www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 2020
Issue 1/2020

67 – 72

10.24425/afe.2020.131285

12/1

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

# Influence of Automatic Core Shooting Parameters in Hot-Box Technology on the Strength of Sodium Silicate Olivine Moulding Sands

**M. Stachowicz *, Ł. Pałyga, D. Kępowicz**
Department of Foundry Engineering, Plastics and Automation, Wroclaw University of Technology, ul. Smoluchowskiego 25, 50-372 Wrocław, Poland
* Corresponding author: E-mail address: mateusz.stachowicz@pwr.edu.pl

Received 16.08.2019; accepted in revised form 04.11.2019

## Abstract

The paper presents the results of preliminary research on the application of olivine moulding sands with hydrated sodium silicate containing 1.5 % wt. of binder to perform ecological casting cores in hot-box technology using a semi-automatic core shooter. The following parameters were used in the process of core shooting: initial shot pressure of 6 bar, shot time 3 s, the temperature of the core-box: 200, 250 and 300 °C and the core curing time: 30, 60, 90, 120 and 150 s. The matrix of the moulding mixture was olivine sand, and the binder of the sandmix was commercial, unmodified hydrated sodium silicate with molar module $SiO_2/Na_2O$ of 2.5. In one shot of the automatic core-shooter were formed three longitudinal specimens (cores) with a dimensions 22.2×22.2×180 mm. The samples obtained in this way were subjected to the assessment of the influence of the shooting parameters, i.e. shooting time, temperature and curing time in core-box, using the following criteria: core box fill rate, mechanical strength to bending $R_g^U$, apparent density, compaction degree and susceptibility to friability of sand grains after hardening. The results of trials on the use of olivine moulding sands with hydrated sodium silicate (olivine SSBS) in the process of core shooting made it possible to determine the conditions for further research on the improvement of inorganic hot-box process technology aimed at: reduction of the heating temperature and the curing time. It was found that correlation between the parameters of the shooting process and the bending strength of olivine moulding sands with sodium silicate is observed.

**Keywords:** Foundry, Sodium silicate, Olivine sand, Hot-box process, Core shooting

## 1. Introduction

The introduction of automation of technological processes in foundry industry is conducive to the development of specialized casting machines and equipment, which include: core shooters [1] for blowing cores. The advantage of modern core shooters is their versatility and high degree of automation, as well as, in the case of small sizes such as the LUT/c/CO2/An device, mobility. This type of device can successfully work in the following technologies: hot-box, warm-box, cold-box and warm-air processes [2, 3] or $CO_2$ [4], in the system of organic and inorganic binders [3, 5, 6]. The solutions combining the advantages of: a properly designed [1, 5, 7] shooting and venting system of the device with process modelling [8, 9], simulation [1, 10], selection and control of parameters of sandmix filling [5, 11-13], time of its storage in a core-box [3, 5] with inorganic moulding mixtures are particularly interesting.

The combination of the advantages of an automated moulding machine equipped with a system enabling full control and stabilization of the process with the technology of moulding sands with ecological inorganic type binders can be an excellent alternative to the widely used cold-box process. An example can be moulding sands with hydrated sodium silicate (sodium silicate bonded sand - SSBS) [14], which can be successfully hardened by physical [2, 5, 15, 16], chemical [17,18] and combined [19] hardening methods. The improvement of the moulding sand technology based on inorganic binders [20-26] is a response to the growing quality requirements of casts.

Among the alternatives to the quartz moulding matrix, which are not excessively expensive and have a similar bulk density, which has not been paid much attention so far, is olivine sand. Olivine sand is obtained by crushing dunite rocks. The sand grains are therefore irregular in their shape (Fig. 2). Olivine, an isomorphic mineral [27], is formed by forsterite ($Mg_2SiO_4$) and fajalite ($Fe_2SiO_4$). The forsterite/fajalite ratio in the olivine base-sand should be 9:1 because the presence of Fe compounds reduces the sintering temperature. Usually in the olivine sand mineralogical composition are elements such as: Al and Ca, less frequently Ti. The casting olivine sand is a sand-base with an even and smaller thermal expansion than quartz sand. It was found that it is possible to limit the occurrence of thermal strain phenomena by increasing the wall thickness in the measurement cores [28]. The good refractory properties of olivine sand have an influence on the scope of use of this matrix mainly in casting of cast steel. Refractory strength depends on the chemical composition, including the content of Fe compounds. Due to its lower surface wettability than quartz sand, the olivine sand-base is suitable for the production of, among other things, casting cores that are subject to high heat loads. Dilatometric studies [27] carried out at 900°C showed that olivine sand is characterized by linear expansion of 1.02%. In case of quartz sand, for the same temperature, the linear expansion is greater and fluctuates from 1.40% to 1.56%.

