Experimentální Analýza Napětí 2010
Experimental Stress Analysis

Measuring of Concrete Properties during Hardening

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Abstract: Concrete is basic building material. Their properties depend mainly on hardening process. Acoustic emission, impedance spectroscopy and nonlinear ultrasonic spectroscopy are interesting experimental methods for studying the processes.

Keywords: Concrete, Analysis, Crack, Acoustic Emission, Impedance, Specimen, Hardening

1. Introduction

Concrete is one of the most important building materials. Its properties are predetermined already in the course of the setting and hardening phases. Tracking this phase provides information which can serve as a basis for the resulting quality prediction. Application of selected non-destructive testing methods makes it possible to describe the structure behaviour. The present paper deals with an application of the acoustic emission method, temperature and impedance measurements and non-linear ultrasonic spectroscopy. The mentioned methods have the potential to describe the behaviour of concrete during the setting and hardening phases for a relatively long time. The measurements, which have been carried out, are of a long-term nature, the respective time intervals ranging from 7 days to several months. [1]

2. Theory of measurement

One of the important quantities providing insight into the processes taking place in the specimen structure, particularly during the early phase, is the specimen internal

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Experimentální analýza napětí 2010, Petr Šmíd, Pavel Horváth, Miroslav Hrabovský, eds.,
May 31 - June 3 2010, Velké Losiny, Czech Republic (Palacky University, Olomouc; Olomouc; 2010).

temperature. In consequence of chemical reactions, the highest temperature changes are expected to take place during the setting phase, i.e., the first hours of the measurement. As it is not intended to study processes taking place in purely laboratory (theoretically ideal) conditions the specimen is stored and measured in a room where the temperature fluctuates (i.e. the ambient temperature in the neighbourhood of 20°C). [2]

To track the tension changes and/or the crack generation, the acoustic emission method is used. This method allows us to follow up active (dynamic) processes inside the structure. In consequence of local tension cumulation inside the material, there arise focuses of tension and, consequently, potential sources of acoustic emission. If the tension reaches or even exceeds the critical value at a certain point the accumulated energy will be released resulting in an acoustic event. This event is supposed to be accompanied by the formation of a micro-crack. The tension propagates through the material. The point at which the tension has arisen is called the acoustic emission source. For simplicity, let us assume the propagation medium to be homogeneous and isotropic. In this case, a spherical wave propagates from the source, its energy decreasing with the distance from the source. Once the wave reaches the specimen surface it can be recorded by means of an acoustic emission sensor. It means that the position of the crack can be determined in the case of homogeneous isotropic materials and appropriate sensor positioning. [3,7,8,9,11]

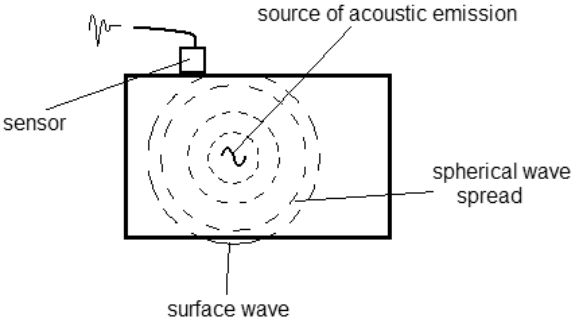

Fig. 1. Formation and pick-up of acoustic emission events.

The impedance of the material under investigation changes in consequence of structural changes, particularly water absorption and evaporation. The change in resistance is obvious. For the capacity of a parallel-plate capacitor it holds:

$$C = \varepsilon_r \cdot \frac{S}{d} \tag{1}$$

where ε_r is the relative permittivity, S is the measuring electrode area, d, their distance and f is the frequency. Micro-structure changes in the material make the material permittivity change. The permittivity value can also be affected by micro-cracks. And, thanks to the existence of micro-cracks, the permittivity will depend on the frequency. [6]

