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Influence of Surwaybest Starch-Based Additive on the Surface Quality of Cast Iron Castings

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Abstract

Though additives developed for foundries are widely used across the globe, their direct effects remain unclear, and the mechanisms of their action within core and moulding mixtures have not yet been precisely described. When utilizing these new additives, it is expected that they will enable the production of castings free from external defects, such as veining or surface flaws. The newly formulated additive, Surwaybest, is composed of iron oxides - specifically magnetite - which promotes cooling through an endothermic reaction while simultaneously generating FeO. The presence of FeO in the core mixture, alongside SiO2, supports the formation of a fayalite layer around the base sand grains, reducing subsurface tension within the mould or core. Surwaybest also contains an insoluble polysaccharide that burns off when the core is cast into the mould, creating space for the quartz base sand to expand. Additionally, it includes carbon, which undergoes dehydrogenation from the molten metal's heat while softening, filling the intergranular spaces, and coating individual grains.

Keywords: Additive, Starch, Quality of Castings

1. Introduction

The additives are used to eliminate the tension generated among individual grains of SiO_2 that are part of the quartz base sand in the moulding or core mixtures when casting cast iron casts into the cavity of a sand mould using the cold-box-amine (CBA) technology. A room for the occurrence of casting defects, especially veining, is thus created – Figure 1. [1]

There are two main principles on which modified sand additives operate. The initial principle involves a high-temperature phase transition in the sand, occurring at approximately 870°C (1598°F). The quartz goes through four main phases, each of which is of interest to the technologist. Alpha SiO_2 is the first quartz phase and is stable from room temperature to 573°C (1063°F). Phase number two is beta SiO_2, which is not as stable as alpha SiO_2, resulting in reduced viscosity and slight surface softening. This transformation is independent of the binder type used. Loss of volume at this stage can be 50-100% of the original sample length. [1, 2, 3].

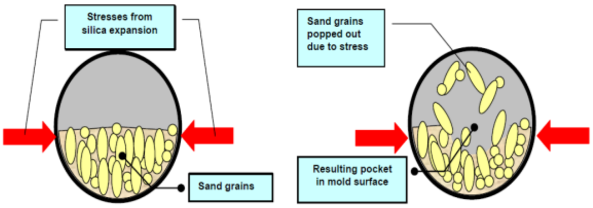


Fig. 1. Formation of crack in sand mould

As long as the viscosity is high enough for the sand grain surfaces to soften and form a liquid, a phase known as tridymite is produced. In the foundry industry, an Engineered Sand Additive (ESA) is commonly used to induce this transformation, causing a significant increase in the sand's volume due to the tridymite formation. This volume expansion, which can reach up to 12%, counteracts surface tension and effectively eliminates flash gutters during iron casting. However, when the sand combined with ESA warms up over 1050°C (1922°F), softening and a loss of strength occur. When examining the expansion of quartz sands with iron oxide additions, it becomes clear that despite the softening, the alpha SiO_2 phase does not transition to beta SiO_2 or tridymite. Volume decline continues as the temperature rises, until a change occurs in the fourth stage [2, 4]. At this stage, the transition from beta SiO2 to beta cristobalite occurs, resulting in a 14.7% volume increase, which takes place at approximately 1470°C (2678°F). The described expansion replicates the effect of ESA at iron casting temperatures, mitigating the occurrence of veining by reducing the tensile stress on the surface of the core or mold through expansion. The cristobalite transformation and its associated expansion lower the sintering point of the sand. However, minimizing veining with the use of iron oxide can be expensive. Additives derived from organic materials, such as saccharides or dextrin, provide a slight cushioning effect during the alpha/beta phase transformation. Their primary function, though, is to serve as a carbon source during the high-temperature sintering of the sand. It has been shown that all available oxygen in the mold cavity is absorbed shortly after it is filled with liquid metal. In the absence of oxygen, organic matter decomposes, with carbon binding to the surface of the sand grains, which increases the viscosity and surface tensile strength of the sand. This rise in tensile strength helps resist stresses and reduces the occurrence of veining (Figure 2) [2,3,5].

