Control of Melt Loss in the Aluminium Cast House

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Abstract

While it is generally acknowledged that dross generation should be kept to a minimum in the cast house, too often, the importance to maximize the aluminium content of the dross is overlooked. Some mistakenly believe that a low metal content is a good thing and that the aluminium is being kept in the furnace. In reality, this metal is most likely being lost due to insufficient cooling and thermiting.

Much can be gleaned from looking at the dross that is generated in a casthouse; in fact, the quality of dross can provide a good indication of the overall efficiency of the cast house operation. Even with low aluminium prices a reduction in dross generation within the furnace can provide huge savings per year. Effective dross management also results in better metal quality, improved fuel efficiency, prolonged refractory life and improved yield in the entire facility.

However we need to remember that dross is a 'by product' of melt oxidation. There are many activities within the cast house that can give rise to melt loss and the consequent dross formation and we will look specifically at the activities in the furnace within the context of this paper and also how certain actions immediately following skimming will assist in increasing the metal recovery from the dross.

In summary by careful attention to the equipment and process techniques around the furnace and the follow on dross management post skimming, significant cost savings and environmental benefits can be realized by cast house operations.

INTRODUCTION

Melt loss comes from a variety of sources within the aluminium cast house as a consequence of oxidation of the aluminium. As was reported by Taylor [1] oxidation of a fresh liquid aluminium surface to Al2O3 at 750 °C will occur if partial pressure of oxygen (Po2) is greater than extremely low pressures (equivalent to vacuums found in deep space !). This would suggest therefore that aluminium would just oxidize away but it doesn't due to the initial thin oxide formation formed immediately aluminium is exposed to air (oxygen) whether this be solid ingots, scrap generated or even the liquid aluminium surface in the aluminium bath in the furnace.

The graph below shows the main causes of melt loss within the cast house by area and as reported by Clarke and McGlade [2] when they carried out a survey of Australian and New Zealand primary smelter by far the greatest contributor is the Furnace area contributing almost 60% of the losses.

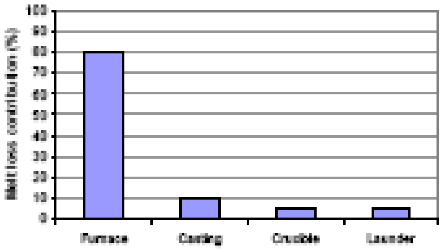

Fig1. Graph showing the estimated melt loss by area within the cast house[2]

Melt Loss within the furnace

When you actually look at the losses within the furnace by activity, as shown in Figure 2 below, as found [2] through interviews of the different plant in Australia and New Zealand, the filling operation in the furnace is by far the largest contributor at 80%, assuming the furnace is not melting scrap.

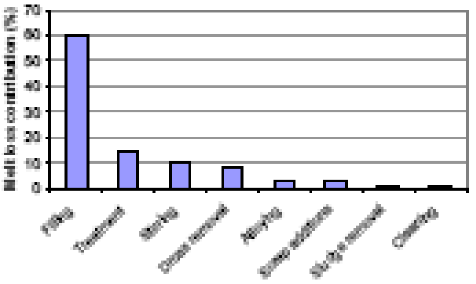

Fig 2. Graph showing the estimated melt loss by activity within the furnace.[2]

Clearly introducing scrap (and also alloys) into the equation can change things significantly also and we will briefly touch on this point.

The key is to avoid melt loss in the 1st instance and by careful attention to the process techniques and technologies in the furnace area and this can go a long way to minimizing melt loss both during the furnace cycle and immediately after skimming.

There are several major activities that contribute to melt loss and the consequent dross generation within the furnace as each has an effect of the oxidation process of aluminium. As has been reported in many papers [1,4,7], the oxide skin formed on the bath surface changes with time and is affected by many activities that then occur within the furnace, such as;

1. Liquid metal addition (from pot lines)
2. Scrap charging and types of scrap addition
3. Burner settings and control
4. Alloy additions
5. Flux additions
6. Stirring techniques
7. Skimming practice
8. Furnace bath temperature control

Technologies for reducing oxidation, dross generation

Opportunities for reducing melt loss and dross generation can come in a multitude of areas depending on the generators existing technology and practices. It should be recognized that furnace design, burner location and type all can have a major influence on dross generation and the appropriate style of furnace should be selected for the particular scrap types that will be melted or re-cycled, and this is relevant for the re-melt operation the re-cycler and the primary cast house alike. Furnace and burner designs are a topic in their own right and it is not the intention of the author to provide an in-depth review on this subject within this paper.