The non-linear ultrasonic spectroscopy method studies the behaviour of the material which is subjected to a mechanical harmonic excitation. In principle, excitation by a single, two or more harmonic signals is used. If a single exciting frequency f is used higher harmonic frequency components are analyzed. If their amplitudes decrease monotonously, no defect is detected in the specimen. In the case where two harmonic signals of frequencies f_1 a f_2 are used to excite the specimen either difference f_1-f_2 or sum f_1+f_2 frequency (and their close neighbourhood) components are analyzed. [4,5]

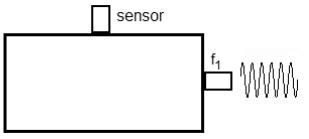

Fig. 2. Single signal excitation.

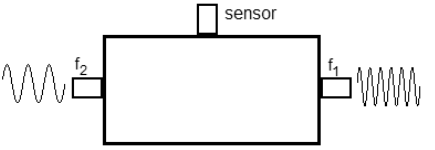

Fig. 3. Two-signal excitation.

3. Experiment setup

The specimens are in the form of concrete blocks of dimensions 100 mm x 100 mm x 400 mm. They are fabricated in special moulds whose oblong wall is uncovered. After the fabrication and final vibration (if necessary) are completed, temperature sensors and resistance and capacitance measuring electrodes are inserted into the mould.

Negative resistance coefficient resistors, i.e. NTC thermistors, whose resistance decreases with increasing temperature, are used to measure the temperature. The sensors are placed inside the specimen. The temperature is calculated from the measured resistance using the following formula:

$$\nu = 12.8 \cdot \log^2(R) - 129 \cdot \log(R) + 280 \qquad (2)$$

where ν is the temperature [^{o}C] and R is the resistance [Ω].

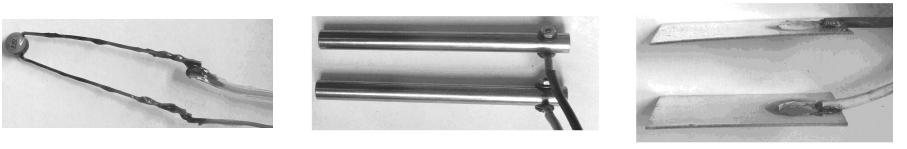

Fig. 4. Photos of measuring fixtures (from left to right): temperature sensor, resistance measuring bars and capacitance measuring plates.

Two cylindrical steel electrodes of a diameter of 6 mm, buried 65 mm under the specimen surface, serve to measure the resistance. To measure the capacitance, two rectangular metal-plate electrodes of dimensions 25 mm x 45 mm are used. All electrodes are fixed in a plastic slab so that their constant configuration is guaranteed. The electrodes and the temperature sensor outputs are connected to an

automated measuring device. The measurements of the capacitance, temperature and impedance are started within 15 minutes from the mixture preparation time.

This phase of the experiment is carried out using an RLCG bridge and a selector switch. The measurement is carried out at selected points of the frequency characteristic in the range from 100 Hz to 20 kHz.

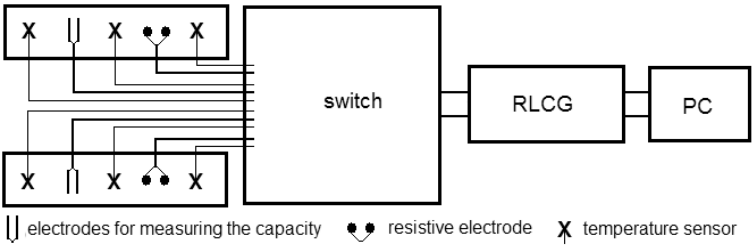

Fig. 5. Block diagram of the temperature, resistance and capacitance measuring apparatus.

Each of the quantities (resistance, capacitance, temperature) is measured separately. Acoustic emission sensors are placed on the specimen surface after the specimen setting is completed, i.e., after six hours approximately. Two sensors are placed on each of the specimens, so that a total of four sensors are used. As a rule, the specimens are taken out from the moulds after 24 hours and, subsequently, the measurements continue.

