Improving casting quality through optimised coating technology

Introduction

This paper reviews the importance of optimised coating technology in the production of high quality castings. By providing an overview of current coating and application technology, and then focusing on a specific coating development project, it aims to highlight the importance of continuous development within this field, in providing solutions to foundry and end-user requirements. The case-study concerns the development of coatings that help prevent reversion to flake within the rim-zone of ductile iron castings and discusses the technical issues, the development procedure and project results.

It is possible to produce castings without the use of a mould coating, however, the use and correct application of the correct coating will improve the as-cast surface finish. This improvement can be as basic as the removal of sand grain definition, but more often is the reduction and potential elimination of a number of casting defects :-

- Metal Penetration
- Poor Casting Strip
- Mould Erosion
- Gas Defects
- Metal / Mould Reactions
- Sand Expansion Defects
- Metallurgical Defects

A mould coating prevents casting defects by providing a protective layer between the molten metal and the mould face, and it is the integrity of this layer that is of paramount importance. Inconsistencies within this layer will ultimately lead to inconsistencies within the as-cast quality of the component.

Through optimised coating technology, as-cast quality can be improved, be consistent and add value to the as-cast component.

Application technology

When applying a coating there is one basic requirement, to apply an even layer of coating free of runs and drips. The layer thickness, when dry, of this even layer of coating should be sufficient to prevent any detrimental interaction between the molten metal and the mould or core.

To apply an even layer of coating the correct application method should be used, and the coating should have the correct properties to maximise the benefits of the application method. It is widely accepted that there are two methods of application that can ensure an even layer is applied.

Dipping

The core is submerged into the coating and removed within a set period of time, the properties of the coating ensure an even layer is applied. By a combination of manipulation of the core after dipping and the properties of the coating, a drip and run free surface is achieved.

Flow Coating

The mould or core is angled to between 20º and 40º to the vertical and coating is applied through a hose, starting at the top and in lateral movements progressively working down to the bottom. The properties of the coating should ensure an even layer build-up, with excess coating flowing into a collection tray.

Other methods that can be adopted do not offer the precise control of either dipping or flow coating. Brushing is very dependant on the operator ensuring an even layer is applied, a process which is very difficult on complicated shapes and has the added drawback of brush marks, whilst spraying is only possible on surfaces which are perpendicular to the spray head, so impossible on flanges and deep pockets.

Coating technology

A coating exists in two states, firstly as a liquid ready for application and secondly as a solid coating layer adhering to the mould surface after drying. The requirements of these two stages sometimes conflict, but it is the successful combination of these stages that produces an optimised product.

Liquid State

It is the role of this state to transfer the components of the subsequent solid coating layer onto the mould surface in an even, homogeneous layer. The rheological system used to perform this is designed, firstly to maintain a homogeneous mixture of all the coating's constituent components, without separation. Secondly to aide the application technique in achieving an even layer thickness, free from runs and drips. The application properties of the coating can be controlled by the manipulation of two main variables within the rheological system :-

- Flow Characteristics
- Matt Time

Flow Characteristics

The flow characteristics can be controlled by manipulation of the gel strength, which is part of the rheological system, and by how the gel performs when shearing stresses are applied and subsequently removed.

When a core is dipped (i.e. a shearing force is applied) the coating should become more liquid to allow complete coverage of a complicated shape. As the core is removed, the gel should regain its strength relatively quickly to ensure the coating does not flow to form runs and drips.

When a mould is flow coated, the coating should flow for a long time, allowing the coating to flow over the mould face, producing an even layer of coating, with the excess coating running off the mould, to be collected for re-use.

Matt Time

The matt time controls how long a coating is active, after application onto the mould face, its purpose is to lock the coating into position, once the correct layer thickness has been applied and all runs and drips have been removed. This ensures that subsequent manipulation of the mould does not cause the applied coating layer to be disturbed. The matt time should be balanced to the application requirements and the flow length of the gel system.

The matt time should be longer than the time it takes to remove runs and drips by manipulating a core after dipping.

Solid Coating Layer

The layer consists of a mixture of refractory materials and binders, and it is this layer that prevents any detrimental interaction between the liquid metal and the mould substrate. The amount of protection offered is directly proportional to the dry coating layer thickness, and the choice of refractories and binders.

