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Moulding Sand with Inorganic Cordis Binder for Ablation Casting

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Abstract

The essence of ablation casting technology consists in pouring castings in single-use moulds made from the mixture of sand and a water-soluble binder. After pouring the mould with liquid metal, while the casting is still solidifying, the mould destruction (washing out, erosion) takes place using a stream of cooling medium, which in this case is water. This paper focuses on the selection of moulding sands with hydrated sodium silicate for moulds used in the ablation casting. The research is based on the use of Cordis binder produced by the Hüttenes-Albertus Company. It is a new-generation inorganic binder based on hydrated sodium silicate. Its hardening takes place under the effect of high temperature. As part of the research, loose moulding mixtures based on the silica sand with different content of Cordis binder and special Anorgit additive were prepared. The reference material was sand mixture without the additive. The review of literature data and the results of own studies have shown that moulding sand with hydrated sodium silicate hardened by dehydration is characterized by sufficient strength properties to be used in the ablation casting process. Additionally, at the Foundry Research Institute in Krakow, preliminary semi-industrial tests were carried out on the use of Cordis sand technology in the manufacture of moulds for ablation casting. The possibility to use these sand mixtures has been confirmed in terms of both casting surface quality and sand reclamation.

Keywords: Innovative Foundry Technologies and Materials, Ablation Casting, Moulding Sand, Inorganic Binder, Thermal Curing

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1. Introduction

1.1. Ablation casting

Ablation casting is a term taken probably from the Latin word *ablatio* meaning removal or *ablutio* which means washing. The essence of the ablation casting technology consists in pouring castings in single-use moulds made from the mixture of sand and a water-soluble binder. After pouring the mould with liquid metal, while the casting is still solidifying, the mould destruction (washing out, erosion) takes place using a stream of cooling medium, which in this case is water.

China is considered to be the precursor of ablation casting technology [1]. A piece of rope or cord was coated with clay. Then it was fired and washed out, and a mould obtained in this way was filled with liquid metal. This technique was used to produce dish handles from around 1600 BC (Figure 1).

Fig. 1. Examples of the use of ablation in ancient China [1]

In 2006, Alotech patented a casting station using the ablation casting method. The sand mould was located on a belt conveyor and after being poured with liquid metal it moved horizontally to a set of spray nozzles, where under high water pressure it was broken down. Figure 2 shows an implementation of the ablation casting process according to the above patent description [2] and publications [3-6].

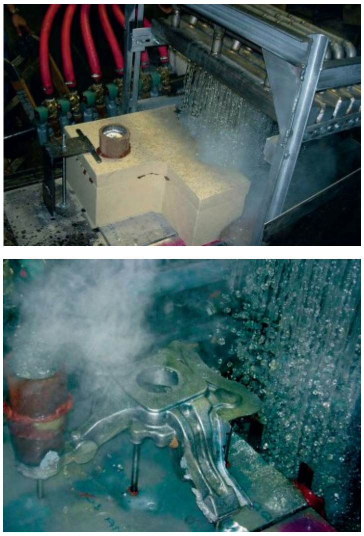

Fig. 2. View of the ablation casting process proposed by Alotech [6]

Ablation casting technology offers a number of advantages. The casting mould is destroyed with a stream of liquid medium still during the casting solidification process, which eliminates the additional operation of casting knocking out from mould and considerably reduces the dust pollution in a foundry shop. It is also possible to reclaim some of the sand mould components.

There is no air gap between the casting mould and the top layer of the cooled casting, which limits the heat flow to the outside. This enables solidification under the conditions of unprecedentedly large temperature gradients and high solidification rates. The mechanical properties of the obtained castings are equal to or higher than the same properties obtained in pressure die castings [7].

Another advantage of this innovative process is controlled, directional cooling, which favours the elimination of shrinkage porosity.

The economic factor of the process of making high-quality castings in compact, single-use moulds as compared to high-tech permanent-mould technologies and the ecological factor associated with the use of an inorganic water-soluble binder are also worth mentioning.

1.2. Hydrated sodium silicate

The use of moulding sands with hydrated sodium silicate in ablation casting technology is well justified. The ecological nature of the binder makes it currently the object of numerous studies, while modern processes using hydrated sodium silicate are increasingly used in foundry practice.

