Granular and powder fluxes for aluminium alloys. Cleaning efficiency, cost and environmental aspects

Introduction

For many years powder fluxes have traditionally been used for the metal treatment of aluminium and aluminium alloys, however these fluxes possess certain disadvantages such as dust generation during application, high toxic emissions, and problems of inconsistent efficiency due to their morphology.

In order to overcome these disadvantages, fluxes in dust free granular form have been developed. This paper describes the differences between granular fluxes and powder fluxes in terms of efficiency, environmental emissions and cost savings. The application of fluxes in aluminium foundries uses both cleaning and drossing, and the difference between these two groups of fluxes is shown in terms of melt cleanliness.

The Prefil® (Pressure filtration) test was used to verify the molten metal cleanliness and results from tests on six products are presented.

Theory

Traditionally, powder fluxes have been utilised commercially in foundries for nearly 70 years. Much research and development work in flux morphology has been carried out during the last few years and from this FOSECO has developed a full range of granular fluxes for all types of application in aluminium foundries.

Compared to powder fluxes, 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 significantly. Additional benefits are better consistency in chemistry from grain to grain and the fact there is no segregation during flux transportation or handling. Granular fluxes have 100% grain uniformity in chemistry since each grain will represent the same chemistry as the flux recipe. Moreover granular fluxes are less polluting to the atmosphere, therefore emissions are greatly reduced [1].

Cleaning fluxes are designed to remove aluminium oxides and other impurities from the melt. The action of a cleaning flux takes place within the melt, beneath the melt surface, by trapping the oxide particles and encouraging them to float out. The flux has to be in intimate contact with the melt, therefore it should be plunged and stirred intensively within the molten metal.

Drossing fluxes are designed to agglomerate the oxides in the dross and to separate them from the liquid metal leaving dry and powdery dross. Skimming is thus facilitated and metal loss due to aluminium entrapment in the dross is reduced. The flux should only be mixed with the dross on the melt surface to avoid the re-introduction of oxides and other impurities into the melt.

In order to have a better understanding of the cleaning efficiency in aluminium melts, a test programme has been devised to compare the melt quality with the use of different flux recipes, morphologies and applications: i.e

☐ cleaning vs. drossing flux

☐ granular vs. powder flux

☐ standard vs. Na-Ca free flux

Flux overview

The following products were examined in the practical study (Table 1):

Product	Supplied state	Application	Type of alloys
COVERAL* 90	Powder	Drossing	Standard
COVERAL GR 2510	Granular	Drossing	Standard
COVERAL 105	Powder	Cleaning	Standard
COVERAL GR 2410	Granular	Cleaning	Standard
COVERAL 67 (Na-Ca free)	Powder	Cleaning and drossing	AlMg and hypereutectic AlSi alloys
COVERAL GR 6512 (Na-Ca free)	Granular	Cleaning and drossing	AlMg and hypereutectic AlSi alloys

Table 1 Application and supplied state of tested fluxes

Experimental work

The Prefil test (figure 1) was used to determine molten metal cleanliness and to give an on-line quantitative measurement of oxide films and other inclusions [2]. The flow-rate of molten metal through a micro filter at constant temperature and pressure is monitored and used to plot a graph of weight filtered vs. time. Inclusions in the metal, such as oxide films, quickly build-up on the filter surface during a test, reducing the flow-rate through the filter. Therefore the slope and overall shape of the weight filtered vs. time curve indicates the level of inclusions present in the metal (figure 2).