Hydrated sodium silicate can be used as a binder of olivine SSBS, which increases the thermal conductivity of the sandmix in relation to bentonite bonds [29]. The addition of a binder to the olivine matrix [27] should not differ from the content used for quartz SSBS.

## 2. Purpose and scope of the research

Longitudinal samples of three pieces (Fig. 1) which were produced on a semi-automatic core shooter of LUT/c/CO2/An type were used to conduct research on the influence of parameters of automatic core production in hot-box technology on the strength of olivine SSBS. The Multiserw-Morek company is the manufacturer of the core blower used in the tests. The semi-automatic operation of the core shooter required: filling a 3 $dm^3$ shot tank with fluffy moulding sand each time and collecting manually the three longitudinal samples (cores) shot in one cycle of the operator. The results of the tests will be used to determine the criterion of recommended settings of the core shooter for the production of cores from ecological olivine SSBS in hot-box technology.

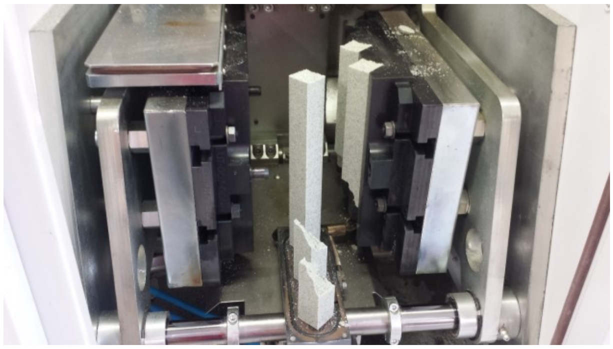
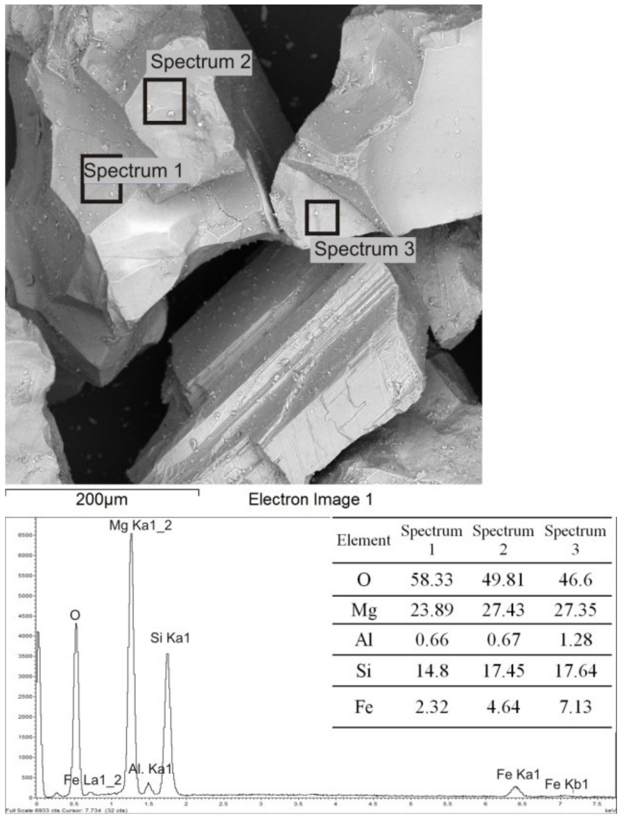


Fig. 1. View of a three-seated core-box with olivine SSBS in the shooting position. Example of unsuccessful attempt to shoot at the stage of selecting the settings of the shooter device operation

