The Extrusion Press Container: Thermal Stability of the Liner Not Uniformity of the Container Mantle

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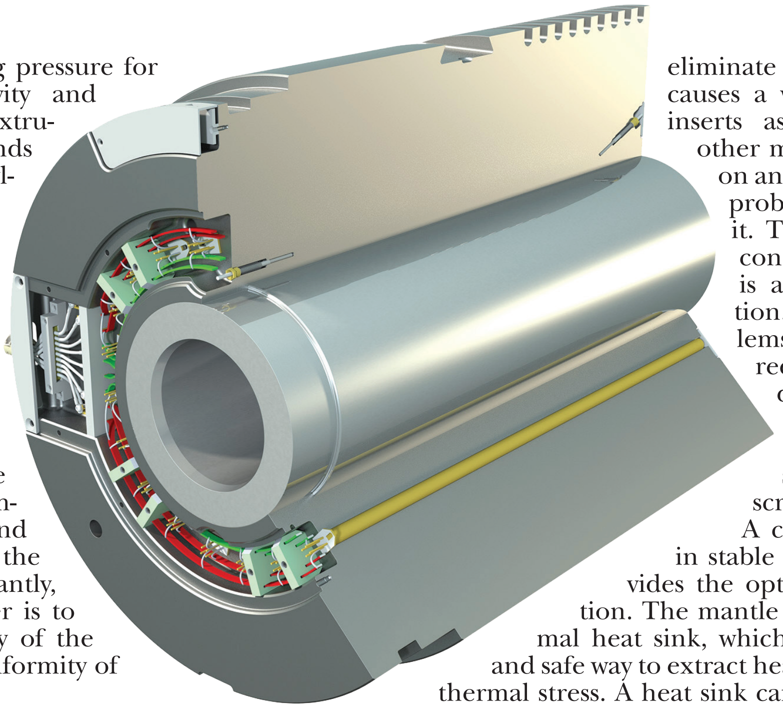


The ever-increasing pressure for higher productivity and recovery at the extrusion press demands better tooling and knowledge of tooling system providers. Containers are probably the most misunderstood press tooling. A container does more than just contain billets at high pressure and high temperature during extrusion. They affect surface, shape, and dimensions of the profile and also the life of the dummy block, liner, mantle and container housing, and the energy bill. Most importantly, the goal for the container is to have temperature stability of the liner, not temperature uniformity of the mantle.

During extrusion, there is a tremendous amount of heat generated within the container. The heat generated depends on the billet length, billet temperature, alloy type, extrusion speed, and extrusion ratio. The temperature can increase by as much as 150°C near the die region.[1] The increase in temperature can induce surface cracking, affect extrusion run-outs, disturb alignment, and reduce the container liner. Also, it changes the clearance between dummy block and liner; resulting in variable skin thickness and alloy build up. Simply put, nothing in extrusion is uniform.

The idea of a uniform container temperature has been touted as the optimal extrusion condition for isothermal extrusion. The container does affect the billet skin and the skin defect flow, but in no way does it affect the taper temperature of a billet. A billet taper heated by 100°C to effect isothermal extrusion does not want to encounter a container liner temperature higher than the billet back end temperature. The ideal situation is to have a constant temperature difference between billet and liner to eliminate skin defect flow.

The container has little if anything to do with isothermal extrusion, as this idea ignores the most fundamental principle of heat transfer; energy flows on temperature gradient from high temperature to low temperature. A container with uniform temperature doesn't allow the temperature gradient for heat energy to flow and dissipate. The extra energy generated during extrusion, accumulates inside the container and causes the container and liner temperatures to increase; leading to thermal/dimensional instability, extrusion inflow defects, and reduced lifetime of all tooling. The conventional solution is to machine an air-cooling groove near the liner to help extract heat away. The groove is usually positioned near or on the liner where the highest mechanical stress and thermal stresses occur. The groove hole acts as a stress riser, which has a multiplying effect on stress. This creates multiple weak points in the container. Still the solution to eliminate the stress riser, which causes a weak point, is to use inserts as reinforcement and other materials. The list goes on and on. It is patching the problem instead of solving it. The idea of a uniform container temperature is a wrong design direction. It causes more problems, uses more energy, reduces tooling life, and does not solve the fundamental problem, liner temperature instability and resulting scrap and other costs.

