Thermal Deformation of Moulding and Core Sands with an Inorganic Binder Containing a Relaxation Additive

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Abstract

The paper presents the results of an investigation of the thermal deformation of moulding sands with an inorganic (geopolymer) binder with a relaxation additive, whose main task is to reduce the final (residual) strength and improves knocking-out properties of moulding sand. The moulding sand without a relaxation additive was the reference point. The research was carried out using the hot-distortion method (DMA apparatus from Multiserw-Morek). The results were combined with linear deformation studies with determination of the linear expansion factor (Netzsch DIL 402C dilatometer). The study showed that the introduction of relaxation additive has a positive effect on the thermal stability of moulding sand by limiting the measured deformation value, in relation to the moulding sand without additive. In addition, a relaxation additive slightly changes the course of the dilatometric curve. Change in the linear dimension of the moulding sand sample with the relaxation additive differs by only 0.05%, in comparison to the moulding sand without additive.

Keywords: Moulding sand, Inorganic binder, Geopolymer, Thermal deformation, Dilatometric studies

1. Introduction

The search for new, ecological and cheap foundry materials led to the development of inorganic binders. Moulding sands made with their participation are characterized by good mechanical properties [1-10]. Inorganic binders allow to obtain castings of high surface quality and they do not emit harmful gaseous products when moulds are poured with liquid metal [11]. Their main disadvantage is poor knocking out and poor susceptibility to the mechanical reclamation process [12-19]. High workload associated with knocking out and cleaning of castings, in particular of a complex shape, means that productivity decreases and production costs increase. Therefore, for many years, methods to reduce these technological inconveniences have been looked for [20-25].

The most well-known inorganic binder used in the moulding sand technology is hydrated sodium silicate, commonly known as water glass. Moulding sands with water glass can be cured with physical agents (temperature, microwave radiation) and through a chemical reaction - using a hardener. Their characteristic feature is an increase in the strength of sands as a result of the influence of temperature. It is observed twice. The first strengthening occurs in the temperature range of 200-300°C, while the second in the range of 600-800°C (the so-called II maximum strength) [12, 26-29]. The occurrence of the first maximum is attributed to the dehydration of unbound hydrated sodium silicate, and the second is the result of melting of dehydrated sodium silicate. There is a reaction between Na_2CO_3 and SiO_2 and formation of the $Na_2O \cdot 2SiO_2$ phase [27], the high strength of which leads to technological problems related to the difficulty of knocking out

moulds and cores. Increasing requirements concerning the environmental protection mean that moulding sands with inorganic binders are again gaining popularity. The result of research work in the field of improving the properties of sands with inorganic binders was the development of the geopolymer binders Rudal A and Geopol® offered by the Czech Company Sand-Team. They are described as modified water glasses containing inorganic polymers based on silicon and aluminium [22, 30-32]. The Rudal A system is dedicated to the technology based on the curing process under the influence of gaseous CO_2, whereas the Geopol® binder is intended for the preparation of moulding sands using the SA71-SA75 ester hardeners.

The own studies indicate, that the substitution of the hydrated sodium silicate binder by the geopolymer does not eliminate the problem of poor knocking out and low susceptibility to the mechanical reclamation process. Therefore, the paper [33] presents the effects of work related to improving this group of moulding sands with the use of mineral relaxant additives.

When modifying the composition of moulding or core sands, by introducing additional components, it should be borne in mind, that such operation should not adversely affect the mechanical and technological properties of sands.

From the point of view of technology, an important issue concerning the behaviour of moulding and core sands under the conditions of pouring moulds with liquid metal is their thermal deformation, which determines obtaining castings free of defects, with high dimensional accuracy, meeting quality requirements. In papers [34-37] discussing thermal deformations of moulding sands, it was pointed out that the mathematical models - currently used in simulation systems - also take into account the problem of dilatation between the mould and the casting, solidifying under the influence of high temperatures. The parameters used in these thermomechanical models (Young's modulus, Poisson's coefficient, yield point) and their changes with temperature changes are not really known for thermally unstable materials such as moulding or core sands.

The article presents the results of thermal deformation tests (hot-distortion) and the results of dilatometric examinations made for moulding sands with an inorganic binder with relaxation additives.

