

# Development, Evaluation and Application of Granular and Powder Fluxes in Transfer Ladles, Crucible and Reverberatory Furnaces

## Introduction

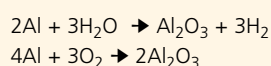
Regardless of the holding or melting furnace design, or the energy used (gas or electricity), formation of dross, non-metallic inclusions, and oxide build-up are inherent characteristics when melting and handling molten aluminum casting alloys. Moreover, improper burner adjustments, metal temperatures, flame type, furnace door conditions, furnace refractory conditions, and melting practices will have further negative effects on the inherent characteristics of molten aluminum alloys.

To overcome these intrinsic characteristics, foundrymen have relied on solid fluxes. Years of casting experience have demonstrated that proper fluxing is the secret to lowering the cost and improving the quality of the liquid melt. Fluxing is the best means of obtaining clean metal, by preventing excessive oxide formation, removing non-metallic inclusions from the aluminum melt, and preventing and removing oxide build-up from furnace walls.

Historically, solid fluxes have been classified in four categories depending on their use and function at the foundry operation. These categories are: cover fluxes, drossing fluxes, cleaning fluxes, and furnace wall cleaning fluxes.

In this article, present foundry practices with respect to the use of powder and granular fluxes involving crucible furnaces, transfer ladles, and reverberatory furnaces are discussed.

It is well known that molten aluminum alloys have two inherent characteristics: the tendency to absorb hydrogen gas, and the ability to readily oxidize. It has been documented (1, 2) that when aluminum alloy melts react with the atmosphere or moisture, they form amorphous continuous alumina ( $\text{Al}_2\text{O}_3$ ) films on the surface of the bath, according to the following reactions:



The alumina films are an intrinsic part of the melting process; they protect the metal underneath the film from further oxidation. However, in actual foundry operations, the surface of the molten bath always has some movement due to one or more of the following melting practices: 1) charging, 2) skimming, 3) cleaning, 4) degassing, 5) transferring, and 6) ladling. Any of these melting practices causes the thin alumina films to break and re-oxidize, causing rapid alumina film thickening.

The constant metal movement and breaking of the alumina films cause the films to crumble, to thicken, and to encapsulate unoxidized molten aluminum, generating what is known as wet dross. A typical representation of this phenomenon can be seen in figure 1. This picture shows metal being tapped from a holding furnace into a transfer ladle. The oxidized metal that results as the molten stream gets disturbed causes the surface of the bath to thicken with wet dross. The aluminum content of wet drosses is typically reported to be in the order of 60% to 80% while the remaining 40% to 20% is aluminum oxide. The amount of trapped liquid metal in the dross varies according to the melting practice. The aluminum oxide is a very stable compound that cannot be reduced to aluminum under ordinary melting conditions. However, the amount of suspended liquid metal could be reduced from the 60%-80% range to 30% by proper fluxing and drossing techniques.

Formation of dross is an intrinsic process when melting aluminum alloys. The dross is considered to be the main contributor in influencing the total metal loss during melting. Depending upon the efficiency of the melting furnace, and melting practices, the amount of dross generated may be from 5% to 10% of the total metal melted.



Figure 1: Metal being tapped from a holding furnace into a transfer ladle causing alumina films to crumble, to thicken, and to encapsulate unoxidized molten aluminum, generating wet dross.

In addition to the formation and elimination of dross, another problem that aluminum foundries face in the molten metal bath is the non-metallic and the metallic impurities that are suspended and floating in the bath. Impurities and aluminum oxides will remain suspended and floating in the liquid bath because they are porous and contain some gas adhering to and trapped in the pores. In this case, the oxide's density is similar to that of the aluminum alloy.

Non-metallic and metallic impurities are introduced into the melt during the charging process, the molten metal treatment, and the handling operations. Even when melting primary ingot, non-metallic impurities like hydrogen and aluminum oxide are introduced. However, as would be expected, the majority of the non-metallic and metallic impurities come from charging "returns" which include scrap castings, gates, risers, trimmings, etc. According to the type and origin of the return metal, and to the conditions of storage, the metal can contain considerable amounts of both non-metallic and metallic impurities.

