INFLUENCE OF TURBULENT AND VIBRO-TURBULENT ACTIVATION ON THE RHEOLOGICAL PROPERTIES OF INJECTION CEMENTS AND GROUTS

I. G. Sovalov, Yu. G. Khayutin, and N. V. Mikhailov

Inzhenerno-Fizicheskii Zhurnal, Vol. 9, No. 4, pp. 467–474, 1965

UDC 532.517.4

Results are presented of experiments on turbulent and vibro-turbulent activation of cement pastes and grouts. It is found that activation lowers the values of all the rheological characteristics.

Injection cements and grouts must have high fluidity, retain their mobility for a long time after preparation, resist stratification, and have good mechanical properties after setting. Endowing injection solutions with these properties is quite a complex task, as conflicting requirements need to be satisfied. Thus, an increase of fluidity requires the addition of water, which increases the tendency to stratify and reduces the final mechanical strength.

In practice such solutions are given the required properties by physico-chemical or mechanical activation. The physico-chemical method employs special additives—dispersing agents—which reduce the attraction between particles and deaerate the mixture, and other additives to prevent stratification (stabilizers). Mechanical activation is based on rapid turbulent processing.

Studies of the influence of turbulent and vibro-turbulent activation on the rheological characteristics of grouts have been made at the test facilities of NIIOMTP (Institute of Organization, Mechanization and Technical Assistance for the Building Industry). Vibro-turbulent activation was effected by recirculating the solutions through a special centrifugal pump with an open impeller. The pump delivered the solution to a hopper equipped with an internal vibrator which thinned the mixture and thus intensified the circulation. It was established that the optimum speed of the pump impeller was 2500 rpm for cement pastes, and 1500 rpm for grouts.

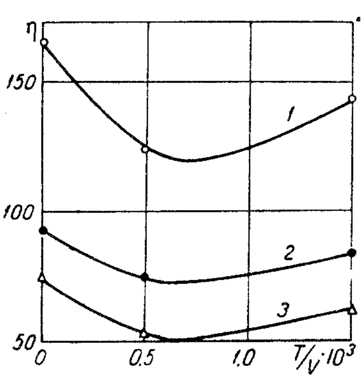

Fig. 1. Dependence of η, N · sec · m^{-2}, on activation time per unit volume of mixture: 1) $\dot{\varepsilon}$ = 4 sec^{-1}; 2) 10; 3) 20.

Since the activation effect depends on the number of passes of a given volume of mixture through the pump, comparable results may be obtained by relating the activation time to the volume of mix.

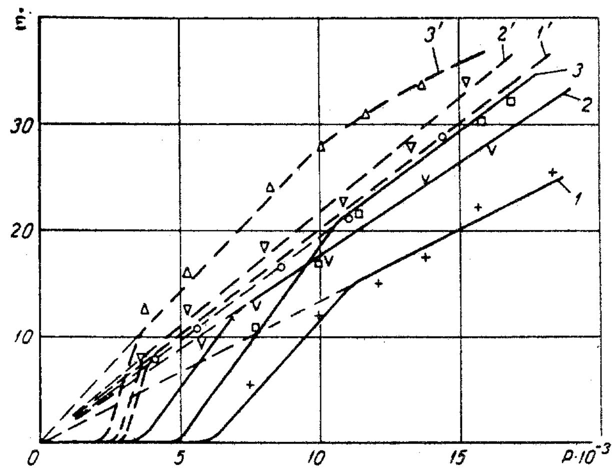

Fig. 2. Rheograms of a portland cement grout (1:1 by weight). The curves represent $\dot{\varepsilon}$, sec^{-1}, versus P, N · cm^{-2}: 1, 2, 3) nonactivated solution, 1', 2', 3') solution after vibro-turbulent activation.

Investigations have shown that cement pastes and grouts are structured liquids, and their flow may be characterized by the equation of plastico-viscous flow (Schwedoff-Bingham equation)

$$\dot{\varepsilon} = \frac{dv}{dh} = \frac{1}{\eta}(P - P_{k_2}).$$

To investigate the influence of turbulent and vibro-turbulent activation on the rheological properties of cement pastes and grouts, a Volarovich rotational viscometer with coaxial cylinders was used. The smooth outer cylinder rotates while the corrugated inner cylinder is at rest.

