

Concrete Structures in Urban Areas



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INFLUENCE OF PARTICULAR COMPONENTS OF CONCRETE COMPOSITION TO RESIDUAL COMPRESSIVE STRENGTH AFTER TEMPERATURE LOADING

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SUMMARY

The composition and structure of hardened cement paste have important influences on the concrete properties exposed to high temperatures. An extensive experimental study has been carried out to analyze the post-heating characteristics of concrete subjected to temperatures up to 1000°C. Major parameters of our experimental study were the water-cement ratio, cement paste content and cement content. In our study concrete mixtures with CEM I 42.5 N-S cement and quartz aggregate were tested and the effects of composition on residual compressive strength also on residual flexural strength in cold state were tested after 20°C, 50°C, 150°C, 300°C, 500°C and 1000°C temperature loading. Results indicated that the failure mode as well as the loss of compressive strength depend on the water-cement ratio and cement paste content and cement contents too.

Keywords: *fire resistance, residual strength, water-cement ratio, cement paste content, temperature load.*

1. INTRODUCTION

Due to the high number of possible effects, many parameters have to be taken into account during design. Service life, frost and fire resistance have become more and more important factors. Importance of fire resistance has become more emphasized due to the high number of building and tunnel fires worldwide [1]. Previous studies have analyzed the effects of composition of concrete on fire resistance, and have concluded that mixture properties significantly influence the residual strength after high temperature loading.

2. EFFECTS OF FIRE ON CONCRETE STRUCTURES

If temperature rises, mechanical properties of concrete change. In addition, if irreversible processes occur in the material structure, consequently original properties can not be regained.

Thielen [2] concluded that changes in strength of concrete subjected to high temperatures depend on type of cement and aggregate, w/c ratio, aggregate-to-cement ratio, initial moisture content and way of temperature loading. Other researchers emphasize the importance of the pore system on residual compressive strength. Hinrichsmeyer [3] observed that up to 150°C the porosity of cement-matrix and contact zone between cement and aggregate rises. Up to 150°C, as a consequence of different thermal expansion coefficients of cement and aggregate, cracks can occur in the contact zone. The cement-matrix is stable up to 450°C but micro-cracks can occur even below this temperature. Between 450 – 550°C portlandite decays and number of pores rises, then composition of cement-stone does not change up to 650°C. Above 650°C CSH compounds start to decay and number of capillaries develops. If temperature exceeds 750°C, the diameter of pores significantly enlarges. As a consequence of all these processes the residual strength changes in case of different loading temperatures (see Sec. 5.: Test results).

3. TEST PARAMETERS

Our research mainly focused on the effects of w/c ratio, cement paste content, relative porosity and cement content. 5 different compositions were tested (Tab. 1). All mixtures have the same cement (type CEM I 42.5 N-S) and the same aggregates (quartz gravel and sand) were used.

Table 1 Tested concrete compositions

Parameter	Mix1	Mix2	Mix3	Mix4	Mix5
c [kg/m ³]	360	360	360	410	320
w [kg/m ³]	216	180	144	164	192
w/c [-]	0.6	0.5	0.4	0.4	0.6
cement paste content [/m ³]	332	296	260	296	295
aggregate 0/4 mm [%]	40	40	40	40	40
aggregate 4/8 mm [%]	25	25	25	25	25
aggregate 8/16 mm [%]	35	35	35	35	35

4. EXPERIMENTAL STUDIES

Residual compressive strength was studied on cylindrical specimens having the diameter of 60 mm and height of 120 mm. Before loading, the bottom and top surfaces of each specimen had been polished in order to get parallel surfaces. Residual flexural strength was measured on prisms of 70x70x250 mm sides. Temperature loading of specimens was carried out at 28 days of age. 3-3 specimens of each mixture were tested without temperature loading or with 50°C, 150°C, 300°C, 500°C and 1000°C maximum temperature load. Relative porosity was tested on cylindrical specimens made of the same mixtures.

5. TEST RESULTS

5.1 Residual compressive strength

It can be observed that the in case of concretes with lower w/c ratios both original compressive strength and residual compressive strength values (after 50°C, 150°C, 300°C, 500°C, 1000°C temperature loading) are higher than for the concretes with higher w/c (Fig. 1a). A possible explanation of this phenomenon is that in concretes with lower w/c ratios, the amount of capillaries increases, while number of pores and gel pores only slightly increase.

