# Plunger Design and Materials

## - the Keys to Die Casting Success -

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## INTRODUCTION

Die casting processes can vary widely. Alloy types, pour weights, pour times, cycle times, die and gating designs, sleeve designs and lubrication types all play a role. In essence, no one plunger design fits all – the plunger tip should be designed and adapted to suit a specific combination of variables. This article will discuss the benefits of plunger tip modularity, and the relationship between materials, hardness, thermal conductivity and working land length to suit most die casting conditions.

Choosing the right plunger tip materials and design however, is only one part of a successful die casting story. We will also examine how careful control of clearances, and Castool's innovative sleeve designs work together to reduce waste, benefit the environment, increase productivity and ultimately, produce the quality and profitability demanded by today's die casters.

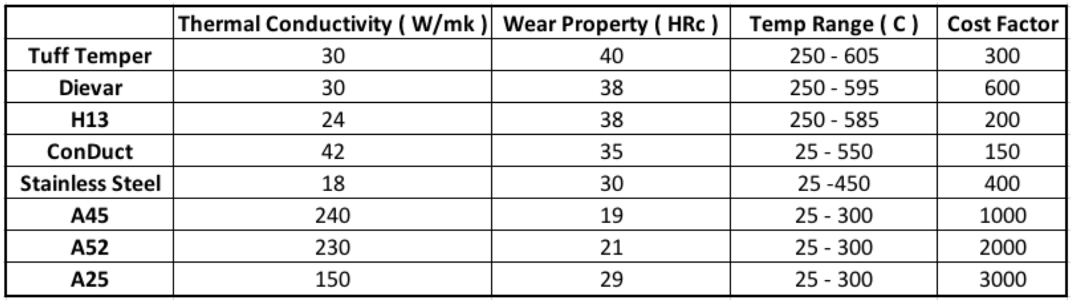
## CON-DUCT MATERIAL

Traditionally, the beneficial thermal conductivity and wear characteristics of beryllium copper alloy has made it the only choice for larger size plunger tips, but beryllium and copper are costly and have negative HSE impacts. Castool has developed a new material called **Con-Duct**, specifically for plunger tip applications, that has higher thermal conductivity than H13 steel – 42 W/mK to 24 W/mK respectively.

We have conducted simulations to study the modular plunger tip design with various material combinations and compared Con-Duct with BeCu alloys and H13. The findings suggest different combinations suit different die casting parameters.

Table 1 below lists the properties of materials used in Castool's plunger tips:

***Table I***



| | Thermal Conductivity ( W/mk ) | Wear Property ( HRc ) | Temp Range ( C ) | Cost Factor |
|---|---|---|---|---|
| **Tuff Temper** | 30 | 40 | 250 - 605 | 300 |
| **Dievar** | 30 | 38 | 250 - 595 | 600 |
| **H13** | 24 | 38 | 250 - 585 | 200 |
| **ConDuct** | 42 | 35 | 25 - 550 | 150 |
| **Stainless Steel** | 18 | 30 | 25 -450 | 400 |
| **A45** | 240 | 19 | 25 - 300 | 1000 |
| **A52** | 230 | 21 | 25 - 300 | 2000 |
| **A25** | 150 | 29 | 25 - 300 | 3000 |

