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PARAMETERS AND PROCESSES OF SYNTHETIC SAND REBONDING IN TURBINE MIXERS

ZJAWISKA I PARAMETRY PROCESU ODŚWIEŻANIA SYNTETYCZNEJ MASY FORMIERSKIEJ W MIESZARKACH WIRNIKOWYCH

Theoretical principles underlying the processes of rebonding of synthetic sand with bentonite are different from those having relevance to fresh sand mixing. The process description should cover the following procedures: disaggregation, distributing the binding agent in the sand volume, grain coating and aeration. In order to provide a theoretical description of turbine mixers operations, it is required that all the processes are identified that are involved in homogenisation of the rebond mass and grain coating with water-clay suspension. In practical applications the analysis is conducted to find how particular design features and construction parameters of turbine mixers should affect the rebonding of synthetic sand with bentonite.

Keywords: sand processing, preparing and rebonding sand, turbine mixers

Podstawy teoretyczne odświeżania syntetycznej masy z bentonitem wymagają ustaleń różnych od opracowań dotyczących sporządzania masy ze świeżych składników. Obejmować muszą opisy zjawisk takich operacji jak: dezagregacja, rozprowadzenie lepiszcza w objętości odświeżanej porcji, powleczenie ziaren oraz napowietrzanie (aeracja), Analiza pracy mieszarek wirnikowych z teoretycznego punktu widzenia będzie dotyczyć wyodrębnienia realizowanych, hipotetycznych operacji związanych z ujednorodnieniem składników masy odświeżonej oraz pokrycia ziaren piasku suspensją wodno-glinową. Praktyczna analiza obejmuje wybrane zagadnienia wpływu czynników konstrukcyjno-technologicznych mieszarek wirnikowych na przebieg i rezultaty odświeżania masy syntetycznej z bentonitem.

1. Introduction

Turbine mixers are widely used in foundry plants for rebonding of the synthetic sand mix with bentonite. They are considered a basic equipment in modern sand mixing plants. Their major advantage is the short rebond cycle time, ranging from 30÷120 s. Another advantage is a large mixer pan, capable of holding huge portions of sand to be rebonded. The height H of the sand column in relation to the pan diameter D equals H/D = 0.27÷0.3 [6]. According to manufacturers' specifications, the ratio H/D for mixers MTI and MTP [3] approaches 0.2÷0.35 whilst in RTM mixers with controllable turbine rpm [12] this ratio is as high as 0.24÷0.4. For comparison, in edge runner mixers the H/D ratio is only 0.05÷0.6 and 0.14÷0.17 in speedmullers [6].

A full theoretical description of the sand mixing in turbine mixers is not available yet. Neither it is justified to wholly adapt the theoretical principles of sand mixing in edge runner mixers [1]. It is reasonable to suppose that the particular basic procedures employed in edge runner mixers: ramming, grinding, mixing, thinning, should be the same, though they might proceed at a different rate and with different intensity. One has to bear in mind that theoretical descriptions cover fresh sand conditioning and this assumption restricts the range of their potential applications to the rebonding of the used sand.

2. Rebonding of the used synthetic sand with bentonite

That synthetic sands with bentonite are in widespread use is mostly due to the fact that they are highly recyclable (95−98%) [8, 9]. After separating the castings, the used sand is tempered, fresh portions of sand are added, together with bentonite and a lustrous

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coal carrier. The amount of rebond materials is relatively small in relation to sand to be rebonded. That is why the properties of rebond mass are largely controlled by the performance of working units in a turbine mixer [5÷13].

These effects are associated with:
- disintegration of sand conglomerates produced after several process cycles,
- even distribution of the rebonding agents in the sand volume,
- sand grain coating with an injected binding agent,
- activation of grain coating.

Disintegration of sand conglomerates

Recycled sand has different grain composition and contains a smaller amounts of active clays that the freshly conditioned sand. The extent of grain size variations depends on the sand composition, the moulding technology, thermal loading of moulds and the applied sand conditioning procedure. The thickness of an inactive clay coating on the surface of sand grains (oolite process) tends to increase with the number of cycles [8, 10, 11].

