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Innovative Die Lubricant Trends for Evolving Productivity and Process Requirements

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ABSTRACT

The continued push for improved productivity in the high pressure die cast (HPDC) industry places ever increasing performance and productivity demands on die lubricants. The majority of new technology developments in die lubricants have been spurred by developments in automotive castings. The relentless push for vehicle weight reduction and improved productivity requirements, coupled with the casting of larger and more complex parts, has brought forward the necessity of significant innovations in die lubricants. This paper discusses the impacts of these trends on die lubricants while examining how new die lubricant technologies address the changing industry needs.

INTRODUCTION

The high pressure die cast (HPDC) process continues to be a very attractive casting method due to high productivity rates and the ever increasing ability to produce high-quality complex casting with a reasonable array of alloys. Due to this attractiveness, the HPDC market has been growing globally and has mirrored the growth of the automotive industry. This growth can only be accomplished by meeting the challenges and industry trends that are faced by the automotive industry. Currently there are three dominant themes in the automotive industry:

1. Increased fuel economy
2. Cost reductions through improved productivity
3. Improved occupant safety

Rising fuel costs, along with new environmental regulations, have necessitated improvements in automotive fuel efficiency. Reduced weight is the key directive in the transportation community as OEMs search for new ways to design vehicles with better fuel efficiency. Lower density alloys such as aluminum and magnesium are gaining market share at the expense of both traditional steel and high strength steels. It is estimated that an average North American vehicle uses ~340 lbs. of aluminum, and ~8.3% of its gross weight is made of aluminum parts. Aluminum is expected to double its vehicle weight share to ~16% by 2025. Aluminum alloys have been widely accepted for the manufacturing engine, transmission and chassis components, and are rapidly gaining market share in steering knuckles, suspension arms and cross-member applications. Magnesium incorporation in automotive powertrain components is still small but increasing rapidly. The migration to aluminum and magnesium alloys from steel will continue.

The global push for improved productivity has brought increased complexity to die casting parts. To increase productivity in automotive assembly, die cast parts are being designed with added complexity in single castings to reduce the number of assembly/joining steps. For a die caster, this trend has translated to higher shot weights injected into larger and more complex dies. Sometimes the complexity of these dies makes it difficult to adequately cool all parts of the dies uniformly. This places an even higher demand on die lubricant (DL) contribution for thermal management of these complex dies.

The third major trend, higher occupant safety standards, has led to the use of new alloys and processes to yield parts with low porosity and high ductility for crash worthiness. Some newer alloys used for this purpose are more abrasive, and typically have low iron content as compared to traditional aluminum-silicon alloys, like A380 or A383 alloys. Along with these alloy improvements, newer techniques like high vacuum techniques have been incorporated in HPDC processes to yield low porosity parts capable of heat treatment.

Coupled with these trends, die casters are continually challenged to make strides in improved equipment efficiency, lower machine downtime, and ever stricter environmental regulations. As a consequence, increasingly complex/big parts are being cast using newer alloys in dies, which are running at higher temperatures. These global trends have spurred the development of a new generation of die lubricants which are capable of meeting the enhanced operating demands. High die surface temperatures are requiring the DL to “wet” the die surface at higher temperatures and work on dies with a wide temperature range. It is not uncommon for these complex dies to have regions with temperatures well in excess of 400°C, while in the colder regions they can be as low as 200°C.

Based on these industry trends, a high performance die lubricant must:

- wet the surface uniformly in a wide temperature range;
- deposit an effective, uniform and lubricious film across all sections of the die;
- provide balanced film performance so as not to create carbon buildup in cold areas of the die while still protecting hot spots to prevent solder;
- minimize machine downtime for removal of ex-cavity build-up; and
- be safe, easy to use and dispose of, and should meet all applicable health safety and environmental regulations.

