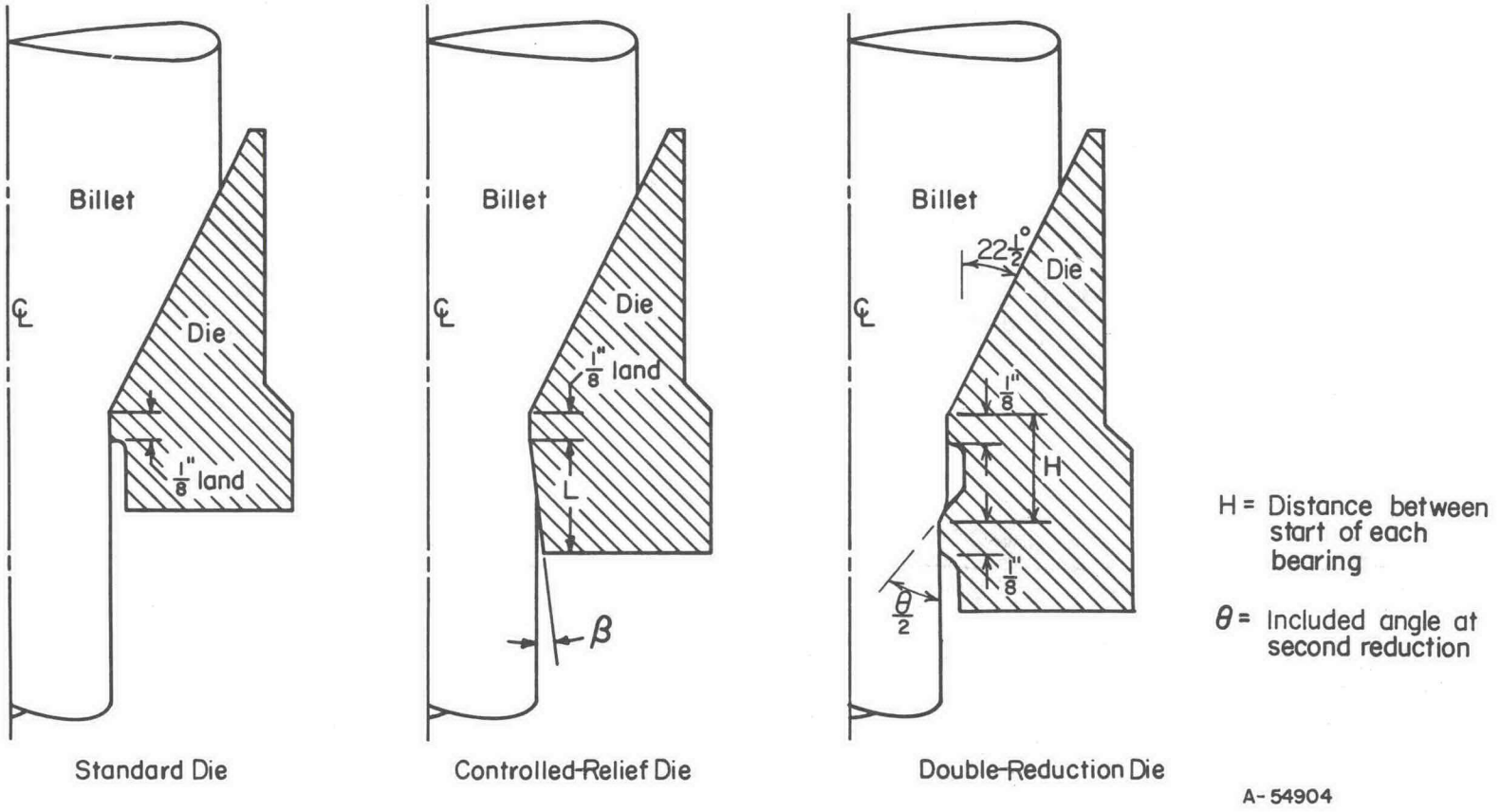

FIGURE 22. STANDARD DIE PROFILE AND TWO DIES DESIGNED TO ELIMINATE CRACKING IN BRITTLE MATERIALS

Effect of Die Design, Extrusion Ratio, and Temperature on TZM

The data given in Table XXVI are for wrought TZM in both the stress relieved and recrystallized conditions. While lower pressures were required for extrusion of the recrystallized TZM, both materials displayed a similar cracking behavior. Thus, both materials are treated together in the following discussion.

Evaluation of Die Designs at an Extrusion Ratio of 2.5:1

All three die designs (standard, controlled-relief, and double reduction) were evaluated with stress relieved TZM at an extrusion ratio of 2.5:1. With the standard-profile die, the extrusion exhibited two types of cracking as shown in Figure 23. For about the first 2 inches of extrusion, the circumferential type occurred, and on the remainder a few longitudinal or axial cracks appeared on the product which otherwise had an excellent surface finish. The longitudinal cracks were generally of the fine, hairline type. The billet lubricant was L17 (20 wt percent MoS_2 in castor wax). Under the same conditions, the short controlled-relief die, C1, reduced the severity and extent of the circumferential and axial cracks. At the same ratio, the double-reduction die, D1, completely eliminated the circumferential cracks although three fine longitudinal cracks persisted. This die was designed with radial ports which could be open or closed to the fluid pressure in the pressure chamber. The purpose of using the die with the ports open was to lubricate at the second reduction. However, the fluid leaked at the second die bearing before runout was completed and, for later trials, the dies used were without ports as shown in Figure 23. With all three die designs, breakthrough pressures were the same but runout pressures for the controlled-relief and double-reduction dies were about 4 percent higher than with the standard die.

Controlled-Relief Die – Extrusion Ratio 3.3:1

At a higher extrusion ratio of 3.3:1, the long, controlled-relief Die C2 was used with Lubricants L17 and L38 on the stress-relieved material and L38 on the recrystallized material. The three extrusions obtained with these lubricants (Trials 452, 455, and 460) exhibited a few circumferential cracks on the nose only and three hairline longitudinal cracks on each. Lubricant L38 gave the better surface finish. A comparison of Trials 455 and 460 shows that the recrystallized material required about 22 percent lower pressures for both breakthrough and runout. Otherwise the performance of the two materials was identical. (The hardnesses of the as-received material were 196 and 276 DPH for the recrystallized and stress-relieved stock, respectively, which accounts for the appreciable difference in pressure requirements.)

Standard Die – Extrusion Ratio 5:1

In previous work at National Engineering Laboratory in Scotland[17], it was reported that cracks were eliminated by extruding above a critical extrusion ratio through standard dies. With molybdenum, the base metal of TZM, this was found to be 3:1. However, in the current program with TZM, cracks persisted even up to a ratio of 5:1, the maximum reduction attempted. This specimen from Trial 443 is included among those shown in Figure 23. The die used in this case had the standard relief profile.