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THE GRANULOMETRIC FEATURES AND PERMEABILITY EXAMINATION OF NO-BAKE RESIN BONDED SAND CORES

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Abstract: A lot of natural and even more artificial sand is used in foundry technology. Foundry sand is the main element of sand mixtures from which molds or sand cores are made. The features of sand are determined by the below factors: chemical and mineralogical composition, sand grain's size, grain size distribution, sand grain's shape and the quality of the surface. Samples made from different foundry sand are used during the research whose features were examined with a new qualification system and then its connection with the gas permeability of sand cores were also analyzed.

Keywords: granulometry, grain size, grain morphology, grain shape, permeability

INTRODUCTION

Sand cores play a significant role in the production of high quality castings; therefore, the knowledge on the features of sand cores is of utmost importance. The thermal, mechanical and granulometric features of sand cores affect their deformation, gas permeability and shakeout. [1, 2]

Appropriate core sand mixtures are to be used in order to meet the requirements of castings. The main components of foundry molding and core sand mixtures, the different types of heat-resistant particulates (natural or synthetic sand) vary in their physical and chemical features, for example in the sand grain's size, shape, grain size distribution, chemical composition, surface structure, hardness, density, heat resistance, thermal expansion and thermal conductivity. [3, 4]

These features' knowledge contributes to opting for the adequate raw material needed for a zero-defect production, although these properties' examination is not able to provide a full picture of the features of foundry sand cores. The granulometric analysis carried out with sieve and image analyses is also inaccurate. In the case of the traditional sieve analysis, the sieve holes could clog, break, get damaged or during shake the sand grains could fragment. During the image analysis, the sand grains are measured in a random layout; consequently, significant differences can occur by the measurement of irregular particles. [5, 6] In case of sand cores, the optimal permeability and the adequate mechanical features can have a significant effect by the

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optimal choice of granulometric features also; hence the precise and complex qualification of these parameters is essential. As a matter of fact, the current qualification of granulometric features primarily describes the base sand, not the features of sand cores. One of the reasons for introducing a new type of qualification system is to draw comparisons among the features of sand cores made from different base sands.

1. THE QUALIFICATION METHOD

By the application of the new qualification system and the introduction of the Core Quality Index (CQ_i), the characteristics in connection with the granulometric features of sand cores could be defined with a single value. The point of the qualification is that this single index incorporates the sand volume in the sand core, the surface of the total sand quantity and the bulk density which independent from the material density. Thus, it can be applied for the complex qualification of the features of sand cores.

The definition of CQ_i – Core Quality Index:

$$CQ_i = \frac{Air\ quantity\ \%}{SM}\ (-) \tag{1}$$

where:

Air quantity %: Percentage of the air in the sand core (%)

SM: Sand Module (cm)

$$SM = V_{sand}\,/A_{sand}\ \ (cm) \tag{2}$$

where:

V_{sand}: The volume of sand in the sand core or part of the sand core (cm^3)

A_{sand}: The total surface area of the sand in the sand core or part of the sand core (cm^2)

The following data is required to determine the Core Quality Index and the Sand Module value:

- V_{core}: The volume of the sand core (cm^3),
- m_{sand}: The mass of the sand core (mass of the sand) (g),
- ρ_{sand}: The density of the sand (material density of the sand) (g/cm^3),
- A_{BLAINE}: The specific surface area of the sand (cm^2/g).

In practice, besides the determination of base sand density and specific surface area the volume and the mass of samples to be examined is necessary.

By the application of the Core Quality Index the features of different base sands can be compared. With the CQ_i the granulometric and bulk density relations of sand cores can be independently qualified from the base sand quality and the size of sand core (dimensions).

2. MATERIALS AND MEASUREMENT

During the research, the factors determining the permeability were examined by the new qualification method. An important parameter is the shape of a sand grain. The shape of a sand grain beyond the binding strength affects the compactibility of the sand mixture and its permeability. Hence sand types with different grain shapes were chosen.

We used two different quartz sand:

1. GBM 45 quartz sand – Badger Sand Mine (USA),
2. Polish quartz sand, ŚREDNI – Grudzeń-Las sand-pit (Poland), and synthetic sand:
3. Bauxite sand W55.

An aspect of selection was to have sands with different shapes although with similar average grain size; as a result, the effect of different grain shapes on gas permeability could be detected.

