Better Interaction — Key to Better Die Casting

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The Moment of Casting

The plunger, moving smoothly with a minimum of lubrication, pushes a measured amount of molten alloy through a round and straight shot sleeve and injects it into the die cavity, where it almost instantly hardens. In that moment when the liquid alloy is converted into a solid casting, most of the added value — the die caster's livelihood — is generated. This is the crux of the die casting process and may be fairly termed, "The moment of casting."

At one time, in the quest for increased productivity, the component of the die casting process that had the greatest potential for improvement was the die itself. Not all die casters realize that in recent years, this priority has changed considerably. With the use of 3-D computer modeling to predict the ideal flow of metal into the die and ultra-accurate multi-axis CNC machining to produce a die that can consistently make large convoluted castings with inordinately close tolerances, the die caster should now be able to assume that the dies being used are likely as good as they need to be. The best opportunity for improvement, therefore, now usually lies with the delivery of the alloy into the die. Analyzing the various forces that impact on the moment of casting, the die caster of today will soon realize that to even approach maximum productivity, the plunger and the shot sleeve must work closely together, since their functions are inseparably combined.

A Critical Interaction

The danger of exceeding a maximum allowable gap between the plunger tip and the shot sleeve has been understood by die casters for many years. The technology of both plunger tips and shot sleeves has improved appreciably in the interim. The parameters of the gap, however, remain unchanged. The interaction between the plunger tip and the shot sleeve is certainly the most critical in the die casting process. It can only be most effective, however, if both components are operating at an equal level of efficiency.

Also, an effective vacuum can only be achieved if the seal between plunger and shot sleeve remains intact at all times. If the seal is broken, an effective vacuum is obviously impossible. The challenge is to maintain a minimal gap without interference, while using the least amount of lubrication.

Maintaining the Gap

The maximum gap between the plunger tip and the shot sleeve during the casting process is 0.004″. If at any time during the shot the gap exceeds that, the alloy is likely to penetrate the space, and flash or blowby will occur. This will inevitably cause excessive wear on both plunger and sleeve.

It is essential, therefore, that a gap of less than 0.004″ be maintained at all times during the casting cycle. If the gap becomes much less than that, there is a danger of interference and inconsistent shot velocity. Scrap will result. The problem is that when metal is heated, it expands. The importance of controlling the temperature of both plunger tip and shot sleeve is shown by the fact that if the temperature of a 6-in. copper tip is allowed to rise by 200°F, the diameter will increase by more than 0.011″.

Shot sleeves are getting bigger, but whatever the size of the sleeve, that critical maximum gap of 0.004″ unfortunately remains unchanged.

Controlling the Plunger Tip Temperature

Plunger tips were originally made of steel, primarily for its durability and economy. A steel tip, of course, has the same coefficient of thermal expansion as the shot sleeve in which it slides. Since the plunger tip is exposed to more heat than the sleeve, the expansion of a steel tip is difficult to control very precisely. The next step in the development of the conventional plunger tip was to make it of beryllium copper, which has a coefficient of thermal expansion more than 50% greater than that of steel. This made the expansion of the tip much easier to control. It was then possible to maintain the thermal, and therefore the dimensional, stability of the tip throughout the length of the stroke.

Die casters usually reduce the temperature of their plunger tips with water. Excessive plunger tip expansion and wear is nearly always simply the result of insufficient coolant. Even experienced die casters sometimes neglect this.

Rate of flow is easily measured and should be monitored constantly. Maintaining an adequate flow of water is vital to controlling plunger tip expansion.

There are some proprietary cooling-intensive plunger tips that utilize the cooling water much more effectively than conventional tips.