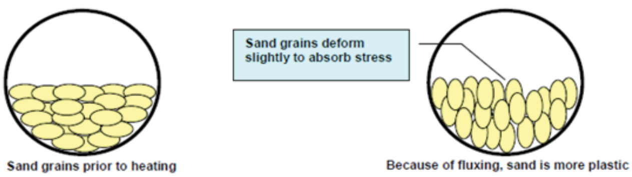


Fig. 2. Influence of additives [4]

Moulding sand additives can be classified according to the different effects they have on the moulding sand. These moulding sand additives reduce the temperature at which SiO_2, the main constituent of silica-based sand, begins to soften in the production of iron castings. They also melt on the grain surface, increasing reactivity and lowering the transition temperature to tridymite and cristobalite. These transitions make it easier to increase the tension in the subsurface of the sand and reduce the tension for the occurrence of veining and other casting defects on the surface of the core or mould.

The so-called attenuating additives constitute the first group. During the thermal exposure, an additive burns out rapidly, creating the intergranular space, and the grains can expand without generating tension. This group includes e.g. dextrin and wood sawdust.

The so-called reactive additives constitute the second group. The principle is the reaction of quartz sand with this additive due to the thermal exposure, resulting in the formation of compounds with a lower melting temperature. For instance, fayalite is formed by the reaction of SiO_2 with FeO. The melting point of fayalite is 1,185–1,205°C. For exam-ple, iron oxides (Fe_2O_3, Fe_3O_4) or artificial base sands based on aluminosilicate ($Al_2O_3.SiO_2$) fall into this group.

The “other additives” group may include e.g. reclaim of a return mixture with phenol or furan resins or reclaim of a bentonite mixture. They are used due to their already coated or oolitised grains that have more space for relaxing the tension being generated thanks to the envelope. The alkaline hardening mechanism of the PUR Cold Box process that is induced by the introduction of amine interferes with all alkaline components introduced into the mixture with the reclaim. Therefore, other return mixtures containing highly alkaline binders (e.g., processes with methylformiate, CO_2-rezol, water glass hardened by CO_2, water glass with ester) are excluded from the repeated use. [2, 3, 6, 7]

It has been long known that the introduction of iron in the oxidic form in the quartz base sand – moulding/core mixture – results in the decreased melting point of the quartz sand – base sand. Quartz sand, the primary component of molding mixtures, doesn't have a specific melting point. Instead, it softens and becomes more pliable at elevated temperatures (Figure 3). This change in properties gives the sand a plastic-like behavior, allowing it to better absorb the mechanical stresses imposed during the casting process.

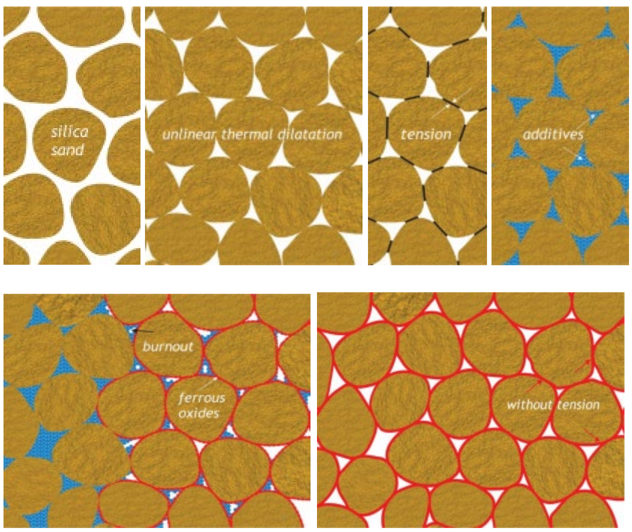


Fig. 3. Effect of Surwaybest additive in core mixture

2. Materials and Methods

At present, there are many additives in the market that considerably affect the overall quality of castings by improving their finish. The chemical or mineralogical effects of such additives have not been thoroughly analysed yet. However, it is necessary to understand their parameters to be able to assess their performance and provide their efficient application. The analysis of additives is crucial because their utilization represents a very efficient yet simple method of eliminating casting defects occurring on castings made in sand cores and moulds using the cold-box-amine technology. [4, 5, 8, 9]

2.1 Methods applied to analyse Surwaybest additive

Based on the knowledge gained and experience in the utilisation of the hitherto used additives, the goal was to develop a new additive that would ensure a surface of cast iron castings free of casting defects by its effect in the core or moulding mixtures.