PERFORMANCE CHALLENGES:

Figure 1 shows the cooling phenomenon exhibited by DL; it shows the change of heat flux with temperature during the forced cooling of the die by the DL spray [1, 2]. The X-axis of the graph (read right to left) depicts temperature. During the initial spray time, heat flux is very small as surface wetting has not taken place; this is the film boiling regime. In the film boiling regime, a gas barrier forms on the surface if the surface temperature is high enough. This vapor film has a high vapor pressure, and therefore resides close to the hot surface. The vapor prevents the physical contact of the water droplets with the heated surface. Therefore the rate of heat extraction from the hot surface is small. Besides the chemistry of the DL, many other mechanical factors affect the Leidenfrost temperature; factors such as spray angle, distance, droplet size, spray pressures, etc. [3]

This regime continues until Leidenfrost point.[4] Once the surface wetting has started taking place, from Leidenfrost point, the cooling curve moves into the transition regime, and rate of heat extraction from the die starts to increase, reaching maxima. At the Nukiyama point the heat transfer coefficient and heat flux maximizes; this maximum heat flux is referred to as critical heat flux (CHF). At this point, the heat transfer curve transitions into the nucleate boiling regime, followed by the boiling regime, and the rate of heat extraction gradually decreases through both these regimes. As discussed earlier, die lubricant film formation starts at Leidenfrost temperature and continues on through the transition and nucleate boiling regimes; film formation is most efficient in these regions.

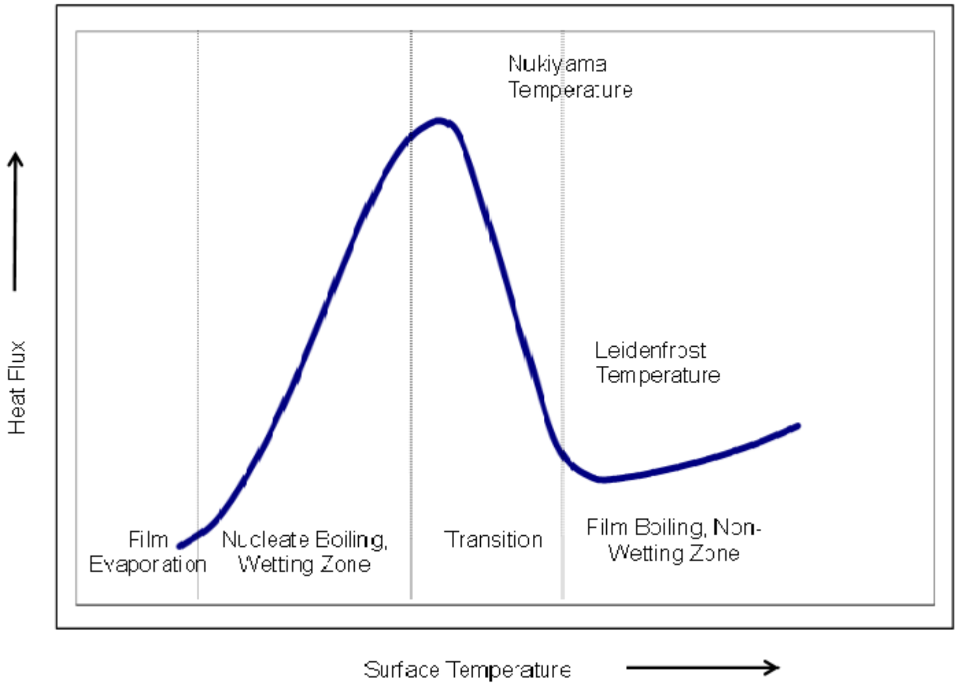

__Figure 1: Change of heat flux with temperature in forced convection cooling due to spray impingement.__

This cooling curve identifies the following functional ways that die lubricant technology can impact process cycle time:

1. Use of DLs that overcome the Leidenfrost barrier at higher die temperatures.
2. Use of DLs with short transition regime, so that CHF is attained in the shortest possible time.
3. Use of DLs with a high CHF point, for maximum heat extraction.

Once the die temperature is below the Leidenfrost temperature, DL spray makes physical contact with the die surface so that the droplets break up and spread out, thereby starting the DL film formation. The maximum temperature at which the film formation starts is referred to as the wetting temperature. One way to reduce cycle time in die casting, and thus increase productivity, is through use of short wetting time DL. Development and incorporation of new chemistries in DL technology is helping to meet the reduced cycle time demand. Figure 2 shows the wetting temperatures of some DL technologies supplied to the industry. The requirement of high wetting temperature should be tempered with the required process conditions. A high wetting temperature DL would not work in a die casting process that is optimized to work with low temperature DL. A few possible downside consequences are increased buildup and incomplete cavity fill.

