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Verification of High-Temperature Stress of Cement-Based Composite by Impact-Echo Method

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Abstract: The paper deals with the applicability of Impact-echo acoustic method to testing of cement-based composites prepared from a mix of cement mortar and quartz sand, which were intentionally degraded by high-temperature treatment (in the temperatures range from 200 °C to 1200 °C). The results of non-destructive testing of such samples by acoustic methods confirmed the differences in the structure of mortar specimens. A significant decrease of the absorbed frequencies was observed depending on the temperature. The largest decrease happened after exposure of samples at 400-600 °C.

Keywords: High–Temperature; Impact-Echo Method; Cement-Based Composite Material; Mortar.

1 Introduction

Impact-echo is a method for nondestructive evaluation of concrete structures. The principle of the method is based on analyzing an elastic impulse-induced mechanical wave [1, 2]. It is a technique for flaw detection in concrete. The method overcomes many of the barriers associated with flaw detection in concrete based on ultrasonic methods. A short-duration mechanical impact produced by tapping a small steel spherical body gives rise to a low-frequency stress waves that propagate into the structure and are reflected by flaws and external surfaces. A transducer records surface displacements caused by reflections of these waves. Classical impact-echo has receiver attached close to impact. Described method has transmitter in different positions. This signal describes transient local vibrations, which are caused by the mechanical wave multiple reflections inside the structure. The dominant frequencies of these vibrations give an account of the condition of the structure of the structure or to determine the location of flaws, at which the waves are rebounded. As a rule, the signal is digitized by means of a data processing system to be transferred into a computer memory [1–5].

2 Experimental

Mortars (of dimensions 40 mm × 40 mm × 160 mm) were produced using a type CEM I 42.5 R Portland cement (Českomoravský Cement-Heidelberg Cement Group) and water to cement ratio (w/c = 0.46) and quartz sand from Filtrační písky, s.r.o. for preparation mixture test mortar, in a ratio of 1 to 3. In compliance with ČSN 721200 standard. The specimens were left in the moulds for 24 hours, then cured in water for 27 days and finally air-cured for 31 days at laboratory temperature (25 ±2 °C) a relative humidity of 53 ± 5 %. After initial curing, the specimens were dried at a temperature of 60 °C for two days. Subsequently, the specimens were subjected to gradual heating in a furnace at 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C. The temperature increase rate was 5 °C/min. A dwell of 60 minutes at each temperature was provided, in other to find out the effect to temperature on the specimens. After heat treatment, the specimens were left to cool down spontaneously at laboratory conditions. The thus prepared samples were measured using the Impact-echo method.

In order to generate the acoustic signal, a hammer of 12 g mass, originally suspended from a hanger, was released to fall down on the specimen from a height of 4 cm. The impulse is reflected by the surface but also by micro-cracks and defects of the specimen under investigation. The response was picked up by an MIDI type piezoelectric sensor. Its output voltage was fed into a TiePie engineering Handyscope HS3, which is a two-channel, digital, 16 bits oscilloscope. The piezoelectric sensor was placed at the end of the beam at the center of transverse side and the hammer hit was carried out on the opposite side in the direction of the longitudinal axis. The sensor was attached to the surface of the sample by beeswax. Subsequently, the fast Fourier transform technique was used to transform the recorded waveform into the frequency domain for each of the output signals. Each measurement run consisted of 5 separate measurements, from which an average was calculated [6, 7].

3 Results and Discussion

Fig. 1 presents the change of predominant frequencies versus the temperatures at which the specimens were subjected. For this measurement, the sensor was placed at the specimen's end at its centerline direction, while the specimen was hit at the opposite end at the centerline direction arrangement U0-S0. Predominant frequencies are shifting towards to the lower frequency range in the course of the degradation. The change is more rapid at the temperature range of 400 °C – 600 °C, where are intense impurities changed.

Fig. 2 shows also the change of predominant frequencies for the specimens during exposure to elevated temperatures, however in this case the arrangement is the U1-S1, where transverse waves are predominant. The difference between U0-S0 and U1-S1 arrangements is that in the latter the measurement took place with the sensor being placed at the mid-point and perpendicular to the specimen. The specimen was hit at the mid-point opposite to the sensor. Higher temperatures result, as in U0-S0 arrangement, in peaks at lower frequencies. The comparison of Fig. 1 and 2 shows that the peaks are obtained at lower frequencies when U1-S1 arrangement is applied.

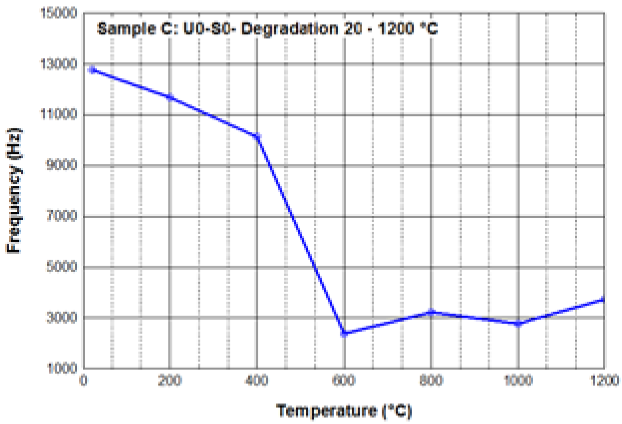

Fig. 1: Shift of dominant frequency induced by degradation at elevated temperatures (arrangement U0-S0).