As a binder for foundry moulding sands, hydrated sodium silicate was first used by L. Petržela in 1947 (Czech patent No. 81931). The hardening operation was carried out by blowing the sand with CO_2. Unfortunately, this technology required the use of a very large amount of binder (about 8 parts by weight), which - due to the inorganic nature of the binder - resulted in a significant deterioration of the sand knocking out properties [8]. A breakthrough in the use of this inorganic binder occurred in 1968 with the development of loose self-hardening sands with hydrated sodium silicate and liquid hardeners. The technology allowed reducing the amount of binder to approx. 3 parts by weight, improving in this way the sand knocking out properties and mechanical reclamation [9].

Previous research works of the authors [9, 10] focused on the development of ester-hardened sands with hydrated sodium silicate, characterized by improved knocking out properties and reclamation.

In the Department of Moulding Materials, AGH Faculty of Foundry Engineering, moulding sands with hydrated sodium silicate and additives improving their knocking out properties were developed. The new additives contained Al_2O_3. According to literature data, this compound positively affects the knocking out properties of the tested sands. A new proprietary inorganic additive called Glassex [11] and nanoparticles of the $\alpha - Al_2O_3$ phase and $\gamma - Al_2O_3$ phase [10] were also applied.

As part of own research, in the Department of Moulding Materials, AGH Faculty of Foundry Engineering, new ester hardeners - ixional SD and jeffsol BC, both based on esters of carbonic acid, were developed. These hardeners are an alternative to the flodur hardener used in ester technology. The possibility of using new ester hardeners has been demonstrated in own research works [9, 10] and implementations. In previous studies, the authors proposed the use of microwave hardening. Samples were cured during 240s, using P_{const} = 1000W power in a microwave oven. For tests, sands with hydrated sodium silicate and various ester hardeners, including also the new inorganic Glassex additive, were selected [10, 11]. Tests were carried out on sand mixtures with the compositions listed in Table 1. The results of the tests are shown in Figure 3.

Table 1.
Selected sand mixtures with hydrated sodium silicate prepared by various technologies [10]

No	Moulding sand number	Composition	Technology
1.	Sand no 1	Hydrated sodium silicate 3.0 p.p.w, Flodur, Glassex 1.0 p.p.w.	Self-hardening moulding sand in ester technology
2.	Sand no 2	Hydrated sodium silicate 3.0 p.p.w, Ixional SD, Glassex 1.0 p.p.w.	Self-hardening moulding sand in ester technology
3.	Sand no 3	Hydrated sodium silicate 3.0 p.p.w, Jeffsol BC, Glassex 1.0 p.p.w.	Self-hardening moulding sand in ester technology
4.	Sand no 4	Hydrated sodium silicate 2.5 p.p.w	Moulding sand hardened by microwave exposure
5.	Sand no 5	Hydrated sodium silicate 3.5 p.p.w	Moulding sand hardened by microwave exposure

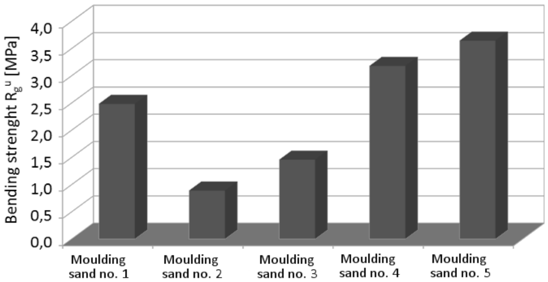

Fig. 3. Effect of the type of hardener and hardening technology on the bending strength of sands with hydrated sodium silicate [10, 12]

Studies [10, 12, 13] have shown that microwave hardening increases the sand strength, which allows for the introduction of a lower amount of hydrated sodium silicate to the sand composition, improving in this way the sand knocking out properties.

2. Own research

As part of own research, it was proposed to use sands with hydrated sodium silicate thermally cured by dehydration as a moulding material for ablation casting. The main advantage of the dehydration process is the achievement of high strength properties, much higher than in the case of chemical hardening, combined with the absence of harmful products of the chemical reaction of hardening.

2.1. Moulding sand selection

The mechanism of thermal curing of hydrated sodium silicate consists in its dehydration. It has been found that in the temperature range from 20°C to about 70°C, free water is removed, while in the temperature range from about 115°C to about 140°C, the removal of bound water occurs [14, 15, 19].

As a result of thermal curing of sodium water glass, a structure composed of precipitated, amorphous, monolithic silicate shells is formed. The inverted reactions produce a gel (physical hardening) [14].

