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Abstract. Article is devoted to the study of sodium silicate solute mass transfer mechanism in capillary under microwave radiation action. To achieve this goal, original technique, which allows structure of sodium silicate solute at different stages of it's drying in the field of microwave radiation photographing, has been used. Based on research results description of sodium silicate solute mass transfer mechanism in flat capillary upon heating by microwave radiation has been first developed. According to the data obtained, transfer of sodium silicate solute in capillary proceeds in stages according to scheme similar to chain reaction. Sequence of these stages is as follows: self-encapsulation of sodium silicate solute water solution; vapor bubble appearance in capsule; vapor pressure in capsule increasing; destruction of capsule shell and ejection of sodium silicate solute that has not hardened inside the capsule; complete removal of sodium silicate solute from capsule and its destruction under the influence of high vapor pressure; finalization of the vapor movement ejected outside the capsule of sodium silicate solute; its repeated self-encapsulation, etc. This process repeats until water is completely removed from the treated sodium silicate solute. Stages and certain cyclical nature of foam structure formation in sodium silicate solute under microwave radiation influence is the reason for its uneven pores dispersion and its gas permeability. Sodium silicate solute with silicate module from 2.8 to 3.0 processing by microwave radiation can reduce water content in dried sodium silicate solute to a relative mass content of less than 0.02%.

Keywords: Mass Transferring, Vapor, Sodium Silicate Solute, Water, Capillary, Capsule, Foaming, Ultra-high-frequency Radiation.

1 Introduction

Currently in foundry manufacturing before casting half-molds are fastened together with brackets, bolts, certain mass weights, clamps, etc., or glued together. In foundries by gluing complex configuration rods consisting of separate parts are also assembled. Console mounting rods are glued by rod sign to one of the half-molds to prevent the

rod from floating up or shifting when pouring. When forming in rods, the rods can also be glued together to prevent their relative displacement during pouring and poured into the mold metal departure through the mating surfaces of the rods.

Among adhesive materials for disposable foundry molds and cores production is sodium silicate solute (SSS). Sodium silicate solute is material that can be solidified and foamed as a result of intense heat influence to it, for example, under the effect of microwave radiation (MWR). However, this gluing method and pure SSS as an adhesive material for foundry molds individual elements pairing and cores in foundries are not currently used. One of reasons for this is lack of information on technological capabilities and of such gluing technology. Also, in particular, the lack of data and description of mass transfer mechanism during SSS foaming in capillaries of granular structured materials under MWR influence.

According to modern concepts two stages are distinguished in the process of SSS foaming during its intense external heating [1...3]. At the first stage, as a result of dehydration (evaporation of its free and adsorption water) or carbonization on the heated SSS surface appear, respectively, gas-not-permeable, viscous-plastic, dehydrated SSS layer (elastic shell) or silica gel. At the second stage heating leads to the fact that SSS, being closed in such shell, foams as result of water vapor releasing in it. In this case, in fact, the external elastic shell of SSS droplet is filled with water vapor bubbles that arise in SSS, which form closed-type pores in solidified SSS. According to various researchers, foaming occurs immediately before or after SSS transition to pyro plastic state, and degree of shell elasticity has a decisive influence on the process and degree of SSS foaming. The greatest number of pores when SSS foaming by thermal action is formed at 120...350 °C [4...7], that is, in temperature range when pyro plasticity of alkaline silicates solutions is most evident and when free and adsorption water is most completely removed from them [8]. Chemically bound water from SSS crystalline hydrates and hydrates is removed at temperatures above 600 °C, which also causes its slight foaming [9].

Described SSS foaming mechanisms are acceptable for analyzing of SSS process foaming in drops that are in process of foaming SSS in suspended state. Conditions of mass transferring in capillary under microwave radiation action significantly differ from the drop state described above, which has not yet been studied and, accordingly, does not have corresponding description.

2 Methods

In these studies, sodium soda SSS (GOST 13078-81) with silicate module of 2.8...3.0 and specific gravity of 1.43...1.46 g/cm^3 has been used. For SSS coloring red ink Color Way E404CN-4.1NC CMYK has been given. Aqueous SSS solutions have been treated with MWR in furnace with working chamber volume of 23 liters, with rated magnetron power of 700 W and of 2450 MHz radiation frequency.

