www.czasopisma.pan.pl PAN www.journals.pan.pl
POLSKA AKADEMIA NAUK

ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 19
Issue 2/2019

91 – 96

10.24425/afe.2019.127122

16/2

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Microwave-Hardened Moulding Sands with Hydrated Sodium Silicate for Modified Ablation Casting

S. Puzio [a, *], **J. Kamińska** [a], **K. Major-Gabryś** [b], **M. Angrecki** [a], **M. Hosadyna-Kondracka** [a]
[a] ŁUKASIEWICZ Research Network - Foundry Research Institute, Zakopiańska 73, 30-418 Cracow, Poland
[b] AGH University of Science and Technology, Faculty of Foundry Engineering, Mickiewicza 30, 30-059 Cracow, Poland
* Corresponding author. E-mail address: sabina.puzio@iod.krakow.pl

Received 05.03.2019; accepted in revised form 16.05.2019

Abstract

The aim of this study is to demonstrate the possibility of using moulds made from the environmentally friendly sands with hydrated sodium silicate in modified ablation casting. The ablation casting technology is primarily intended for castings with diversified wall thickness and complex shapes made in sand moulds.

The article presents the effect of binder content and hardening time on the bending strength R_g^u of moulding sands with binders based on hydrated sodium silicate hardened by microwave technology. The aim of the research was to develop an optimal sand composition that would provide the strength necessary to make a mould capable of withstanding the modified ablation casting process. At the same time, the sand composition should guarantee the susceptibility of the mould to the destructive action of the ablation medium, which in this case is water.

Tests have shown that microwave hardening provides satisfactory moulds' strength properties even at a low binder content in the sand mixture.

Keywords: Ablation casting, Moulding and core sands, Environmental protection, Hydrated sodium silicate, Microwave hardening

1. Introduction

The technology of casting into sand moulds intensively cooled with water during casting solidification and destroyed when the casting solidification is over is called ablation casting. This is a relatively new technology, not used in Poland so far.

Ablation casting is mainly applicable to aluminum alloys cast in disposable moulds. The process uses sand moulds with water-based binders. The liquid alloy is poured into the casting mould, and while it is still in a liquid state, the mould is washed from a certain distance with the jet of a cooling medium (e.g. water). The casting mould is successively subject to destruction, allowing direct contact of water with the casting surface, and thus eliminating the air gap, occurring in practically all other traditional casting methods and hampering the heat flow to the outside [1-3].

The ablation casting process is intended for making castings from non-ferrous metal alloys. The aluminum alloy castings made by this technology are used in the automotive industry, e.g. by Honda in Acura NSX. The cast elements are fixed in the body, in the crumple zones, and as connectors of the frame beams. Owing to this solution it was possible to design a shorter front and rear overhang, which reduced the vehicle weight and improved the collision protection [4].

The ablation casting method was patented by Alotech in 2006. The patent describes the technology in detail, taking into account all its parameters [5-7]. The process consists in pouring the metal into sand moulds, which are intensively cooled with water during casting solidification until complete disintegration of the mould takes place. The process applies to aluminum and magnesium alloys cast into disposable moulds. The liquid alloy is poured into a sand mould with a water-based binder, and while the alloy is still in a liquid state, the jet of a coolant (water) is directed onto the mould through a set of nozzles resulting in the mould destruction [8]. The method of carrying out the process is shown in Figure 1.

This allows water to enter into direct contact with the casting surface and enables avoiding the presence of a gas gap, which occurs in classical casting methods and hampers the release of heat to the mould environment. A large temperature gradient on the cross-section of the casting facilitates the elimination of shrinkage porosity, especially in thin-walled castings. Crystallization under conditions of rapid heat dissipation results in the formation of a very advantageous microstructure, which in turn improves the mechanical properties of the finished casting [9-11].

