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Properties of concrete intended for further testing measured by the Impact-Echo and the ultrasonic pulse method

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Abstract. The aim of the paper is non-destructive measurement of differently degraded specimens by high temperature intended for further testing of joints of stainless steel helical reinforcement glued into the groove and differently degraded concrete. Measurement intended for determination of possibilities of estimation of future properties of named joints is performed by the Impact-Echo method and by the ultrasonic pulse velocity method on specimens of dimensions 400 × 100 × 100 mm made of concrete of the C20/25 strength class degraded by different elevated temperature. Five sets of specimens were manufactured - four sets of specimens were heated in the furnace at temperatures of 400 °C, 600 °C, 800 °C and 1000 °C and one set was kept intact as reference. Specimens will be afterwards additionally strengthened at the tensile side of specimens and broken by four-point flexural strength test. The non-destructive measurement aims to evaluate the residual physical-mechanical properties of plain concrete in terms of resonance frequency of test specimen, and sound velocity in tested specimen before and after the temperature degradation. This assessment will serve as material information basis for interpretation of the expected behaviour of used helical reinforcement for a retrofitting process and the thermally damaged concrete reaction to such intervention.

1. Introduction

Due to economical and serviceability demands on structures either in housing or industry buildings, a building structures damaged by fire is more often rehabilitated by retrofitting methods. There are many possible approaches and tools to strengthen, retrofit and repair the damaged elements such as partial replacement of structure elements, concrete or steel jacketing and retrofitting of structural members by fiber reinforced polymers (FRP) or stainless steel helical reinforcement [1].

Presented paper focus on the inspection process of thermally degraded concrete before the application of retrofitting tool – in this case a stainless steel helical reinforcement glued into groove in tensile area of test specimen. The inspection process in relation to retrofitting by this reinforcement is not described yet.

This kind of additional reinforcement is made of high strength (800 – 1300 MPa depending on type and manufacturer) stainless steel which is twisted due to better cohesion with mortar used to bond reinforcement with basic material. Its cross-section also ensures that even if it is able to carry a large load the worker is still able to bend it by hands to desired shape – this advantage is very useful for structure retrofitting [2].

Concrete can withstand up to 400 °C without notable changes in macrostructure and physical-mechanical properties. When silicate aggregate with a cement binder are burned, the greatest weight loss occurs due to the dehydration of physically bonded water and chemically bonded water from the individual components of the binder [3].

In this process of thermal degradation, a cement stone tends to shrink and opposingly the aggregate tends to expand in volume. In range 600 °C to 800 °C the main composite C-S-H gels starts to decompose at around 560 °C and it decomposes into ß-C2S at around 600 °C to 700 °C. The most visible reduction of compressive strength is in range 800 °C to 1000 °C when C-S-H decomposes and decarbonation of carbonates continues [4, 5].

For the purpose to test the joints of stainless steel helical reinforcement bonded to grooves with the basic material concrete beams of dimensions 400 × 100 × 100 mm were manufactured and then non-destructively measured. Concrete of the C20/25 strength class was heated in furnace to temperatures of 400 °C (set B), 600 °C (set C), 800 °C (set D) and 1000 °C (set E). Reference specimens (set A) that were not heated were laid aside under the laboratory conditions. For temperature - loaded specimens, various levels of degradation are expected, which will subsequently affect the tested joints. The intended objective of these measurements is the future comparison of the results of non-destructive measurements in relation to the real behavior of the joints.

For assessing the change in physical and mechanical properties before and after heating, measurements were made using the acoustic non-destructive method Impact-Echo [6] and the ultrasonic pulse method [7]. Similar assessment was conducted in previous studies [3], [8] which proves the IE method to be a suitable tool for assessing the thermally degraded concrete. In the vast assessment of Wisconsin highway bridge in 2003, where numerous test methods where used on thermally degraded concrete structures, Ghorbanpoor concluded [9] that acoustic non-destructive testing is one of the most suitable test tools for thermally degraded concrete structures.

