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RHEOLOGICAL PROPERTIES OF CERAMIC SLURRIES WITH COLLOIDAL BINDERS USED IN THE INVESTMENT CASTING TECHNOLOGY

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The article presents results of analyses of ceramic slurries made using materials currently tested in this technology, i.e.: colloidal silica (Ludox AM and Ludox SK) as a binder and Al_2O_3 as the ceramic matrix material. To characterise the binder, the size of colloidal binder particles, the Zeta potential and the binder pH were determined. Rheological properties were studied for slurries whose proportion of the (technologically justified) solid phase amounted to: 73; 74; 75 %. The impact of the solid phase proportion on the thickness of subsequent coats applied to the wax model, the dynamic viscosity and the density was determined. Research also included the impact of the size of matrix grains and the temperature on the above properties.

Key words: investment casting method, rheological properties, colloid silicate, dynamic viscosity

INTRODUCTION

The investment casting technology is one of the oldest methods, utilised in the machine, transportation (railway, aviation, motorisation) and armaments industries. Presently multilayer moulds forming a certain shell kind are applied in this method. The binder being a component of liquid ceramic moulding sands decides, to a significant degree, on the quality of the produced casting moulds and on the casting quality.

In the previous technology, and partially also currently, ethyl silicate has been applied as a binder. Due to its alcoholic character, this binder relatively easily transfers from the sol state into the gel one, providing the proper technological strength of the layer. Alcohols, having a low evaporation temperature and nearly three times smaller than water heat of vaporisation, are fast removed from the layers of the mould being formed.

Presently, new regulations of the environment protection were introduced, which are forcing to withdraw ethyl silicate from the technological process and substituting it by the new (water) binder of the new generation – colloidal silica [1, 2].

Changing of the binder, forces also changes in the ceramic materials applied in the new technology. Ceramic moulding sands with a binder in a form of colloidal silica have several different properties than the ones applied up to day. This concerns the properties, which are very important in the moulds production process. These important properties are as follows reological properties including the dynamic and kinematic viscosity, tendency for sedimentation, wettability of wax patterns. All these properties depend on the ceramic mixture composition, kind of colloidal silicate, amount of solids in the mixture, temperature, etc. [3, 4]

METHODOLOGY AND PERFORMING OF MEASUREMENTS

As the first step of investigations the particle size in a binder was determined by means of the device: Nanosizer-ZS of the Malvern Instruments Company. This device allows to determine three basic parameters describing particles in a suspension, it means: size*, Zeta potential and molecular mass.* The particle size measurement is based on the Brownian movement effect and the dynamic light diffusion technique.

The successive stage of investigations constituted viscosity measurements of a binder and ceramic moulding sand, which were based on the flow curve determination at the increasing and then decreasing shear rate value. Stress values obtained at the decreasing shear rate were accepted for the results analysis.

The rotary viscometer RHEOTEST 2 was used in measurements. This device is applied for investigating rheological characteristics of fluids in a wide ranges of shear rate, shearing stress and dynamic viscosity. The tested ceramic moulding sand (Ludox AM) and the binder (Ludox AM and SK) was placed in the ring-shape crevice in between two coaxial cylinders of the measuring system. The outer cylinder was not moving when the inner one (called a spindle), which rotated with a constant angular velocity, was connected with the meas-

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uring shaft by means of the calibrated spring. The measuring cylinder was filled with the proper amount of fluid (binders: Ludox AM and SK of 25 cm^3, and ceramic sand on the basis of Ludox AM in an amount of 30 cm^3) and then connected with the viscometer measuring mechanism [5, 6]. Tests were perfor-med at an ambient temperature (app. 22 ^{o}C).

The micrometric tests of the thickness of the ceramic moulding sand layer deposited on the wax pattern were aimed at the determination of the mixture composition influence on the formed layers thickness. Measurements were carried out for three different fractions of the solid phase, being respectively: 73; 74; 75 %. Three layers of the ceramic mixture were placed on the wax pattern of dimensions: 60 x 60 x 5 mm. After each layer deposition its thickness was measured.

