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Dilatometric Characterization of Foundry Sands

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Abstract

The goal of this contribution is summary of physical – chemistry properties of usually used foundry silica and no – silica sands in Czech foundries. With the help of dilatometry analysis theoretical assumptions of influence of grain shape and size on dilatation value of sands were confirmed. Determined was the possibility of dilatometry analysis employment for preparing special (hybrid) sands with lower and/or more linear character of dilatation.

Keywords: Innovative Foundry Technologies and Materials, Product Development, Silica Sands, Hybrid Sands, Dilatometry and Chemical Analysis

1. Introduction

Foundry technology use a lot of various natural materials – sands for preparing mixtures and cores. Sand is defined as granular, refractory major portion of mixture (90 – 98% in dependence on used binder) with non – plastic character. Grains sand size has to be over then 0.02 mm. Sand properties depend on its chemical and mineralogical composition; particle – size distribution and shape of grains.

Foundry sand markedly affects moulding mixture properties, especially mechanical properties (e.g. green compression strength, splitting strength etc.), physical – thermal accumulation, heat conductivity, dilatometric behaviour and generation of tension from braked dilatation [1, 2].

Sands are usually divided on the basis of their origin, chemical character, grain shape etc. A natural material as silica sand or olivine or synthetic sands (dunite, chamotte) is the mainly used classification of foundry sands.

According to chemical nature foundry sands can be divided on “acid sand” – silica sand; “neutral sand” – chamotte, chromite and “basic sand” – magnesite. This classification is very important for choosing optimal sand for casting made from selected alloy. For example reaction between silica sand and oxides of special steels (Mn – steel) are very well known.

Except of physical – chemistry properties of sand suitable economic features are cardinal parameter for using of given sand, mainly acquisition costs and availability. From this point of view the most widespread sand of middle Europe is silica sand. In the north Europe foundry technology prefers olivine sand. On the other hand for keeping optimal casting production it is better to combine several kind of sand with reference to their physical – chemistry properties (chemical composition – ratio of feldspar, pH, coefficient of thermal accumulation etc.).

Foundry sand based on silica is the most used sand in foundry technology according to reasons mentioned above. Silica is the most widespread mineral occurring in the nature in optimal shape and its properties under elevated temperatures are sufficient for standard utilization.

On the other hand utilization of silica sand for moulding mixture preparations affords a few technological or hygienic problems. At first, silica sand should be a cause of danger pneumonia disease – silicosis. Due to acid nature of silica sand it can react with basic oxides to formation low – melting compound, e.g. fayalite ($2FeO \cdot SiO_2$, melting point 1205°C), thus the melting point of sand decrease. The most important disadvantage of silica sand utilization is its behaviour at elevated temperatures. As a result of modification varies silica sand changes its mass density that it is also results in volume changes.

Especially modification changes occur at
573°C: $\beta(SiO_2) \rightarrow \alpha(SiO_2)$
(volume change about 0,8%)
1025°C α (SiO_2)→ α – cristobalite
(volume change about 15,0%)

Result of modifications changes is non – linear (dis-continuous) character of dilatation. Dis – continuous process of dilatation and its high value causes accumulation of tension in a mould during breaking of its discrete dilatation. Increase of tension value in a facing part of mould can lead to forming a lot of casting defects, especially scabs, veining, sand inclusions etc.

The goal of this contribution is summary of physical – chemistry properties of usually used foundry silica and no – silica sands in Czech foundries. With the help of dilatometric analysis confirm theoretical assumptions of influence of grain shape and size on dilatation value of sands. Determinate a possibility of dilatometric analysis employing for preparing special (hybrid) sands with lower and/or more linear character of dilatation.

