HOMOGENEOUS FRACTALS IN SUPERCRITICAL GLASS COMPOSITES

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The existence is experimentally identified of homogeneous fractal structures with the dimensions about 2.5 in two-phase glass composite materials when they are supercritically filled with the second phase.

Two-phase composite materials are widely used in science and technology, in particular, glass composite materials are considered as promising media for insulation of hazardous agents. The problem of the composite structure in the supercritical region when filling of the basic matrix (glass) with the second phase goes over the leakage threshold is substantial. For a three-dimensional space ($d = 3$) the critical filling with spherical particles is determined by the relevant Scher−Sellen invariant $\Phi_c = 0.15$ [1].

In the present work we have studied the structure of glass composites based on soda-lime glass, in which, as the second phase, we used emulsified in the melted state sodium sulphate, having low solubility in a glass melt (1-2%). The choice of the filler is also governed by practical interest in the possibility of its fixation in the glass matrix. The specimens were prepared by the well-known procedure [2]. The volume filling of the matrix with sodium sulphate varied from 0.06 to 0.23. The second phase is distributed in the matrix uniformly in the form of spherical particles whose average size is 100 μm.

Figure 1 shows the dependence on the filling Φ of the total amount of sodium P removed from the specimens when they were kept in distilled water (the leaching test [3]) for 672 h. In transition to the supercritical region ($\Phi > \Phi_c$) one can observe a pronounced jump in the value of P which indicates the formation of macroscopic structures of the percolation cluster (PC) type. Indeed, in this case there emerges a possibility to easily remove soluble components via PC chains [4]. Analyzing photographs of the specimen sections show the absence of visible formations of contacting filler particles in both the region $\Phi < \Phi_c$ and the supercritical region. However, particles of the second phase in the PC chains must not necessarily contact. Suffices their relative close position, when in direct contact are fine particle shells constituted by the glass enriched with the second phase components. For $\Phi > \Phi_c$, P is proportional to the power of PC, i.e., $P(\Phi - \Phi_c)^\beta$, where the critical exponent is $\beta = 0.45$ [1].

It is well known that the geometric structure of PC corresponds to the structure of a homogeneous fractal [5]. On the length scales, smaller than the correlation length $\xi \sim (\Phi - \Phi_c)^{-\nu}$, where $\nu = 0.88$ is the critical exponent, PC forms a fractal with the dimensions $D = d - \beta/\nu$. For a three-dimensional space $D = 2.55$. At the same time on the scales, larger than ξ, PC is homogeneous. To test the belonging of particles of PC second phase we measured the sodium sulphate density in the glass composite by various measuring scales. It appeared that the second phase is distributed in a glass matrix in the form of a homogeneous fractal whose dimensions coincide within the limits of measurement error with the dimensions of a homogeneous PC.

Figure 2 presents the results of measuring the second phase density ρ versus the "measuring" cube side dimension a for specimens with the supercritical filling $\Phi = 0.22$. It is only for the dimensions $a > \xi_0 = 3$ mm that glass composites are homogeneous structures. In the $a < \xi_0$ region the second phase density ρ is $\approx a^{-0.5}$, i.e. the geometric structure of glass composites corresponds to the fractal with the dimensions 2.5.

Thus, the second phase in a two-phase glass composite material when supercritically filled is distributed in the form of a homogeneous percolation cluster. Let us draw our attention to the fact that in the vicinity of the critical filling $\Phi \to \Phi_c$ the value of ξ_0 (having the sense of a correlation length) increases beyond all bounds. In this connection, experimentally obtaining the reproducible results here is extremely difficult, which is due to an unbounded increase either in the dimensions of the studied specimens or in their number.
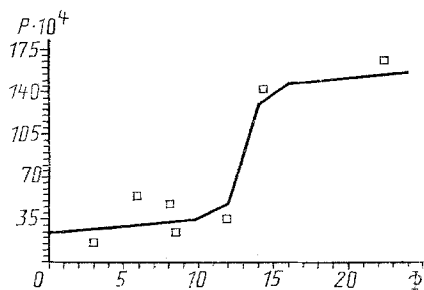
Fig. 1

Fig. 2

Fig. 1. Losses P (mass %) of sodium in leaching of soda-lime glasses with dispersed sodium sulfate vs filling Φ (vol. %).
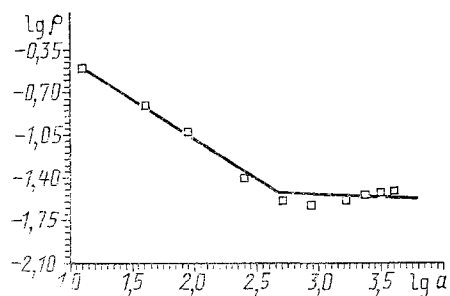
Fig. 2. Second phase density ρ in a two-phase glass composite vs side dimension of cube a, isolated in the composite (double logarithmic scale).

NOTATION

d, dimensions of space; Φ, filling; Φ_c, critical filling; P, amount of leached matter; β, ν, critical exponents; D, dimensions of fractal; ξ, correlation length; ρ, density of the second phase; a, side dimension of measuring cube.

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