Thermal Control of the Extrusion Press Container

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ABSTRACT --- The ever increasing demands for higher productivity and recovery at the extrusion press focus attention on the mechanical, thermal, and electrical design of the container, this increasingly complex but essential part of extrusion press tooling. Research and development into the design and operating conditions of the modern thermally controlled container started by revisiting the traditional approach to container design and, in doing so, revealed many modern misconceptions as to the cause of container failures, whether they be catastrophic cracking, softening of the mantle, or slipping liners. Employing the finite element method to extend the research has enabled an understanding of the optimum placement and control of heaters, cooling passages, and thermocouples. The paper discusses a package of features that are becoming essential to manage the aluminum extrusion process.

INTRODUCTION

Laue and Stenger, in their work *Extrusion*[1], emphasise that because it is the most expensive piece of press tooling, the life of the container and its inner liner - employing a large volume of hot work tool steel - has a major impact on the economy of the extrusion process. The container, and its liner (and if necessary a sub-liner) must be designed to operate for long periods at high temperature while withstanding the large cyclical loads of each press cycle.

The stress analyses described in *Extrusion*, while a gross simplification of the actual loading and hence the actual stresses which might be encountered in service, nevertheless help explain some of the causes of premature failure. It serves as a good introduction to the more complete solutions offered by finite element analysis. These results can then be used to find the effects of the thermal conditions experienced by the container. This will give insight into effective methods for thermal control and help improve container performance and extend life.

STRESSES IN THE CONTAINER

When examining the likelihood of failure in a container design, it is necessary to consider stresses due to pressure. The shrink-fit within container components, and the extrusion process itself both contribute to the container's overall stress distribution.

As Laue and Stenger explain, the press stem and the die are subjected to axial loading. The liner carries axial loading due to friction between the billet and container. In addition, the liner (and hence the container assembly) has to carry the thermal stresses that develop during shrink fitting and extrusion. The force of extrusion generates very high tangential and radial stresses in the container assembly.

Laue and Stenger, using *thick cylinder* theory, assume symmetrical stressing of the container around its axis, and the temperature distribution is assumed to be axisymmetric over the full length of the container. Local thermal stresses, longitudinal stresses resulting from temperature variation between the mantle and the liner during shrinking, and the longitudinal stresses from friction between billet and container are ignored. All materials are assumed to have the same modulus of elasticity, and the stress is assumed to be purely elastic.

Also, the service stresses are calculated using classic elastic theory, superimposing the residual stresses from shrink fitting onto the stresses developed from the deformation loads. Thick cylinder theory is used to calculate the individual stresses in the container liner(s) and the mantle.

The resulting model is used in day-to-day work on container design.

Figures 1-4 illustrate why liners and, when applicable, sub-liners are essential to lower the service stresses to that which can be carried by readily available hot work tool steels. The examples show three containers with the same inner and outer diameters, and 60 ksi (413 MPa)of internal pressure.

For the sake of simplicity, an examination of stress due to internal (extrusion) pressure in a monobloc container will be presented first. Figures 1 and 2 show the stress distributions in a container under 60 ksi (413 MPa) of internal pressure. In these examples, the one-piece container has an 11.5-inch (292mm) bore, 40-inch (1016mm) outer diameter, and temperatures are assumed to be constant.

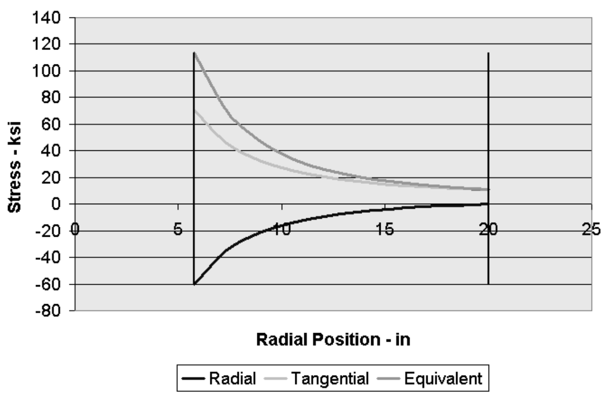

Figure 1. Stresses in a single-layer container; maximum equivalent stress: 113 ksi (779 MPa)

The Finite Element Method (FEM) result is shown in Figure 2 for comparison. This verifies that both methods give the same solution.

