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The Influence of the Knock-out Additive on the Mechanical Properties of Cores Made in the Core Blowing Process

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Abstract

The article presents the results of research on the effect of an additive improving shakeout (perlite ore with a specified grain size) on the mechanical properties of cores produced by the blowing process. The study was conducted on cores (standard specimens for tensile strength testing) made from core sands with varying amounts of loosening additive, depending on the core box temperature and shooting time, at a constant operating pressure of the shooting machine. The temperature of the core box at which the cores achieved the best mechanical properties was identified, and the necessity of optimizing both the amount of perlite ore additive and the binder content in the core sand to ensure the required mechanical properties of the cores was demonstrated.

Keywords:

foundry, core sand, blowing process, inorganic binder, knocking-out, perlite ore

1. INTRODUCTION

Sand cores are a key component of a casting mold, and their purpose is to reproduce the internal shapes of the casting with a surface that is as smooth and defect-free as possible. In foundry practice, single-use sand cores are most commonly used, and they must meet numerous requirements, including technological and mechanical ones [1]. Good cores should provide adequate initial mechanical strength to allow safe removal from the core box. They should maintain the required strength during storage before being placed in the mold cavity just prior to pouring, as well as during assembly in the mold cavity itself. However, the core-making process using blowing methods has two main disadvantages: a higher degree of compaction along the axis of the core vents and binder migration under the influence of the air stream [2].

Another important technological feature that high-quality cores should possess is resistance to thermal deformation. To reduce the roughness of the internal surface of the casting, cores are usually made from fine-grained base sands. Cores are exposed to the extreme conditions prevailing inside the mold cavity and are often completely burned out during casting. If organic binders are used, no technological problems arise during the removal of the core from the finished casting. In contrast, when inorganic binders (e.g. water glass or other silicate binders) are employed, problems with shakeout occur. Under the influence of the high temperature of the molten metal, so-called secondary hardening takes place in silicate binders, accompanied by a rapid increase in strength – referred to as final strength [3, 4]. This hardening effect causes technological difficulties associated with removing the core from the casting or the entire mold. Poor shakeout leads to additional production costs due to increased labor and energy consumption, reduced efficiency, and sometimes the need to remake the casting. Many attempts have been made to improve the shakeout properties of molding and core sands by modifying the binder itself or by introducing additives into the sand mixture to reduce final strength, thereby improving shakeout.

Inorganic binders are among the most environmentally friendly, as they do not emit harmful decomposition products during mold pouring [5, 6] and can be hardened by both physical and chemical methods [4, 7–13]. When selecting additives for molding and core sands, both technological and environmental aspects must be considered.

The search for a loosening additive that improves shakeout while also meeting environmental requirements led to the selection of perlite ore as an inorganic material characterized by its volume change under the influence of temperature [14–17], which consequently disrupts the continuity of the hardened binder, reducing final strength and enhancing shakeout [18]. As an inorganic material, it does not emit harmful chemical compounds. The aim of this study was to determine the effect of the selected perlite ore on the mechanical properties (bending strength) of foundry cores produced using the warm-box technology with the inorganic binder Cordis [19]. The work includes a detailed analysis of changes in core strength depending on the amount of loosening additive and the varying parameters of the blowing process. The optimal parameters of the core production process using a core shooting machine were determined. Previously published studies in this area covered research on mechanical and technological properties of cores (standard specimens) produced by vibration compaction [18, 20, 21], made with the inorganic binder Geopol [4, 22].

2. METHODOLOGY

For core production, a LUT-type core shooter manufactured by Multiserw-Morek (Fig. 1) [23] was used. This device allows for the adjustment of blowing process parameters such as shooting pressure, shooting time, heating temperature, and heating time.

a)

b)