- An initial Surwaybest additive analysis was conducted using a scanning electron microscope (SEM) with integrated energy dispersive X-ray spectroscopy (EDX). The samples were mounted on a carbon strip to ensure electrical conductivity.
- A chemical analysis was performed next. To determine the additive chemical composition, sequences of analytical methods were applied, starting with an analysis of atomic absorption spectroscopy (AAS) elements supported by optical quantifica-tion. The chemical composition was defined by the Niton XL3t GOLDD+ mobile spectrometer powered by an X-ray tube which optimises the geometry between an X-ray radiation source, fluorescence detector, and a sample. This EDX analyzer is equipped with GOLDD™ technology, a high-performance detector capable of analyzing elements from magnesium (Mg) to uranium (U).
- Determining phase composition
- X-ray diffraction (XRD) analysis with a PANalytical X'Pert PRO MRD X-ray spectrometer was used to determine the phase material composition.
- Veining analysis process reveals that molding mixtures containing resins have a compressive strength that is significantly greater (4-5 times) than their tensile strength. Hence, all tensile strains are dangerous for the mixtures. Another mechanism is feasible as well, where the thermal strain in the surface layer induces a combined tensile and bending stress and the subsurface layer of the core cracks. The occurrence of veining is more likely in rounded non-cylindrical shapes than in cylindrical cores where the dilating layer increases the compressive stress (Figure 4), while a bending moment M is also created. It will rise as the angle of curvature drops, and the probability of cracking will then increase as well. [6, 7, 8, 10, 11]

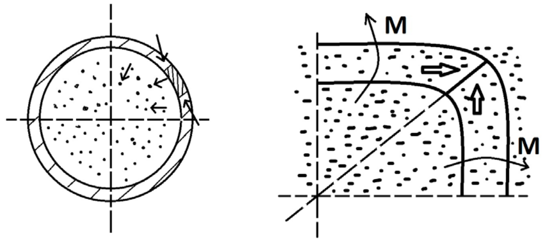


Fig. 4. Stress in cores of various rounding radius

The criterion applied to evaluate the strength of the core mixture is its ratio R – a theoretical dimension comparing the bending strength and the tensile strength of the core calculated using the equation (1):

$$R = \sigma\ bending\ /\ \sigma\ tension, \quad (1)$$

σ bending – bending strength [$N.mm^{-2}$]
σ tension – tensile strength [$N.mm^{-2}$]

Production of samples in prepared core boxes is part of strength determination. After setting of prepared samples, the samples were loaded in the designated position in a strength measuring device. LRu-2e, a product from Multiserv-Morek, is designed to measure the strength of molding and core mixtures in their raw, dried, or hardened states. The apparatus allows measuring the compressive, shear, cleavage, double shear, tensile, and bending strengths. The apparatus is controlled and set up using a membrane keyboard that communicates with a numeric display indicating the settings and work status of the apparatus.

For the tensile strength, a figure-eight-shaped object was used with the area of 5 cm^2 loaded by tension in the measuring position F within the range of Rm1 0 to 130 N/mm^2.

For the bending strength, a block-shaped object was used with the bent section of 5 cm^2 (22.4 × 22.4 mm) in the measuring position B within the range of Rg1 0 to 870 N/mm^2 [12, 13].

The strength measurements were conducted on core mixtures with and without the Surwaybest additive. The results are summarized in Table 1.

Table 1.
Mechanical Properties of Core Mixtures

Property	Without Additive (N/mm²)	With Surwaybest Additive (N/mm²)
Compressive Strength	25.3	33.7
Shear Strength	14.2	21.1
Cleavage Strength	9.6	13.4
Double Shear Strength	11.8	17.6
Tensile Strength	6.4	9.3
Bending Strength	8.9	12.7

Analysis: The addition of Surwaybest significantly enhances all measured mechanical properties. This is attributed to its dual role of reducing subsurface tension and facilitating the formation of a cohesive fayalite layer, which strengthens the core mixture.

