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The Use of Coatings to Minimize Soldering and Eliminate the Need for Lubrication during Aluminum High Pressure Die Casting

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ABSTRACT

In the aluminum high pressure die casting process, the lubrication spray acts as a parting agent, to prevent the aluminum from sticking and soldering to the die. The spray also helps to control the die surface temperature. There are, however, a number of disadvantages resulting from the application of liquid lubricant spray, including the reduction in quality of the castings, a significant reduction in die life, and an overall increase in manufacturing costs. This paper will report on two recent studies on the application of PVD, PACVD and diffusion coatings to the surface of die inserts and core pins to minimize or eliminate the need for conventionally sprayed die lubricants. For the first trial, two dies with simple flat plate geometries were covered with an AlCrN PVD coating, which resulted in the successful production of more than 200 castings in a totally lube-free condition. The second trial involved core pins that experienced severe soldering behavior, as they were located directly in front of the gate in a die used to produce a large automotive casting. In this second trial, since only the core pins were coated, the die was run using a conventional application of lubricant spray. The core pins were covered with four different coatings by PVD, PACVD, and a diffusional process, and around 2,500 castings were produced using each set of coated pins. A qualitative comparison, together with quantitative measurements were performed, to identify the amount of aluminum soldered to each coating.

INTRODUCTION

In the aluminum high pressure die casting process, the lubrication spray acts as a parting agent, to prevent the aluminum from sticking and soldering to the die[1]. The spray also helps to control the die surface temperature. There are, however, a number of disadvantages resulting from the application of liquid lubricant spray, including the reduction in quality of the castings, a significant reduction in die life, and an overall increase in manufacturing costs[2]. Even though the spray of lubricant is a common practice, new possibilities have been demonstrated by research led by the Colorado School of Mines, where plant trials showed that the use of conventional lubrication spray could be reduced by ~85% after covering the entire die with a PVD coating[3-6].

Within the published technical literature, several mechanisms have been proposed to explain the adhesion of aluminum to die casting dies. For castings produced using uncoated dies, soldering normally occurs at the hottest part of the die. For example,

Viswanathan and Han in 2002[7] have suggested that the die has to be above a critical temperature (Tc) for soldering to occur, and suggested that soldering occurs due to the molten aluminum reacting (alloying) with the die steel to produce Al-Fe-based intermetallic phases. For castings produced in PVD coated dies, Han proposed[8] that soldering is a result of the molten aluminum reaching the underlying die steel through defects and cracks in the PVD coating, allowing the aluminum to dissolve the steel beneath the coating, and the coating then detaches from the steel substrate. The Al-Fe phase diagram can be used to predict that the reaction products (the Al-Fe-based phases) will have a larger volume than the original steel substrate, causing a volume expansion to occur beneath the coating, again resulting in delamination of the PVD coating, and allowing the entire steel die substrate to be covered in Al-Fe-based intermetallics similar to the uncoated condition[8].

Several laboratory tests have been used to predict and test different die materials and coatings for aluminum die casting applications. The most used are: (i) simple dipping tests[9-11], (ii) the ejection test[12] or ease-of-release[13] test for cylindrical samples, (iii) the molten aluminum adhesion test for flat samples[3,14], (iv) the immersion rotating test for rods[15-18], and (v) wettability tests as the sessile drop technique[19]. Even though the laboratory tests are of great interested to initially identify new die materials and coatings, these laboratory tests lack on two fundamental aspects of the die casting process: (i) high gate speeds of between 25 and 75 m/sec, and (ii) high pressures of 70 MPa or higher[20]. Even though more complex and expensive, more realistic tests have been done using die casting machines in the laboratory and in industrial environments to test die materials and coatings.

From die casting laboratory tests, it is worth to mention the work done by Shivpuri et al in the 90s[21], who designed a die with several pins in front of the gate to generate accelerated erosion. Alloy A390 was used, as it should be more abrasive due to the higher Si content on this alloy combined with a higher melting temperature. Shivpuri et al. also used the application of a high superheat (735ºC was the molten temperature used on these tests). The authors measured weight loss and shape change in the sharp edges of square core pins facing the gate. Different coatings produced by several process were tested, and it was found that wear resistant TiN, VC, B4C, and CrC coatings significantly improved erosion resistance in comparison with uncoated H13 die material[21].

From industry die casting trials there are several reports to mention. Bobzin et al[17] tested coated core pins in a commercial die casting machine for 5884 die casting shots, and reported good performance of their laboratory made CrN/AlN/Al_2O_3 coating in comparison to industrially produced coatings. Nunes et al[22] showed an improved resistance of TiAlN coatings in comparison with uncoated H13 core pins, where after 30,000 the $Ti_{0.40}Al_{0.60}N$ performed better than the $Ti_{0.50}Al_{0.50}N$ coating. Paiva et al[23] tested coated core pins to determine the maximum number of shots that could be produced until castings with inadequate quality were produced. They found that the nanocomposite coating AlCrN/Si_3N_4 was the best, based on a combination of hardness, adhesion, soldering and oxidation resistance. This coating had a 92% life improvement in comparison with AlCrN coating for the same die. Kovačević et al[24] tested core pins and found that a duplex TiAlN resisted 22,000 shots, and was better than a CrN coating, followed by a core pin that had only the nitriding treatment. Even though they reported an improvement in performance, they raised the concern that even when using the same die casting machine and the same die, they observed a large scatter in performance due to variation in the die casting process. This shows the need of more die casting trials to test and compare a great number of coatings that can be used on aluminum die casting dies.

Therefore, this paper will report on two recent studies on the application of PVD, PACVD, and diffusion coatings to the surface of die inserts and core pins, aiming to reduce soldering and eliminate the need for conventional die lubricants in aluminum die casting. The firsts series of casting trials were performed using a 250-ton Buhler die casting machine located at The Ohio State University in Columbus, OH. Two new dies were designed and fabricated, PVD coated, and operated in the lube-free condition, without the application of any die lubricant. The second series of casting trials were performed at the Stellantis die casting plant in Kokomo, IN. A production die was chosen that had two core pins location directly in front of the gate of the casting, and both these core pins exhibited severe soldering after only 2,500 shots or so. A number of different PVD coatings were placed onto these core pins, and the die was run in the normal condition (with the application of die lubricant), and the amount of soldering on the core pins was measured after the production of 2,500 castings.

MATERIALS AND METHODS

CASTING TRIALS AT THE OHIO STATE UNIVERSITY

The lube-free laboratory die casting experiments were tested using a Buhler 250-ton die casting machine at the Center for Design and Manufacturing Excellence (CDME) at The Ohio State University (OSU). Two die casting dies were designed using the principle that, to avoid soldering and run in the lube free condition, they should be simple in shape, and so complex shapes including cores and changes in section thickness were avoided. To evaluate the impact of thermal mass of the casting upon soldering, one of the castings was relatively thin, while the other relatively thick. The first die (called die #1) produces thin plate castings approximately 100 x 165 x 4 mm in size, with a total casting weight of 0.35 kg. The second die (called die #2)

produces much thicker plate castings, approximately 100 x 165 x 19 mm in size, with a total casting weight of 0.90 kg. The die inserts were fabricated using heat treated H13 with a final hardness of 46-48 HRC.

The die inserts, the ejector side shot block and ejector pins for the two dies tested at OSU were PVD covered with an AlCrN coating using a duplex process that consisted of initially nitriding the heat treated H13 steel via ion implantation, followed by the deposition of a Cr adhesion layer, and then an AlCrN top layer with total deposition time from 120 to 180 minutes (note that the runner insert on the fixed side of the die was not coated). For purpose of characterization of the coatings, polished flat 25 mm by 25 mm test plates of heat treated H13 steel received the same coating. The deposition process was a patented filtered CAE utilizing a substrate pre-heat temperature of 450 – 500 °C, employing targets positioned at 350 mm from the substrates, with the application of a DC bias voltage. Deposition was conducted using a nitrogen pressure in the range of 0.3 – 0.6 Pa as the substrates rotated at 3 - 6 rpm. The two dies tested at OSU are shown in Figure 1.

A variety of techniques were utilized to characterize the coating, including calo testing, optical profilometry, scratch testing, VDI 3198 indentation, pin-on-disk, X-ray photoelectron spectroscopy (XPS), grazing incidence X-ray diffraction (GIXRD), and scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS). Details on the characterization procedures can be found elsewhere[14].

