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Water Glass Modification and its Impact on the Mechanical Properties of Moulding Sands

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Abstract

The purpose of the presented experiment was to develop an effective water glass modifier. In the conducted research, an attempt was made to determine the effect of modifier addition on the wettability of quartz grains, viscosity and cohesion of binder and strength R_m^U of the sand mixture. Water glass modification was carried out with, obtained in electrochemical process [1], colloidal suspension of ZnO nanoparticles in methanol (modifier I) or propanol (modifier II), characterised by a constant molar concentration of c = 0.3 M. It was demonstrated that the addition of a colloidal suspension of ZnO nanoparticles in propanol (modifier II) had a significant effect on wettability of quartz grains improvement without the accompanying increase in binder viscosity. Testing the mechanical properties R_m^U of sand mixtures containing modified binder (modifier II) hardened at ambient conditions showed an approximately 28% increase in strength compared with the R_m^U of the sand bonded with an unmodified binder.

Keywords: Innovative materials and foundry technology, ZnO nanoparticles, Viscosity, Wettability, Cohesion, Sand strength R_m^u

1. Introduction, scope and aim of studies

Water glass as a foundry binder has been used in metal casting practice for many years. Moulding and core sands prepared with this binder are characterised by poor reclamability. Other drawbacks of these sand mixtures include their brittleness, poor collapsibility, and tendency to stick to the surface of casting. The advantages of this binder are mainly its low price, the availability on the market and non-toxic character.

Previous studies have claimed that an effective method to improve the quality of the sands bonded with water glass is modification of the binder itself carried out with polyacrylamide, polyvinyl alcohol and carbamide [2]. Introduced to a binder system, these nanoparticles by entering into reaction with the binder can change its original properties. Both structure and the chemical nature of the modifier play a very important role in this process. Literature lacks the description of systematic studies on the effect that water glass modification with nanoparticles of inorganic compounds may have on the functional properties of sands, such as the strength at ambient conditions and collapsibility. The studies are mainly qualitative in nature and do not explain the effect that the modifier may have on the structure and properties of binder [3,4].

This study will discuss the influence of the type of modifier on the wettability of quartz grains, viscosity and cohesion of the binder and strength R_m^U of the sand mixture at ambient conditions. Based on the results of the conducted research, the best modfier of water glass will be selected as conferring optimum properties to the sand mixture, i.e. high strength at ambient conditions combined with good collapsibility.

2. Research part

2.1 Test materials and methods

Modification was carried out for sodium water glass type R "145" characterised by the following parameters: modulus M = 2.5, density d^{20} = 1470 kg/m^3, pH = 11.2.

As modifiers, colloidal suspensions of ZnO nanoparticles, obtained electrochemically in the process of anodic dissolution of metals [1], characterised by a constant concentration of c = 0.3 M, were applied.

The applied modifiers comprised:

- **modifier I** - suspension of ZnO nanoparticles in methanol, nanoparticle size - about 50 nm,
- **modifier II** – suspension of ZnO nanoparticles in propanol, nanoparticle size <10 nm.

Water glass modification comprised adding the modifier and homogenising the mixture.

The wettability was measured in a quartz – binder system, determining time-related changes in the contact angle until full stabilisation of its value has been reached. For the wettability measurements, a prototype device determining the contact angle was used [5].

The viscosity of binder was determined by plotting the respective flow curves with a RHEOTEST 2 rotational rheometer.