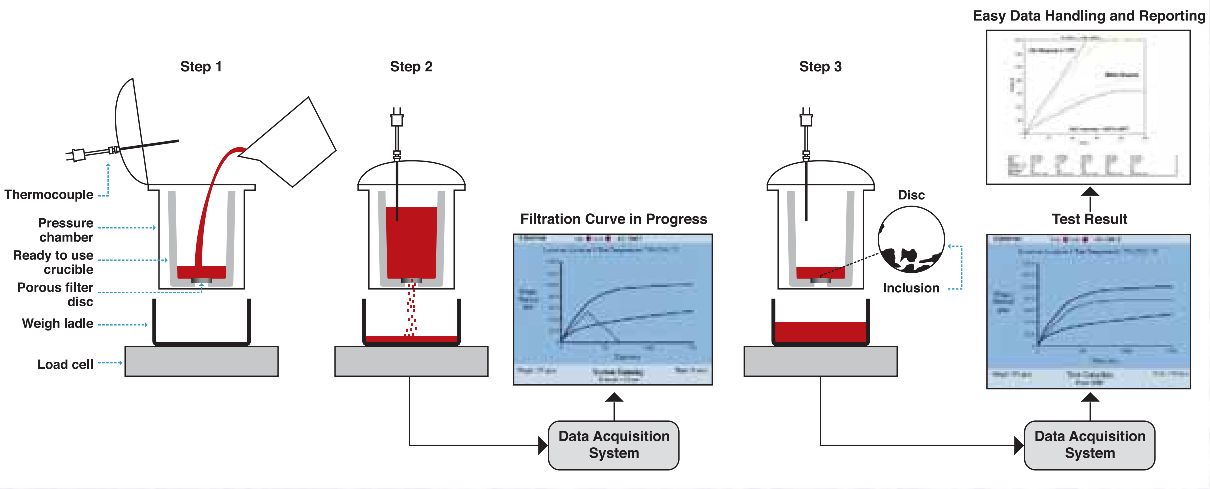

Figure 1 Operation of the Prefil test, which outputs a weight, filtered vs. time curve and a filter residue for metallographic analysis

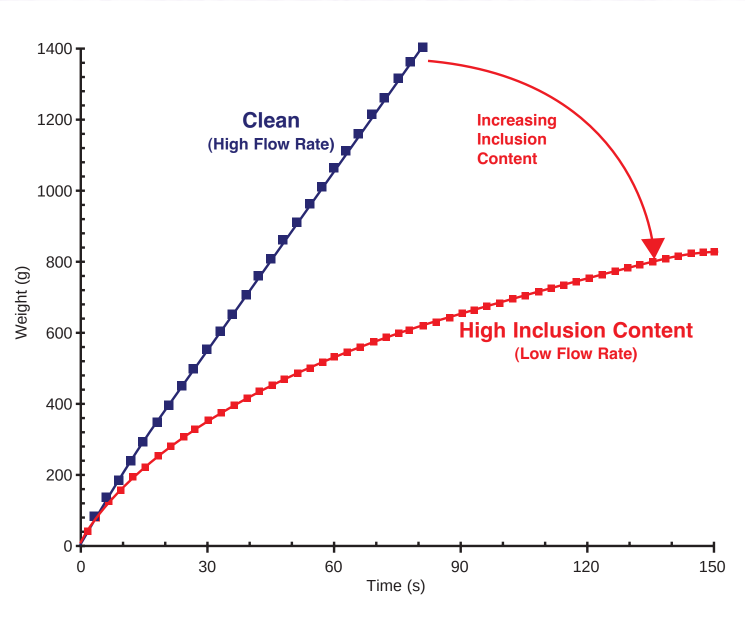

Figure 2 Introduction to Prefil Curves – 'clean' vs. 'dirty' metal

Oxide films affect the initial slope of the curve (20 - 30 seconds), with a slope that decreases as the number of oxide films increases.

Fine particulate inclusions such as TiB_2, fine Al_2O_3 or carbides cause the curve in the Prefil test to deviate from a straight line. The loading of fine particles can be inferred from the point at which the curve begins to deviate from the initial slope.

Acceptable cleanliness can therefore be defined by using Upper and Lower boundary curves. If a test curve falls between these boundaries the metal tested is acceptable. Boundaries are defined by prior knowledge from previous tests.

The build-up of inclusions on the filter, which is known as an inclusion band, can often be seen with the naked eye in metallographic samples. The width of this band gives a quick indication of the level of inclusions within the metal.

Prefil curves are usually defined by comparison to industrial data. Each Footprint is compiled from an upper boundary that relates to super clean material and a lower boundary that relates to the industrial range of data. Figure 3 shows an example Prefil plot illustrating the window for alloys that are not grain refined.

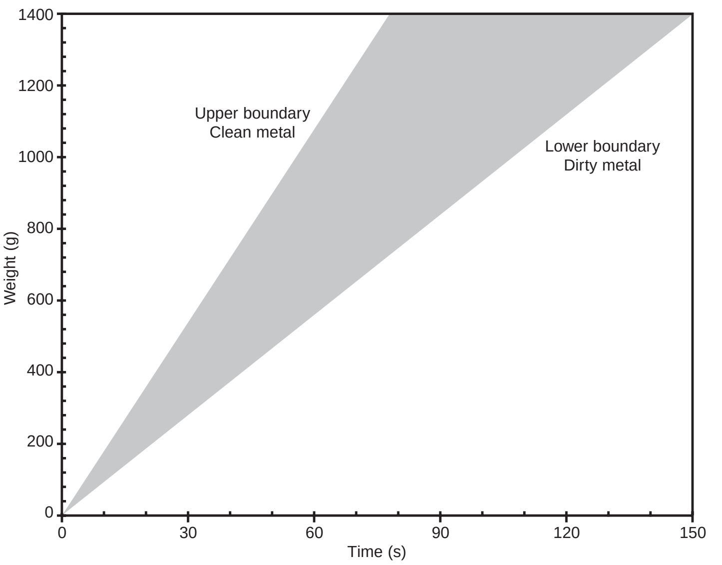

Figure 3 The Prefil World Class Production Window

Experimental procedure

Tests were carried out on AlSi9Cu3 alloy type made up from in-house ingot and turnings (figure 4).

