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Determination of application possibilities of microwave heating in the curing process of water glass molding sands with fluid esters. Part 1

K. Granat[a,*], D. Nowak[a], M. Pigiel[a], M. Stachowicz[a], R. Wikiera[b]
[a] Foundry and Automation Dep. of Technical University of Wrocław, ul. Łukasiewicza 5, 50-371 Wrocław, Polska
[b] Ronal Polska Sp. z o.o., ul. Inżynierska 3, 55-221 Jelcz Laskowice, Polska
*Correspondence contact: e-mail: kazimierz.granat@pwr.wroc.pl

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Abstract

This article presents results of the experimental trial of combination of the chemical method of water glass molding sands' curing, used in foundry industry, with an innovative microwave heating. The research objective was to indicate at new areas of microwave energy application. The sands prepared, according to recommendations for curing technology, with the use of ethylene glycol diacetate, have been subject to microwave influence. The attempt at determination of microwave influence on qualitative changes of the binding bridges created during the curing process concerned such parameters as: bending and tensile strength, permeability as well as wear resistance. Moreover, we also determined the influence of microwave curing on the phenomena accompanying the process as well as bond stability (storage time of the prepared molding and core sands). It has been found, basing on the result analysis, that the innovative microwave heating might constitute a very good supplementation of the ester curing method. The advantages of the combined chemical and microwave gelation process include, among others, improvement of the described resistance and technological parameters as well as significant decrease of preparation time of foundry moulds and cores. The subject discussed in this article will be continued in its second part.

Key words: innovative foundry materials and technologies, ester curing, water glass, molding sand, microwaves

1. Introduction

Water glass molding sands used for production of foundry molds and cores have been known for over sixty years. Numerous methods of curing them have been developed over this time, including [1]: blowing with carbonic acid anhydride during CO_2 process, drying with an increased temperature (heated) air and applying chemical compounds, e.g.: ester curing agents. Publication [2] presented results of the experiments with the use of an additional, innovative microwave heating of the molding sands cured with CO_2 process. It also compared the influence of a very efficient microwave curing with a conventional hot air drying on the parameters of the sands. Microwave heating gave positive results in both cases, consisting in the improvement of resistance parameters of quartz grains' bonds. The methods utilizing effects of fluid ester curing agents constitute an especially large group of the currently applied ways of hydrated sodium silicate curing. The conducted experiments have been aimed at determination whether it is possible to combine two curing methods: with fluid esters and microwave heating. The equivalent objective included demonstration of the advantages obtained while applying the innovative combination of these methods in the process of preparation of foundry moulds and cores.

2. The process of water glass curing with ester curing agents

The studies of water glass molding sands' curing with fluid esters have been described in detail in other publications [3,4]. The information contained there concerns, among others, derivatives of physical-chemical reactions of the cured bonding agent. The authors devote plenty of space to the role played by water during gelation process, that is formation of gel from orthosilicic acid sol [1]. Water particles contained by the cured sand may also come from humidity collected on the surface of the used molding sand. However, the greatest influence is undoubtedly exerted by the water constituting a component of the used non-organic binding agent. This water determines, among others, resistance of bonds between grains as well as quality of casting surfaces and the number of their defects. The problem of water remaining in the sand after curing has also been touched in publication [5]. Curing of water glass molding sand with esters at the ambient temperature results in the consequences of long time necessary for removal of the water bound in the sands into atmosphere. Therefore, the second part of the article contains the results of studies on water content change in the function of duration of physical and chemical reactions of the curing process. The evaporation process depends on temperature and humidity of the storage room where moulds and cores are stored as well as the amount of binding agent used for sand preparation. The process developed for industry takes even 24 h of time from the moment of the sand components' mixing until complete curing. Unfortunately, the prolonged curing reaction time does not guarantee full removal of water bound in the cured sand [5]. Hence, the problems appearing during pouring and solidification of the alloys in the moulds produced with this method. A sudden release of the water, bound and still remaining in gel, and its migration into the mould or, in case of insufficient permeability, its collection at the contact surface of cast-mould cavity, results in the above mentioned defects. Also, a combination of gel transition into a plastic state may negatively influence casting surfaces [6]. Transition of the binding bridges, formed during mixing and curing processes, into a plastic state takes place at the temperature range between about 550^{o}C up to 1000^{o}C. The phenomenon is basically beneficial because of the expected flexibility, however, in case of insufficient wall thickness of moulds and cores, all phenomena weakening bonds (the presence of over-humid zones) of sand grains may have a dangerous influence on the quality of the solidifying casting while appearing simultaneously.

