Factors in increasing the profit from short runs of extrusions*

By P Robbins

The author examines a number of aspects of the extrusion process including single die-heating ovens, containers and dummy blocks

The market for light-alloy extrusions is undergoing a period of change. If extruders fail to respond to this challenge by adapting their production to meet the current and future needs of their customers, they will find that they are no longer competitive.

So how is the market changing? There are two main trends.

First, light metal extruders are being called upon to produce ever more complex and difficult profiles. Aluminium extrusions are now being used in applications where previously such products would never been considered. As a result, the demand for an increasingly diverse range of extrusions is steadily increasing. Many of those new uses are to be found in the automobile industry, which is by far the fastest-growing segment of the market. There are a number of extruders who would like to share in this expanding market. Unfortunately, although they have adequate production equipment at hand, they simply cannot meet the required levels of quality, service or price offered by their competitors.

So why have some extruders proved more successful than others? The answer is that they are simply better extruders. They have no equipment which is not available to everyone else, nor do they have more knowledge of the extrusion process. However, they all take rules of the game seriously and they try very hard to do everything consistently right. And most of the time they succeed.

One way in which these top-flight extruders differ from the rest is that they are never completely satisfied with their individual performance. All are firmly committed to a corporate policy of ongoing improvement.

The second, and more troublesome change lies with purchasing policy. Over much of the industrialised West, customers who once carried large inventories based on long runs of extrusions now often carry no stocks at all, ordering in small lots. Major customers are also becoming more challenging in their requirements. Even where they place a large order, they often insist on a series of small deliveries of exact quantities. The extruder cannot afford to inventory his product and, consequently, is forced to produce the order in a number of small batches. As a result of this trend, the industry is beginning to lose the economies of scale which extruders have always counted upon.

In the past, if an extruder was commencing a fifty-billet run, he might not be too concerned if he was halfway through the second billet before he was obtaining an acceptable product. However, if the run is only five billets long, unless there is a change in the process, the scrap level will be 30% even before starting to produce a good extrusion. The chance of making a profit in such a situation is rather less than zero. In addition, because production runs are becoming so short, the number of die changes per shift is rising rapidly.

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Advantage of single-cell die ovens

Nevertheless, it is possible, as many extruders have discovered, to profit from short runs. These successful companies are employing single-cell die ovens, and as a result are producing much better than average extrusions. This equates to virtually zero scrap and minimal press downtime.

Chest ovens are still used by the majority of extruders, despite a number of limitations. For example, if the die fails to reach the necessary uniformity of temperature, it may require the extrusion of several billets to heat it to the optimum temperature necessary to produce good material. If the die is too cool, there is always the danger that it might break at the first push. Alternatively, if a die is left too long at temperature, the bearings may oxidise, resulting in the extrusion of scrap material. As a result, the die will have to be pulled, refinished and reheated. Last of all, short runs will inevitably result in more dies being crowded into a chest oven, thereby worsening an already marginal situation.

Conversely, a modern single-cell die oven will bring an extrusion die up to the desired uniform working temperature, ready to go on the press in an hour or so. The time to temperature in a single-cell die oven depends on several factors – primarily the mass of the die and the amount of exposed surface area. The cycle must also include enough soaking time to ensure that the temperature is uniform throughout the die.

A major area of concern relates to the control of the die temperature, whilst heating it uniformly, since the heat is conducted from the surface to the interior. The difficulty lies in measuring the temperature of the tool as only the surface is accessible. This problem can be resolved by positioning a controlling thermocouple at the hottest point in the heating chamber, closer to the elements, and arbitrarily setting it to allow a maximum oven temperature of only 540°C. This level is well below the annealing temperature of H-13 (1.2344) die steel which is 585°C at a hardness of 46-48 HRC.

Apart from the speed of heating, there are a number of other advantages to be had from single-cell die ovens;

1 No billets are wasted in bringing the die to operating temperature;
2 because the die is installed in the press at the correct temperature, a quality product is obtained from the first billet, thereby obtaining the correct sequencing of orders at the press;
3 dies are protected from overheating, and
4 the finish of the profile is improved because oxidation of the die bearings is reduced.

A problem with container cracking

Another topic of interest relates to a recent in-depth investigation into the cause of container cracking. This highlights the importance of carefully-controlling the temperature of the container while it is being preheated, and the consequence of repeated overheating.

One of the author's customers had to shut down an 11.5 in (290 mm) ID container. He complained that it had only been in operation for a comparatively short time before it began to "belly". In other words, it developed a definite increase in the bore diameter near the centre of its length. The extruder first noticed a build-up of aluminium on the back of the dummy block, then substandard alloy began to appear in the extrusion.

Any unusable portion of a billet is likely to originate from the surface, because of the presence of oxidation, dirt, etc. This metal usually ends up in the butt. However, if a big enough gap develops between the dummy block and the liner at the centre of the container, some of this inferior alloy will often accumulate in this

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region, and from time to time end up in the product.

The customer's container also developed visible surface cracks at several locations, primarily from the corners of the keyways.

