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The Influence of Silica Sand Granulometry and Sorting Level on Thermal Expansion

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Abstract

The quality of the castings depends, among other influences, on the quality of the moulding mixture used. The silica sands used are characterized by high thermal expansion compared to other sands. The tendency to dilatation of the moulding mixture can be influenced by the choice of the granulometric composition of the basic sand and the grain size. The aim of this work is to present the influence of grain distribution of foundry silica sand BG 21 from Biala Góra (Poland) and the degree of sorting (unsorted, monofraction, polyfraction) on the degree of thermal dilatation of the sand and thus on the resulting quality of the casting and susceptibility to foundry defects. For the purpose of measuring thermal dilatation, clay wash analysis was performed, sieve analysis of the sand was carried out, and individual sand fractions were carefully sorted. The measurements confirmed a higher thermal expansion in the case of monofractional sand grading, up to 51.8 %. Therefore, a higher risk of foundry stress-strain defects, such as veining, can be assumed.

Keywords: Foundry sand, Dilatometry, Sand grains distribution, Sieve analysis, Moulding mixtures

1. Introduction

The quality of the castings can be influenced in various ways. We can improve the quality of the liquid metal [1], the casting technology such as optimizing the gating system [2] or choose the appropriate basic sand and moulding mixture [3]. Silica sands are one of the most widely used basic sands in foundry moulding mixtures. This is due to their easy availability and low cost compared to other types of sands [4]. However, unlike other types of basic sands, silica sands are characterized by a reversible phase transition β↔α SiO_2 at 573 °C, which is accompanied by discontinuous thermal dilation. Depending on the type of silica sand, its purity and grain shape, this dilation varies [5, 6]. In the case of moulding mixtures, the dilatation of each grain then results in overall mould or core dilatation and leads to stresses from braked thermal dilatation, dimensional inaccuracies in the castings produced and a high risk of foundry defects from thermal stresses, such as veining [4, 7-9]. The degree of stress from thermal dilatation depends, in the case of the sands themselves, on the degree of compaction of the mixture, the shape of the sand grains and also the degree of sorting of the sand grains [10]. For different types of moulding mixtures and different technologies, more or less polyfractional sands with a proportional representation of several sand grain sizes larger than 0.02 mm or completely monofractional sands are used. The example of the use of monofracional sands can be found in 3D sand printing technology where the sand is usually sorted and already supplied that way.

The aim of the experiment is to determine whether and how much the fractional sorting of silica sand will affect the magnitude of thermal expansion and thus theoretically increase the risk of defects due to braking stress. Since graded sands are used for certain applications, as mentioned above, it is necessary to consider this effect on the final quality of the casting. The experiment was conducted with silica sand of the same location and composition, which was subsequently sorted. The magnitude of thermal dilatation as a function of the degree of grading was evaluated and the theoretical tendency of the graded sand to promote the occurrence of veining-type retained stress defects was determined. Casting tests to demonstrate the occurrence of these defects and real stresses in the casting were not part of the experiment.

2. Materials and methods

2.1. Material

For the purpose of the experiment, silica sand BG 21 from Biala Góra (Poland) with a mean grain size d_{50} of 0.21 ± 0.02 mm was chosen. It is a sand with high chemical purity (<99.7 % SiO_2), and angular grain shape. This sand was used both as unsorted in supplied condition (washed and dried) and sorted into monofraction (all grain sizes equal between 0.250 mm and 0.180 mm) and polyfraction (grains smaller than 0.500 mm and larger than 0.090 mm in equal amounts by precise mixing). The condition was to maintain d_{50} of 0.21 ± 0.02 mm. The individual sand samples can be seen in Figure 1 (digital microscope Keyence VHX 6000, Japan).

