The Single-Cell Die Oven

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ABSTRACT--- Case studies of recent installations document the reduction in die trials, and the increase in productivity and recovery, which is achieved through control of the temperature of tooling - dies and support tooling, containers, stems, and fixed dummy blocks - before the tooling is loaded into the extrusion press. Heat transfer models, which take account of the influence of radiation, convection and conduction of heat between radiant heating elements, and press tooling, enable the proper design and configuration of the tooling ovens. This paper describes the development of the modern single-cell die oven, emphasizing the control of the surface temperature of the tooling and consequently the heating times; to ensure that heating times are minimized, while the properties of the tooling steels are maintained. Experiments with instrumented tooling are described. Essential facts debunk the use of vacuum or inert gases as means to prevent or delay the oxidation of tool steels.

INTRODUCTION

Quotation from a Web article by William Beatty, *Messing About with Infrared Light*, “I’ve always been fascinated with the term ‘heat radiation,’ which is the misleading name for long wave infrared light.”

Despite the fact that the majority of extrusion dies can be designed and manufactured for use in production without a die trial, the average extruder wastes valuable press time and recovery getting new dies to run properly. All too often, extrusions from the first, and sometimes the second and third billet twist and wave down the press run-out table, before the die starts to run properly and acceptable extrusions are produced. Although the production order can then be completed, it is at the cost of valuable press time, and less than acceptable recovery.

For an extrusion die to run properly the press must be mechanically aligned and the billet, container, die and support tooling must be heated to the correct operating temperatures with the variation in the temperature gradients minimized. Improper thermal alignment of the extrusion process is a major cause of lost production, poor recovery and die failure.

Figure 1. Extrusions from the first two billets must be scrapped before acceptable production is achieved

The traditional chest type die oven, often with a single heat source, a large door, and the ability to hold numerous pieces of press tooling, is an inherent source of temperature variations in the extrusion die. In addition to the problems caused by uneven temperature distribution, ovens holding more than one die (traditional chest ovens, multiple-die drawer ovens, or rotary ovens) are often misused and abused. Dies are left in the ovens for eight, twelve, twenty-four or more hours at temperature causing oxides to build up on the surface of the die bearings with predictable damage to the finish of the extrusions and the life of the extrusion dies.

The inherent problems regarding type and age of the die oven can, to some extent, be overcome by the way it is managed by the die shop and press crew. A die oven can be kept perfectly clean and in good working condition, and dies can be loaded, heated and moved to the press in strict sequence. But, ovens holding a number of dies do not lend themselves to one-by-one sequencing and the visible management of dies.

Alternative heating systems such as induction heaters and smaller ovens, which employ both convective and, more recently, radiant heating, have been used by the aluminum extrusion industry for many years. Illustrations of press systems in Japan, employing numerous small ovens, have appeared in the proceedings of earlier ETs.

However, outside Europe and Japan there has not been much interest in the use of single-cell die ovens, and it is not unusual to find new aluminum extrusion press installations in North America equipped with traditional chest ovens. In the light of the advantages offered by the single-cell die oven, one can only wonder, why?

THE CONVENTIONAL CHEST OVEN

Improperly managed and operated chest ovens generate scrap, and are often responsible for unnecessary die corrections and die trials. Because dies are not uniformly heated in the chest oven, die corrections and die trials become meaningless. The oven contributes to die breakage and reduced die life. Dies are more likely to break and billets are used to preheat the dies. Because dies are in the oven too long, the bearings oxidize, and die life and surface quality of the extrusions are reduced.

The disadvantages of the conventional chest oven and those designs dependent on relatively long heating cycles were summarized in the following note [1]:

> "The production of high-quality extrusions depends on a number of factors, including satisfactory heating of the die before it is loaded into the press. A die that is not at the correct temperature, and particularly one which has significant temperature differences, will not run true until the temperature differences are dissipated during production. This may lead to increased difficulty during breakthrough, and the likelihood of producing excessive off-tolerance material. This is particularly serious in the case of dies made for short production runs."

In a die oven, heat is transferred from the heat source to the die by a combination of convection and radiation. The relative importance of convective and radiant heat transfer depends on the design of the oven. Within the die or die stack the heat diffuses, and temperature equalization occurs by conduction. Temperature uniformity is dependent on the maintenance of uniform oven temperature.