For each of the die casting trials at OSU, around 130 kg of A380 aluminum alloy was melted, and nitrogen gas degassing was performed on the molten bath for 15 minutes to ensure metal cleanliness. Standard samples for composition analysis were produced for each casting trial, and measured using a desktop SpectroMaxx spark Optical Emission Spectrometer (OES). A two-axis servo-driven Rimrock ladle was used to ensure consistent casting weight during the die casting trials. For mapping the effect of process conditions on the ability to produce lube-free castings, two parameters were varied during the trials, (i) two aluminum alloy melt temperatures were examined (680 and 720 °C) and (ii) the oil used to pre-heat the dies was varied between 200-305 °C. Table 1 shows the six combinations of conditions examined.

Prior to the trials, shot profiles were calculated based on NADCA recommendations designed to provide gate speeds of around 1,400 ins/sec. Unfortunately, problems with the Buhler machine prevented programing of the shot profile, and a shot profile stored in the machine's memory from a previous run had to be used. This generated an extremely high gate speed of 2,665 ins/sec, which may have encouraged soldering in the die cavity by exposing the die surface to an extremely aggressive filling condition. Figure 2 shows the desired shot profile, along with the profile actually used.

Each casting trial started with the application of a BN spray to the surface of the die, and then transitioned to a decreasing application of a manual spray of die lube (Chem-Trend SL-90078 diluted 1:30 in water), until the lubricant was totally removed from the process and lube-free conditions were run for a series of castings.

Following ejection of each casting, a FLIR thermal camera were used to track the die surface temperature of the ejector side of the dies. To estimate the maximum temperature experienced for both dies at each of the first five conditions examined, HPDC simulations were performed using ProCast software, and these predictions were compared with actual temperatures measured by the thermal camera.

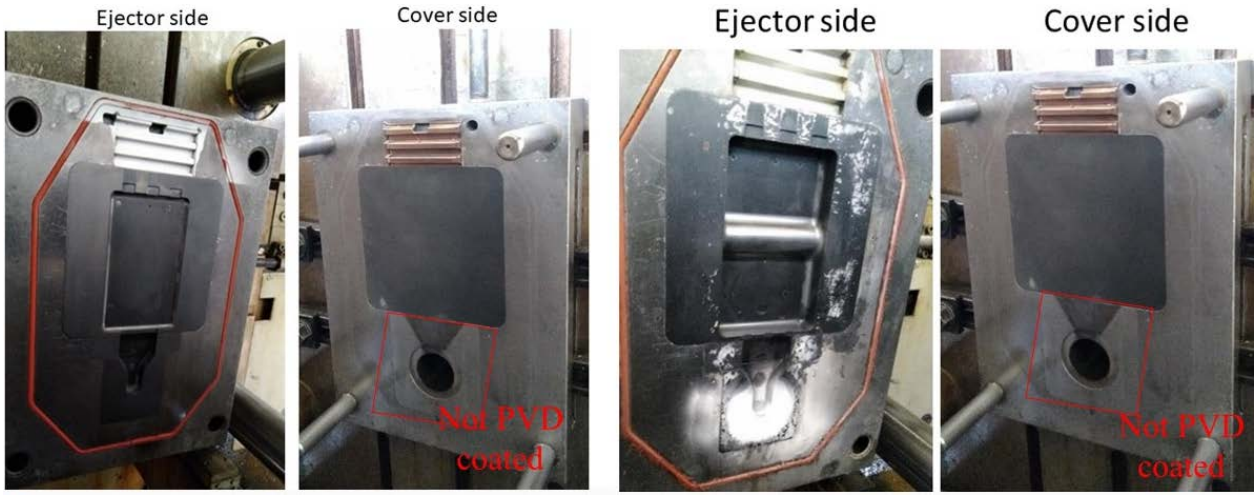

Figure 1 - The two dies for OSU die casting trial (a) for die #1 and (b) die #2. The cover side was the same for both dies.

Table 1 - Six conditions of A380 melt temperatures and heating oil temperatures examined in this study.

Condition	Temperature (°C)	
	A380	Oil
C1	680	200
C2	720	200
C3	720	230
C4	720	260
C5	720	290
C6	720	305

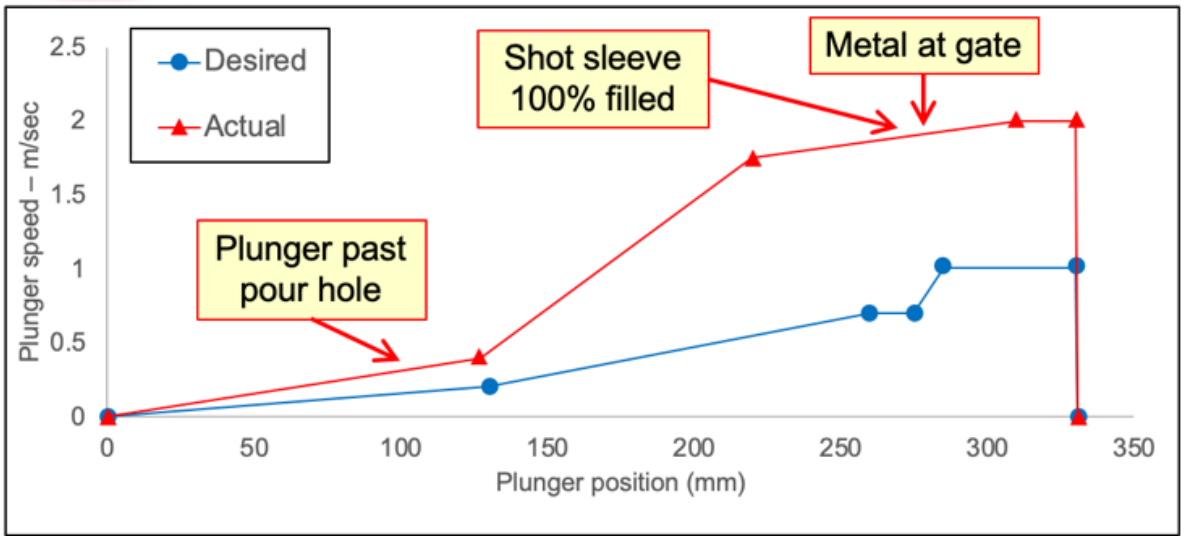

Figure 2 - Differences in shot profiles from the desired to the profile actually used during the test.

CASTING TRIALS AT STELLANTIS

The second series of experiments were performed at the Stellantis die casting plant in Kokomo, IN. As shown in Figure 3, these experiments involved core pins that experience severe conditions as they are located directly in-front of the gate in a die used to produce a large automotive casting. Since only the core pins were coated, this die was run using conventional application of lubricant spray, and around 2,500 castings were produced using each set of coated core pins. Qualitative comparison and quantitative measurements were performed to identify the amount of aluminum soldered to each PVD coating. The qualitative assessment was based on visual inspection of the core pins after each trial by Stellantis personnel. The quantitative analysis was performed in two ways: (i) the mass change on the core pins due to aluminum soldering, and (ii) by the fraction of surface area of the core pin that was covered with aluminum based on image analysis of macrographs taken using a Keyence VHX-5000 microscope.

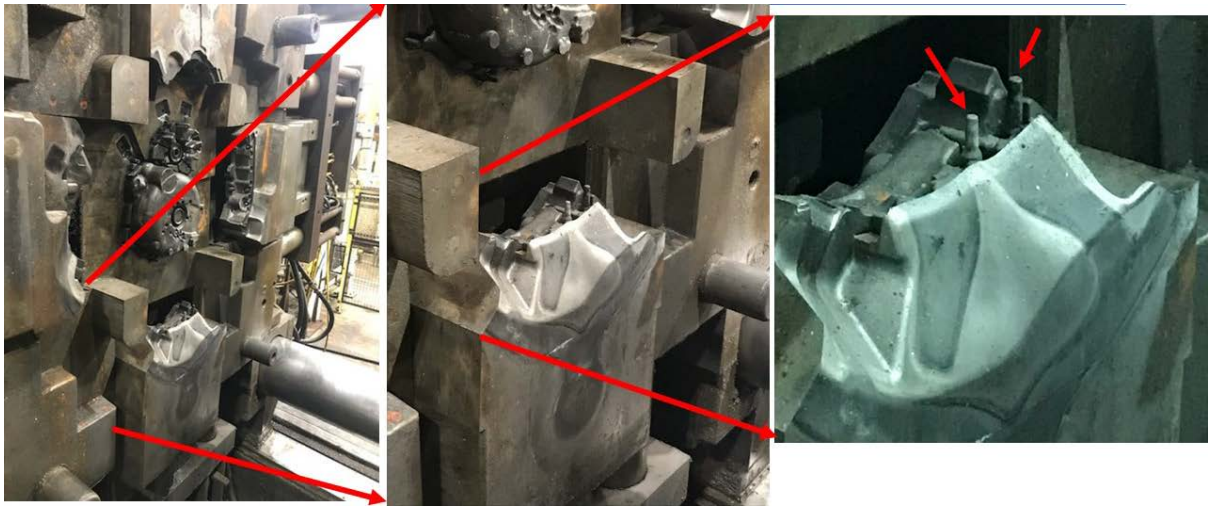

Figure 3 - Pictures of the die used for the soldering trial at Stellantis. Detail for the two core pins (models 5205 and 5215) located in front of the gate that received different PVD coatings.

