IMPROVING THE PERFORMANCE OF EXTRUSION DIES IN ALUMINIUM EXTRUSION PLANTS

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Abstract
The extrusion die is an expensive item subjected to high stresses, temperature and wear during the extrusion process. The performance of the die is critical to the viability of the plant. The contribution of the die manufacturer is to ensure that the die is made to a high standard in terms of both design and machining and that the hot-working steel used is of a high quality and correctly heat-treated. The extrusion press operator can also make a significant contribution to the success or failure of the die by ensuring that the die and billet are preheated to the correct temperatures, extrusion speeds are matched to the difficulty of the profile, the support tooling is in good condition and the press is alignment is within tolerance. Treatment of the die after extrusion also plays a role. This paper discusses the factors that influence die performance with particular reference to nitriding, die-heating, and temperature control.

INTRODUCTION

The extrusion process is ultimately controlled by the quality of the billet being processed and the performance of the die. However, if the correct procedures in the die shop and at the press are not followed the full potential of the die in terms of shape, tolerances, speed and die life will not be achieved.
This paper discusses the factors that influence die performance and the steps the extruder can take to optimise this performance.

It is important to have good liaison between the die corrector and the die manufacturer and it is a fact that specialist makers will have more experience in die design and die manufacturing techniques than an in-house die manufacturing facility.

DIE RINGS AND SUPPORT TOOLING

The design and quality of the die rings and support tooling play a critical role in the performance of the extrusion die. Areas of concern are shown in figure 1. The extrusion die is subjected to very high stresses and temperatures during the extrusion process and these stresses have to be transmitted to the press frame through the support tooling, i.e. the bolster, sub bolster and platen support ring. The die ring locates the die in the die ring and often has to withstand the container sealing load. Die rings can be subjected to a lot of abuse at the press and in the die shop and do need to be replaced on a regular basis. Problems with flashing are associated with a build up of aluminium on the sealing surface and an incorrect sealing area. If the sealing area is too small then the high stresses at the start of extrusion will result in indentation of the surface of the die ring and also the container. If the sealing area is too large then flashing will occur. Care should be taken to ensure that the extrusion load and sealing load is transmitted correctly through the die or the die ring onto the support tooling. If the die ring “bends” around the die then internal cracks can form. Routine inspection of die rings for aluminium build up, flatness and cracking must be carried out and the die ring replaced when necessary.