The removal of these non-metallic and metallic impurities from the molten bath is of vital importance to any foundry operation. There are numerous technical references dealing with technologies for assessment, analysis, removal, and separation of these impurities (3, 4, 5, 6).

Sedimentation, flotation, filtration, degassing, and fluxing are common techniques being used to remove and separate inclusions from aluminum alloy melts. Any of these techniques will have an impact on metal cleanliness. However, fluxing is a primary factor for ensuring metal cleanliness.

Fluxing is a term commonly used in foundries more and more these days, especially within the melting department work force, to refer only to the addition of chemical compounds to clean molten aluminum alloy baths in either, the furnaces (melting or holding) or the transfer ladles. Fluxing is the first step in obtaining clean molten metal by preventing excessive oxide formation, removing non-metallic inclusions from the melt, and preventing and/or removing oxide build up on furnaces walls.

In general, fluxes may be grouped in two classes: gaseous or solids. Gaseous fluxes may be a blend of an inert and a chemically active gas that is injected into the molten bath. Solid fluxes are blends of salts, and seem to be the most preferred type of fluxes used in foundries. Thus, this article will focus on the understanding of solid fluxes.

Solid fluxes can broadly be categorized as passive or active fluxes. Passive fluxes protect the surface of the molten aluminum from oxidation and prevent hydrogen pick-up by the melt. Active fluxes react chemically with the aluminum oxides and clean the melt more effectively.

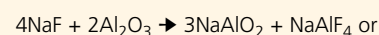
Foundrymen recognize the importance that furnace type, furnace design, furnace maintenance, quality grade of smelter ingot, quality of the in-house returns, condition of the skimmers, ladles and the like, and the charging and melting practice have on the starting quality of the molten metal to make a casting.

Nonetheless, it seems that foundrymen still have some concerns over the lack of general accepted information on conventional solid fluxes.

### Solid Fluxes

Even though, there are a lot of different commercial fluxes in the market, the basic ingredients of such commercial fluxes are based on the very early work, conducted about one hundred years ago, in improving the electrolytic production of aluminum by reducing the aluminum oxide using molten cryolite ( $\text{Na}_3\text{AlF}_6$ ). Since then, both natural and synthetic cryolite and fluorides have been evaluated.

The removal of aluminum oxide by halides has its foundations in basic research and development on the systems  $\text{NaF-AlF}_3\text{-Al}_2\text{O}_3$  and  $\text{NaF-AlF}_3$ . Studies on these systems have shown that the solubility of aluminum oxide increases with the sodium fluoride content. The reaction between cryolite and aluminum oxide in the presence of a surplus of NaF takes place according to the following reactions:



In addition, halide and fluoride salts have been thoroughly researched by secondary (recycled) aluminum producers during the melting and processing of aluminum scrap and dross. The aluminum recovered results from the effectiveness with which non-metallic and metallic impurities are removed or reduced to acceptable levels. In these operations, low-melting-point fluxes are typically used. They are basically sodium and potassium chloride with additions of fluorides and some other chlorides, such as calcium chloride and magnesium chloride.

Salts are used in fluxes because of the following general characteristics:

- Cost effective
- Easy to use
- Combine easily with other ingredients
- Serve as fillers for active ingredients
- Have lower density than aluminum
- Give ability to cover the molten surface
- Allow a low-melting-point, high-fluidity product
- Have capability to absorb oxides and reaction products from the fluxing action

Solid fluxes are basically blends of sodium chloride and potassium chloride salts, with or without addition of fluorides. In addition, small quantities of oxidizing compounds, such as carbonates, sulphates, and nitrates, are added to promote exothermic chemical reactions (7). Exothermic reactions are important because they prompt the coalescence of the trapped liquid aluminum particles in the dross.

The mechanism of how salt fluxes work has been attributed to thermodynamic chemical reactions and surface tension effects between A) the aluminum oxide and the flux, B) the aluminum oxide and the molten metal, and C) the molten metal and the flux. This interaction between aluminum oxides, flux, and molten metal has been explained in earlier papers (7, 8, 9).