Based on the literature data it can be stated that the properties of such a casting are comparable to or better than the properties of a casting made by pressure die casting technology [7]. Therefore ablation casting is mainly predestined for castings with complex shapes and diversified wall thickness made in sand moulds in which a lower rate of cooling can cause unfavorable grain growth [1].

Fig. 1. The ablation casting process: a - the beginning of the ablation process, b - ready casting [8]

At the Foundry Research Institute, preliminary research work has been carried out on a modified technology of ablation casting. The result is a device covered by patent application, which ensures mould degradation and controlled cooling of the casting [12]. Figure 2 shows a scheme of the device.

The method of operation of the device for moulding sand removal from the casting and its cooling according to the developed assumptions is as follows (numerical designations according to Figure 2): The sand mould (14) is placed on the work table (2) extending outside the chamber (1). The mould (14) after pouring is introduced into the chamber (1) at a controlled speed of the rotation and vertical movement of the working table (2). By lowering the working table (2), the mould (14) is introduced into the nozzle operation zone (5). The mould is broken down, the casting is cooled, and it undergoes the process of directional solidification. The slurry of moulding sand and water flows into the tank (6), in which the moulding sand from the broken mould (14) is deposited on the sieve (7), and water through the pump (8) and the filter (9) is fed by the distribution bar (11) to the nozzles (5). After breaking the mould (14), the work table (2) slides out of the chamber (1) and the ready casting is removed. An integral part of the device is a high-pressure pump from BOSCH that enables obtaining a liquid flow of 6.5 l/min at a maximum pressure of 12 MPa [12].

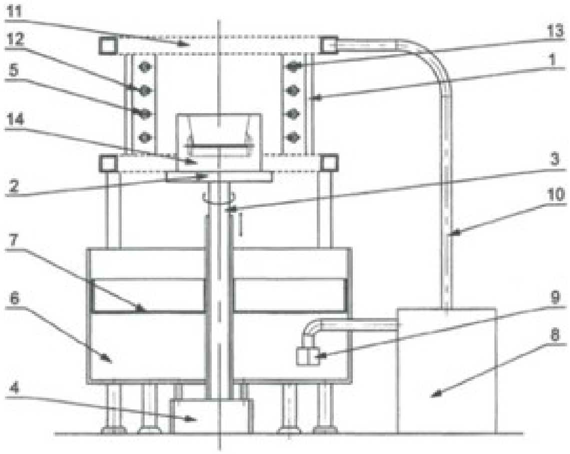

Fig. 2. Scheme of the device for ablation casting [12]

2. Own research

As part of this research work, the possibility of using moulding sands with hydrated sodium silicate hardened by dehydration in microwave hardening technology has been demonstrated.

2.1. Selection of moulding sands for disposable moulds used in ablation casting

The sand mixture used for the ablation casting process should be characterized by durability sufficient to transfer the hydrostatic pressure of the liquid metal, combined with susceptibility to the destructive effect of the cooling medium [6]. Therefore it is justified to use the hydrated sodium silicate as a binder for ablation casting technology. The binder is a water-borne inorganic compound friendly to the environment. The ecological character of moulding sands is currently the basic criterion for their development [13, 14, 15]. As a binder for foundry moulding sands, hydrated sodium silicate was first used by L. Petržela (Czech Patent No. 81931) in 1947 [13]. The hardening process was carried out by blowing the moulding sand with CO_2. Yet, to make this process feasible, up to 8 parts by weight of the binder were used. Due to the large addition of binder, the sand was characterized by very poor knocking out properties and the process has never been introduced into the large-scale industrial practice. It should be noted, however, that it gave origin to the development of cold-box technology, which until today has remained the leading technology for making foundry cores.

The breakthrough in the use of moulding sands with hydrated sodium silicate took place in 1968 together with the development of a process in which liquid organic hardeners were used to cure the binder. This allowed reducing the amount of binder to 3 parts by weight and largely improved the sand knocking out properties. Unfortunately, the use of hardeners based on acetic acid esters negatively affected the quality of reclaim obtained from these sands [16]. Additionally, the use of organic hardeners has deteriorated the process ecology.

