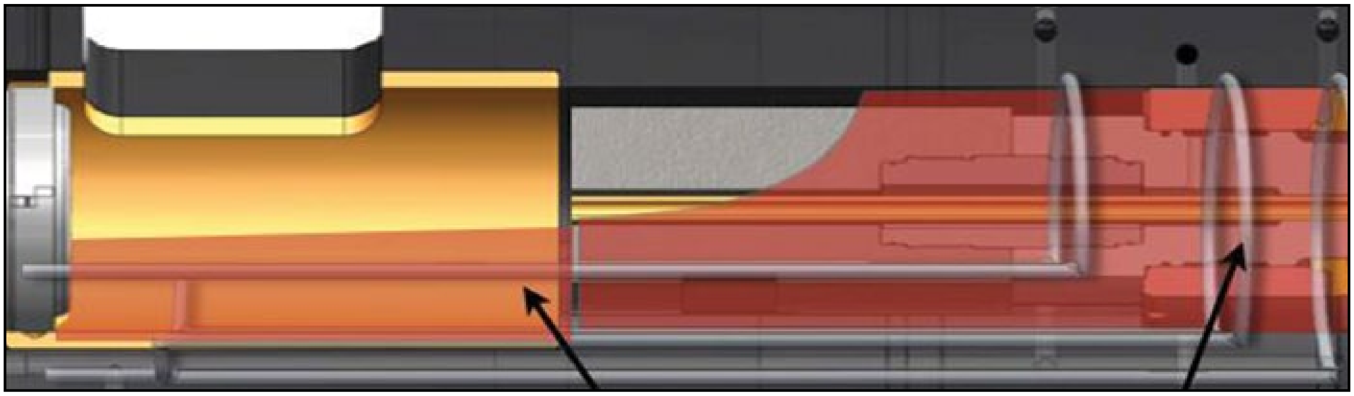

High Pressure Die Casting Structural Aluminum

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The high pressure die casting (HPDC) process is a very versatile process, and has been the default choice for high volume production for more than a century. HPDC aluminum alloy, however, only works with aluminum alloy having 1.3-2.0%wt iron content, because the iron helps the alloy to release from the die. It, therefore, reduces scrap rates and increases production volume. On the other hand, the iron hinders heat treatments of aluminum alloy and consequently its mechanical strength. The strength of the as-cast aluminum is only in the 100 MPa range, and after heat treating, the aluminum, in fact, would become brittle due to formation of Al_5FeSi needles. For this reason, HPDC aluminum is only for components where strength and impact toughness are not critical.

Today there is a tremendous interest in replacing structural steel with structural aluminum alloys; in order to reduce automotive weight and fuel consumption. The structural aluminum components are thin-walled and need to be heat treated (special T6 heat treatment) to improve the yield strength. Only aluminum alloys with zero porosity, and low iron content, less than 0.15%wt, can use such heat treatment. The T6 heat treatment can improve yield strength of aluminum from 100 MPa to 200 MPa, which equals 30% in weight reduction. One of the most popular structural aluminum alloy, Silafont™, can reach even higher yield strength, 280 MPa, after T6 heat treatment.

Silafont™ requires a 686°C casting temperature, which is 36°C higher than conventional alloys. In order to fill the mold cavity, which is usually larger than conventional ones, the pouring temperature needs to be as high as 700°C to prevent premature solidification.

The combination of large casting with long pouring time; high pouring temperature, thin-walled geometry and zero porosity, poses an enormous challenge for HPDC. Consequently, the scrap rates for structural aluminum could be as high as 80%, however, HPDC structural aluminum is an inevitable movement. 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 a lean 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 plunger system must provide consistent shot velocity, low cycle time, minimal contamination and zero porosity in castings. It is necessary for the plunger tip and shot sleeve to prevent the alloy from penetrating between the sleeve and plunger. The gap between plunger tip and shot sleeve must be less than 0.1mm at all times otherwise, aluminum will blowby and cause excessive wear.