2. Materials and methods

2.1. Used raw materials

In order to determination of basic physical – chemistry properties range of sands usually used in foundries of Czech region were chosen. These samples was divided into a few groups: (i) silica sands: Provodín (CZ), Šajdíkovehumence – ŠH (SR), Grudzeń Las – GL (PL), (ii) the other natural sands – olivine (Nor), chromite (JAR),(iii) synthetic sand – chamotte (CZ), dunite (AUT), kerphalite (Fr.) and Specialsand (Ger). Sample of ŠH sand was selected as a standard.

2.2. Methods

General description of sands (determination of physical – chemistry properties) includes determination of loss of ignition. Dried samples of sand (under temperature of 105 °C up to constant weight according to the CSN 44 1377) were exposed to temperature 900°C for 2 hours and loss of weight was evaluated. Values of pH were determined in water suspension (1:10 ratio) by employing of WTW InoLab pH/Cond Level 1.

Granulometry (distribution of particles) of studied sands was determined by using equipment Mastersizer 200, ver. 5.60 UK. Thermo dynamical function of probability – log W was evaluated [1]. Parameter log W describes a character of particle size distribution without any information about granulometry integral curve. This parameter of particle size distribution ranged from 0 (mono – fraction) up to 202.53. The maximum of log W depends on a number of sieves, which were used for granulometry analysis.

Dilatometric analyses were conducted on laboratory samples at 5 °K/min under Argon protective atmosphere by using NETZSCH – Gerätebau GmbH equipment DIL 402C/7 at temperature range from laboratory temperature (20 – 25°C) up to 1100°C.

2.3. Dilatometry analysis

Dilatometry analysis is thermoanalytical technique for the measurement of expansion or shrinkage of a material when subjected to a controlled temperature/time program.

Accurate measurement of dimensional changes is required in the traditional ceramic and glass industries and for carrying out sintering studies on reactive powders used in the fields Results of dilatometry analysis are displayed as thermo –dilatometric curves as dL/dL0 = f(T) (length changes) or dV/dV0 = f(T) (volume changes) dependence [3].

Degree of material expansion or shrinkage can be also described as physical expansion coefficient. The
physical expansion coefficient is the slope of the relative length-change curve at the respective temperature. Thus it corresponds to the first derivative of the dL/Lo curve according to the temperature. The following equation is specified as length expansion coefficient:

$$\alpha_1(T) = \frac{1}{l_0}\left(\frac{\partial l}{\partial T}\right) \tag{1}$$

where l_0 corresponds to sample length at 20°C.

Length changes (dilatation characteristics) of sand or more precisely moulding mixture mainly depend on grain size and shape and also on chemical composition of sand. It is usually known, that spheroidal shape of grain showed higher dilatation then angular grain, because there is not enough free space between spheroidal grains to relax a tension formed due to length (volume) changes of grain at elevated temperatures. From the same point of view bulk density has same affect. With increasing value of bulk density, dilatation value of sand (moulding mixture) increases. Higher degree of dilatation changes will also be observed for bigger grains.

3. Experimental results end discussion

In order to basic characterization of sand physical –chemical properties the loss of ignition (LOI) and pH was determined. It was also replenished by chemical composition of sands and their melting point. Experimental data added by literature parameters [1, 4 – 9] are summarised in Table 1.

Table 1.
Chemical analysis

	Chemical composition (major parts)	density mass	density bulk	pH	LOI	Melting point*
	[%]	[g/cm3]		[-]	[%]	[°C]
Provodin	98,5% SiO_2, 0,4% Al_2O_3, 0,05% Fe_2O_3,	2,6	1,5	6,9	0,05	±1713
ŠH	96% SiO_2, 2,0% Al_2O_3, 0,4% Fe_2O_3,			6,8	0,24	
GL	99,3% SiO_2, 0,1% Al_2O_3, 0,03% Fe_2O_3,			7,1	0,09	
Olivine	49% MgO, 41% SiO_2, 7% Fe_2O_3, 0,5% Al_2O_3	3,4	1,85	8,9	0,30	±1760
Chromite	46% Cr_2O_3, 15,2% Al_2O_3, 28,3% Fe_2O_3, 9,4% MgO, 0,8% SiO_2,	4,5	2,5	8,4	0,01	2300
Chamotte	42,1% Al_2O_3, 52,6% SiO_2, 2,12% TiO_2, 1,19% Fe_2O_3,	2,3	1,54	7,9	0,06	nad 1730
Dunite	44% MgO, 35% SiO_2, 8,5% FeO, 0,2% CaO	3,1	1,45	9,6	0,01	±1380
Kerphalite	58,0% Al_2O_3,41,0% SiO_2,	3,13	1,7	7,3	0,06	1850