In the case of ablation casting it seems necessary to examine the possibility of physical hardening of the sand with hydrated sodium silicate through dehydration but without the use of chemical reaction for hardening of the binder. This is important for the recovery of water used in the process and further utilization of waste water. Moreover, the elimination of the organic hardener will have a beneficial effect on process ecology during pouring of the mould with liquid casting alloy.

Earlier own research [16] confirmed the applicability of sands with hydrated sodium silicate prepared by hot-box technology for moulds used in ablation casting. Initial semi-industrial tests showed the possibility of using this technology for the ablation casting of Al alloys, while macroscopic examinations of the obtained castings did not reveal any defects [16].

An alternative solution for the physical hardening of hydrated sodium silicate is the use of microwaves. Own research [13] and literature data [17, 18] have shown that, at a lower content of binder, this technology enables obtaining moulding sands with a strength higher than the strength of the sands hardened with an ester hardener (Fig. 3).

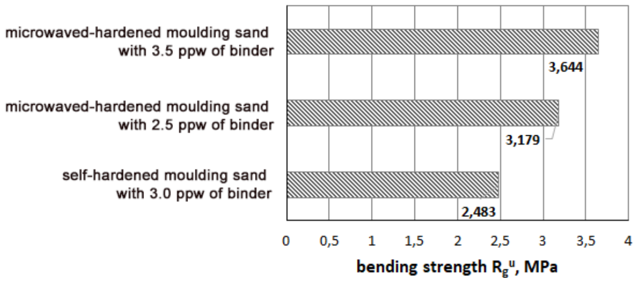

Fig. 3. Effect of hardening technology on the strength of sand with hydrated sodium silicate.

Research has shown that the technology of microwave hardening of sands with hydrated sodium silicate allows for a significant reduction of the amount of binder, while maintaining appropriate strength of the sand [18].

2.2. Research methodology

The aim of research was to develop a composition of the moulding sand with hydrated sodium silicate producing optimal strength during microwave hardening. The main task was to prepare a mould with an adequate strength using the lowest possible addition of inorganic binder to ensure fast destruction of this mould while washed with water.

The tests were carried out on sands with water glass R145 [20] and with modified binders based on hydrated sodium silicate available on the market, intended for hardening at elevated temperature. The binders were designated as A [21] and B [22]. Table 1 presents the basic physicochemical parameters of the binders used.

In all tests, the Grudzeń Las silica sand classified according to the Polish PN-85/H-11001 standard as medium (main fraction 0.20/0.16/0.315) was used.

Tests were carried out on sands with the following composition:

Silica sand	100 parts by weight
Binder R145 or A or B	1.0, 1.5, 2.0 parts by weight

Table 1.
Physicochemical properties of water glass R145 and of binders A and B [20-22].

Property / unit	Water glass R145	Binder A	Binder B
Form	water solution	water solution	water solution
Physical condition	liquid	liquid	liquid
Colour	colourless	colourless	colourless-yellow
Smell	odourless	odourless	odourless
SiO_2/Na_2O	2.4-2.6	max. 2.5	2.1-2.4
pH (at 20°C)	-	11.5-12.5	11.5-12.2
Density (at 20°C) / g/cm^3	1.45-1.48	1.36-1.47	1.34-1.39
Dynamic viscosity (at 20-25°C) / mPa*s	20-40	20-60	30-40

At the stage of the sand mixture preparation, 0.5% of distilled water was added to the base sand to ensure more even spreading of the binder. Without the addition of water, the mixture was too loose and dried up too quickly, which made the removal of samples from moulds much more difficult. Standard longitudinal samples of 22x22x172 mm were made from the sand mixture to test the bending strength. The sand was pre-compacted using an

LUZ-1, apparatus for vibratory compaction of samples. The vibration time was 20 seconds and amplitude of vibrations was 1mm. Then the samples were hardened with 800 W waves in a microwave chamber for the time of 4, 5, 6 and 7 minutes. Frequency of microwaves was 2.45 GHz.