The chest oven, which is designed to hold numerous dies, is still the most common form of die heating. As a die reaches temperature and is removed to the press, the next cold die within the press schedule replaces it. Chest die ovens are usually fitted with a fan to circulate heated air through the length of the oven chamber, with the intent of enhancing heat transfer by forced convection. However, any substantial enhancement of convection requires a high capacity circulating fan, and careful attention to die oven geometry to ensure uniform distribution of air around the load. This apart, the chest oven design suffers from a number of potential drawbacks:

- The air flowing through the chest oven is gradually cooled by its passage over the cold dies so that there is a temperature variation along the furnace length.
- When cold dies are added to a chest oven already containing hot dies, they will affect downstream air temperatures, and hence die temperatures, and may cause a drop in overall air temperature.
- If, as they often are, the relatively large lid seals are distorted or badly maintained, cold air enters which will cause further temperature loss along the length of the chest oven. In addition, if temperature control is based on that of the air entering the load chamber, downstream parts

of the furnace are prevented from ever reaching the specified control temperature.

- When the die oven lid is opened to remove or add dies, there is a detrimental effect on the temperatures of those that are already in the furnace. When a cold die is put into a hot die oven, its heating profile will depend on the balance between heat available from the source and the rate at which it is transferred to the die. However, it will usually approximate to an exponential curve, where the heating is comparatively rapid at the start of the cycle, but is much slower at the end. Similarly, if a hot die is exposed to cold air, it will initially cool quickly, but then progressively more slowly as its temperature approaches that of the cold air. It follows that if one die oven is used to heat a number of dies, all to be called for at different times, there is a problem, since each time the die oven is opened to add or remove a die, any die which is near its final soak temperature will tend to cool relatively rapidly. When the die oven is closed, it takes longer for the die to recover the lost heat, because its heating is now represented by the slow part of the temperature profile. It follows that in such die ovens it is very difficult to achieve and maintain close temperature control.

The effects described above are illustrated in Figures 2 and 3.

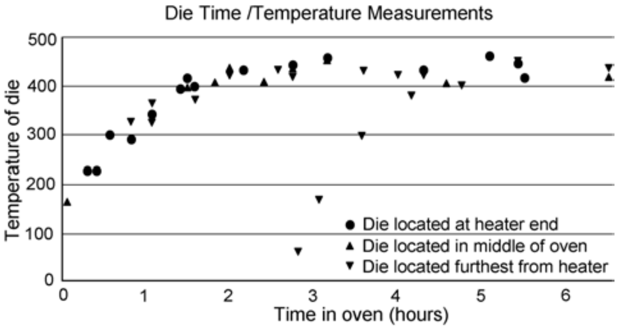


Figure 2. - Time/temperature data from a process audit of a conventional chest oven

Three dies, each comprising die, backer and die-ring holder, were loaded into the middle and each end of the oven. A fourth die was added after three hours. The plots show typical heating times, and the effect of adding the fourth die.

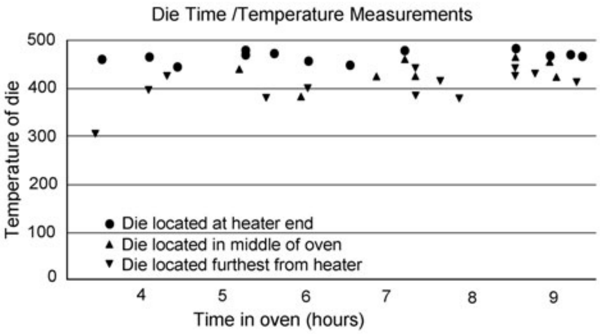


Figure 3. - Time/temperature data from a process audit of a second conventional chest oven

The data presented in Figure 2 shows die temperatures varying between 750°F and 860°F (400°C and 460°C). Data taken after extended time in a second oven, Figure 3, shows die temperatures varying between 720°F and 910°F (380°C and 490°C)

- Because chest ovens are often over-loaded, or poorly managed, with cold dies being placed next to dies due to be loaded to the press, the temperature of dies reaching the press has been measured to be as low as 450°F (250°C). During the operation of press installations equipped with chest ovens, dies that are observed to be settling down are in fact being heated by the successive billets.

- Improper heating is a major cause of multiple die trials because, unless the die is properly heated, the die trials provide incomplete data.

- Extended heating time results in excessive oxidation of the die bearing. Four hours at temperature is recognized to be sufficient to mar the surface of the extrusion.

- Extended heating times damage the nitride layer. Fifteen (15) hours at 900°F (500°C) is sufficient time to effectively remove the nitride layer from salt-nitride dies.

- As shown in Figure 4, the build-up of oxide on dies is dependent on the time at a given temperature. Each vertical bar represents a range of times at a specific temperature. The longer the time at temperature, the thicker the oxide. The higher the temperature, the faster the oxide builds. The difference between the oxide build-up on a die heated two hours and 30 hours at about 880°F (475°C) – a typical die temperature and range of heating time recorded in practice – shows that in that time the oxide on the sample builds from 50 to over 300 micrograms per cm^2.