Figure 4 Starting stock material for melt make-up

Melting was carried out in a 230 kg capacity electric tilting furnace. Initially 50 kg of ingot was charged and melted and held at 750°C. Turnings were then charged into the furnace, and the lubricant on them allowed to burn off while they sat on the surface of the melt. Once this was completed, the turnings were then plunged into the melt and vigorously stirred in.

The furnace was then allowed to stand for approximately 30 minutes and then skimmed before a Prefil test was taken. Increasing amounts of turnings were then added in a similar manner until the metal was considered dirty enough to replicate industrial practices, as measured by the Prefil technique.

Pre–heated clay graphite crucibles were used for transferring the metal. This was stirred before transfer and re–heated to 700°C before the flux additions were made (0.1% by weight for granular / 0.35% by weight for powder).

Manual stirring of the flux was carried out for 1 minute with the induction power off. The melt was then heated to 740°C and held for 10 minutes. After holding the induction power was switched off and the metal drossed off (figure 5).

The metal temperature was again raised to 740°C before a Prefil test was taken.

Figure 5 Melt with addition of flux

Results

The Prefil graph (figure 6), shows the cleaning characteristics of each flux. These characteristics are the result of a curve subtraction technique, as outlined below.

$$\text{Efficiency} = \frac{\text{Flux Curve - Control}}{\text{Clean Reference - Control}} \times 100\%$$

This is effectively a comparison technique, allowing all the flux tests to be compared side by side despite their different reference values. The vertical (y) axis is cleaning efficiency, with positive efficiency above the x-axis, and negative below. Thus, those points above the zero point show cleaning and inclusion removal, whilst those below show inclusion generation, possibly from the flux or other complex interactions with the metal. The horizontal (x) axis is a Prefil inclusion characteristic, which is a complex interaction between test time and inclusion shape and size. The inclusion size ranges in the diagram reflect the following approximate values:

- "fine oxides" – 1-10 µm
- "mixed inclusions" – 10 -100 µm
- "coarse inclusions" – >100 µm.

The cleaning efficiency gives a summary of the impact of inclusion removal from the melt. All tested flux recipes gave a positive cleaning effect and improved the melt quality. The cleaning efficiency starts from average 25% up to 160%. Figure 6 does not show a significant variation in cleaning the melt from different inclusion sizes for each flux.