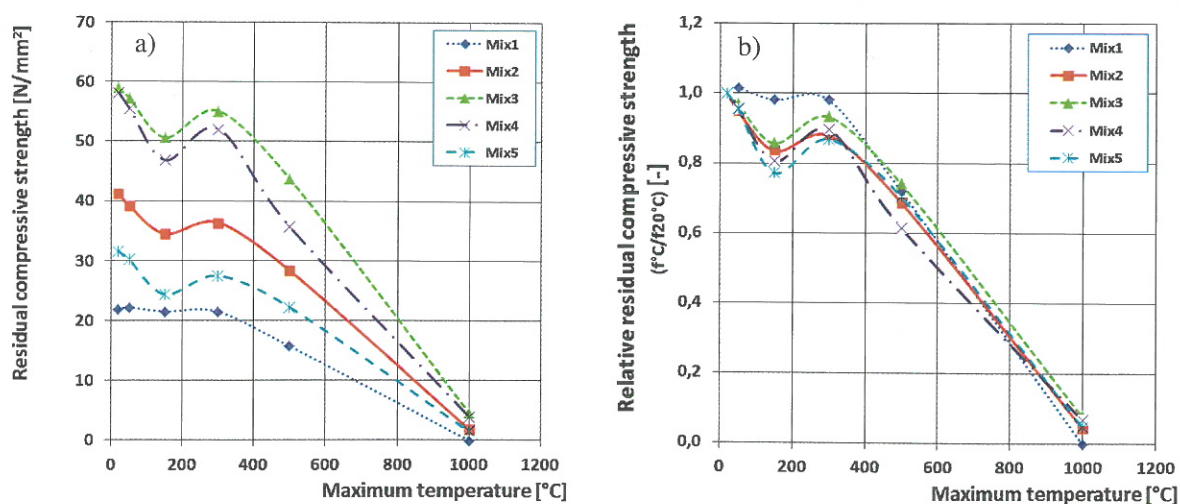


Fig. 1 a) The residual compressive strength and b) the relative residual compressive strength for the different concrete mixes the as a function of maximal temp. (every point is an average of 3 meas.)

Moisture contents and values of apparent porosity of specimens (measured at the age of 28 days) are summarised in Tab. 2.

Table 2 Porosity of the specimens

	Mix1	Mix2	Mix3	Mix4	Mix5
Max moisture content [m%]	6.48	4.80	3.36	3.86	5.20
Moisture content in air-dry state, before test [m%]	2.16	1.57	1.16	1.27	1.63
Apparent porosity [V%]	3.63	2.77	1.99	2.28	2.97

In all load cases of mixtures with same w/c ratio (in Mix1 and Mix5 w/c=0.6; for Mix3 and Mix4 w/c=0.4) reduction of cement paste content resulted in higher residual compressive strength. Concerning apparent porosity, the lower apparent porosity caused higher initial and residual compressive strength.

Residual compressive strength after 150°C temperature load were in all cases lower than the initial strength values, while above 300°C maximum temperature, residual compressive strength showed a temporary increase. Decrease of residual strength around 150°C was less significant in case of mixtures with higher apparent porosity, because in these cases water could evaporate faster.

Regarding the relative residual compressive strength the same tendencies can be seen for Mix2, Mix3, Mix4 and Mix5 (Fig. 1.b). However, the residual strength of mixture Mix1 in 150°C was higher than strength of other mixtures. One explanation of this fact can be that high water and cement paste content an extended capillary system developed through and water could easily leave the specimens.

- In structural concretes it is not sufficient that the relative residual strengths are high, but these values have to be checked together with the initial and the residual strengths. Up to 300°C, relative residual strength of mixture Mix1 is higher, but absolute values of initial and residual strength are lower than the relative and absolute strength of other mixtures.

5.2 Residual flexural strength

In case of mixtures that had similar paste content (Mix2, Mix4 and Mix5), lower w/c ratio resulted in higher residual flexural strength in all load cases. In addition to this, the highest initial flexural strength was observed for mixture Mix3 (w/c ratio: 0.4, paste content: 260 l/m³), but after being exposed to temperatures between 50°C and 150°C, residual strength decreased significantly (Fig 2.a). In case of maximum temperature loads between 150°C and 300°C, mixture Mix2 (w/c ratio: 0.5, cement paste content: 296 l/m³) had more advantageous residual flexural strength than mixture Mix3.

