Better Profiles Faster: Material Selection for Extrusion Tooling

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Correct material selection and proper heat treatment for tooling are vital factors of profitability. A good decision theory must consider different aspects and variables, including cost, longevity, cycle time, recovery, energy, health and safety, and environmental impact. All tooling fails at some point; the questions to ask are how long it lasts and why it fails. The process is mostly to blame for premature failures such as improper temperature, cycle time, alignment, pressure, and lubrication. Next come design-related issues such as strength, thermal management, lubrication, and wall thickness. Making a design change at little to no cost is often the solution for these problems. As a last resort, alternative materials may exist to offer better protection and extend useful life with better strength, conductivity, wear resistance, and other factors. Finally, it is necessary to avoid overspending on tooling materials by optimizing a combination of variables: cost, longevity, ram speed, and recovery. Simulation is a powerful tool for material selection, evaluation, and optimization before ever committing.

Introduction

Material selection for extrusion tooling is a key factor in profitability [1]. Hot work tool steels with a tempering temperature of around 600°C (such as H13) are the primary materials used for extrusion tooling that directly contact the workpiece. These materials are appropriate because they provide a good combination of mechanical properties (wear resistance and strength) at elevated temperatures. Hot work tool steels are suitable up to about 50°C below the tempering point, which allows them to perform properly for extrusion of a wide range of materials such as Aluminum, Magnesium, and Zinc alloys. For extrusion of materials with higher melting points such as copper, the surface temperature of tooling in direct contact with the workpiece can reach 700°C and above, which is well above softening temperature of hot work tool steel. Depending on the process and expected tooling life, alternative materials can be used, such as superalloys and hot work tool steels with higher Mo and W.

The tooling that is not in direct contact with the workpiece, such as the container subliner, usually performs at lower temperature ranges. They do not have to be hot work tool steel, except the super hot billet temperature or process parameters mandate using hot working materials. For example, using hot work tool steel for the container body is overspending considering that some low alloy steels (such as 4340) are suitable based on strength and temper resistance. 4340 is even better than hot work tool steel in terms of toughness and conductivity, and it makes it a better choice for the container body.

One may see a conflict of interest when some steel manufacturers promote overspending in materials. In contrast, Castool Tooling Systems does not manufacture steel but uses over 5,000,000 lbs per year for various tooling products. The goal is to deliver the best tooling possible to extruders.

Decision Theory

There are several aspects to consider when deciding on a suitable material, including:

- Cost
- Longevity
- Cycle time
- Recovery
- Energy
- Health and safety
- Environmental impact

Extruders want tooling with maximum longevity and minimum cost. Therefore, it is essential to have a reasonable estimation of a reliable life span of the tooling to avoid unscheduled downtime. Besides, cost and life are not the only important parameters. Good tooling is supposed to improve productivity [2] by helping the extruder make “Better Profiles Faster.”

The most important parameters for extrusion tooling materials are listed in Table 1 (below). By defining weighting factors for material parameters, one can easily select the best material that fits the specific application.

The material cost usually accounts for more than half of the total price of tooling. There might be materials that can extend tooling life, but they are often more expensive, making the new material economically unreasonable. For example, E40K is 100% more costly than H13 (Table 1) but using it in the container liner should extend the liner life by at least 50%. E40K has better toughness than H13 but with the same strength level. Considering that wear is the leading cause of failure, using E40K may not truly increase the useful life of the tooling.

Longevity is a function of several parameters, including strength, toughness, and temper resistance.

Extrusion cycle time consists of contact time and dead time. Contact time is in direct relation with the ram speed. Therefore, a more conductive material can dissipate more deformation heat to extrude faster and shorten the cycle time.

Dead cycle time is usually as short as possible, depending on press capabilities. However, in copper extrusion with super hot billets, dead cycle time is deliberately prolonged so that the tooling has enough time to dissipate the heat absorbed during the contact time. In this case, a material with higher thermal conductivity can help to reduce the dead cycle time.

The effect of tooling material on recovery is not as obvious. However, any scrap due to tooling material limits and tooling failure will decrease the recovery.

Energy can be saved by shortening the contact time.

Table 1: Key properties for materials used for extrusion tooling

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	Container body Subliner (34-38 HRC)
Hot Work Tool Steel	**H11 (1.2343)**	●●●	●●○	630 (42 HRC) 650 (38 HRC)	26	100	Container subliner (38-42 HRC)
	H13 (1.2344)	●●●●	●●○	620 (48 HRC) 630 (46 HRC) 650 (42 HRC) 660 (38 HRC)	24	100	Container liner (46-48 HRC) Container subliner (38-42 HRC) Dummy block
	E40K	●●●●	●●●○	600 (48 HRC) 620 (46 HRC)	30	200	Container 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

Optimization and Simulation

Optimization of the process can only be achieved with consideration of the mechanical and physical limitations of the tooling material. For example, press manufacturers are constantly increasing the face pressure of the extrusion presses, allowing the extruders to extrude colder and longer billets faster. On the other hand, this can also shorten the tooling life and cause unscheduled downtime. Simulation software can help to effectively prevent such inconsistency between the machine's capabilities and the material's limits.

A simulation is an ideal tool for visualizing the outcome before committing [3]. Furthermore, material selection, design and even recipe development can be optimized and balanced using simulation software. Figure 1 shows the simulation results for the effect of the sub-liner material on heat flux inside the container. Calculated average heat flux inside the ID of the container with a 4340 subliner is ~23 kW/m^2, while that of the container with an H13 sub-liner is ~20 kW/m^2. Therefore, simulation predictions show that using a 4340 sub-liner instead of an H13 subliner would improve the container heat dissipation capacity by 15%.

