Abstract
The consumer is and will continue to place increasing demands on the aluminium casting industry to improve and deal with metal cleanliness concerns from an overall process perspective. The following presentation is definitive in promoting to the foundryman what he must do as a standard works practice dealing with molten metal cleanliness and keeping an edge on his competitor. Significant controls must be in place with in the foundry when studying all the process areas, particularly charge control, melting process and procedure, metal treatments and additives, fluxing, degassing, molten metal holding, transfer and pouring of aluminium alloys, filtration and mould filling to guarantee total metal cleanliness of the final cast shape.

Introduction
Flux treatment is our immediate interest and is a widely used term when applied to the aluminium foundry industry. From the following information, it would be quite clear that the use of flux is a pre-requisite for casting high quality, sound aluminium castings.

Why should aluminium alloys be treated with flux?
All aluminium alloys solid and liquid are covered with a protective oxide skin. This layer consists mainly of oxides with some nitrides, carbides, sulphides as well as alloying elements and impurities. With this in mind some of these elements are enriched in the protective skin because they are oxidised preferentially compared to aluminium. These being elements such as beryllium, magnesium, sodium, potassium and calcium to name a few. Boron is also enriched in the oxide layer. Interestingly, if the oxide skin on the molten aluminium is ruptured, due to turbulence or some form of disturbance it would reform almost immediately.

Oxides are carried into the molten aluminium bath by plunging scrap and ingots, turbulent transfer, active ladling and stirring. The higher the proportion of scrap in the feed charge and the smaller the pieces, the larger the amount of oxides introduced to the moisture present on the scrap, on corroded ingot and in the furnace atmosphere which greatly increases the amount of oxides formed within the melt.

After a melt down, a heat of molten aluminium alloy will have finely divided oxides and other non metallic particles suspended in the body of the melt and a layer of wet dross on the surface of the aluminium alloy.

Aluminium alloys require special fluxing treatments when compared to other metals, because the oxides have an apparent density very similar to that of molten aluminium. Instead of separating readily from the melt as in heavier metals, considerable amounts of finely divided oxides float in the body of the molten aluminium alloy. Oxides invariably are porous and contain a certain amount of occluded and trapped gas. Hence this will lower the specific gravity of the oxide close to that of molten aluminium. The removal of these suspended, finely divided oxides is fairly difficult and does require that the flux comes into close contact for effective removal.

It must be made very clear, that this discussion of melt cleanliness will be limited to the levels of undissolved aluminium oxide contaminants within the aluminium melt. Dissolved contaminants such as hydrogen gas will be present with aluminium oxide, since its origin within molten aluminium is often from the same source as that of aluminium oxide, namely water vapour.

What can we do to improve aluminium melt cleanliness and soundness?
For the purpose of this discussion, we would like to explain the importance, to the foundryman, the use of complex chemical fluxes for the injection, covering and protection of aluminium melts, to deoxidise the aluminium melt, and to show the importance of recovering molten metal from the surface dross layer. The important benefits of these complex chemical fluxes is that they do deoxidise degass, modify and grain refine molten aluminium alloys if used and applied correctly. From the many flux compositions used in aluminium metallurgy many are based on the NaCl - KCl system. To this basic mixture other salts are added to increase the effectiveness of the NaCl - KCl compound or for special purposes where it is required to obtain stringent aluminium alloy specifications using various melting and casting practices. The following flux treatment processes are readily available and will be the topics of this presentation:

The Flux injection process
For years the classical method for using fluxes have involved the mechanical stirring of the flux powders into the melt. This fluxing method is extremely inefficient in that the physical contact between flux and
liquid alloy, which is absolutely essential for the proper functioning of the flux, is difficult to achieve in a reproducible and effective way.

From an important metallurgical aspect, inclusions in molten aluminium alloys are encouraged and the excess agitation of the bath may actually enhance hydrogen gas pickup. Recently, we have designed and manufactured a user-friendly, trouble-free FLUX INJECTION SYSTEM.

This is an automated method of flux addition which encourages good flux to liquid contact—increasing fluxing efficiency, reducing treatment time and offers lower flux cost to aluminium tonnage output than traditional fluxing methods. With the flux injection process, specially prepared flux powders are injected into the melt using an inert carrier gas, which may be nitrogen or argon. The addition of the flux is via a ceramic coated lance and the flux is blown into the bottom of the bath. A flux powder dispersed in this manner will float to the surface, reacting chemically throughout the entire depth of the bath. From this method it is therefore possible to contact significantly more of the alloy than by using the traditional covering/dressing methods. A broad range of injection flux blends are available to meet any application and in just one operation, it is possible to:
- deoxidise,
- degass,
- modify,
- and grain refine molten aluminium alloys.

