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Using modal-parameter-based analysis of the behaviour of alkali-activated material with surface degraded by ultraviolet radiation

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Abstract. Monitoring the behaviour of constructions, building structures, and materials caused by degradation processes is the main purpose of non-destructive testing methods. Most building materials are exposed to the action of environment. As some parts of building structures come into contact with external effects such as sunshine, they may be altered by ultraviolet radiation.
For building materials, monitoring their structure degradation is a much more difficult task than for metal structures mostly due the non-homogeneity. Since, for homogeneous structures, impulse (acoustic) methods can be used to advantage particularly because the monitoring they enable is non-destructive, they were used in this case, too. To monitor the degradation caused by ultraviolet radiation, the impact echo method was employed [1-4].

Introduction

To accelerate the development of new materials and get a better understanding of their behaviour in their application environment, it is necessary to carry out various experiments. One of the parameters influencing the internal material structure is, for example, ultraviolet radiation. In addition to the traditional, using the modal parameters may be another method suitable for monitoring changes in materials during impulse excitation.

Modal analysis can be defined as the process of characterizing the dynamic response of a system in terms of its modes of vibration. Because any (periodic) function can be represented as a series of sinusoidal functions, vibration of a real structure can be represented as a series of modal contributions. [5] Each mode is defined by its natural frequency, damping, and mode shape. The basic idea is to compute the Frequency Response Function (FRF), which requires a response of the structure to the applied force. Note that the force applied and the response are measured simultaneously. [6] Using the Fourier transform, the signals obtained are then transferred to the frequency region. [7] Thus, if measuring acceleration, the outcome is

Accelerance, which is proportional to the quotient of acceleration to force. The impulse force may be induced by a hammer with a piezo element. [8]

Ultraviolet radiation (UV) may be defined as electromagnetic radiation with a wavelength of 100 to 400 nm, which is shorter than the visible light but longer than X-rays. For humans, it is invisible. It can be divided into three radiation types UVA radiation with a wavelength of 315 to 400 nm, which forms about 90% of sunshine and is not captured by the atmosphere, glass or clothes. UVB radiation has a wavelength of 280 to 315 nm, forms about 10% of sunshine, is largely blocked by the atmosphere, captured by glass, clothes, and sunglasses. UVC radiation is the hardest UV radiation having a wavelength of less than 280 nm.

Experimental set-up

The size of the specimens monitored is 323 mm × 83 mm × 19 mm as shown in Fig. 1. Their density is 2100 kg/m^3. Composition of the mixture is in Tab. 1. For the measurement purposes, a regular 2-by-5 grid was created of points on both sides of each specimen. Two sensors (S1 a S2) were placed on a specimen at extreme points opposite to each other each on the opposite side of the specimen (Fig. 1 right side).

Table 1: Mixture

Materials	Ratio [%]
Slag	22.2
Crushed sand 0-2 mm	66.3
Water	7.9
50% NaOH solution	3.4
plasticizer (lignosulfonate-based)	0.2

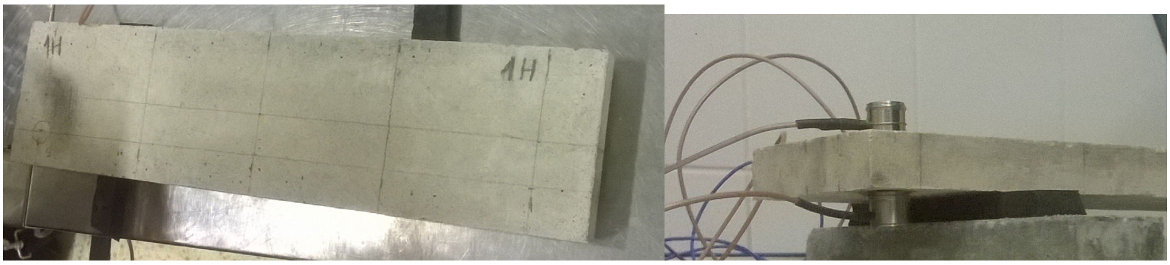

Fig. 1: Sample

The actual measurement was carried out with a sensor placed at the bottom corner on a rectangular grid (see Fig. 1) with individual mechanical impulses (strikes) transferred to other nodes of the grid. The evaluation is based on frequency analysis using modal parameters, that is, eigen-frequencies, attenuations, and transfer functions. The modal frequencies were calculated by [9] in Matlab. To estimate the natural frequencies and damping ratios, the least-squares complex exponential (LSCE) algorithm was used [10,11]. From the theoretical computation, we get the basic frequencies at approximate values of 755 Hz, 1.73 kHz, 2.04 kHz, 2.52 kHz, 3.55 kHz, etc. For the evaluation, however, we were interested in the frequency range above 20 kHz where increased sensitivity is expected to changes in the internal material structures [14].