*) in dependence on chemical composition

Values of pH confirmed partly theoretical assumptions (samples of Provodin, ŠH, GL). These sands based on silica show only slightly acid character (6.8 – 7.1) due to different chemical composition. It can influence of its melting point. With increasing amount of feldspar, the value of melting point decrease. The most purity silica sand was found for GL sample (99.3%). Important contrast was found for bulk and mass density values of single sand samples. Mass density was ranged from 2.3 g/cm^3 (chamotte) up to 4.5 g/cm^3 (chromite). These differences can influence a possibility of hybrid sand preparation. Cores prepared from hybrid sand includes materials of different bulk density will have heterogeneous character due to un-mixing of used sands during core preparation.

All the samples of studied sand demonstrate high mineralogical purity in relation to minimal values of LOI (burned portion). The highest LOI value was found for non –silica sand, olivine (0.30%).

3.1. Granulometric and chemical analysis

Granulometry analyses give key parameters about sand properties for possible utilization as foundry sand. The most important value of granulometry is median grain (determined as d_{50} or AFS Number). AFS number is usually used for sand description in North America region. It valid, that increasing AFS number means decreasing d_{50}. Results obtained by granulometry analysis (Table 2) shows that the largest median grain (d_{50}) indicate chamotte (1,21 mm) in contrast to the smallest value of median grain of olivine (0.21 mm). Furthermore, it was found the most uniformed occurrence of single fractions for olivine, which was confirmed by the value log W = 138.89 (olivine), in contrast to Specialsand, value of log W = 83.87. Shape of chromite and specialsand grains approximate to sphere, both values of sand samples was SPHT = 0.923 in contrast to the most angular grains of chamotte (SPHT = 0.832).

Table 2.
Granulometric analysis

	SPHT	Medium grain d50	Medium grain AFS	Log W
	[-]	[mm]	[-]	[-]
Provodin	0,855	0,35	40,51	111,99
ŠH	0,905	0,25	55,16	92,03
GL	0,856	0,25	59,82	100,65
Olivine	0,846	0,21	56,41	138,89
Chromite	0,923	0,43	51,10	121,27
Chamotte	0,831	1,21	12,34	89,71
Dunite	0,838	0,34	48,26	126,63
Kerphalite	0,837	0,32	50,75	101,18
Specialsand	0,923	0,32	46,29	83,87

3.2. Results of dilatometry analysis

Behaviour of sand samples at elevated temperatures was determined by using dilatometry analysis. At first influence of size and shape of grain on degree of length changes was evaluated for standard sample (ŠH). It was confirmed dis-continuous character of silica sand dilatation due to modification changes theoretically occurs at 573 °C. Exact value of modification temperature depends on chemical composition of studied sample. It was found a difference of dilatation value between dissimilar fractions of the same sand sample (Fig. 1).