In the present research, Cordis binder [16] produced by the Hüttenes-Albertus Company was used. It is a new-generation inorganic binder based on hydrated sodium silicate. Its hardening occurs under the effect of high temperature. In this technology, a loose inorganic Anorgit additive [17] is also used as an agent which prevents burn-on defects and improves the durability of cores, mitigating the adverse effect of humidity present in the environment.

As part of the research, loose moulding sands based on 1K silica sand from the Grudzeń Las mine with a main fraction of 0.20/0.40/0.315 were prepared. As a binder, the inorganic Cordis binder was used in an amount of 1.5, 2.0 and 2.5 parts by weight. Additionally, 1.0 part by weight of the Anorgit additive was introduced. Reference studies were carried out on the sand mixture without the additive. Moulding sands were prepared in a laboratory ribbon mixer, type LMR-2. The sand was mixed with the additive for 60 seconds, then the binder was introduced and the whole was mixed for another 150 seconds.

From the ready moulding sands, standard specimens were prepared for bending tests using two methods of thermal curing.

Specimens of the first type were made in a universal LUT device. They were cured at 140, 160 and 180°C for 30, 60, 90 and 120 seconds. The time and pressure of shooting were the same for all the specimens and amounted to 2 seconds and 0.5 MPa, respectively.

Specimens of the second type were cured in a laboratory furnace at 180°C for 3, 4 and 5 minutes.

Measurements of the sand bending strength were carried out on an LRu-2 type apparatus in accordance with guidelines given in the PN-83 / H-11073 standard.

The sand properties were tested in both hot state (directly after the removal from furnace or shooting machine) and cold state (after 1 hour of curing in the air). Tests covered moulding sand compositions listed in Table 2. Figures 4 - 8 show the results obtained.

First, the starting sand mixture, Sand no I, was tested. It was prepared in accordance with the manufacturer's recommendations. Specimens were hardened by the warm box technology at 140, 160 and 180°C for the time of 30, 60, 90 and 120 seconds, and in a laboratory furnace at 180°C for the time of 3, 4 and 5 minutes

Table 2.
Tested moulding sand compositions

No	Moulding sand number	Composition	The technique of making standard specimens
1.	Sand no I	Cordis binder 2.0 p.p.w, Anorgit 1.0 p.p.w.	A. shooting, warm box technology temperature: 140, 160 and 180°C, time: 30, 60, 90 and 120 seconds B. furnace, temperature: 180°C, time: 3, 4 and 5 minutes
2.	Sand no II	Cordis binder 1.5 p.p.w	A. shooting, temperature: 140, 160 and 180°C, time: 30, 60, 90 and 120 seconds
3.	Sand no III	Cordis binder 2.0 p.p.w	A. shooting, temperature: 140, 160 and 180°C, time: 30, 60, 90 and 120 seconds
4.	Sand no IV	Cordis binder 2.5 p.p.w	A. shooting, temperature: 140, 160 and 180°C, time: 30, 60, 90 and 120 seconds

