Material Selection for Extrusion Tooling – Part III

Die, Dummy Block, Stem, and Auxiliary Tooling

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This article is the last part of a series of three. The first article dealt with decision theory and most important aspects of material selection for extrusion tooling [1]. The second one was focused on material selection for containers [2] and the current article will continue with discussing the material selection for the rest of extrusion tools specifically die, dummy block, clean-out block and stem. Among these, dies and dummy blocks are in direct contact with deforming workpiece and under more sever mechanical and thermal conditions. Stem is not in direct contact with workpiece, and it does not experience high temperatures. Clean-out block is an auxiliary tool used after the main process to scoop off the remaining of billet skin on liner ID and clean the liner.

Extrusion Die

Extrusion die is the main tool shaping the workpiece into profile and usually it has complex geometry with many stress rising features such as bridges and corners (Figure 1-left). Most of the deformation takes place inside the die which is accompanied with high rate of heat generation from plastic deformation and friction. Most of the heat will remain inside the deforming aluminum and exits the die while part of it transfers into the die. The deforming material is hottest at the bearing so that the bearing surface is the hottest part of the die, and it is also the hottest spot among the whole extrusion tooling set. Model predictions, shown in Figure 1-right, indicate that the bearing temperature can get close or exceed 600°C. If hot work tool steel remains at such temperatures for extended period, it will lose majority of its hardness. Other then high temperature, the die bearing is also under intense sticking friction that can cause sever wear. Other than bearing surface, at the rest of workpiece-die contact surfaces there is no considerable wear as the aluminum sticks to the die surface due to high pressure and the only mechanism for movement of aluminum inside the die is shear or deformation rather than sliding on die. The bearing surface is often nitrided for better wear resistance and lower friction coefficient.

In conclusion, the die material should have excellent strength and temper resistance, as well as hot wear resistance to withstand the friction at bearing surface. These properties can be found in hot work tool steels. Table 1 lists chemical compositions and selected key properties for some of the hot work tool steels used for manufacturing aluminum extrusion dies. Cr, Mo and V play important role in hot strength and precipitation hardening of hot work tool steel by formation of stable carbides and other compounds dispersed throughout the material. Generally, a porthole extrusion die needs an initial strength of at least 1500 MPa [3] (equivalent to 46-47 HRC). H13 material have better temper resistance than H11, but lower toughness. The lose of toughness to gain temper resistance can be observed in Table 1.

Depending on the process and geometry complexity, extrusion dies may get heat treated up to initial strength of 1800 MPa (~52 HRC), with a significantly lower toughness and temper resistivity. For instance, H13 material tempered to 52 HRC would start to soften at 530°C, while the same material with the initial hardness of 46 HRC can tolerate temperatures up to 580°C without considerable softening.

The bearing surface is the most susceptible to softening as it is the hottest spot. Although the nitride layer at the bearing does not soften at such temperatures, but the high hardness material is needed underneath the brittle nitride layer to support it.

Figure 1: Model predicted stress and temperature distribution in extrusion die during the process. Left: stress distribution in the mandrel of a porthole die with two cavities; Right: temperature distribution in a porthole die (sectioned view).