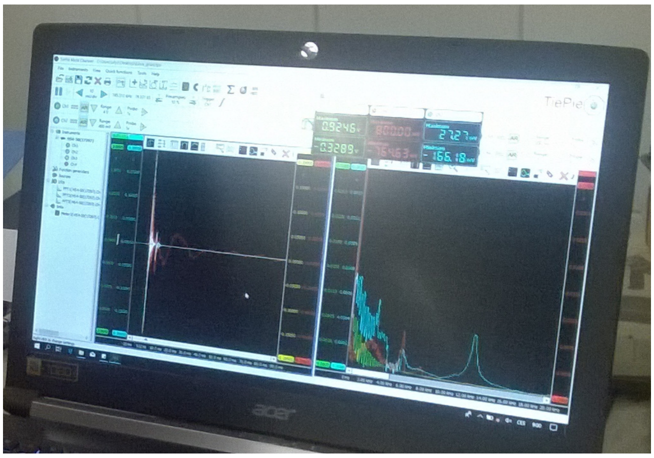

Figure 2: Measurement process

Since, because of waste material processing, alkali-activated materials are considered more environment-friendly than those based on the Portland cement, the specimens were made of such material. If this material is exposed to a degradation process, UV radiation in this particular case, its properties will change. Alkali-activated materials are based on suitable aluminosilicate precursors with sufficiently high content of amorphous phase, such as granulated blast furnace slag, fly ash and metakaolin. Compared to those based on the Portland cement, alkali activated materials are usually more durable in being equally or better resistant to aggressive media such as acid solutions, sulphates, chlorides, and others [12,13].

Each specimen was measured in a reference state (submerges in water at a laboratory temperature of 21° C) and in a state with one of its sides having been UV irradiated for 28 days and sprinkled with water. The irradiation intensity was chosen to correspond to three-month exposition to sunshine. Both specimen types were tested at the same age.

Results

The measurement was carried out as follows. A sensor (S1) was placed on the side that was free of the mould, the one with rough surface denoted by (h). Another sensor (S2) was placed on the side that was in the mould (d). A modal hammer was used to strike at the nine points chosen both on the upper side (h) and at the nine opposite points on the lower side (d).

The diagrams in Figures 3 to 6 show the dependency of the calculated modal attenuation (dr) on the modal frequencies (fn). The first four modal frequencies calculated were chosen for the evaluation in the frequency region above 20 kHz.

As this is one of the basic construction elements, concrete, its structure is non-homogeneous from the viewpoint of mechanical wave motion. Thus, the application of modal frequencies, which are expected to behave linearly, is not so simple and unequivocal as it is with homogeneous materials. From Figures 3 and 4, it can be concluded that, if the upper side is struck, the way the waves propagate with respect to a sensor placed on the same side (Figure 3 diagram hS1 and Figure 4 diagram h28S1) is different from the way the waves propagate with respect to the one placed on opposite side (Figure 3 diagram hS1 and Figure 4 diagram h28S1).

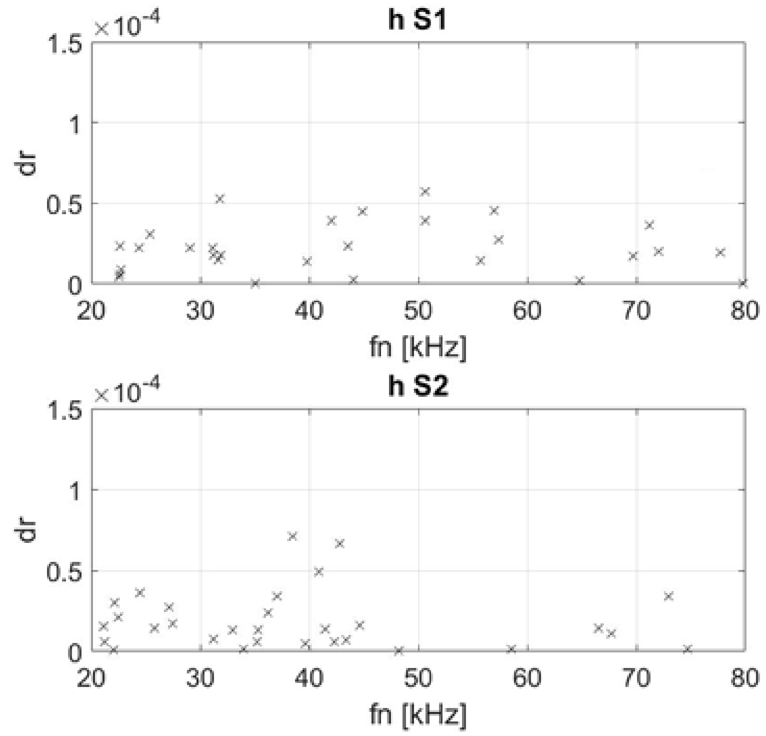

Figure 3 The dependency of the modal attenuation (dr) on the modal frequency (fn) after strikes on upper side of the original specimen