As regards the grain composition, the sand to be rebonded has a large proportion of coarse-grain fractions. Grain size analyses reveal the presence of sand conglomerates (Fig. 1).

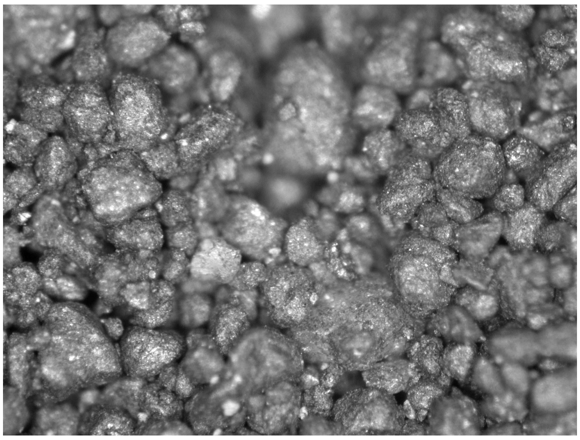

Fig. 1. Microscopic image of sand grains in a turbine mixer MTI-2500 [10]

Apart from single coated grains, there are conglomerates of grains differing in the number and size of their constituents. Characteristic sizes of sand grains and sand conglomerates are [7, 9]:
- single grains of silica with an adhesive coating 10÷30 μm in thickness (mono-grains),
- 0.4÷0.6 mm; blocks of newly formed grains strongly bonded by a formed adhesive coating, containing fine-grained fractions of broken silica grains and inactive clay powders (chamotte),
- 0.6÷1.0 mm; aggregates containing the original and newly-formed grained bonded by an adhesive substrate,
- 1.6÷2.5 mm and more; conglomerates containing the lumps of the above-mentioned grains- sand residues bonded by the binding material formed during the thermal decomposition of sand mix components (Fig. 2).

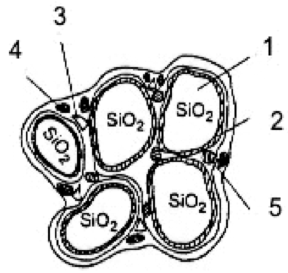

Fig. 2. Conglomerated grains of used sand: 1 – silica grains, 2 – adhesive coating; 3 – broken grain fractions; 4 – chamotte; 5 – core sand grains residues [7]

During the rebonding mixing larger particles ought to be subjected to forces acting upon them intensively and selectively.

Work required to disintegrate conglomerates of the size D_z is equal to [3]:

$$L_{koh} = 3 \times \left(\frac{D_z}{d_z} - 1\right) \times \frac{\sigma_{koh}^2}{2 \times E} \times V_{zr} \times (1 - \varphi); J, \quad (1)$$

where: d_z – grain size after disintegration; m,

V_{zr} – volume of grain conglomerates; m^3,

σ_{koh} – unit work of cohesion; Pa,

E – modulus of elasticity of the hardened binder coating; Pa,

$\frac{\sigma_{koh}^2}{2\times E}$ – work of deformation per 1 m^3 of disintegrated material; J/m^3,

φ – proportion of particles with the diameter d_z in a portion of sand mix to be rebonded.

Besides, it is required that sand grains should not be damaged. Work of disintegration should not exceed the level given by the formula [3]:

$$L_z = 3 \times \frac{D_z}{d_z} \times \frac{\sigma_z^2}{2 \times E_z} \times V_z; J, \quad (2)$$

where σ_z, E_z i V_z stand for the resistance interval and modulus of elasticity of silica grains, expressed in Pa and grain volume in m^3.