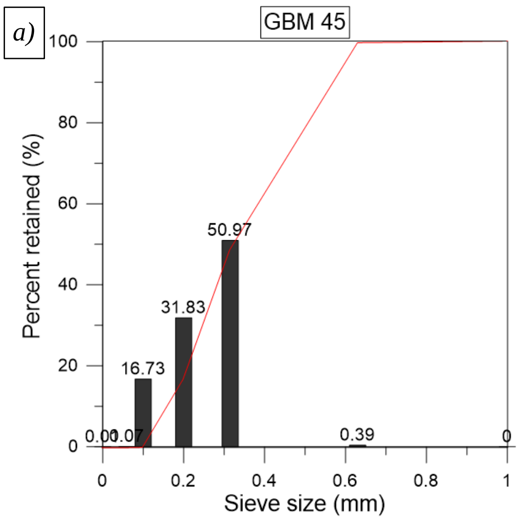
The results of the granulometric analysis of the investigated sands show summarized in *Table 1*.

Table 1

Measurement data of the investigated sands

	GBM 45	**ŚREDNI**	**Bauxite sand W55**
Average granularity, d_{50} (mm)	0.303	0.319	0.325
AFS granularity number (–)	61.7	52.66	57.44
Homogeneity degree (%)	44	64	55
Angularity coefficient (–)	1.14	1.38	1.08
Specific surface, A_{BLAINE} (cm²/g)	105	125	100
Density (g/cm³)	2.65	2.6	3.1
Bulk density (g/cm³)	1.6	1.45	1.91
pH (–)	6.8	5.73	6.3
Grain shape	sub-rounded	angular	rounded

The results of the sieve analysis of the investigated sands show in *Figure 1*.



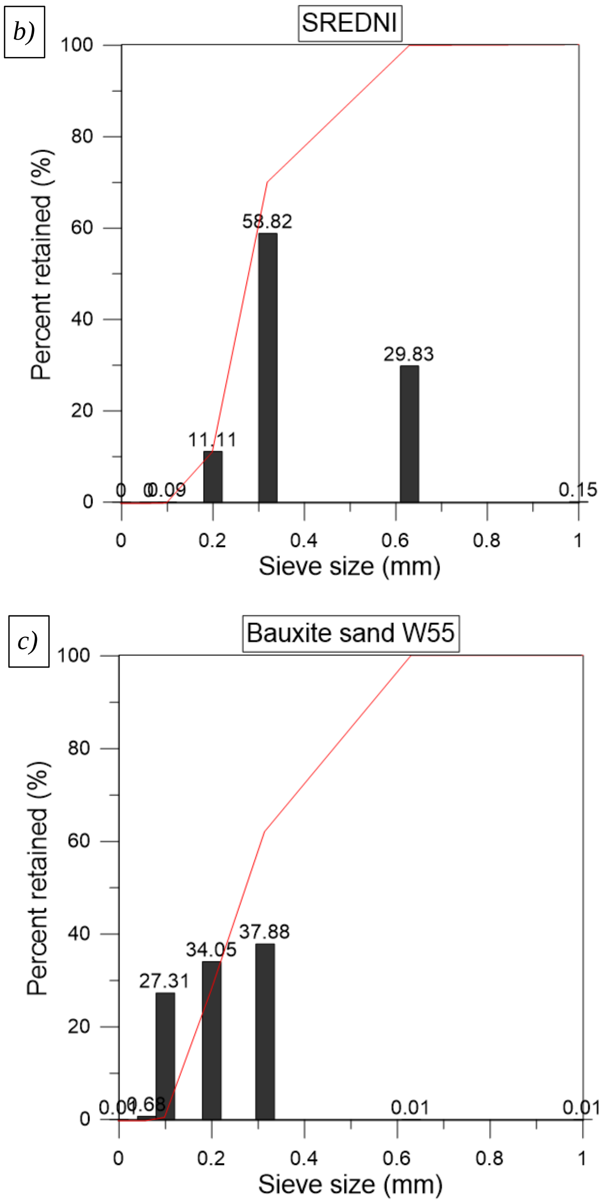
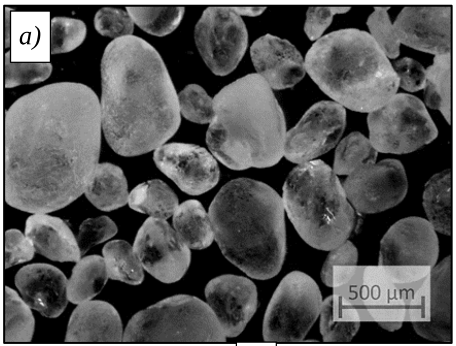
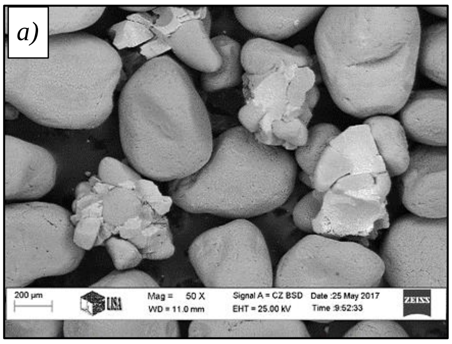


