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K. MAJOR-GABRYŚ[#], M. HOSADYNA-KONDRACKA^{**}, A. GRABARCZYK^{*}, J. KAMIŃSKA^{**}**SELECTION OF HARDENING TECHNOLOGY OF MOULDING SAND WITH HYDRATED SODIUM SILICATE BINDER DEVOTED TO ALUMINUM ALLOYS ABLATION CASTING**

The ablation casting technology consists in pouring castings in single-use moulds made from the mixture of sand and 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.

The following paper focuses on the selection of moulding sands with hydrated sodium silicate technologies for moulds devoted to the ablation casting of aluminum alloys. It has been proposed to use different types of moulding sands with a water-soluble binder, which is hydrated sodium silicate. The authors showed that the best kind of moulding sands for moulds for Al alloy casting will be moulding sands hardened with physical factors – through dehydration. The use of microwave hardened moulding sands and moulding sands made in hot-box technology has been proposed. The tests were carried out on moulding sands with different types of modified binder and various inorganic additives. The paper compares viscosity of different binders used in the research and thermal degradation of moulding sands with tested binders. The paper analyzes the influence of hardening time periods on bending strength of moulding sands with hydrated sodium silicate prepared in hot-box technology.

The analysis of literature data and own research have shown that molding sand with hydrated sodium silicate hardened by dehydration is characterized by sufficient strength properties for the ablation foundry of Al alloys.

Keywords: foundry engineering, ablation casting, moulding sands, hydrated sodium silicate, hot-box technology

1. Introduction

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 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]. In the clay mould, a material such as a rope was placed. It was ignited and then washed out. Thus prepared mould was filled with molten metal. This technique was used to produce dish handles from around 1600 BC.

In 2006, Alotech patented a casting stand using the ablation casting method [2]. The sand mould was located on a conveyor belt 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 (Fig. 1) [3-7].

At the Foundry Research Institute in Krakow, a modification was introduced to the casting stand for its subsequent use in the

ablation casting (Fig. 2) [8]. 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 movement. In the side walls of the chamber, nozzles (5) with holes of various diameters are installed permanently or on articulated joints for feeding a liquid cooling medium. Under the chamber, a tank (6) is installed for the flowing liquid cooling medium. It is equipped with a basket (7) to collect sand from the broken down mould (14) and with a pump (8) with a filter (9) connected by high-pressure lines (10) for supplying a liquid cooling medium to the nozzles (5). The nozzles (5) are situated on joints (12) and have deflectors (13) [8].

The device construction allows for simultaneous rotation and vertical plane movement, which ensures simultaneous removal of the mould by a stream of water supplied from the nozzles and controlled directional cooling of the casting. In addition, the rotary motion of the working table helps rinsing of the moulding sand from all fragments of the solidified casting.

Ablation casting technology offers a number of advantages, which include, among others, the elimination of an additional operation of casting knocking out from the mould and avoiding in this way the dust pollution in a foundry plant.

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Fig. 1. Ablation casting presented by Alotech, Co. [7]

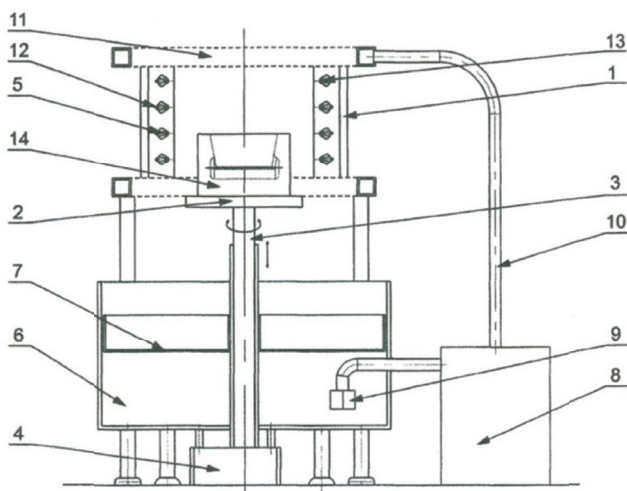


Fig. 2. The principle of operation of a device developed at the Foundry Research Institute for mould destruction and controlled casting cooling [1,8]

There is no air gap between casting mould and 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 level of analogical characteristics obtained in the pressure die casting process [1]. Another advantage of this innovative technology is controlled directional cooling, which eliminates shrinkage porosity.

