

Improved Iron Casting quality through application of advanced coating technology

In high production iron foundries worldwide, silica sand is predominantly used for core production due to its availability and relatively low cost compared to other refractory sands.

In many instances the silica sand is bonded using a phenolic – urethane binder system cured with a gaseous amine catalyst.

This process has become a dominant core production technique in most foundries because of its operational and production benefits compared to other processes.

There are, however, certain fundamental deficiencies with the process such as poor refractoriness of the sand, non – linear thermal expansion of the bonded core and inherent low hot strength of the phenolic – urethane system. These deficiencies can be largely overcome by the use of refractory core coatings.

This paper describes defects that are commonly seen, and then models the effect of coatings on heat transfer, and the stress/strain within the core. Confirmation of the modelling in test blocks and in actual foundry trials using RHEOTEC XL coating is reviewed.

Introduction

High production iron foundries worldwide typically utilise silica sand for core production due to its availability and relatively low cost compared to other refractory sands. In many instances the silica sand is subsequently bonded using a phenolic-urethane binder system cured using gaseous amine catalyst. This type of cold-box process has become the dominant core production technique in most foundry markets around the globe due to the significant operational and production benefits it provides compared to hot-box and shell processes.

Nevertheless, certain fundamental deficiencies of the technology remain, notably:

- ❑ Poor refractoriness of silica sand
- ❑ Non-linear thermal expansion of the bonded core sand
- ❑ Inherent low hot strength of the phenolic-urethane system

Poor refractoriness of the silica sand can lead to sand burn-in and / or metal penetration defects. However it is generally accepted that these defects can be overcome through the use of refractory core coatings.

Unfortunately, in many cases a conventional refractory coating is not sufficient to overcome the combined effects of the non-linear thermal expansion of silica sand and the low hot strength of the phenolic-urethane binder. The typical outcome is the formation of sand expansion defects known as “veins” or “fins” (figure 1).



Figure 1 Vein defects in cylinder head

The formation of sand expansion defects

In recent times, many theories have been proposed to try to describe the process in which a vein might form during the pouring and subsequent solidification of a casting. These theories tend to be qualitative rather than quantitative, and do not describe a mathematical model that can be used to predict sand expansion defect formation. Without such predictive models, the development of products to overcome the variables that promote veining has been an iterative process rather than one that focuses on the relevant technical factors and parameters.

This qualitative process has led to considerable success, and many products are widely available within the foundry industry that claim to eliminate the defects associated with sand expansion. However at FOSECO it is felt that the current approach has reached its limits, and that a more scientific approach to research and development is required in this area if significant advances in technology are to be made which benefit the foundry industry in terms of superior coating products and core sand additives.

Vein formation

As liquid iron surrounds an uncoated core during the casting process, the immediate surface temperature of the core rapidly increases - subsequently this heat diffuses deeper into the core substrate. The rate of this heat transfer is governed by many factors, including :-

- Thermal conductivity of the core substrate
- Heat transfer between the liquid metal and the core surface

The effect on the core of this temperature rise is a thermal expansion of the substrate. Due to the fact that the expansion is non-uniform across the cross section of the core, physical stresses are created, i.e the core surface wants to expand more than the inner areas of the core. During the rapid temperature rise there is little risk of crack formation because only compressive stresses are created. These stresses are significantly greater with silica sands than other refractory sands, due to the non-linear thermal expansion brought about by the Alpha / Beta phase change of quartz at 573°C (figure 2).