In addition, the effect of the flux on the liquid metal will depend on the chemistry of the flux used, morphology of the flux, total amount of flux added, molten metal temperature, flux contact time, rabbling (stirring) technique, etc. Nevertheless, from the point of view of flux chemistry, it is important to understand that different combinations and proportions of ingredients will impart different flux properties, such as density, fluidity, wettability, and reactivity.

These four different flux properties are responsible for the characterization of any particular flux.

To understand better how these flux properties are accomplished, it is necessary to recognize that essentially each different ingredient provides different effects that directly influence the final property of a flux. Generally, ingredients can be classified in four major groups based on their primary influence over the mixture.

### Chlorides

Examples are: aluminum chloride ( $\text{AlCl}_3$ ), barium chloride ( $\text{BaCl}_2$ ), calcium chloride ( $\text{CaCl}_2$ ), lithium chloride ( $\text{LiCl}$ ), magnesium chloride ( $\text{MgCl}_2$ ), potassium chloride ( $\text{KCl}$ ), and sodium chloride ( $\text{NaCl}$ ).

The melting point of these compounds, in their pure state, may range from  $180^\circ\text{C}$  to  $960^\circ\text{C}$ . However, they form low temperature eutectics in combinations. In addition, it is very typical to have at least three compounds in a given flux so that none of these compounds would be used as a single compound in a flux recipe.

Chlorides are mainly used because of their fluidizing effects, and because they are used as fillers. Fluxes based only on chloride salts should not react with molten aluminum, or at least the reaction should be negligible. In addition, these salts provide negligible effects on surface tension as compared to fluorides.

### Fluorides

Examples are: simple fluorides such as aluminum fluoride ( $\text{AlF}_3$ ), barium fluoride ( $\text{BaF}_2$ ), calcium fluoride ( $\text{CaF}_2$ ), lithium fluoride ( $\text{LiF}$ ), magnesium fluoride ( $\text{MgF}_2$ ), potassium fluoride ( $\text{KF}$ ), sodium fluoride ( $\text{NaF}$ ), and double fluoride compounds such as sodium silicofluoride ( $\text{Na}_2\text{SiF}_6$ ), and potassium silicofluoride ( $\text{K}_2\text{SiF}_6$ ).

The melting point of these compounds, in their pure state, may range from  $845^\circ\text{C}$  to  $1427^\circ\text{C}$ . The high melting point of these compounds provides thickening effects on a flux.

Fluoride salts have limited solubility for oxides, however, no fluoride salts can dissolve massive aluminum oxides. Fluorides salts act as surfactants affecting surface tension forces between flux, liquid metal, and aluminum oxides. As the flux wets the interface between the aluminum oxide particles and the liquid metal, the adhesion force between the liquid aluminum and the oxides decreases, promoting oxide separation and metal coalescence.

Fluorides are still the most effective compounds being used in fluxes to improve aluminum recovery from wet dross.

### Oxidizing compounds

Examples are:

- ❑ Nitrates such as potassium nitrate ( $\text{KNO}_3$ ), sodium nitrate ( $\text{NaNO}_3$ ),
- ❑ Carbonates such as calcium carbonate ( $\text{CaCO}_3$ ), potassium carbonate ( $\text{K}_2\text{CO}_3$ ), sodium carbonate ( $\text{Na}_2\text{CO}_3$ ),
- ❑ Sulphates such as potassium sulphate ( $\text{K}_2\text{SO}_4$ ), and sodium sulphate ( $\text{Na}_2\text{SO}_4$ ),

The melting point of the nitrates range from 302°C to 338°C; the melting point of the carbonates range from 851°C to 1338°C; and the melting point of the sulphates range from 860°C to 1450°C.

Oxidizing compounds are used to promote exothermic chemical reactions. They react with the smallest molten aluminum particles that are present in the dross, yielding aluminum oxides as well as considerable heat.

The purpose of the exothermic reaction is twofold: 1) allows larger pockets of entrapped aluminum to coalesce and fall back into the molten bath, and 2) facilitates reactions between aluminum and fluorides. The exothermic reaction continues until all of the fine aluminum particles are burned.

### Solvents of aluminum oxides

Examples are: borax ( $\text{Na}_2\text{B}_4\text{O}_7$ ), potassium borate ( $\text{K}_2\text{B}_2\text{O}_4$ ), and sodium cryolite ( $\text{Na}_3\text{AlF}_6$ ).