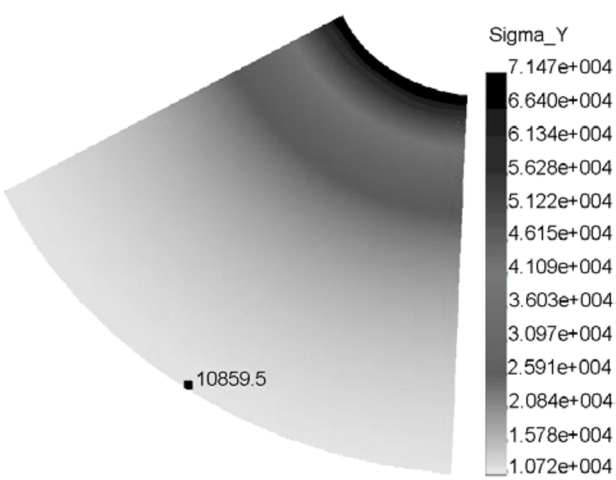

Figure 2. FEM solution showing tangential stresses

Figures 3 and 4 show the stress levels as more layers are added to the container assembly. Note that as layers are added, the maximum equivalent stress decreases, while the stress on the outer diameter (at 20-inch or 508mm)) increases slightly.

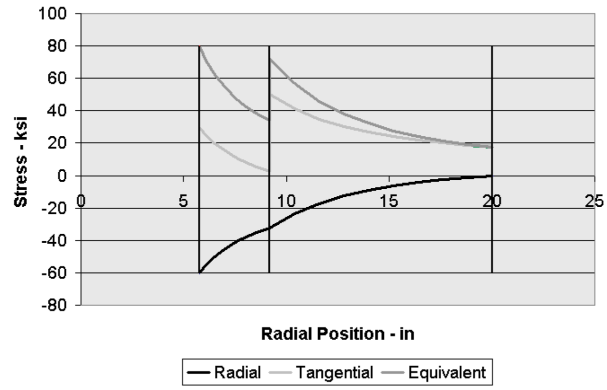

Figure 3. Stresses in a two-layer container; maximum equivalent stress: 79 ksi (544 MPa)

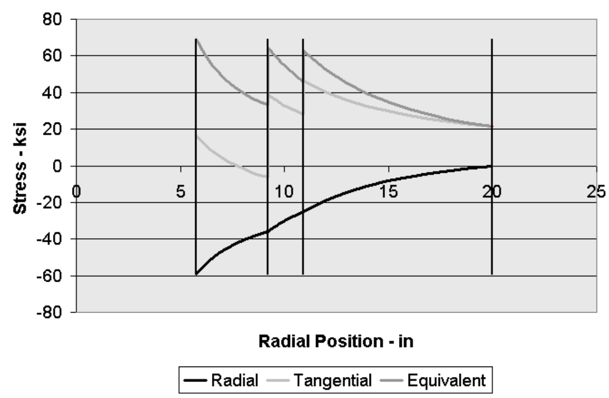

Figure 4. Stresses in a Three-Layer Container. Maximum equivalent stress: 69 ksi (475 MPa)

The effect of the shrink fit in multi-layer containers is to make the stress distribution along the radius more uniform. By passing some of the stress from the inner elements to the outer ones, maximum stresses at the billet interface are limited.

When features are added into a container body, they change local stress patterns. For example, as shown in Figure 5 where a keyway is added to the outer diameter of a container, it is evident the state of stress becomes aggravated.

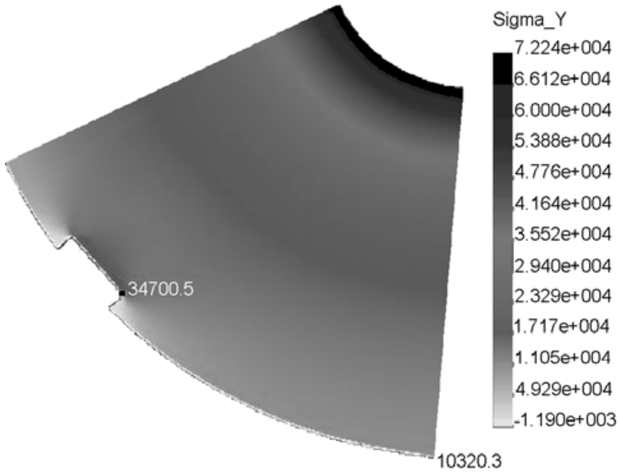

Figure 5. Stress concentrations introduced by a keyway

Under normal conditions, this stress concentration would not pose a problem, however combined with other factors (such as a softened container body) such features can potentially be troublesome.

