SECTION I

A STUDY OF THE CRITICAL PROCESS VARIABLES IN THE HYDROSTATIC EXTRUSION OF SEVERAL MATERIALS

VI

SUMMARY SECTION 1

For this phase of the program, a range of materials was selected and the various parameters controlling their effective extrusion into round bar were examined. The materials ranged from relatively easy-to-work materials, such as 7075-0 aluminum, to high-strength alloys such as superalloys, and brittle materials such as beryllium. The aim with every material was to achieve a sound, high-quality product at minimum pressure levels and to determine the technology required to achieve these aims.

The critical process variables controlling effective extrusion were thoroughly evaluated with three basic materials:

(a) 7075-0 aluminum
(b) AISI 4340 steel
(c) Ti-6Al-AV titanium alloy.

The variables evaluated with these materials were:

(1) Extrusion ratio
(2) Billet lubricants and coatings and hydrostatic fluids
(3) Billet finish
(4) Die design
(5) Stem speed.

The important results from this study were applied in the hydrostatic extrusion of the more difficult to work materials such as superalloys, TZM molybdenum alloys, beryllium, and powder compacts. The main problem in producing sound, good quality extrusions with the relatively ductile materials was lubrication but in the cases of brittle materials, die design was important. Major strides have been made in the development of lubrication systems for the different alloys and a better understanding of their operational effectiveness has been achieved. Novel die designs have enabled the achievement of sound extrusions with TZM and beryllium. As a result of this work new frontiers in the potential cold working of brittle materials have been opened.

Empirical equations which permit estimations of the pressure requirements for a given extrusion ratio range for the wide variety of materials evaluated in this program are listed in Table V.

TABLE V. EMPIRICAL EQUATIONS RELATING PRESSURE AND EXTRUSION RATIO FOR COLD HYDROSTATIC EXTRUSION OF SEVERAL MATERIALS

Material	Extrusion Ratio Range	Fluid Extrusion Pressure P, 1000 psi
1100-0 Al(a)	20-200:1	$P = 23 \ln A/a$(b)
Dispersion-hardened sintered-aluminum product (SAP)	10-20:1	$P = 36 \ln A/a + 8$
7075-0 Al	2.5-20:1	$P = 44.6 \ln A/a$
	20:1-60:1	$P = 28.5 \ln A/a + 32$
AISI 4340	2.5-6:1	$P = 130 \ln A/a$
Ti-6Al-4V	2.5-4:1	$P = 160 \ln A/a + 7$
TZM (stress relieved)	2.5-5:1	$P = 116 \ln A/a + 23$
TZM (recrystallized)	4:1 only	$P = 116 \ln A/a + 4$
Be	2.5-4:1	$P = 116 \ln A/a + 23$
Alloy 718	3.3:1 only	$P = 182 \ln A/a$
A286	3.3-5:1	$P = 125 \ln A/a + 17$

(a) Data for 1100-0 aluminum obtained in previous program(1).

(b) A = billet cross-sectional area, a = extrusion cross-sectional area.

The extrusion pressure in hydrostatic extrusion is made up of three components.

(1) The work done in uniform plastic deformation per unit volume of material. This is the work of homogeneous deformation such as that which could be achieved if the billet were pulled in tension without necking to produce the same change in length. This is given by:

$$P = \bar{Y} \ln A/a \quad , \qquad (1)$$

where

$\bar{Y}$ = mean yield stress in a true stress/true strain curve. It is seen that this equation is of the same basic form as the empirical equations obtained for extrusion pressure, P, in Table V.

(2) <u>Redundant work</u>

In assuming that the billet is reduced by homogeneous deformation, no account was taken of the internal shearing of individual elements. An element near the surface of the billet moves axially towards the die but