The Hall and Heroult patents both covered the electrolysis of aluminum oxide in a bath of molten halide salts. Since then, dissolution of aluminum oxides ( $\text{Al}_2\text{O}_3$ ) by cryolite has been documented.

### Flux development

The development of fluxes may be based on new formulations or improved variations of existing and traditional formulations. Regardless of the type of development, there are two basic considerations, what compounds, and in which proportions. It should be taken into consideration that the salts used in fluxes have unique effects that will complement each other during the application of the final product.

The effect (activity or reactivity) of each individual salt when in contact with molten aluminum alloys, at different metal temperatures, may not necessarily be the same as when mixed with other salts, but it will provide useful information that could be used to better understand, evaluate, and develop new flux formulations.

### Flux morphology (Granular Fluxes)

The manufacturing of fluxes requires compliance with strict general quality requirements for the raw ingredients (commercial purity, grain size uniformity, and less than 1% moisture content) and for the manufacturing process (blending of the ingredients). Control over these variables assures consistent products and consistent performance.

For most of the aluminum foundry history, powder fluxes have been utilized. Powder fluxes have been in commercial use for nearly 60 years. However, the basic formulations and compositions of the fluxes have not changed dramatically over this period. Present day research and development in flux chemistry are still based on trial and error procedures.

In the last ten years, research and development for possible new formulations and variations of traditional mixes have evaluated more closely the use of fluorides because of environmental emission concerns. It has been reported that if fluorides were removed from the formulation, it would render a powerless and inefficient flux (10). At the same time, it has been reported that in fluxes containing fluorides, the emissions could be reduced at least by half only if the morphology of the flux changed from powder to granular. It is still prudent to mention that emissions from powder fluxes are within standard environmental limits.

Fluoride-containing salts are being subjected to stricter environmental regulations and constraints. Therefore, fluoride-free fluxes are available. However, it is important to realize that fluoride-free fluxes will never perform as efficiently as fluxes containing fluorides. On the other hand, fluoride-free fluxes are the best option to eliminate internal smoke and odour in the plant, as well as to treat metal in electrical resistance furnaces without damaging the electrical elements.

A granular flux may or may not have the same formulation as a powder flux, however, because of the different grain morphology, granular fluxes offer other operational and product advantages over powder fluxes.

Granular fluxes are less polluting to the atmosphere; emissions are reduced by at least 50%. Furnace operators appreciate the fact that granular fluxes greatly reduce smell and smoke, facilitating working closer to the furnaces during drossing operations. Granular fluxes are easier to apply and to spread over the molten surface since they are fines and dust free, therefore, application rates can often be reduced. Additional product benefits are better consistency in chemistry from grain to grain, and the fact that there is no segregation during flux transportation or handling.

Figure 2 and Figure 3 depict the difference, which is very noticeable, when applying a powder or a granular flux. Figure 2 shows that, as the furnace operator adds the powder flux, the flux really falls down in a big cloud as soon as it leaves the cup. On the other hand, Figure 3 shows that the granular flux will travel farther before falling down into the melt. That difference in traveling distance facilitates spreading and directing the granular flux inside a furnace.



Figure 2: Powder flux being thrown inside the furnace



Figure 3: Granular flux being thrown inside the furnace

Consistency in chemistry is based on the fact that since powder fluxes are blends of salts, each grain will represent only one of the different chemical compounds from which the flux is made. On the other hand, and because of the manufacturing process, granular fluxes have 100% grain uniformity in chemistry, since each grain will represent the same chemistry as the flux recipe. Figure 4 and Figure 5 are used to illustrate this fact.