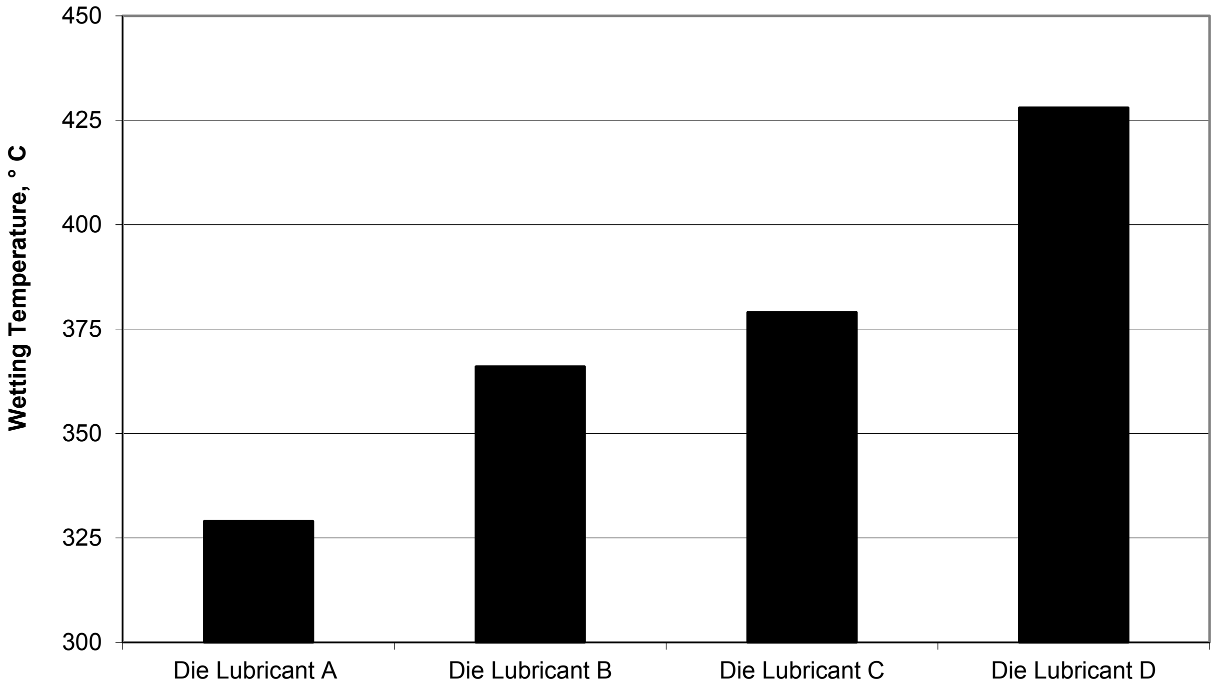

Figure 2: Wetting temperatures of a select few die lubricants.

As explained in the preceding section, one way to reduce cycle time is through the use of faster wetting die lubricants. An important point to note is the dependence of wetting time on die temperature[5]. Figure 3 shows the wetting temperature vs. die temperature for two die lubricants. As expected, the time taken to breach the Leidenfrost barrier increases with increasing die temperature. Since not all areas of the die are at the same temperature at any given time, the wetting time, and subsequent heat extraction by die lubricant, will vary in different areas of the die. Therefore, there is a paramount need for a die caster to understand the die temperature profile in order to make appropriate adjustments to spray equipment to compliment the internal cooling of complex dies. On a related note, a caster must be cautious no to over-dilute their die lubricant. As has been noted above, die lubricants have customized performance properties, excessive dilutions negatively affect the positive wetting, spreading and cooling performance attributes associated with a die lubricant. This, in turn, can lead to increased spray volumes, lower functionality and longer cycle times.