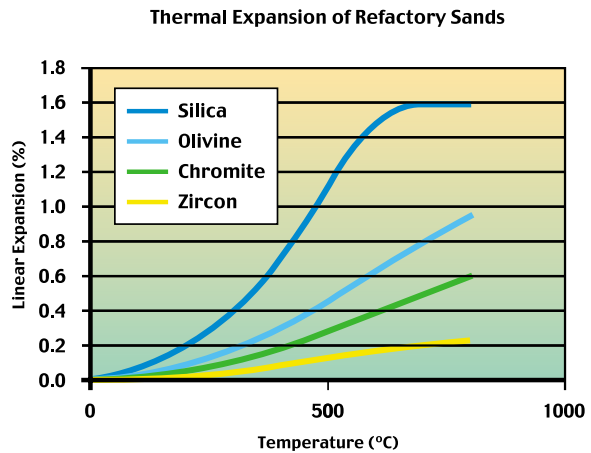


Figure 2 Thermal expansion of typical foundry sands as temperature increases

As the temperature at the metal / core interface exceeds 600°C, the effect on the core is that the thermally expanded core surface starts to contract while the material slightly below the surface is still expanding. This is the point at which cracks in the substrate surface can potentially appear if the hot strength of the binder cannot overcome the contractive forces. If a crack does form it does not necessarily mean that a vein will automatically result. The crack will only be filled with liquid metal if the metal at the metal / core interface is still liquid and if the substrate surface is at a temperature above the solidus of the metal. Under these conditions, the ingress of metal into the cracks in the substrate can certainly occur.

This very simple model is complicated considerably by the incorporation of the effects of both sand additives and core coatings, but it is only by being able to determine the effects of these materials on the heat transfer into the core substrate and the stresses produced due to the thermal expansion of the core, that we can start to use the model to focus research and development.

To incorporate these into the model, parameters such as those listed below need to be determined for each type of coating and core additive.

- Thermal conductivity and diffusivity of coating filler materials
- Dilatometry of the sand and additives
- Thermal conductivity of sands (with and without additive)
- Flexural stress / strain curves for sand and coatings

Modelling the effect of coating on heat transfer

Information on these properties can be used to model the behaviour of both the solidifying casting and the stress / strain build up within the core due to heat transfer from the metal. In the following examples the effect of coating and sand additive is determined for a standard veining test block, which utilises a 50mm diameter core.

The effect of coating on the cooling of the metal

Immediately after casting the temperature of the metal cools rapidly, and then adopts a comparatively lower cooling rate. The use of a core coating and the type of coating has a minor effect on this subsequent cooling rate, where no coating is used the metal temperature reaches 1100°C in 5.0 minutes, whereas with the highest insulating coating (RHEOTEC XL) it takes 6.4 minutes (figure 3).

Effect of coating on cooling of cast test piece

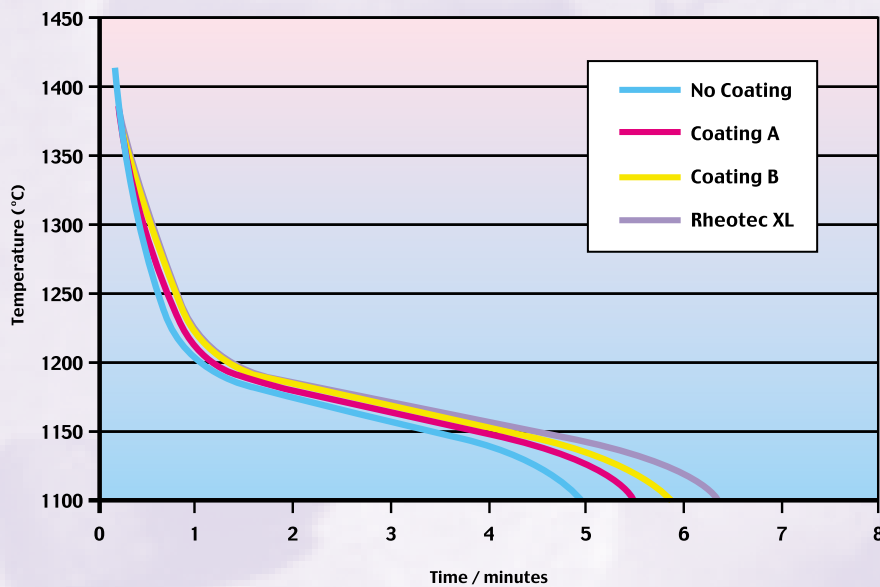


Figure 3 Effect of coating on cooling of the metal

Although this is a relatively small difference, its effect on solidification can be predicted using software such as *Magmasoft® (figures 4a & 4b).

