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Thermally Hardened Moulding and Core Sands with Hydrated Sodium Silicate Designed for Al Alloy Castings

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Abstract

The necessity of obtaining high quality castings forces both researchers and producers to undertake research in the field of moulding sands. The key is to obtain moulding and core sands which will ensure relevant technological parameters along with high environmental standards. The most important group in this research constitutes of moulding sands with hydrated sodium silicate. The aim of the article is to propose optimized parameters of hardening process of moulding sands with hydrated sodium silicate prepared in warm-box technology. This work focuses on mechanical and thermal deformation of moulding sands with hydrated sodium silicate and inorganic additives prepared in warm-box technology. Tested moulding sands were hardened in the temperature of 140°C for different time periods. Bending strength, thermal deformation and thermal degradation was tested. Chosen parameters were tested immediately after hardening and after 1h of cooling. Conducted research proved that it is possible to eliminate inorganic additives from moulding sands compositions. Moulding sands without additives have good enough strength properties and their economic and ecological character is improved.

Keywords: Innovative Foundry Technologies and Materials, Moulding sands, Hydrated sodium silicate, Thermal hardening

1. Introduction

The growing demands placed on moulding and core sands create the need to seek further solutions in terms of their properties. There are several requirements that a modern core mixture has to face, among them are: high resistance to humidity and temperature (mainly during storage), sufficient strength (both for handling and mould assembly), high resistance to erosion and penetration by molten metal, low thermal deformation. What is more, modern moulding and core sands should be easy to shake-out from the finished casting, and need to have good reclamation ability [1-4]. All of the mentioned requirements can be easily achieved by using moulding sands bonded with petrochemical resins. Unfortunately this solution is not environmentally friendly. Requirements for high quality castings determine the path of scientific investigations. The main goal is to obtain moulding and core sands which not only have good technological properties, but are also environmentally friendly. In the Department of Moulding Materials on Faculty of Foundry Engineering AGH (University of Science and Technology) research on new binding systems based on ecological inorganic binders has been conducted. The biggest group of inorganic binders includes moulding sands with hydrated sodium silicate. Unfortunately this eco-friendly inorganic character of the binder is the cause of moulding sand's low knock-out properties and their low ability to undergo mechanical reclamation.

From the standpoint of knock-out properties, the use of moulding sands with hydrated sodium silicate for casting aluminum alloys is fully justified. The pouring temperature of the liquid alloy coincides with the temperature of minimum retained strength R_c^{tk} of the moulding sands with hydrated sodium silicate (600°C) is present [5]. This argument supports the use of moulding sands with hydrated sodium silicate on ceramic moulds for aluminum casting.

Moulding sands bonded with inorganic hydrated sodium silicate provides a variety of hardening solutions. It is possible to cure the hydrated sodium moulding sand with gaseous media such as CO_2 or air, liquid or solid hardeners [6] or microwaves [7-10].

Thermally hardened moulding sands create the group of so-called hot-box moulding sands. The classic hot-box process is a development of the shell-forming process. One of it's developments is warm-box process, which is a kind of thermally hardened technology with decreased temperature of hardening [6]. Due to the high strength and resistance of the cured moulding sand, the hot-box technology is used to produce the most responsible cores, such as cores used for detailed internal engine cooling parts. The shell-forming method for making thin-walled castings is still widely used, especially in the automotive industry [6, 11-12]. Although the most popular version is based on organic resins, the inorganic technology developed on the basis on hydrated sodium silicate is gaining interest in companies as well as researchers [13-17].

The aim of this paper is to optimize the parameters of hardening process of moulding sands with hydrated sodium silicate prepared in warm-box technology.

2. Methodology

The paper presents mechanical deformation tests conducted in ambient temperature and thermal deformation tests of moulding sands with hydrated sodium silicate prepared in warm-box technology. The used binder is a modified mixture of a silicate binder containing lithium and sodium hydroxide. The binder under ambient conditions takes the form of a colorless, odorless liquid. The binder is completely miscible with water, but reacts strongly with acids.

