Table II, when thin samples of different metals are twisted between opposing anvils, an increase in the pressure exerted by the anvils results in increases in the torsional stresses required to shear the samples; however, the amount of increase in each case depends upon the specific metal involved. This data can be of assistance in the solution of metal-forming problems. More particularly, the comparatively low frictional increase exhibited by such materials as indium provides a clue to the solution of high interface friction problems.

PRESSURE GENERATING EQUIPMENT

To take advantage of the unusual properties of materials under high pressure it is necessary to provide equipment capable of containing the tremendous forces required. At the same time—and this requirement is one of the more difficult aspects of high-pressure work—the equipment should also be capable of being cycled repeatedly. To these ends a number of methods are now available.

The earliest form of high-pressure chamber, a piston and cylinder arrangement, continues to be the most useful for purposes of metal forming. Of such arrangements the simplest is a monoblock design consisting of an open heavy-walled cylinder filled with suitable fluid and pressurized by pistons thrust in from either end. The pistons, which are made of material capable of withstanding heavy compressive stresses, normally include special sealing gaskets designed to prevent the leakage of fluid.

This type of pressure vessel has a limited pressure-containing ability related to the yield strength of the material at the surface of the bore. Faupel has shown with good experimental agreement that the pressure P containable in such a vessel is given by

$$P = \frac{S_y\,(R^2 - 1)}{\sqrt{3\,R^4 + 1}}$$

where S_y is the yield strength of the material and R is the ratio of the outer to the inner diameter.[4]

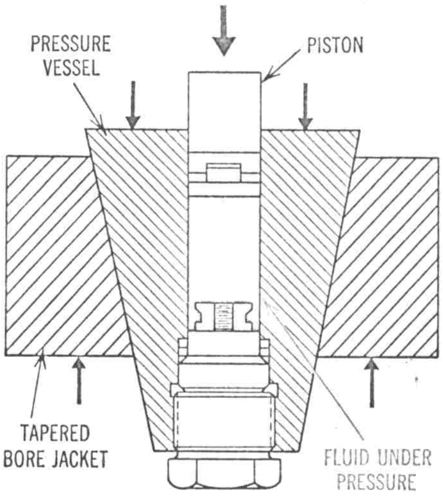

Figure 2. Use of a tapered bore jacket provides added radial support.

From this formula it can be seen that, even if the wall thickness of the vessel were increased indefinitely, the containable pressure would approach a limiting value equal to the yield strength divided by the square root of three. For the strongest available material, which has a yield strength of 300,000 psi, the maximum containable pressure in this type of vessel is thus less than 173,205 psi.

The situation can be improved considerably by making the vessel out of a series of shrunk rings such that a tangential compressive prestress exists at the bore before pressurizing. Yet even with this improvement limiting pressures are less than 250,000 psi.[5] Furthermore, if the pressure vessel is to be used for production cycling, it is necessary to use fatigue strength in place of yield strength as the measure of strength. In this case the maximum usable pressure becomes only about 150,000 psi for the best possible design.[6]

[4] J. H. Faupel, "Yield and Bursting Characteristics of Heavy-Wall Cylinders," *Transactions*, American Society of Mechanical Engineers, July 1956.

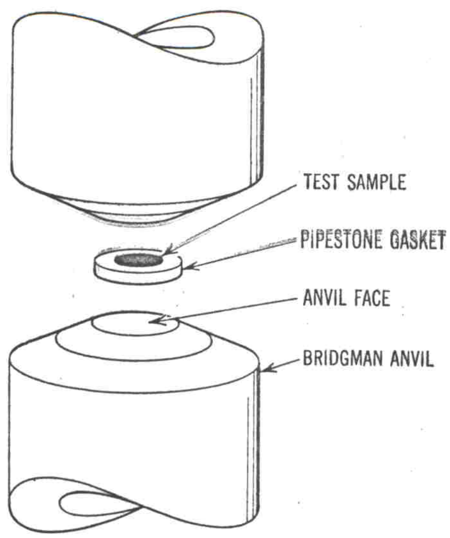

Figure 3. Conical anvils used for testing torsional shear strengths.

To attain higher pressures it is necessary to apply a radially supporting force to the outside of the pressure vessel. Bridgman found a way of supplying the required support by using a tapered bore jacket. As shown in Figure 2, the tapered jacket was forced down onto a pressure vessel designed with a matching taper on its outside surfaces. By coordinating the application of this support with the rise in pressure inside the vessel he was able to develop fluid pressures up to 450,000 psi.[7]

Although it is very useful, this type of equipment suffers from the difficulties involved in coordinating the increase in the radial pressure with that of the fluid pressure. In addition, variations in friction between the tapered members are hard to overcome.

On the other hand, the application of high pressure need not utilize fluid. For example, for testing thin materials under high pressure (as is normally done in torsional shear or friction tests) two opposing conical anvils are urged together by a press, as shown in Figure 3. While the sample compressed must necessarily be very thin to avoid extrusion out from between the ends of the anvils, it is possible to produce extremely high pressures by this method.

The pressures are made possible because the compressive forces, which

[5] The prestress provided at the bore by the shrunk rings can be added directly to the yield strength of the material. When a maximum prestress of 150,000 psi at the bore is added to a maximum yield strength of 300,000 psi, Faupel's equation shows a limiting pressure of approximately 250,000 psi.

[6] This figure is based upon a fatigue strength of 130,000 psi and a prestress compression of 130,000 psi.

[7] P. W. Bridgman, *Op. Cit.*, p. 38.