Material Selection for Extrusion Containers

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Introduction

The most critical tools in extrusion that work under high stress and/or high temperatures are dies, containers, dummy blocks, and stems. However, due to harsh thermomechanical conditions, these tools are susceptible to failure more than other tooling components. Therefore, determining the most common failure modes and selecting the proper alloy is essential to extend their operational life.

Among these tools, the container is the heaviest and the most expensive. On average, containers represent about 80% of the total mass of the tooling group. For example, an 8-inch container weighs about 4 tons while the total weight of the stem, dummy block, die set, and bolster is under a ton. Therefore, the mass share of the container body (mantle) is 60-90% of the total weight of the container. Since the container body weighs more than 50% of the total mass of the tooling group, this explains how material suppliers are affected by material selection for container bodies, considering that about half of the total cost of the tooling is spent on the material [1].

Sauer [2] suggests using hot work tool steels such as 1.2343, 1.2344 and 1.2367 for all container parts (Liner, Sub-liner and Body) as the container is subjected to high temperatures. Contrarily, Robbins et al. [3] believe that using low-alloy high-strength steels with higher thermal conductivity, such as 4340, is more than safe as a container body and improves productivity by providing better heat dissipation and thermal control.

A previous article was published in the last issue of Light Metal Age on material selection for extrusion tooling in general [1]. This article discusses the most important aspects of material selection and its interaction with design features for container components. Then, experimental observations and simulation studies are used to verify and evaluate the theory.

Decision Theory

Different parts of the container need different properties. The liner is under severe wear due to contact with the billet surface and the dummy block, while the body is under cyclic tensile stresses due to the mixed effects of shrink fit, temperature and billet pressure. Therefore, the liner must have high hardness and wear resistance at elevated temperatures, while the body needs to have high toughness to impede crack propagation and fatigue. On the other hand, the body must last longer as it is the biggest and most expensive part of the container, so it must have excellent fatigue-resistant properties.

Table 1 lists common materials used in extrusion containers and their key properties and proposed application in the container.

Table 1: Common alloys used for extrusion containers [1]

Alloy		Strength	Toughness	Tempered /Aged [°C]	Thermal conductivity [W/mK]	Cost factor	Application
Low Alloy Steel	**4340**	●●	●●●●●●	540 (38 HRC) 600 (34 HRC) 630 (32 HRC)	42	75	Body Sub-liner (34-38 HRC)
Hot Work Tool Steel	**H11 (1.2343)**	●●●	●●○	630 (42 HRC) 650 (38 HRC)	26	100	Sub-liner (38-42 HRC)
	H13 (1.2344)	●●●●	●●○	620 (48 HRC) 630 (46 HRC) 650 (42 HRC) 660 (38 HRC)	24	100	Liner (46-48 HRC) Sub-liner (38-42 HRC)
	E40K	●●●●	●●●○	600 (48 HRC) 620 (46 HRC)	30	200	Liner (46-48 HRC)
Super Alloys	**IN718**	●●●	●●●●	720 (44 HRC)	13	1500	Copper Extrusion Liner (40-44 HRC)
	A286	●●	●●●●●	720 (34 HRC)	15	750	Copper Extrusion Liner

Material selection for a container should be based on process parameters, and among them, the billet material is the main factor [1]. Table 2 summarizes how the billet material can affect process parameters, hence the proposed container material configuration.

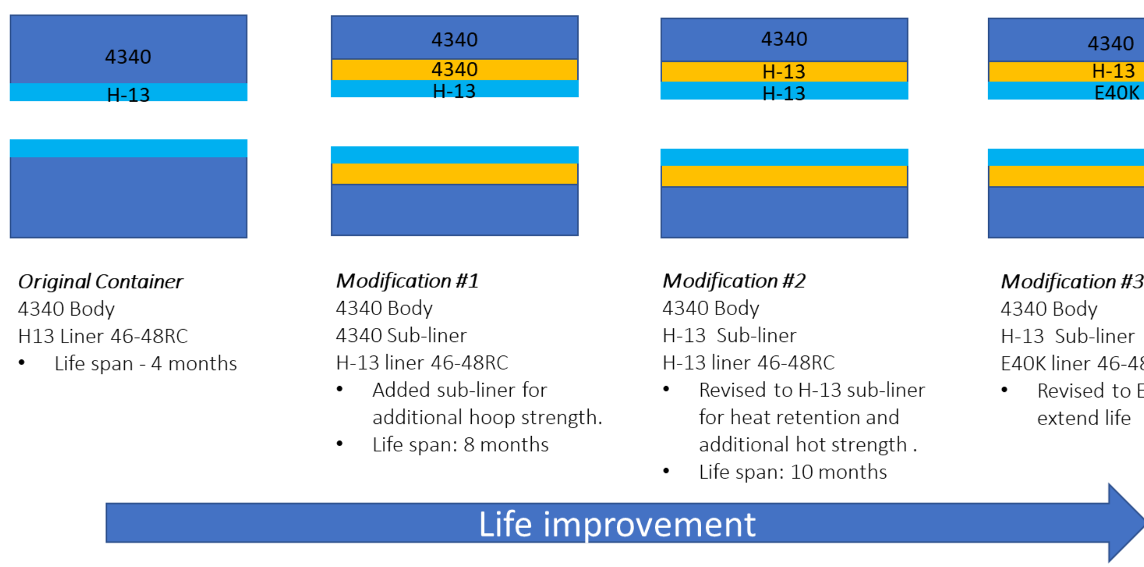
Table 2: Container material/design and process parameters based on billet material [1]

