Examination of correlation between the granulometric properties of molding and core sand mixtures and their production parameters

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Abstract. Foundry technology uses a lot of several natural materials. The chemically bonded sand mixtures main component is the foundry sand approx. 90-98%. Sand properties depend on it has chemical and mineralogical composition; mainly particle-size distribution and shape of grains and its size and sand surface texture. A comparative measurement of 3 foundry sand with different surface quality was carried out. Chemically bonded sand mixtures were prepared to measure their gas permeability and 3-point bending strength. A new qualifier number, CQ, was used to compare our investigations.

1. Introduction

Numerous types of natural or nowadays widely-used synthetic (artificially produced) sand are applied for the preparation of molds and cores in foundry technology. The sand mixture is made from base sand and added bonding agents from which molds and core sand can be made. The molding and core sand mixtures are quite complex systems. Many factors affect the stability of molds and cores. The strength of cores depends on the sand’s granulometric features, the bonding agents (quantity, quality, different curing conditions) and the bulk density of core sand. [1-4]

The aim of the research is to create a complex qualification for the important casting features of cores. The quality of molding and core sand mixtures is mainly determined by the parameters of foundry sand, that is, its granulometric parameters (sand grain’s form and surface, size, structure and specific surface). Beyond the granulometric features of the refractory matrix, the parameters of core sand also depend on the type and quantity of the bonding agent and the bulk density. Since the current qualification methods of granulometric features are imprecise and not clearly quantified, the core sand parameters and the different setting parameters cannot be compared.

The relevance of the topic is also confirmed by the project being carried out by the Chair of Metal Forming and Casting (UTG) at the Technical University of Munich. From input parameters such as the manufacturing process and the materials used, they calculate effective physical properties like strength, gas permeability and thermal conductivity. They can accelerate development by modelling and simulating the process.

They state we need to consider the following properties since they influence the physical properties of the composites: grain shape of the sand, size of the grains, size distribution of the grains in the sand, volume content of the binder, chemical composition of the binder. [5-6]
2. Material and measurements

2.1. Investigated materials
Quartz sand of two and one of synthetic foundry sand was used for our tests (polish quartz sand - SREDNI (from Grudzeń-Las mine), GBM 45 (from Badger mine USA) and Bauxite sand W55). The investigated foundry sand types were all different in shape, but it was important their average grain size needed to be nearly the same. Figure 1-3. shows the grain morphology of different sands while a grain size distribution of them can be seen on Figure 4.

![Image](image-url)

Figure 1. Stereo and scanning electron microscopy (SEM) image, EDS analysis of SREDNI quartz sand.
Figure 2. Stereo and scanning electron microscopy (SEM) image, EDS analysis of GBM 45 quartz sand.

Figure 3. Stereo and scanning electron microscopy (SEM) image, EDS analysis of Bauxite sand W55 sand.
Figure 4. Grain size distribution of the used sands.

Results of granulometry analyses show that the properties of the various types of foundry sands are quite different.

| Table 1. Measurement data of the investigated sands. |
|-----------------------------------------------|
|                                | SREDNI | GBM 45 | Bauxite sand W55 |
| Average granularity ($d_{50}$) (mm)       | 0.319  | 0.303  | 0.325          |
| AFS granularity number                    | -      | 52.66  | 61.7           | 57.44         |
| Homogeneity degree (%)                    | 64     | 44     | 55             |
| Angularity coefficient of sand            | -      | 1.38   | 1.14           | 1.08          |
| Specific surface ($\text{A}_{\text{BLAINE}}$) (cm$^2$/g) | 125    | 105    | 100            |
| pH                                           | -      | 5.73   | 6.8            | 6.3           |
| Density (g/cm$^3$)                         | 2.6    | 2.65   | 3.1            |
| Bulk density (g/cm$^3$)                    | 1.45   | 1.6    | 1.91           |
| Grain shape                                 | angular | rounded | rounded |

The results of the granulometric analysis show summarized in Table 1. The difference between the different sands is not significant considering that the average grain size. The Bauxite sand W55 has the lowest surface area due to its rounded grain shape and high sphericity. SREDNI quartz sand has the highest surface area since it is the most angular sand.

2.2. Measurements

No-bake binding sand mixtures were made from a different type of sands. Binder quantity and quality were the same. We used phenolic no-bake resin 1 % (instead of the mass of sand refer in respect of sand surface) (Furtolit 4003) and hardener 0.4% (in respect of resin mass) (Härter RS 20). For different types of sand equal binder layer thickness is achieved.

