Extrusion: the Value of Thermal and Physical Alignment

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Introduction

Maximum productivity is only achieved when the alloy passes through the die at maximum speed and produces good product with no scrap or unscheduled downtime from the first push of the first billet, every time. Until fairly recently, this was an unlikely event. Now, however, an exponential rate of improvement in the technology of aluminum extrusion not only makes max. productivity achievable, it also makes possible thinner, more complex, and more precise shapes, thereby increasing the available market for light metal extrusions. A critical part of the production process is the management of the billet from the time it is heated until it enters the die.

Billet temperature management, the importance of alignment, both thermal and physical, and the function of the die oven, the container, and the dummy block will be discussed.

The Extrusion System

In discussing the function and effect of different parts of the extrusion process with the aim of improving productivity, care should be taken to avoid evaluating each part individually, without regard for the influence of other components. Maximum productivity can only be approached if all parts of the process work together, complementing each other as a coordinated system.

Alignment

Consider the importance of exact alignment during the extrusion process.

1. The press should be in precise physical alignment from the ram through the exit of the container.
2. The die should be positioned exactly in the centre of the container exit.
3. Before the first push, the die should be completely and uniformly preheated to the optimum extrusion temperature of the alloy.
4. The temperature of the billet when it leaves the billet heater should remain unchanged until it enters the die.
5. The temperature of the container liner should remain constant and uniform at all times. It should not change the temperature of the alloy in any way.

At each stage of production, precise alignment, ther-

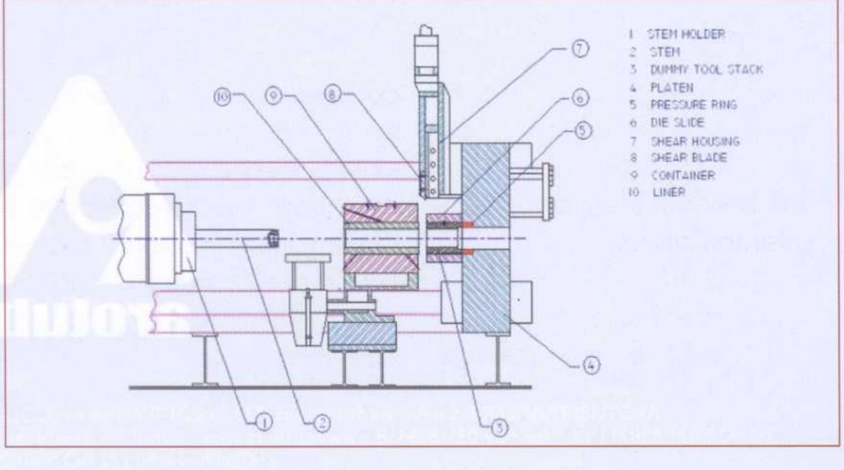


Fig. 1) Physical Alignment of the Extrusion Press.

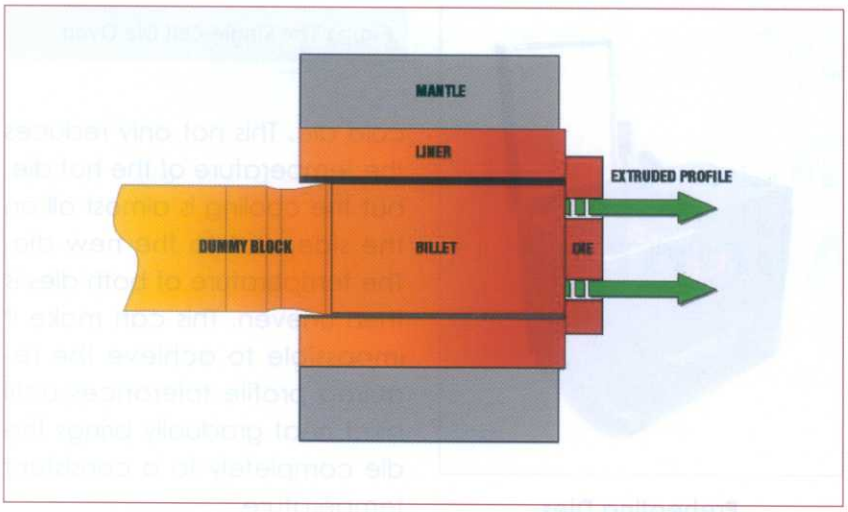


Fig. 2) Thermal Alignment.

mal as well as physical, is critical. Zero tolerance must be the goal. Without absolute alignment, maximum productivity can never be achieved.