The moulding mixtures were prepared in accordance with the recommendations of binder manufacturers [17], in a Vogel & Schenmann laboratory mixer, with a capacity of 6 kg. The hydrothermal conditions in which the mixtures were prepared and the fittings were stored ranged between 22-26°C and 30-32% humidity. The hardening process was conducted in the temperature of 140°C (temperature suggested by the binder manufacturer) in different time periods (30 s, 60 s, 90 s, 120 s), detailed sample symbols were placed in table 1. The mechanical deformation tests were conducted immediately after the samples were removed from the core shooter (marked A). The second part of mechanical tests and the thermal deformation tests were performed after the samples have reached room temperature, which was set to an hour after the sample was taken out from the core shooter (marked B). A minimum of 3 samples was used for each test.

For the mechanical deformation and bending strength tests, the indenter velocity was set for 20 mm/min.

The heating temperature for hot-distortion tests was set to 900°C.

Table 1.
Samples

Sample symbol	Hardening time [s]	Hardening temperature [°C]
A (sample tested immediately - hot)	30/60/90/120	140
B (sample tested after cooling - cold)		

The studies investigated the influence of the hardening time of the samples on: bending strength R_g^u and sample resistance to mechanical deformation, in two variants "hot" – referring to tests carried out immediately after removing the sample from the heated core-shooter, and "cold" – after the samples have reached ambient temperature. Thermogravimetry studies of moulding sands were carried out on the Iota derivatograph in the following measurement conditions: heating temperature range 20 – 1000°C, heating rate 10°C/min. The measurement was conducted in oxygen atmosphere.

Measurement of moulding sands resistance to mechanical deformation has been tested on a universal apparatus for studying hot-distortion phenomena and bending strength R_g^u, produced by Multiserw-Morek Company.

Fig. 1. Universal Hot-Distortion and Bending Strength Machine [11, 18]

The measurement of mechanical deformation is based on the analysis of the deflection curve of a standard longitudinal sample (fig. 1) during bending. The measuring equipment as well as the whole process has been described in detail in previous works of authors [11, 17-19].

Measurements of the hot-distortion parameter are carried out on rectangular samples which measure 114×25.4×6.3 mm on Multiserw-Morek Company measuring equipment (fig 2).

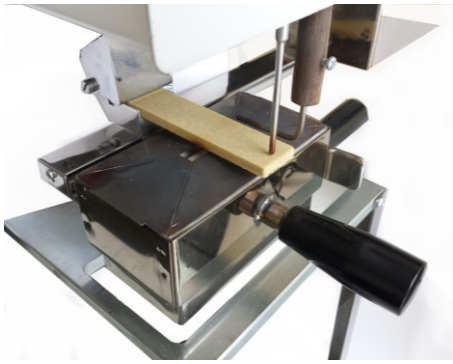

Fig. 2. LRu-DMA measuring device from MULTISERW-Morek Company – hot distortion module [17]

The tested samples were prepared according to the binder manufacturer's instructions. Prepared moulding sand samples have been compacted on LUZ-1 vibration device and placed in a preheated furnace (140°C) for 10 min. The thermal deformation tests were performed after the samples have reached room temperature.

The measuring device as well as the methodology has already been described in previous works of authors [11, 17].

3. Own research

The following paper focuses on the analysis of the influence of hardening time on mechanical and thermal deformation of moulding sands with modified hydrated sodium silicate (binder) and inorganic additives prepared in warm-box technology. Obtained results were divided into two groups – mechanical deformation in ambient temperature and thermal deformation. The compositions of tested moulding sands have been presented in Table 2.

Table 2.
Compositions of tested moulding sands

Quartz sand [p.p.w.]	Binder [p.p.w.]	Additives [p.p.w.]
100	2.2	0.95
100	2.2	-

Quartz sand from the Szczakowa Sand Mine S.A was used in all of the conducted tests. According to the Polish standard PN-85/H-11001, it classifies the tested sand as medium. In the studied matrix, the value of the main fraction is 84%, which determines the sand as homogeneous.

The first step of the research were tests of thermal degradation of inorganic additives and moulding sand samples. Figure 3 shows the derivatographic measurement results.

