

# Plunger System for Silafont

**Paul Robbins**  
Castool Tooling Systems  
Uxbridge, Ontario, Canada

Today, there is a tremendous interest in replacing structural steel with die casting structural aluminum alloys in order to reduce automotive weight and fuel consumption. The structural aluminum components are “thin-walled” and require high yield strength. Silafont-36™ structural aluminum alloy has almost three times the strength than the “as-cast” aluminum alloys with excellent elongations of 7-12%. These properties translate into improved crush resistance and 30% weight reduction. High pressure die casting structural aluminum such as Silafont is an inevitable movement for die casters; however, the aggressive chemistry, high casting temperature and zero porosity to die cast Silafont pose an enormous challenge. It becomes the biggest challenge and also the biggest opportunity for die casters. In order to lower the scrap rates and make HPDC structural aluminum an economic manufacturing process; a holistic system approach from plunger tips, shot sleeves, lubrications to vacuum components is required. No single component should be examined or evaluated in isolation.

## Plunger System

The market for larger light metal castings is increasing, this is especially true for structural castings. Larger and more complex castings require a plunger system with supreme thermal and dimensional stability for consistent shot velocity, low cycle time, minimal contamination and zero porosity. The gap between plunger tip and shot sleeve must be maintained

at less than 0.1mm at all times, otherwise aluminum will blow-by and cause excessive wear.

Unfortunately, the gap between the plunger and the shot sleeve never remains constant during casting. Figure 1 depicts the situation when the plunger tip is not thermally stable and the sleeve is not thermally regulated for a 165.1 mm sleeve. Typically for such a plunger system, a water jacket is implemented to assist biscuit cooling, because the conventional plunger is so hot.

At the beginning of the casting cycle the sleeve is very hot where the alloy is poured (left end), due to direct impact of molten aluminum. The plunger tip is comparatively cool at the beginning of the cycle. As the plunger moves toward the die end (right end), the tip becomes hotter since the plunger face is in direct contact with liquid aluminum. The die end sleeve is normally cooled as mentioned. If the initial clearance at the pour end is small enough to prevent penetration of the alloy past the tip of plunger, and the temperature of both plunger and short sleeve is not adequately controlled; the plunger may seize in the sleeve before reaching the end of the stroke. Figure 2 shows the uniform scorching marks due to the shot sleeve restricting the movement of the plunger at the die end. The water jacket (blue circular pattern) is clearly shown at 80°C.

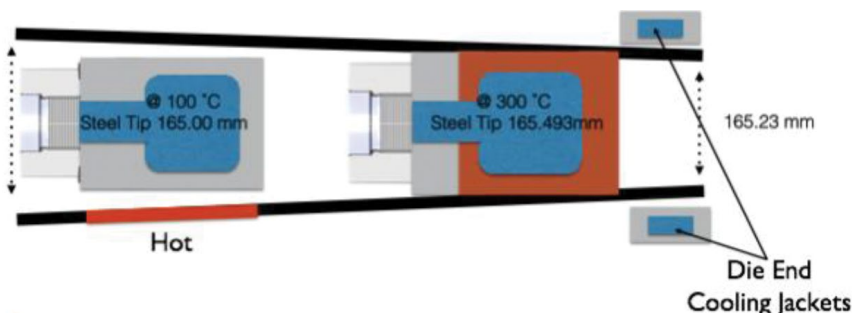


Figure 1 - The plunger tip over-expands and the sleeve contracts near the die end.

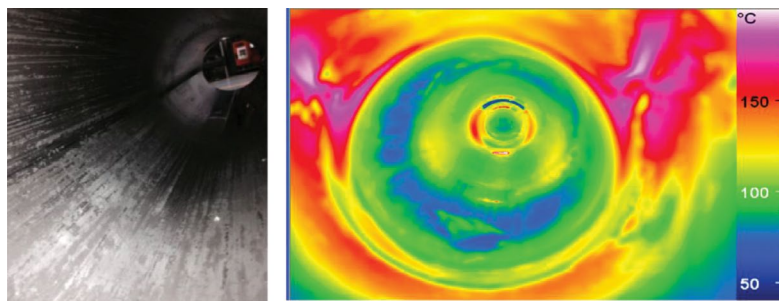


Figure 2 - Scorching marks due to plunger tip over-expanding and a cold sleeve at the die end.

