THE IGNITION OF A LOW-ALLOY TITANIUM α-ALLOY DURING FRACTURE IN AN OXYGEN-CONTAINING ATMOSPHERE

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UDC 699.295:620.193

Owing to their high corrosion resistance and their high specific strength, titanium and titanium alloys are widely used in the chemical industry. However, it is known [1-3] that under certain conditions titanium and its alloys have a tendency to ignite in oxygen-containing atmospheres. In [4] is noted the occurrence of an explosive reaction between titanium and fuming nitric acid, and in [5, 6] is reported the ignition of titanium in chlorine and in liquid bromine at room temperature, and in iodine with slight heating. The basic requirement for the occurrence of ignition of titanium and titanium alloys in oxygen containing atmospheres in the simultaneous presence of the following three factors: oxygen, freshly formed surfaces, and the temperature necessary for the commencement of burning (oxidation reaction) of titanium materials. The critical pressure of oxygen, which gives rise to ignition, varies according to the experimental conditions (pressure, type of stressing and consequent nature of fracture, test temperature).

The present work is concerned with the study of the influence of various factors on the value of the critical oxygen pressure causing ignition in low-alloy titanium α-alloys: the partial pressure of oxygen in admixture with nitrogen under various types of loading (tensile, bending, and internal gas pressure on tube specimens); temperature; and sample dimensions.

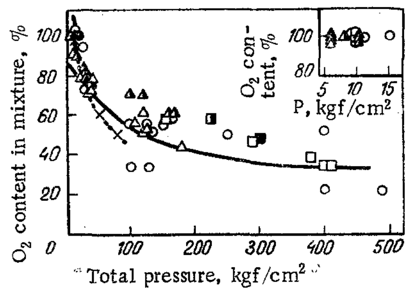
TABLE 1

Test conditions		Bend angle to fracture, in deg	Results of tests
Temp. °C	P in kgf/cm²		
25	20	90	Ignition and melting absent
400		180	Specimen did not break
		180	Specimen did not break
25	25	97	Ignition and melting absent
		90	the same
		90	the same
		90	the same
25	50	90	the same
	150	—	Sample ignited

Tensile tests in a mixture of oxygen and nitrogen were carried out in a special apparatus [7]. The oxygen/nitrogen mixture was prepared in an auxiliary high-pressure vessel and the oxygen content was determined before transfer to the working vessel. After filling this with the mixture, the specimens were tested in tension up to fracture. From 2 to 6 cylindrical specimens of 6 mm diameter and 60 mm gage length were tested under each set of conditions. The tests were conducted at pulling speeds of 1, 70, and 140 mm/min. However, as tests in pure oxygen had already shown, the pulling speed (within the range used) did not show any significant influence on the critical ignition pressure for the alloy.

The results of the tensile tests in the oxygen/nitrogen mixtures are shown in Fig. 1, where it can be seen that the pressure to produce ignition (or partial melting of the fracture surfaces) increases for decreasing oxygen content. It may be said that the limiting concentration of oxygen, in mixture with nitrogen, below which ignition or partial melting did not occur at the highest pressures attained was 35-40%.

All-Union Scientific-Research Institute for Petrochemical Processes, Leningrad. Translated from Fiziko-Khimicheskaya Mekhanika Materialov, Vol. 7, No. 1, pp. 16-19, January-February, 1971. Original article submitted August 21, 1968.



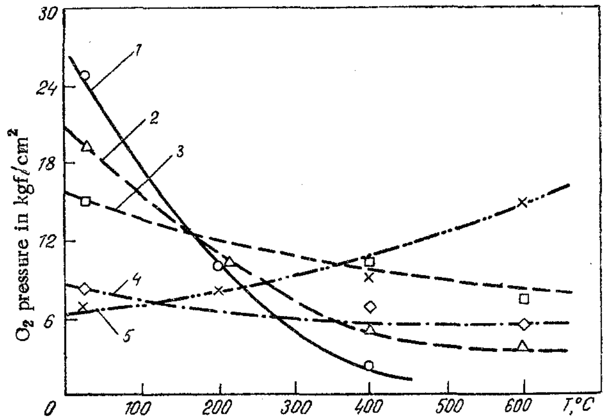


Fig. 1

Fig. 2

Fig. 1. Influence of oxygen content in the oxygen/nitrogen mixture on the critical pressure for ignition at room temperature (the P_{cr} for pure oxygen is shown in the top right-hand corner of the figure). Pulling speed 1 mm/min: ○) no ignition; ◐) fused areas on fracture surfaces; ●) with ignition. Pulling speed 70 mm/min: □; ◧; ■. Pulling speed 140 mm/min: △; ◭; ▲, ×) data from [1].

Fig. 2. Relation between critical oxygen pressure for ignition and testing temperature and specimen dimensions. (1) 3.0 × 0.15 mm; (2) 3.0 × 0.45 mm; (3) 3.0 × 1.0 mm; (4) 3.0 × 3.0 mm; (5) 3.0 × 5.0 mm.

In the tensile tests in air (21% oxygen) there was no case of ignition or partial melting at pressures up to 500 kgf/cm^2.

Bend tests on sheet specimens of the low alloy titanium α alloy were carried out in the same apparatus [7] using a special fitting enabling bending to be carried out on specimens 3 × 10 × 20 mm.

