

Preventing Molten Metal Explosions in Smelters

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Abstract

Molten metal safety in many smelters is an afterthought. This mistake comes back to haunt them later when molten metal incidents occur in the potlines, casthouses, and rodshops. Not only are production stoppages commonplace but workers are being injured and killed. There is a gap in literature detailing molten iron and aluminium safety in a smelter. This paper will explain why explosions occur with aluminum as well as iron. This paper will review specific molten metal incidents and explain how they could have been prevented. Common reasons for molten metal explosions in smelters will be discussed. Failure to consider both molten iron and molten aluminium safety in smelter not only endangers workers but the smelter as a whole.

Keywords: Explosion, Molten metal safety, Molten aluminium, Molten iron.

1. Introduction

Explosions occur when molten metal reacts with water in either a physical reaction or a chemical reaction. Water can be present visually in its physical form (e.g., puddle of water) or invisible to the eye in a molecular form. Physical reactions are the most common type of molten metal explosions. A physical reaction results in a change in texture, shape, temperature, and state, without a change in the composition.

When molten metal covers water in a physical reaction, the water molecules expand as it turns from a liquid to a vapor. Water expands by a factor of 1 600 when it turns into steam [2]. "It expands because the bonds holding water molecules to each other are broken in the transition from water to steam, and the steam behaves like a gas -- it takes up much more space." This rapid expansion results in the molten metal being propelled away in distances as great as 30 meters. A fire or injury or death can occur when the molten metal lands on a combustible material (e.g., cardboard, wood, etc.) or on a worker. In a physical reaction the mass of the metal remains unchanged after the explosion. For example, if 500 kg of molten metal explodes afterwards there is 500 kg of solidified metal spread around the workplace. Physical reactions are common with all types of metals, aluminium, iron, bronze, steel, etc.

Chemical reactions involving aluminum and water are our industry's worst nightmare. These types of explosions can destroy a plant as well as injure and kill countless numbers of workers. They occur because aluminum is a very reactive chemical element that has a strong chemical attraction for oxygen with which it is almost always attached in nature (e.g., Al₂O₃). Just as aluminum requires a large amount of energy to break the aluminum-oxygen bonds and produce metallic aluminum in a reduction cell, that energy will be released if aluminum is able to recombine with oxygen. The energy released from one kilogram of aluminum that fully reacts with oxygen is equivalent to detonating 3 kilograms of trinitrotoluene (TNT) [14].



These explosions can be very large destroying workplaces, injuring and killing workers. Shockwaves radiating out from the workplace can be detected by earthquake monitoring stations.

As stated before, in a physical reaction the mass of aluminium after an explosion does not change. But, in a chemical reaction the mass of the aluminium is turned into aluminium oxide and energy. The aluminium oxide in the form of powder commonly billows up in a mushroom like cloud from the workplaces is common in chemical reaction explosions.



Figure 1. Common physical reaction explosion involving a drain pan.



Figure 2. Aluminium oxide mushroom cloud from 2016 Noranda Aluminum chemical reaction explosion in the USA.

2. History of Explosions

From the very earliest days of the aluminium industry, explosions were common and varied in size and destruction. These explosions were viewed by the industry as an individual corporate or plant issue, not as a larger industry issue. The communication between aluminium companies that is commonplace today was rare. Companies would not share information of an explosion at their workplace with others in the industry. That narrow focus would ultimately change due to catastrophic explosions. There are too many explosions to review them all. This paper will briefly mention specific explosions that in this author's opinion had notable consequences for our industry.



Figure 3. 1957 Georgia, United States.

One of the earliest photos of explosions that this author has is from Georgia, United States in 1956. Three workers were killed and twelve others were injured. The force of the explosion broke trees two kilometers from the workplace. The company owner was quoted by a local newspaper afterwards that “the blast was caused by the dumping of wet scrap aluminum into melting pots containing molten metal” [5].

The defining incident in our industry occurred on September 11, 1967 in Muscle Shoals, Alabama (USA). Prior to this incident molten metal explosions were considered an individual company's issue. This catastrophic explosion forced the companies in our industry to move their focus from individual companies to our industry as a whole. A large explosion occurred at the Reynolds

Aluminum smelter, “So forceful was the blast that it crumbled a 200-foot section of a concrete wall, snapping and twisting steel beams, and shaking the ground for a radius of (10 km)” [1]. Four workers died in the explosion and over 40 workers were injured. In the months afterwards the Aluminum Association (USA) would organize the aluminum companies to jointly fund research into molten metal explosions. This cooperation between aluminium companies resulted in numerous industry funded studies focusing on molten metal explosions. The results of each study were shared within the industry. Overtime the studies expanded to other safety topics. The industry most recently has worked together to test fire resistant clothing fabric and boots in molten bath.

On October 8, 1975, an explosion at a billet casting station killed one worker and injured another in the USA. It was determined that two out of four bolts holding the casting station’s starting head base (aka bottom block or doghouse) to the platen was left off. There was a metal hang up in the casting table during casting. The casting cylinder descended pulling the platen and starting head base down. However, because there was a metal hangup, one or more billets were stuck to the mould on the casting table. Normally, the rectangular shaped starting head base is secured with four bolts, one on each corner. But, on this day, maintenance personnel only secured one end with only two bolts started to lift up. As the platen descended the end of starting head base not secured began to raise. Eventually, the stuck billets let loose resulting in the starting head base slamming down onto the platen resulting in an explosion.

The aluminium company theorized the force of the starting head base hitting the platen resulted in a shockwave traveling through the molten metal triggering an explosion. The company told others in the industry about the severity of the explosion and their theory on how the explosion occurred. Which resulted in research investigating the impact shockwaves have upon generating molten metal explosions.