Refractories

The refractories chosen must be effective at the temperature of the molten metal being poured, but by careful selection of type and grading other properties can be imparted to the coating. Some examples are :-

High Insulation

A highly insulating layer can delay the thermal expansion of a silica sand substrate long enough to prevent sand expansion defects such as veining.

Lustrous Carbon

Inclusion of lustrous carbon forming agents improve the surface finish of most iron castings.

Metallurgical Enhancers

By the inclusion of active components within the coating beneficial reactions can take place within the surface of the casting, improving surface metallurgy e.g. localised grain refinement or the elimination of reversion to flake (see case-study).

Binders

The binders ensure the coating layer is stable at both room temperature, to allow for handling requirements and at extremely high casting temperatures, to ensure the prevention of erosion to both the coating and the substrate.

Coating control

To ensure the coating is applied at the correct layer thickness at all times it is essential to control the dilution of the coating. The governing factor is the dry layer thickness of the applied coating, and this should be established through trials to determine the optimum layer for maximum protection. It is difficult to check on a regular basis, within the production environment that this dry layer is always being achieved, therefore a simpler measure must be used.

- ❑ Dry layer thickness is proportional to wet layer thickness, which can be measured with a wet thickness gauge (see Figure 1).

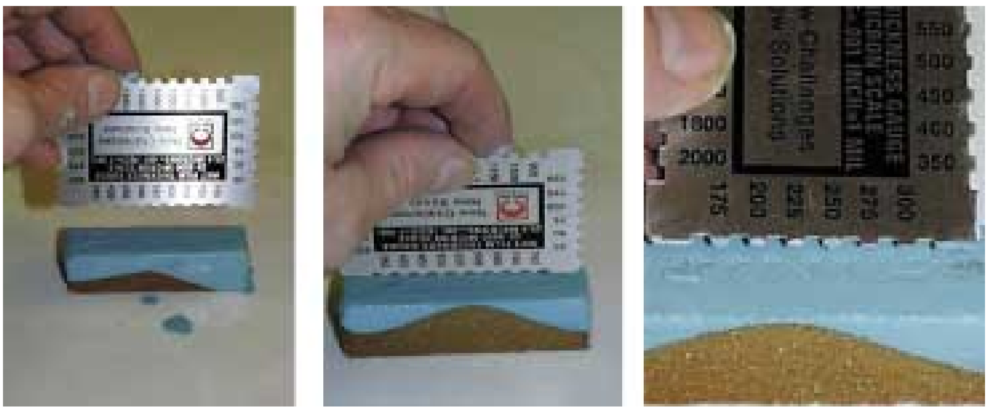

Figure 1: Measuring the wet thickness layer of a coating

Figure 2 : Measurement of viscosity with a Flow Cup (DIN 4mm)