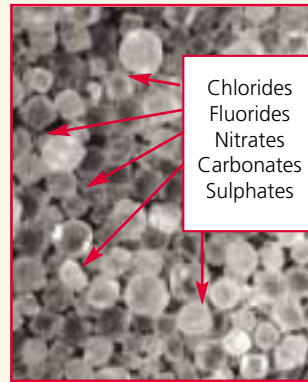


Figure 4: Powder flux grains

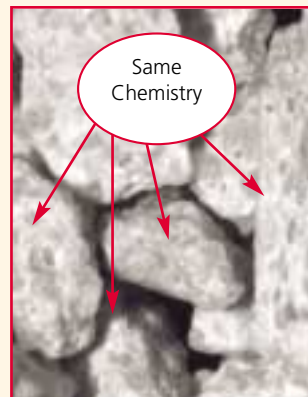


Figure 5: Granular flux grains

Historically, solid fluxes have been classified in four categories depending on their use and function at the foundry operation. These categories are; cover fluxes, drossing fluxes, cleaning fluxes, and furnace wall cleaner fluxes.

Cover, drossing, and melt-cleaning fluxes are usually manually spread, shovelled, or thrown onto the melt surface, while furnace wall cleaner fluxes are typically blown (with a gunning device) onto the furnace walls at the melt line.

To ensure that melt-cleaning and drossing fluxes will do their job effectively (regardless of if they are either powder or granular type), it is essential that, after addition, the flux be stirred into the melt to achieve as much as possible contact with the molten metal and dross layer. Based on the size of the furnace, the stirring can be accomplished manually by the furnace operator, or mechanically by a forklift or mechanized vehicle. Typically, agitation and stirring of the flux is completed between 1 to 3 minutes in crucibles or transfer ladles, and between 5 to 10 minutes in reverberatory furnaces up to 90,000 pounds of liquid capacity.

It is also important to emphasize that the flux reaction efficiency depends on three factors that are interrelated to each other: molten metal temperature, stirring, and activation time. Improper control of these factors will result in having un-reacted flux floating on top of the dross as shown in Figure 6.



Figure 6: Un-reacted flux

### Cover fluxes

Cover fluxes are designed to be liquid at operating metal temperatures in such a way that the flux will form a molten barrier "blanket" on the surface of the metal to protect it against oxidation and hydrogen gas adsorption. The basis of any cover flux is mainly a blend of NaCl and KCl salts with small quantities of fluorides. Fluxes having these three compounds are suitable for almost all types of aluminum alloys, excluding hypereutectic aluminum alloys and aluminum magnesium alloys with over 7% Mg.

Over the years, a great number of different commercial cover fluxes have been developed with preferred additions and proportions of NaF, KF, Ca<sub>2</sub>F, and other compounds such as CaCl<sub>2</sub> for lowering the melting point of the flux, as well as for providing cleaning effects.

Cover fluxes are used in foundries and smelting operations. Foundries use these types of fluxes during the melting of heavily oxidized foundry returns and machining chips, as well as when metal holding temperatures exceed the 770°C to 778°C range.

In smelting operations, cover fluxes are mixed in the rotary furnace during the melting of fine scrap, turnings, sawings, fines, etc. Typically, cover fluxes for smelting applications have lower melting points than those used for foundry applications (e.g., 424°C to 666°C).

### Drossing fluxes

Drossing fluxes may be based on salt blends of chlorides, simple and or double fluorides, and oxidizing compounds. Therefore, drossing fluxes are able to react exothermically, generating heat and improving flux wettability. The wetting action of the flux promotes coalescence, which brings the fine aluminum drops tighter to form larger drops that are much easier to recover. The work of drossing fluxes is considered to be due to both the surface tension effects and dissolution of aluminum oxides.

There are wide commercial ranges of different flux compositions. Even though a drossing flux will always be considered as "hot or reactive flux" in furnace operator terms, it is important to realize that the reactivity in a drossing flux is due to a combination of the oxidizers and the double fluoride compounds. This is an important concept to understand, because even without double fluorides, the flux may look too reactive due to an excess of oxygen-bearing compounds that may be burning excessive amounts of good metallic aluminum without actually dissolving aluminum oxides in the melt.

Some manufacturers may decrease the use of double fluorides, since they are more expensive as compared to other compounds. At the same time, it is important to note that a lower grade compound, which is cheap, may also decrease the effectiveness of the flux, the same concept will be true for any other type of flux the quality of the chemical compounds will influence the price of the flux.