After a thorough analysis of the newly developed Surwaybest additive, the additive was tested in operating conditions where it was added to the core moulding mixture at the ratio of 1 % to the total amount of the core mixture. The cores for future castings were made using the cold-box-amine technology.

Additives for Cold-Box Amine Casting are specifically designed to reduce veining in cold-box amine cores, especially at high temperatures. They are typically added to silica sand prior to the resin, at a dosage of 0.5-0.75% by weight. This improves core flowability and dimensional accuracy. To assess additives and sands impact on casting surface quality, real-world testing and evaluation are essential. The KSA 40 Core Shooting Machine utilizes pressurised air to push the core sand mix containing a binder into core boxes. Following the pushing process, flushing air or gas is introduced through fumigation equipment and gas supply panels to rapidly cure the sand within the boxes. This results in a hardened core. New and recycled sand is transported to the mixing machine (100 MRI) via two screw feeders. The quantity of sand is precisely controlled by measuring the running time of the feeders, which can be calibrated to match specific sand quantities.

Figure 5 illustrates the veining observed in manufactured castings. The EDX analysis reveals an engineered flash, as evidenced by the presence of iron oxides (red ferrous) and silica oxides (green) in the liquid metal area. Silica oxides, the main component of quartz sand, are used in mold and core manufacturing. This indicates that after pouring the molten metal into mold, it interacted with the core. The increased subsurface stress, resulting from the transformation changes in the silica sand, caused the molten metal to penetrate the core, leading to veining on the casting surface and compromising the casting quality.

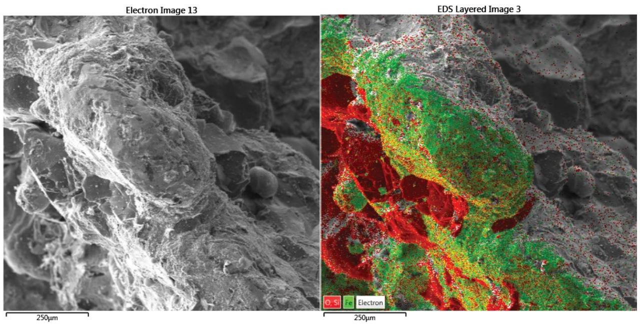


Fig. 5. Detail of the veining on castings where ST silica sand is used in the core

2.2 Forming mixtures analysis

A wide range of additives are available to improve cast surface quality and overall casting performance. One of the most efficient and straightforward ways to prevent veining is through the use of additives. Therefore, analysing these additives is crucial for ensuring optimal casting quality. Due to the often-limited information provided in supplier datasheets, several analyses were conducted to characterize the additives used in foundries. One of the initial analyses was an EDX microscopic examination (Figure 6), which aimed to identify the individual components of the additive.

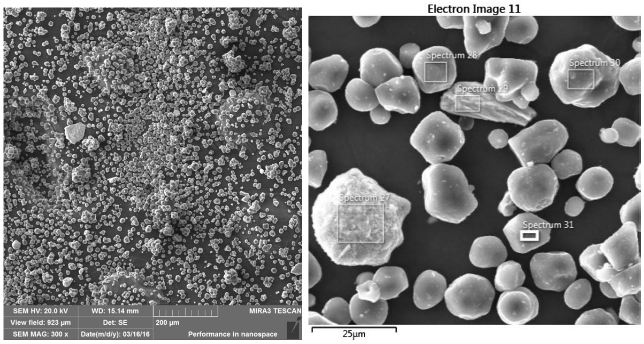
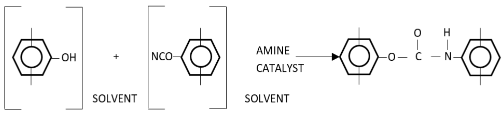


Fig. 6. Aditive analysis performed by EDX microscopy

The bonding of the core is a significant factor influencing the quality of casting in its own right. The type and quantity of the used binder, as well as the binder/base sand ratio, affect the composition of the moulding core. A gaseous amine catalyst was used to harden the mould mixtures using the reaction (2). [9, 10, 11, 17]



(2)

A core for the future casting was the result of the production process – Figure 7. It is intended to create a mould cavity and the future casting.