- The data also shows that the oxidation rate at about 880°F (475°C) is 100 times faster than that at 660°F (350°C)

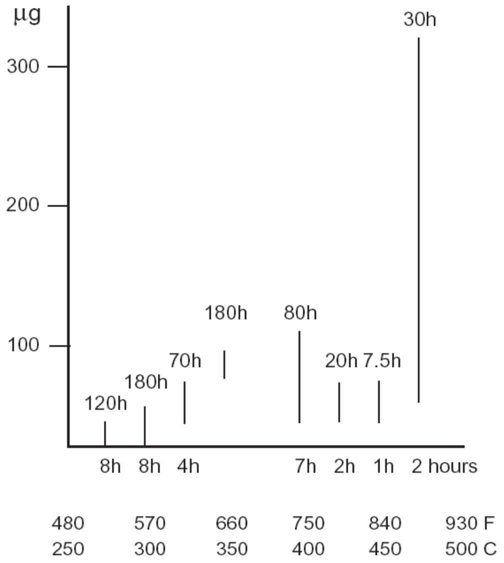


Figure 4. The effect of time at temperature on the oxidation of iron; prepared from data presented by Caule, et al.[2]

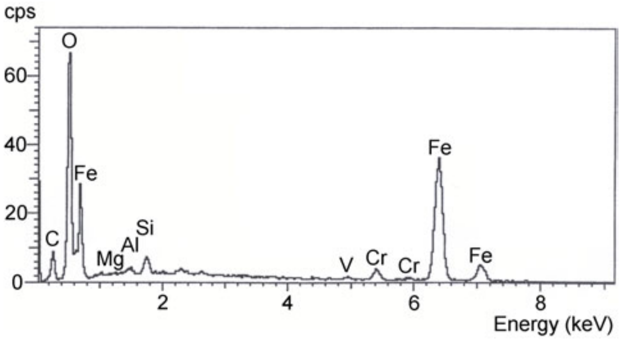


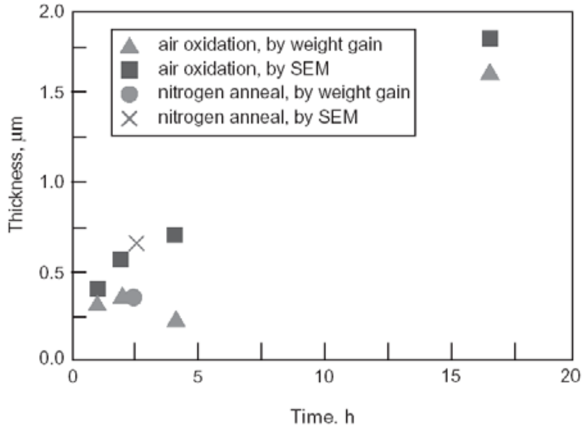
Figure 5. Scanning electron microscopy (SEM) of the front-end samples of a large extruded profile; the spectrum shows clear evidence of a thick layer of iron oxide coming from an oxidized die bearing; the largest peaks are Iron (Fe) and Oxygen (O), with minor traces of Chromium (Cr) and Vanadium (V), both of which are additions to the H13 steel

Research Into the Oxidation of H13 Die Steel [3]

The oxidation of the H13 or nitrided H13 die bearing in atmospheric air is progressive. The thickness or weight of the oxide formed being a function of the temperature and the time the die bearing is exposed to that temperature. The data compiled from that reported by Caule et al.(Figure 4) is typical. At the lower temperature of 500°F (260C), iron samples exposed to atmospheric air gained little weight whether exposed for eight hours or 120 hours. At the higher temperature of 850°F (470°C) iron exposed to atmospheric air for 2 hours gained measurable weight of oxide, and those exposed for 30 hours (not uncommon in the conventional chest oven), gained over 300 µg per cm^2.

