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# Tooling System for Precision Tubing

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## Introduction

The aluminum precision tubing "PT" market used mainly for HVAC or automotive radiator and refrigeration is growing. The reason is that aluminum is about one-fourth the price of copper.

The aluminum alloys used (typically 3xxx or 1xxx series alloys) for precision tubes have relatively low flow stress with high solidus temperatures. These alloys enable the use of long billets for potential high productivity, thin walls and high extrusion ratios "ER", long run out lengths (meaning less joins in a coil), and high speed for high productivity.

## Extrusion Dies

A precision tube is typically extruded at high speed, at a high extrusion ratio and at high specific pressures typically in excess of 75 kg/mm2. The alloys therefore run at high die exit temperatures and having a high solidus temperaturecause regularH-13 dies bearingsto burn out quickly.Most PT precision tubing dies today are therefore CVD coated using proprietary designs and coatings technology.

In speaking with WEFA, one of the best known coated die suppliers to the PT industry, extrudersmust follow best die heating practices and minimize the time dies are kept at high temperature. A properly designed **Single Cell Die Oven** is recommended to avoid any potential bearing oxidation.

In addition to low flow stress alloys, coated specialty dies, and proper die heating,consistent and successful PT extrusion requires a thermally stable container enabling continuous process reliability and a high-pressure dummy block to accommodate the high specific pressures. Without a completely customized extrusion tooling system productivity optimization is not possible.

## Alloy Flow Stress

Simply, flow stress is a measure of the material's resistance to deformation, or being pushed through small aperture. The 3xxx and 1xxx alloy groups have lower flow stress and able to be extruded thru die aperturesless than 0.5mm. This ease of extrudability through thin openings also applies to the gap between dummy block and container liner. If the gap or the active clearance between dummy block and container liner is not precisely controlled, the alloy can backward extrude over the dummy block.

## Backward Extrusion

Dummy blocks must expand and retract under controlled conditions to generate a stable yet thin container skin without the risk of backward extrusion (or blow-by) over the dummy block under the higher pressure conditions at the start of the pressure cycle. Backward extrusion depends upon the active clearance between the dummy block and container under operating conditions of temperature and applied pressure - the active clearance being the real clearance during extrusion, or the effective skin generation thickness on the container liner wall. However, the active clearance is also dependent on the initial cold clearance incorporated into the design, i.e. the difference in diameter of the cold dummy block and the cold container liner under a no-pressure situation.

This initial cold clearance needs to be customized for precision tubing extrusion, and will be different than at a plant extruding 6xxx traditional alloys. A typical extrusion ratioin a 6xxx alloy operation is considered to be in the preferred range of 40-60. However,in a plant producing 1xxx or 3xxx alloys for micro-port heat exchanger or automotive a/c applications typical extrusion ratios can be in excess of 400.

Due to the high extrusion ratios, and the desire to extrude with long length billets to optimize coiling, micro-port extrusion cycle times can be lengthy in comparison to traditional 6xxx alloy cycles – i.e. 5-6 minutes compared to around 1 minute. The conditions for blow-by over the dummy block, and the tendency for the alloy to do so, are therefore quite different in these two situations.

## High Pressure Dummy Blocks

Most commercially available dummy blocks operate satisfactorily under applied pressures (or press specific pressures) of 700 MPa (100,000 psi) and cycle times of 2 minutes or less. However, under higher applied pressures of825 MPa (120,000 psi) and longer cycle times permanent yielding of a standard dummy block can become an issue, and overall performance and function of the dummy blockmay suffer. Permanent deformation of the ring can become excessive at high pressure resulting in the dummy block failing to retract enough to clear the container skin during withdrawal. Alloycan then be picked up from the container skin after relaxation of the container liner.

The resulting alloy from the container skin collects on the rear of the bearing land, influencing how a dummy performs during the burp cycle, risking more blister on extrusion surfaces, and creating press downtime due to the need to frequently clean or change the dummy block.

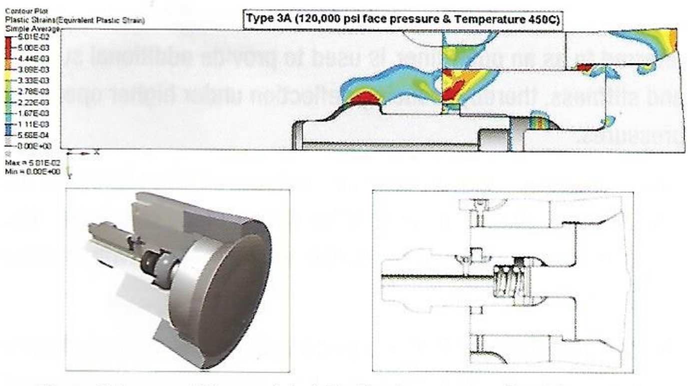

*Figure 1. Improved Dummy block Design to accommodate high applied pressures at elevated temperature.*

A high-pressure dummy block design illustrated in Figure 1 has been designed and manufactured for this severe application. Component contact areas are increased to reduce applied stresses, along with other design features to improve force and pressure distribution throughout the dummy block. The effect of the redesign in reducing plastic strain under load is illustrated; the block can cater for pressures up to 825 MPa (120,000 psi) and long cycle times without plastic yield.

