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

ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.24425/118809

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

ISSN (2299-2944)
Volume 18
Issue 1/2018

41 – 46

8/1

Influence of the Reclaim Addition into the Matrix on the Hardening Process Kinetics of the Moulding Sand with Furfuryl Resin

Ł. Jamrozowicz *, J. Kolczyk, P. Wojtuń
AGH University of Science and Technology, Faculty of Foundry Engineering,
Reymonta 23, 30-059 Cracow, Poland,
* Corresponding author. E-mail address: ljamroz@agh.edu.pl

Received 12.07.2017; accepted in revised form 25.09.2017

Abstract

Measurements of the hardening process course of the selected self-hardening moulding sands with the reclaimed material additions to the matrix, are presented in the hereby paper. Moulding sands were produced on the „Szczakowa" sand (of the Sibelco Company) as the matrix of the main fraction FG 0,40/0,32/0,20, while the reclaim was added to it in amounts of 20, 50 and 70%. Regeneration was performed with a horizontal mechanical regenerator capacity of 10 t/h. In addition, two moulding sands, one on the fresh sand matrix another on the reclaimed matrix, were prepared for comparison. Highly-fluid urea-furfuryl resin was used as a binder, while paratoluensulphonic acid as a hardener. During investigations the hardening process course was determined, it means the wave velocity change in time: $c_L = f(t)$. The hardening process kinetics was also assessed (dClx/dt = f(t)). Investigations were carried out on the research stand for ultrasound tests. In addition strength tests were performed.

Keywords: Loose self-setting sands, Reclaim, Hardening kinetics, Ultrasound investigations

1. Introduction

Self-setting moulding sands are the ones in which all components (sand matrix, binder, hardener) are introduced, in a proper sequence, into the mixer. A hardening occurs at an ambient temperature. Presently, mainly loose sands are used in the foundry industry.

Loose, self-setting moulding sands - in dependence on the binder kind - can be divided into two basic groups [1]:

- inorganic – in which water glass is the most often used as a binder
- organic - in which phenol-formaldehyde or furfuryl resins are the most often used as binders

These moulding sands have several advantages, such as : binding at an ambient temperature, good fluidity, good knocking out properties, small binder amounts needed for these moulding sands preparation, possibility of making cores of complicated shapes (without the need of their dividing). Their negative features constitute: short working time, long time of binding, high costs of moulding sands and their harmfulness for surroundings [1, 13].

The hardening process of a moulding sand starts when a binder and hardener are in contact with each other, it means when all components are mixed in the mixer. The binding process rate of the moulding sand, it means the chemical reaction rate between a hardener and binder, depends on the reagents concentration, ambient temperature, catalyst additions or a surface development [2 - 4].

In dependence of the applied binder, hardener amount, and ambient temperature the hardening process will occur with various intensity. Thus, knowing the course and kinetics of the self-setting moulding sands hardening process is very important from the research as well as from the utilitarian point of view. However, in the industrial practice, it is necessary to determine strength properties of the given moulding sand, its service life, time of its preliminary and complete hardening as well as determining the advancement degree of the hardening process [4,5,6].

During the hardening process the moulding sand is changing its reological properties, which causes changes of the sand ability to the ultrasound wave propagation. Therefore, the ultrasound testers are adapted to measuring time of the ultrasound wave passage through the moulding sand layer. Due to that, it is possible to perform non-destructive investigations of the moulding sand binding process, both under laboratory and under industrial conditions [4,7-10,12,14].

The proceeding of the hardening process depends on: a size and shape of matrix grains, kind and amount of the used binder and hardener, and also on the moulding sand compaction degree [4,6,8,11,15].

Presently the application of the moulding sand reclamation process is the necessity, from which several benefits of the foundry practice functioning result. The most important are economic, technological and related to the environment protection, aspects [16].

The reclamation of spent moulding and core sands is defined as a treatment of spent, refractory foundry materials, allowing to reclaim at least one component - of properties similar to the fresh component properties - and its reuse for producing moulds and cores. Since as the result of the moulding sand reclamation treatment, only a matrix can be reclaimed, often the term 'reclamation of spent matrix' is used [17].