It is also worth mentioning the economic factor of the process of producing high-quality castings in compact, unstable moulds in relation to high-cost stable (die-metal) moulds technologies. Another advantage is an ecological factor related to the use of an inorganic water-soluble binder.

2. Selection of moulding sands for single-use ceramic moulds designed for ablation casting

The ablation casting technology consists in making casts in a single-use form, made on the basis of a sand matrix and

a binder, which is water-soluble. Therefore, it seems reasonable to use moulding sands with hydrated sodium silicate as a binder.

Hydrated sodium silicate as a foundry moulding sand binder was first used in 1947 by L. Petržela (Czech patent no. 81931). The moulding sand curing was carried out by blowing with CO_2 . Unfortunately, this technology required the use of a very large amount of binder (about 8.0 p.p.w.), which – due to binder inorganic nature – resulted in a significant decrease of the moulding sand's knock-out properties [9]. A turning point in the use of this inorganic binder was the development of 1968 loose self-hardening moulding sands with hydrated sodium silicate and liquid hardeners. The technology allowed to reduce the amount of binder used to approx. 3.0 p.p.w. which meant improvement of knock-out properties and mechanical reclamation of moulding sands with hydrated sodium silicate [10].

The ecological nature of the binder makes it the object of many current studies and modern technologies using hydrated sodium silicate are increasingly used in foundry practice. The previous work of the authors [10-11] concerned the development of moulding sands with hydrated sodium silicate hardened in ester technology with increased knock-out properties and ensuring a better quality of reclaim.

In the Department of Moulding Materials of the Faculty of Foundry Engineering of AGH, moulding sands with hydrated sodium silicate and additives improving their knock-out properties were developed. The new additives contain Al_2O_3 . According to literature data, this compound positively influences the knock-out properties of the tested moulding sands. The new inorganic addition of Glassex [10-12] and nanoparticles of the $\alpha - \text{Al}_2\text{O}_3$ phase and $\gamma - \text{Al}_2\text{O}_3$ phase were used [11].

From the standpoint of knock-out properties, the use of moulding sands with hydrated sodium silicate for the ablation casting of aluminum alloys is fully justified. The pouring temperature of the liquid casting alloy coincides with the temperature at which there is a minimum retained strength R_c^{tk} of the moulding sands with hydrated sodium silicate (600°C). Although in ablation casting technology water will support both the knocking-out properties and mechanical reclamation of moulding sands, nevertheless this argument additionally sup-

ports the use of moulding sands with hydrated sodium silicate on ceramic moulds for aluminum casting.

As part of our own research in the Department of Moulding Materials of the Faculty of Foundry Engineering of AGH, new ester hardeners were developed: ixional SD and jeffsol BC, based on esters of carbonic acid. 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 work [10-11] and implemented in foundry practice.

In the case of ablation casting, however, the possibility of applying physical hardening to the moulding sands with hydrated sodium silicate should be considered. This is important from the point of view of the water recovered in the process, as well as the utilization of waste water. The elimination of chemical hardening of the moulding sands will additionally have a positive effect on the ecology of the process. The use of physical hardening could allow to recover, not only the matrix, but also a part of the binder.

In previous studies, the authors proposed the use of microwave curing. For the tests, moulding sands with hydrated sodium silicate and various ester hardeners were selected, as well as moulding sands with the new inorganic additive – Glassex [11-12].

The moulding sands of the compositions listed in Table 1 were tested. The results of the tests are shown in Figure 3.