The large gap between the cylinders (14 mm) permitted the investigation of mixes with a sand particle size of 2.5 mm. Unfortunately, in view of the relatively small dimensions of the cylinders of this viscometer (D = 4 cm, d = 1.2 cm) it is not certain whether the shear is sufficiently uniform and always extends to the outer cylinder. At the same time, determination of the limits of shear propagation from Volarovich's equations is invalid for grouts owing to the presence of velocity micro-gradients associated with the rotation and motion of the sand grains, which destroy the structure and increase the zone of shear propagation

Table 1

Influence of Turbulent Activation on the Rheological Properties of Cement Paste

Type of activation	Activation time, sec/l	Cement	W/C ratio water/cement ratio	Rheological properties: $P'_r \cdot 10^{-2}$, $N \cdot cm^{-2}$	$P_{k_2} \cdot 10^{-2}$, $N \cdot cm^{-2}$	$P'_m \cdot 10^{-2}$, $N \cdot cm^{-2}$	$\eta^*_{m'}$, $N \cdot sec \cdot m^{-2}$	η_m, $N \cdot sec \cdot m^{-2}$
No activation	0.0	slag-portland	0.38	11.5	12.0	—	4.3	—
Turbulent	0.6			10.0	10.5	—	3.7	—
No activation	0.0		0.40	8.2	9.7	—	4.1	—
Turbulent	0.6			5.0	5.1	13.0	3.1	5.2
No activation	0.0	portland	0.55	4.3	4.4		3.0	—
Turbulent	0.5			3.6	3.7	11.3	4.8	5.0
No activation	0.0		0.58	4.0	4.2	7.7	2.6	5.8
Turbulent	0.4			3.0	3.1	4.2	1.2	4.4

in the solution. In view of the foregoing, and the impossibility of using the Volarovich equations to determine the effective viscosity, the variation of which with activation is of very great interest, it was conditionally decided to use a formula derived for the propagation of uniform shear $\dot{\varepsilon} = 2\pi n\alpha$ to calculate the shear velocity gradient.

This may be regarded as permissible, since the work in question was not directed towards the determination of absolute values of the viscosity of grouts, the chief interest being in the nature of the variation of the rheological properties of the mixtures resulting from activation.

From the experimental results we obtained ratios of the force applied to rotate the outer cylinder and its speed of rotation for various mixes. From these data rheological curves were constructed relating velocity gradient $\dot{\varepsilon}$ and shear stress P. From the rheograms thus obtained we determined, for activated and nonactivated samples, values of the limit shear stress P_{k_2}, the plastic viscosity η^*_m, the viscosity corresponding to maximum breakdown of η_m, and the critical stresses P'_r and P'_m.

Analysis of the results obtained shows that turbulent and vibro-turbulent activation results in lowered values of all the rheological properties of cement pastes (Table 1).

In tests with cement paste based on slag portland cement with reduced water content (water/cement ratio = 0.38), the paste structure was quite strong, and in the possible range of shear velocity gradients (of the equipment) maximum structural breakdown was not achieved. After a certain increase in water content (water/cement ratio = 0.4), the rheological constants of the mixture fell, but maximum structural breakdown could be achieved only in the activated cement paste.

In tests with cement paste based on portland cement at high water/cement ratios, maximum structural breakdown was achieved without activation. In this case activation lowered the critical stress P'_m considerably.

Prolonged turbulent processing of the cement paste resulted in the rheological constants beginning to increase due to the increasing amount of colloidal particles became thinner and the mixture began to thicken. Figure 1 shows the dependence of the effective viscosity of cement paste with a water/cement ratio of 0.48 on the activation time. These data were confirmed by the results of cone measurements of the consistency

Table 2

Influence of Turbulent Activation on the Structure Formation Process in Cement Pastes and Grouts

Cement	Cement/sand (by weight)	Water/cement	Nonactivated: $P_{m(crit)}$, $N \cdot cm^{-2}$	τ_k, min	α, $N \cdot cm^{-2} hr^{-1}$	Activated: $P_{m(crit)}$, $N \cdot cm^{-2}$	τ_k, min	α, $N \cdot cm^{-2} hr^{-1}$
Slag-portland	1 : 0	0.38	140	550	150	120	520	190
	1 : 1	0.46	200	630	120	180	580	200
	1 : 2	0.60	280	500	470	250	460	560
Portland	1 : 0	0.48	220	500	160	180	470	220
	1 : 1	0.48	380	520	500	320	490	1000

of the cement paste at the StroiTsNIL (Central Scientific Research Building Construction Laboratory).

Similar tests were carried out with grout solutions. The present investigation did not include a study of the effect of varying the amount of sand on the rheological properties of the grout with the other characteristics of the solution fixed. Such a study would have been complicated by the need to adhere to known limits of mobility of the mix, i. e., for a constant water/cement ratio it would not have been possible to vary the sand content of the mixture over a wide range.

