EFFECT OF CHEMICAL COMPOSITION OF SILICA SAND ON THERMAL DILATATION

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https://doi.org/10.37904/metal.2023.4682

Abstract

One of the factors influencing the surface quality of castings is the resulting thermal expansion when silica sands are used. This is characterised both by its high value compared to other non-silica sands, and by its typical discontinuous behaviour, leading in many cases to defects such as veining or increased surface roughness, which further lead to increased costs of processing the castings or, in extreme cases, to scrap pieces. The amount of thermal expansion of silica sand is influenced by various factors, including granulometric composition and chemical purity. It is the SiO_2 content of the sand that contributes significantly to the degree of dilation, and which can vary depending on grain size alone. Two silica sand samples from the same locality of origin with different mean grain sizes were evaluated. The granulometric composition as well as the SiO_2 and impurity content were evaluated by SEM analysis and XRFS and their effect on the linear thermal expansion. The effect of grain size on the final SiO_2 content was observed, with sands of the same origin with larger grains containing 1.3% more SiO_2 and achieving 36.8% higher dilatation. This combination increases the susceptibility of the sand, and hence the resulting moulding mixture, to the formation of foundry defects from braked stress as veining.

Keywords: Silica sand, linear thermal expansion, chemical purity, SEM analysis, foundry defects

1. INTRODUCTION

In European foundries, non-silica or highly pure silica sands with varying particle size distributions and different levels of expansion are used for the production of disposable sand molds due to the high-quality requirements for castings [1]. Silica sands, compared to other sands, are the most widely used and readily available raw material [2]. However, their main disadvantage is their non-linear thermal expansion characteristic of quartz, the main component. Of particular importance from a foundry perspective is the β↔α SiO_2 transformation occurring at a temperature of 573°C, accompanied by a volume change of up to 3.9% [3]. The expansion of individual grains subsequently contributes to the overall expansion of the molding mixture. When this expansion cannot be relaxed [4], it leads to the generation of stress in the mold or core, known as restrained dilatation stress, resulting in various foundry defects such as increased surface roughness, veining, and potential penetration defects [5-8]. A study [9] confirmed that in addition to grain size, shape, particle size distribution, and mold or core compaction, the magnitude of dilatation also depends on the chemical composition of the silica sand, particularly the SiO_2 content. It was found that a higher SiO_2 content in the sand sample corresponds to a higher degree of thermal expansion. However, the direct relationship between grain size, chemical purity, and their direct influence on dilatation has been scarcely investigated.

Foundry sands are supplied to foundries already classified according to the desired median particle size d_{50}. The aim of this experiment is to determine the difference in chemical purity of sands from the same mining location but with different mean grain sizes, and its impact on the resulting degree of thermal expansion and potential susceptibility to defects caused by restrained stress.

2. MATERIALS AND METHODS

For the purpose of the experiment, natural washed silica sand from the same deposit, Biala Góra in Poland, was chosen. This silica sand is characterized by smooth-grained particles and a high SiO_2 content (declared as 99.5% SiO_2). Two different types of sand were used, provided by the manufacturer, differing in their mean grain size based on the grading level. They were labeled as BG 21 (finer grain) and BG 27 (coarser grain) according to the manufacturer's designation.

The samples underwent a complete sieve analysis using a laboratory sieve shaker with sieves ranging from approximately 1.0 to 0.063 mm, including the determination of washout fractions and the construction of grain size distribution curves for precise determination of the mean grain size (d_{50}).

Subsequently, the individual samples were evaluated using a scanning electron microscope (SEM) with a field emission gun (FEG) and autoemission nozzle FEI QUANTA - FEG 450. Backscattered electron images were taken at magnifications of 120x and 600x, and a chemical analysis was performed using an energy-dispersive X-ray spectroscopy (EDX) analyzer.

The precise chemical composition of the samples was determined using X-ray fluorescence spectroscopy (XRFS) on a Rigaku Supermini 200 analyzer. Prior to analysis, sand samples were converted into tablets consisting of 4 g finely ground sample (grain size <0.1 mm) and 1 g of Hoechst wax C binder.

The dilatation measurements were conducted using a Netzsch DIL402/C dilatometer with a special corundum container designed for measuring bulk materials. The samples were freely poured into the container and compacted with three strikes to achieve a sample height of 10 ± 0.1 mm. The measurements were carried out under an inert atmosphere of 6.0 argon at a constant flow rate of 100 ml/min, within a temperature range of 25 - 1130°C. The temperature was gradually increased at a rate of 15°C/min during the measurement process.

