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INFLUENCE OF THE GAS DOSAGE METHOD ON PRESSURE CHANGES AND TECHNOLOGICAL PROPERTIES OF CORE SAND USED IN THE TECHNOLOGY RESOL-CO_2

WPŁYW SPOSOBU DOZOWANIA GAZU NA PRZEBIEGI ZMIAN CIŚNIENIA I WŁAŚCIWOŚCI TECHNOLOGICZNE MAS STOSOWANYCH W TECHNOLOGII RESOL-CO_2

The results of gas pressure measurements in intergranular spaces of fast-setting sands hardened by active gaseous factor are presented in the paper. The research stand and the measuring methodology are described. Investigations concern the determination and recording gas pressure changes in the core sand along the hardened core, in three measuring points. The hardening gas was introduced both in a continuous and impulse way (gas-pause) at a constant pressure. The determined pressure changes of the active gas, which takes part in the chemical reaction of the hardening process, are compared with pressure changes of the neutral gas. The influence of the impulse way of a gas dosage on the core sand strength properties is presented as well as methods of limiting the active gas consumption are shown.

Keywords: fast-setting sands, pressure measurements, impulse gas dosage, moulding sand strength

W artykule zaprezentowano wyniki pomiaru ciśnienia gazu w przestrzeniach międzyziarnowych dla mas szybkowiążących utwardzanych aktywnym czynnikiem gazowym. W pracy przedstawiono stanowisko pomiarowe, a także opisano metodykę pomiarową. Badania dotyczą wyznaczenia i rejestracji przebiegów zmian ciśnienia gazu w masie po wysokości utwardzanego rdzenia w trzech punktach pomiarowych. Gaz utwardzający był wprowadzany w sposób ciągły i pulsacyjny (gaz-przerwa) o stałym ciśnieniu. Wyznaczone przebiegi zmian ciśnienia dla gazu aktywnego, biorącego udział w reakcji chemicznej procesu utwardzania, porównano z przebiegami zmian ciśnienia dla gazu obojętnego. Przedstawiono wpływ impulsowego sposobu dozowania gazu na właściwości wytrzymałościowe masy formierskiej, ponadto zaprezentowano sposoby ograniczenia zużycie gazu aktywnego.

1. Introduction

Production of foundry cores of fast-setting sands by applying the process in which the hardening (binding) of core sands with chemical binders is obtained by means of blowing an active gas (properly selected for the applied binder) through the thickened sand, dominated in the last years other core production technologies. However, an excessive consumption of an active gas – too long time of gas dosage – is a weak element of this technology. A core sand is a porous – grained medium. A gas flow through such medium is relatively poor known, and difficult for description especially when a gas flowing through a core sand is reacting with the binder. Determination of pathways of active gas pressure changes in a core sand will allow for better understanding of its hardening process, which – in turn – will enable to determine the optimal time of a gas dosage into a core box, limiting its consumption.

In the world literature, there is a lack of a mathematical model describing a gas flow through a grained, porous medium such as a core sand. Kaczmarek [1,2] presents the mathematical model, of the gas flow (penetration) through a porous rocky medium. Mathematical description of the gas flow through highly porous graphite matrices and its verification is given by Biloe and Mauran [3]. In turn, Claisse et al. [4], Lafhaj et al. [5], Gardner et al. [6], Finsterle et al. [7] and Zeyanaly-Andabily et al. [8] present, in their works, models of the gas flow through concrete, limestone or rocks. However, due to the assumptions and process conditions, the proposed mathematical models can not be applied for the gas flow through the core sand, thickened in the core box.

The scheme of the laboratory stand for theoretical considerations of the gas flow through the porous medium is presented in Fig. 1.

$$\frac{\partial \mathbf{p}}{\partial \mathbf{t}} - \frac{\mathbf{k}}{\varepsilon\mu} * \frac{\partial}{\partial \mathbf{x}}\left(\mathbf{p} * \frac{\partial \mathbf{p}}{\partial \mathbf{x}}\right) = \mathbf{0} \tag{1}$$

where: p – gas pressure in a moulding sand; ε – moulding sand porosity; k – core sand permeability; μ – dynamic viscosity of a gas.