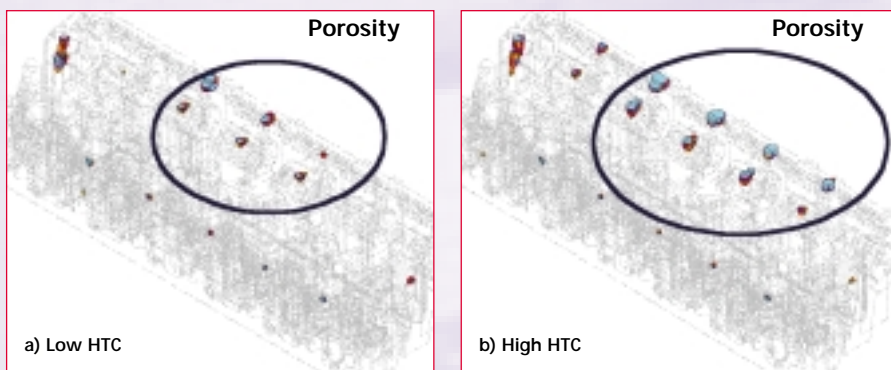


Figure 4 Porosity differences in a Diesel Cylinderhead Casting due to different heat transfer coefficients (HTC) at the metal / core interface

*Magmasoft® is a registered trademark of Magma Giessereitechnologie GmbH

The effect of coating on the heating up of the core

The most significant effect is recorded within the outer layers of the core during the first minutes after pouring, the heat transfer into the core is significantly reduced by the application of a coating (figure 5). With no coating the uppermost layer of the core reaches a peak temperature of approximately 1300°C before cooling begins and falling to 1100°C within 5 minutes. The most insulating coating (RHEOTEC XL) ensures the top layer of the core reaches no more than 1120°C, and there is little subsequent drop off in temperature during the first 5 minutes.

Effect of coating on heating and subsequent cooling of the core surface layer

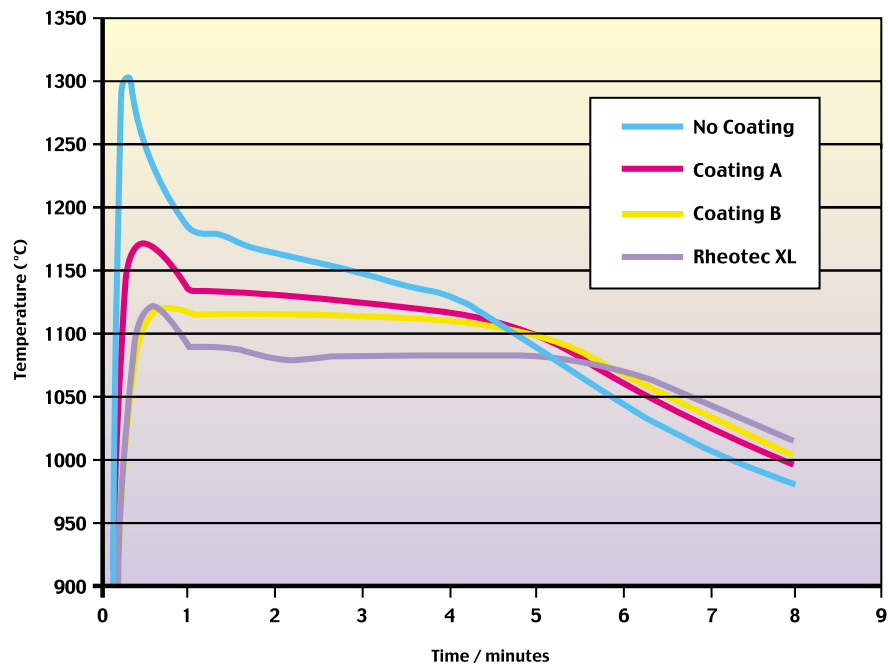


Figure 5 Temperature measured at just below the core surface at time after casting

