Study of temperature influence of cement and water on the fresh cement paste consistency

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Abstract. The consistency of a fresh cement paste, which is formed after mixing Portland cement with water, depends significantly on the water to cement ratio (w/c), the cement fineness and its composition, but also on the other parameters as temperature of cement and water. The paper is focused on researching the influence of increased temperature of cement and water on the fresh cement paste consistency. Various cement pastes with different w/c ratio (0.28, 0.32 and 0.36) and different temperatures of water and cement (20±2°C, 40°C, 60°C) were investigated. The consistency of cement paste was measured by Vicat roller penetration method. The tendency of losing the consistency of the fresh cement paste with increasing of its temperature was observed and exhibited as linear correlation with the coefficient of determination $R^2(0.28) = 0.9695$ and $R^2(0.32) = 0.9147$ respectively.

1. Introduction

The properties of the cement paste are crucial for the overall properties of concrete in fresh as well as in hardened state [1]. The consistency is one of the rheological characteristics of non-Newton liquids, what the cement paste is [2]. The consistency of a fresh cement paste, which is formed after mixing Portland cement with sufficient amount of water, depends significantly on the water to cement ratio (w/c), the cement fineness and its composition, the temperature and the plasticizer type [3-8]. First, the cement particles are uniformly dispersed in the liquid phase and flocculation of the cement particles occurs within minutes of mixing, which is associated with an increase in paste viscosity. There is a formation of aggregates of cement particles which trap part of the mixing water so that they are unable to participate in the paste flow. At this stage, weak van der Waals forces between molecules and particles are applied. The paste viscosity also increases due to the cement hydration process, leading to a gradual increase in the existing solid/liquid ratio and roughening of the cement particle surface due to the formation of hydrates. At this stage, the amount of hydrated material rapidly increases and the liquid phase volume decreases. Between the individual cement particles on which the hydrates have already been occurred are formed chemical bonds that are stronger than van der Waals and electrostatic forces that are responsible for flocculation. As chemical bonds increase, a continuous three-dimensional solids network develops in the paste, coupled with loss of paste deformability. As the hydration progresses, the amount of hydrated material increases at the expense of the porous space filled with water, leading to a gradual increase in the strength of the cured paste. [9-11]

The consistency of cement composites characterizes its workability and therefore the need of labour during the casting. For cement, there is the technical standard [12] which provides methodology
for the cement paste testing. The parameter „normal consistency of cement paste“ is defined as water need to reach the specific depth of the Vicat roller penetration (the distance between plate and roller end must be 6 ± 2 mm) and is input information for testing the initial and final setting time of the cement. In noted technical standard, the testing conditions are specified for temperature for cement (20 ± 2 °C) as well as for water (20 ± 2 °C). These are often in a conflict with real conditioning on delivery of the cement, when the temperature of cement often reaches temperature in the range of 20 to 60 °C, rarely up to 80°C. Also, temperature of water in concrete production can reach temperature up to 60°C, mainly in winter for RMC or in precast industry, when there is the need of achieving minimum concrete temperature. Higher temperature of cement paste could also affect initial and final setting time. Considering that it is not usual for concrete producer to measure current cement temperature, there is not water temperature correction providing, but consistency of fresh concrete is mostly adjusted by adding the mixing water, what leads to decreasing the mechanical properties as well as the durability [13-16].

The objective of the paper was to investigate the impact of cement and water temperatures, used in cement pastes preparation, on the fresh cement paste consistency.

2. Materials and methods
Totally 16 cement pastes were prepared for the experiment, using cement CEM II/A-S 42.5 R from locality Turňa and tap water. The pastes preparation was designed as a combination of three different w/c ratios (0.28, 0.32 and 0.36) and three temperatures of water ($T_w$) – 21, 40, and 60 °C and three temperatures of cement ($T_c$) – 22.5, 40, and 60°C (Table 1). The cement as well as water were heated prior the experiment in electric oven. The initial water/cement ratios were chosen as 28%, then 32% and finally 38% for control for $T_c = 40$ and 60 °C and $T_w = 60°C$.

| w/c | $T_w$ (°C) | $T_c$ [°C] |
|-----|------------|------------|
|     | 22         | 40         | 60         |
| 0.28| 21         | CP28 - 21 - 22 |
|     | 40         | CP28 - 40 - 22 |
|     | 60         | CP28 - 60 - 22 |
| 0.32| 21         | CP32 - 21 - 22 |
|     | 40         | CP32 - 40 - 22 |
|     | 60         | CP32 - 60 - 22 |

Table 1. Labelling of the samples (CPw/c - $T_w$ - $T_c$).
Table 1. Completion

| Completion | 0.36 | 21 | - | - | 40 | - | - | 60 | CP36 - 60 - 40 | CP36 - 60 - 60 |
|------------|------|----|---|---|----|---|---|----|---------------|---------------|

For every batch, 500g of cement and calculated amount of water according to the selected w/c ratio were weighed and mixed according to the technical standard (90s on low speed of blade - 140±5 rpm in rotation and 62±5 rpm in planetary movement, 30s pause and another 90s on low speed). Immediately after mixing, temperature of fresh cement paste ($T_{cp}$) was recorded and consistency (d) on Vicat apparatus was determined in time of 30s. Considering that already at $T_c = 40°C$ and $T_w = 40°C$ was reached stiffens at w/c = 28% (could be supposed that the Vicat roller did not penetrate the paste), testing at this w/c ratio for $T_c = 60°C$ was not performed.