Fig. 7. Produced core for casting – RC brake disc made using cold-box-amine technology with Surwaybest additive

3. Results

The analysis results of the new additive called Surwaybest, which serves as an additive to the core mixture in the process of core production using the cold-box-amine technology for the future castings, are presented in Figures 8 – 11.

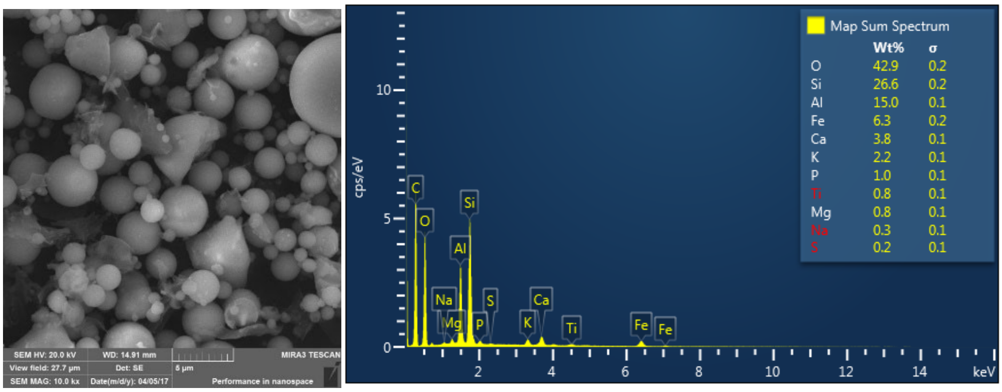


