The Difference Between Excellence and Mediocrity

Extrusion Productivity and the Effects of Billet Geometry, Container and Die

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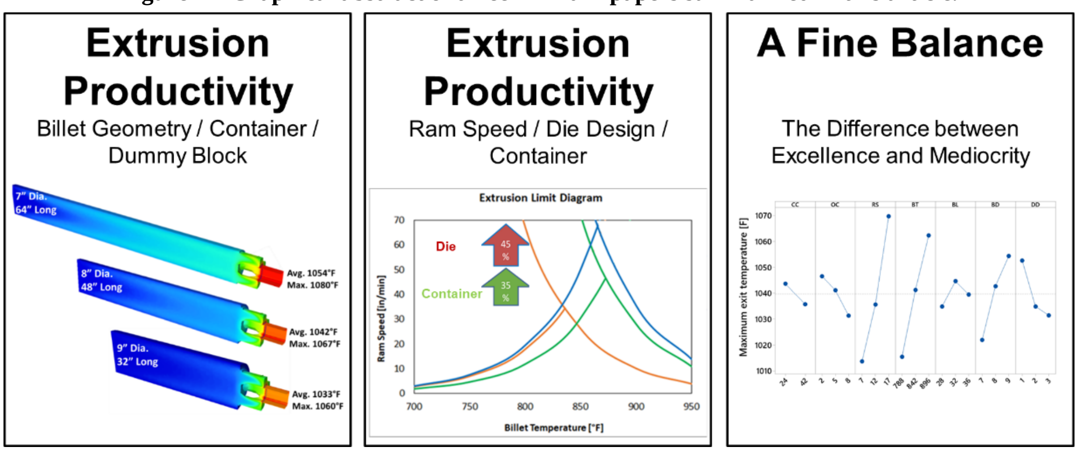
ABSTRACT – This article summarizes three papers [1]–[3] presented by same authors at the ET-2022 seminar held on May 2022 in Orlando, FL. These papers focus on how to maximize extrusion productivity by fine balancing the process and tooling parameters. The first paper deals with the effect of billet geometry on extrusion productivity and explains how shorter billets can improve it. It also provides some tooling solutions for extruders using long billets. The second paper talks about ram speed being the main measure of productivity and looks at the effect of die design and container parameters (such as container material and air cooling). The third paper used the technical information mentioned in previous papers to talk about how to balance different parameters and overcome management issues to create optimum productivity.

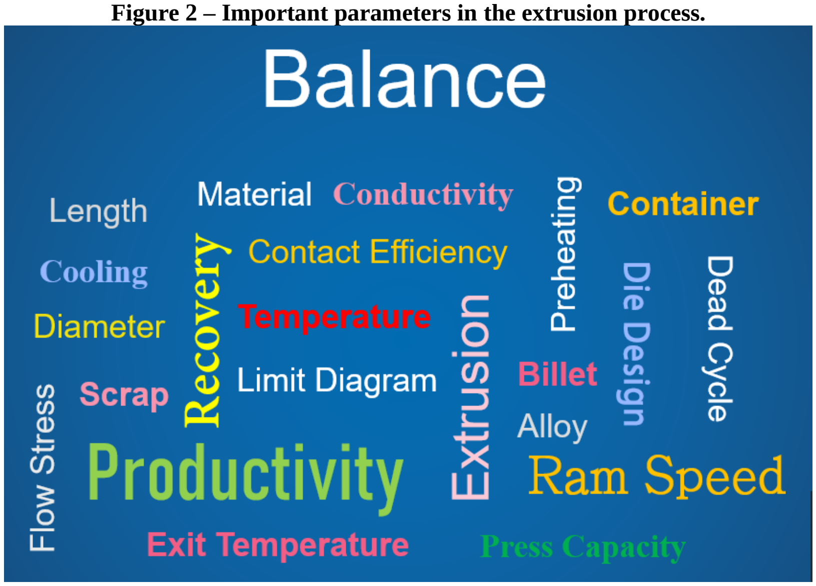
Figure 1 – Graphical abstract of three ET-2022 papers summarized in this article.



INTRODUCTION

Extrusion is a balancing act between so many parameters; it is full of trade-offs and highly dependent on the physical realities of the tooling, equipment, and processes. Excellence in extrusion results not from doing extraordinary things, but from doing ordinary things extraordinarily well: such as controlling the temperature of every single component of the process. Superextruders existed more than three decades ago and achieved significantly better productivity than a good extruder nowadays. They did this simply by paying extra attention to the most important details of the process rather than being creative and trying new methods.

