Portland cement easy treatability as the basis of concrete structure stable quality

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Abstract An opportunity is discussed to improve operational parameter stability of concrete and reinforced concrete articles on Portland cement basis in heavy-duty environment. Demonstration of binding properties of cements with identical normative parameters was shown to be dissimilar under amended operational conditions. Such behavior may be supposedly connected to insufficiently stable relation between alkalinity and dispersity of consumed Portland cement. It was found feasible to arrange preventive control of incoming Portland cement with due consideration of its application conditions. The results of such control were shown to be efficient at substantiated correction of applied Portland cement activity.

The purpose of this research has been expansion of methodological basis of mineral binder quality control for stabilization of consumer properties of concrete and reinforced concrete structures produced on their basis.

1. Introduction

Efficient maintaining of concrete and reinforced concrete structure operation parameter stability depends substantially on stable properties of applied Portland cement (PC) [1,2]. It was previously found that physical-mechanical strength of tested cement beam samples was in direct proportion to their content of new hydrate formations [3]. Such characteristics as modulus of elasticity, creep, fracture strength, freeze resistance, durability, etc. are known to be connected not only to concentration of these new formations, but also to their formation rate on the basis of cement rock [4,5]. It follows that in order to ensure necessary stability level of concrete and reinforced concrete structure operational properties, corresponding dynamics of their hardening must be maintained at least at initial maturing stages. Nevertheless, substantially different conditions of PC control and application preclude direct control of this dynamics without additional analysis of consumed binder properties.

PC of identical activity are known to often have different relations between their clinker content and dispersion which are in inverse relationship [6]. Such cements cannot by definition have identical water interaction dynamics at any conditions, including at the same normative activity values. The value of this relation is not subdued to regular control, it is usually determined by on-site needs, economic feasibility and equipment capabilities of a particular facility [7]. Besides, Portland cement clinker (PCC) with its mineral properties being formed at all stages of its manufacture does not belong to materials with easily predicted behavior under various conditions of interaction with water.

The described multi-factored character of PC consumer properties formation requires selection of direct control methods of its setting and hardening dynamics, so that their confidence level was sufficient to correct this dynamics with known means. One of the main problems in arrangement of such control is considered to be insufficient methodological basis for PC binding activity testing under conditions different from standard. Another input control problem is too long procedure of PC physical-mechanical activity determination [8]. Due to clumsy cement quality determination time is unreasonably lost and material resources overspent, trying to ensure necessary product properties stability. This is especially evident in application of PC from different vendors, which substantiates
feasibility of search for additional alternative analysis methods of their properties after different hardening conditions.

2. Equations and materials

Behavior of identical class cements under various hardening conditions was performed on PC 500 from vendors Kryvyi Rih-Cement, Podolsk-Cement and Lafarge-Cement. Additional materials were quartz flour (below 50 μm), LST plastifier and C-3 superplastifier PC setting and hardening dynamics was controlled by penetration methods using a plastometer and a durometer [9,10]. In order to expedite physical-mechanical properties evaluation of cements in mixtures of different composition and different preparedness, tested samples were thermos matured at 45 °С for 9 hours. The samples were sealed to ensure 100 % humidity under hardening.

3. Main part

Table 1 specifies the results of air filtration time through tested cement samples (0.012 kg) in PSH unit measurement cell and the values of their specific surface as calculated from these values. Additionally normal cement paste density was determined on the basis of tested PC.

**Table 1. Dispersion properties and water consumption of tested PC.**

| №  | PC vendor             | Air filtration time, s | $S_{sp.}$, m²/kg | Normal density, % |
|----|-----------------------|-------------------------|------------------|-------------------|
| 1  | Kryvyi Rih-Cement 1   | 133                     | 300              | 26                |
| 2  | Kryvyi Rih-Cement 2   | 125                     | 290              | 25                |
| 3  | Podolsk-Cement        | 203                     | 370              | 25                |
| 4  | Lafarge-Cement        | 432                     | 540              | 31                |

As seen from Table 1, both PC batches from Kryvyi Rih-Cement were actually identical as regards their dispersion characteristics and water consumption. Podolsk-Cement sample was more finely ground, but this fineness did not affect its water consumption, as distinct from more finely ground PC from Lafarge-Cement whose normal density turned to be much higher than in three other samples.

Dynamics of setting and initial hardening of cement paste based on the above PCs were analyzed under the following preparation and maturing conditions:

1. W/C = 0.30; $t = 24$ °С; mixing time – 5 minutes.
2. As in 1, but W/C = 0.33.
3. As in 1, but W/C = 0.26 and C-3 -0.6 % and LST - 0.1 % added.
4. As in 1, but one third of PC was substituted for quartz flour.
5. As in 1, but every 30 minutes within 2.5 hours period after mixing cement paste was kneaded for 5 minutes each time.

The samples were poured to prepared molds and penetration depth in these was measured for conical indenter. Measurements were from time to time corrected depending on developing dynamics of cement paste setting. The value of maximum shear stress was calculated from indenter penetration depth according to applied plastometer parameters.

Figure 1 shows the results of obtained cement rock setting dynamics for all tested samples.
Figure 1 – Effect of hardening conditions for cement paste on the basis of PC 500 samples from various batches and vendors on their setting dynamics:

1 – W/C = 0.30; 2 – W/C = 0.33; 3 – 0.7% complex plastifier added at W/C = 0.26; 4 – one third of PC substituted for quartz flour at W/C = 0.30; 5 – additional regular kneading within 2.5 hours at W/C = 0.31.