All measurements were always conducted on at least 3 samples of each sand. If the measurement result showed deviations greater than 5% compared to other results for the same sample, the measurement was repeated.

3. RESULTS AND DISCUSSION

The sieve analysis reveals different grain sizes of the sand samples (**Figure 1**). While BG 21 had the majority of grains in fractions below 0.180 mm and 0.125 mm, in the case of BG 27, the highest representation was in the 0.250 mm and 0.180 mm fractions. The mean grain size (d_{50}) corresponded to 0.19 mm for silica sand BG 21 and 0.23 mm for BG 27. This confirms the coarser grading of silica sand BG 27.

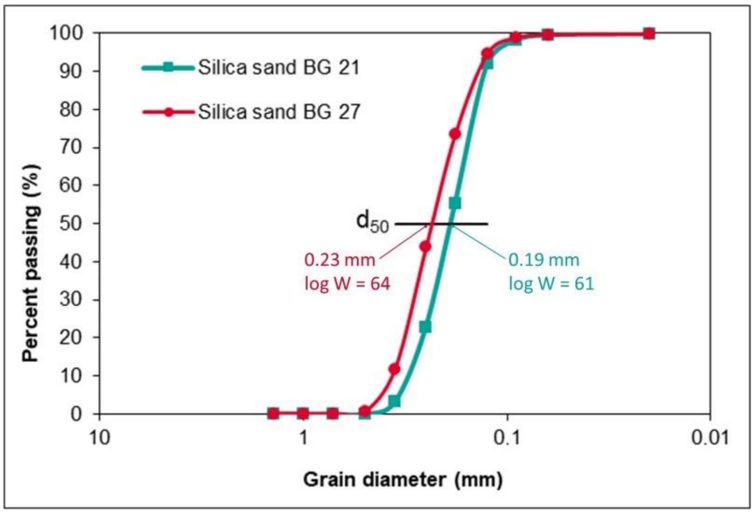

Figure 1 Cumulative curves of granularity for BG 21 and BG 27 samples

Chemical analysis using XRFS demonstrated in **Table 1** distinct chemical compositions of both sand samples, despite their origin from the same source. The influence of granulometric grading on chemical composition was evident, with larger grains exhibiting higher chemical purity in terms of SiO_2 content. In the case of BG 27, the SiO_2 content was 99.127%, 1.3% higher than that of BG 21 (97.8% SiO_2). BG 21, with its lower chemical purity, also showed higher concentrations of Al_2O_3, K_2O, TiO_2, and Fe_2O_3, indicating impurities, clay residues, and feldspar residues.

Table 1 Chemical composition by XRFS (chemical purity of BG 21 and BG 27 samples)

	SiO_2 (wt%)	Al_2O_3 (wt%)	SO_3 (wt%)	K_2O (wt%)	CaO (wt%)	TiO_2 (wt%)	Fe_2O_3 (wt%)	ZrO_2 (wt%)
BG 21	97.800	0.778	0.012	0.083	0.036	0.829	0.234	0.151
BG 27	99.127	0.459	0.028	0.052	0.052	0.107	0.145	0.030

SEM analysis further confirmed this chemical composition, with higher presence of non-silica white grains observed in the BG 21 sample, as shown in **Figure 2**. These white particles, confirmed by EDX analysis, exhibited a high content of Ti and TiO_2. Visual evaluation also revealed slight differences in the shape of grains between both samples, with larger grains in BG 27 appearing more rounded at the edges compared to the fine grains in BG 21. This suggests a higher concentration of sharp-edged grains in BG 27, possibly due to fragmentation or the presence of non-silica grains.