For moulding sands applied in foundry practice the mechanical, pneumatic, thermal or combined reclamation can be applied. The most widely used is the mechanical reclamation since it is relatively cheap and allows - in practice - to reclaim a matrix from every kind of a spent moulding sand. In addition, simple devices can be used and the whole process occurs at an ambient temperature. However, in case of chemically bound moulding sands the mechanical reclamation does not remove 100% of a binder from grain surfaces, which can influence the hardening process when such reclaim is added to the moulding sand. Therefore, the mechanically reclaimed matrix should be applied for the same moulding sand. That is why it is necessary to perform investigations concerning the reclaim amount influence on the hardening process and on the moulding sand properties [17].

2. Own investigations

2.1. Aim and the investigation methodology

One of the factors deciding on the hardening process course of loose self-hardening moulding sands is the kind of the applied matrix. The aim of the performed investigations was the determination of the reclaim addition influence on the hardening process kinetics. Investigations were carried out on the research stand for ultrasound tests – figure 1.

Fig. 1. Research stand, for investigating the hardening kinetics of moulding sands with chemical binders, together with the chamber stabilising a temperature [4,6] – 1 – air conditioned measuring chamber; 2– pneumatic servo-motor; 3– ultrasound heads; 4– sample of the tested moulding sand; 5– suspended table with an open bottom; 6– control valve of a servo-motor;

2.2. Kinds of the performed investigations

For the moulding sand preparation a highly fluid urea-furfuryl resin in amount of 0.9 parts by weight for 100 parts by weight of sand, was used as a binder. As a hardener paratoluensulphonic acid was applied in amount of 30% in relation to resin.

The high-silica sand, Sibelco BK4 „Szczakowa" of the main fraction FG 0.20/0.32/0.40 was used as the moulding sand matrix. FG = 89,2%, The reclaim obtained from moulding sand on the BK4 sand matrix, was added to the matrix. Main fraction of reclaim FG 0.2/032/040 and FG = 85.9%. Reclaim grain d_L=0,264 mm. The reclamation was performed by means of the mechanical horizontal reclaimer of the output of 10 t/h. The loss on ignition (LOI) of reclaim was 2,4%. The reclaimed material addition was equal 20, 50 and 70%. Two moulding sands were prepared for comparison, it was the moulding sand on the matrix of 100% of fresh sand and another one on 100% of the reclaim.

During tests the wave velocity c_L = f(t) as well as the process kinetics dc_{Lx}/dt = f(t) was determined. In addition, the moulding sand tensile strength was determined by the Brasilian method. Investigations were carried out at a constant ambient temperature being 25°C.

2.3. Hardening process course

Figure 2 presents wave velocity changes during the moulding sand (on the matrix of 100% of fresh sand) hardening process. Two periods can be determined when analysing this course. The first period is very short, and the wave velocity obtains 1200 [m/s] after app. 30 minutes. It can be assumed, that the time after which the wave velocity reaches 1200 [m/s] is the time of the preliminary hardening of the moulding sand. After that time, the moulding sand obtains enough strength and the pattern can be removed without a fear that the mould cavity will be damaged. In the second period the hardening process is not so fast and due to this changes of the wave velocity are not so intensive. After 6 hours of testing the moulding sand hardening process C_L value equals nearly 1500 [m/s], while after 24 hours 1560 [m/s].

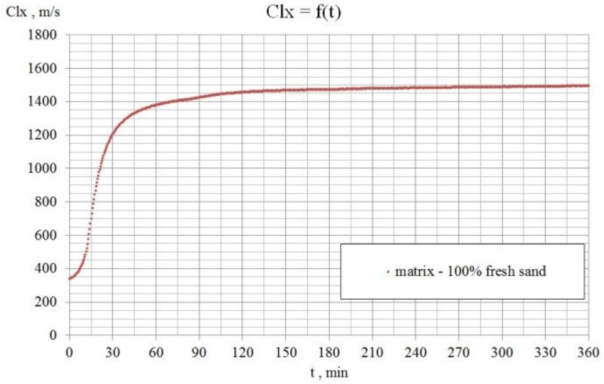

Fig. 2. Changes of wave velocity in time for moulding sand with the matrix of 100% of fresh sand. Investigations performed at a temperature of 25^{o}C

