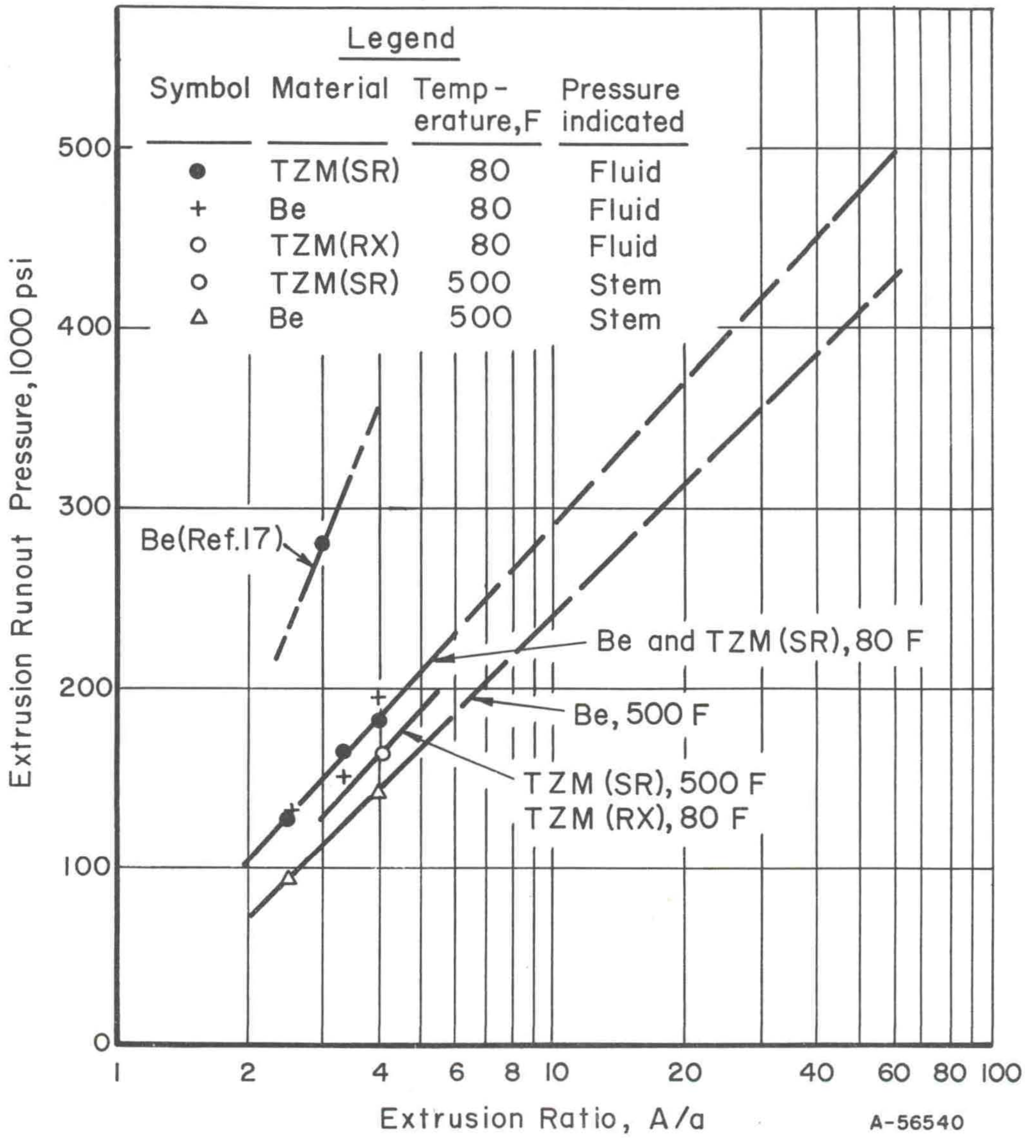

FIGURE 21. INFLUENCE OF EXTRUSION RATIO ON PRESSURES FOR BERYLLIUM AND WROUGHT TZM

TZM (SR) - stress-relieved TZM
TZM (RX) - recrystallized TZM

for an extrusion ratio of 3:1 is shown plotted in the upper curve in the figure. Even this result is significantly higher than the remainder in Figure 21. Due to the lack of more details of the billet material and extrusion conditions used by other workers however, it is not possible to account for these discrepancies.

Bobrowsky and Stack[18] obtained an extrusion from recrystallized TZM at a ratio of 4:1 without back pressure. The extrusion pressure of 175,000 psi lies close to the 169,000 psi level obtained in this program. Information on the surface condition of the extrusion, however, was not reported.

Die Designs

Figure 22 shows two die designs intended for use with materials which exhibit circumferential cracking or longitudinal cracking. The standard die design 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. These elastic stresses are believed to be one of the major factors causing circumferential cracks on exit from the die bearing. 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 of a degree) x 1/4-inch long (β x L in Figure 22) and the other for use at a ratio of 3.3:1 where the controlled relief was 1' 35" x 2 inches long. These were designated Dies C1 and C2, respectively.

The double-reduction die in Figure 22 was designed to take a very small reduction of the product at a second land shortly beyond the first. It is believed that the second reduction, in addition to preventing transverse cracks by imposing a longitudinal compressive stress, could prevent longitudinal cracking by effecting a favorable change in the residual stress pattern. Specifically, a favorable change would be in the direction of reducing the level of residual hoop tensile stresses in the product which give rise to longitudinal cracking. The magnitude of change in the pattern would appear to depend on extrusion conditions including the size of the second reduction, the distance between lands, the relief configuration after each land, billet material, die angle, extrusion speed, and extrusion temperature. It was only possible to investigate the effect of some of these variables in this program.

Several double-reduction die designs were evaluated:

Double-Reduction Die Designation	Second Reduction, percent	Distance Between Lands, H, inch[a]	Included Angle of Second Reduction, θ degrees[a]	Total Reduction, percent
D1	1.5	5/8	45	60
D2	3.3	5/8	45	75
D3	2.0	5/8	45	74.6
D4	2.0	1/8	45	74.6
D5	2.0	5/8	22	74.6

(a) See Figure 22 for details.