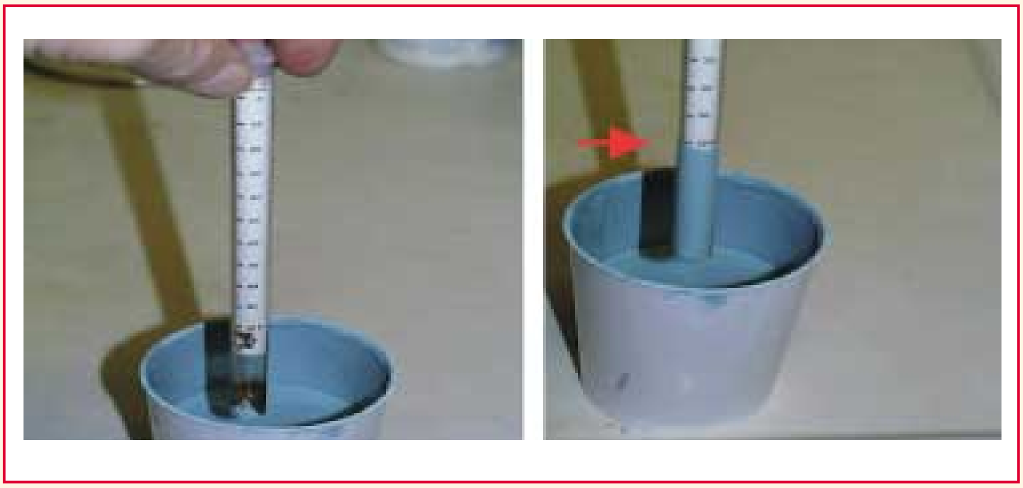

Figure 3: Measurement of Baumé with a Baumé Stick

- Wet layer thickness is proportional to coating viscosity, measured using a "Flow cup" (see Figure 2) or Baumé, measured with a "Baumé stick" (see Figure 3)

It should always be remembered that these other methods are only relative to the dry layer thickness of one type of coating on one type of substrate. For example a coating with a viscosity of 14 sec (DIN 4mm) applied to a furan bonded chromite core will give a different dry layer thickness when compared to the same coating applied to a Phenolic Urethane Cold Box (PUCB) bonded silica sand core.

Case study: The influence of coatings on the graphite structure in the rim zone of ductile iron castings (1)

The following case-study provides an example of the importance of controlling the layer thickness of a coating, and highlights the benefits to the foundry of an optimised coating technology.

Introduction

With the production of castings in ductile iron with larger cross-sections, faults in the graphite structure in the rim zone can be observed. The occurrence of these structure anomalies can be due to the reactions at the metal mould interface. For ductile iron one of the main demands is that the graphite structure is completely spheroidal. Should degeneration of this structure appear, then there will be a corresponding deterioration in the mechanical properties of the component, which under cyclic or dynamic loading, as in the machine or automotive industry, could lead to failure.

The factors influencing the graphite development are many (2), however the appearance of irregular graphite development has been observed when casting in moulds that contain sulphur. This case-study focuses only on the effect of sulphur within the moulding media on the degradation of spheroidal graphite within the rim zone.

From a number of other studies (3,4,5) it is noted that in moulding sands containing sulphur (i.e. reclaimed sand bonded with furan or phenol binders catalysed by sulphur bearing catalysts), there will be a sulphur pick-up in the rim zone, resulting in the presence of flake graphite to depths of 1.3mm. This problem can seriously affect the amount of sulphur bearing reclaimed sand that can be used in the production of moulds for the casting of ductile iron.

Testing Procedure

For the tests a trial casting was used, a U-shaped casting with dimensions 175 mm x 195 mm x 120 mm (l x w x h) and weighing 25kg, the wall thickness in the area of the core was 50 millimetres. The casting was simulated to determine solidification times and in-mould temperatures during the casting process.

The moulds were produced in reclaimed sand with known sulphur content, and a furan binder catalysed with PTSA was used.

Coatings with four different combinations of refractory filler materials were tested, by applying a dry layer thickness of 0.20 to 0.25mm to the mould. The properties of the coating filler materials can be seen in Table 1.

	Base Material	Density g/cm3	Raw Density g/cm3	Porosity	S content %	C content %
A	Aluminium Silicate	2.70	1.05	0.611	0.027	1.50
B	Zirconium Silicate	4.36	2.33	0.465	0.013	0.83
C	Coke Flour	2.21	1.16	0.475	0.082	25.70
D	Zirconium & Magnesium Silicate	4.15	2.11	0.491	0.010	2.34

Table 1: Properties of the investigated coating filler materials

Casting Results

The Structure development was checked with the help of micrographs of the samples, which were taken from the hot spot of the casting. The moulds that were coated with coating A (Figure 4a.) and coating B (Figure 4b.), show defective development of the graphite in the rim zone, mainly in the form of flake graphite. With coating C (Figure 4c.) no flake graphite was observed but the nodule structure is disturbed. In the rim zone many relatively small nodules can be seen compared to the other coatings. This effect can be classified as inoculation by the coating.

Figure 4a: Casting structure using coating A

Figure 4b: Casting structure using coating B

The best results concerning nodule structure were obtained with coating D (Figure 4d.). The trial series was repeated, and each time comparative results were observed.

