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Effect of Water Glass Modification on Its Viscosity and Wettability of Quartz Grains

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Abstract

The aim of the present study was to develop a modifier for water glass. The method of thermal generation of metal oxide nanoparticles was adapted and used in the research. Nanoparticles of ZnO from the thermal decomposition of basic zinc carbonate were used. A method for the modifier introduction was developed, and the effect of modifier content and organic solvent type on the physico-chemical properties of binder (viscosity) and quartz wettability was determined. Binder viscosity was examined from the flow curves plotted with the help of a RHEOTEST 2 rotational rheometer equipped with proper software. Quartz wettability was determined examining time-related changes in the value of the contact angle in a quartz-binder system, until full stabilisation of the angle value has been achieved. Binder modification was carried out on sodium water glass designated as R"145". The water glass modifiers were suspensions of ZnO nanoparticles in propanol and methanol at a fixed concentration of c = 0.3 M and with the size of nanoparticles comprised in a range of <61 - 981 nm>. Water glass modification with the suspensions of ZnO nanoparticles in methanol and propanol showed the effect of modifier on the water glass viscosity and quartz wettability. This effect depends on the type of alcohol used. The ZnO suspension in propanol (alcohol with a longer hydrocarbon chain) affects more strongly the viscosity of binder and quartz wettability than the methanol suspension.

Keywords: Water glass, Modification, Thermal synthesis of ZnO nanoparticles, Viscosity, Wettability

1. Introduction

Moulding sands with organic binders exhibit significant toxicity. This involves, on the one hand, the necessity of additional investments to ensure an adequate level of safety and proper working conditions in foundries, while, on the other, increases the sand cost, especially when it contains binders with furfuryl alcohol. These drawbacks forced the researchers to look for binders that do not show these characteristics.

One of such binders is water glass - cheap, readily available and nontoxic. However, the disadvantage of the sands with water glass is their brittleness, poor knocking out properties and low degree of reclamability. At the same time, the potentials of water glass as a binder for foundry sand moulds and cores are not fully utilised. This is because the technological process should simultaneously meet the following demands: ensure optimal conditions for the core and mould hardening, ensure the required level of mechanical and physico-chemical properties (strength, hygroscopicity, brittleness, etc.) as well as the lowest possible residual strength of moulds and cores in a wide range of temperatures (300-1200°C), which will improve the knocking out properties of the sand and, last but not least, will improve the moulding and core sand reclamability.

Studies have shown that the most effective improvement in the quality of sands with water glass is obtained through modification of the binder [1-2]. So far, as modifiers, the multimolecular components have been used, such as e.g. polyphosphates and polyacrylamides, differing in the degree of polymerisation, in molar mass, and in the type and number of functional groups.

Recent decades have brought the development of a new family of materials known as nanoparticles. These are, among others, the nanoparticles of ceramic materials (e.g. SiO_2, Al_2O_3, $CaSiO_3$, ZnO, aluminosilicates, etc. [3-8]). These nanoparticles, when introduced into the matrix (binder), create new systems, called nanocomposites. Because of their similar molecular size and highly developed specific surface area, nanoparticles exhibit quite a unique and never observed in typical composites ability to interact with the binder matrix and modify the properties of binder in its interface layers. The improvement mainly consists in upgrading the mechanical and thermal properties (modulus of elasticity, breaking stress, hardness, adhesion, thermal stability, etc.). The improvement of nanocomposite properties depends on the following factors: the impact of nanofiller on the structure of the binder matrix, the size of nanofiller particles and their mutual arrangement.

Operating through chemical or physico-chemical effects, nanoparticles may alter the original properties of the binder. So far, most studies on the water glass modification have been focused on the use of organic compounds. Very scarce results reported in the literature suggest a positive impact of micro-and nanoparticles of MgO and Cr_2O_3 on the residual strength, which is associated with an improvement of the sand knocking out properties [9].

In nanotechnology, there are two manufacturing techniques, called top-down and bottom-up [10-14]. The first technique consists in disintegration of the material to a very fine form, mainly by grinding and cutting. The bottom-up method produces larger structures from individual atoms or molecules. This technique includes the processes of chemical synthesis in liquid phase (e.g. sol-gel, precipitation methods) or in the gaseous phase (e.g. pyrolysis).

Literature data on the water glass modification with nanoparticles of inorganic compounds are random and qualitative in nature [15]. There are no systematic studies that would interrelate the technique of modification with the modification effect, and structure of produced nanobinder (nanocomposite) with its properties.

2. Scope and purpose of the research

The purpose of the study was to develop a modifier for water glass.

