Minimizing Soldering Using High Quality PVD Coatings

Part 2: Performance of PVD Coatings in Casting Plants

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Introduction

A recent paper in the Die Casting Engineer(1) summarized mechanisms responsible for soldering in die casting applications, showing that soldering commonly occurs with inserts and cores that are difficult to cool, and so become extremely hot during the die casting operation. That paper also described how PVD coatings applied to die components can minimize or eliminate soldering by providing a physical barrier that prevents the molten die cast alloy from contacting the steel die. However, defects in the coatings will cause the coating to quickly fail(2) making it important to choose a supplier that produces high quality coatings. Without consistently sound coatings, consistent die casting performance cannot be achieved. Research performed by the U.S. Army recently demonstrated that Phygen's proprietary PVD coating process can produce extremely high quality coatings with low defect contents(3).

This paper will describe practical applications of Phygen's PVD coatings at the Mercury Castings facility in Fond du Lac, WI, showing examples of coated die inserts and cores where die performance has been significantly enhanced. In addition, an update will be provided on the performance of a die where all the surfaces contacted by the liquid aluminum were covered with a PVD coating(4,5), summarizing process improvements and estimating cost savings associated with using the coating.

Mercury Castings

The Mercury Castings plant in Fond du Lac, WI has 29 die casting machines, ranging in size from 650 tons to 4,500 tons. Mercury produces aluminum die castings both for in-house marine propulsion applications, as well as for non-marine customers. Every die is given some form of surface treatment, with about 60% utilizing PVD coated cores and/or die inserts. Approximately 90-95% of all Mercury's PVD coating is done by Phygen, as Mercury uses Phygen PVD coatings as the benchmark for all surface treatments and considers these coating as the standard to significantly reduce soldering in critical areas of die casting dies. Typical candidate inserts are adjacent to gates, long cores, and in difficult to cool areas. Both CertiPhy Plus and FortiPhy Plus coatings from Phygen have been demonstrated as valuable. Details of these coatings are listed in Table 1, and both are duplex in nature, consisting of an initial ion nitrided layer covered by the PVD coating.

***Table 1** – Information on Phygen coatings.*

Coating	FortiPhy Plus	CertiPhy Plus
Chemical Composition	CrN	AlCrN
Plasma ion nitrided intermediate layer	Yes	Yes
Typical coating thickness	3 to 6 µm	3 to 6 µm
Nanoindentation Hardness, (GPa)	23-27	31-35
Maximum operation temperature based on oxidation resistance	825-875°C	~950°C

Phygen's coatings are reliable in nature, providing excellent coating-to-coating consistency. The coatings never have to be reapplied and are considered permanent. Below are some extremely successful applications of Phygen's PVD coatings on cores and cavity inserts at Mercury Castings.

Figure 1 shows two core inserts for bearing carriers. Both have FortiPhy Plus PVD coatings. The core on the left is shown after approximately 10,000 shots, while the core on the right is shown after 13,800 shots, and both photographs were taken directly following a casting run, before any maintenance work was performed. This application is aggravated by the fact that the liquid aluminum is gated directly onto the cores. The gate location can be seen in Figure 1a, and the dark lines on both cores show the position where the liquid aluminum impinges onto the cores. In addition, the castings are produced using a low-iron Mercalloy structural aluminum alloy. Experience at Mercury has shown that without a PVD coating, soldering will occur extremely quickly in this application, and un-coated inserts will be quickly stuck, soldered and/or eroded, causing extreme drag marks long before these shot counts.

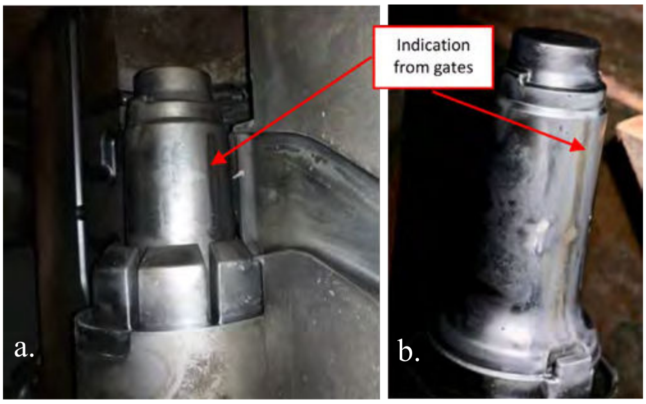

***Figure 1** – Core inserts for bearing carrier (photographs by Phygen).*

Figure 2 shows a rod well insert for a 4-cylinder engine block coated with Phygen's FortiPhy Plus. The casting requirements allow for little heat checking. Un-coated inserts have a short life because they see both high metal velocity and high temperatures. Phygen coated inserts resist soldering and delay the onset of heat checking. The result is improved insert life, reduced machine downtime, and minimized risk of quality issues related to the die components.

