SCIENTIFIC RESEARCH AND DEVELOPMENT

NANODISPERSED SILICA AND SOME ASPECTS OF NANOTECHNOLOGY IN THE FIELD OF SILICATE MATERIALS SCIENCE. PART 3*1

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On the example of highly concentrated binding suspensions (HCBS) of fuzed quartz the effect of their concentration with wet grinding is specified governing the content of nanoparticles in a system. On the basis of the limiting concentration of HCBS \( C_V = 0.82 \) castings are prepared with a nanoporous structure. As applied to the technology of different silicate materials theoretical aspects are specified connected with preparation and control of colloidal-chemistry and rheological properties of nano-containing dispersed systems for their preparation.

CONCENTRATION OF HCBS AS A FACTOR DETERMINING NANOPARTICLE CONTENT

In preparing and studying numerous types of HCBS it has been established that in the field of concentrations approaching critical there is a sharp change in properties both of suspensions and castings based on them. For example, with an increase in quartz glass suspension concentration by 5% in the range \( C_V = 0.70 \) – 0.75, \( \Pi_{\text{cas}} \) decreases by 25 – 30% (rel.), but \( \sigma_{\text{hela}} \) increases by a factor of 1.5 – 2.0. As \( C_V \) increases further the intensity of the change in properties increases. Analysis of this feature has shown that dependences of the change in HCBS properties on their concentration should be considered from the position of the volumetric solid to liquid ratio (SLR) that is the ratio in a system of volume fractions of solid \( C_V \) and liquid \( C_W \) phases, i.e. \( \text{SLR} = C_V / C_W \).

As follows from Fig. 1, in the field of high values of \( C_V \) the SLR indices increase more markedly than in the field of low values. For example, with an increase in \( C_V \) from 0.7 to 0.8 (i.e. by 14%) the value of SLR increases by 71% (from 2.33 to 4.00).

In publication [41] in order to establish regularities in the change in properties of suspensions and castings based on them in relation to SLR index a study was made of fuzed quartz suspensions prepared both in an industrial mill \( (C_V < 0.70) \) and in a 50-liter laboratory vessel \( (C_V < 0.77) \). Here the grain size composition was about the same \((< 5 \, \mu m \, 28 - 35\%, > 50 \, \mu m \, 3 - 10\%) \) and pH \((5.5 - 6.0) \), but the temperature differed markedly \((-90^\circ C \, \text{in the industrial mill and } 65^\circ C \, \text{in the laboratory}) \). Thus, in the range of change of \( C_V \) within the limits 0.68 – 0.77 or SLR within the limits 2.12 – 3.34 the dependence of fuzed quartz suspension phase composition (volume concentration of solid phase \( C_V \), critically free \( C_{Wk} \) and bonded \( C_{Ws} \) of a dispersed medium), critical concentration \( C_{Wcr} \) and casting porosity \( \Pi_{\text{cas}} \) on SLR index were studied (Fig. 2). As SLR increases there is a reduction in the system of both kinetically free and bonded liquid. Here a rectilinear dependence of index \( C_{Wcr} \) and \( \Pi_{\text{cas}} \) on SLR is noted.

fig1.png

Fig. 1. Interconnection between indices of volume concentration \( C_V \) and SLR.
Taking account of analysis of both the data in question and similar data in many other forms of HCBS in publication [41] empirical rules were formulated for the first time describing the interconnection between suspension characteristic and concentration (SLR) during their preparation.

1. The product of indices of volumetric solid-liquid ratio and kinetically bonded liquid in HCBS or the porosity of castings based on them is a constant value, i.e. \( \text{SLR} \cdot \frac{c_{\text{ws}}}{c_{187}} \text{const} \).

2. Index \( c_{\text{ws}} \) in stabilized HCBS or the porosity of castings based on them is inversely proportional to suspension SLR during wet grinding, i.e. \( (\text{SLR})^{l} \cdot (\text{C}_{\text{ws}})^{s} \text{ = const} \), where indices “l” and “s” signify indices SLR, \( c_{\text{ws}} \) and \( c_{\text{cas}} \) with large and small values of concentration respectively.

It is undoubted that these regularities, depending on SLR, are caused by several different factors, including the specific “packing” capacity of HCBS solid phase particles during structure formation, and also interphase reaction during HCBS preparation and stabilization. The latter determines the composition, dispersed medium properties and it depends markedly on concentration of the system. In order to evaluate this factor an understanding was proposed for the specific interface of phases in a unit volume of suspension, determined by the dispersion of solid phase particles \( \Pi_{\text{cas}} \) and concentration of the system \( S_{p}^{c} \text{ = SC}_{p} \). In order to analyze this regularity a similar index is proposed below for the specific interface of phases in the calculation per unit volume of dispersed medium \( S_{d,c}^{p} \text{, i.e. } S_{d,c}^{p} = S \cdot \text{SLR} \).

It can be seen from Fig. 3 that \( S_{d,c}^{p} \) depends rectilinearly on SLR. With an increase in SLR by a factor of two the \( S_{d,c}^{p} \) also increases by a factor of two. As suspension concentration in the system increases there is a marked acceleration of the process changing properties of the dispersed medium and connected, for example, with solid phase solubility. Due to this in preparing HCBS in a system there is more rapid formation of the content of nanoparticles required for providing the optimum rheological and binding properties. According to preliminary experimental data, HCBS that have a high SLR under stable uniform conditions contain a considerable fraction of colloid component (nanoparticles). Substantiation of this feature is given below.

We shall proceed from the assumption that the solubility of quartz glass or another form of silica during wet grinding is determined by the volume fraction of solid phase in the suspension, i.e. the volume of solid substance in the system is a function of the solid-liquid phase interface. Here a condition for the concentration of dissolved SiO\(_2\) in the dispersed medium of the suspension (in g/liter of dispersed medium) will be a function of index \( C_{p} \) or SLR, as follows from curve 1 in Fig. 4. By comparison with a suspension that has the minimum concentration of those shown in Fig. 4 (\( C_{v} = 0.4 \), SLR = 0.66), the content of dissolved SiO\(_2\) in HCBS (\( C_{p} > 0.72 \)) increases repeatedly. The real difference appears to be markedly greater in view of the fact that as suspension \( C_{v} \) increases there is an increase in the temperature of the wet grinding process. If the latter with \( C_{v} = 0.40 – 0.50 \) does not exceed 30°C, then on reaching \( C_{v} = 0.75 – 0.80 \) under certain conditions the temperature increases to 90 – 95°C. Taking account of published data for the effect of temperature on the solubility of amorphous silica [19] and real values of temperature during wet grinding in relation to suspension concentration, an estimate of the relative solubility of SiO\(_2\) for this case is shown in Fig. 4 (curve 2). It fol-