Fig. 8. Microscopic EDX analysis of Surwaybest additive

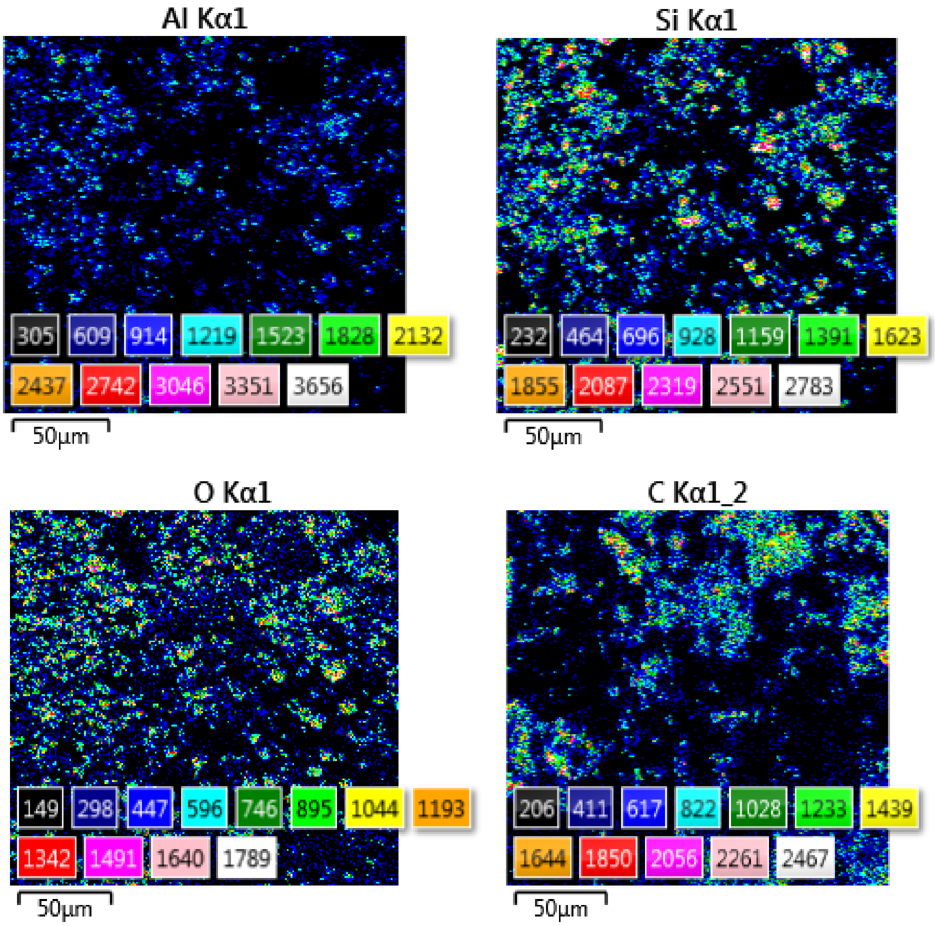


Fig. 9. Representation of individual elements in general EDX analysis of Surwaybest additive

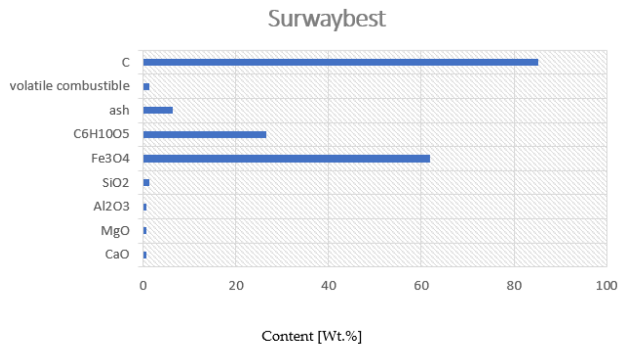


Fig. 10. Surwaybest additive chemical composition determined by Niton XL3t GOLDD+ mobile spectrometer

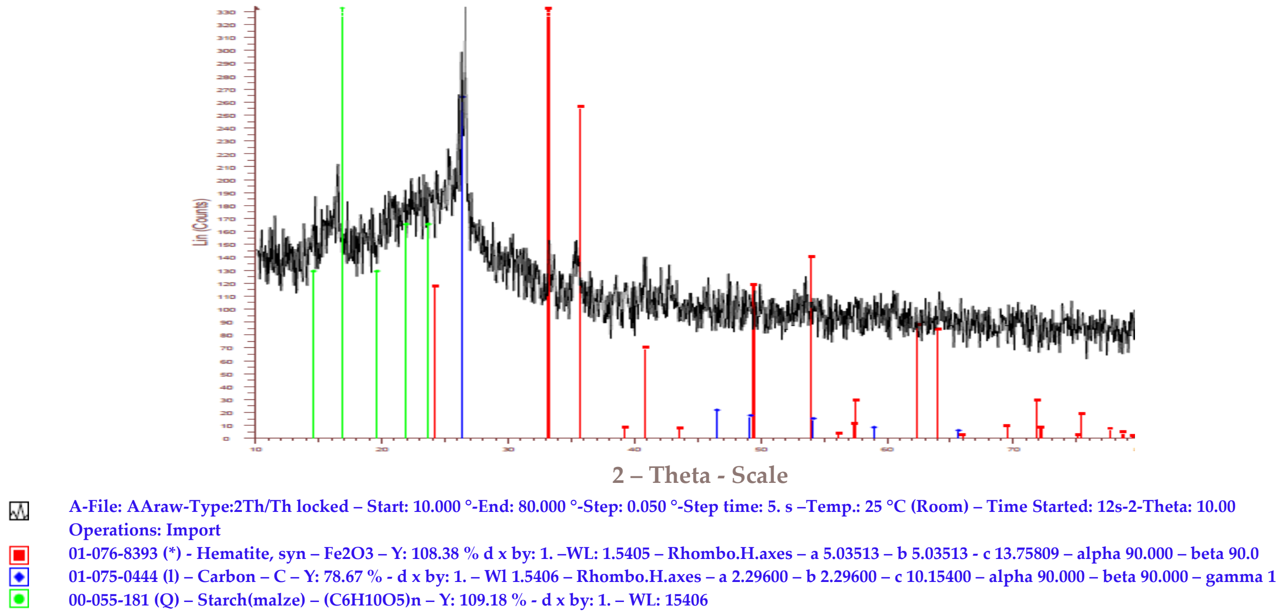


Fig. 11. Phase composition of designed Surwaybest additive.