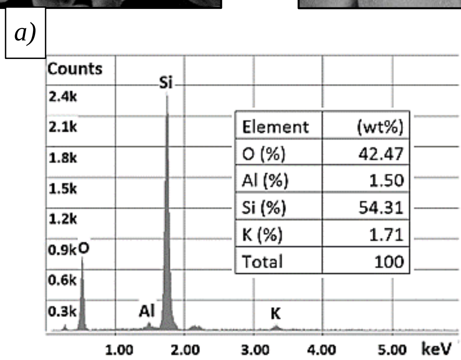
Figure 1

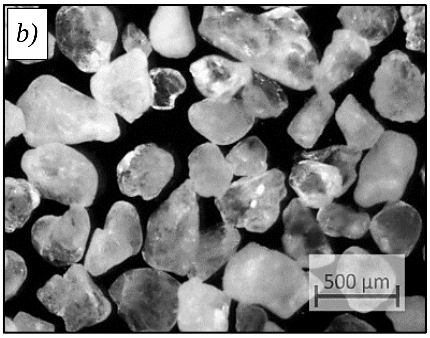
Sand grain size distribution of a) GBM 45 quartz sand,
b) ŚREDNI quartz sand and c) Bauxite sand W55

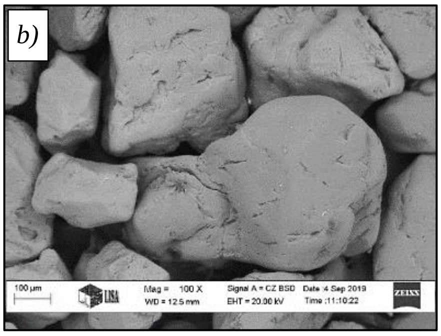
The stereo microscope and scanning electron microscope (SEM) images of the investigated sands, as well as the results of EDS analysis are shown in *Figure 2.*

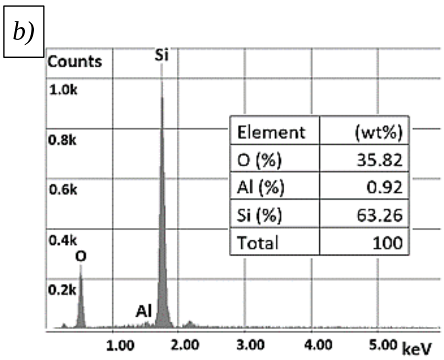

a)
500 µm


a)
200 µm
Mag = 50 X
WD = 11.0 mm
Signal A = CZ BSD
EHT = 25.00 kV
Date :25 May 2017
Time :9:52:33


a)
Counts
2.4k
2.1k
1.8k
1.5k
1.2k
0.9k
0.6k
0.3k
O
Si
Al
K
1.00
2.00
3.00
4.00
5.00
keV
Element | (wt%)
O (%) | 42.47
Al (%) | 1.50
Si (%) | 54.31
K (%) | 1.71
Total | 100


b)
500 µm


b)
100 µm
Mag = 100 X
WD = 12.5 mm
Signal A = CZ BSD
EHT = 20.00 kV
Date :4 Sep 2019
Time :11:10:22


b)
Counts
1.0k
0.8k
0.6k
0.4k
0.2k
O
Si
Al
1.00
2.00
3.00
4.00
5.00
keV
Element | (wt%)
O (%) | 35.82
Al (%) | 0.92
Si (%) | 63.26
Total | 100

