Mechanical properties of cement paste curing at different isothermal conditions

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Abstract. The paper studies the intensity of strength generation in the concrete paste during the time period of 0–67 hours, at 40, 50 and 70 °C isothermal curing. It is shown that at these temperatures the yield stress increases by one order of magnitude. The elastic properties of the cement paste also significantly increase. The plastic strain range reduces with curing time, and the catastrophic failure of specimens occurs at the end of the investigated temperature range. Stress-strained curves in the plastic range are non-monotonous, with a high density of breaks. The yield stress is the main parameter for evaluating the strength properties of the cement paste.

1. Introduction

In different types of concrete, the main binding material is cement paste (Portland cement). Local stresses under the external load distribute in concretes non-homogeneously. Aggregates in heavy concretes usually exhibit high strength properties. Therefore, strength properties of concrete are determined particularly by heavy fractions which concentrate local stresses in their interfacial regions which substantially exceed the average stress values for concrete. On the contrary, mechanical properties of concretes with a high porosity are determined by elastic properties of the cement paste [1–10].

Concrete hardening is a multifactorial process influenced by the water/cement ratio, temperature, moisture conditions, phase composition, etc. As a consequence, the achievement of performance properties is individual for concretes. Although the literature in this field evaluates the strength properties of concretes, there are merely normalized yield values for deformed concretes which correspond to 28 days of curing [4]. According to the authors, this parameter is insufficient for detailed research into the strength properties of cement paste. Also of interest is a study of mechanical properties of hydrated cement paste depending on time and temperature of isothermal curing with a view of the quantitative estimation of changes in the Portland cement yield stress and the intensity of strength generation which develop during curing up to in-service values.

The aim of this work is to investigate mechanical properties of hydrated cement paste depending on time and temperature of isothermal curing. As a result, the quantitative estimation is provided in relation to changes in the yield stress and the strength generation intensity in Portland cement during its curing up to in-service values.

In this paper, we continue research presented in [11-12].
2. Material and model approximation

Portland cement manufactured at Topkinskii cement plant, Kemerovo region, Topki, Russia, was studied in this experiment [13]. The test machine INSTRON-3382 was used to measure the ultimate compressive strength of the cement paste. Tests were carried out on 20×20×20 mm specimens at a room temperature and 1 mm/min deformation rate. The load determination accuracy was 5 N, the maximum load equaled 100 kN. Isothermal tests were conducted in a curing room. The values of the yield stress and the module of elasticity were averaged over those obtained for five dependences.

Figure 1 plots isothermal curves of cement paste curing. The cement paste was warmed up to 40, 50 and 70 °C for isothermal curing during 3, 5 and 8 hours, respectively. At the next stage, the cement paste was cured in a moist curing room at a constant temperature. As can be seen from Fig. 1, the following time values were selected respectively for 40, 50 and 70 °C isothermal curing: 0, 3, 6, 19, 30, 43, 54, 67; 0, 3, 6, 19, 30, 43 and 0, 3, 17, 27, 41, 51 hours.

A chromel-copel thermocouple with 0.5 mm diameter was used for more accurate temperature measurements (±0.5 °C). Measurements were performed on-line, using a temperature recorder ‘Teplograf’ equipped with a general-purpose multichannel adapter ‘Terem’.

3. Results and discussion

Figure 2 contains plots of the typical stress-strain (σ–ε) dependences which correspond to 40 °C initial curing at 0 h (Fig. 2a) and 67 h (Fig. 2b).

According to Fig. 2b, the dependence is characterized by the initial transition area, elastic strain (long linear) range and plastic strain range.