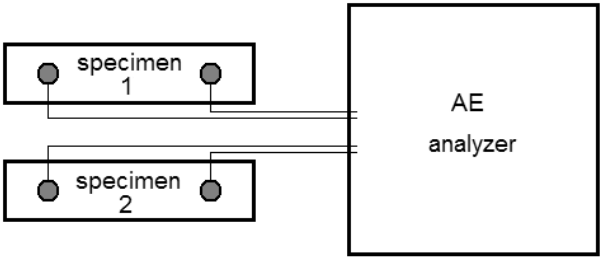

Fig. 6. Block diagram of the acoustic emission measuring apparatus.

4. Results

Two concrete blocks of dimensions 100 mm x 100 mm x 400 mm have been prepared for the measurements. The composition of the mix is shown in Table 1. One of the blocks was wrapped up to prevent it from spontaneous drying, whereas the other was left naked to ripen in open air.

Fig. 7. The specimens.

Table 1. Composition per 1 m^3 of the mix

Mixture	Weight [kg]
Ordinary Portland Cement	420
Condensed Silica Fume (CSF)	35
Water	150
Plasticizer, water reducing admixture	7.5
Sand 0/4 mm	625
Crushed aggregates 4/8 mm	245
crushed aggregates 8/16 mm	975

Table 2. Mechanical characteristics of the mix shown in Table 1

water to cement ratio	0.33
workability	F3
one-day cube (compressive) strength	33.8 MPa
two-days cube (compressive) strength	52.1 MPa
28-days cube (compressive) strength	94.4 MPa

The diagram (Fig. 8) shows a cumulative overshoot count (N_C) versus time (t) plot (solid lines). It is evident from the shape of the curves that the naked specimen features a substantially higher acoustic emission activity, from which a higher number of micro-cracks in the specimen can be inferred. At the same time, differences between the temperatures of the specimen and its environment (Δv) for both the wrapped and naked specimen are shown. It is seen that the temperature peak measured in the naked specimen at the measurement beginning is lower than

that of the wrapped specimen. This temperature change is probably due to a higher rate of the specimen surface cooling in consequence of water evaporation.

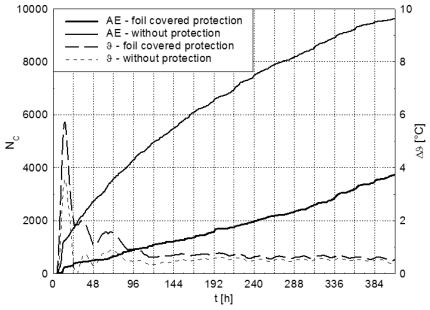

Fig. 8. Comparison of the wrapped and naked specimen.

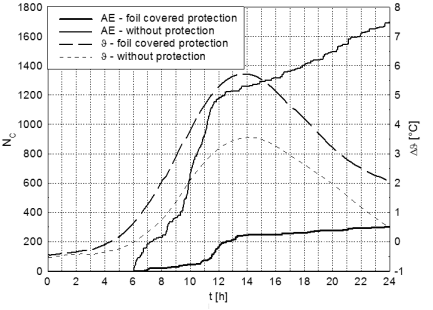

Fig. 9. Comparison of the wrapped and naked specimen behaviour (during the first 24 hours following the mix preparation).

The diagram of Fig. 9 shows a detail of the first 24 hours of the measurement. The temperature measurement starting point is shifted by about 6 hours against that of the acoustic emission. The temperature is negative at the measurement start time. This is due to the fact that the temperature of the mix components was below that of the ambient air at the time of mixing. It is evident from the detailed view of the diagram that the naked specimen shows a more abrupt onset of the acoustic emission event counts during the first 6 hours (from the acoustic emission measurement starting point) and, consequently, larger phase changes.