Specimens (Figure 5.) of standard size made from laboratory sand rammer (compressed with 3, 5, 7 and 9 rams) of sand mixture with the Multiserw-Morek laboratory mixer, within 2 minutes of mixing time (resin - 1 minute and catalyst 1 minute).
I carried out a 3-point bending flexural test and an air permeability test on samples made from the sand mixture. Air permeability test was carried out on standard cylinder samples (50x50 mm). The 3-point bending flexural ($\sigma_{\text{bending}}$) test was carried out on standard prism samples; like by the cylinder samples I used a rammer machine with rams of 3, 5, 7 and 9. The bending strength test was made after 30 minutes, 1 hour and 24 hours. The parameters of granulometric and bulk density were examined in a correlation system of a new qualification method.

3. Rating method
The comparison based on bulk density is incorrect, include with an error when comparing these sand types. The cause of the error is the diverging densities of the different materials which affect bulk density. In the case of sand cores with the same bulk density, different results can be obtained due to the different material densities. I would like to correct this fault, eliminate it with a new qualification parameter, which characterizes the total granulometric and bulk density conditions of sand cores at the same time.

One single index includes the core sand’s volume, surface and bulk density not dependent on material density; therefore, it is eligible for the complex qualification of core parameters.

$$ CQ_i = \frac{\text{Air quantity} \%}{\text{SM}} $$

where:

- $CQ_i$ = Core Quality Index
- Air quantity $\%$ = Percentage of air in the sand core
- SM = Sand Module (cm)

$$ SM = \frac{V_{\text{sand}}}{SA_{\text{sand}}} \text{ (cm)} $$

where:

- $V_{\text{sand}}$ = Volume of sand in sand core (cm$^3$)
- $SA_{\text{sand}}$ = Total surface area of sand in sand core (cm$^2$)

The following data are required to determine the value of SM (Sand Module):

- Volume of sand core = $V_{\text{core}}$ (cm$^3$)
- Mass of sand core (sand) = $m_{\text{core}}$ (g)
- Density of sand (material density) = $\rho$ (g / cm$^3$)
- Specific surface area of sand = $A_{\text{BLAINE}}$ (cm$^2$ / g)

For each specimen, the mass was measured to thereby determine the Air quantity $\%$, the SM, and the $CQ_i$ values.

4. Results
Figure 6. shows the air permeability test results and the Figure 7. shows the bending strength test results of sand mixtures. The air permeability values shown in the diagram are the result of one measurement each. The illustrated bending strength measurement results come from the average of the 3 measurements. The curves put on the chart were placed for better visibility and easier comprehension of the results. In case of bending strength values of curves were inscribed only for 3 rams and 9 rams values.
Figure 6. The air permeability test results.

Figure 7. The bending strength test results.

In each used foundry sand case, the number of rams increase in raise gives a lower permeability. By the connection of CQ\textsubscript{i} and air permeability, it is visible that higher CQ\textsubscript{i} values have higher air permeability values. The sand core samples with the lowest CQ\textsubscript{i} were made of bauxite sands (Bauxite sand W55), this sand type was the most rounded of the three, it has the smallest specific surface area. The highest CQ\textsubscript{i} value is given to the sand core samples made of Polish quartz sand (SREDNI), and this sand type is the most angular compared to the other sands and it has the largest specific surface area.
The rounded grains have better compaction because it has less porosity between the grains and thus it has lower air permeability. Due to the lower porosity, the proportion of air in the specimen is lowered, so the CQ value is also low.

In addition, angular shape grains reduce the bulk density of the sand thereby increasing the air permeability of core sand.

In case of values of bending tests after 30 minutes and 1 hour there are no significant strength differences; the reason for this is that the bonding agent has not reached its final strength. In case of the 24-hours bending tests, the higher CQ values have higher bending strength values. While there was no significant change over time in the strength values of Bauxite sand, until then the 24-hours strength values increased nearly tripled in the case of Polish quartz sand compared to 30 minutes strength values.

Angular grains (SREDNI) show higher bending strength than rounded grains (Bauxite sand). Because a rounded shape grain has a less contiguous surface like a subangular or angular grain.

5. Conclusion
The air rate (%) or air quantity (%) of samples made from different sand is similar; as a consequence, the sand volume within the samples is nearly the same. Furthermore, as the average grain size of the sand is similar, that is, the sand types are similar from granulometric (sieve analysis) viewpoint, the difference of bending strength values can be put down to variable specific surface areas.

As a result, the bonding agent’s thickness and the characteristic of the bonding bridge cause diverse bending values. The strength of cores has two parts: the adhesive and cohesive force among the bonding agent and the sand grains. During my examinations, I assumed that due to similar granulometry the cohesive force of strength is similar in case of the application of diverse sand types. The growth derives from the increase of the adhesive force. This statement is underlined by the results of the bending test. It is visible from the results that there is no significant difference between the strength values after 30 minutes values because the bonding agent has not reached its full cohesive force; thus, the increase of adhesive force cannot be detected within the strength values. After 1 and 24 hours cohesive force develops within the strength values, so the effect of the adhesive force can be detected. The biggest difference among values can be seen during the bending test made after 24 hours.

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