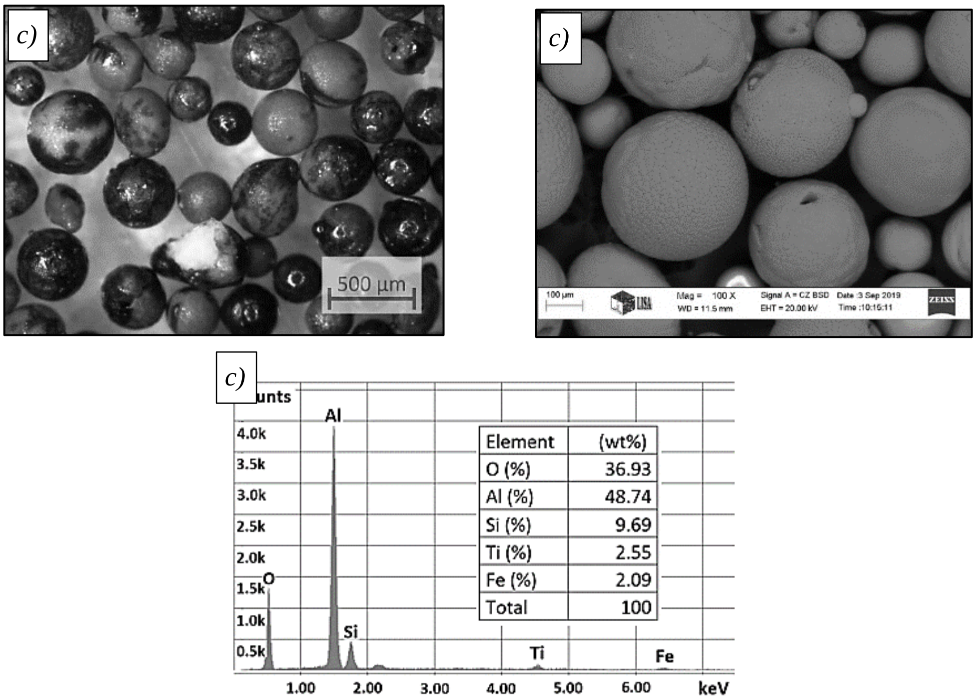


Figure 2

Stereo microscopy image and scanning electron microscopy (SEM) image with EDS analysis of a) GBM 45 quartz sand, b) ŚREDNI quartz sand and c) Bauxite sand W55

Based on the result of the granulometric analysis, it can be defined that the applied sands consist of 3 fractions and the grain size distribution of the investigated sands is different. The Polish quartz sand contains fine grains whereas Bauxite sand contains rough grains in a larger quantity. The elemental analysis shows that their components are diverse.

The sand mixture used for making specimen was made with phenolic resin (Furtolit 4003) and a catalyst as set by the recipe (Härter RS 20). The quantity of the phenolic no-bake resin needed to the mixture was 1% of the sand quantity, the catalyst was 40% of the resin quantity. In all cases, the sand mixture was made with a laboratory mixer for 2*1 minutes (for 1 minute with a catalyst and 1 minute with the resin). After the preparation of sand mixtures and within the shortest period of time and keeping a stable temperature (circa 20–22 °C), standard Ø50 × 50 mm cylindrical samples were made with a traditional sand rammer machine and with the different rams of 3, 5, 7 and 9. The process of preparing the specimens is illustrated in *Figure 3*.

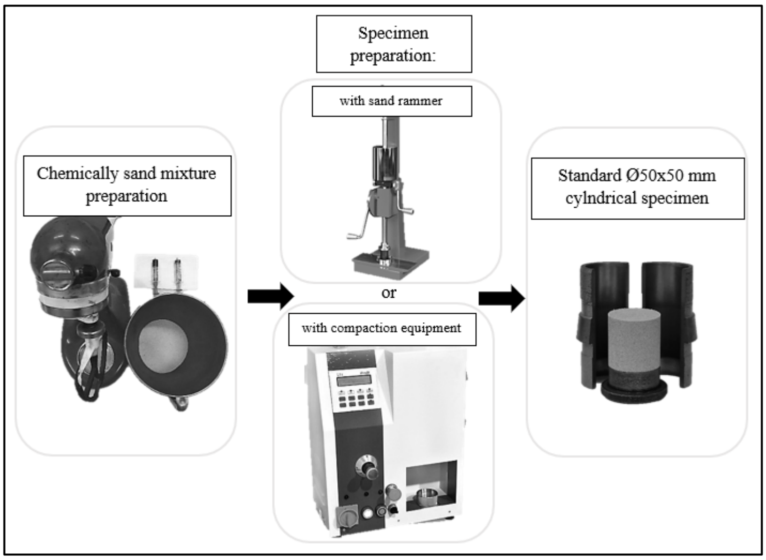


Figure 3
The process of specimen preparation

3. THE PERMEABILITY TEST

The permeability on the solidified cylindrical samples was measured by a tube with inflatable lining. The measurement results are given by the average of 2 measurements value.

