	Constants $\times 10^{-3}$				Mean Yield Stress At True Strain, $\bar{Y}$, 1000 psi	Extrusion Pressure, 1000 psi	
Material	A	B	Reference	Extrusion Ratio		Actual	Predicted
1100-0 Al	1.16	14.1	7	2:1	13.7	14.6	9.5
				20:1	16.25	69.2	48.5
				200:1	19.0	122	101
AISI 4340	72.2	104	8	2.5:1	97.8	119	89.6
				6:1	161.8	233	290
Ti-6Al-4V	66.7	143	9	2.5:1	137.5	154	126
				4:1	168.8	229	234
A286	131.4	38.6	10	5:1	118.2	217	189

It is seen that the predicted extrusion pressures are of the same order as the measured extrusion pressures but that some rather large discrepancy exists. The predicted pressures are generally lower than the measured. The inaccuracies in predictions may be attributed to:

(1) Errors in extrapolation of the true stress-true strain curves. Except for 1100-0 aluminum most of these curves were obtained at true strains below unity, yet most of the extrusion ratios evaluated in Table VI represented strains beyond this level. To obtain true stress values at high levels of strain, a plane strain compression test would be necessary.

(2) Possible variations in strengths and work-hardening characteristics among materials of the same grade.

(3) Possible influence of effective temperature during extrusion on strengths of workpiece.

(4) Effect of neglecting die friction and non-uniform deformation.

In the remaining experimental work reported in Section 1 an investigation was conducted into hydrostatic compaction of Ti-6Al-4V alloy powder. At a pressure level of 225,000 psi, compacts having a 98 percent theoretical density were obtained.

This section also gives details of the effect of process variables on the mechanical properties of hydrostatic extrusions. The heavy cold work of hydrostatic extrusion gave high strength levels combined with good ductility. In some cases, the strength levels obtained were higher than could be achieved by other working processes.

VII

COLD HYDROSTATIC EXTRUSION OF 7075-0 ALUMINUM ROUNDS

The main process variables studied in the cold extrusion of 7075-0 aluminum were extrusion ratio, stem speed, and lubrication. Many trials were conducted at a ratio of 20:1 and a stem speed of 20 ipm with the aim of determining the best lubrication system for use at higher ratios and stem speeds, and for application to the extrusion of tubing and T-sections. These data are given in Table VI. Additional data obtained at higher ratios and/or stem speeds are presented in Table VII.

The development of a good lubrication system with 7075-0 aluminum was of primary concern because of the tendency of this alloy to stick-slip during extrusion. Stick-slip originated from momentary breakdown of the billet lubricant, most often at the point of breakthrough. The problem was overcome by the formulation of satisfactory billet lubricants and by billet nose design. Consequently, excellent surface finishes were obtained on extrusions made at ratios up to 60:1 and extrusion exit speeds as high as 250 fpm. In the earlier experiments with this alloy, surface cracking of the extrusion had resulted from bad lubrication.

7075-0 aluminum is known for its tendency to crack during conventional hot extrusion. To prevent cracking in this operation, the exit extrusion speeds are kept very low, in the order of 2-3 fpm. The exit speeds of 250 fpm obtained in hydrostatic extrusion offer significant potential advantages in a production operation.

The tensile and yield strengths of products extruded from annealed 7075-0 aluminum were doubled and tripled, respectively, without any sacrifice in ductility.

Extrusion Ratio

High-quality extrusions of 7075-0 aluminum were obtained over a range of extrusion ratios from 2.5 to 60. Figure 13 shows the relationship between fluid runout pressure and extrusion ratio. The upper curve in the figure depicts the data obtained with Lubricant L17. At ratios of 20:1 and above, stick-slip occurred with this billet lubricant. Later data obtained with Lubricant L53 at these ratios under good lubrication conditions are shown in the lower curve. Fluid-runout pressures were used in Figure 13 because they provide an accurate basis from which projections of pressure requirements can be made. The alternative measure, breakthrough pressure, is not so accurate because its level is sensitive to extrusion conditions such as stem speed and lubrication conditions and can vary from trial to trial under apparently identical conditions. The decrease in slope in the top curve at ratios above 20:1 may be associated with a decrease in the billet flow stress caused by adiabatic heating during deformation.

Extrapolation of the pressure requirements at the higher ratios indicate that ratios of 1000:1 are possible within the 250,000 psi pressure capacity of the hydrostatic extrusion container. The lubrication systems developed to date may not be capable of extension to such high ratios. In a single trial at 200:1, the lubricant (L53) broke down. However, other factors such as excessive adiabatic heating may be the limiting factor at these high ratios.