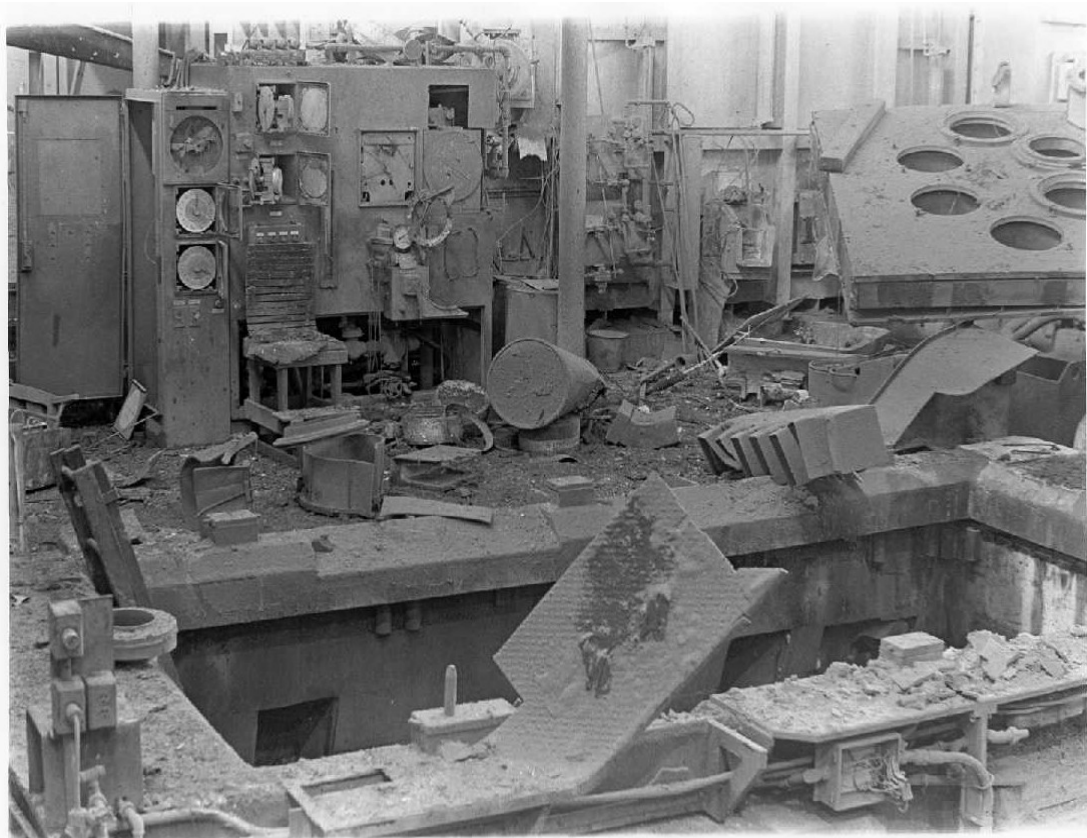


Figure 4. October 8, 1975, Explosion that occurred due to starting head base not bolted down on one end.

On March 24, 1986, a terrible storm hit an aluminium plant in Europe. At least two explosions occurred in the casthouse. Lightning was recognized as the initial factor of the explosion. As one witness from that night stated: “On that day there was stormy weather when lightning fell on the gas pipe, which immediately severed, allowing the release of the gas and the explosion of the furnace” [9]. Subsequently, a second explosion occurred in the casting pit “by the action of liquid aluminum on water.” Examination of the damages to the casting pit and to the surrounding buildings, evidence was gained that the TNT equivalent was about 200 kg and 100 kg respectively for the first and second explosions. Pieces of equipment of the casting line were thrown up to 700 meters [10]. Four workers and over 36 workers were wounded in the explosions. This incident brought awareness and education to European companies who lacked the awareness and education to acknowledge the severity of molten metal explosions.



Figure 5. August 19, 2007, Explosion occurred when furnace lining failed and contents emptied into casting pit.

An explosion occurred on August 19, 2007, in the aluminum busbar casting branch of an aluminium company in Asia. The governmental investigative report after the explosion stated “During the shift production, the inner sleeve of the furnace hole brick (made of silicon carbide) was missing (whether it fell off or broken, because all the insiders on the scene were killed in the accident, and the site repeatedly searched for the inner sleeve of the furnace brick without success, and it is difficult to judge the true state of the inner sleeve before the accident), resulting in the furnace hole becoming larger and the molten aluminum out of control, a large amount of high-temperature molten aluminum overflowed into the chute and flowed into the circulating cooling water return pit on the south side of the distributor of the No. 1 16-tonne ordinary aluminum ingot casting machine, in a relatively confined space. The molten aluminum reacts with water and at the same time produces a large amount of steam, the pressure rises sharply, and the energy gathers and explodes.” [12]. The explosion destroyed the casthouse resulting in 16 deaths

and 59 injuries (including 13 of which were serious injuries). This tragedy was the first large explosion in China. It made international news and shocked the global industry by its sheer destruction and large death toll.



Figure 6. August 4, 2015, Noranda Aluminum explosion.

On August 4, 2015, explosions were reported at the Noranda Aluminum casthouse in New Madrid, Missouri, USA. The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) said the cause of the explosions appeared to be the failure of a furnace lining and the leaking of the molten aluminum contacting water in the vent pipe of the direct chill casting pit. Thirty-three employees were injured in the explosions, most suffering eye and throat irritation and ringing of the ears. One worker, an overhead crane operator, injured his back descending an emergency ladder after the explosion knocked the power out to the building.

This explosion was notable for the force of the explosion destroying the casthouse. The explosion was the first step that ultimately led to the shuttering of the entire Noranda Aluminum corporation. This incident shocked many aluminium companies because the explosion resulted in the shuttering of a billion-dollar business.