BINDING AGENTS PROPERTIES

The simplest classification divides fluids into the Newtonian and non-Newtonian fluids. Ceramic fluidal sands due to their rheological behaviour can be classified into non-Newtonian, pseudoplastic fluids, where viscosity (apparent) decreases when the shear rate increases [6, 7].

Several factors influence dynamic viscosity, among others: mixture and binder temperature, particle size, percentage fraction of a solid phase, etc. [8, 9]. It can be noticed in Figures 1 and 2 that Ludox SK (pH = 4-5) is characterised by larger particles in the binder as compared with Ludox AM (pH = 9). Particle sizes have a signi-ficant influence on the binder viscosity, which is confirmed by the results presented in Figures 3 and 4.

Flow curves of the Ludox AM and SK binders are shown in Figure 3. These binders behave as the Bingham plastic, otherwise it is non-Neutonian rheostable fluid, which starts flowing only when shearing stresses exceed a certain critical value.

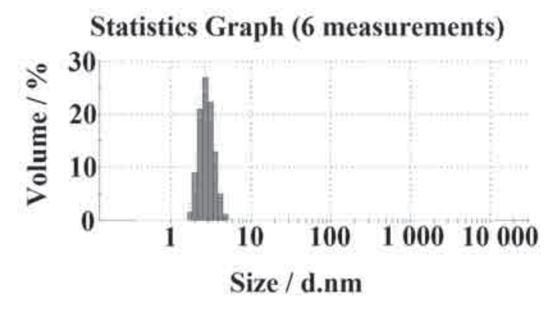

Figure 1 Particle size in the Ludox AM binder

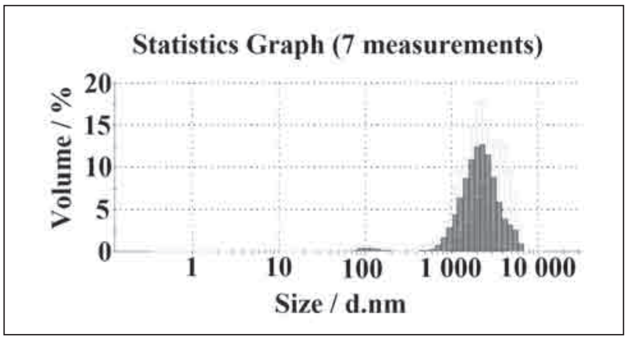

Figure 2 Particle size in the Ludox SK binder

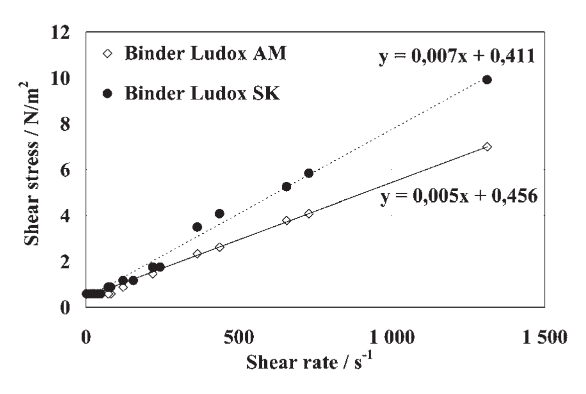

Figure 3 Binders flow curves Ludox: AM and SK

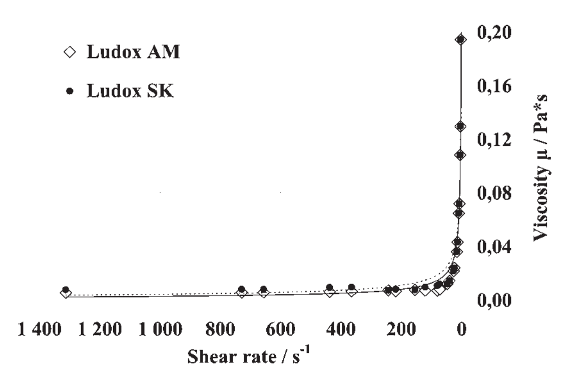

Figure 4 Binders viscosity curves Ludox: AM and SK

Tests indicated the Ludox SK binder has a higher dynamic viscosity, being equal 0,007 [Pa·s]. The viscosity curves of binders are presented in Figure 4. The viscosity correlates with the particles size in a binder. Thus, on this basis it is possible to infer that occurrence of larger particles in a binder or in a moulding sand matrix will cause an increase of its viscosity.