Physical Press Alignment

The importance of the physical alignment of the extrusion press cannot be overstated. For example, if the die is not mounted exactly in the centre of the container, the flow of alloy into the die will be uneven, and the profile will be distorted. Also, the stem, and dummy block must pass through the container smoothly, straight and true. For this to happen, the press itself must always be kept in complete physical alignment. (Fig. 1)

Press misalignment is a major cause of dummy block wear. Accordingly, uneven wear on the front edge or land of the dummy block is usually the first indication of physical misalignment. This can be easily seen. Unfortunately, once a press becomes badly worn, absolute alignment is often impossible. It is important, therefore, that wear on bushings and seals, particularly the ways and the main ram bushing, be checked regularly.

Physical press misalignment is insidious, because it can result from so many different factors such as the press foundation, tie rods, stem, billet loader, die changer, and so on. None of these alone may appear to be too significant, but combined they can result in one of the most common and serious problems in extrusion.

The key to maintaining good press alignment is regular, detailed and diligent inspection. Emphasis must always be on prevention, not on correction. Physical alignment can, of course, only be accurately measured when the press is completely at operating temperature.

Thermal Alignment

The need for the physical alignment of all parts of the extrusion process is obvious. It can be determined and corrected fairly easily. No deviation is acceptable. Absolute thermal alignment, however, is a goal for extruders to strive for. It is difficult to achieve.

Isothermal extrusion is usually considered to be the maintaining of the optimum extrusion temperature of the alloy as it passes through the die. For this, the billet is taper-heated to compensate for the heat generated by the friction of the die bearings. Absolute thermal alignment, however, also requires that the tapered temperature of the alloy being used remains completely unchanged from the time the billet is heated until the alloy enters the die. (Fig. 2)

The Extrusion Die

At the moment when the alloy passes through the die, about 93% of the value added to the billet is generated. This added value is what the extruder depends on for his livelihood. All of the production process before the alloy enters the die is dedicated to ensuring that the flow into the die is completely uniform, and the optimum extrusion temperature for the type of alloy being used with the specific die is maintained throughout the extrusion stroke, with the billet initially having been accurately taper heated.

Until fairly recently, most extruders assumed that at least for new dies, the need for die trials and correction was inevitable. Today, the technology of both die design and production is sufficiently advanced that if an extruder is working closely with a skilled and experienced die maker who is aided by a comprehensive database of proven die designs, and he still can't get good product from the first push every time, he has a production problem. His problem is most often thermal misalignment. The die has been designed to run at maximum speed only when it is completely and uniformly at the optimum operating temperature.

All too often the first, and even the second or third billet is wasted simply to bring the die uniformly to the desired operating temperature. It was never intended that billets would be used to heat the die.

Wasted billets and start-up scrap is costly, and machine time unnecessarily lost can never be recovered.

Unfortunately the die maker does not have the luxury of making a perfect die for perfect operating conditions. He must provide a die best suited for the anticipated production.

If the die maker knows that likely his die will not be uniformly at operating temperature before the first push, he must make it strong enough to withstand the necessarily high breakthrough pressure. Press speed can then never be maximized. A die that is too strong is too slow.

Fig. 3) The Single-Cell Die Oven.

Preheating Dies

The traditional chest oven, usually heated by recirculating hot air, and with a large door, is an inefficient and often inaccurate way to heat dies. All the dies to be used in at least the next shift are usually placed together in this large box-type oven. This oven is kept continually at, or slightly above, an average extrusion temperature.

