Bigger Castings, Bigger Problems
Using Giga Presses to Cast Massive Automotive Parts

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Thanks to ground-breaking innovations, the automotive industry is increasingly interested in manufacturing massive structural parts, known as giga-castings (or mega-castings), through cold-chamber die casting techniques. This introduces new opportunities and challenges for the die cast industry by pushing the limits of tooling and material. The larger cast parts can significantly simplify automotive manufacturing; in some cases, a single giga-cast body piece can replace 70 or more parts in the vehicle.

A few years ago, the largest die cast machines had a 3,000–4,000 ton clamping force and used shot sleeves with a 6–7 inch bore diameter. Nowadays, there are die cast machines with a 9,000 ton capacity and shot sleeves with a 13 inch bore diameter. These hot work steel parts can be up to 90 inches long and 20 inches in diameter, which makes every single part of manufacturing more challenging, including design, material quality, heat treatment, and nitration.

The clearance between the plunger and the shot sleeve cannot exceed 0.004 inches (0.10 mm) or it will cause excessive wear.[1] If the clearance becomes more than this, the alloy can penetrate as a “flash” or blow-by. The clearance between the plunger and shot sleeve never remains constant. At the start of the casting cycle, the sleeve is very hot, while the plunger tip is quite cold at the pour end. As the plunger moves forward, the tip becomes hotter and expands, but the inner diameter (ID) of the sleeve contracts as the heated ID layer cannot expand into the bulk of the shot sleeve. If the initial clearance at the pour end is small enough to prevent penetration of the alloy past the tip of the plunger, the plunger may seize in the sleeve before reaching the end of the stroke. The chance of this happening increases with the size of the shot sleeve.[2]

For large castings, due to thicker sections in the tooling and the aluminum biscuit (an excess of ladled metal remaining in the shot sleeve), the plunger tip cooling needs to be more efficient to maintain reasonable cycle times. Using a stronger material for the tip (like steel instead of copper), makes it possible to implement more complex designs, such as conformal grooves for better cooling. ConDuct steel with good conductivity and superior thermal shock resistance is the material of choice for a Conformal Ring Plunger.

In long sleeves, keeping a consistent layer of lubricant along the ID of the sleeve is a challenge. Using lots of high viscosity lubricant under the pour and hoping it will reach the end of the sleeve is the wrong solution, and it can introduce many defects in cast parts. The proper method is to use well-designed equipment, which allows the operator to put as little lubricant as possible where needed.

Shot sleeves are often made of H13 hot work tool steel tempered at around 600°C, so any operating temperature close to this is of concern. The 3 inch sleeve with a maximum temperature of 583°C can last for an acceptable number of cycles, but 6 inch and higher will experience temperatures at or above the tempering temperature of H13 steel. This indicates the necessity for a cooling or thermal regulation system in larger shot sleeves.

Simulation Study

A simulation study was conducted to better understand the effect of size and temperature on the shot sleeve. Figure 1 shows a simulation of the predicted distribution of temperature at early stages of solidification and maximum temperatures for different shot sleeve sizes working under similar process parameters. The bore sizes studied here are 3, 6, 9, and 12 inches. These results indicate the need for thermal regulation for larger shot sleeves.

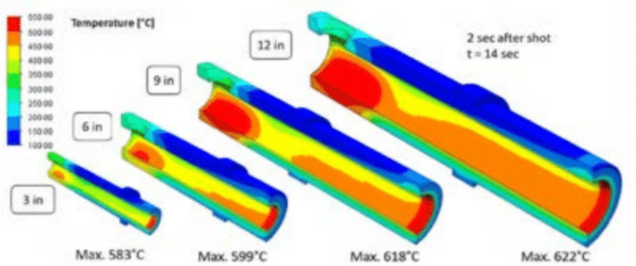

Figure 1. Temperature distribution in shot sleeves of different sizes during the solidification cycle (no thermal regulation).

Table I lists important information regarding the deformation of the shot sleeve bore and deflections, called the banana effect. The difference between maximum and minimum radial expansion of the shot sleeve bore, called “range,” is a good measure for tooling performance. If the difference is more than the critical value of 0.004 inches (0.10 mm), it will be very hard to maintain a consistent gap of less than 0.004 inches (0.10 mm) between plunger and sleeve during the shot. An effective method to reduce this range is thermal regulation.

Sleeve ID	Deflection [mm] (Banana Effect)	Radial Expansion of the Bore [mm]		
		Maximum	Minimum	Range
3 inch / 76 mm	0.55	0.09	0.070	**0.02**
6 inch / 152 mm	0.98	0.23	0.13	**0.10**
9 inch / 229 mm	1.7	0.31	0.18	**0.13**
12 inch / 305 mm	2.21	0.40	0.26	**0.14**

Table I. Calculated radial expansion along the shot sleeve during the plunger shot (effect of size).

The effect of thermal regulation on the temperature, deflection, and bore expansion for 9 inch shot sleeves with similar geometries and process parameters is shown in Figure 2 and Table II. For thermal regulation, a series of connected channels are drilled on the wall of the sleeve for coolant flow. Usually, hot oil is used as coolant fluid. Due to a better distribution of temperature across the shot sleeve, deflections and banana effect is minimized by thermal regulation and, more importantly, the range of radial expansion in the bore is reduced from 0.13 mm to below the critical value.