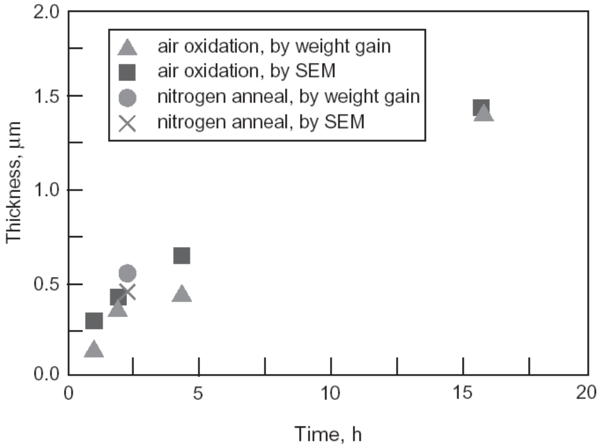
Aware of the importance of this issue to the aluminum extruder, Castool supported a series of trials at the Institute for Microstructural Sciences at Canada's National Research Council, Ottawa to measure the growth of oxide on nitride and non-nitride H13 die bearings at the temperature of the die oven, and specifically to measure the effect on oxide growth of heating two hours in an inert atmosphere before exposing the samples to air. Drs. R. J. Hussey and M. J. Graham, who have done extensive research into the oxidation of iron and steel, performed the work. Oxidation of the samples at 840°F (450°C) was performed in flowing air or nitrogen in a Pyrex container placed inside a Lindberg Blue M furnace. (Thus preventing possible contamination from oxygen absorbed onto the furnace walls.) Scanning electron microscope (SEM) micrographs were acquired before and after oxidation using a JEOL 840A SEM.

The effect of the time the nitride and non-nitride samples of die bearings were exposed to the furnace atmosphere at 840°F (450°C) is illustrated in Figures 6 and 7. With the exception of the sample of nitride H13 steel, which spalled after four hours heating in air, all measurements follow parabolic curves, with oxidation proceeding rapidly in the first hour, and the nitride samples gaining marginally more weight than the non-nitride samples.



Average oxide thickness determined by weight gain (▲), (●), and by SEM of fractured oxide scale (■), (×), for nitrated steel at 450°C

Figure 6. - The oxidation rate – in air and commercial grade nitrogen, of Nitrided H13 at 840°F (450°C)



Average oxide thickness determined by weight gain (▲), (●), and by SEM of fractured oxide scale (■), (×), for non-nitrated steel at 450°C

Figure 7. - The oxidation rate – in air and commercial grade nitrogen, of Non-Nitrided H13 at 840°F (450°C)

In an attempt to reduce or prevent oxidation of the die bearing, there has been some interest in using an inert atmosphere to prevent or slow the rate of oxidation in the oven.

However, as the research shows, H13 heated for two hours in commercial grade nitrogen containing less than 5ppm oxygen, followed by exposure to air for 10 minutes, showed the same weight gain as those exposed to air throughout the heating cycle.

The relevance of this finding to extrusion plant practice can be explained as follows: The die ring, die and backer, with the obvious exception of the die bearing, and except when new, will generally be oxidized to a greater or lesser extent when they are brought to the die oven. The die oven walls, and the surfaces of the tooling (the die ring, die and backer) absorb oxygen when exposed to plant air.

Even after purging with commercial grade nitrogen, there is enough oxygen available in the system to oxidize the polished, highly reactive die bearing. This data supports the conclusions that the die heating time should be kept as short as possible. And, there is no advantage to heating the die in an atmosphere of commercially pure nitrogen.

Because the oxidation rate of H13 steels is dependent on temperature, and the rate of oxidation is fastest during the first few minutes of exposure of oxygen, oxide formation cannot be prevented during transfer from the die oven to the extrusion press.

The extruder must therefore manage his die ovens to minimize the time in the oven at temperature, while also minimizing the time transferring the die to the extrusion press.

Defining the Limiting Heating Rate: Problems of Overheating Dies

It has traditionally been the practice to recommend that extrusion dies (and related tooling) be heated in air circulating ovens. This is because of the obvious dangers involved in heating the die too quickly. However, the reduction in the size of production lots, created by pressures for just-in-time deliveries, and the necessity of accurately controlling the temperatures of the extrusion dies, has resulted in the development of a family of single-cell, direct radiant heated die ovens.

But, the time taken for a typical die stack to reach temperature is controlled by the energy available, the rate of heat transfer to the surface of the die, and the conductivity of the die steel. The only way a die can be heated quickly is to raise the temperature of the oven and operate it with a heat head.

Because the readily available sources of radiant energy operate at high temperatures and, depending on the design of the heater, radiant energy can be concentrated, there is a possibility of overheating. The possibility of overheating the die, or more specifically small details within the die, was recognized during the development of this single-cell radiant heated oven. An arbitrary minimum was initially placed on the distance between the die and the nearest infrared source.

We commissioned a third party to investigate the effect of radiant heating on small details typical of those found in heat-sink dies.

In the initial experiments, 9-inch diameter by 1/4-inch (4mm) thick die plates, having a typical heat sink profile WEDM into them were heated for 30 minutes at temperatures of 1112, 1202, 1292 and 1382°F (600, 650, 700 and 750°C).