Modelling the stress / strain within the core

There is a risk that a vein will form if two parameters combine, a crack is propagated in the core surface and the core surface temperature is higher than the liquidus of the metal. This second parameter can be used to define the time slot that veins are likely to form, and hence focus the investigation into whether a surface crack is likely to form. For comparative purposes within the casting test block, an uncoated core is at risk during the period of 15 seconds to 5 minutes after casting, whereas a core coated with RHEOTEC XL is at risk only for the period 20 seconds to 55 seconds after casting (figures 6, 7 and 8).

Assessing the strain within the surface of these cores during the respective periods of time, can predict the risk of vein formation and even the severity of the vein itself.

Uncoated core

It is shown that throughout the period of risk the surface of the core is undergoing tensile strain to a maximum of 10 millistrain, indicating that a crack is likely to occur. A tensile strain is apparent at all depths up to 9mm indicating that the crack severity is in the region of 9mm in depth (figure 6).

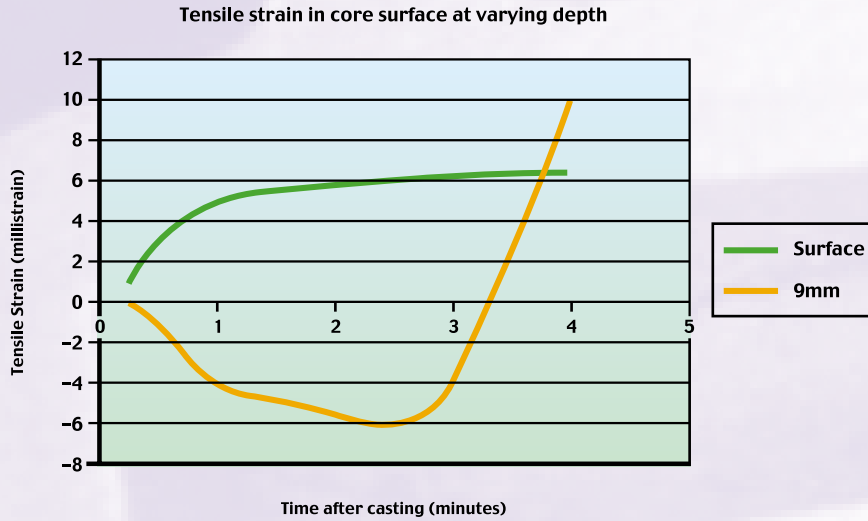


Figure 6 Tensile strain¹⁰ at the surface of an un-coated core during the critical period after casting

Core coated with RHEOTEC XL

It is shown that during the period of risk the surface of the core is undergoing tensile strain, although the maximum strain is reduced at 5 millistrain. The severity of the vein is also reduced significantly to approximately 3mm (figure 7).

