



Investigation of dilatancy mechanism of Portland cement paste



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HIGHLIGHTS

- We used new dilatancy testing equipment for cement paste volume changes registration during flow behavior.
- The dilatancy mechanism of Portland cement pastes was investigated.
- The influence of additions with difference specific surfaces area was determined.

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ABSTRACT

The increase in cement paste volume during the flowing has been determined by specially developed equipment and the investigation methodology was proposed. Pressure (kPa), under which the cement paste starts flowing, the average cement paste flow rate (cm/s), elastic deformation (%) and the increase in cement paste volume due to redistribution of solid phase particles (%) were established in experimental tests of Portland cement pastes with different W/C ratio, Portland cement pastes with SiO₂ microparticle suspension and quartz sand additive. With the increase of W/C ratio or liquid phase in cement pastes the elastic deformation drops from 0.83% to 0.27%, while the volume of dispersion when the paste starts flowing increases from 0.63% to 1.31% due to cement particle redistribution under shear stress. When elastic rebound occurs, the volume of pastes with SiO₂ microparticle suspension does not increase when solid phase particles redistribute during the flow; dilatancy is not observed in the pastes with this additive either or it is insignificant. When quartz sand particles of irregular size and large than cement particles redistribute during the flow, the volume of the paste increases more (1.24–1.64%) and dilatancy is observed in pastes with this additive. The test results confirm the earlier statements of researchers stating that disperse systems are subject to dilatancy because of the increase of the system's volume under shear stress (during the flow), i.e. because of redistribution of the solid phase in the system subjected to shear stress.

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1. Introduction

Most authors who investigated the mechanism of dilatancy in dispersions state that the phenomenon of dilatancy is caused by the increase in the volume of a disperse system. According to them the volume of a disperse system increases due to the change in solid phase particles distribution, when particles collide with each other, and a relative decrease of dispersion medium [1–6]. It is not so easy, however, to evaluate the increase in dispersion volume when the change in solid phase particle distribution occurs. Special testing equipment and methodology must be developed

in order to analyze this complicated phenomenon, which is not studied to the full extent yet because its origin in many cases remains unclear.

The first investigation into dilatancy phenomenon was carried out by Reynolds. According to the author, the increase of a systems viscosity can be explained by the increase of disperse system volume after the change of solid particles volume displacement caused by the movement of particles against each other. The expansion of dispersion volume causes the relative reduction of dispersion medium volume and the increase of system viscosity. Spherical solid particles have the pyramid volume distribution and the cubic one. Solid pyramid particle distribution takes up a minimum volume. Under the affect of shear force the pyramid distribution of solid particles can be changed to cubic distribution that will increase the volume occupied by solid particles by 1.41 times [1,2].

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The authors [3–5] explain the phenomenon of dilatancy by the change in particle distribution and increased mixture porosity (increased volume of voids between sand particles). Part of the water penetrates into the increased pores and the mixture becomes ‘dry’. When the pressure stops, the sand particles return to their previous position, the mixture porosity reduces and free water comes up.

Most suspensions of higher or lower concentration are subject to dilatancy, which is observed by the increase of suspension viscosity at higher shear stress. *Dilatatio* in Latin means “expansion”. The analysis of Pivinskij experiments has revealed that the occurrence of dilatancy and the intensiveness of dilatancy-caused stiffening in disperse systems depend on many different factors: chemical nature, dispersiveness, dispersed phase particle distribution and particle concentration by volume, temperature, the presence adsorbing and ionic layers as well as stability of the system in terms of coagulation, pH of the medium, electro-kinetic or zeta potential. The afore-listed factors show the complexity of dilatancy in disperse systems [6].

In Fig. 1 we can see that dilatancy in a disperse system will be not observed if the volume of dispersion medium is sufficient to fill the voids occurring between solid phase particles during deformation (in a specific case the volume of dispersion medium must increase by ΔV). This scheme also shows that the increase of dilatancy directly depends on the increase of system volume during deformation (ΔV) or reduction of liquid phase spans between solid phase particles in the initial compacted state of the system. When liquid phase between solid phase particles reduces, the system’s cohesion also reduces and the particles start sliding along the so-called ‘air bags’. When such a system is subjected to shear stress, its viscosity increases significantly.