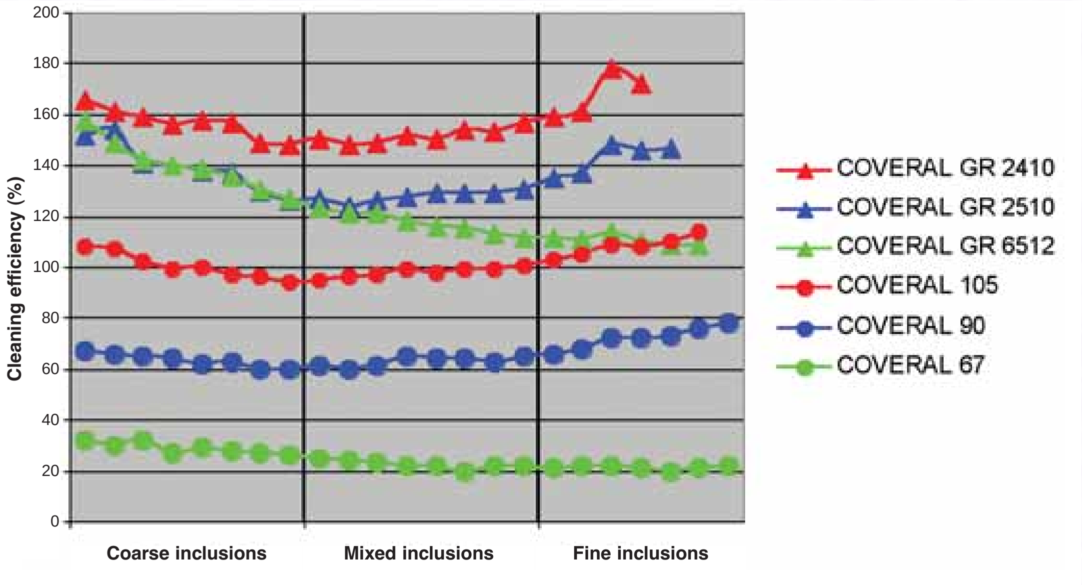

Figure 6 Cleaning efficiency for all tested fluxes

Cleaning vs. drossing flux

The COVERAL GR 2410 cleaning granular flux gives the best melt quality in the test. Compared to COVERAL GR 2510 drossing granular flux, the cleaning granular flux performed about 20% better in terms of inclusion removal. The same result was shown by the comparison between COVERAL 105 cleaning powder and COVERAL 90 drossing powder (figure 7).

In addition to a strong cleaning action the use of a cleaning flux provides a light and dry dross, and the metal content left in the dross is similar compared with the application of a simple drossing flux.

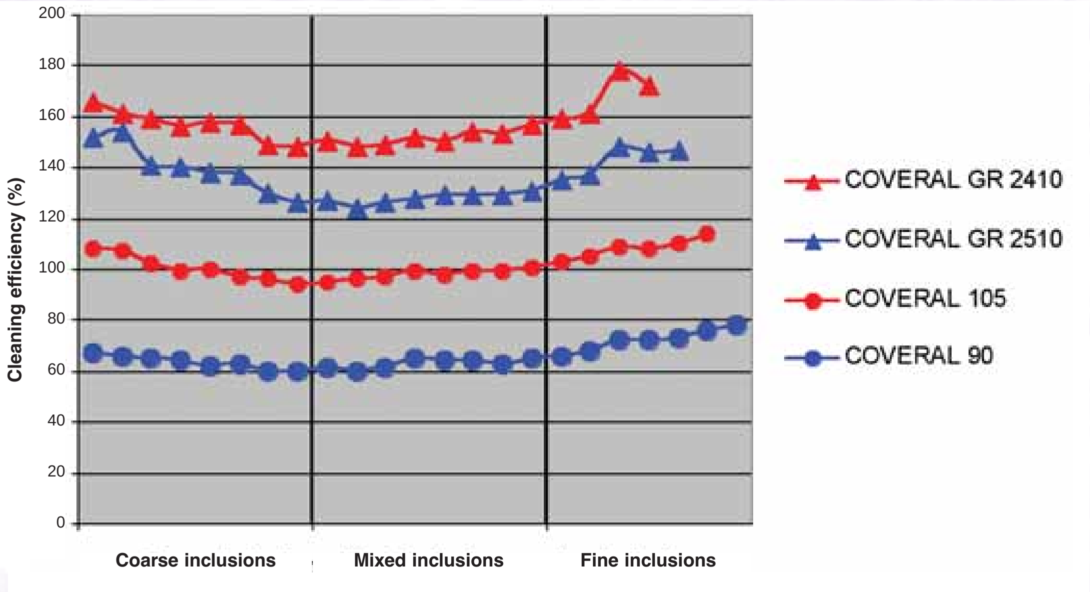

Figure 7 Cleaning efficiency comparison between cleaning and drossing fluxes

Granular vs. powder flux

All granular fluxes, which were used in this test, provided a significantly better melt quality compared to powder fluxes. The granular fluxes performed up to 100% better than the comparable powders. Even with a much lower addition rate of 0.10% compared to 0.35%, the melt cleaning with granulated fluxes was much more efficient (table 2).

Application	Granular		Powder		Granular vs. powder
	Product	Efficiency	Product	Efficiency	
Cleaning	COVERAL GR 2410	158%	COVERAL 105	102%	+ 56%
Drossing	COVERAL GR 2510	137%	COVERAL 90	65%	+ 72%
Na-Ca free	COVERAL GR 6512	125%	COVERAL 67	25%	+ 100%

Table 2 Cleaning comparison between granular fluxes and powder

Standard vs. Na-Ca free flux

All of the sodium and calcium free fluxes used in the tests can be used for both drossing and cleaning. As they contain no sodium or calcium salts the range of available raw materials and recipes is limited. The cleaning efficiency of the melts were, however, found to be close to standard granular fluxes (figure 8). If specified to use Na or Ca free fluxes, dependent on the alloy, the result showed a measurable quality improvement with a dry low metal content dross.