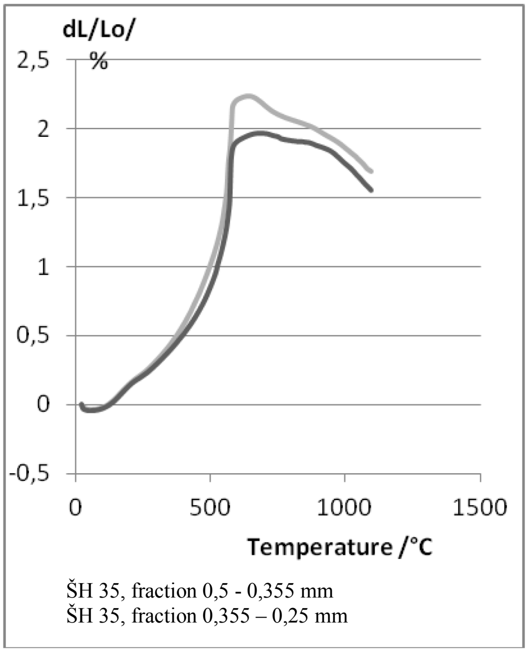

Fig. 1. Thermal expansion of sand ŠH 35

Fraction of grain size 0,355 – 0,50 mm exhibits higher value of dilatation (dl/dl0 = 2,35%) in contrast to dl/dl0 = 2.0% founded for fraction of 0,25 – 0,335 mm. It is very interesting, that difference of observed dilatation values of adjacent fractions is so enormous (15%).Comparison of two kind of silica sand with different grain shape is shown in Fig. 2.

For determination of influence of grain shape on degree of dilatation samples of silica sand GL and Provodin was chosen. Grains shape of GL is more spherical (SPHT = 0.856) then angular grains of Provodin sand (SPHT = 0,855). Obtained results confirm a fact, that sands of spherical shape grains exhibit higher dilatation then sands wit angular grain due to not existing free space for dilatation relaxing between individual grains.

Sand mixtures based on ŠH35 and Olivine; ŠH35-Olivine with the most closed grain configuration and finally ŠH 35 and Specialsand were selected as hybrid sands.

The sands were chosen to eliminate phase transition $\beta(SiO_2) \rightarrow \alpha(SiO_2)$ and to product sand with wide grain distribution in order to decrease of discontinual thermal out dilatometry behaviours of foundry sands dilatation. Similar bulk density of used sands with silica sand ŠH 35, which prevents unmixing of individual hybrid sand components, and their low costs are the reason for their application in these experiments.

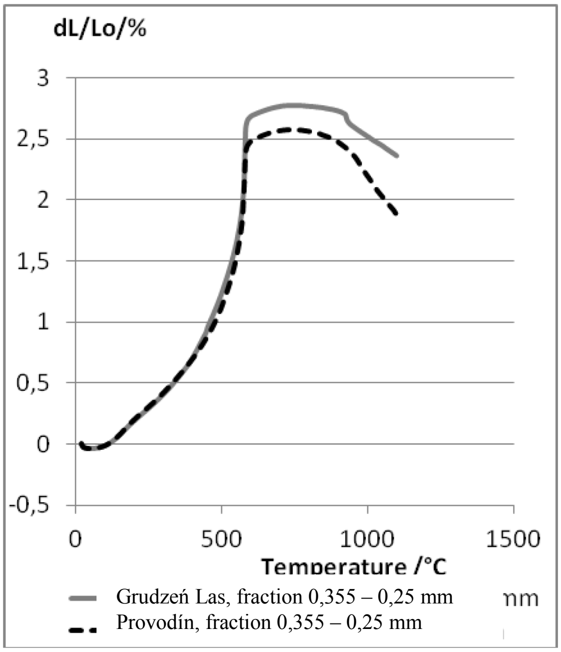

Fig. 2. Thermal expansion of silica sand

Results of these experiments was compared with dilatation curves of no-silica sands, which exhibit lower degree and linear character of length changes of sample at elevated temperatures (Fig 3). Dilatation curve of the closest arrangement of the system ŠH 35 - olivine (Fig. 3) does not show conversion (β (SiO_2) → α (SiO_2)) and the total value of the dilation is lower (0.9% at 980°C).

Hybrid sand system ŠH 35 - olivine assembled according to standard sieve analysis shows a phase transformation of SiO2, but the degree of dilatation is lower (up to 1.5% at 800 ° C) than the value of pure sand ŠH 35 (> 2%). Dilatation curve of hybrid sand aggregated on the same principle, using only Specialsand, indicate a smooth dilatation curve with a maximum of 0.85% at 1000 C.