The Surwaybest additive is primarily composed of iron oxides, particularly magnetite. This magnetite contributes to the additive's cooling effect through an endothermic reaction, resulting in the FeO formation. The combination of FeO and SiO_2 facilitates the creation of a fayalite layer around the sand grains, which helps to reduce subsurface tension in the mold or core. In addition to iron oxides, Surwaybest contains insoluble polysaccharides that decompose during casting, creating space for the expansion of the quartz sand. The additive also includes carbon, which undergoes dehydrogenation when exposed to the heat of molten metal. This dehydrogenation process contributes to softening the sand, filling the spaces between grains, and forming a protective coating around individual grains (consistent with the "coating theory"). The Surwaybest additive was successfully used in the production of various castings, not just the test samples. In all cases, the castings exhibited excellent surface quality without any defects.

Before implementing the additive in production, relevant core mixtures were evaluated to determine their coefficient R values (Table 2). This coefficient represents the likelihood of stress development and, consequently, the potential for veining on the casting surface. [12, 13]

Table 2.
Coefficient R comparison for mixtures containing the new Surwaybest additive versus standard production mixtures

Core mixture	(SiO_2 – 1) Without additive	(SiO_2 – 1) Without additive	(SiO_2 –) Without additive	(SiO_2 – 1) + Additive A	(SiO_2 – 1) + Additive B	(SiO_2 – 1) + Surwaybest additive
Coefficient R [-]	0.28	0.32	0.292	1.56	0.782	1.89

The coefficient, defined as the ratio of bending strength to tensile strength, serves as a predictor for stress development and potential veining on the casting surface. The values of in Table 1 were derived using Equation (1).

Methodology for Deriving

Samples were prepared in core boxes and subjected to LRu-2e testing. Tensile strength was measured using figure-eight-shaped samples, while bending strength was measured with rectangular block samples. The ratio was calculated for each core mixture.

Significance of:

Higher values indicate greater bending strength relative to tensile strength, implying better resistance to tensile stress and reduced likelihood of veining.

As seen in Table 1, the Surwaybest additive substantially increases, demonstrating its effectiveness in minimizing stress-related defects.

Based on our evaluation of castings produced with the Surwaybest additive, we recommend its continued use due to its effectiveness as a carbon-reducing agent and insoluble polysaccharide. Iron oxides, specifically Fe_3O_4 (magnetite), are a significant component of the additive. Unlike Fe_2O_3, magnetite is unique among iron oxides in its ability to undergo an endothermic reaction (reaction 1) during casting. This reaction has a noticeable effect on the casting surface, as illustrated by reaction (3).

$$Fe_3O_4+mCO \rightarrow 3FeO+CO_2+/m-1/CO \quad H°298 = 26{,}669 \text{ kJ} \qquad (3)$$

Figure 12 illustrates the process of producing cast iron castings using the Surwaybest additive. Figure 12 illustrates the production process for cast iron castings using Surwaybest additive. Below is a stepwise explanation:

Mix Preparation:

The core mixture is prepared by adding Surwaybest to silica sand in a ratio of 1% by weight, followed by binder addition.

Core Formation:

The mixture is compacted in the core box using the cold-box-amine process. This involves gaseous amine catalyst curing, producing a hardened core.

Casting:

The prepared core is inserted into the mold cavity, and molten metal is poured. The Surwaybest additive facilitates uniform cooling via endothermic reactions and minimizes thermal stress on the mold/core interface.

Defect Prevention:

Surwaybest decomposes during the casting process, forming a fayalite layer and reducing subsurface tension. This eliminates common defects such as veining and surface cracks.

For a comparison, Figure 13 shows the production of a casting without the use of an additive in the core mixture (a) and with the use of Surwaybest (b).

