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Influence of water-glass grade and quantity on residual strength of microwave-hardened moulding sands. Part 1

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Abstract

The paper presents a research on influence of dielectric drying process on mechanical properties of water-glass containing moulding sands. Examined were moulding sands containing additions of 1.5 and 2.5 % of hydrated sodium silicate grades 145, 149 and 150, most often used in foundry practice. Standard, cylindrical specimens for mechanical testing were held at temperatures from 100 to 1200 °C for 30 minutes and next cooled-down to ambient temperature. Then their residual strength was determined. Comparison of the obtained results with literature data indicates that dielectric drying is favourable for reduction of residual strength of used water-glass moulding sands, and thus improves their knock-out properties.

Keywords: Water glass moulding sand; Microwave hardening; Hydrated sodium silicate; Residual strength; Knock-out properties

1. Introduction

Selection of proper moulding and core sands is decisive for quality of the manufactured castings. When designing technology of sand casting, several factors must be considered of which the most important are costs of moulding sand components, mixing devices, accessories and equipment for cleaning castings and disposing used moulding and core sands. Nowadays, the most important production costs of castings include also recovery of used moulding sands. Following stronger and stronger pressure on protecting environment, natural resources and human health, possibility of repeated application of used sandmixes or some of its components becomes very important when selecting composition of moulding and core sands.

Currently, a search is in course of a cheap material, environmentally harmless and neutral for the persons in contact with it. Moreover, it is expected that hardening moulding sands with such a binder will be a fast and technologically simple process and the used sand will be reusable after a recovery process guaranteeing its properties from before the mould was poured with metal. Hydrated sodium silicate (sodium water-glass) fulfils the conditions of small environmental harmfulness due to its inorganic nature. The practically known ways of chemical hardening, e.g. with carbonic anhydride (CO_2 process), do not present special difficulties when preparing moulds and cores, permit also flexible manufacture of castings. A disadvantage of such solutions are poor knock-out properties caused by high residual strength of these moulding sands. This fact can restrict possibility of wide application of water-glass as a universal foundry binder. As compared to the other technologies employing organic binders used in particular in core sandmixes, hydrated sodium silicate makes much more difficulties at knocking-out cast steel and cast iron, especially at removing cores, which increases production costs.

As the results of the so-far performed researches indicate, water-glass containing moulding sands can be successfully hardened with microwaves at 2.45 GHz [1,2,3,4]. In foundry practice, this innovative technology based on the dielectric drying phenomenon can bring significant benefits, resulting among others from reduced time and costs of manufacturing moulds and cores. Water-glass containing moulding sands, hardened during heating in electromagnetic field, can be also an alternative for several technologies based on organic resin binders.

The phenomenon of microwave heating of dielectric media is described in literature as the dielectric drying method [5]. The main result of the dielectric polarisation phenomenon is volumetric heating due to high-frequency polarisation of dipole-nature molecules. In the case of hydrated sodium silicate, water molecules and the created water solutions participate in the polarisation process. It should be noted that not all the phenomena accompanying dielectric drying of micellar solutions, as water-glass is deemed to be, are completely explained. Thorough recognising the results of dielectric drying can deliver information on the process of releasing water molecules from a solution of hydrated sodium silicate, as well as make its use more reasonable.

It was found by analysis of the researches comparing various methods of water-glass hardening, described in [1,4], that the methods involving the physical dehydration process are distinguished by more profitable properties than those hardened in the traditional process of purging with CO_2.

Apart from methods based on the introduction of special additives [6], the first factor that can significantly facilitate the processes of cleaning castings and knocking-out cores, as well as recovery of moulding sands is restricting the binder content. In the paper [7] presented is a research on influence of quantity of five grades of sodium water-glass on ambient-temperature strength of moulding sands prepared with their part, hardened in the quick dielectric drying process. It was evidenced that there is a possibility of significant reduction of binder quantity with maintained profitable properties of the sandmix, see Fig. 1.

