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THE ROLE OF AUTOMATION IN EXPLOSION PREVENTION IN SHEET INGOT CASTING

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Abstract

Over the past decades, sheet ingot production has evolved from completely manual systems using float and diptube and steady-eddy metal level control to more sophisticated automatic systems that have primarily been introduced for improved safety and process consistency. The reliability of these systems has allowed the adoption, in specific cases, of a complete "hands-off" cast start-up procedure that has entirely eliminated the need for operator intervention during this critical phase of the cast. These systems have not only reduced the probability of explosion through less process variability during the start-up phase, but have also decreased the possibility of injuries that could be caused by a DC explosion. This presentation will highlight the evolution of the use of automation for sheet ingot casting in Rio Tinto Alcan (RTA) as well as the need to expand the "hands-off" approach to other casting processes such as billet and T-ingot casting.

Introduction

Fabrication of the first sheet ingots using the book mould technology in the 50's has quickly moved to a more productive casting process called Direct Chilled or DC, where, contrary to the book mould technology, water is in direct contact with the solidified aluminum.

At the beginning, the control of the DC casting parameters was essentially manual. Operators controlled water flow, casting speed, etc., making process repeatability poor by today's standards. In the absence of basic automation, the proximity of water to molten aluminum also represented a significant danger of explosion, especially during the start-up phase, putting at risk the operators closely supervising the process around the DC pit.

During the 70's, the main casting parameters were controlled in an automated fashion to bring more process consistency, repeatability and, without any doubt, a decreased potential of human error that could cause molten metal-water explosions.

During the 80's and 90's, further automation was eventually introduced by the addition of automatic molten metal level control in the moulds and by the introduction of pre-programmed alarm limits that would automatically stop a cast in case of abnormal conditions and thus, prevent possible molten metal explosion.

Nowadays, several sheet ingot casting facilities are equipped with automation systems that allow a complete "hands-off" operation, thus requiring zero intervention from operators at the start of the cast, during steady-state and at the end of the cast period. From a safety standpoint, physically removing the operators from the vicinity of the casting pit is probably the best solution to prevent burns or serious injuries resulting from a potential explosion.

This paper aims at presenting the evolution of automation systems used in the sheet ingot casting process. Secondly, this paper will expose the best practice to which Rio Tinto Alcan has adhered to in order to minimize the risk of burns and injuries caused by molten metal explosion during sheet ingot casting.

Sheet Ingot Casting Principles

The DC casting process set-up comprises a mould-bottom block assembly where molten metal is fed via a trough and a metal distribution device.

As shown in Figure 1, the solidification process relies on:

1) The primary cooling exerted by the mould face in contact with the molten metal. The heat extraction thus obtained is sufficient to generate a solid metal shell, and represents about 5% of the total heat extraction required by the process.
2) The secondary cooling obtained by the water flow directly impinging onto the solidified shell. This cooling provides 95% of the heat extraction required by the process.

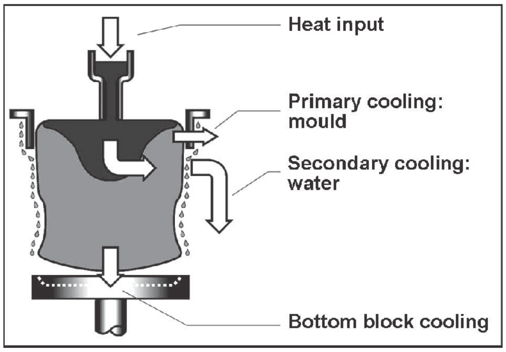

Figure 1. DC casting process.