Figure 4
The DISA type permeability measuring device and accessory for sand cores measuring

The CQ_i and permeability values of the specimens made of three different sands with different compaction forces (different ramming numbers) are shown in *Figure 5.*

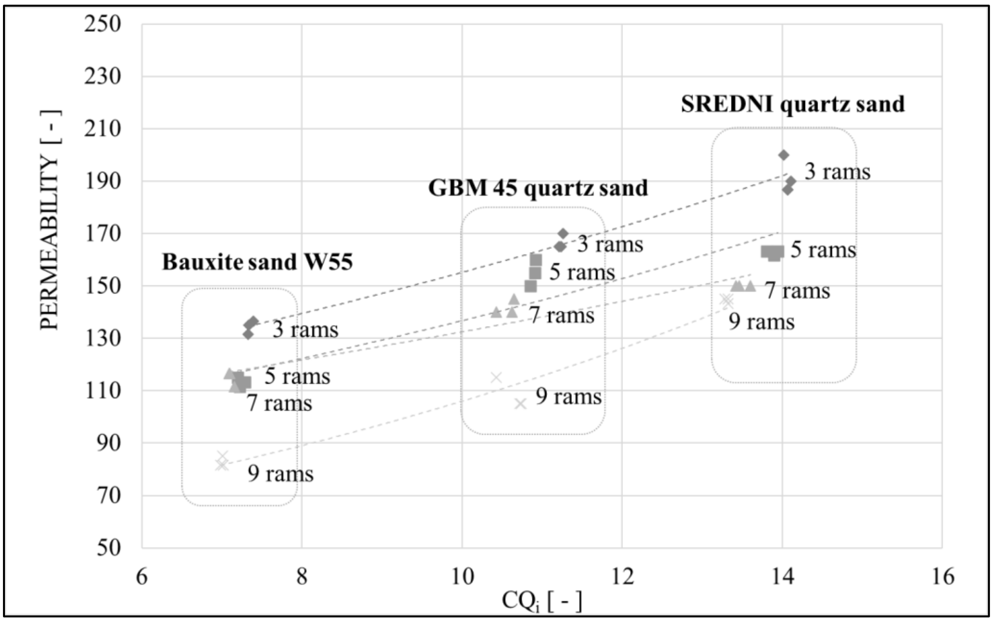


Figure 5

The permeability test values as a function of Core Quality Index (CQ_i) in the case of the three investigated sands

The sand cores with the lowest CQ_i were made from Bauxite sand; this sand type from the three was the rounded with the lowest specific surface area. The sand cores with the highest CQ_i were made from Polish silica sand; this sand type is the most angular with the largest specific surface area. In case of all three sand types by increasing the ramming, it is visible that the permeability has decreased and CQ_i has gone down slightly too since the air quantity in the sand cores has reduced. According to literature data, the permeability of samples made from more angular sand with higher specific surface area is worse than of samples made from more rounded sand with lower specific surface area, but our results have shown even the opposite. The rounded grains in compressed in the sand core get into less contact with each other; as a consequence, the core becomes more permeable among the sand grains for releasing gases. By Bauxite sand, the smaller grains fill the space among the larger grains better; therefore, the permeability worsens.

In order to eliminate the effects of the mixed grain structure by the GBM 45 quartz sand other examinations were carried out on samples made from sand mixture with different fractions per size. To get different grain sizes, the chosen GBM 45 quartz sand was divided with sieving into fractions per size, as follows:

- fine fraction – 100–200 μm;
- medium fraction – 200–315 μm;
- and coarse fraction – 315–630 μm.

In case of sand mixtures made from the fractioned sand, the specimens were made with the Multiserw-Morek compaction machine with the pressure of 1 MPa or 100 N/cm^2 for 20 seconds.

The permeability and CQ_i values of the specimens made of fractionated GBM 45 quartz sand are shown in *Figure 6*.