In addition, fluxes for the refinement of primary silicon in hypereutectic alloys have been developed.

**The combination rotary degassing and flux injection system**

The innovative combination rotary degassing and flux injection units are “state of the art” equipment. This equipment offers considerably reduced degassing times, lower metal melt losses and cleaner quality metal with lower flux consumption. This unique, sophisticated molten metal treatment system offers the proven benefits achievable through spinning rotor degassing and flux injection systems. With the combination of the two now possible, metallurgical test results obtained are superior to results previously obtained from either system. Moreover, the benefits to
the foundry are a competitive edge, reduced treatment times, lower achievable hydrogen gas levels than ever before, fewer incidents of inclusion defects, reduced overall treatment costs and most importantly - a greater percentage of “good” castings available to the customer.

Benefits from the mechanical properties - oxide removal
The treatment times were identical for the spinning rotor degassing unit and the combination degassing, flux injection unit. The Combination spinning rotor degassing, flux injection unit treatment used only a total flux addition of 0.05% by metal weight using nitrogen as the carrier gas. In each of the samples collected, this system resulted in greater percentage of elongation and an increase in the tensile strength over the metal treated with a spinning rotor degassing unit. The K-MOULD notch bar test is effective in evaluating the incidence of large inclusions that can be observed with the naked eye. The test is conducted by pouring a number of test bars into a flat mould that has four notches. The test bars are then fractured at the notch sites. The test is carried out by observing each fracture site for inclusions and the inclusions are counted to generate the results. From tests carried out on 25 fractures after combined spinning rotor degassing and flux injection treatment, no inclusions were observed. Observation of samples before the treatment showed an average of 1 to 5 inclusions per sample.

Benefits of hydrogen removal
The Combination spinning rotor degassing/flux injection treatment was done using a total flux addition equal to 0.05% addition by metal weight, using nitrogen as the carrier gas. In the foundries using the spinning rotor degassing or flux injection, they found that overall degassing times decreased an average of 0 to 40 percent with noticeably higher specific gravity results achieved after converting to the combination process.

Benefits of metallic content of dross
It is common knowledge with the spinning rotor degassing equipment the dross produced and if left untreated, can contain a substantial amount of aluminium. With the Combination degassing/flux injection system, introducing a small amount of flux with the purge gas can dramatically reduce the metal loss. The kinetic interaction of flux, inert gas, and molten aluminium results in a reaction producing a dross that is extremely dry and low in metallic content. With the use of a Combination spinning rotor degassing/flux injection unit, treating a transfer ladle, it was found that the dross contained less than 20 percent metallic content and weighed 80% less than the dross skimmed from an untreated ladle using the spinning rotor degassing machine.

Benefits in purchasing a combination spinning rotor degassing and flux injection machine
Throughout the world, consumers of aluminium castings are demanding sound, clean, high quality products. The combined technology of spinning rotor degassing and flux injection moves foundries closer to having a total quality management process which will reduce foundry costs and provide customers with excellent product standards.

These systems are currently operating in a number of casting facilities around the world, which includes the production of aluminium alloy wheels, secondary operations for producing ingots, die casting operations, sand foundries and gravity mould foundries. Furnaces and ladles that are now being treated and range from 100kg to 5000kg batch treatments.
Cover fluxes for Aluminum Alloys

Cover fluxes are absolutely essential for protection of aluminium alloys. Cover fluxes are mixtures of various salts which form a molten layer on the surface of the liquid metal bath, protecting the bath from oxidation and reaction with moisture in the air. The flux cover will isolate the molten aluminium liquid from the air and allow the alloy to be maintained at correct operating temperature. A large number of flux compositions are available but all cover fluxes contain alkali chlorides in various proportions and some also contain various fluorides. The composition of a cover flux is determined by its melting point. Cover fluxes which are liquid at operating temperatures are usually desired. It should be emphasised that the lowest melting point is obtained when approximately equimolar quantities of NaCl - KCl are used. Increasing either the NaCl or KCl content raises the melting point.

It is important to understand that fluxes containing sodium salts are not to be used with alloys having more than about 2 percent magnesium additions.

Magnesium will replace sodium in the salt according to the following reaction:

\[ \text{Na-halide} + \text{Mg} \rightarrow \text{Mg-halide} + \text{Na} \]

For aluminium alloys containing magnesium, fluxes based on magnesium chloride ie (MgCl₂, KCl) are used. While those fluxes containing magnesium chloride salts are more hygroscopic, it is important to use very careful storage procedures to keep hydrogen contamination to a minimum.