RESULTS AND DISCUSSIONS

LUBE-FREE DIE CASTING TRIALS AT OSU

Table 2 shows the results from the general characterization of the AlCrN coating applied to the dies for the lube-free trial for composition, thickness, roughness, and adhesion. The ratio of Al/(Al+Cr) for this coating is 0.64. It has been reported for (Al,Cr)N that the phase transition from the cubic B1 (NaCl) structure to the hexagonal B4 (würtzite) structure occurs when the Al/(Al+Cr) is above 0.75[25], and so the coating examined in this study should consist of the cubic hard phase since the composition is well below this phase transition limit. The crystal structure of the coating was confirmed from the GIXRD measurements shown in Figure 4, where the AlCrN coating has been indexed as the B1 (NaCl) cubic structure (the α-Fe for the uncoated H13 is also shown in Figure 4 for comparison).

The thicknesses of the coatings were within the range commonly reported for PVD nitride coatings used in aluminum die casting applications (typically from 1 to 10 μm[13]). Surface roughness measurements showed that the coating was very smooth, with Ra values in the nanometer range. The cohesive critical loads (Lc1) was 8.7 ± 2.0 N and the adhesive critical loads (Lc2) was 23.0 ± 6.1 N, greater than previously reported for similar coatings[14]. VDI 3198 tests were performed, and the results showed no cracking or coating spallation around the indentation, indicating adequate coating adhesion to the substrate (indexed as HF1)[26].

Table 2 - Composition, thickness, roughness, and adhesion for AlCrN coating.

Composition by XPS (at. %)	Thickness (μm)	Roughness Ra (nm)	Cohesion Lc1 (N)	Adhesion Lc2 (N)	VDI 3198
$Al_{29.3}Cr_{21.0}N_{49.8}$	8.6 ± 0.2	100 ± 13	8.7 ± 2.0	23.0 ± 6.1	HF 1

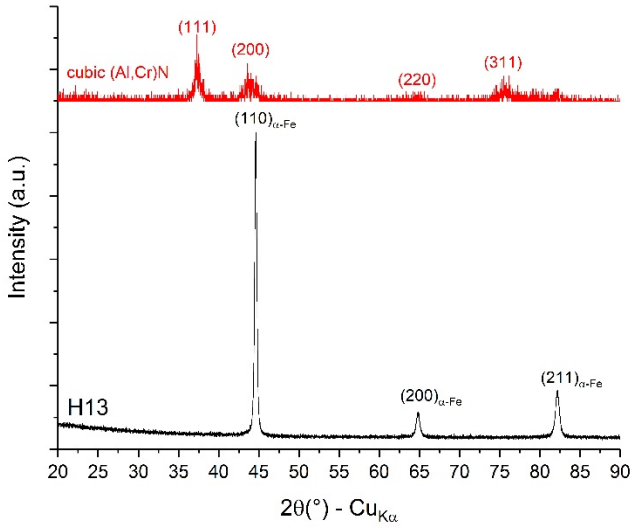

Figure 4 - GIXRD from the uncoated H13 indexing α-Fe and AlCrN coating indexing the B1 (NaCl) cubic phase.

The structure and microstructure of the AlCrN coating can be seen in the SEM BSE images and EDS maps of polished cross sections shown in Figure 5. The coating is structured with a thin Cr/CrN adhesion layer deposited onto the H13 prior to the growth of the thicker AlCrN top layer. As noted in Table 2, based on XPS measurements, the composition of the top layer is $Al_{29.3}Cr_{21.0}N_{49.8}$. This coating should also contain an ion nitrided layer underneath the thin Cr adhesion layer, produced during the duplex deposition process, but this feature is not apparent in Figure 5.

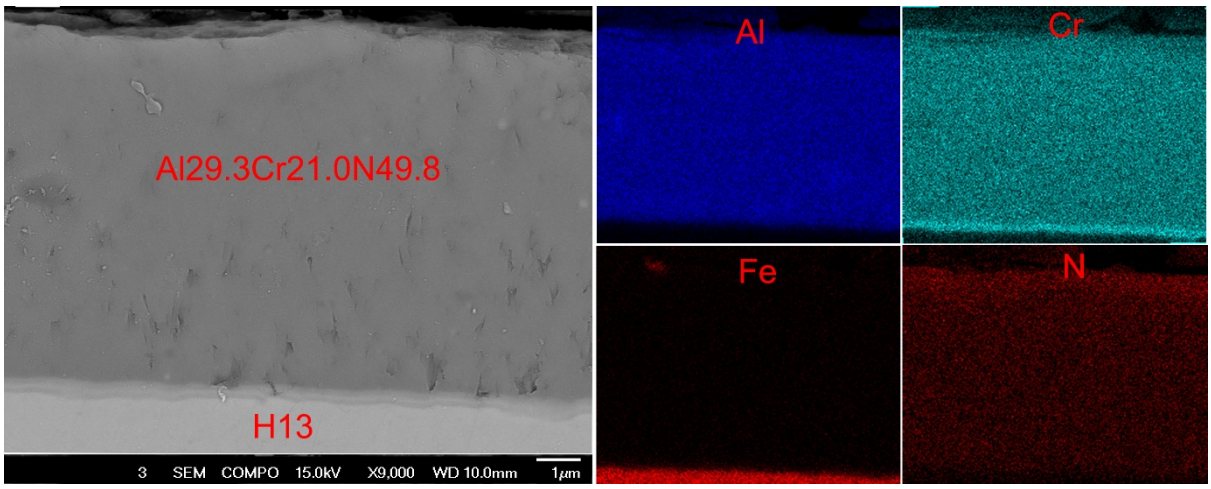

Figure 5 - Coating structure from SEM BSE images and EDS maps on polished coating cross-section of AlCrN coating.

The results of the pin-on-disk measurements performed on the AlCrN coating are shown in Figure 6, and for uncoated H13 for comparison. The AlCrN friction coefficient was 0.51 ± 0.10 and for uncoated H13 was 0.54 ± 0.08. Consistent with these results, the 3D profilometry from the wear tracks were very similar for AlCrN and for uncoated H13.

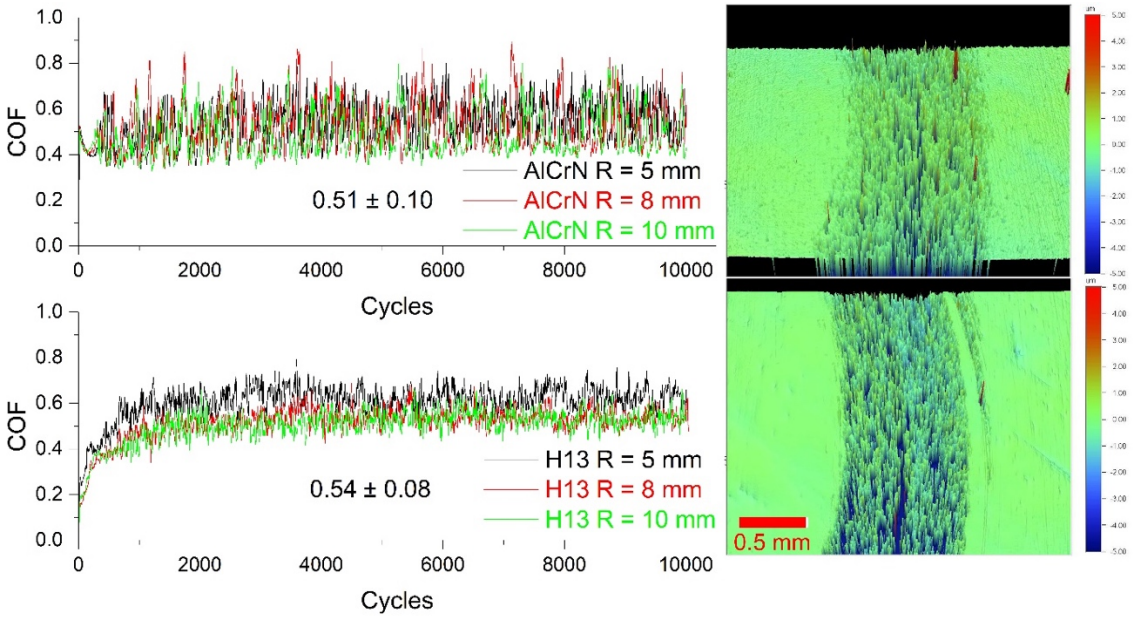

Figure 6 - Pin-on-disk results using pure Al balls against the AlCrN coating and uncoated H13 showing the measured coefficient of friction (COF) and 3D optical profilometry of wear tracks.

