TABLE 3. EXPERIMENTAL DATA FOR HYDROSTATIC EXTRUSION OF Ti-6Al-4V TITANIUM ALLOY

Die angle – 45 degrees included
Fluid – Castor oil

Nominal tube dimensions -
Billet - 0.750 OD x 0.069 wall
Extrusion - 0.663 OD x 0.030 wall

Trial	Objective or Variable	Temperature, F	Extrusion Ratio	Stem Speed, ipm	Billet Nose Design[a]	Billet Lubrication: Coating	Billet Lubrication: Lubricant	Extrusion Pressure, 1000 psi: Breakthrough Stem	Breakthrough Fluid	Runout Stem	Runout Fluid	Type of Curve, p 25	Length of Extrusion, inch	Comments
					Rounds									
376	Reference	80	4	6	S	C3	L17	271	242	242	222	D3	9	Interim Report VI
487	Elimination of stick-slip	80	4	20	C, A = 1.2	C3	L17	266	228	240	207	B1	13	
416[b]	Reference	400	4	6	S	None	L33	212	198	206	194	B2	8-1/4	Interim Report VII
496[b]	Lubricant	400	4	20	C, A = 1.2	C3	L33	210	195	198	187	B2	12	
		Mandrel Dimensions: Max Diameter, in.	Mandrel Dimensions: Taper, in./in. on Diameter		Tubing (80 F)									
437	Reference	0.613	0.0012	2.5[c]	6	S	C3	L17	85	79.5	87	77	B3	4-1/2	Interim Report VIII
485	Mandrel	0.613	0.002	2.5[c]	20	S	C3	L17	84	79	81	78	B3	10	
506	Mandrel	0.606	0.0008	2.5[c]	20	S	C3	L17	85	75	84	74	B3	6-1/2	

(a) S - Standard nose; C - compound nose, 45 degrees at apex, 30 degrees beyong diameter A in.
(b) Fluid - silicate ester.
(c) Nominal ratio; ratio varied slightly over tube length because mandrel was tapered.

Tubing

Hydrostatic extrusion of Ti-6Al-4V tubing was continued with the aim of investigating the mandrel-design requirements for continuous extrusion of tubing from thin-wall tube blanks without billet upsetting. Data are given in Table 3 for the two trials conducted in the current series and for a single trial (Trial 437) previously reported in which billet upsetting had occurred. Billet upsetting occurs when the billet end pressure developed from the mandrel guide exceeds the fluid pressure by roughly the billet's compressive yield strength. (The billet end pressure can be greater than the fluid pressure because of the unsupported cross-sectional area of the mandrel).

In Trial 485, the mandrel taper was increased over that used in Trial 437 and this allowed a longer length of extrusion to be obtained. However, the diameter on the mandrel at the point where billet upsetting commenced for both these trials was approximately 0.608 inch. This diameter represented an extrusion ratio of about 2.7:1 in both cases. The billet end pressure was apparently sufficiently high at this ratio to preferentially cause upsetting rather than to effect further extrusion.

Thus in Trial 506, the maximum mandrel diameter was reduced in order to lower the maximum extrusion ratio to below 2.7:1 in an attempt to prevent or minimize billet upsetting. However, the effectiveness of this procedure was not determined because some lubricant breakdown occurred at the commencement of extrusion and progressively became more severe, possibly resulting in premature billet upsetting. The reduced extrusion ratio caused the extrusion pressures to be lower by about 5 percent compared with Trials 437 and 485.

Compaction

The hydrostatic extrusion process offers 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 has been selected for investigation at this point, 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 Ti-6Al-4V powder was made by mechanical attrition and was shipped under a helium atmosphere to minimize oxygen contamination. Five rubber bags with nominal internal dimensions of 1-7/8-inch-diameter by 10 inches long were filled with powder.