Optimizing a Contemporary Extrusion Production System

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Introduction

Anything that can be measured can be improved. This old maxim is as true for light metal extrusion as it is for any other process. In fact, the mere act of regularly and accurately measuring, recording, and displaying results can be almost guaranteed to ensure some improvement in productivity, because close attention is being focused on the critical factors that affect the measured results, and the extent of their effect is being quantified. Few aluminum extruders really know with much accuracy how their performance compares with that of other extruders. The estimated figures in Table I reflect information gained from a large number of extruders in several countries over a number of years.

	Average Extruder	Good Extruder	Super Extruder
Net Product Produced (per manned hour)	3,000 lbs/hr (1360 kg/hr)	4,500 lbs/hr (2040 kg/hr)	5,300 lbs/hr (2404 kg/hr)
Ram Speed	23 in/min (58.4 cm/min)	26 in/min (66 cm/min)	29 in/min (73.7 cm/min)
Contact Efficiency	60%	62%	65%
Net Recovery	80%	81.5%	83%

Table I. Estimated performance figures assuming 8" (20.3 cm) billet of 6063 alloy.

In considering the real worth of any component of the production process, it is important to estimate its effect on ram speed, contact efficiency, and net recovery. If the extruder doesn't clearly measure results in this way, it is virtually impossible for the press operator to improve productivity.

The Market

Today, automakers throughout the world are preparing to produce smaller, lighter cars in order to reduce fuel consumption. For almost all components, they are evaluating the comparative strength-to-weight ratio of steel, plastic, and aluminum. As a result, a vastly increased market is anticipated for aluminum extrusion. In the past, relatively few super extruders participated in the automotive market, because its demands are so exacting and the price level so low. In North America, however, the recent financial meltdown has reset our market in such a way that the product quality, service, and prices of the past will be inadequate in the future. This is not a temporary situation. This reset is undoubtedly permanent. For many extruders, improving productivity is no longer simply a means of increasing profit; it has already become necessary for survival. Yesterday's automotive standard is today's norm.

The Moment of Extrusion

The moment of extrusion is in fact the essence of the entire production process. Extruding aluminum alloy appears deceptively simple. A billet is heated until it becomes soft, and then is pushed through a die, which determines the resulting profile. In this very brief moment of extrusion, as the alloy passes through the die, hardens, and the shape is set, most of the added value on which the extruder depends is generated. The die is, of course, the heart of the extrusion process. Over the years, however, too much emphasis has perhaps been placed on the die as the prime source of improving productivity. It is fairly recently that breakthroughs in the technology of accurately measuring temperature and speed has revealed the importance of the effective interaction of all components in the production system.

If the die is well designed and well made, the shape that leaves it should meet all required dimensional tolerances, have a good surface finish, and be moving at a profitable speed from the first billet to the last. This can only happen, however, if three specific conditions are met: First, the alloy must enter the die uniformly at or near its optimum operating temperature. Second, the die itself must be completely and uniformly at the operating temperature of the alloy being used. Third, the temperature of the die and the exit temperature of the extrusion should remain virtually unchanged from the beginning to the end of each cycle. To satisfy these conditions, all parts of the extrusion production process must act and interact together as a system, and the temperature of the die must be effectively controlled from start to finish.

Premise

Every extrusion production system can be improved. There are no exceptions. For example, maximum ram speed is actually limited only by the mechanical properties of the alloy being extruded. Better extrusion is done by better extruders, not just better equipment. However, the number of constantly changing variables in the extrusion production system can be daunting. Because light metal extrusion is a process in which components interact closely, and temperatures and speed continually change, the number of combinations and permutations that can occur at any point in time is virtually infinite.

If, however, the press operator can know the temperatures at several critical areas during the extrusion cycle, plus the ram speed, he can positively control the process while the press is running. He will then have a much better opportunity to operate closer to optimum productivity. Recent advances in the technology of ultra-accurate remote temperature measurement, plus the introduction of computer-controlled smart containers, has made possible the development of a visual optimizer, one of the best tools yet devised to assist the extruder in improving his productivity.

Visual Optimzer

The operator is given the press, profile, die, and type of alloy. This information, combined with the operator's experience and talent, allows for the preparation of an initial production recipe. This will contain all necessary temperatures, ram speed, dead cycle time, etc. that he can instantly and positively control, and that will safely produce saleable product.

At the operators post, above the press, a large back-lit monitor screen shows the actual temperature or speed at each point being monitored, plus the target from a previously prepared recipe (Figure 1). If the actual temperature is equal or greater than the target, it will appear in green. If not, it will be shown in red. The operator will then be able to tell at a glance how close he is to target at each point being monitored, and take whatever action is required to bring the system back on track.