Final water content in the sand might be limited in several ways, for example through decrease of binding agent content – at the expense of resistance decrease of the obtained molding sand. A proper modification of the used hydrated sodium silicate at the stage of its acquiring is also possible [4,8]. Evaporation might be facilitated by application of coarse-grained sands – at the expense of resistance, surface quality and detail reproduction. A process of drying up with the use of classical dryers might also be found among the investigated methods of influencing water content decrease in foundry moulds and cores cured with fluid esters. The process is undoubtedly time and energy consuming one. Considering the presented solutions, it has been proposed to use an innovative methods of microwave heating, assuring quick and economical evaporation of the remaining water.

Frequency of electromagnetic waves used for curing is selected in such a way that it remains in resonance with the frequency of own oscillation of water in the whole volume of the sand. As a result, electromagnetic energy can be transferred with identical intensity within all layers of the microwave heated stock of molding sand. In case of materials of high lossiness (e.g. containing high amount of water, such as water glass) penetration depth remains within the range of characteristic dimensions of the stock. Therefore, heat source concentration takes place in subsurface areas, however, as a result of conductivity, we have to do with a more intense heat exchange than in case of indirect heating, for example, during classical curing process. Microwave energy is changed into thermal energy of water particles penetrating the sand and is absorbed by subsequent sand parts, located closer to the internal mould layers. Because of the limited permeability of the compacted molding sand as well as the resulting fact of impeded water evaporation process, microwave heating allows for removal of H_2O particles from the whole volume of porous mixture of sand, binding agent and curing agent, thus intensifying molding sand curing process.

Since curing mechanisms as well as physical and chemical reactions taking place during binding agent gelation are not thoroughly known, there is a risk of weakening of the formed sand grains' bonds through, for example, cracking in the gel film resulting from temperature increase and its sudden dehydration, both in case of ester curing agents and microwave heating process.

3. Materials used for research, preparation of molding sands

A silica sand 1K from Nowogród Bobrzański sand mine of 0.32/0.20/0.16 main fraction has been used for experiments. The molding sand composition have been determined basing on the recommendations for fluid ester curing technology. The used binding agent has been sodium water glass manufactured by Zakłady Chemiczne „Rudniki" S.A., whose properties (according to certificate) are presented in table 1. Fluid hardeners of trade names Flodur 1 and Flodur 3, of different curing times and constituting mixture of esters, whose specification is also presented in table 1, have been used.

Edge runner mixer has been used for preparation of the sand [6,7]. The individual components have been batched in portions: quartz sand 100%, fluid hardener 0.4% and water glass 3.5%. Proper sequence of component addition has been maintained while mixing. First, quartz sand has been mixed for about 120 seconds with hardener, next binding agent added and mixed for another 120 seconds.

The obtained results have been compared with the previously conducted studies in order to evaluate efficiency of various methods [2,9,10]. The sand containing 3.5% of the binding agent and 0.5% of water but without fluid hardener has been prepared for comparison. The samples made of this sand have been cured using only the innovative method of microwave heating.

The samples for determination of bending and tensile strength, permeability and wear resistance have been prepared in a standard rammer from the above described molding sands [1].

Concentration degree of the tested samples have been determined on the basis of the conducted initial testing and it has been found that triple ramming of the prepared sands with standard rammer ensures their sufficient concentration allowing for taking the casts out of the moulds without damage [11]. Constant apparent density, remaining within the range of 1.56 up to 1.62 g/cm^3 and playing an important role during our experiments, has also been determined in this way.

4. Intensification and modification of ester curing process of water glass

All the samples of molding sands (cylindrical, octal and oblong) have been taken out from the moulds 50 minutes after addition of the binder to the mixture. Next, after 1 hour, 3, 5 and 24 hours, their resistance and technological parameters have been measured. The samples, initially cured in the ester process, have been subject to heating for 4 minutes in order to investigate microwave influence on formation of silica gel. Measurements of parameters have been conducted at identical time intervals (after 1, 3 and 5 hours).

