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THE THICK-FILM HYDROSTATIC EXTRUSION PROCESS

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MF71-103 This paper describes a modification of the pure hydrostatic extrusion method which offers the potential of extending the process capabilities even further for selected applications. Advantages include; achieving production rates comparable to conventional extrusion and both mechanical and hydraulic presses can be used with minimal design modification.

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ABSTRACT

This paper describes a modification of the pure hydrostatic extrusion method which offers the potential of extending the process capabilities even further for selected applications. This new approach of "thick-film" hydrostatic extrusion offers the possibility of achieving production rates comparable to those obtained by conventional extrusion while still retaining many of the benefits of pure hydrostatic extrusion. In addition, both mechanical and hydraulic presses may be used with a minimum of design modification. Moreover, this technique, called the "Hydrafilm Extrusion Process", renders the hydrostatic process about as operationally routine as conventional cold and hot extrusion.

INTRODUCTION

The numerous advantages of the hydrostatic extrusion process over conventional extrusion as well as other competitive techniques have been amply demonstrated in many laboratories throughout the world. Extensive work has been published in England, Sweden, Russia, Czechoslovakia, Japan, France, and the United States. The process has advanced to the point where several companies are now offering production presses to industry for commercial application.

The purpose of this paper is to describe a modification of the hydrostatic extrusion process which extends its potential capabilities even further for selected applications. This new approach of "thick-film" hydrostatic extrusion* will allow, for example, a considerable improvement in production rate capabilities in hydraulic presses. It will also permit one to obtain the benefits of hydrostatic extrusion in mechanical presses at potentially the same cycle rates of 40 to 60 billets/minute now achieved in conventional cold extrusion. This improved concept, which we have termed the "Hydrafilm Extrusion Process", is based on limiting the effect of the hydrostatic fluid only to those aspects that are actually functional for a given application.

Before describing the Hydrafilm extrusion process, it is important to reexamine the pure hydrostatic extrusion process, how it compares to conventional extrusion, and what are its relative advantages over conventional techniques. Subsequently, the details of the Hydrafilm process will be discussed along with how it extends the capabilities of pure hydrostatic extrusion.

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* A patent application has been filed.

PURE HYDROSTATIC EXTRUSION PROCESS

Figure 1 shows a schematic comparison of the conventional and pure hydrostatic extrusion processes. In pure hydrostatic extrusion, a fluid completely surrounds the billet. A quantity of fluid is always maintained between the stem and the billet, even under pressure. When the fluid reaches the extrusion pressure, the billet extrudes through the die. The billet does not contact the container bore. Thus, container friction is virtually eliminated because of the low shear strength of the fluid layer between the container and billet. Also, the hydrostatic fluid appreciably reduces die friction.

Separate billet lubricants can be used, in addition to fluid, depending on the billet material and extrusion conditions. For relatively low-strength billet materials which do not tend to gall, the hydrostatic fluid generally is sufficient. However, for certain materials which tend to seize or which are extruded under severe conditions (high speed, temperature, ratio, or a complex shape), then a separate billet lubricant may be used.

In conventional extrusion, the billet upsets tightly against the container and very substantial container friction can exist even when the billet is lubricated. This is shown rather dramatically in Figure 2. The plot shows the effect of billet length-to-diameter (l/d) ratio on pressures required for conventional and hydrostatic extrusion of mild steel bar. For conventional cold extrusion(1), the steel billets were coated with zinc phosphate + sodium stearate soap (Bonderlube 235), a commonly used lubrication system for cold extrusion of steel. It is well known also that this lubrication system is extremely effective in that bare metal-to-metal contact is generally prevented and excellent surface finishes are obtained on the extruded product. Yet, by comparison to what would be expected by hydrostatic extrusion, the energy lost to container friction is indeed excessive.

Even for billets in the l/d range of 1 to 3, the common range used in conventional extrusion, the pressures are about 23 to 95 percent greater, respectively, than that expected in hydrostatic extrusion. It is no wonder that billets with l/d ratios much greater than 3 are seldom used. Moreover, just moderate increases in billet l/d ratios to the range of 4 to 6 would result in corresponding pressure increases of about 134 to 203 percent above that for hydrostatic extrusion. These ridiculously high pressure levels are totally unnecessary. By hydrostatic extrusion, commercial extruders can immediately go to billets with l/d ratios of 4 to 6, and without a concern for stem buckling since stems of this slenderness ratio can easily withstand pressures up to 250,000 psi and beyond.