When the door is opened to remove a die, or to add another, the oven partially cools. It then takes some time to completely return to temperature. Often a crowded chest oven never does reach the desired operating temperature. Also, dies are often left in the oven at high temperatures for too long. This causes oxides to build up on the surface of the die bearings, with predictable damage to the finish of the extrusions. It also shortens the operating life of the dies.

If the chest oven is crowded, and it generally is, when a cold die is placed close to a die that is already heated, heat will naturally flow by radiation from the hot die to the cold die. This not only reduces the temperature of the hot die, but the cooling is almost all on the side next to the new die. The temperature of both dies is then uneven. This can make it impossible to achieve the required profile tolerances until billet heat gradually brings the die completely to a consistent temperature.

Unless the temperature of a die is completely uniform, die trials can be a very costly mistake. Inaccurate profile angles or dimensions may be followed by corrections that are unnecessary, because the profile inaccuracy is not caused by faulty die design, but by incomplete preheating.

Chest ovens almost inevitably generate scrap, and are frequently responsible for unnecessary die corrections and die trials.

The length of time needed to heat a die in a traditional chest oven is several hours, but inconsistent heating is a far greater problem for the extruder than time to temperature.

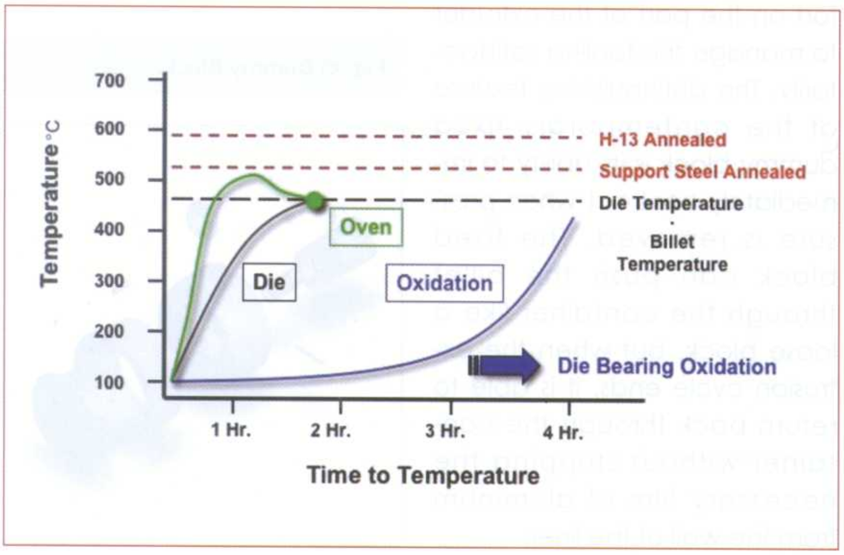
The solution is the single-cell die oven. Each oven heats only one die at a time... completely, uniformly, quickly, and economically.

Single-Cell Die Ovens

(Fig. 3) This shows the construction of a popular single-cell die oven, with several radiant heating elements, a hands-free foot pedal to open the top lid, a heating status time panel at the front, and a status light stack indicator at the rear. As the name indicates, a single-cell die oven has a single heating chamber which heats only one die at a time. With a single-cell die oven ensuring that the die is properly and uniformly heated, good product is as achievable from the first billet as from the last.

A computerized controller calculates the necessary heating time required to bring the die safely and completely to the optimum extrusion temperature for the alloy being used. This calculation is primarily based on the mass of the die, its surface area, the thermal conductivity of the steel that the die is made from, the known heat loss of the oven, and the number of kilowatts of energy being used. In a fraction of the time taken by chest ovens, the die is then individually brought to temperature.

Fig. 4) Heat Curve/Oxidation.



With a single-cell die oven, the die is individually heated to uniform operating temperature so rapidly that oxidation of the bearings is minimal. Scrap due to surface imperfections is reduced.