Both of the dies tested at OSU for the lube-free die casting trial were covered with this AlCrN coating. The composition measurements of the A380 aluminum alloy used in the trials are listed in Table 3. For the testing performed on day 1, die #1 was installed on the die casting machine, the molten A380 temperature were kept at 680 ± 20 °C, the hot oil temperature was 200 ± 5 °C, and the test sequence showed in Table 4 was followed for lubricant application. By the end of the trial, 40 castings had been produced under lube-free conditions (i.e., without the application of any die lubricant, although the plunger lubricant PL-208 from ChemTrend was painted onto the shot tip prior to each shot).

The same die (die #1) was used for testing performed on day 2, where the objective was to examine the effect of different processing conditions on the ability to produce die castings under lube free conditions. The testing followed the conditions listed in Table 5, where the molten metal temperature and the oil temperature used to pre-heat the die were varied. As shown in Table 5, it was possible to produce 117 castings in the lube-free conditions, for all conditions examined. Combining the two days of testing, a total of 157 lube-free castings were produced using die #1.

Table 3 - Measured composition of the A380 alloy used at OSU trials.

A380	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti
Day 1	Balance	8.2	1.0	3.1	0.20	0.20	0.03	0.05	1.0	0.06
	Balance	8.4	1.0	3.1	0.20	0.21	0.03	0.05	1.1	0.06
Day 2	Balance	8.0	1.0	3.1	0.19	0.22	0.03	0.05	1.2	0.06
	Balance	8.1	1.0	3.2	0.19	0.22	0.03	0.05	1.2	0.06
Day 3	Balance	9.1	1.0	3.1	0.19	0.18	0.03	0.05	1.2	0.06

Table 4 - Die casting trial sequence at Day 1.

Castings		# of die lube sprayed			
#	Quantity	cavity	runner	cover	shot block
1 to 6	6	BN			
7 to 11	5	3	3	3	3
12 to 14	3	2	2	2	2
15 to 17	3	1	1	1	1
18 to 57	40	Lube-Free			

Table 5 - Die casting trial sequence at Day 2 mapping six different combinations of A380 and oil temperatures.

Castings		Temperature (°C)		Condition
#	Quantity	A380	Oil	Lube
1 to 5	5	680	200	BN, spray
6 to 25	20	680	200	**Lube-Free**
26 to 45	20	720	200	
46 to 65	20	720	230	
66 to 85	20	720	260	
86 to 105	20	720	290	
106 to 112	7	720	305	
113 to 122	10	720	200	

During the testing using die #1, occasionally the aluminum casting would stick to the ejector pins during ejection, as shown in Figure 7 (a). Little-to-no adhesion strength was evidenced, since a lateral touch was enough to remove the casting. It is possible that the flat ends of the ejector pins are areas of low PVD coating, due to the line of sight nature of the PVD deposition process. Figure 7 (b) shows the ends of the ejector pins, where aluminum soldering can be observed around their periphery. Intermittent build-up of aluminum was also observed on the cavity faces close to the gate (identified by the red circles in Figure 7 (c)). This build-up would intermittently appear and then disappear after a few castings. Although this phenomenon occurred throughout the entire trial, there were no evidence of the build-up developing into soldering in these areas of the coated inserts. It is possible that this build-up may be a consequence of the extremely high gate speed used to produce these castings (as shown in Figure 2).



Figure 7 - Lube-free casting trial using die #1 where (a) ejector side showing the casting stuck to the tip of the ejector pins, (b) side of tip of the core pins with aluminum adhered, and (c) intermittent aluminum build-up at the coated die surface appearing at casting #20 and disappearing at casting #21.

Die #2 was installed in the machine and tested on day 3 of the trials. The plan for this trial was to test the conditions listed in Table 1, but due to a problem with the die casting machine, the trial had to be interrupted at condition C3 (molten A380 temperature of 720 °C and die oil temperature of 230 °C). Table 6 shows the conditions and number of castings produced in day 3 for each condition examined. This trial demonstrated that was possible to run lube-free with die #2, and that 56 castings lube free castings were produced under different conditions.

Table 6: Die casting trial sequence at Day 3 mapping the first three combinations of conditions.

Castings		Temperature (°C)		Condition
#	Quantity	A380	Oil	Lube
1 to 5	5	680	200	BN, spray
6 to 25	20	680	200	Lube-Free
26 to 45	20	720	200	
46 to 61	16	720	230	
-	-	720	260	-
-	-	720	290	-

Similar to that observed with die #1, sometimes the castings would stick to the tips or sides of the ejector pins with die #2, but no significant load was required to extract the castings. A different condition was noted half-way through the trial with die #2, where significantly flashing started to occur. During normal conditions, the injection pressure was around 125 bar, but when flashing was observed, a pressure spike (to above 700 bar) was observed during injection, and it is likely that this pressure spike was the cause of the flashing (see Figure 8).

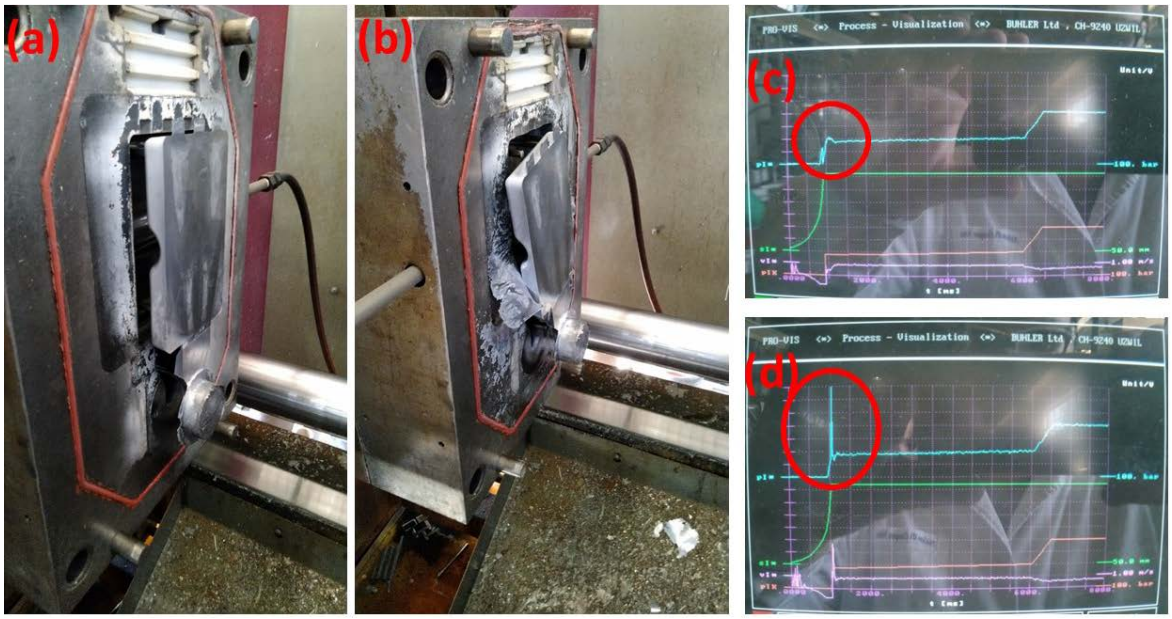

Figure 8 - Lube-free casting trial on day 3 using die #2 where (a) ejector side showing the casting stuck to the side/tip of the ejector pins, (b) casting with aluminum flashing, (c) normal injection pressure, and (d) pressure spike during injection.