### Container Design

The container undergoes the same stress with PT extrusion as the dummy block. It is also affected by pressure and cycle time.

### Three piece container design

Three-piece containers are recommended when presses are used to extrude alloys with lower flow stress alloys, i.e. 1xxx and 3xxx alloy groups, at higher extrusion ratios and at higher specific pressures. A 3-piece assembly,i.e. mantle with sub-liner often referred to as an outer liner, is used to provide additional support and stiffness, thereby reducing deflection under higher operating pressures.

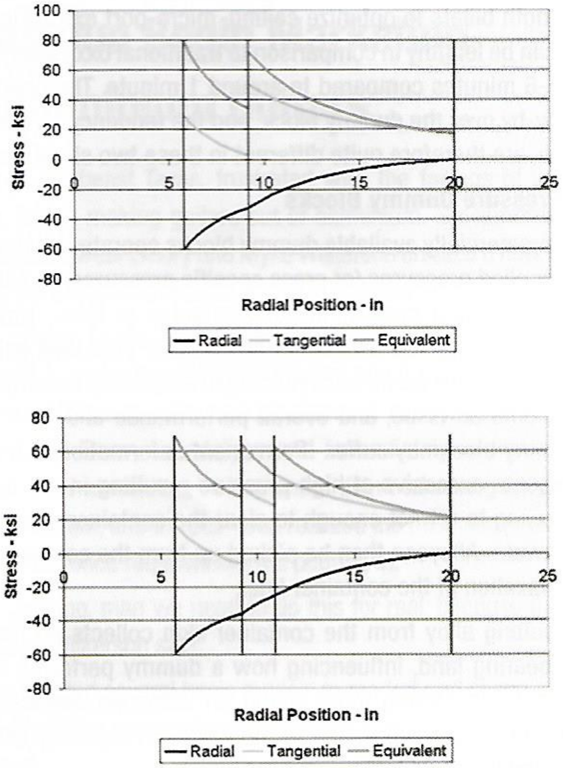

*Figure 2. The multi-layer constructions redistribute the equivalent stress in the container.*

Figure 2 shows equivalent stress is lowered from 110,000 psi (760 MPa) to 80,000 psi (550 MPa) with 2-piece container. The stress is further reduced to 65,000 psi (450 MPa) with 3-piece container construction.

The calculationsshow that a 3-piece container is stronger than a 2-piece container. The strength of a 3-piece container is about 20% higher, equivalent to 20% less deflection during extrusion.

It is important to maintain a smaller clearance between the container liner and dummy block because of the higher sensitivity of these softer, lower flow stress alloys to the gap around the dummy block, and their natural tendency to back extrude over the dummy block. Therefore, in order to ensure the gap between container and dummy block is better controlled, a three-piece container with the additional sub-liner support and reduced expansion is required in these situations, along with the use of a high-pressure dummy block.

### Container Cooling

Due to high extrusion ratios and high strain rates, PTextrusion generates more deformation heat in the container.Therefore, to attain better process control, there is a need for additional container cooling to avoid both the container and the process overheating, and to avoid the need to slow down.

Traditionally when cooling is applied to a container, spiral grooves machined into the container body (mantle) or liner, circulate air around the outside of the liner. While air by nature is a poor conductor of heat, it is the most convenient and safest cooling medium to use. Figure 3 illustrates a typical heat balance during extrusion. Assuming the container and the die remain at constant heat, the billet heat A increases during deformation by B – the heat of deformation being the area under the force/displacement curve less the energy required to overcome container friction.