The sand-base of the investigated SSBS was a casting olivine sand LE50 from a Norwegian deposit with the chemical composition shown in Figure 2 and sieve analysis in Figure 3. The main fraction (94.62%) was collected on sieves (Table 1) with the following numbers: 0.20/0.315/0.16, which is shown in.




| Element | Spectrum 1 | Spectrum 2 | Spectrum 3 |
|---|---|---|---|
| O | 58.33 | 49.81 | 46.6 |
| Mg | 23.89 | 27.43 | 27.35 |
| Al | 0.66 | 0.67 | 1.28 |
| Si | 14.8 | 17.45 | 17.64 |
| Fe | 2.32 | 4.64 | 7.13 |

Fig. 2. Surface of olivine sand grains with marked areas (Spectrum), where element composition analysis was carried out, data in % by weight. Spectra of measurements of the intensity of the occurrence of elements were obtained from the EDS/EDX probe

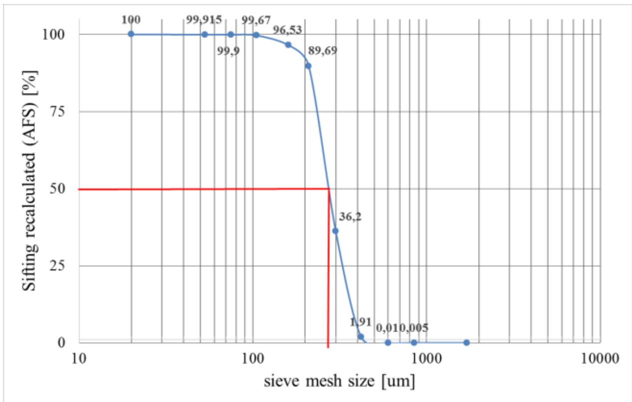


Fig. 3. Sieve analysis of the olivine matrix LE50 (Table 1)

Prepared olivine SSBS had the following composition:
-100 parts by weight of olivine LE50 sand (6000 g) shown in Table 1,
-1.0 part by weight of water, an addition wetting the olivine sand-base was used due to relatively high content of fine fractions collected on the sieves with the numbers: 0.071, 0.051 and at the bottom, whose presence was also proven by SEM observations (Fig. 2),
-1.5 parts by weight of hydrated sodium silicate type 145, from Zakłady Chemiczne Rudniki SA (Table 1).

Table 1.
Physico-chemical properties of sodium silicate used in the examined type of olivine-base moulding sands mixture

| **Binder type:** | **Molar module $SiO_2/Na_2O$** | **Oxide content ($SiO_2$ +$Na_2O$) %** | **Density (20 °C) g/cm$^3$** | **$Fe_2O_3$ max. %** | **CaO max. %** | **Dynamic viscosity min. (P)** |
|---|---|---|---|---|---|---|
| 145 | 2.5 | 41.5 | 1.47 | 0.01 | 0.1 | 1 |
| **Matrix type:** | **grain number L:** | **average grain size $d_L$** | **median a $d_M$** | **$D_{50}$** | **main fraction $F_g$ [%]** | **GG [%]** |
| LE50 | 49.8 | 0.255 | 0.326 | 0.28 | 94.62 | 87.0 |

Casting olivine sand was poured into the chamber of the ribbon mixer, water was added after starting the mixing process. The process of sand-base wetting was continued for 60 s. The addition of water effectively limited the unfavourable phenomenon of dusting during initial mixing. The olivine SSBS was mixed for 180 s after the addition of the binder type 145.

The plan of preliminary tests included the execution of several dozen series of longitudinal samples (casting cores) of dimensions 22.2×22.2×180 mm for various settings of the shooting device operation. The influence of parameters such as: shooting time, core-box heating temperature and post-shot curing time on the quality of longitudinal samples was initially evaluated in the preliminary tests. The influence of filling the chamber of the shooting tank on the filling of the core-box in the process of shooting the measuring cores was also examined.

The appropriate tests which consisted in determining the mechanical strength and quality evaluation of the samples were begun after determining the effective settings of the core shooting process.