As the result of theoretical considerations equation 1 was developed which, after the boundary conditions determination, can be used for modelling pressure changes in a sample. The presented equation is correct for inert gases, it means

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for gases not taking part in the sand hardening process. In case of active gases, consumed in the sand hardening process, the model describing gas pressure changes during its flowing through the core sand is complicated, and much more difficult for the development.

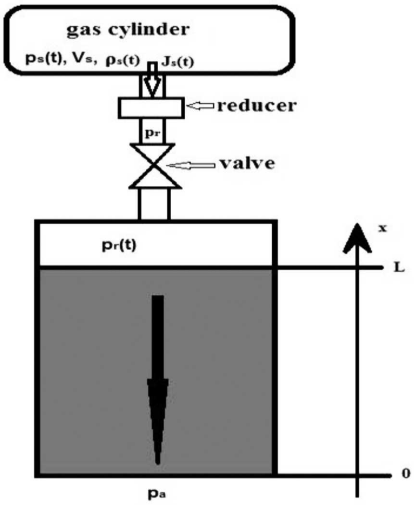

Fig. 1. Scheme of the stand for theoretical considerations of the gas flow through the porous medium [10]

2. Own investigations

2.1. Purpose and methodology of investigations

The purpose of the performed investigations was to find out the pressure distribution during the active gas flow through the thickened core sand, during its hardening process. In addition, the influence of the impulse way of a gas supply on the hardening process and pressure changes inside the hardened core, was determined.

Figure 2 presents the stand for testing gas pressure changes in the core box.

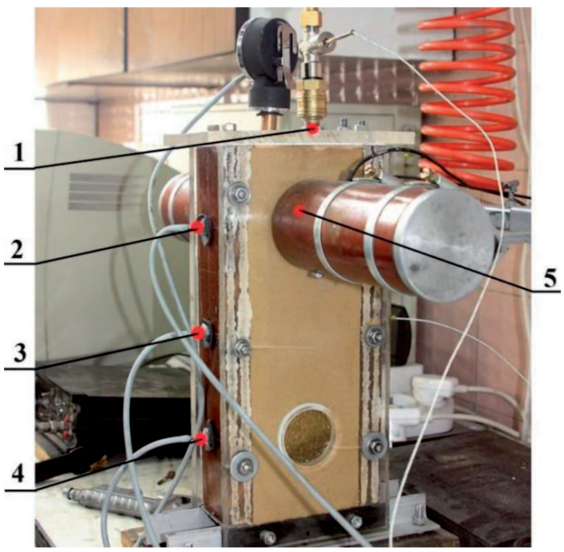

Fig. 2. Stand for testing gas pressure changes in the core box (view of the core box); 1 – place of a gas introduction into the core box; 2,3,4 – pressure sensor, measuring point 1,2,3; 5 – ultrasound head [10]

The gas was dosed from the gas cylinder via the heater, reducer and electric valve. The electric valve was coupled with the control system allowing for the impulse gas dosage. Changes in a gas pressure were recorded in a continuous way, simultaneously in all measuring points. The results were stored in the computer. In addition, the influence of the way of gas dosage on the core sand strength was determined.

Moulding sands on matrices of high-silica sand, 'Szczakowa' of an average grain diameter d_L = 0.24 mm were subjected to tests. Phenol-formaldehyde resin, resol type, added in amount of 2.5%, was used as a binder. Cores were blown by CO_2 of a pressure of 0.25 atmosphere.

2.2. Gas pressure distribution in the core box during the moulding sand hardening

Figures 3 present pressure changes inside the mould during the core sand hardening process. Pressure recorded by sensors (**Δp**) is „de facto" a difference between a pressure inside the core box in intergranular spaces (**p_w**) and a pressure in the surroundings (**p_0**).