The condition of the die inserts by the end of the three days of lube-free casting trials are shown in Figure 9. Figure 9 (a) shows the ejector side of die #2, where aluminum marks in a vortex shape can be seen towards the center of the lower and upper portions of the cavity, and blue oxidation marks on the center cored section. Figure 9 (b) shows the fixed side of the die, with aluminum marks in a similar position towards the top of the die, and the blue oxidation marking downstream from the three gates. The red arrows in Figures 9 (c) & (d) show that relatively thick aluminum solder built up on the lower part of the PVD coated ejector-side shot block, and on the un-coated cover shot block. Most likely these are regions of the die that became extremely hot during die casting. Even though soldering did develop at these positions, it was not enough to stop the coated dies from running in a lube-free condition during the trials. A total of 157 lube-free castings were produce using die #1 and 56 lube-free castings using die #2.

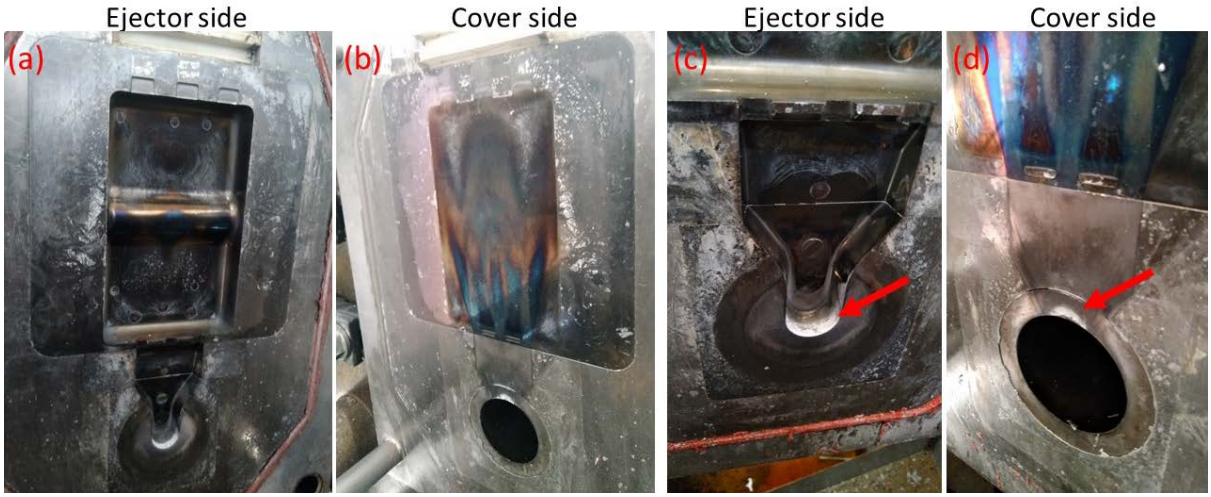

Figure 9 - Condition of the die inserts by the end of the three days of lube-free trials, (a) ejector side showing the presence of aluminum marks, (b) aluminum marks on the top and blue oxidation marks at the gate area, (c) soldering on the coated shot block, and (d) soldering on the uncoated cover shot block.

The surface temperature for the ejector side of the die was monitored between shots by a thermal camera for all casting conditions in the three days of the lube-free trials. Figure 10 (a) shows the temperature distribution for all conditions for die #1, and in Figure 10 (b) for die #2. The casting number relating to each picture is shown in the Figures. The data from the thermal camera shows that the temperature increased and became more uniformly distributed as the test progressed. As expected, due to the higher thermal mass of the casting produced in die #2, the maximum temperature experienced was higher by ~60 °C.

ProCast simulations were performed for both dies for the first five conditions tested (conditions C1 to C5 listed in Table 1). Figure 11 shows the results of the simulation, showing the maximum die temperature for each condition. By comparing Figure 10 and Figure 11, it can be seen that the simulated results match well with the experimental observations. Also, the positions of highest temperature for all conditions shown in Figure 11 corresponds to the regions were soldering was observed on the shot block (shown in Figures 9 (c) & (d)).

Also, as was observed in Figure 10 (b) for the center of the lower and upper part of the cavity for die #2, the simulation confirmed the thermal camera results, as those positions showed the presence of some aluminum vortex of a similar shape as the highest temperatures observed in the simulation. By combining these results, the positions where soldering or aluminum marks were present in the die are similar to those where maximum temperatures were observed. This is in agreement with Han[7,8], who suggested that a critical temperature has to be achieved for soldering to occur. The difference here is that build-up was also observed, but did not progress to soldering, suggesting that Han's theory might not only be related to soldering, but also as an indicator of build-up.

The quality of the lube-free castings was visually inspected based on five criteria: (i) castings produced without filling defects, (ii) castings with filling defects, (iii) castings with surface marks due to build-up on the die, (iv) castings with gas blistering, and (v) castings with surface marks from excessive plunger lube. Figure 12 shows examples of each of these classes of castings for the thin plate casting (die #1), while the thicker plate casting defects (die #2) are shown in Figure 13. The results of this analysis are summarized in Figure 14.

As is shown in Figure 14, as the trial progressed, a higher percentage of castings without filling defects were produced, most likely due to an increase in melt and die temperatures, and as a result of reaching steady-state production conditions. Also, as the temperature increased during the trial, a greater percentage of castings with build-up surface defect marks and with gas blistering were produced.

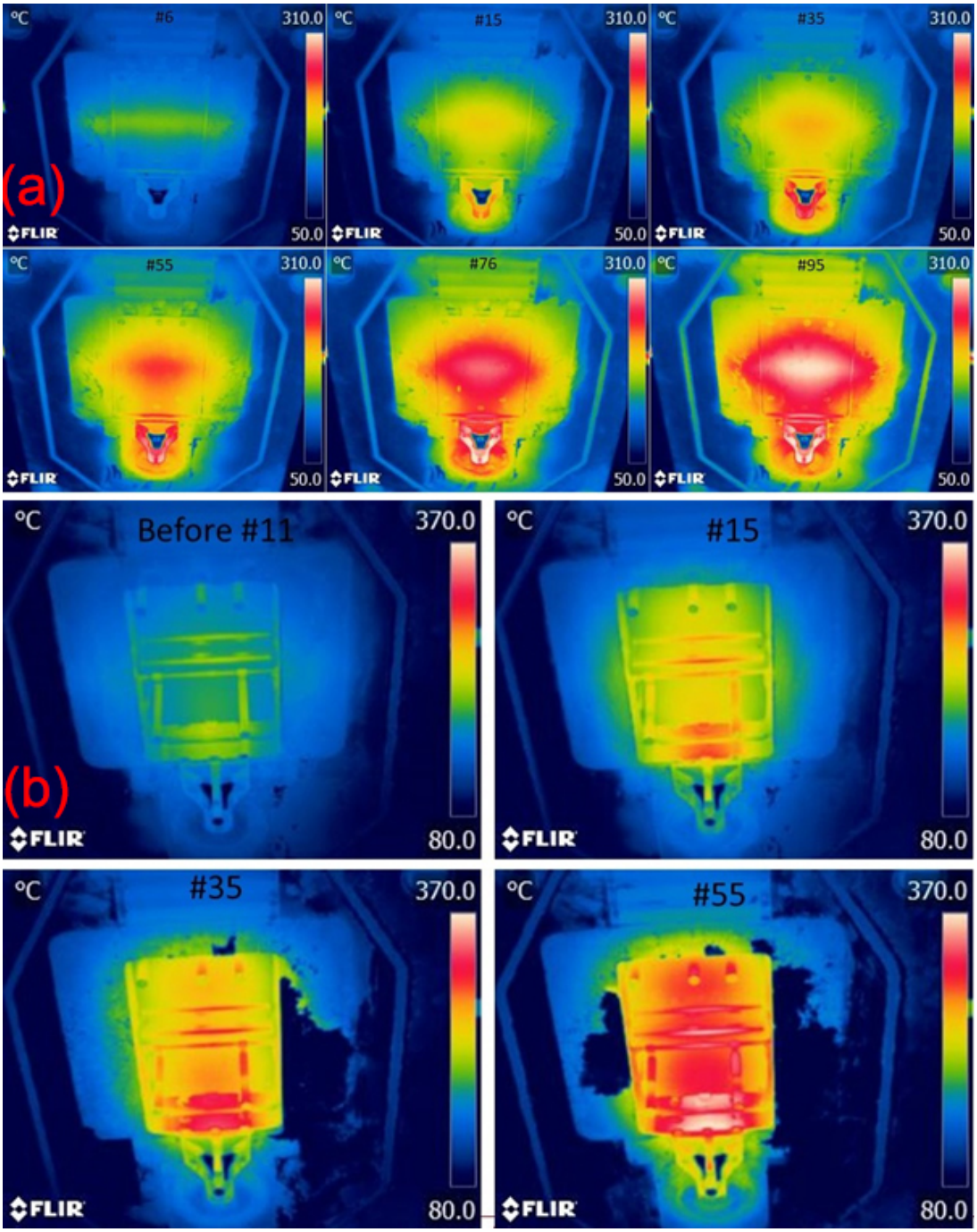

Figure 10 - Temperature distribution for (a) die #1 and (b) die #2 during the lube-free trial for all tested conditions.