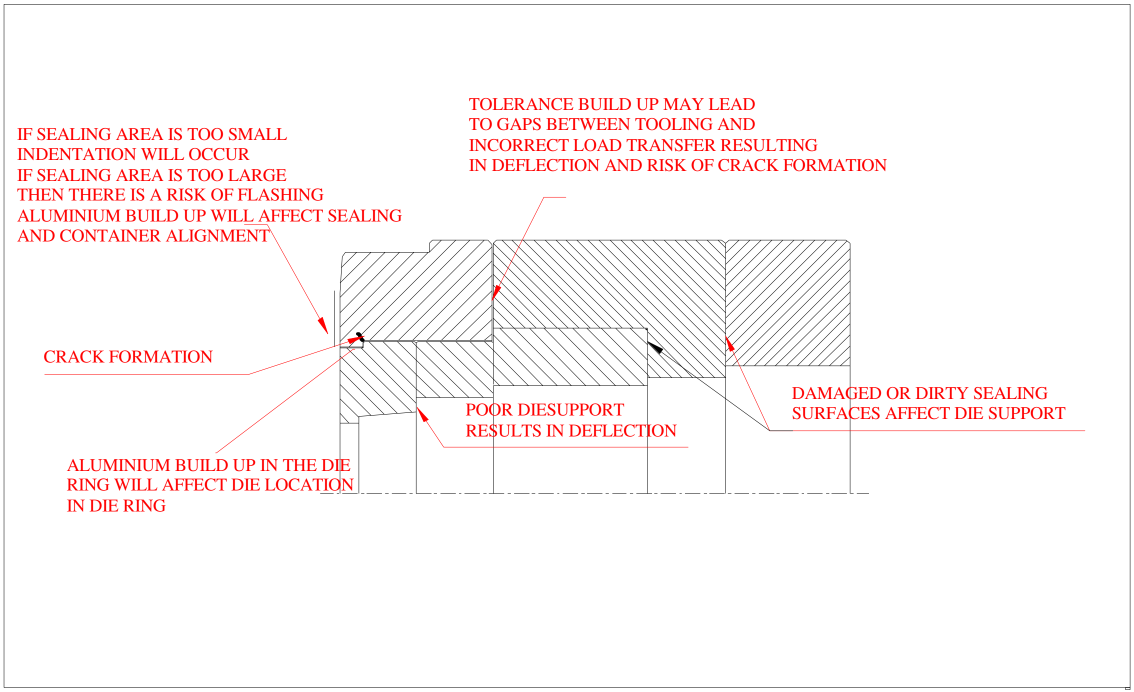

Figure 1: Typical tool stack problems

Deflection of the die and support tooling cannot be avoided but it can be minimised. Press manufacturers have recognised the importance of reducing the deflection of the tooling and tool stack dimensions are now significantly higher now than they used to be. The typical tool stack dimension for a 1600 ton press thirty five years ago was 305mm diameter x 305 mm thick, Today it will be at least 100mm larger in each direction. Increasing the depth has more effect than increasing the diameter. Platen stiffness has also been increased over the same period of time.
This implies that older presses are more likely to have deflection problems than more modern presses but underlines the need to pay particular attention to the dimensions and design of the tool stack. The design of the tool stack should be given careful consideration when installing a new press as mistakes are expensive to rectify.

It is obviously more economic to use standard bolsters and sub bolsters but in many cases custom bolsters are needed to provide the necessary support to the die and backer. This applies, in particular, to thin wall sections where the extrusion loads will be high.

The importance of die support can be seen in figure 2 which shows a heat-sink die manufactured using the patented Autotool process where the die backer closely follows the back of die profile. Dies produced using this process can be more cost effective than other designs for high tongue ratios.

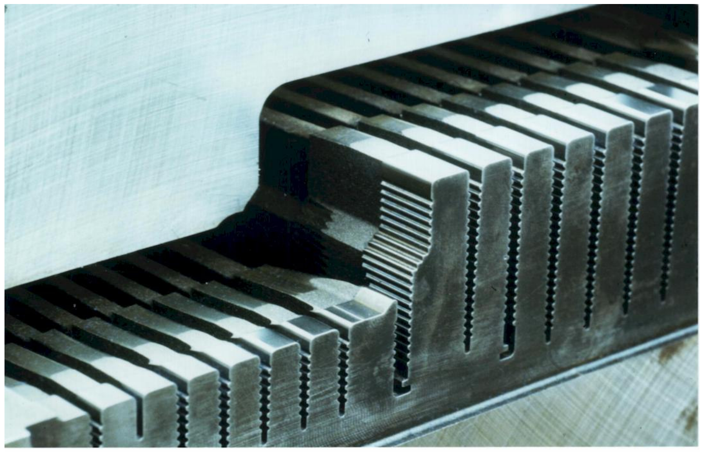

Figure 2: Heat Sink Die Manufactured using the Autotool Process

Changing the dimensions of the tool stack is difficult but not impossible. However, the quality of the components of the stack should be regularly monitored and replaced where necessary.
Handling and storage of bolsters and die rings is an area where good housekeeping brings benefits. Die rings and bolsters scattered on the floor around the press indicate that the tooling is not being treated correctly. Dies should be removed with a hydraulic press and not with a sledge hammer.

Die Inspection

As stated at the beginning good liaison with the die manufacturer is the first step towards optimising die performance. The importance of this cannot be overemphasised. The die designer needs to know the specific needs of the extruder and requires regular feedback on the performance of dies and problems that have arisen. Today it is easy to send photographs and video clips of die trials and any specific problems by e-mail.
Unfortunately, too many plants are reluctant to provide their die-makers with sufficient feedback. This can only have a negative effect on the performance of both new and replacement dies. The extruder and die maker should have regular meetings to discuss specific problems and to develop new ideas.