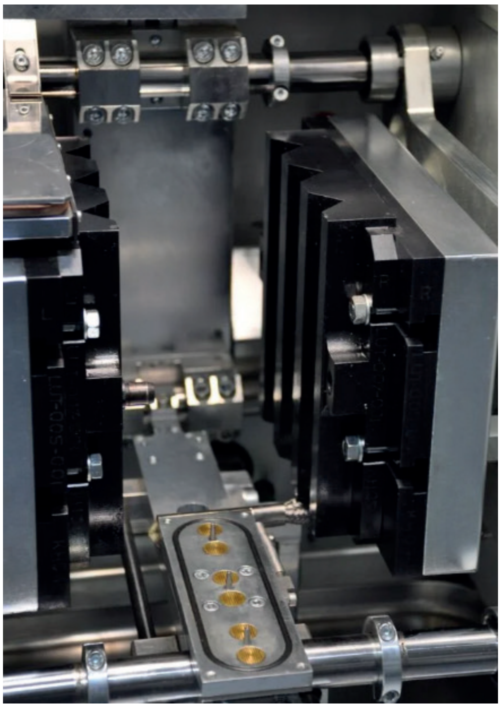

Fig. 1. Universal machine for making test samples and small cores (a) and core box for making standard bending samples (b) [23]

The core sands were prepared using quartz sand BK 5.0D from the "Szczakowa" mine, owned by DBCargo [24]. The perlite ore originated from a Slovak deposit. Sieve analysis was performed on a standard set with mesh sizes ranging from 0.056 to 1.6 mm (average of two measurements), in accordance with the Polish Standard PN–85/H–11001 [25]. The analysis was carried out twice for each material on 50 g samples, and the results are presented in Tables 1 and 2.

Table 1
Sieve analysis of quartz sand

Sieve number	Residue on sieves [%]		Characteristic indicators of the tested quartz sands
	Sample 1	Sample 2	
1.600	0.00	0.00	Number of grains, AFS = 56.10
0.800	0.02	0.00	Average grain size = 0.23 mm
0.630	0.07	0.06	Geometric average = 0.25 mm
0.400	1.76	1.76	Arithmetic average = 0.26 mm
0.320	6.51	6.62	Harmonic average = 0.26
0.200	30.11	30.06	Median = 0.25
0.160	6.82	7.13	Average grain size = 0.25
0.100	4.55	4.23	Main fraction = 87.25%
0.071	0.15	0.13	Separation factor = 1.22
0.056	0.01	0.01	Inclination indicator = 0.96
Bottom	0.00	0.00	Degree of homogeneity = 75%
Total	50.00	50.00	Surface area = 9.59 m^2/kg

Table 2
Sieve analysis of perlite ore

Sieve number	Residue on sieves [%]		Characteristic indicators of the tested perlite ore
	Sample 1	Sample 2	
1.600	0.00	0.00	Number of grains, AFS = 52.27
0.800	0.00	0.00	Average grain size = 0.24 mm
0.630	0.84	1.00	Geometric average = 0.31 mm
0.400	15.10	14.98	Arithmetic average = 0.34 mm
0.320	10.85	9.77	Harmonic average = 0.26
0.200	13.09	16.00	Median = 0.33
0.160	4.28	3.65	Average grain size = 0.33
0.100	4.15	3.21	Main fraction = 79.79%
0.071	0.71	0.51	Separation factor = 1.38
0.056	0.26	0.27	Inclination indicator = 0.93
Bottom	0.72	0.61	Degree of homogeneity = 50%
Total	50.00	50.00	Surface area = 8.79 m^2/kg

The core sands were prepared with a constant binder content – 2.5 parts by weight of binder per 100 parts by weight of the sand base. As the binder, the inorganic Cordis binder from Hüttenes-Albertus [19] was used. The first prepared core sand mixture, which did not contain the loosening additive (perlite ore), was treated as the reference mixture. The other two core sand mixtures contained the loosening additive – perlite ore. The composition of the core sand mixtures used in the study is presented in Table 3.

Table 3
Composition of core sands M0, M4 and M8

Core sand	Component of the core sand, in parts of mass		
	Quartz sand	Binder	Perlite ore
M0	100	2.5	0.0
M4	100	2.5	4.0
M8	100	2.5	8.0

All core sand mixtures were prepared using a rotor mixer, with a mixing time of 1 minute. The prepared standard specimens (cores) for determining bending strength were set aside for 1 hour to cool and properly harden. The bending strength tests were carried out using an LRu-2e testing device manufactured by Multiserw-Morek (Fig. 2) [26].

Standard specimens for bending strength testing were produced each time at an operating pressure of 5 bar, but with two different shooting times (0.8 and 1.2 s) and three temperature levels: 140, 160, and 180°C. The holding (curing) time of the samples in the core box was constant and amounted to 120 s. The results presented in the article represent the arithmetic mean of three measurements.