Figure 2 *- Cavity insert for rod well for Mercury 4-cylinder engine blocks (photograph by Phygen).*

Figure 3a shows the cores used to produce gearcases, and this slide historically has needed extra lubricants from the operators to avoid soldering, dragging and sticking. The advantages of the coating can be seen best near the gates (see Figure 3a). The use of Phygen's FortiPhy Plus PVD coating on all of the inserts was a big step towards the automation of gearcases, as it eliminated the need for added operator intervention related to spray and wax. Note that some soldering still occurs, especially on the long inserts adjacent to heavy sections, as these inserts do not have sufficient cooling. Combining PVD coating with conformally cooled additively manufactured inserts shows great promise in early continuous improvement projects.

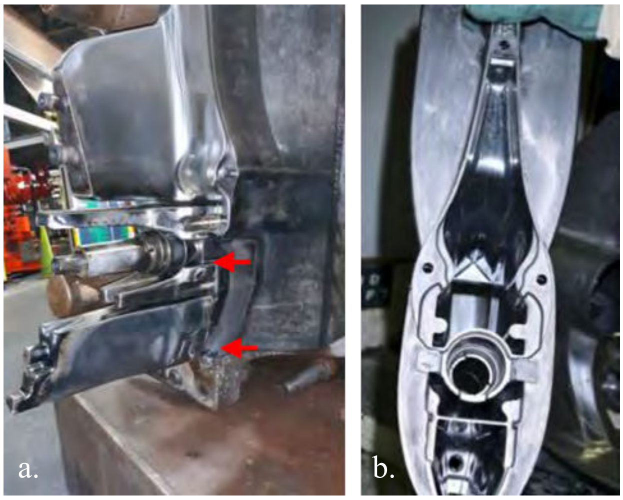

Figure 3 *- Outboard gearcases:*
a) Photograph of the PVD coated core (red arrows show gate locations and indicate metal flow direction).
b) Photograph showing the excellent surface finish on the casting (photograph by Phygen).

Reduced Lube on Balance Shaft Housing Die

Papers presented at the 2016 and 2017 NADCA Congress[4,5] documented the results of a plant trial performed at Mercury Castings where the entire cavity for a balance shaft housing component was covered with Phygen's AlCrN CertiPhy Plus PVD coating, with the goal of eliminating the use of die spray. Figure 4 shows a model of the balance shaft housing, which weighs about 1¾ lbs, and is produced in a 700-ton machine. The die is shown in Figure 5. For the fixed side, the runner, cavity, overflows and chill block (not shown) were coated, while for the moving side the shot block, runners, cavity, overflows, and chill block were all coated.

These balance shaft housings have been produced for a number of years, and data is available on castings previously produced in un-coated dies, to allow direct comparison with performance of the coated die. Although the AlCrN coating was not successful in totally eliminating die spray, it was possible to significantly reduce the amount of spray applied to the die. Overall, the following improvements were reported for the coated die[5]:

- Die spray time was reduced by 85%
- Cycle rate was increased by 12%, as the time required for spraying the un-coated die was significantly reduced in the cycle
- Testing showed that the internal quality of the castings appeared to be higher (less entrapped gasses)
- Although only 16,000 shots had been produced at the time of the 2017 paper[5], the overall heat checking resistance appeared to be improved

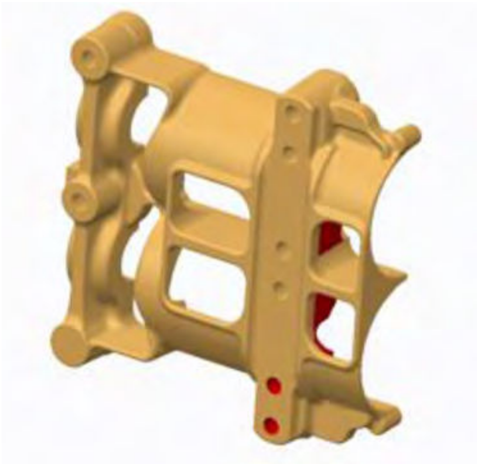

***Figure 4** – Model of the balance shift housing.*

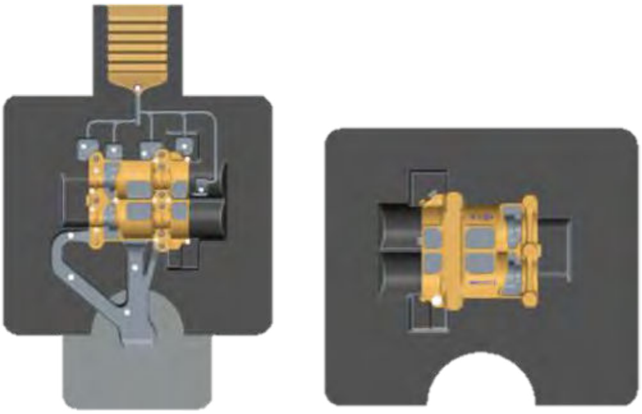

***Figure 5** – Models of the die used to produce the balance shaft housing. All die faces contacted by the liquid aluminum were coated.*