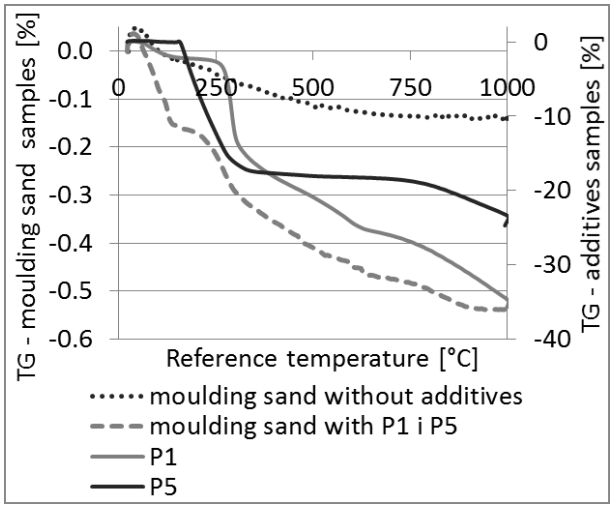

Fig. 3. The TG curves for tested moulding sands and used additives

Thermogravimetric research carried out on moulding sand with P1 and P5 additives showed losses in samples weight in the temperature range of 25 - 1000°C. In the case of additives, we observe a loss of approx. 23 and 35%. The biggest loss for the additives takes place at the temperature of approx. 300°C. At this temperature, the largest weight loss for the moulding sand sample with the mentioned additives can be observed. The moulding sand with P1 and P5 can be characterized with a total loss of about 0.5% of its initial weight. The moulding without additives is characterized by a loss of about 0.13%. Weight losses of used inorganic additives will need to be clarified during further tests.

The second stage of the research were mechanical deformation tests (conducted in ambient temperature) of chosen moulding sands. The tests were carried out according to the methodology presented in point 2 of this paper. The obtained results are illustrated on fig. 4-5.

All tested moulding sand samples showed similar tendencies in growth of deformation accompanied by the growth of applied force.

The results obtained in the tests carried out immediately were characterized by a large discrepancy depending on the time of sample hardening in the core box. The lowest result was recorded for the moulding sand heated for 30 seconds (A30), and reached 0.25 mm for 77 N of pressure. The remaining samples achieved values of 0.38 mm deformation at 69 N for samples heated for 60 s, 0.38 mm at 137 N pressure - samples hardened for 90 s, and 0.31 mm for 157 N for samples kept in the core box for 120 s.

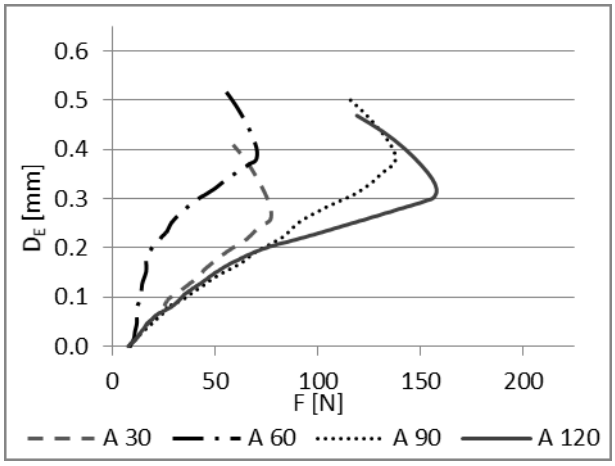

Fig. 4. Mechanical deformation curves ("A"-immediate tests) for moulding sands with additives

Assuming the pressure was constant, the moulding sands did not exhibit large discrepancies in deformation. For the deformations for a set pressure of 50 N, the analyzed sample deformation ranged from 0.11 mm to 0.13 mm.