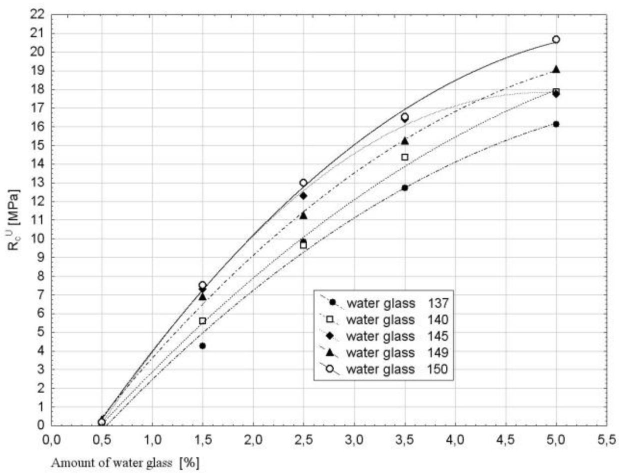

Fig. 1. Effect of water-glass quantity and grade on compression strength of moulding sand [7]

According to the data included in [7] and statistical analysis carried-out in [8], the innovative microwave heating of moulding sands prepared with various grades of sodium water-glass, see Fig. 1 – three of which were selected for examinations within the presented research – guarantees, in comparison with the much slower, convective drying process, obtaining more favourable mechanical properties. Mechanical properties of moulding sands dried dielectrically were significantly higher than those obtained by traditional drying, especially at very small binder content of 1.5 and 2.5 %. With increasing binder percentage (over 3.5 %) observed was decreasing effectiveness of dehydration processes described by strength per 1 % of binder for both the convective and the dielectric drying method.

Moreover, analysing quality of linking bridges created by dehydration of hydrated sodium silicate (in the hot core-box process) and the related mechanical parameters, the author of [14] explains the very profitable influence of the applied drying method by absence of secondary reaction products, like:

- dicalcium silicate in sandmixes hardened with self-decomposing slag U-10,
- sodium carbonate in moulding sands hardened in the CO_2 process.
- sodium acetate and multihydroxide alcohol in moulding sands hardened with esters.

The secondary products created after applying various ways of chemical hardening can to higher or lower degree affect the process of knocking-out moulds and cores. This phenomenon was more widely described for the CO_2 process. To determine the difficulties related to removing used moulding and core sand, one can use the diagram of the relationship between residual strength and heating temperature, see Fig. 2.

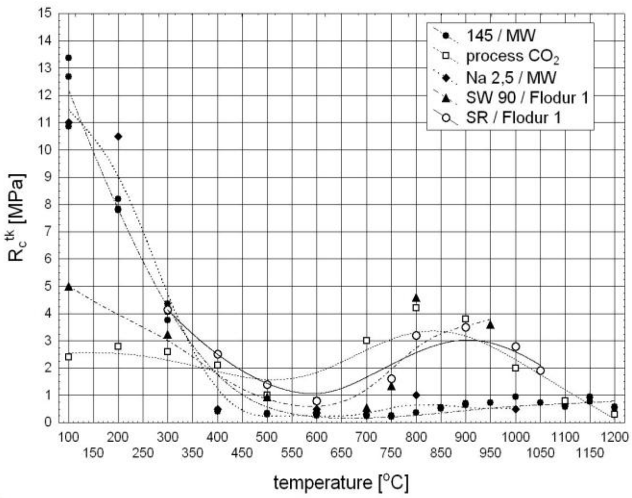

Fig. 2. Influence of temperature on residual strength in ambient temperature of moulding sands prepared with various binders:

- grade 145, microwave hardened / MW (content 2.5 %), on the ground of own research,
- Na 2.5 with module 2.75 and density 1.51 g/cm^3 (content 3.0 %), microwave hardened [1],
- modified SW90 with module 2.04 and density 1.504 g/cm^3 (content 2.5 %), hardened with Flodur 1 [12],

- SR with module 2.0 (content 2.5 %), hardened with Flodur 1 [13],
- silica-type, hardened in the CO_2 process [15].

In the case of chemical hardening methods, analysis of the curves in Fig. 2 indicates occurrence of very high, secondary residual strength. To compare the effects (Fig. 1), selected were binders with approximate molar module and content in the moulding sand. After the strength (R_c^{tk}) drops to the level below 1 MPa at 600 °C, it starts increasing again. In the case of binders hardened with Flodur and in the CO_2 process, after heating the moulding sands till 700 – 950 °C, their residual strength reaches values between 3 and 5 MPa. The so high residual strength makes the key problem in the case of the silica binder, on solving that working are many research centres.

2. Purpose of the research

The planned research was aimed at determining nature of changes of linking bridges in the sand base, created after the microwave (f = 2.45 GHz) process of water-glass hardening. From the point of view of possible application of innovative microwave hardening in foundry practice, especially interesting are changes of residual strength of used moulding sands. Determining this strength should provide significant information about possibilities of knocking-out moulds and recovering used moulding sand. Influence of temperature on residual strength was determined by measurements of compression strength of standard cylindrical specimens held at a temperature from 100 to 1200 °C and cooled-down to ambient temperature.