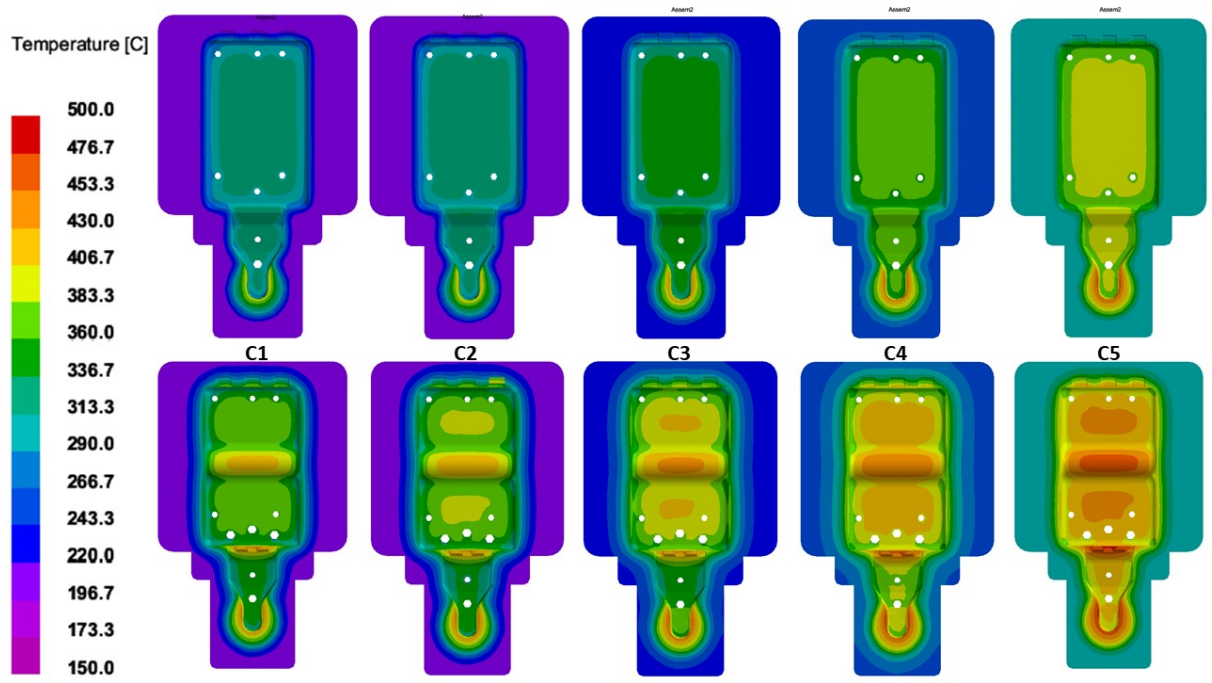

Figure 11 - Simulated temperature distribution for die #1 and die #2 for conditions C1 to C5.

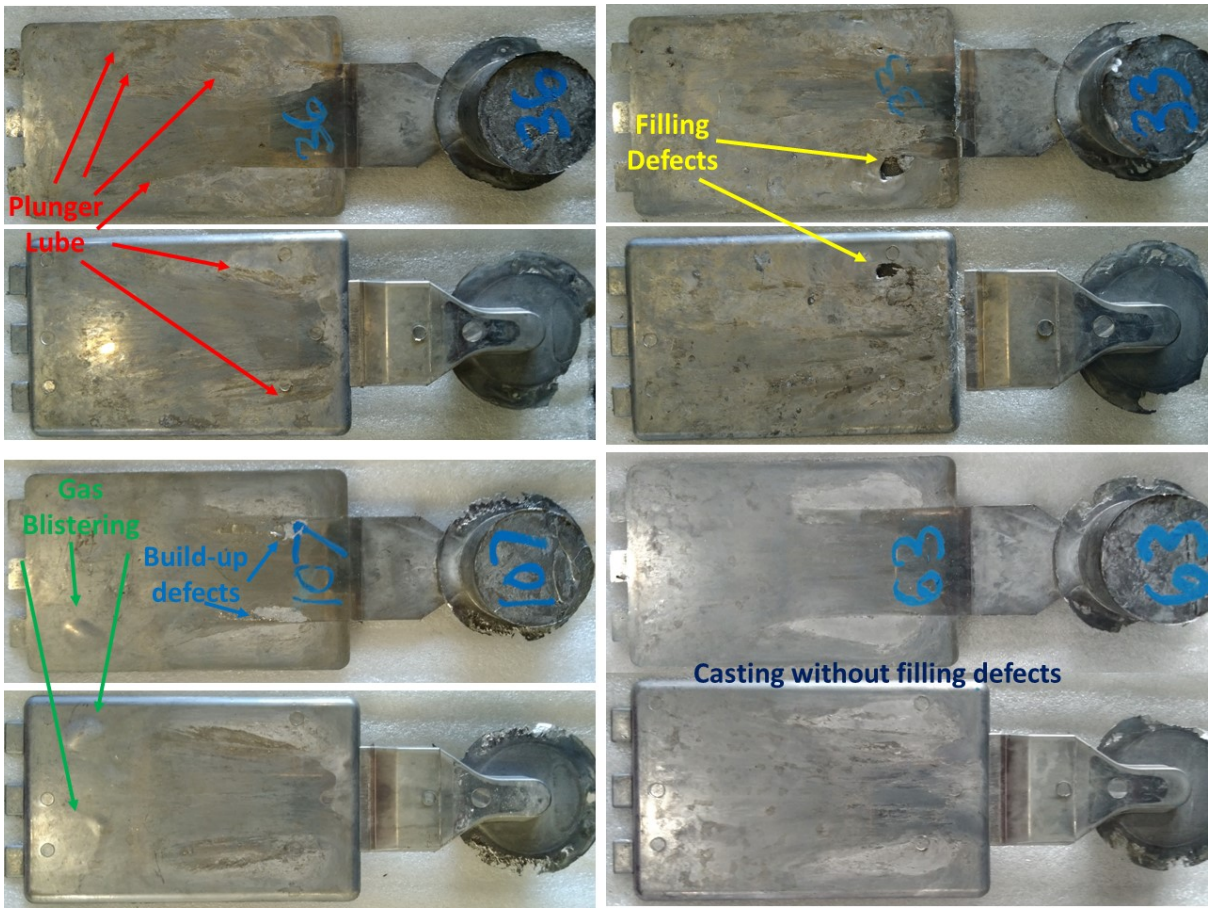

Figure 12 - Inspection criteria for the thin plate castings (die #1).