Maximum production requires that the next die is always ready to put on the press as soon as the previous run is finished. The most usual reason why the next die is not ready is that it is not completely at operating temperature. With a single-cell die oven, from the status indicator light on the oven, the operator can see when the next die is ready go on the press. No time is lost. If the extruder has a sincere commitment to ongoing improvement, and accurately records the length of time taken for each die change, a considerable reduction in press downtime is assured.

Radiant heat is usually generated in single-cell ovens by several high performance sheath heaters.

Thermocouples monitor the temperature in the heating chamber, which is designed to reflect the radiant heat to the surface of the die with maximum efficiency. The steel outer shell is lined with high quality rigid ceramic insulation.

To heat a die rapidly, the surface of the die must initially be heated considerably above the target operating temperature. Care must be taken, however, to avoid exceeding the annealing temperature of the die steel which is usually about 585 °C. Overheating is prevented by locating a temperature controlling thermocouple at the hottest point in the oven chamber, close to the heating elements. This is conservatively set well below the annealing temperature of the die steel. At the expense of a shorter time to temperature, this safety margin positively protects the die from overheating.

To harden the surface and extend the life of an extrusion die after it has been produced, the die is usually nitrided. If the die is then overheated, this nitrided layer on the surface of the die is soon destroyed, and its operating life considerably shortened. This is avoided in the single-cell oven.

Another common cause of scrap is that if left too long at or near operating temperature, die bearings will oxidize and need to be re-polished. This is a difficult problem because usually the extruder's first indication of bearing oxidation is surface deterioration of the product. Tests have shown that quite rapid oxidation begins after a die has been held at temperature for only about three hours. This also is avoided with the single-cell die oven. (Fig. 4) Single-cell die ovens are typically modular in design. Usually they are initially used to augment, not replace, the existing chest oven. The extruder holds the dies to be used in his chest oven at a temperature low enough to preclude oxidation of the bearings. When required, the die is removed and placed in a single-cell oven for a brief period, where it is brought completely and uniformly to operating temperature.

The extruder then monitors his savings in reduced scrap loss and downtime, and adds additional units as their investment proves to be justified. By reducing both scrap and unscheduled downtime, single-cell ovens almost immediately increase profit.

The breakthrough pressures of dies preheated in single-cell ovens vs. chest ovens are often reduced by as much as 40%.

The Dummy Block

The function of the fixed dummy block initially appears to be quite straightforward. It is the extension of the ram and stem that actually pushes the softened alloy through the die. This is, of course its main purpose. If the extruder is aiming for maximum productivity, however, there are a number of additional functions that must be satisfactorily performed by an effective dummy block. (Fig. 5)

1. To expand quickly under load and maintain a secure seal with the container wall, leaving only a thin film of alloy on the liner.
2. To separate cleanly from the billet at the end of the stroke.
3. To contract immediately, and return through the container without stripping the film of alloy from the liner.
4. To cause no gas entrapment that can result in blistering, or damage the face of the container or dummy block.
5. To accommodate minor press misalignment.
6. To be quickly and easily removed and replaced.

Today's fixed dummy block is the much more efficient successor to the original loose dummy block that was simply a solid disk of steel that created a barrier between the stem and the billet. The loose block worked, but only moved one way through the container. This meant considerable extra effort on the part of the extruder to manage this tooling satisfactorily. The distinguishing feature of the contemporary fixed dummy block is its ability to immediately contract when pressure is removed. The fixed block can push the billet through the container like a loose block, but when the extrusion cycle ends, it is able to return back through the container without stripping the necessary film of aluminum from the wall of the liner.

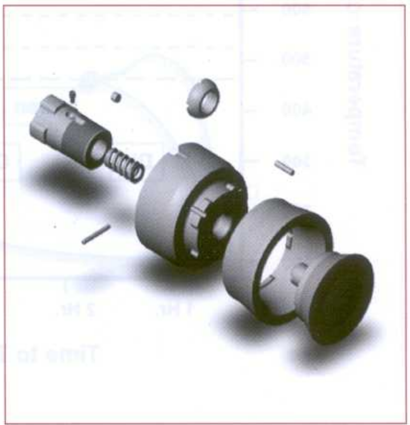
Operation

A usual approach to expanding the block is by means of a tapered cone or mandrel, which is forced back into the block as pressure is applied on the billet. The forward axial pressure is redirected into a radial force that pushes against a surrounding ring thereby expanding the block's outer diameter.