The Evolution of a Plunger Tip

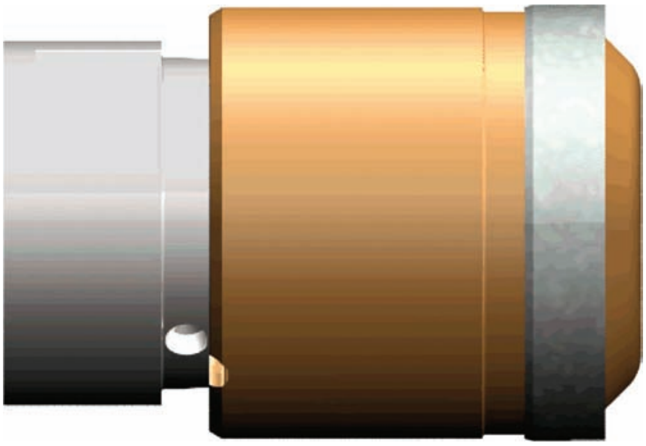

Figure 1 – The ARP Plunger Tip

The plunger tip in Figure 1 was developed a number of years ago by Allper of Switzerland. It has evolved over time in response to changing market demands, without compromising its original mandate of performing its function most effectively at the least cost to the die caster. The body of the plunger tip is of beryllium copper for its high coefficient of thermal expansion. A conventional plunger tip screws directly onto the hollow plunger rod. With the ARP, a stainless steel tip holder is screwed onto the shot rod, and the copper tip is securely fastened to it with a quick release bayonet type connector. The front of the steel holder lies in full contact with the inside face of the plunger tip and absorbs the total pressure of the shot. The face can then be very thin for better heat exchange.

The water flow is from the center of the shot rod, through the stainless holder, and directly to the inside face of the plunger tip where a turbulent flow is generated to maximize the heat transfer. It then goes through four channels to the circular external coolant return passage.

Beryllium copper is an ideal medium to dissipate heat from the plunger to the cooling water. It is, of course, not nearly as wear-resistant as the steel of the shot sleeve. Since the tip was then dimensionally stable and the gap controllable, this problem was resolved with the development of a steel wear ring. This tempered steel ring rests freely in a groove machined near the front of the plunger tip. It is split and expands against the inside wall of the shot sleeve. Only the ring wears — not the copper body. The wear ring is easily removed or installed with a special hand tool in about five minutes.

The die end of the shot sleeve is chamfered to compress the ring and guide it back into the sleeve. Because the ring is flexible, it makes continuous contact with the inside of the shot sleeve. Flash, which is a major cause of wear, is essentially eliminated. Shot speeds are consistent. Since the expanding wear ring ensures a secure seal between the plunger and the shot sleeve, a better vacuum can be drawn.

As only the long-lasting steel wear ring is replaced instead of an entire copper body, the cost of consumables is considerably reduced.

With a conventional tip, failure of the body is from wear. Failure of the ARP body is only from thermal and pressure fatigue. Operating life is therefore many times longer.

An additional advantage is that the face of the ARP is considerably cooler than that of other plunger tips. This cools the biscuit much faster and reduces the cycle time significantly.

This does not compromise compression, because since the wear ring remains relatively hot, while the face of the tip is much cooler, the outside of the biscuit tends to remain liquid slightly longer, allowing better than usual compression.

Die casters commonly attempt to reduce cycle time by cooling the die end of the shot sleeve. This unfortunately tends to shrink the sleeve at the point where the plunger tip is hottest and is likely at its greatest diameter.

A New High-Strength Plunger Tip

The ARP plunger tip has been successfully and profitably used for a number of years, but the market for aluminum castings is changing. Castings are required, especially in the automotive sector, to be larger, more complex and to have closer tolerances than ever before. They also require a faster rate of production than previously thought possible. Plunger tips used to seldom be larger than 6″. Now, 8″ tips and even larger are common.

The demands on the plunger tip, particularly in strength and stability, outgrew the replaceable wear ring plunger. This led to the development of the Allper high-strength AMP plunger tip.

This high-strength modular plunger tip was designed specifically for the production of large castings. The beryllium copper body is longer, and features a replaceable high-strength steel head.

Figure 2 – High-Strength AMP Tip

The challenge to the Allper R&D engineers was to develop a plunger tip that would remain relatively stable so as to consistently maintain the required gap with the shot sleeve, but also be strong enough to withstand extreme pressures, as well as the impact of a short shot if the plunger contacts the die. Their aim was to use as little copper as possible, primarily for the strength of steel and also for economy.

As with the ARP, a steel holder screws onto the plunger rod. The beryllium copper body with its steel head is similarly connected with a quick-release bayonet fastener.

With the AMP, after a considerable period of incremental redesign and field testing, the heat transfer to the coolant has become much more effective. The tip is more dimensionally stable, and thermal control is less dependent on the high coefficient of thermal expansion of copper.

Cycle times are reduced, as well as the cost of consumables. With experience, minimum operating life of wear rings and tip bodies can now be fairly accurately estimated, and downtime for replacement scheduled in advance so that production runs are never unexpectedly interrupted.