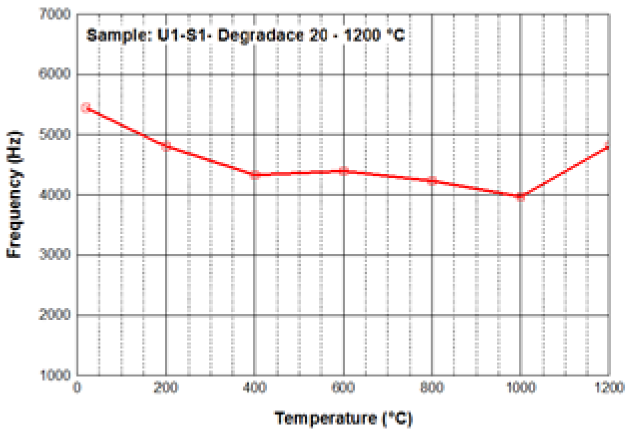

Fig. 2: Shift of dominant frequency induced by degradation at elevated temperatures (arrangement U1-S1).

Fig. 3 presents the pattern of spectral density versus frequency for the specimens during subjection to high temperature (for temperature stress at 200 °C, 400 °C, 1000 °C, 1200 °C). For this measurement, the sensor was placed at the specimen's end at its centerline direction, while the specimen was hit at the opposite end at the centerline direction – arrangement U0-S0. Longitudinal waves, which propagate within the sample at a speed of about 5100 mm.s^{-1}, can affect the mortar element oscillations. In Fig. 4, the pattern of spectral density versus frequency for the specimens during subjection to high temperatures is shown (for temperature stress at 200 °C, 400 °C, 1000 °C, 1200 °C). In this case, the measurement took place with the sensor being placed at the mid-point and perpendicular to the specimen. The specimen was hit at the mid- point opposite to the sensor – arrangement U1-S1. The comparison of Fig. 3 and 4 shows that the peaks are obtained at lower frequencies when U1-S1 arrangement is applied. Fig. 3 and 4 shows visible frequency reduction at spectral density peaks. However, this shift is nearly unnoticeable for the samples exposed to 400 °C and 600 °C (on Fig. 1 and 3). For the specimen exposed to 400 °C the frequency was 4333 Hz, while for the one exposed to 600 °C the nearly identical value of 4398 Hz was recorded (U1-S1 arrangement). In all cases, the spectra density reaches a peak value at different frequencies, depending on the heating temperature. Higher temperatures result in peaks at lower frequencies.

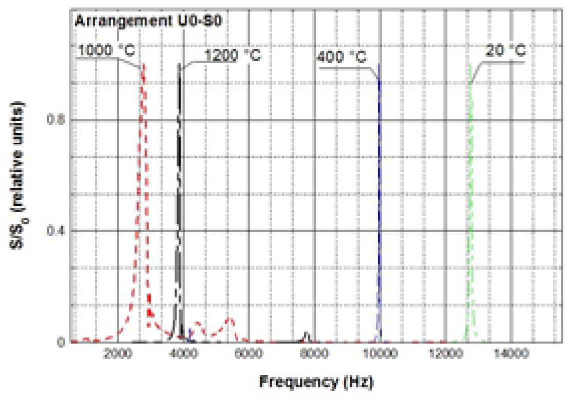

Fig. 3: Frequency spectrum for specimen REF and specimen which were heated at 400 °C, 1000 °C and 1200 °C (Arrangement U0-S0).

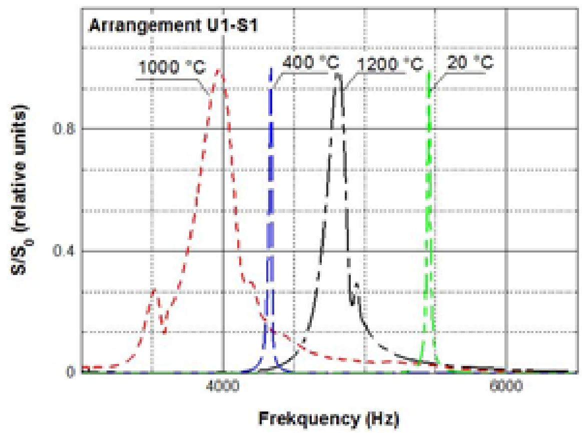

Fig. 4: Frequency spectrum for specimen REF and specimen which were heated at 400 °C, 1000 °C and 1200 °C (Arrangement U1-S1).

4 Conclusion

The paper deals with analyzing the feasibility of composite material testing by means of Impact-echo acoustic method. The specimens were made of cement composites, which in turn were prepared from a mixture of cement mortar and quartz sand.

The specimens were intentionally degraded by application of elevated temperatures of 200 °C to 1200 °C. A shift of the predominant frequencies and a change in the damping coefficient were observed to occur during the degradation process. The obtained results shows that the frequency inspection carried out by means of the Impact-echo method makes a convenient tool to assess the quality and life of these composite materials when exposed to elevated temperature. The acoustic results confirmed the differences in the structure of mortar specimens. He specimens were made of cement composites, which in turn were prepared from a mixture of cement mortar and quartz sand.

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