Fig. 2. LRu-2e device for testing the strength of molding and core sands [26]

3. RESULTS

Figure 3 presents the bending strength results for the reference core sand mixture – without the loosening additive (perlite ore) – as a function of the core box temperature, for two shooting times: 0.8 and 1.2 s.

From Figure 3, it follows that for the mixture without the addition of perlite ore, the highest bending strength (3.58 MPa) was obtained at a core box temperature of 140°C and a shooting time of 1.2 s. Increasing the core box temperature resulted in lower strength values, namely 2.89 MPa at 160°C and 3.32 MPa. The obtained results also indicate that shortening or extending the shooting time of the core sand into the core box is not particularly significant, as the bending strength values obtained are very similar, and the differences are mainly due to statistical error.

The introduction of 4.0 parts by mass of perlite ore into the core mixture while maintaining the binder content at 2.5 parts by mass relative to the base material resulted in a decrease in bending strength by approximately 1.0 MPa (Fig. 4). This significant, about 20%, reduction in strength should be attributed to the introduction of an additional component, which increased the specific surface area that needed to be coated with the binder layer. The higher number of individual grains requiring binder coverage means that, in quantitative terms, there is less binder available relative to the total amount of grains – quartz sand and perlite ore. It should also be noted that the loosening additive (perlite ore) contains approximately 2% of particles smaller than 0.1 mm (Table 2), which further intensifies the increased binder demand.

It was also observed that for this core mixture, the best mechanical properties were obtained at a core box temperature of 180°C. The lower strength values obtained with a longer shooting time result from the reduced flow rate from the shooting chamber of the core shooter, which may lead to a lower degree of compaction of the core mixture in the core box – particularly in the case of core mixtures with lower flowability.

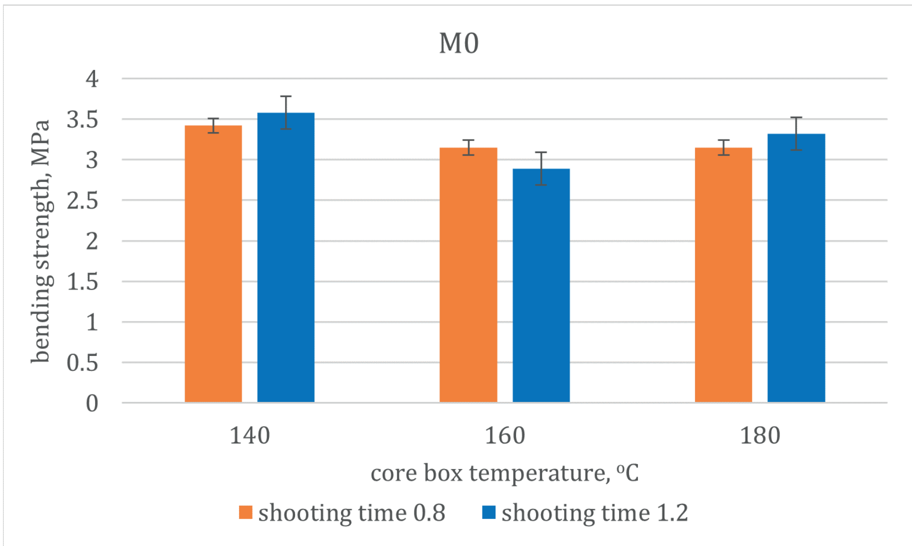

Fig. 3. The bending strength of standard specimens made from the reference core sand mixture (without the addition of perlite ore, M0) as a function of the core box temperature and shooting time for the mixture