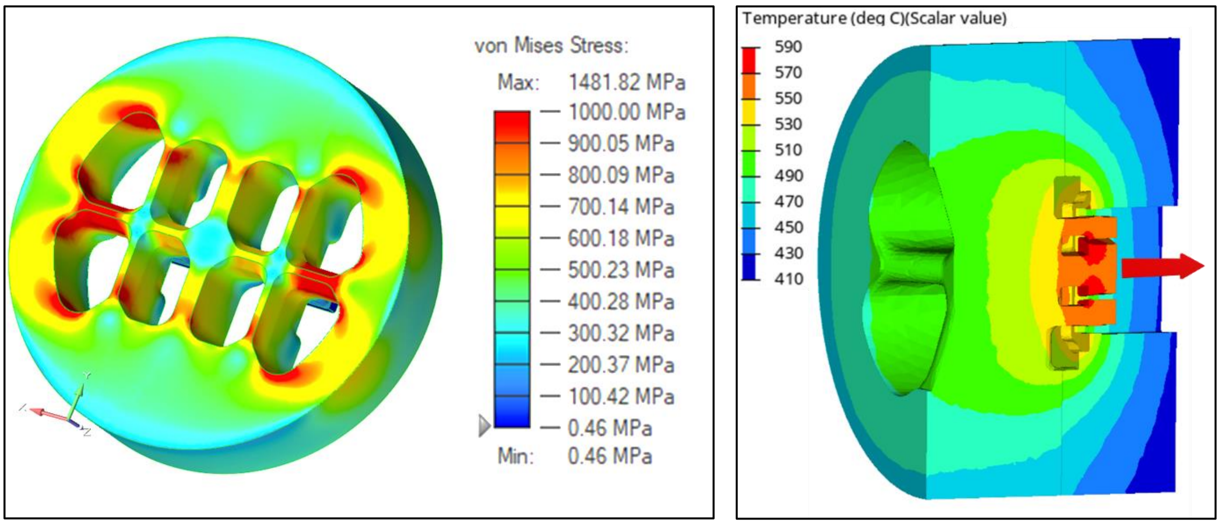


Table 1: Chemical composition of some hot work tool steels used for dies in aluminum extrusion [3], [4].

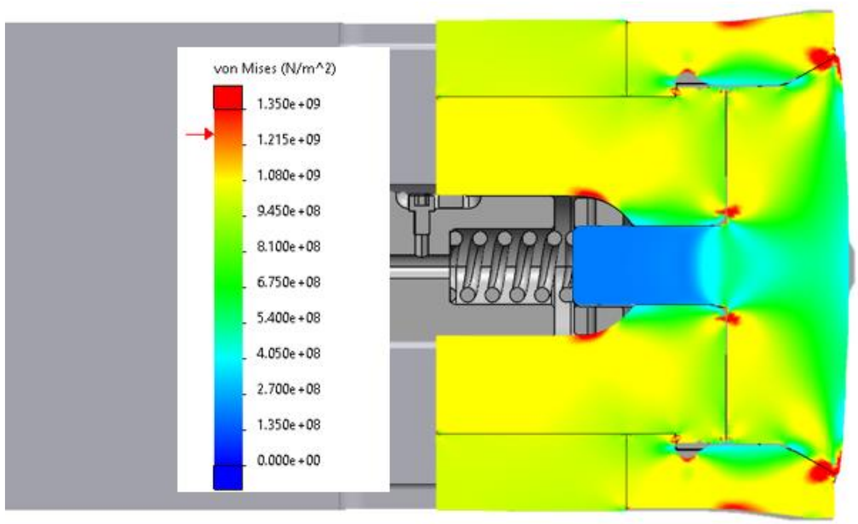
Alloy	Major alloying elements (Wt%)							Temper point to get initial hardness of 46 HRC	Maximum safe operation temperature for material tempered to 46 HRC	Toughness
	C	Si	Mn	Cr	Mo	V	Co			
1.2343 (H11)	0.38	1	0.4	5	1.3	0.4	---	620°C	570°C	●●●○
1.2344 (H13)	0.40	1	0.4	5	1.4	1	---	630°C	580°C	●●●
1.2367	0.37	0.3	0.4	5	3	0.6	---	640°C	590°C	●●○
1.2885	0.32	0.3	0.3	3	3	0.6	3	650°C	600°C	●●

Dummy block

Majority of dummy blocks used for extrusion of aluminum alloys are mechanically expandable. They have moving mandrel that pushes on the expandable ring during the process and opens the ring to desirable diameter. Dummy block is one of the most stressed tools in extrusion, and it is multicomponent which move or slide against each other. This makes it difficult to balance the stress and deformation among its components. The face pressure can reach 825 MPa (120 ksi) during the extrusion of high strength aluminum alloys, this level of pressure can be harmful at stress concentration locations where stress can reach 1500 MPa. The yield stress of the material should be high enough to avoid failure at these locations, so that for extrusion of hard alloys such as 7xxx aluminum alloys stronger material is recommended.

Outer surface of the expandable ring (Ring OD) and its surrounding is the hottest part of the dummy block. Generally, a thin layer of aluminum remains on liner ID due to a gap between the ring and liner, this makes the deformation and friction conditions at ring OD very similar to die bearing, so that it experiences quite high temperature, which can be high enough to locally soften the material. This makes it necessary to use hot work tool materials such as H13 and TuffTemper [5], for manufacturing of dummy blocks.