Figure 7. June 20, 2022, Casthouse explosion in Italy.

Annually, since 2000 there has been one or more catastrophic molten metal explosions around the globe. Foundries, potlines, casthouses, die-casting manufacturing plants have blown up resulting in the destruction of workplaces, fatalities and injuries to countless workers. In first half of 2024 three casthouses have blown up resulting in the deaths of over 15 workers and the injuries of over 50 workers. The casthouses were in Taiwan, Italy, and China.

A valuable resource for companies who process molten aluminium is the Aluminum Associations (USA) Molten Metal Incident Reporting Program. Started in 1980 it arose from a request within the industry to develop a program where companies could learn from one and other on an anonymous basis about molten metal explosions. For the past 42 years this program has been a valuable safety tool for companies around the globe. There are currently 200 reporting plants worldwide that forward a detailed report when they experience an explosion in their workplace. All reporting companies receive a detailed annual report listing where in the workplace the explosions occurred (e.g., transfer, charging, casting, etc.).

2.1 Research in Molten Aluminium Explosions

The earliest scientific studies on molten aluminum explosions took place in the 1950's. Companies were investigating how to prevent molten aluminium explosions from occurring in their workplaces. Companies conducted research for internal company use and usually did not share their findings within the industry. However, one researcher, George Long with Alcoa, published a landmark article in 1957 "Explosion of Molten Aluminum in Water - Cause and Prevention". The opening sentence of that publication resonates 67 years later. "Accidental spilling of molten materials into water or onto a wet surface is a serious industrial hazard." Mr Long pioneered research into molten aluminum explosions and many of his findings remain valid today. He and his associates at the Alcoa Technical Center developed a testing apparatus for molten metal explosions. The procedures were well documented and subsequent studies followed his design for testing apparatuses [15].

Alcoa Technical Center researchers Paul D. Hess and Kenneth J. Brondyke published in 1969 *Metal Progress*, "Causes of Molten Aluminum-Water Explosions" [16]. They built upon the foundation George Long laid a decade prior. Hess & Brondyke concluded through a series of tests that they understood the mechanism involved in the explosions. They proposed "efficient ways"

to prevent explosions on the substrates molten metal could come into contact. They also defined the differing levels of explosions. The scientists' "*Explosion Rating Force Criteria*" including definitions and nomenclature of the differing levels of molten metal explosions are still in use today [16].

Guidelines	Force 1	Force 2	Force 3
Property Damage	None	Minor	Considerable
Light	Minimal	Flash	Intense
Sound	Short cracking	Loud report	Painful
Vibration	Short and sharp	Brief rolling	Massive structural
Metal Dispersion	< 4.5 m	4.5–15 m	> 50 m

Figure 8. Force level of explosions.

Paul D. Hess and Ron Miller, Alcoa Technical Center researchers, headed an Aluminum Association sponsored research project in 1980. The project was undertaken "*to extend the margin of safety in casting operations by improving the engineering solutions to the inherently hazardous casting operations where molten aluminum and water are often in close proximity.*" It was during this study that epoxy safety coating Wise Chem E-212-F was tested and proved to prevent molten metal explosions in both physical and chemical reactions on steel, concrete and stainless-steel substrates.

In late 1995, thirteen aluminium companies funded a study at the Alcoa Technical Center administered by the Aluminum Association. The final report titled "*Investigation of Coatings Which Prevent Molten Aluminium/Water Explosions*" was released in 1997 [17]. This comprehensive research study determined (that previously tested) Wise Chem E-212-F coating and newly tested Wise Chem E-115 coating prevented molten metal explosions on concrete, steel and stainless-steel substrates.[17].

The Journal of Light Metals in January 2001 published "*Fundamental Studies on Molten Aluminum-Water Explosion Prevention in Direct-Chill Casting Pits*" by R. P. Taleyarkhan, Seokho Kim, and Calvin L. Knaff was published [18]. This research project, funded by the aluminium industry in conjuncture with the U.S. Department of Energy, developed an apparatus that could quickly test coatings on their ability to prevent explosions. The research findings confirmed the results of past studies [18].

3. Preventing Molten Iron Explosions

Incidents involving molten iron in rod shop departments can occur in a myriad of ways. Charging wet or damp metal into the melt can cause a physical reaction explosion. Workers can make mistakes during temperature taking, sampling, causing metal splashes. Splashes can occur if large pieces of charge material are dropped into a furnace. One furnace was fed by a conveyor belt that was approximate 1.5 meters from the opening. The workplace quickly learned that the distance of drop resulted in continuous molten metal splashing occurring. There have been reports of workers tripping and either falling into or accidentally stepping into a furnace. Lastly, carelessness during charging, can cause a bridging condition to occur. Commonly resulting in an explosion. To further understand how molten iron incidents occur in a rod shop. We need to review induction furnaces which are used to melt iron in smelters.

These electric furnaces have alternating current from an induction power unit flowing into a furnace and through a coil made of hollow copper tubing. Electrical current flowing in one direction through the induction coil creates an electromagnetic field that induces an electrical current flow in the opposite direction in the metal charge inside the furnace, producing heat that rapidly causes the metal to melt. Running a powerful electric current through the coils creates a

magnetic field that penetrates the refractory and quickly melts the metal charge material inside the furnace. The copper coil is kept from melting by cooling water flowing through it. It is this cooling water that is unique to an induction furnace compared to a combustible fueled furnace design. If the flowing water in the cooling tubes contacts the surrounding molten iron an explosion could occur [7].