The cast start-up phase is by far the period during which the risk of molten metal/water explosion is the greatest. The cooling conditions must be controlled precisely to avoid excessive cooling resulting in too much butt curl. As shown in Figure 2, an excessive butt curl amplitude or rate during the start-up phase can lead to the formation of a gap between the mould face and the ingot shell and potentially cause a "run-over" of molten metal that would fill this gap. This can create two situations:

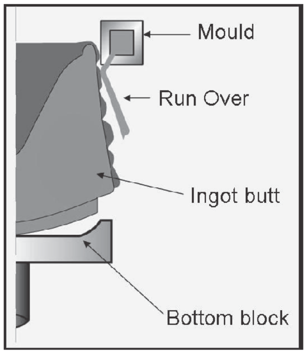

Figure 2. Formation of a gap between the mould and the ingot butt curl.

1) The "run-over" metal will spill along the short face of the ingot and fill the space between the bottom block and the ingot butt (see Figure 3). Because this area is flooded with water, a significant explosion can be triggered.

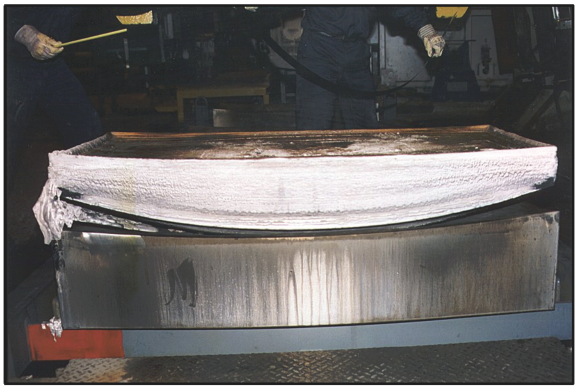

Figure 3. Run-over of metal on bottom block.

2) A so-called "hang-up" where the "run-over" metal will wedge the ingot being cast against the mould face and prevent its free downward movement (on one or both sides). While this is occurring, the bottom block will continue its descent resulting in a complete loss of contact with the bottom block. Thus, a significant loss in heat extraction will occur between the bottom block and the ingot butt (see Figure 4).

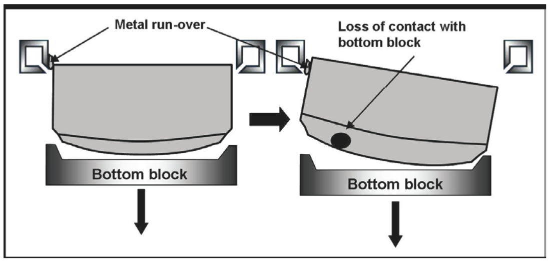

Figure 4. Schematic view of a hang-up.

As a result of this loss of contact, hot molten metal fed in the sump may remelt the bottom of the ingot, allowing molten metal to be in direct contact with the water on the bottom block surface. The result can be catastrophic and a forceful explosion can occur.

There are "hang-up" situations where the ingot will release itself from the mould face. The ingot butt will fall onto the bottom block surface and if the height of the fall is large enough, may expose the molten metal pool in the head of the ingot to secondary cooling water. This creates conditions that could trigger a strong explosion.

Conversely, insufficient cooling during the start of the cast can result in the remelting of the ingot shell and the potential run-out of metal into the secondary cooling water curtain or jets. This can also result in a forceful molten metal-water explosion.

These examples are illustrative of the severity of the explosions that can occur. The Aluminum Association (AA) has been collecting data on molten metal explosions since 1980. Several companies subscribe to this voluntary reporting, and all names are withheld to preserve confidentiality. The AA statistics show that in the 1980 to 2002 period, 34% of all the incidents reported are attributed to sheet ingot casting, and account for 30% of all the reported fatalities [1]. More particularly, 78% of the sheet casting-related incidents occur during the start-up phase. Ingot hang-ups accounted for 54 incidents which resulted in 32 injuries including seven serious and one fatality.

Evolution of Automation Systems

Early DC Machine Automation

As mentioned in the introduction, automation of the DC process for sheet ingot casting started in the 1970's. In the early stages of DC technology, control of the casting parameters was manually performed: adjustments to the water flow and speed ramping were done by the operators using a control panel located very close to the casting pit. The introduction of programmable logic controllers provided better repeatability of key casting parameters and minimised deviations from set targets, allowing the operations to be as safe as possible [2].