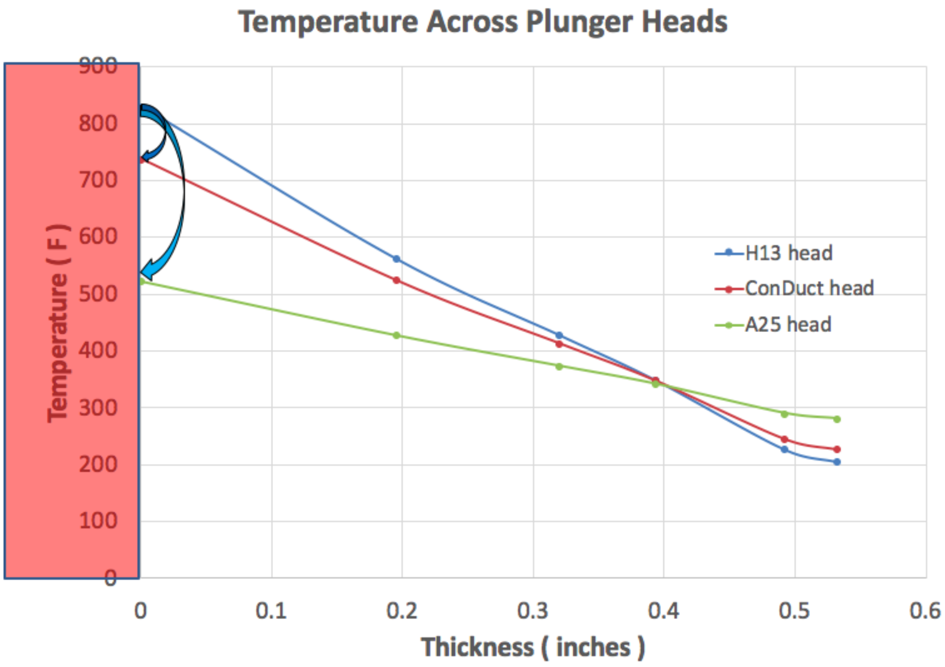


*Figure 1. Temperature across different plunger tip materials*

The plunger surface will reach its maximum temperature just before releasing the hot aluminum biscuit. Figure 1 shows the simulated temperature results of three different plunger head materials, H13, Con-Duct and A25 (high Beryllium Copper alloy) at this point in the cycle. Con-Duct has higher thermal conductivity (42 W/mK) than H13 (24 W/mK), and lower maximum surface temperature. It's also about 100ºF cooler than the H13 tip.

Thermal expansion of H13 is also higher than Con-Duct. This affects the tip face, where greater expansion induces repetitive compression, and can initiate cracking. Con-Duct has better thermal stability and is more economical than H13. From Table 1, we can see that A25 has the lowest surface temperature, but it's about 20 times the cost of H13 steel.

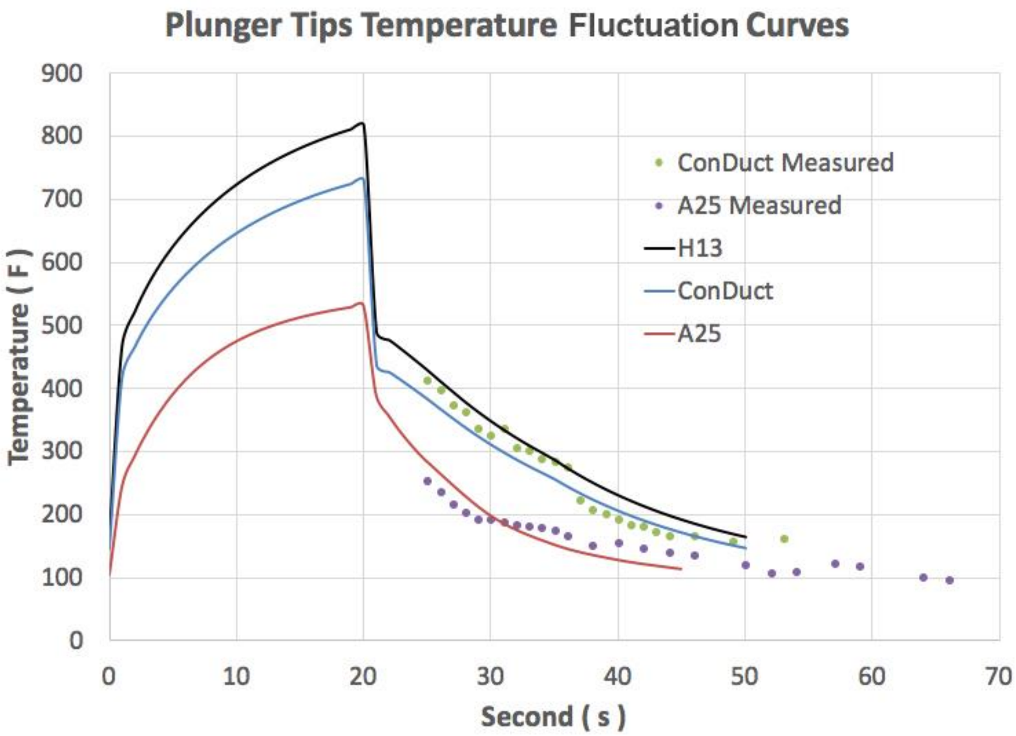


*Figure 2. Plunger tip temperature fluctuation*

***Table II***

| Material | H13 | Con-Duct | A25 |
|---|---|---|---|
| Cooling Capacity<br>(Watts, higher the better) | 6,184 | 9,322 | 18,074 |
| Maximum Temperature<br>(F, lower the better) | 831 | 738 | 522 |
| Thermal Stability<br>(∆F, Temp. Fluctuation, lower the better) | 699 | 586 | 381 |
| Cost Factor | 200 | 150 | 3000 |