Once the die is received at the plant there should be a standard computer based procedure for booking the die in and initial inspection. The aim is to ensure that when the die goes to the press the die has the maximum chance of producing a product with the correct dimensions, surface finish, mechanical properties and extrusion speed. The die maker should also have a similar system for inspecting dies before shipping. If there are any problems the two inspection documents can be compared.

The inspection should follow a clearly defined process and cover the following:
Visual assessment of die finish
Dimensional Check
Hardness
Bearing lengths
Bearing squareness
Die clearance
Support of thin tongues

Any problems should be immediately reported back to the die-maker and a remedy agreed.
Only when the die corrector is satisfied should the die be released for trials or production. Many extruders now release a high percentage of dies straight into production without trials. This speeds up the production process but is only possible if good inspection procedures are in place.

Die Preheating
Before the die can be loaded into the press it has to be pre-heated to a temperature close to the billet temperature and it is at this point that problems can start. The die should be loaded into a die ring before loading into the die oven as it is difficult and time consuming to load hot dies into die rings at the press.

Preheating the die increases the toughness of the steel, reduces any stresses associated with thermal shock when the hot billet comes into contact with the die and minimises heat losses from the billet into the die. In practise this:

- Reduces the risk of premature die failure
- Reduces the amount of scrap produced at the start of a production run attributed to uneven metal flow
- Avoids the cost of the lost production associated with sticking billets.

Although over the last ten years there have been developments in die-heating technology including the introduction of single cell ovens, nitrogen atmosphere and even induction heating the majority of plants still depend on the basic air circulating chest furnace. These can give reasonable results if used correctly but few plants have increased their die heating capacity to match increase in the number of die changes per shift associated with smaller production batches. Dies are often packed into the oven resulting in non-uniform heating and uncontrolled die temperatures. The time of loading the die and the location of the die in the oven should be recorded. Software systems are now available for this. These also indicate dies that have been in the oven too long.

Most plants now realise the importance of temperature control in the aluminium extrusion process and it is unusual today to find a press without exit temperature measurement. Modern non-contact pyrometers give reliable measurements for most profiles and the most recent developments in this field are plug and play units capable of giving accurate measurements on even the most complex sections. The leading extrusion companies also measure and record the following:

- Billet temperature and temperature profile – either by contact or preferably non- contact systems.
- Container temperature profiles – zone heating and cooling is not unusual
- Down stream temperature to determine the cooling rates

Very few plants, however, measure die temperature let alone record it even though non-contact measurement of the die surface temperature as the die is loaded into the press is both possible and cost-effective. Control of the die heating process is usually limited to recording on a board the time a die was loaded into the oven and, but not always, the location in the oven. The only planning is to ensure that the die has been in the oven for a minimum time. This is the same technology as that used forty years ago!! Extruders are quite correctly placing more and more demands on the quality of the dies produced by their die suppliers but many of the benefits of a modern die will be lost by poor control of the die heating process. One factor that is sometimes overlooked is the importance of correct die heating in die trials. If die trials are carried out on dies that are at different temperatures to the production dies then the material flow will differ. This can occur if a different oven is used for die trials, different heating times are used or, as has been observed in more than one plant, die trial dies are preheated by placing the dies on top of the production dies in the oven.

DIE HEATING TRIALS

Ask any extruder the die temperature he uses he will almost, without exception, reply with the temperature of the oven. This will give the temperature of the air in the oven measured by a thermocouple. What is needed is the temperature of the die. Die oven manufacturers will make many claims about the heating capacity of their ovens and the time taken to bring the die up to temperature. It should always be remembered that the heating of a die in a furnace is controlled by the laws of physics. The aim is to put the die into the press as close to the billet temperature as possible and with the minimum of temperature variation within the die. The first billet extruded will still change the temperature distribution within the die as heat is developed during the deformation process. The closer the die temperature to the extrusion temperature the quicker the material flow will stabilise through the die. This reduces the scrap at the start of the production run, which is particularly important if the order size is small requiring only a few billets for completion.

