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Testing the Veining Elimination using Pressure Changes and one Type of Additive in a Cold-box-amine Core Mixture

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Abstract

This article presents a analysis of the impact of varying amounts of a specific additive in the core mixture and adjustments in shooting pressure on the elimination of surface defects in castings, particularly veinings. These defects, often located in inaccessible areas of the casting, cannot be effectively removed through conventional methods like punching, making the optimization of the core mixture composition crucial. Additives are frequently incorporated into the core mixture, as they have become an essential component in its production. For the core mixture to be effective, it is not only essential to identify the appropriate type of additive but also to precisely determine the optimal quantity of the additive and accurately set other critical production parameters, such as shooting pressure.This study investigates the influence of additive concentration and shooting pressure on the surface quality of cast iron castings, employing the cold box method for core production. The findings reveal that higher shooting pressure contributes positively to the reduction of veining defects. However, an increased additive content in the core mixture does not necessarily ensure vein-free castings. The additive also plays a role in reducing the gas content within the core, and increased core hardness is associated with a decrease in the occurrence of veining defects. The casting with the highest surface quality and the fewest veinings was produced using cores made from a mixture with 1% additive content, subjected to a shooting pressure of 4 bars.

Keywords: Cold-box, Additive, Shooting pressure, Veinings, Core mixture

1. Introduction

The cold-box method is a modern approach to core production [1][2][3], characterized by the use of technologies focused on minimizing emissions and optimizing energy consumption [4][5]. This method aims to enhance the efficiency of cores, improve the quality of the final product, and achieve complex core geometries with high dimensional accuracy and minimal negative impacts [6][7]. The term "cold-box" refers to the curing process of sand and resin mixtures at room temperature, which is accelerated by a gaseous catalyst passing through the mixture [8][9].

It is a three-component system comprising two liquid binder components. The first component is a curable phenol-formaldehyde resin, while the second is a hardener. Although phenolic resin is most commonly used in practice, other resins such as epoxy, alkyd, polyester, and phenol-formaldehyde can also be used [10]. The hardener is a liquid polyisocyanate. The hydroxyl group in the first binder component reacts with the isocyanate group in the second component, forming a solid polymer in the presence of the third component, a gaseous catalyst [11].

Quartz sand is the most commonly used type of sand for producing molds or cores [12][13], including in cold-box core

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production, due to its abundance and durability, despite having the highest thermal expansion compared to other types of sand [14]. Although there are increasingly stringent requirements for the quality of quartz sand, this material has its limitations. One of the main issues is the expansion of quartz due to its non-continuous thermal expansion during the casting process [15][16]. The discontinuity in the dilation curve is caused by phase changes in SiO_2. These changes can be best observed on the dilation curve of mixtures with water glass and quartz sand, such as those hardened by the CO_2 process [17]. The discontinuous dilation process in the initial stage of this curve causes a rapid increase in tension within the mold [18].

The most common surface defects arising during the cold-box core method are veinings. These defects primarily occur in castings made from alloys with high thermal expansion, cast into molds and cores bonded with artificial resins using the cold-box-amine and hot-box methods. Cracking typically appears in rounded areas on the casting surface. This cracking is caused by the thermal expansion of quartz sand when heated and by polymorphic transformations in quartz [19][20].

One way to eliminate these defects in castings is by using an additive - an auxiliary substance added to the core mixture. Additives help reduce the surface tension caused by sand transformation. They also positively affect the temperature at which the material begins to soften. Combining SiO_2 with an additive increases the transition temperature of tridymite and cristobalite grains [21]. However, there is a limit to the amount of iron oxide that can be added to the core mixture. Excessive addition of oxides can make the sand sticky, with an upper limit typically around 2%. It is important to note that iron oxides can improve the surface quality of castings by forming a glassy layer, or glaze, on the mold surface. This glaze creates a smoother surface that is less susceptible to metal penetration into cracks [22].

The quality of casting is influenced by many factors, including the properties of the molding mixture, such as the ratio of constituents, the preparation method of green sand, and the mixing and pressing processes. Author [23] studied the effect of molding parameters, specifically bentonite content, mixing time, and compactability percentage on the properties of green sand molds using the Taguchi method. The study found that 47% compactability, 9 minutes of mixing time, and 6% bentonite content resulted in the highest values for these properties simultaneously. Another study [23] attempted to optimize sand molding parameters, including compactability, compaction time, and air pressure, and their effects on the flowability of green sand using an L4 design of experiments. It was found that compaction time significantly affected the flowability of green sand, while compactability and air pressure had only slight effects. In a different study [24], the effect of binder composition on the dimensions of chemically-bonded sand cores over time was investigated. The maximum shrinkage observed was 0.15 % in length when the resin content was 2.4 % by weight of sand. Shrinkage rate increased with a higher amount of catalyst. This study [25] aimed to apply the Taguchi technique to identify the major factors involved in the core shooter machine for producing cold-box cores and to determine their optimal levels to achieve consistently high-quality castings with minimal gas evolution in cold-box cores.Another study [26] deals with the shrinkage of cores made of different materials under different conditions.