2. Materials for research

Material for investigations consisted of moulding sand with the inorganic binder Geopol®, containing mineral relaxants prepared on the basis of quartz sand from the "Szczakowa" mine. For comparison, moulding sand without additives was used. The sands were prepared according to the composition shown in Table 1.

Table 1.
Quantitative composition of moulding sands with the inorganic binder Geopol®

Sample	Type of the relaxation additive	Content of the additive in sand, parts by weight	Quartz sand, parts by weight	Content of the binder Geopol®, parts by weight	Content of the hardener SA72, % in relation to the binder
M0	-	-	100	12	8
M1	S1	2	100	12	8
M2	S2	1	100	12	8

For the tested additives and quartz sand, constituting the matrix of moulding sands, the sieve analysis was performed. Selected parameters of the tested samples obtained on its basis are presented in Table 2.

3. Research methodology

The research using the DMA apparatus from Multiserw-Morek, which allows to determine the temperature stability of sands and their tendency to deformations caused by thermal loads, were carried out. The measurement method consists of heating the sample and recording the deformation as a function of time (or temperature) until it is destroyed, or reaching the maximum deformation resulting from the limitations of the apparatus [38].

Dilatometric studies were performed using the Netzsch DIL 402C dilatometer. Samples measuring 25×8×6 mm were used. The heating rate was 10°C/min and the pusher pressure was 15 cN. This method also allowed to determine the coefficient of linear expansion, described by the law showing the body length dependence on temperature (1) [33, 39,40]:

$$l_T = l_0(1 + \alpha \Delta T) \tag{1}$$

where:
l_T - body length at temperature T,
l_0 - body length at temperature T_0,
$\Delta T = T - T_0$,
α - linear expansion coefficient.

After the transformation of the equation 1 to form 2, one can determine α (the linear expansion coefficient) which is equal to the tangent of the slope angle of the curve in the graph showing the dependence of the relative elongation $\Delta l/l_0$ on the temperature increase ΔT.

$$\frac{l_T - l_0}{l_0} = \alpha \Delta T \tag{2}$$

Table 2.
Sieve analysis of relaxation additives and quartz sand [33]

Parameter	Unit	Sample		
		Additive S1	Additive S2	Quartz sand
Main fraction		0.16/0.10/0.071	0.071/0.056/bottom	0.32/0.20/0.16
Average grain size, d_L	mm	0.08	0.06	0.23
Average grain size, $D50$	mm	0.10	0.07	0.26
Share of the main fraction, F_g	%	92.61	82.96	81.94
Distribution coefficient, S_0	-	1.27	1.93	1.27
Inclination indicator, S_k	-	1.04	0.98	1.00
Degree of homogeneity, GG	%	61.00	21.00	68.00
Specific surface, S_t	m^2/kg	27.36	38.35	9.42

4. Results and their discussion

Figure 1 shows the deformation of the moulding sand with the geopolymer binder Geopol®.

Fig. 1. Deformation of moulding sand with the geopolymer binder Geopol® during hot-distortion tests [33]

The obtained research results indicate, that the introduction of the relaxation additive "S1" (sand M1) and additive "S2" (sand M2) favours the thermal stabilization and limits the deformation value in relation to the moulding sand without additions (sand M0) (Fig. 2 and 3). A detailed analysis of the degree of deformation showed that the deformation value of the moulding sand without additives (sand M0) was initially +0.30 mm. Then, the change in the direction of deformation was recorded, and the final deformation value was -1.1%, in relation to the initial value. For the sand sample marked M1 the maximum strain of +0.35 mm was recorded while for M2 sand +0.75%.

The results of dilatometer tests show, that moulding sand with the geopolymer binder, which did not contain mineral additives, is characterized by a gentle course of the curve expressing the dependence of the linear dimension change of the sample in relation to the temperature. In a large part this course can be characterized as linear. In the temperature range 515-519°C the largest change in the sample size was recorded (approximately 0.80%), in relation to the initial dimension (Fig. 4) [33].
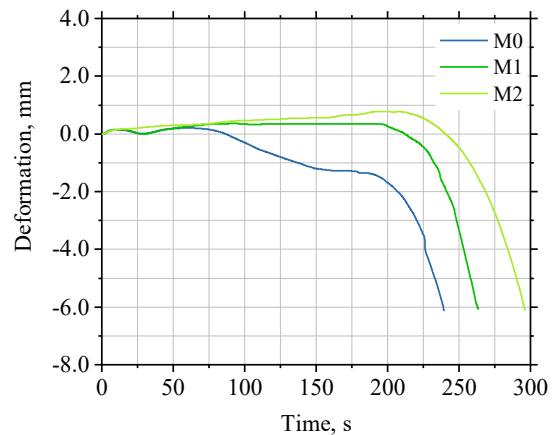