The AMP high-strength plunger tip responds to the demands of an increasing and changing market. It makes better castings.

Cooling the Shot Sleeve

Typically, a shot sleeve may become 200-300°F hotter at the bottom under the pour hole than at the top in front of the hole. If the temperature of the sleeve is much higher at the bottom than at the top, unequal expansion will cause it to become oval instead of round and slightly bowed rather than straight. Either of these conditions will cause premature wear of both tip and sleeve. The extent of ovality and distortion is directly related to both the diameter and length of the shot sleeve. To avoid too much variance in thermal expansion, the bottom of the shot sleeve should be cooled so that the difference in temperature, bottom to top, does not exceed 100°F.

Nearly all die casters cool their plunger tips. Effectively controlling shot sleeve temperatures, however, is a more difficult challenge.

Figure 3 – Water-Cooled Shot Sleeve

The pour end of the shot sleeve is where the temperature is highest. This is obviously where cooling is most necessary. Accordingly, another method of temperature control is the pour-end cooling jacket. This effective and economical device puts shot sleeve cooling where it is needed most, directly below the pour spout. The cooling jacket can also be reused when the sleeve is replaced.

If uncontrolled, the vertical temperature variance in the shot sleeve at the pour end will result in a distortion which may allow some of the alloy to enter part of the gap between the plunger and the sleeve. This will cause premature wear and inconsistent shot velocity.

As well, the alloy being poured into the sleeve is at about 1300°F, while the annealing temperature of H13, the usual shot sleeve material, is only 1085°F. If the shot sleeve is not adequately cooled, it will likely lose some of its hardness. Wear will then more quickly result from the abrasive action of any alloy that penetrates the gap.

Porosity and Vacuum

In cold chamber die casting of light metals, because of the turbulence of the alloy as it is forced at a high pressure into the die cavity and the complex shape of many casting molds, air and other gases are often trapped in the metal. This, of course, results in porosity in some parts of the casting.

If the casting is to be chromed, painted or powder-coated, or if any part of the casting is very thin, any air or gas inclusions usually result in rejection. Porosity also affects the mechanical properties of the product. In structural applications, porosity can act as a stress concentrator and, therefore, create a site where cracks may occur.

An additional problem is the fact that porosity in a casting may not always be immediately apparent. If discovered after subsequent processing, customer dissatisfaction can be extreme.

Porosity in the casting can be almost completely eliminated by an efficient vacuum system.

Vacuum-Assisted Casting

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 and quickly evacuated.

Figure 4 – A Contemporary Vacuum System

A good vacuum in the mold cavity enables the alloy to flow into blind recesses in complex shapes. It also allows the fronts of the molten metal to merge freely without forming shuts.

Whatever vacuum method is employed, if it works well, improved quality and reduced scrap can be guaranteed.

The principal benefit of vacuum is to eliminate porosity.

Product that is rejected is unusually costly to the die caster. For example, the value of the machine time that is lost while producing the rejected product can never be recovered.

Adding a vacuum system to the operating process benefits a die caster in several ways. First, it reduces his rate of rejection. Secondly, by lessening the force required on the plunger, it increases the life of almost all components of the DCM. But most importantly, by allowing the die caster to produce thinner, stronger and more complex castings, it makes it possible for him to participate in a fast growing market sector which would otherwise be denied.

For Better Die Casting

The market for light metal die castings continues to grow. Castings are becoming bigger, more complex and better in every way. Technology is keeping pace with the changing market, but castings are still made by die casters, not just by machines, and the die caster's basic approach to the production process is now more important than ever.

For better die casting, the effectiveness of interacting components should never be considered individually, but always together. Die casting is, in fact, a process that can only improve when all parts work together as a system.

The most obvious interaction is between the plunger and the shot sleeve, but vacuum is becoming increasingly essential, and it requires an effective plunger-shot sleeve function. All three components are therefore connected and form part of the overall system.

Experience has proved that always considering the casting process to be a unified system, rather than merely a group of disparate components, virtually assures increased productivity.

About the Author

Paul Robbins, general manager of Castool Tooling Systems, has been in the light metal die casting industry for nearly 30 years. After earning a postgraduate degree from the Schulich School of Business, he joined his father, a Toronto tool maker who made high quality die casting molds. Robbins is a recognized authority on light metal die casting. He has had many articles published in industry magazines and has presented numerous technical papers at conferences both in the U.S. and abroad.