TABLE 1

Tested moulding sands compositions

Name	Moulding sand no. 1	Moulding sand no. 2	Moulding sand no. 3	Moulding sand no. 4	Moulding sand no. 5
Technology	Self-hardening moulding sand prepared in ester technology			Moulding sands hardened by microwave exposure	
Binder	hydrated sodium silicate				
	3.0			2.5 p.p.w.	3.5 p.p.w.
Hardener	flodur	ixional SD	jeffsol BC	microwave exposure	
Additive	Glassex 1.0 p.p.w.				

Studies [11,13-14] have shown that the use of microwave curing increases the strength of the moulding sands, and thus allows to reduce the content of hydrated sodium silicate in their composition, thereby improving their knock-out properties.

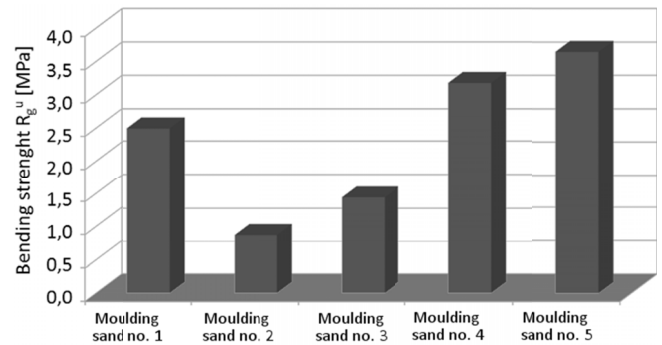


Fig. 3. Influence of the hardener type and curing technology on the bending strength of moulding sands with hydrated sodium silicate [11,13]

Self-hardening moulding sand with 3.0 p.p.w. of hydrated sodium silicate and with 1.0 p.p.w. of Glassex additive hardened by: flodur characterizes with bending strength after 24 h of curing approx. 2.2 MPa; ixional SD – approx. 0.7 MPa; jeffsol BC – approx. 1.3 MPa. The moulding sand with the addition of Glassex, cured by microwave, achieves a bending strength of almost 3.0 MPa with the content of hydrated sodium silicate 2.5 p.p.w. and almost 3.5 MPa at the binder content of 3.5 p.p.w.

3. Own research

In this work, the possibility of using moulding sands with hydrated sodium silicate hardened by dehydration in hot box technology has been demonstrated.

The following paper focuses on comparing the properties of moulding sands prepared in hot box technology with two different binders – A and B – and different inorganic additives – A (1), A (2), B (1). In Table 2 physicochemical properties of A and B binders and A (1), A (2), B (1) additives were presented [15-16].

The first step of the research were tests of viscosity of binders used in the research.

Figure 4 shows the flow curves determined for the tested binders.

The obtained flow curves have a linear character, where the shear stress τ is proportional to the shear rate $\dot{\gamma}$ described by the Newton equation (1).

$$\tau = \eta \cdot \dot{\gamma}, [\text{Pa} \cdot \text{s}] \quad (1)$$

TABLE 2

Physicochemical properties of A and B binders and A (1), A (2), B (1) additives [15-16]

Property / unit	A binder	A (1) additive	A (2) additive	B binder	B (1) additive
form	water solution	powder	powder	water solution	powder
physical condition	liquid	solid	solid	liquid	solid
colour	colourless	grey	grey	colourless-yellow	grey
smell	odourless	odourless	odourless	odourless	odourless
pH (in temp. 20°C)	11.5-12.5	—	—	11.5-12.2	—
Density (in temp. 20°C) / g/cm ³	1.36-1.47	—	—	1.34-1.39	—
Bulk density / g/cm ³	—	0.40–0.70	0.40–0.70	—	0.35-0.50
Dynamic viscosity (in temp. 20-25°C) / mPa·s	20-60	—	—	30-40	—

The viscosity of the fluid under simple shear conditions is described by η [17].

On the basis of the obtained relations of shear stress τ as a function of the shear rate $\dot{\gamma}$ the values of the viscosity parameter η were determined (Fig. 6).

