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Characterization of spray lubricants for the high pressure die casting processes

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ABSTRACT

During the high pressure die casting process, lubricants are sprayed in order to cool the dies and facilitate the ejection of the casting. The cooling effects of the die lubricant were investigated using thermogravimetric analysis (TGA), heat flux sensors (HFS), and infrared imaging. The evolution of the heat flux and pictures taken using a high-speed infrared camera revealed that lubricant application was a transient process. The short time response of the HFS allows the monitoring and data acquisition of the surface temperature and heat flux without additional data processing. A similar set of experiments was performed with deionized water in order to assess the lubricant effect. The high heat flux obtained at 300 °C was attributed to the wetting and absorbent properties of the lubricant. Pictures of the spray cone and lubricant flow on the die were also used to explain the heat flux evolution.

1. Introduction

During the die casting process, the dies are sprayed with a lubricant, dies are closed, and liquid metal is injected into the die cavity under high pressures. Net shape parts are produced after subsequent metal solidification and cooling, dies are opened, and parts are ejected. Lubricants facilitate the ejection of the finished product, reduce the soldering effects (Fraser and Jahedi, 1997), and cool the dies (Piskoti, 2003). The lubricant film thickness on the die surface was used to quantify the lubricant adhesion performance. The lubricant film thickness was usually determined indirectly, using optical or X-ray techniques (Fraser and Jahedi, 1997) or die temperature (Piskoti, 2003). Channels are drilled into the dies for heating or cooling in order to maintain temperature levels that will yield progressive solidification and uniform cooling of the parts. In order to minimize casting defects, the metal delivery and heating/cooling systems are designed based on the analysis of heat transfer and solidification phenomena. One of the parameters required for the die design is the amount of heat removed during lubricant application. Data on heat transfer coefficients or heat flux evolution during lubricant application are used to characterize the heat removal capability of lubricants and perform numerical simulations of the die casting process (Liu et al., 2000).

Spray cooling was mainly studied for other applications than the die casting process. There is significant effort on the study of spray impingement for power electronics using water and refrigerants, and steel industry using water and oils (Stewart et al., 1995). Few predictive models for heat transfer exist other than those for critical heat flux (CHF) (Pautsch and Shedd, 2005). A CHF correlation that accounts for volumetric

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Nomenclature

df/dt	weight fraction rate (1/s)
DTA	differential thermal analysis
DTG	first derivative thermogravimetry, i.e., df/dt
f	weight fraction
h	heat transfer coefficient (W/m^2 K)
HAZ	heat affected zone
HFS	heat flux sensor
q''	heat flux (W/m^2)
T_A	ambient temperature (25 °C)
T_S	plate surface temperature (°C)
TGA	thermogravimetric analysis

flow rate, fluid properties, spray angle, droplet diameter, and subcooling was proposed by Mudawar and Estes (Mudawar and Estes, 1996). For low superheat, Hsieh et al. (Hsieh et al., 2004a) presented correlations for heat flux removed as a function of dimensionless parameters such as droplet Webber number and liquid Jacob number. Although this information would be useful for the formulation of new lubricants, it is difficult, if not impossible, to use correlations on boiling, droplet or water sprays developed for other processes. For example, boiling in droplets deposited on a hot surface differs from that observed in a pool boiling, since heat transfer relies on the contact area between the droplets and surface (Cui et al., 2003). The correlations obtained in the spray impingement studies are not applicable to the lubricant application process since there are significant differences between these processes. These differences include:

- Different superheat: in the die casting process, the superheat varies from 150 to 400 °C, while for power electronics and steel quenching is approximately less than 150 and larger than 1100 °C, respectively;
- different surface materials;
- different flow rates;
- transient versus uniform: most of boiling studies are for uniform state processes while the die lubrication is very transient, lasting from 0.2 to several seconds.

In the steady-state boiling three distinct regions exist: forced convection and evaporation, nucleate boiling, and critical heat flux, while in the transient cooling, the film boiling and transition boiling play an important role (Hsieh et al., 2004b). Gonzalez and Black (Gonzalez and Black, 1997) found that the interaction between spray and buoyant jet issued from a heated surface would reduce the droplet velocity.

The first principle approach, which was used to investigate spray cooling for other industries, is useful to investigate the fundamental phenomena and assess the effect of numerous parameters, but it would be difficult to implement in a plant environment. Other techniques, such as visualization had been recently used for the study of spray cooling. For low superheats, an array of individually controlled microheaters mounted on a transparent silica substrate was employed (Horacek et al., 2005). The spatial distribution of the heat flux was obtained at constant surface temperature while visualization and measurements of the liquid–solid contact area and the three-phase contact line length were made using an internal reflectance technique (Horacek et al., 2005). For die lubrication, the interaction between powder lubricants and molten alloy was observed with high-speed video system (Kimura et al., 2002). The result of in situ observation revealed that an enhanced insulating ability was due to formation of thin gaseous film between molten alloy and die by vaporized wax.

In most studies on the lubricant application effects, heated plate systems that mimic the die casting dies were employed and temperature data were obtained using thermocouples that were embedded into the plates (Lee et al., 1989; Garrow, 2001). The heat transfer coefficients (or heat fluxes) were obtained using either simple data extrapolation or inverse heat transfer procedures. In some of these studies, the data were recorded at low frequencies, e.g., only two data points per second were taken in Liu et al. (Liu et al., 2000). Due to the thermocouple response time, the temperature data could be very different than the actual temperature. In order to avoid cumbersome analysis of the data, such as performing inverse heat transfer analysis or accounting for the thermocouple response time (Reichelt et al., 2002), a sensor was used by Sabau and Wu (Sabau and Wu, 2007) for the direct measurement of heat flux. In addition to the heat flux data, the sensor provided data on the surface temperature, enabling the computation of the heat transfer coefficient. The temperature distribution of the average heat flux for water spray, which was presented by Sabau and Wu (Sabau and Wu, 2007), was similar that for the well-known pool-boiling curve, validating the use of these sensors for the direct measurement of heat fluxes under conditions specific to the die casting process.

In this study, a complementary effort to the first principle approach was undertaken to characterize the lubricant performance. The lubricant behavior was evaluated using thermogravimetric analysis (TGA), heat flux sensors (HFS), and infrared imaging. The Diluco 135™ lubricant, which was supplied by Cross Chemical Company, Inc., was used in this study. This Diluco lubricant was formulated for magnesium castings. Based on the information provided by the manufacturer, this lubricant was formulated with refined oils, natural and synthetic polymers, natural and synthetic waxes, wetting agents and emulsifying agents in order to aid in the mold release process. A dilution ratio of 15:1 for the water:lubricant mixture was recommended by the manufacturer.

In the second section, thermogravimetric analysis differential thermal analysis (DTA) was used to determine lubricant decomposition characteristics since these properties of the lubricant are important for its performance and casting quality. For example, if the lubricant vaporizes fast and at low temperatures, the molten metal would make contact directly with the die material and lubricant would not fulfill its function. On the other hand, if the atmosphere in the die cavity would include significant amounts of volatile decomposition products, there is higher probability of gas entrapped into the molten metal, giving rise to defects that would decrease the casting quality. In the third section, the results for the heat flux and surface temperature, which were measured using a heat flux sensor, were presented. During the experiments, the distance between the spray nozzle and plate was held constant.