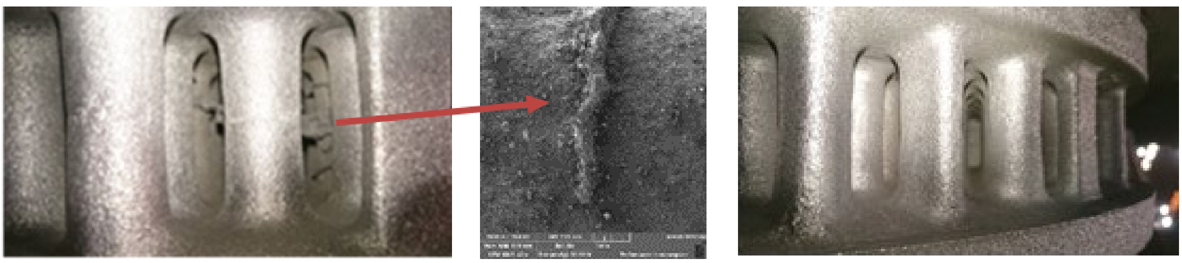
Figure 13 compares casting outcomes with and without the Surwaybest additive:

- Figure 13(a): Additive-Free Casting This image shows visible veining and surface imperfections caused by non-uniform thermal expansion of quartz sand. The absence of an additive leads to higher tensile stress, resulting in crack formation.
- Figure 13(b): Casting with Surwaybest In contrast, castings produced with Surwaybest show a defect-free surface. The additive's cooling properties and ability to reduce subsurface tension prevent the formation of veining and other defects.

Quality Improvements:

1. Defect Reduction: Surwaybest eliminates veining and associated surface flaws.
2. Economic Benefits: Fewer casting defects reduce material waste and rework costs.
3. Enhanced Reliability: Improved casting quality enhances the performance of components in critical applications.

Fig. 12. Process of cast iron casting production



(a) (b)

Fig. 13. (a) Additive-free castings with veining, (b) Casting with Surwaybest – without veining and other casting defects

4. Conclusions

The quality of castings significantly impacts their subsequent use. Unfortunately, producing defect-free castings in the foundry industry is a challenging task. It's essential to adopt a comprehensive approach when considering casting defects, examining them from various perspectives. To effectively address casting defects, we must consider multiple influencing factors simultaneously. Ignoring any one factor may lead to the elimination of one defect type, only to be replaced by others, such as burn-on, scab, or sand inclusion.

Sand/silica mold casting defects often arise from stress caused by non-uniform thermal expansion of the quartz based sand. While this is a known issue, the widespread availability and cost-effectiveness of quartz sand continue to make it a popular choice for foundries. Given the critical nature of castings used in automotive or railway applications, where defects can pose a serious safety risk, it was essential to explore alternative methods for preventing these defects.

The foundry industry is a complex ecosystem involving more than just raw materials. What works in one foundry may not be applicable to another. To effectively address casting defects, it's essential to consider various contributing factors:

- Evaluate the quality of incoming raw materials, including their chemical and mineralogical composition;
- control the dosage of the base sand which can enhance the strength of the core;
- apply a coating on the produced cores which prevents the penetration of the molten metal into the mould and the core;
- use the quartz base sand with the granulometric composition where the fractions under 0.1 mm are in the ratio of at least 12 % to the total quantity of the base sand;
- regulate the shooting pressure of the machine, as cores will thus not be compacted that much and the grains of the quartz base sand will have room for their expansion;
- use non-quartz base sands in the core mix if necessary, where we eliminate the presence of irregular thermal expansion in the core/moulding mixture. [14, 15, 16, 17, 18]

Finally, employ additives in the core mix that are specifically designed for their intended purpose. However, due to the current practice of providing limited information in supplier datasheets, it's important to be aware that these additives may potentially cause long-term issues in the foundry's operations. Based on the positive results obtained, it is recommended to use the newly developed Surwaybest additive in the production of cast iron castings using cold-box amine technology with silica molding mixtures. This additive effectively reduces or eliminates casting defects.

Acknowledgements

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