Apart from induction heating, where the heat is generated within the die and which is associated with different problems, dies are heated by conduction. The die oven heater will heat the surface of the die by convection and/or radiation. The interior of the die can only be heated by conduction of heat from the surface. The thicker the steel the longer it will take for the die to reach temperature. As a general rule hollow dies are heated for longer than flat dies even though the flat die may be heavier. Heat transfer to the die will depend on several factors. The higher the temperature of the surrounding air or the higher the temperature of the radiating heat source the greater the heat transfer and the quicker the heating cycle. Forced air circulation is necessary to improve heat transfer as it ensures that the air in contact with the die is always at the maximum temperature and forces the heated air through the die apertures. Overheating of the dies also has to be avoided as this increases the rate of surface oxidation and will affect the integrity of the nitrided layer. There is also the risk of localized softening. Large temperature gradients within the die could also produce internal stresses high enough to initiate cracking. One other factor that will affect the heating will be the number of dies in the furnace and the temperature of adjacent dies. One outcome of the increase in the number of die changes is the tendency to increase the number of dies in the oven above the original oven specification. This reduces the airflow within the oven and will increase the heating time. Hot dies will also radiate heat and if a cold die is placed close to a hot die the latter will lose heat.
It is a good idea to test the die oven by carrying out controlled tests with a die fitted with thermocouples. Some results from trials on a 480mm x 280mm ring size porthole die are described below. The die consisted of a die plate and mandrel and a feeder plate. Three thermocouples were located in the die. Thermocouple one was located in the centre of the mandrel legs at a depth of 60mm. Thermocouple two was 54 mm deep in the mandrel core. Thermocouple three was located 20m deep and 20 mm away from the periphery of the feeder plate. This die was then place into three ovens. The first was a single cell oven the other two were standard chest ovens. The set temperature in each case was 460°C.The graphs show the results for the different ovens.

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DIE OVEN ONE

This was a single cell oven with no air circulation fan. The set temperature was 460°C and the furnace control system required the operator to input the die dimensions or weight. The control system then calculated and displayed the required heating time. The furnace design had two banks of heating elements either side of the die providing radiant heat and the air temperature during heating was 565°C. The recorded results are shown in Figure 3.Two points stand out from these results:
The set temperature is reached close to the surface (thermocouple 3) after two hours and there is a temperature differential of about 25°C between the surface and the core. However, the furnace continued to heat the die for a further 35 minutes and during this period the die temperature increased to over 500°C close to the surface and 490°C in the core. Once the controller had timed out the indicated air temperature fell to 497°C within 10 minutes but the die temperature stabilized at 500°C. When the die was removed from the oven the temperature close to the surface fell to 436°C at the edge and 463°C in the core within 10 minutes. A temperature of 500°C will not soften the die as it is well below the tempering temperature but the degree of oxidation of the bearing surface will increase. Problems could occur if the differential between the set and the actual die temperature is maintained at higher temperatures. If this is the case then overheating could become a problem.

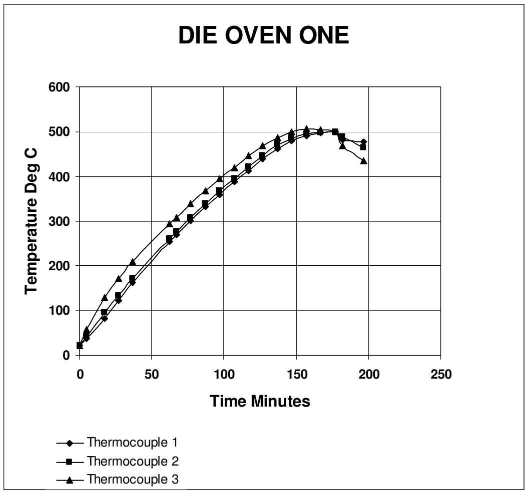

Figure 3 Temperature Against Time for Die Oven One

DIE OVEN TWO

This was one of a bank of three ovens built as an integral unit but with individual controllers for each oven. The oven was a conventional electrically heated air circulation chest design and the die was located between two preheated dies.

