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Experimental Stress Analysis

Evolution of Cement Paste Strength in Tension and Compression for Temperatures up to 300 °C

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Abstract: The temperature change has a strong impact on material properties influencing the behavior of structural elements and whole structures, respectively. The paper presents the evolution of strength of cement paste exposed to temperatures up to 300 °C, while focusing on a peak strength expected to be close to 200 °C.

Keywords: Cement paste, High temperature, Compressive strength, Tensile strength

1. Introduction

Cement as a basic ingredient of concrete still belongs to the most important materials in the building industry. Many researchers at different research centers try to examine and improve properties of cement. The approaches are essentially based on the experimental work (e.g. forming of cement paste [4], properties of cement with a regard for its composition [2]) and often supported by numerical studies (e.g. hydration of cement paste [1], evolution of cracking in cement based composites [2]).

An important property of cement paste is its strength. The structure and compactness of cement paste are dramatically influenced by extreme conditions, e.g. fire. The influence of increasing temperature on the mechanical properties of cement paste is described in this paper. The experimental work is closely connected to previous results presented in [5] and [6]. Three different mixtures with a water ratio 0.3, 0.4 and 0.5 were chosen for this study. The mechanical properties in tension and compression were examined on prepared specimens. Each set of specimens was exposed to a different temperature. The temperature increase rate was chosen equal to 100 °C/10 minutes (simulation of fire). When the prescribed temperature was reached, it was kept constant for 2 hours. Originally, four temperature conditions were applied: 20 °C (ideal condition); 200 °C (water removal); 450 °C (clay decomposition); 600 °C (portlandit decomposition). One extra experiment with peak temperature 300 °C was proposed later for an intermediate measurement. Note that the specimens exposed to temperatures equal to 450 °C and 600 °C were almost destroyed that brought difficulties in subsequent test i.e. bending and compression.

Unexpected results, i.e. increase in strength, were observed for specimens subjected to 200 °C. Following pages offer detailed description of used methodology and experiments focused on changes of compression and tensile strength of cement paste made of CEM I subjected to temperatures between 100 °C and 300 °C.

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2. Methodology

Specimens were made of portland cement CEM I 42.5 R, the obtained from Radotín cement plant. During previous experiments portland cement CEM I 42.5 R and portland mixed cement CEM II 32.5 R from the Mokrá cement plant was used. From cement and defined quantities of water were made three groups of specimens – water to cement ratio (w/c) was 0.3, 0.4 and 0.5. Specimens with w/c equals 0.3 also include plasticizer reasoning order to gain better workability.

2.1. Specimens

For the need of the experiment two types specimens were made. In forms of the stainless steel were made beams with the dimensions 20 x 20 x 100 mm. In the forms made of plastic were made cylinders with diameter 10 mm and height 100 mm. Before the measurements the cylinders were cut so the final height was 40 mm. Both types of specimens are clear from the Fig. 1 and Fig. 2. Specimens were left in forms for 48 hours. After removal from forms were the specimens placed into the water bath with temperature 20 °C. After 28 days specimens were subjected to the temperature load and immediately tested afterwards.

Fig. 1. Beam shape specimens

Fig. 2. Cylindrical shape specimens

2.2. Temperature load

During the previous experiments following temperatures 20 °C, 100 °C, 200 °C, 300 °C, 450 °C and 600 °C were applied (more in introduction). In additional experiments was the selected group 100 °C, 150 °C, 200 °C, 250 °C and 300 °C. Temperature increase rate was 100 °C/10 minutes. The temperature was acting for 120 minutes. The selected temperatures were low enough to avoid damaging the specimens and so the strength test was carried out without further difficulties.

2.3. Performed experiments

Two types of destructive experiments were carried out. On cylinders was tested compressive strength and on beams was tested tensile strength. For experiments was used testing apparatus MTS Aliance RT-30 with maximal loading power 30 kN in both compression and tension. Loading area of cylinders was 78.5 mm^2. Tensile strength was evaluated from the three point bending tests. Load was applied in the middle of the specimen. Support distance was 80 mm.

3. Evaluation

Every group of specimens consisted of 5 samples. Measured data were analysed using statistical approach. Standard deviation was less than 5%.

3.1. Volume weight

Every specimen was weighed and measured after removal from the water bath and after the heat being applied. Volume weight was then calculated. Results obtained agreed with the idea, the volume weight of specimens of the cement paste tend to decrease with the increasing temperature and with increasing value of w/c ratio. Table 1 presents dependence of volume weight temperature and w/c ratio. Values in Table 1 are relative to representative value of volume weight measured for specimens without thermal loading. It can be seen, that the biggest decrease of volume weight takes place for thermal loading at 200 °C. The highest decrease can be observed for specimens with w/c ratio 0.5 while lowest decrease was observed for specimens with w/c ration 0.3 respectively.