One might ask what are the advantages of going to longer billets? One big advantage is the potential of greater throughputs per unit time and, consequently, a reduction of extrusion conversion cost/lb by very substantial margins. Assuming for the moment the same number of billet pushes/hour at given set of extrusion conditions, the extrusion conversion cost/lb for a billet with an l/d = 2 could be cut roughly to one-half for a billet twice as long (l/d = 4) and to about one-third for a billet three times as long (l/d = 6). This is, of course, a very rough estimate but it does indicate 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 1/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 1/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, additional advantages which cold and warm hydrostatic extrusion enjoy over conventional hot 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., l/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.

There may be selected applications, however, where the advantages of the pure hydrostatic extrusion process may be offset by its somewhat lower production rate capabilities compared to conventional extrusion (or other competitive processes). The lower production rates result from the extra cycle time required to handling and pressurizing the sizable volumes of hydrostatic fluid normally used in this technique.

However, suppose a significant portion of a company's products requires the use of only plain round billets of a given diameter. Then the question that arises is "can the pure hydrostatic extrusion process be simplified for plain round billets to be even more efficient and competitive with conventional extrusion?"

To answer this, one has to reexamine the precise role of the hydrostatic fluid. For plain round billets, the main function of using a fluid is to eliminate or minimize container friction and reduce die friction. Then why not limit the effect of the fluid to only this aspect for this particular application?

In view of this, another question is "what is the minimum thickness of a fluid film under pressure between the billet and container that would essentially eliminate container friction?" Theoretically, the fluid film need only be thick enough to avoid asperity contact and still be of low enough shear strength to minimize container friction. Then why not use the very minimum of hydrostatic fluid in that region?

With this in mind, the Hydrafilm extrusion process was conceived which extends the capabilities of the pure hydrostatic process. In so doing, the many benefits of hydrostatic extrusion can now be obtained for a greater number of products.

THE HYDRAFILM EXTRUSION PROCESS

A schematic of one approach to the Hydrafilm extrusion process is shown in Figure 3. The key features of the process include the following:

(1) Hydrostatic fluid minimized. This is minimized in two locations:

(a) Between billet and container. The radial clearance can be less than 0.010 inch. By comparison to normal practice in pure hydrostatic extrusion, this is a thin film. However, by definition in lubrication terminology, it is a thick-film. For this reason, we refer to the process technically as "thick-film" hydrostatic extrusion.

(b) Between billet and stem. Only enough fluid is used to allow enough fluid pressurization to prevent or minimize billet upsetting and, if necessary, to achieve the proper thick-film viscosity to minimize friction. The fluid "head" above the billet need only be slight since it does not take much stem stroke to pressurize the very small amount of fluid between the billet and container. For some applications, no fluid "head" at all may be required.

(2) Stem contacts billet. Allowing the stem to contact the billet prior to and during extrusion not only permits further minimization of the hydrostatic fluid, but more importantly, largely avoids the potential problems of stick-slip and billet motion control.

In pure hydrostatic extrusion, stick-slip (rapidly intermittent billet motion) can occur on occasion with poor or marginal lubrication. This problem, due largely to the high elasticity or compressibility of the fluid under pressure, increases in severity with the ratio of fluid/billet volume.

For example, with poor lubrication, the pressure developed in the fluid prior to billet extrusion can far exceed that required once extrusion breakthrough is achieved. The excess energy stored in the fluid is suddenly released by extremely rapid extrusion of the billet until the fluid pressure drops to the "minimum" or runout level normally required for extrusion with reasonably good lubrication.

By the stem contacting the billet in the Hydrafilm process, there is little or no opportunity for stick-slip to occur, except perhaps at extremely slow ram speeds. Moreover, the possibility of unintentional complete billet extrusion is essentially eliminated.

(3) Billets precoated with hydrostatic medium. Because we have now minimized the amount of hydrostatic medium used, this allows a very significant simplification of the hydrostatic process. With production presses currently offered to industry, a large portion of billet extrusion cycle time is lost to fluid handling, i.e., fluid injection, fluid compression and decompression, and fluid removal. With the Hydrafilm process, the billets can be precoated with the hydrostatic medium which may be in the form of waxes, greases, or viscous fluids. By precoating, the billet cycle time, and thus production rates, can now closely approach or equal that achieved in conventional extrusion.

If the hydrostatic medium used as a precoat is too viscous under pressure, then the tooling (container, die, mandrel) can be warmed slightly (in the order of 100-200 F for some media) to lower the medium viscosity precisely where it is needed -- right at the tooling surfaces. In this approach, close technical control over a lubrication system is being exercised in order to maximize its capability or effectiveness for a given application.

(4) Separate billet lubricants may be used. As mentioned earlier, separate billet lubricants independent of the hydrostatic medium are sometimes necessary or desirable, depending on the billet material and the severity of the extrusion conditions.

Production Rate Capabilities

One of the most important advantages of the Hydrafilm extrusion process is the potential ability to achieve production rates comparable to those obtained in conventional extrusion in either hydraulic or mechanical presses.