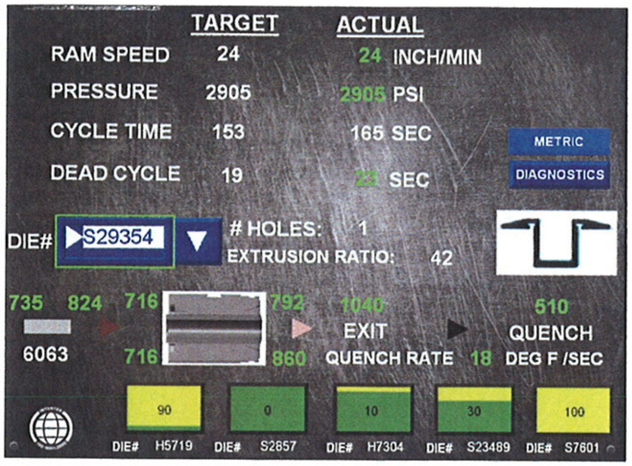

Figure 1. Visual Optimizer screen.

The visual optimizer is customized to fit each user's needs and budget, but it will typically include ram speed, dead cycle time, billet temperature, container liner temperature top and bottom at both entrance and exit, die temperature, profile exit temperature, quench rate, and also graphically, the temperature status of the die in each single cell die oven, i.e., time to temperature and time at temperature.

Whenever the combination of temperature and speed being used produces a new level of productivity for the die, a freeze-frame automatically records all the information being monitored at that precise instant. This then becomes the new recipe for the next repeat run. Once the die has been optimized, leaner alloys can be tried. This can dramatically increase ram speed and productivity. The world's best extruders today consistently use extremely lean alloys, i.e. those with minimal amounts of magnesium and silicon (Figure 2). Eventually every die will be accompanied by a current recipe. The goal of the extruder using a visual optimizer is to determinedly and knowledgeably eliminate any barriers to improved productivity.

A Closed Loop?

The reason that a visual optimizer is preferable to a PLC or computer driven closed loop system at the present time is that the die has not been optimized for a completely thermally controlled process. If the loop is closed with a die that is designed for an imperfect production process, ram speed cannot be optimized. Only by manually controlling temperatures and speeds while using a visual optimizer and updating both the die and the recipe for its use, can the operator continually improve productivity.

Single Cell Die Oven

Most extruders understand the technology of the single cell die oven, but their use is not universal despite the increase in productivity that it can produce. A properly designed and made single cell die oven will heat each die safely, accurately, and quickly to the required operating temperature thereby allowing increased ram speeds, increased recovery, and reduced dead time (Figure 3). Other factors and outcomes associated with its use include:

- The need to use at least the first billet in nearly every run to bring the die uniformly to operating temperature

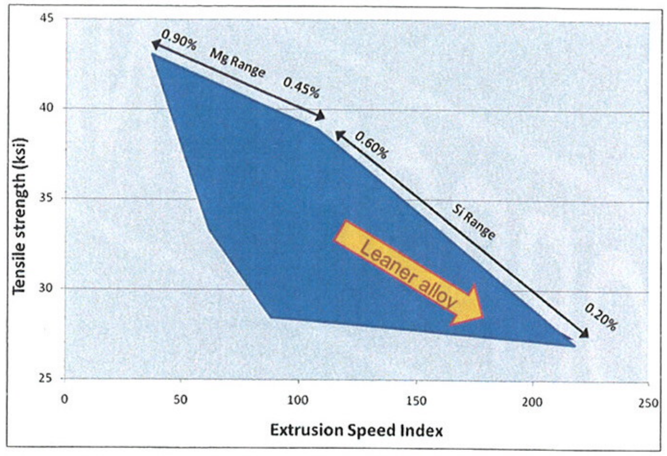

Figure 2. Strength and extrudability in 6063 alloy.

Figure 3. Single cell die oven.

is eliminated. For an extruder using 100 dies per day, the immediate reduction in operating costs is considerable.

- The incidence of cold dies going to the press is eliminated. Broken dies are reduced.
- Breakthrough pressures are relative to die temperature. When dies are delivered to the press at the expected temperature, breakthrough pressures are consistently lower. When the die designer is confident that dies will be used at the required temperature, more efficient dies can be designed and made. Thus ram speed is increased.
- Dies tend to work better. The occurrences of dies being pulled from the press prior to completing the planned production (knock-offs) are reduced (Figure 4).
- Dies remain at temperature for shorter periods of time. The amount of oxidation on die bearings is reduced and profile surface finish is better.

