TABLE III. BILLET LUBRICANTS EVALUATED IN HYDROSTATIC EXTRUSION PROGRAM

Lubricant	Source[(a)]	Description
L1	C	Sodium stearate soap lubricant
L2	C	Lithium-soap grease containing MoS_2
L3	B	Silver chloride (solid lubricant) .... 15.9 wt% 30 percent lead naphthenate in oil (E. P. agent)............................ 11.9 wt% Calcium-soap grease (base material).. 72.2 wt%
L4	B	Cadmium iodide (solid lubricant)...... 15.9 wt% 30 percent lead naphthenate in oil (E. P. agent)............................ 11.9 wt% Calcium-soap grease (base material).. 72.2 wt%
L5	C	E. P. grease
L6	B	30 percent lead naphthenate in oil (E. P. agent)............................ 2 wt% Antimony diamyl dithiocarbamate (E. P. agent)............................ 2 wt% Dibenzyl disulfide (E. P. agent)........ 2 wt% Ortholeum (commercial E. P. agent)... 2 wt% Chlorowax 40 (commercial E. P. agent). 2 wt% Calcium-soap grease (base material)... 90 wt%
L7	C	Graphite contained in volatile carrier (aerosol spray)
L8	B	10 wt% graphite in commercial self-drying, semihydrogenated gum resin
L9	B	20 wt% MoS_2 in commercial self-drying, semihydrogenated gum resin
L10	B	50 wt% MoS_2 in epoxy resin
L11	C	"Castor wax" (hydrogenated castor oil; 158 F m. p.)
L12	B	5 percent antimony phosphorodithioate in lead dinonylnaphthalene sulfonate.......... 5 wt% Non-soap thickened mineral oil........ 95 wt%
L13	C	MoS_2
L14	B	10 wt% graphite in castor wax
L15	C	Chlorinated paraffin (70 percent chlorine)
L16	C	Fluorosilicone fluid thickened with PTFE
L17	B	20 wt% MoS_2 in castor wax
L18	B	20 wt% PbO in castor wax
L19	C	Polyethylene glycol of a waxy consistance, MP 143 F and MW 6000
L20	C	L19, but MP 111 F and MW 1540
L21	C	Microcrystalline petroleum wax, MP 180 F
L22	B	20 wt% MoS_2 in polyethylene gylcol, MW 1000
L23	B	20 wt% MoS_2 in low-melting castor oil product
L24	B	20 wt% I_2 in naphthalene
L25	B	20 wt% I_2 and 10 wt% MoS_2 in naphthalene
L26	B	20 wt% I_2 in chlorinated terphenyl (42% chlorine); Arochlor 5442
L27	B	50 wt% I_2 in oleic acid
L28	C	20 wt% MoS_2 in chlorinated paraffin (70% chlorine); Chlorowax
L29	C	20 wt% MoS_2 in chlorofluorocarbon wax, MP 200 F; Kal-F wax
L30	B + C	Cindol 4616, 50% 4616 castor wax, MP 70 F
L31	C	Fluorocarbon telomer
L32	C	Polyethylene bag
L33	B	55 wt% MoS_2 and 6 wt% graphite in sodium silicate
L34	B	50 wt% MoS_2 in castor wax (more than 20 wt% MoS_2)
L35	B	20 wt% graphite in castor wax
L36	B	66 wt% graphite in soda ash paste
L37	C	Eutectic salt
L38	C	PTFE lacquer
L39	B	20 wt% I_2 and 20 wt% MoS_2 in chlorinated terphenyl (42% chlorine); Arochlor 5442
L40	C	Flurosilicone/PTFE; Supermill 125
L41	B + C	20 wt% MoS_2 and Supermill 125
L42	C	Shell ETR
L43	B	20 wt% MoS_2 in Shell ETR
L44	B	20 wt% I_2 in Shell ETR
L45	C	Low density polyethylene (0.92g/cc)
L46	B	50 wt% MoS_2 in low-melting castor wax (Paracin No. 1)
L47	B	50 wt% MoS_2 in carbowax 1000 (more than 20 wt% MoS_2)
L48	B + C	L17 lubricant plus metallic lead, copper flake, and graphite (Kopr-Kote)
L49	B	20 wt% graphite in fluorocarbon telomer
L50	B	20 wt% graphite in low-molecular-weight polyethylene
L51	C	Metallic lead, copper flake, and graphite (Kopr-Kote)
L52	C	Stearyl stearate
L53	B + C	Stearyl stearate plus 20 wt% MoS_2
L54	B + C	Stearyl stearate plus 10 wt% graphite and 20 wt% MoS_2
L55	C	Carbowax 1000 (low-melting-point wax)
L56	C	Aerosol fluorocarbon with MoS_2 (Herculon Super)

(a) B = Battelle source, C = commercial source.

A detailed account of the performance of the lubricants with individual materials is given in Sections 1 and 2. During the course of the program, however, a number of efficient lubricants suitable for a wide variety of materials was developed.

Lubricants L11 (castor wax) and L17 (20 weight percent MoS_2 in castor wax) were used in the previous program with AISI 4340 steel but mainly in conjunction with either billet coatings or warm castor oil as the fluid. Further work with these lubricants and AISI 4340 showed that neither the billet coating nor the warm fluid was necessary though L11 was less efficient than L17. Lubricant 17 was also an efficient lubricant with Ti-6Al-4V alloy when the billets were anodized. The anodized coating (C5) was found to be necessary for room-temperature trials with this titanium alloy.

The castor wax-based lubricants were not so efficient with 7075-0 aluminum at high extrusion ratios. A improved base lubricant with this alloy was the stearyl stearate type (L52, L53, L54) which provided excellent lubrication and good surface finishes.

A good general-purpose lubricant with all materials at both room temperature and up to 500 F was PTFE. This lubricant was used with all the difficult-to-work materials such as the superalloys and brittle materials and only in a few cases did the lubricant partially break down. However, this lubricant is relatively expensive to apply, troublesome to remove (by heating to 600 F where PTFE is toxic), and may be too expensive to use commercially except for extrusion of the more exotic materials.

A wide range of lubricants was found to be effective at 500 F with AISI 4340 steel but the selection of good lubricants for Ti-6Al-4V alloy at this temperature was more limited. The best candidate billet lubricant for further evaluation was L33 (55 weight percent MoS_2 and 6 weight percent graphite in sodium silicate) which was easily applied and removed. Lubricants having a sodium silicate base show considerable promise for warm hydrostatic extrusion.

It is worthy of note, that the techniques required for applying these billet lubricants were important. In the case of the waxes and stearyl stearate, there appeared to be a minimum thickness of the solid film below which lubrication breakdown occurred. It was found that if the lubricant flaked off at the conical billet nose due to careless handling, then the billet would either seize in the die or the product would be badly scored in the area where flaking occurred. To ensure a good "bond" between the lubricant film and the billet surface and to prevent excessive film thickness, it was found necessary to heat the billets before lubricant application rather than apply the melted lubricant to the cold billet.

Billet Conversion Coatings

Billet conversion coatings were evaluated with AISI 4340 steel and Ti-6Al-4V alloy. The investigation of coatings on steel billets was a carry-over from the previous program(1) where conventional cold forging lubrication was used in the initial studies in hydrostatic extrusion. Coating Cl, which is described with the other coatings evaluated in this program in Table IV, was not found to be necessary on steel but it always provided marginally lower pressure requirements than when it was not used. Coatings C3 and C4 were not as effective as Cl.