RHEOLOGICAL PROPERTIES OF MIXTURES

The comparison of viscosities of suspensions containing the same solid phase fractions but of different Al_2O_3 grain size, allows to notice that the ceramic moulding sand with addition of aluminium oxide of the grain size: d_L = 29 μm is characterised by a higher viscosity than the sand containing Al_2O_3 of the grain size: d_L = 16,5 μm (Figure 5). The dynamic viscosity was increasing along with the solids content increase due to strong particles interactions.

Introduction of a higher amount of the solid phase into the moulding sand causes its viscosity increase (Figures 6 and 7). For sands containing 73 % of the solid phase η = 0,110, for 74 % η = 0,254, and for 75 % η = 0,651 [Pa·s].

At the moulds production, the selection of the mixture components proportions should enable obtaining the high final strength of the mould.

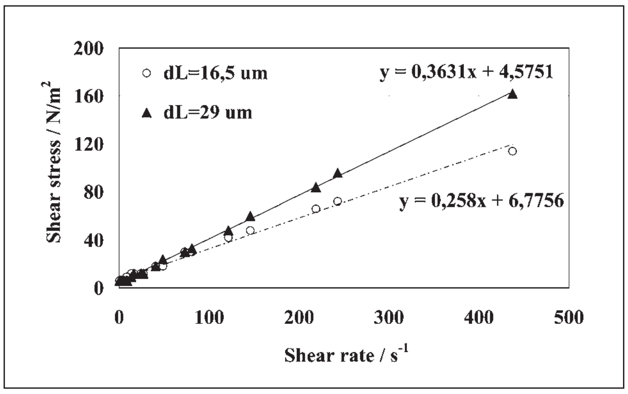

Figure 5 Influence of Al_2O_3 grain size on the ceramic moulding sand viscosity, Al_2O_3 fraction = 74 %

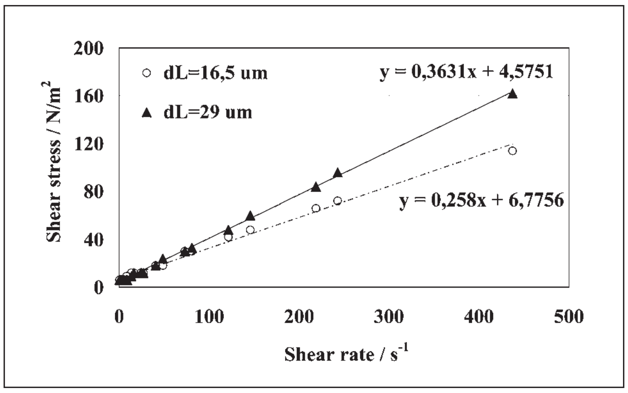

Figure 6 Ceramic moulding sand (on the Ludox AM basis) flow curves; influence of the solid phase fraction

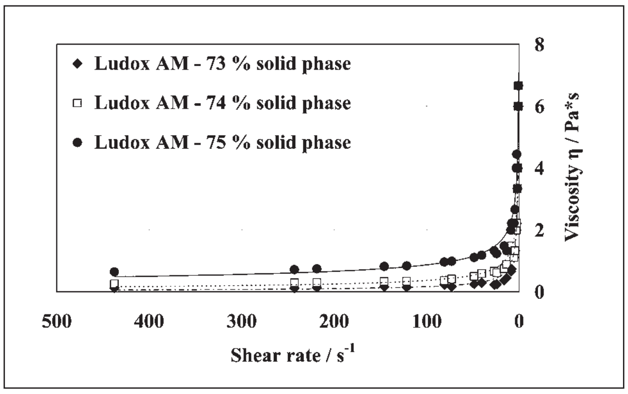

Figure 7 Ceramic moulding sand (on the Ludox AM basis) viscosity curves; influence of the solid phase fraction

CERAMIC LAYERS THICKNESS

Introducing into ceramic mixture too small as well as too large solid phase fraction influences unfavourably the quality of produced ceramic moulds, which is seen in Figure 8. The influence of the solid phase content on the thickness of the layer formed on the wax patterns is presented in Figure 9.