This study examines the influence of technical parameters of the machine on core quality. For achieving cores with optimal properties, shooting pressure is crucial. High shooting pressure ensures perfect compaction without veinings, minimizes catalyst consumption, and maximizes strength. Conversely, very low shooting pressure results in insufficient compaction, while excessive pressure can cause excessive resin accumulation under the shooting hole and increased stickiness. The size of the shooting head is matched to the core size to prevent air from stirring the mixture [27]. Previous research has indicated that a 1% addition of an additive called Antifinning Agent 002 is most suitable for improving the surface quality of castings [28]. This research aims to determine the minimum amount of this additive required to achieve a casting surface free of veinings when shot into the core mixture under pressure. Initially, the parameters of the shooting machine were investigated. It was found that setting the shooting pressure to 2 bars is sufficient to produce high-quality cores without unshot points. A total of five core mixtures with varying additive contents were prepared, and three test cores were made from each mixture at pressures of 2 and 4 bars.

2. Materials and methods

The primary material used for producing cores was natural washed quartz sand, suitable for foundry molds and cores, sourced from the Biała Góra locality and designated as BG 27. The key characteristics of the quartz sand are detailed in Table 1.

Table 1.
Basic characteristics of BG 27 sand

Medium grain d_{50} [mm]	0,27
Sintering temperature	1600
Content SiO_2 [%]	Min. 99,5
Content Fe_2O_3 [%]	Max. 0,04
Content Al_2O_3 [%]	Max. 0,2
Content TiO_2 [%]	Max. 0,02
Flushable fractions [%]	Max. 0,2
pH range	5,5

The binder consisted of two components mixed in a 1:1 ratio. The first component, Sigmacure 6747 P1, is a condensed phenolic resin designed for the cold-box process. It is traditionally dissolved in organic solvents and is known for its high thermal stability, long workability of the sand mixture, and low stickiness of the core [29]. The second component, Sigmacure 8196 P2, is a solution of modified polyisocyanate dissolved in an organic solvent. This component contributes to a very long service life of the prepared foundry mixture. The basic parameters of the resin and activator are listed in Table 2 [29].

Table 2.
Basic characteristics of binder

	Sigmacure 6747 P1	Sigmacure 8196 P2
State	Liquid	Liquid
Color	yellow	brown
Density [g.cm^{-3}]	1,07 – 1,08	1,21 – 1,23
Viscosity [mPa.s]	150 ± 20	16 – 22
Flash point [°C]	52	65
pH	3 - 5	3 - 6

The resulting mixture is then highly compacted in a mold. To accelerate the reaction between the binder components, a tertiary catalyst in the form of amine gas is passed through the pores of the compacted core sand [29]. The hydroxyl (OH) group of the phenolic resin reacts with the isocyanate (NCO) group to form a solid urethane polymer, which bonds the individual sand grains together (Figure 1) [28].

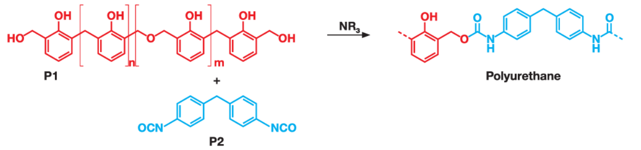

Fig. 1. Chemistry of the cold box binder system [29]

Both components can be modified with different additives to improve specific parameters and to adapt them to special foundry applications [29]. To the core mixture an additive called Anti-finning agent No 2 was added to each core mixture. This additive is agent to produce cores by the cold-box method, which eliminates the occurrence of veinings in cast iron at high temperatures. It ensures better fluidity of the mixture and better dimensional stability of the cores.

2.1. Preparation of core and core mixture

The preparation process involved cleaning the core, referred to as "TEAR." Afterward, the adapter had been installed in the LAEMPE device, and the corer had been mounted on this adapter. Silica sand, weighing 50 kg, along with the additive, had been prepared in a mixer according to the specified weights outlined in the experimental tasks. Next, 45 grams of each binder component (0.9% by weight of sand) had been added to the sand. The mixture had been blended for 5 minutes before it was transferred to the reservoir of the Laempe LL 20 machine.