Fig. 2. Dependence of the thermal deformation of moulding sands with the geopolymer binder Geopol® on the heating time

In the case of moulding sand M1, the course of the dilatometric curve changes only slightly (Fig. 5). The average increase in the linear dimension of the sample is 0.85%, which is close to the moulding sand without additives.

Introduction of additive "S2" (sand M2) to the moulding sand with the geopolymer binder caused almost two times increase of the linear dimension of the sample - on average 1.52% (Fig.6), in relation to moulding sand with the additive "S1" (sand M1). This should be taken into account when designing the technological process in the foundry. However, it should be remembered that dilatometric examinations take place under conditions in which no forces are inhibited to increase the linear dimensions of the sample. Under real conditions, the movement of the moulding sand in the casting mould is limited - on the one hand - by the forming box, and - on the other - by the metallostatic pressure. The same occurs in the case of cores [33].
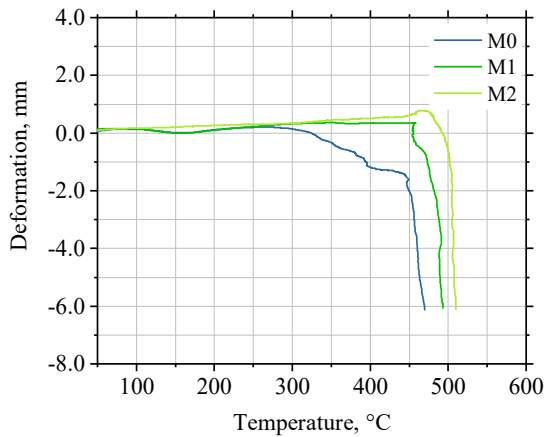
Fig. 3. Dependence of the thermal deformation of moulding sands with the geopolymer binder Geopol® on the temperature
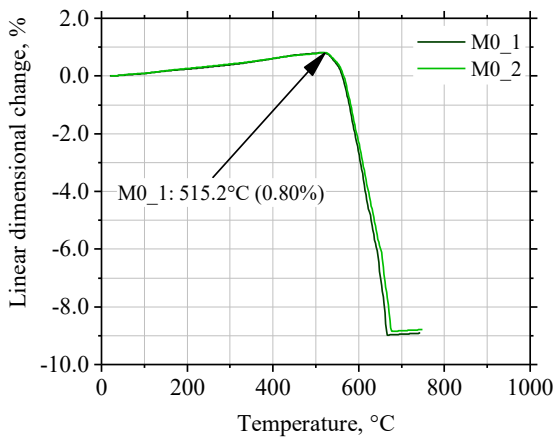