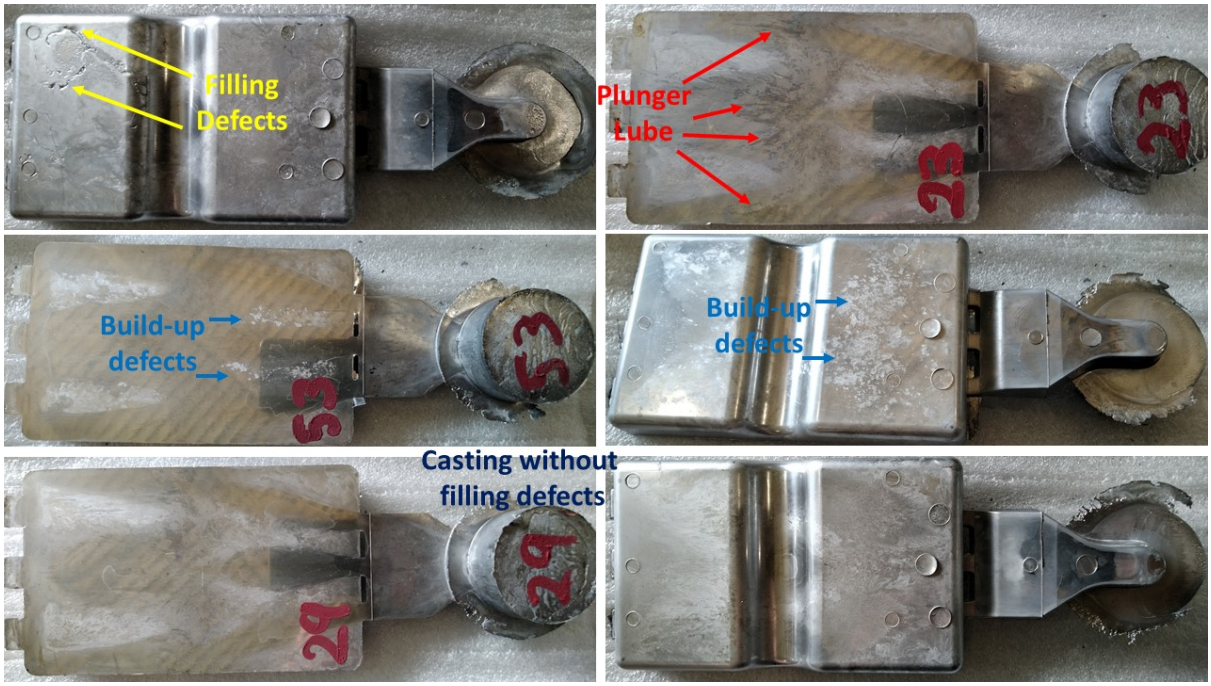

Figure 13 - Inspection criteria for the thicker plate castings (die #2).

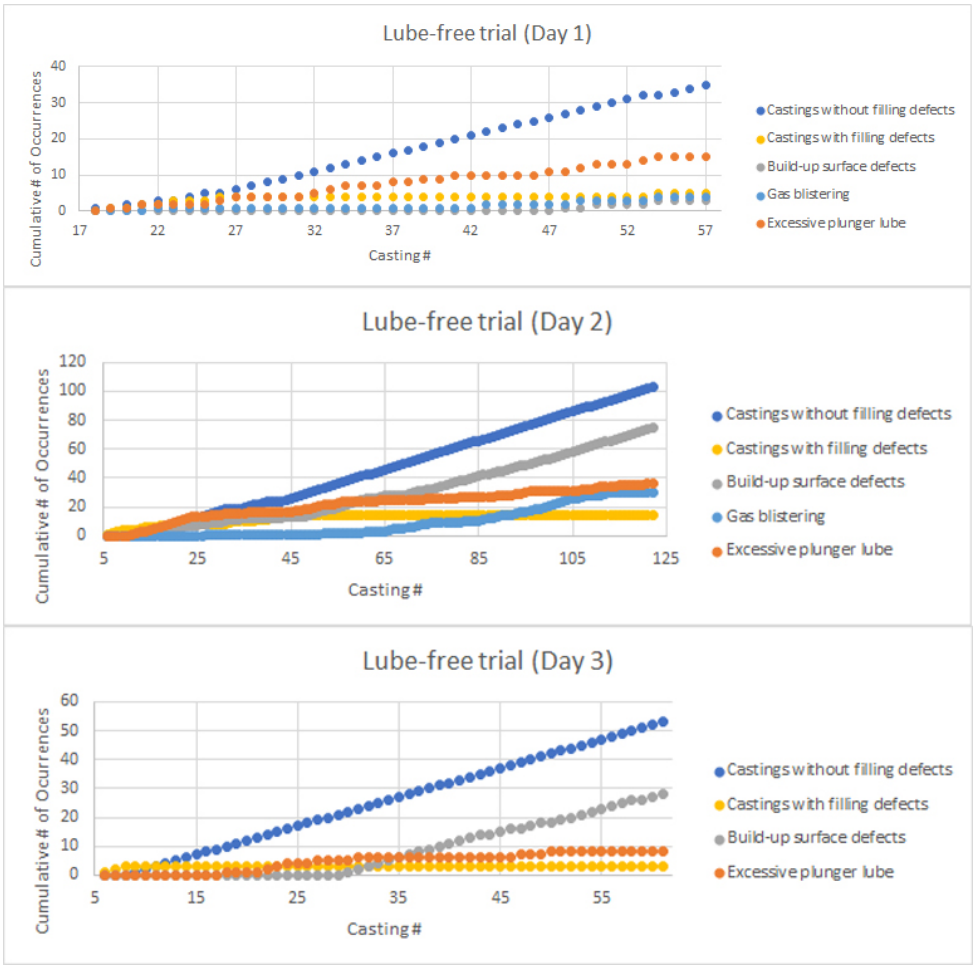

Figure 14 - Results of the quality inspection analyses on the lube-free castings produced during the lube-free trials.

COATED CORE PIN DIE CASTING TRIAL AT STELLANTIS

Four surface conditions have been tested on the core pins from the commercial die casting die tested at Stellantis. The first condition is the “normal core” where the surface of the core pins received only a nitriding treatment. The three coated conditions, deposited on highly polished core pins with roughness of Ra = 52 ± 17 nm and Rz = 0.304 ± 0.096 µm, were: (i) a Si doped DLC coating deposited by Plasma Assisted Chemical Vapor Deposition (PACVD), (ii) a VC layer produced by a hot diffusion process, and (iii) an amorphous Al_2O_3 coating deposited by High Voltage Low Temperature Sputtering (HVLTS).

Figure 15 shows photographs of the core pins and castings after the completion of each trial (since the VC core pins were destroyed during removal from the die, a picture of the last casting produced with this set of core pins is shown). Photographs of the normal core (nitrided condition) shows the presence of a large amount of soldering. The coated cores exhibited a smaller amount of soldering after the trial, with the Si doped DLC coating exhibiting the least amount of soldering. Personnel at the Stellantis plant graded the performance of each of the four sets of cores based on visual analysis of soldering resistance, and their grades are shown in Table 7.

A more detailed 3D reconstruction of both sides of the cores was acquired using a Keyence microscope only for the nitrided and Si doped DLC coating (since the Al_2O_3 and VC coated core pins were destroyed during removal from the die, Keyence photographs of these cores were not possible). By using image analysis from the Keyence software, these images were used for the quantification of the percentage of surface area covered with aluminum. These results are also shown Table 7, along with the mass change results for the Si doped DLC coated core pins.



Figure 15 - Figure of the core pins after the Stellantis test for relative visual inspection and grading.

