1-0 and VT 1-1 commercial titanium and OT4, VT6, and VT14 industrial alloys. A sample was rigidly attached to a metal holder at a fixed distance \( l = 1.0-6.0 \) mm in front of a nozzle (a metal nipple with an aperture diameter of \( d = 1.2-3.0 \) mm). The nozzle was attached through a valve and a pipe to a reservoir filled with gaseous oxygen \( (P_0 \leq 70 \text{ MPa}, T_0 = 300 \text{ K}) \). After the valve was opened the wide side of the sample was blown for 1-3 sec by a flow of oxygen (angle of attack 90°) from the nozzle aperture at the critical velocity \( (w_{cr} = 340 \text{ m/sec}) \). The experiments were done as a sequence of stepwise increases in the pressure in the reservoir (steps of 1 MPa) with ten shots of oxygen at each value of \( P_0 \). The entire apparatus was placed in an air atmosphere in a boxed-in area with remote control.

In order to determine the total pressure of oxygen at the metal surface \( P_w \) during the flow with a pressure probe (DDM100) some special calibration tests were performed on samples with holes in them at the site of the interaction with the flow. In other experiments the temperature of the sample in the flow was measured by a thermoelectric method.

It was found that for a sufficiently high oxygen pressure in the reservoir \( (P_0) \), a high velocity flow around the sample could, in a number of cases, produce ignition of the titanium surface. The combustion intensity and percent of burnt surface increased with \( P_0 \) (Fig. 1). The minimum (critical) pressure \( (P_{wcr}) \) at which the samples ignite did not change significantly with the sample thickness (from 4.5 to 1.5 mm) and turned out to depend on the distance from the sample to the nozzle cutoff and on the diameter of the aperture.

The calibration experiments showed that the total pressure at the sample surface also depends on these parameters in a way satisfactorily described by the equation

\[
P_w = A P_0 \exp\left(-B \frac{l}{d}\right),
\]

where \( A = 0.49 \) and \( B = 0.65 \).

In calculating the values of \( P_{wcr} \) for different combinations of \( l \) and \( d \) it turned out that the critical conditions for deflagration of the samples are attained at a definite value, for each alloy, of the total oxygen pressure at the point where the flux acts on the surface \( P_{wcr} \). The critical pressure for the materials tested are listed in Table 1. Also given there are the values of \( P_{cr} \) for these alloys during mechanical fracture of samples in oxygen under natural convection conditions [1, 2]. The ordering

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Fig. 1. Samples of VT 1-10 titanium (×3) after interacting with a flow of oxygen. p (MPa): (a) 19 (<\(p_{\text{cr}}\)), (b) 20 (\(p_{\text{cr}}\)), (c) 25 (>\(p_{\text{cr}}\)).

TABLE 1

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Critical pressure for deflagration of the samples (MPa)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>in a flow during fracture [1,2]</td>
</tr>
<tr>
<td>VT1-1</td>
<td>7.7</td>
</tr>
<tr>
<td>VT14</td>
<td>7.0</td>
</tr>
<tr>
<td>OT4</td>
<td>6.5</td>
</tr>
<tr>
<td>VT1-0</td>
<td>5.2</td>
</tr>
<tr>
<td>VT6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

TABLE 1

The critical pressures for deflagration of the samples are given in the table for different alloys and oxygen pressures. The critical pressure for deflagration of the samples is obtained in the present experiments is the same as in that determined under other conditions.

Beker [6] has explained the deflagration of preheated metal samples, including titanium, in supersonic air flows at elevated temperatures in terms of the heating of the samples to the ignition temperature as a result of the conversion of the kinetic energy of the gas flows into thermal energy. That explanation cannot explain the spontaneous deflagration of titanium in the present experiments since the samples were cooled to 270-280 K in the flow as a result of the throttling of the gas. The assumption that the kinetic energy of the oxygen molecules was sufficient to destroy the oxide film on the titanium and form a fresh metal surface was also unjustified.

In the author's opinion the most reasonable explanation of the experimental data can be obtained from visual observations and photographs of the gas flow around the samples. This revealed the following behavior:

- at the time the oxygen is started in a number of cases a luminosity in the form of a corona discharge or sparks could be seen in the gap between the nozzle and the sample (Fig. 2); a dark spot was seen on the surface of the sample after this at the point where the flow interacts with the spot (Fig. 1a);
- luminosity is observed in the flow when the sample is replaced by another material (stainless steel, copper, bronze) and disappears when the sample is removed;
- when a nonmetallic barrier is inserted or the sample has a nonmetallic coating (enamel, lacquer, teflon, silicate glass), no luminosity is observed in the flow; this luminosity also occurs when a metal sample is placed in a high pressure nitrogen flow;
- the luminosity of the flow and the deflagration of the samples are of statistical nature and are sensitive to the experimental conditions; in a series of experiments no luminosity or deflagration of titanium were observed when samples were placed in a gas flow with oxygen pressures in the reservoir of up to 70 MPa.

Beginning with these observations it would be logical to assume that the deflagration of titanium is initiated by an electrical discharge in the flow. In this case, as when titanium is ignited by a spark from a Rumkorff coil [7], the discharge...