Figure 2: Model predicted stress in dummy block during extrusion of high strength aluminum alloy



Stem

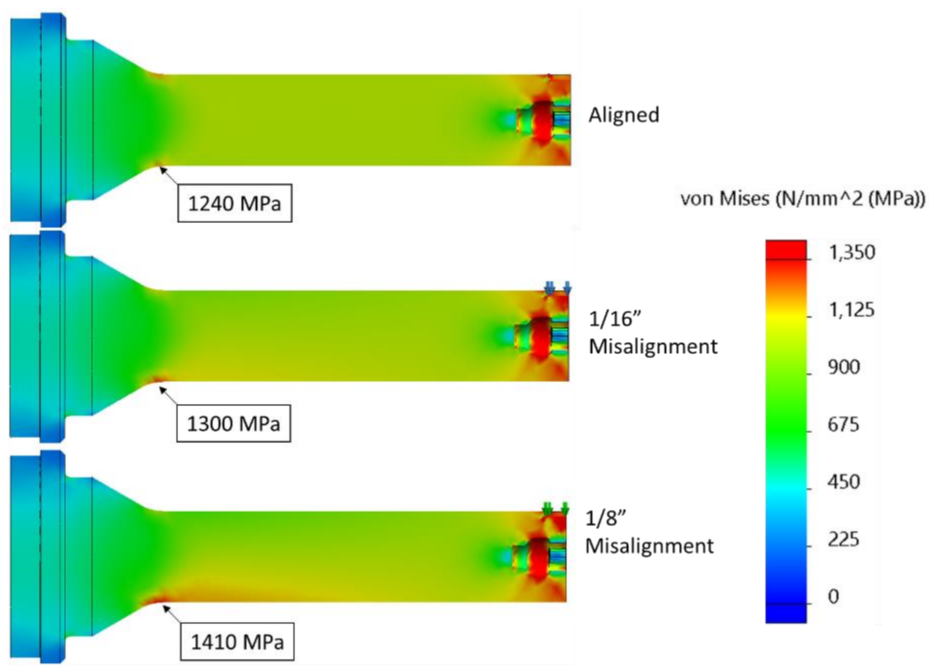
Stem is one of the heaviest and longest single piece tools used in extrusion. It is not in contact with hot aluminum nor exposed to high temperatures (Figure 3), so it may seem possible to use low-alloyed steel to manufacture them. But, due to large thickness change at the end of the stem, getting uniform microstructure and hardness after heat treatment is a big challenge, so that more alloyed steels with better hardenability, such as H13, is needed to get uniform structure. Figure 3 shows the temperature distribution in stem and dummy block. As observed, the temperature levels throughout the stem is much below critical values for hot work tool steel.

Figure 3: Model predicted temperatures in a 10" stem and dummy block.

In perfect alignment conditions, stem only needs high compressive strength, but since it is long, the bending forces from possible misalignments can cause raise in stresses, specially at the surface of the stem (Figure 4). So that, a combination of toughness and hardness is needed.

Figure 4 shows the effect of misalignment on stress concentration at the back of the stem. Because the stem is already under huge compressive stress during the extrusion, any misalignment can bring the stress level above the elastic limit. Stress concentrations are more sever at the front side of the stem due to more details. To recover local deformations and prolong the life of the stem, stress relief anneal must be performed on recommended schedule.

Figure 4: Model predicted stress in an 8" stem under 3600 ton load: effect of different misalignments.



Clean-out Block

Clean-out or Cold Clean-out Block (CCB) is used in cold condition, and it is pushed fast through the container so that it does not get very hot, but it needs to have good wear resistance. Another key parameter for CCBs is drop-resistance as they are usually dropped on the floor after the clean out cycle. Hence, they might have lower hardness than the dummy block to accommodate some shock resistance. In contrast to dummy block, there is no gap between CCB and liner, so that hardness of clean-out block should be less than the liner to avoid any scratches on the more expensive tool (liner). On the other hand, clean-out block temperature is much lower than the liner so that at the same hardness level, its temperature compensated hardness is higher than the liner during the clean-out process, which must be considered in material selection and heat treatment of CCB.