Figure 2 – Important parameters in the extrusion process.



WHAT ARE MEASURES OF PRODUCTIVITY?

Roger Fielding used three parameters (known as Bennett numbers) for benchmarking extrusion operations: contact efficiency, recovery and ram speed [4]. But is contact efficiency a proper measure of productivity? At constant billet length, increasing ram speed will decrease contact efficiency. So that instead of contact efficiency maybe we should rename it to “Efficiency of Contact” which is basically ram speed. Recovery matters but the process parameters do not change it significantly. The lifecycle is the biggest portion of the process therefore shortening it by increasing ram speed has the largest effect on productivity.

Figure 3 - The extrusion press cycle (left); and the recovery billet (right).

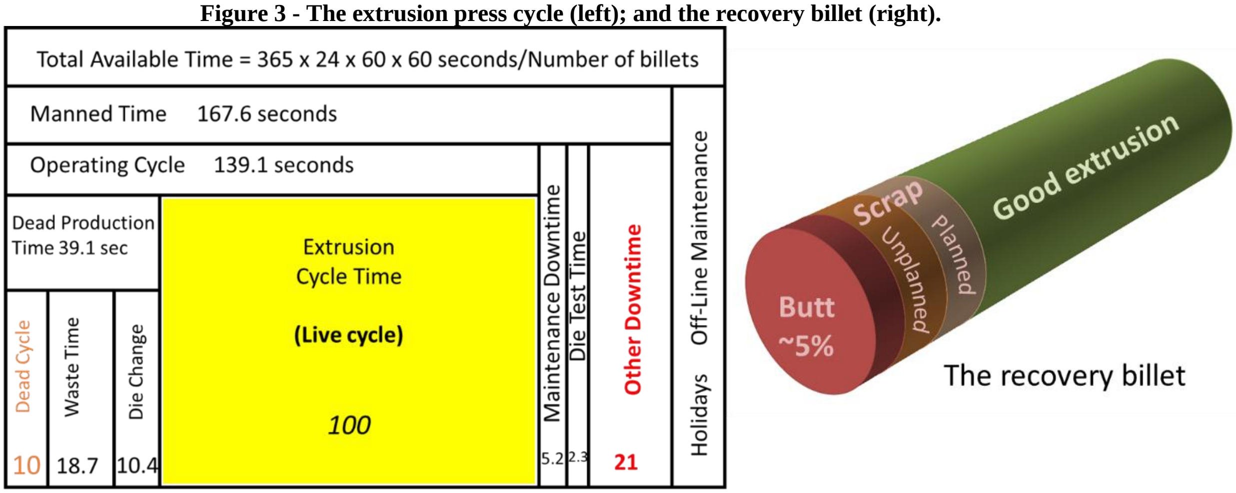
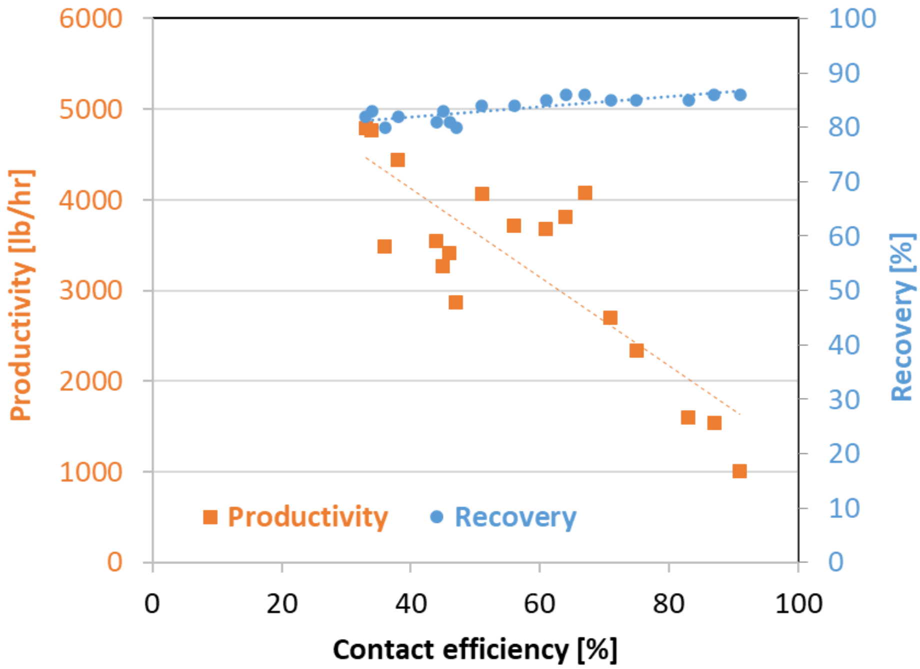