A microprocessor controlled device, allowing for magnetron power output control and microwaves' amplitude regulation (which allows for a smooth power control) has been used during the modified microwave heating process of the sands containing water glass and fluid curing agents. The device also allows for a possibility of programming of duration and number of heating cycles depending on a degree of working chamber filling with stock. The studies have been conducted in a research station described in our earlier publications [2].

Bending and tensile strength measurements have been conducted with LRuE-2e apparatus. Permeability has been measured using LPiR-2e device, while wear resistance with E. Janicki method.

5. Research results

Comparison of research results of curing methods' influence of molding sands containing sodium water glass on bending and tensile strength as well as permeability and wear resistance has been presented in figures 1 to 6. Figures 1, 2 and 5 concern studies with Flodur 1 hardener, the remaining ones (3, 4 and 6) with Flodur 3 hardener of reduced gelation time. Measuring points are mean values of three measurements. The last column of each figure contains, for comparison, the results of microwave heating studies of the sand prepared without addition of fluid ester curing agent.

As appears from figure 1 analysis, bending strength of the sand with addition of Flodur 1 hardener increases with time increase of ester curing process. Maximal strength value for this method is observed after 24 hours from mixing moment. The samples subject to additional microwave influence increased their strength, exceeding even condition after a full 24 hour curing with esters. Similar changes have been observed in case of bending strength measurements (figure 2). Molding sands, initially cured with esters, subject to additional influence of microwave process could have been fully useful for foundry purposes even after 1 hour, while simultaneously demonstrating R_m^U strength higher of about 1MPa.

The applied curing methods had no influence on permeability and wear resistance (figure 5) of the studied sands.

Figure 3 presents results of bending strength studies for the sands containing Flodur 3 hardener. In this case the results of combination of both curing methods have also been satisfactory. The sand subject to microwave effects already after 1 hour had higher bending strength than the one stored for 24 hours. After more than 3 hours additional supplementary microwave heating does not result in any positive effects with regard to gel resistance improvement.

The studied curing methods have not resulted in permeability change of the sands in case of Flodur 3 hardener. However, a significant decrease of the sand resistance to mechanical wear in comparison to the samples cured with Flodur 1 (figure 6) has been observed.

Table 1. Physical and chemical properties of sodium water glass and ester curing agents

Water glass kind	Mole module SiO_2/Na_2O	Oxide content (SiO_2+Na_2O) %	Density (20 °C) g/cm^3	Fe_2O_3 % max	CaO % max	Dynamic viscosity (P)
145	24÷2.6	39.0	1.45÷1.48	0.01	0.1	1
Curing agent – trade name:		Gelation time (minutes)	Density	Flash point	Acid number	Content of ethylene glycol diacetate %
Flodur 1		40	1,104	91	20	85
Flodur 3		20-30	1,100	103	20	-

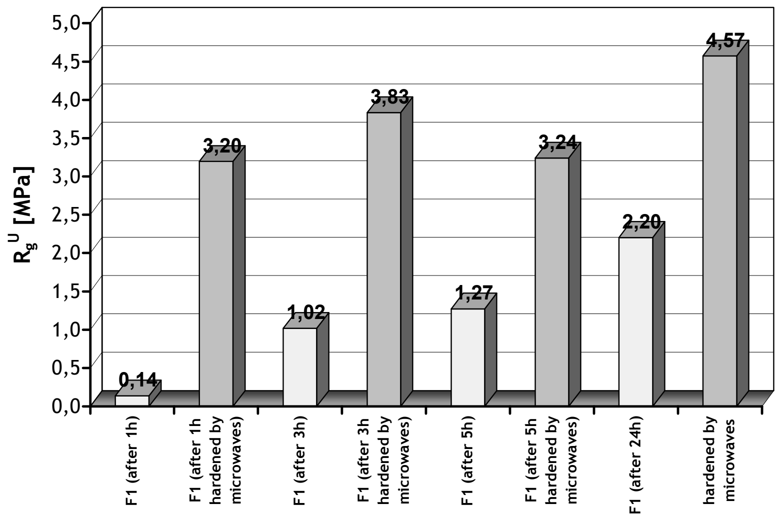

Fig.1. Influence of curing method and storage time on bending strength of the molding sand containing Flodur 1 hardener