This scenario can occur if improper charging of the furnace results in bridging. Bridging occurs where the charging material forms a cover or hat above the molten metal. If the temperature in the area below the bridging becomes superheated. The molten metal will quickly deteriorate the surrounding refractory and penetrate the water-cooling coils. This scenario can also occur during excessive stirring in the bottom of the furnace. Due to the small metal mass and high-power density, they will combine with the high metal temperature to cause rapid lining erosion or possibly complete refractory failure.



Figure 9. February 20, 2022, Cleveland, Ohio, USA foundry explosion.

This is a very dangerous condition commonly resulting in an explosion. This occurred on February 20, 2022, at a foundry in Cleveland, Ohio in the USA. The explosion destroyed the foundry, initially killing one worker and injuring fifteen workers. "What happened was a massive amount of water got into the furnace, and then it somehow got under mixed in with molten metal trap and created a massive explosion," said Howie Eberts, Area Director, OSHA's Cleveland Office [13].

According to the Occupational Safety & Health Administration's (OSHA) investigation, the company did not make sure the required lockout/tag-out procedures were followed during the inspection. Investigators with OSHA also said they learned that the explosion happened when employees were inspecting a water leak in a furnace and did not have evacuation orders in place.

4. Preventing Molten Aluminium Incidents

Molten aluminium incidents commonly happen in two departments in a smelter: potline or the casthouse. Incidents have also been reported during the transportation between those two departments. The Aluminium Association's Molten Metal Incident Reporting Program (MMIR) annual report is a useful reference for determining the most common tasks/procedure or localized areas where an incident can occur.

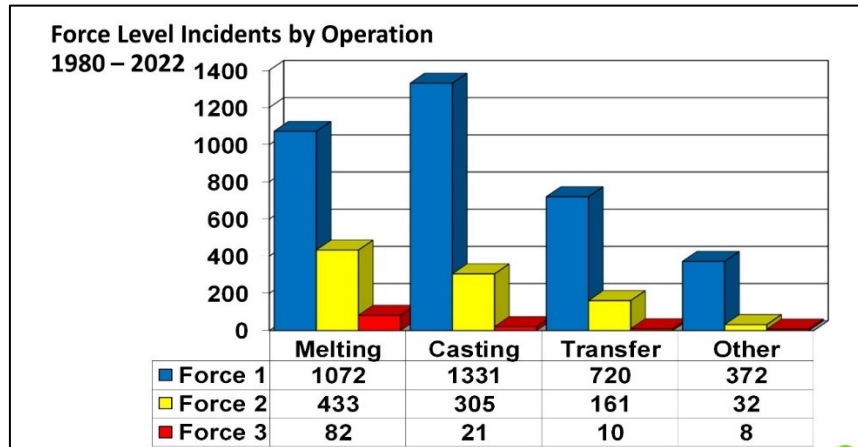


Figure 10. Force Level Incidents by Operation for 1980-2022, September 2023.

Explosions occur most commonly when molten aluminium escapes its holding spot (e.g., furnace, pot, casting mold, trough, crucible) and comes into contact with water on bare steel, concrete, and stainless steel. Preventing the potential escape is the first line of defense. Maintaining furnaces, troughs and crucibles linings to prevent premature failure is an important preventive measure. Properly preparing and coating drain pans is another important safety practice. There were nine explosions from wet/drain pan or molds reported in the 2022 Molten Metal Incident Reporting Program Final Report [19].

5. Drain Pans

Drain pans are an overlooked area that have generated a considerable number of explosions. The MMIR lists 348 reports of explosions from drain pans over its history. The Guidelines for Handling Molten Aluminum states “Drain pans should be clean, dry and warm before the cast is started.”

Drain pans fall into two uses: production and for emergency. Production drain pans are used throughout the shift and after use are emptied after each cast. Emergency drain pans are used infrequently. Some casthouses state their emergency drain pans are used only a few times during the year. This use is usually the result of an aborted cast, issue with a filter box, or other irregular event.

Drain pans need to be properly blasted and oiled. The Aluminum Association’s Casthouse Safety Workshop states the following products can be used on the drain pans:

- Canola oil (non-food grade can be used)
- Other DC casting lubricants
- PyroDraw HVI46 (Pyrotek)
- Total Nevastane Clear 68 (pharmaceutical grade),
- Shell Morlina S2BL22
- Phillips 66 Spindle Oil 22.

A growing number of companies have applied Wise Chem E-212-F or E-115 to their emergency drain pans, ensuring they will be ready for use and there is no need to be oiled.