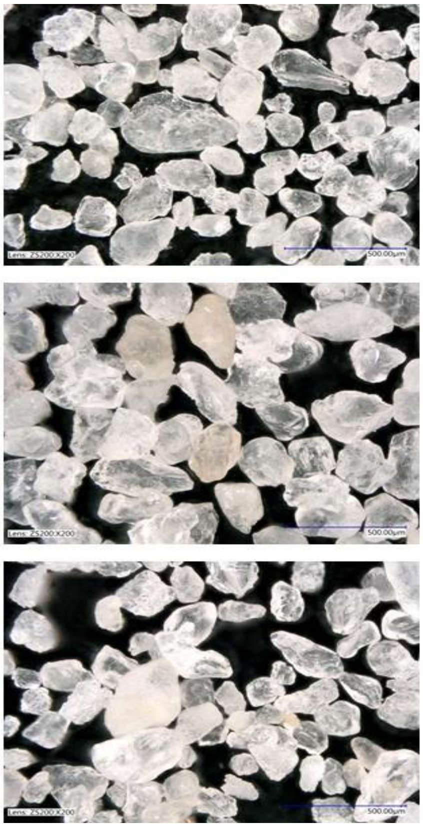

Fig. 1. Sorted sand grains: (a) unsorted, (b) monofraction, (c) polyfraction

2.2. Sand evaluation

A detailed overview of the particle composition was performed by sieve analysis. Washing of dust and particles below 0.02 mm was performed using the principle of different sedimentation rates of different sizes of the particles, i. e. clay wash analysis. The weight of individual sample was 50 g. The measurement was carried out with a laboratory sieving machine (LPzE-2e, Multiserw-Morek, Poland) with sieves mesh sizes 0.710 – 0.063 mm acc. to ASTM E11 and sieving time 10 min. The weight of sand fraction remained on each sieve after shaking represented a percentage proportion to the weight of initial sample. Measurements were always made on 3 samples from a given sand.

In addition to the sieve analysis, the following were evaluated: Homogeneity degree S (equation 1), log W as the Criterion of the grain-size distribution probability (equation 2) and Cumulative curves of granularity.

$$S = (d_{75}/d_{25}) \cdot 100\ (\%) \tag{1}$$

where d_{25} and d_{75} are mesh diameters of 25 and 75 % of the total weight of the sand.

$$logW = 100 \cdot log(100) - \sum N_i\, log(N_i) \tag{2}$$

where N_i represents fraction captured on the sieve [%].

2.3. Thermal dilatation of the sands

For the measurement of thermal expansion of sands a dilatometer DIL 402/C (Netzch, Germany) with corundum components was used. Sand samples were poured into the corundum container with plugs and compacted by three strokes of a laboratory spoon. Correction of the container was made by Ø6 x 10 mm correction sample. Height of each sand sample was 10 mm ± 0.05 mm. The temperature measurement range was set at 25 °C to 1130 °C (increase of 15 °C/min) and the inter atmosphere of 6.0 argon with flow rate 100 ml/min was used.

The measurements were always performed on at least 3 samples from a given sand. In case of an erroneous measurement, uneven curve shape or a result too different from the other values (more than 5%), the measurement was performed again. Sample preparation and measurements were carried out by the same person and in the same way. The final resulting values (without errors) were then averaged.

3. Results and discussion

The granulometric composition of the differently sorted sands can be seen in Table 1. The condition of maintaining the same d_{50} of 0.21 ± 0.02 mm was achieved. For the Homogeneity degree S is valid, the sand is more homogeneous, the more the S is closer to 100%. The measured results show, it is possible to increase the homogeneity of the sand by 38.1 % by selecting only one fraction (0.250 to 0.180 mm) compared to the unsorted sample, and so S rule was met by the monofractional sand. In contrast, the polyfractional sand, where 5 fractions were mixed, shows 30.16 % higher heterogeneity than the unsorted sample. The inclusion of larger grain size fractions and the 0.063 mm fraction was not undertaken due to the requirement to maintain the same mean grain size d_{50} and the very small grain contents trapped on the finest sieves.

Table 1.
Basic parameters of sand and particle size distribution.

