DIE HEATING IN PRODUCTION

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ABSTRACT
Extrusion dies have to be pre-heated before they are loaded into the extrusion press. If dies are not heated to the correct temperature there is the risk of premature die failure, incorrect metal flow and sticking billets. Most extrusion plants set the die oven at a fixed temperature in the range 450 – 500^o C and rely on time to control the temperature. In many plants there has been a significant increase in the number of die changes per shift but no increase in heating capacity reducing the individual die heating time. This paper discusses the factors that control die heating and presents some practical results of heating trials using a die set fitted with thermocouples. The trials were carried out in several different ovens and show the temperature changes with time. The results give a practical indication of the minimum time needed to adequately preheat a die.
Another problem is the effect of the die bearing being exposed to the furnace atmosphere. Polished samples of H13 die steel were placed in a die oven for different times and then removed. The changes in the surface are described.

INTRODUCTION

The reasons for pre-heating dies are well known throughout the extrusion industry:

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

Over the last ten years there have been some developments in die-heating technology including the introduction of single cell ovens, nitrogen atmosphere and even induction heating. However, the majority of plants still depend on the basic air circulating chest furnace. 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. Planning is restricted to ensuring that the die has been in the oven for a minimum time. The maximum time, temperature or die heating history does not come into the equation. 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 can be negated by poor control of the die heating process. Over the last decade the number of die changes per shift has increased from 10 to as many as 30 but few plants have increased their die heating capacity to match this increase. 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 stabilization of the material flow through the die and the production of good acceptable product. 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.

In order to verify the true time for a die to reach temperature a 480mm x 280mm ring size porthole die was fitted with three thermocouples. The die consisted of a die plate and mandrel and a feeder plate. 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 1.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.

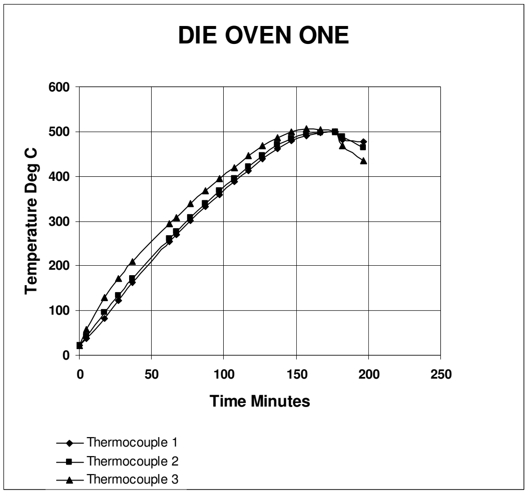

Figure 1 Temperature Against Time for Die Oven One

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.

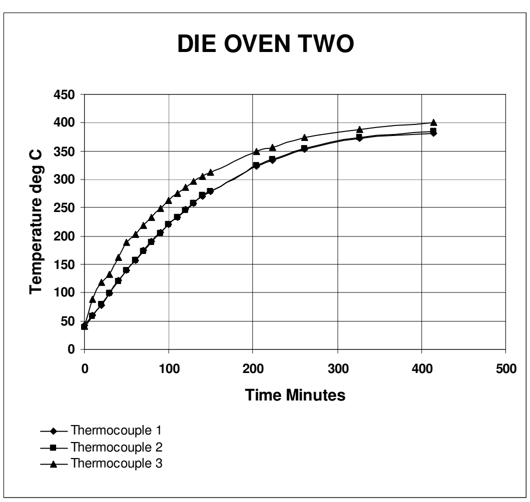

Figure 2 Temperature Against Time for Die Oven Two

The preset temperature was again 460^{o}C but in this case the die temperature had only reached 400^{o}C at the surface after seven hours with the core temperature still 15^{o}C lower, figure 2. 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^{o}C. Well below the billet temperature of 460^{o}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.

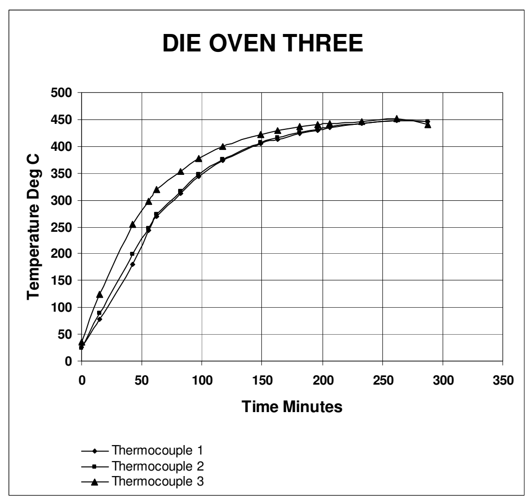

Figure 3 Temperature Against Time for Die Oven Three

The set temperature was again 460^{o}C and a stable temperature of 450^{o}C was reached in just over 4 hours, figure 3. The temperature difference between the surface and the core was approximately 20^{o}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. If the controller does not select the correct heating cycle for the die then overheating will occur and, more importantly, will not be recognised. 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 need to measure 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

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 is important for two reasons. The first is the quality of the surface finish. 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[1]. 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°C for periods ranging from 2 hours to 24 hours.
Figure 4 shows the changes in the surface appearance after the different preheat times.

Figure 4. Surface Finish on Test Pieces after Heating to 480°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 5. 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.

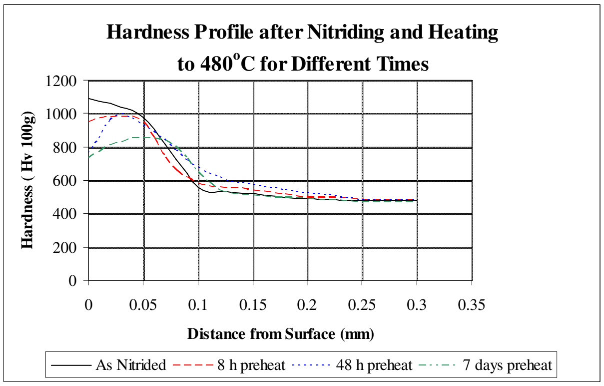

Figure 5. Hardness Profiles in Test Pieces After Heating for DifferentTimes at 480°C

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.

CONCLUSION

Die heating is an important part of the extrusion process but is rarely controlled to the same extent as the rest of the process. Variations in the die preheat temperature will affect the material flow through the die at the start of a production run increasing the scrap rate. 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. Die oven management software should be used to ensure planned effective and controlled use of the die oven capacity available and non-contact temperature measurement of the die as it is removed from the die oven and loaded into the press should be standard practice.

ACKNOWLEDGEMENTS

The authors would like to thank
Hydro Aluminium Extrusion Bedwas,
Sapa Profiles Tibshelf,
RGB Metallurgical,Wolverhampton,
and the Materials Department Imperial College, London for their assistance with this project.

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