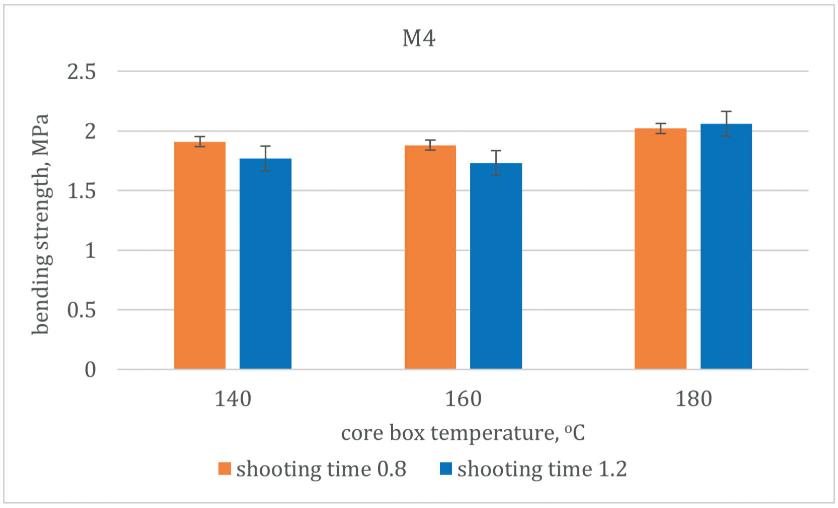

Fig. 4. The bending strength of standard specimens made from the core sand mixture (M4) containing 4.0 parts by weight of perlite ore as a function of the core box temperature and shooting time for the mixture

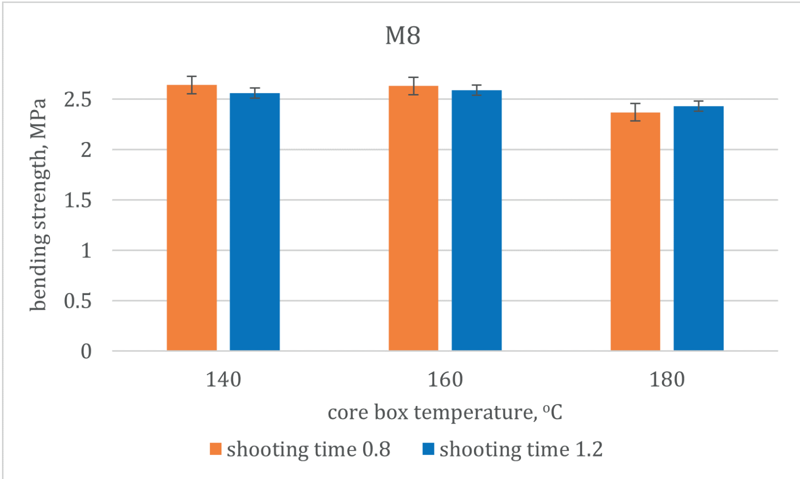

Fig. 5. The bending strength of standard specimens made from the core sand mixture (M8) containing 8.0 parts by weight of perlite ore as a function of the core box temperature and shooting time for the mixture

The core mixture containing 8.0 parts by mass of perlite ore exhibits better mechanical properties than the mixture with 4.0 parts by mass, but inferior to the mixture without the loosening additive. It should be noted that at core box temperatures of 140 and 160°C (Fig. 5), the obtained bending strength values are very similar, ranging between 2.56 and 2.64 MPa, with differences falling within the limits of statistical error.

For this core mixture, the lowest bending strength (approximately 2.4 MPa) was recorded at a core box temperature of 180°C. This is likely due to the physical process of solvent removal in the inorganic binder, which reduces its binding capacity. This confirms that such a binder performs best when cured at temperatures between 140 and 160°C. Further research should therefore focus on optimizing the holding time of samples in the core box, as increasing the temperature may only be justified if, when combined with a shorter holding time, it leads to higher production efficiency.

Figures 6 and 7 show the bending strength for all tested systems depending on the core box temperature, for two shooting times.

Figures 6 and 7 provide a summary and, at the same time, a more illustrative representation of the previous research results. They show that shooting time has no significant effect on the obtained bending strength values, regardless of whether the core mixture contains additives or not. As mentioned earlier, the increased specific surface area resulting from the introduction of an additional loose material (perlite ore) leads to a decrease in core strength, which is particularly evident for the M4 core mixture. With the same binder content (2.5 parts by mass), the M8 mixture (8.0 parts by mass of perlite ore) exhibited better mechanical properties at all tested core box temperatures. This may be attributed to the improved flowability of the core mixture, better compaction, and more uniform distribution of perlite ore grains, which are statistically larger and have a coarser main fraction compared to the base sand grains. The obtained results indicate the validity of optimizing the composition of the core mixture for each specific formulation and set of blowing process parameters.