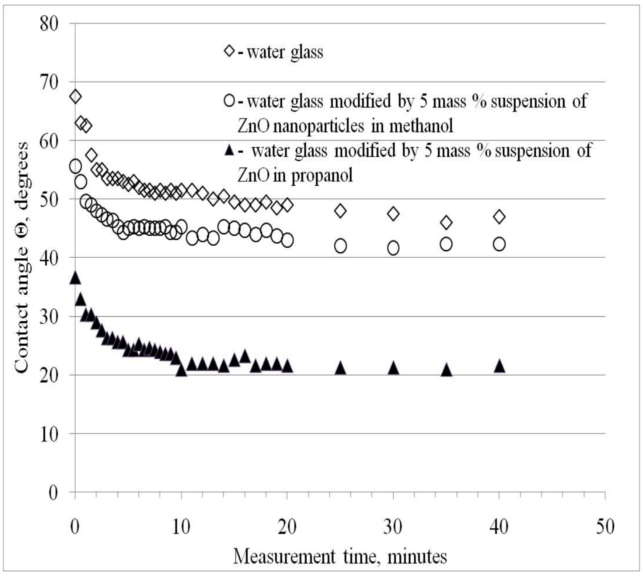
For the cohesive strength σ_K test were used on paddle-shaped samples of different thicknesses (from 0.3 to 0.8 mm) hardened for 6 days at 20°C. The cohesive strength was determined through the tensile strength measurements taken on a prototype apparatus at a constant loading speed of V = 1 mm/min.

The effect water glass modification was determined examining the tensile strength R_m^U of the sand after various times of hardening. For analysis, the results of hardening the sand for 24 hours in the air were adopted.

2.2 Results and discussion

Figure 1 shows time-related changes of the contact angle in a quartz – binder system. Studies have demonstrated that the lowest quartz wettability (largest contact angle) has the unmodified water glass and water glass modified with 5 mass% of ZnO suspension in methanol (modifier I). This applies to both the initial (θ_0) and equilibrium (θ_r) contact angle values.

Water glass modification with a colloidal suspension of ZnO in propanol (modifier II) significantly improves the wettability of quartz as indicated by the low values of the θ_0 and θ_r angles.



Rys. 1. Time-related changes in the value of contact angle in a quartz-modified water glass system (5 mass % suspension of ZnO nanoparticles (obtained by electrochemical method) in methanol or propanol). Measurement temperature: 20°C

As demonstrated by the studies conducted recently, an important role in the wettability improvement plays the type of the organic solvent used. This has also been confirmed by studies of the quartz wettability when binders containing various modifiers are used [6-9].

In the case of water glass modification with the colloidal suspensions of ZnO nanoparticles, the use of propanol (C_3H_7OH), i.e. the solvent with a long hydrocarbon chain, gives much better results compared with methanol (CH_3OH) [10-11].

Figure 2 shows the effect of water glass modification on its viscosity. The flow curves are straight lines emanating from the origin of a coordinate system of γ, τ, which indicates the Newtonian nature of binders with the rheological parameter - viscosity η, characteristic of this type of fluid.

According to the following equations (1-3), the viscosity of water glass modified with 5 mass% suspension of ZnO nanoparticles in methanol or propanol is 0.16 and 0.15 [Pa·s], respectively, and about 0.12 [Pa·s] for the unmodified binder.

$$\tau/\gamma = 0{,}12; \qquad (1)$$

- unmodified water glass,

$$\tau/\gamma = 0{,}16; \qquad (2)$$

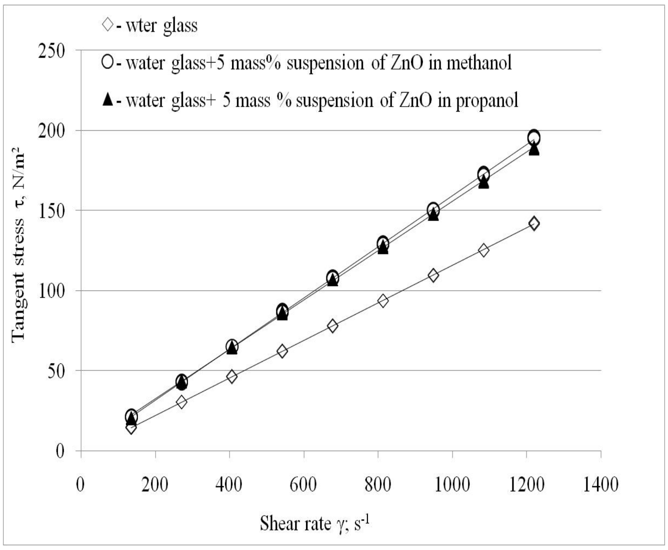
- modified water glass (modifier I),

$$\tau/\gamma = 0{,}15; \qquad (3)$$

- modified water glass (modifier II).

where:

τ – tangent stress [N/m^2],
γ – shear rate [s^{-1}].