Another important DL performance parameter that will change with die temperature is the amount of film formation. At high die temperatures, a lesser amount of DL film is laid down on the die surface as compared to low temperature areas of the die. Figure 4 shows this phenomenon for a commercial die lubricant supplied by Chem-Trend. This property has an important consequence on solder prevention, in-cavity buildup and ex-cavity buildup. All of these can lead to machine downtime and consequent loss of productivity. Thus, in order to get the high productivity demanded by business conditions, a die caster must complete surface temperature mapping of their dies to understand the temperature profile of their die.

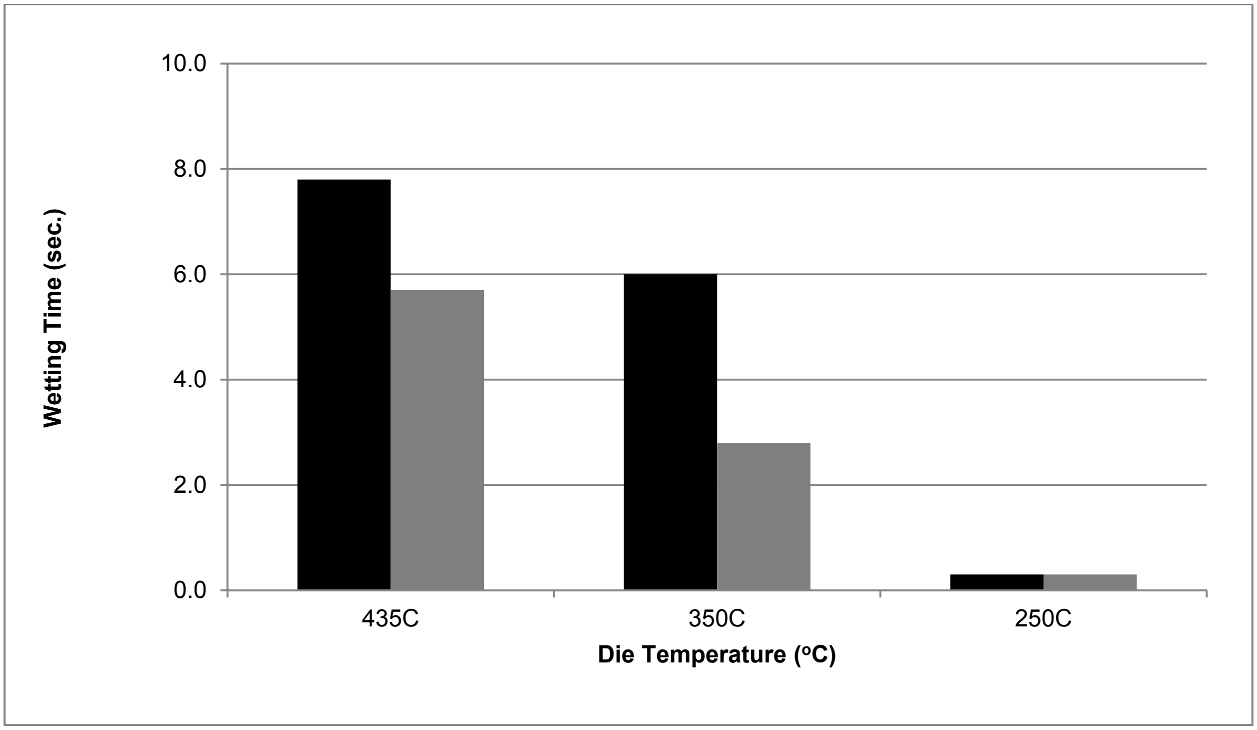

Figure 3. Effect of die temperature on wetting time for two commercially available die lubricant technologies