2.2 Molding and casting

A molding board named "TEAR" had been placed in the molding line. The molding mixture had been composed of quartz sand with a fraction of 0.255-0.27 mm, combined with Geko Optimum Bentonite and mixed bentonite. Geko Optimum Bentonite is an activated bentonite used for joining cast sand molds for both ferrous and non-ferrous alloys, providing specified strength, rapid high mold activation, and excellent heat resistance. Mixed bentonite is a combination of selected coal dust and 75% bentonite, used in the green sand molding process for all iron and metal alloys. Both products are supplied by Clariant International Ltd.

After a visual inspection, the appropriate number and letter for the core group used in the mold had been stamped into the cavity defining the mold shape. The cores had been inserted into the molds.

After both parts of the molds had been connected, the mold was transported by conveyor belt to the casting area. The temperature for casting the melt into the mold had been set at 1381 °C.

Three test cores had been made from each selected composition. From each group, the two best cores had been selected and had been inserted into the molds for casting. After the castings had been cleaned of the molding compound, their surfaces were visually evaluated.

The conventional sand casting procedure is outlined in the flow chart in Figure 2 [30].

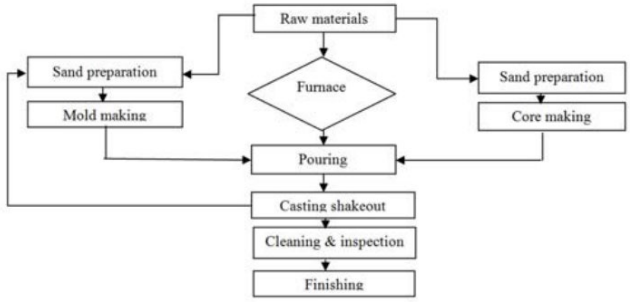

Fig. 2. Flow chart of sand casting process [30]

During the production of cores, test rods were simultaneously prepared from all core mixtures. The hardness of these rods was measured, and samples were taken to analyze the gas content. The methods used are described below.

2.3 Hardness measurement

The hardness was measured by evaluating the depth of the indentation created after placing and activating the portable digital hardness meter ISH-SPHA directly on the surface of the manufactured core.

2.4 Measurement of gas evolution

The gas formation of the mixture for each sample was measured twice at 900°C. A sample weighing 2 grams was placed in a copper tube and introduced into the Gas Determiner Georg Fischer +GF+ for analysis.

3. Results and discussion

3.1 The effect of the shooting machine on the produced cores quality

The parameters of the shooting machine were changed 5 times (a, b, c, d, e). The description of the parameters is given in Table 3. The tested castings are in Figure 4.

Table 3.
Shooting machine parameters

	a	b	c	d	e
Shooting pressure [bar]	1	1,3	1,5	1,7	2
Gassing time [s]	8	13	20	20	20
Venting time [s]	1	2	3	3	2,5
Overdose [s]	7	9	12	15	18
Additional dosing [cl]	5	8	10	10	10
Figures	4a	4b	4c	4d	4e

The graph in Figure 3 illustrates the changes in the parameters of the shooting machine Laempe LL20. All adjustable values showed an increasing trend, except for the "venting time," which decreased by 0.5 seconds. The minimum required values to achieve optimal core shooting are : 2 bars for shooting pressure, 20 seconds for gassing time, 2.5 seconds for venting time, 18 seconds for overdose time, and 10 cl for additional dosing. Shooting pressure is a crucial parameter; if it was lower than 2 bars, unshot areas were observed on the cores.

a) After starting the device and removing the core, it was evident that the core had not been sufficiently shot. Additionally, the core was brittle, indicating poor amine gassing.

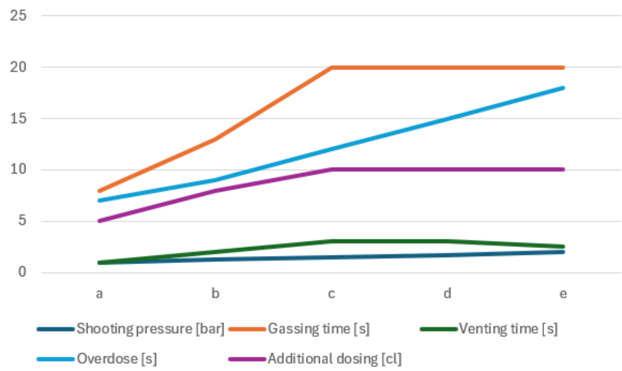

Fig. 3. The parameters of the shooting machine Laempe LL20

b) When using the adjusted parameters (b), the areas of undershooting places were reduced, and a sparse structure appeared on the core surface. It is necessary to increase the device parameters.

c) Adjusting the parameters did not fully resolve the issues with amine gassing. Although the affected areas decreased slightly compared to the previous parameters (b), problem persisted.

d) The areas with poor gassing have visibly shrunk. This improvement was achieved by adjusting the device parameters, specifically the working pressure of the device and the additional dosage of amine.

e) The cores were completely free of any uncoated area. The cores accurately replicated the shape.