Quick Response Container

A properly designed and operated container will keep the die at a uniform temperature during the extrusion process. The flow of alloy through the die is therefore as planned by the die designer. Use of a Quick Response (QR) Container (Figure 5) improves recovery and reduces downtime for the following reasons:

- The incidence of uneven run-outs is reduced.
- Profile shape and dimensional tolerances are improved.
- Dies remain in the press until the planned amount of profiles are completed, thus knock-offs are reduced.
- Dies requiring correction to slow the flow of alloy through the top ports or aperture are eliminated.
- Dies can be designed and made knowing that the flow of aluminum through the die will be as planned. More

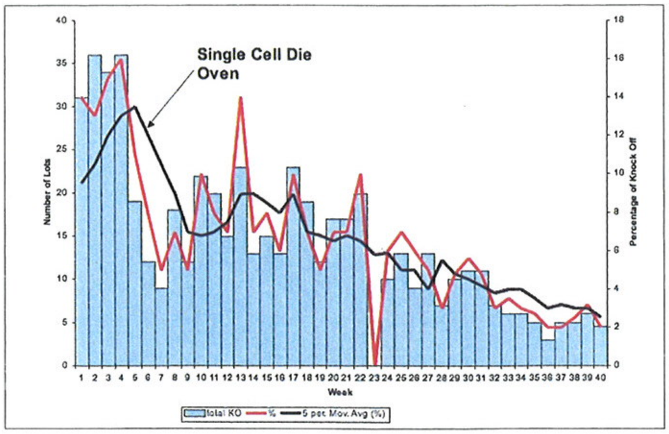

Figure 4. Incidence of knock-offs is reduced by using a single cell die oven.

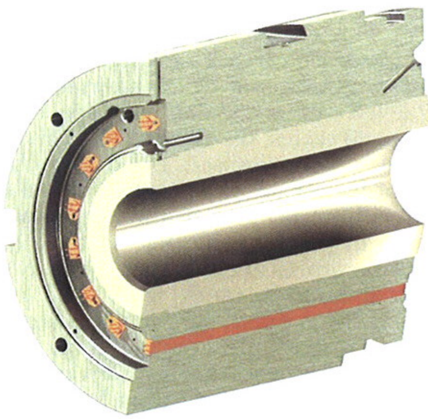

Figure 5. Quick response container.

efficient and repeatable dies that allow faster ram speeds can be used, thus ram speed is increased.

The concept of a container managing die temperature is relatively new and may require some explanation. The thermal mass of the container is much greater than that of the die (Figure 6). Accordingly, as soon as the die is firmly sealed to the end of the liner, heat transfer begins by conduction, and continues so rapidly that a thermal equilibrium is soon reached between the container liner and the die.

In developing an improved container, therefore, the goal was to control the temperature of the liner as effectively and efficiently as possible, so that the die would remain at optimum temperature, and taper heated billets could optimize exit speed. This would require almost absolute temperature control at all times. The QR Container approaches this ideal. The liner temperature is best controlled by correcting any variations as soon as possible. The time taken to respond to a demand for heat is in direct proportion to the distance between the temperature sensor and the heat source. In the QR container, cartridge heaters are located very close to the liner. Their purpose is to immediately summon heat to the liner when needed, not to the container mantle. Specially designed double thermocouples are used to monitor the temperatures of both the liner and the mantle simultaneously. Heating elements are positioned very close to the sensors. As a result, a quick response keeps the temperature of the liner, and thus the alloy, fairly constant.

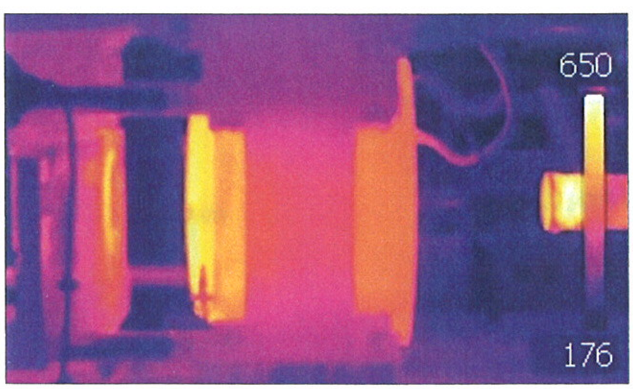

Figure 6. Thermal image of tooling system.

The energy required to control the temperature of the alloy is, of course, a function of the extent of the temperature variations. Think of smoothing ripples rather than waves. This is evidenced by the fact that when replacing conventional containers with QR containers, energy savings of as much as 75% are not uncommon. In addition, the risk of overheating, tempering, and softening the mantle is practically eliminated.