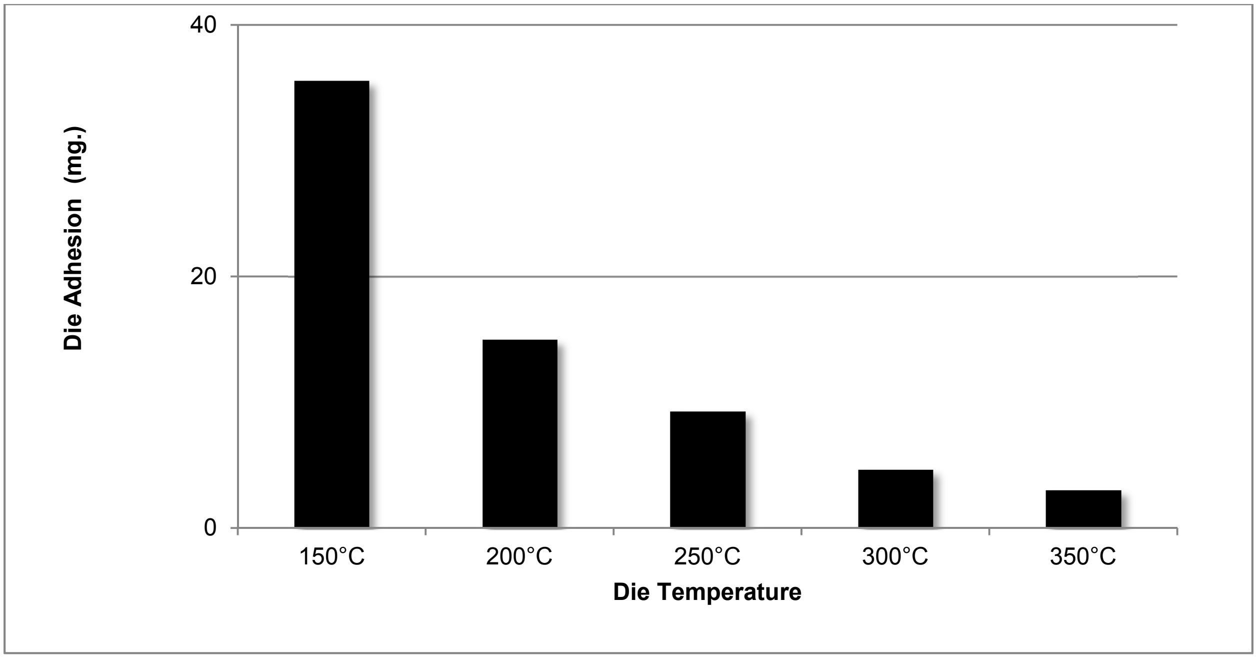

Figure 4. Effect of die temperature on film formation.

Field experience at many different die casting companies in different regions of the world has shown us that a wide temperature range exists between different areas of the same die, sometimes in excess of 200°C variance. Die designers have limitations with placement of internal cooling lines, and thus it is unavoidable for hot and cold spots to be present in the casting cavity. Due to the reasons explained in the previous section, the DL film will form rapidly in the cooler sections of the die and will form at a much slower pace in the hot regions of the die. For a casted part to be released from the die, an optimum (not excessive) amount of lubricant film has to be formed on all sections of the die cavity. The need for sufficient film formation at all temperatures on the die places another high technical hurdle on well-designed die lubricants. Die Adhesion Index tests are a good way to measure the performance of different DLs for meeting this criterion. A comparison of select generations of DL technologies supplied by us to the industry is shown in Figure 5.