## Plunger Tips

Castool Tooling Systems features a modular plunger tip (AMP-R) using forged ultra high strength and high thermal conductivity BeCu alloy with a plunger head and hot working steel wear split ring. The AMP-R plunger tip has excellent thermal and dimensional stability. The cost per casting is reduced since the consumable is the plunger head and split ring only. The specially designed stainless steel holder with coolant channels produces a high velocity turbulent flow of water passing the inner face of the holder. This achieves a maximum heat transfer and cooling effect. Figure 3 illustrates the temperature profile inside the plunger tip.

The following table lists the thermal conductivity of tips, final tip temperatures, thermal expansions and heat extraction of conventional steel tip and Castool AMP tip.

	Thermal Conductivity (W/m°C)	Tip Temperature (°C)	Thermal Expansion (mm)	Heat Extraction (W)
<b>Steel Tip</b>	25	349.9	0.3632	11203
<b>Castool AMP Tip</b>	150	115.4	0.1403	18720

The Castool AMP tip has 60% less thermal expansion and 65% better heat transfer than the conventional steel tip. The AMP tip is more dimensionally stable and capable of cooling the biscuit.

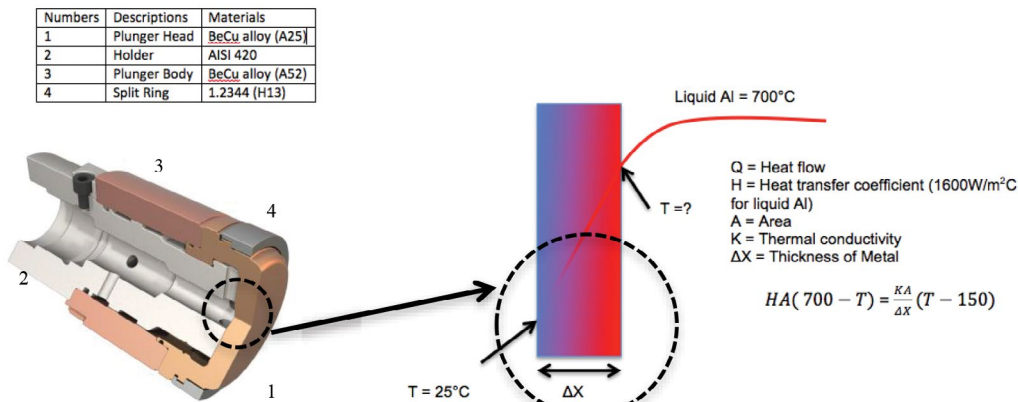


Figure 3 - Heat transfer calculation of a plunger tip.

Under pour spout 500°C and Top 176°C

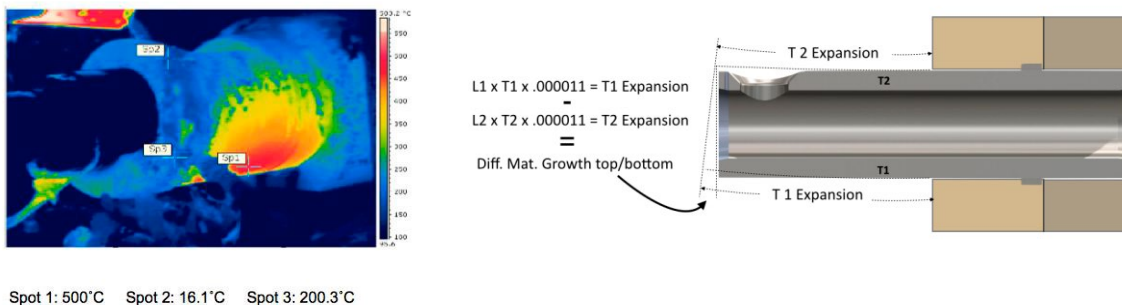


Figure 4 - Shot sleeve distortion due to unequal thermal expansion.

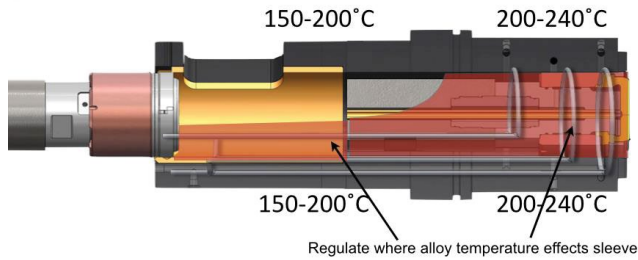
## Shot Sleeves

Regardless of the sleeve size, the maximum allowable gap, 0.1mm, must remain unchanged. The same increase in temperature of a six-inch shot sleeve will result in it expanding twice as much as a three-inch sleeve. The importance of precise temperature control on a larger diameter plunger tip and sleeve becomes paramount.