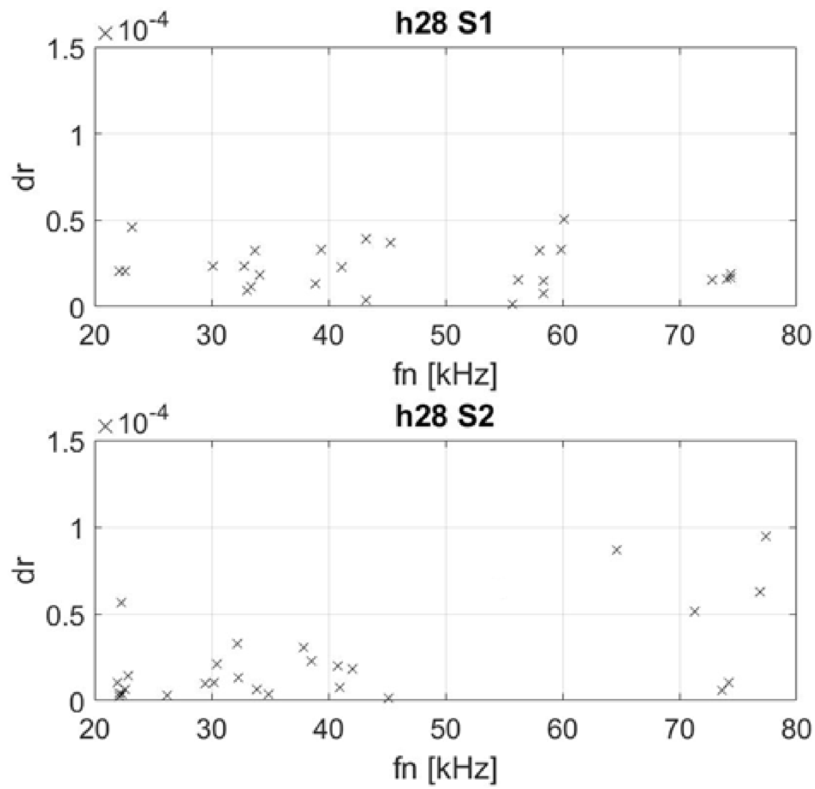

Figure 4 The dependency of the modal attenuation (dr) on the modal frequency (fn) after strikes on upper side of the specimen degraded by UV irradiation

The influence of the modal parameters, i.e., frequency and attenuation through irradiation is stronger for the higher frequencies. This is apparently due to the impact of the ageing of the specimen surface by the simulated sunshine. With a sensor placed on the side that was struck, the frequencies are cumulated in small regions (Figures 3 and 4 diagrams S1). Also in the non-degraded specimen, there is attenuation of high frequencies above 60 kHz up to a size of $5 \cdot 10^{-5}$. A similar character can be observed in a non-degraded specimen with the strikes carried out on the side on which a sensor is placed (Figure 4 diagram S1). It may be concluded that the influence of degradation is stronger for the waves moving through a non-degraded surface. Thus, the attenuation of high frequencies is stronger (Figure 4 diagram S2) achieving values above $5 \cdot 10^{-5}$. The influence of the attenuation in the frequency region about 40 kHz is opposite. Due to the specimen degradation, the frequency region about 50 kHz is freed.

Conclusions

The use of "high-frequency" modal analysis makes it possible to determine the impact of ultraviolet radiation on the degradation of alkali-activated material. A disadvantage of the impact-echo method is the necessity to know the initial, that is, the starting status of the material to be monitored. Its indisputable advantage is the application of non-destructive monitoring of the changes of the material structure, with an identical testing sample being monitored in the course of the degradation process making it possible to see the development of degradation by ultraviolet radiation. The main application area of this analysis is research and development because, for industrial applications, the measurement and evaluation are excessively demanding. This type of analysis may perhaps be used to judge the degree of degradation by sunshine of alkali activated concretes. It should be noted that, in this particular case, the term "modal" is not entirely compatible with its usual use.

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