Although this step change was a key milestone in casting facility automation, other parameters still required a significant level of manual intervention. It was the case for the metal level control in the mould which was maintained using a float and diptube arrangement (see Figure 5). This was a self-controlled device that would rely on the buoyancy of a refractory float positioned on the surface of the liquid metal pool in the ingot head. When the metal level increased, the float would rise and close the opening between its upper inner surface and the tip of the diptube, choking the flow of molten metal. Conversely, if the metal level was decreasing in the mould, the float would lower and the gap between its upper inner surface and the tip of the diptube would be greater, thus allowing more metal to flow.

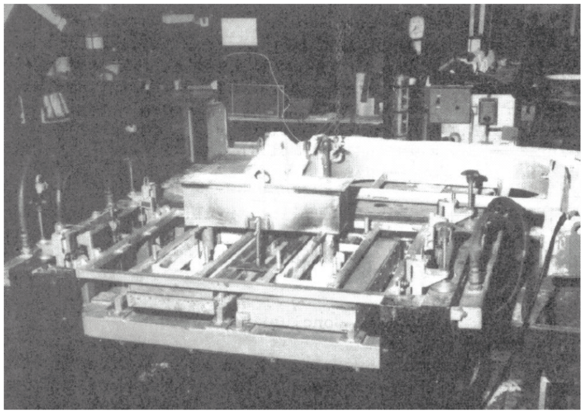

Figure 5. Float and diptube level control system.

However, despite this apparent self-control function, this metal level control device did not offer any possibility of regulating the filling rate of the bottom block during the start-up phase of the cast. It was also very sensitive to blockage. For example, the level control capability could be impaired when metal would unintentionally overflow the float and leave solid metal interfering with the vertical movement of the float. During those frequent cases, the operators had to physically move the float to remove the solid metal pieces interfering with the float movement. This level control system was also sensitive to the levelling of the trough, which would result in uneven filling rates as a function of the ingot position along the trough.

The float and diptube system were combined with a large head screen distributor to allow a more even molten metal distribution into the ingot head. This glass cloth screen required rapping by the operators in order to ensure proper priming with molten metal.

This level control system required a lot of attention and intervention from the operators to ensure that it would function adequately. Several operators would typically be required to stand very close to the DC pit and watch for any float malfunction. As a consequence, their exposure to molten metal, in case of an explosion during the start-up phase, was significant.

Steady-Eddy Level Control System

During the late 70's, several casthouses within the RTA organization replaced the float and diptube/head screen combination to adopt the so-called "steady-eddy" system (see Figure 6).

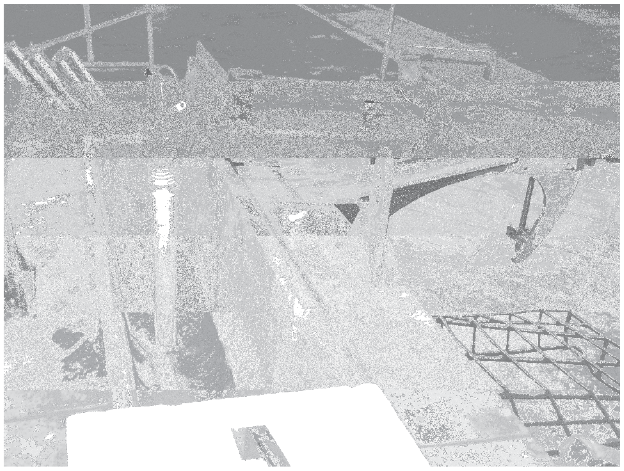

Figure 6. Steady-eddy metal level control system.

