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Validation of the Theoretical Model of Determining the Strength of Cores Made by the Blowing Method

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Abstract

Core sands for blowing processes, belong to these sands in which small amount of the applied binding material has the ability of covering the sand matrix surface in a way which - at relatively small coating thickness - allows to achieve the high strength. Although the deciding factor constitute, in this aspect, strength properties of a binder, its viscosity and ability to moisten the matrix surface, the essential meaning for the strength properties of the prepared moulding sand and the mould has the packing method of differing in sizes sand grains with the coating of the binding material deposited on their surfaces.
The knowledge of the influence of the compaction degree of grains forming the core on the total contact surface area can be the essential information concerning the core strength.
Forecasting the strength properties of core sands, at known properties of the applied chemically hardened binder and the quartz matrix, requires certain modifications of the existing theoretical models. They should be made more realistic with regard to assumptions concerning grain sizes composition of quartz sands and the packing structure deciding on the active surface area of the contacts between grains of various sizes and - in consequence - on the final strength of cores.

Keywords: Moulding sand, Core sand, Blowing method, Core properties

1. Introduction

Properties of core sands can be assessed on the basis of several parameters such as a thermal analysis, which warrant their application in individual technologies [1], or a determination of their strength properties [2] very important for foundry technologies. The existing theoretical models of calculating the tensile strength of moulding sands concern the tensile strength of model moulding sands represented by idealised grains. The binding material in a coating or not coating form is present on surfaces of grains joined with each other in a few characteristic methods [3-7]. Forecasting of strength properties of moulding sands, when the properties of the used chemically bound binder and the quartz matrix are known, requires modifications of known theoretical models. These modifications should take into account the grain size composition of the matrix, its main fraction and the packing structure deciding on the active surface area joining grains of various sizes, and - in consequence - on the final moulding sand strength. These demands were considered in article [8], in which the expansion of existing models was developed.

2. Theoretical model of the determination of the moulding sands strength

On the basis of the existing models assuming the same idealised grains of the matrix [3-6], or two grains of different shapes [7] it is possible to calculate the theoretical tensile strength value. In each case the fresh matrix, not subjected previously to production processes and resulting from them reclamation treatments (mechanical or thermal) [9-11].

As it was proved in paper [8] these calculations are burdened with a large error. Thus in order to eliminate the existing gap, the calculation method of the system presented schematically in Figure 1, was developed for the following detailed assumptions:

- spheres, representing matrix grains, marked with symbols: O1, O2, O3 has various radiuses marked different radiuses marked R1, R2, R3 respectively and are covered by the binder coating of a constant thickness g causing their permanent joint,
- spheres have smooth surfaces and are placing themselves in the moulding sand in a way corresponding to three-dimensional system for the coordination number CN = 8 (inclined parallelepiped), which corresponds to the moulding sand compaction being app. 1600 kg/m^3,
- hypothetical fractions of grains of dimensions R_1, R_2 and R_3 in the matrix correspond to the main fraction of the sand matrix.

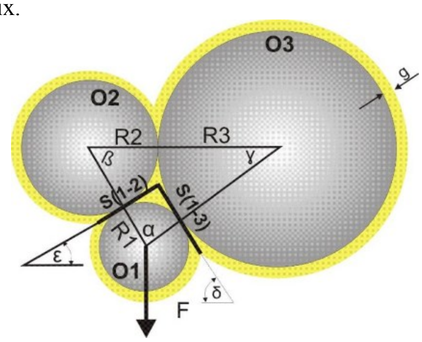


Fig. 1. Model system for calculating the contact surface area of grains of various sizes in the system corresponding to the coordination number CN=8

According to Zych [6], the equation for calculating the contact surface area S of two grains of different diameters (subjected to stretching) derived from the geometric dependences is of a form:

$$S = \pi \cdot g \left[d \cdot \left(1 + \frac{R-r}{R+r}\right) + g\left(1 - \left(\frac{R-r}{R+r}\right)^2\right)\right] \quad (1)$$

$$g = \frac{d \cdot \sqrt[3]{1 + L\frac{\rho_z}{\rho_g}} - d_Z}{2} = \frac{d_Z}{2} \cdot \left(\sqrt[3]{1 + L\frac{\rho_z}{\rho_g}} - 1\right) \quad (2)$$

where:
D, R – diameter and radius, respectively, of the larger grain; m,
d, r – diameter and radius, respectively, of the smaller grain; m,
g – thickness of the binding material coating; mm.
L – binder amount, %
ρ_g – binder density, kg/m^3,
ρ_z – density of the matrix grain, kg/m^3.