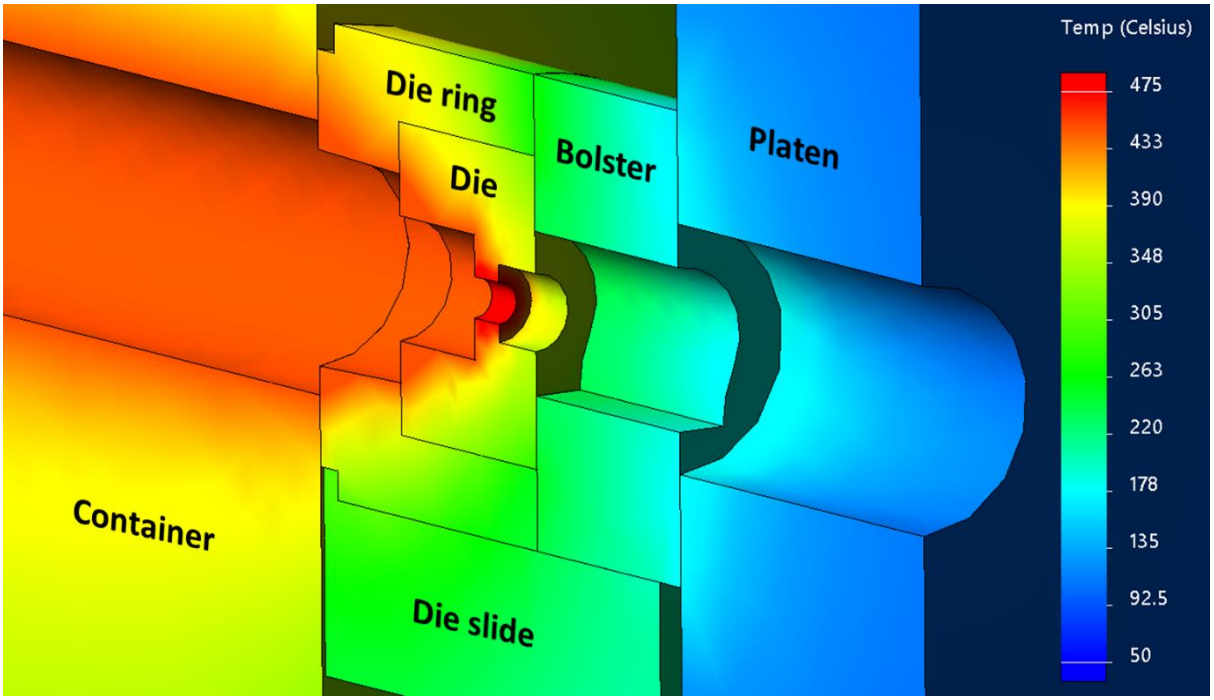
Die Ring and bolster

Die ring is an auxiliary tool to support the die set. It is under less stress and temperature than the die itself (Figure 5). Hot work tool steel is a conservative selection based on operational conditions. But it must be noted that the die ring is heated with die during the die preheat cycle and as it is closer to the oven heat source than the die, it can get hotter than die during preheat so that a hot work tool steel can be a safe selection to make sure the die ring will not lose mechanical strength over time.

Bolster is another auxiliary support tool that works under much less temperature than die and container (Figure 5) but it is under high stresses as the whole press load and container sealing force is transferred to bolster.

In terms of temper resistance and strength, the H13 material provides more than enough properties but due to the good price per mechanical capabilities it wins over other materials economically and provides better life.

Figure 5: Temperature distribution in tooling during Aluminum extrusion process.