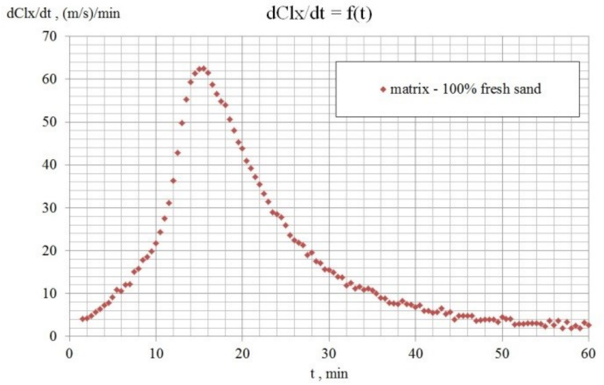

Fig. 3. The hardening process kinetics for moulding sand with the matrix of 100% of fresh sand. Investigations performed at a temperature of 25^{o}C

Figure 3 presents the hardening process kinetics, it means the speed of the wave velocity changes in time. Two parameters can be determined from the diagram, the maximum value of the process speed changes, being 64 (m/s)/min, and the time after which this value is reached (in this case it is 15 minutes). It is assumed that this time determines the moulding sand lifespan.

The analogous waveforms, it means changes of the wave velocity during the moulding sand hardening process and its kinetics - for moulding sands on the matrix being the mixture of the fresh sand and the reclaim- are presented in figures 4 – 9:

80% of fresh sand + 20% of reclaim (Fig. 4-5),
50% of fresh sand + 50% of reclaim (Fig. 6-7),
30% of fresh sand + 70% of reclaim (Fig. 8-9).

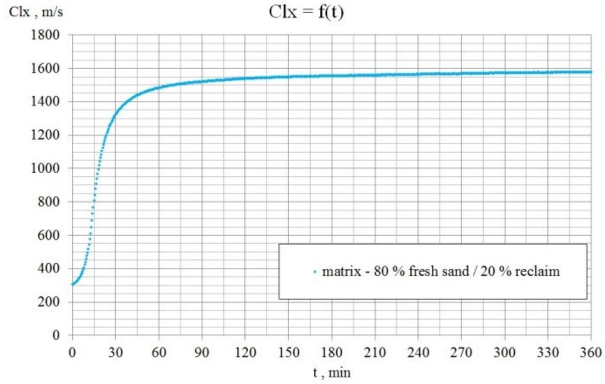

Fig. 4. Changes of wave velocity in time for moulding sand with the matrix of 80% of fresh sand and 20% reclaim. Investigations performed at a temperature of 25^{o}C

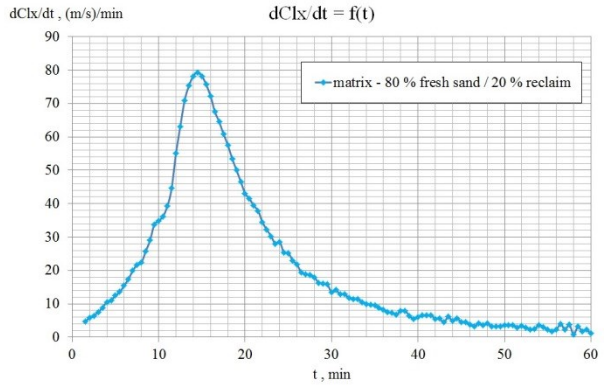

Fig. 5. The hardening process kinetics for moulding sand with the matrix of 80% of fresh sand and 20% reclaim. Investigations performed at a temperature of 25^{o}C

The hardening process course is in each case similar to this process course for the moulding sand on the basis of the fresh sand matrix. However, certain differences can be noticed, especially in the intensity of the process. Along with an increase of the reclaim content the preliminary hardening time becomes shorter and shorter. Thus, for the moulding sand containing 20% of the reclaim the wave velocity of 1200 [m/s] is obtained after 23.5 minutes, for the sand containing 50% of the reclaim after 20 minutes, while for the sand containing 70% of the reclaim after 18 minutes. It means, that the reclaim addition positively influences the preliminary hardening time. In turn, after 6 hours of the hardening process the wave velocity of the moulding sand containing 20% of the reclaim equals 1570 [m/s], and is higher than of the moulding sand not containing the reclaim. Each additional increase of the reclaim content in the moulding sand matrix causes that the wave velocity after 6 hours of binding is lower and lower. For the moulding sand containing 50% of the reclaim it equals 1524 [m/s], while for the sand containing 70 % of the reclaim 1452 [m/s]. The similar situation occurs in case of wave velocity after 24 hours of binding. It means that for the moulding sand containing 20% of the reclaim C_L is higher than for the sand without the reclaim and equals 1643 [m/s], while for the sand with 50% of the reclaim C_L equals 1577 [m/s] and for the sand with 70% of the reclaim it equals 1503 [m/s].