3. Preparation of moulding sands

The sand used for examinations was a reference high-silica sand coming from the mine Nowogród Bobrzański, with main fraction 0.40/0.32/0.20, and commercially available grades of non-modified sodium water-glass made by Chemical Works „Rudniki" S.A., whose properties (acc. to the manufacturer's certificate) are given in Table 1 (in bold type are the grades most commonly used in foundry practice [9]).

Moulding sands were prepared in a laboratory roll mixer [10,11]. A 4-kg batch of high-silica sand was poured to the mixer and, after starting rotations, added was 20 ml (0.5 %) of water, as determined on the ground of literature data and results of the research. Preliminary wetting the sand is advantageous for repeatability of results guaranteed, among others, by homogeneity of moulding sand due to good distribution of binder in the entire volume. Addition of water reduces also dusting during stirring. After 60 seconds of mixing, water-glass was added and stirred for the next 180 seconds. According to the data in [7,8], the best strength of the examined sandmixes after dielectric drying is obtained for small quantities of water-glass. Following conclusions of these publications, accepted were qualities of the binder equal to 2.5 and 1.5 % for all the three grades of hydrated sodium silicate.

From the so prepared moulding sands, standard cylindrical specimens for compression testing were compacted on a standard rammer. The compacting degree determined by preliminary testing showed that threefold ramming with a standard rammer guarantees sufficient compacting. Apparent density of the moulding sand ranged from 1.56 to 1.62 g/cm^3.

Table 1.
Physicochemical properties of water glass grades used in foundry practice

Water glass grade:	137	140	**145**	**149**	**150**
Molar module SiO_2/Na_2O	3.2÷3.4	2.9÷3.1	**2.4÷2.6**	**2.8÷3.0**	**1.9÷2.1**
Oxide content (SiO_2+Na_2O) %	35.0	36.0	**39.0**	**42.5**	**40.0**
Density (20 °C) g/cm^3	1.37 ÷1.40	1.40 ÷1.43	**1.45 ÷1.48**	**1.49 ÷1.51**	**1.50 ÷1.53**
Fe_2O_3 % max.	0.01	0.01	**0.01**	**0.01**	**0.01**
CaO % max.	0.1	0.1	**0.1**	**0.1**	**0.1**
Dynamic viscosity (P)	1	1	**1**	**7**	**1**

Then, the specimens were hardened in a microwave oven with rated power of 900 W. After 240 seconds of heating, temperature of the specimens reached ca. 100 °C. Next, after cooling down to ambient temperature, the specimens were placed in the chamber of a syllite furnace. After holding in this furnace at a specified temperature for 30 minutes, the specimens were taken out and cooled-down to ambient temperature in free air. Then, their compression strength was determined on a testing machine for moulding sands LRuE-2e. The material taken from fractured specimens was observed on a scanning microscope to determine nature of mechanical destruction of linking bridges. Results of these observations will be presented in the subsequent papers.

4. Examination results

Results of the performed examinations are settled in Figs. 3 to 6. The measurement points in Figs. 4 and 6 are concentrated (every 50 °C) to increase exactness of determining influence of heating temperature on the parameter R_c^{tk} at temperatures within 600 to 1200 °C. This range is of particular importance because of occurring there phenomenon of partial melting surfaces of high-silica grains and the layer of hardened silica glaze. The process of partial melting of the matrix surface is especially important for minimising risk of surface defects of castings.

5. Discussion of examination results

Analysing the relationships between strength R_c^{tk} and temperature shown in Figs. 3 to 6, one can distinguish the three ranges of temperature effect on quality of linking bridges, known from literature.

The first range covers heating temperatures from 100 to 400 °C, where all the microwave-hardened moulding sands lose their mechanical properties nearly linearly down to ca. 0.5 MPa, see Figs. 3 and 5.

In the second temperature range from 400 to 750 °C, the examined moulding sands demonstrate the lowest residual strength not exceeding 0.5 MPa, see Figs. 3 to 6. The measured small values, irrespective of the applied binder grade and quantity, permit a very easy process of removing used moulding sand. Observed was the phenomenon of spontaneous falling-off of some cooled-down specimens.