Extrusion	**Aluminum Alloys**				**Copper**
	Soft	**Medium**	**Hard**	**Extra Hard**	
Aluminum Alloy	1100 / 1060 / 1350 / 3003 / …	6063 / 6005A / 6061 /…	6082 / HS6S / 7003 / …	7075/7B04/ 2XXX/5XXX/…	Copper and Copper Alloys
Container	3 pc (4340/4340/H13)	2/3 pc (4340/4340/H13)	3 pc (4340/4340/H13)	3 pc (4340/H13/E40K)	3 pc (4340/H13/Inconel)
Ram Speed	8 - 20 in/min	15 - 40 in/min	8 - 20 in/min	2 - 8 in/min	> 20 ipm
Exit Temperature Window	Large	Medium (6061: Small)	Small (7003:Medium)	Small	Large
Load	Low	Medium	High	Extra High	High

Extrusion Ratio	High	Medium	Medium	Low	Low
Profile Complexity	Thin Walled (Micro-Tube, etc)	Medium to High	Medium	Low	Low
Container Taper (°F/cm)	0.5	1	0.5	No Taper	No Taper
Container Air Cooling	Free Air with Fins	Forced Air Through Fins	Free Air with Fins	No Cooling	Forced Air Through Fins

Figure 1 shows the evolution of a container's design and material configuration for a 7XXX extra hard alloy. The life span of the liner was extended from four months to more than ten months.

Figure 1: Evolution of a container to improve the life for extrusion of 7XXX extra hard aluminum alloy.

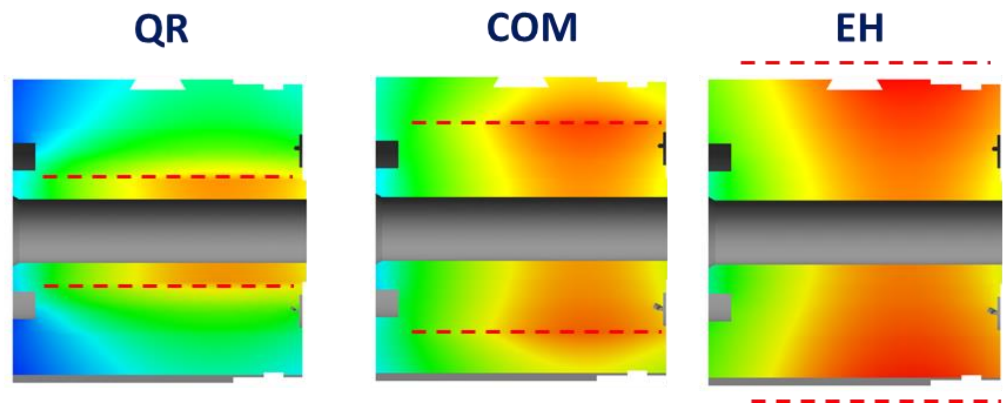


How Does Design Affect Material Selection?

Material and design have a close relationship. A weak design can dictate the usage of improper material. For example, in externally heated containers, the outer surface of the container can get overheated before the inner surface of the container reaches the desired temperature (Figure 2). On the other hand, an overheated container body can soften if its temperature gets higher than 50°C below tempering temperature [2]. For example, a 4340-body tempered to the hardness level of 34 HRC would start to degrade at temperatures above 550°C, while H11 hot work tool steel tempered to 38 HRC resists softening up to 600°C.