The author's company has run across this unfortunate condition a number of times before. The likely cause was immediately recognised, an assumption soon to be proved correct. In order to share with others a cautionary example of an inevitable and costly problem that occurs far more often then it should, the full-scale investigation of this problem was documented. In addition to the usual analytical and FEM solutions, a detailed metallurgical analysis was made of the material of the damaged container. This clearly confirmed the results of the other studies.

From time to time, probably occurring during reheating after extended shutdowns, the container had, inadvertently, been allowed to overheat. If such overheating occurs repeatedly over time, the material of the mantle will anneal. As a result, the steel will soften and lose its strength. It will therefore no longer support the liner adequately in the area of greatest pressure – at the middle of its length. The result will be bellying. The container will also crack at the weakest points, often in the corners of the keyways.

Castool's standard Finite Element Method of modelling predicts the degree of annealing and loss of strength which can occur at high temperatures. In fact, repeated overheating makes annealing eventually inevitable.

In the case of the container under investigation, the target temperature of the liner was likely to be about 425°C. The mantle was 4340 Machine Grade Steel, which has an annealing temperature of about 540°C at a hardness of 34-36 HRC. The liner was made of H13 (1.2344) Hot Work Tool Steel with an annealing temperature of about 585°C at a hardness of 46-48 HRC. However, the external container heating elements generated a surface temperature of about 650 - 750°C. These figures clearly indicate what happened. What's more important to the extruder is why it happened and how it could be prevented.

It is apparent that the amount of power used could easily result in an overheating situation, before the control thermostat, with its sensor on the liner, turned off the heater. During operation, similar high temperatures would occur near the heaters, whenever they were switched on for an extended length of time, such as during a long interruption to production.

It was concluded that the failed container had been softened to what was, essentially, the annealed state, especially in the region where the cracks were worst. The reason for the cracking was the loss in the strength of the mantle material, because of the softening. Overheating to softening temperatures can easily result from excessive power input during the initial heat-up, with further annealing occurring over time during successive heat ups.

The problem of overheating and annealing containers is more common than most extruders realise. It's a serious and insidious problem, because unless cracks become visible on the mantle, a great deal of costly scrap may be produced before the extruder discovers the cause.

The possibility of overheating is directly proportional to the distance between the controlling thermocouple and the primary heat source. The further the sensor is from the heater, the greater is the potential for annealing and softening of the container to occur. If an external heater is used with a single thermocouple on the liner, the optimum safe time required to reach operating temperature must therefore be very carefully calculated and programmed.

The best method of monitoring and managing container temperature, both during the heat up period and also while the press is in operation, is to limit the rate of energy input, and to have two sensors working in tandem. One of these should be directly on the liner, and the other close to the heating element. Overheating is then virtually impossible.

Castool's single-cell die oven

It will be seen that constant and effective control of container temperature is crucial to better extrusion. It provides the following benefits:

- **a** It reduces both scrap and downtime;
- **b** it reduces distortion of the liner and mantle;
- **c** it helps to keep the aluminium skin on the inside of the liner consistent;
- **d** it provides better control of the flow of alloy into the die, and
- **e** it makes isothermal extrusion more attainable.

Dummy blocks

The author, at this point, would like to focus on that essential gap between the dummy block and the liner. It will be seen that it is impossible for the dummy block to operate effectively unless the container is absolutely stabilised and the ID of the liner remains constant from end to end. For the dummy block to work properly, a thin film of alloy must 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 must be about 0.006 in. (0.15mm). If more, the alloy will penetrate the gap in the first push – if less, the film of alloy will be stripped. Stripping the film of aluminium 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.

The problem, of course, is that when it's heated, the dummy 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 100°C difference between block temperature and operating temperature, an 8in (200mm) dummy block will expand by about 0.010in (0.25mm). Most of this expansion will occur during the first push. The danger of inadequate preheating is obvious.

Recent analysis of the fixed dummy block has provided an unprecedented understanding of the mechanics involved during an extrusion cycle. The behaviour of the lip of a dummy block during the extrusion procedure was investigated using Finite Element Analysis, as well as physical testing and calculations.

Comments on deflection

It was previously thought that the amount the dummy block expanded was determined only by the amount of overlap between the OD of the compressed mandrel and the lip of the dummy block shell's ID. As a result of FEA testing, it has become apparent that this is actually not the case.

It is evident that as pressure on the face of the block increases, displacement is shared by both the mandrel and the shell. Since they are made of the same material, the result is that there is not only the expected dummy block expansion, but also some unexpected compression of the mandrel.

If loaded beyond the extent of elastic deformation, the dummy block will not return to its original diameter due to plastic deformation. Since the shell and the mandrel are of the same material, under high pressures the shell will naturally expand, but the mandrel will also compress. For maximum efficiency, both of these factors must be considered when designing dummy blocks.

Improved dummy block design provides better extrusion for the following reasons:

1. There is a reduction in both scrap and downtime;
2. a consistent film of alloy is maintained inside the liner;
3. extended operating life reduces cost, and
4. the operator can now focus on extruding his product, rather than concentrating in the main, on the die and the dummy block.

This concludes a short survey of several important aspects of extrusion technology. It will be seen that as suppliers continue to learn more about components such as containers and dummy blocks, their products will improve. As a result, the extrusion industry will become better equipped to meet the changing needs of the market by the provision of better extrusions.

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