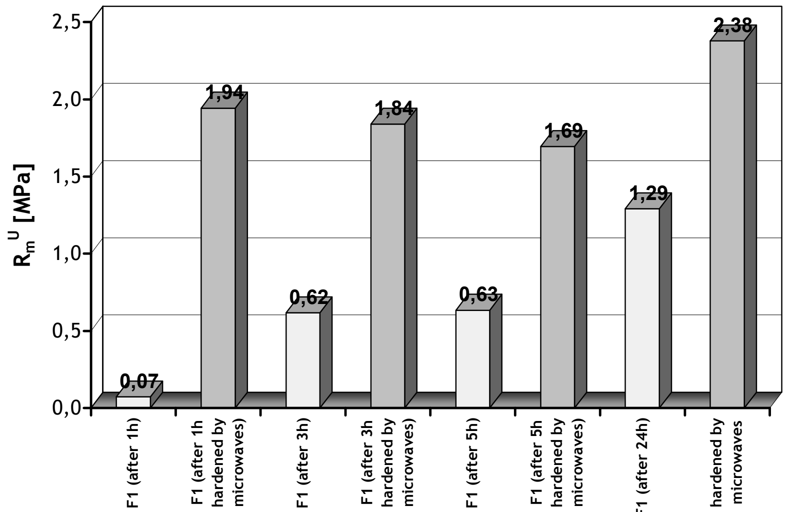

Fig.2. Influence of curing method and storage time on tensile strength of the molding sand containing Flodur 1 hardener

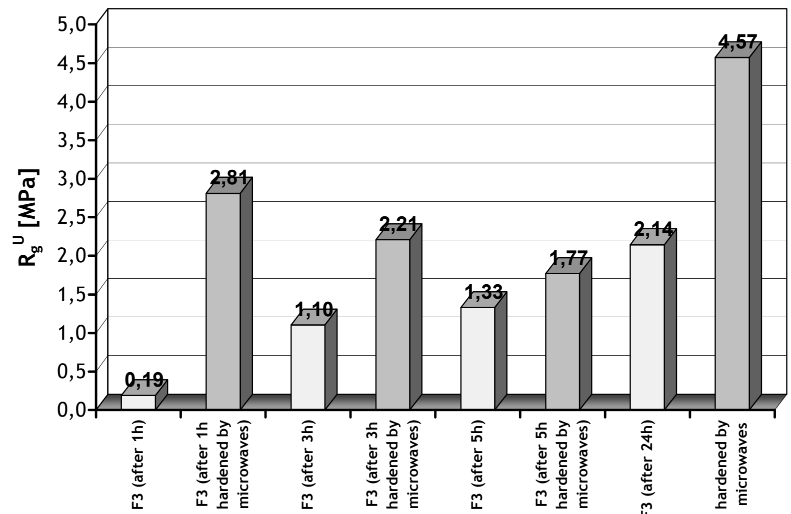

Fig.3 Influence of curing method and storage time on bending strength of the molding sand containing Flodur 3 hardener

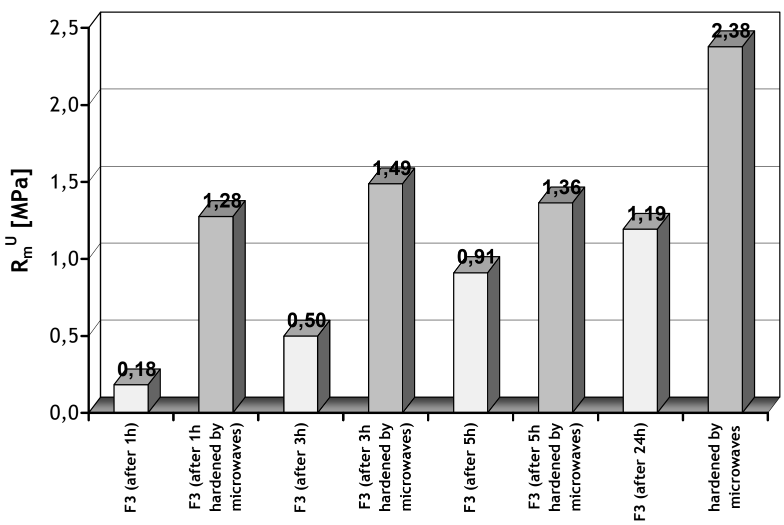

Fig.4. Influence of curing method and storage time on tensile strength of the molding sand containing Flodur 3 hardener