Table 1. Development of volume weight of specimens made from cement paste CEM I 42.5 R in dependence on temperature and water ratio

Temperature	*Water Ratio*		
	0.3	*0.4*	*0.5*
20 °C	1.00	1.00	1.00
100 °C	0.91	0.88	0.86
200 °C	0.86	0.82	0.78
300 °C	0.83	0.78	0.73
450 °C	0.80	0.78	0.69
600 °C	0.79	0.73	0.69

3.2. Compressive and tensile strength

The values of compressive and tensile strength of cement paste after 28 days with water ratio 0,3 with used plasticizer are on Fig. 3 and Fig. 4. The value of tensile strength happened to increase from 150 °C up to 250 °C and to decrease from 250 °C to 300 °C. The compressive strength decreases is considerably from 100 °C.

Fig. 5 and Fig. 6 illustrate values of compressive and tensile strength of cement paste after 28 days with water to cement ratio equals 0,4. In this case both tensile and compression strengths happened to increase until temperature 200 °C is reached and decreased after it is exceeded.

Cement paste with water to cement ratio equals 0.5 and its values of compressive and tensile strength its dependence on temperature after 28 days are on Fig. 7 and Fig. 8. Behaviour is the same as in case of specimens with w/c ratio 0.4 – the highest values are at 200 °C.

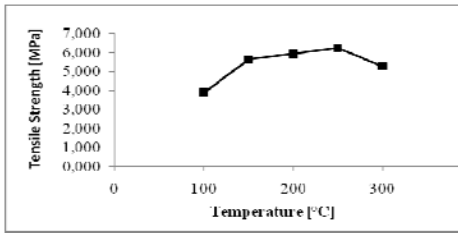

Fig. 3. Dependence of tensile strength of the cement paste on temperature with water ratio 0.3 after 28 days

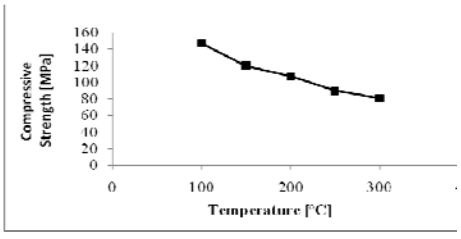

Fig. 4. Compressive strength of cement paste dependence on temperature with water ratio 0.3 after 28 days

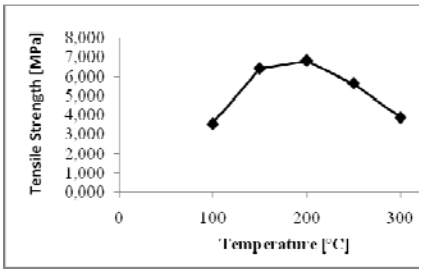

Fig. 5. Tensile strength of cement paste dependence on temperature with water ratio 0.4 after 28 days

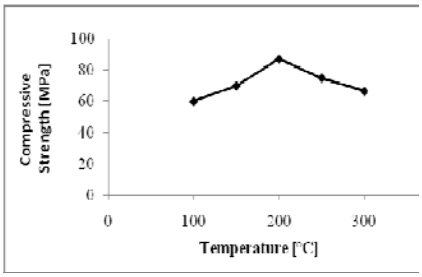

Fig. 6. Compressive strength of cement paste dependence on temperature with water ratio 0.4 after 28 days

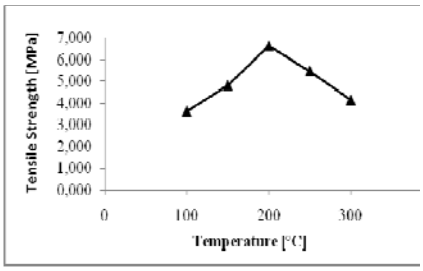

Fig. 7. Tensile strength of cement paste dependence on temperature with water ratio 0.5 after 28 days

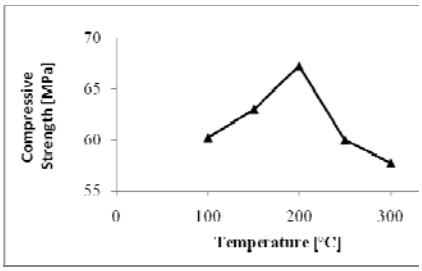

Fig. 8. Compressive strength of cement paste dependence on temperature with water ratio 0.5 after 28 days

4. Conclusion

The experiments described in this paper confirmed previous measurements, within which the influence of high temperatures on the compressive and tensile strength of cement pastes was analyzed. It was shown that the w/c ratio has also an important impact on the results. The increasing amount of water in cement paste reduces the values of investigated mechanical properties. Experiments were carried out on cement paste made from CEM I 42.5 R and CEM II 32.5 R. Values of w/c ratio were 0.3; 0.4 and 0.5. Temperatures were chosen from 20 °C up to 600 °C. Compressive and tensile strength in most cases increased for temperature around 200 °C. The largest rate of volume weight decrease is around 100 °C. For higher temperatures the rate decreases and beyond 200 °C is the volume weight decrease nearly negligible. Additional set of experiments was carried out for temperatures 100 °C, 150 °C a 200 °C. The additional tests confirmed the assumptions made from the results of the original series.

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