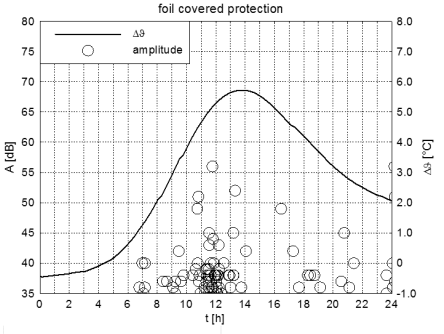

Fig. 10. Amplitude during the first 24 hours after the mix preparation – wrapped specimen.

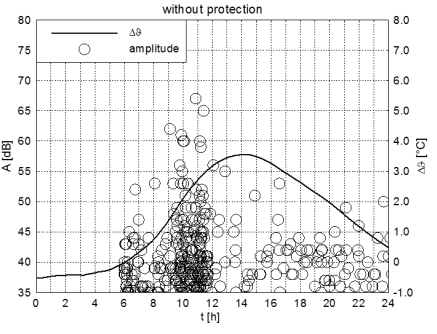

Fig. 11. Amplitude during the first 24 hours after the mix preparation – naked specimen.

The diagrams of Figs. 10 and 11 show a detailed view of the amplitudes at the measurement start. The magnitude of the amplitude is indicative of the micro-crack size or the formation of new phases in the material. The naked specimen shows a good many high-amplitude events, which is indicative of a higher number of larger micro-cracks or a more abrupt material phase change than in the wrapped specimen.

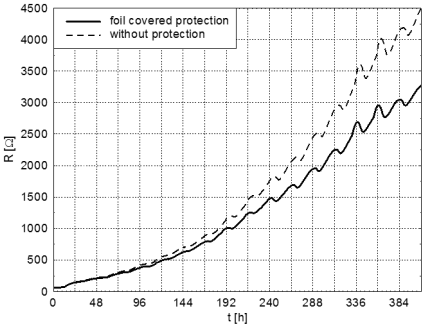

Fig. 12. Specimen resistance variation in the course of the specimen setting and hardening.

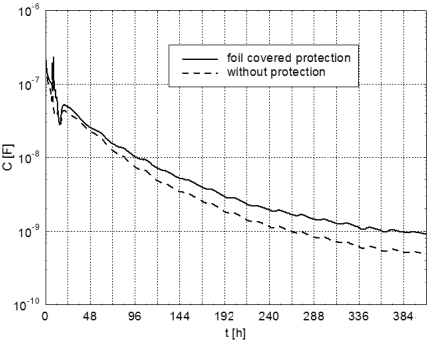

Fig. 13. Specimen capacitance variation in the course of the specimen setting and hardening.

The curves in the diagram of Fig. 13 illustrate the change in capacitance. It is seen that the capacitance of the naked specimen decreases faster. "Free" water appears to take a substantial effect in both diagrams (Figs. 12 and 13). Higher water content of the wrapped specimen results in higher electrical conductivity and, at the same time, lower capacitance. This is due to the amount of "free" water in the specimen.

5. Conclusion

Application of the above described methods proves to be useful for the description of the processes of concrete setting, hardening and ripening. The temperature diagrams show both the "classical" shape and various anomalies depending on the particular mixes. As this is a „lossy“ sensor measurement it can be inferred that the temperature thermometer complies fully with the requirements. It is sufficiently small-sized and can be inserted into the structure without affecting it substantially.

The impedance characteristic measurement is limited to frequencies below 20 kHz. The measurement range can be extended by modifying the measurement method. In this way, another important region could be investigated. Thanks to the simplicity of the „lossy“ electrode measurement method, interesting results can be obtained in this case.

More information could be obtained using other methods to track the concrete setting, hardening and ripening. This applies, in particular, to the use of the non-linear ultrasonic spectroscopy.

Methods of non traditional signal analysis (as STFT) will apply too. [10]

Acknowledgement

This research has been supported by project of GACR No. P104/10/0535 and as part of the research project MSM 0021630519 and CIDEAS.

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