A container with a built-in stable thermal gradient provides the optimal extrusion condition. The mantle becomes a large thermal heat sink, which is the most efficient and safe way to extract heat without introducing thermal stress. A heat sink can absorb any arbitrary amount of heat from a target object without significantly changing the temperature of that target. Three key components are required for the heat sink: a temperature gradient between the target and surface of the heat sink, high thermal conductivity materials of the heat sink, and constant physical contact of the target with the heat sink. A quick response cartridge heater is positioned near the liner to maintain a constant and stable thermal gradient. A high thermal conductivity mantle used as a heat sink in the container and liner as the target can dissipate a large amount of heat without significantly changing liner temperature. The mantle is always contacting the liner by shrink fit, utilizing the entire available surface. The liner exit temperature can be stabilized and maintained at approximately 30°C below billet temperature at all times to reduce direct billet surface inflow onto the profile, reducing scrap from the surface finish. The difference between a uniform temperature container and a stable thermal gradient container is shown in Figure 1.

The ideal temperature gradient of a container is to have its housing at around 100°C and the container mantle surface at 250°C. This creates a thermal gradient in the container and dissipates heat as soon as it is created during extrusion. The calculation shows the

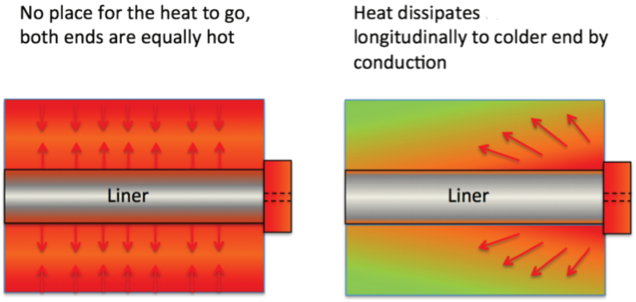
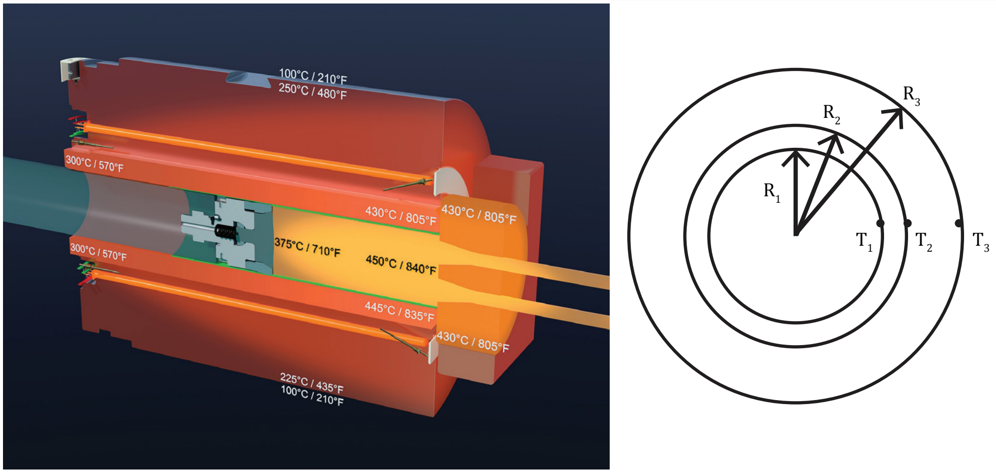


Figure 1. Heat dissipates both longitudinally and diametrically from the die end of the liner.



A_1: average liner surface area = 2.574 m^2
A_2: average container surface area = 4.785 m^2
K_1: liner thermal conductivity = 30 W/mk:
K_2: mantle thermal conductivity = 42 W/mk
r_1: radius of liner = 0.304 m
r_2: inner radius of mantle = 0.508 m
r_3: outer radius of mantle = 1.016 m
T_1: billet/liner temperature
T_2: liner/mantle temperature
T_3: mantle surface temperature

$$Q=\frac{T_3-T_1}{\frac{r_2-r_1}{K_1A_1}+\frac{r_3-r_2}{K_2A_2}}$$

$$Q=\frac{100-450}{\frac{0.508-0.304}{30*2.574}+\frac{1.016-0.508}{42*4.785}}$$

Q = -67,704 J

Figure 2. Ideal container temperatures and the calculation showing what intrinsic heat extraction is provided by the container.

thermal gradient provides the container intrinsic heat extraction at 67,704 J (Figure 2). It allows heat to dissipate from the liner without using auxiliary cooling or an air groove.

