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THE INFLUENCE OF SHORT TIME WATER COOLING ON THE MECHANICAL PROPERTIES OF CONCRETE HEATED UP TO HIGH TEMPERATURE

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Abstract. This paper deals with the description of tests on concrete subjected to a high temperature and then cooled in two ways. Two series of cylinder specimens (103 mm in diameter, 200 mm in height) made of concrete C25/30 and C40/50 were tested. Specimens were heated in the electric furnace to 270, 370 and 500 ºC. After heating, some of specimens were left in the open air and some of them were put in water for 10 sec and then left in the open air. Next day the compressive strength of concrete was tested. Test results are presented. In addition, the paper includes some test results taken from the literature.

Keywords: concrete, tests, experiments, high temperature, fire, cooling, compressive strength, residual strength.

1. Introduction

The problems of fire safety assessment in construction and predictions of structural element fire resistance have recently become more and more important. There is an increasing number of research works in this field and new standards and legal regulations are being created. Some parts of Eurocodes deal with fire safety of concrete structures [1–3].

At present in most cases assurance of the required fire resistance of reinforced concrete elements is carried out by the tabulated recommendations [3]. In these recommendations the minimal cross-section dimensions of the element and the minimal distance from the middle of the reinforcement to the surface of the cross-section are determined. However, in Poland the outdated instruction [4] is mostly used. It includes similar recommendations but different in details.

At the same time, with simple tabulated requirements, more accurate but more sophisticated methods for determining fire resistance of elements are developed. These methods are based on analysis of the cross-section ultimate limit states in fire conditions, considered as an accidental design situation of the structure [3, 5–12].

A very important part of the reinforced concrete element analysis under fire conditions relates to prognosis of concrete mechanical properties degradation. This problem has been studied since the 1950's [13–15]. The general reviews of concrete response to high-temperature exposure are presented [16–18].

During analysis of concrete elements at high temperatures the compressive strength of concrete is usually the most significant feature. The maximal heating temperature is the basic factor resulting in concrete strength degradation.

The Eurocode drafts [1–3] give recommendations for determining the degradation of concrete strength in relation to the maximal heating temperature. However, it is known that the concrete strength degradation depends also on a number of other factors. The kind of aggregate used, loading level during heating period, concrete moisture content, rate of temperature increase and rate of cooling also play a very important role.

During a fast cooling self-equilibrating stresses appear in concrete. They can cause a destruction of its structure and cracking. Concrete heated to comparatively moderate temperature, which during slow cooling down would not be damaged, can be destroyed due to a violent cooling. This situation can develop during fire fighting, when, in some cases, structural elements may be heated up and cooled down many times.

It is known that the residual strength of concrete is significantly smaller than that one observed at high temperatures. However, the number of test results, available in literature, dealing with elements heated up to high temperature and then cooled with water is rather negligible.

2. Test results described in the literature

Sarshar [19] has examined the compressive strength degradation of cement paste specimens made of ordinary Portland cement. Cylindrical specimens, 63 mm in diameter and 63 mm in height, were used. Specimens were heated up to 300 or 520 °C, and then cooled in three ways.

In Fig 1 test results of the compressive strength degradation depending on the heating temperature and the way of cooling are presented. Square markers relate to the specimens left in the hot furnace. Round markers show the specimens cooled freely in the open air, and triangle markers the specimens quenched with water. Unfortunately, in [19] no precise description of specimens cooled with water was given. The description was only limited to general information, that specimens were quenched with a small quantity of water, and then cooled freely.

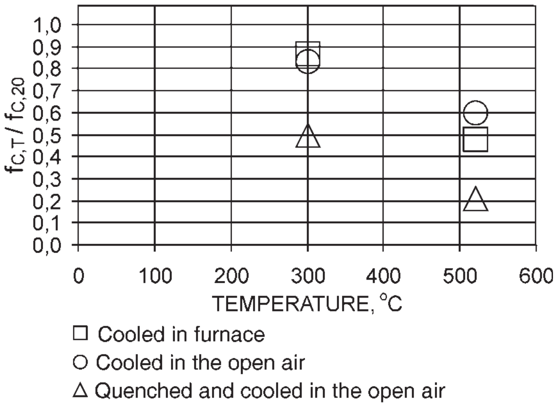

Fig 1. The effect of cooling on the specimens strength degradation [19]

In specimens cooled with water, much bigger strength decrease was observed than in those ones cooled slowly. Specimens heated up to 300 °C and quenched with water lost about 50 % of its strength. It was more or less the same as for the specimens heated up to 520 °C, but cooled slowly.