From reviewing the analysis of major melt loss contributors described in the findings by Clark and McGlade [3], it is interesting to look at possible solutions and technologies to consider in order to minimise melt loss.

Siphoning

In primary smelters the method by which the liquid aluminium is added to the casting furnaces has the largest potential affect on melt loss as discussed earlier. In a situation where liquid is poured into the furnace through a pouring spout in the side of the furnace, the cascading and turbulence effect created by pouring the liquid aluminium generates a significant amount of Al_2O_3. The normal protective layer that encapsulates the fresh liquid aluminium, does not exist, and this layer is continually being broken and the oxides being wrapped and mixed within the aluminium causing a significant amount of dross. It is reported that [3] that this type of liquid metal addition through pouring (and the greater the distance the worse the effect), can contribute between 0.8% and 2% of metal loss of the metal being transferred.

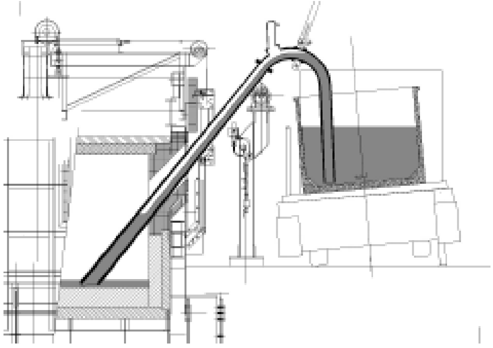

Fig 3 – Typical Smelter Siphon system in operation [3]

Not only do you see a larger amount of dross generation in the furnace as a consequence of this but the area around the pouring spout very quickly becomes built up with dross causing the covers or ‘hatch’ to not work effectively.

Siphoning when adding liquid to the furnace is a very efficient way of minimizing melt loss in a smelter’s casting furnace.

It is suggested that siphoning can reduce the melt loss in a furnace by as much as 75% [3] in a primary smelter casting furnace operation. Figure 3 below shows a typical siphon operation.

Scrap Type and Quality

There is an old rule in the aluminum industry that for every 1% of contamination charged into a melting furnace, there will be at least an equivalent 1% melt loss [2]. The scrap type and makeup will therefore make a significant difference with regard to dross generation. While it is not always possible to choose the type of scrap that is charged into the furnace, it should be recognized that the level of contamination (water, oil, paint, plastic, dirt, etc.) will hinder the melting process and reduce the recovery of metal that is present. This paper does not intend to discuss the methods of scrap preparation and there are many reference papers that have discussed this in greater detail.

Scrap size and surface area to weight also have a huge effect on melt loss if not charged in the correct way. Charging clean, loose scalping chip or sawing chips into the bath will almost certainly lose a huge proportion of the aluminium content of that scrap and this type of scrap should be charged away from burner impingement using vortex type technologies or similar.

Alloying

Alloying the furnace can also have a big impact on melt loss and dross generation. Certain allows as is well known such as Al-Mg and as reported by Taylor [xxx] have a higher probability of more oxide film growth and thickening compared to pure aluminium alloys.

The addition of such alloys into the furnace becomes very important [7] to minimize such alloy metal losses and further dross generation within the furnace.

Furnace Charging

Charging a furnace is the next important step in control of the dross generation. It is always an advantage to be able to submerge lighter scrap directly under the molten metal. Depending on the types of scrap and the furnace being utilized, this is not always possible; however, as a general rule, light scrap should be protected from direct burner impingement.

Burner Technology and Burner Control

The selection and type of burners used in a furnace and their control during the cycle is very important and there is often a fine balance between providing sufficient heat transfer to meet the demands of production while at the same time minimizing oxidation of the metal.