All the experiments carried out indicate that the rheological characteristics become more favorable for transportation and injection processes as a result of turbulent and vibro-turbulent activation. This applies both to cement pastes and to grouts.

The flow curves in Fig. 2 obtained in various tests differ somewhat due to differences in the experimental conditions (variation of temperature and moisture content of the surrounding medium and of the materials), but when all the experimental points are superimposed on one coordinate grid, the result is two clearly expressed and sharply differing fields of points for the activated material and for control mixes with the same water to cement ratio.

The experiments show that all the rheological constants are reduced as a result of turbulent and vibro-turbulent activation.

At low sand contents and sufficiently high mobilities beyond the region of maximum structural breakdown, the viscosity of activated grouts increases with increase of velocity gradient. This viscosity increase is explained by the transition from laminar flow of the liquid-like structured system to turbulent flow. It is interesting to note that in experiments with cement paste a zone of flow transition from laminar to turbulent was not obtained. It is evident that at low sand contents in a thin solution, turbulence arises from rotation of the sand grains, which increases the velocity gradients within the mixture.

Just as in the experiments with cement paste, prolonged turbulent and vibro-turbulent activation has an inverse, negative effect: the values of the rheological constants increase.

In grouting practice it is very important to know not only the rheological constants measured immediately after preparation of the mixture, but also the nature of change in the plastic properties with time.

Structure-formation processes in untreated and activated cement pastes and grouts were investigated on a balanced cone plastometer and a lever cone plastometer at Moscow State University.

The value of the load required to make the cone penetrate into the material to a depth of 5 mm was determined at various intervals from the time of preparation. The plastic strength P_m was determined from the force acting on the projected area of the part of the cone that penetrated the material.

The balanced plastometer was used to determine the plastic strength in the first few hours after mixing, the lever plastometer at later points in the setting process (from 4–6 to 14 hr after mixing).

The cone plastometer was first used to investigate structure formation in cement pastes and grouts by Kalmykova and Mikhailov. Agranat and Volarovich have given a theoretical basis for the use of this instrument specifically for coagulation structures, but with some approximation it can also be applied to coagulation-crystallization structures, as in the setting of cement.

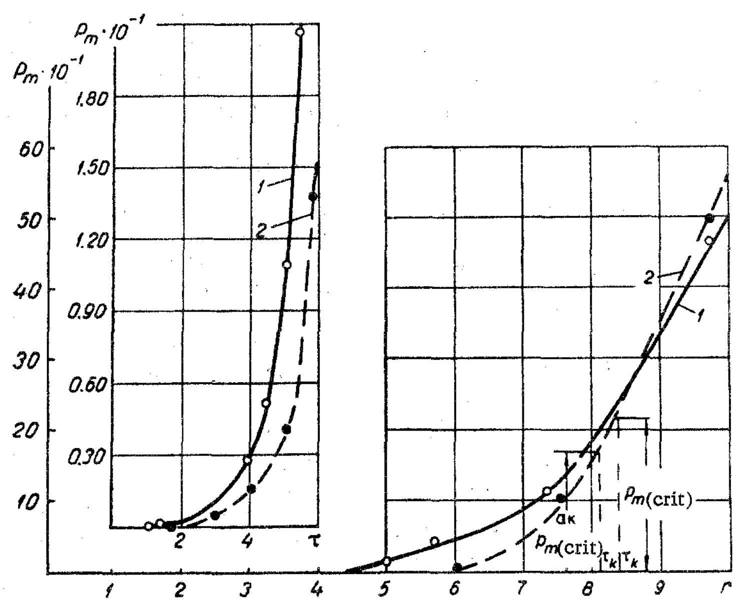

Fig. 3. Plastograms of cement paste (portland cement). Dependence of P_m, $N \cdot cm^{-2}$, on τ, hr: 1) cement paste W/C = 0.48; 2) the same, after turbulent activation for for 3500 sec $\cdot$ m^{-3}.

The process of structure formation in cement pastes and grouts may be divided into two parts: the first is characterized by the formation of a predominantly coagulation structure with thixotropic-reversible properties; the second is a period of hardening characterized by the predominance of a crystallization-coagulation structure with the properties of an elastic-brittle body.