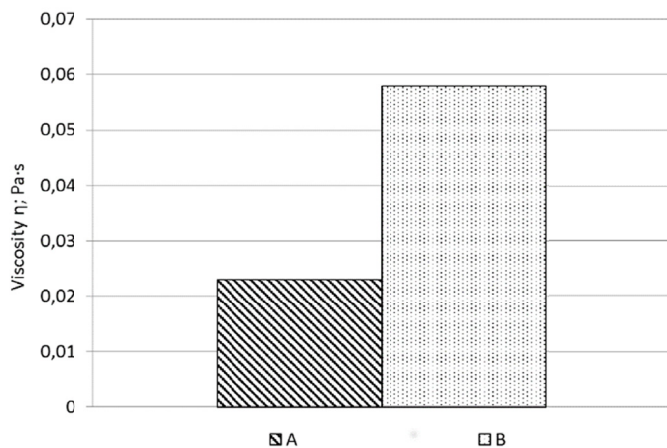
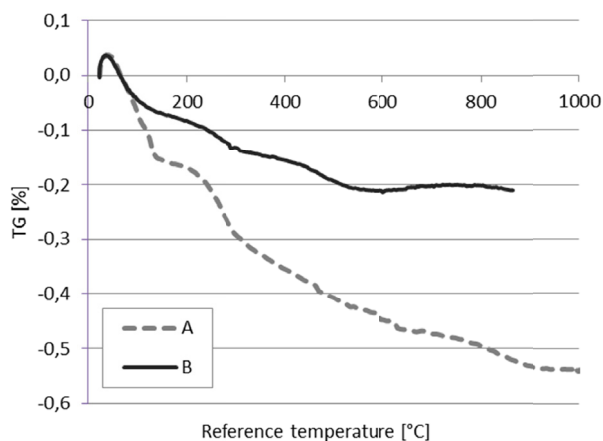


Fig. 5. Viscosity determined for binder A and B

Viscosity tests (Fig. 5) of selected binders showed that the B binder (η – about 0.058 Pa·s) is characterized by more than twice the viscosity from the binder A (η – about 0.023 Pa·s). The obtained results confirm the own observation of binders made during moulding sands preparation. The increased viscosity of the binder may affect the need to prolong the moulding sands mixing operation to accurately cover the matrix grains with the binder material. However, it should be stated that the obtained viscosity results for both binders are at a level similar to other moulding binders (e.g. organic resins).

The second step of research were tests of thermal degradation of inorganic additives and moulding sands with different binders. The thermal degradation was tested by derivatographic research. The tests were carried out on the Iota derivatograph in the following measurement conditions: heating temperature range 20-1000°C, heating rate 10°/min. The measurement was conducted in oxygen atmosphere.



a)

Moulding sands compositions have been presented below.

Quartz sand	100 p.p.w.
Binder A or B	2.2 p.p.w.
Inorganic additive/additives	0.95 p.p.w.

Quartz sand from the Szczakowa Sand Mine S.A was used in all of the conducted tests. According to the Polish standard PN-85 / H-11001, it classifies the tested sand as medium. In the studied matrix, the value of the main fraction is 84%, which determines the sand as homogeneous.

The moulding mixtures were prepared in accordance with the recommendations of binder manufacturers [15-16], in a Vogel & Schenmann laboratory mixer, with a capacity of 6 kg. Mixing parameters were: sand + loose additives –1 min, + binder 1 min. The hydrothermal conditions in which the mixtures were prepared and the fittings were stored ranged between 22-26°C and 30-32% humidity. The hardening process was conducted in the temperature of 140°C in different time periods (60 s, 90 s). Detailed sample symbols were placed in Table 3.

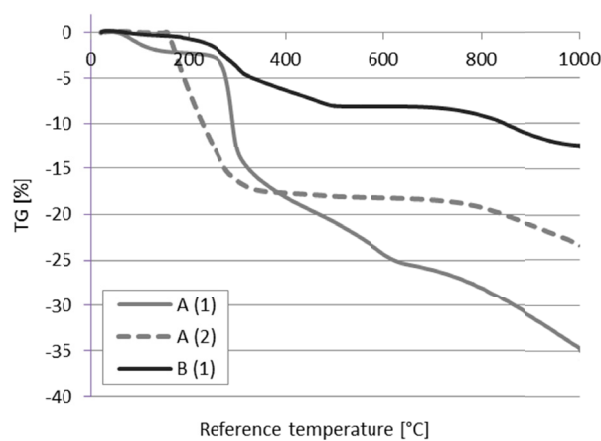
TABLE 3

Samples symbols

Sample symbol	Hardening time [s]
A _{HOT} , B _{HOT} (sample tested immediately)	60/90
A _{COLD} , B _{COLD} (sample tested after cooling)	

The samples used for derivatographic research were hardened in 60 s time. Figure 6 shows the derivatographic measurement results.

