Study of the properties of an aqueous sodium silicate film on the surface of a refractory filler

N A Kidalov, N V Grigoreva, N I Gabelchenko, A A Belov and A I Savchenko,
Departament of Machines and technology of foundry, Volgograd state technical university, 28 Lenin Avenue, Volgograd 400005, Russia

mitlp@vstu.ru

Abstract. We investigated the effect of the method of solidification of aqueous sodium silicate on the formation of its film on the surface of a refractory filler. The structure of liquid-glass films on the surface of a refractory filler cured by convective drying, blowing with carbon dioxide, and with the addition of organic ether (butyl acetate) was studied. Quartz and chromite sands were used as a refractory filler.

1. Introduction

In the manufacture of molding and rod mixtures, a liquid-glass binder has been used for a long time, since it has a number of positive qualities, such as non-toxicity, relatively low cost, high binding ability, etc [1, 2]. It should be noted that for these mixtures there are a number of solidification methods: convective drying, blowing with carbon dioxide, the insertion of liquid hardeners, which allow to obtain various properties. A lot of scientific works are devoted to the study of these curing processes of liquid glass mixtures [3, 4]. Of particular interest are the studies of liquid glass films formed on the surface of a refractory filler.

But, along with positive qualities, it is necessary to mention the main problem of casters when working with liquid glass molds and cores - their poor knocking-out ability [5, 6]. For this reason, today, preference is given to resin-based materials [7-11]. However, for the production of large-sized complex shape steel casting, this material is not convenient due to the differing strength characteristics and the release of a significant amount of toxic gases during the destruction of resins under high temperatures.

The works, devoted to problems of poor knocking-out ability, discuss the use of softening additives [12-14], various methods of modifying a solution of sodium silicate and a liquid-glass mixture [15-16], the addition of organic hardeners [17, 18], which optimize the residual strength of the compositions. But also of great interest is the question of the films structure formation, their variability depending on the curing method and the influence of high temperatures and various additives.

The formation of the structure of a film of aqueous sodium silicate has been studied since the 70s [19]. However, research methods and technologies of that time did not allow to conduct detailed and full structural studies. The physical and mechanical properties are largely affected by the quality of the liquid glass film, therefore, studies that allow us to analyze the effect of curing methods on the properties will provide recommendations on the management of the properties of liquid glass molds and rods.
The aim of this work was to study the effect of various curing methods on the quality of a liquid glass film.

2. Materials and methods
During the study, quartz (GOST 2138–91) and chromite sand (TU 0741-001-23081308) as a filler and liquid glass as a binder of GOST 13078-81 were used as materials. Samples were cured by the following methods: convective drying, blowing carbon dioxide and adding, as a hardener, butyl acetate - organic ether (GOST 8981-78). Photographs of the obtained samples are presented in figure 1. The compositions of the mixtures for the manufacture of samples and notes on curing methods are presented in table 1.

| Mixture code | The composition of the mixtures, wt% | Curing method |
|--------------|-------------------------------------|---------------|
|              | Sand                                |               |
|              | Quartz K2O0.03                       |               |
|              | Chromite AFS 45-55                  |               |
|              | Liquid glass                        |               |
|              | Ether (butyl acetate)               |               |
| 1            | 94                                  | Convective drying in an oven at a temperature of 150-180 °C for 20 minutes |
| 2            | -                                   | Carbon dioxide purge (CO₂ process) for 5 minutes in a closed box |
| 3            | 94                                  | The refreshment was carried out by adding organic ether to the mixture |
| 4            | -                                   |               |
| 5            | 94                                  |               |
| 6            | -                                   |               |

Figure 1. Liquid glass samples based on quartz and chromite sand, cured by: (a) convective drying; (b) blowing carbon dioxide; (c) with the addition of butyl acetate.

After curing the samples, the structure of the liquid glass films was studied on a refractory filler using a Versa 3D double-beam electron scanning microscope.

3. Results and discussion
It has been found that liquid glass films have different structures depending on the curing method.

Liquid glass films on quartz sand after convective drying have a globular structure (figure 2. a, b). Binder swelling occurs when the temperature rises to 100 °C, and accordingly, the process of removal
(evaporation) of moisture, contained in liquid glass, occurs, which leads to the destruction of the liquid glass film.

![Figure 2](image1.png)

The structure of the liquid glass film on the surface of chromite sand has a more solid structure with a similar curing method (figure 2. c, d) and there are no signs of the films destruction, since moisture evaporation occurred more smoothly due to the high heat-storage ability of chromite.

Figure 3 shows images of the structure of liquid glass films cured by blowing carbon dioxide.
Figure 3. The structure of liquid glass films on samples cured by blowing carbon dioxide: (a) on quartz sand at a magnification of × 500; (b) on quartz sand at a magnification of × 1000; (c) on chromite sand at a magnification of × 500; (d) on chromite sand at magnification × 1000.

The cuffs of the liquid glass film (figure 3.a, b) between the grains of quartz sand are broken, there are cracks, and in some places the film is peeled off from the grain due to the carbonization process that occurs during carbon dioxide purging.

When the liquid-glass mixture is cured by blowing carbon dioxide, defects in the films structure on the surface of chromite sand samples (figure 3. c, d), are also visible (the growth of needle crystals breaking films is observed). The carbonization process on these samples proceeds more intensively, due to the more loose packing of grains of chromite sand (they have a more pronounced angular shape) during the manufacture of the sample, which is confirmed by gas permeability indicators (for samples on chromite sand - 430 units, on quartz sand - 255 units).