The strength of the moulding sand was measured on an LRU-2e apparatus. The samples were tested directly after hardening (hot strength) and after 1hour hardening at ambient temperature (cold strength).

2.3. Discussion of results

The results of hot and cold bending strength tests are summarized in Tables 2-4.

Table 2.
The results of testing the average bending strength of sand containing 1.0 part by weight of binder

Hardening time [min]	**Average bending strength R_g^u, MPa**					
	Water glass R145		**Binder A**		**Binder B**	
	Hot	Cold	Hot	Cold	Hot	Cold
4	0.36	2.34	0.18	1.94	0.32	1.72
5	0.42	2.63	0.32	2.24	0	1.78
6	0.75	3.05	1.04	2.33	0.30	2.03
7	1.21	2.72	0.62	2.31	0.38	2.08

The obtained values of cold strength are shown in Figures 4-9. The value of the bending strength is an average of at least three measurements.

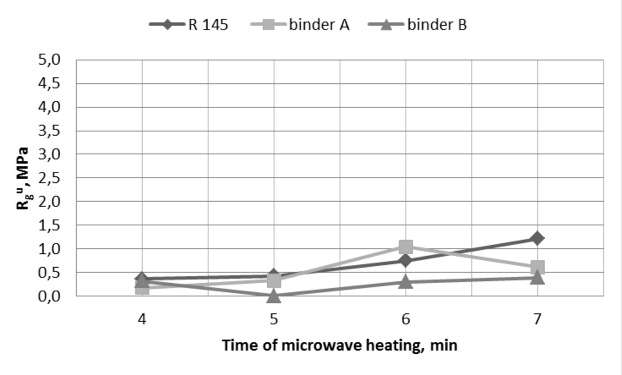

Fig. 4. Effect of hardening time on bending strength R_g^u of sand containing 1.0 part by weight of binder (measured "hot")

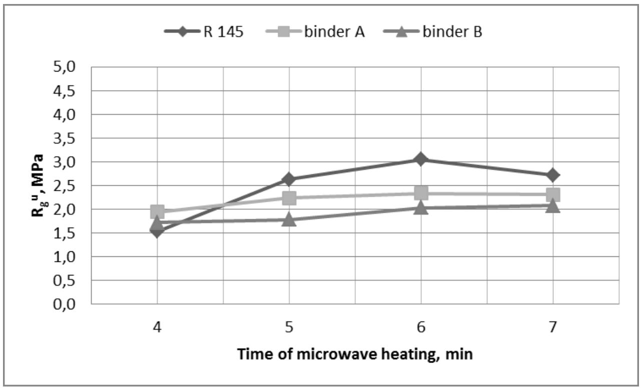

Fig. 5. Effect of hardening time on bending strength R_g^u of sand containing 1.0 part by weight of binder ((measured "cold")

In case of moulding sands containing 1.0 part by weight of binder (Fig. 4-5), the highest values of cold bending strength (Fig. 5) were obtained for the hardening time of 6 minutes. The maximum strength of 3.05 MPa was obtained in the sand with water glass 145. As regards hot bending strength (Fig. 4), practically for all hardening times, the best proved to be the sand based on water glass R145. The value of its hot bending strength was steadily increasing with the increasing time of hardening and after 7 minutes it reached 1.21 MPa. This value was twice as high as in the case of binder A and three times higher than the value obtained for binder B.