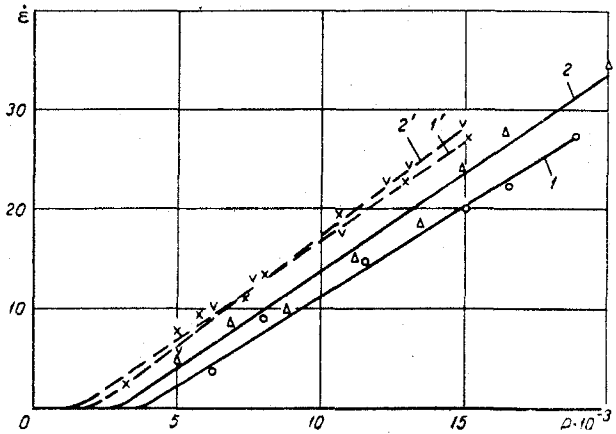

Fig. 4. Rheograms for cement paste (portland cement). Dependence of ε, sec^{-1}, on P, $N \cdot cm^{-2}$: 1) W/C = 0.39, without activation; 1') the same, after turbulent activation at 5000 $sec \cdot m^{-3}$; 2) W/C = 0.35, without activation and with addition of 2% plasticizer; 2') the same, after turbulent activation at 5000 $sec \cdot m^{-3}$.

Kalmykova and Mikhailov have investigated the influence of vibro-activation on the structure-formation process in cement pastes and grout. Their researches show that for very stiff systems with small τ_k, vibro-processing increases τ_k, while for systems with large τ_k, vibro-mixing decreases it. In all cases vibro-processing increased the rate of structure formation in the hardening period.

The investigation of the processes of structure formation in cement pastes and grouts subjected to turbulent and vibro-turbulent activation reveals a picture similar to that obtained for vibro-activation.

It can be seen from Fig. 3 that immediately after activation the plastic strength of activated cement paste is lower than that of a paste not subjected to activation. This confirms the results of the investigations of the influence of turbulent and vibro-turbulent activation on viscosity using the Volarovich viscometer.

The plastometer investigations showed that in the interval 4–6 hr after preparation, in the period of structure formation, the activated mixtures retain less structural strength than the controls. The delayed thickening of the activated mixtures creates favorable handling conditions where a long period must elapse between preparation and use.

In the hardening period the growth of the plastic strength of the crystallization-coagulation structure of the activated mixtures is more intense. This is also favorable, since more intense structure formation leads to accelerated strengthening of the crystallization compounds. As a result of activation the value of τ_k is reduced by 30–45 min.

The change of values of $P_{m(crit)}$, τ_k, and α as a result of activation for the various compositions is shown in Table 2.

Turbulent and vibro-turbulent processing may be successfully replaced by the use of plasticizing and stabilizing additives. However, according to the theories of physico-chemical mechanics, the best results may be obtained by a combination of physico-chemical and mechanical activation processes.

When additives and mechanical processing are combined, the properties of the activated material can be improved to a greater extent than when one of these means is employed alone.

Tests were conducted to determine the influence of turbulent and vibro-turbulent activation of cement pastes and grouts with the addition of sulfite liquor-distiller's grains as plasticizer. The tests showed that activation of such mixes, and also of mixes without additive, caused an increase in mobility, and decreased separation of water and stratification. Before activation, the rheograms of the two mixes in Fig. 4 are very close. The penetration of the StroiTsNIL cone is identical—13 cm. Activation caused an appreciable lowering of viscosity, both of the cement paste without additive and of the paste with additive. The rheograms after activation almost run together. The cone penetration is the same—13.5 cm. It may be concluded that the extent to which viscosity is diminished as a result of turbulent activation does not depend on the presence of additive.

Turbulent and vibro-turbulent activation causes the additives introduced to be distributed extremely uniformly. This is particularly important in relation to the possible use of powder additives. Tests were conducted on the turbulent and vibro-turbulent activation of cement paste and cement-sand solutions with an aluminum powder additive. In all the tests activation led to lower values of the rheological constants.

NOTATION

n) number of revolutions of viscometer cylinder; a) a coefficient depending on the dimensions of the viscometer cylinders; $\dot{\varepsilon} = dv/dh$) velocity gradient; P) shear stress; η) viscosity; P_{k_2}) limit shear stress; η_m^*) plastic viscosity; η_m) viscosity corresponding to maximum structural breakdown; P_r') shear stress corresponding to transition from practically undestroyed to destroyed structure; P_m') shear stress corresponding to transition from destroyed to maximally destroyed structure; P_m) plastic strength; τ) duration of structure formation; τ_k) duration of structure formation period; $P_{m(crit)}$) plastic strength of structure, indirectly characterizing the viscosity of the cement paste at the end of this period; α) rate of structure formation process in the hardening period, expressed as the increment of plastic strength in unit time; C) weight of cement; W) weight of water; S) weight of sand; T) activation time.

10 November 1964

Institute of Organization, Mechanization, and Technical Assistance for the Building Industry, Moscow