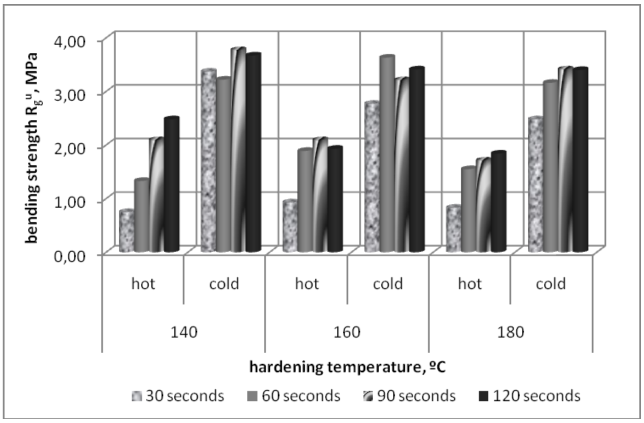

Fig. 4. Sand no I, warm box technology

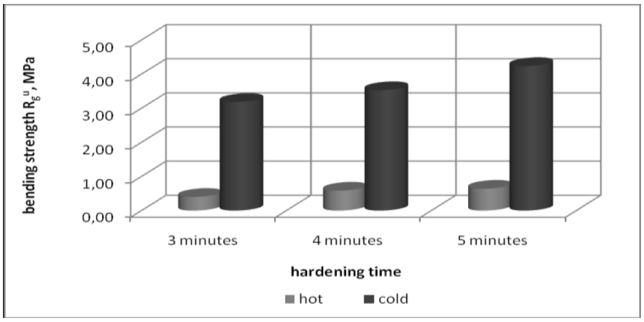

Fig. 5. Sand no I, hardening in furnace

With the use of 2.0 parts by weight of Cordis binder and 1.0 part by weight of Anorgit additive, the sand strength upon removal of the specimens from the furnace was 0.40 - 0.64 MPa. In the case of warm box technology, with the temperature of the core box from 140 to 180°C, the hot strength of the sands was 0.75 - 0.93 MPa after 30 seconds of curing, 1.33-1.89 MPa after 60 seconds of curing, 1.71 - 2.09 MPa after 90 seconds of curing and 1.84 - 2.48 MPa after 120 seconds of curing. For both curing techniques, the cold strength of Sand no I was from 3 to 4 MPa in the majority of specimens. The obtained results confirmed the possibility of making both moulds and cores by Cordis technology.

The next step involved testing the sands with an inorganic Cordis binder but without the addition of Anorgit. Using this technology for ablation casting is justified in terms of both economy and ecology. Sand of this type is assigned for the foundry moulds, and therefore the use of an additive increasing the post-curing sand strength is not necessary.

The test results obtained on the ready sand mixtures are presented below for Sands no II, no III and no IV.

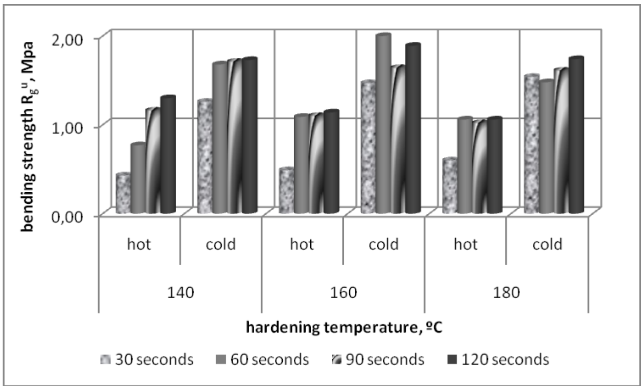

Fig. 6. Sand no II, warm box technology

The hot strength of Sands no II, III, IV was 0.43 - 0.93 MPa after 30 seconds of curing, 0.77 - 1.62 MPa after 60 seconds of curing, 1.02 - 1.73 MPa after 90 seconds of curing and 1.06 - 2.04 MPa after 120 seconds of curing, and it depended on the core box temperature and binder content.

The cold strength of Sand no II containing Cordis binder in an amount of 1.5 parts by weight was from 1.26 to 2.03 MPa, and it depended on the core box temperature and time of curing. The cold strength of Sand no III containing Cordis binder in an amount of 2.0 parts by weight was from 1.66 to 2.92 MPa, and it depended on the core box temperature and time of curing. The cold strength of Sand no IV containing Cordis binder in an amount of 2.5 parts by weight was from 2.04 to 3.42 MPa, and it depended on the core box temperature and time of curing.

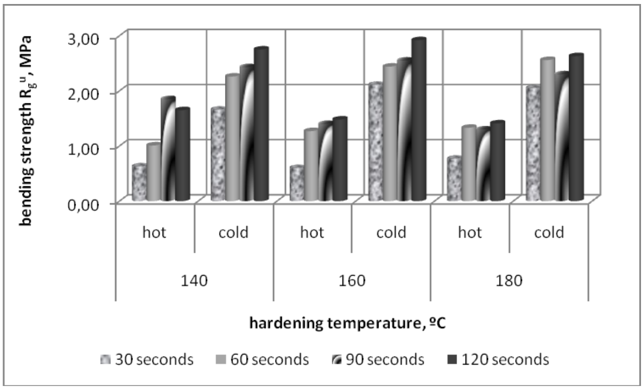

Fig. 7. Sand no III, warm box technology

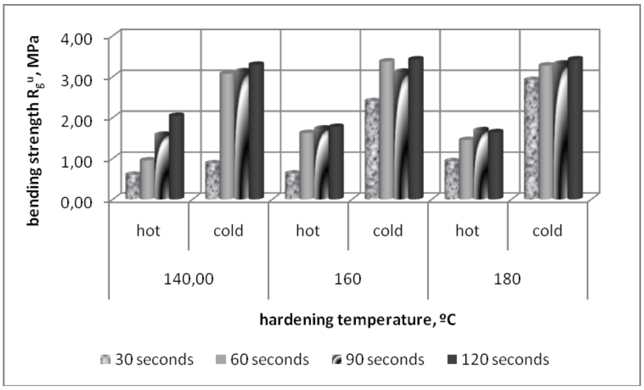

Fig. 8. Sand no IV, warm box technology

Tests have proved that the strength of sands with Cordis binder and without the addition of Anorgit is sufficient to make foundry moulds from this mixture.