The evaluation of mechanical strength to bending after hardening and cooling was carried out on the LRuE-2e stand supplied by Multiserw-Morek. After the cores had cooled down, they were weighed on the Ohaus PA4102CM/1 laboratory scale with an accuracy of 0.01 g. The weight of measuring cores was estimated in order to confirm the repeatability of the adopted forming process on the LUT/c/CO2/An type shooter.

The evaluation included the following results: apparent density measurements of correctly produced cores, as well as a visual assessment of the surface quality during manual manoeuvring of the cores as their susceptibility to friability of sand grains.

# 3. Results

In order to avoid the dimensional and shape defects shown in Figure 1 and Figure 4, the first steps were taken to determine the effective settings of the LUT/c/CO2/An type shooting device. The effectiveness of core production with the shooting method was tested for [30]: shot time (1.2, 1.7, 2.0, 2.5 and 3.0 s), initial shot pressure (5.0, 5.2, 5.8, 6.0, 6.1, 6.2, 6.4, 6.7, 6.9 bar) and filling the chamber of the shooting tank. At the initial stage of recognition of the influence of the settings of the automatic shooting machine on the olivine SSBS only 12 successful attempts were found, which is 42.86% of all the shots made. Among the dimensional and shape errors, the following were observed: lack of core filling and air bubbles (Fig. 4), insufficient core hardening during the attempt to remove them from the core-box (Fig. 1) as well.


Fig. 4. Example of dimensionally - shaped defects in made from olivine SSBS cores caused by inadequate adjustment of the LUT/c/CO2/An device's operating parameters

It was found on the basis of the analysis of core production effectiveness [30] that the core shooter should work with the following settings:
- shot time: 3 s,
- time after shot 4 s,
- initial shot pressure of 6 bar,
- heating temperature: 200, 250 and 300°C;

– curing time: 30, 60, 90, 120 and 150 s,
– filling the chamber of the shooting tank (c.a. 3 dm$^3$) at the level of 88%.

The influence of the core shooting parameters was observed on: bending strength after curing ($R_g^U$) and technological parameters of hardened cores of olivine SSBS.

The average results of apparent density measurements are presented in Figure 5, whereas the results of calculations of the compaction degree of properly produced measuring cores after hardening and cooling to ambient temperature are presented in Figure 6.

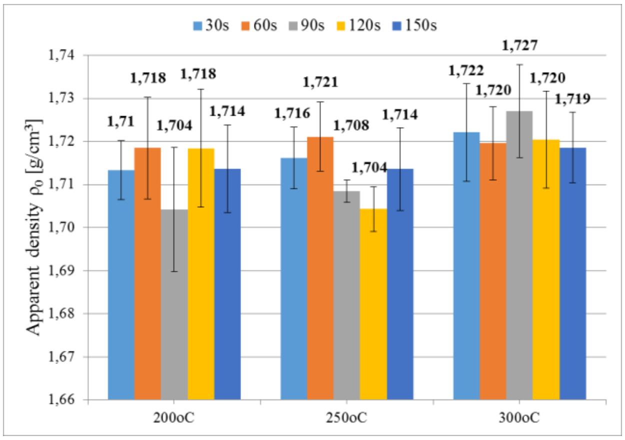



Fig. 5. Calculated apparent density of hardened olivine SSBS with different shooter parameters (temperature and the time of curing)

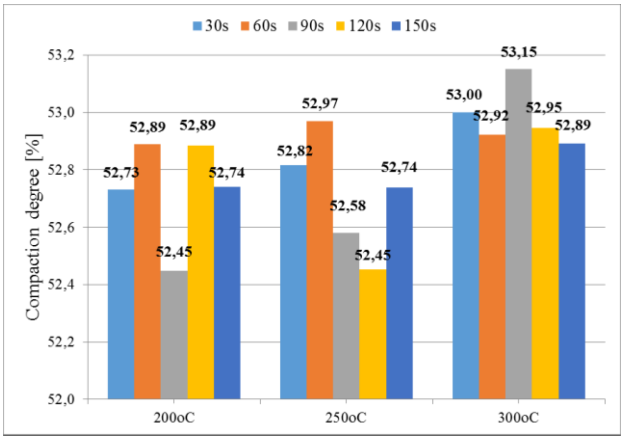



Fig. 6. Compaction degree of hardened olivine SSBS with different shooter parameters (temperature and the time of curing)