All burners will produce some quantity of dross which will be generated from one of two sources; direct impingement of the flame with either the charge or the molten metal or, from the creation of hot spots below the flame on the molten metal surface. The area directly below a burner can be subject to overheating and wicking of the molten metal into surface dross, this generates further oxidation and thus more dross. The increase in dross buildup insulates the metal from the heat and will require harder firing; this will again generate more dross. It's a vicious cycle!

As previously stated, movement of the molten metal through stirring will also help prevent these hot spots.

Furnace Skimming

Skimming removes most of the dross from the furnace allowing for more efficient melting and temperature control. When and how to skim is very important and will affect the overall aluminium recovery that is experienced from dross that is removed. Timing is everything, skimming too late can cause dross to build up, reducing melting efficiency and causing overheating of the molten surface which ultimately generates more dross.

Traditionally, forklift trucks equipped with homemade tools are used in the aluminum industry to carry out routine furnace operations such as skimming and cleaning. While functional, the results are inconsistent and reliant on the judgment and skill of the operator. Improper skimming technique can pull a significant amount of aluminum out of the furnace. It is far more economical to keep as much of the aluminium in the furnace than it is to remove it with the dross and recover it in other ways.

Dedicated furnaces skimming machines can provide a far more economical solution to the traditional forklift truck. Such systems are specifically designed for the arduous casthouse environment and have a useful life in excess of 10 years. Precise control is possible with such technology enabling the operator to minimize the amount of metal removed from the furnace.

To Flux or not to Flux

Fluxes are used for a variety of purposes in the aluminium melting and holding furnaces there is much debate and opinion however on whether to use fluxes in the reverbatory melting furnace or side well melting furnace to aid aluminium recovery from the dross. In general, a flux is typically used to separate the oxides and dirt from the free metal. Exothermic fluxes were widely used in the past to "heat-up the dross" and make the aluminum flow back into the bath. It is now generally recognized that the opposite actually occurs. The capillary action of the aluminum seeking the low pressure area where the reaction is occurring "sucks" up the aluminum adding additional fuel to the reaction. On the most part, endothermic fluxing is now generally used in the industry although exothermic fluxes are still predominantly used in Asia. Operator training and understanding of the use of flux is critical to making any material achieve the intended result.

Furnace Temperature

The temperature of the metal is the single most important controllable factor that determines the level of dross generation in a furnace. Once the temperature of the metal exceeds 782°C, dross generation increases exponentially [6] as shown in Figure 4.

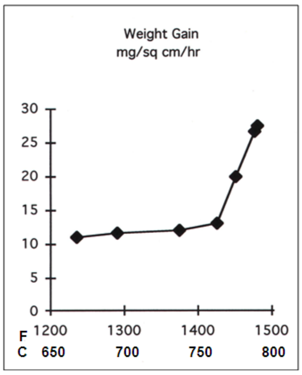

Fig.4 [3] Dross Generation

When the molten metal temperature is not properly regulated, dross can begin to thermite. Any time a thermite reaction occurs, metal units are being lost and thus every very effort should be made to prevent this from occurring. The fuel in a thermite reaction is the aluminum; the excessive temperatures generated by this reaction can cause the surface temperature of the molten bath to increase rapidly above the 782 ^{O}C mark causing further oxidation of the surrounding metal.

In addition to excessive metal loss, thermite reactions can cause damage to refractory, shortening the life of the furnace lining.

As we know the predominant heat transfer mode from the combustion space in a furnace to the surface of the aluminum bath is via radiation, and because the aluminum bath is opaque, then the predominant mode of heat transfer from the bath surface to the bath itself is via convection and conduction.

To illustrate the heat transfer dependency between the combustion space and the bath, where heat is supplied to the bath surface by a chemical flame and the dominant heat transfer mode in the furnace is the thermal radiation. The thermal radiation rays are transferred both directly from the flame (combustion gases), and from the heated refractory walls.

This link between the various furnace zones and physics are further complicated by the fact that the aluminum bath surface heat transfer characteristics change with time, furnace oxidizing atmosphere, amount of heat transferred to the bath surface, and amount of impurity in the charged scrap (if any). These changes in the heat transfer characteristics are triggered by a chemical change in the composition of the aluminum bath at the bath surface layers. This chemical change is commonly known as aluminum oxidation or dross layer formation. As is well known this oxidized layer, despite the fact it is thin in its size, impacts on the heat transfer to the bath significantly, and at its extreme can cause significant reduction to the furnace overall thermal efficiency and even damage to the furnace refractory due to overheating.