Figure 4 shows the optimum productivity and recovery for different contact efficiencies. It is clearly showing that productivity and contact efficiency have an inverse relation. Increasing the contact efficiency can increase the recovery by a few percent but it is not worth losing such a significant amount of productivity.

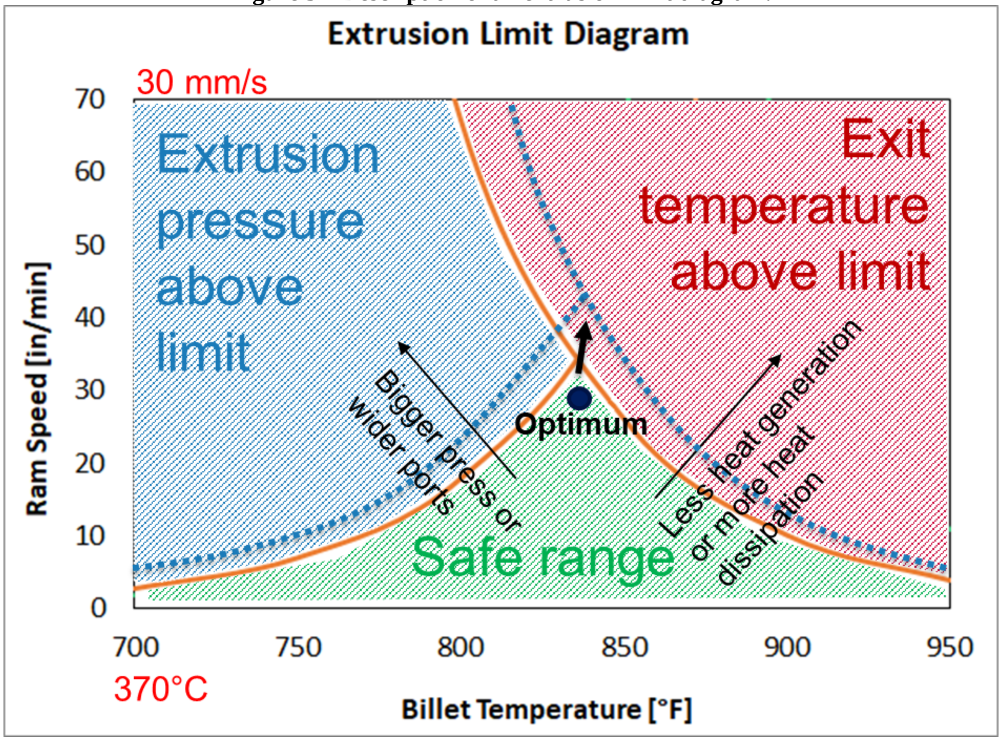
Figure 4 – Optimum productivity and recovery plotted versus contact efficiencies.



HOW TO IMPROVE RAM SPEED?

Knowing that ram speed is the most relative measure of productivity, what are the best ways to improve it? Looking at the extrusion limit diagram (Figure 5), anything that can move the pressure limit and temperature limit curves up has the potential to increase the ram speed and hence the productivity. Using a bigger press or dies that are easier to push can move the left curve up. Encouraging more heat dissipation, or generating less heat during the process will move the right curve up.