Over heating, which can be easily achieved by excessive power input, will lead to a softened container body. It therefore becomes necessary to control temperatures not only for good performance, but also for increasing the life of the container.

CONTROLLING TEMPERATURE

The performance, and the useful life of containers, is affected by the service conditions - billet temperature and work done in extrusion - and to a much greater extent than was previously understood, by the configuration of the container heating system.

Writing in 1944, Pearson and Parkins[2] addressed the need to heat the bore of the container to “avoid chilling the first billets when starting from cold.” This was achieved by introducing a gas burner, a hot billet, or an electric resistance heater into the bore. While acknowledging that the container is heated by the extrusion of successive billets, he pointed out “the extent to which additional heating is necessary depends on the *alloy* concerned, (Pearson and Parkins used the term *metal*) and the capability of the press to carry out the extrusion in as short a time as possible.”

Because of the relatively high container temperatures required to successfully extrude aluminum (and magnesium) alloys, electric resistance or induction heating of the container was employed. The resistors, backed with insulation, were mounted on the inside of the container housing. Low frequency induction heating was done with insulated copper rods, connected in series, and inserted in longitudinal holes drilled in the container body. Pearson and Parkins pointed out that with induction heating, “since the heat is developed within the container, stresses due to thermal gradients, which play an important role in determining container life, are much reduced.” But, writing in 1976, Laue and Stenger[1] stated that: “Almost all containers are now heated electrically with cartridge elements inserted in holes in the mantle arranged parallel to the container axis.”

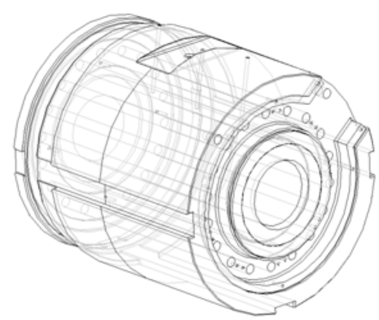

Figure 5. Internal details of a container with cartridge element heating

However, as is well known, many aluminum extrusion presses have been supplied and are still fitted with wrap-around resistance elements controlled by thermocouples installed in the mantle at some distance from the elements. In many cases, this heating arrangement can be shown to be the source of premature failure of the container.

Writing in 1982, Markiewicz[3] described experiments conducted in an extrusion plant environment, which showed that the “wrap around” container heating elements, which were common at that time could, unless properly controlled, result in overheating. He proposed a dual control system, with one thermocouple located close to the heating elements, and one measuring the temperature at the liner.

TEMPERATURE GRADIENTS OF OPERATING CONTAINERS

To minimize thermal stresses and to preserve the shrink fit of the liner, the container and liner must be brought up to the temperature required for extrusion over a period of 8 hours or more, limiting the temperature rise to no more than 100°F (56°C) per hour. During extrusion the container and liner should seldom be above 840°F (450°C), but if they are overheated and softening takes place, the container and liner will require reannealing and heat-treating.

Sudden heating or cooling of the mantle or the liner will result in excessive thermal stresses. This may cause cracking of these components, or shifting of the liner. To minimize thermal stresses, the temperature distribution within a container should be controlled, with temperature gradients minimized. Although the container experiences a variety of thermal conditions and is never really in a steady state, there are consistent temperature profiles that occur within the container.

When considering thermal gradients in a container, it is necessary to examine both the radial and axial distributions. The radial distribution has a much more extreme gradient and is therefore harder to control. Inevitably, due to the extrusion process, the inner bore of the liner is the hottest part of the container with temperatures approaching the temperature of the billet. A working container will generally follow the non-linear thermal profile as seen in Figure 6.

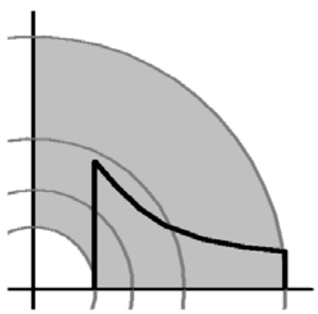

Figure 6. – Radial distribution of temperature

Within the container, conduction is the main type of heat transfer. The temperature at the outer surface of the container is dictated by radiant heat loss, while the temperature of the liner bore depends on billet temperature and the energy imparted during extrusion.