Drying effect of SSS under microwave radiation influence on amount of residual moisture has been evaluated by weighing of silicate blocks weights before and after drying in MWR furnace. For this aim, sample of ash-like silicate block weighing

50...55 g has been used. It has been previously weighed with an accuracy of 0.01 g and placed in porcelain container of known mass. Then 100...105 g of distilled water has been added to weighed silicate block in porcelain container. Silicate block was completely dissolved in water at temperature of 70...80 °C. Obtained SSS has been evaporated at 95...97 °C to viscous-fluid state and treated (dried) with microwave radiation during 20...25 min. After drying finalization container with dry residue has been re-weighed and relative residual moisture content in sample has been calculated with relative error of ± 0.02%.

Based on similarity conditions, process of water evaporation from capillary space of wetted by water granular material and liquid transfer in it have been investigated in infinite flat capillary. For this, two glass plates have been used, between which SSS drop has been placed. Distance between parallel positioned plates (capillary channel thickness) has been ranged from 30 to 1000 μm. In order to visualize areas of solidified SSS with free water, red ink has been filled into the SSS.

For processing by microwave radiation, plates have been placed in horizontal position in the center of rotating table of MWR furnace. Processing time of SSS treatment by microwave radiation was from 10 to 90 sec. At the end of treatment plates have been cooled in air, thickness of flat capillary has been determined and plates have been separated mechanically from each other. Structures of solid substances formed in the slot capillary (silicate, metasilicate) have been studied using binocular microscope with magnifications of 25 to 200 times.

3 Results

Based on structure of solidified in flat capillary SSS visual assessment results, it has been found that in initial period of microwave radiation on free surface of unsolidified SSS, due to water evaporation from its surface layer, continuous elastic shell 1 of partially dehydrated solid state forms, which follows from Fig. 1.

Inside the shell 1 with short drying time unsolidified SSS 2 remains. In its colony center silicate substances of certain shape 3 appear (see Fig. 1, a, b). In some cases colonies of silicate substances 3 which are located on the shell side, forming single relatively thick layer of solid silicate material with shell (see Fig. 1, c, d), have been observed.

With relatively large droplet sizes of initial SSS, incompletely solidified SSS in capillaries with h <200...350 μm thickness is two-dimensional foam structure with flat open gas bubbles. Such structure in terms of area in plan exceeds the area of initial SSS drop by more than 20 times and consists of alternating voids and volumes with unsolidified SSS, which is shown schematically in Fig. 2.

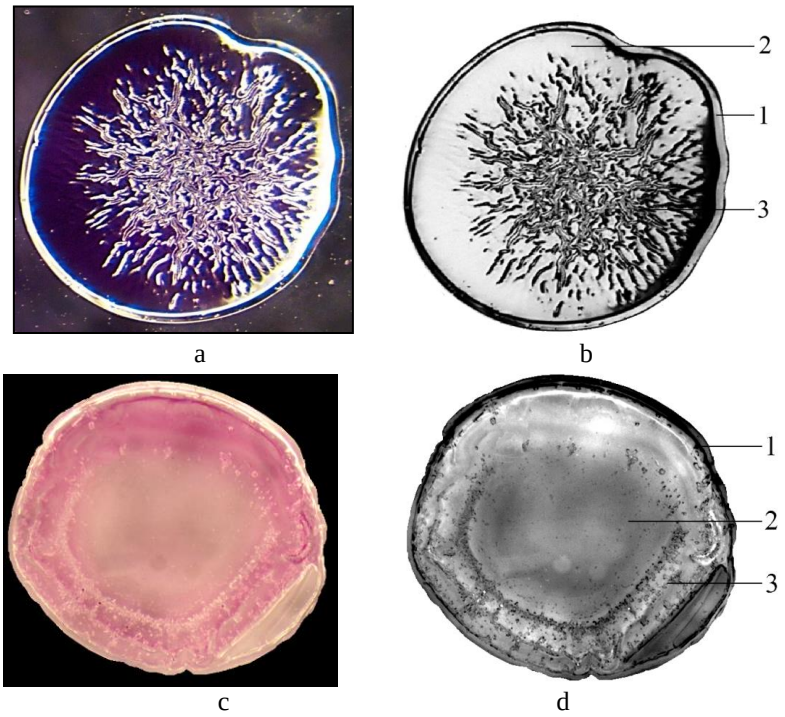


Fig. 1. Appearance of SSS droplet inner surface (×25) in flat capillary at initial stage of MWR treatment: black field (a, c), black-white image after colors inverting (b, d): 1 – SSS dehydrated shell; 2 – SSS; 3 – silicate substances colony.