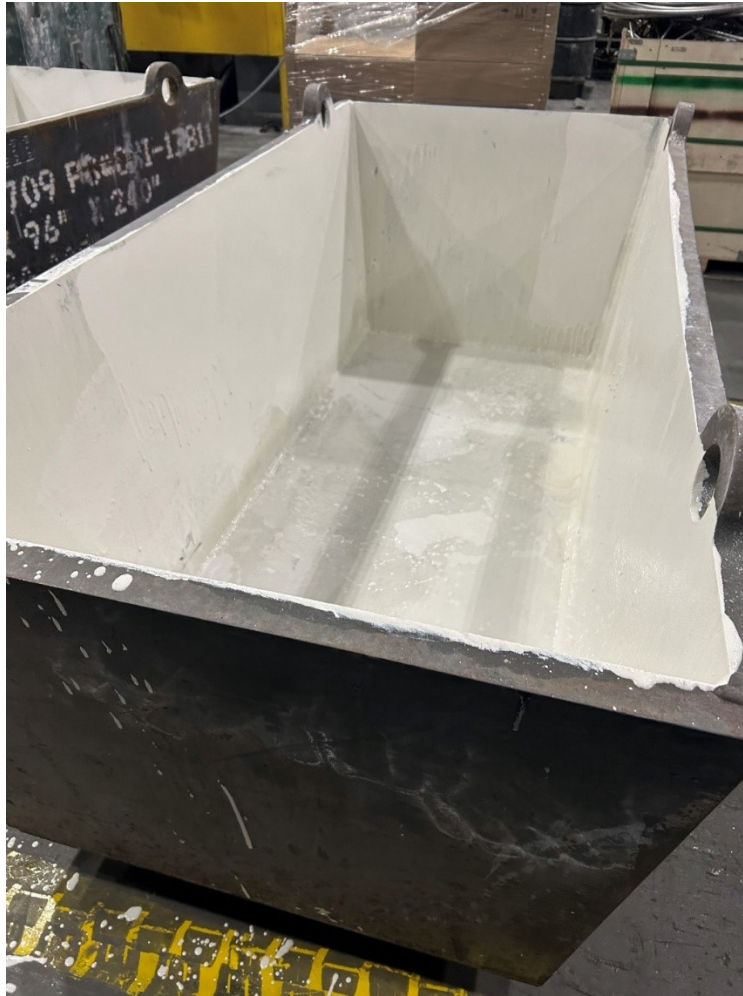


Figure 11. Emergency drain pan coated with Wise Chem E-115.

Lids should never be placed on drain pans. Companies reported explosions in drain pans propelling the lids through the workplace. In addition, lids on drain pan prevent visual inspection to ensure the drain pan is free of contents prior to use.

One common incident plants need to prevent is when one shift cracks a drain pan and sets it aside. The following shift cracks another drain pan and replaces it with the previous drain pan saying the “crack(s) is not too bad.” When the drain pan is needed for use an explosion occurs because of moisture in the crack. The Guidelines for Handling Molten Aluminum state “cracked pans should be repaired or replaced.” Pans should be inspected and removed from service if cracks are larger than 3 mm. If the cracked pans cannot be properly repaired, they should be cut in half to prevent any future shifts from using them.

6. Hand and Furnace Tools in Casthouses

The MMIR has reported over 45 explosions from “wet tools” in 2022 and more than 400 over the past 45 years. Hand or furnace tools were the number one reason reported for thirteen transfer explosions in 2022. These tools are used on every shift for a variety of tasks from sampling, skimming, alloying, etc. If that tool is “wet” an explosion will result. Tools can become wet either through exposure to moisture (stored outside, or near an open door), or when tools come into contact with chemical salts. Chemical salts are found throughout our casthouses in fluxes. In colder climates, salt is used on roadways and tracked into the casthouses on the sole of the workers’ footwear. Salts naturally attract moisture from the air. Hand tools become contaminated

with salts when they come into contact with a horizontal surface. Salts can be found on a myriad of horizontal surfaces including on top of DC casting station, concrete floor, edge of troughing, etc. It is impossible to visually inspect a tool for salt contamination, because salt contamination occurs on a molecular level that is invisible to the naked eye.

The location of hand and furnace tools is often overlooked in smelters and can have a contributing factor in molten metal incidents. Architects during the design of casthouses do not consider where to store furnace tools. For example, furnace tools are large heavy tools that are infrequently used by forklifts. With lengths of 10 meters long and 1-2 meters wide casthouse departments are forced to store furnace tools wherever possible. Outside exposed to the elements or inside near a truck door are common areas to store furnace tools.

All tools furnace and hand should be stored indoors and away from any open doors. This will minimize any moisture from the outside weather (e.g., rain, snow, dew) landing on them. Some workplaces install hand tool storage next to furnaces to assist in keeping the tools warm and free of moisture.



Figure 12. Example of how to properly store molten metal hand tools.

When a molten metal tool is contaminated with salt, moisture (e.g., H_2O) is chemically bond to the salt. If that tool is not properly heated an explosion will occur if inserted into molten bath. To prevent this all tools, no matter their size, should be preheated prior to use. All tools also must be free of any solidified metal prior to use too. Solidified metal can have cracks and voids that can hold moisture.

Commonly hand tools are constructed within a workplace. Due to weight concerns most hand tools are constructed with hollow tubing versus solid round bars. Workers have been injured when a hand tool made of hollow tubing heated up when inserted into molten bath. The air trapped inside expanded and eventually the pipe exploded. These incidents can be prevented by drilling

vent holes into the shaft as far away from the tool head as possible. This allows the air inside the tool to properly vent and prevent pressure building up when placed into a molten bath.

7. Hand Tools in Potlines

Wet tools in the potline are common source of molten metal incidents. Potline tools must be preheated prior to insertion into the bath. The presence of chemical salts in the potline department is low so any moisture on the tools comes from ambient conditions. Most potline buildings are designed to allow maximum airflow with sidewalls filled with vents/windows. It is these openings that will allow occasional moisture (e.g., rain, dew, etc.) into potline. Tools are often stored along the walls near the openings and come into contact with moisture. Workers in a rush to complete the task may fail to follow the training to properly preheat the tool prior to inserting it into the bath.

Another contributing factor to molten metal incidents in the potline department is one specific tool, green wood sticks. The “green” means that these sticks are typically fresh from cutting and have some internal moisture in them. These sticks are used by workers to kill anode effects in the pots, causing bubbling that helps eliminate gases below the anodes and dissolve alumina from the anode cover.



Figure 13. Green wood sticks storage.

Green wood sticks vary in type from some tree saplings to bamboo. Typically, 3-4 meters in length to allow the worker to stand away from the pot while using the green stick to penetrate the bath. As can be seen in the photo, green sticks combust and ignite. Overtime the length of the green stick will decrease. This can become a hazard because the worker now has to lean or place their body over the bath to perform the task at hand. Workplaces should have a minimum length of green sticks to be safely used. Green sticks should be discarded when they are shorter than the minimum length.

