Table X shows that, except at the extrusion ratio of 6:1, Coating C1 with Lubricant L17 was generally a more effective lubrication system than L17 alone at both low stem speeds (6 ipm) and various die angles. At a ratio of 6:1, there was little difference between pressure levels for these two systems. In the evaluation of Lubricants L18 and L11 in conjunction with C1 at this ratio, moderate lubrication breakdown occurred on runout in both cases.

In summary, using Coating C1 with several good billet lubricants appears to be slightly more effective than the lubricants alone or with other coatings. However, it would not be necessary to use a billet coating if some small sacrifice in pressure level of about 4 percent could be tolerated. Billet Lubricant L17 alone was satisfactory at all ratios up to the maximum of 6:1 and economically would be the better choice for a production operation.

Hydrostatic Fluids

The results of trials with several hydrostatic fluids are summarized in Table XIII. The breakthrough and runout pressures are compared with the same reference system that was used for comparing billet lubricants, i.e., castor oil with Lubricant L17 alone. In addition, comparisons are made between data obtained when castor oil and other liquids were used as pressurizing fluids in the cases where billet lubricants and coatings were common.

The data in Table XIII indicate that the hydrostatic fluids tried had no significant difference in effect on the surface finish of the extruded product.

With coated billets, using ethylene glycol and polyethylene glycol as the pressurizing fluid gave virtually similar results. Both glycols usually resulted in lower extrusion pressures than castor oil. The results on uncoated billets, Item 1, for Lubricants L22 and L23 are exceptions to that statement. In those cases, the higher extrusion pressures with polyethylene glycol are attributed to effects of the billet lubricants rather than the hydrostatic fluid. Those lubricants appear to be pressure sensitive and less effective at higher pressures because they performed quite well under the less severe conditions indicated in Item 8.

Although the decrease in extrusion pressures attributed to the glycol fluids, indicated in Item 3, are small they appear to be real. The differences of about 2 percent indicate that the ethylene glycol type fluids provide lower friction conditions at the die/billet interface than does castor oil. However, polyethylene glycol and Coating C1 with Lubricants, L19, L20 and L21 (Item 4, 5, and 6) was not so effective in maintaining low friction conditions because during runout these systems broke down and stick-slip occurred. In spite of the stick-slip, breakthrough and initial runout pressures were less than obtained with castor oil. These apparent discrepancies in the performance of polyethylene glycol may be connected with the compatibility of the fluids with the billet lubricants.

Silicate ester was a particularly good fluid at 400 F, but in a single trial at room temperature (Item 1) it showed only marginal improvement over the reference system. Its high cost in comparison to castor oil prevents this fluid from being competitive in cold hydrostatic extrusion. Water, on the other hand might well prove to be an economical and practical replacement for castor oil. Four trials with water at a ratio of 4:1 (Item 7) proved it to be equally as effective as castor oil. Water is not known to be a good lubricant, therefore, its ability to lower breakthrough pressures by about 2 percent is attributed to its lower viscosity at that pressure level. The practical objection that water causes corrosion might be overcome by using an emulsion of soluble oil and water typical to that used in machining.

Billet Surface Finish

The effect of billet surface finish on extrusion pressure and surface quality was investigated for AISI 4340 at ratios of 4:1 and 5:1 (Tables IX and X). A comparison was made between standard machined surfaces (60-120 microinch) and relatively rough surfaces obtained by grit blasting followed by vapor blasting. The latter step was used to remove superficial grit and any sharp points and edges caused by grit blasting. Stem speeds of 20 and 80 ipm were used. Castor oil and water were used as the fluid media and L17 as the billet lubricant.

The extrusion pressures and extruded surface finishes were found by visual examination to be about the same for either the machined or grit-blast finish. This is an indication that the billet lubricant used was quite effective by itself and that a rough billet-surface finish in this case does not cause any significant pressure change.

Stem Speed

The influence of stem speed on extrusion pressures and surface quality was evaluated for uncoated AISI 4340 rounds at a ratio of 3.3, 4.0 and 5.0:1. Stem speeds up to 80 ipm, the maximum speed of the hydraulic press used, were investigated. The data for comparison are given in Table X.

At an extrusion ratio of 5:1, the complete range of speeds from 1 to 80 ipm was investigated and the effect of this range in speed on fluid pressures is seen in Figure 17. It is seen that increases in stem speed up to 20 ipm result in lower pressures but little further lowering of pressures is obtained beyond this speed. At 1 ipm, stick-slip occurred and consequently breakthrough pressures were high but above this stem speed, smooth runout-pressure curves were obtained.

The reductions in pressure requirements down to a constant level, as stem speed increased (shown in Figure 18) were consistent with previous findings with 7075-0 aluminum. Also, the fact that both the stem and fluid pressure readings followed the same pattern indicates that these pressure reductions are real and not due to any temperature change in the fluid due to the adiabatic heat of pressurization. Experiments on the effects of temperature in the accuracy of the manganin pressure-gage confirm these conclusions. They were reported in an earlier section of this report. The exit velocity of the extrusion at 80 ipm stem speed and a ratio of 5:1 was about 62 fpm. This speed is well within the range used in production processes for conventional hot and cold extrusion. It is worthy of note that no problems in sealing were encountered at 80ipm. Probably even higher exit speeds could be used without difficulty.