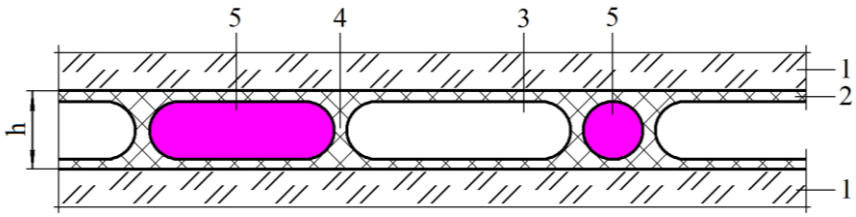
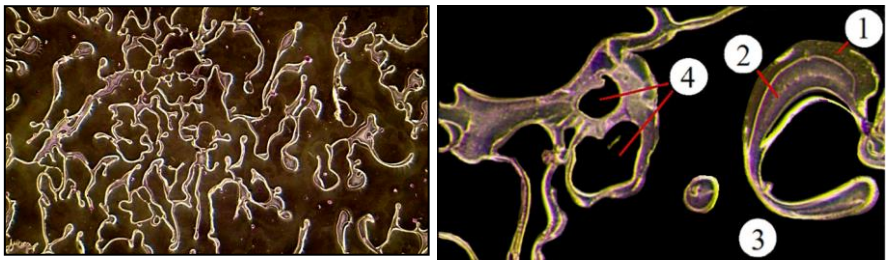


Fig. 2. Scheme of partially solidified SSS in flat capillary in side view: 1 – glass plate; 2 – horizontal layer of solidified SSS; 3 – vapor channel (bubble); 4 – vertical sodium silicate jumpers; 5 – unsolidified SSS

It is clear that, in accordance with Fig. 2, in capillary (on glass plates surface 1) solidified SSS forms continuous layer 2 (see Fig. 1) and transverse jumpers 4 between them. Jumpers and layers not only separate vapor channels 3 from each other, but also hold the micro volumes 5 of non-solidified SSS during drying process.

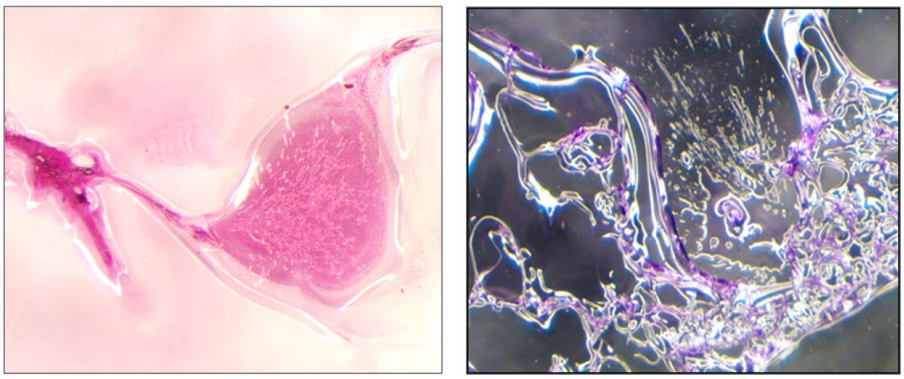
Analysis of this structure on view in plan (see Fig. 3) shows that jumpers (position 4 in Fig. 2) are extended chains of vertical walls of finite length. Presumably they arose simultaneously with vapor channels appearance in capillary and are part of capsules, in which another part of unsolidified SSS is retained.



a b

Fig. 3. Black field appearance of SSS solidified in flat capillary (plane view) at magnification ×14 (a) and ×100 (b): 1 – dehydrated sodium silicate; 2 – unsolidified SSS; 3 – vapor channel; 4 – vapor bubble

Figure 3 demonstrates the transparent walls of partially dehydrated SSS 1 capsules grown from each other. Inside of capsules are unsolidified SSS 2 remains. Continuous chain of unsolidified SSS capsules differently oriented in direction and elongation of capsules suggests that with MWR treatment water temperature increasing in encapsulated SSS leads to vapor bubble (bubbles) 4 appearances in capsule and, accordingly, gas pressure in capsule increasing. Gas pressure increasing inside the capsule leads to deformation and its shell destruction and, in some cases, forced residual liquid jet outflow from the capsule (see Fig. 4, a), in other cases to an instant («explosive») leftover liquid ejection beyond capsules (see Fig. 4, b).



