TABLE IV. BILLET CONVERSION COATINGS EVALUATED IN THE HYDROSTATIC-EXTRUSION PROGRAM

Coating	Source	Description	Billet Material Treated
C1	Commercial	Zinc phosphate coating	AISI 4340
C2	Battelle	Fluoride-phosphate coating	Ti-6Al-4V
C3	Battelle	Metal-free phthalocyanine	AISI 4340
C4	Battelle	Lead coating	AISI 4340
C5[a]	Watervliet Arsenal	Anodized coating	Ti-6Al-4V
C6[a]	Battelle	Diffused nickel-plating	Ti-6Al-4V

(a) C5 and C6 were numbered in the Interim Reports as C3 and C4, respectively, in error. However, duplication of coating numbers did not occur in the individual reports.

As a contrast, however, Coating C5 was always necessary in the cold hydrostatic extrusion of Ti-6Al-4V alloy at room temperature. Without C5, severe lubrication breakdown occurred often and resulted in a poor quality product. However, at 500 F, it was not necessary to use coatings with this alloy; excellent lubrication was obtained with billet lubricant (L33) alone.

IV

CHARACTERISTICS OF PRESSURE-DISPLACEMENT CURVES

The effectiveness of lubrication systems in hydrostatic extrusion is evaluated by comparing extrusion pressures, extruded surface finishes, and the general characteristics of the pressure-ram displacement curves produced during extrusion. The pressure-curve characteristics were found to differ considerably for different lubricant systems and billet materials.

It has been found that the extrusion pressure-displacement curves can be classified into families as shown in Figure 26. That figure is placed at the end of the text in Section 1 on a foldout page for ready reference when the extrusion data are being examined. Each family of curves is designated by a letter, and the number following it classifies the typical runout characteristics within each family.

Curves Types A, B, C, and D represent quality of lubrication in decreasing order of effectiveness. These curve types have been numerically classified further according to the following characteristics during runout:

Number	General Runout Characteristics
1	Constant
2	Decreasing
3	Increasing
4	Special

Type A Curves. One of the aims of the experiments on lubrication systems in the program was to obtain conditions giving a curve of Type A 1 which represents completely effective lubrication throughout the extrusion stroke. Experience has shown that once this type of curve is achieved, for a given material and extrusion ratio, other lubrication systems may not lower the value of P_r (runout pressure) markedly and therefore the curve very likely represents near-optimum lubrication conditions. There is no breakthrough pressure (P_b) peak above the runout pressure which suggests that the static friction, μ_s, is about the same as the kinetic friction coefficient, μ_k, developed once the billet starts to move.

The runout characteristics in the other Type A curves may represent partial lubrication breakdown due to pressure-temperature effects at the billet-die interface or changes in flow strength due to adiabatic heating of the billet.

Type B Curves. All the curves in this category are generally characterized by a rounded breakthrough pressure peak (P_b) followed by a smooth runout curve at a lower pressure (P_r). The occurrence of a rounded pressure peak has been attributed to the fact that μ_s is somewhat higher than μ_k(1), but not sufficiently to cause a sharp stick-slip peak. In some cases, the breakthrough pressure peak is sharp, indicating a stick-slip situation at breakthrough only.

Type C Curves. These curves are similar to Type B curves except that one or a few cycles of stick-slip follow the breakthrough pressure peak. Here stick-slip is generally not severe, its amplitude decreasing to give a smooth runout curve.