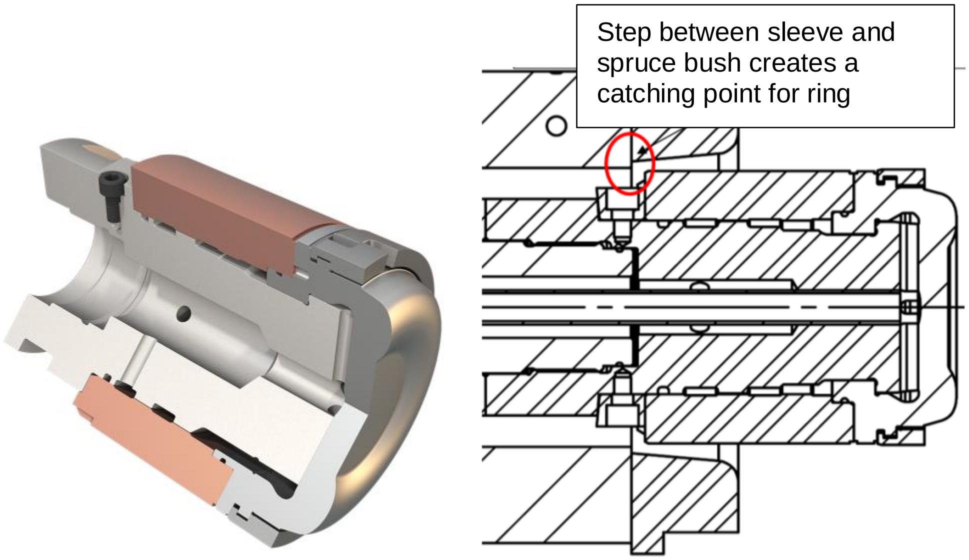
Materials used in plunger tip design affect thermal stability. Figure 2 compares the temperature fluctuation of Con-Duct to H13 and A25. The hot biscuit is released after 20 seconds of dwell time and as soon as the biscuit is removed from the plunger tip face, the temperature of the head drops significantly. Table II shows the cooling capacities, maximum tip temperatures, thermal stability and cost factor of the same materials. It’s obvious that Con-Duct is superior to H13 in all four aspects and can replace H13 for all purposes.

## DESIGN MODULARITY

The best design combination for a plunger tip depends on the customer's die casting conditions. Some set-ups will limit the use of ring plunger tips, while others may need a higher vacuum – requiring an additional vacuum ring added to the body of the tip.

### *Solid Tips*

In some situations, customers cannot use ring-style tips. For example, some spruce bush designs create a step between the sleeve ID and the spruce, as shown in figure 3. This creates a catch point that inhibits the use of expanding ring plunger tips.



Step between sleeve and spruce bush creates a catching point for ring

***Figure 3. The spruce bush is inhibiting the use of a ring plunger tip***

The step between the spruce and sleeve will catch the ring during the return stroke. The performance and ring life will be dramatically reduced. In situations like this, a solid plunger tip is recommended.

A ring plunger tip is more forgiving on sleeve distortion, misalignment and mismatched thermal expansion between tip and sleeve – so when a solid tip must be used, proper clearance and the length of working land requires better understanding of plunger tip and sleeve interaction, since the tip doesn't have a flexible ring to prevent aluminum flash back. Figure 4 shows the location of the working land length. The clearance between working OD and sleeve ID needs to be less than 0.004" at all times to prevent aluminum flash back, and yet the clearance cannot be too small to cause plunger tip seizure.