Disintegration should proceed in the conditions of fluidization of a portion of fine grains in the mixer pan volume [7]. Fluidization conditions are achieved by correct shaping of the paddles or blades and their arrangement. Sand grains are lifted and their lifting velocity becomes greater than hang-up velocity. The hang-up velocity u_z might be derived experimentally or from the relationship $Re_z = f(Ar)$ [4]:

$$\mathrm{Re}_z = \frac{Ar}{18 + 0,61\sqrt{Ar}}, \tag{3}$$

where *Re* i *Ar* stand for the Reynolds number and Archimedes number, respectively; $Re = u_z \times d_z/\upsilon$, $Ar = g \times d_z^3 \times (\rho - \rho_p)/(\upsilon^2 \times \rho_p)$, ρ – density of grain material, ρ_p – density of air, υ – cinematic viscosity of air.

Experimental hang-up velocity of grains with the size $d_z = 0.2$ mm is $u_z = 1.6$ m/s [4]. When conditions are right for fluidization, a zone is formed where the forces acting upon the grains $d_i > d_z$ are more intense. Grains with $d_i \leqslant d_z$ are not subject to interactions, which helps to eliminate undesirable disintegration of grains. The critical size d_z is imposed by technological considerations, while the time required to reach that dimension is associated with the design features and construction parameters: turbine size and shape, mixing time. The hang-up velocity of grains $d_z = 0.2$ mm is 1.6 m/s. Selected research data [9] reveal that in a turbine operating at 265÷275 1/min with a blade inclined at 41° a set of grains of d_z shall be fluidized. In these conditions sand conglomerates are reduced in size, to reach $d_z = 0.2$ mm without increasing the fine-grain fraction. Fluidization allows for selective disintegration. It is shown that increasing the turbine rpm and the mixing time makes the disaggregation process more and more intense [7, 11].

The authors' research program confirmed the observed grain size variations, yielding grain distributions in the used sand, rebonded sand mix and sand added during the rebonding process in a turbine mixer operating at $n_w = 375$ rpm and the pan operating at $n_m = 15$ rpm. The used sand contained 28% of grains > 0.2 mm, the sand grains contain 13% of such particles.

Distribution of rebonding agents, grain coating with a binding material, activation of coating

Preparation of fresh sand mix requires:

- thorough mixing of dry components (to ensure the ordered distribution of all components),
- coating the grains with a wet, dough-like binding agent.

Efficiency of the mixing process is measured by the following indicators: mixing level $S_m = s/x_{śr}$ and mixing quality $J_m = x_{śr}/x_{rz}$ [2], where: s – variance, x_i – contents of a given component in the i-th sample, $x_{śr}$ – average content of a given component in the sand mix, x_{rz} – the real content.

Similarly, the efficiency of mixing of the rebonded sand and of the coating process is measured by a coefficient (standard deviation and variance), associated with the resistance of the sand mix $S_\delta = s/\delta_{śr}$. Where: $\delta_{śr}$ – sand mix resistance R_c^w, average from samples collected at various points in the mixer pan. The resistance R_c^w and its homogeneity are selected as the basic indicators as they depend on the quality of binder distribution on the grain surface [11]. Even distribution of the binder ensures the highest values of R_c^w without major deviations. Selected values of mixing level are shown in Fig. 3. The values S_δ. The values S_δ are taken from literature [11] and were collected during the testing of an experimental turbine mixer operating at $n_w = 700$ rpm and an edge runner mixer.

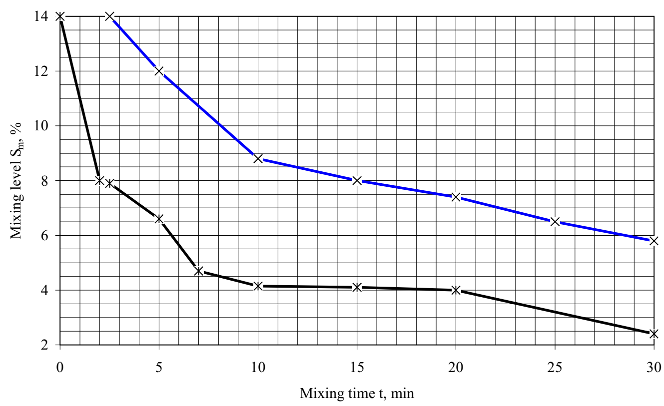

Fig. 3. Mixing quality indicator for a synthetic sand mix with bentonite [10]