On this basis, it can be assumed that 20% of the reclaim addition to the moulding sand matrix will improve the moulding sand strength – higher wave velocity. On the other hand, further increasing of the reclaim content in the matrix will cause a decrease of the moulding sand strength. At high reclaim contents, such as 70%, the moulding sand strength will be lower than for the sand containing fresh components.

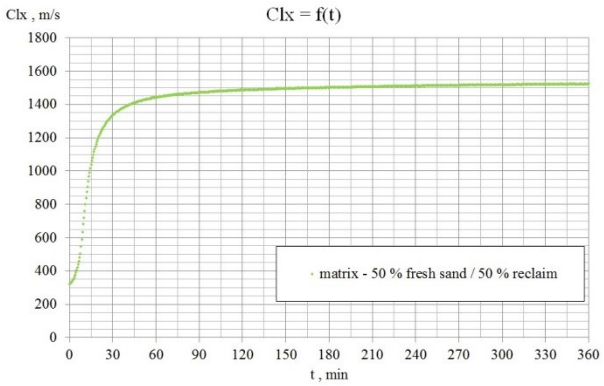

Fig. 6. Changes of wave velocity in time for moulding sand with the matrix of 50% of fresh sand and 50% reclaim. Investigations performed at a temperature of 25°C

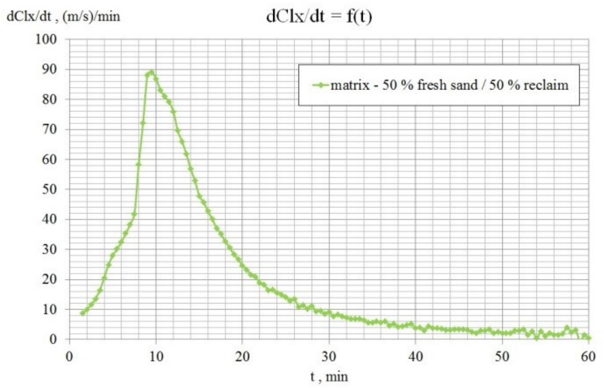

Fig. 7. The hardening process kinetics for moulding sand with the matrix of 50% of fresh sand and 50% reclaim. Investigations performed at a temperature of 25°C

Comparing the kinetics of moulding sand binding processes (Fig. 5,7,9), it can be noticed that the reclaim addition into the moulding sand causes that the moulding sand livespan, it means the time after which the kinetics achieves the maximum value, decreases when the reclaim content increases, while the speed of the process changes increases. Thus, for moulding sands containing 20%, 50% and 70% of the reclaim in the matrix, the moulding sand lifespan equals 14.5 min, 9.5 min and 7.5 min, respectively. The moulding sand lifespan decrease with the increase of the reclaim content in the matrix is disadvantageous. A short lifespan means a short time when the moulding sand is suitable for forming due to having the optimal technological properties (among others a good strength and low sand friability).

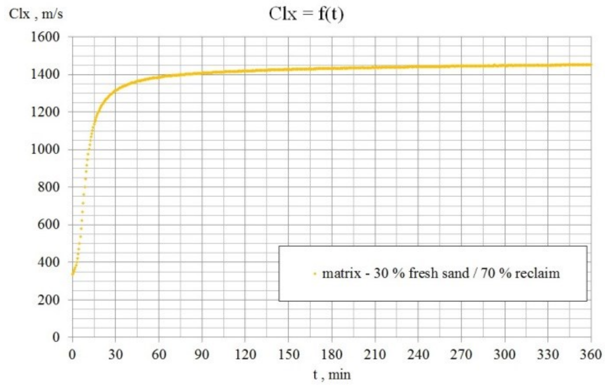

Fig. 8. Changes of wave velocity in time for moulding sand with the matrix of 30% of fresh sand and 70% reclaim. Investigations performed at a temperature of 25°C