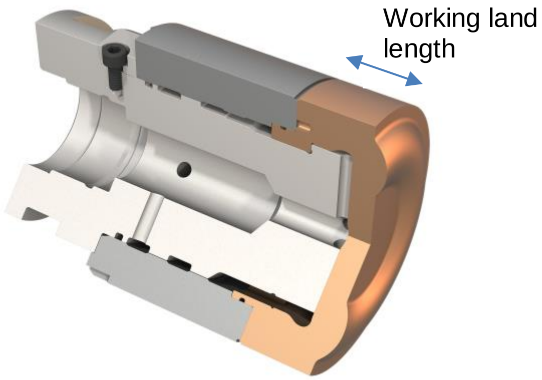


*Figure 4. The working land length of a solid tip*

### *Clearance and Working Land Length*

The initial clearance design for solid tips is a function of sleeve temperature characteristics, cooling capacity of the plunger tip, plunger head materials, tip size, and length of the working diameter. A solid plunger tip requires a better thermally-regulated sleeve to create good concentricity, roundness and straightness, and to prevent seizure and aluminum flash back. A bushing can be added to the body of the solid tip to improve fit and prevent seizure – however, a bushing doesn't have the same ability to prevent aluminum flash back as a ring.

The cooling capacity of the plunger tip increases if a copper head is used. This will raise the thermal conductivity of the tip, reduce dwell time and improve overall production. The friction coefficient of steel on steel is about double that of copper on steel, therefore, the working land length should be reduced when a steel head is used instead of copper.

### *Small Plungers*

Figure 5 shows Castool's AMP-R plunger tip, which uses a Con-Duct face, A45 (Beryllium free copper alloy) body and an H13 ring. This will suit most die cast customers. The replaceable ring tip design saves downtime to replace tooling and associated cost and provides a constant seal and smooth shot profile. The ring is made of nitrided H13 steel, which provides good wear and longevity. For small diameter tips (less than 100mm in diameter), the dwell time for biscuit solidification is short and thermal distortion is small, allowing the customer to exchange the A45 body with Con-Duct for further cost savings and a superior robust tip. The thermal stability requirement for smaller tips is not high, so there is little benefit in using copper plunger heads when cost is considered.

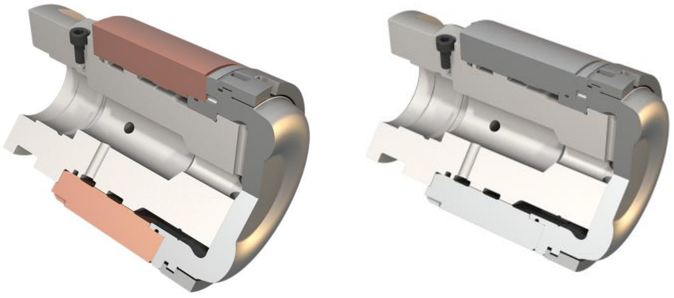


*Figure 5. Castool ring plunger tip (AMP-R)*

### *Large Plungers*

Large plungers typically have higher heat loads, due to the large volume of pour. The greater heat load causes the temperature of the sleeve to fluctuate. Typically, structural castings are large, and require a plunger system with good thermal and dimensional stability to provide consistent shot velocity and achieve minimal perturbation. Figure 6 depicts a typical situation when the plunger tip temperature (and hence, its diameter) varies significantly between the parking and the dwell positions. At the parking position, the tip is at 212ºF(100ºC) and its diameter is 6.496” (165.00mm). At the dwelling position, the tip is at 572ºF(300ºC) and its diameter is 6.515” (165.49mm). The plunger tip grows as much as 0.019” (0.493mm). This can cause plunger tip seizure and irregular shot velocity.

The sleeve has a water jacket near the die end to assist biscuit cooling. This creates a condition where the sleeve is hotter and larger at the pour end, and relatively cooler and smaller near the die end. The plunger tip may seize or scratch the sleeve when it moves forward. This makes achieving the proper clearance of the plunger tip OD very difficult, if not impossible. A thermally stable and robust plunger tip is the pre-requisite to having high quality and profitable casting.

