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Technical Physics

THE PROBLEM OF STRENGTHENING HIGH-PRESSURE VESSELS

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Rupture of a high-pressure vessel occurs when the stresses which arise under the action of the internal pressure in the walls of the vessel attain a definite magnitude, whose value depends on the strength of the material used for making the vessel.

Usually, the design of a vessel leads to a determination of the pressure at which the stress at the inner wall attains the yield strength of the material. An approximate solution of this problem is given by numerous theories of strength. It is known from experiment that thick-walled vessels sustain, before rupture, a pressure substantially larger than that calculated from these theories. This happens as a consequence of the fact that a significant amount of work-hardening of the material occurs during plastic deformation, and the stress distribution is improved in the so-called plastic zone [1]. However, even for the best modern steels, the rupture pressure of vessels, in which a plastic layer is spread over the entire thickness of the wall, does not exceed 20,000 to 25,000 kg/cm^2. In order to increase the pressure which a vessel can sustain, it is necessary either to lower the stresses in the walls of the vessel, or to have materials for its construction which possess much higher strength than contemporary steels.

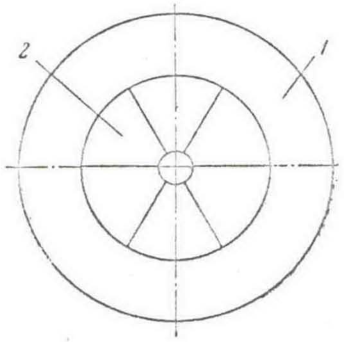

Fig. 1. Principle of the construction of the wedge vessel.

Various methods, described repeatedly in the literature, are used for lowering the stresses in the walls of a vessel — methods of hydraulic and mechanical backing, the method of concentrating the basic load on an area surrounded by a large mass of unloaded material, etc. [1].

In recent times, an important trend in the construction of high-pressure apparatus is the method of replacing tensile stresses in the structure by compressive stresses. This makes use of the fact that the strength in compression of such materials as tungsten carbide and hard steels is 3 to 4 times as large as the strength in tension. This principle is applied, for example, in a structure which is known under the name of a tetrahedral anvil [2], and it permits, even now, the attainment of pressures up to 200,000 atmos in conjunction with very high temperatures inside the apparatus.

In this structure, four pistons move in a highly viscous medium (pyrophyllite) in a direction toward a common center. The triangular plane ends of these pistons, between which is the pyrophyllite packing supporting them, form a tetrahedral "vessel" for high pressure. Thus, two fundamental problems are solved in the tetrahedral anvil structure: support of the moving piston, and the creation of a "vessel" for high pressure sustaining extremely large stresses and high temperatures.

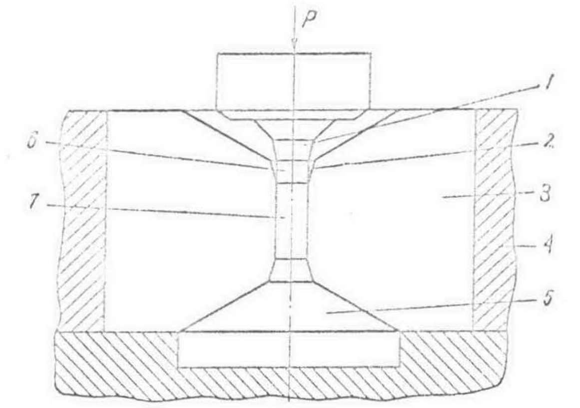

Fig. 2. Diagram of the construction of an apparatus with a wedge vessel.

However, the two indicated problems can also be solved separately with the use of the same principle which is used in the basic tetrahedral anvil. Without dwelling on the support of the piston, let us examine the problem of making a high-strength pressure vessel. Let us recall how thick-walled vessels act at pressures exceeding the ultimate strength of the material. A plastic layer, in which the equivalent stresses have a constant value independent of the pressure, is formed on the inner fibers of the vessel. The thickness of the plastic layer increases with increasing internal pressure. It turns out that the cylinder can be divided into two layers — plastic and elastic. The latter keeps the plastic layer from breaking. At some pressure, the elastic layer ruptures, having become thinner and thinner as a consequence of the thickening of the plastic layer over more and more of the wall thickness; this marks the onset of rupture of the entire apparatus. Experiment shows that high-pressure vessels do indeed crack on the outside.