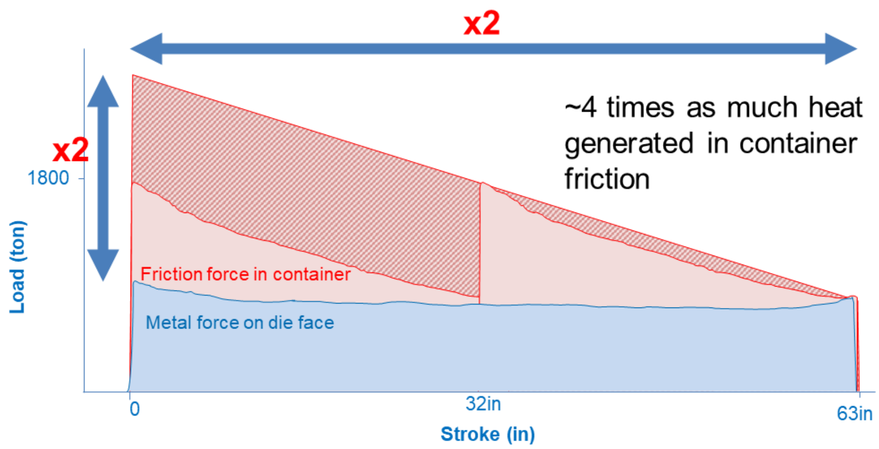
Figure 5 – Description of an extrusion limit diagram.



LONG VS SHORT BILLET

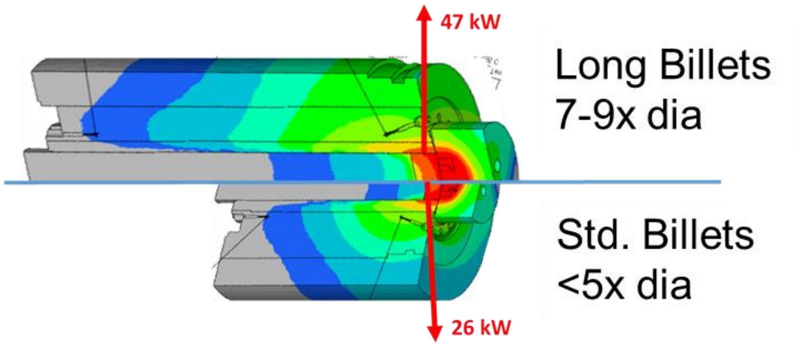
The pressure on the die face remains constant during the process but the friction force between the billet and container decreases by shortening the billet length. The blue area in Figure 6 indicates the energy used for deforming the workpiece inside the die and the red area under the curve is the energy used to overcome the friction between a 7" billet and container. A simple calculation shows that when extruding 64" billets instead of 32" billets, 100% more energy is used inside the container to extrude the same amount of material. The majority of this energy is converted into heat and absorbed by the container.

Figure 6 – Load-Stroke curve for two 32" long billets VS one 64" long billet.



Any heat that goes into the container should exit the container, otherwise, the container saturates and loses its ability to dissipate the extra heat. Then the only solution would be to decrease the ram speed to avoid a high exit temperature and surface defects. Long billets generate much more heat inside the container than short billets, which can dictate a decrease in ram speed and productivity.

Figure 7 – Required heat dissipation during extrusion of long and standard billets.



Longer billets need bigger presses. For example, extrusion of a 7” diameter, 64” long billet with a ram speed of 39ipm needs 2,270 tons of press load. A 32” billet needs just 1,778 tons. Due to the shorter billet length, a 32” billet results in a 12°F lower exit temperature which allows for faster ram speed. A ram speed of 50ipm, with a short billet, results in the same exit temperature when compared to a long billet with 39ipm ram speed and only 12 tons of load increase. The 11ipm increase in ram speed is more than enough to compensate for the extra dead cycle time between two 32” billets. The end result is that by using a shorter billet, the face pressure is decreased significantly while the net productivity is increased. Figure 9 shows the same information but for different billet diameters and similar billet weights. It shows how productivity can increase by more than 20% by extruding shorter and thicker billets and decreasing the face pressure at the same time.

Figure 8 – Temperatures, load, face pressure and exit temperatures for long VS short billets.