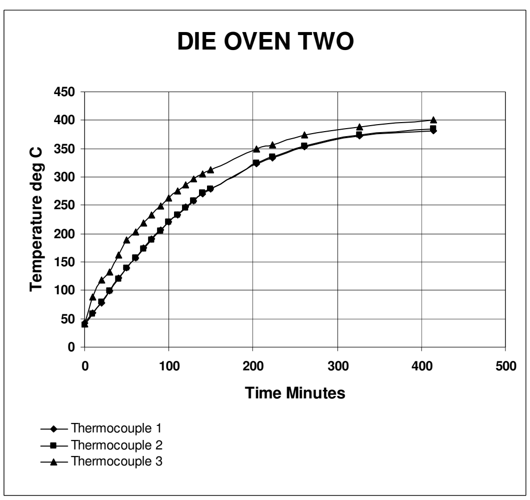

Figure 4 Temperature Against Time for Die Oven Two

The preset temperature was again 460°C but in this case the die temperature had only reached 400°C at the surface after seven hours with the core temperature still 15°C lower, figure 4. A general rule of thumb often used in production is that a hollow die needs four hours in the furnace. In this case the die would only have reached 360°C. Well below the billet temperature of 460°C.

After the trial had been completed the oven was checked and a faulty thermocouple location found. The policeman thermocouple adjacent to the heating elements was controlling the air temperature.

However, the operator would not have been aware of this and would have assumed that the die was at temperature. This underlines the need to measure the temperature of the die as it is taken from the oven and the importance of regularly checking the performance of the oven.

OVEN THREE

This oven was the middle one of the three ovens mentioned above.

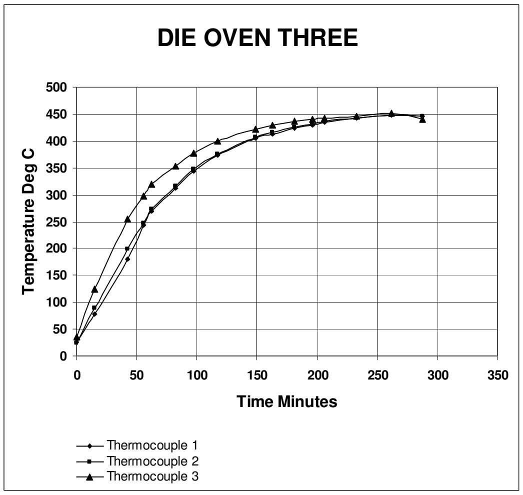

Figure 5 Temperature Against Time for Die Oven Three

The set temperature was again 460°C and a stable temperature of 450°C was reached in just over 4 hours, figure 5. The temperature difference between the surface and the core was approximately 20°C during the heating period and then evened out. When the die was removed from the oven the surface temperature fell by 27°C and the core by 12°C within 5 minutes.

These results demonstrate that the die oven set temperature can give misleading results. The single cell oven gave the fastest heating time but this is achieved by raising the furnace air temperature above the set value. There is a risk of overheating. The conventional chest oven can give good results providing the oven is working correctly and is not overloaded. However the die will take longer to heat and the temperature will be below the set temperature. These results emphasize the importance of measuring the actual die temperature when the die is removed and also to carry out tests on the ovens to determine the true oven characteristics.

EFECT OF PROLONGED DIE HEATING

As stated above the majority of plants leave dies in the ovens for a minimum time. This should ensure that the die reaches the maximum temperature possible taking into account the limitations of the oven. But leaving the die in the oven too long can result in serious problems.