2. Testing Methodology

The Impact-Echo method is based on excitement of the low-frequency vibration of the test specimen by a mechanical impact and subsequent measuring of excited vibrations [10]. The recorded signal is then converted by Fast Fourier Transform [11] into a spectrum that can be easily analyzed (figure 1, figure 2 and figure 3). The mechanical waves propagate in the form of longitudinal, transverse and torsional waves, and more easily pass through a solid homogeneous material without the presence of cavities. When impacting on the interface of two dissimilar materials, the reflection, shattering, absorption or transition of the waves to another type may occur, depending on the ratio of the acoustic impedance of these two materials. In the case of the mechanical wave in the material strikes a defect or a crack, the mechanical waves partially diminish, resulting in a change in the frequency spectrum [12]. Using this method, it is possible to locate defects within subtle structures, profile thickness or to determine the physical and mechanical state of the material that has succumbed to any degradation factor.

The testing specimens were made of concrete of expected strength class C20/25 and specific mix design of used concrete is shown in table 1. For the experiment was designed usual concrete with no special requirements.

Table 1. Mix proportions.

Material	Weight (kg/m^3)
Cement	376
Aggregate 0-4	1058
Aggregate 8-16	706
Water	226
w/c	0.6

Measurement by Impact-Echo was conducted on test specimens placed on rubber pads. As exciter of mechanical stress waves a spherical hammer of total mass 25.5 g was used. For recording of vibrations, a piezoelectric sensor MIDI 446s12 was used and for processing the signal was used a digital oscilloscope Handyscope HS3 with sampling speed set to 0.2 MHz.

The ultrasonic pulse method is based on the principle of measuring the shortest ultrasound signal passing through the specimen. The presence of cavities, cracks and defects forces the signal to travel more complicated and thus longer. From the knowledge of the velocity of the propagation of the mechanical waves in the material, the dimensions of the tested test body and the bulk density, the dynamic modulus of elasticity E_{cu} [7] can be calculated.

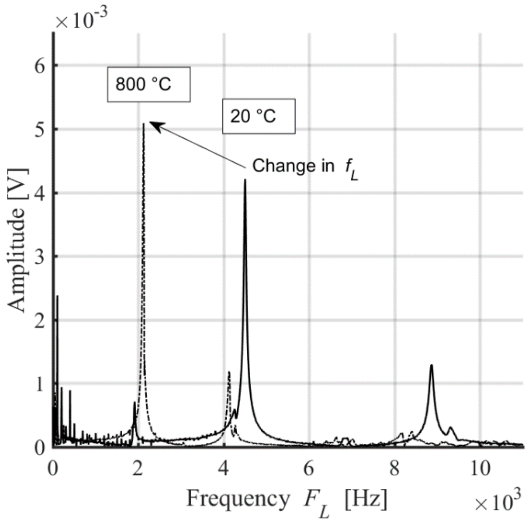

Figure 1. Change of first own longitudinal wave frequency for DP1 specimen before and after heating to 800 °C.

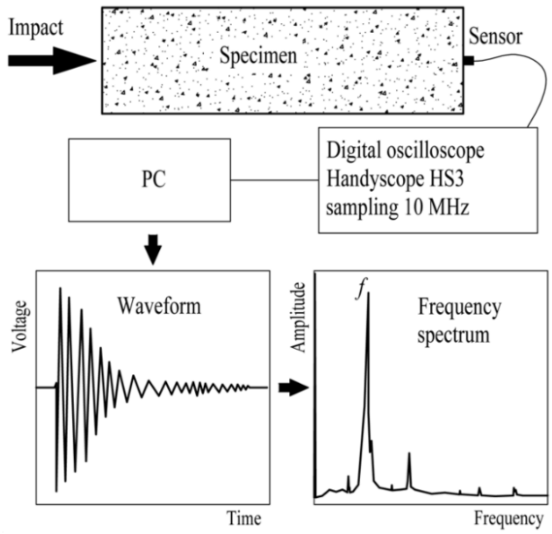

Figure 2. Impact-Echo test setup [3].