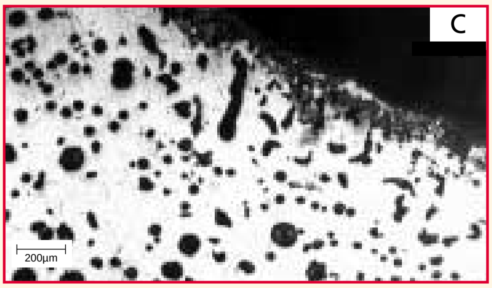

Figure 4c: Casting structure using coating C

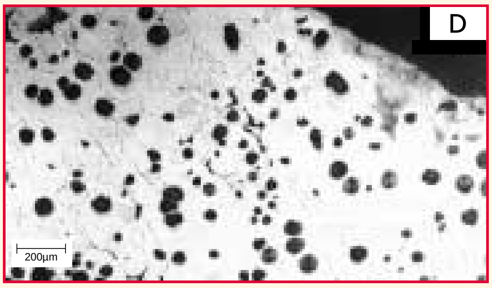

Figure 4d: Casting structure using coating D

Further Investigation

The initial results showed a difference between the amount of reversion to flake within the test castings. To further assess the effect of the coatings, samples of the coating were removed from the hot spot after casting, and the hot spot of the casting was machined to 0.5mm and 1.0mm respectively. All samples were then tested for sulphur
(see Figures 5 and 6).

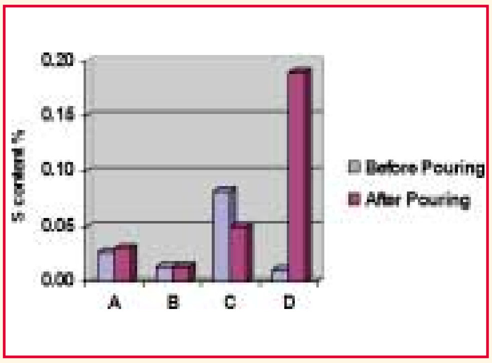

Figure 5: Sulphur content of coating before and after pouring

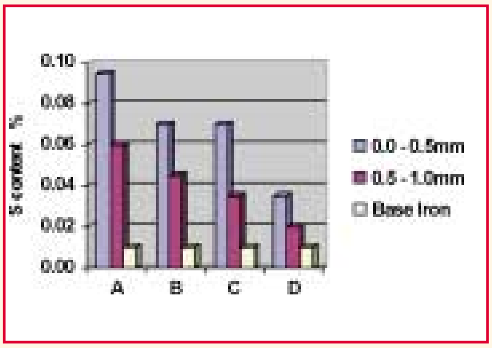

Figure 6: Sulphur content of the casting surface

The sulphur content of coating D showed an increase of approximately twenty times its initial value, and the corresponding metal samples showed sulphur values of half those observed for the other coatings.

To fully assess the effectiveness of this coating, the sulphur within the mould was manipulated to higher levels, and then the sulphur content after casting of the sand, coating and metal within the hot spot region were determined (see Figures 7, 8 and 9).