The elastic strain range is restricted by the linear stress-strain dependence. In the plastic strain range, this dependence is complex. The length of this range depends on the curing time. At the initial stages, the plastic strain range turns to be long and comparable with that of the elastic strain range. A gradual increase in the yield stress up to the strength limit values is normally observed, followed by the long area of the stress decrease. This order of σ–ε dependence behavior is characteristic for the initial stages of curing at all the investigated temperatures. The temperature has an effect only on the quantitative parameters, such as the yield stress, strength and curing intensity on σ–ε dependences. With increasing curing time and temperature, the plastic strain range significantly reduces, and a high density of breaks is normally observed beyond the yield stress. In some cases, the strength limit values coincide with that of the yield stress, i.e. the difference between σ–ε curves composes shares of percent of strain. It does not appear feasible to determine how curing temperature and time affect the yield stress in the plastic strain range at advanced stages. The yielding curves show both the jump-like growth and decrease in stresses. Portland cement specimens tend to a catastrophic failure.
Figure 2. Stress-strain ($\sigma-\varepsilon$) dependences at 40 °C curing and different curing time: a) – 0 h; b) – 67 h. Red lines indicate approximations of linear curve sections.

with curing time. In the plastic range, they deform individually. During the isothermal warming, the transition area varies a little at the initial curing stages. The increase in isothermal warming and heating time leads to a significant reduction in the transition area on the yielding curves.

The analysis of the elasticity modulus and the yield stress on $\sigma-\varepsilon$ curves shows that the former characterizes the intensity of strength generation within the elastic strain range. The yield stress $\sigma_0$ shown on $\sigma-\varepsilon$ curves corresponds to the transient stress between the linear and plastic ranges. The red line shown in Fig. 2 indicates the approximation of the linear curve section as

$$\sigma = A + G \cdot \varepsilon,$$

where $\sigma$ is the stress applied; $\varepsilon$ is the strain; $A$ is the constant; $G$ is the elasticity modulus. The linear correlation coefficient is close to unity (not less than 0.998) for all specimens of interest.

Figures 3–5 present dependences between the yield stress and the elasticity modulus of the cement paste depending on the curing time or the time of strength generation. These dependences are obtained at different curing temperatures.

Figure 3. Time dependences for 40 °C curing: a) – yield stress; b) – elasticity modulus.
As shown in Figs 3–5, mechanical properties substantially increase with the curing time. Thus, starting from the isothermal warming time point, the yield stress increases by more than one order of magnitude at 40 °С and 50 °С curing (Figs 3–4), respectively during 0–67 h and 0–43 h time periods. At 70 °С (Fig. 5) curing, the yield stress increases by almost one order of magnitude during 0–51 h time period. The elastic modulus also considerably grows. As can be seen from Fig. 6, the warming temperature has a great effect on the intensity of strength generation and the yield stress. This figure contains the temperature dependences for the yield stress and the elasticity modulus during 0, 3, 30 and 43 h curing.
According to Fig. 6, the values of the yield stress and elasticity modulus increase with the temperature growth. During a rather short period of time (not over 67 h), the cement paste generates a greater deal of strength as compared to 28-day curing at a room temperature. The values obtained for the yield stress and the elasticity modulus after 28 days match the design parameters. It is found that the elasticity modulus is ~3630.6 MPa, while the yield stress is 51.75 MPa. Apparently, after 67 h curing strength properties come to not less than 75% of the design strength values. With the temperature growth, this percentage is achieved during considerably shorter time of curing.

4. Conclusions
In conclusion, it is evident that the behaviour of the stress-strain curves includes three stages, namely: transition, elastic and plastic strain ranges. The temperature and time of isothermal curing substantially affected the intensity of strength generation in the plastic strain range. At the end of the isothermal curing, the values of the limit strength and the yield stress almost coincided. Stress-strain curves in the plastic range are non-monotonous, with a high density of breaks, and a catastrophic failure of specimens occurred at the end of the investigated temperature range. Within 0–67 h curing, the yield stress increased almost by an order to magnitude, and the elasticity modulus increased also. It was shown that with the growth in the curing temperature, these parameters also increase, and a more intensive strength generation was observed. The yield stress was found to be the main estimation parameter of the strength properties at different curing temperatures. After 67 h curing the strength properties of Portland cement achieved not less than 75% of the design strength values corresponding to 28-day curing.

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