TABLE 3. EXPERIMENTAL DATA FOR COLD HYDROSTATIC EXTRUSION OF AISI 4340 STEEL ROUNDS

Die Angle - 45 degrees (included)
Fluid - Castor oil

Stem speed - 20 ipm

			Extrusion Pressure, 1000 psi						
			Breakthrough		Runout		Type of	Length of	
	Extrusion	Billet					Curve	Extrusion,	
Trial	Ratio	Lubricant	Stem	Fluid	Stem	Fluid	(see p 25)	inches	Comments
277	5	L17	240	224	240	217	B1	14	Reference Trial[4]
429	5	L38	267	230	264	218	B1	13	--
430	5	L31	266	230	262	217	B1	10	--
462	5	L53	260	225	255	221	B3	11	--
465[a]	5	L17	255	219	255	219	A1	14	--
451	6	L17	285	246	--	--	--	--	P_b not achieved

(a) Fluid used was silicate ester.

TABLE 4. EXPERIMENTAL DATA FOR COLD HYDROSTATIC EXTRUSION Ti-6Al-4V ALLOY ROUNDS AND TUBING

Die Angle - 45 Degrees (included)
Fluid - Castor oil
Stem Speed - 6 ipm

Tube Dimensions
Billet - 0.750" O.D. x 0.069" wall
Extrusion - 0.663" O.D. x 0.030" wall

					Extrusion Pressure, 1000 psi						
		Extrusion	Billet Lubrication		Breakthrough		Runout		Type of Curve	Length of Extrusion,	
Trial	Billet Type	Ratio	Coating	Lubricant	Stem	Fluid	Stem	Fluid	(see p 25)	inches	Comments
374	Solid Round	3.3	C3	L17	223	206	207	195	B1	9-3/4	Reference Trial[5]
450	Solid Round	3.3	C3	L31	250	222	220	196	C4	6-1/2	--
426	Solid Round	3.3	C3	L38	232	204	216	192	B4	6-1/2	--
427	Solid Round	4	C3	L33	291	245	--	--	--	--	P_b not achieved
466	Solid Round	4	C3	L31	285	250	--	--	--	--	P_b not achieved
437	Tube	2.5	C3	L17	85	79.5	85	77	B3	4-1/2	--
438	Tube	2.5	None	L33	103	94.5	--	--	--	1/2	P_b not achieved
439	Tube	2.5	C3	L33	104	98.5	--	--	--	5/8	P_b not achieved

In extrusion of solid rounds at an extrusion ratio of 3.3:1, products having good surface finishes were obtained with both L31 (fluorocarbon telomer) and L38 (PTFE). However, severe lubricant breakdown occurred after breakthrough in both cases. By comparison, L17 on C3 (see Trial 374) did not breakdown and gave a uniform pressure during runout.

At an extrusion ratio of 4:1, Lubricants 31 and 33 were evaluated. However, breakthrough was not achieved in either case by fluid pressures in the range of 245,000-250,000 psi. It is worthwhile to point out, however, that L33 was a very effective lubricant in hydrostatic extrusion of Ti-6Al-4V at 400-500 F[6] even without C3 coating. This was also true for L38 which, as mentioned above, was not effective at 3.3:1 at room temperature.

COLD HYDROSTATIC EXTRUSION OF WROUGHT TZM MOLYBDENUM ALLOY AND BERYLLIUM ROUNDS

The results obtained in several hydrostatic extrusions of TZM molybdenum alloy rounds and a single extrusion of beryllium are presented in Table 5. Both materials are discussed together because each displayed similar cracking tendencies during cold hydrostatic extrusion. In fact, crack-free extrusions at extrusion ratios greater than 2:1 of both these materials are generally obtainable only when the product is hydrostatically extruded into a fluid back-pressure chamber[7, 8]; this technique is sometimes referred to as differential-pressure hydrostatic extrusion or fluid-to-fluid extrusion. An alternative method is being investigated in the current program with the aim of eliminating the complexity and limitations of a second high-pressure fluid container. This method, described below, is based on novel die design concepts.

DIE DESIGN

Figure 7 shows two die designs intended for use with materials which exhibit circumferential ("rattlesnaking" or "fir-tree") cracking or longitudinal cracking. The standard die design used is also included. The controlled-relief die was designed to effect a gradual release of the elastic stresses present in the extrusion on exit from the die land. To determine the amount of taper relief required, the elastic strain on exit was calculated based on an estimated flow strength of the extruded product. Two dies of this type were made: one for use at a ratio of 2.5:1 where the controlled relief was 10' (minutes) x 1/4-inch long (β x L in Figure 7) and the other for use at a ratio of 3.3:1 where the controlled relief was 1' 35" x 2 inches long.

It was thought that cracking might also be prevented by applying a longitudinal compressive stress to the extruded product during exit from the die. This was achieved by using a double reduction die shown schematically in Figure 7. The die was made in two pieces with six radial ports at the side which could be opened or closed to the fluid pressure in the container. This enabled the die to apply an axial compressive stress to the extrusion under two conditions. One condition is where the extrusion is surrounded by a high fluid pressure which also assists in lubrication for the second reduction; the other is where the second reduction takes place "dry", i.e., without fluid pressure.