Derivatographic research carried out on moulding sand and applied additives showed moulding sands losses in the temperature range 25-1000°C. In the case of additives, we observe a loss of approx. 12% for technologies with B binder and approx. 23 and 35% for technologies with A binder. The biggest losses for all additives take place at temperature of approx. 300°C. At this temperature, the largest moulding sands losses with used additives are observed. And so the moulding sand made in technology A is characterized by a loss of about 0.5%, and the moulding sand made in technology B by a loss of about 0.2%. Weight losses of



b)

Fig. 6. The TG curves for: a) moulding sands with A and B binder and b) used additives

used inorganic additives will need to be clarified during further testing. In addition, future tests will be carried out for moulding sands without the use of inorganic additives. These additives are used to improve strength and the knock-out properties of moulding sands with hydrated sodium silicate. In the case of ablation casting, the problem of low moulding sand knock-out properties will be solved by using water – a solvent for the binder.

The paper also analyses the influence of hardening time periods and binders types on bending strength of moulding sands with hydrated sodium silicate prepared in warm-box technology.

The bending strength tests were performed immediately and after the samples have reached room temperature, which was set to an hour after the sample was taken out from the core shooter. A minimum of 3 samples was used for each test. The results of bending strength tests are shown on Fig. 7.

The tests have shown that moulding sands with applied binders are characterized by similar strength properties in the tested ranges. The moulding sands with both A and B binder achieved better strength properties after curing in the warm box for 90 seconds (about 1.83 MPa “hot” and 3.2 MPa “cold”). Nevertheless, the strength of moulding sands hardened for 60 seconds seems to be sufficient from the point of view of the casting mould: “hot” strength of about 1.0 MPa and “cold” about 2.5 MPa. It should be emphasized here that the possibility of shortening the time of moulding sands thermal hardening in the core box is very important from an economic point of view. By obtaining the appropriate strength properties, it is also possible to consider lowering the content of binder, which will also have a positive effect on the economics of technology and will additionally increase its environmentally friendly character.

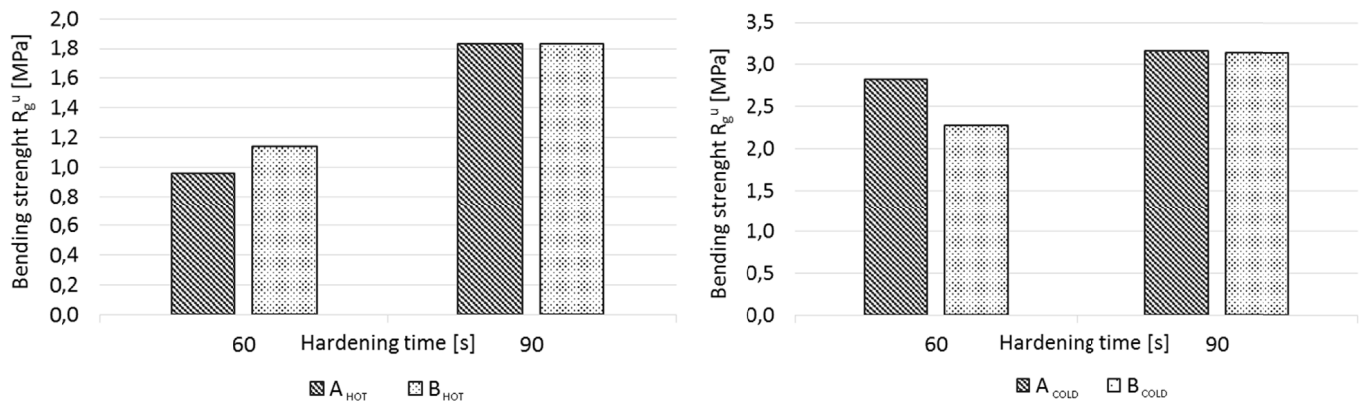


Fig. 7. The influence of hardening time and the binder type on moulding sands bending strength tested immediately and after 1 h standing out