The following effects were observed:

- The white layer disappeared, and the morphology of the nitride layer changed after 30 minutes at 1112°F (600°C). (See Figures 8 and 9.)
- The oxide layer grew and the nitride layer continued to change. The nitride layer grew (diffused) by 25 percent after 30 minutes at 1202°F (650°C).
- The oxide layer continued to grow (to about one-thousandth of an inch,) and the nitride layer reached 150 percent of its original thickness.
- The adverse effects continued at the higher temperature.

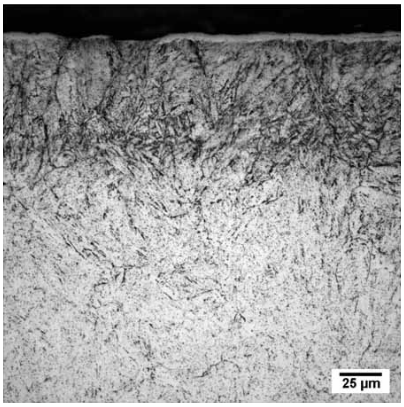


Figure 8. Surface of the die plate as nitrided, showing the white layer

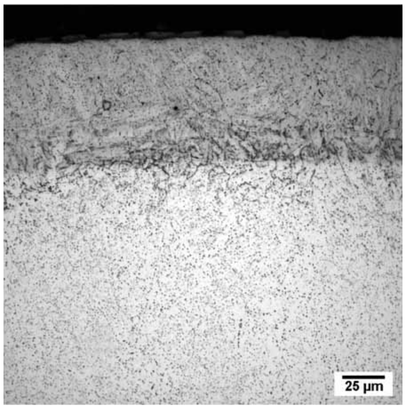


Figure 9. After 30 minutes at 1112°F (600°C) white layer removed, morphology of the structure changed

In the light of excessive die breakage being experienced by some users of radiant infrared ovens, a number of light-gauge precision thermocouples, placed at varying depths in an extrusion die were used to establish the optimum distance between the selected radiant source and the extrusion tooling. The data confirmed that the surface temperature can be controlled at a safe level, provided that due consideration is given to the fact that heat transfer within the H13 die steel is controlled by conduction. There is little or no penetration of infrared radiation into H13, or any other steel. There is however, a limiting rate of heating that is governed by the heat transfer coefficient of the die steel and the need to maintain the quality of the nitrided extrusion die. Heating dies faster can only be achieved by raising the temperature of the steel surface. This will result in heavy oxidation and, as is demonstrated above, premature diffusion of, and changes to, the form of the nitride layer.

Since it is essential to limit the surface temperature, particularly on the small details that are found in many extrusion dies, precise control of the die oven heating is essential. Figure 9 illustrates what happens when the surface of a detail is over-heated.

In spite of the fact that properly designed radiant heating systems should not result in local overheating of the extrusion die, the time to reach a desired temperature can only be reduced by increasing the surface temperature of the die. This is illustrated in Figure 10.

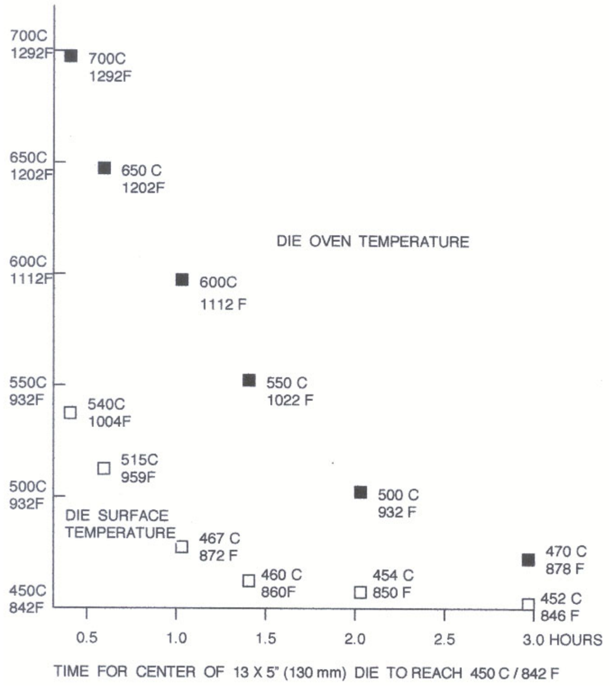


Figure 10. - The relationship between the die oven temperature, the die surface temperature, and the time to heat the center of a 13" X 5" (330mm x 125mm) die to 450°C (840°F)**;** for example, if the die oven cavity is at 1112°F (600°C), the center of the die will be at 842°F (450°C) after one hour; at this time, the surface temperature will be 870°F (467°C)

As is evident from Figure 10, the time for the center of the 13-inch by 5-inch die illustrated to reach operating temperature of 840°F (450°C) is dependent on the die oven temperature, which in turn controls the maximum temperature reached by the surface of the die. The higher the oven temperature, the faster the surface temperature rises.