Nassif et al [20] have examined degradation of Young's modulus of concrete. Cylindrical specimens, 75 mm in diameter and 175 mm in height, were used. They were drilled out of concrete blocks, of dimensions 700 x 500 x 200 mm made of concrete with limestone aggregate. Specimens were heated in the electric furnace to 217, 287, 320, 378 and 470 °C. After reaching the required temperature, some of the specimens were cooled freely in the open air and some of them were sprayed with water for 5 min and then cooled freely too.

In Fig 2 the test results of initial Young's modulus of concrete degradation are shown depending on heating temperature and the cooling way. Round markers (Fig 2) relate to the specimens cooled freely in the open air, while triangular markers represent the specimens sprayed with water. In Fig 3, in a similar way, the degradation of chord Young's modulus of concrete is shown.

The above graphs presenting the degradation of initial and chord Young's moduli of concrete are rather similar. In the authors' opinion, this can confirm the hypothesis that, as a result of action of high temperature, the mechanical properties of concrete undergo almost the same proportional degradation.

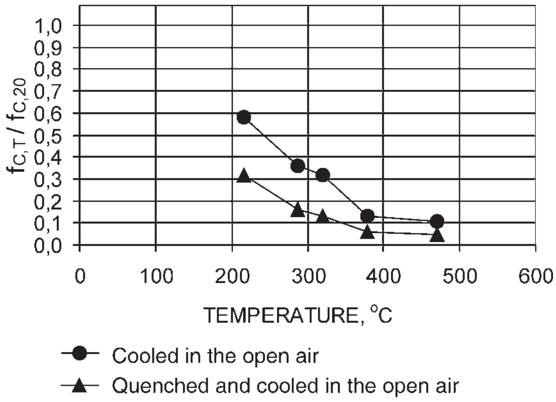

Fig 2. The effect of cooling method on the initial Young's modulus of concrete [20]

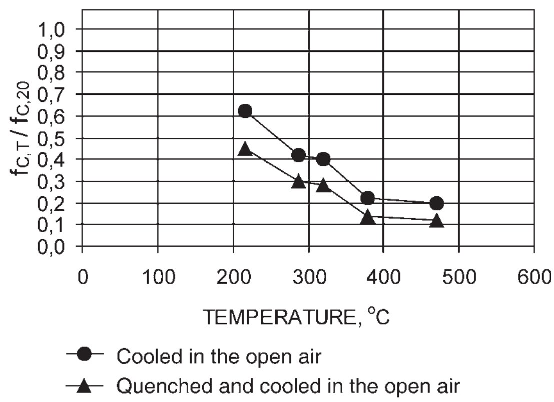

Fig 3. The effect of cooling method on the chord Young's modulus of concrete [20]

The comparison of test results presented in Figs 2 and 3 leads to the conclusion that spraying specimens with water has a significant influence on degradation of Young's modulus of concrete. For example, the decrease of this modulus of specimens heated up to 217 °C and then cooled with water and the decrease of specimens cooled in the open air but heated up to 287 °C or 320 °C were almost the same.

Tests performed by Zoldners [18], should also be mentioned. Some specimens were heated up to 500 ºC and cooled by quenching with water for 5 minutes. They had much lover compressive strength than specimens not quenched but allowed to cool slowly overnight in the closed furnace.

Test results mentioned above suggest that even not very long spraying with water of heated concrete may cause very significant degradation of its mechanical properties.

3. Tests by the authors

The specimens were heated up and cooled in two ways. Then the tests of compressive strength were performed. Two series of twenty-one cylindrical specimens,

Fig 4. The furnace chamber

103 mm diameter and 200 mm height, made of concrete C25/30 and C40/50 with siliceous aggregate, were examined. 18 specimens from each run were used for strength tests and 3 for temperature measurements. Points of measurement were located inside specimens in ½ of height, in the middle of the cross-section and in the middle between central axis and external edge (in ½ of the radius). In specimens the holes of 5 mm diameter drilled and thermocouples were placed in them. Next the holes were filled up with dry sand and plugged with mineral wool. Specimens were heated up in the electric furnace.

In Fig 4 the furnace chamber with some specimens inside is shown. In Fig 5 the specimens arrangement in the furnace chamber and the thermocouples are shown. More details about specimens, concrete, equipment and the course of testing can be found in [21].