Thus, a good drossing flux must be designed to reduce the rich metallic aluminum content of the dross. As the dross is treated with the drossing flux, it changes from a wet dross appearance (bright, shiny metallic color) to a dry dross appearance (dark, powdery). Proper flux treatment could reduce the amount of metallic aluminum content of the dross to 30%. Figure 7 shows the difference in appearance between untreated and treated dross with flux.



Figure 7: Un-treated (left) and treated (right) dross

### Cleaning fluxes

Melt cleaning fluxes are designed to remove aluminum oxides from the melt. Melt cleaning fluxes usually have similar chlorides and oxidizing compounds as the ones used in the drossing fluxes, but in different proportions. In addition, the composition of a melt cleaning flux will typically include only simple fluorides as compared to the simple and double fluorides that are present in drossing fluxes. Since a melt cleaning flux is less reactive than a drossing flux, it will yield less dry dross than a drossing flux.

The work of metal cleaning fluxes is considered to be only due to the surface tension effects as previously stated. It is very important not to confuse a metal cleaning flux with a furnace wall cleaning flux.

**Furnace wall cleaning flux**

Wall cleaning fluxes are specifically designed for the softening and removal of excessive aluminum oxide build-up that occurs on melting furnaces walls, especially along the melt line. This type of flux helps keep crucible and furnace walls above and below the melt line free of oxide build-up.

Wall cleaning fluxes contain the highest amounts of double fluoride compounds such as  $\text{Na}_2\text{SiF}_6$  and  $\text{Na}_3\text{AlF}_6$ . The exothermic reactions that occur because of the oxidizing compounds and the double fluorides enhance more penetration of the flux into the oxide build-up, facilitating the removal of the oxide build-up at the furnace wall. Fluoride free fluxes cannot be used effectively as a wall cleaning flux.

**Foundry practices**

Powder and granular fluxes can be added either by weight percentage of the total metal charged or melted, or by weight in pounds based on the molten surface area to cover. Manufacturer recommendations are the starting point. Typical recommendations are shown in Table 1. However, the exact quantity of flux will depend on a variety of operating conditions such as furnace type, charging and melting practices, initial metal cleanliness, molten metal temperature, and final metal cleanliness required.

APPLICATION FOR	ADDITION BASED ON	POWDER FLUX	GRANULAR FLUX
Crucibles and Ladles	Percentage of total metal charged or melted	.25% to .50%	.20%
Reverberatory	Pounds of flux per ft <sup>2</sup> of molten surface area	.35 to .50 lbs	.30 lbs

Table 1: Typical addition rates for powder and granular fluxes.

Molten metal cleaning with fluxes varies from foundry to foundry, with some performing a systematic and very careful fluxing and dressing procedure, and others skimming molten metal or cleaning furnaces without any flux at all. The difference in the furnace conditions and the scrap defects related to molten metal quality is very obvious. Although often overlooked, the furnace operator plays a key role in the success or failure of the use of any type of flux.

A recent national market study was conducted regarding molten metal treatment practices in aluminum foundries and die casters (11). Among other findings, it revealed how these industries determine when and how much flux to add, as well as how long they flux. These results are presented in Table 2 and Figure 8 respectively, and refer to the foundries that responded to a question regarding flux usage.

HOW TO DETERMINE FLUX USE	ALL RESPONDENTS	ALUMINUM FOUNDRIES	DIE CASTERS
Judgement based on experience	77%	75%	80%
Supplier recommendations	7%	-	14%
Based on pounds in each furnace	5%	9%	-
Depends on how much scrap in the melt	2%	2%	3%
Based on the K-fracture mould test	1%	2%	-
Others	8%	12%	3%

Table 2: How aluminum foundries and die casters determine when and how much flux to use.