When too small fraction of the solid phase is introduced into the mixture the wax pattern surface is not equally covered. After three times immersion of the wax pattern in the ceramic moulding sand some wax gaps can be seen (Figure 8 a). The layer is very thin and its average thickness is 0,16 mm. However, when too large fraction of the solid phase is introduced the dynamic viscosity increases which leads to uneven covering of wax patterns by the ceramic moulding sand. In addition, it causes pellets formation on the surface (Figure 8 b, c). The layer thickness is then 0,35 mm. Layers deposited on wax patterns become more and more thick which can lead to a mould weakening and decreasing its structural strength.

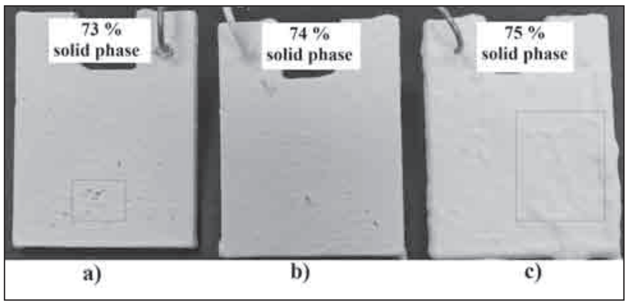

Figure 8 Wax patterns after placing 3 layers of the ceramic moulding sand of various solid phase contents

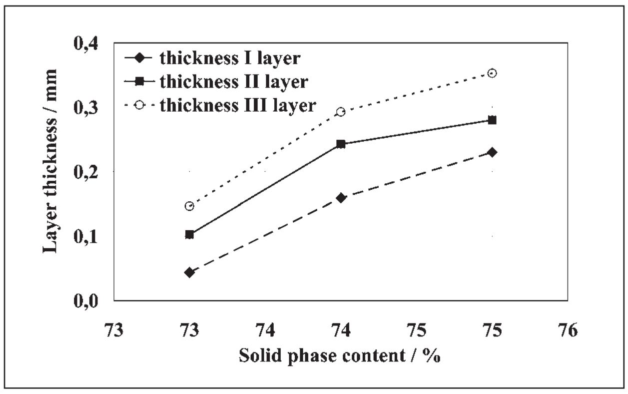

Figure 9 Influence of solid phase fraction in the mixture on the thickness of layers formed on wax patterns

The obtained results are the preliminary ones leading to the development of new optimal compositions of ceramic moulding sands applied in the technology, in order to obtain moulds fully suitable for the production process. The basic properties such as: viscosity, solid phase content and pH value were determined for the Ludox AM binder. The performed tests allowed to state that the ceramic mixture containing 74 % of the solid phase is optimal in respect of rheological properties and the layer thickness equals: 0,29 mm. The wax pattern is equally covered.

CONCLUSIONS

An important feature of the colloidal silica based binder is its long working time, and none self-gelating tendency (contrary to the ethyl silicate based binders), however this binder can change its viscosity. On the basis of the obtained results, it can be stated that the larger matrix grain size the higher moulding sand viscosity. The second essential factor influencing rheological properties of the suspension is the solid phase fraction. The analysis of the measurements indicates that along with the solid phase content increase the investigated moulding sand viscosity also increases. This is not favourable for the ceramic moulds production. The proper selection of the sand components is important to obtain the high mould strength.

When the dynamic velocity of the mixture increases the deposited layers become thicker and thicker. This makes difficult their drying and can cause moulds cracking during that process. Since the ceramic moulding sands dynamic viscosity is one of the most important features deciding on the ceramic moulds quality, it is constantly controlled in the technological process.

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Note: The responsible translator for English language: "ANGOS" Translation Office, Kraków, Poland.