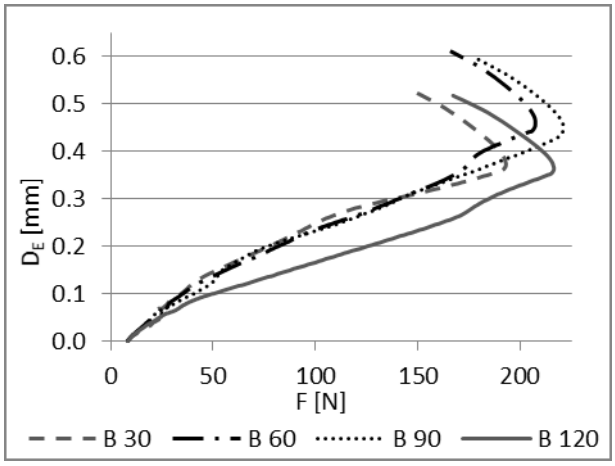

Fig. 5. Mechanical deformation curves ("B"-tests performed on room temperature samples) for moulding sands with additives

The results obtained in "B"-tests (carried out on samples which have cooled down and reached room temperature) are different. The maximum deformation for tested moulding sand samples reached about 0.44 mm, under pressures of 204 N (B60) and 221 N (B90). The samples heated for 30 sec (B30) and for 120 sec (B120) reached the deformation about 0.35 mm under pressure of 190 N (B30) and 215 N (B120). The differences between the different hardening times are far less visible than for the "A" samples.

On fig. 6-7 the influence of time hardening period on bending strength of tested moulding sand has been shown. Figure 6 presents values obtained for moulding sands with additives P1 and P5 and Figure 7 presents values obtained for moulding sands without additives. In case of moulding sands with additives, bending strength of samples tested immediately after removing them form the core box ("hot" samples – "A") tend to increase with the increase in hold-up time, from about 1.5 MPa for samples hardened for 30 s and 60 s, to 3.15 MPa for 120 s samples (Fig. 6). In case of moulding sands without additives, bending strength of samples tested immediately after removing them form the core box ("hot" samples – "A") tend to increase with the increase in hold-up time, from about 0.7 MPa for samples hardened for 30 s and 60 s, to 2.1 MPa for 120 s samples (Fig. 7).

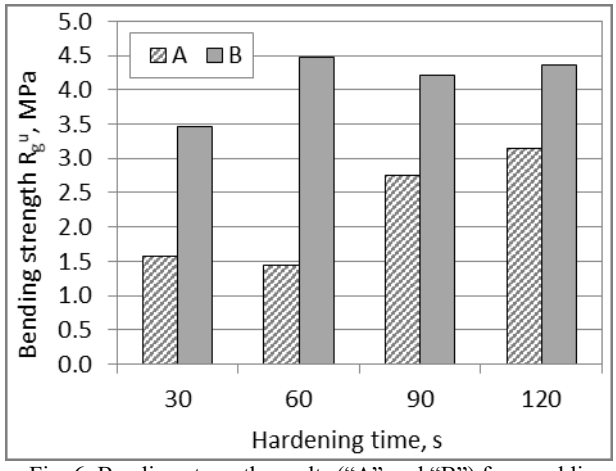

Fig. 6. Bending strength results ("A" and "B") for moulding sands with P1 and P5 additives

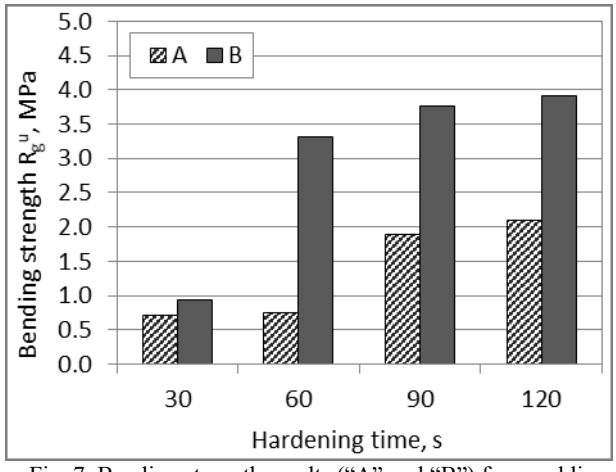

Fig. 7. Bending strength results ("A" and "B") for moulding sands without additives

The results of the bending strength tests of cooled down samples ("cold" samples – "B") of moulding sands with P1 and P5 oscillates round 4.5 MPa for the sample heated for 60, 90 and 120 s. The lowest result of 3.46 MPa was obtained for the moulding sand heated for 30 s (Fig. 6). In case of moulding sands without additives, bending strength of cooled down samples ("cold" samples – "B") tend to increase with the increase in hold-up time, from about 0.94 MPa for samples hardened for 30 s to 3.31 MPa for 60 s samples, 3.76 MPa for 90 s samples and 3.92 MPa for 120 s samples (Fig. 7).