During the melting cycle (in a scrap melting furnace) the surface temperatures and the factors defining the heat transfer to the bath change continuously and in a non-linear way. It is well known that the molten metal bath, as it circulates inside the high temperature and oxidizing atmosphere of the furnace, forms a thin oxide layer that covers the aluminum bath surface. This thin oxide layer (typically the first surface layer forms in milliseconds) as it grows in thickness changes completely the optical properties of the molten aluminum surface. [4]

The prolonged bath surface exposure to heat causes the thin flexible oxide layer to start undergoing a physical change from its amorphous flexible structure to the crystalline rigid structure. Unlike the amorphous structure the crystalline structure does not allow for flexibility in its microstructure and during that phase the oxide layer starts to rupture (what is called in material micro-structure as lattices slip along preferred fault lines) and further exposes more of the pure aluminum metal below to the oxidizing atmosphere, and hence transform it also to oxide-alumina (Al_2O_3) in a process that is continuous. This transformation problem arises mainly when the bath receives excessive heat from the flame, and in a prolonged exposure time, with presence of oxygen molecules, which is the case when the bath is stagnant in furnaces. The presence of impurities (from melting coated and dirty scrap for example), which already have crystalline structure, causes further acceleration to this transformation process (acts as a seed for the crystalline transformation). Hence the oxide dross layer keeps getting thicker and accordingly the thermal resistance keeps steadily increasing. This process of increased thermal resistance causes less heat dissipation into the bath depth, which in the absence of effective circulation yields to a large temperature gradient, where the bath surface temperature is considerably higher than the bath depth. This causes a reduction in the furnace thermal efficiency, along with refractory temperature rise.

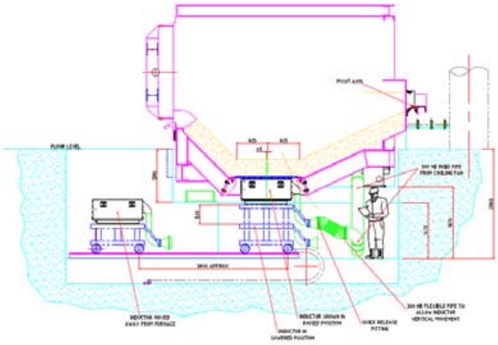

Figure 5 Bottom mounted EM Stirring

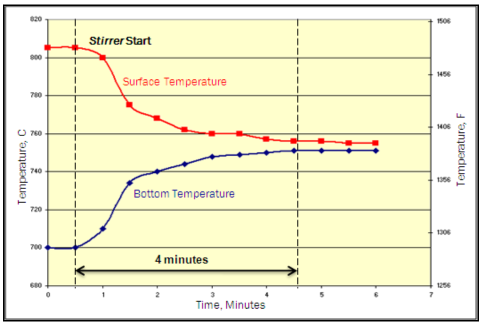

Fig. 6 Effect of stirring on metal temperature

As introduced in earlier sections of this paper, stirring a furnace can reduce the temperature gradient between the top and bottom of the furnace in a matter of minutes (see figure 6) and reduce dross generation by as much as 25%.

There are a variety of stirring technologies on the market today Electromagnetic systems have increased in popularity in the last 10 years (20 years if we consider the Japanese cast houses) and although more expensive to install, there are no moving parts and many are non contact, so allow a non intrusive stirring possibility to the furnace, providing minimal maintenance requirement and risk if failure or breakdown to the furnace operation. Permanent magnetic pumps and stirrers are a new comer to the industry and have been quite extensively used in China and Japan during the past several years. They give single, directional stirring.

In general, any form of ‘sub surface’ stirring technology is advantageous in helping to reduce metal surface temperature and reducing dross generation. Keeping the surface temperature as low as possible will also improve refractory life and reduce energy consumption.

There are also other consequences to circulating a furnace to minimize dross generation, the positive impact it can have on energy reduction and therefore CO2 also.

Impact of Circulation on energy consumption and CO2.

When considering the use of electromagnetic stirring devices within the furnace it is also important to consider the contribution that the stirrer itself adds to the energy footprint.