The viscosity of the alloy being extruded is extremely temperature-sensitive. The die designer must, however, assume that the die will remain completely and uniformly at optimum operating temperature at all times during extrusion. Primarily, the QR container function is not to control the temperature of the container mantle, but the liner. Its real purpose, therefore, is to manage the temperature of the die during extrusion. For example, unless closely controlled, heat lost from the bottom of the container mantle rises inside the housing, and considerably increases the temperature at the top. With conventional containers, the vertical temperature difference at the liner exit is typically 55-110°C (100-200°F), as seen in Figure 7.

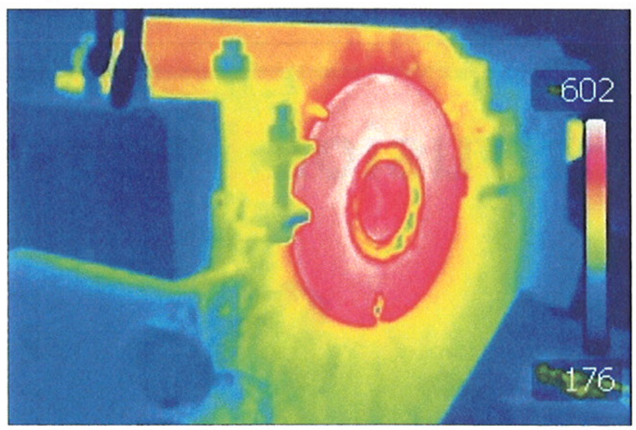

Figure 7. Thermal image of conventional container.

Thermal measurements have proven that during extrusion the difference in temperature between the top and bottom of the die is approximately the same as between the top and bottom of the liner exit. Experience has also shown that for every 5°C (10°F) of vertical temperature variance, the runout length from the top apertures of a multi-hole die will exceed that of the bottom openings by approximately 1%. This presents a serious problem for both pullers and cutting to length. It also makes it difficult to maintain required tolerances on a profile. The problem of the vertical temperature difference, which, if uncontrolled, will occur at the die end of the container liner, is further compounded by another vertical temperature difference in the die itself.

The die slide in which the die sits has enough mass to act as a heat sink and leach heat from the lower half of the die. Equalizing the temperature at the top and bottom of the end of the liner will therefore not completely eliminate unequal runouts. The liner temperature must be made slightly hotter at the bottom than the top to completely eliminate any vertical temperature difference in the die.

Properly designed temperature controlled containers solve the problem of vertical temperature variance in the liner, and thus in the die, by having vertical as well as horizontal temperature control zones. The velocity of the product leaving the top or bottom of the die will therefore be the same.

Quench

A component that contributes to the mechanical properties of the product, but is often simply taken for granted, is the quench. A new and unique PLC controlled cooling quench is now in the final stages of development and field trials, and will shortly be on the market. Each cooling zone will use the latest technology in nozzles, allowing air, mist, and flooding, from the top, bottom, or each side, depending on the requirements of the profile (Figure 8). This will include shape, weight per foot, surface area, type of alloy, speed, and function of the product. The function will determine the mechanical properties required. An extruder will be able to control the air pressure and water flow going to each manifold and therefore control the precise rate of cooling.

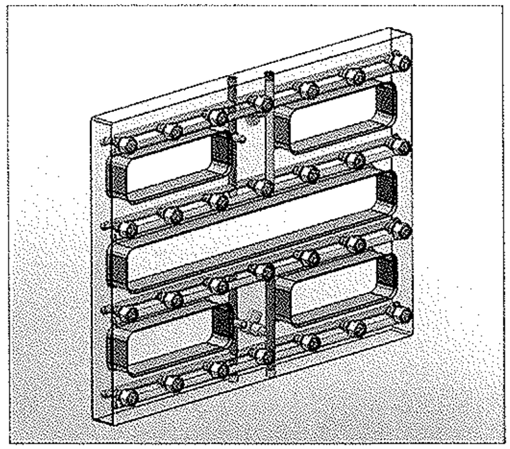

Figure 8. Atomizing manifold of new design of cooling quench.

Conclusion

Now we finally have the die on the press uniformly at the right temperature, a container that maintains the temperature of the die, an effective visual optimizer, and a PLC-driven cooling quench. The next logical step in the evolution of light metal extrusion is to automatically control an accurately calculated tapered billet temperature within +/- 5°C, from when it enters the container until it exits the die, because varying ram speed is no longer an option. The longtime goal of isothermal extrusion can only be achieved with a constant ram speed. As soon as the die exit speed varies, the dimensional integrity of the section profile is compromised. Die design optimization and the use of leaner alloys will allow increased speeds. Most extruders have no idea of the immediate and dramatic increase in productivity that usually occurs when operating temperatures are controlled closely enough to permit leaner alloys to be used.

When this has been done, light metal extrusion will enter new markets with a superior, repeatable, and low-cost product that can be produced quickly and sold profitably. Light metal extrusion will then have been reset to prosper in a permanently reset market.