a b

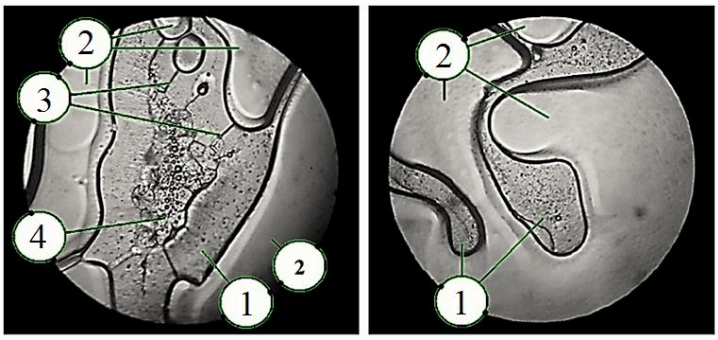
Fig. 4. Appearance of SSS solidified in slot-type capillary formed at slow (a) and «explosive» (b) character of unsolidified SSS release from capsule, ×100

In any case, SSS movement beyond the capsule is apparently accompanied by its intense surface dehydration. As a result of dehydration, on the surface of slowly moving liquid flow «stocking» is formed. It is continuous elastic shell of partially dehydrated SSS or pyro plastic sodium silicate. That is, at the moment of SSS extrusion from previous capsule finishing (at the moment of squeezed SSS flow stopping) SSS

turns into new capsule, and from old capsule only its transverse walls remain in the structure - «jumpers» from sodium metasilicate (see Fig. 3, b). This is due to a sharp vapor pressure of substance squeezed out into vapor channel decreasing in old capsule as a result of the capsule walls destruction.

This process, obviously, cyclically repeats and continues until there is at least some fluid-moving SSS capable for self-encapsulation in capillary. Moreover, each subsequent capsule of unsolidified SSS will be smaller in volume than its previous capsule. From this it follows that each subsequent vapor bubble of analyzed structure will have a smaller volume than previously arisen. This means that foamed under the action of microwave radiation substance in capillary will always be characterized by a certain gas permeability and uneven size of its bubbles.

Upon further SSS heating (see Fig. 5, a), water remaining in capsules goes into vapor state and, softening, breaking and in some cases changing configuration (see Fig. 5, b) of jumper 1, goes through cracks 3 into the vapor channels, forming a new vapor bubble 2 inside encapsulated SSS. This process repeats and continues probably until all water (including chemically bound water) is removed from the SSS. This is evidenced by the type of transverse SSS jumpers shown in Fig. 5, b, which has been dried by ultra MWR for 90 sec, as well as data determination on relative water content in SSS, dried in MWR, which is less than 0.02%.

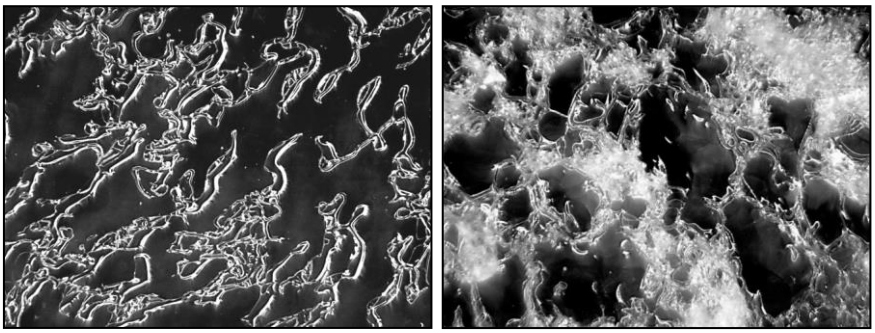


a b

Fig. 5. Structure of solidified in flat capillary of semidried (a) and completely dried (b) SSS (× 200): 1 – dehydrated SSS «jumper»; 2 – vapor bubble; 3 – cracks; 4 – unsolidified SSS

Further SSS processing with microwave radiation does not change its previously formed structure. That is, as a result of going through this multi-stage process, finally dried SSS in a flat capillary (in plan) takes the form shown in Fig. 6, a.

In the case of SSS drying by MWR in capillary of greater thickness (h = 400...1000 μm), SSS forms spatial (three-dimensional) foam structures (see Fig. 6, b).