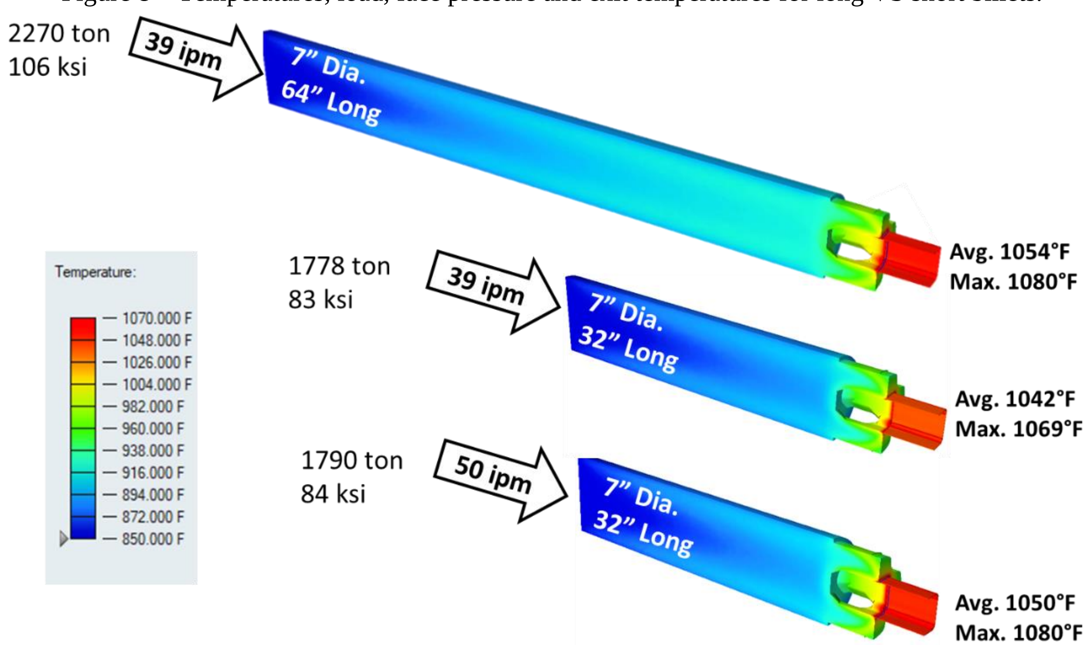
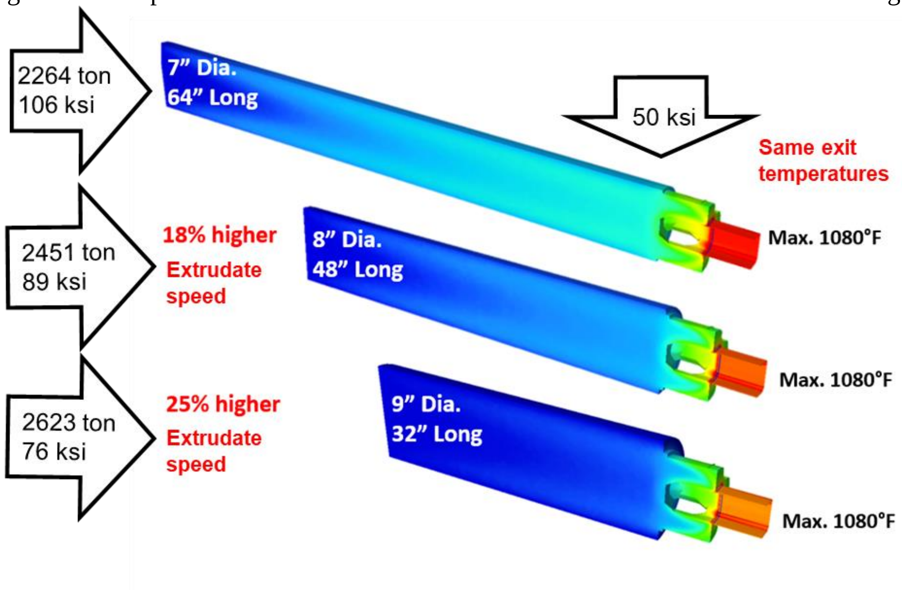


Figure 9 – Temperatures and loads for billets of different dimensions but similar weights.