Fig. 5. Dilatometric curves for moulding sand M1

Fig. 4. Dilatometric curves for moulding sand M0

Fig. 6. Dilatometric curves for moulding sand M2

Figure 7 shows, that the introduction of relaxation additives to moulding sands with the geopolymer binder does not reduce their resistance to the temperature. In each case considered, the moulding sand sample degraded below 520°C, which may also be related to the thermal expansion of the matrix as a result of polymorphic transformation of quartz.
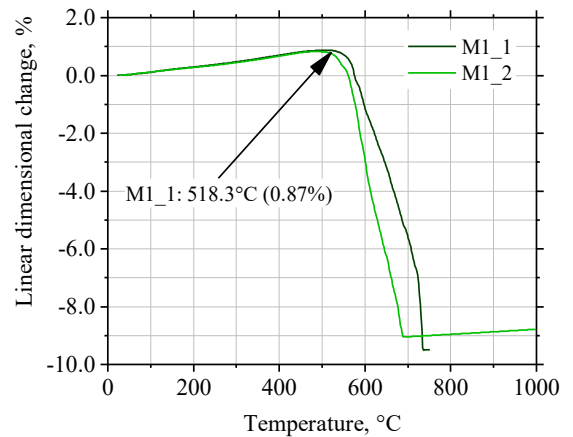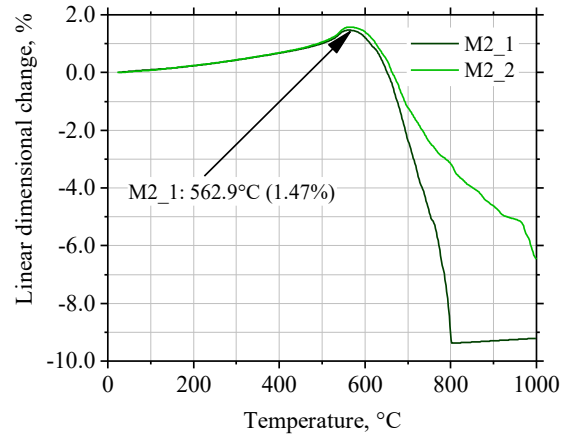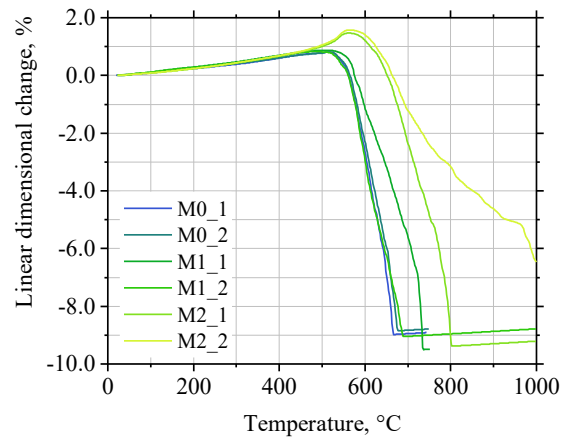

Fig. 7. A set of dilatometric curves for the examined sands

Table 3 presents the value of the linear expansion coefficient of the samples determined in the given temperature range.

Table 3.
The thermal expansion coefficients for moulding sands with the geopolymer binder and mineral relaxation additives

Designation of sand sample	Temperature range, °C	The value of the linear coefficient of thermal expansion $\alpha \times 10^{-6}\,K^{-1}$	The average value of the linear coefficient of thermal expansion $\alpha \times 10^{-6}\,K^{-1}$
M0_1	25-500	16.57	16.41
M0_2	25-500	16.24	
M1_1	25-500	18.06	18.28
M1_2	25-450	18.51	
M2_1	25-500	21.13	21.65
M2_2	25-500	22.17	

The obtained results indicate that the introduction of relaxation additives to sands causes an increase of the value of the linear expansion coefficient. In relation to sands without additives, an increase of 11% was recorded for moulding sand with additive "S1" (sand M1) and nearly 32% increase for moulding sand containing additive "S2" (sand M2) (Table 3).

5. Conclusions

Based on the results of the research, the written below conclusions were formulated.

- Introduction of the relaxation additive "S1" (sand M1) and additive "S2" (sand M2) promotes thermal stabilization and limits the deformation value, in relation to moulding sand without additions (sand M0)
- Moulding sand with the geopolymer binder without mineral additives, is characterized by a gentle course of the curve of the linear dimension change of the sample with respect to the temperature. This curve in a large part can be characterized as linear.
- Dilatometer curve for moulding sand with additive "S2" changes only slightly. The average increase in the linear dimension of the sample is 0.85%, which is close to the moulding sand without additive.
- Using additive "S1" as a loosening material should not significantly affect the deformation of the mould cavity, and the dimensional accuracy of the castings.
- When additive "S2" is added (moulding sand M2), the linear dimension of the sample increases almost twice as much as when additive "S1" is added (moulding sand M1). However it should be remembered that unlike under the measurement conditions, the moulding sand movement in the casting mould is limited - on the one hand - by the moulding box, and - on the other - by metallostatic pressure, as well as the construction of the casting, which can counteract this phenomenon.
- Addition of relaxation additives to moulding sand with the geopolymer binder does not reduce their resistance to the temperature. The sand samples were degraded at a similar temperature (below 520°C), which may result

from the polymorphic quartz transformation taking place and the change in the matrix volume associated with it.
- The course of dilatometric curves is similar to the course of curves of the thermal deformation of moulding sands (hot-distortion). Both research methods allow to capture characteristic points where the maximum deformation of the sample occurs.

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