Rys.2. Flow curves plotted for water glass modified by 5 mass. % suspension of ZnO nanoparticles (obtained by electrochemical method) in methanol or propanol; Measurement temperature : 20 °C

Figure 3 shows a dependence between the cohesive strength of binder σ_K and thickness g of samples of the unmodified water glass and water glass modified with 5 mass% suspension of ZnO nanoparticles in propanol (modifier II).

The exponential nature of the relationship obeying the following equations:

$\sigma_K = 1{,}91 \bullet e^{-0{,}80g}$; $R^2=0{,}91$; (4)

- in the range of $0{,}6 < g < 2{,}0$ mm;

unmodified water glass,

$\sigma_K = 15{,}12 \bullet e^{-2{,}85g}$; $R^2=0{,}90$; (5)

- in the range of $0{,}30 < g < 0{,}80$ mm;

water glass modified with 5 mass% suspension of ZnO nanoparticles in propanol (modifier II).

Mathematically, the pre-exponential constant of equations (4 and 5) denotes a limit to which the function is tending, when the argument g tends to zero. Physically, it corresponds to the strength of a "perfect" sample (in MPa), free from the macro-discontinuities. A comparison of the pre-exponential constants in equations (4) and (5) shows that water glass modification with 5 mass% suspension of ZnO nanoparticles in propanol increases approximately 8 times the strength σ_K of the binder. The pre-exponential constant in the considered equations means that when the thickness of the examined sample is equal to "1 / g", the strength σ_K will decrease "e" times. For example, when the thickness of the sample is 1/2, 85 = 0.35 mm (Equation 5), the cohesive strength of the modified binder will be 5.58 MPa.

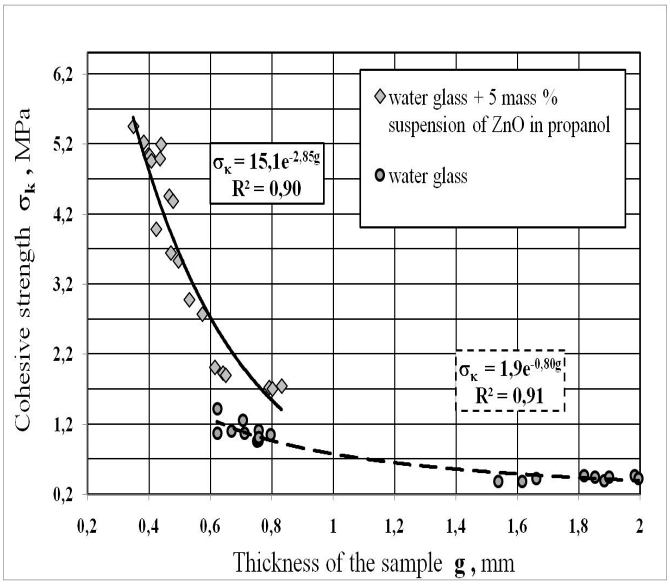


Fig.3. The cohesive strength σ_K sample thickness dependence for water glass unmodified and modified by 5 mass% suspension of ZnO nanoparticles in propanol; hardening time 6x24 h, loading rate V=1 mm/min.

Figure 4 shows the collective results of the tensile strength R_m^U test carried out on moulding sands with water glass unmodified and modified with 5 mass% of ZnO suspension after various times of hardening.