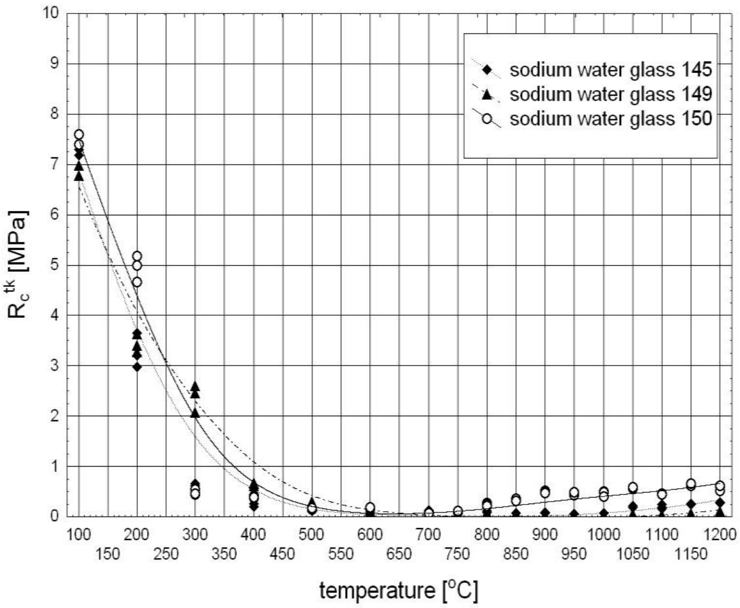

Fig. 3. Influence of heating temperature on residual strength of moulding sands containing 1.5 % of each applied grade of water-glass, temperature of heating 100 – 1200 °C

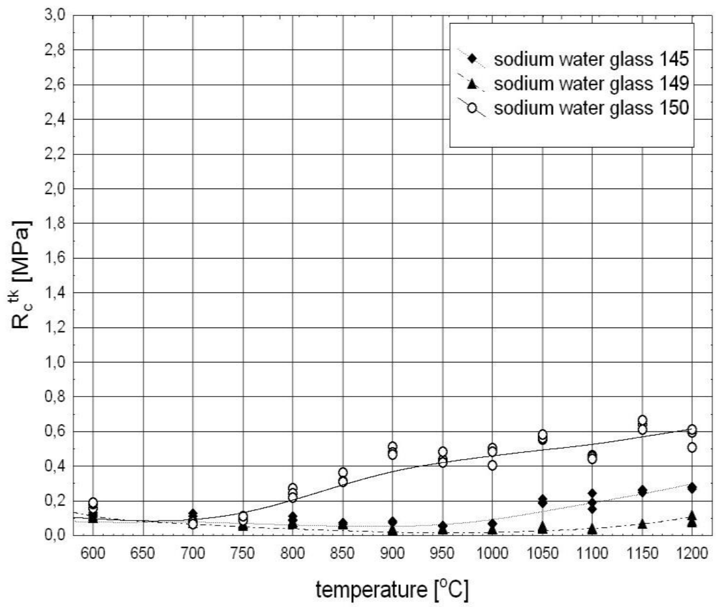

Fig. 4. Influence of heating temperature on residual strength of moulding sands containing 1.5 % of each applied grade of water-glass, temperature of heating 600 – 1200 °C

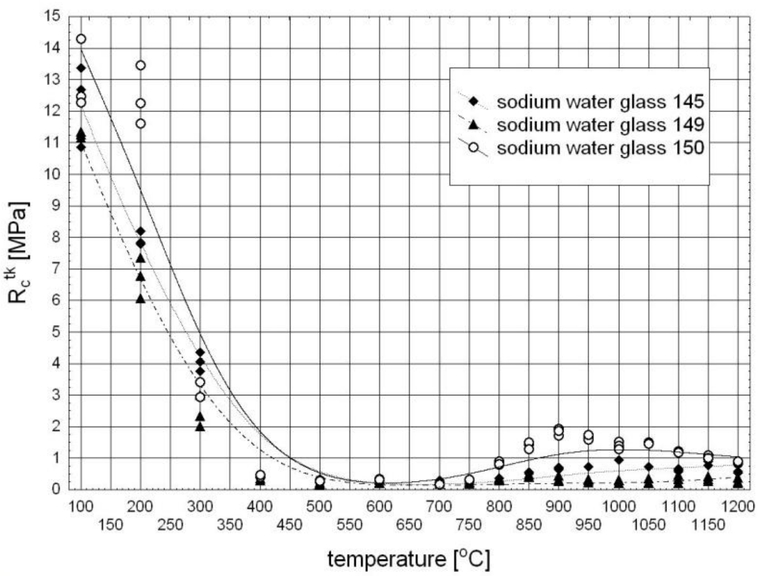

Fig. 5. Influence of heating temperature on residual strength of moulding sands containing 2.5 % of each applied grade of water-glass