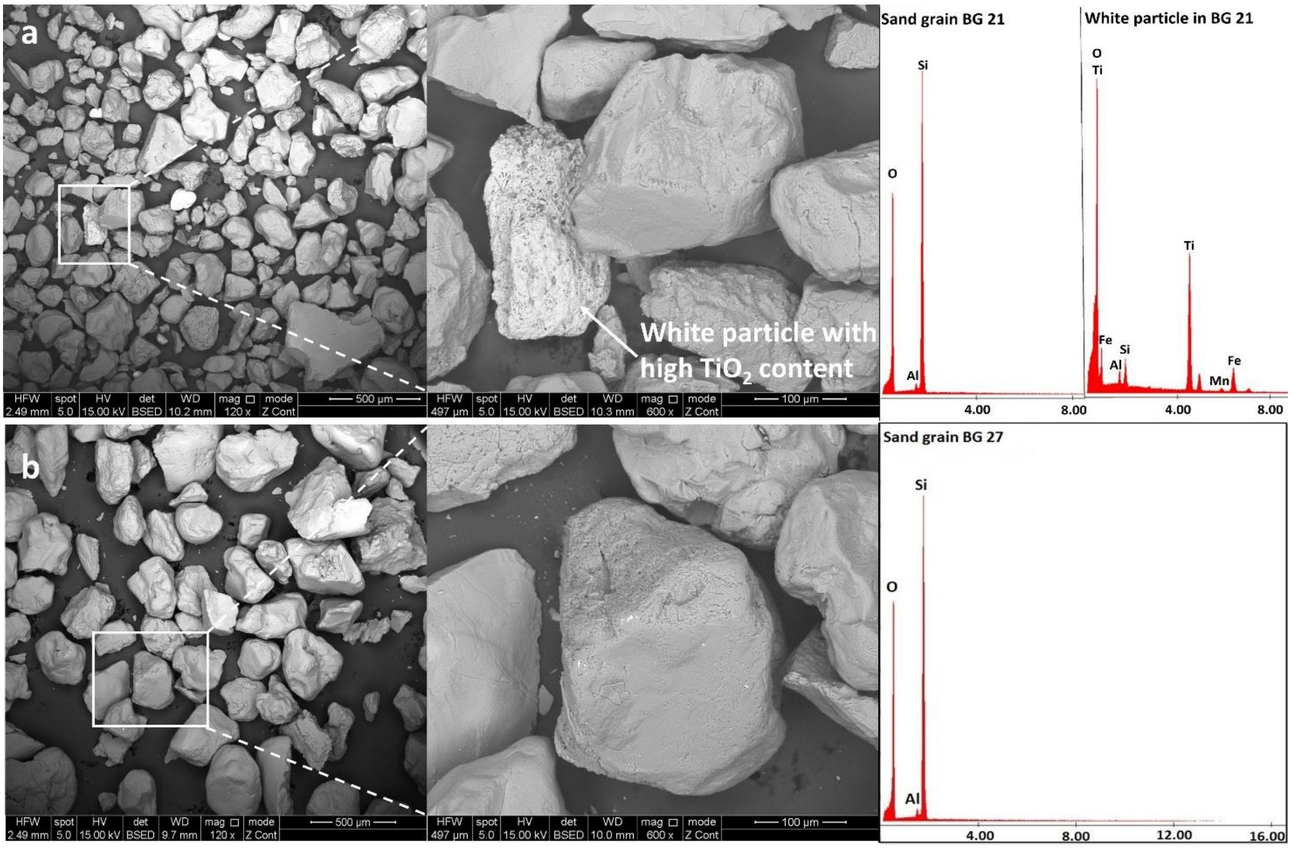

Figure 2 The results of SEM analysis and EXD – sand detail for: a) BG 21, b) BG 27

The final dilatation of the two samples differed significantly (**Figure 3**). The thermal dilatation of coarse-grained BG 27 reached a value of 3.12%, 36.8% higher than the fine-grained BG 27, which had a dilatation of only 2.28%. Previous studies have indicated the influence of grain size on the resulting dilatation of silica sand, with larger grains exhibiting higher dilatation. It was also found that pure silica generally demonstrates the highest dilatation since the presence of feldspars and other minerals with lower refractoriness can reduce the dilatation rate. However, these two factors were not directly correlated. The measurement results confirm these previous findings, demonstrating that the reason why larger grains exhibit higher dilatation is, in fact, their higher chemical purity, while sands with smaller grains contain more particles with different chemical compositions than silica.