Maintaining Temperature: Heating Press Tooling. Although the use of properly designed single-cell die ovens will ensure that the die stack leaves the die oven soaked to a uniform and correct temperature, the die must be moved quickly and not be placed on the plant floor, or into a cold canister or die slide. In addition, the support tooling must be heated.[5] This can be accomplished by heating the bolster in a separate single-cell or traditional chest oven, or by using a heating system built into the tooling.

Figure 11 and 12 show examples of heated support tooling. The purpose of the heated tooling is to ensure heat is not drawn away from important components by the structure of the extrusion press.

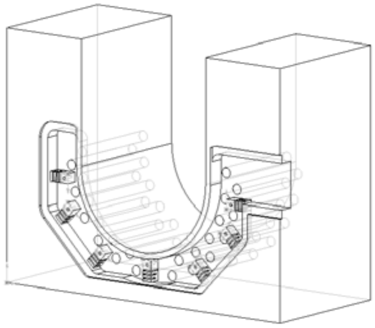


Figure 11. Example of a die slide equipped with cartridge heaters

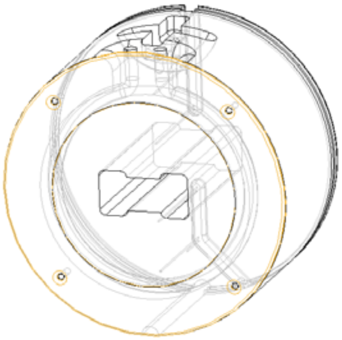


Figure 12. Heated bolster with circular element surrounding the center channel

THE SINGLE-CELL DIE OVEN

In an earlier *Light Metal Age* article, we wrote:

> "Those who visited Japan's aluminum extrusion industry in the late 1960s and early 1970s invariably returned with tales of presses working steadily, extruding relatively few different shapes in long production runs. But, by the early 1980s, the Japanese extruder of residential window and door shapes was being forced to reduce the number of billets in each order to meet the just-in-time targets of their fabricating plants. Unable to react fast enough, an inventory of finished extrusions was often to be found between the extrusion and fabricating plants. Already a goal of the Japanese automobile manufacturer, reducing set-up time became a necessity for the extruder. Traveling around Japan in 1982, this visitor to one extrusion plant was shown an induction die heater and a number of heated die boxes with two or three dies in each. By 1988, the heated

boxes had evolved into separately insulated, electrically heated ovens, capable of heating the average die stack to temperature in less than two hours. Each oven held one die; each was fitted with its own cover door. Dies were brought from the die shop to the press area in batches to match the number of ovens installed at each press. Dies heated in these ovens ran properly from the first billet, at the designed extrusion speed and recovery. The single-cell die oven had become an integral part of the production management system."[1]

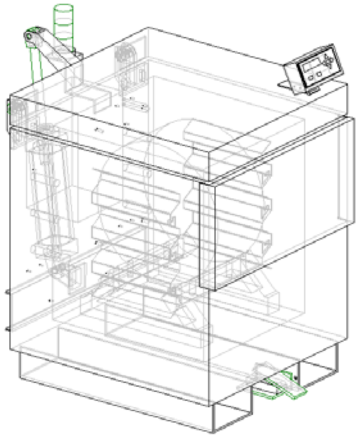


Figure13. The single-cell die oven showing structural details

The modular design of the single-cell oven means that each die or die stack is heated in its own oven. Temperature control is optimized and the shortcomings outlined above are eliminated. When heating steel die components in an oven of this type, radiation is the dominant mode of heat transfer. The design of the single-cell oven is therefore based on heating by radiation, although radiant heat transfer is naturally supplemented by free convection. With radiation as the main heat transfer mechanism, consideration must be given to the uniformity of heating, and in particular whether or not there may be any danger of local overheating of the die, which is in close proximity to the source of heat. This is not seen as a problem for the following reasons:

- Although the heaters will be hotter than the die oven generally, they represent only a fraction of the oven area to which the load is exposed. While the heaters are the primary heat source, the internal surfaces of the die oven act as a secondary heat source, and exercise an important moderating effect as they reflect, absorb and re-radiate energy.
- The heaters only operate at full power during the early stages of the heating cycle, when the die oven is coming to its maximum temperature and the load is comparatively cool. Thereafter, the power is reduced, thus reducing the temperature difference between heaters and die oven. The proximity of the load to the heaters then becomes correspondingly less and less of an issue as the load approaches its final temperature.

Design Criteria: Numerical Simulation of a Single-Cell Die Oven

The numerical simulation of a single-cell oven is done in two separate but complementary models.