The last stage of the research were thermal deformation tests of chosen moulding sands. The tests were carried out according to the methodology presented in point 2 of this paper. The obtained results are illustrated on fig. 8-9.

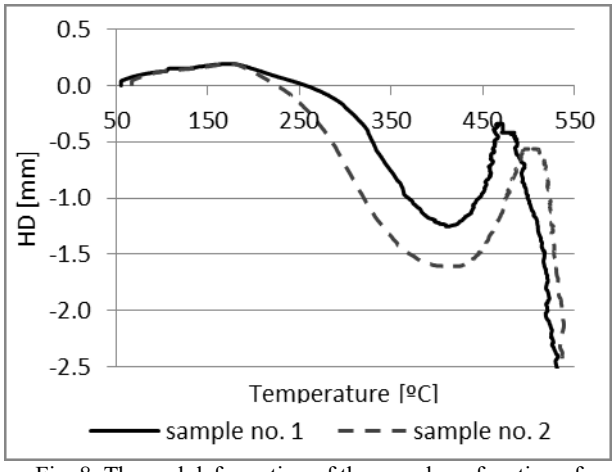

Fig. 8. Thermal deformation of the sample as function of temperature for tested moulding sands

Observations from thermogravimetric studies have been confirmed in the thermal deformation diagrams of the tested moulding sands (Fig. 8). All analyzed moulding sands after exceeding the temperature of 160°C have shown deformation towards the heat source. Then, after reaching the temperature of about 400°C, one can observe a change in the deformation direction of the samples and the beginning of their destruction after exceeding the temperature of 460°C.

The duration of the measurement (Fig. 9) of the moulding sands deformation under the influence of elevated temperature is the longest one obtained for moulding sands with hydrated sodium silicate.

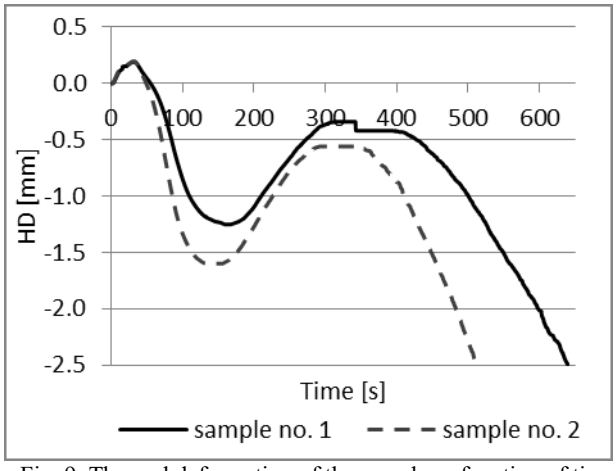

Fig. 9. Thermal deformation of the sample as function of time

The observed moment of destruction is related to the plasticity and deflection of the fitting, not its violent fracture, as is the case with loose, self-hardening moulding with furfuryl resin [20-23].

5. Conclusions

Literature analysis and own research allowed to formulate following conclusions:

- The hardening time in the range 90 – 120 sec in temperature of 140°C does not impact significantly the bending strength of tested moulding sands with P1 and P5 additives. It seems enough to harden moulding sands for 90 sec. The mechanical deformation tests for the moulding sands proved that hardening time in the range 60 – 90 ensures the best moulding sand elasticity.
- The hardening time in the range 90 – 120 sec in temperature of 140°C does not impact significantly the bending strength of tested moulding sands without additives. It is economically justified to harden moulding sands for 90 sec.
- It is possible to eliminate inorganic additives from moulding sands compositions. Moulding sands without additives have good enough strength properties and their economic and ecological character is improved.
- The tested inorganic moulding sands prepared in warm-box technology after exceeding the temperature of 160°C have shown deformation in the temperature range of about 160°C to 400°C. The duration of the measurement of the moulding sands deformation under the influence of elevated temperature is the longest one obtained by authors for moulding sands with hydrated sodium silicate.

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