Concerning residual flexural strength similar tendencies can be seen for Mix2, Mix3, Mix4 and Mix5, however a significantly different tendency for Mix1. Strength increases in 50°C and significantly decreases in 150°C. Intensive changes in case of mixture Mix1 can be explained by high water and cement paste content that helped the development of a capillary system.

Between 150°C-500°C in case of mixtures with similar cement paste (Mix2 – Mix4 – Mix5) less w/c ratio caused higher relative residual flexural strength (Fig. 2.b) if the temperature load reaches 1000°C then no significant difference can be seen in the relative residual flexural strength values.

It is visible that mixture Mix3 (cement paste content: 260 l/m³, w/c ratio: 0.4) had the most significant change for relative residual flexural strength. On the other hand mixture Mix4 that had the same w/c ratio of 0.4 but higher paste content (296 l/m³) showed a more advantageous behaviour concerning residual flexural strength.

Comparing mixtures Mix3 and Mix4, that had similar w/c ratio, final residual strength of mixture Mix4 become higher although Mix3 had higher initial strength, due to the significant decrease of strength in case of temperature loads of 150°C, 300°C and 500°C.

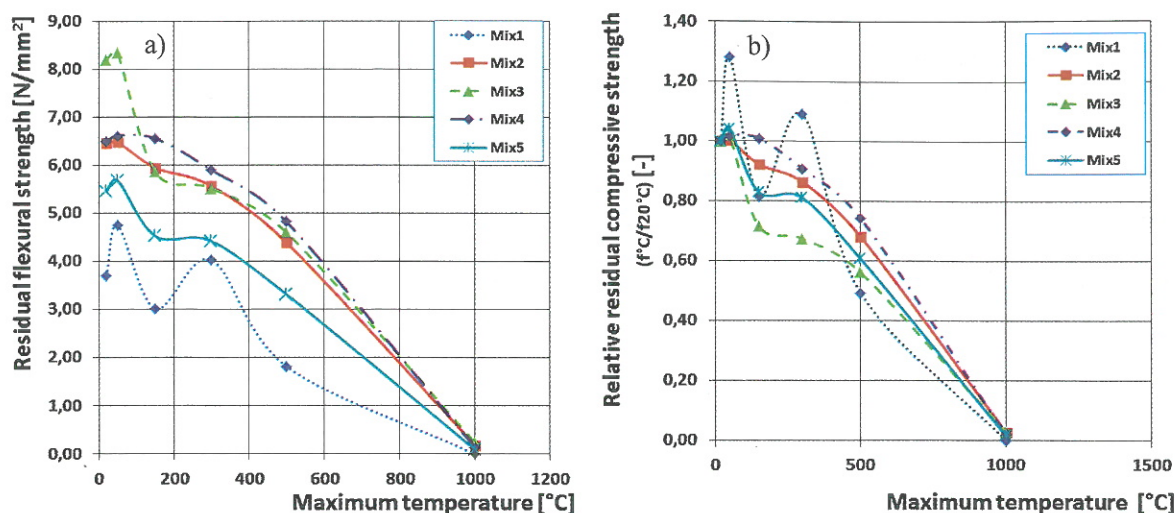


Fig. 2 a) The residual flexural strength and b) the relative residual flexural strength for the different concrete mixes as a function of maximal temperature (every point is an average of 3 measurements). Based on the tendencies that could be seen it can be told that w/c ratio has a dominant effect on residual flexural strength. Cement paste, water and cement content are also of importance.

6. CONCLUSIONS

Laboratory experiments have been carried out at the Department of Construction Materials and Engineering Geology, Budapest University of Technology and Economics that aimed to study the importance of different parameters on the residual strength of concrete being exposed to high temperature loads. In this research test parameters were the w/c ratio, cement paste content and cement content.

In case of lower w/c ratio initial the residual compressive strength increased. In case of similar w/c ratios, lower cement paste content resulted in higher residual compressive strength. This phenomenon can be explained by the fact that concretes with higher value consistency and less free water in pores have higher initial and residual strength than mixtures having higher apparent porosity and w/c ratio. On the other hand spalling can be a possible type of deterioration in case of dense concretes. According to our results the capillary system that develops during heat loading can significantly affect residual strength, the higher the apparent porosity, the lower the initial and residual strengths. Moreover decrease in residual strength that occur around 150°C of maximum load is less pronounced in case of higher apparent porosity (specimen tested at the same age).

To sum up, in order to develop the resistance of concretes against high temperature loads, capillary system is of high importance that is mainly influenced by w/c ratio, cement paste content, water content and cement content of concrete.

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