Unfortunately, the gap between the plunger and the shot sleeve never remains constant during casting. At the beginning of the casting cycle the sleeve is very hot at the pour end, due to the fact that liquid aluminum directly impacts the sleeve. The heat transfer is at the maximum at that moment, and the plunger tip is comparatively cool. As the plunger moves toward the die end, the tip becomes hotter since the plunger face is in direct contact with liquid aluminum. The shot sleeve, on the other hand, becomes cold and shrinks near the die end as heat dissipates to the platen and die. The tip therefore expands while the shot sleeve contracts. 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 1 depicts the situation when the plunger tip is not thermally stable and the sleeve is not thermally regulated.

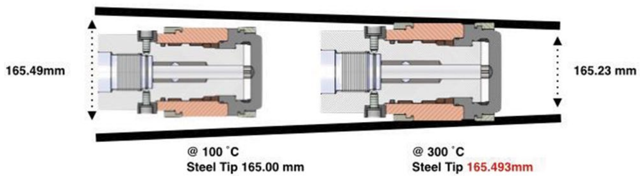

Figure 1 – The plunger tip over expands and sleeve contracts near die end.

Structural aluminum usually has a larger casting of 25 – 35kg and a higher pouring temperature 680°C – 700°C. The thermal expansion mismatch of plunger tip and shot sleeve definitely increases. This leads to severe wear and premature failure of both plunger tips and shot sleeves.

Plunger Tips

The market for larger light metal castings is increasing; this is especially true for structural aluminum. Larger castings require a plunger tip with supreme thermal and dimensional stability. Castool Tooling Systems features a modular plunger tip (AMP) using ultra high strength and high thermal conductivity BeCu alloy with excellent thermal and dimensional stability. The modular design enables the consumable and can be reduced to the plunger head only. The cost per casting is also reduced. The specially designed stainless steel holder with coolant channels produces a high velocity flow of water past the inner face of the holder. This achieves a maximum heat transfer and cooling effect. Figure 2 illustrates the situation with corresponding equation and data used to calculate the temperature of the tip surface.

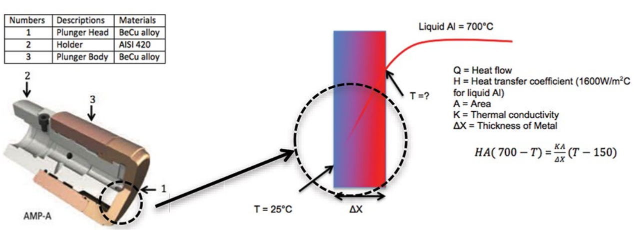

Figure 2 – Heat transfer calculation of a plunger tip.

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.

Table 1

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

Castool Tooling Systems provides a thermally and dimensionally stable plunger tip. The Castool's AMP tip is 60% less thermal expansion than the conventional steel tip. The Castool's AMP tip can extract heat 65% faster than conventional steel tip.

Shot Sleeves

The size of the shot sleeve is also increasing. Unfortunately, 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, for example, 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 3 shows a thermal image taken at a shot sleeve without proper thermal control.

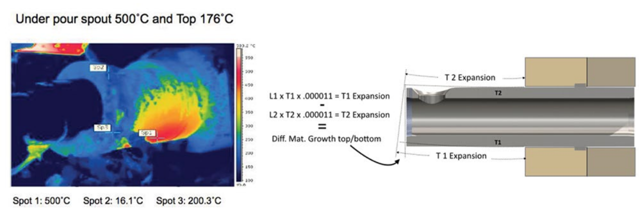

Figure 3 – Shot sleeve distortion due to unequal thermal expansion.

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 sleeve. The areas where the pouring alloy temperature impacts the sleeve the most can be regulated. Figure 4 represents the thermally regulated shot sleeve with optimal sleeve temperature.

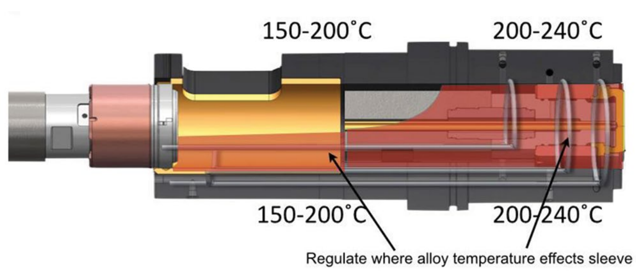

Figure 4 – Thermally regulated shot with optimal sleeve temperature.