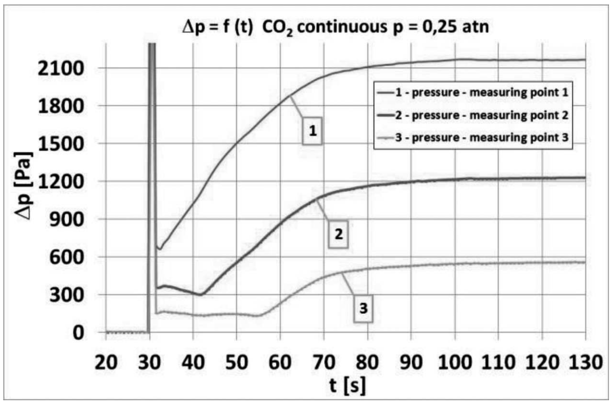

Fig. 3. Pressure changes pathway of the hardening gas (CO_2) in the tested core during the core sand hardening in the core box

Gas was not introduced into the core box in the first 30s. Thus, the pressure inside the core box was equal the pressure outside and the measured overpressure equalled 0 (Δp = 0). The hardening gas dosage started in the 30th s. A pressure increase can be seen in the diagram. From this moment the hardening process starts. The gas overpressure in the core box is not constant. In point 1, from the 30th s, a gradual increase of overpressure is seen to the 90th s, when it stabilizes. During an overpressure increase the hardening process of the core sand layer occurs. The gas amount supplied in the time unit is the same, since the dosed gas pressure is constant. During the hardening process, a part of the supplied gas reacts with a binder – is consumed. As a result the initial overpressure value is much lower than in the moment of the complete core hardening. This overpressure increase is not uniform. The character of changes is very similar to the core sand hardening recorded by ultrasound technique [9,10]. In measuring points 2 and 3 the pressure changes are similar. A gradual overpressure increase is also observed, the only difference being delays of 13 and 26s. in starting these increases in measuring points 2 and 3, respectively. Delays are related to shifting of the core sand hardening front. In the first place the layers being the closest to the gas dosage surface are hardened – point 1. As a result of the hardening reaction a majority of gases is consumed and only its small amount reaches the successive layers causing a small overpressure. In addition, this hardening gas 'pushes out' air from intergranular spaces and the recorded overpressure is probably caused by the 'pressed' air layer.

In the case of neutral gas – argon, the overpressure obtained during gas flowing through the moulding sand is practically constant, because argon is not participating in the hardening process – is not consumed [10].

By analysing the character of pressure changes it is possible to determine the end of the core sand hardening process. When the overpressure in the given layer stabilizes it means that the hardening process is finished. By observing the gas overpressure changes in the moulding sand layer, which is near vents (measuring point 3) it is possible to determine the dosage time needed for hardening the whole core and by that to limit the excessive gas consumption.

Figures 4 – 5 present pressure changes pathways in the core box during the core sand hardening, when the dosed gas was cyclically introduced, alternately: 1s of a dosage followed by 1s of not dosage [gas-pause 1s-1s]. Changing the way of the gas introduction is aimed at limiting its consumption and at improving technological properties including the hardened core sand strength.

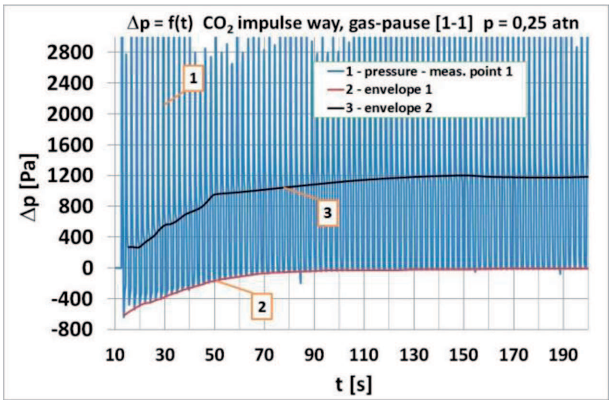

Fig. 4. Pressure changes pathway of the hardening gas during the core sand hardening in the core box – measuring point 1. Impulse gas dosage: gas-pause [1s-1s]