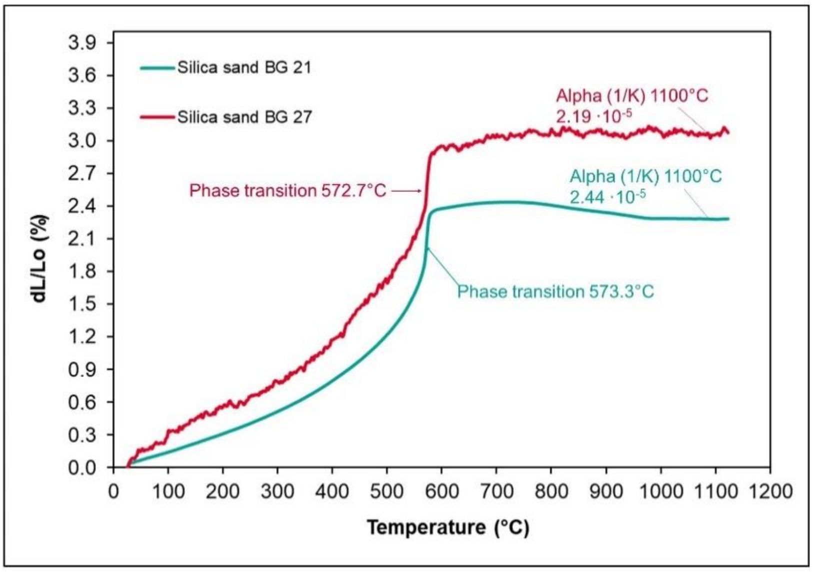

Figure 3 Thermal dilatations for BG 21 and BG 27

In the case of silica sand, thermal expansion has a discontinuous character, which is caused by the reversible phase change from β-SiO_2 to α-SiO_2. It is precisely this phase transformation and its abruptness that leads to the cracking of sand molds and cores, allowing the flow of metal into these cracks and the formation of defects such as veining. By evaluating the dilatation, a difference in the temperature at the beginning of this phase transformation was observed (**Figure 3**). In the case of chemically purer sands with larger grains (BG 27), the phase transformation began at a temperature of 572.7°C, 0.6°C lower than in the case of the less chemically pure sand BG 21 (beginning of transformation at 573.3°C). Therefore, it can be inferred that the higher the SiO_2 content in the sand, the earlier the phase transformation occurs, or at a lower temperature.

In earlier studies, the dilation of silica sands was always associated with grain size, resulting in the conclusion that larger grains dilate more than smaller grains. Measurement results demonstrate that the reason larger grains dilate more is actually due to their higher chemical purity, whereas sands with smaller grains contain more particles with a different chemical composition than quartz. Sands with larger grains, therefore, with a coarser granulometric composition, are typically used for the production of larger castings, mostly made of iron alloys, such as cast iron or cast steel. In these cases, there is also a higher degree of overheating of the silica sand at the interface between the mold and the metal above the β-SiO_2 to α-SiO_2 transformation temperature, and due to the higher chemical purity of the coarse-grained sand, there is a higher risk of defects caused by restrained stress, most commonly increased surface roughness or, in the worst case, veining. These defects then need to be costly removed by grinding on accessible surfaces, and in the case of inaccessible internal surfaces, they can potentially result in irreparable scrap pieces. A more suitable option in the case of coarse-grained sands could be the replacement with silica sands of lower chemical purity. However, reducing one risk in this case would lead to the emergence of another, as grains containing a significant amount of impurities or feldspars, in particular, significantly decrease the refractoriness of the entire mixture and, conversely, increase the occurrence of defects such as burn-in. Therefore, it is always necessary to choose the molding mixture and the type of sand used with regard to the nature of the production, the propensity for various defects, and the possibilities of suitable measures for specific operations.

4. CONCLUSION

This study observed the influence of grain size on the final SiO_2 content and the degree of thermal dilation of sand samples from the same origin but with different mean grain sizes (d_{50}). The results indicated that sands with larger grains contained 1.3% more SiO_2 and achieved 36.8% higher dilation. Furthermore, sands with smaller grain sizes had higher levels of impurities and contaminants, which were confirmed by XRFS analysis, and subsequent SEM analysis confirmed the presence of "white particles" with high TiO_2 content. Thus, the impact of sand sorting based on mean grain size on its chemical purity and resulting degree of dilatation was demonstrated. The combination of higher chemical purity and high dilatation increases the sensitivity of the sand, and consequently the resulting molding mixture, to the formation of defects associated with restrained stress (veinings). Conversely, a higher presence of impurities or feldspars may lead to increased occurrences of defects such as burn-in sand.

ACKNOWLEDGEMENTS

This research was funded by the project of MEYS (grant number CZ.02.1.01/0.0/0.0/17_049/0008399). This research was carried out with the support of projects of student grant competition (project number SP2023/022). Experimental results were accomplished by using Large Research Infrastructure ENREGAT supported by the Ministry of Education, Youth and Sports of the Czech Republic under project No. LM2023056.

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