Production hydraulic presses currently offered to industry for hydrostatic extrusion are designed for production rates ranging from about 20-35 billets/hour, depending on press and billet size. This is appreciably below the usual production rate of 60 billets/hour and more achieved in conventional hot extrusion. The difference in rate is due mainly to "dead" cycle time lost to hydrostatic-fluid handling which is presently a sequential, "on-stream" part of the total billet extrusion cycle. The Hydrafilm process eliminates this problem by allowing the billet to be precoated with the hydrostatic medium, independent of the sequential steps of the extrusion cycle. Thus, it is quite reasonable to expect that precoated billets can be loaded and extruded at about the same rate now achieved in conventional extrusion. This capability will undoubtedly have considerable impact on the potential economic savings that will be possible by hydrostatic extrusion.

Conventional extrusion presses currently in existence should require minimal modification to gain the advantages of the Hydrafilm process. For example, existing presses could be modified to improve considerably the efficiency of present operations for the billet sizes currently used. It may also be economically advantageous to increase billet length-to-diameter ratios to the maximum possible within the existing "daylight" (distance between the die-support and ram crossheads). This could be done by "muzzle-loading" the billet at the die-end of the container rather than "breech-loading" at the ram-end. This approach alone could result in approximately a 50 percent increase in the billet weight/push. As mentioned earlier, the conversion cost/lb of extrusion potentially can be reduced roughly by a factor proportional to the increase in billet length.

Of course, should a company be in need of a new hydraulic extrusion press, it could be designed to utilize the Hydrafilm and/or the pure hydrostatic process at maximum efficiency, i.e., allowing for billets of maximum length-to-diameter ratio as well as including other special features.

Another very significant fall-out of the Hydrafilm process is that it now becomes possible to achieve the benefits of hydrostatic extrusion in a mechanical press and potentially at the same production rates currently being achieved in conventional cold extrusion, i.e., 40 to 60 billets per minute or more for relatively short billets. Billet length is somewhat limited in mechanical presses, of course, because of the relatively short ram stroke compared to that of a hydraulic press. However, it is well to keep in mind that, even for a billet with an l/d of 2 or 3:1, the pressure required can be roughly 50 to 100 percent greater, respectively, than that needed by hydrostatic extrusion. Thus, the potential gains are indeed appreciable.

Prior to the Hydrafilm concept, there was never any hope of using hydrostatic extrusion techniques in a mechanical press economically because the competitive production rates were simply too fast. Precoating the billets with the hydrostatic medium, however, should allow one to obtain comparable production rates and yet enjoy the advantages of hydrostatic extrusion.

Conventional vertical hydraulic presses are occasionally used for conventional cold extrusion operations when the billet length required to make a given part exceeds the typical ram stroke for a mechanical press. In such instances, the Hydrafilm process could be used quite effectively, yet with little or no sacrifice in production rate. This would be in the order of 10 to 20 billets/minute, depending on the hydraulic press characteristics and product to be extruded.

Additional Advantages

In addition to improved production capabilities, the Hydrafilm process extends the capabilities of hydrostatic extrusion in several other areas. Already mentioned is the minimization of the occasional problem with stick-slip, billet motion control, and sudden energy release. Also, less fluid-handling problems can lead to lower-cost equipment and less maintenance problems. In addition, for a container of given fluid-pressure capability, somewhat higher extrusion ratios are possible. This is because the billet-end pressure developed by the stem can be higher than the fluid pressure by an amount approximately equal to the compressive yield stress of the billet. The amount of billet-pressure augmentation can be quite significant for high-strength materials. For example, many materials have yield strengths greater than 50,000 psi at room temperature. In these cases, with a 250,000 psi container, the billet-end pressure could go to 300,000 psi or somewhat above. Stem pressures of this range are readily withstood by many tool steels currently available. Thus, the extrusion ratio capability can potentially be increased by the Hydrafilm process. Alternatively, a given extrusion ratio could be achieved at a lower fluid-pressure level, thus offering the prospects of better fatigue life in containers.

Another important factor that should not be overlooked is the problem of billet bulging. If there is too much radial clearance between the billet and container in billet-augmented hydrostatic extrusion, the billet tends to bulge just ahead of the die entry point. This was found to be a serious problem by Alexander and Thiruvarudchelvan(3). Higher extrusion pressures were obtained by billet-augmented extrusion and this was associated, in part, with higher die friction. Bulging was suspected of contributing to the higher die friction. In addition, of course, bulging increases the extrusion ratio as well as the amount of redundant deformation which, in turn, would contribute to the higher extrusion pressure. In the Hydrafilm process, however, bulging can be minimized or avoided by keeping the radial clearance to the absolute minimum. In fact, in Hydrafilm extrusion of 7075 aluminum billets, we actually obtained the typical "sinking in" profile on the billets.