The cartridge heaters are required to be close to the liner to create a stable thermal gradient, when extruding and when the press is at rest. The quick response and proximity of the thermocouple to the liner reduces the thermal fluctuation of the container. The heaters will be on and off at a higher frequency, and the temperature fluctuation is more like a ripple versus big waves of heat. The container never overheats nor underheats. The container temperatures are stabilized. The liner is subjected to less thermal fluctuations and the useful life of the liner is extended. The mantle will not be overheated and the useful life of the mantle is increased. Energy consumption is reduced. The liner and mantle are thermally and dimensionally stable. The temperature of the liner is maintained and extrusion inflow defects are reduced. The dummy block life is extended and, more importantly, die performance increases and profile surface finish is improved.

The radial direction temperature difference in the mantle has very little effect on the liner compression. The liner compression is due to the misfit between liner outer diameter (OD) and mantle inner diameter (ID). The misfit can only be created when liner OD is larger than mantel ID or the liner OD is hotter than the mantel ID. Since the liner OD is in close contact with mantle OD, there can only be one interface temperature. In other words the liner OD has the same temperature as the mantle ID.

Materials Selection

Laue and Stenger calculated the stress distributed in a shrink-fitted multi-layer container.[3] In a typical container the tangential stress, which causes crack initiation, is about 600 Mpa inside the container. Such tangential stress is already higher than the hot work tool steels fatigue limit (for example, WNr. 1.234, which has only 350 Mpa). The life of the hot work tool steel will be significantly lowered.

Some machinery grade steels offer much better fatigue limit and fracture toughness compared to hot work tool steels. Ultra high-strength steels have superior toughness, strength, and fatigue strength compared to any hot work tool steel below 500°C. The choice of a hot work tool steel for the mantle does not make any sense, since the mantle temperature in a proper extrusion operation should never go above 500°C. For example, AISI 4340 (800 Mpa fatigue strength) will be more appropriate for the mantle. In addition, AISI 4340 steel has double the thermal conductivity than hot work tool steels; it will help to keep a stable thermal gradient by heat sink effect. Table I summarizes the mechanical and thermal properties of pertinent hot work tool steels.

Failure of Containers

The number one cause of failure of mantles is cracking due to temperature instability, not unequal distribution of temperature. When the temperature is not stable, the thermal stress keeps changing. For example, in a uniform temperature container, the temperature distributions during extrusion and when idle are different. During extrusion, the temperature inside the container is very high. When the container is in idle, the temperature becomes uniform. This temperature instability would cause alternating stress (tension/compression). It is known that alternating stress is the most aggressive fatigue-loading fac-

Mantle Mechanical

	Fracture Toughness (Mpa/$m^{1/2}$)	Critical Crack Length (mm)	Fatigue Limit (Mpa)
WNr.1.2343	38	0.6	350
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AISI 4340 (WNr. 1.6582)	60	2.0	795

Mantle Thermal

	Thermal Expansion (X 10^{-6})	Thermal Conductivity (W/mk)	Thermal Stress (Mpa) 10^6 W @ 10 cm
WNr.1.2343	12.6	24	110.25
WNr.1.2344	12.6	24	110.25
AISI 4340 (WNr. 1.6582)	12.1	42	60.5

Table I. The mechanical and thermal properties of two hot work tool steels (WNr. 1.2343 and WNr. 1.2344) and AISI 4340.

tor. Alternating stress induces crack ten times faster compared to pulsating stress (tension or compression only).[2] The container cracks at the weakest points.

With a stable thermal gradient, the additional energy is dissipated away by the built-in gradient. The temperature fluctuation is eliminated and the alternating stress is also eliminated. The container is only under pulsating stress during extrusion. The container will last much longer. The number two cause of mantle failure is local overheating by the elements. The number three is thermal and mechanical stress by cooling grooves. A cooling system is used only if needed; it should be located on the outside of the mantle to assist heat moving away from the liner. These three most likely container failure modes are eliminated if a stable thermal gradient is created and maintained in the containers.