The use of PVD coatings should be expected to provide an extension in die life, not necessarily from the PVD coating itself, but due to the 85% reduction in die spray. In a paper published in 2007(6), Prof. Jack Wallace and co-workers used the Case Western Reserve University dunk tester to examine the impact of die spray on heat checking. As shown in Figure 6, they reported that the amount of heat checking decreased significantly when the spray time was reduced from 13 seconds to 3 seconds. In fact, no heat checking was observed in their dunk samples when zero spray was applied.

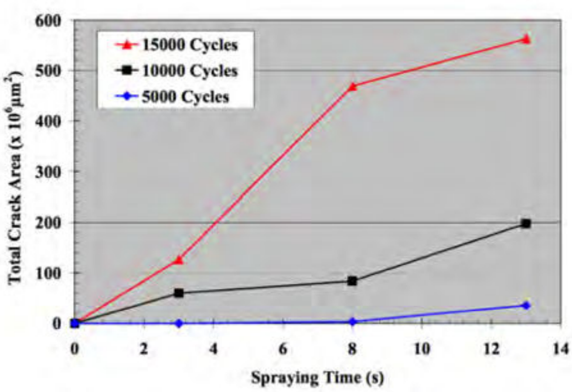

***Figure 6** – Impact of spray time on heat checking using the Case Western Reserve University dunk tester(6).*

At the time of the 2017 paper(5), only 16,000 shots had been produced using the coated balance shaft housing die, and so at that time information on die life extension was preliminary in nature. Today, however, more than 70,000 shots have been produced on the die, the AlCrN coating appears to be surviving, and a photograph of a recent casting is shown in Figure 7. This photograph shows that there is remarkably little heat checking visible on the casting, and Mercury reports that this is significantly less heat checking than observed with castings produced previously using un-coated dies.

***Figure 7** – Photograph of the balance shaft housing after more than 70,000 castings have been produced in the die (photograph by Phygen).*

Along with reduced heat checking, there are several other process improvements associated with utilizing the PVD coating on the die, and as listed in Table 2, an attempt has been made to document the cost savings associated with these improvements. The calculations have been performed based on the 70,000 shots produced to date, as future performance of the coated die is still unknown. The rationales for these estimated cost savings are listed below:

- Based on data collected from previous un-coated dies used to produce the balance shaft housing, by the time 70,000 castings had been produced, dies without PVD coatings typically required significant maintenance (such as solder removal, and re-welding small pieces in critical areas) on at least three separate occasions. The low level of heat checking on the current die, utilizing the CertiPhy Plus AlCrN PVD coating, means that this type of maintenance has not yet been required, and so these maintenance costs have been avoided. From internal records, the value of the avoided maintenance is worth 10% of the purchase price of the tool.
- Obviously reducing lubricant spray time by 85% reduces the amount, and so the cost, of die lubricant applied per shot. Based on the purchase price of the lubricant, this represents a saving of 5% of the tool capital cost over the 70,000 shots.
- A 12% improvement in cycle rate means that more castings will be produced per hour. In this case, the reduced cycle and downtime enabled redeployment

of another 700 ton die casting machine. Conservatively this was valued as 5% of the cost of the tool for the production of the 70,000 castings.
- The die is still producing castings, and so the data does not currently exist to demonstrate total die life. However, based on information generated to-date, it is estimated that the reduced spray could extend die life by at least 25%. This is direct savings over the life of the tool.

These savings are listed in Table 2, as a percentage of the initial purchase price of the cavity inserts, for the 70,000 castings produced to-date. For the four items listed in Table 2, total cost savings represent 45% of the value of the tool. Subtracting the cost addition for applying the coating (see Table 2), this shows that the PVD coating cost can be readily recouped.

Table 2 *– Estimated cost savings for a producing castings in a die coated with AlCrN.*

Item	Saving Over 70,000 Shots (as a percentage of original tool cost)
Reduced die repair	10%
Reduced die lubricant	5%
Faster cycle	5%
Extended die life	25%
Cost of coating	(20%)
TOTAL SAVING	**+25%**

Summary and Conclusions

The paper summarizes applications at Mercury Castings where PVD coatings have been shown to minimize soldering, sticking and dragging. In addition, the cost savings associated with coating an entire die with a PVD coatings have been estimated, demonstrating that the investment in the PVD coating can be readily recovered due to process improvements associated with the PVD coatings, with the total savings representing about 25% of the cost of the die inserts.

References

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