Research has shown that the maximum strength R_m^U of the sand with unmodified binder after 24 h hardening is 1,43 [MPa], while binder modification with 5 mass% of the colloidal suspension of ZnO nanoparticles in propanol (modifier II) confers to the sand the strength R_m^U of 1.8 [MPa], i.e. by about 28% higher compared with the strength of the sand containing unmodified binder. On the other hand, binder modified with the ZnO suspension in methanol (modifier I) conferred to the sand the strength values similar to the R_m^U of the sand with unmodified binder.

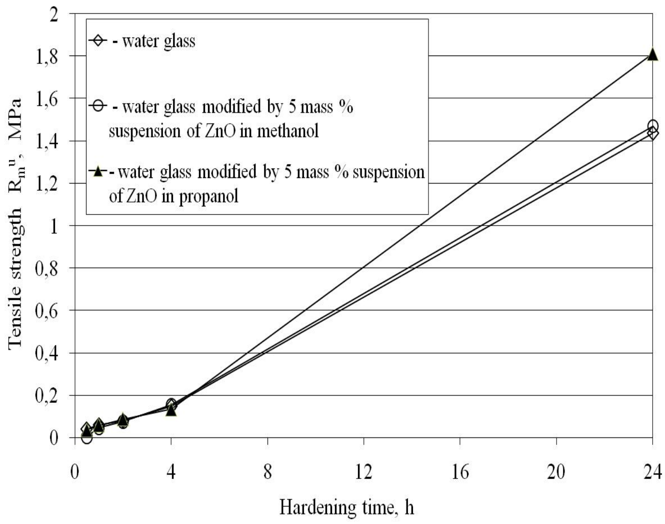


Fig.4. Effect of hardening time on the tensile strength R_m^u of loose self-setting sands with water glass. Sand composition (in parts by weight): **1)** 'Szczakowa'silica sand - 100, water glass '145'- 3, **2)** Modifier: 5 mass % suspension of ZnO in methanol, calculated in respect of binder, **3)** Modifier: 5 mass % suspension of ZnO in propanol, calculated in respect of binder. Hardened in air. Hardening conditions: $t_{ot} \approx 24\ ^0$C; moisture ≈ 51%.

5. Summary

Modification of water glass with colloidal suspensions of ZnO nanoparticles showed a significant impact of this treatment on selected physico-chemical properties (wettability, viscosity, cohesion) of binder and mechanical properties (strength R_m^U) of the resulting sand mixture.

Of great importance is the type of the organic solvent used. It has been established that the solvent with a long hydrocarbon chain exerts greater impact on the interfacial interaction (wettability) and also on the improvement of the sand strength. From the conducted studies it follows that much more effective is modifier II, consisting of a suspension of the ZnO nanoparticles in propanol.

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Streszczenie

Celem badań zaprezentowanego eksperymentu było opracowanie skutecznego modyfikatora szkła wodnego. Przeprowadzone badania miały na celu określenie wpływu dodatku modyfikatora na: zwilżalność kwarcu przez szkło wodne, lepkość i kohezję spoiwa oraz wytrzymałość R_m^U masy.

Do modyfikacji szkła wodnego zastosowano koloidalne zawiesiny nanocząstek ZnO otrzymanych w procesie elektrochemicznym [1] w metanolu (modyfikator I) lub w propanolu (modyfikator II) o stałym stężeniu molowym c = 0,3 M.

Wykazano, że dodatek w postaci koloidalnej zawiesiny nanocząstek ZnO w propanolu (modyfikator II) wpływał znacząco na poprawę zwilżalności ziaren kwarcu nie zwiększając równocześnie lepkości spoiwa. Weryfikacja właściwości wytrzymałościowych R_m^U mas z dodatkiem spoiwa modyfikowanego (modyfikator II) utwardzanych w warunkach otoczenia wykazała ok. 28% wzrost wytrzymałości w porównaniu z R_m^U masy ze spoiwem niemodyfikowanym.

Słowa kluczowe: innowacyjne materiały i technologie odlewnicze, nanocząstki ZnO, lepkość, zwilżalność, kohezja, wytrzymałość R_m^u masy