As the pressure is released, the block contracts to its original state so that it is free to return through the container.

The design used in most of today's fixed dummy blocks employs a limited taper. This principle controls the amount of mandrel travel and therefore controls the amount of mechanical expansion and internal stress levels. Compared to a free-moving taper, the limited or controlled taper puts a limit on the stress that is applied to the surrounding ring. Since the ring no longer has to support the movement of the mandrel, it can have a thinner design. This allows it to be ex-

Fig. 5) Dummy Block.



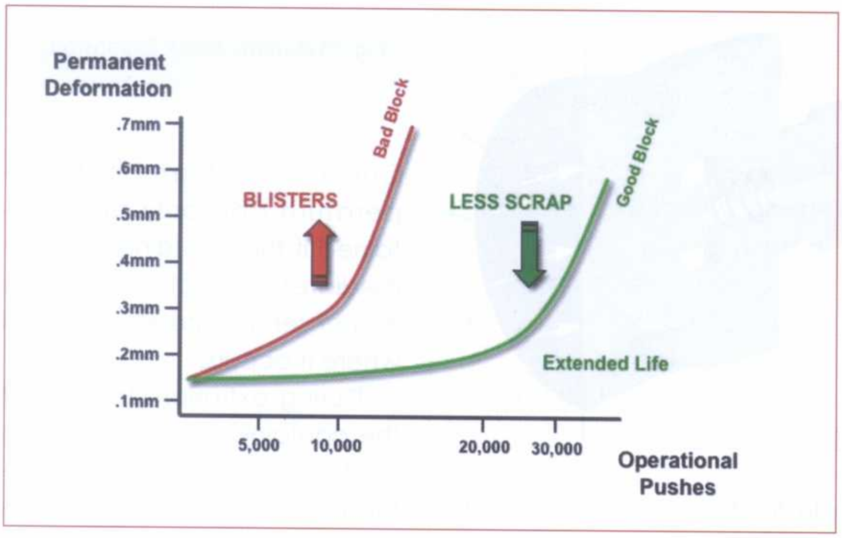


Fig. 6) Block Longevity.

panded with less force. The block therefore reaches full expansion earlier in the extrusion cycle. This can be especially beneficial in the extrusion of alloys with low viscosity. This design is also easier to control, which makes it more practical for all applications.

The thickness of the ring is directly proportional to the diameter. The amount of expansion must be closely controlled. If you move H13 steel more than about 0.040in permanent deformation will result. The ring in an effective dummy block will have uniform thickness and considerable length. This is a major factor in its ability to repeatedly expand and contract without gradually developing permanent set. A poor dummy block produces blisters, and the skull ends up in the product instead of being discarded in the butt. (Fig. 6) Several years ago we knew what we wanted fixed dummy blocks to do. Today they are doing it, and doing it well. We've solved the tough problems such as soft alloys, hot billets, and high pressures. And in doing so, the contemporary fixed dummy block has become a much better, and more productive product. As suppliers continue to learn more about components such as dummy blocks, these products improve, and the industry we serve becomes better equipped to meet the changing needs of the market by better extrusion.

The Dummy Block and the Container

A good example the importance of thermal alignment in all components of the extrusion production process is the relationship between the dummy block and the container, and their dependence on each other. (Fig. 7) The operation of neither the dummy block nor the container can be usefully studied individually. They should always be considered as a small system, working closely together. The effective functioning of the dummy block depends on the condition and the temperature of the container. For example if, from misalignment of temperature, the container has become distorted in any way, the operation of the dummy block will be negatively affected immediately. Consider the critical gap between the dummy block and the container liner.