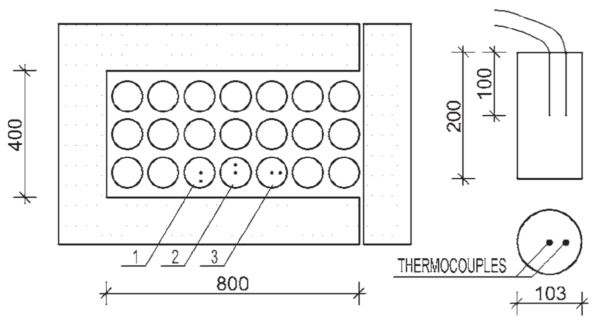

Fig 5. The arrangement of specimens in the furnace and the position of thermocouples

Heating the specimens was started in the cold furnace. Temperature measurements were taken every 15 min. When temperature inside specimens reached the average value of 270 °C, the furnace was opened and 6 specimens were taken out. The remaining specimens were heated further. After reaching the average temperature of 370 °C the furnace was opened again and the next 6 specimens were taken out. The rest specimens were removed when the average temperature inside them reached 500 °C.

In Fig 6 graphs of temperature increase inside the specimens are shown. The fine solid line shows the average temperature in the middle of the specimen section. The fine detached line shows the average temperature in the middle between central axis and external edge of the specimen section. The round markers relate to the time when specimens were taken out of the furnace (when average temperature inside them was 270, 370 or 500 °C). In addition, in Fig 6 the standard curve of temperature increase used in fire resistance tests of elements is shown.

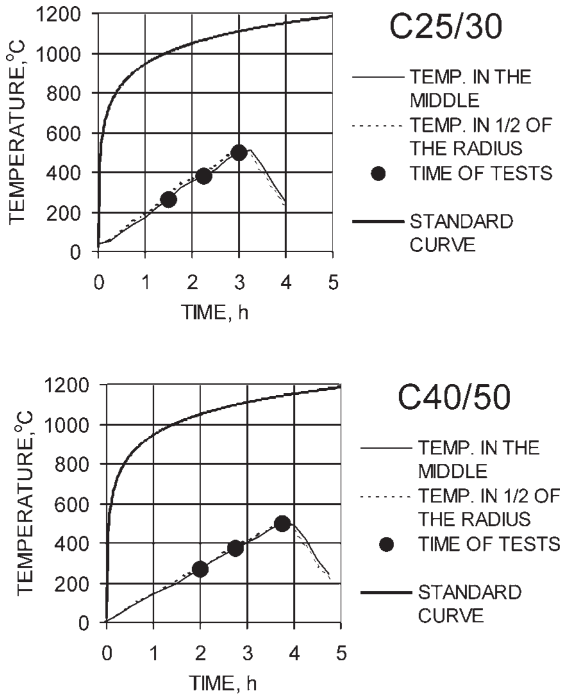

Fig 6. The temperature increase

The temperature increase inside specimens and later its decrease after taking them out of the furnace had a linear character. The rate of temperature increase can be estimated as about 2,4 °C/min. The average temperature in the centre of specimens and in 1/2 of radius of the section were almost similar. This indicates that the equalisation of the temperature inside specimens was relatively rapid.

The temperature increase in specimens was considerably smaller than the one corresponding to the standard curve. However, if the increase in the furnace followed the standard curve, it would result in a very quick increase in specimens which, in turn, would result in a rapid destruction of concrete. It is known that concrete heated up to temperature exceeding 500–600 °C loses the majority of its strength. In this situation, from the practical point of view, the consideration of the strength degradation of concrete is useless. During tests, carried out on specimens of relatively small dimensions, aiming to predict the strength degradation of concrete, it is more useful to apply the temperature increase slower than the increase according to the standard curve. In this way it is possible to examine concrete subjected to temperatures in which its strength degradation is only partial. The increase of temperature according to the standard curve should be applied during testing elements with dimensions met in nature. In the authors' opinion, in these tests instead of average concrete strength degradation the range of concrete destructed zone should rather be considered.

As it has been mentioned above, after removing the specimens from the furnace, they were cooled in two ways. Three of the six specimens were cooled down freely in the room of about 25 °C. Remaining three specimens were immersed in water of about 20 °C for 10 seconds. After they were also cooled down freely in the room temperature. In Fig 7 the way of specimens cooling in water is shown.