The majority of die ovens in use today heat the dies in air and the bearing surfaces will oxidise The longer the die is exposed to the high temperature the greater the degree of oxidation. This affects both the quality of the surface finish and the effectiveness of the nitriding

A heavily oxidized bearing surface is unlikely to produce a high quality surface finish on the product. This is where die oven management software can play an important role. These programs visually show the operator when dies are ready for use and when they have been in too long. The general rule of thumb is that eight hours in an oven should be the maximum.

The second reason is the effect on the nitriding of the die. The die bearing oxidizes in the die oven and this removes the nitrided layer replacing it with iron oxide. The pits formed on the bearing surface during the oxidation are further attacked when the die is cleaned in caustic and results in flaking.

Some test pieces were machined from 1.2344 (H13) steel to represent a die bearing, hardened and double tempered to HRc 47-49 and then nitrided using the Nitrex process. These pieces were heated in an air circulation furnace at 480^{o}C for periods ranging from 2 hours to 24 hours.
Figure 6 shows the changes in the surface appearance after the different preheat times.

Figure 6. Surface Finish on Test Pieces after Heating to 480^{o}C for Different Times
Top Row : 4 hours, 24 hours
Bottom row : Initial state, 2 hours

Oxidation cannot be avoided when heating in air but the degree of oxidation will depend on the time at temperature. After 2 hours at temperature the test piece exhibited a light grey coating. This gradually darkened as the time at temperature increased and the oxide layer increased in thickness. After seven days at temperature there was a distinctive brown film on the test piece.

Oxidation can be avoided by heating in a non-oxidising atmosphere and some oven manufacturers offer ovens with nitrogen atmospheres. One point to be considered is the speed with which the nitrogen atmosphere can be introduced. Approximately five changes of atmosphere are needed to displace all the air in an oven. Oxidation of the bearing will occur during this transition but this will stop as soon as the air has been replaced by the inert nitrogen atmosphere.

The effect of the different heating times on the nitrided layer was examined by sectioning the test pieces and measuring the hardness profiles. These results are shown in figure 7. The effect of the pre-heating on the nitride layer is summarized in Table 1. The surface hardness values on the oxidized samples are only approximate due to the difficulty in reading the size of the indentation on the lightly polished oxidized surface but the trend is very clear. The compound layer on the as- nitrided sample was 1-2 microns. The oxide layer increased in thickness with increasing pre-heat time and the compound layer could no longer be identified. The surface hardness falls significantly with increasing preheat time and there is a dramatic decrease beyond 8 hours as diffusion of nitrogen away from the surface takes place. At longer pre-heat times the hardness profile elongates and the peak hardness falls further. One interesting feature is the slightly higher hardness of the 48h and 7 day pre-heat profiles at around a depth of 0.1mm. Presumably, diffusion takes place towards the core of the sample as well as towards the surface.

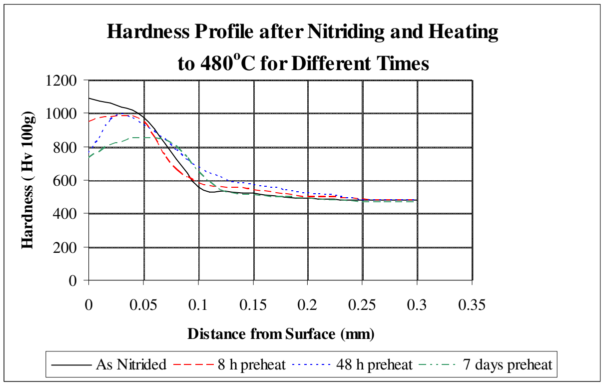

Figure 7. Hardness Profiles in Test Pieces After Heating for DifferentTimes at 480^{o}C

Sample	Surface Hardness Hv 1Kg	Hardness at 0.5mm Hv 0.1Kg	Hardness at 0.1mm Hv 0.1kg	Compound Layer/oxide Thickness
As Nitrided	1092	980	570	1-2 microns
8 hours pre-heat	950	960	580	3-5 microns
48 hours pre-heat	760	950	640	5-7 microns
7 days Pre-heat	730	860	625	9-11 microns

Table 1

From the practical point of view prolonged heating in a die oven will result in a thicker oxide layer and a significant reduction in the surface hardness. This will affect both the surface finish quality of the product and the die life. There will also be a cumulative effect if a die is used several times before re-nitriding.