It is impossible for the dummy block to work well unless the temperature of the container is stabilized, and the diameter of the liner remains virtually unchanged from end to end. For this to happen, and for the gap to remain constant, the temperature of the container liner must be carefully controlled throughout the extrusion cycle.

For the dummy block to work properly, a thin film of alloy must, of course, remain between the block and the container liner at all times during the extrusion process. Its thickness must be uniform. With a soft alloy, the clearance that creates this film will be only about 0.015 cm. If the clearance is more, the alloy will penetrate the gap in the first push. If much less, this essential film of alloy will be stripped.

Stripping the film of aluminum off the liner results in scrap due to blisters, and also to inferior alloy being carried into the product instead of being discarded in the butt. A problem, of course is that when it is heated, the dummy

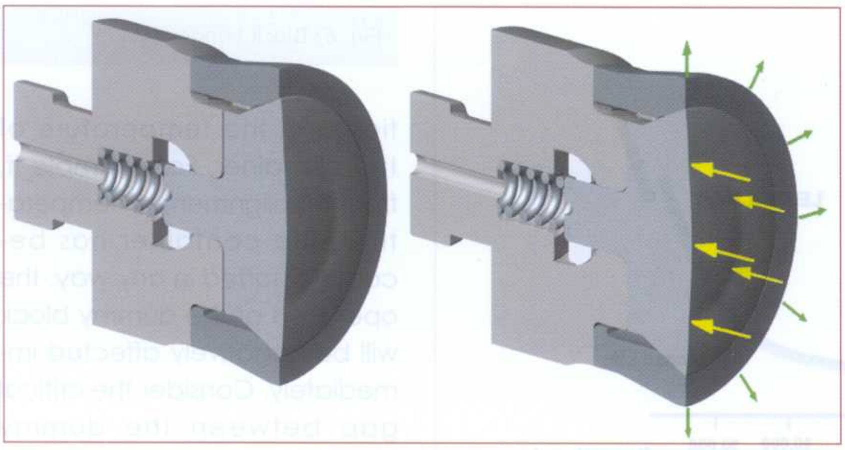


Fig. 7) Dummy Block Expansion.

block expands. During extrusion, the dummy block operates at the same temperature as the billet and the container. Care must be taken, therefore, to preheat the block to operating temperature before it enters the hot container. For every 93 °C difference between initial block temperature and operating temperature, a 200 mm dummy block will expand by about 0.25 mm. Most of this expansion will occur during the first push.

Thermal Alignment of the Extrusion Container

A high level of technological sophistication is required in a container to allow the extruder to operate his press confidently and consistently at close to maximum speeds.

The die designer must assume that the flow of alloy into the die during extrusion is uniform. The sizing of die bearings, pockets and ports is based on this assumption. The total rate of flow of alloy from the container depends solely on the speed of the ram. However, the billet is extremely thermoplastic. The viscosity of the alloy changes almost instantly with any change in temperature. As the dummy block moves through the container, if the temperature at any part of the periphery of the billet changes, the rate of the flow of alloy from that part, will also change. For example, if the temperature at the top of the billet becomes hotter than at the bottom, the rate of flow from the top of the container into the die will increase, and the flow from the bottom will accordingly decrease. On a large section, this can distort the shape of the profile. Also, with a large multi-hole die, the length of the runouts will vary. A 5°C difference in temperature top to bottom will result in 1% difference in length of runout. This may cause problems both with pullers and with cutting to length. (Fig. 8)

It is difficult to regulate the flow by cooling the top of the liner. The practical solution is therefore to heat the bottom of the liner, making the temperature, and thus the rate of flow of alloy into the die uniform.

Continual uniform billet temperature can only be maintained if the container can immediately correct any change in liner temperature when and where it occurs.

During extrusion, the top of the container usually becomes hotter than the bottom. Although conduction is the principal method of heat transfer within the container, heat lost from the bottom of the container rises inside the container housing, and increases the temperature at the top. This makes it an advantage to have a heating system that can heat the lower zone independently from the upper.