For netter clearness all plots are shown in one drawing on one scale. In order to visualize PC setting commencement and finish time vertical axis of maximum shear stress value begins at 0.15 and ends at 0.5 MPa. In this case any curve crossing time with plot bottom grid (0.15 MPa) corresponds to setting commencement time of tested sample, whereas crossing with plot top grid (0.5 MPa) corresponds to its setting end time.

From locations of curves in Figure 1 we can see that most active setting under conditions close to norm (Curves 1) proved to be finely ground PC from Lafarge-Cement. With W/C increased by 10% cement paste plastic condition retention time turned to be roughly identical for all PC samples (Curves 2). Effect of plastifier additives on cement behavior was not so unambiguous. Both batches of Kryvyi Rih-Cement PC responded identically to plastifiers, as distinct from Podolsk-Cement and Lafarge which demonstrated such lower demand of this additive (Curves 3), especially Sample 3 (Table 1). Substitution of one third of cement for quartz flour also showed individual response of initial structure formation dynamics for all PC. If plastic condition retention time reduced insignificantly for Kryvyi Rih-Cement PC, Podolsk-Cement PC, on the contrary, slightly increased this time, as distinct from Lafarge PC whose setting time actually doubled after introduction of quartz
flour (Curves 4). Additional kneading of PC after mixing also caused different responses of cement pastes.

After determination of setting dynamics cement paste samples were sealed and stored for subsequent analysis their initial hardening dynamics (up to 3 days) under 100 \% humidity. One day after preparation the samples were extracted from molds and after hardness measurement put into water. At 2\textsuperscript{nd} and 3\textsuperscript{rd} day of hardening we measured hardness of samples after their stay in water. Hardness value after each test was determined as an average of 8 parallel measurements. In order to compare comprehensive dynamics of sample hardening for total tested period the value of their average hardness was determined from values obtained for Days 1, 2 and 3. Besides, samples prepared by Case 1 for all four cements were also hardening under thermos maturing (45 °C within 9 hours).

The results of physical-mechanical tests for all samples are specified in Table 2.

### Table 2. Physical-mechanical properties of tested PC.

| № | PC vendor                | Average hardness for 1-3 days of maturing, MPa |
|---|-------------------------|-----------------------------------------------|
|   |                         | W/C=0.30 / W/C=0.33 / Plastifier / Quartz flour / Additional kneading / *Thermos maturing, MPa |
| 1 | Kryvyi Rih-Cement 1     | 193 / 161 / 250 / 138 / 246 / 160             |
| 2 | Kryvyi Rih-Cement 2     | 232 / 190 / 282 / 155 / 258 / 145             |
| 3 | Podołsk-Cement          | 221 / 181 / 263 / 133 / 251 / 155             |
| 4 | Lafarge-Cement          | 213 / 170 / 265 / 135 / 245 / 170             |

*) Note: hardness of samples was determined after 9 hours of retention at thermostat

Having analyzed PC hardening dynamics (Table 2), we may note that all cements behaved differently within three days hardening under normal conditions and else. In this finely ground cements did not actually show any advantage over others. Also PC from the same vendor demonstrated insufficient stability (Kryvyi Rih-Cement samples 1 and 2). Authors suppose some additional causes for such different activity of tested PC, which may be connected, for instance, with insufficient stability of their feed clinker.

The obtained results of cement paste structure formation under setting and initial hardening showed certain unique behavior features when PC application conditions are amended which served as information basis for purposeful correction of their activity indications. Taking Kryvyi Rih-Cement Sample 1 hardening dynamics as a basis, authors selected in relation to its value the structure formation rate for other PC by corresponding W/C increase while mixing. At the same time for stabilization of hardening dynamics inherent in Kryvyi Rih-Cement Sample 2 PC, hydration rate of other cements was, on the contrary, initiated by introduction of respective amount of calcium chloride (CaCl\textsubscript{2}). Results of this correction are specified in Table 3.

### Table 3. Results of PC physical-mechanical tests after their correction.

| №  | PC vendor                | W/C, relative units | Setting time, min | Average hardness at Days 1-3, MPa | Hardness under in thermos maturing, MPa |
|----|-------------------------|---------------------|-------------------|-----------------------------------|----------------------------------------|
|    |                         |                     | commence / finish | Average                        | CaCl\textsubscript{2} | no additive / with additive |
| 1  | Kryvyi Rih-Cement 1     | 0.30                | 200 / 230         | 193                             | 0.3 / 0.3 | 160 / 169 |
| 2  | Kryvyi Rih-Cement 2     | 0.31                | 205 / 235         | 200                             | 0.6 / 0.6 | 145 / 172 |
| 3  | Podołsk-Cement          | 0.32                | 195 / 225         | 200                             | 0.2 / 0.2 | 155 / 175 |
| 4  | Lafarge-Cement          | 0.35                | 200 / 234         | 188                             | 0.0 / 0.0 | 170 / 170 |
The results as specified in Table 3 prove that after a dedicated correction of binding activity all PCs demonstrated a closer setting and hardening dynamics at initial maturing period than their previous characteristics. Such behavior gives ground to expectation for improved stability of consumer properties of articles and structures on the basis of similar corrected binders.

4. Conclusion
The results of our work obviously proved that arrangement of due preliminary control of PC activity under its application conditions constitutes a necessary stage in guaranteed ensuring of operational properties stability in production of concrete and reinforced concrete articles. Presence of such control enables a more reasonable consumption of building materials.

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