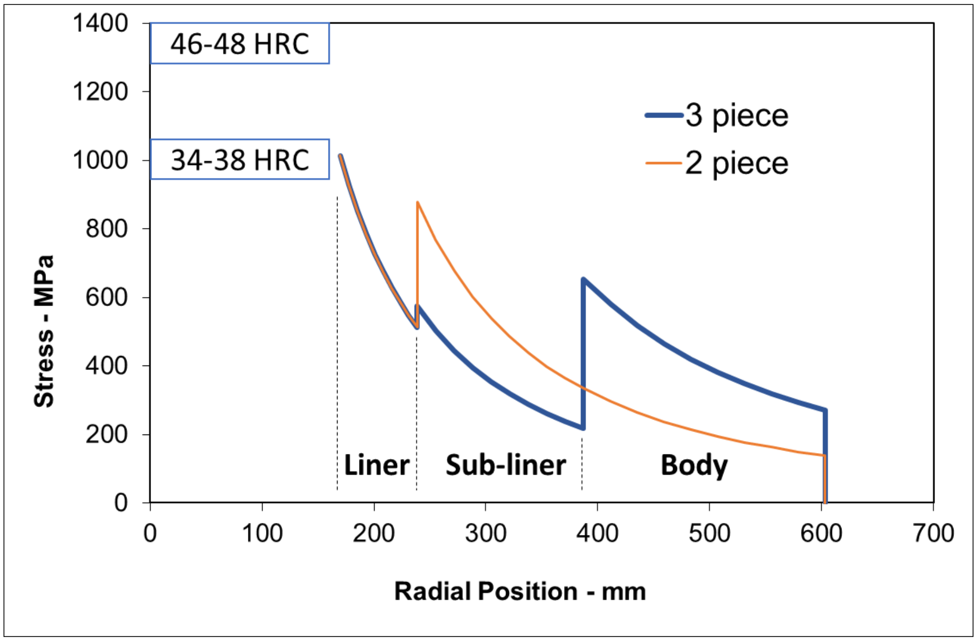
Figure 2 shows that by moving the heating elements toward the liner, the container body works at a lower temperature which puts it in a safer position and opens the door for using lower-alloyed, more conductive steels.

Figure 2: Simulation predictions for the effect of heating element location on temperature distribution in the container (QR: Quick Response; COM: elements at Centre of Mantle; EH: Externally Heated).



From a mechanical point of view, the design of the container also affects the material choice. In a 2-piece container, the body's ID is under more stress than that of a 3-piece container as it is further away from the pressurized liner (Figure 3). In a 3-piece container, the sub-liner is supported through the shrink fit with the body, which neutralizes a portion of the stress during the process and decreases the stress on the subliner. An H13 liner with 46-48 HRC hardness has more than enough strength to avoid yielding during extrusion, no matter if the container is a 2-piece or a 3-piece. On the other hand, a 4340 body with a hardness of 34-38 HRC is under high stress at the ID, which is close to the yield strength of the material. By using a 3-piece container, the peak stress at both subliner and body can be reduced to improve the safety factor.

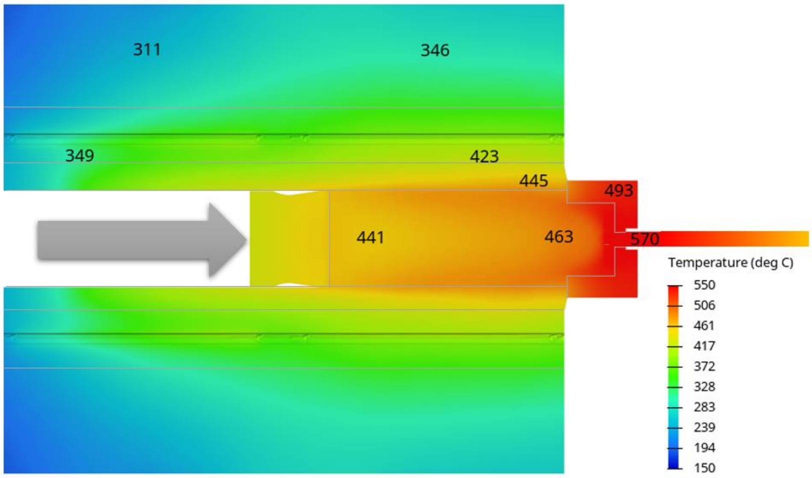
Figure 3: Stress distribution in a 2-piece VS a 3-piece container with 90 KSI (620 MPa) face pressure: equivalent strengths for two different hardness ranges are marked.