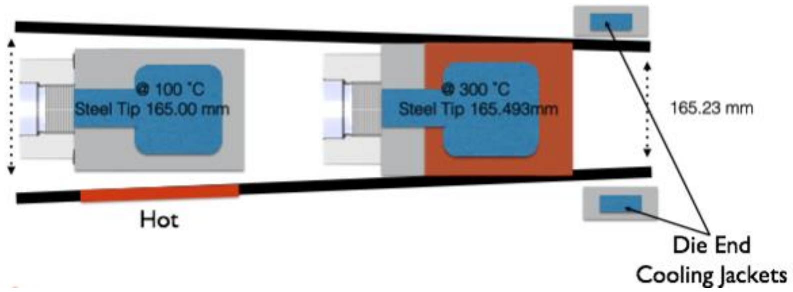


***Figure 6. The plunger tip over expands and sleeve contracts near die end***

### *Copper Rings to Extend Sleeve Life*

For some customer set-ups, it would make sense to extend the life of the sleeve by using a copper ring. A typical copper ring is about twice as expensive as a typical nitride H13 ring, but the cost of a large and complicated sleeve can be as much as 50 times more than an H13 ring – so it makes sense to use copper to extend the longevity of the most expensive tooling. In addition, it takes less than a minute to replace a copper ring whereas, it takes 2 - 3 hours to replace a sleeve. After sleeve replacement, the die cast machine needs 3 - 4 slow velocity shots to warm up the sleeve. The savings are significant when sleeve set up time is considered.

### *Shot Sleeve Designs*

Large diameter shot sleeves require thermal regulation to reduce the amount of thermal distortion. The common approach is to gun-drill channels in the body of the sleeve. Gun-drilled sleeves work well, however, safety is a concern. Since, the channels are close to the bore of the sleeve and are under high temperature fluctuations and stress, they can become potential sites for cracks. The mixing of water/oil with molten aluminum can result in porosity in the casting and even cause explosions. Castool has successfully pioneered and implemented the **M-Loop** sleeve design. Figure 7 shows how the M-Loop design eliminates all the potential cracking sites. The water/oil is enclosed in a copper pipe embedded in the sleeve’s outer diameter surface. The design of M-Loop patterns on the sleeve is almost limitless – they can be full M-Loop, partial M-Loop or focused cooling at certain areas.

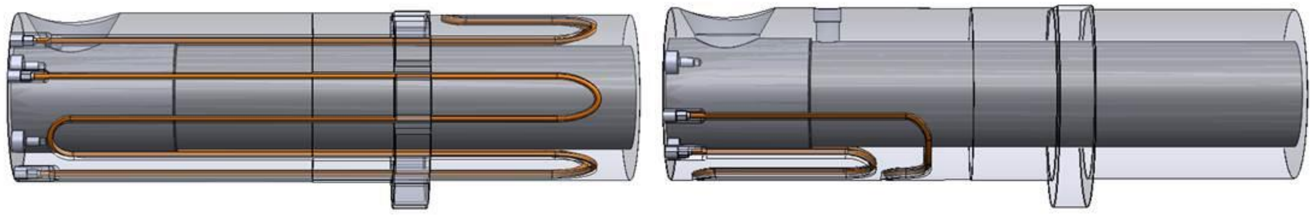


***Figure 7. Castool M-Loop sleeves***

The cost savings and functional modularity concepts also apply to shot sleeve design. The bore surface of sleeves, especially the area under the pour hole, is in contact with molten aluminum and receives constant wear. This requires high grade steel with high heat strength to counter these stresses. A replaceable insert under the pour hole area can save the cost of replacing the whole sleeve due to erosion under the pour hole only. A replaceable full length insert sleeve design can further combine the hot strength and wear of H13 with the superior toughness and thermal stability of a Con-Duct sleeve body. In addition, the long-term cost of a sleeve is substantially reduced by replacing only the insert.

A specialty hot-work tool steel is an excellent choice for shot sleeve applications. To address this, Castool has developed **Tuff-Temper**, which is tailored for high hot strength. Tuff-Temper has hot yield strength of 1144 MPa as opposed to H13 – which has hot yield strength of 1054MPa – at 430ºC. Therefore, Tuff-Temper provides better wear and erosion resistance than H13.

## SUMMARY

The best die casting results are assured only when all the components of plunger design work together. Choice of plunger tip and sleeve materials, the right design features, and careful consideration of clearance values are all critical parts of a system that leads to the optimum set up. Castool is leading the way, with innovative materials and game-changing design that brings their customers to the next level of die casting success!