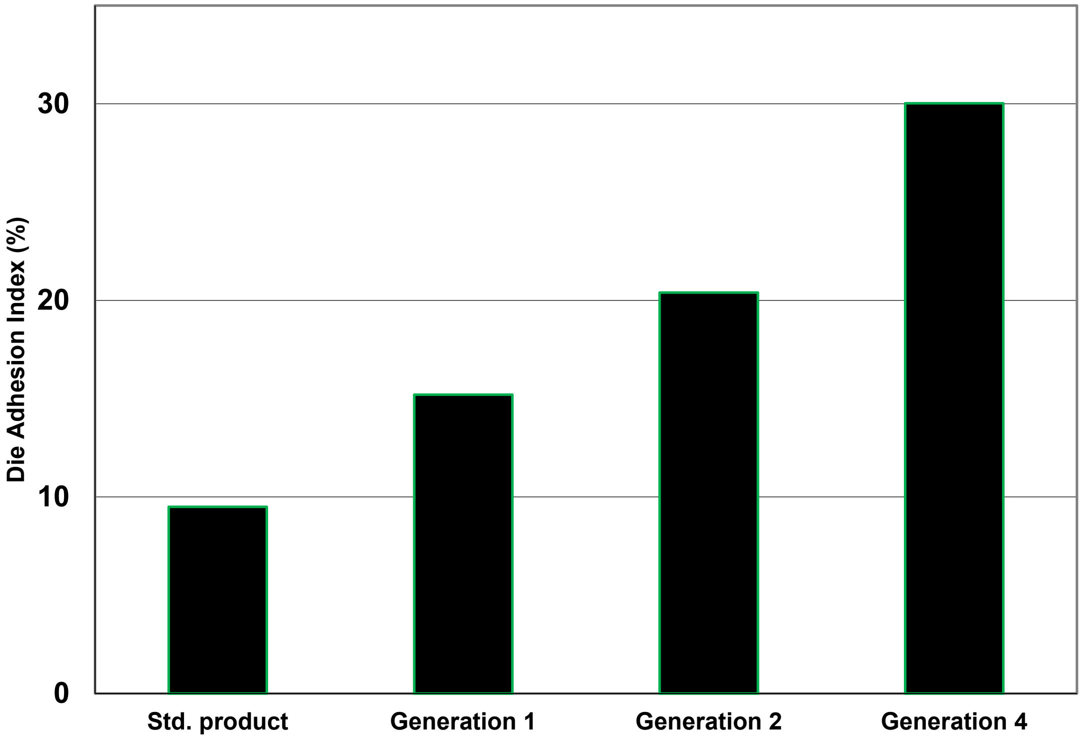

Figure 5: Die Adhesion Index of key die lubricant generations.

The Y-axis of this graph plots the ratio (in percent) of the weight of the film formed at 350°C to that formed at 250°C. This test is performed under controlled laboratory conditions and it correlates well with the actual on-die performance. These two temperatures were chosen as the majority of the die areas in aluminum casting are around 250°C, while the hot spots on the die area are around 350°C. A ratio close to zero indicates very little film formation on hot regions of the die, and a ratio of one represents an equal amount of film formation in hot regions and cold regions of die. The challenge for DL suppliers is to maximize this ratio. The higher the ratio, the more uniform the die lubricant film formation.

As the dies have become more complex in recent years, there has been an increased demand placed on DL film to uniformly spread on the die surface. The spreading ability of a DL is a key performance attribute needed to produce intricate, complex parts. Not all areas of the die cavity receive direct spray from the spray nozzles, but DL is expected to spread onto the unsprayed regions and make a film on those regions as well. Figure 6 shows the spreading behavior of some commercially important die lubricant chemistries. The challenge for DL technology companies is to develop technologies which will aid spreading of the DL film at the high temperatures encountered on die surfaces.