Apparent density of the examined olivine SSBS after the shooting and hardening process, measured at ambient temperature, was in the range from 1.70 to 1.73 g/cm$^3$ (Fig. 5). The determined compaction degree ranged from 52.45 to 53.15 % (Fig. 6). The obtained results of compaction degree correspond to the shares presented in the paper [31] and, as it was assumed heretofore, they exceed aftermaths obtained as a result of vibratory compaction. During the attempts to shoot with the settings: shot time 3 s, time after shot 4 s and shot pressure 6 bar, no significant defects in the construction of longitudinal shaped cores were found. A small number of small air bubbles, whose appearance is shown in Figure 7, were found in the upper part of the cores.

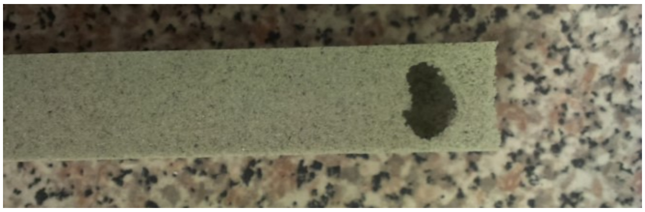


Fig. 7. View of air bubbles in the upper part of the cores, which made it possible to carry out bending strength measurements

All the examined samples, regardless of the shooting machine parameters, during manual manipulations did not show a tendency to excessive friability of sand grains.

All successful series of attempts allowed further evaluation of the influence: of the time and temperature of curing of olivine SSBS in the core-box on the mechanical strength after hardening. The results of bending strength ($R_g^U$) tests, which are established by the arithmetic mean comprised of three determinations, are presented in Figures from 8 to 10.

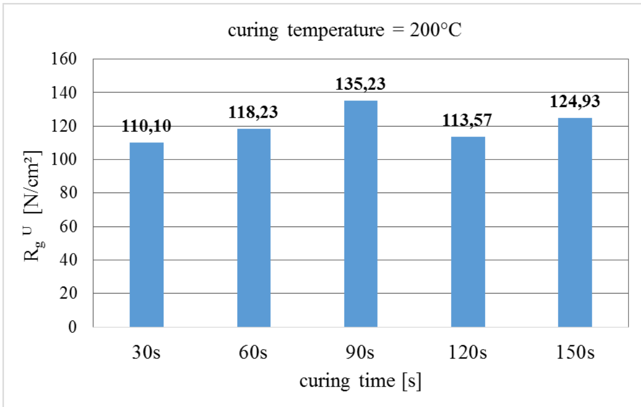



Fig. 8. Average results of the bending strength tests of cores cured at time of 30 – 150 s in temperature of 200°C

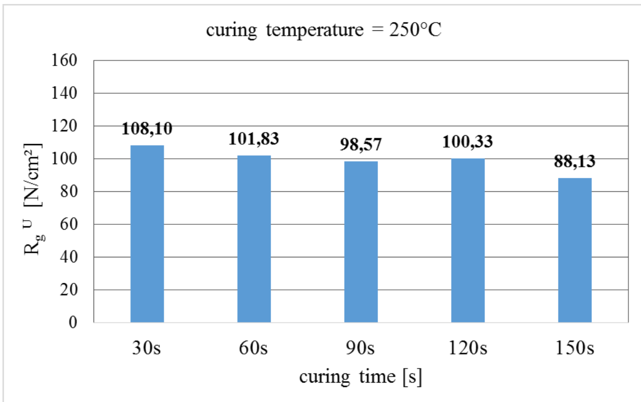



Fig. 9. Average results of the bending strength tests of cores cured at time of 30 – 150 s in temperature of 250°C