3. Results

The results of final cement paste temperature ($T_{cp}$) and of the height between base plate and the bottom of the Vicat roller (d) are given in Table 2.

Table 2. Measured parameters of cement pastes.

| Sample         | $T_{cp}$ (°C) | d (mm) |
|----------------|---------------|--------|
| CP28 - 21 - 22 | 25.7          | 11.0   |
| CP28 - 40 - 22 | 32.6          | 24.5   |
| CP28 - 60 - 22 | 34.4          | 32.5   |
| CP28 - 21 - 40 | 31.4          | 25.0   |
| CP28 - 40 - 40 | 35.5          | 32.5   |
| CP32 - 21 - 22 | 24.8          | 1.0    |
| CP32 - 40 - 22 | 33.0          | 9.0    |
| CP32 - 60 - 22 | 35.4          | 11.0   |
| CP32 - 21 - 40 | 29.8          | 1.0    |
| CP32 - 40 - 40 | 35.2          | 12.5   |
| CP32 - 60 - 40 | 40.4          | 15.0   |
| CP32 - 21 - 60 | 33.4          | 9.0    |
| CP32 - 40 - 60 | 37.3          | 12.5   |
| CP32 - 60 - 60 | 41.9          | 18.0   |
| CP36 - 60 - 40 | 40.2          | 0.0    |
| CP36 - 60 - 60 | 44.0          | 3.0    |

The lowest d for w/c = 0.28 (28%) equals 11mm and was obtained for the lowest temperature of cement paste ($T_{cp} = 25.7°C$), when testing was performed at laboratory conditions. The highest d for the same w/c ratio equals 32.5mm and was obtained for 2 cases, when $T_w = 60°C$ and $T_c = lab$ (ca. 22.5°C) while $T_{cp} = 34.4°C$, respectively $T_w = 40°C$ and $T_c = 40°C$ while $T_{cp} = 35.5°C$.

Using higher w/c ratio, the lowest d for w/c = 0.32 (32%) equals 1mm and was obtained for the lowest temperature of cement paste ($T_{cp} = 24.8°C$), when laboratory conditions were retained. The d equals 1mm was also obtained for $T_{cp} = 29.8°C$, while $T_w = lab.$ and $T_c = 40°C$. Considering other results within the table, at this w/c, the d started to raise at higher temperature of cement paste or that for the first two cases there was too much water in cement paste and temperature did not have significant impact. The highest d for the same w/c ratio equals 18.0mm and was obtained for $T_w = 60°C$ and $T_c = 60°C$ while $T_{cp} = 41.9°C$. 
At the w/c = 0.36 (36%), for \( T_w = 60^\circ C \) and \( T_c = 40^\circ C \) was \( T_{cp} = 40.2 \) and \( d = 0 \) mm, what means, that there was excessive amount of water in cement paste. For \( T_w = 60^\circ C \) and \( T_c = 40^\circ C \) was \( T_{cp} = 44.0^\circ C \) and \( d = 3.0 \) mm, what is decrease of 15.0mm for the same material (water, cement) temperature conditions with w/c raising of 0.04 (4%).

The dependences of \( d \) on \( T_{cp} \) for w/c = 0.28 and 0.32 are rendered in Figures 1 and 2.

**Figure 1.** The correlation between \( d \) parameters and the temperature of the cement pastes of w/c = 0.28.

**Figure 2.** The correlation between \( d \) parameters and the temperature of the cement pastes of w/c = 0.32.
Based on results, it could be seen the obvious tendency to lose consistency of cement paste with increasing of its temperature. According to figures 1 and 2, it could be concluded, that the tendency for this experiment with given cement has linear character with the strong positive correlation with the coefficient of determination ($R^2$) 0.9695 for w/c = 0.28 and 0.9147 for w/c = 0.32. There is also the tendency obtaining the similar consistency at the same temperature of cement paste within the same w/c ratio.

4. Conclusion
The experimental study was focused on temperature influence to cement paste consistency. Based on the results, it can be deduced, that consistency of cement paste (CP) is direct depended on its temperature, when increasing the temperature of CP caused increasing its resistance to Vicat roller penetration. Then, adjusting the consistency is often performed by adding plasticizer or water. In case of water, it could be connected with the decreasing of mechanical properties as well as durability of cement composite. Adding plasticizer could lead to deceleration of setting, decrease of early compressive strength as well as hardness of CP / modulus of elasticity of early age concrete. It can be also assumed, that temperature has also impact on another rheology properties as well as other parameters of fresh CP. Considering the results of water need to achieve normal consistency of CP using standard procedure conditions and the real conditions on the plant, the standard method seems to be inadequate for concrete producers.

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