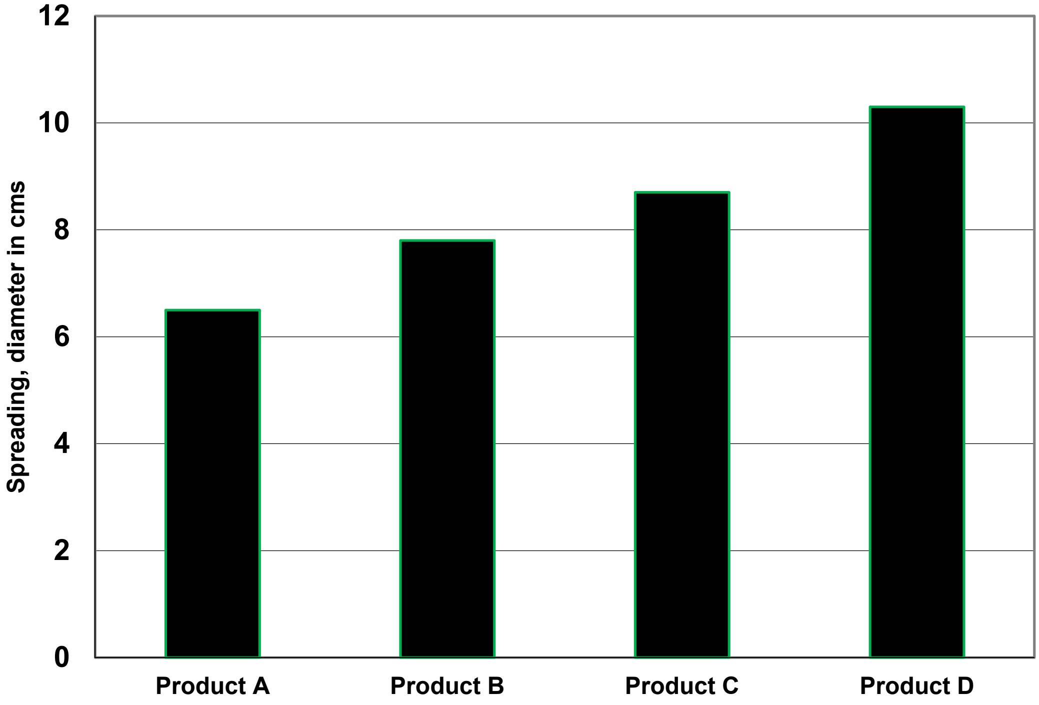

Figure 6: Spreading ability of some commercially important die lubricants.

Another detriment to high productivity faced by die casters is machine downtime due to unplanned maintenance. One way to improve productivity is through use of new DL technologies incorporating higher solder protection, better lubrication of moving parts (like core and ejector pins) less carbon buildup, etc. These trends have been discussed in detail in previous sections. A new area of focus that has become apparent in recent years is to have DL chemistries which would produce lower ex-cavity buildup.

There is no good way to protect ex-cavity areas, vents, etc., of the die from overspray of die lubricant. These areas of the die are significantly cooler than in-cavity areas, and consequently DLs have a tendency to accumulate in these regions. If this accumulation happens in vent areas, then evacuation of air/gasses is impeded, and leads to gas porosity in casted parts. Furthermore, accumulation in the retainer area of the die can lead to improper closing of dies and subsequent safety problems (such as die spitting).

This accumulation in ex-cavity areas forces die casters to shut down the machine, and clean the buildup through mechanical means. An area of focus in recent years has been to develop DL chemistries which reduce this accumulation/buildup. Figure 7 shows a comparison of overspray accumulation of a standard technology product with that of latest technologies. As is evident from the graph, these newer technologies can reduce this buildup by a very significant amount. Field results have matched with our expectations from lab results.

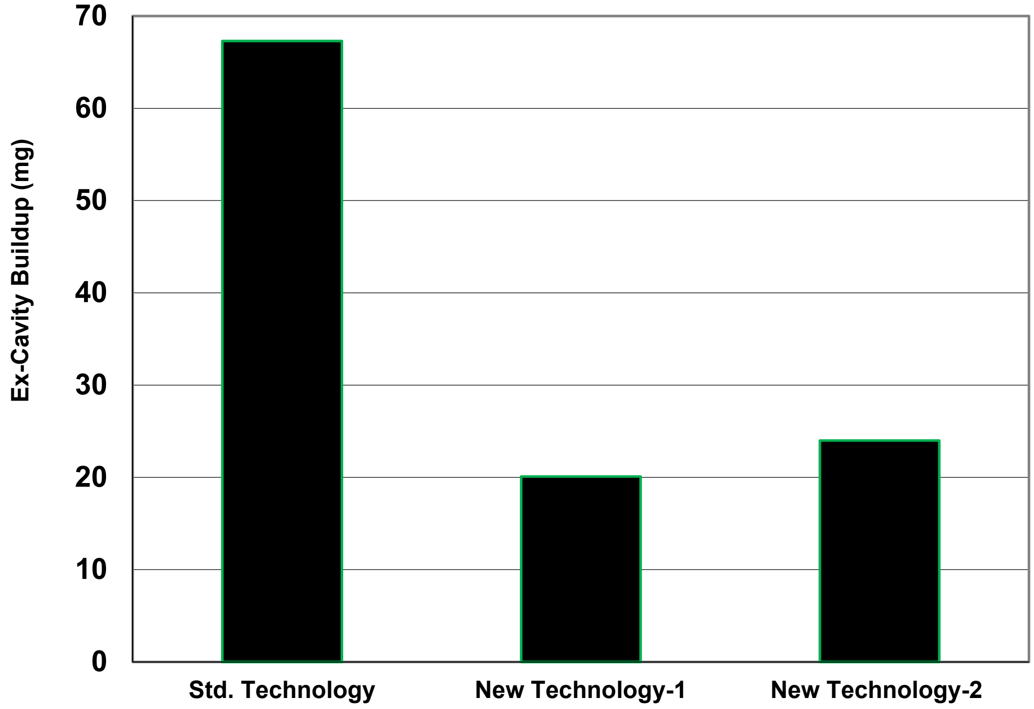

Figure 7: Comparison of ex-cavity buildup properties of standard technology with those of new generation die lubricant technologies.

