High-temperature degradation confirmed by Impact-echo Method tested on Cementations Composite Materials Containing Rubber Aggregates and Acrylic or Ethylene Vinyl Acetate Polymer Binder

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Abstract
The present paper deals with the applicability of Impact-echo acoustic method to testing of cement-based mortar composites degraded at high-temperatures. The specimens were prepared by using a type CEM I Portland cement and siliceous sand, as well as by substituting 25% of sand with shredded automobile tires and by adding of EVA polymer binder (10% w/w to cement mass). The samples were subjected to high-temperature treatment in the temperature range of 200°C - 400°C. The results of non-destructive testing of such samples by acoustic methods confirmed the differences in the structure of mortar specimens. Addition of rubber aggregates in samples caused absorption of lower frequency as compared to reference specimens. A significant decrease of the absorbed frequencies was observed depending on the temperature. The largest decrease happened after exposure of samples at 200-300 °C. It indicates that the effect of heat treatment was reduced when the EVA binder was added.

Keywords: Acoustic Emission (AE), High – temperature degradation, rubber aggregates, Impact-echo, Mortar, Eva polymer, bulk density.

1. Introduction

The impact-echo method is a non-destructive acoustic analysis of a sample and the principle is based on the fact that the mechanical characteristics of a tested specimen influence its spectral properties [1-3]. The source of a signal is an impact of a small object, which is a calibrated hammer in our case. This impact induces mechanical vibration of the specimen and the time development of the oscillations is sensed by accelerometers attached on the pre-determined spot of the tested sample. In theory, the impact resembles a delta-function containing all possible frequencies. During wave propagation, each frequency component is affected by the geometry of the sample, the material properties, defects, non-homogeneities, cracks or any other structural characteristics [4,8]. The frequency spectrum of the gathered signal calculated using Fourier transform is a good measure of the condition of the specimen.

The amount of discarded automobile tires is estimated to about 10 billion tires per year, on a worldwide basis. The scrap tires market utilizes around 80% of the used tires. The rest 20% is disposed in landfills, stockpiles or illegal dumping grounds [5, 6]. These disposal methods are of environmental concern due to the difficult degradation of tire rubber, increased risk of accidental fires and public health hazards, as well as due to aesthetic reasons [7].

Mortars containing tires, as rubber aggregates, and polymer binders can be used in various applications and environments. The present study was focused on investigating the durability of such materials when subjected to acid attack. The polymer used in the present study was polyethylene-co-vinyl acetate (EVA). EVA co-polymer is a water redispersible powder added to mortar and concrete to improve some of their properties. EVA can be added to anhydrous cement and aggregates before mixing with water, or it can be added as an aqueous latex dispersion. It is considered that EVA particles prolong the induction period and reduce the cement reaction rate in the acceleration period.
2. Experimental

2.1 Materials

Mortars were produced using a type CEM I Portland cement (Českomoravský Cement - Heidelberg Cement Group); aggregates to cement ratio of 2, and water to cement ratio (W/C) of 0.50-0.55. Both mineral and rubber aggregates were used; siliceous sand (maximum size of 2 mm) and shredded used automobile tires (size range of 1-2 mm). A system of EVA polymer particles, dissolved in water, was used as a polymer binder in two percentages (5% and 10% of the cement mass). Each mortar composition and its plasticity are presented in Table 1.

<table>
<thead>
<tr>
<th>Code</th>
<th>Cement [g]</th>
<th>Sand [g]</th>
<th>Rubber aggregates [g]</th>
<th>Polymer binder [g]</th>
<th>Water [g]</th>
<th>W/C</th>
<th>Plasticity [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>500</td>
<td>1000</td>
<td>-</td>
<td>-</td>
<td>275</td>
<td>0.55</td>
<td>15.5</td>
</tr>
<tr>
<td>PAG</td>
<td>750</td>
<td>750</td>
<td>250</td>
<td>50</td>
<td>275</td>
<td>0.55</td>
<td>13.0</td>
</tr>
<tr>
<td>PAG-EVA</td>
<td>750</td>
<td>750</td>
<td>250</td>
<td>50</td>
<td>275</td>
<td>0.55</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Mortar specimens (prisms: 40mm×40mm×160mm) were prepared. The specimens were left in the moulds for 24 hours, then cured in water for 27 days and finally air-cured for 32 days at laboratory temperature (25±2 °C).