For the purpose of the study, a method of thermal generation of metal oxide nanoparticles was adapted. Nanoparticles of ZnO were produced by thermal decomposition of the basic zinc carbonate.

A technique for the modifier introduction was developed, and studies were carried out on the effect of the type and content of an organic solvent on the physico-chemical properties of binder (viscosity) and quartz wettability.

3. Research methodology

3.1. Test materials

Binder modification was carried out on:

- sodium water glass grade R „145 ” characterised by the modulus M = 2,5, the density d^{20} = 1470 kg/m^3 and pH = 11,2

Water glass modifiers were:

- suspensions of ZnO nanoparticles in propanol and methanol at a fixed concentration of c = 0.3 M and with the size of nanoparticles comprised in a range of <61 - 981 nm>.

3.2. Measurement apparatus and method

The size of nanoparticles was measured with a Philips XL30 SEM coupled with LINK ISIS EDX system and with a Philips ESEM with EBSD orientation imaging system.

Binder viscosity was examined from the flow curves plotted with the help of a RHEOTEST 2 rotational rheometer equipped with proper software.

Quartz wettability was determined examining time-related changes in the value of the contact angle in a quartz-binder system, until full stabilisation of the angle value has been achieved. The wettability was measured using a prototype device for the contact angle measurements [16].

Modification of "R145" water glass consisted in the introduction of 5wt.% of the alcohol-based, colloidal suspension of ZnO nanoparticles in propanol or methanol and in homogenising of the mixture next.

4. Results and discussion

Figures 1-6 show the effect of water glass modification on its viscosity (Figs. 1-3) and wettability of the quartz grains (Figs. 4-6). All the flow curves (Figs. 1, 2 and 3) are straight lines extending from the origin of a coordinate system (γ, τ), which indicates a Newtonian nature of the binder with characteristic for this type of fluids rheological parameter - viscosity η (1):

$$\tau = \eta \cdot \gamma \qquad (1)$$

where:

τ – the tangent stress,
η – the absolute viscosity,
γ – the shear rate.

The presented results show that water glass modification with alcohol suspensions of nanoparticles affects the intermolecular phenomena. It manifests itself in an approximately 13% increase of viscosity after the modification with methanol suspension, or in an approximately 20% drop of this parameter as a result of modification with ZnO suspension of nanoparticles in propanol.

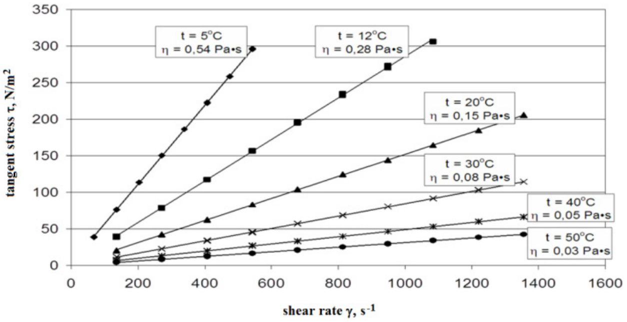

Fig. 1. Flow curves plotted for unmodified „R 145" water glass at different temperatures

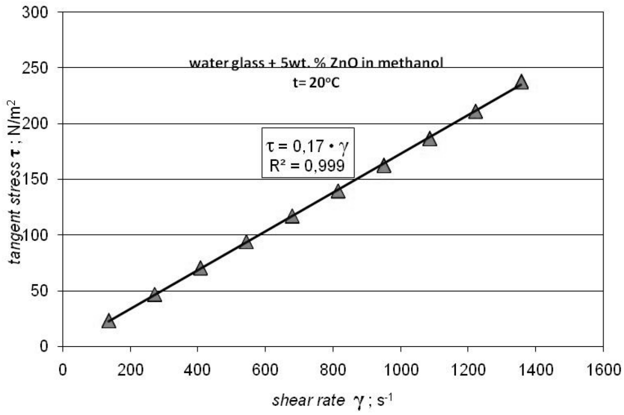

Fig. 2. Flow curve plotted for water glass modified with 5 wt.% suspension of ZnO nanoparticles in methanol. Measurement temperature: 20^{o}C