	Retained [%]		
Mesh size [mm]	Unsorted	Monofraction	Polyfraction
0.710	0.00	0.00	0.00
0.500	0.06	0.00	0.00
0.355	3.12	0.00	20.00
0.250	19.65	0.00	20.00
0.180	32.35	100.00	20.00
0.125	36.64	0.00	20.00
0.090	6.37	0.00	20.00
0.063	1.31	0.00	0.00
Pan	0.34	0.00	0.00
d_{25} [mm]	0.24	0.23	0.32
d_{50} [mm]	0.19	0.21	0.21
d_{75} [mm]	0.15	0.20	0.14
Homogeneity degree S [%]	63	87	44
log W [-]	61.3	0.0	69.9

For the log W, the closer is the log W value to 0, the sand is more sharply sorted, i.e. it has a monofractional character. The largest part of sand grains is then composed of one or two sand fractions. In this experiment, the samples representing sorted monofraction actually have log W equal to 0, i.e. pure monofraction. In contrast, the differences in log W values between the unsorted sand and the polyfraction are not as pronounced. Despite the significantly higher heterogeneity of the polyfraction mixture demonstrated by the S calculation, the log W value, and thus the polyfraction of the mixture, is only 14.0 % higher due to the non-inclusion of fractions above 0.355 mm and below 0.090 mm. If these sand fractions were also included in the same amount, the log W value would increase proportionally. Cumulative curves of granularity (see Figure 2a) correspond to results, where the monofraction corresponds to a steep curve. The more polyfractional sand, the more linear the resulting cumulative curve.

Characteristic for polyfractional mixtures with more angular grain shape are usually higher binder consumption and lower permeability caused by higher specific surface area. This may lead to the development of foundry defects (gas defects) or higher material costs. The monofractional mixtures with partly angular grain shape are characterised by good permeability and is possible to reduce binder content while keeping good strengths of the mixture. On the other hand, a higher risk of penetration of metal into the intergranular spaces is the result of higher porosity of mixture, smaller number of contact surfaces between grains and the absence of fine sand in the intergrain space. For this reason are more inclined to have higher surface roughness or associated foundry defects

When exposed to high temperatures during casting the polymorphic transformations of silica sand are taking place, which is accompanied by discontinuity in thermal dilation curve. This discontinuity is caused by the reversible phase transition β ↔ α SiO_2 starting around 573 °C which is accompanied by a linear dilation of the mixture and this significantly differentiates silica sand from another sand types. If this expansion is braked (e.g. a core in already solidifying casting), the stresses will increase and the core or mould will expand. This result is then dimensional inaccuracy of the casting and the development of a number of foundry defects from thermal stresses (rat tails, veining). The degree of mould expansion then depends on the ability of the mixture to relax the dilatation of the sand grains. Different overall expansion rates are therefore achieved by mixtures using different types of binders, sands, additives or level of compaction in the mixture. Generally the thermal expansion is increasing especially when using high purity silica sands.