In the first, standard relationships for heat transfer by free convection, radiation and conduction are used. It is assumed that at any instance the die is at a uniform temperature. The rates of heat transfer to the die from the heaters by means of radiation (directly and via reflection from the oven wall,) and by free convection are calculated. Hence the heating curve for the average temperature of the die is obtained.

At the same time, heat transfer through the oven walls is calculated for thermal insulation of a prescribed thickness and conductivity, assuming external radiation and convection to the surrounding space, which is at a prescribed ambient temperature. By combining the peak rate of heat absorption by the die and the rate of heat loss through the oven walls, this model may therefore be used to determine the total power rating necessary to achieve the desired oven performance.

In the case of larger dies, it would be unreasonable to assume a uniform die temperature; particularly where higher oven temperatures are involved, and is is essential to know if there may be a risk of overheating parts of the die. In this case, a finite difference model was developed in which the die was divided into discrete radial and longitudinal zones.

Assuming a prescribed control temperature for the surfaces (if any) of each zone was calculated as before, with simulation of conduction between the adjacent parts of the die.

The calculation proceeds until the hottest region of the die reaches the maximum allowable temperature. The subsequent thermal history of temperature equalization within the die can be then be followed.

Case Studies of Recent Installations

The single-cell oven's effect on extrusion production has been to significantly improve the first-time performance of extrusion dies. And, because of the reduced time to reach uniform temperature, to greatly reduce the oxidation of the die bearing and the consequent die life.

The following observations and reports from the operating companies attest to the contribution to improved control of extrusion process rendered by quickly and consistently heating extrusion dies to the correct uniform temperatures prior to placing them in the extrusion press:

- Multiple, single-cell die ovens enable lot size to be reduced to 200 kg (440 lb), and die changes to be increased to 150 per day.
- Multiple single-cell die ovens enable 10 die changes per hour while maintaining productivity at 1000 kg/hr (2200 lbs/hr) and recovery at 87 percent.
- Die trials eliminated on 95 percent of dies in a multi-press installation.
- Prototype second generation single-cell die ovens were reported to have “eliminated problems starting dies.”
- One single-cell die oven has been added to each extrusion press in a multi-plant facility to “ensure that ‘difficult dies’ run first time.”
- Soft alloy starter billet and short hard alloy billet proved unnecessary to start hard alloy extrusion after installation of single-cell die ovens.
- Multiple starter billets eliminated when changing dies on large 5600-ton press.
- Scrap due to surface defects reduced by 50 percent following installation of single-cell die ovens.
- Breakthrough pressure reduced at all installations.
- Die breakages reduced.
- An unbroken sequence of 85 dies runs on the first billet.
- Rapid heating, single-cell die ovens, which minimize surface oxidation, displace ovens designed to hold dies at temperature.

DISCUSSION

The paper presents the results of research and development directed at understanding why extrusion dies fail. The research has shown that the control of die heating rate, control of time at temperature, and control of the temperature of the die when it is delivered to the extrusion press have a major impact on die performance, and by extension, the extrusion press.

The outcome of the research, which has investigated the rate of formation of oxides on the surface of the die bearing, the effect of overheating on the surface of the extrusion die, and the transfer of energy from a source of infrared heating to the extrusion die, has been the development of a series of single-cell die ovens.

The development work has included work on prototypes involving alternative heating and control systems, the modeling work described above, and considerable effort to bring a cost-effective product to market.

The performance of the resulting single-cell die oven can be compared with that designed to hold two or more dies as follows.

In the multi-die oven:

- The time to heat a given size extrusion die will be longer.
- A cold die is always loaded next to a hot die, cooling its surface and creating temperature gradients in the hot die.
- Opening and closing the door - to remove and insert dies, results in cooling the other dies in the oven. The heating process is not repeatable.

- Because oxidation of the die bearing is proportional to the time in the die oven, heating two or more dies at the same time results in the dies having twice (or more) the thickness of oxide when moved to the press.

- Ovens containing more than one die become a depository for dies not immediately required at the extrusion press.

The "Case Studies of Recent Installations," which are listed above, can be summarized as follows: The installation of single-cell die ovens have been observed to have the following impact on the operations of the extrusion plants:

Temperature Uniformity

Die heating systems, which ensure that the dies and support tooling are uniformly heated, contribute to reducing die trials: less time wasted at the press.

Surface Quality

Die heating systems, which ensure that the dies and support tooling are uniformly heated in minimum time, contribute to better surface finish: recovery is improved.

Just-in-Time, the Visible Management of Dies

The paper has only made passing reference to the other advantages of single-cell die ovens, which were the reason for their initial development in Japan.

