Extending Life of Shot Sleeves in
Demanding Die Casting Applications

D. Schwam
Case Western Reserve University, Cleveland, OH

D. Bell
Phygen, Minneapolis, MN

ABSTRACT

As new, low-iron aluminum alloys are making inroads into die casting of parts for structural applications, the demands on shot sleeves are increasing, especially accelerated washout under the pour hole. This paper describes a few methods of extending shot sleeve life. Application of an AlCrN coating on the ID has promise as a relatively simple method to improve performance of shot sleeves. This coating has been extensively evaluated under laboratory condition with the rotating pin experiment. The results, especially the long-term washout protection it provides to H13 pins have been very favorable, often reducing washout by an order of magnitude. This AlCrN coating was applied on the area across from the pour hole of a H13 shot sleeve and evaluated in production. Another approach to extend life of shot sleeves is to clad the ID with a layer of washout resistant alloy. Performance of shot sleeves cladded with a maraging steel and Daido DHW is described.

INTRODUCTION

While simple in design, the shot sleeve plays a key role in the die casting process. Molten metal is poured into the shot sleeve through a poring hole, as illustrated in Figure 1. A plunger tip then moves along the shot sleeve to inject the molten metal into the cavity.

![Figure 1: Shot sleeve configuration used for accelerated performance evaluation](image)

The OD of the plunger tip is machined to tightly fit the ID of the shot sleeve. If the tolerance at operating temperature is not sufficiently tight, molten metal will wedge between the plunger tip and the shot sleeve and damage both. In most cases, shot
sleeves are removed from service because of excessive damage under the pouring hole. This area is usually exposed to impingement of the hot molten metal being poured by a ladle from above the shot sleeve. This leads to an accelerated reaction of molten aluminum with the steel, with formation of brittle intermetallic compounds. The intermetallics spall off the surface leaving behind a depressed zone that grows in depth and area over time. Efforts to slow down this washout effect under the pouring hole have met so far with partial success. Figure 2 illustrates the progression in washout damage under the pouring hole of a nitrided shots sleeve (1) similar to the one shown in Figure 1.

APPLICATION OF AN ALCRN COATING UNDER THE POURING HOLE OF THE SHOT SLEEVE

Phygen developed its patented Arc Plasma Acceleration (APA) process to deposit what has become known as FortiPhy, a general purpose CrN coating widely used in many industries including die casting and then recently CertiPhy (AlCrN) coating for the most demanding applications. This unique process improves upon traditional PVD methods to produce a very uniform coating layer (see Figure 3), with exceptionally high adhesion and high coating density. One of the most critical improvements over other coatings is a drastic reduction in the number and size of macroparticles (see Figure 4), a common but highly undesirable byproduct of cathodic arc evaporation process. Macroparticles form when unwanted droplets of liquid metal splashed from the arc source land on the substrate during coating growth. They compromise the integrity of the layer and are the main reason that many other arc PVD coatings have poor corrosion resistance.
Figure 3: Cross section of FortiPhy coating on a steel substrate

Figure 4: Coating surface appearance for FortiPhy (left) vs traditional cathodic arc PVD CrN (right) coating with white microparticle inclusions and dark pores of various sizes.

With the patented Phygen APA technique, the coating growth can be controlled independently by both the intensity of ion bombardment (through the plasma density) and the energy of arriving particles (through the substrate bias potential). During
the coating growth, adding a lot of energy to the surface without knocking away too many of the atoms on the surface is desirable. Therefore, the key is to ensure that a large number of ions are bombarding the surface with a velocity in a specific range. By tuning that range, crystalline configurations with weaker bonding can be eliminated while preserving the strongest bonds and thus promoting their formation. This phenomenon results in preferential growth of dense and highly textured coatings with the highest possible bonding strength. This is believed to be one of the major contributing factors that lead to the superior mechanical properties (i.e., high toughness) of the Arc Plasma Accelerator-produced coatings as compared to any other conventional PVD process.

The intense bombardment also promotes metallurgical bonds between the substrate and the coating, which leads to superior adhesion strength. One illustration of CertiPhy AlCrN excellent adhesion is shown in the micrograph of Figure 5 below. A Vickers indenter has been used to apply force to the cross-section of a coated pin, right at the outer edge. Despite the deformation under the indenter at stresses as high as 10 GPa, the coating’s bond to the surface remains intact.

Figure 5: An indent from a Vickers diamond indenter applied stresses as high as 10 GPa to the interface area between the substrate and the CertiPhy Plus coating. There was no loss of adhesion or cracking in the interface.
The AlCrN coating has demonstrated superior resistance to washout damage and is a strong candidate to protect the ID of shot sleeves from reacting with molten aluminum. Since the application of the coating requires a line of sight, the approach is to apply it through the pouring hole. Preliminary experiments were conducted with the rotating pin set-up for evaluation of washout. The set-up includes a resistance furnace with a SiC crucible for melting aluminum alloys. A rotating pin is attached to a bench drill and lowered into the molten aluminum for a pre-determined exposure time. The set-up is illustrated in Figure 6. The molten low-iron 356 alloy was held at 1,380°F. The pins were rotated at 590 RPM.

Two 5/8” dia. H13 ground pins (30-35HRC) were provided to Phygen for coating with a 5μm thick CrAlN coating. The coated pins are shown in Figure 7. The head of the pins was removed before the testing.
For comparison, an uncoated 5/8” H13 pin was also tested for one hour and is shown in figure 8 (top) after the test. While the uncoated H13 lost almost half of the diameter due to washout of the steel, the AlCrN coated pin is still intact.

![Uncoated H13 and AlCrN-coated specimen](image)

**Figure 8:** (a) Uncoated H13 (top) and AlCrN-coated specimen (bottom) after one hour rotation in molten low-iron 356

**EVALUATION OF THE COATING IN PRODUCTION**

The area under the pouring hole of a new H13 shot sleeve was coated with the CrN coating as illustrated in Figure 9. The shot sleeve was placed in production of a 390 die cast part and was performing well until the time of this writing, having logged 10,790 shots w/o visible damage to the ID.

![CrN-coated shot sleeve](image)

**Figure 9:** CrN-coated shot sleeve

**CLADDING OF THE SHOT SLEEVE ID WITH A WASHOUT RESISTANT ALLOY**

Another approach to extending life of shot sleeves is to clad the ID with a washout resistant alloy. The cladding can be done on new or worn-out shot sleeves. It requires machining the ID of the shots sleeve 1/8” or so undersize, to allow for the thickness of the cladded layer. Finish machining is performed after cladding. The cladding was performed with a Bore Repair system illustrated in Figure 10. This is a simple setup that allows the welding torch to be moved axially while the shot sleeve is being rotated. The axial motion of the torch is controlled, yielding a nice, regular welding as illustrated in Figure 11. Two H13 shots sleeve were cladded, one with a 18% Maraging steel, and the second with a Daido DHW wire. The composition of the wires is shown in Table 1.
Table 1: Composition of the wires used for cladding the ID of shot sleeves

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Co</th>
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<td>0.4</td>
<td>-</td>
<td>5.2</td>
<td>1.2</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>18% Maraging steel</td>
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<td>-</td>
<td>-</td>
<td>18.5</td>
<td>-</td>
<td>4.8</td>
<td>-</td>
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<tr>
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<td>1.0</td>
<td>0.4</td>
<td>-</td>
<td>5.3</td>
<td>1.2</td>
<td>1.0</td>
<td>-</td>
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Figure 10: Bore Repair Systems linear welded for cladding shot sleeves

Figure 11: View of the cladded ID of a shot sleeve before machining

EVALUATION OF THE CLADDED SHOT SLEEVES IN PRODUCTION

The Maraging cladded shot sleeve was evaluated in production of 390 die cast parts at General Die Casters. It made 50,584 shots vs. ca. 75,000 for a new shot sleeves casting 390 alloy. The DHW was still under evaluation at the time of this writing.
ACKNOWLEDGMENTS

The support of Advanced Products Corp. and Bore Repair Systems with cladding and machining the shot sleeves is acknowledged. Daido Steel and International Mold provided in-kind welding wire for cladding. General Die Casters performed the in-plant evaluation of the shot sleeves. This study was coordinated by NADCA. The support and guidance of the Die Material Committee and Mr. Stephen Udvardy, Director of R&D are gratefully acknowledged.

REFERENCES

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