Fig. 4 Test casting cores produced using shooting machine parameters labeled a, b, c, d, e

3.2 The effect of different shooting pressure on the produced cores quality

For the experiment, four test core mixtures (A, B, C, D) with varying amounts of a specific additive (Antifinning agent 002, ASK Chemicals) were selected, tested at two different shooting pressures (2 bars, 4 bars) on the shooting machine. All mixtures consisted of the same type and amount of sand and resin. An overview of the conducted experiments is provided in Table 4.

Table 4.
Overview of the conditions of the performed experiments

Label	Additive amount [%]	Shooting pressure [bar]	Hardness [$N.mm^2$]	Gas evolution [$ml.g^{-1}$]	Veinings height [mm]
A1	1.2	2	1.8	6.8	1.67
A2	1.2	4	2.4	6.4	1.5
B1	1	2	2	7.1	1
B2	1	4	2.5	6.3	0.5
C1	0.8	2	1.9	6.9	1.83
C2	0.8	4	2.6	6.5	1.33
D1	0.6	2	2.1	7.2	2.5
D2	0.6	4	2.7	6.7	2

A1: At a working pressure of 2 bars, deterioration of the core surface was observed, primarily visible on the sides of the core, which showed signs of rarefaction (Figure 5 A1)
A2: At 4 bars, the core showed no signs of gassing. The surface of the core was homogeneous, with no signs of rarefaction (Figure 5 A2).
B1: Surface thinness defects occurred at a working pressure of 2 bars. A large number of small defects appeared on the sides, although the surface of the core was otherwise homogeneous (Figure 5 B1).
B2: At an increased pressure of 4 bars, the core exhibited fewer sparse areas compared to the previous case. The number of small flaws on the sides was reduced (Figure 5 B2).
C1: The device's working pressure of 2 bars, combined with these raw materials, caused small unshot areas on the core's surface. On the sides of the core, imperfections and areas of surface thinness increased (Figure 5 C1).
C2: Increasing the working pressure to 4 bars reduced the unshot areas. Additionally, the regions of sparse surface decreased, and the imperfections on the sides of the core were smaller compared to those at lower pressure (Figure 5 C2).
D1: Cores produced at a working pressure of 2 bars showed large unshot areas (Figure 5 D1). The core surface was homogeneous but contained extensive areas of surface sparsity.
D2: At a working pressure of 4 bars, the unshot areas were reduced, but despite the increased pressure, they remained large (Figure 5 D2). The regions of sparse surface were smaller but still larger compared to the experiment labeled D1.

Cores produced at shooting pressure of 4 bars had fewer defects compared to those shooted at 2 bars. However, all underfilled places on the cores were filled with sealing paste, making them suitable for casting.

Fig. 5. Test cores A1, B1, C1, D1, A2, B2, C2, D2

3.3. The test casting surface evaluation

After casting, the castings were cleaned of molding and core mixture. The inlet system was removed from the casting. The casting after processing weighed 21 kg.
A1: Melt flow into the core mark was observed on the casting. A significant growth of 1.9 mm was visible in the large cavity. Two smaller veinings, measuring 1.1 mm and 2 mm, were present in the small cavity (Figure 6 A1).
A2: The casting had a roughened surface in both the small and large cavities, caused by poor mechanical processing of the core surface during production. Large veinings, approximately 2 mm and 1.5 mm, were visible in the large cavity. Circular objects protruding into the space created by sand applied to the core were also observed in this cavity. Two smaller veinings of 1 mm and one larger veining of 2 mm were found on the surface of the smaller cavity. These results were consistent across both test castings (Figure 6 A2).
B1: On the surface of the small cavity, there was a small growth of 1 mm. The large cavity was free of veinings (Figure 6 B1).
B2: Slight inclusions were present in the large cavity of one of the test castings. Both large cavities were otherwise free of defects. A small veining of 0.5 mm was observed in the small cavity (Figure 6 B2).
C1: In the large cavity of one of the test castings from C1 cores, a 4 mm veining was visible. In the small cavity, three small protrusions measuring 1.1 mm were observed; this phenomenon was noted in both small cavities of the castings (Figure 6 C1).
C2: The small cavity contained two small veinings up to 1 mm and one veining of 2 mm. The surface of the large cavity was free of veinings. A small particle was found in the large cavity of the second test casting (Figure 6 C2).
D1: The large cavity of the casting did not contain veinings. However, three large veinings measuring 2.5 mm were present in the small cavity (Figure 6 D1).
D2: The test casting contained large particles on the surface and in the cavity. In both large cavities, two veinings of 1 mm and one veining of 0.5 mm were observed. Additionally, three veinings of 3 mm were found in the small cavity (Figure 6 D2).