In a just-in-time system, single-cell ovens are used to enhance (some might say enforce) the sequence of extrusion press operations.

In a properly engineered system, the number of single-cell die ovens installed at each press matches the maximum demand rate for the extrusion press. For example, if each production run takes 1.5 hours to complete, a press using dies which take 1.5 hours to preheat can operate with one single-cell die oven. As the lot size, and hence the duration of each production run, is reduced, more ovens must be added to ensure that the dies are at temperature when moved to the extrusion press. Obviously, the number of ovens must accommodate the longest heating time and the shortest production run at any particular extrusion press. In a properly managed system, dies are moved from the die shop to the extrusion press in numbers that match the number of die ovens. And, as one die is moved to the press, a new die is placed in that single-cell oven.

Because each die oven holds a single die, the status of each die can be indicated to all persons in the area of the press by a simple pole-light, showing whether the oven is active, heating the die, or at temperature.

Dies can be managed into and out of the die ovens with confidence that they will run the first time and every time.

This combination of "smart" ovens (which display their condition) and a properly managed die shop, supplying the number of dies required to replace those in each oven constitutes the "visible management system" that is at the center of any just-in-time program. Visible management follows the principle that a press operator should not have to look for the next job. It should be obvious what must be done next. The die oven should be equipped to display the readiness of the die or tooling being heated.

Figure 14. Multiple single-cell die ovens

Saving Press Time

Press time is the extruder's most critical resource. Press time must be managed. The use of single-cell die ovens brings discipline to the press operation. Dies are uniformly heated to the correct operating temperature; with the result that most dies now run properly without the need to extrude billets to heat them up. The time to complete each order is reduced; productivity and recovery are increased.

System Integration

With the installation of single-cell die ovens, the die oven becomes an integral part of press scheduling and sequencing. Dies are now loaded to the ovens one-by-one, and are ready for use in minimal time. As each die is loaded into the press, another replaces it. The frequency of die changes and the size of the die stack dictate the number of single-cell die ovens required to service each press. The oven controls can be integrated into the production control system, providing a record of the time spent in the die oven.

Since the die oven is part of a system comprising the customers, production planning and control, the die shop, the press, and the downstream operations, it is reasonable to expect that the status of a heated die to be monitored. The information should be available for the die management system, production control, and maintenance.

Automation

In numerous press installations, the single-cell die oven has been integrated with proprietary pick and place systems to automatically load and unload die ovens and deliver dies to the extrusion press.

Energy Consumption

Properly engineered single-cell die ovens minimize the consumption of energy. The heating system is designed to convert electrical or hydrocarbon energy to radiant energy as efficiently as possible. The heating media and the inside of the oven should transfer energy as efficiently as possible to the load, and the properly insulated door is only opened for loading and unloading the oven. The insulation of the oven itself is designed to reduce the outside shell temperature to a minimum, thereby ensuring the oven dissipates minimum energy to its surroundings. An oven holding a typical die stack for a 2000-ton (1800MT) press at 840°F (450°C) dissipates about 800 watts.

Return on Investment

The return on investment from the installation of single-cell die ovens can be calculated from the following benefits:

- Recovery rate is increased because dies run properly from the first billet
- Productive press time is increased
- The surface quality of extrusions is improved
- The lead-time, from order entry to delivery of the extruded product to the customer is reduced
- Die life is increased.

Note that the return on investment is a function of the size of the press–the bigger the press, the faster (greater/bigger) the return.

CONCLUSIONS

The advantages of the single-cell die oven include:

- Dies run properly from the first billet
- The first billet is run at the same speed as subsequent billets
- Recovery is maximized by correctly programming the size of the first (and last) billet
- Die trials are minimized
- The surface of the extrusions is enhanced
- Die life is extended
- Die breakage is minimized
- As a consequence, press utilization, productivity and recovery are increased. The percentage of completed orders is increased

Note that the research demonstrated that there is no advantage to using commercially pure nitrogen in die ovens.

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GLOSSARY OF TERMS

Conduction - The transmission of heat through a conductor (in this case, the die steel or, the oven insulation and outer shell).

Convection - The transfer of heat by the circulation or movement of a heated gas or air. (To rapidly heat a steel body by convection requires high-velocity air.)

Induction - The process by which a device having electrical properties induces similar properties in an adjacent body without direct contact.

Infrared - Electromagnetic waves in the frequency range from about 750 nanometers (just longer than red in the visible spectrum) to 1-millimeter, on the border of the microwave region (just below visible light). When the infrared energy reaches the surface of steel the energy is converted into heat. Heat then travels through the die by conduction.

Radiation - The emission of rays of energy. In this case, heating the steel die.