CONCLUSION

The technical and economic advantages of pure hydrostatic extrusion over conventional methods appear to be quite significant for many potential product applications. The Hydrafilm technique offers the real possibility of extending the process capabilities even further for selected applications.

Of particular significance is the potential of achieving production rates comparable to those obtained by conventional extrusion while still enjoying many of the important benefits of plain hydrostatic extrusion. In addition, both mechanical and hydraulic presses may be used effectively with the minimum of design modification. Equally important from the standpoint of commercial implementation, this new approach renders the hydrostatic process about as operationally routine as conventional cold or hot extrusion and thus would be virtually ready for in-plant production operations.

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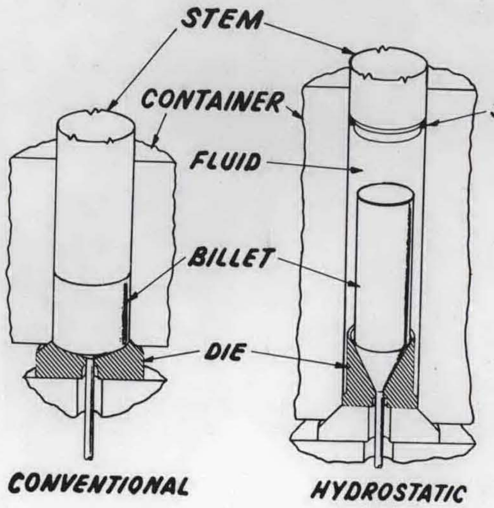

FIGURE 1. SCHEMATIC DIAGRAM OF CONVENTIONAL EXTRUSION AND HYDROSTATIC EXTRUSION PROCESSES

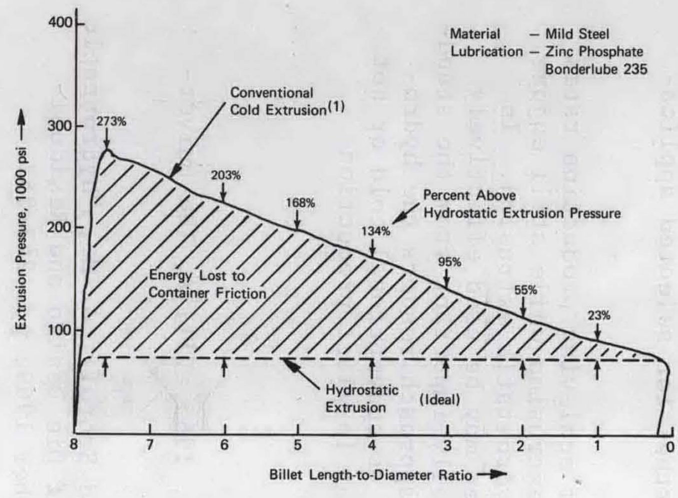

FIGURE 2. EFFECT OF BILLET LENGTH ON PRESSURES FOR CONVENTIONAL AND HYDROSTATIC COLD EXTRUSION OF MILD STEEL BAR

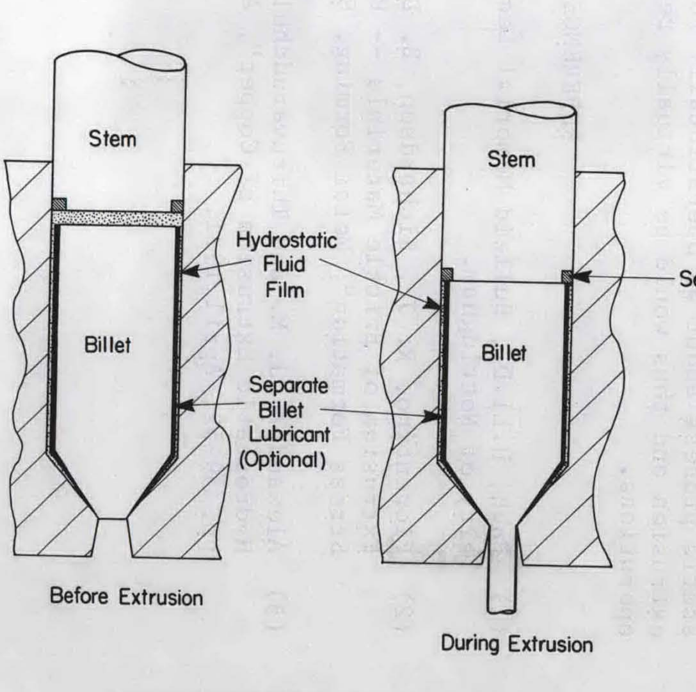

FIGURE 3. A SCHEMATIC OF HYDRAFILM EXTRUSION PROCESS