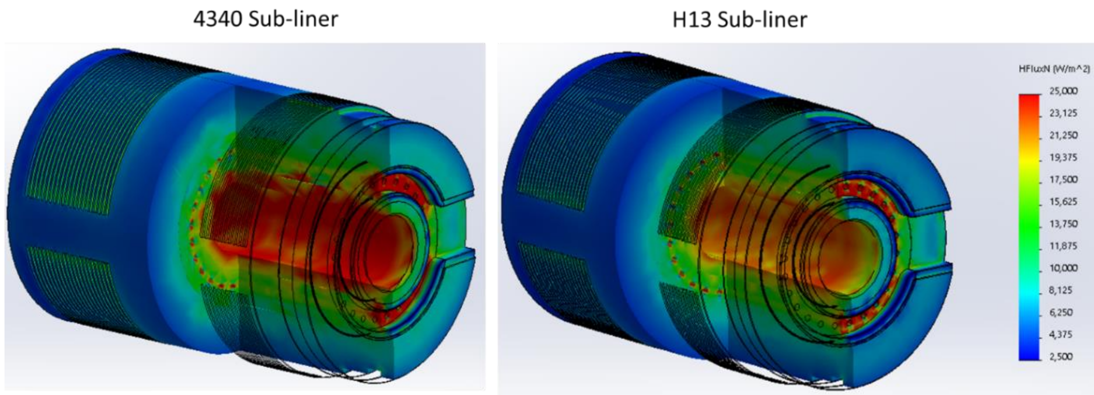

Figure 1: Simulation results for heat flux distribution inside the container with 4340 sub-liner (left) and H13 sub-liner (right). For both containers, the liner material is H13, and the body is 4340.

Figure 2 shows the simulation results for the effect of body material on temperatures during the extrusion. The model-predicted results show that after the extrusion of 30 billets, the liner of the container with a 4340 body runs 6°C cooler than the container with an H11 body. The difference grows after more billets are extruded. The extrusion exit temperature is also affected in a similar way by using a 4340 body instead of an H11 body.

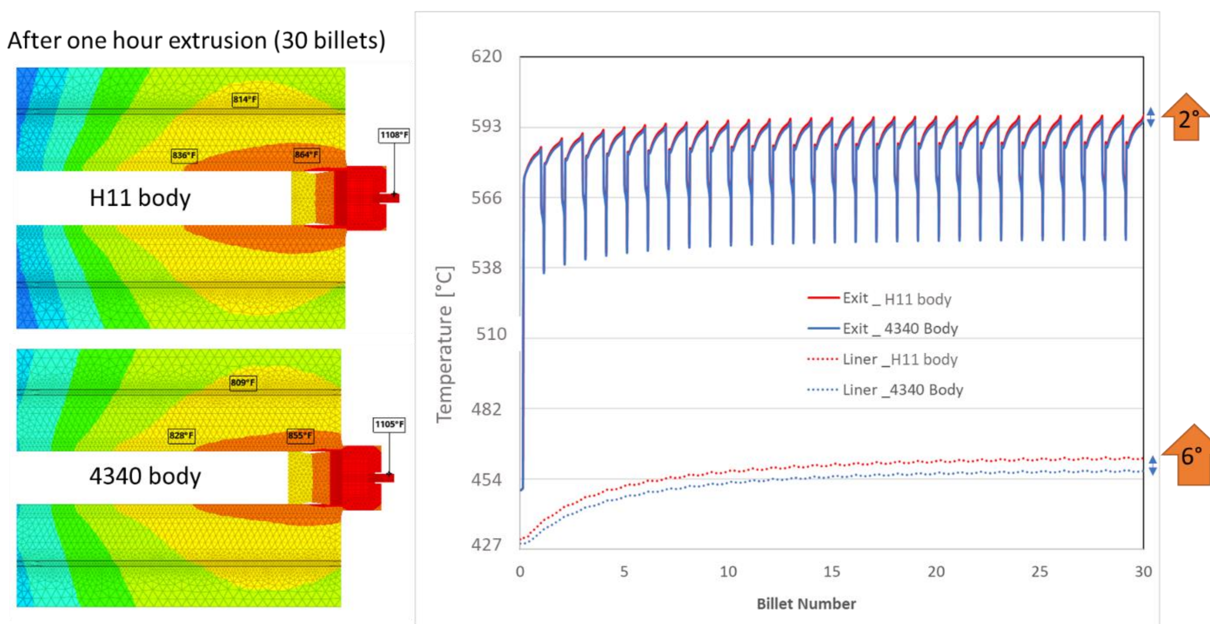

Figure 2: Simulation predicted temperature distribution inside the container with 4340 and H13 bodies.

Conclusions

- Material selection for extrusion must be consistent with the process conditions and failure mode of the tooling.
- There may be materials that provide better tooling life, but overspending must be avoided.
- Simulation is an inexpensive and efficient method to both optimize the process and predict the outcome.

References

[1] R. Akeret, A. Ames, M. Bauser, W. Eckenbach, A. Frei, and H. H. Groos, *Extrusion, Second Edition*. 2012.

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[3] K. Chien, P. Robbins, C. Jowett, Y. Mahmoodkhani, and Y. Wang, “Extrusion productivity, part II - Predicting ram speed,” *Light Met. Age*, vol. 77, no. 1, 2019.