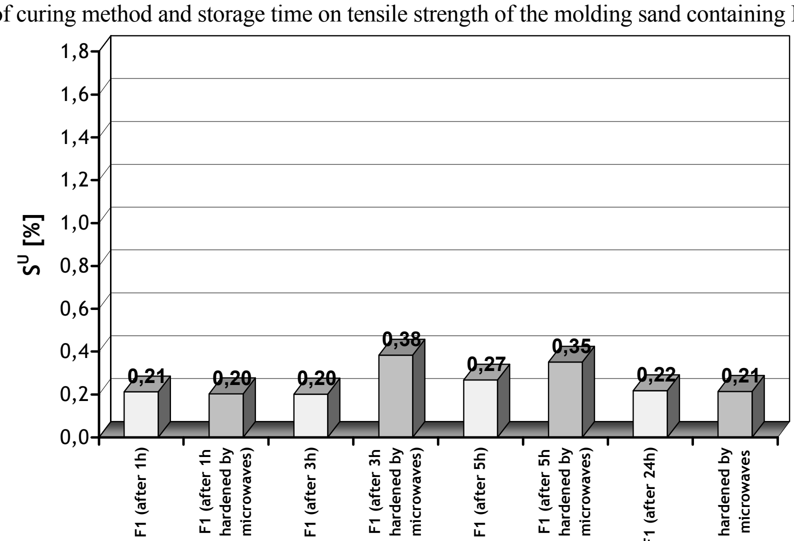

Fig.5. Influence of curing method and storage time on wear resistance of the molding sand containing Flodur 1 hardener

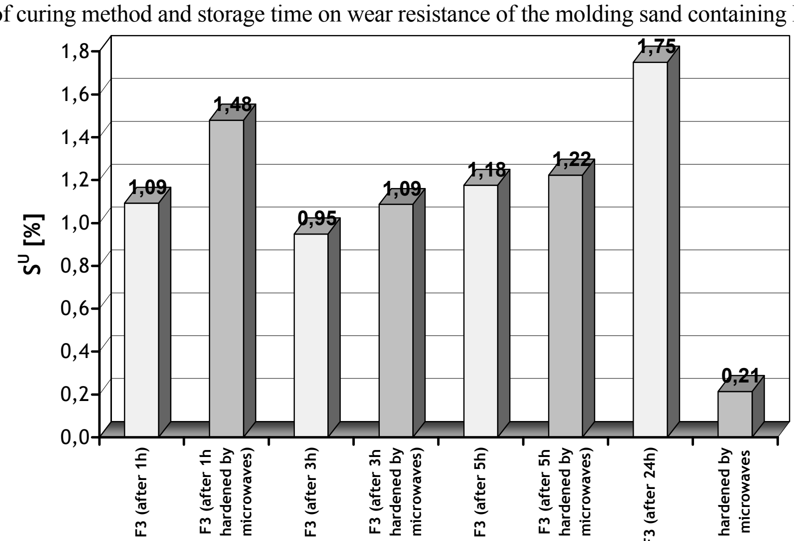

Fig.6. Influence of curing method and storage time on wear resistance of the molding sand containing Flodur 3 hardener

6. Final conclusions

While analyzing the results of curing methods' influence on basic properties of water glass molding and core sands it might be stated that:

- innovative microwave curing of molding sands might constitute one of economically beneficial ways of intensification of curing process of the sands containing water glass and addition of fluid ester hardeners,
- the greatest influence of microwave heating process is observed in case of bending and tensile strength of the sand with addition of Flodur 1 hardener,
- in order to intensify bonding process, microwave heating might be applied optionally any time from the moment of mixing of all components of the sand,
- a two-stage curing method does not influence permeability changes of the studied sands,
- wear resistance of the sands depends on the kind of the used hardener,
- application of a two-stage curing method ensures significant time decrease of moulds and cores preparation as well as production flexibility improvement,
- in case of microwave heating there is a possibility of binder consumption reduction, reduction of the amount of the used hardener (or even its elimination) as well as reduction of final water content.

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