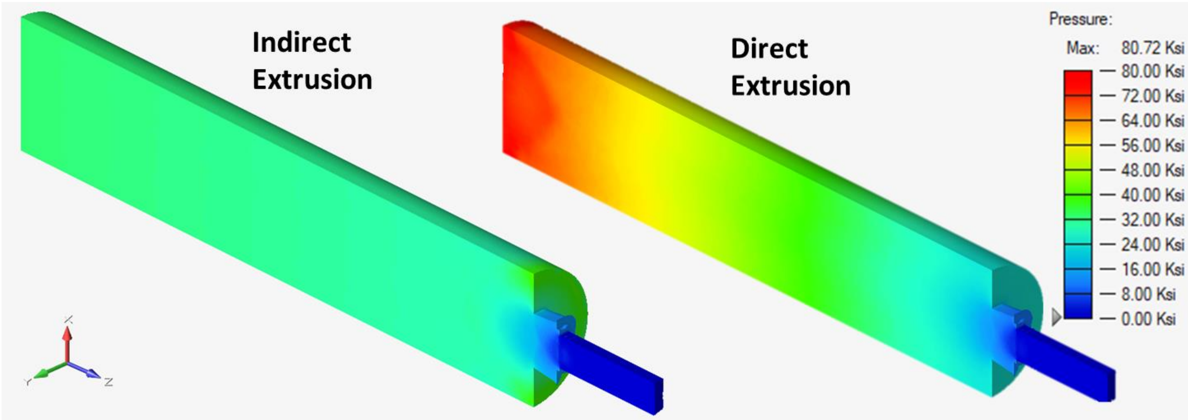
Shear blade

Shear blade acts like a machining tool tip, except in very larger size scale. The main difference is that the workpiece is too hot (close to melting point) and too ductile and sticky, which makes it too hard to get a clean cut. Preserving the cutting edge is the main factor in quality of shear. Due to high ductility of workpiece the material surrounding the cutting edge undergo huge amount of deformation and shear, hence high rate of deformation heat localizes at the cutting edge that can cause thermal shock and also softening. H13 material provides good combination of wear and temper resistance for this application. The durability of the tool may get improved by using a more conductive hot work material and surface treatment to decrease friction coefficient between hot aluminum and tooling.

Indirect tooling

During Indirect extrusion, pressures and loads are generally lower than direct extrusion, basically because there is no friction or relative movement between billet and the container. The distribution of pressure on the liner ID is uniform as there is no friction consumed by friction inside container. Figure 6 shows a comparison of pressure distribution in Direct and Indirect extrusion with same parameters. Although the stress in indirect extrusion container decreases significantly, but the stresses on die and stem may increase due to dimensional constraint for indirect extrusion tooling. During indirect extrusion the workpiece absorbs significantly lower amount of deformation heat inside the container, so that when it reaches the die it is much colder than direct extrusion. This makes the indirect extrusion die bearings to run in lower temperatures than direct extrusion, and higher stresses due to higher flow stress of material inside the die.

Figure 6 – Pressure distribution during extrusion; direct VS indirect.



Reclaimed material

Using reclaimed material is an economical option for clean-out blocks, die rings and other auxiliary tooling. For example, previously used H13 liner without cracks can be used for manufacturing of cleanout blocks and die rings without additional heat treatment.

Summary and Conclusions

- Material selection for extrusion tooling was discussed based on thermal and mechanical state of each tooling.
- Simulation tools were used to evaluate thermal and mechanical states of tooling during the process.
- Among extrusion tools, the die experiences the highest temperatures. Die bearing temperature during the extrusion can reach critical temperatures for hot work tool steel.
- Complex geometry of porthole dies can cause significant stresses during extrusion of high strength alloys.
- In direct extrusion, which is the most popular extrusion method, the dummy block is under highest pressures and stresses. The stresses at some points of the dummy block can reach and even exceed the yield stress during the extrusion.
- Although stem is not working under hot conditions as dummy block but due to specific dimensional features of stem, tool steel is recommended for generating uniform microstructure and avoid deflections during heat treatment.
- Auxiliary tooling such as bolster and die slide, do not get as hot as main tooling so that using hot work tool steel is a conservative selection.
- As and auxiliary tooling, die ring is not as hot as die during the extrusion. But it is always preheated with the die. This can explain the choice of H13 for this part.
- In shear blades, the cutting edge is under harshest thermal and mechanical conditions so that it is the main point of attention for material selection.

- Indirect tooling can decrease the face pressure significantly which is in favour of container, but the stresses on die holding stem and the die may increase due to dimensional restrictions dictated by indirect extrusion method.
- Using reclaimed materials for making auxiliary tooling not only causes cost saving, but also increases the safety factor when using materials with grades higher than required.

References

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