After initial curing, the specimens were dried at a temperature of 60 °C for two days. Subsequently, the specimens under investigation were heated in a furnace at the temperatures of 200 °C, 300 °C and 400 °C with a temperature increase rate of 5 °C/min. A dwell of 60 minutes at the maximum temperature was provided, in order to find out the effect of high temperature on them. After heat treatment, the specimens were left to cool down spontaneously at laboratory conditions.

2.2 Tests

To generate the signal, a hammer of a mass of 12 g, originally suspended from a hanger, was released to fall down on the specimen from a height of 4 cm. The response was picked up by an MIDI type piezoelectric sensor, whose output voltage was fed into a TiePie engineering Handyscope HS3, which is a two-channel, digital, 16 bits oscilloscope. Subsequently, a special smoothing algorithm was used to determine dominant frequencies for each of the output signals. Each measurement run consisted of 10 separate measurements, from which an average was calculated.

A shift of the predominant frequencies and a change in the damping coefficient were observed to occur during the degradation process.

3. Results and discussion

Fig. 1 presents the spectral density versus frequency plot for the specimen REF during high temperature degradation. For this measurement, the sensor was placed at the mid-point and perpendicular to the specimen, while the specimen was hit at the mid-point opposite to the sensor – arrangement U1-S1. Longitudinal waves, which propagate within the sample at a speed of about 5100 m.s\(^{-1}\), can affect the mortar element oscillations. In Figs. 2 and 3, the spectral density versus frequency plots are presented for the specimens PAG (containing rubber aggregates) and PAG-EVA (containing both rubber aggregates and acrylic polymer binder), respectively. The spectra density peaks are higher for REF specimens, followed by those for PAG and PAG-EVA ones. 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. Furthermore, the spectra peaks at 300 °C and 400 °C are observed at rather similar frequencies. However, for the REF and PAG specimens the peaks at 300 °C and 400 °C are distinct from those at 200 °C. This is not the case for PAG-EVA specimens, where the peak at 200 °C is observed at a frequency close to those of the specimens exposed at higher temperatures.

In Fig. 4, the change of spectral density versus frequency plot for the specimen PAG-EVA during high temperature degradation is shown. The difference between Fig. 3 and Fig. 4 is that in Fig. 4 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 and in Fig. 3 the sensor was placed at the specimen's end in its center line direction, while the specimen was hit at the opposite end in the center line direction – arrangement U0-S0.

The comparison of Figs. 3 and 4 shows that the peaks are obtained at lower frequencies when U1-S1 arrangement is applied. Furthermore, the frequency values at which spectral density peaks are observed, are more distinct at 300 °C and 400 °C in the case of the U1-S1 arrangement.

Fig. 5 presents the change of predominant frequencies versus the elevated temperatures at which the specimens REF, PAG and PAG-EVA were subjected (arrangement U1-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 200 °C - 300 °C, where are intense impurities changed. Fig.6 shows also the change of predominant frequencies, however in this case the arrangement is the U1-S0 one, where transverse waves are predominant. The comparison of Figs. 5
and Fig. 6 indicates that the frequency change is slower when arrangement U0-S1 is applied. Moreover, both Figs. 5 and Fig. 6 show that the predominant frequencies of the specimen REF, which does not contain rubber aggregates, are in higher frequency values than those observed for PAG and PAG-EVA specimens.

4. Conclusion

The paper deals with analysing the feasibility of composite material testing by means of Impact-echo acoustic method.

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. The addition of rubber aggregates in PAG and PAG-EVA specimens resulted in lower frequencies compared to REF specimen. It was also observed the dropping down of the frequencies for the temperatures between 200-300°C, indicating that the effect of heat treatment was mitigated when the acrylic binder was added.

The results showed that the frequency inspection carried out by means of the Impact-echo method consists a convenient tool to assess the quality of the composite materials studied, after their exposure to elevated temperatures.

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References