Table 3.
The results of testing the average bending strength of sand containing 1.5 parts by weight of binder

Hardening time [min]	**Average bending strength R_g^u, MPa**					
	Water glass R145		**Binder A**		**Binder B**	
	Hot	Cold	Hot	Cold	Hot	Cold
4	0.38	3.64	0	2.28	0	2.39
5	0.43	3.64	0	2.80	0.32	2.77
6	1.51	4.16	0.65	2.80	0.38	2.90
7	1.92	3.89	0.93	3.14	0.60	3.05

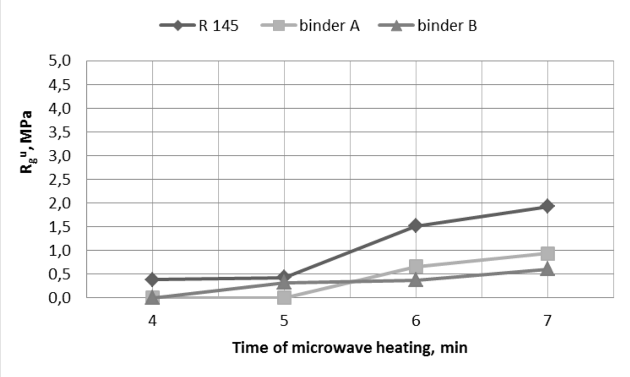

Fig. 6. Effect of hardening time on bending strength R_g^u of sand containing 1.5 parts by weight of binder (measured "hot")

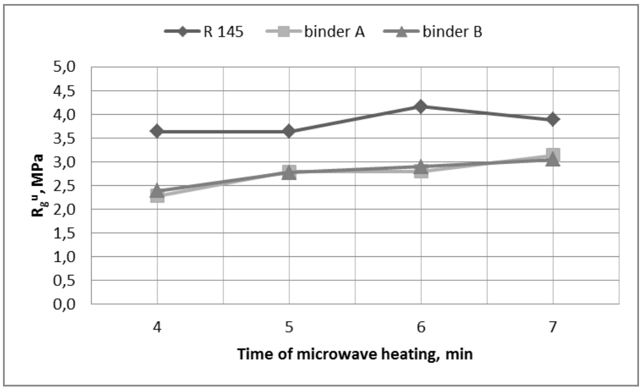

Fig. 7. Effect of hardening time on bending strength R_g^u of sand containing 1.5 parts by weight of binder (measured "cold")

In case of moulding sands containing 1.5 part by weight of binder (Fig.6-7), the highest values of cold bending strength (Fig. 7) were obtained for the hardening time of 6 minutes for moulding sand with water glass 145 and 7 minutes for moulding sands with A and B binders. The maximum strength of 4.21 MPa was obtained in the sand with water glass 145. As regards hot bending strength, practically for all hardening times, the best proved to be the sand based on water glass R145. The value of its hot bending strength was steadily increasing with the increasing time of hardening and after 7 minutes it reached 2.21 MPa. Samples of moulding sands with A and B binders measured "hot" after 4 minutes of hardening were not strong enough to be measured. Just as the sample of moulding sand with A binder after 5 minutes of hardening.

Table 4.
The results of testing the average bending strength of sand containing 2.0 parts by weight of binder

Hardening time [min]	**Average bending strength R_g^u, MPa**					
	Water glass R145		**Binder A**		**Binder B**	
	Hot	Cold	Hot	Cold	Hot	Cold
4	0.17	4.2	0	2.47	0.19	3.04
5	0.50	4.7	0	3.07	0.19	2.98
6	1.04	4.8	0.41	3.42	0.36	3.74
7	2.23	4.7	0.65	3.47	0.51	3.73

Within the investigated range of hardening times, sands containing 2.0 parts by weight of binder showed the same relationships (Fig. 8-9). The hardening time of up to 6 minutes increased the value of their strength, while further hardening had no significant effect on this parameter. Among the tested sands, the highest strength for the hardening time of 5-7 minutes had the sand based on water glass R145. The value of the strength amounted to 4.8 MPa.