The container has the largest thermal mass and strongly influences die temperature and the vertical gradient of temperature within the die—or at least in the metal entry regions of ports and feeders. The container temperature also affects the frictional conditions between the billet and liner, which changes billet surface inflow. The larger the liner size, the larger the die size, and the bigger the problem. The temperature variance is also higher with larger billets, liners, and dies; therefore, it is necessary to have multiple heating zone control in large containers, especially at the die end.

Small Sized Containers (7 inch and below): Small sized containers with a liner diameter from 7 inches and under, with two individually controlled heating zones can create the thermal gradient required to have good thermal stability. The top and bottom heating zones cover approximately two-thirds of the area from the die end. The temperature would taper naturally at the ram end to create the thermal gradient as desired.

Regular Sized Containers (7 inch-12 inch): Medium sized containers require four individually controlled heating zones with four double acting thermocouples located equidistant between the heating elements and liner. It is recommended for liner diameters from 7 inches to 12 inches. The heating zones are positioned in the die end top and bottom, and at the entrance top and bottom. It provides the container with the ability to control and maintain a stable thermal gradient from top to bottom and exit to entrance for quick heat dissipation. Air cooling is not usually required.

Large Sized Containers (12 inch and above): For such a large container it is recommended to have six individually controlled heating zones with six double acting thermocouples. There are four zones: top, bottom, left, and right at the die end, and two zones top and bottom at the entrance. The additional zone heating gives the extruder unprecedented ability to control the extrusion profile shape, dimensions, and surface quality. A simple calculation shows that for a 12 inch container, there is enough space and distance to manipulate temperatures (Figure 3).

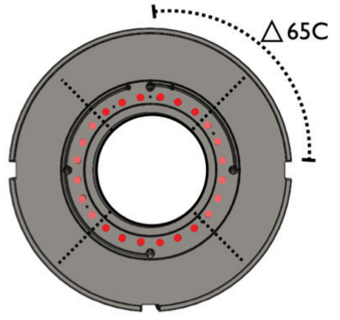

Figure 3. Temperature manipulation range for a 12 inch container.

The temperature between the adjacent zones could be as high as 65°C, therefore the temperature of a die can be controlled and manipulated. The run-out variance across the cross-section of large and complex profiles can be corrected. This gives extruders the unprecedented ability to correct/control the extrusion profile, extrusion run-outs, and extrusion surface quality, especially for those extruders making an HSR profile and other large and wide complex extrusions.

At steady state the temperature between zones is described by the steady state heat flux equation as follows:

$$Q = \frac{k}{L}(T_1 - T_2)$$

Where q is the power density of heating element (46,000 W/m^2), k is the thermal conductivity of 4340 mantle (42 W/m°C), and L is the distance between zones (0.119 m).

Conclusion

The demand for ever-higher productivity can only be met when extruders understand the fundamental impact of press tooling. The challenge with the container is to have temperature stability, not uniformity. Nothing in extrusion is uniform. A thermal gradient using the right design and materials allows for movement of temperature or energy as it is created during extrusion. Energy consumption is reduced and the liner, mantle, and dummy block life are extended. Die performance is increased and profile surface finish is improved. All of these benefits are obtained using simple physics to stabilize the container's thermal profile.

References

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Paul Robbins was educated at Upper Canada College and York University. He received a postgraduate degree at the Schulich School of Business. He has worked in the light metal extrusion industry for more than 30 years. He is general manager of Castool Tooling Systems and Castool 180 Co. Ltd. He is also the vp of Exco Technologies Ltd. These Canadian companies make production tooling and equipment for the global extrusion and die casting industries. Robbins holds 34 patents, several of which present key improvements in tool and die equipment for extrusion processing. He is well-known internationally for the many technical papers he has presented at extrusion industry conferences, including recently at Extrusion Technology (ET) 2012, Aluminium Two Thousand, ALEX, and Aluminium Middle East. He has published many articles in English, Japanese, and Russian publications, such as: Light Metal Age, Alutopia, *and* Alusil Russia.