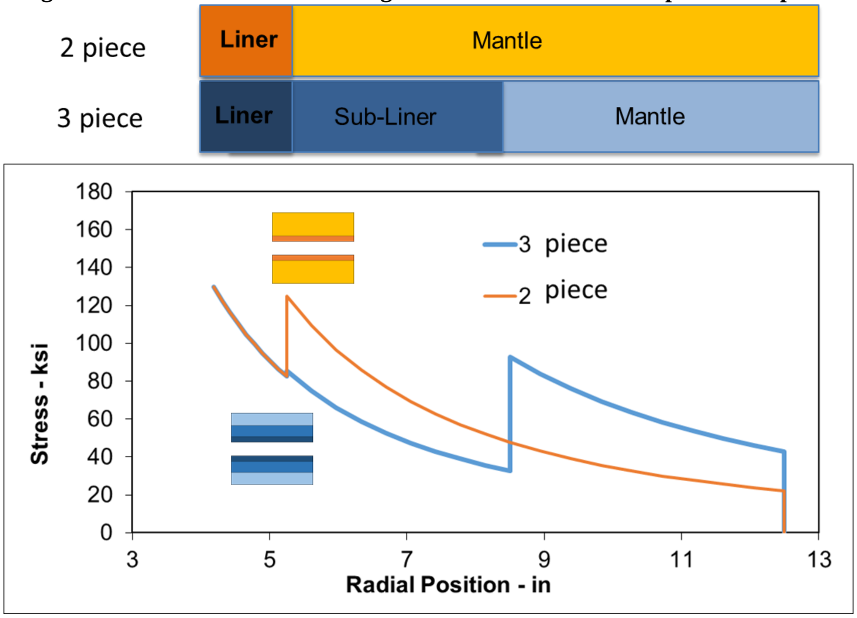


I HAVE TO USE LONG BILLETS, NOW WHAT?

Longer billets put more stress on tooling and can decrease tooling life significantly. The solution is to use tooling designed specifically for high-pressure applications such as high-pressure dummy blocks (Figure 10) and 3-piece containers. Figure 11 shows how stress can be distributed between sub-liner and body in a 3-piece container, rather than the concentration of stress at the body ID in a 2-piece container.

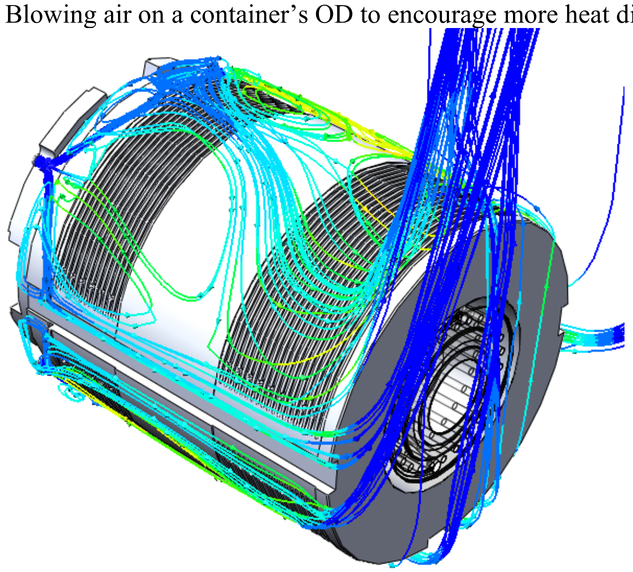
Figure 10 – Different dummy blocks designed for different face pressures

Figure 11 – Stress distribution along the radius of container: 2-piece VS 3-piece.



In terms of thermal control, the extrusion of a longer billet may need some extra heat dissipation to avoid the thermal saturation of the container. The best way to remove extra heat from the container is to remove it from container OD, which has the largest area. Blowing cold air at any location inside the container disturbs the natural thermal gradients inside the container and causes unstable processes and thermal shock inside the hot container.