As both front and back of the container are exposed, they lose more heat than the centre. If the temperature is not closely controlled, this will result in the centre section of the container becoming hotter than the ends. As well, the temperature at the die end of the container will be slightly higher than at the back, because the billet heats it for a longer period of time.

Maintaining a consistent thermal profile in the axial direction usually requires the addition of only relatively small amounts of heat applied near both ends of the container when needed, to offset the heat loss from the exposed faces. For effective temperature control, however, the container should have at least four separate heating zones, top, bottom, front, and back.

Temperature Control of the Container During Extrusion

Both the performance, and to a lesser extent the useful life of a container, are affected by the temperature of the billet during extrusion. They are also affected considerably by the configuration of the container heating system. That is, the location of the heat source, and of the thermocouples which control it. Ideally, the heat source will be close to the need. That is, close to the liner. Also, the heat source should be close to the thermocouple that controls it, so that response to the demand will be more immediate. While aluminum is being extruded, the temperature of the billet in the liner is usually at or about 425-480 °C. The liner is normally of H13 tool steel that anneals at 585 °C. The mantle is usually of 4340 steel that has an annealing temperature of about 540 °C. It is obvious therefore that during extrusion, the temperature of the billet cannot come close to softening either the mantle or the liner, and so when the press is running around the clock, there should be no problem.

The Container Sub-Liner Method

A recently developed solution to the need for close thermal control of the container, places internal heating elements as well as heat sensors within a sub-liner, between the liner and the mantle.

This sub-liner method makes it possible to closely monitor the temperature around the heating elements, and to compare it with the temperature of the liner. It heats the liner quickly, while preventing it from overheating. The temperature gradient within the container during preheating closely resembles that of the profile during the extrusion process. The possibility of the mantle overheating, annealing, and cracking, is virtually eliminated. The shrink fit stress that secures the liner remains stable. The mantle now simply supports the liner and sub-liner, and acts as a heat sink, dissipating excess thermal energy from its surface. (Fig. 9)

The new sub-liner control system reacts quickly to changes in demand for heating. Since the heat source is right next to the liner, elements are positioned just in areas where heat is required. Only small amounts of thermal energy are therefore necessary to effectively control the rate of flow of aluminum into the extrusion die. Once the extrusion process begins, the thermal profile of the container will remain almost uniform.

Preheating the Container

When the press has been stopped, however, the container must be preheated to minimize "chilling", or thermal shock to the billet on start-up. Preheating the container in a manner that is both quick and efficient, as well as maintaining operating temperature during brief stops, can be difficult. Ideally, each time production stops, the extruder would insert some type of heating unit into the bore of the container to hold it at temperature. This is, of course, impractical. The real danger comes when production is interrupted, and the extruder tries to maintain operating temperature at the liner by

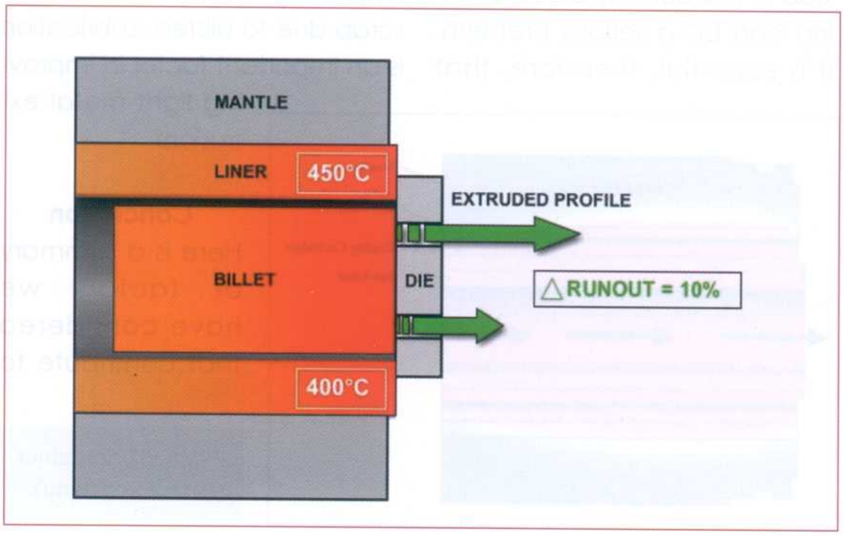


Fig. 8) Result of Non-uniform Liner Temperature.

introducing a remote heat source that is actually outside the mantle. The container sub-liner thermal control system appears to be an effective solution to this problem.