This system consists of a diptube into which a control pin is inserted. The pin is actuated to move vertically within the diptube and acts as a kind of needle valve with the controlling point at the very bottom end of the diptube. The pin is connected with a lever to a refractory block floating at the liquid metal surface. If the metal level is increased, the float will rise and close the pin in the diptube to reduce the metal flow via the cantilever rod. Conversely, if the metal level would decrease, the float would come down and the pin would open to allow more metal to flow. Metal distribution around the mould is obtained by the use of a "combo-bag" that does not require rapping for priming purposes.

This system is inherently less sensitive to trough misalignments, but it still requires constant supervision from the operators around the pit. Synchronization of the filling rate from mould to mould required frequent operator interventions. It was not uncommon to see operators working to ensure equal (more or less) metal levels in individual moulds during the bottom block and mould filling stage.

There have been a few instances where the manual operation of a steady-eddy has been the cause of ingot hang-ups or run-outs leading to a potential strong explosion and molten metal projections. The presence of operators close to the casting table dramatically increases the possibility of serious injuries related to the shock wave and to the metal projections that result from an explosion.

Automatic Metal Level Control

During the course of the 80's, with new upcoming casting technologies such as EM casting and low level casting, the industry started to adopt automatic systems aiming at controlling the metal level in the moulds during all stages of the cast [3,4,5].

Figure 7 shows an example of an industrial implementation of a molten metal level control system.

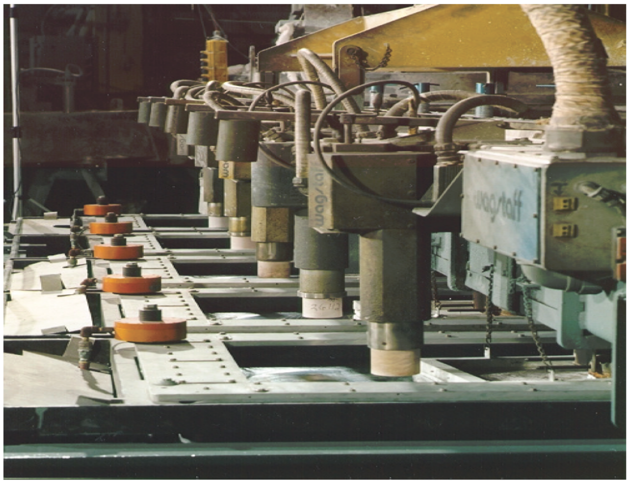

Figure 7. Automatic molten metal level control equipment.

The molten metal level measurement is achieved using three types of equipment:

a) Fixed capacitance sensors.
b) Moving capacitance sensors allowing constant distance between the metal and the sensor.
c) Single or double beam laser sensors.

In all cases, metal level data is fed to a PLC and enables a step motor/cam assembly to open or close the control pin in the diptube to either increase or decrease the metal level in the mould in a very similar fashion as the steady-eddy system.

This technology allows real-time monitoring of the metal level during the cast start-up phase allowing rapid detection of variations from process set-points. Depending on the magnitude and the duration of the metal level deviation from the target values, alarms as well as complete cast aborts can be triggered. The sensitivity of the automatic system can also be adjusted according to the cast start-up phase in progress. For instance, larger molten metal level deviations from the target can be allowed during the bottom block filling phase compared to those permitted during the subsequent mould filling sequence where the cooling water touches the ingot surface. In particular, if a sensor detects a loss of the metal level for longer than a pre-determined period of time, due to a run-out condition, the cast can be automatically aborted to avoid the risk of an explosion.

Along with molten metal level sensors, the pin opening is also monitored on a continuous basis. The movement of the control pin should be such that it smoothly controls the metal level in the mould. The deviation of the pin opening from expected values can also trigger alarms as well as cast aborts in specific abnormal situations such as:

a) Potential ingot hang-ups indicated by the absence of metal flow and the closed position of the pin for an extended time.
b) Run-out conditions where molten metal level loss will trigger a maximum opening of the control pin for an extended time.