At this point it is worth mentioning that the manufacturer recommends additional blowing of hardened cores with hot air to increase their strength, but when the Cordis technology is used in ablation casting, this operation seems to be superfluous. The sand acquires satisfactory strength without this operation, increasing in this way even more the process economics.

2.2. Semi-industrial tests of ablation casting

The preliminary semi-industrial tests on the use of moulding sands with Cordis binder in the manufacture of foundry moulds for ablation casting were carried out at the Foundry Research Institute in Cracow.

The moulding mixture was based on silica sand from the Grudzeń Las mine with a main fraction of 0.20 / 0.40 / 0.315 and it contained the inorganic Cordis binder in an amount of 2.0 parts by weight. The sand mixing process was carried out in a laboratory ribbon mixer, type LMR-2. The base sand was mixed with the additive for 60 seconds, then the binder was introduced and the whole was mixed for another 150 seconds. The sand was placed in a preheated to 250°C moulding box with a pattern and the whole was heated in a furnace at 250°C for 30 minutes. Thus prepared mould with a diameter of 90 mm and a height of 190 mm (Fig. 9) was installed in the device for ablation casting developed at the Foundry Research Institute in Cracow (Fig. 10). The device, ensuring mould destruction and controlled cooling of the casting, is covered by a patent application [18].


Fig. 9. View of the ready mould

The device consists of a chamber (1) open from the top, inside which there is a movable work table (2) mounted on a hoist set in vertical and rotary motion. In the side walls of the chamber, nozzles (5) with holes of various diameters are installed, permanently or on the articulated joints for feeding a liquid cooling medium. A tank (6) is installed under the chamber for a flowing liquid cooling medium. It is equipped with a basket (7) to collect sand from the broken down mould.

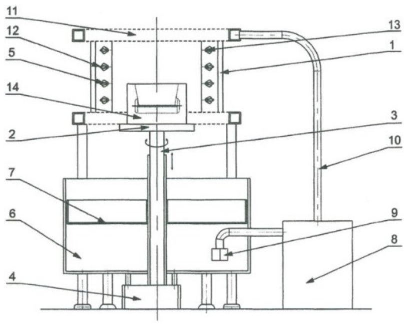

Fig. 10. The principle of operation of a device developed at the Foundry Research Institute for mould destruction and controlled cooling of the casting [18]

The construction of the device allows for a simultaneous rotary and vertical movement, which enables both mould removal due to the action of a water jet flowing from the nozzles and controlled directional cooling of the casting. Additionally, due to the rotary motion of the working table, it is possible to thoroughly wash away the residual moulding sand from all parts of the solidified casting.

The test was carried out on a molten AK7 aluminium alloy. The pouring temperature was 730°C. After filling the mould with liquid metal poured by hand from the top, the process of rinsing the mould with water was started using evenly spaced, twelve 1.6 mm diameter nozzles (Fig.11). The pressure of water jet was 11 MPa. The ablation process was going on until the mould was totally destroyed and casting was free from any traces of the sand (Fig.12). The duration of the ablation casting process was about 5 minutes. Figure 12 shows the ready casting.


Fig. 11. View of the ablation casting process


Fig. 12. View of the casting

The macroscopic examination of the casting showed total absence of defects, while moulding sand remaining in the device was easily disintegrated, thus indicating that the binder was removed by rinsing and the material obtained was initially reclaimed.

3. Conclusions

A review of the literature and own research allowed formulating the following conclusions:

- It is fully justified to use moulding sands with binder in the form of water-soluble hydrated sodium silicate for ablation casting.
- It is possible to use moulding sands with hydrated sodium silicate hardened by various techniques, but for the ablation casting technology, the best is the use of moulding sand hardened by physical factors.
- Used for foundry moulds for ablation casting, the sand with Cordis binder produces moulds with satisfactory strength properties.
- The initial semi-industrial tests of ablation casting have proved that sands made by the Cordis technology are suitable for ablation casting in terms of both casting surface quality and sand reclamation.

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