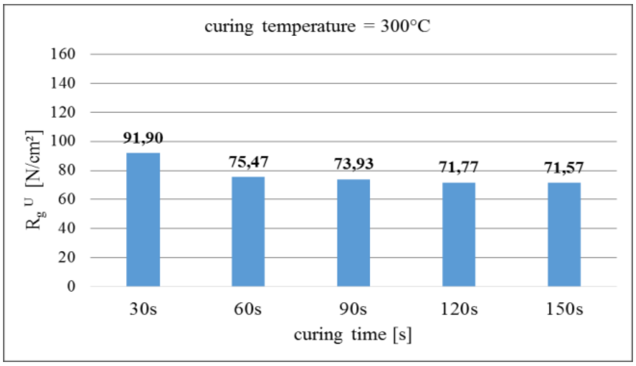



Fig. 10. Average results of the bending strength tests of cores cured at time of 30 – 150 s in temperature of 300°C

As can be seen from the comparison of Figures 8, 9 and 10, it is advantageous, in the case of olivine SSBS with binder (molar module 2.5), to use shortened curing times to 30 - 60s in core-box heated to 250 - 300°C. Increasing the core-box temperature from 250 to 300°C in comparison of the extreme series with 30s to 150s of curing time, resulted in 18.5% (250°C) and even 22% (300°C) decrease in bending strength. In the case of core-box temperature of 200°C, using shorter than 30 s of curing time may cause the risk of insufficient heating of the olivine moulding sand (Fig. 1) and its un-hardening. Furthermore there is a potential risk to prevent the cores from being removed out of the core-box.

Moreover, on the basis of the obtained results of tests of olivine SSBS it is possible to conduct a preliminary analysis (Fig. 11) of the dependence of strength on the working parameters of the shooter (curing time and temperature of core-box). The determination of this dependence will enable further prediction of mechanical parameters of the olivine-based core sandmixes.

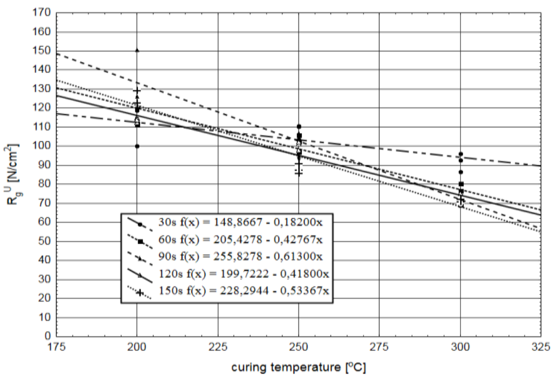



Fig. 11. Effect of curing time and core-box teperature on bending strength $R_g^U$ of moulding sand heated for 30s, 60s, 90s, 120s and 150s

Values of $R_g^U$ shown in Fig. 11 are arranged according to increasing temperature of core-box in the hot-box hardening process. Basic statistical calculations were performed using the program STATISTICA 13. For all the cases, significance level of 0.05 was accepted. Results of linear approximation of the $R_g^U$ / T (temperature of core-box) are given in Table 2.

The calculated correlation coefficients given in Table 2 indicate a good matching of the linear function between $R_g^U$ and temperature (T) in range of 200 – 300°C for all tested time of cores curing. Because of this good matching of regression values it can be assumed that cores bending strength depends on temperature of core-box in hot-box process.

Table 2.
Correlation parameters between $R_g^U$ and temperature of core-box (T) made of tested olivine SSBS

| curing time [s] | Correlation: $R_g^U$ / T | Correlation coeff. „r” | „r2” | p |
|---|---|---|---|---|
| 30 | Yes | -0.76 | 0.59 | 0.02 |
| 60 | Yes | -0.96 | 0.93 | 0.00003 |
| 90 | Yes | -0.95 | 0.91 | 0.00007 |
| 120 | Yes | -0.97 | 0.95 | 0.00001 |
| 150 | Yes | -0.97 | 0.95 | 0.00001 |

## 4. Conclusions

The susceptibility to the occurrence of dimensionally - shaped defects in the form of lack of core-box filling, un-hardened olivine SSBS samples or air bubbles is directly related to the settings of the LUT/c/CO2/An shooter, i.e.: shooting time, shooting pressure and filling the chamber of the shooting tank, which was confirmed by extensive preliminary studies of the process of shooting the cores.