Although, under normal circumstances, the container mantle will not usually become hotter than the liner, this can occur when the control thermocouple is located remote from wrap-around heaters and the liner cools. Under such circumstances, the use of full ram pressure will cause the liner to break.

To maintain the shrink fit during temporary shut downs of the extrusion press, the container should be closed, and the main ram advanced to insert the face of the dummy block into the container bore. During longer delays, an electric resistance heater should be placed in the bore of the liner, and the ends of the container should be covered.

Management of the relatively slight axial temperature gradient is equally important. The temperature curve follows a pattern as shown in Figure 7.

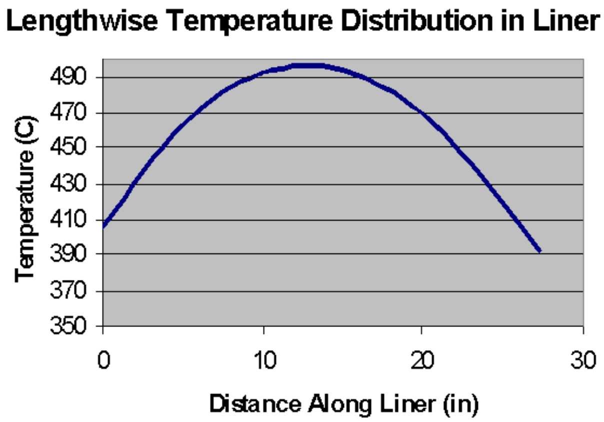

Figure 7. Axial distribution of temperature; the vertical axis shows the die end of the container

Heat loss from the ends of the container will result in the center of the container being hotter than the ends. This can result in bulging at the center. Also, the die end is hotter than the entry end since the billet resides in the die end for a longer period of time.

CONTAINER HEATERS

Regulating the temperature inside containers is important for several reasons. Not only does it reduce stress in the container, thereby increasing the life of the container, but it also boosts productivity and increases the quality of the extrudate. Good temperature control is crucial for achieving maximum productivity.

There are essentially two roles for container heating systems:

1. Preheating the container

2. Maintaining the temperature of the container during extrusion.

However, since the extrusion process provides most of the heating during operation, little or no additional heating is required for the system. In some cases a little heating and/or cooling is necessary for optimal performance.

Sustaining a consistent thermal profile in an axial direction usually only requires adding relatively small amounts of energy to specific locations within the container. For example, to make the axial temperature uniform, heating can be added in the region of the die end and entry end to make up for heat lost from the container faces.

However, since the die end of the container is at a hotter temperature than the entry end, the heating system must be able to recognize this difference and compensate. A front/back two-zone heating system along with the requisite thermocouples can identify and compensate for the temperature discrepancy, as well as apply energy as required. By adding more heat at entry end and less at the die end, a profile can be maintained that is more constant than with a single zone system.

In addition, it may be necessary to divide the heating between the top and bottom of the container. The top half of a container is usually hotter than the bottom half. Although conduction is the prime mode of heat transfer within the container, heat lost from the bottom of the container rises within the container housing, and it is sometimes necessary for containers to have heating systems that can heat the lower zones independently.

Preheating the container, as well as maintaining temperature when extrusion stops, can be much more difficult. Containers should be heated to minimize the thermal shock that is experienced when extrusion begins. Also, the container should be preheated in a manner that is quick and efficient. Many containers are made for use with external heaters that heat from outside the container body. This generates a thermal profile opposite to the one produced during extrusion where the outside of the container is hottest and the liner bore is coldest. Obviously, this type of heating is undesirable, and the resulting temperature gradients in container and liner are not right for extrusion. The solution is to move the heaters closer to the center in order to heat the liner.

The use of cartridge elements brings the source of externally supplied heat to a location within the container body. Since the supply of heat is closer to the liner, it takes less time for heat to soak through to the liner. Therefore less energy is required to achieve the desired temperature.

CONCLUSIONS

1. Improper control of the extrusion press container heating can soften the mantle of the container, reducing service life.

2. Improper heating can result in the liner shifting during service.

3. Improper heating can result in structural failure of mantle or liner.

4. Sophisticated, multi-functional heating elements, properly located and controlled, ensure that over-heating will not occur.

5. In combination with controlled cooling of the liner, the multi-functional heating elements can be used to optimize the temperature distribution in the container during service, thereby enhancing productivity and recovery at the extrusion press.

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