the magnitude of the cost savings possible. Another cost advantage is much less butt scrap loss because the unextruded butt represents a much smaller percentage of a long billet compared to that of a normal size billet. Still another potential advantage is the ability to produce longer extrusions which may be desirable for selected products, particularly tubing.

In addition to the ability to extrude longer billets, Figure 2 illustrates that very substantial reductions in pressure can be achieved by hydrostatic extrusion. For example, with billets of l/d = 8, the pressure reduction possible is 70 percent. That is, instead of 278,000 psi, the extrusion pressure could be reduced to 75,000 psi. In effect, this means that a 300-ton press could do the same job that normally requires a 1000-ton press. Alternatively, if one had a 1000-ton press on hand, it could now do work that normally would require a 3300-ton press. Thus, the hydrostatic extrusion process offers the prospects of either (1) reducing initial press costs by lowering tonnage requirements or (2) increasing the "effective" tonnage capacity of existing presses. Either approach can result in appreciable reductions in overall production costs.

Lower extrusion pressures for a given billet reduction and billet l/d, of course, also mean lower stresses in the critical tooling components (stem, container, die, mandrel, etc). This means better tooling life. In addition, lower pressures mean the ability to achieve much larger billet reductions within a given press tonnage capacity.

Another inherent advantage of pure hydrostatic extrusion is that it is easier to extrude relatively brittle materials. The presence of a fluid helps in two ways. First, the pressurized fluid imposes a uniform hydrostatic compressive stress to the billet above the deformation zone, thus minimizing the possibility of developing microcracks within the billet. This is the basic reason for the well-established observation that materials possess improved ductility during forming when they are subjected to a superimposed hydrostatic compressive stress. In conventional extrusion, microcracks can possibly develop in a brittle billet during initial upsetting to the container wall. Second, the fluid eliminates container friction, thus avoiding the possibility of surface damage or cracking due to poor lubrication in that region.

However, surface cracking of the extrusion product can still occur on exit from the die even with hydrostatic extrusion. Such cracking, however, can be prevented by either (1) resorting to fluid-to-fluid extrusion or (2) remaining with fluid-to-air extrusion but in conjunction with a double-reduction die.[2]

The foregoing advantages discussed prevail over conventional cold and warm extrusion at comparable temperatures. There are, however, <u>additional</u> advantages which cold and warm hydrostatic extrusion enjoy over conventional <u>hot</u> extrusion for selected materials and products. These extra advantages stem largely from the better lubrication, lower billet temperatures, and lower tooling temperatures. Not only are higher working pressures possible with lower tooling temperatures but the tooling is much more rigid and greater precision in tooling alignment can be achieved. All these factors contribute to the following:

- Better tube concentricity
- Much less die, mandrel, and liner wear
- Better product finishes (5 to 30 microinches)
- Greater precision in product dimensions
- Less finishing machining
- Faster extrusion speeds for materials sensitive to surface cracking.

Still another advantage exists and this is in the case where the indirect extrusion method is used to avoid container friction. This technique, which is gaining popularity in hot extrusion of aluminum, requires the use of a hollow ram which bears directly against the extrusion die. The extrusion die is pushed into the container in a way so that there is no relative motion between the billet and container. With this method and for a given container bore size, the circumscribed size of the extrusion cross section is limited to about 1/4 to 1/2 inch less than the ID of the hollow ram. Moreover, the ram ID must be kept to a minimum in order to minimize ram stresses. By hydrostatic extrusion, the same goal of eliminating container friction is achieved with a standard press design (solid ram, etc) rather than with the very specialized press design for indirect extrusion. Furthermore, the extruded product size is no longer restricted to that of a hollow ram.

In addition to these advantages, there is another special advantage of process flexibility associated with the use of a fluid medium. This flexibility can be manifested in the following ways:

(1) Can use preshaped, noncylindrical billets

(2) Can use coils of wire stock as billet material

(3) Can extrude extra-long billets (e.g., 1/d ratios greater than 10:1) by means of using a stepped-bore container which can keep the slenderness ratio of the ram down to a reasonable level

(4) Can use for making parts where the billet tends to rotate during extrusion, e.g., parts with helical ribs

(5) Can use round billets of various diameters in the same liner.

In summary, it is quite apparent that there is indeed a host of advantages that the pure hydrostatic extrusion process offers over conventional extrusion methods. Moreover, for many product applications, the potential technical benefits and cost savings are sufficiently large to readily offset some of the limitations of the process.