II

SUMMARY VOLUME I

The experimental work conducted in this program has taken the technology of the hydrostatic-extrusion process from the experimental stage to the threshold of its application in a production operation. Commercial exploitation of the process is possible without any further major experimentation and it is believed that this report gives the guidelines which will enable these steps to be taken immediately. What remains now is the complete design of production hydrostatic-extrusion equipment. At the time of this writing, a program is underway at Battelle-Columbus Laboratories in which such equipment is being designed. The program, "Design Study of Production Press for Ultrahigh-pressure Hydrostatic Extrusion Equipment", is sponsored by the Metallurgical Processing Branch, Manufacturing Technology Division at Wright-Patterson Air Force Base, Ohio, on Contract No. F33(615)-67-C-1434.

This report describes the steps which were taken to firmly establish the production potential of hydrostatic extrusion. It was convenient to divide the report into four distinct sections, each covering a specific area of work:

Volume I

Section 1. A Study of the Critical Process Variables in the Hydrostatic Extrusion of Several Materials.

Section 2. Production Aspects of Hydrostatic Extrusion.

Volume II

Section 3. Analysis of Several High-Pressure-Container Design Concepts.

Section 4. Hydrostatic-Extrusion Containers Designed and Constructed in the Program.

These sections are complete in themselves and contain their own summaries. However, it is possible to summarize the results more generally at this point to give an overall picture of the achievements. Major accomplishments obtained in Sections I and II of the program are given below:

(1) Beryllium was cold extruded into a 7/8-inch-diameter round at a ratio of 4:1 virtually free of cracks. This is an extremely significant advancement in the cold working of beryllium, particularly since it was achieved using Battelle's double-reduction die and without the need of an expensive, fluid counter-pressure system.

Another brittle material, TZM molybdenum alloy, was also cold extruded at 4:1 without cracks, using the double-reduction die.

(2) Several samples of 0.020-inch diameter, beryllium wire originating from both ingot and powder material were hydrostatically extrusion-drawn to 0.0124 inch diameter (a reduction of 60 percent) at 500 F.

Two other wire materials, Ti-6Al-4V alloy and TZM molybdenum alloy were cold hydrostatic extrusion-drawn at reductions of up to 60 percent.

(3) High-quality thin-walled Ti-6Al-4V tubing, 0.663-inch OD and 0.030-inch wall, was produced in a single-pass reduction of 60 percent at room temperature.

Good-quality thin-walled tubing was also produced by re-extruding previously hydrostatically extruded tubing.

(a) With AISI 4340 steel, the cumulative reduction was 91 percent.

(b) With 7075-0 aluminum, the cumulative reduction was 98 percent.

(4) A selection of fluids and billet lubricants have been developed which provide optimum pressure levels and good finishes for a variety of materials at temperatures up to 500 F.

(5) With most materials evaluated, extrusion at 500 F resulted in marked reductions in pressure requirements. Few problems in lubrication occurred at this temperature level.

(6) Two superalloys, A286 and Alloy 718, were cold extruded without cracking through a die of standard design. The maximum extrusion ratios achievable within the 250,000 psi pressure capacity of the tooling were 5:1 and 3.3:1, respectively.

(7) Tandem extrusion (of two billets in sequence) of 7075-0 aluminum billets with a counterbored joint was achieved without separation or any discontinuity in the extrusion pressures.

(8) 7075-0 aluminum was cold extended at ratios up to 60:1 and exit speeds up to 250 fpm without surface cracking.

(9) In the extrusion of T-sections from round billets, a compound-angle entry orifice was found to provide minimum pressure requirements.

(10) Tensile test data obtained on hydrostatic extrusions of all materials indicated significant increases in strength over that in the billet material with good retention of ductility.

Beryllium wire was markedly strengthened by the area reductions indicated in Item (2). Its ductility (as measured by elongation) was reduced from 2.5 percent to less than 1 percent, but remained sufficiently high to withstand the application of a draw stress and coiling around a 3-inch-diameter reel without breakage occurring.

Figures 1 and 2 give examples of hydrostatic extrusions obtained with the range of materials used in this program. The 1100-0 extrusion in Figure 1 was obtained in the previous program[1]. In each case, the extrusions represent the maximum extrusion ratios that were attempted in the program. The notable developments made in achieving