It can be seen from the results of the bend tests in oxygen (see Table 1) that at room temperature ignition occurs if the pressure exceeds 50 kgf/cm^2, i.e., at a pressure higher than the critical ignition pressure in the tensile case. This is apparently connected with the fact that the nature of the fracture from bending a plate is different from that obtained in a tensile test on a cylindrical specimen. A similar difference was discovered by other workers [1]. At higher temperatures (300-400°C) fracture did not occur with the bend tests, and therefore ignition did not come into question.

The bend tests in air on low alloy titanium α alloy at pressures up to 400 kgf/cm^2 at temperatures up to 400°, and also at pressures up to 300 kgf/cm^2 at temperatures up to 600°, showed that in these cases the alloy did not exhibit a tendency to ignite. At room temperature the specimens broke at bend angles between 80° and 100°, at temperatures of 300-600° the specimens did not break.

In order to evaluate the tendency of the alloy to ignite in air under different tensile conditions, tests were also carried out on the tube specimens fractured by internal air pressure. A special apparatus [8] was used for the tests, capable of providing a high pressure of compressed air inside the specimen. The pressure was determined by a manometer. The specimens were prepared from cold rolled tube of 32 mm I.D., and 2-2.5 mm wall thickness. After the specimens were broken, the nature of the fracture and the residual deformation (measured as circumference) were determined. The results of these internal pressure tests on tube specimens in air showed that at temperatures up to 600° the fracture was ductile with considerable opening. Ignition or melting of the fracture surface was not observed on any specimen.

The influence of specimen dimensions and temperature on the critical ignition pressure were studied in commercially pure oxygen on rectangular specimens of the following cross-sections, 3.0 mm by: 0.15; 0.45; 1.0; 3.0; and 5.0 mm. The gage length was 60 mm. The tensile tests on these rectangular specimens were carried out on the same apparatus as the cylindrical ones. After reaching the assigned temperature. the specimens were given one hour soak at temperature in air, and then oxygen was introduced into the vessel up to the assigned pressure. The results of the tests on specimens of various thicknesses at various temperatures are given in Fig. 2.

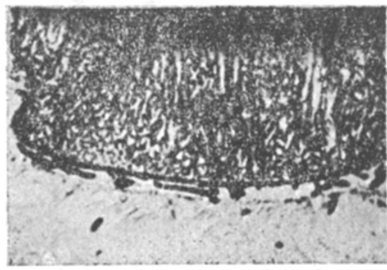


Fig. 3

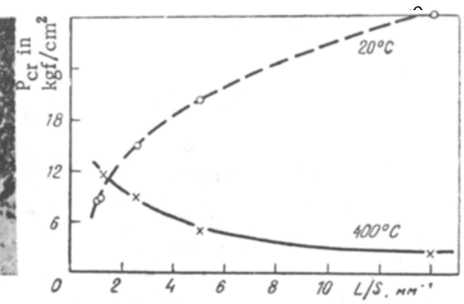


Fig. 4

Fig. 3. The metal structure at a place where melting occurred on the fracture surface (× 300).

Fig. 4. Critical oxygen pressure for ignition, P_{cr}, against the ratio of specimen cross-section perimeter (L) to cross-section area (S) for temperatures 20° and 400°.

As can be seen from the figure, the critical pressure of oxygen (P_{cr}) depends to a considerable degree on the temperature at fracture. As was established earlier [1, 9], in the tensile tests on plate specimens of 0.15, 0.45, and 1 mm thickness, P_{cr} decreases with increased test temperature, this effect being more sharply evident with the thinner specimens, a considerably lowered P_{cr} being already observed at temperatures of 100-200°. For the thickest specimens (3.0 × 5.0 mm) the relation between P_{cr} and the test temperature is reversed, with increasing temperature a tendency to a higher P_{cr} was observed.

The ignition of the specimens takes the form of combustion* of one or both of the fractured halves, or in partial melting in one or more places of the freshly formed surfaces (Fig. 3). Partial melting was observed principally on the large cross-section specimens (both rectangular and cylindrical).

The relation between P_{cr} and specimen dimensions was established at the same time as the relation between P_{cr} and test temperature. At room temperature P_{cr} decreased with increased cross-section area, but at high temperatures (400-600°) it increased.

The relation between P_{cr} and the ratio of lateral surface to volume (L/S) for temperatures 20° and 400° is shown in Fig. 4. From this it is seen that in tensile tests on the titanium alloy in oxygen, the relation between P_{cr} and the specimen dimension and the temperature is complicated. Whereas at room temperature P_{cr} increases with decrease of cross section (as measured by increase of L/S), for higher temperatures, 200° and above, the reverse was observed – P_{cr} decreases with decrease of specimen cross-section.

From the whole series of results the following conclusions may be drawn. When the concentration of oxygen is reduced, the total pressure of the gas mixture necessary to give ignition of the titanium α alloy is raised. The critical concentration of oxygen below which ignition of the alloy does not take place at pressures around 500 kgf/cm^2 is 35-40%. Ignition takes place, both in oxygen and oxygen containing mixtures, at lower pressures with tensile testing than with bend testing. When fractured at room temperature, thinner specimens require higher oxygen pressures to ignite; at elevated temperatures (200-600°) the reverse is the case. As the relation between the P_{cr} of low alloy titanium α alloy and specimen dimensions and temperature is complicated, it follows that it is necessary before using titanium wares in oxygen or oxygen-containing mixtures to carry out thorough tests on the alloys under conditions closely approximating those to be used.

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*When combustion of the specimen occurs, the oxygen pressure in the chamber falls as part of the oxygen is expended in burning the metal.

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