There have been reported incidents of workers stepping into a reduction cell (pot). This might occur when a worker is performing a task where their body needs to be near the pot. Or their body must be over the pot if the worker is performing a task with a shortened green stick. When a worker loses their balance, instinctually places their foot in front to stop themselves. This may result in the worker placing their foot into the bath. A minimal length of green stick for use will prevent a worker from placing their body over the molten bath.

Wet sampling tools is another source of molten metal incidents in the potline. In 2022 the MMIR reported 3 incidents where workers received “minor” injuries from inserting a wet sampling tool into the bath. All sampling tools, no matter the department, should be free of solidified metal. As the solidified metal may have cracks in it hiding moisture that is nearly impossible to drive off. Proper heating to drive off any moisture would eliminate the possibility of a molten metal incident occurring when placed into the bath.

8. Other Molten Metal Incidents in Potlines

Other common molten metal incidents reported to the MMIR in the potline departments vary in location and tasks being performed. Each has the possibility of halting production and injuring and killing workers.

Pot leaking through cracked linings and potshell damage and through cathode bars openings are a nightmare for potline departments because the entire volume of the cell might escape to the area below the potline. There have been incidents where the leaking molten bath encountered moisture (e.g., water, snow, etc.) and bare concrete resulting in an explosion.

Splashes from crucible transports stopping suddenly is a twofold hazard [11]. Molten metal will spill on to the moveable equipment and the work floor surface. The transport vehicle might take fire and the driver be injured. Nearby pedestrians are at risk and any nearby combustibles (e.g., wood pallet, cardboard box) may ignite.

Wet floors can result in an explosion if molten metal is splashed onto the surface. It is very difficult to prevent wet floors in potlines. Smelters must therefore require proper personal protection equipment (PPE) for any individual entering the potline department. Workers performing tasks with sampling tools or wet green sticks need to be educate on the importance of making sure their protective visor is down to prevent molten metal contacting their face during an explosion.

Wet pans in potlines have been reported as a frequent source of explosions to the MMIR. Dealing with wet pans is challenging due to the length and design of the potline building. As previously stated, the walls of potline buildings are commonly vented to allow for air movement. These vents also allow moisture to enter the department landing in empty pans. Potline departments rarely preheat of pans as casthouse departments commonly do. Potline personnel performing tasks that require pans to be used need to visually inspect the pans prior to every use. Any visual moisture should result in the pan being set aside and quarantined from use.

9. Transfer Incidents

Transfer incidents involve two common tasks: interplant means within the smelter, and movement outside of the smelter. Movement inside the smelter most often involves the transfer of crucibles between the potline and casthouse. Most incidents are commonly associated with crucible carriers stopping or turning suddenly. The sudden movement results in a sloshing or wave effect in the crucible. If there is no lid on the crucible the molten metal can escape.

Interplant transport from potline to casthouse is done around the clock at smelters. The distances from potlines to casthouse vary in length but the hazards of other vehicles, pedestrians, potholes, driver fatigue, sudden stops, and excessive speed can be contributing factors to molten metal spills and splashes. One trend observed in smelters is moving crucibles without lids.

Numerous incidents occur when molten metal spilled from an uncovered crucible because of a sudden stop, pothole, or quick turn. All crucibles, no matter their size and distance travelled, should have a lid on to prevent splashing and spilling. Some smelters have also established dedicated roadways for transporting molten metal to casthouses.

There have been incidents where the crucible lining fails and molten metal breaks through the steel shell. Smelters have minimized this potential hazard by keeping the exterior of the crucible freshly painted. It is easier to see any damage to the steel shell if the exterior of the crucible is a uniform color versus a shell that is covered in dirt that may camouflage the damage. The use of inferred cameras provides smelters with valuable information if the internal ceramic lining is failing.



Figure 14. June 27, 2024, Owensboro, Kentucky, USA. Driver fell asleep.

Movement outside the smelter such as transporting crucibles to customers is increasing around the globe. Incidents are unfortunately increasing. Smelters quickly realize the differences if an

incident occurs resulting in a molten metal spill during interplant transport versus outside their gates in the surrounding community.

In some over the road instances, the truck driver died, and the molten metal spill set the roadway on fire. In one incident, in the United States, in 1986 *“A semi-tractor trailer overturned and spilled its load of molten aluminum on a car, killing two people in the auto [8].”*

Mechanical problems with the vehicle are commonly cited as a root cause during an accident. *“Inspectors in Canada, Mexico and the U.S. conducted 18 875 commercial motor vehicle inspections during Aug. 20-26, 2023 for the Commercial Vehicle Safety Alliance’s (CVSA) Brake Safety Week [4]. For the weeklong inspection and enforcement initiative, inspectors focused on the brake systems and components of commercial motor vehicles and submitted brake-related data to the Alliance. Of the total vehicles inspected, 13 % had brake-related out-of-service violations. (2023)”* This number is shocking considering the size and weight of fully loaded tractor trailer.

Travelling too fast for road conditions and speeding are two actions resulting from poor driver decisions that have caused accidents while hauling over the road crucibles. The Federal Motor Carrier Safety Administration in the USA states *“speed is a factor that increases the risk of being involved in a crash”*. Near Dortmund, Germany, in August 2015, an over the road transport struck the central reservation barrier or concrete median with such force the trailer containing three crucibles became disconnected from the tractor, spilled its contents and set the roadway on fire. Travelling too fast for the wet conditions was a possible contributing factor in that accident as well as many others [3].

Driver fatigue has been cited as a contributing factor in the accident in the photo above. After the crash the truck driver admitted to the responding police officer that he fell asleep while driving. No one was injured or killed in the accident. Governments have made “hours of service” rules for truck drivers to address fatigue. The U.S. Department of Transportation revised the hours of service rule in 2011. The net effect of these changes was to reduce the average maximum hours a driver could work per week from 82 hours to 70 hours. Aluminium companies can assist in preventing driver fatigue by minimizing shift changes for drivers and reducing mandatory overtime [3].

