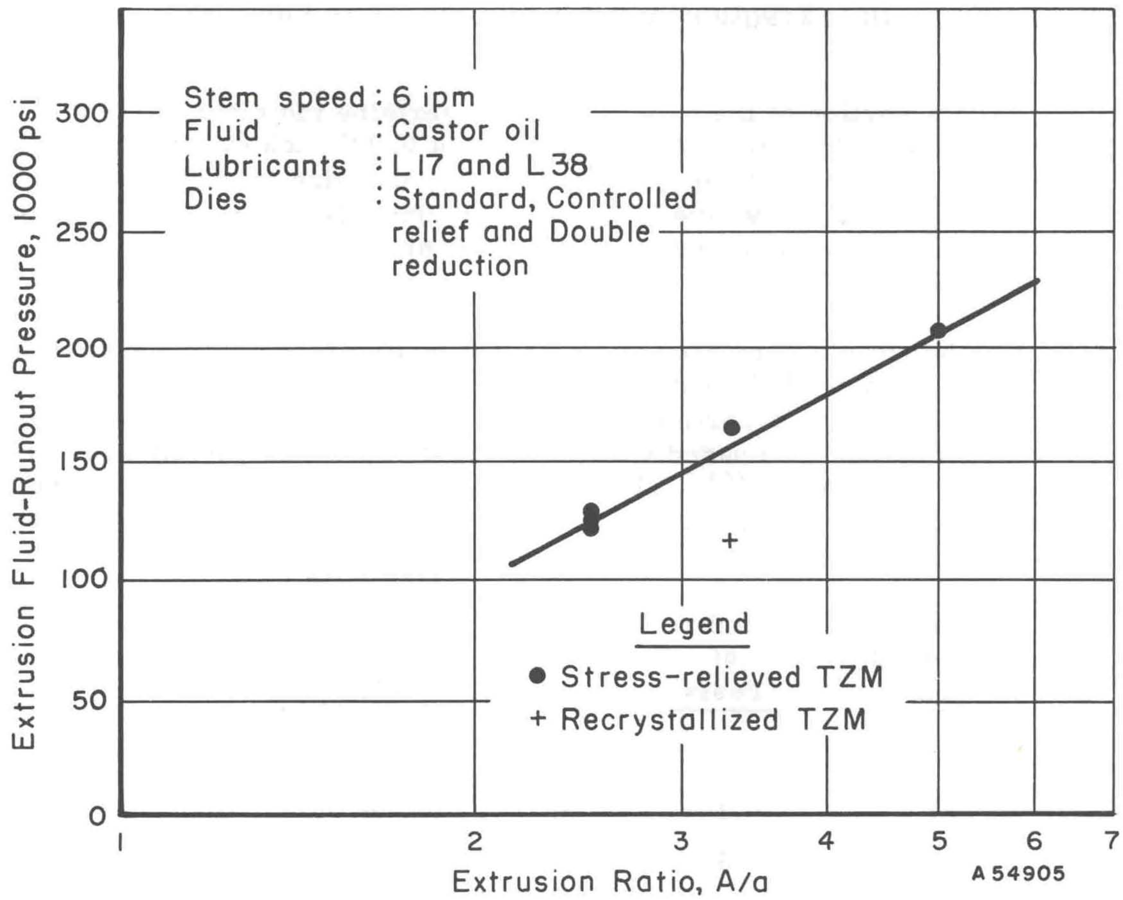

FIGURE 9. THE INFLUENCE OF EXTRUSION RATIO ON THE EXTRUSION FLUID-RUNOUT PRESSURE FOR WROUGHT TZM MOLYBDENUM ALLOY

EXTRUSION OF RECRYSTALLIZED TZM AND BERYLLIUM

Both recrystallized TZM molybdenum alloy and beryllium were extruded at an extrusion ratio of 3.3:1 with the long controlled-relief die (Trials 460 and 461). Lubricant 38 (PTFE) was applied to both billets. The data are given in Table 5.

The extruded product of recrystallized TZM was similar to that obtained with stress-relieved TZM in that a few circumferential cracks at the very beginning were followed by three longitudinal hairline cracks. The extrusion runout pressure with the recrystallized material, however, was 12 percent lower.

In the extrusion of beryllium, a very considerable reduction in the number and severity of circumferential and longitudinal cracks was obtained in comparison with that obtained at a lower ratio with the short controlled-relief die. The improvement is believed to be attributed to both the longer-relief die design and the higher extrusion ratio.

The overall results obtained thus far with dies designed to minimize cracking are quite encouraging. Further die modifications and changes in extrusion conditions will be made with the aim of eliminating cracking completely.

HYDROSTATIC EXTRUSION AND DRAWING OF BERYLLIUM WIRE

The aim of this portion of the program is to determine the technical feasibility of producing beryllium wire down to a target diameter of 0.001 inch by hydrostatic extrusion and drawing. In this Battelle-developed process, the wire is subjected to hydrostatic fluid pressure on the entry side of the die and controlled draw stress on the exit side. The equipment for exerting and monitoring the draw stress on the wire was described in Interim Report VII[6].

The starting beryllium wire used in the initial trials originated from cast-ingot material. It was in the annealed condition and had a nominal diameter of 0.020 inch. A microscopic examination of a portion of the starting material revealed that it is relatively free from inclusions compared with other ingot or powder-metallurgy wire on hand to be drawn in this program[6]. The lower inclusion content may have contributed to the ductility of the material. Average data from tensile trials are given below:

Distance Between Grips, inches	Extensometer Gage Length, inch	Number of Tests	Ultimate Strength, 1000 psi	0.2% Yield Strength, 1000 psi	Elong., %	Reduction in Area, %
2	1	4	88.6	49.5	6.8	6.7
2	(a)	4	88.2	47.3	9.0	7.7
10	(a)	5	80.6	47.3	5.5	7.8

(a) Extensometer not used.

As mentioned in the previous Interim Report[6], attempts to extrude and draw the annealed ingot wire indicated that pressure requirements were excessive for an area reduction of 60 percent. For the 0.020-inch-diameter wire, a 200,000 psi fluid pressure plus an external draw stress of up to 20,000 psi were found to be inadequate for 60 percent reduction, whereas only 150,000 psi fluid pressure alone was required to extrude 1-3/4-inch-diameter billet at a 70 percent reduction. While it was considered that die angles smaller than those specified contributed to the high pressures needed for wire, preliminary trials with soft copper wire and experience with other materials have indicated that there is a "size effect" in extrusion. That is, the total energy required to reduce a billet or wire a given amount increases as the starting billet or wire diameter decreases. This is believed to be associated with the greater surface area to volume ratio for a given reduction as the billet diameter decreases. In view of this, such factors as die bearing length, entry angle, and lubrication will play an even more important part in keeping the extrusion pressure plus draw stress (P + D) requirements to a minimum.

In subsequent trials, an attempt to extrude and draw beryllium wire at about 25 percent reduction was successful. Data for the production of a 5-foot length of wire is given below: