Preventing Soldering using High Quality PVD Coatings

Part 1: Factors Affecting Soldering

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Soldering occurs when a die casting alloy sticks (or solders) to the die, forming a solid bond between the casting and the die that must be broken when the casting is ejected from the die. Soldering is a problem for all die casting alloys, but is worst for aluminum alloys. Bonding between the aluminum alloy and the steel die occurs when the molten metal, hitting the die surface at high velocity, removes the lubricant and oxide layers, allowing a reaction to occur that produces aluminum-iron compounds.[1]

Soldering produces a defect on the surface of the casting, and a small amount of aluminum remains adhered to the surface of the die (Figure 1). The aluminum remaining on the die represents a location where additional soldering can occur on subsequent shots, and so soldering tends to continue until the soldered aluminum is physically removed from the surface of the die (normally by stoning), or a replacement die component is produced. Soldering can be a huge problem for many die casters, and casters often expend a large effort to minimize soldering for a number of their dies.

Figure 1 *– Solder on the surface of a core pin.*

Soldering occurs when the surface of a die component gets too hot, and commonly occurs on dies with long, thin cores and/or small die inserts. Cooling of such cores can be difficult, as a large amount of heat is transferred into the core from the solidifying metal surrounding the core, and all of that heat must be extracted through the small cross-section at the core base. One common method that die casters use to solve this problem is to heavily spray the core, but this approach creates additional problems, including the application of too much lube (which can increase porosity) and the over-cooling of the surrounding die faces, potentially leaving liquid water on the die surface that again can create problems with porosity.

A better solution is to apply a PVD coating to the surface of the core or to the insert. This paper is the first of a series of two papers summarizing test results that show that PVD coatings can significantly reduce soldering in the die casting process, but also demonstrating that, to maximize the life of the coating, it is important that the PVD coating be of extremely high quality. In this first paper, the soldering mechanisms proposed by several researchers are summarized, and factors that control the life of the PVD coatings are described. The second paper in this series will describe both the quality and economic benefits of using PVD coatings on die casting dies.

Soldering Mechanism

Several researchers have examined the mechanisms responsible for soldering. Han and Viswanathan[2] have shown that soldering occurs due to a reaction between the molten metal and die steel, and found that the die has to be above a critical temperature (Tc) for the soldering to occur. This confirms a fact well-known by die casters, that keeping the die cool is important for preventing soldering. NADCA's book on thermal design[3] presents procedures that die designers and casting engineers should use to control the temperatures of their dies, but for certain configurations, the application of adequate cooling can be difficult. For example, Figures 2a and 2b reproduce information from the NADCA literature showing the results from mold filling simulations, indicating that the surfaces of cores can become extremely hot during the die casting process. The mechanism suggested by Han and Viswanathan[2] indicates that soldering can initiate at these extremely hot locations. This is especially true as the diameter of the cores decreases, or their length increases.

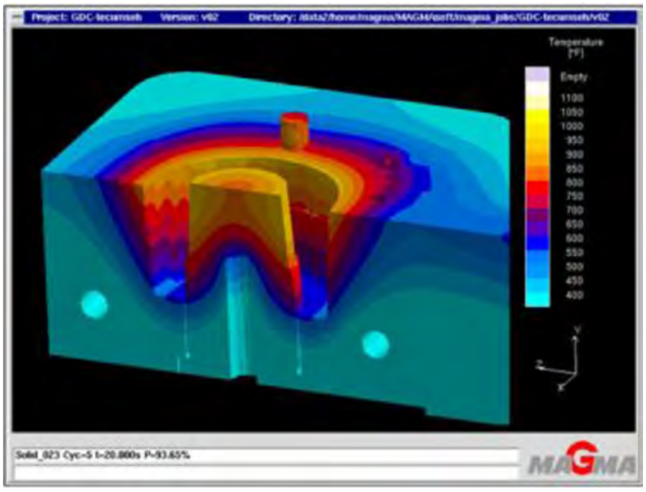

Figure 2a *– Simulation showing the temperature of a core 20 seconds after the die was opened.*[4]

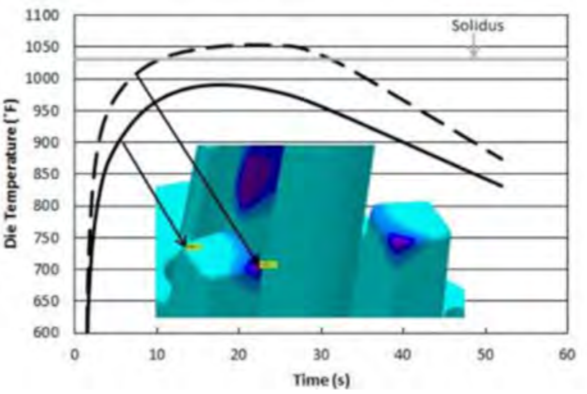

Figure 2b *– Plot of die surface temperature against time, showing that the surface of the core reaches a temperature of >1050°F.*[5]

To prevent soldering from occurring, Han and Viswanathan[2] reported that, if it is not possible to keep the tool temperature cool, an alternate approach to avoid soldering is to apply a coating to the surface of the die, as a coating will physically separate the liquid metal from the H13 die steel, preventing the chemical reaction from occurring. This was confirmed by research performed by David Schwam and Jack Wallace at Case Western Reserve University in 2008,[6] where they showed that PVD coatings significantly minimized soldering during die casting. More recent research has also confirmed the effectiveness of using PVD coatings. For example, Schwam provided a rather dramatic illustration of the benefits of PVD coatings[7] when he rotated H13 steel core pins in a bath of molten aluminum alloy, and as shown in Figure 3, a bare (un-coated) pin was nearly fully dissolved after only one hour in the molten alloy. However, a similar pin with an AlCrN PVD coating exhibited essentially no reaction after the same time in the molten aluminum. This remarkable demonstration shows the usefulness of PVD coatings for preventing soldering and reaction between steel die components and aluminum die casting alloys.

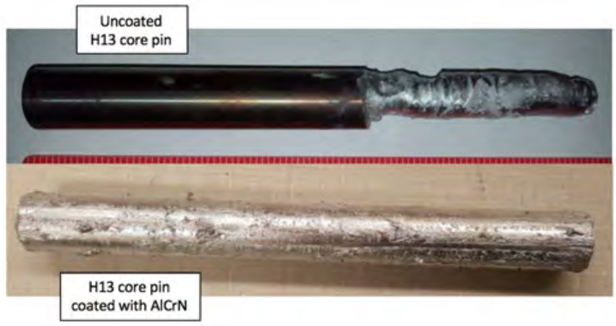

Figure 3 *– Results of a test showing the impact of rotating a steel core pin in molten aluminum. Upper, un-coated H13 pin; lower, pin with an AlCrN coating.*[7]

Why Pick Phygen PVD Coatings?

Clearly selecting a PVD coating that will last a long time is commercially important for die casters. Research at Case Western Reserve University indicated that the quality of the coatings is a major factor controlling how long the coatings will survive.[6] Experimental studies at Purdue University[8] confirmed that failure of PVD coatings typically initiates at defects in the coatings, such as non-uniform areas (such as macro-particles), microcracks in the coating, and areas not well adhered to the steel substrate. Figure 4 shows some examples of initial coating failures, and the Purdue researchers showed that once failure has started, the molten aluminum can directly contact the H13 steel beneath the coating, forming a pit that further damages the integrity of the coating, allowing more of the coating to detach from the substrate. In this manner, once failure of the coating has initiated, it will quickly detach from the steel substrate, allowing soldering will start. Therefore, when purchasing PVD coatings it is important to choose a supplier that can provide extremely high quality coatings to maximize life.

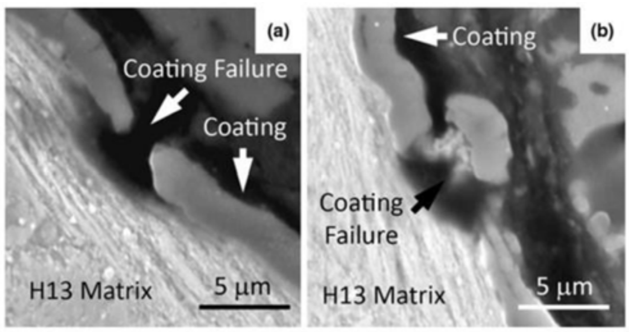

Figure 4 *– SEM images illustrating failure in PVD coatings.*[8]

Phygen has developed a proprietary PVD coating process that produces extremely high quality coatings. Called the Arc Plasma Acceleration (APA) process, it utilizes a magnetic field generator that creates a magnetic field with a distinctive cusp shape, so that the plasma density and deposition rate is higher per unit of magnetic field strength than can be obtained with conventional designs. A key to the process is to ensure that a large number of ions are bombarding the substrate with a velocity in a specific range, and by tuning that range, crystalline configurations with weaker bonding can be minimized while preserving the strongest bonds. This phenomenon results in growth of a dense and highly textured coating, having an excellent metallurgical bond to the substrate. In addition, Phygen's APA process minimizes the volume fraction of macro-particles that produce defects commonly found in coatings produced by conventional PVD processes.

The US Army recently reported on a study to evaluate the quality of Phygen's coatings.[9] Measurements performed by Chris Mulligan and his co-workers at the U.S. Army Armament Research and Development Center at the Benét Laboratories confirmed that the quality of Phygen's coatings is appreciably higher than conventional PVD coating processes.[9] For example, Table 1 shows data measured by the US Army, demonstrating that the number of harmful macro-particles (that can initiate coating failure) is significantly lower in Phygen's coatings, as compared with competing PVD processes. Testing by the US Army proved that Phygen's coating out-performed eleven coatings produced by a range of processes, leading the US Army to choose Phygen for the coating of the spindle for their M777A2 howitzer. Officials at the Picatinny Arsenal have estimated that use of the Phygen coating will realize a $5 million saving over the life of the howitzer.[10] Translating these results to die casting, based on the research performed at Purdue University,[8] it is likely that the low defect content of Phygen's coatings will also extend life for Phygen's coatings applied to die casting dies.

Table 1 *- Comparison of macro-particles in Phygen's coatings and typical PVD coatings produced by Cathodic Arc.*[9]

Defect	Phygen's Coating	Typical PVD Coating
Average micro-particle size	0.67µm	2 to 16 times higher
Macroparticle density	$3.5 \times 10^3/mm^2$	4 to 8 times higher

Phygen has several PVD coating compositions that can be used for die casting (CrN, AlCrN), but the optimum coating for die casting applications is the CertiPhy Plus coating, which consists of an initial ion nitride layer covered by 3-6 µm of AlCrN. Engineers at Mercury Castings have demonstrated the benefits of applying Phygen's PVD coatings to die casting cores.[11] Mercury was experiencing severe soldering to a long core used in the production of driveshaft housing (Figure 5), which often resulted in bending of the entire casting during ejection. To solve the soldering issue, Mercury coated the cores with Phygen's CertiPhy Plus AlCrN coating, which solved the soldering problem (see upper core in Figure 6).

Figure 5 *- Solder build-up on un-coated core.*[11]

Figure 6 *- Comparative photo of two slide inserts after 1,256 shots. The upper insert was treated with CertiPhy Plus and shows no soldering, while the lower (soldered) insert was un-coated.*[11]

Summary

So, in summary, PVD coatings can help minimize soldering for those regions of a die casting die that are difficult to cool, and can become excessively hot during the die casting operation. However, as defects will cause a coating to quickly fail, it is important that die casters choose a process that can produce extremely high quality coatings. Research performed by the US Army has demonstrated that Phygen's proprietary PVD coating process can produce extremely high quality coatings with low defect contents, and so is an excellent choice for die casting applications.

A second paper in this series will provide case stories demonstrating the performance of PVD coatings in die casting applications, describing extension of die life, together with cost savings associated with reduced part finishing and lower die maintenance costs.

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