As has been previously discussed at earlier conferences there are many factors one needs to consider when choosing the correct device for circulating a furnace [7]. There are several new technologies that are promoting minimal CO2 footprints while achieving the significant objectives of continuous furnace circulation.

Figure 7 shows the air cooled side mounted EM Stirrer which has been widely adopted throughout the Russian primary industry over the past 15 years. Its unique design promotes very low energy consumption reported at 1 to 2 kW/tonne, based upon 40 kW power.


Figure 7 – Side Mounted EM 'air cooled' stirrer

Additional benefits are clearly the lack of necessity for water, as the inductor is air cooled providing lower installation costs and high reliability due to the solid construction of the inductor's coil.

The energy operational cost for a typical cycle at a primary cast house would then be 2 US$ per kWh per tonne

Clearly capital costs, the overall TIC (Total Installed Cost) and payback calculus become important in determining which furnaces can justify such an investment. Typically any furnace that has a large proportion of scrap added or produces a high alloy product (for example 5xxx) would benefit from investment in Electromagnetic Stirring based upon production increase (reduced cycle time, energy and dross reductions) and also the less tangiable 'qualitive' benefits of chemical and temperature homogeneity and improved metal cleanliness.

Additional to the energy savings achieved through continuous circulation of melting and casting furnaces is the carbon footprint reduction for the cast house. By far the largest contributor to carbon emissions is energy production. Any technology that reduces energy consumption is therefore extremely advantageous.

The CO2 released from energy production using natural gas is = 0.185 kg per kWh used [8]

If we assume a conservative figure of 10% to 15% as the energy reduction from having continuous circulation applied to the melting or casting furnace this equates to a saving of approximately 2770kWh per furnace cycle assuming a 50 Tonne melting furnace operating a 6 hour melt cycle equipped with regenerative burners (assuming a 550kWh/tonne efficiency). Clearly the cycle time will also reduce and it is possible to operate at a higher roof temperature without overheating the surface of the bath due to the improved heat transfer.

However it is not just the energy saving from a reduced cycle time and improved energy efficiency of the furnace due to the reasons explained earlier that is important, relative to CO2 contribution, one also needs to consider the impact of the stirring device that is used as these devices do consume electrical energy. One therefore needs to consider the nett figure. The table below shows the impact of this.

It is reported for every 1 kWh of electricity purchased it generates 0.537 kg of CO2 [8]. This supports the need to use low energy consuming devices to achieve the energy reduction and production improvement objectives from any investment.
If we take the following assumptions we can then assess the savings that can be obtained on energy and CO2 contribution from furnace circulation.

Assume:-

50 Tonne 'melting' furnace
Regenerative burners @ 550 kWh/tonne
Cycle time – 6 hours (including 1 hour alloying/holding @ 200kWh)
Cycles per day – 4
Operating days per year – 330
Cost of electricity - $0.10/kWh

Cost of natural gas - $0.055 per kWh

	EM Stirring (Water Cooled)	EM Stirring (Air Cooled)	Permanent Magnet Stirring
Energy Saving %	10%	10%	10%
Energy Saving per year (kWh)	3,656,400	3,656,400	3,656,400
CO2 Saving per year (Kg)	676,434	676,434	676,434
Energy Saving (US$)	201,102	201,102	201,102
Operating Energy (Stirrer) per year (kWh) – See Note 1	396,000	99,000	90,000
CO2 contribution from stirrer energy consumption	212,652	53,163	48,330
Nett CO2 saving	463,782	623,271	628,104

Table 2 – Evaluation of CO2 impact of different Stirring technologies on a 50 T melting furnace

Note 1 – Based on kWh/tonne from Table 1 above.

Dross Management within the Cast House

Following skimming of the furnace, it is critical that the dross is dealt with very quickly and very efficiently to avoid any further loss of the aluminium within the dross through burning. Rapid cooling of the dross to stop any burning of the aluminium and also combined with pressure to allow agglomeration of the aluminium particles within the dross to form larger aluminium ‘plates’, see Figure 8 below, increases significantly the chances of higher aluminium recovery from the dross.