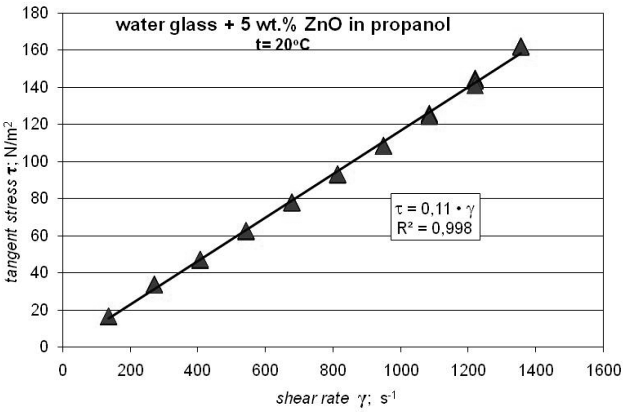

Fig. 3. Flow curve plotted for water glass modified with 5wt.% suspension of ZnO nanoparticles in propanol. Measurement temperature: 20^{o}C

Wetting of quartz by unmodified water glass (Fig. 4) is taking place with the dynamics that has the highest value of the initial angle θ_0 (about 45 deg.) and equilibrium angle θ_r (about 33 deg.), and the longest time necessary for the system to reach the steady state τ_r (about 20 min). Binder modification with the ZnO suspension in methanol (Fig. 5) improved the wettability of quartz grains reducing the above mentioned parameters, i.e. θ_0, θ_r, τ_r to 33 deg, 22 deg, 7 min., respectively. The best wettability was achieved by binder modification with the ZnO suspension in propanol (Fig. 6). The symptom of improvement was a significant drop in the value of both angles θ_0 and θ_r to 20 deg. and 5 deg., respectively. Attention also deserves much shorter time lapse necessary for the system to reach its steady state (about 2 min.).

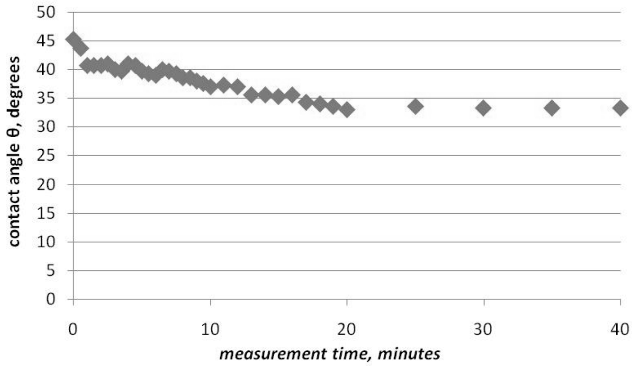

Fig. 4. Time-related changes in the value of contact angle in a quartz-unmodified water glass system. Measurement temperature: 20^{o}C

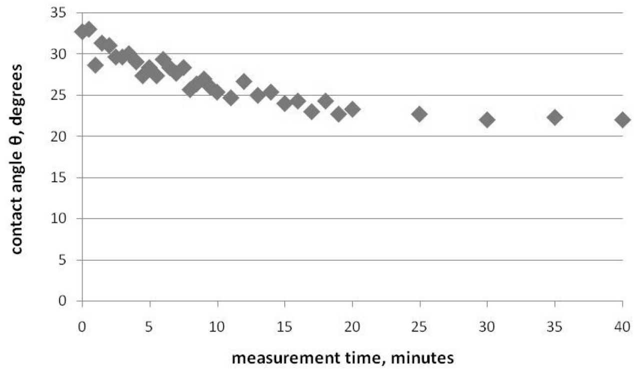

Fig. 5. Time-related changes in the value of contact angle in a quartz-modified water glass system (5wt.% suspension of ZnO nanoparticles in methanol). Measurement temperature: 20^{o}C

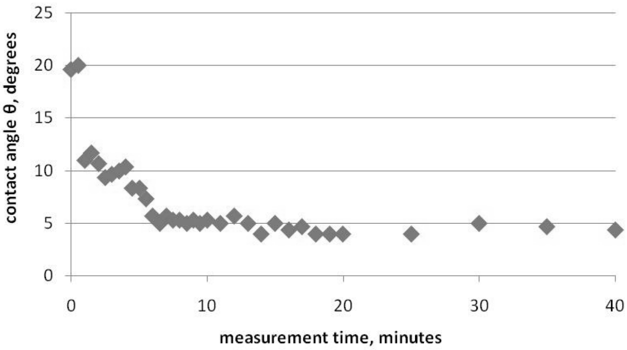

Fig. 6. Time-related changes in the value of contact angle in a quartz-modified water glass system (5wt.% suspension of ZnO nanoparticles in propanol). Measurement temperature: 20°C

5. Summary

Water glass modification with the suspensions of ZnO nanoparticles in methanol and propanol shows the effect of modifier on the viscosity of binder and wettability of quartz grains in a quartz - binder system.

This effect depends on the type of alcohol used. The ZnO suspension in propanol (alcohol with a longer hydrocarbon chain) affects more strongly the viscosity of binder and quartz wettability than the methanol suspension.

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