Lubrication

In the billet delivery system, the final factor is the introduction of lubrication. Ideally, the dummy block would pass smoothly through the container liner, and at the end of the stroke, the butt would fall off. Unfortunately this just doesn't happen. Too much lubrication has always been anathema to extruders. The old saying used to be, "Use no lubrication, then wipe off any surplus." We have learned much about extrusion since then, and much about the necessity and the effective use of lubrication.

At the end of each extrusion cycle, the fixed dummy block must separate instantly and cleanly from the butt, without pulling the extruded section from the die. Also without breaking the mandrel or stud in the dummy block. Sticking can be a serious problem. It is essential, therefore, that both the dummy block and the billet are properly lubricated to ensure instant and effortless separation. Every technology improves over time, and becomes increasingly effective. In light metal extrusion, lubrication is no exception to this rule. What began many years ago as an oily rag on the end of a stick, evolved into acetylene sooters which, although fairly effective, are often difficult to control. They also produce toxic fumes that are no longer tolerated by most extruders.

Just now, both powdered and liquid boron nitride are universally considered to be the ultimate lubricant for extrusion. It is easily applied in precisely calculated amounts to the billet, log or butt shear blade, and container seal face.

Effective lubrication ensures instant and clean separation of the dummy block from the butt. It also ensures clean butt release from the shear. It keeps the container seal face clean and free of alloy, prevents aluminum oxide from entering the gap between log shears, and reduces scrap due to blisters. Lubrication is an important factor in improving light metal extrusion.

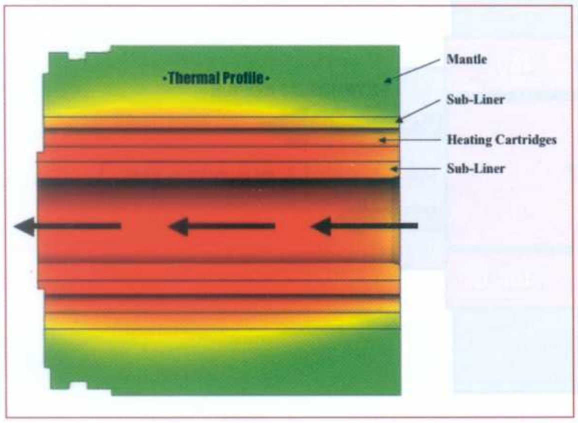


Fig. 9) SL Container (Patent Penching).

Conclusion

Here is a summary of factors we have considered that contribute to improved productivity and profit.

- Components of the extrusion production process should never be evaluated in isolation, but always as part of co-ordinated system.
- Precise thermal as well as physical alignment is essential to maximum production.
- It is too costly to use billets to heat dies'
- A die that is too strong cannot run at maximum press speed.
- The ultimate goal is profit, not productivity. Operating life of any component is therefore a major factor to consider.
- A measure of the operating life of any dummy block is the number of times it will immediately contract at the end of the extrusion stroke before developing a permanent set, and stripping the liner on the return stroke.
- Adequate lubrication not only makes the extrusion process run more smoothly, but also by reducing friction it extends the operating life of all moving parts.
- The billet should be at the calculated and tapered optimum operating temperature when it enters the preheated container. The container should then simply maintain its liner temperature, immediately correcting any fluctuations as they occur. Ideally, the container should not alter the billet temperature in any way.
- Maximum productivity and maximum profit are today actually achievable.