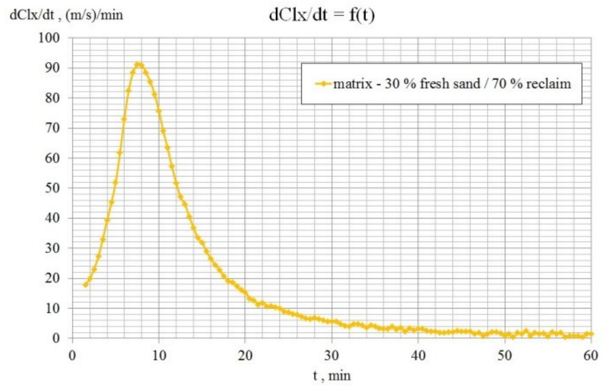

Fig. 9. The hardening process kinetics for moulding sand with the matrix of 30% of fresh sand and 70% reclaim. Investigations performed at a temperature of 25°C

In order to have the total image of the influence of the reclaim addition into the matrix on the moulding sand hardening process, investigations were performed also for the sand which matrix contained 100% of the reclaim. The results are shown in figure 10 and 11. When analysing the hardening process diagram (Fig. 10) it can be noticed, that the time after which the wave velocity reaches 1200 [m/s] equals only 15 minutes, it means is twice shorter than for the moulding sand prepared on the fresh sand matrix (30 minutes). On the other hand, the wave velocity after 6 hours of moulding sand hardening equals 1350 [m/s] and after 24 hours 1397 [m/s] and is approximately by 150 [m/s] lower than of the moulding sand prepared on the fresh sand matrix, which probably will cause much lower moulding sand strength. Significant differences are also observed in case of the hardening process kinetics (Fig. 11). The lifespan of the moulding sand on the matrix containing 100% of the reclaim equals only 2.5 minutes and is 6 times shorter than the lifespan of the moulding sand on the fresh sand matrix, which equals 15 minutes. So short lifespan is unfavourable since the moulding sand can be friable and can cause sand holes in castings.

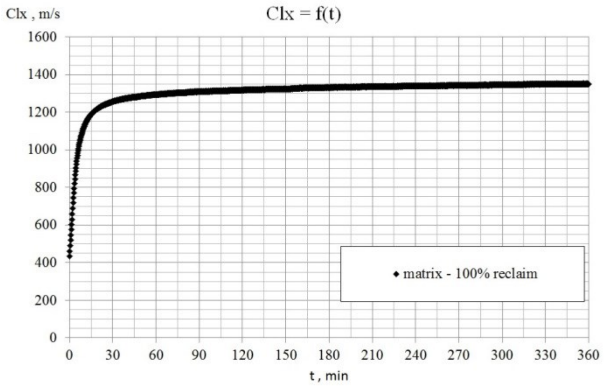

Fig. 10. Changes of wave velocity in time for moulding sand with the matrix of 100% of reclaim. Investigations performed at a temperature of 25^{o}C

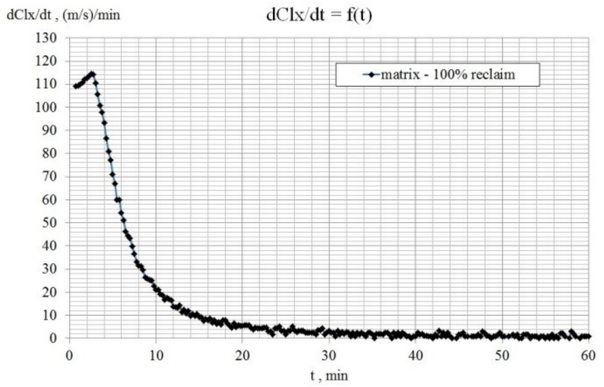

Fig. 11. The hardening process kinetics for moulding sand with the matrix of 100% of reclaim. Investigations performed at a temperature of 25^{o}C

For a better visualisation of the influence of the reclaim additions on the moulding sand hardening process the comparison of the hardening process courses (Fig. 12) and these processes kinetics (Fig. 13) - for various reclaim contents in the matrix - are shown. The hardening process courses shown in figure 12, are after 24 hours, to be able to compare wave velocities after 24 hours.

