condition at which billet upsetting occurred. Consequently, it was possible to determine from these trials the parameters controlling extrusion of this alloy using the floating-mandrel arrangement.

Extrusion Ratio

Figure 30 summarizes the pressure data obtained at the nominal extrusion ratios of 2.7 and 2.5:1. Because the tubing billet was thin-walled, its area with respect to the mandrel cross-sectional area is small and therefore there is a large difference between billet-end-pressure and fluid pressure for tubing. It was not surprising that the fluid pressure required to produce solid rounds at a given extrusion ratio was more than twice that required for tubing. However, the billet-end pressure for tubing was higher than that for rounds by a larger factor than that for steel or aluminum. One possible explanation is that there might be a higher proportion of mandrel and die friction expended to extrude thin-walled tubing per unit volume of extrusion, than for the thick-walled tube blanks of 7075-O aluminum and AISI 4340 steel.

The low fluid pressures required to extrude tubing in comparison to those for solid rounds are indeed significant. However, the results indicated that, for the arrangement and tube dimensions used here, the maximum extrusion ratio was probably about 2.7:1. At this ratio (Trials 437 and 485), the unbalanced axial pressure of 157,000 psi on the billet was 25,000 psi in excess of the compressive yield strength of the material and billet upsetting occurred. Any higher extrusion ratios with the size tube blank would, of course, involve higher fluid pressures and hence billet upsetting.

Effect of Mandrel Taper

In the hydrostatic extrusion of thin-walled tubing, the mandrel taper is important because its magnitude causes appreciable variations in extrusion ratio along its length. In Trial 437, the mandrel taper used was 0.0012 in./in. which would cause variations in extrusion ratio of 2.6 to 2.9:1 over its 8-inch length. During extrusion runout, billet upsetting commenced at the point where the extrusion ratio was 2.7:1. Even though the mandrel taper was increased for Trial 485, billet upsetting again commenced when the ratio achieved during runout was 2.7:1. In both cases, the extrusion finish was excellent showing no signs of lubricant breakdown. Both the diameter of the mandrel and the mandrel taper were reduced in Trial 506 so that the maximum extrusion ratio was 2.7:1. However, the effectiveness of this procedure was not determined because some lubricant breakdown occurred at the commencement of extrusion and progressively became more severe, possibly resulting in premature billet upsetting. An extrusion ratio of only 2.5:1 was achieved which resulted in lower extrusion pressures than those obtained at 2.7:1. The data obtained at this ratio are plotted in Figure 30.

Lubrication

The best lubrication system for Ti-6Al-4V solid rounds, Coating 3 with Lubricant L17, also proved to be the most effective for tubing. Excellent surface finishes were obtained. However, Lubricant L33 both with and without the billet Coating C3 apparently was not as effective since a product was not obtained and billet upsetting occurred at high fluid pressure levels.

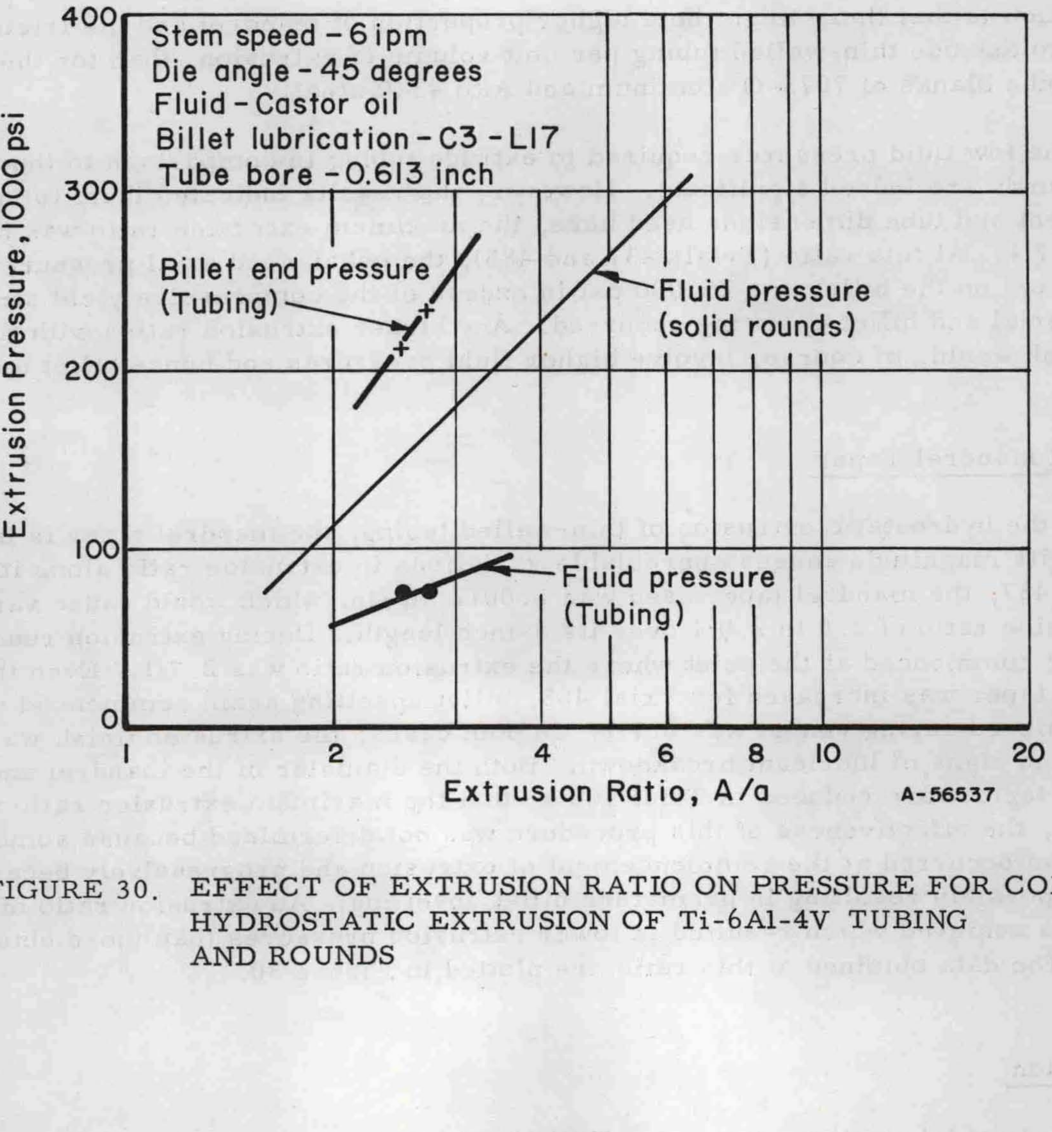

FIGURE 30. EFFECT OF EXTRUSION RATIO ON PRESSURE FOR COLD HYDROSTATIC EXTRUSION OF Ti-6Al-4V TUBING AND ROUNDS