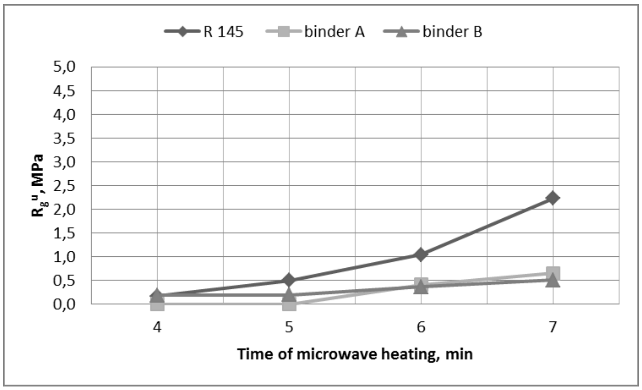

Fig. 8. Effect of hardening time on bending strength R_g^u of sand containing 2.0 parts by weight of binder(measured "hot")

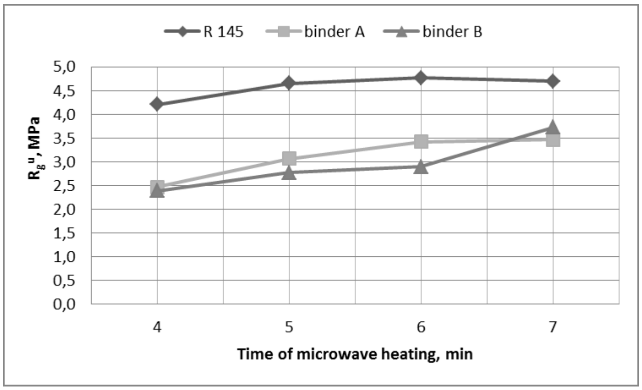

Fig. 9. Effect of hardening time on bending strength R_g^u of sand containing 2.0 parts by weight of binder (measured "cold")

3. Conclusions

Literature analysis and own research allowed formulating the following conclusions:

- It is fully justified to use moulding sands with water-soluble hydrated sodium silicate as a binder for ablation casting.
- It is possible to use moulding sands with hydrated sodium silicate prepared by 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 highest values of the bending strength were obtained for the sand with water glass R145. The strength of this sand was by even 50% higher than the strength of the sand based on binders A and B. The hot bending strength of this sand also assumed the highest value. This enabled easy removal of samples and then of moulds from the tooling directly after preparation, significantly simplifying the entire process.
- Lower strength of sands based on binders A and B may be due to the fact that these binders are intended for hardening at a temperature higher than the temperature that can be reached in the microwave chamber used for testing. In chamber like this we can reach temperature maximum 80°C

after 7 minutes of heating and the hardening temperature recommended by the manufacturers is in the range of 120-160°C for binder A and 180-220°C for binder B.

- The best strength properties by microwave hardening of samples were obtained in a time of up to 6 minutes. Longer time of hardening had no significant effect on the strength increase. Therefore, especially for economic reasons, it is not recommended to harden the sand for a longer time.

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

Acknowledgements

The article was prepared as part of the project No. LIDER/21/0125/L-8/16/NCBR/2017.

Reference

[1] Dudek, P., Fajkel, A., Reguła, T. & Bochenek, J. (2014). Research on the technology of ablative casting of aluminum alloys. *Prace Instytutu Odlewnictwa.* LIV/2, 23-35. DOI: 10.7356/iod.2014.06. (in Polish).

[2] Fajkiel, A., Dudek, P., Saja, K., Reguła, T. & Bochenek, J. (2016). Device for removing foundry sand from casting and controlled cooling of sand molds. *Dziennik Polski*. (in Polish).

[3] Dudek, P., Fajkiel, A. & Reguła, T. (2015). The Research on the Ablation Casting Technology for Aluminium Alloys. *Solid State Phenomena*. 223, 70-77. DOI: https://doi.org/10.4028/www.scientific.net/SSP.223.70

[4] Motonews: Honda NSX, https://www.motonews.pl/autoblog/43905-honda-nsx-unikalna-jednostka-napedowa.html

[5] Grassi, J.R., Campbell, J. (2008). US Patent No. 20080041499 A1.