The influence of the reclaim addition in the matrix on the moulding sand tensile strength, measured by the Brasilian method after 1, 2 and 24 hours of the moulding sand hardening, are shown in figure 14. It can be noticed when analysing this diagram, that the moulding sand strength measured after one and two hours of hardening increases when the reclaim content increases. However, in the case of measuring the moulding sand tensile strength after 24 hours of its hardening, the highest strength was obtained for the moulding sand containing 20% of the reclaim in the matrix. Further increasing of the reclaim content caused the strength decrease. This strength decrease is probably caused by the fact that together with the reclaim addition the hardener content increases causing accelerations of the binding process. A faster binding process means the lack of relaxation of stresses occurring during the resin hardening. Due to that, bridges joining matrix grains - formed during the moulding sand hardening - are breaking.

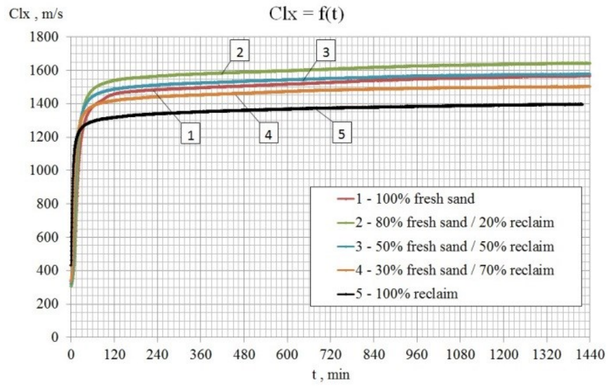

Fig. 12. Comparison of changes of wave velocity in time for moulding sand with different contents of reclaim matrix Investigations performed at a temperature of 25^{o}C

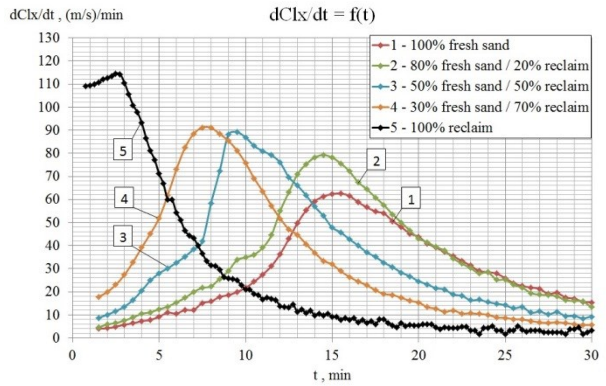

Fig. 13. Comparison of the hardening process kinetics for moulding sand with different contents of reclaim matrix. Investigations performed at a temperature of 25^{o}C

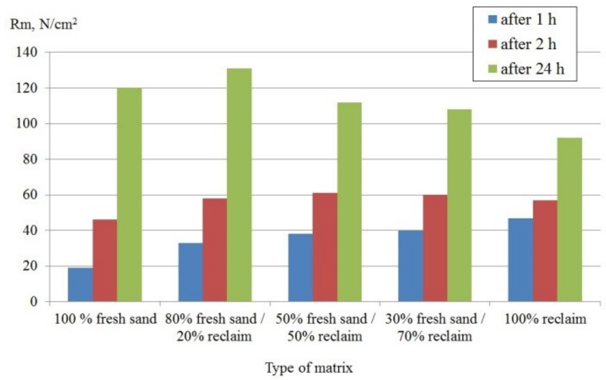

Fig. 14. The influence of the reclaim addition in the matrix on the moulding sand tensile strength after 1, 2 and 24 hours of the moulding sand hardening. Investigations performed at a temperature of 25^{o}C

3. Summary and conclusions

The written below conclusions can be formulated on the basis of the performed investigations.