3.3. Thermal expansion coefficient

As an additional measurement a thermal expansion coefficient of studied sand samples were determined (Fig. 4). It was found that the highest value of thermal expansion coefficient was obtained for sample GL (2,20607.10-5.K-1). It corresponds to results of dilatometry analysis. The lowest value exhibit a sample of chamotte, which confirms the theoretical assumption ab (influence of shape grains). Influence of grain size is also evident in the case of comparison of ŠH sample with different size of grains.

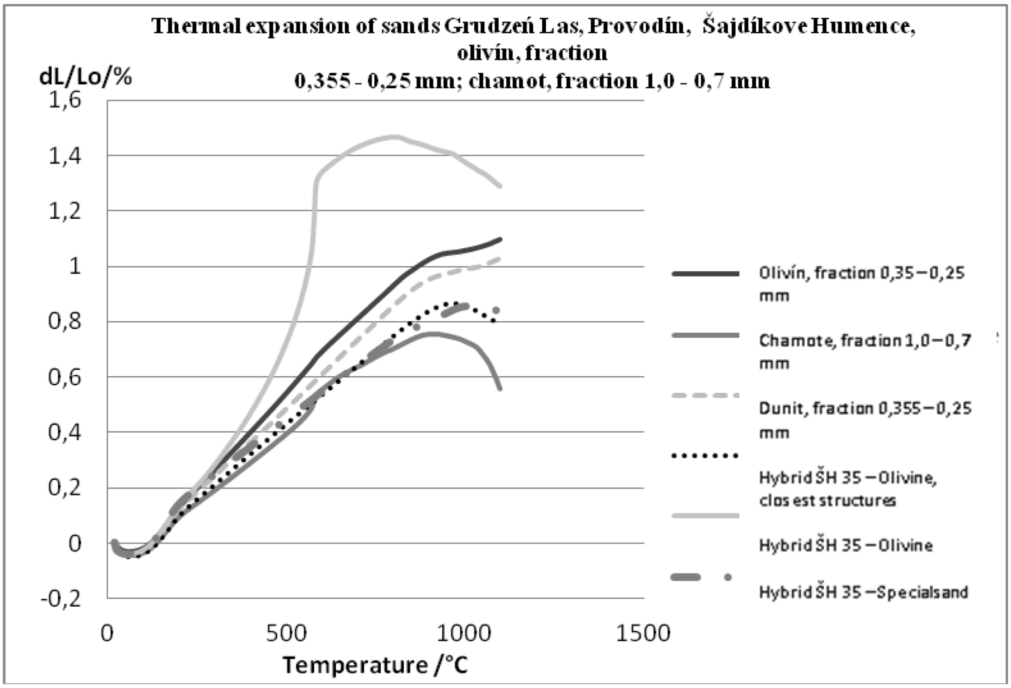

Fig. 3. Thermal expansion evaluated grog

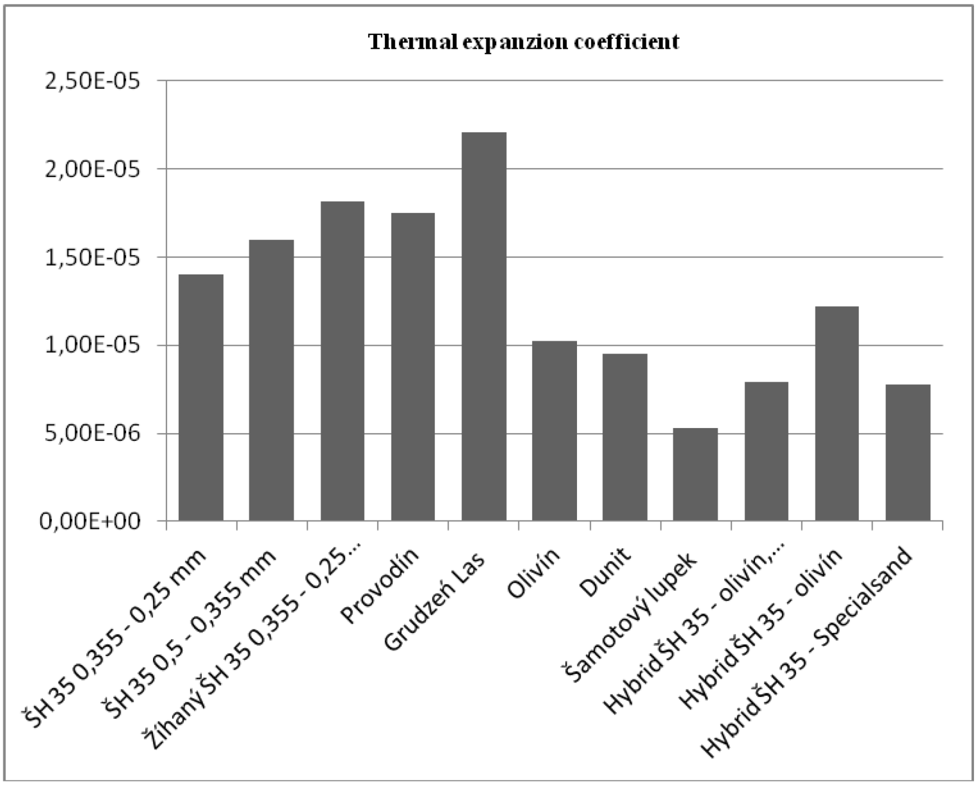

Fig. 4. Thermal expanzion coefficient

4. Conclusion

Dilatometry analysis is suitable tool for preparing hybrid foundry sand with adequate mainly physical – chemistry properties. On the basis of these experiments it is possible to eliminate dis-continuous character of silica sand dilatation.

From the obtained experiments it is evident there are a lot of differs between the sand samples. Spherical shape of grain was observed for Slovak sand ŠajdíkoveHumence grain, on the other hand the highest value of thermal expansion was found. From this point of view determination of influence of grain shape on dilatation was disabled.. Therefore, the Polish Grudzeń Las sand was also tested, and rounded isometric grains and high chemical purity was observed. The value of the dilatation of above described sands was compared with the sample of Provodin sand dilatation. This analysis confirmed the influence of grain shape on the final value of the dilatation and so that the spherical grains indicate a higher expansion than angular grains (Las Grudzeń - up to 2.8% at 780°C; Provodín up to 2.6% at 780°C).