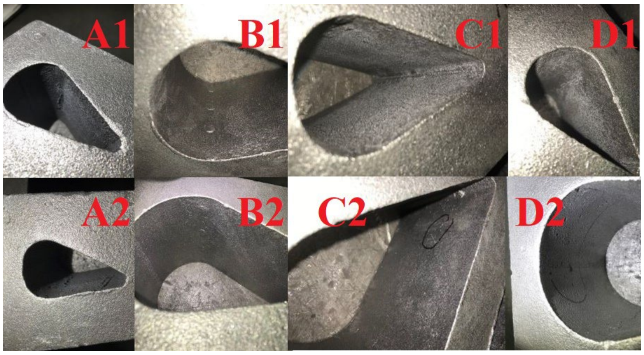

Fig. 6. Test casting
A1, B1, C1, D1, A2, B2, C2, D2

Veinings were present in all the cavities of the tested castings, but their occurrence was minimal, with a content of up to 1%. The veinings primarily differed in height. The results of the conducted experiments are shown in the following graph (Figure 7).

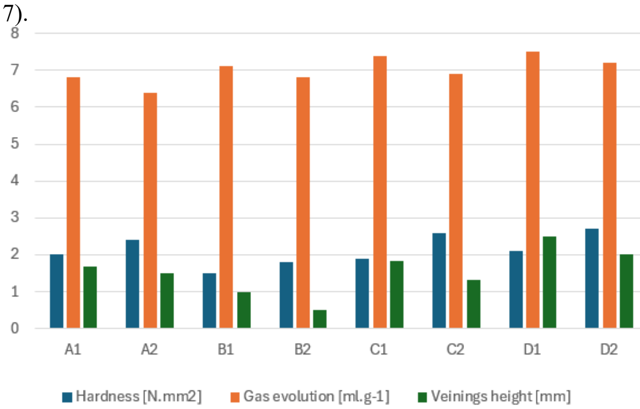

Fig. 7. Dependence of average veinings height on the hardness, amount of gases, shooting pressure and additives in the individual tested mixtures

The graph indicates that the smallest veinings were observed in the test castings labeled B2. Notably, for each pair of cores (those with identical additive content but subjected to different shooting pressures), an increase in shooting pressure consistently demonstrated a beneficial impact on the reduction of veinings. Although it was hypothesized that a higher additive content would diminish the size of the veinings, this was not corroborated by the findings of this study. In fact, castings produced from cores containing 1.2% additive exhibited larger veinings compared to those derived from cores with 1% additive content. The castings with the minimal veinings originated from cores with 1% additive content, which also exhibited the lowest hardness values. The additive in the core mixture functions to mitigate gas formation, a process that is also influenced by the shooting pressure. At lower shooting pressures, the increased presence of trapped gases is attributed to insufficient compaction. Consequently, the most critical parameters for evaluating core quality remain shooting pressure, additive content, and hardness.

4. Conclusions

The cold-box method facilitates the rapid production of medium and small-sized cores. However, a notable drawback of cores produced using this method is the increased incidence of casting defects, such as veinings. These defects can be mitigated by incorporating additives into the core production process. The experimental section of this study focuses on optimizing the equipment parameters for core production, specifically using a core shooter designated as "TEAR." The experiments led to the following key conclusions:

- Shooting pressure is a critical parameter in core production; the minimum shooting pressure required to produce a core suitable for casting is 2 bars.
- Higher shooting pressure positively impacts the reduction of veining defects. For castings produced from cores with identical chemical compositions, those compacted at a shooting pressure of 4 bars exhibited smaller veinings.
- Increasing the additive content in the core mixture does not necessarily guarantee vein-free castings. In fact, cores containing 1.2% additive showed more pronounced veining compared to those with a 1% additive content.
- The optimal strategy to minimize veining is to add 1% additive to the core mixture. Lower additive levels result in the formation of larger protrusions due to insufficient space for silica expansion, leading to an increased number of surface defects in the casting cavity.
- The additive also helps reduce the gas content within the core.
- Additionally, greater core hardness correlates with a reduced occurrence of veining defects in castings.

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