In a casting cycle, the area underneath the pour hole of the shot sleeve contacts hot liquid aluminum first, and directly. Typically, this area is much hotter than the top part of the sleeve, leading to unequal thermal expansion and shot sleeve distortion. Figure 4 shows a thermal image taken at a shot sleeve without proper thermal control.

The sleeve becomes slightly bowed rather than straight and oval instead of round, causing premature wear of both the tip and sleeve. A number of factors contribute to the temperature of sleeves and degree of distortion. These include casting weight, alloy temperature, fill ratio, cycle time, thickness of sleeve wall, length of sleeve and size of pour hole. To avoid too much variation in thermal expansion; a series of gun-drilled holes are positioned along the length of the shot sleeve under the pour spout, and are connected to another series of holes around the die end of the sleeve. The areas where the pouring alloy temperature impacts the sleeve can be regulated. Figure 5 represents the thermally regulated shot sleeve with optimal sleeve temperature.

Shot sleeve wear, and consequent replacement, can be an ongoing and costly problem for die casters. Many mistakenly assume that sleeve wear results primarily from the abrasive contact and wear of the plunger and shot sleeve; as a result of unequal thermal expansion. Actually, the opposite is true. If the temperatures of both the shot sleeve and the plunger



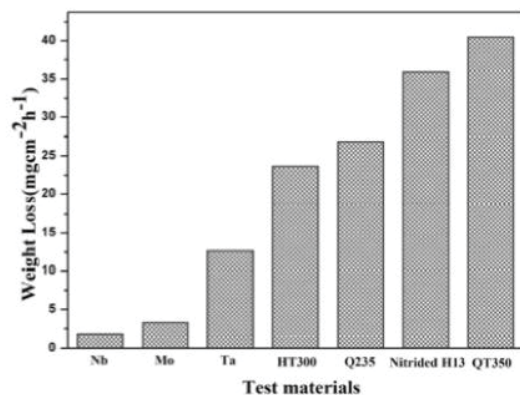
**Figure 5** - Thermally regulated shot with optimal sleeve temperature.

tip are not constantly and accurately controlled, the clearance may increase sufficiently to allow the aluminum alloy to penetrate the gap, where liquid aluminum dissolves into the shot sleeve and forms the  $Al_5Fe_2$  brittle intermetallic compound. The brittle compound breaks away by the movement of the plunger tip. The repeated formation and break of brittle compound results in the erosion of the shot sleeve.

Effectively managing the clearance between the plunger and the shot sleeve is a prerequisite for any successful light metal die casting system. Clearance problems can only be resolved by good design and thermal management.

## Shot Sleeve Washout

The surface temperature of the sleeve directly under the pour hole can reach as high as 680°C during pouring, especially true for Silafont alloys. Such a high temperature destroys the mechanical integrity of a sleeve. A typical hot working steel, H-13, has a working temperature at 585°C. The surface of an H-13 sleeve would erode at such high temperatures during pour. Castool works with steel manufacturers to produce modified W.Nr 1.2367M steel with high Molybdenum content. The addition of Molybdenum in low alloy steels improves high temperature strength and hardness. It resists the tendency of steel to decay in a high temperature environment. The modified W.Nr 1.2367 steel has working temperature up to 630°C. In addition, an experimental study shows molybdenum only loses 2mg/hr compare to H-13 loses 37mg/hr in liquid aluminum for 24hrs at 750°C. Figure 6 shows corrosion of H-13 and molybdenum alloy in liquid aluminum.

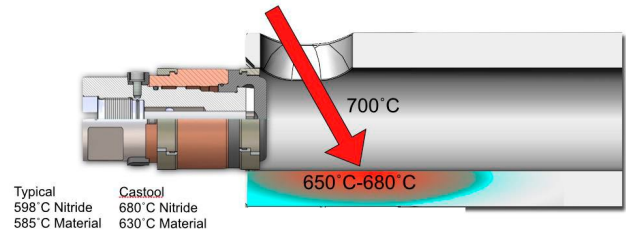


**Figure 6** - Corrosion of H-13 and molybdenum in liquid aluminum.

To further protect the underlying shot sleeve, a special nitride process is developed. This nitride layer is less brittle and stable up to 680°C. The combination of modified W. Nr. 1.2367M steel with special nitride layer will eliminate the issue of having pour

hole erosion in large structural casting. Figure 7 illustrates the thermal stabilities of different shot sleeves and iron nitrides.

