PTFE lacquer (L38, Trial 398) also yielded a good extruded surface finish and a low breakthrough-pressure peak. However, continuous increase in the runout pressure after breakthrough indicated some lubrication breakdown.

Other lubricants investigated (L30, L40, L43, and L44) either did not permit breakthrough at relatively high pressures or, if breakthrough was achieved, broke down to the extent that severe stick-slip occurred during runout.

Effect of Temperature

Pressures for hydrostatic extrusion of Ti-6Al-4V at 400 F are plotted against extrusion ratio in Figure 19 with the pressures required at 80 F and 120 F. It is seen that in comparison with the pressures required at 80 F the pressures were reduced by 12 to 15 percent when extruding at 400 F. It is recognized, however, that a portion of this reduction may be attributable to other process conditions (including lubricants and fluids) which, of necessity, were changed for extrusion at 400 F.

Mechanical Properties of Ti-6Al-4V Titanium Alloy Rounds Produced by Cold Hydrostatic Extrusion

Tensile evaluations on Ti-6Al-4V alloy extrusions were not conducted in this research program because a study of their mechanical properties was made earlier[1]. A summary of the data for extrusion ratios of 3.3:1 and 4:1 is given in Table XXI.

TABLE XXI. TENSILE PROPERTIES OF Ti-6Al-4V ALLOY ROUNDS PRODUCED BY HYDROSTATIC EXTRUSION

Stem speed - 6 ipm Exit speed - 60 ipm Die orifice - 3/4-inch diameter

Extrusion Ratio	Reduction in Area of Extrusion, percent	Trial	Ultimate Tensile Strength, 1000 psi	Yield Strength (0.2 Percent Offset), 1000 psi	Reduction in Area in Tension, percent	Elongation in 1 Inch, percent
1	0	As-received billet stock	143	135	39	21
1	0	Typical heat-treated properties	165	150	50	15
3.3	70	191	181	162	31	11
4	75	193	184	165	31	11

The strength levels obtained were significantly high for this alloy and were combined with reasonably good ductility. In fact, by heat treatment, a tensile strength of 165,000 psi and a yield strength of 150,000 are near the limits obtainable. Heat treatment, however, clearly provides for greater ductility than obtained by extrusion at this lower strength level.

Judging by the marginal increase in strength obtained in raising the extrusion ratio from 3.3 to 4:1, further increases in ratio probably may not cause any marked changes in the levels obtained.

X

HYDROSTATIC COMPACTION AND HYDROSTATIC EXTRUSION OF POWDER COMPACTS OF Ti-6Al-4V ALLOY POWDER

Hydrostatic Compaction of Ti-6Al-4V Titanium Alloy Powder

The hydrostatic extrusion process might be incorporated in several possible approaches in the area of compaction and extrusion of metal powders:

(1) Simultaneous hydrostatic compaction and extrusion of powder billets with or without subsequent sintering.

(2) (a) Hydrostatic compaction of powder billet
(b) Sintering of billet
(c) Hydrostatic extrusion of sintered billet.

The second approach was selected for investigation in this program, although it would be worthwhile to explore the first method as well sometime in the future.

Ti-6Al-4V prealloyed powder was selected for evaluation because of the strong current interest in it for aerospace applications, and also because of the opportunity to compare its mechanical properties with those obtained from the wrought alloy previously hydrostatically extruded in the program. The as-received Ti-6Al-4V powder was made by mechanical attrition and was shipped to Battelle under a helium atmosphere to minimize oxygen contamination.

In preparation for compaction, five rubber bags with nominal internal dimensions of 1-7/8-inch-diameter by 10 inches long were filled with powder. The compacts were vibrated during loading and the maximum fill density achieved was 2.04 g/cc or 46 percent of theoretical density based on the theoretical density of 4.43 g/cc for this titanium alloy.

Two billets were produced by compacting at a fluid pressure of 60,000 psi and three billets were compacted at fluid pressure of 225,000 psi. Each compact was held at pressure for between 10 and 15 seconds before the maximum pressure was slowly released. To compensate for shrinkage during compaction and the consequent lowering of fluid level in the container, the three billets pressed at 225,000 psi were compacted at two intermediate pressures, 15,000 and 65,000 psi. On attaining these pressures, the pressure was removed and fluid added, but the compacts were not disturbed.

The compacted billets were sintered at 2200 F for 1 hour in an argon atmosphere and water quenched as is customary with this alloy. One of the billets pressed at 60,000 psi broke up upon quenching. The theoretical densities of the billets before and after sintering are given below:

Compacting Pressure, psi	Percent of Theoretical Density: Before Sintering	Percent of Theoretical Density: After Sintering
60,000	93.4	93.2
225,000	97.5	97.5