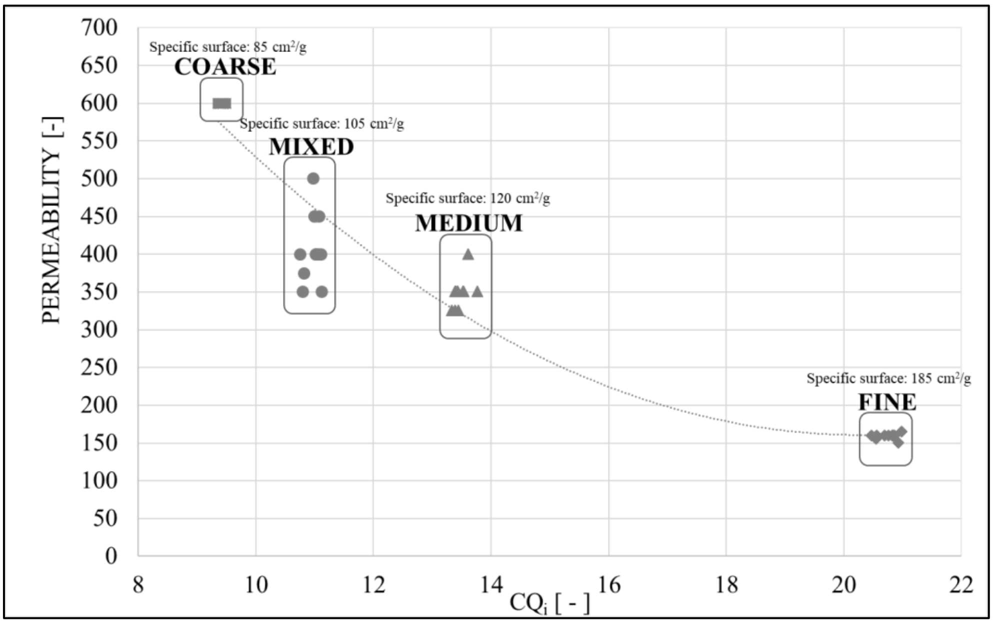


Figure 6

The permeability test values as a function of Core Quality Index (CQ_i) in the case of the fractionated GBM 45 quartz sands

The results showed that the permeability of samples made from the coarse fractioned sand mixture was the highest (the value exceeded the measurement threshold limit), although this fraction possessed the lowest CQ_i value. The lowest permeability was detected by sand cores made from fine fractions compared to the values of sand cores made from coarse or medium fractions. In case of samples made from different sand mixtures, containing air proportion is nearly the same, so there is no difference in the bulk density. Based on the measurement results, it can be verified that the permeability of sand cores (besides having the same voids content) made with the same production parameters (same content and quality of binder, same bulk density) with the coarse fraction is higher than of those sand cores containing medium or fine fractions. Despite samples made from different fractions possessing almost equal air percentage, that is, there is no significant alteration in their bulk density, their permeability can vary due to the different shape of 'channels' (voids) among sand grains. When the grain structure is mixed, variable permeability values can be detected due to the inhomogeneous distribution of smaller grains compared to the systems of homogeneous grain structure.

CONCLUSION

The main purpose of the research was to reveal the correlation between the Core Quality Index (CQ_i) and the permeability of sand cores.

Sand core samples made from dissimilar foundry sands (GBM 45 quartz sand, ŚREDNI quartz sand and Bauxite sand W55) are used during the investigation whose features were analyzed with a new qualification method and then its relationship with the gas permeability of sand cores were also examined.

As the measurement results show, there is a correlation between the new qualification method and the permeability values. The diverse foundry sands can be easily compared with this qualification method introduced otherwise the different density values would make it difficult.The new type of qualification method makes it possible to predict the gas permeability of sand cores containing different base sands, thus making them easier to the planning of the characteristic feature.

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REFERENCES

[1] Flemming, E., Tilch, W. (1993). *Formstoffe und Formverfahren*. Deutscher Verlag für Grundstoffindustrie, Leipzig, Stuttgart.

[2] Bakó K. (1976). *Öntödei formázóanyagok*. Budapest, Műszaki Könyvkiadó.

[3] Brown, J. R. (1999). Foseco Non-Ferrous Foundryman's Handbook. Foseco International Ltd, Butterworth-Heinemann, Oxford.

[4] Bakó K., Sándor J., Szabó Zs., Szíj Z. (1986). *Öntvények gyártástechnológiája*. Budapest, Műszaki Könyvkiadó.

[5] Dargai V., Polzin, H., Varga L., Dúl J. (2015). Öntödei homokok granulometriai tulajdonságainak meghatározása képelemzéssel. *XXIX. microCAD International Multidisciplinary Scientific Conference*, 9–10 April 2015, Conference Proceedings, Miskolc, pp. 1–7.

[6] Dargai, V., Polzin, H., Varga, L. (2018). Die Bestimmung der granulometrischen Eigenschaften von Gießereisanden mittels dynamischer Bildanalyse. *GIESSEREI PRAXIS*, 4/2018, pp. 19–22.