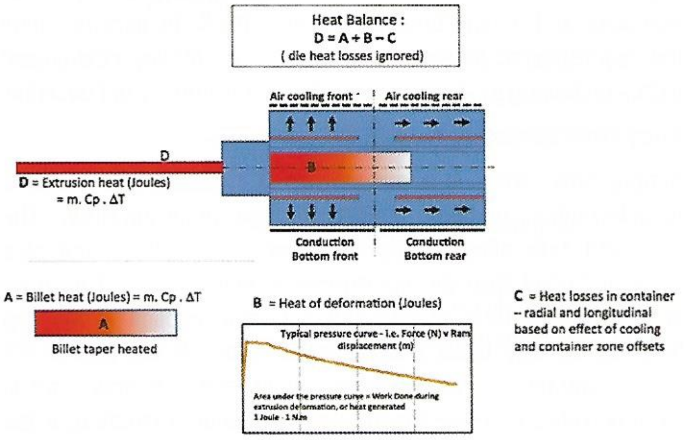

*Figure 3: Heat balance during extrusion, showing the need for a container to be capable of removing the heat of deformation during extrusion.*

Heat losses C occur due to heat flow through the container. The sum of these, i.e. (A + B) – C is the heat transported away in the extrusion. This somewhat simple approach ignores heat generated in the die, which will add to the heat mass in the extrusion, but the important part of this equation in terms of the container, and design of cooling if necessary, is that C must

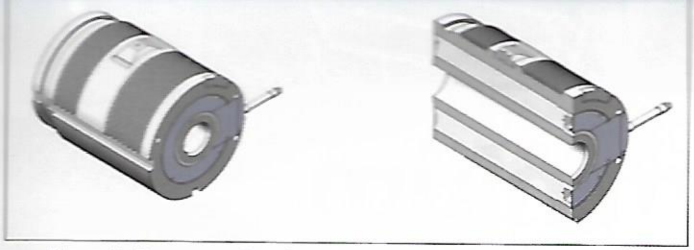

*Figure 4: Two zone external cooling arrangement in a QR container – designed for high productivity microtubing extrusion.*

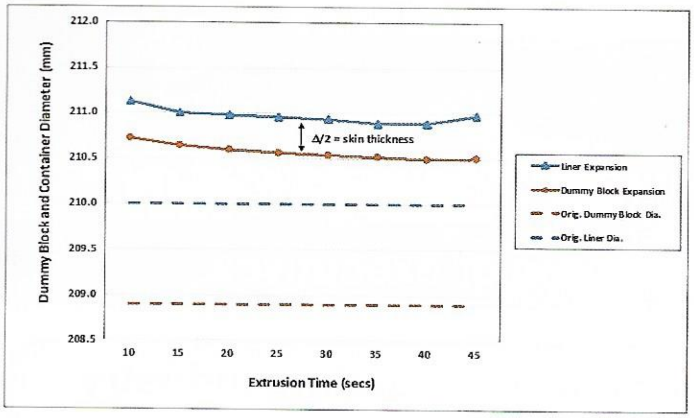

***Figure 5: Model predictions of container expansion, dummy block expansion, and container skin thickness under extrusion conditions.***

be capable of equaling or exceeding B. (In the case of external heating elements, C may be a positive term in the equation, having a net effect of increasing the liner temperature.)

Recognizing high productivity processes with high heat generation, and that cooling is indeed necessary, a container can be designed with external cooling of the body, rather than cooling around the outside of the liner. Cooling the liner disrupts both the radial and longitudinal heat flux through the container body, while cooling the outside of the container complements it. A container design with two-zone external

This type of container design successfully removes additional heat from the high deformation process, and can develop optimum heat flux gradients in the container body by use of both longitudinal and radial offsets, generated by smart selection of container zone temperature settings.

**Active Clearance**

Actual extrusion pressure curves were recorded for a 25MN, 8" front-loading direct extrusion press. The process was then FEM modeled using a 42" (1100mm) long QR container and a new improved high-pressure (HPR) block. The predicted model result is within 5% of real press data, and the model was therefore considered acceptable and accurate in predicting pressures on both the dummy block and container during extrusion cycle simulations. After 5 simulated extrusion cycles, the process was considered stable allowing both container and dummy block expansion to be predicted with confidence. The findings are shown in Figure 5, along with an estimated skin thickness based on the difference between the dynamic container and dummy block expansions, i.e. combined thermal and mechanical expansion under varying extrusion pressure and as the dummy block passes through the container from start of extrusion to the final position of the butt length. The active clearance, aluminum skin thickness, is around 0.008" (.2mm) at all times.

Summary

For many years dummy blocks have been considered to some extent a disposable tooling item, typically after 20,000 to 30,000 billets. However, under the high requirements of precision tube extrusion with its inherent high extrusion pressures, and the need for tighter active clearance control,a standard dummy blockwill cease to function properly and may need be replaced in less than one week (or less than 4000 billets).An optimized dummy block designed to accommodate the specific needs of this specialty market is therefore a critical item of tooling to enable optimal process control to attain high quality and increased productivity.

In addition, only thermally stable and structural sound containers can meet the specific needs of high productivity extruders producing heat exchanger and automotive climate control tubing in 1xxx and 3xxx alloys, by introducing external cooling to the container body to maximize beneficial thermal gradients in the container, and by the use of a sub-liner to bettercontrol the active clearance between dummy block and container.