Smelters must realize the importance of drivers being familiar with their course prior to departing from the smelter with a molten metal. One wrong turn can result in an accident. It is dangerous to assume that a vehicle’s GPS navigation system can safely direct the transport to its destination. There have been numerous incidents where GPS directions contributed to the accident.

Additional roadway problems can include potholes, railroad crossings, roadway construction. In addition, the recent trend of installing traffic circles (runabouts) around our plants to eliminate roadway intersections has had the unintended consequence of making it very difficult to navigate them safely with an over the road crucible.

One notable accident occurred a road slick due to recent rain caused the truck to slide and eventually overturned. The crucible lid failed and molten metal flowed down the side of the dirt road into metal culvert (e.g., drainage pipe) that crossed under the road. The molten metal contacted moisture in the culvert and a series of explosions occurred. [16]

Traffic circles have become such a problem that a smelter declined a contract solely based on the numerous traffic circles that would have to be navigated to the prospective customer. The smelter felt the hazard was too great and that a truck might overturn due to the traffic circles.

Responsibility of transport varies from smelter to smelter. Regardless of who is legally responsible for the delivery of the molten metal to the customer, if an incident occurs the news media will only mention the smelter where the metal came from. It is important that smelters take control of safety during the transport of molten metal whether inside or outside of their smelter's gate.

10. Future Molten Metal Hazards

Every smelter is studying how to incorporate scrap into their processes to reduce their carbon footprint. The addition of scrap opens a new chapter in molten metal safety in smelters. Whereas remelt facilities have learned over time the numerous dangers associated with scrap. Smelters lack the knowledge and awareness to this hazard. In 2022, over 47 incidents generated from scrap were reported to the MMIR.

**Melting Explosions – Charge Material Involved
1980 – 2022**

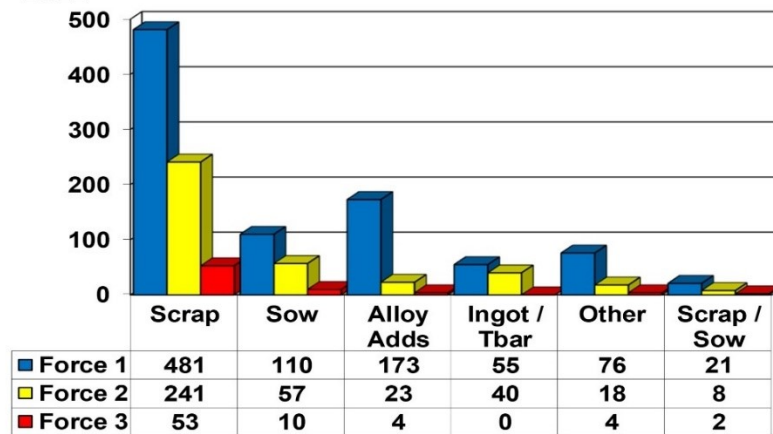


Figure 15. Melting Explosions by Charge Material 1980-2022, September 2023.

11. Safety Pit Coatings

The importance of safety pit coatings can not be diminished. Many of the catastrophic explosions that occurred could have been prevented with the proper use and maintenance of Wise Chem coatings. That previous statement is supported by the countless examples of similar incidents (e.g., bleedouts, furnace lining failures, etc.) where no explosion occurred in the workplace. Because these companies had applied Wise Chem in the localized areas where molten metal and moisture can meet, thus preventing the molten metal explosion from occurring.



Figure 16. Wise Chem E-212-F coated on a vertical direct chill casting table.

The Aluminum Association's "*Guidelines for Handling Molten Aluminum, Fourth Edition, May 2016*" [6] list Wise Chem E-212-F and E-115 as "*identified as having the ability to prevent explosions from bleedouts into the pit during casting*". For example, in a casthouse the pit walls and bottom under the vertical direct chill casting machine should be coated with Wise Chem. The maintenance pit adjacent to the casting pit as well as the maintenance pit under any furnaces should be coated with Wise Chem. All steel and stainless tooling should be coated with Wise Chem to prevent an explosion from arising. The floors and walls where crucibles are filled should be coated with Wise Chem.

Maintenance of the Wise Chem coatings is very important in preventing explosions. Scientists have theorized that Wise Chem prevents explosions by releasing gases when contacted with molten metal. A gas release pierces through the molten metal allowing for any trapped moisture to escape and not generate an explosion. Overtime and through repeated molten metal exposure Wise Chem coatings wear away exposing the bare substrate below. Wise Chem coatings must be applied directly on a substrate and no primer should ever be used. There are 50 years of scientific studies on Wise Chem preventing molten metal explosions. None of these studies had a primer underneath during any of the testing.