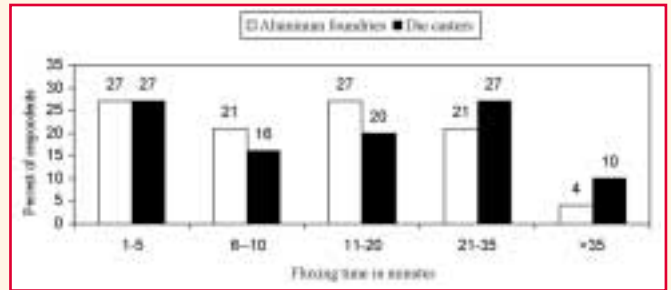


Figure 8: Fluxing time in aluminum foundries and die casters

Present day fluxing practices include the use of flux in one or in several stages within the treatment and processing of molten aluminum. Conventional locations in which flux is used in aluminum foundries and die casters are presented in Figure 9. This Figure shows that at least 50% of the molten metal is being fluxed in the melting furnace. In addition, the metal may be fluxed in a subsequent or different location.

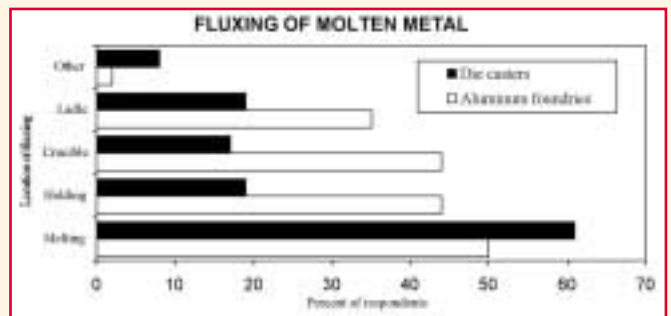


Figure 9: Locations for fluxing molten metal in aluminum foundries and die casters.

### Crucible furnaces

Crucible furnace melting is commonly used at small foundries, as well as at medium and high volume production jobbing foundries in which melting versatility is a must. The most popular material for the crucible is silicon carbide. In these foundries, it is typical that the metal skimmings or dross be placed in a small metal bin located by the crucible furnace. Fluxing procedures in these shops are batch type, and depend basically upon the management philosophy about fluxing. It is very common that after the melting and alloying procedures some degassing takes place. It is around the degassing stage when the fluxing and skimming operations occur. Typically there are three variations in the use and the application techniques of fluxes.

1. Melting, degassing, and skimming without any flux. With this procedure it is very common that the skimmings contain very rich metallic aluminum content, sometimes up to 85%. The dross coming from the dross bin sometimes looks like an aluminum ingot.
2. Melting, degassing, fluxing, and skimming. A very small number of foundries would flux after the degassing operation. Proper fluxing can be accomplished after the degassing operation without introducing hydrogen gas, however, it is imperative that: A) the flux added be dry, B) the skimmers be cleaned and dried, and C) the stirring of flux and the dross skimming be performed in a gentle manner. Nevertheless, the major drawbacks are that the metal temperature is usually at its lowest operating temperature, so the flux takes more hand stirring to get it activated, and the metal treatment process takes longer. With this technique, strict discipline is a must.
3. Melting and degassing while flux is applied on the metal surface; then skimming. This would be the preferred method to flux a crucible and take advantage of the mixing capabilities and oxide removal of the rotary equipment. However, with this procedure it is very important to pay close attention to the degassing technology being used.

Assessment and evaluations of fluxes and degassing equipment have shown that the reactivity and molten surface coverage by the powder or granular fluxes is greatly affected by the design of the rotor, as well as the efficiency of the equipment. The effects of different rotor designs and degassing equipment on the stirring and activation of fluxes can very easily be documented by videotape. It will be shown that, if fluxing is conducted with the proper degassing technology, it is very easy to obtain powdery and dry dross that has very little metallic aluminum (about 30%).

### Transfer ladles

Transfer of molten metal by a ladle is a typical operation during the handling of molten aluminum in low-pressure permanent mold foundries and in die-casting foundries. At preset time intervals, the ladle is taken to the holding furnace from which metal would be tapped into the ladle. If degassing is part of the process, then the ladle is taken to the degassing station. If degassing is not part of the process, then the ladle is usually moved away from the furnace before performing the skimming operation.

In any case, the molten metal cleanliness and drossing operations performed on the metal in the ladle may include any of the three variations previously described for fluxing the molten metal in crucible furnaces. In addition, there are two supplementary variations with respect to degassing and fluxing at the same time. One variation is to add the flux at the bottom of the ladle before tapping metal into it. The other variation is to add the flux by directing it at the molten metal stream during the tapping of the furnace into the ladle. In both cases, not all the flux reacts when making contact with the stream of liquid aluminum. In the majority of the cases, the flux tends to be pushed away from the molten stream.

