A vacuum-fusion chemical analysis was made on the starting Ti-6Al-4V alloy powder and on samples of a billet after pressing to determine the oxygen and hydrogen levels. The results follow:

	O_2, ppm	H_2, ppm
Powder, as-received	700±20	140±3
Billet, pressed-and-sintered	1900±20	175±5

Although the oxygen level increased during processing it was only 100 ppm greater than industry specification for titanium and this level should not have caused the quench cracking obtained. The oxygen and hydrogen pick-up could have originated from either loading prior to compaction or in sintering. Metallographic examination showed the voids in the microstructure to be expected for material 97 percent dense. No directional effects were noted in the microstructure.

Two tensile tests were conducted on the specimens hydrostatically compacted at 225, 000 psi. The ultimate tensile strength values were 120, 800 and 107, 500 psi. Both specimens exhibited brittle fractures and elongation values of zero. The properties of sintered compacts made by conventional compacting techniques (cold pressing) were reported by the powder supplier to be approximately 150, 000 psi ultimate tensile strength and 4 percent elongation. The sintering conditions detailed above were generally as recommended by the powder supplier but they apparently were inadequate and perhaps resulted from incomplete bonding between the particles during sintering. Additional precautions to prevent oxygen pick-up might also assist in improving mechanical properties.

Hydrostatic Extrusion of Powder Compacts of Ti-6Al-4V Alloy Powder

Two billets obtained from hydrostatic compaction of Ti-6Al-4V alloy powder at 225, 000 psi were prepared for hydrostatic extrusion. A nose conforming to the die-entry angle of 45 degrees was machined on the billets. They were anodized with the C5 coating, lubricated with L17 and attempts were made to extrude them at a ratio of 3.3:1 at a stem speed of 6 ipm. These were the extrusion parameters that produced good extrusions from wrought Ti-6Al-4V alloy billets. Each powder-compacted billet, however, fractured in the die entrance at about 225, 000 psi and no material could be salvaged for testing (Trials 527 and 532). The breakthrough pressures required for wrought material under the same conditions are about 210, 000 psi. Severe galling that occurred between the powder-compact billet and die during extrusion caused considerable die wear. This galling probably accounted for the higher pressure requirements. The poor extrusion behavior exhibited here was not surprising in view of the low ductility detected in tensile tests on the materials.

XI

HYDROSTATIC EXTRUSION OF SUPERALLOYS ALLOY 718 AND A286

The objective of this series of trials was to determine the extrudability of the A286 (iron-base) and Alloy 718 (nickel-base) superalloys. The results obtained are shown on Table XXII. With both alloys, good lubrication and excellent extrusion surface finishes were obtained.

TABLE XXII. EXPERIMENTAL DATA FOR HYDROSTATIC EXTRUSION OF SUPERALLOYS

Die angle – 45 degrees (included
Fluid – Castor oil at 80 F
Polyphenyl ether (PPE) at 500 F

Billet surface finish – 60-100 microinches (RMS)
Billet lubricant – L38
Billet diameter – 1-3/4 inches
Stem speed – 20 ipm

Trial	Extrusion Ratio	Extrusion Temperature, F	Extrusion Pressure: Breakthrough Stem	Extrusion Pressure: Breakthrough Fluid	Extrusion Pressure: Runout Stem	Extrusion Pressure: Runout Fluid	Type of Curve(b)	Length of Extrusion, inch
			Superalloy – A286 (iron-based)					
479	3.3:1	80	198	173	190	165	B1	13
480	5:1	80	280	234	258	217	B1	19
500	5:1	500	235	(a)	217	--	B3	5
			Superalloy – Alloy 718 (nickel-based)					
481	3.3:1	80	273	225	258	217	B1	15
484	3.3:1	80	285	238.5	270	226.5	B1	11
499	3.3:1	500	245	(a)	228	--	B3	3

(a) Fluid pressure gage out of order.
(b) See Figure 26.

A286 and Alloy 718 billets were received in the solution-treated condition. The initial hardnesses were 12 R_C and 16 R_C, respectively. All billets were lubricated with L38 (PTFE) and extruded at a stem speed of 20 ipm through standard-profile dies of 45-degree included angle.

It is particularly noteworthy that all extrusions were free of cracks. Extrusion at 500 F at the same ratios reduced the pressure requirements by about 15 percent. The lubrication here was not quite so effective as at room temperature because on runout lubricant breakdown resulted in increasing pressures.

Tensile Properties of Hydrostatic Extrusions of Alloy 718 and A-286 Superalloys

The results of tensile tests and hardness measurements made on hydrostatic extrusions of these superalloys are shown in Table XXIII. Prior to testing, each alloy was given a recommended aging heat treatment. Alloy 718 was heated at 1325 F for 8 hours, cooled 100 F/hr to 1150 F, held at 1150 F for 8 hours and air cooled. The A286 samples were heated at 1325 F for 12 hours and air-cooled.