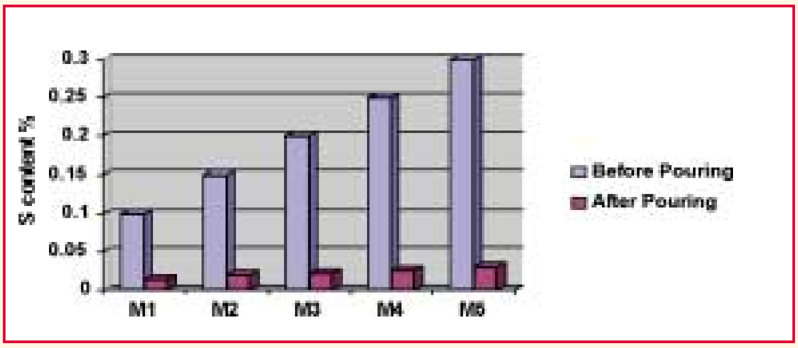

Figure 7: Sulphur content of furan bonded sand

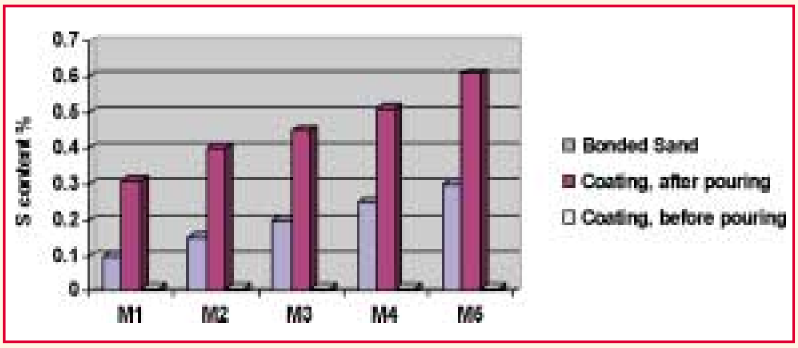

Figure 8: Sulphur content of coating D

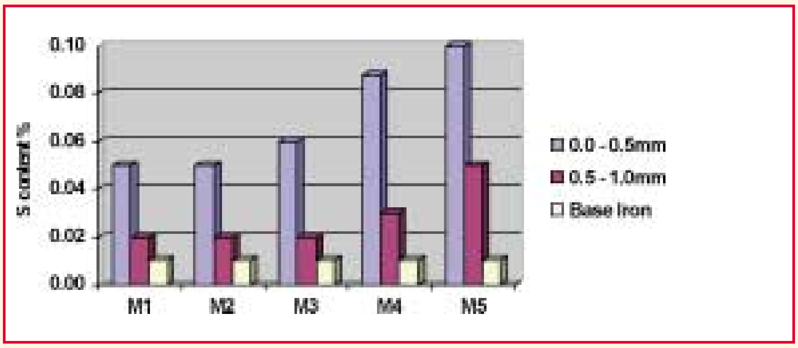

Figure 9: Sulphur content of the casting surface

Results

After casting the sulphur content of the moulding sand lies between 0.014 and 0.030% (see Figure 7), indicating that the sulphur within this part of the mould was burnt out almost completely.

The sulphur content in coating D after casting was approximately three times the initial values (in the moulding sand) for the trial M1 (S=0.1%) and M2 (S=0.15%). When the sulphur content of the moulding sand is increased further, only about twice the amount in the coating could be determined (see Figure 8).

The surface of the trial castings were removed again to a depth of 0.5 and 1.0 millimetres and tested for sulphur (see Figure 9). With sulphur content of 0.15% or less within the moulding sand the sulphur content in the surface of the casting is limited to 0.05%. As the content within the moulding sand increases above 0.15%, the value within the casting increases steadily.

No significant reversion to flake was determined with a sulphur content within the moulding sand of up to 0.2%, when using coating D. Should the sulphur content be increased further, the bonding of sulphur in the coating layer is progressively less effective and rim zone graphite degenerations are likely to occur. This may be avoided by increasing the layer thickness of the coating.

Summary

It has been shown that by selection of the correct refractory filler combination, that a coating can be developed to prevent the effects of reversion to flake of ductile iron within the rim zone, due to the sulphur content of the moulding media. A dry coating layer thickness of 0.20 to 0.25mm can help prevent reversion to flake .within the rim zone, where the moulding media contains up to 0.20% sulphur. It is shown that as the coating becomes saturated with sulphur its preventive mechanism is overcome and the sulphur level within the casting rim zone rises to above acceptable values.

The effectiveness of the coating is proportional to the amount of active ingredient applied to the mould surface, the amount of active ingredient applied is directly proportional to the dry layer thickness of the coating. Through careful use of such a coating, benefits can be seen for the foundry, through increased use of reclaimed sand.

Conclusion

Mould coatings are used to prevent many defects, and in all cases it is the combination of the refractory components and the dried layer thickness that ensure a repeatable casting finish. The optimisation of coating technology aides the application of this layer. Coatings designed to meet the needs of the application process, allow a consistent layer to be applied time after time, without runs, drips and brush marks.

By careful selection and optimisation the refractory filler types can be chosen to provide more than simple improvements to surface finish. As the case-study outlines, metallurgical properties can be improved, and by similar focus on the requirements of the modern foundry, coatings have been developed to suppress other defects such as veining and localised metal penetration.

References

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