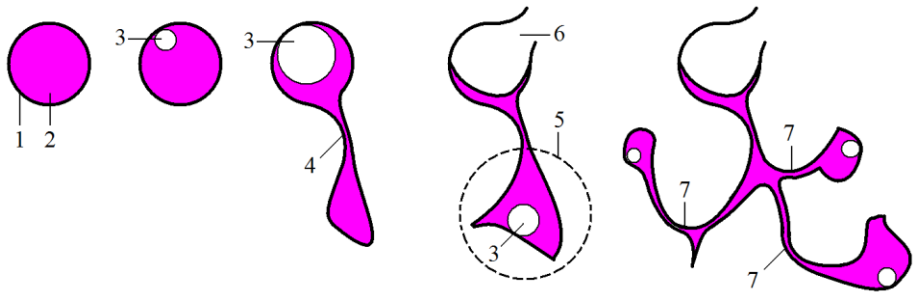
a b

Fig. 6. Section view of SSS layer in flat capillary at h = 40 μm (a) and h = 900 μm (b) after 90 sec processing with microwave radiation (× 75)

4 Discussion

Based on features of structures obtained, it can be stated that principle of SSS mass transfer in capillary-porous medium under microwave radiation influence is similar to its rapid external heating (thermal shock) action and is caused by foaming of SSS. However, the foaming mechanisms, as well as properties of formed SSS foam, are different under external thermal shock and under MWR influence.

In particular, SSS mass transfer mechanism under MWR action is characterized by multi-staging and proceeds according to chain reaction principle. This regularity, apparently, is due to SSS components microwave heating rate targeting and can be represented by scheme in Fig. 7.



a b c d e

Fig. 7. Scheme to mechanism description of SSS foaming under MWR action: 1 – shell of partially dehydrated SSS; 2 – unsolidified SSS; 3 – vapor bubble; 4 – primary channel; 5 – new capsule; 6 – water vapor release into vapor channel; 7 – secondary channel

At first stage of heating (see Fig. 7, a), thin viscos-plastic continuous film (shell) of partially dehydrated sodium silicate 1 appears on SSS drop free surface as free

water evaporation result. At the same time, residual in drop unsolidified SSS 2 turns out to be closed (encapsulated) inside this shell.

At the second stage of heating (see Fig. 7, b), upon boiling point of water reaching, in drop of non-solidified SSS gas bubble 3 appears.

Third stage of heating (see Fig. 7, c) leads to mass of evaporated water in the SSS capsule increasing and, accordingly, pressure in both vapor bubble and capsule increasing. At certain point in time, when the rate of vapor pressure increasing in capsule exceeds ultimate deformation of its shell ability, shell ruptures and unsolidified SSS extrudes beyond its boundaries. Process of SSS displacing from primary capsule 4 will continue until increased pressure remains in it or supply of unsolidified SSS runs out. Reason for vapor (see Fig. 7, d – 6) displacements from primary capsule may also be vapor pressure decreasing in capsule as result of its shell breaking.

At the fourth stage of heating (see Fig. 7, d), surface of SSS jet displaced from primary capsule is covered with a similar shell, secondary capsule forms, and primary channel 4 between old and new capsule 5 solidifies, new encapsulation of displaced SSS processing finishes. Subsequently, in new drop, as in previous one, vapor bubble 3 appears. Again, vapor pressure in capsule rises and unsolidified SSS ejects by jets outside the capsule, forming new capsules and secondary channels 7 (see Fig. 7, e).

Analysis of obtained data shows that microwave radiation using for drying sodium SSS in capillary-porous medium makes it possible to dehydrate sodium SSS almost completely in short period of time without increasing its temperature to 600°C.

Under microwave radiation influence, stable foam structure forms with a certain gas permeability and multiplicity of more than 20 in dried sodium SSS.

This circumstance, together with short duration and targeted heating inherent in MWR drying, allows to consider this technology as the most effective and promising from the point of view of developing new methods and approaches in solving the problem of structuring of granular materials optimizing and, in particular, for foundry molds and cores production.

5 Conclusions

1. Description of mass transfer of sodium silicate solute mechanism in flat capillary during heating by microwave radiation has been developed. According to this mechanism, mass transfer of SSS in capillary occurs as a result of multiple reproductions repeating of the stages. Among these stages: encapsulation of SSS water solution in treated sodium silicate solute structure; increase of vapor pressure in capsule; ejection of solidified SSS from capsules; movement stopping of SSS flow ejected outside the capsule as result of pressure increasing finishing due to capsule shell destruction; encapsulation of released SSS, etc. Until removal of water from treated sodium silicate solute will be completed.

2. Foam structure staged formation in sodium silicate solute under MWR influence is the reason for significant of its pores dispersion unevenness and gas permeability presence in SSS foam.

3. Drying sodium SSS with silicate module from 2.8 to 3.0 by microwave radiation can reduce the water content in dried sodium silicate solute to 0.02% (by weight) without its temperature increasing by more than 150 °C.

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