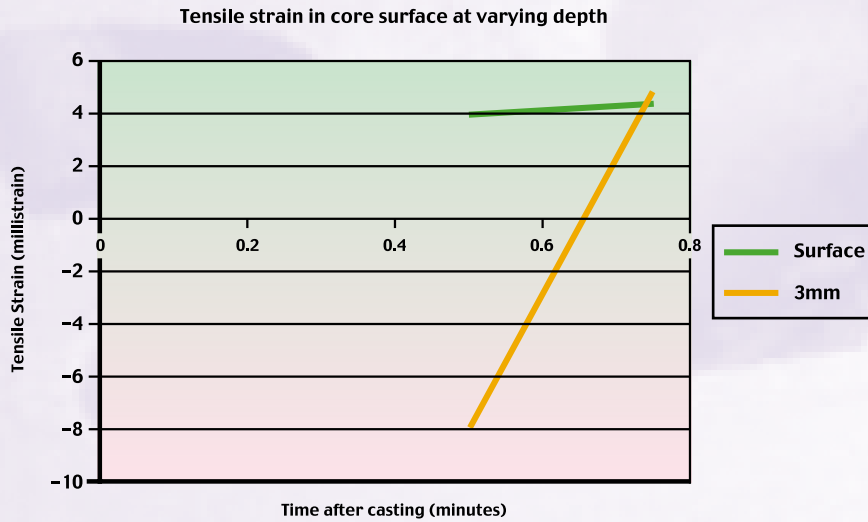


Figure 7 Tensile strain at the surface of a core coated with RHEOTEC XL during the critical period after casting

Core produced with an addition of NORACEL* M75 sand additive (8% BOS) and coated with RHEOTEC XL

The addition of a sand additive does not affect the period of risk, however it will reduce the tensile strain developed within the core. It is shown that the maximum tensile strain is achieved at 2mm below the surface, at the surface itself the core is in compression during the period of risk. This could eliminate veining altogether in this example (figure 8).

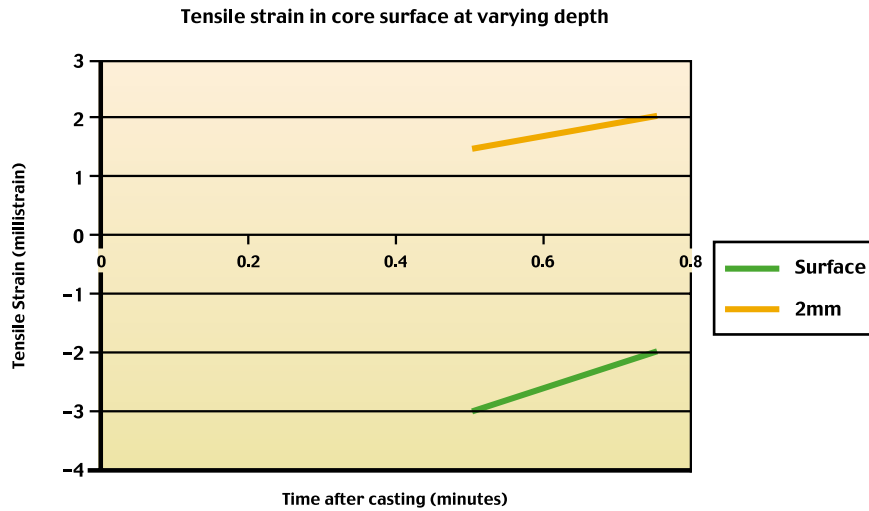


Figure 8 Tensile strain at the surface of a core containing 8% NORACEL M75 additive and coated with RHEOTEC XL, during the critical period after casting

Confirmation of the model using casting test blocks

Note for test purposes an un-coated core was not cast as the amount of veining and metal penetration made analysis impractical. However, based on the model described a simple non-insulating coating will have little effect on preventing vein formation and this is demonstrated in the test casting in figure 9a. In a number of circumstances it is found that by improving the insulation at the metal / core interface by using RHEOTEC XL, veining is eliminated or reduced significantly. This is demonstrated in figure 9b where the RHEOTEC XL cannot quite overcome the severe casting conditions of the veining block. Under such severe casting conditions only the subsequent addition of an anti-veining sand additive can completely eliminate veining (figure 9c).