The main reason of this variation is difference arrangement of grains. It was expected the value of dilatation is also affected by grain size, which was further verified. This claim was confirmed by measuring the fraction from 0.5 to 0.355 mm and 0.355 to 0.25 mm of ŠajdíkoveHumence sand when the value of dilatation greater fraction was higher (0.5 to 0.355 mm - up to 2.35% at 600°C 0.355 - 0.25 mm - up to 2% at 650°C). Further the dilatation of no-silica sand as olivine, dunite and chamotte was determined. Expected linear character of these sands dilatation was confirmed. Based on results of this measurement hybrid composite sand consists of olivine and quartz and/or Specialsand and ŠH 35were prepared. Dilatation curve of the closest arrangement of the system ŠH 35 - olivine does not show conversion (β (SiO_2) → α (SiO_2)) and the total value of the dilation is lower (0.9% at 980°C). Hybrid sand system ŠH 35 - olivine assembled according to standard sieve analysis shows a phase transformation of SiO_2, but the degree of dilatation is lower (up to 1.5% at 800°C) than the value of pure sand ŠH 35 (> 2%). Dilatation curve of hybrid sand aggregated on the same principle, using only Specialsand, indicate a smooth dilatation curve with a maximum of 0.85% at 1000°C. These systems require further investigation to be verified in real process under normal conditions, which is the subject of further research.

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