Loading the Die and Start of Extrusion

Loading the die and die ring into the press along with the corresponding support tooling has to be carried out as quickly as possible to minimise the dead cycle time. The die and support tooling should be loaded into the die carrier before the last extrusion from the previous die has been completed. Before the die and tooling are loaded into the carrier the latter should be checked to ensure that it is clean and nothing will prevent the accurate location of the die. As soon as the die has been removed from the die oven it will start to cool and it is important to ensure that the die is not removed too early. Ideally, the die temperature should be measured before loading the die into the die carrier. Dirt on the die should be blown off before loading. Any excessive build up of aluminium on the container sealing surface needs to be removed before the next die is loaded.
The die is very vulnerable at the start of extrusion and care must be taken as the die fills.
Small tongues can easily break at the start of the first extrusion if the press operator tries to fill the die too quickly, the billet is too cold or the die has not been pre-heated to the correct temperature. The first billet can be heated to a higher temperature to reduce the material flow stress and thus lower the extrusion load. Once the die has been filled and the section has emerged from the press the extrusion speed can be increased to the desired value. Sudden changes in speed should be avoided to prevent sudden increases in the load and the associated high stresses in the die. Marks will also be formed on

the section. Sudden noises from the tooling during extrusion are a good indication of tooling problems and need to be investigated.

The temperature of the die bearing increases during extrusion and locally can exceed the tempering temperature of the tool steel. If the order requires a large number of billets to be extruded then it is good practise to have a second die in the oven and change dies typically after 40 billets have been extruded. The exact number will depend on the complexity of the section.

POST EXTRUSION HANDLING

The handling of the die after extrusion is also important. As the die cools thermal stresses can develop within the steel and in some cases these are high enough to result in crack formation. Dies should therefore be allowed to cool slowly. Leaving them on the floor exposed to draughts from open doors is not recommended. With very large dies it may be necessary to have a separate cooling chamber.
Dies should be removed from the die-rings using hydraulic presses and not sledge-hammers. The residual aluminium is removed using in baths of hot caustic soda and then rinsed. Although many plants still use simple heated caustic baths there are now better solutions available that reduce the volume of caustic soda used and minimise the volume of fumes produced resulting a better environment in and around the caustic shop. It is important to ensure that all residues of the caustic soda are removed during the rinsing process. If this is not done the caustic can attack any small pits in the nitrided layer resulting in flaking. Small tongues can easily be damaged when dies are split and some plants are now using die-splitting machines to separate the dies. After cleaning the dies should be checked and prepared for storage. The die apertures should be protected by sealing them with tape before placing them in racks or by spraying them. The dies are then protected against corrosion during storage and can be quickly prepared. The method used should ensure that the die does not corrode during storage and that it can be quickly prepared for extrusion when needed. In some cases there is no need to remove the aluminium from the die. After cooling the die is placed in the storage rack complete with the aluminium residue. This is then pushed out by the first billet at the start of extrusion. This approach saves the cost of caustic cleaning but the die cannot be checked or cleaned.
It is therefore not suitable for sections that require a high surface finish or have delicate tongues. The extrusion load with the first billet will also increase as the aluminium in the die is only heated to the die temperature and may be below the billet temperature.

CONCLUSION

If correct procedures are not followed from the time the die arrives in the plant then the performance of the die will be reduced. Inspection before releasing the die to production, control of die heating, good working practises at the press, controlled nitriding procedures, and correct cleaning and storage all play a role in optimising the performance of a die. Oxidation of the die bearings will occur if the die is left in the oven for long periods of time. The effectiveness of the nitrided layer will also be reduced. Good oven management and temperature measurement of the actual die should form an essential part of the process control in a modern extrusion plant. Good liaison with the die manufacturer is essential but press operators and plant maintenance also have a role to play in ensuring that good operating practises are used at the press and the press alignment is correct