The occurrence of defects in the cores is also the result of the operation of the nozzle venting system in the shot head of the blowing device [5]. Partial elimination of these defects can be achieved by a thorough analysis of each of the tested parameters of the shooting process as well as a properly conducted process of modification of the shoot-and-vent system for a specific core types.

The conducted analysis of the test results unequivocally indicates a decrease in bending strength of the cores with the increase in the heating temperature (250°C -300°C) and the time of curing (over the 30s) the olivine SSBS in the core-box.

The best mechanical properties of the tested samples were obtained from cores cured in the temperature of 200°C for 30s to 150s. The bending strength reached after cooling-down was about 110 to 135 N/cm$^2$.

The conducted research also confirmed that, at a constant shot pressure of 6 bar set points parameters of the device (shot time and temperature of the core-box) do not have a significant impact on the olivine moulding sand density.

Due to the ecological character of the olivine SSBS, it is advisable to continue work with other (with various viscosity) inorganic binder kinds and other olivine sand-base granules in order to examine the impact of these parameters on the quality of the cores produced in the automatic core shooting process.

## Acknowledgement

The research was financially supported from the grant for statutory activity No. 0401/0015/18.

## References


[1] Dańko, J. (1992). *The process of manufacturing cores and foundry molds by blowing methods. Research and theory.* Metalurgia i odlewnictwo. Zeszyt 145. Kraków: Zeszyty naukowe AGH. (in Polish).

[2] Izdebska-Szanda, I., Kamińska, J., Angrecki, M., Palma, A. & Madej W. (2016). An innovative method for the dehydration hardening of modified inorganic binders. *Archives of Metallurgy and Materials*. 61 (4), 2097-2102.

[3] Fedoryszyn, A., Dańko, J., Dańko, R., Asłanowicz, M., Fulko, T. & Ościłowski, A. (2013). Characteristic of Core Manufacturing Process with Use of Sand, Bonded by Ecological Friendly Nonorganic Binders. *Archives of Foundry Engineering.* 13(3), 19-24.

[4] Kim, E.-H., Lee, J.-H., Jung, Y.-G., Jang, J.-Ch. & Paik, U. (2013). Control of $H_2O$ generated during $CO_2$ hardening process in a casting mold. *Ceramics International.* 39, 3993-3998.

[5] Stachowicz, M., Granat, K., & Obuchowski, P. (2017). Evaluation of the Possibilities of Sodium Silicate Sands Application in Automated Hot-Box Process of Cores Shooting. *Archives of Foundry Engineering*. 17(4), 155-160.

[6] Schrey, A. (2007). The new environment-friendly binder system SOLOSIL TX for core making for the mass production of complex cast components. *Foundry Practice.* 263, 15-23.

[7] Dańko, R., & Jamrozowicz, Ł. (2017). Density distribution and resin migration investigations in samples of sand core made by blowing method. *Journal of Casting & Materials Engineering*. 1(3), 70-73.

[8] Dańko, R., Dańko, J., Burbelko, A. & Skrzyński, M. (2014). Core Blowing Process - Assessment of Core Sands Properties and Preliminary Model Testing. *Archives of Foundry Engineering.* 14(1), 25-28.

[9] Dańko, R. (2017). Validation of the Theoretical Model of Determining the Strength of Cores Made by the Blowing Method. *Archives of Foundry Engineering*. 17 (3), 27-30.

[10] Nowalczyk., Ch. (2014). Core shot simulation - as an economic and ecological asset of the casting process. *Przegląd Odlewnictwa*. 11-12, 472-474. (in Polish)

[11] Dańko, J., Zych, J. & Dańko, R. (2009). Diagnostic methods of technological properties and casting cores quality. *Archives of Metallurgy and Materials.* 54 (3), 381-392.

[12] Ni, C. J., Lu, G. C., Zhang, Q. D., Jing, T., Wu, J. J., Yang, L. L., & Wu, Q. F. (2016). Influence of core box vents distribution on flow dynamics of core shooting process based on experiment and numerical simulation. *China Foundry*, 13(1), 22-29.