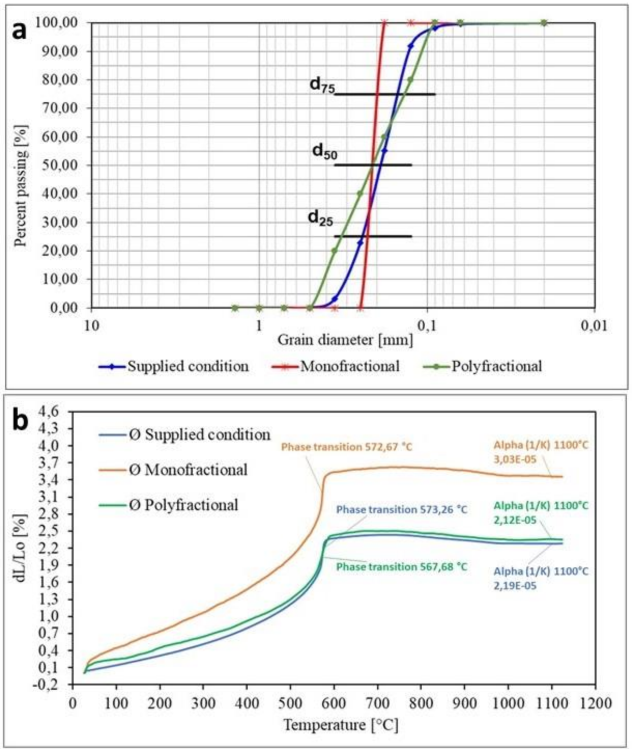

Fig. 2. (a) Cumulative curves of granularity and (b) dilatation curves for unsorted (supplied condition), monofractional and polyfractional sorting

The resulting dilation curves can be seen in Figure 2b. The highest values of linear thermal expansion were measured for the monofraction, where the average dilation value reached 3.46 %. For the polyfraction, an average dilation of 2.36 % and for the unsorted sand 2.28 % dilation were achieved. Thus, the monofraction achieved 51.8 % higher dilation compared to the unsorted sample. Thus, the effect of different particle sizes of individual sand grains and sorting levels was confirmed. In the case of monofractured sands with perfectly round grains, the high dilation is caused by the minimal volume of pores between the individual grains, which cannot effectively compensate the dilatation. In the case of this experiment, however, the sand was a sand with a more or less angular shape and a smooth grain surface. In this case, on the other hand, the volume of pores in the monofraction is highest due not to point contact of the grains, as would be the case with round grains, but to an area contact, where the grain edge surfaces touch each other. Each microdilatation of grains of the same size in the monofraction ultimately resulted in a higher macrodilatation of the entire sample. Even though the polyfractional sand had the same mean grain size d_{50}, it contained small and very fine grains in addition to the large grains, which accounted for 50% of the total weight of the sand. Thus, 50% of the grains were characterized by much less dilation due to their size than was the case in the monofractional sand, and the overall dilation of the polyfraction sample was therefore lower. This effect is then also evident when comparing the unsorted and polyfraction sands, where the difference in dilatation was only minimal, at 3.5 %. This slightly higher increase in dilatation in the case of polyfraction samples can be explained by slightly higher relative porosity (more free inter-grain spaces), either due to equal amounts of fine and coarse sand grains, or due to the composition of the sample using fewer fractions (sizes) of sand grains than in the supplied condition. That is to say, the absence of the finest fractions that would fill the inter-grain spaces. Thus, the results suggest that monofraction silica sands are the most susceptible to casting defects from retained stresses compared to the polyfraction or unsorted state.

The phase transition $\beta(SiO_2) \leftrightarrow \alpha(SiO_2)$ took place in the case of unsorted sand at 573.26 °C. In the case of monofraction, the phase transition took place at 572.67 °C and was accompanied by the most significant change in linear dilatation. In contrast, for the polyfraction, where the change in linear dilation is comparable to the unsorted samples, the phase transition took place as early as 567.68 °C, i.e. 5.58 °C lower temperature. This is most likely again an effect of the granulometric composition and the sorting degree. From this point of view, it appears to be more advantageous to use the sand in the unsorted state, since the mould or core will undergo a sharp change in dilation at a higher temperature during casting. The temperature difference of 5.58 °C is, however, negligible considering the degree of mould heating during casting.

4. Conclusions

On the basis of the sieve analysis performed, the individual sand fractions were sorted and then mixed in different proportions to form monofraction, polyfraction and unsorted samples, i.e. in the supplied condition with the same d_{50} of 0.21 mm ± 0.02 mm. For all the samples, the individual parameters of the granulometric composition were evaluated and the thermal dilatation was measured. The influence of the sorting degree of sand on the dilatation value was confirmed, with the highest thermal dilatation values being achieved by the monofraction samples, namely 3.46 %, 51.8 % higher than the case of the unsorted supplied condition. Thus, given the results, an increased incidence of stress-strain defects such as veining or dimensional changes of castings, and associated reduced casting quality, can be expected when using pure monofraction silica sands.

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