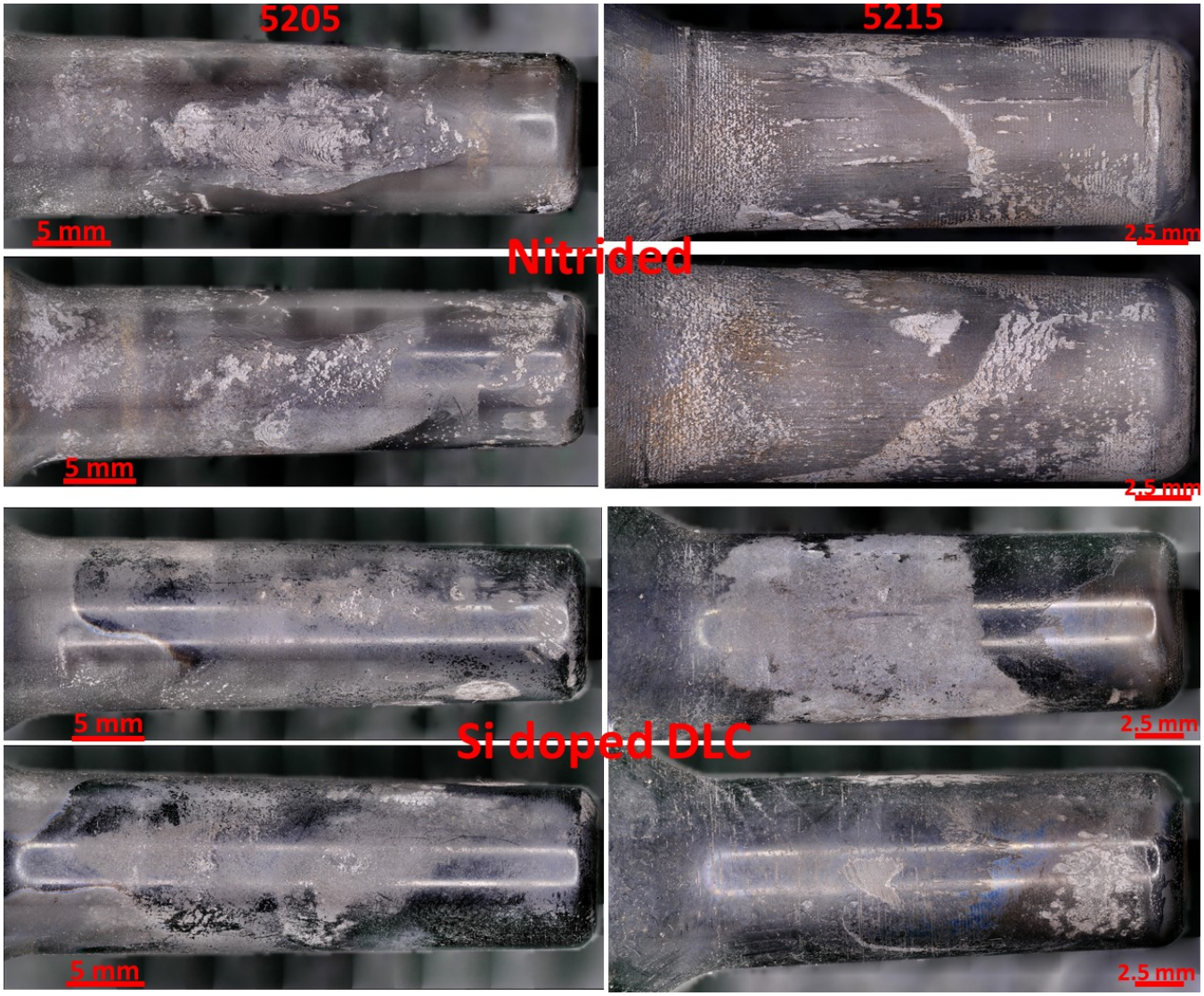

Figure 16 - 3D reconstruction acquired on the Keyence microscope for both sides of the surface of the tested core pins models 5205 and 5215.

Pin-on-disk measurements were conducted on the 25 mm by 25 mm samples to better understand the performances of the different coatings. The COF results are shown in Figure 17. The Si doped DLC coating has the lowest COF (0.16 ± 0.04), and also exhibited the lowest wear based on wear track measurements. All the other coatings showed similar COF values of 0.51 ± 0.06 for Al_2O_3, 0.51 ± 0.10 for AlCrN, 0.54 ± 0.12 for VC, and 0.54 ± 0.08 for the uncoated H13. The higher wear resistance might be one of the reasons for the Si doped DLC coating outperformed the other coatings on this test.

Table 7 - Results of the Stellantis test for the core pins model 5205 and 5215.

Coating	Coating Supplier	# of Shots	Stellantis Observations	Stellantis Grade	Mass change (5205)	Mass change (5215)	Surface Soldered (5205)	Surface Soldered (5215)
Nitriding (“Normal Core”)	-	2500	Both cores soldered	D	N/A	N/A	46 ± 5 %	58 ± 5 %
Si doped DLC (“E”)	#1	2430	Cores basically clean - no solder. Coating looks like it is intermittent.	A-	+ 0.20 g	+ 0.28 g	31 ± 9 %	38 ± 17 %
VC ("F")	#1	4469	Some light solder (cores got destroyed)	B-	N/A	N/A	N/A	N/A
Al_2O_3 Alumina (“H”)	#1	2572	Some solder (cores got destroyed)	C+	N/A	N/A	N/A	N/A

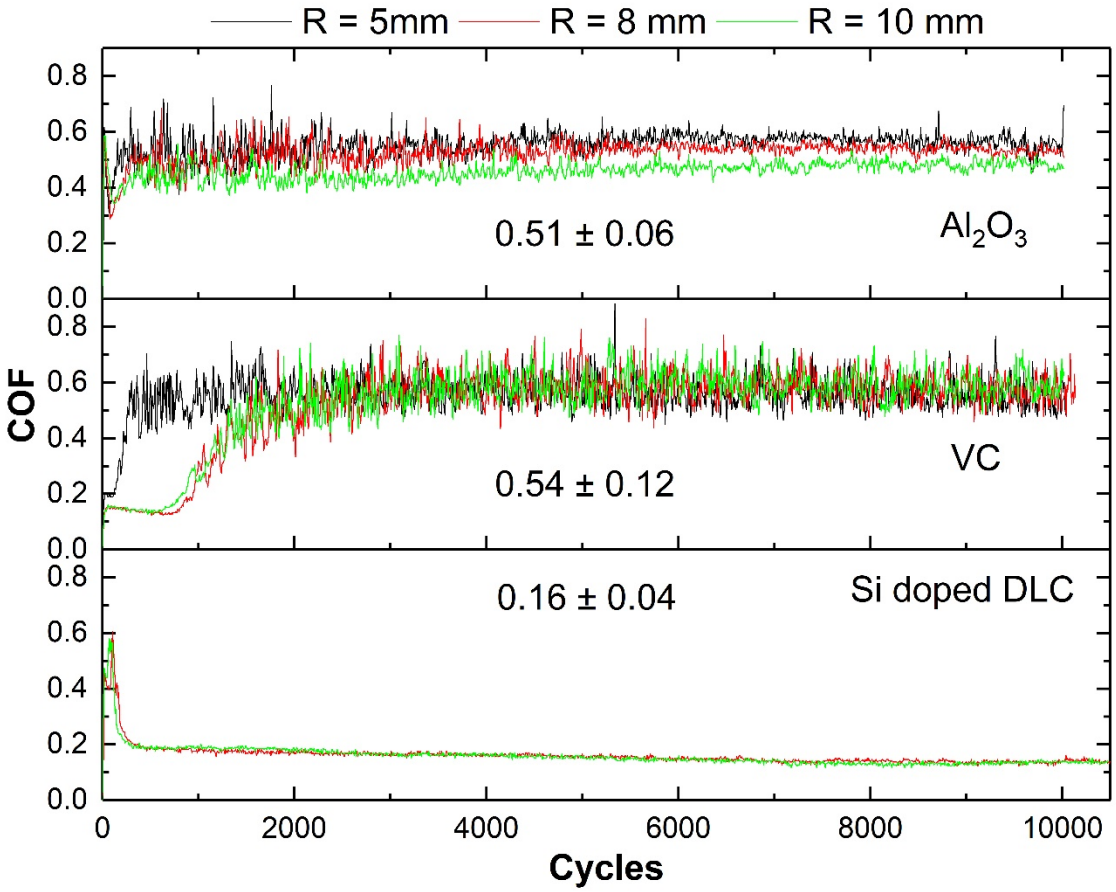

Figure 17 - Pin-on-disk wear tests using a pure Al ball sliding on coating surface.

SUMMARY & CONCLUSIONS

- Two dies with simple geometries have been coated with an AlCrN PVD coating, and tested using a 250-ton die casting machine at OSU. Due to the PVD coating, it was possible to run both in the lube-free condition (without the application of any die lubricant). More than 200 lube free castings were produced in both dies.
- The temperature simulation on the dies matched well the observed from the thermal camera, where the hottest spots where those were small amounts of soldering developed on the shot blocks, but also where aluminum marks were seen inside the insert cavities.
- Aluminum build-up on the die surface was observed as an intermittent phenomenon, but did not progress to soldering. Based on an analysis of the surface condition of the castings, it was concluded that the casting conditions with higher melt and die temperatures leaded to a greater percentage of castings with build-up surface defect marks and with gas blistering.
- Casting trials have also been performed at Stellantis by coating core pins located directly in-front of the gate of a large commercial die casting. Four different coated pins have been evaluated, and a Si doped DLC coated core pin exhibited the least amount of soldering.
- The results of both trials have shown that coatings can be used to minimize soldering and eliminate the use of die lubricant in aluminum HPDC.

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