Is it Necessary to Use Hot Work Tool Steel in the body?

The use of hot work material, such as H13 tool steel, in a container liner is mandated by the need for hot strength and hot wear resistance. However, is it necessary to use hot work tool steel for the sub-liner and the body? Well, it depends on the temperature levels during the process. Nominal temperature distribution during the extrusion of AA6063 aluminum alloys is shown in Figure 4. The level of temperatures is much less than the tempering temperature of H13 at 46-48 HRC. Low alloyed steels (such as 4340) at required hardness levels for a container subliner and body can handle these temperatures.

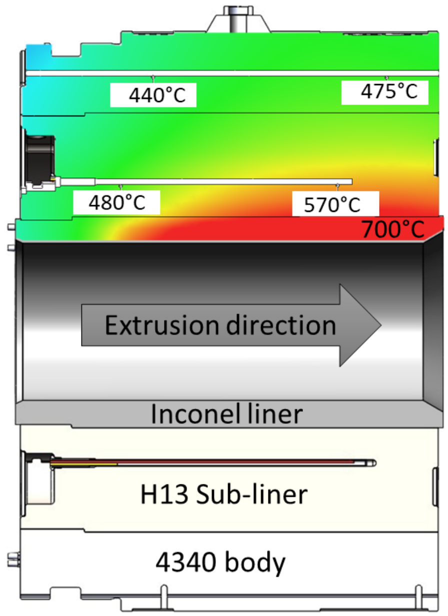
Figure 4: Temperature distribution during the extrusion of AA6063 aluminum alloy.



Depending on the process parameters and container design, even during the extrusion of higher melting point alloys such as copper, the temperature of the container body can be tolerated by 4340 steel. However, the liner temperature can reach 700°C (

Figure 5), and higher, which even hot work tool steels can not tolerate and a more heat-resistant material such as Inconel is needed.

Figure 5: Model-predicted temperature distribution in a container during copper extrusion.



The use of low alloyed steels such as 4340 in a container is favourable due to the higher thermal conductivity and toughness.

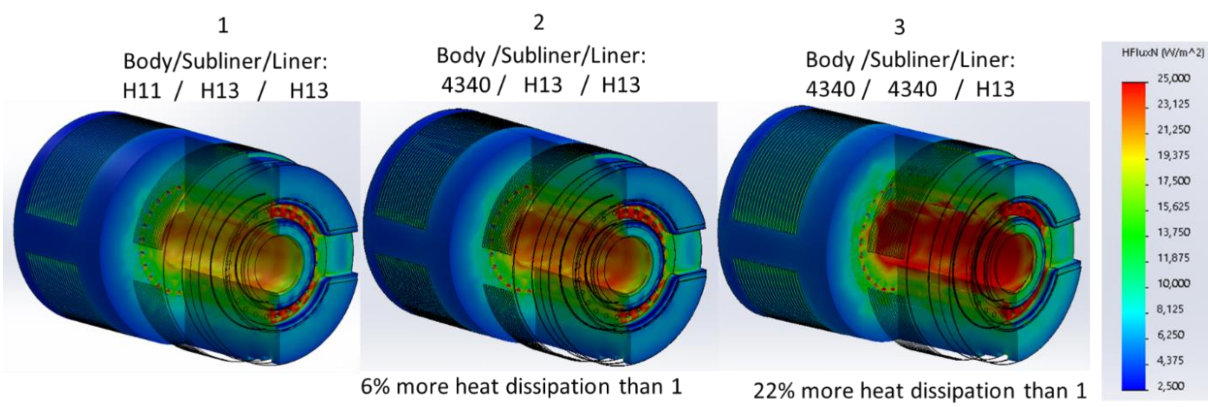
Material Conductivity Can Affect Productivity

A more thermally conductive material can potentially increase productivity by improving heat dissipation throughout the container and allowing the extruder to increase the ram speed [4].

Figure 6 shows simulated predictions for the effects of material conductivity on heat dissipation during extrusion. For example, 4340 has about 75% more thermal conductivity than H13. Therefore, using 4340 in the body and subliner can add 22% more heat dissipation which delays the thermal saturation of the container and decreases the exit temperature. The extruder will then be able to increase the ram speed and improve productivity.

A side note: for slow ram speed processes where the press capacity and tooling strength are the limitations (such as the extrusion of extra hard aluminum alloys), the rate of heat dissipation dominates the heat generation inside the container so that an H13 subliner with lower conductivity may work better.

Figure 6: Effect of container material on heat flux during extrusion.



References

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