When programmed adequately, the targets and temporization of the alarms will minimize the number of false alarms and trigger emergency stops when genuine abnormal conditions occur. In such cases, not only does the DC machine stop, but also the furnace tilt-back and proper closure of gates will be enabled to avoid further metal flow through the in-line treatment units to the casting pit.

During normal cast end procedure, the automatic system will read the ingot length cast and will tilt back the furnace so that the remaining metal will top up the ingot length to meet the exact customer specifications ordered.

Automation is not limited to metal level control in the moulds and to the end–of-cast procedures, but also governs the cast start-up sequence, opening up gates and detecting the presence of molten metal in the trough on its way to the casting pit using capacitance or laser-based sensors in the troughs.

"Hands-off"Operations

Automation packages were introduced in our facilities to allow operation of DC casting machines in a "hands-off" fashion from start to end of the cast, thus avoiding exposure of operators to molten metal explosion related risks.

These systems, including automation of furnace tilting, DC machine start-up together with the management of metal level control in the moulds as well as the cast end phase are all performed in a full automatic mode. In fact, in most RTA plants, starting a cast is performed from an explosion proof control cabin without having any operators outside the cabin and around the casting pit (see Figure 8). Some facilities have even installed hi-definition CCTV systems to allow monitoring of several critical areas where molten metal is present (furnace spout, trough, ingot heads, etc.) during the cast start-up phase.

The CCTV can also be used to troubleshoot cast start-up performance, and to visualize, along with the process data, potential abnormal situations occurring during the start-up phase, which could cause premature stoppage of the casts.

Figure 8. Explosion-proof control cabin for DC pit operation.

During the cast start-up phase, not only are operators situated remotely from the DC pit to observe the equipment and ingots being cast, but a large perimeter around the DC pit is delimited, and is no longer accessible by other people. It is thus impossible for maintenance or other non-operational personnel to be inadvertently present at the start of a cast and expose themselves to unnecessary risks.

Some plants have installed curtains at strategic locations close to the DC pit to stop possible metal projection from passing outside of the delimited area (see Figure.9). These shields will block metal projections in case of an explosion and protect pedestrians in authorized areas.

Figure 9. Protective curtains lowered at cast start-up to avoid metal projections in pedestrian zones.

Conclusions

Over the past decades, sheet ingot casting has evolved from a completely manual operation to a fully automated, "hands-off" operation allowing the complete withdrawal of operators from dangerous areas and thus eliminating the risk of exposure to molten metal projections in case of an explosion.

The systems in place manage abnormal situations potentially occurring - especially during cast start-up – and initiate cast aborts without operator intervention and without having to put the operators' judgement into play.

Furthermore, safety perimeters around the DC machines were put in place and enforced in the casthouse to ensure pedestrian safety from metal projections as far as 20 meters from the potential explosion location.

RTA is committed to this approach and will continue to invest effort and capital in order to ensure that 100% of all sheet ingot production is undertaken using the current best practices and the best available automation equipment.

This also applies to T-ingot production for which the exact same approach is proposed. Several RTA locations producing T-ingots have already converted to automatic casting systems such as the ones described for sheet ingot production. More conversions from manual operation to "hands-off" will take place.

Billet casting remains the most difficult DC process to convert to a "hands-off" operation. The multiplicity of the moulds involved during a cast makes automation more difficult. However, the smaller quantities of metal involved in billet casting do not make the process less prone to explosions. Although the best equipment preparation and casting practices are known as far as explosion prevention is concerned, explosions are still a very significant threat in extrusion billet casting [6]. The aluminum industry clearly needs to apply the same safety guidelines as sheet ingot casting but in a customized fashion to take into account specificities of the billet casting process. In order to do so, strong leadership of change is required along with support from the equipment suppliers that can design and implement equipment tailored to this need.

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