The effect of organic hardeners on the structure of liquid glass films was investigated. Butyl acetate, an ester of acetic acid, was used as an organic hardener. The structure of the liquid glass films is shown in figure 4.
Figure 4. The structure of liquid glass films on samples cured with organic ether: (a) on quartz sand at a magnification of × 260; (b) on quartz sand at a magnification of × 500; (c) on chromite sand at magnification × 260; (d) on chromite sand at magnification × 1000.

The structure of liquid glass films during curing of the mixture with organic ether has no cracks and chipping. With this curing method, it can be predicted that the strength of the sample is higher than that of samples cured by convective drying and blowing with carbon dioxide.

4. Conclusion

It was experimentally proved that the structure of a liquid-glass film formed on grains varies depending on the curing method and the type of filler.

Samples cured by convective drying and the CO₂ - process have structural defects. During convective drying of samples, the film has a globular structure. This is due to the removal of moisture, which is part of the liquid glass. When using the CO₂ - process, cracks are visible on the film due to the ongoing carbonization process, and crystal growth is observed. The course of these processes leads to stresses and notches of the film.

On samples made on the basis of quartz and chromite sand, in which ester was added, the structure is smooth and has no obvious defects.

Studying the behavior of the film of a silicate binder on the surface of a refractory filler with various curing methods will allow us in the future to predict the process of structure formation of liquid-glass mixtures.
References

[1] Zhukovsky S S and Kvasha F S 2012 Production of rods from liquid-glass mixtures in the mass production of castings Foundry worker of Russia. 7 pp 41-4.

[2] Zhukovsky S S and Boldin A N 2002 Foundry technology: molding and core mixtures (Bryansk: BSTU) p 470.

[3] Korneev V I and Danilov V V 1996 Liquid and soluble glass Production Edition (St. Petersburg: Stroyizdat) p 216.

[4] Krutilin A N, Guminsky Yu Yu, Rusevich O A and Kulbitskaya L V 2018 Improving the use of liquid glass mixtures. overview information. Part 1. Modification Casting and metallurgy. 1 (90) pp 47-54.

[5] Krutilin A N, Guminsky Yu Yu., Rusevich O A and Kulbitskaya L V 2018 Improving the use of liquid glass mixtures. 4. Combined hardening Casting and metallurgy. 4 (93) pp 38-44.

[6] Sun Q Z, Xu R F, Zhao Z K, et al. 2010 Reclamation of green sand containing hot – box resin sand and its application. Advanced Materials Research 97-101: pp 1037-40.

[7] Manabe T, Yamamoto Y and Hoshiyama Y. 2005 Effect of using furan resin reclamation sand in evaporative pattern casting process. Transactions of the American Foundry Society. 113 pp 1029-37.

[8] Kamińska J and Dańko J. 2012 Preliminary research on granulation process of dust waste from reclamation process of molding sands with furan resin. Archives of Foundry Engineering. 12 (3) pp 53–8.

[9] Guigo N, Mija A, Vincent L, et al. 2010 Eco-friendly composite resins based on renewable biomass resources: polyfurfuryl alcohol / lignin thermosets. European Polymer Journal 46 (5) pp 1016-23.

[10] Monti M, Hoydonckx H, Stappers F, et al. 2015 Thermal and combustion behavior of furan resin / silica nanocomposites. European Polymer Journal 67 pp 561-9.

[11] Li, Y.-L., Wu, G.-H., Liu, W.-C., Chen, A.-T., Zhang, L. and Wang, Y.-X. 2017 Effect of reclaimed sand additions on mechanical properties and fracture behavior of furan no-bake resin sand. China Foundry. 14 (2) pp 128-37.

[12] Kidalov N A, Osipova N A and Potashova I E 2012 The use of waste oil extraction production to improve the knockability of liquid glass mixtures. Procurement in engineering. 11. pp 5-8.

[13] Kidalov N A, Osipova N A and Potashova I E 2015 Filtration products of vegetable oils to improve the knockability of liquid-glass mixtures. Foundry. 10. pp 29-32.

[14] Kidalov N A and Osipova N A 2005 The effect of metal oxides on the properties of liquid glass mixtures for the manufacture of foundry moulds and cores. Mashinostroitel. 3. pp 46-51.

[15] Stechman M, Różycka D and Bialiński A 2003 Modification of aqueous sodium silicate solutions with morphoactive agents. IV Conference on Chemical Technology, Polish Journal of Chemical Technology. 5 (3) p 47.

[16] Al-Saraireh F M 2018 An assessment of the efficiency of utilizing complex modifiers for softening the liquid-glass mixtures to improve iron and steel casting ARPN Journal of Engineering and Applied Sciences 13 (9) pp 3231-5.

[17] Kidalov N A, Volchkov V M and Knyazeva A S 2015 Optimization of mixture composition for foundry. Creativity in Intelligent Technologies and Data Science. Communications in Computer and Information Science (535) pp 341-53.

[18] Kidalov N A, Volchkov V M and Osipova N A. 2005 Optimization of sodium silicate bonded sand composition. Foundry. 6 pp 11-6.

[19] Akulova M, Slizneva T, Sokolova Yu and Sokolova A 2019 Nanostructuring sodium silicate solutions applied as binding substance of molding sands in foundry. IOP Conference Series: Materials Science and Engineering. (560) 012136. 10.1088/1757-899X/560/1/012136.

[20] Ryzhkov I V and Tolstoy V S 1975 Physicochemical basis for the formation of the properties of mixtures with liquid glass (Kharkov: Vishka school.) p 139.
Acknowledgments

The reported study was funded by RFBR, project number 19-33-90111.