Dynamics of the mixing process prompts intensive distribution of the rebonding agents in the total sand volume. Due to dynamic action of turbine elements, the temperature of the sand mix goes up by about 1÷1.5°C/min. [6]. It is suggested [11] that velocity of the grain stream should be ⩽ 20 m/s; to ensure intensive grain-grain and grain-pan walls interactions. A stream of grains set in motion by the paddles is shown in Fig. 4.

Fig. 4. Stream of sand grain set in motion by paddles [14]

Velocity of the grain stream is controlled by the turbine rpm. Typically, the turbine rpm is set as constant during the whole rebonding process. The exception here is the concept whereby the turbine rpm and mixer pan rpm are variable. Mixers: RTMN, Rotomax [12] operate at variable rpm, adjustable in the range $n_w = 400 \div 570$ 1/min the pan operates at $n_m = 8.3 \div 11.3$ 1/min. Other values of these parameters are assumed during the charging, disintegration of sand conglomerate, mixing, aeration and unloading. Times of these operations are controllable, too. The proposed concept of the rebonding mixing allows for cost reduction and reduced driving power.

Relating the drive power N (kW) to the performance rate W (tone/hour), we obtain a proportionality factor $L_{wł}$ (kJ/kg) expressing work required to prepare and rebond a unit mass of sand [6]:

$$L_w = 3.6 \times N/W. \tag{4}$$

The factor $L_{wł}$ obtained during investigations of an experimental mixer capable of holding 45 kg of sand to be rebonded, was found to be 5 kJ [6]. This applies to a turbine-type mixer equipped with 2 sweep gears: one in the bottom and one in the side wall of the mixer pan.

According to manufacturers' data, the value of this indicator falls in the range 7÷12 kJ/kg (MTI, MTP mixers) [13]. The value of specific work in the case of turbine-type mixers RTM (Rotomax) with controllable rpm [12] falls below 4 kJ/kg.

During the rebonding mixing in a turbine mixer, sand conglomerates are intensively broken, exposing grain surfaces and activating bentonite layers on the sand grains. The thickness of the molecular film on tempered montmorillonite is 2×10^{-3} μm, which implies that the cover on sand grains contains 10^3 films of clay, one the average [5, 6, 9]. During each elementary event one layer is separated, so the potential of activating the coating are rather high.

The performance of rebonding (activation) is evaluated by conducting tests on used sand with no fresh components [7]. During mixing, sand grains were subjected selectively to the action of pertinent forces. After 150 s the research team obtained the sand mix with $R_c^w = 0.082$ MPa in an experimental mixer and the sand mix with $R_c^w = 0.032$ MPa in an edge runner mixer after 180 s.

3. Conclusions

1. Turbine-type mixers are the basic machines in sand mix rebonding plants. Their widespread use is due to the improved mixing plant design, aimed to reduce the cycle time by intensifying the sand mix treatment. Their major advantages include the short rebond cycle time and a high sand mix columns.
2. Rebond performance is controlled chiefly by the used sand condition and the sand processing in the turbine mixer. In the first place, sand mix has to be disintegrated to obtain mono-grains with the required diameter. To eliminate the disintegration process, we resort to fluidization of the sand layer, which is achieved by ensuring the proper shape and arrangement of paddles and by their rpm control.
3. Design features and operational parameters of the turbines determine the efficiency of other involved operations: mixing and distribution of sand mix components and activation of the binding agent. Work required to prepare the sand mix portion and to ensure its correct parameters falls in the range 4÷12 kJ/kg. The lower limit applies to mixers with controllable rpm of the turbines and mixer pans, depending on the phase of the process.

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