[13] Ganesh, R. Chate, Bhat, R.P. & Chate, U.N. (2014). Process parameter settings for core shooter machine by taguchi approach. *Procedia Materials Science*. 5, 1976-1985.

[14] Ji, S., Wan, L., & Fan, Z. (2001). The toxic compounds and leaching characteristics of spent foundry sands. *Water, Air, and Soil Pollution*. 132 (3-4), 347-364.

[15] Stachowicz, M. (2017). The role of the densification of moulding sands with inorganic binders in the modeling of their strength obtained after microwave hardening. *Prace Instytutu Odlewnictwa*. 57 (2), 103-113.

[16] Jina, W., Zitian, F., Xiaolei, Z., & Di, P. (2009). Properties of sodium silicate bonded sand hardened by microwave heating. *China Foundry*. 6 (3), 191-196.

[17] Lewandowski, J.L. (1997). *Materials for foundry molds*. Wydawnictwo Akapit. (in Polish).

[18] Ünlü, N., & Odabaş, A. (2018). Development and Evaluation of a New Eco-friendly Sodium Silicate-Based Binder System. *International Journal of Metalcasting*, 12(4), 765-771.

[19] Huafang, W., Wenbang, G., & Jijun, L. (2014). Improve the humidity resistance of sodium silicate sands by ester-microwave composite hardening. *Metalurgija*. 53(4), 455-458.

[20] Liu, F., Fan, Z., Liu, X., Huang, Y., & Jiang, P. (2016). Effect of surface coating strengthening on humidity resistance of sodium silicate bonded sand cured by microwave heating. *Materials and Manufacturing Processes*. 31(12), 1639-1642.

[21] Mocek, J., Zych, J., & Chojecki, A. (2004). Study of erosion phenomena in sand moulds poured with cast iron. *International Journal of Cast Metals Research*. 17(1), 47-50.

[22] Izdebska-Szanda, I. & Balinski, A. (2011). New generation of ecological silicate binders. *Procedia Engineering*. 10, 887-893.

[23] Bobrowski, A., Drożyński, D., Jakubski, J., Szumera, M., Kaczmarska, K., & Grabowska, B. (2018). Thermal Deformation of Moulding and Core Sands with an Inorganic Binder Containing a Relaxation Additive. *Archives of Foundry Engineering*. 18(4), 93-98.

[24] Major-Gabryś, K. A., Grabarczyk, A. P., & Dobosz, S. M. (2018). Thermally Hardened Moulding and Core Sands with Hydrated Sodium Silicate Designed for Al Alloy Castings. *Archives of Foundry Engineering*. 18(3), 132-137.

[25] Puzio, S., Kamińska, J., Major-Gabryś, K., Angrecki, M., & Hosadyna-Kondracka, M. (2019). Microwave-Hardened Moulding Sands with Hydrated Sodium Silicate for Modified Ablation Casting. *Archives of Foundry Engineering.* 19(2), 91-96.

[26] Zaretskiy, L. (2019). Microsilica in Sodium Silicate Bonded Sands. *International Journal of Metalcasting*. 13(1), 58-73.

[27] Lewandowski, J.L. (1991). *Molding and core sands*. Warszawa: Wydawnictwo Naukowe PWN. (in Polish).

[28] Stachowicz, M., & Paduchowicz, P. (2018). The influence of heating method and the thickness of measuring cores made of olivine moulding sands with sodium silicate on the deformation tested with a DMA Hot-Distortion device. *Prace Instytutu Odlewnictwa*. 58(4), 277-293.

[29] Hess, K., Ignaszak, Z. (1980). Thermal conductivity of molding sands as a function of temperature. Międzynarodowe sympozjum – Krzepnięcie Metali i Stopów, Gliwice 6-9 XI 1980, 264-278. (in Polish).

[30] Kępowicz, D. (2018). Evaluation of the possibility of using an automatic core blower LUT for the casting cores production from olivine sand with sodium silicate. Master thesis. Wroclaw University of Technology. (in Polish).

[31] Gal, B., Granat, K., & Nowak, D. (2017). Effect of compaction degree on permittivity of water-glass containing moulding sand. *Metalurgija*. 56(1-2), 17-20.