With both the shot sleeve and the plunger tip thermally and therefore physically stabilized; an unusually extended operating life can be reasonably anticipated; providing the area of interaction completely and effectively lubricated.



**Figure 7** - Thermal stabilities of different shot sleeves and iron nitrides.

## The Split Rings

Copper is an ideal medium to dissipate heat from the plunger tip body to the cooling water. It is, however, not nearly as wear-resistant as the steel of the shot sleeve. Since the gap between tip and sleeve are stable and controlled; a flexible split wear ring of tempered steel floats freely in a groove machined near the front of the plunger tip, to ensure a secure seal with shot sleeve walls. It can easily be removed and replaced with a special hand tool. The ring expands to meet any changing diameter or contour of the shot sleeve and makes continuous contact with the inside of the shot sleeve. The flash or blowby is essentially eliminated. Shot velocities are smooth and consistent. Since the expanding ring ensures a secure seal between the plunger and the shot sleeve; a better-than-usual vacuum can be drawn.



**Figure 8** - Copper chill vents require no water cooling and no ejector pin.

## Chill Vents

In cold chamber die casting, the alloy is forced into the mold cavity with such force and velocity that small quantities of air and gases are often trapped in the casting. If the casting is structural, heat treated, or porosity sensitive, air or gas inclusions usually result in rejection. This impacts directly on the die caster's bottom line. In today's competitive market, this preventable problem is no longer acceptable.

A vacuum is drawn in both the shot sleeve and the mold cavity and maintained until the injection cycle is completed. Almost all of the air is positively evacuated from the mold. A good vacuum in the mold cavity



enables the alloy to flow into blind recesses in complex shapes. It also allows the front of the molten metal to merge freely. One of the biggest problems with vacuum is the downtime related to vacuum valve. Vacuum valve has many moving components and prone to component failure. The cost, downtime and maintenance make the use of vacuum valve prohibitive.

A properly designed copper chill vent with higher thermal conductivity has no moving part, requires no additional water-cooling and no ejector-pin. Figure 8 shows copper chill vent with no water cooling and ejector-pin. The venting section of chill vent can be as high as 150 mm<sup>2</sup>. Also 20-40,000 shots can be expected before maintenance is required. A problem that is shared by most die casters, is the unplanned downtime that occurs when casting must be discontinued before the scheduled production run has been completed.

## Lubrication

The primary purpose of the shot sleeve lubricant is to reduce the friction between the sleeve and the plunger in order to ensure the smooth passage of the plunger through the sleeve. This is essential for consistent shot velocities and to extend the operating life of both the shot sleeve and the plunger tip. The amount of lubricant used must be adequate, but care should be taken to avoid any excess. Lubrication should therefore be kept to an absolute minimum. Every effort must be made to eliminate the possibility of any non-metallic substance getting into the mold. Graphite-based lubricants, for example, can cause porosity in the casting. Lubricant should be applied

only where it is needed. Any excess lubricant is an unnecessary cost, and a workplace pollutant.

Boron Nitride is now universally accepted as the most effective lubricant available for the aluminum die casting industry. Its unmatched lubricity far exceeds that of traditionally used lubricants. It is also completely benign and produces non-toxic fumes.

For larger and longer sleeves, it is difficult to adequately lubricate the complete interior of the shot sleeve. This can be accomplished with a Lube System developed by Castool. A carefully measured amount of liquid boron nitride is applied between ring and sleeve. In addition, liquid boron nitride is sprayed to protect the impact zone right under the pour hole. This ensures complete coverage without costly overspray. A controlled dosage injection pump provides the precise amount of lubricant required for each process cycle. This controlled dosage prevents the danger of contaminating the casting with excessive lubricant.

## Summary

The issue of having a high scrap rate has proven to be greatly reduced and often completely eliminated by the adoption of a modular plunger, thermally controlled shot sleeves, an effective lubrication system and chill vents. Each contributes to an improvement in productivity. Combined, these interactive components combat a number of costly problems. The HPDC aluminum will be the biggest opportunity for die casters when a holistic plunger system is applied.



# Castool makes die casting better



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