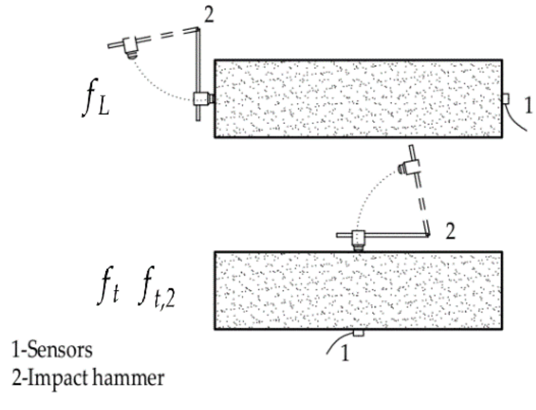

Figure 3. Test position of test specimens in longitudinal way f_L of measurement and transverse way f_t and $f_{t,2}$ [3].

3. Results and Discussion

Results of bulk density loss in relative scale for set E burned to 1000 °C are given in figure 4. The largest drop in the bulk density of 4.5 % occurred between the reference set A and set B burned at 400 °C can be seen. This temperature was higher than a critical water temperature of 374 °C, after which water can no longer be present in the form of physically bonded water. The lowest decrease of 1 % occurred between 800 °C and 1000 °C, which was mainly due to calcite decomposition ($CaCO_3 \rightarrow CaO + CO_2$) at about 930 - 960 °C.

The change in the bulk density is also associated with the change in mechanical properties of the material. As shown in figure 5, the dynamic modulus of elasticity reaches 38 GPa for the unheated set A, while the set B reaches 23 GPa. Like the bulk density, there was the largest drop between set A and B. The minimal modulus of elasticity was reached by set E, which showed the value of the dynamic modulus of elasticity of 0.5 GPa. The surface of these burnt test specimens was covered by cracks with widths ranged from 0.1 to 2 mm. The cover layer degraded to the greatest extent and where parts of the aggregate and the cement matrix lost its cohesion and fell apart.

The measurement of the test specimens by the resonance method of Impact-Echo also showed a change in the first dominant frequency of longitudinal and transverse waves (see figure 6). The resonance frequency of the longitudinal waves for the unloaded set A was 4.55 kHz and for the set E degraded to 1000 °C the resonant frequency was 0.75 kHz. Due to the chosen aging, hydration and recipe, the test specimens were tested by Impact-Echo in a worse condition than would be in the case of optimal aging according to CSN EN 12390 Part 2: Testing hardened concrete - Part 2: Making and curing specimens for strength tests. This reference state is therefore slightly degraded from the start compared to properly aged concrete [13]. It is important to note that the method of aging was chosen respectively to further testing of the application of stainless steel helical reinforcement in temperature-degraded concrete and was therefore not intended to produce perfectly "healthy" test specimens.

The highest drop of 28 % in the resonance frequency for longitudinal waves occurred between 800 and 1000 °C. Although the ultrasonic pulse velocity method showed the highest loss in dynamic modulus of elasticity between 20 °C and 400 °C, Impact-Echo measurement indicates the highest loss of physical-mechanical properties between 800 and 1000 °C. A second sharp drop in the resonance frequency of longitudinal waves by 21 % occurred between the reference set and the temperature of 400 °C. A similar behaviour is shown by the measurement of transverse waves.

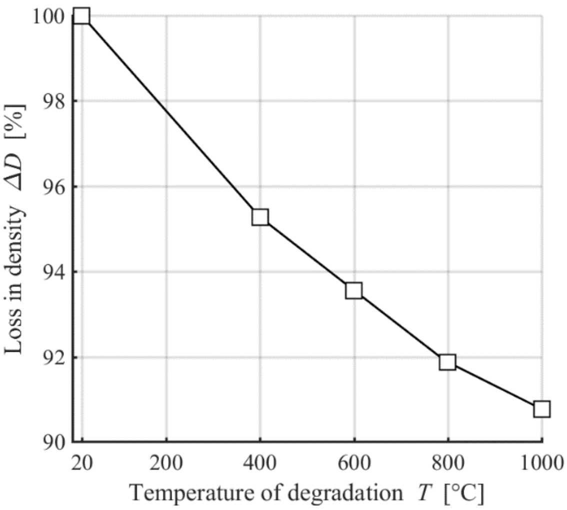

Figure 4. Relative bulk density change. The average bulk density before burning was 2350 kgm^{-3}.