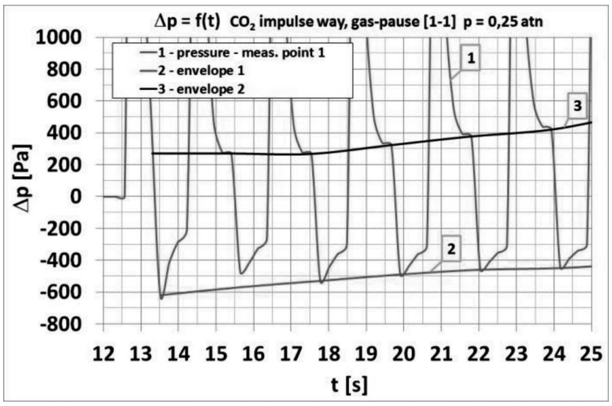

Fig. 5. Pressure changes pathway of the hardening gas during the core sand hardening in the core box – measuring point 1 – several cycles. Impulse gas dosage: gas-pause [1s-1s]

Two additional curves were introduced in Figure 4, which presents the pressure change in measuring point 1. As the result of a gas-pause pulsation as well as the hardening reaction during which a gas (CO_2) is consumed, both overpressure and under pressure occur in intergranular spaces. Envelope 1 presents under pressure changes, while envelope 2 presents overpressure changes. In order to explain the effect of overpressure and under pressure occurrence several impulse cycles of the core sand hardening are presented in Fig. 5.

Impulse gas dosage started in 12.3s. The first impulse fills intergranular spaces with CO_2, which starts the core sand hardening reaction. The second impulse of gas blowing starts in 14.3s and lasts for 1s, which is seen as the pressure increase to app. 300 Pa. In 15.3s the breaker stops the reactive gas dosage into the core sand and for 1s there is a pause. Since intergranular spaces are filled with gas, the hardening reaction proceeds, which cause a gas consumption and pressure decrease to app. -500 Pa (sign is minus, since the inside core box pressure, in the measuring point, is lower than outside, which is the reference pressure in a differential measurement). When the under pressure obtains its maximum the pressure begins slowly increasing, which is related to equalizing the pressure in the system: core box – hose supplying gas to the core box (fragment from the valve to the core box). Air flowing from the bottom of the open core box can also participate in the pressure equalization. Due to a short pause – 1s – the pressure equalisation is not finished and the process is broken by the successive gas impulse, which starts in 16.3s of the measurement. The valve is open and the cycle repeats. As the result of core sand hardening and smaller and smaller gas consumption in an individual cycle, under pressure and overpressure values are gradually increasing. Finally they are stabilising when the given core layer is completely hardened; since this means that the chemical reaction had ended. The character of changes expressed by envelopes in Figure 4, is similar as in case of a continuous gas dosage and the difference between over and under pressure oscillates round a constant value. Pressure oscillations in micro spaces of the moulding sand at impulse gas dosage has probably a beneficial influence on bridges 'formation' and by that on improving the core strength at simultaneous limiting the consumption of gas dosed into the core. In addition, in the first stage of the process, when the binder is still liquid it can improve the binder distribution round the bridge.

Decreasing the rate of the hardening process of core sands with chemical binders favours their strength increase. It is caused by the formation of different structures of chemical compounds aggregates (products of polycondensation, coagulation, etc.) and also limits the bridges tendency for breaking, due to shrinking during bonding. At short pauses in hardenings the probability of stress relaxations round bridges is much higher. Therefore the impulse way of the gas dosage (with pauses) should improve the core sand strength. Figure 6 presents the influence of the impulse gas dosage on the core sand strength.

The tensile strength was determined by means of the so-called Brazilian method based on splitting – by compressing – a roll sample. The pressure leading to sample breaking is applied on the sample side surface (along a roll generating line). Samples for tests were each time cut out from the hardened core. The influence of impulses on the core sand splitting strength (R_p) is presented in Figure 6. The moulding sand splitting strength at the continuous gas dosage (R_{p100}) was assumed as the base value (100%), and then the strength change was calculated by the ratio of the strength measured at various variants of impulse time (R_{px}) to the base strength (R_{p100}) (expressed in percentages).