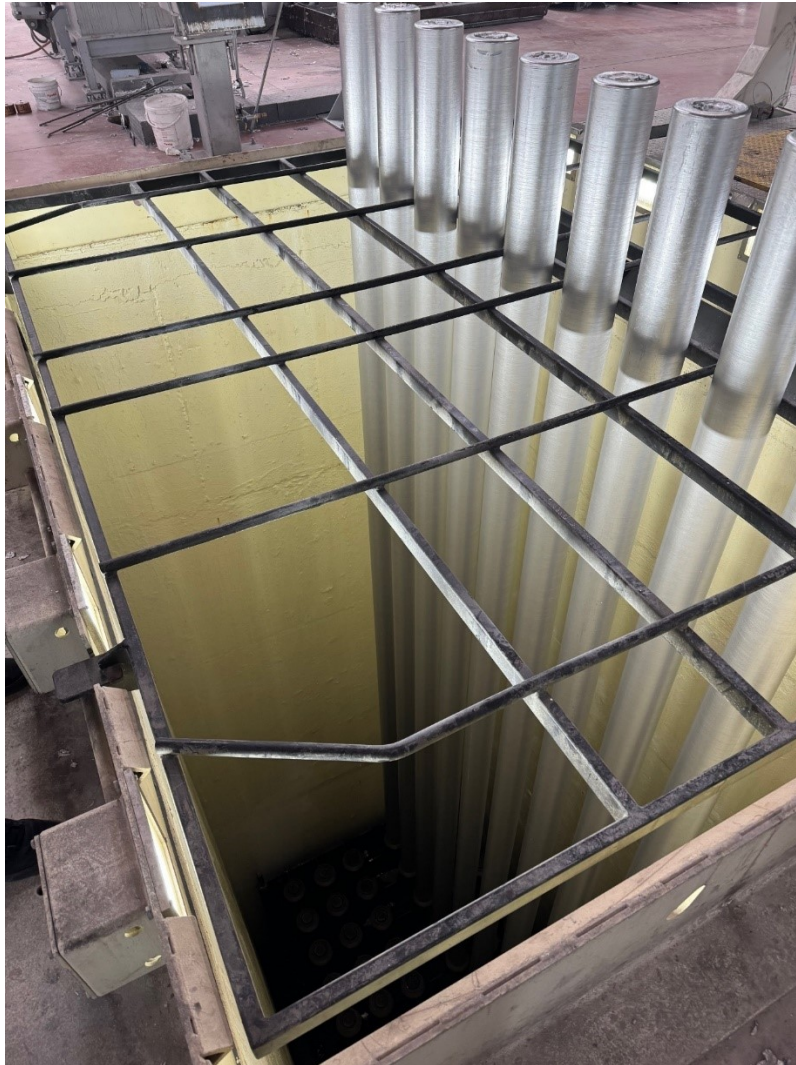


Figure 17. Wise Chem E-212-F coating casting pit.

Scientific studies have determined that some coatings actually promote an explosion upon contact with molten metal. The concern is Wise Chem coatings will wear away exposing any primer underneath and the primer may generate an explosion. Hess & Brondyke determined the minimum bare substrate area to generate an explosion on steel and stainless steel is 2 cm × 2 cm and on 4 cm × 4 cm on concrete. Some companies incorrectly calculate the minimum bare area by using multiple bare areas in the calculation. For example, four individual 1 cm bare areas on a steel tooling cannot generate an explosion, only one localized area that measures four square centimeters in area (or greater) should be repaired. Repair of damaged Wise Chem can be accomplished easily and quickly. First, begin by properly cleaning the bare area to remove any surface contaminants (e.g., grease, dirt, etc.). Second, apply the Wise Chem repair kit covering the bare area. Maintenance of the Wise Chem coating should be done on a regular basis once a month depending on the quantity and frequency of molten metal exposure. Wise Chem coatings turn brown upon contact with molten metal. That browning or charring will continue to provide protection even when the coating turns brown. It is only when the coating wears away exposing the bare substrate that inspection of the Wise Chem is warranted. The areas that are coated with Wise Chem needed to be recoated. It is imperative that recoating is fixed in a calendar. The recoating must be regularly scheduled. If recoats is not set on a fixed scheduled plants will wait till too long to recoat.

Table 1. The industry standard on recoating Wise Chem.

Location	Substrate	Recoat time
Vertical/horizontal casting pit	Concrete, steel, stainless	Concrete 16-20 months Steel/Stainless steel 12-16 months
Maintenance pit adjacent to casting pit	Concrete	20-24 months
Maintenance pit under furnace	Concrete	20-24 months
Tooling	Steel/stainless steel	12-16 months

Note: These time ranges can be shorten depending on the frequency and quantity of molten metal exposure as the Wise Chem will wear away with repeated contacts of molten metal.

Research into molten metal explosions began over seventy years ago. Through countless scientific studies the best practices for preventing molten metal explosions were developed and refined. Companies that had access to these best practices minimized molten metal explosions occurring in their workplace. These workplaces apply and maintain Wise Chem when they were first constructed. But some companies fail to follow the industry’s best practices toward safety and suffer the consequences. They fail to realize that the use of Wise Chem in preventing molten metal explosions goes back nearly 50 years. This lack of knowledge results in their workplace and workers unknowingly being placed in danger when a molten metal leak occurs.

12. Conclusions

From the beginning of our industry molten metal explosions occurred. Workplaces were destroyed, workers were injured and killed. For decades aluminium companies lacked knowledge on how to prevent these explosions from occurring. It was only after a horrific explosion in 1967 [1] that our industry came together to jointly fund a scientific study on this topic. Subsequent scientific studies determined how explosions occur and proved how to prevent molten metal explosions through the proper use and maintenance of specific coatings (e.g., Wise Chem E-212-F and E-115). The findings of the past studies are the foundation for our industry’s best practices toward safety.

Some aluminium companies lack awareness and education to molten metal explosions in their workplaces. As we have seen over the past number of years. It is these companies that suffer a catastrophic molten metal explosion. Their workplace is destroyed, their workers are injured and killed. Almost every workplace states after the explosion they were unaware of the hazard as they had been operating safely for years. If you do not follow the industry’s best practices toward safety, you are gambling with the viability of your business and the health and safety of your workers.

13. Acknowledgements

I would be remiss if I did not mention the countless number of workers who have died in workplace incidents as a result of a molten metal incident. As I wrote this paper, I reviewed numerous incidents that I previously covered. I learned a lot about the individual workers whose lives were cut short. Though I did not include their names nor their life stories in this paper. I will not forget their names, their photos, and their stories. It is my sincere hope that this paper will be used to make a workplace safer and prevent a recurrence.

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