Multiple die casters are now utilizing this new low ex-cavity buildup technology. As an example, one caster was producing a truck oil pan with a shot weight of around 9 Kg with A 380 alloy. The caster was using a conventional DL at 1:80 dilution. Die temperature, before spray, ranged from 230°C to 400°C. According to the customer, in-cavity buildup was acceptable, but ex-cavity buildup was poor with the conventional DL. Furthermore, the customer rated both release and solder protection as acceptable with the conventional DL. The caster conducted a 200 part trial run utilizing both the current and new technologies. A metal template was built to collect DL buildup from the flange area of the cover and ejector dies. Figure 9 shows the region of interest from where DL buildup was collected. Care was taken to collect DL buildup material only from the area enclosed by the template and no process variable was changed.

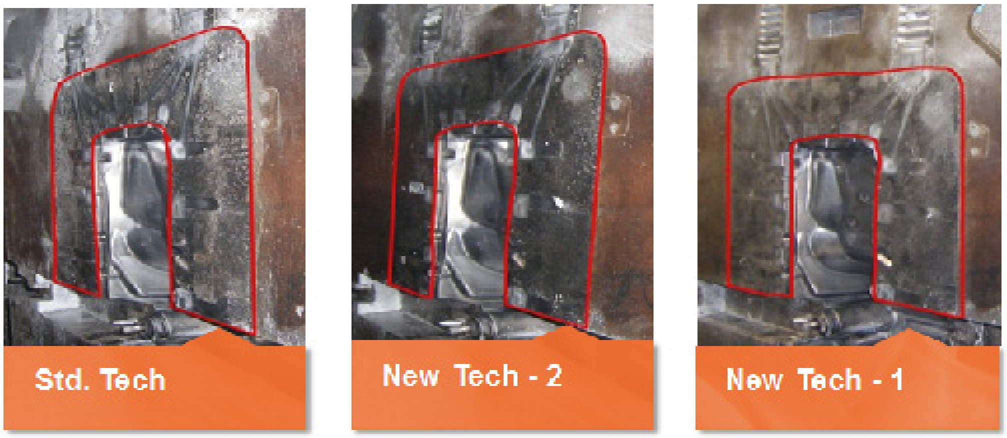

Figure 8: Pictures of dies from trials for low ex-cavity technology. Picture on left is for die sprayed with conventional technology die lubricant, picture in middle and right is for die sprayed with new technology die lubricants.

The actual amount of buildup collected after the trial with new technology DL was almost 50% less than the material collected with the conventional technology. In addition to these benefits, the customer judged release, solder protection, and in-cavity buildup to have improved to an excellent rating from an acceptable rating. In some cases, this new technology has been able to reduce the ex-cavity cleaning frequency from 2-3 times a shift to once in eight shifts.

CONCLUSION

HPDC technology is rapidly evolving to meet new market trends. This in turn is pushing the introduction of new die lubricant technologies into the die casting market. These new technologies yield higher productivity in die casting plants through the ability to help casters produce high-quality and complex castings at high die temperatures while reducing machine downtime.

As the leading, global supplier to the HPDC industry, Chem-Trend has a commitment of partnership to the industry to continually develop advanced die lubricant chemistries that will improve die casters' quality, productivity and profitability.

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ABOUT THE AUTHOR

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Dr. Asthana has Masters in Chemical Engineering, and Ph.D. in Polymer Science from University of Akron. He has published numerous articles on polymers. He sits on the editorial board of International Journal of Fuels and Lubricants, and is member of Society of Automotive Engineers technical committees on Lubricants. He is a member of Society of Lubrication and Tribology Engineers, American Institute of Chemical Engineers, and American Chemical Society.