Figure 12 – Blowing air on a container's OD to encourage more heat dissipation

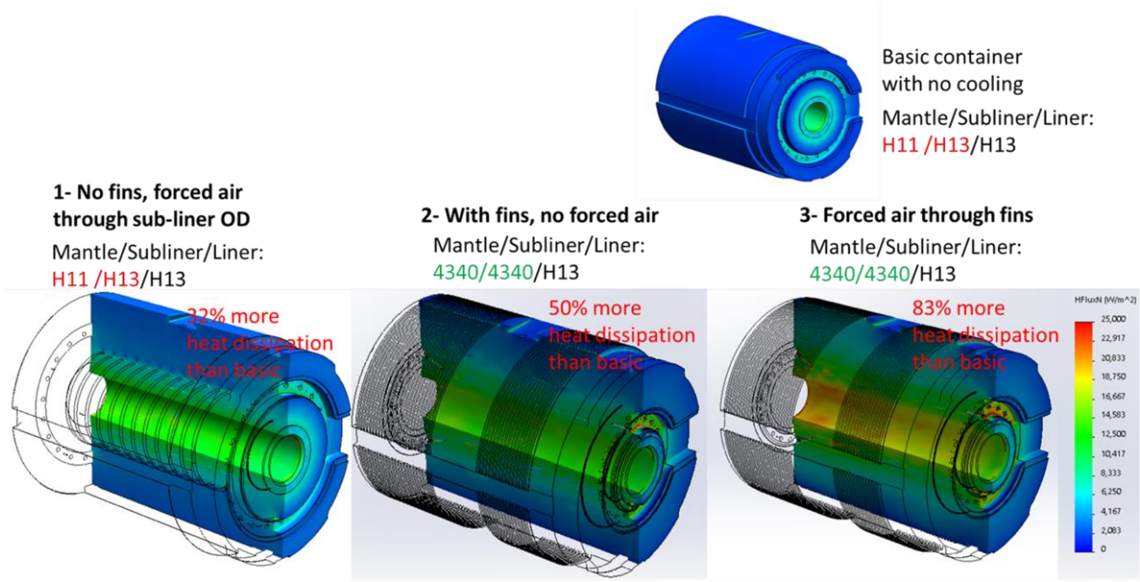


CONTAINER HEAT DISSIPATION

Heat transfer inside the container is governed by the equation $h = k.\nabla T$, where "h" is heat transferred per unit area, "k" is material conductivity and ∇T is the temperature gradient. Then, the amount of heat dissipated from the container ID is a direct function of material conductivity and temperature gradient inside the container.

Using more thermally conductive steel for the container body and sub-liner and creating a larger temperature gradient inside the container by blowing air on the container OD will significantly improve the heat dissipation through the container (Figure 13). Blowing air to container OD is more effective than forcing air between liner and body (Figure 13). The main reason is the available contact area for convective heat removal.

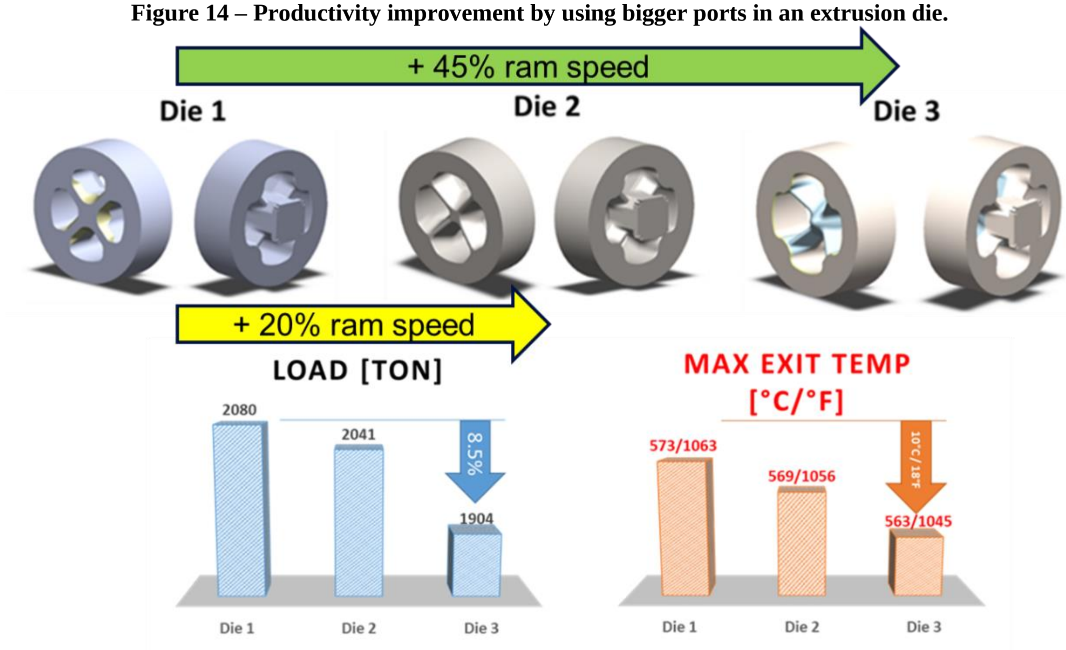
Figure 13 – Heat dissipation improvement by using more conductive 4340 steel and forced air through container OD.