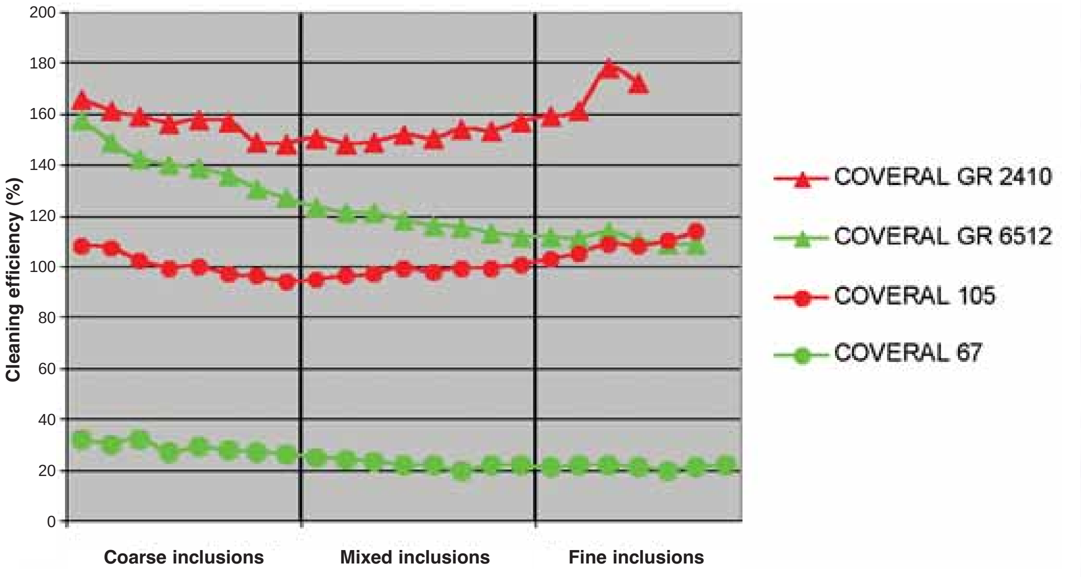

Figure 8 Cleaning efficiency comparison between standard and Na-Ca free fluxes

Environmental aspects

In a further study the environmental emissions during flux use were measured. The study was carried out with two fluxes, which are in powder and granular form. The test was made on different types of furnaces and under different conditions [3]. Table 3 shows the average analysis of two drossing flux recipes:

- ☐ Flux A – mild exothermic drossing flux
- ☐ Flux B – sodium free cleaning and drossing flux

	Flux A		Flux B	
	Powder	Granular	Powder	Granular
	Concentrations in mg/m³			
Total particulate	1.5	0.46	1.35	0.52
Total Cl	0.73	0.72	0.83	0.82
F	11	3.4	7.5	3.6
Nox	-	-	-	-
SOX	8.5	1.6	4.9	2.5

Table 3 Overall comparison of emissions for several furnace types in several conditions

The overall indications from the work are that the amount of emission is significantly reduced using the granular fluxes. This work highlights that the most significant advantages are to be had by going from powder to granular flux, rather than changing the formulation of the powder flux. This really supports the theory that the morphology of the flux is a very significant contributor to the type and quality of pollutants that may emanate. The move from powder to granular fluxes will improve the working environment by the reduction of pollutants in the atmosphere.

Cost aspects

The price of a granulated flux compared to a powder flux is higher due to its manufacturing process, however as shown in the trials, the addition rate of granular fluxes is significantly lower. Besides the stronger cleaning impact and the environmental benefits of granular fluxes, there can also be an economical benefit which is illustrated in the following example (ME = "money equivalent", it does not relate to a certain currency)

	Powder A	**Granulate A**
Selling price:	1 ME / kg	2 ME / kg
Addition rate:	0.35%	0.10%
Price per treatment of 100 kg:	0.35 ME	0.20 ME

The use of granular flux therefore can give a sensible economical advantage per treatment in spite of its higher unit cost.

Conclusions / summary

Fluxes in both powder and granular form have been compared in terms of melt cleaning efficiency using the Prefil Test and have shown the granular fluxes to be superior in all cases.

Different applications require different recipes but generally cleaning fluxes give better melt quality than simple drossing fluxes, however, the actual dross quality of both types of flux is similar.

A change to a granular flux from a powder flux significantly improves working conditions by reducing the amount of pollutants in the atmosphere.

In addition to technical and environmental benefits, the higher efficiency of granular fluxes results in lower addition rates and significant reductions in overall treatment costs are frequently achievable.

References

1. R. Gallo; Development, Evaluation and Application of Granular and Powder Fluxes in Transfer Ladles, Crucible and Reverberatory Furnaces; Foundry Practice 237 (2002)

2. N-Tec Ltd. – The Prefil technology; Report number 040109; (2005)

3. S.R. Sibley; Granular fluxes for aluminium alloys, environmental and technological advances; Foundry Practice 227 (1996)