Shot sleeve wear, and consequent replacement, can be an ongoing and costly problem for die casters. Many mistakenly assume that sleeve wear result primarily from the abrasive contact and wear of plunger and the 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 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 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 area under the pour hole is subjected to rapid temperature increase during the pouring period. With the recommended temperature for Silafont structural alloy, 700˚C, the surface temperature of sleeve can reach as high as 680˚C. At such a high temperature the mechanical integrity of sleeve is destroyed. A typical hot working steel, H13, has a working temperature at 585˚C. Castool works with steel manufacturers to produce modified DIN 1.2367 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 DIN 1.2367 steel has working temperature up to 630˚C. In an experimental study, it shows molybdenum only loses 2mg/hr compare to H13 loses 37mg/hr in liquid aluminum for 24hrs at 750˚C. Figure 5 shows corrosion of H13 and molybdenum ally in liquid aluminum.

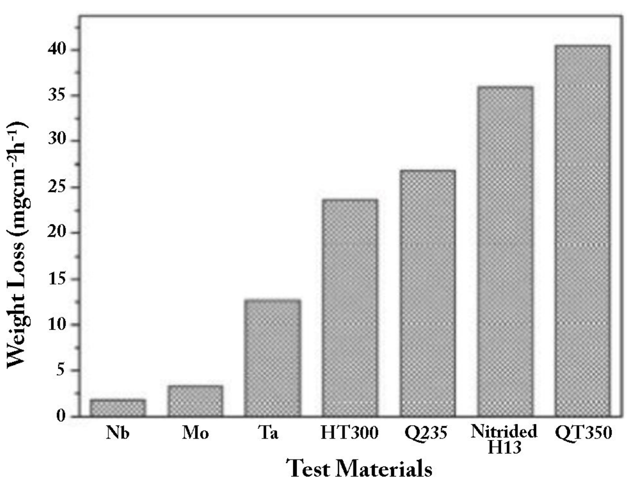

Figure 5 – Corrosion of H13 and molybdenum in liquid aluminum.

To further protect the underlying shot sleeve, a special white layer is developed. This special iron nitride white layer is less brittle and stable up to 680˚C. The combination of modified DIN 1.2367 steel with special iron nitride white layer will eliminate the issue of having pour hole erosion in large structural casting. Figure 6 illustrates the thermal stabilities of different shot sleeves and iron nitrides.

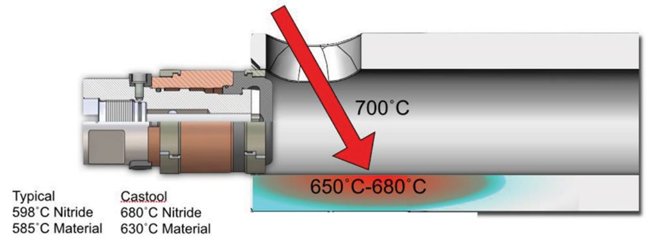

Figure 6 – Thermal stabilities of different shot sleeves and iron nitrides.

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.

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.

Lubrication

The primary purpose of the shot sleeve lubricant is to reduce the friction between the sleeve and the plunger; to thus 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 a shot sleeve. This can be accomplished with a Lube-Spray system developed by Castool. A carefully measured amount of liquid boron nitride is vaporized to form a fine mist. This is blown throughout the length of the shot sleeve, ensuring that the surface is completely and evenly coated with a thin film of lubricant. The lubricant spray and air nozzle assembly is securely mounted behind the pour hole of the shot sleeve. Spray pressure and duration are both adjustable. 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.

Vacuum

Before the injection shot occurs, a vacuum is drawn in both the shot sleeve and the mold cavity. The vacuum is 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. A properly designed chill vent with improved thermal conductivity can increase quality and reduce scrap due to porosity. 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.

Summary

The problem of high scrap rate has proven to be greatly reduced and often completely eliminated by the adoption of modular plunger, thermally controlled shot sleeves, an effective lubrication system and chill vent. Each contributes to improved 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.