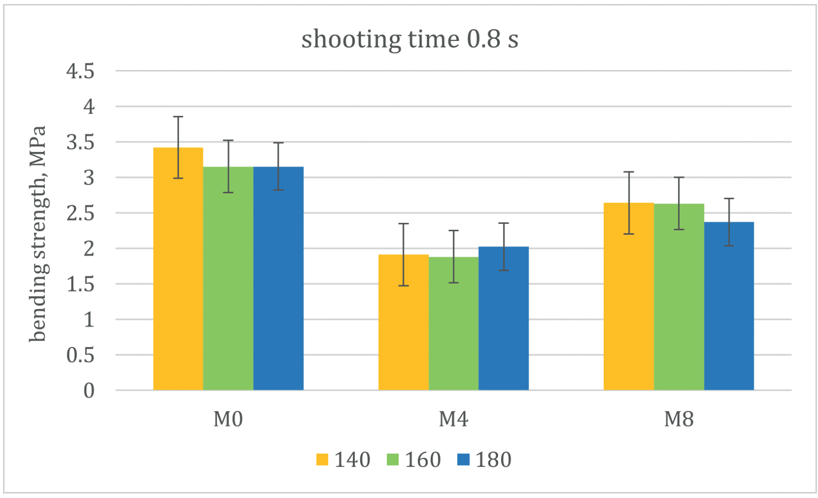

Fig. 6. Comparison of strength depending on core box temperature and shooting time of 0.8 s

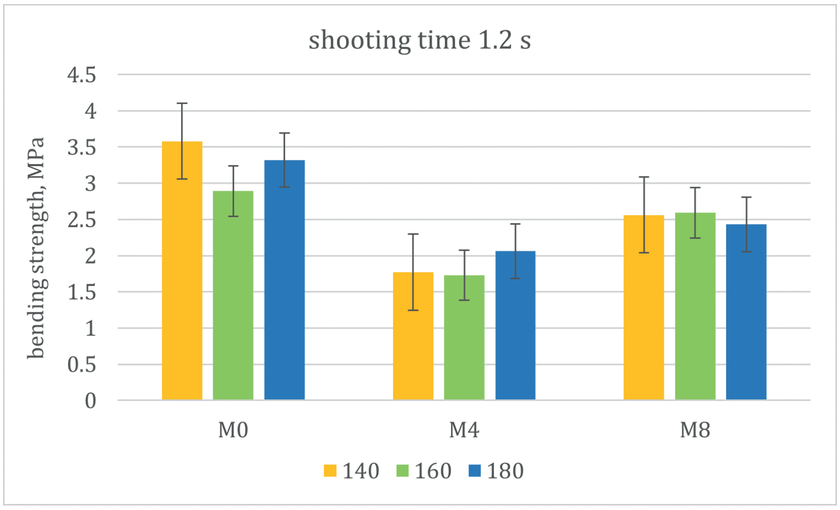

Fig. 7. Comparison of strength depending on core box temperature and shooting time of 1.2 s

4. CONCLUSIONS

The conducted research on the influence of a loosening additive in the form of perlite ore on the mechanical properties of cores produced by the warm-box process using an inorganic silicate binder has shown that:

- in the case of core mixtures prepared with the inorganic Cordis binder, increasing the core box temperature does not bring any benefits in terms of higher strength of standard cores (standard samples for bending strength testing) cured for 120 s. The best properties were obtained at temperatures of 140°C and 160°C, while increasing the temperature to 180°C may lead to the physical removal of the solvent from the binder, reducing its bonding ability;
- extending the shooting time results in increased strength only for the mixture without the addition of perlite ore. For the other tested systems (with 4.0 and 8.0 parts by mass of perlite ore), a decrease in strength was observed, which is due to a reduced flow rate of the core mixture from the shooting chamber and a lower concentration of the sand-air stream;
- with a constant binder content in the core mixture (2.5 parts by mass), the mixture containing 8.0 parts by mass of perlite ore exhibited better mechanical properties at all tested core box temperatures than the mixture with 4.0 parts by mass of perlite ore. This may be attributed to improved flowability and, consequently, a higher degree of compaction;
- the introduction of additives into molding and core sands requires case-by-case optimization of both the mixture composition and the blowing process parameters;
- the research will continue, focusing on determining the effects of binder type, grain size, and loosening additive, as well as the influence of operating pressure on the density and strength of cores in the core box. The amount of loosening additive introduced also requires optimization to achieve the desired improvement in core knockout properties.

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