Let us now represent the high-pressure vessel as made of two layers: an outer elastic band 1, and an inner layer consisting of several hard wedges 2 (Fig. 1). It is easy to see that the material of the wedges operates not in tension, but in compression, as a consequence of which the wedges can sustain a substantially higher pressure than the walls of an ordinary vessel. The pressure at the inner surface of the wedge cylinder (i.e., the cylinder formed from the wedges ground in to one another), is transmitted through the body of wedges to its outer surface. The value of the stress thereby is decreased (in the limiting case of no friction between the wedges) by the ratio R/r, where R and r are the outer and inner radii of the wedges.*

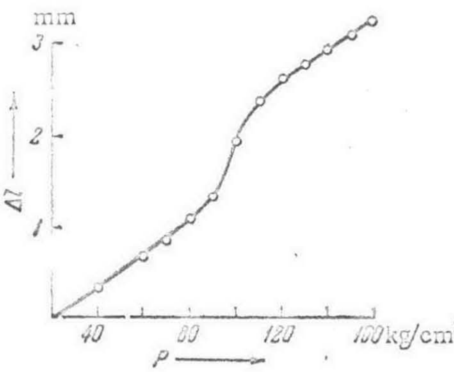

Fig. 3. Polymorphic transition of bismuth in coordinates of piston displacement versus pressure at the press multiplier.

On the basis of this principle, we designed and constructed the apparatus with a high-pressure vessel, a diagram of which is shown in Fig. 2. Four wedges 3 with spherical surfaces are carefully ground to one another and placed in a steel band to form the high-pressure vessel. The apparatus is closed at the bottom by the plug 5. A small steel cylindrical piston 6 is placed at the top in the bore formed by the wedges. The pressure on this piston is created by the conical piston 1. The shape of this piston was selected from the follow- considerations. It is known that the geometrically most-favorable form for specimens subjected to axial loading is a truncated cone. It withstands a larger pressure than a cylinder of the same area of cross section because the atoms on the truncated surface have mechanical bonds fanning outward, to the extent that the area increases in the direction of the base of the cone. For the same reason, we used wedges whose shape is nearly that of a truncated cone.

The specimen under investigation is placed inside of a pyrophyllite cylinder 7, which is situated in the bore. During motion of the piston, the pressure inside the bore increases rapidly, attaining a maximum at the end of the piston stroke. At this instant, the cone of the piston closes the wedge vessel, forming a compact assembly capable of withstanding a pressure higher than 50,000 atmos in conjunction with a high temperature in the given design.

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*It should be noted that the idea of the application of similar wedges in high-pressure apparatus was first expressed by P. V. Mil'vitskii, but it was not realized practically in his time.

In the structure described, the cylindrical and conical pistons 6 and 1 operated almost without backing (if the lead collar 2 is not counted), which permitted an evaluation of the pressure attained from the displacement of the pistons. Figure 3 shows the results of one of these experiments in which a small cylinder of bismuth was placed inside the pyrophyllite cylinder. The polymorphic transformation of bismuth, taking place at around 25,000 atmos, and accompanied by a decrease of volume, is clearly apparent from the break of the curve of piston displacement versus pressure on the press multiplier.

It follows, from an examination of Fig. 3, that, in this experiment, there was attained a pressure exceeding almost double the pressure of the bismuth transformation. It should be noted that experiments carried out repeatedly in an apparatus of the indicated construction, at pressures of around 50,000 atmos and temperatures to 1500° for several hours, did not leave any noticeable changes on the internal surfaces of the wedges forming the bore of the high-pressure vessel.

Obviously, the limit of pressures attainable in an apparatus of the described type can be raised by the application of backing to the moving piston, making the pistons and wedges out of hard alloys and, when necessary, construction of mechanical backing of the wedges by known methods.

M. D. Pyshkinskii participated in the work.

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