In the case of connection presented in Figure 1 the total surface S area counteracting the sample breaking equals:

$$S = S_{(1-2)} \cdot \cos\varepsilon + S_{(1-3)} \cdot \cos\delta \quad (3)$$

Knowing the contact surface area S, it is possible to calculate for this system the breaking force value F_r:

$$F_r = \sigma_{rozc} \cdot S \quad (4)$$

The above dependencies are the right ones for the ideal system of three grains. In reality, in the moulding sand, there is a great number of grains of diameters R1, R2, R3 which can be situated randomly according to the scheme presented in Figure 1. Knowledge of a mutual fractions of grains of diameters R1, R2, R3 allows to apply the proper probability dependencies to determine the expected contact surface area between grains. Dependencies resulting from the probability theory and determinations of variances of grain connections, occurring in various configurations can be applied at calculating the expected value of the contact surface area (of the known main fraction), when these grains are contacting in the system corresponding to CN = 8. In accordance to that, the expected contact surface area equals EV(S):

$$EV(S) = \sum S \cdot P_{I-XXVII} = S(I) \cdot P(I) + .. + S(XXVII) \cdot P(XXVII) \quad (5)$$

The tensile strength value R_m, MPa of the moulding sand prepared from grains of dimensions R_1, R_2, R_3 can be calculated from equation:

$$R_m = \sigma_{rozc} \cdot i \cdot EV(S) \quad (6)$$

where:
σ_{rozc} - tensile stress, MPa,
i - total number of grains falling to the surface area unit.

3. Model verification

Verifying investigations of the presented above model consisted of calculations of the expected values of the tensile strength of moulding sands which matrices constituted grains of three radiuses values: R1, R2, R3 and the known mass and quantitative fractions of individual grains. Then the real core sands were made which matrices constituted grains of the assumed values. These core sands were prepared in the warm-box technology and from them the specimens for stretching were made by means of the experimental core shooter.

The matrix of the core sand constituted the properly chosen spheres of quartz glass and the selected grains of the quartz matrix. In calculations and in verifying investigations the following grain classes of radiuses: R1, R2, R3 were used: R1=0.090 mm, R2=0.180 mm, R3=0.358mm.

The variable quantitative fraction of grains R1 being from 0 to 100% was applied in investigations.

The following composition of the core sand was used:

– Matrix – 100 parts by weight,
– Resin: Furesan 8885 – 1.2 parts by weight,
– Catalyst: furedur 8099 – 0.3 parts by weight.

On the bases of the tensile tests of the model spheres systems, in accordance with the methodology presented in paper [8], the adhesive strength of the matrix with the Furesan 8885 resin was estimated, as equal 51.12 MPa (1.09%)

The moulding sand, after mixing acc. to the producer's recommendations, was shot into the core box of a shape of bending strength samples. Cores were made with using the experimental shooting machine LUT-c of the Multiserw Morek Company. The shooting pressure was 5.0 MPa. Cores were made at hardening times 40 s at a temperature of 220 °C. The shaped samples were tested after 4 hours of cooling (cold) in the universal apparatus for flexural strength testing LRu-2e.

The morphologies of surfaces of moulding sands of the assumed particle dimensions at magnifications 50x, 250x and 1000x [8], are shown in Figure 2. Photographs of the matrix prepared from the selected fractions of various diameters reveal the domination of fine grains filling spaces between larger grains and due to their excess forming larger clusters. This indicates that - under real conditions - during the moulding sand preparation process, a total homogenising of the space system of grains does not occur. This creates conditions for the strength anisotropy occurrence in micro-spaces differing in grain sizes and in number of active joins by binder bridges. In addition bridges can be of classic shapes indicating that binder is dripping into grains contact places (Fig. 2c), or can have forms of stretched poles joining surfaces of grains being slightly separated (Fig. 2b).

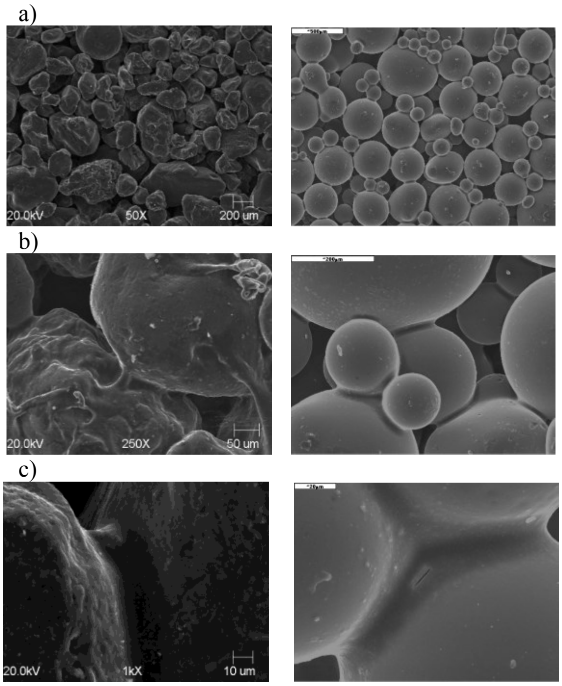


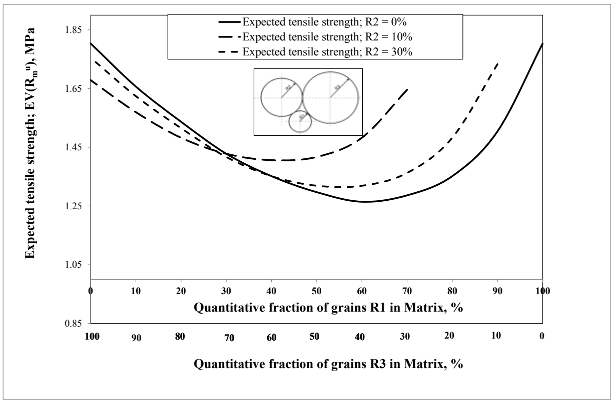
Fig. 2. Microscope photographs of the moulding sand, which matrix constituted quartz sand grains (left side) and glass spheres (right side) of dimensions: R_1=0.090 mm (fraction of 50%), R_2=0.180 mm (fraction of 30%) and R_3=0.358 mm (fraction of 20%): a) Magnification 50x, b) Magnification 250x, c) Magnification 1000x [8]