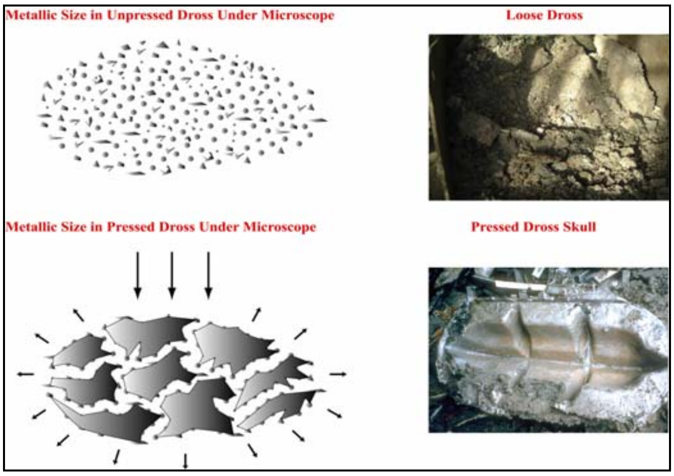

Figure 8 – Pictures shows the effect of agglomerating aluminium particles within the dross through pressing.

Figure 9 below shows the results of a study conducted at Cressona Aluminium in the mid 1990’s comparing various dross management techniques. It is important to recognize that these tests were conducted using the same type of dross, i.e. dross from the same facility skimmed from the same furnaces managed by the same operators. This is the only way to compare technologies. We have assumed an aluminium price of $1400 per tonne for RSI.

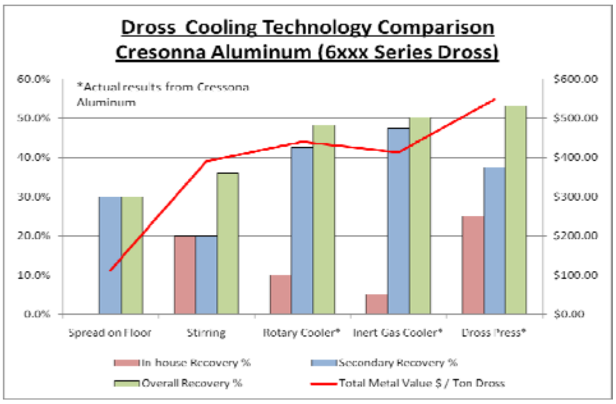

Fig. 9 Dross Recovery Study at Cresona Aluminium, USA

Dross Presses

The Dross Press became commercially available in the early 1990's and today there are several manufactures that supply different versions of this technology [9]. Dross pressing technology is based on the principle that a liquid placed under pressure will separate from a solid and flow to the areas of least pressure.   The press system consists of a steel frame, hydraulic unit, a pressing head and a skim pans set. Once skimmed, the dross is transferred into the press and the head is slowly lowered. The pressure forces metal out into the sow mold which is located under the skim pan, and agglomerates the fine particles of aluminium on the outside surface of the dross. This encapsulates the oxides preventing dusting and thermiting (see figure 5 below). Dross presses were the first technology to physically reshape the dross, improving the cast house environment and recoveries at the secondary processor. The system not only rapidly cools dross but can also provide the highest in-house drain. Overall dross recoveries can range from 60 – 70%. Two conditions where the dross press may be less effective are if the dross is too cold to press or if the dross is heavily therminting. Therminting dross can be processed but requires revised practices, longer cycle times and special cooling techniques.

Fig. 10 Dross after pressing

Fig.11 ALTEK Dross Press

CONCLUSIONS

Commercial and environmental pressures will continue to make the aluminium industry ever more competitive. Those companies who focus on effective furnace melt loss and dross management will not only minimize their unit cost of production but will also benefit from the many process and environmental advantages of a well managed casthouse. This, when done correctly, translates to a better work environment and major cost savings.

Focusing on keeping the aluminium in the furnace and minimizing melt loss is the key practice through techniques discussed above as these not only benefit reduced metal losses but also can provide significant benefits in energy and CO2 reductions.

Each stage of the aluminium production process within the casthouse should be carefully evaluated to determine the potential for improvement verses the required capital investment. Typically, return on investment for melt loss improvements and total dross management projects are extremely short since metal units are extremely valuable.

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