Freundlich and Roder [5] described the mechanism of dilatancy using the experiment with quartz and starch water suspensions, where the density of solid particles per unit volume was 0.42–0.45. When suspension flow rates are low, solid particles can slide against each other without any significant distortion of the system that causes the system to thicken. When suspension flow rates are high, the system structure is distorted and interacting particles form a more open structure. The dosage of liquid phase in the system decreases as a result of bigger hollow spaces between the particles and the system stiffens. The dosage of liquid phase is insufficient to reduce friction between solid particles. Dilatancy

of disperse systems has not been researched completely as in many cases the nature of dilatancy remains unclear.

Bumiller and Rodolewicz [7] explain dilatancy in disperse systems by the change of particle distribution under shear stress. The graphics presented by the authors (Fig. 2) illustrate the change in distribution of non spherical particles and the increase of the system’s volume.

Cement pastes are classified as structural systems that have certain rheological properties. By the form of rheological curve of a structural system [8,9] several groups of structural fluids are distinguished: Newtonian fluids, pseudo-plastic fluids, dilatant fluids, Bingham bodies, plastic dilatant bodies and pseudo-plastic bodies. Cement pastes and concrete slurries are often classified as Bingham bodies (systems) that have two basic rheological characteristics – yield stresses τ_0 and structural viscosity η [10–13].

The fluid in which the linear relationship between shear stresses τ and shear rate $\dot{\gamma}$ is confirmed after the yield stress, is called a Bingham fluid, and the fluid in which a nonlinear relationship is confirmed, is called a non-Bingham fluid. Cement based materials correspond to non-Bingham fluids, but rheological analysis is often applied by assuming it to be a Bingham fluid [14]. The research into rheological properties of cement pastes using a rotational viscometer with coaxial cylinders revealed that cement paste behaves as Bingham plastic fluid and may be characterized by shear stresses (Pa) and plastic viscosity (Pa·s). The previous studies revealed that the Bingham model, which is suggested for describing cement paste flow curves, is not correct. The flow curve of cement pastes is not straight line, as it is in Bingham model, but it becomes a curve when the share stress is increased [15–18]. This demonstrates that cement pastes are characterized by dilatancy, i.e. the viscosity of the system increases with higher shear stresses. There are no characteristics for quantitative evaluation of dilatancy of mixtures.

Kaplan, Pivinskij and Saprykin [19] researched rheological properties and dilatancy of concentrated hydro-dispersive quartz glass and detected a correlation between dilatancy and electrical conductivity and electro-kinetic (zeta) potential with the change of medium pH from 2 down to 9. Rheological properties of disperse systems were determined by means of rotating viscometer with coaxial cylinders within velocity gradient shift limits of 0.7–700 s^{-1} . The authors described the initial dilatant flow of concentrated disperse system by the equation.

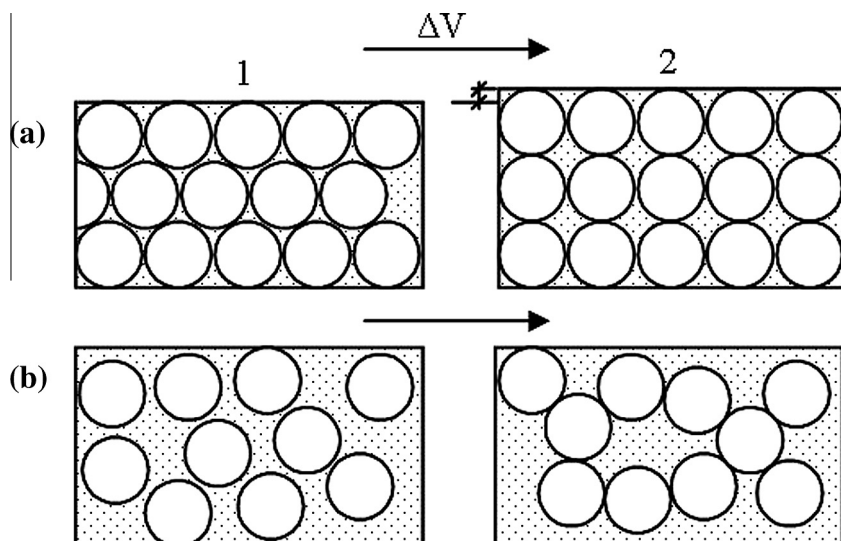


Fig. 1. The scheme of dilatancy mechanism according to Reynolds (a) and Freundlich–Roder (b): initial state of the system in quiet mode (1); state of the system during deformation (2). Arrows indicate the direction of deformation [6].

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