The results of model and verifying investigations, presented in Fig. 3a - 3c, indicate that when moulding sands are prepared with matrices consisting of three different grain classes the maximal tensile strength values are obtained when the mixture is approaching the homogenised state in respect of geometric dimensions of grains. In the situation when the matrix dimensions satisfy the condition: $R_1<R_2<R_3$, the smallest fluctuations of the tensile strength R_m^u, being the result of different quantitative fractions of matrix components, occur at a higher fraction of R_2 grains, of the intermediate radius value (between R_1 and R_3).

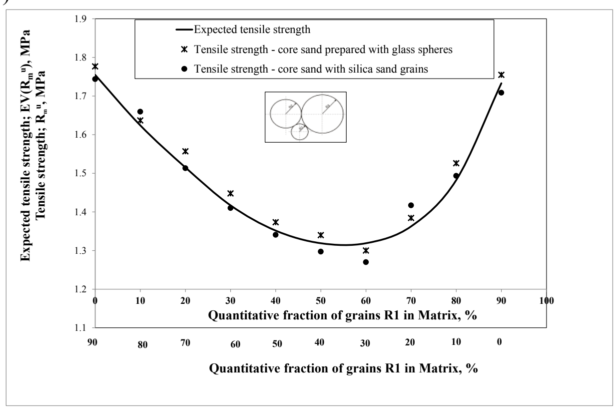
The practical aspect of the described above strength tests for various matrix compositions lies in the possibility of forecasting the rational range of grain sizes for which obtaining the highest approximation of the tensile strength to its expected value, being the result of model calculations. Obtaining the synthetic matrix of a grain composition being close to the assumed one does not constitute the essential technical problem at the present state of techniques (among others the pneumatic classification) shaping grain size compositions of polydispersive granular materials.

The verifying tests allowed to determine the forecasting average absolute error which for the moulding sand made with using quartz spheres was 4.17%. The forecasting average absolute error determined for the core sand made with the matrix prepared from the selected quartz sand grains was 5.76%. Calculations according to the model of Lass at assuming the average grain size resulting from grain diameters R1, R2 R3 and their mutual fractions, were performed for comparison. In this case the average absolute error of forecasting was 17.86%.

a)



b)



c)

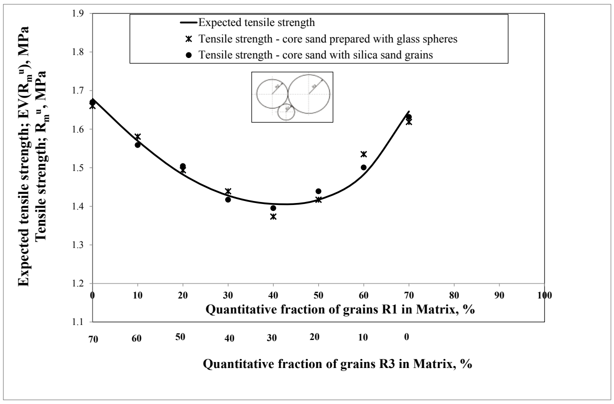


Fig. 3. Results of theoretical calculations and tensile strength experimental tests of moulding sands made with the matrix consisting of grains: R_1=0.090 mm, R_2=0.180 mm, R_3=0.358 mm; a) Results of theoretical calculations, b) Results of theoretical calculations and experimental tests; fraction: R_2=10%, c) Results of theoretical calculations and experimental tests; fraction: R_2=30%

4. Summary

The presented own expanded model of determining the tensile strength of organic self-hardening moulding sands, including core sands, performed by means of blowing methods, satisfies to a higher degree than up to now the demand of becoming closer to the real conditions. In the presented model the sand matrix consists of grains of various sizes, however with the simultaneous taking into account a lot size of each of them in the grain set of the known mass fraction in the main fraction. The model is based on calculations of the contact surface area of three grains of different radiuses, constituting the base of calculating the total surface area of grains contacts in the cross-section subjected to stretching. All possible variances of radiuses of the spheres forming the hypothetical systems of grain joints, allowing to determine the tensile strength of the moulding sand, were taken into account.

The verification of the model as well as experimental tests allow to notice the utilitarian aspect of the performed theoretical considerations, concerning possibilities of determining the tensile strength maximal level of the organic moulding sand with the matrix of the known grain size characteristic.

Acknowledgements

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