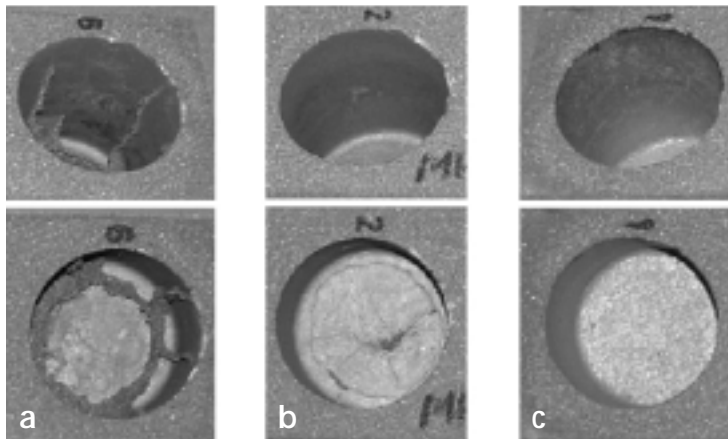


Figure 9 Veining block test casting results

Case Study

The company Monforts (Iron Foundry) GmbH & Co is located in Monchengladbach, Germany and is a specialist producer of iron castings for the automotive sector. A key product line is turbo housing castings (figure 10), which are produced in various grades of ductile iron, and are typically prone to veining defects located within the volute section of the manifold. The location of the veins in a confined area makes for incredibly difficult location and removal, and slows down production rates and can result in increased levels of scrap (figure 11).



Figure 10 Monforts Turbo Housing Casting



Figure 11 Veining defects prior to the use of RHEOTEC XL coating

The customer was looking for ways in which improving the manufacturing route for turbo housings could produce a casting with improved internal surface finish, eliminate the veining defects and ensure no subsequent degradation to the cast surface, such as burn-on. This would provide significant benefits to both the customer and the end user as follows:

- Reduction in scrap
- Improved productivity
- Reduction in overall manufacturing costs
- Improved surface finish

Casting Data

Casting Weight	9.0kg (net)
Alloy	GGG SiMo 5.1
Castings per mould	4
Casting Temperature	1,420°C
Castings per annum	50,000 x 2 types
Coresand	Silica (L40 – 50)
Corebinder	Phenolic Urethane Coldbox

Trial Data

After a number of trials the practice outlined below has been adopted for these castings, the dipped cores are shown in figure 12.

Coating	RHEOTEC XL
Anti-Veining Additive	1% (based on sand)
Coating Method	Dip (one layer applied)
Baume	32 – 35
Viscosity	13.5 –14.0 seconds (DIN 4mm flow cup)
Coating Layer	0.33mm (wet layer)
Drying	1 hour in convection oven at 120°C



Figure 12 Turbo housing cores dipped in RHEOTEC XL coating

The internal surface finish of the casting was improved and veining defects were eliminated or reduced significantly (figure 13), and the objectives of the foundry were met:

- Reduction of veins and sand expansion defects by 80 – 100%
- Reduced casting scrap
- Reduced cost and time of after-cast operations
- Faster throughput in the fettling and cleaning area.

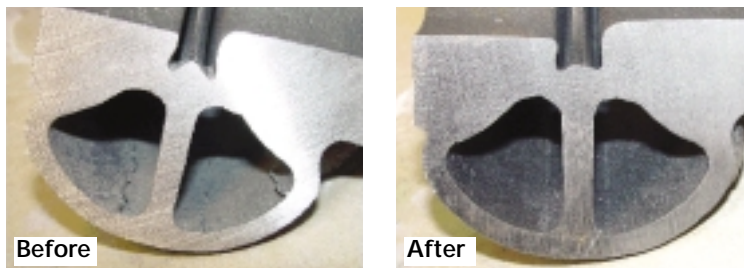


Figure 13 Internal finish before and after the introduction of RHEOTEC XL coating

Conclusion

As the specification, complexity and quality requirements of cast products increases it is essential that the processes and consumable products that form the basis of the casting process develop to fulfil the end user requirements. These requirements must fit hand-in-hand with the competitive environments that foundries operate in and focus on improved performance to deliver quality cast components, whilst reducing overall costs. The coreshop offers significant opportunities to reduce overall foundry costs, by eliminating the cause of the subsequent re-work at source. RHEOTEC XL coating is an example of a product which can save significant costs within a foundry. A more fundamental understanding and modelling of the thermal dynamics of the casting process at the metal-mould interface, will ensure supply to the industry of further high performance coating products in the years to come.

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