- Application of the ultrasound technique provides the possibility of the continuous monitoring of the moulding sand binding process.
- The determination of the wave velocity courses Clx = f(t), and the process kinetics dClx/dt = f(t) allows to determine - in a simple way -the most important technological parameters, such as: moulding sand lifespan, time of the preliminary binding, and time after which the mould can be poured with liquid metal.
- After a regeneration process on the grains are not removed hardener particles, which accelerates the bonding process the mass on a mixture of the matrix made of fresh sand and reclaimed
- Together with the reclaim content increase in the moulding sand matrix the time of the preliminary binding, it means the time after which the pattern can be taken out from the mould without its destruction, decreases from 30 minutes (for the moulding sand on the fresh sand matrix) to 15 minutes (for the moulding sand on the reclaimed matrix).
- The reclaim addition into the moulding sand matrix has an unfavourable effect, since when this addition increases the moulding sand lifespan decreases from 15 minutes (for the moulding sand on the fresh sand matrix) to 2.5 minutes (for the moulding sand on the reclaimed matrix).
- The highest moulding sand tensile strength, after 24 hours of hardening, was obtained when the reclaim content in the matrix was equal 20%. Higher reclaim amounts in the matrix resulted in decreasing of the moulding sand strength.

Acknowledgements

The research was performed within the project 11.11.170.318 zad.4

References

[1] Lewandowski, J.L. (1997). *Molds for molds*. Kraków: Wydawnictwo Akapit. (in Polish).
[2] Staronka, A. (1994). *Physical chemistry*. Kraków: Wydawnictwa AGH. (in Polish).
[3] Zych, J. (2002). The setting kinetic of moulding sands with water glass. *Acta Metallurgica Slovaca*. 8(2), 93-98.
[4] Zych, J. (2007). *Synthesis of ultrasound technology applications in kinetics analysis of selected processes occurring in molding materials*. Cracow: Uczelniane Wydawnictwa Naukowo-Dydaktyczne. Seria: Rozprawy i Monografie nr 163. (in Polish).
[5] Zych, J. (2001). The influence of temperature on the setting kinetics of moulding sands with chemical binders. *Archives of Mechanical Technology and Automation*. 21(1), 161-169.
[6] Zych, J. (2002). The new non-destructive method of the control of the quality of the elements of forms executed from moulding sand with chemical binder. *Archives of Foundry* 3(5), 132-139 (in Polish).
[7] Deputat. J. (1996). New ultrasonic materials testing techniques. *Solidification of Metals and Alloys*. 26, 101-110. (in Polish).
[8] Zych, J. (2007). Das Verhalten chemisch gebundener Formstoffe unter wechselnden Umgebungsbedingungen — [Behaviour of moulding sand with chemical binders in changeable weathers conditions]. *Giessereipraxis*. Jg. 58 H. 1-2, 22-28.
[9] Dańko, J. & Zych, J. (2002). Non-destructive testing of cores for the assessment of evenness of mass densities and determination of strength distribution and permeability. *Archives of Foundry*. 3(5), 132-139. (in Polish).
[10] Jamrozowicz, Ł. & Zych, J. (2010). Forms and cores of rapid-setting masses - Determining the speed of movement of the hardening front. *Archives of Foundry Engineering*. 10(spec.2), 173-176. (in Polish).
[11] Jamrozowicz, Ł. & Zych, J. (2010). Advancement of the hardening front in forms and cores made of quickly bonding composites - ultrasonic analyses. *Archives of Metallurgy and Materials*. 55(3), 963-968.
[12] Jamrozowicz, Ł. & Zych, J. (2011). The change of the gas pressure in cores made in cold-box technology during their hardening. *Archives of Foundry Engineering*. 11(4), 204-208.
[13] Bieda, S. (2006). Production of molds and cores using Hüttenes-Albertus cold hardened resin resins. *Przegląd Odlewnictwa*. 7-8, 324-329. (in Polish).
[14] Zych, J. (2003). Novo método ultra-sonico de monitoração do processo de cura — [The novel ultrasonic mothod of monitoring the setting process of moulding sands with chemical binders]. *Fundição e Serviços*. 14(128), 146-156.
[15] Zych, J. (2000). Prüfen von kunstharz- und wasserglasgebundenen Formsanden mit der Ultraschallmethode — [Ultrasonic testing of moulding sands with resins and water-glass]. *Giesserei-Erfahrungsaustausch*. 4, 193-196.
[16] Bushby, A.D. (1994). The disposal of used foundry sand – future prospects. *The Foundryman*. p. 68.
[17] Dańko, J, Dańko, R., Łucarz, M. (2007). *Processes and devices for regeneration of worn molded matrix*. Cracow: Wydawnictwo Naukowe AKAPIT. (in Polish).