Plunger Tip Design: The biscuit solidification capability of six different tip designs with different materials is studied by means of fluid flow and thermal simula-

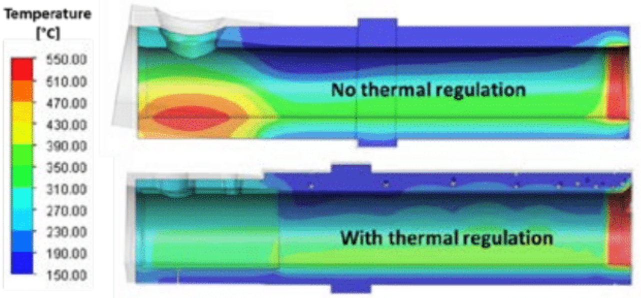

Figure 2. Effect of thermal regulation on temperature distribution in a large shot sleeve (9 inch bore).

Type	Deflection [mm] (Banana Effect)	Radial Expansion of the Bore [mm]		
		Maximum	Minimum	Range
9 inch solid shot sleeve without thermal regulation	1.71	0.31	0.18	0.13
9 inch gun-drilled shot sleeve with thermal regulation	0.29	0.29	0.20	0.09

Table II. Calculated radial expansion along the shot sleeve during the plunger shot (effect of thermal regulation).

tion (Figure 3). The water pressure was kept constant for all simulations, which were based on the amount of friction and cooling channel design (Figure 4). The most influential factor on the biscuit's solidification rate seems to be the tip material conductivity—all copper tips have a very high solidification rate, while H13 and maraging steel tips have meager solidification rates. Instead, steel has a higher strength, allowing for more complex designs, such as AM1 and AM2. Cases 1, 2 and 3 in Figure 4 are only presented to show the thermal effect of the tip material with the same dimensions; otherwise, the material change would mandate some dimensional changes to compensate for the mechanical and thermophysical property changes. For example, when switching from steel to copper (with lower hardness), the thickness of the tip face should increase to provide enough strength.

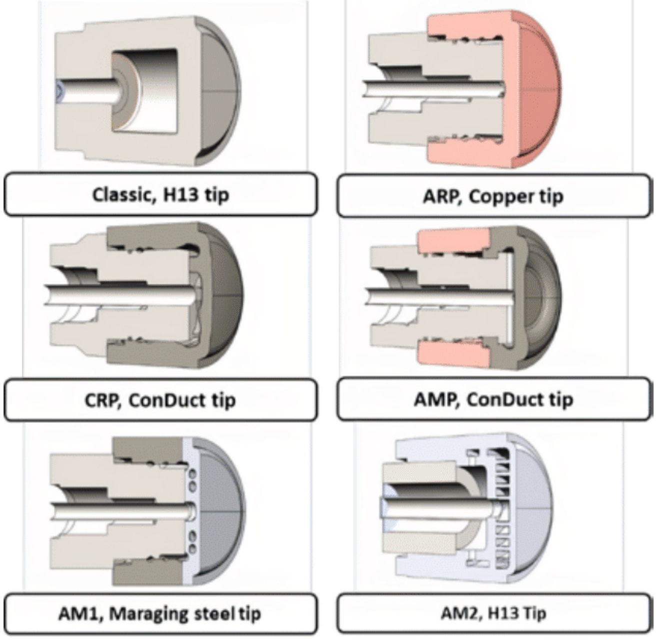

Figure 3. Different plunger tip designs: alper ring plunger (ARP), conformal ring plunger (CRP), alper modular plunger (AMP), laser powder bed additive manufacturing (AM1), and ultrasound additive manufacturing (AM2).

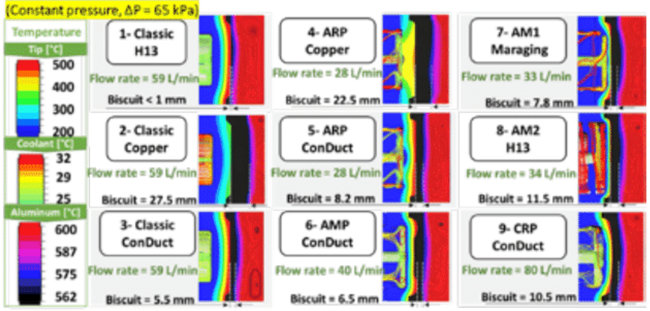

Figure 4. Biscuit solidification (black layer), tip, and coolant water temperature at the end of dwell time, when there is a constant water pressure of ΔP = 65 kPa at the tip. The water flow rate is reported for each case.

Expensive additively manufactured tips (7 and 8) did not make considerable improvements in the cooling performance of the tip. AM1 made of maraging steel has less of a cooling effect than ARP and CRP ConDuct tips. AM2 made of H13 steel can improve the cooling to some extent, but it provides lower structural strength due to its design features.

Conclusion

Model predicted thermal history of the shot sleeve indicates that a large sleeve with no thermal regulations can experience temperatures at or above the critical temperatures of the sleeve material. For larger sleeves, the variation of bore expansion can become larger than the critical gap between the plunger and sleeve bore, making it difficult to create a consistent gap between the plunger tip and sleeve.

Material selection is an important part of product design—the mechanical and thermo-physical properties of the material affect productivity and tooling durability. A thinner face generally shows a better solidification rate in steel tips, but for copper with high thermal conductivity, the thicker tip may show a better solidification rate due to more thermal mass. A CRP ConDuct steel tip with cooling grooves shows a considerable advantage over the previous generation of tips (ARP and AMP) in solidification rate and tip temperature. Additive manufacturing does not add considerable value to plunger tip performance, when considering its much higher manufacturing costs. On the other hand, the complex design of these tips can cause excessive thermo-mechanical stresses.

Good lubrication is a combination of proper lubricant and proper lubrication methods. Plunger lubricants help with the smooth running of the die casting system. A good lubricant can improve the castability of the metal, limit porosity, and improve injection. On top of these, plunger lubrication prolongs the life of the shot sleeve and plunger. For large tooling, low viscosity lubricants with spray application methods are recommended.

References

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