4. Conclusions

Literature analysis and own research allowed to formulate the following conclusions:

- The use of moulding sands with water-soluble hydrated sodium silicate as a binder for ablation casting is fully justified.
- It is possible to use moulding sands with hydrated sodium silicate prepared in various technologies. However, from the point of view of ablation casting technology, the most desirable is the use of moulding sands hardened with physical factors.
- The applied binders are characterized by viscosity at a level similar to other moulding binders (e.g. organic resins). The appropriate viscosity of the binders is necessary from the point of view of the moulding sand preparing time.
- Derivatographic research in the temperature range of 20-1000°C showed moulding sands losses at the level of 0.2 and 0.5%. These losses are mainly related to losses of additives applied to the moulding sands.
- The moulding sands with both A and B binders achieve better strength properties after curing in a core box with a temperature of 140°C for 90 seconds. The strength proper-

ties of the moulding sands are comparable to the strength properties of the microwave-hardened moulding sands. The high strength properties of the tested moulding sands allow to shorten the curing time and / or to reduce the amount of used binder.

The presented results are part of a broader, ongoing research concerning mechanical and thermal behaviour of various types of moulding and core sands.

REFERENCES

- [1] P. Dudek, A. Fajkiel, T. Reguła, J. Bochenek, Transactions of Foundry Research Institute **2**, 23-35 (2014).
- [2] T. Derui, L. Haiping, 69th WFC Paper, 127-136 (2010) <http://www.foundryworld.com/uploadfile/201131449329893.pdf>
- [3] Patent US 2008/0041499 A1.
- [4] D. Weiss, J. Grassi, B. Schultz, P. Rohatgi, AFS Proceedings, (2011), <http://www.afsinc.org/files/mcdp/stories/magazine/webonly/11-057.pdf>
- [5] J. Grassi, J. Campbell, M. Hartlieb, F. Major, Mater. Sci. Forum **618** (19), 591-594. (2009).

- [6] D. Weiss, B. Schultz, P. Rohatgi, *Metal Casting Design & Purchasing*, **1-2**, 36-39, (2012).
- [7] D. Weiss, J. Grassi, B. Schultz, P. Rohatgi, *Mod. Casting*, **12**, 26-29, (2011).
- [8] P. Dudek, A. Fajkiel, K. Saja, T. Reguła, J. Bochenek, PL Patent no. 222130 B1, (2013).
- [9] J.L. Lewandowski, *Tworzywa na formy odlewnicze*, Akapit, Kraków (1997).
- [10] St.M. Dobosz, *Woda w masach formierskich i rdzeniowych*, Akapit, Kraków (2006).
- [11] K. Major-Gabryś, *Odlewnicze masy formierskie i rdzeniowe przyjazne dla środowiska*, Archives of Foundry Engineering, Gliwice (2016).
- [12] St.M. Dobosz, Patent PL 206691 B1, (2010).
- [13] K. Major-Gabryś, St.M. Dobosz, J. Jakubski, M. Stachowicz, D. Nowak, *Archives of Foundry Engineering* **12** (1), 130-134 (2012).
- [14] M. Stachowicz, K. Granat, D. Nowak, *Archives of Foundry Engineering* **11** (2), 203-208 (2011).
- [15] Hüttenes-Albertus Poland, *The characteristics card for Cordis* (2016).
- [16] ASK CHEMICALS, *The characteristics card for: Inotec HS 3000, Inotec VW P 1, Inotec Promotor VW P 5* (2104).
- [17] B. Hutera, *Archives of Foundry Engineering* **3** (9), 203-208 (2003).