Fig 7. Cooling the specimens

A very short time of immersing the specimens in water was assumed due to fear of their destruction as the result of a thermal shock. This fear appeared to be real after analysis of the results presented in [19] (Fig 1). In these tests spraying with a small quantity of water of heated cement paste specimens caused a very significant loss of their strength.

The compressive strength tests of concrete were carried out next day after heating. In Fig 8 the strength degradation of tested concrete is presented depending on the maximum heating temperature and the way of cooling. The round markers refer to the strength of specimens cooled in the open air, while the triangle markers describe the specimens immersed in water. Additionally, the curve for prognosis of concrete strength degradation taken from the Eurocode draft [3] is shown.

The relative degradation of concrete strength of both kinds of concrete (C25/30 and C45/50) was actually

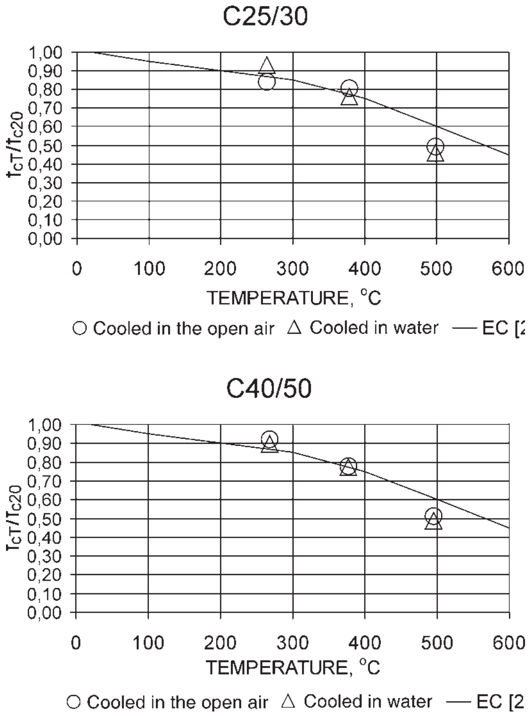

Fig 8. The cooling method effect on the concrete strength

equal. It confirms the rule that in case of ordinary concrete the relative degradation of its compressive strength does not depend on its strength at ordinary temperature. A short immersion of heated specimens in water has not produced any significant effect on the decrease of concrete strength. At of 270 and 370 °C, degradation of concrete strength was in accordance with this one predicted in [3]. At heating temperature of 500 °C, the loss of concrete strength was bigger than it could be expected by the Eurocode recommendations [3]. This can confirm that the residual concrete strength is smaller than the one at high temperature.

4. Conclusions

- The short time immersion in water of specimens heated up to temperature of 270, 370 and 500 °C has not produced any significant effect on the decrease of concrete strength.
- Specimens of cement paste [19] heated up to 300 and 520 °C and quenched with water showed a significant degradation of strength.
- Concrete specimens heated up to 217, 287, 320, 378 and 470 °C and then sprayed with water [20], showed a significant degradation of Young's modulus.
- The results of the studies show that depending on the way and speed of cooling heated concrete, one could expect essentially different degradation of its mechanical properties. In case of violent cooling of the heated concrete compared with a slow cooling, even twice-smaller residual strength can be expected.

- The authors' studies have confirmed the rule that in case of exposing ordinary concrete to high temperatures its relative degradation of compressive strength does not depend on its compressive strength in the room temperature.

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TRUMPALAIKIO ATŠALDYMO VANDENIU ĮTAKA AUKŠTA TEMPERATŪRA PAVEIKTO BETONO MECHANINĖMS SAVYBĖMS

M. Abramowicz, R. Kowalski

S a n t r a u k a

Pateikiami aukšta temperatūra paveikto ir atšaldyto betono bandymų duomenys. Bandytos dvi cilindrinių bandinių serijos – 103 mm skersmens ir 200 mm aukščio bandiniai, pagaminti iš C25/30 bei C40/50 klasės betono. Cilindrai kaitinti elektrine kaitinimo įranga iki 270, 370 ir 500 °C. Po kaitinimo kai kurie bandiniai buvo palikti atvėsti natūraliomis sąlygomis, o kai kurie – 10 s palaikyti vandenyje ir tik vėliau palikti atvėsti natūraliomis sąlygomis. Kitą dieną buvo nustatytas gniuždomojo betono stipris. Pateikti bandymų duomenys, taip pat ir kitų autorių atliktų tyrimų duomenys.

Raktažodžiai: betonas, bandymai, eksperimentai, aukšta temperatūra, gaisras, atšaldymas, gniuždomasis stipris, liekamasis stipris.

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