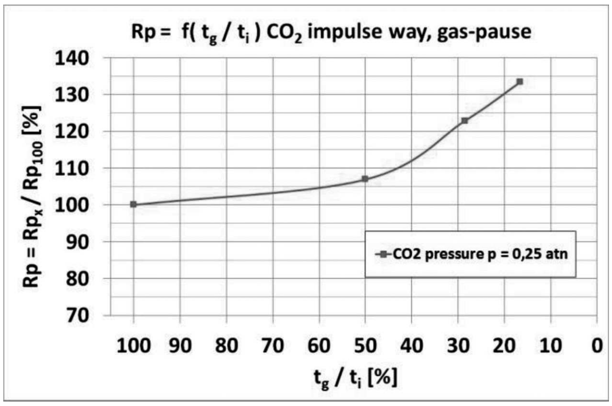

Fig. 6. Influence of the ratio of the blowing time of CO_2 to the full cycle time on the core sand splitting strength

The impulse way of gas dosage is determined by the ratio of the dosage time (t_g) to the single impulse duration (t_i), which consists of the dosage time (t_g) and pause (t_p). The lowest tensile strength was obtained when the ratio t_g/t_i equals 100% it means when the gas is continuously introduced. The application of a pulsation: gas - pause [1s-1s] (ratio: t_g/t_i = 50%) improves the moulding sand strength by a couple of percentages (8%). Prolongation of the pause time – pulsations [1s-2.5s, 1s-5s] (ratio: t_g/t_i = 29% and 17%) causes a significant increase of the core sand strength, in case of [1s-5s] even to 35%. The change of the dosage method leads to the core strength increase and to the gas consumption decrease.

3. Conclusions

It was shown, on the bases of the performed investigations that the hardening gas pressure inside intergranular spaces, during the hardening process, is not constant, regardless of the constant pressure value of gases supplied from the gas cylinder. At the initial stage of hardening the gas pressure in the core sand is low. As the hardening proceeds, when the reaction rate decreases and the 'hardening gas demand' also decreases, the pressure gradually increases. When the hardening is finished the pressure reaches the maximum and constant value in the given micro space.

Applying the impulse way of the gas dosage (gas-pause) allows limiting the hardening gas consumption and improves the core sand strength. For impulses [1s-1s] the core sand strength increase by a few percentages is obtained at a simultaneous gas consumption decrease by app. 50%. The prolongation of the pause time – pulsations [1s-2.5s; 1s-5s] causes the strength increase even by 35% for pulsations [1s-5s].

The core sand strength increase caused by the impulse gas dosage occurs due to obtaining the bridges joining matrix grains of a better quality.

On the basis of pressure changes pathways in intergranular spaces the end of the core sand hardening can be determined. This means, that the optimal dosage time of the gas needed for hardening the whole core can be determined and by this the excessive gas consumption can be limited.

REFERENCES

[1] M. Kaczmarek, Transport Porous Med **75**, 151 (2008).
[2] M. Kaczmarek, Transport Porous Med **84**, 95 (2010).
[3] S. Biloe, S. Mauran, Carbon **41**, 525 (2003).
[4] P.A. Claisse, E. Ganjian, T.A. Adham, Cement Concrete Res **33**, 47 (2003).
[5] Z. Lafhaj, G. Riczard, M. Kaczmarek, F. Skoczylas, Build Environ **42**, 3042 (2007).
[6] D.R. Gardner, A.D. Jefferson, R.J. Lark, Cement Concrete Res **38**, 360 (2008).
[7] S. Finsterle, P. Persoff, Water Resour Res **33**, 1803 (1997).
[8] E.M. Zeyanaly-Andabily, S.S. Rahman, Measure Sci Technol **6**, 1519 (1995).
[9] J. Zych, Ł. Jamrozowicz, Arch Metall Mater **55**(3), 963 (2010).
[10] Ł. Jamrozowicz, Application of ultrasonic technique for monitoring the processes occurring by the creation of cores made of fast-setting masses. PhD thesis, AGH University of Science and Technology, Krakow, October 2011.

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