[6] Izdebska-Szanda, I., Angrecki, M. & Palma, A. (2015) Selection of technologies for the modified ablation method of casting. *Prace Instytutu Odlewnictwa.* LV/2, 55-66. DOI: 10.7356/iod.2015.08

[7] Weiss, D., Grassi, J., Schultz, B. & Rohatgi, P. (2011). Testing the limits of ablation. Ablation of Hybrid Metal Matrix Composites. *AFS Proceedings*, 1-7.

[8] Weiss, D., Grassi, J., Schultz, B. & Rohatgi, P. (2011). Testing the Limits of Ablation. *Modern Casting*. 101/12, 26-29.

[9] Taghipourian, M., Mohammadaliha, M., Boutorabi, S.M. & Mirdamadi, S.H. (2016). The effect of waterjet beginning time on the microstructure and mechanical properties of A356 aluminium alloy during the ablation casting proces. *Journal of Materials Processing Technology.* 238, 89-95.

[10] Sandeep, Y. & Gupta, N. (2017). Ablation Casting Process – An Emerging Process for Non Ferrous Alloys. *International Journal of Engineering Technology Science and Research.* 4(4), 29-32.

[11] Bohlooli, V., Shabani Mahalli, M. & Boutorabi, S.M.A. (2013). Effect of Ablation Casting on Microstructure and Casting Properties of A356 Aluminium Casting Alloy. *Acta Metalurgica Sinica.* 26(1), 85-91.

[12] Dudek, P., Fajkiel, A., Saja, K., Reguła, T., Bochenek, J. (2013). PL Patent No. 222130 B1.

[13] Major-Gabryś, K. (2016). *Foundry molding sands and environment-friendly cores*. Wydawnictwo Archives of Foundry Engineering. Katowice-Gliwice. (in Polish).

[14] Bacanu, I.A. (2014). Modern technologies Hüttenes-Albertus: A look at the future of technology in global foundry. IVth Conference Hüttenes-Albertus Poland, 28-30 August 2014. Iława, Poland, on CD-ROM (in Polish).

[15] Holtzer M. (2012). Technologies of molding and core sand and environmental protection. IIIrd Conference Hüttenes-Albertus Poland, 20-22 May 2012 (pp. 19-40). Zakopane, Poland (in Polish).

[16] Hosadyna-Kondracka, M., Major-Gabryś, K., Kamińska, J., Grabarczyk, A. & Angrecki, M. (2018). Moulding Sand with Inorganic Cordis Binder for Ablation Casting. *Archives of Foundry Engineering*. 18(4), 110-115.

[17] Stachowicz, M., Granat, K. & Nowak, D. (2010). Effect of hardening method and structure of linking Bridges on strength of water glass moulding sands. *Archives of Foundry Engineering*. 10(2), 141-146.

[18] Pigiel, M., Granat, K., Nowak, D. & Florczak, D. (2006). The use of microwave energy in foundry processes. *Archiwum Odlewnictwa*. 21, 443-452. (in Polish).

[19] Granat K., Nowak D., Pigiel M., Stachowicz M. (2009). Comparison with companies involved in the production and processing of materials. *Sborník Vědeckych Prací Vysoké Školy Banské* Technické Univerzity Ostrava. Řada Hutnicka. 52(2), 69-74. (in Polish).

[20] Z. Ch. Rudniki SA. (2016). Offer specification of the product Nr 14/7. (in Polish).

[21] Hüttenes-Albertus Poland (2016). The characteristics card for Cordis.

[22] ASK CHEMICALS (2014). The characteristics card for: Inotec HS 3000, Inotec VW P 1, Inotec Promotor VW P 5.