Cleaning fluxes for Aluminum alloys

Cleaning fluxes are designed to strip oxide particles and films of alumina and aluminium oxide from the melt. The active ingredient here is sodium fluorosilicate, Na₂SiF₆ which removes the aluminium oxide by a chemical reaction to produce silica;

\[ 6\text{Na}_2\text{SiF}_6 + 2\text{Al}_2\text{O}_3 \rightarrow 4\text{Na}_3\text{AlF}_6 + 3\text{SiO}_2 + 3\text{SiF}_4 \]

From this reaction it appears that the cleaning action is due to the surface energy effect. The sodium fluorosilicate "coats" the interface between the aluminium oxide particles and the unreacted aluminium, which occurs at the centre of the oxide particle. The oxide is stripped away, mechanically enveloped by the flux and floats into the dross.

While oxide removal is a problem common to all aluminium foundry alloys, there are some special cases in which a cleaning action is required, for example, the removal of calcium or sodium. This is accomplished by
using a base flux of simple composition such as NaCl - KCl and adding to it a reactive component. If sodium removal is desired, MnCl₂ is added and sodium is removed by reaction:

\[ \text{MnCl}_2 + 2\text{Na} \rightarrow 2\text{NaCl} + \text{Mn} \]

To eliminate calcium, AlF₃ can be added to produce the reaction:

\[ 3\text{Ca} + 2\text{AlF}_3 \rightarrow 3\text{CaF}_2 + 2\text{Al} \]

Magnesium can similarly be removed according to:

\[ 3\text{Mg} + 2\text{AlF}_3 \rightarrow 3\text{MgF}_2 + 2\text{Al} \]

So it is clear that the cleansing action of the cleaning fluxes requires a reaction, both mechanical and chemical, between the active ingredients of the flux and the elements or compounds of the alloy. We would be pleased to discuss this procedure further. The process of melting aluminium can result in significant metal loss through the formation of wet dross i.e. the physical entrapment of large quantities of metal alloy in dross. The alloy is present as fine solid or liquid particles which are extremely difficult to separate from the dross. The basic low melting point flux carries the reactive constituents to provide effective reaction and it is essential that the flux be mixed in with the bulk of the liquid aluminium alloy and dross.

In order to produce a powdery, dry dross, cleaning fluxes most often contain small quantities of reactive oxidising compounds such as sulphates and nitrates. These compounds trigger a series of exothermic reactions. Which increases the temperature of the dross to a point where the larger trapped aluminium particles coalesce into large liquid droplets. These droplets, because of their mass, fall out of the dross back into the bulk metal leaving a clean dry, powdery dross and subsequently increase the aluminium retail yield.

The Exothermic Reaction within the Dross Layer

It is perhaps important to note that up to 80% of metal is tied up in the dross layer. The oxidation reaction is set up by the sulphates or nitrates in the flux products. This promotes the oxidation of the finest aluminium particles in the dross to alumina. This exothermic reaction raises the dross temperature to values in excess of 660 degrees C and molten aluminium metal is allowed to drain out of the dross layer, and also, to a lesser degree, a further oxidation reaction of aluminium particles with fluorides in the flux occurs according to the following reactions:

\[ \text{AlF}_3 + 2\text{Al} \rightarrow 3\text{AlF} \]

\[ 3\text{AlF} + 30 \rightarrow \text{Al}_2 \text{O}_3 + \text{AlF}_3 + \text{HEAT} \]

Problems related to the use of fluxes

FLUX INCLUSIONS

As we previously discussed, flux powders must be stirred well or injected into the melt and ultimately complete separation of the two may not occur unless the Foundryman allows for the following procedure to take place:-

a) In principle, fluxes should float to the melt surface and combine with the dross. This process requires an adequate flotation time, which will vary with:

- furnace size and bath depth

  - proper metal temperature is a prerequisite to obtaining quality castings.

b) Proper metal temperature will allow flux flotation. If the metal bath temperature is too low the metal is excessively viscous and this will increase the difficulty of separating flux from metal along with many other metallurgical problems. Temperatures in the range of 700 degrees C to 770 degrees C are usually recommended for most aluminium silicon alloys.

Interaction of flux with strontium master alloy

With salt fluxes containing reactive elements, notably halides, they can chemically interact with additions made to the melt for other purposes. For example, strontium modifiers will react to form the very stable strontium halide, i.e. (SrCl₂ or SrF₂). Strontium, present in this chemically combined form, is unable to act as a modifier. So the order of melt treatment is important flux treatment should always precede modification.

Hydrogen pickup

It is important to understand that many of the salts combined to form foundry fluxes are extremely hygroscopic and will naturally pick up moisture from the air if the flux package is left open for considerable time to the air. It will add hydrogen to the melt, increasing melt hydrogen levels instead of decreasing it. Manufacturer's instructions on storage and usage of flux products should be rigidly followed.