DIE DESIGN

Using larger ports and chambers in the extrusion dies reduced the redundant mechanical work consumed to deform the workpiece inside the die, this will decrease the extrusion load and exit temperature. This means moving up both curves in the extrusion limit diagram (Figure 5) and opening the space for a significant ram speed increase. Figure 14 shows that by using Die 3 with bigger ports, the extrusion load decreases by 176 tons and the exit temperature decreases by 19°F. These can translate into a 45% increase in productivity.

Figure 14 – Productivity improvement by using bigger ports in an extrusion die.



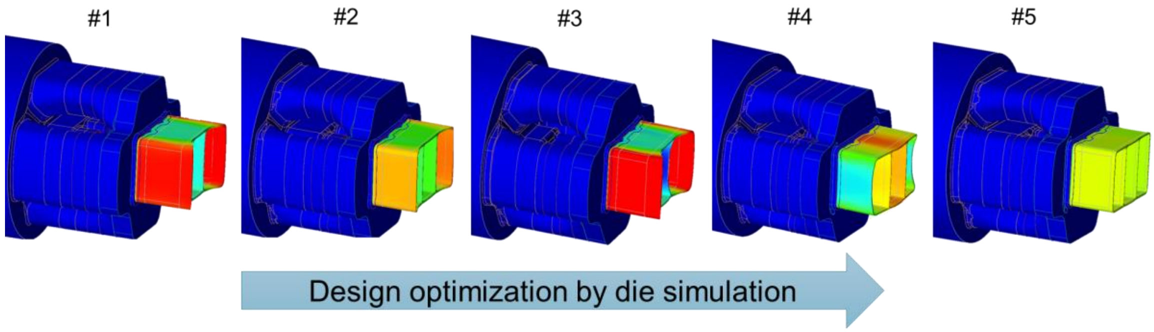
CHALLENGES WITH HIGH PRODUCTIVITY DIES

The question is why don't die makers make all of their dies like Die 3 - with larger ports? Die 1, with short and thick bridges, is the most conservative die and it makes more room for possible die corrections. Using Die 3 requires great attention to detail. For example, the die must be properly preheated in a single cell die oven (Figure 15) to avoid overheating or underheating. Overheating the die can temper and soften the die material and underheating will increase the die face pressure and possible die deformation. Single cell die oven, reduces break through pressure starting a new die, which is needed when using weaker dies.

Figure 15 – Single-cell die ovens: the most accurate and efficient pre-heating method.

Another method to increase the success rate - especially when using Die 3 – is to use die simulation tools to decrease or even eliminate the need for die corrections and die trial iterations.

Figure 16 – Die design optimization by simulation.



Bigger die ports can slightly increase the scrap rate, but it is not comparable to productivity gain. According to calculated numbers in Table 1, the amount of productivity gained by using Die 3 (16%) is about 10x the lost recovery (1.5%) for the specific die and process conditions here.

Table 1 – Predicted productivity and recovery for dies shown in Figure 14.

	Optimum productivity (lb/hr)	Normalized productivity	Recovery (%)
Die 1	4690	100	83
Die 2	5088	108	82.5
Die 3	5428	116	81.5

SUMMARY AND CONCLUSIONS

Any part of the process that increases temperature potentially reduces the ram speed! Any part of the process that increases resistance to flow has a doubled effect: the resistance to flow uses up the pressing force while generating redundant heat. Both of these are unfavourable to high productivity. Any part of the process that causes temperature instability requires a die with more features that use friction to gain control of the flow, which again reduces ram speed.

Superextruders obviously didn't get to be superextruders purely by luck, and it's unlikely that they have all shared the same magic formula for success, but there are things they have in common. When one looks at their net productivity gain over the average, numbers are seen in the 40-50% range. What average extruder wouldn't want to see that kind of improvement?

The most important concept to take away from this discussion is balancing the three factors of material, time, and speed. If one attempts to push the envelope on any individual one of them, one runs the risk of failure in the other; and productivity (and, of course, profit) goes out the window. Understanding this balance is the first prerequisite to becoming a superextruder. The path to getting there may vary. It depends on all of the physical factors of a given extruder's equipment, their operators, how diligent they are in following procedures, how carefully they measure and control temperatures, and ultimately how much they care about producing a final product that maximizes quality and profitability.

REFERENCES

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[4] Roger Fielding, "Benchmarking," in *Extrusion Technology Seminar*, 2016.