When the flux is added to the bottom of the ladle before tapping metal into the ladle, the only flux that reacts is that which gets trapped below the initial surge of the molten metal cascading on top of it. The remaining flux stays un-reacted, and tends to float and stay on the surface of the bath. Once the ladle is full, the flux must be stirred and rabbled to get it activated before the degassing operation.

Even in ladles in which an inert gas is introduced at the bottom of the ladle through a porous plug, the problem of un-reacted flux exists. Some flux will float to the top surface un-reacted. The only way to react the flux is to create an excessive gas bubbling turbulence coming from the porous plug. Unfortunately, this would cause more molten metal oxidation, so that the benefits of fluxing are defeated.

A technique not often used is to introduce the flux into the molten stream coming from the tapping of the reverberatory furnace. Again, this technique has the same negative effects with respect to activating flux. Only flux that becomes trapped in the molten stream gets activated while the flux falling down inside of the ladle remains un-reacted. As mentioned before, the un-reacted flux will float to the top surface of the molten bath. In addition, this process of adding flux is not a very safe practice since, splashing molten aluminum may burn the furnace operator more easily.

## Reverberatory furnaces

Reverberatory furnaces are usually used as breakdown furnaces or holding furnaces. In some cases, melting and metal ladling are performed from the same furnace. In addition, some furnaces may have a dip-out and a degassing well at the front of the furnace. These wells may be divided by a ceramic baffle or by a refractory wall. Basic use of fluxes in reverberatory furnaces is concentrated in two areas: molten metal and furnace sidewalls.

Furnace sidewalls are susceptible to aluminum oxide build-up, especially along the sidewall areas that are exposed to combustion furnace atmospheres during the expected molten metal level fluctuations inside the furnace. As the oxide build-up continues over time, eventually it will convert to corundum (the hardest phase of  $Al_2O_3$ ). When this occurs, two things happen as the oxide builds up 1) furnace efficiency and melting capacity are reduced, and 2) it becomes too late for a wall cleaning flux to be effective. Eventually, the furnace will have to be shut down for relining. However, having a routine maintenance schedule for cleaning furnace sidewalls can minimize the problem.

Operational procedures for the skimming and the drossing of the molten metal, and the cleaning of the furnace sidewalls are normally divided in exclusive sections according to the design of the furnace. It is very typical to have a specific procedure and frequency for the melting chamber, the charging well, the dip-out well, and the degassing well. Furnace sidewall cleaning should be done once a week but it is normal to do it three times per week. Often, a good and conscientious furnace operator determines the frequency of using the wall cleaning flux.

Even though different foundries have different furnace cleaning procedures, it is very common that good fluxing practices be based on well written procedures and that furnace operators adhere to: proper flux addition, proper sequence by which the burners must be turned on and turned off, and the furnace doors opened and closed, minimum flux activation time, and thoroughly scraping off furnace sidewalls.

An important consideration in the selection of fluxes for reverberatory furnaces may be derived from the fact that, as the furnace capacity increases, the furnace operators tolerance for discomfort decreases. A furnace operator who is subject to incessant heat, noise, and other working related discomforts is going to be less likely to be effective and efficient, especially if, he has to deal with dust, smoke and fume from the flux. In such cases, a typical flux manufacturer should be able to recommend an environmentally friendly flux for the application.

Good management philosophy will make the furnace operators comfort an important consideration when selecting a flux to use. A furnace operator that is happy with the working conditions usually has the right attitude towards proper flux use.

## Summary

This paper has presented basic flux development with respect to new flux formulations and flux morphology. Granular fluxes are being developed and introduced in order to address environmental and application concerns. It is anticipated that granular fluxes will become the preferred type of flux to use.

In addition, flux practices and applications have been reviewed, and best flux practices recommended. Still, the application of fluxes varies among aluminum foundries and among die casters as well as between both types of industries. Therefore, there is a need to provide better guidelines for the most effective use of fluxes, which in consequence will improve molten metal quality and ultimately, foundry profitability.

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