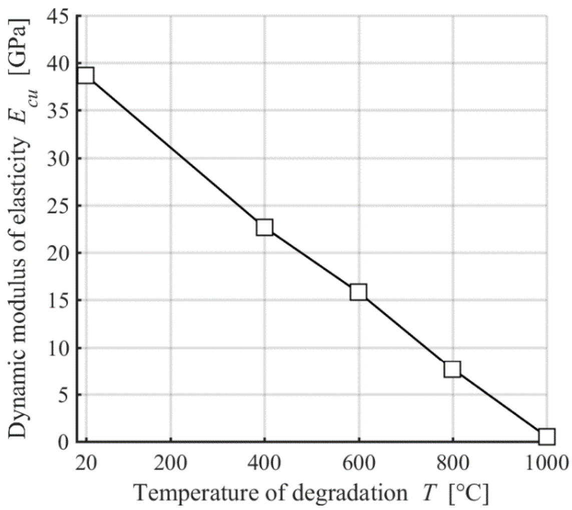

Figure 5. Change of the dynamic modulus of elasticity E_{cu} for each temperature set.

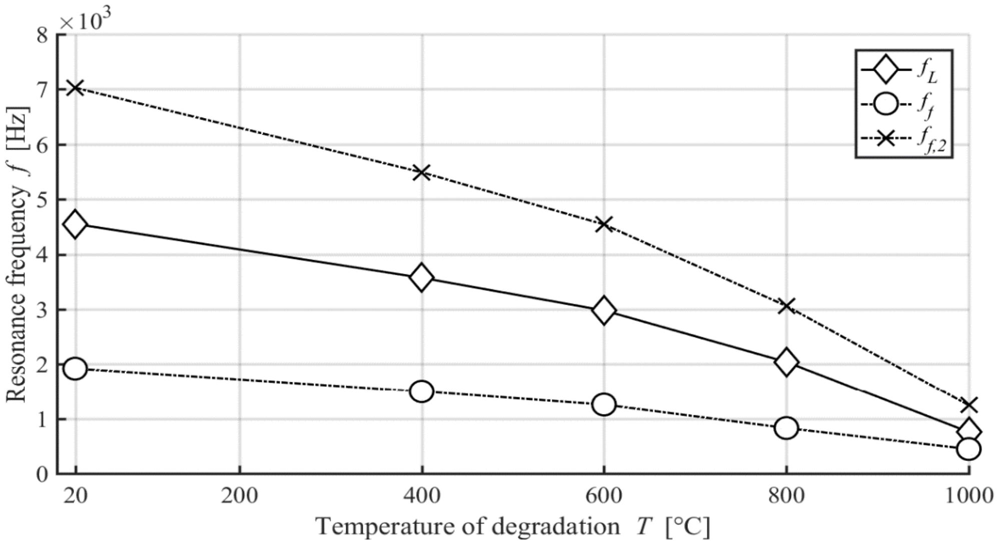

Figure 6. The first own frequencies of the longitudinal waves f_L and the first own frequencies f_f and the second own frequency $f_{f,2}$ of the transverse waves for each temperature set.

4. Conclusion

The sets of test specimens (a total of 42 specimens in six sets) were subjected to ultrasonic pulse and Impact-Echo methods measurement after exposure to various high temperatures. For these sets, the bulk density was also determined before and after burning. For all measured values it can be stated that they show changes that may indicate the subsequent behavior of the base material which will be surrounding the intended joint. The tested specimens will be strengthened on the tensile side with a stainless steel helical reinforcement placed into the groove according to the manual [2] and then tested by a four-point bending test similar to description in the standard for testing of the cohesion of steel reinforcing autoclaved aerated concrete [14]. The results from this measurement will be assigned to the quality of the connection failure in the differently degraded specimen sets.

Acknowledgement

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