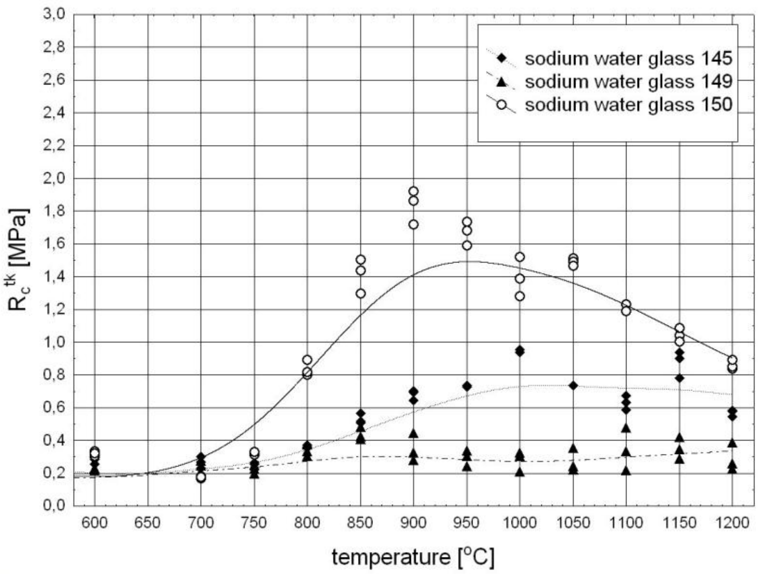

Fig. 6. Influence of heating temperature on residual strength of moulding sands containing 2.5 % of each applied grade of water-glass

In the third temperature range from 750 to 1200 °C, observed is strong influence of molar module of the applied water-glass on residual strength of moulding sands. Along with the module of the hydrated sodium silicate decreasing from 2.9 through 2.5 to 2.0, residual strength increases reaching the highest values for the water-glass grade 150, see Figs. 4 and 6.

The very significant factor influencing residual strength is quantity of a silica binder introduced to the moulding sand. To determine importance of this parameter, often decisive for knock-out properties, used was the binder grade 150. Along with decreasing content of this binder from 2.5 % to 1.5 %, strength of the moulding sand was significant reduced. The largest difference between the strength measured for 2.5 % and 1.5 % of the binder is visible in the third temperature range from 750 to 1200 °C. Reducing the binder content by 1 % permits lowering residual strength even by ca. 1.5 MPa. It is generally known that, in many chemical methods of hardening moulding sands containing hydrated sodium silicate, impossible is limiting its content below the critical value of 2.5 %.

Assuming that drying a moulding sand involves the binder dehydration process in that no secondary products of chemical reactions are created, increase of residual strength observed over 750 °C can be attributed to the changes occurring in structure of the linking bridges and to melting the sodium-silicate binder on grain surfaces of high-silica matrix. An attempt to explain the influence of holding moulding sands at high temperature on a microwave-hardened silica binder and behaviour of high-silica matrix in the discussed three ranges, in particular in the range from 750 to 1200 °C, will be presented in subsequent elaborates being prepared for printing.

6. Conclusions

Comparison of the results presented in literature indicates that the most important for the knocking-out process of water-glass containing moulding sands is the applied binder grade and its hardening method. The described microwave-hardening method that permits reaching much lower and thus more favourable properties of used moulding sands gives possibilities of extending the water-glass application range, which was confirmed in the presented research.

Analysis of the results shows that of decisive influence on residual strength of dielectrically dried moulding sands is modulus of the applied binder and its content in the sandmix. Effect of the mentioned parameters is the most significant in the case of the heating temperature ranges from 100 to 400 °C and from 750 to 1200 °C. The most advantageous results, consisting in loss of the original strength of untreated moulding sand, were obtained for the smallest applied binder content of 1.5 % for all the examined binder grades 145, 149 and 150. The knock-out properties determined by residual strength are satisfactory and even very good for a microwave-hardened, used moulding sand containing no more than 2.5 % of a binder, after heating within the temperature range between 400 and 1200 °C. Therefore, possible is applying water-glass containing moulding sands hardened in the innovative dielectric drying process for preparing high-quality, easy to be removed cores, designed for castings with high pouring temperature. However, a special attention should be paid to the third temperature range in that observed is partial melting of silica glaze. The commonly used methods of protecting casting surfaces against binder adherence, consisting in applying ecologic protection coatings, are insufficient in this case [16].

Summarising, in the temperature range over 700 °C, most interesting from the viewpoint of the alloys with high pouring temperature, use of the innovative microwave hardening of moulding sands that allows reduction of water-glass content guarantees up to elevenfold decrease of residual strength (at 800 °C) in comparison with the other hardening methods.

Application of suitable equipment as well as fast and efficient dielectric drying process permits using moulding sands containing hydrated sodium silicate not only as core sands, but also as facing or backing sands.

Acknowledgements

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