**Acoustic Emission Method as a Comparative Tool for Result Obtained Using Impedance Spectroscopy – Applied for Cementing Compound Specimens with Various Porosity Levels**

**Ivo KUSÁK, Miroslav LUŇÁK, Luboš PAZDERA**
Department of Physics, Faculty of Civil Engineering, Brno University of Technology, Veveří 95, 602 00 Brno, Czech Republic; kusak@dp.fce.vutbr.cz, lunak@dp.fce.vutbr.cz, pazdera.l@fce.vutbr.cz, tel. +420 541147657

**Keywords:** Frequency analysis, Acoustic Emission, Impedance Spectroscopy, Loss Factor

**Abstract**

The paper deals with an application of the acoustic emission method to cementing compound specimens featuring different capillary porosity levels. The experiment has been intended to contribute another method of checking the impedance-spectroscopy method results. The different capillary porosity levels of the cementing compound have been confirmed and distinguished successfully.

**Introduction**

In the course of material (micro) structure changes, measurable acoustic waves are emitted frequently. This phenomenon is called acoustic emission. In general, acoustic emission (AE) is defined as elastic waves originating in consequence of local, dynamic and irreversible changes in the material structure. These changes are due to the solid deformation or structural integrity deterioration. Acoustic emission accompanies a number of phenomena, such as earthquakes, avalanches, earthslides, rock bumps, propagation of cracks in dams, buildings as well as materials. [1,8]

If the material strength is exceeded, the accumulated potential energy is released in impulses, mostly in the form of thermal and acoustic radiation. In this way, an energy emitting primary source of acoustic emission is formed. Depending on the specimen physical properties (finite dimensions, inhomogeneities, damping, dispersion etc.), this energy is transformed into impulse-nature elastic waves. A secondary acoustic emission source arises, which emits periodic, non-harmonic and strongly damped oscillations of various frequencies, known as Rayleigh waves, to the specimen surface. [2,3,4]

**Material to be measured**

![Concrete specimens](image-url)
The cementing compound specimens were manufactured using the following mixture. Starting from the per meter cubed amount, the amount per specimen was calculated and mixed. The specimen dimensions are 70 mm x 70 mm x 10 mm (see Fig. 1). Each specimen set consists of five specimens. The mass of each specimen is about 0.1 kg. The sample surface was shown in Fig. 2.

Concrete specimen mixtures (per 1 m$^3$):
- 500 kg of CEM I 42,5 R cement
- 1650 kg of standard sand (grain size about 1 mm)
- water/cement ratio: 0.3; 0.5; 0.6 for various specimen sets

Water/cement ratio $W$ have been computed by

$$ W = \frac{m_w}{m_c} $$

(1)

where $m_w$ is added water mass and $m_c$ = cement mass.
Three type of specimen were made (see Fig. 3 and Fig. 4). These sets differed in the pressing force and the water/cement ratio (in connection with our intention to achieve different capillary porosity levels). The table 1 lists the specifications and fabrication details for the different specimen sets:

Tab. 1. Table lists the specifications and fabrication details for the different specimen sets

<table>
<thead>
<tr>
<th></th>
<th>$F$ [kN]</th>
<th>water/cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st set</td>
<td>100</td>
<td>0.6</td>
</tr>
<tr>
<td>2nd set</td>
<td>200</td>
<td>0.5</td>
</tr>
<tr>
<td>3rd set</td>
<td>400</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Fig. 4. Used machine for the manufacture of concrete samples tested

Experiment

An acoustic emission measuring system LOCation ANalyser (LOCAN) 320 made by PAC (France) was used for the measurements. Wide-band sensors (made by 3S Sedlak company) were used. The sensor output was connected to pre-amplifiers (PAC company) with a 2 kHz high-pass filter. Proprietary PAC program package was used to record the acoustic emission parameters. The acoustic emission signals were token LOCAN 320 acoustic emission localizer. This device has been designed to record and evaluate ultrasonic signals. It can process signals coming from four measuring points at a time. Each event which has been picked up, can be characterized by following acoustic emission parameters: recording date and time, (maximum) amplitude, acoustic emission energy, count, rise time and mean frequency. Loaded force was recorded too. [7]
The specimens were loaded in a pressing machine (see Fig. 5). The acoustic response was picked up by two piezoelectric sensors (see Fig. 6). The force was measured by strain gauge. [10]

Measurement results

The quantity relationship we are looking for is the amplitude versus time plot (in the diagram shown together with the force time development curves). Fig. 7-9 illustrates the different, easy-to-distinguish event phases in the material under test.

The A set (highest porosity level): The loading force is growing up progressively from the time \( t = 0 \) (zero) seconds. The first event is recorded at \( t \sim 15 \) s (this is the deformation phase, the material is compact). At \( t = 35 \) seconds the material starts losing strength gradually, the force sets to fall – at this time, the maximum event count is recorded. The final phase (irreversible destruction of the specimen) takes place at \( t \sim 40 \) seconds. The diagram end region (with an event dwell time) corresponds to the specimen post-destruction fall down after the sensor removal (zero loading force).

The B set (medium porosity level): the various events are distributed evenly over the whole time interval. The first event occurs at \( t \sim 0 \) s. The loading force is growing up progressively (this is the deformation phase – the material is compact). The material strength is fading gradually. The force reaches its maximum at \( t = 25 \) seconds. The highest event count occurs at \( t = 50 \) s,
which is just before the final destruction phase (it occurred at about 52 s). The diagram end region (with an event dwell time) corresponds again to the specimen post-destruction fall down after the sensor removal (zero loading force).

The set C (lowest porosity level): Here, the events show the longest delay to occur. The loading force starts growing up at $t = 0$ seconds again. The first event is recorded at $t \sim 30$ s (this is the deformation phase, the material is compact). The material strength is fading gradually. The force reaches its maximum at $t = 130$ seconds. The highest event count occurs at $t = 150$ s, which is just before the final destruction phase (it occurred at about 160 s). The diagram end region (with an event dwell time) corresponds again to the specimen fall down after the sensor removal (zero loading force).

Fig. 7. Amplitude and loading force versus time plots for cementing compound - porosity level $\text{Pa}$

Fig. 8. Amplitude and loading force versus time plots for cementing compound - porosity level $\text{Pb}$
Although the various force versus time diagrams differ from each other, the next diagram (Fig. 10) can be taken as indicative for the event times, from the first occurrence up to the destruction. It shows the mean amplitudes $U$ for the different sets (this diagram is to be considered a rough estimate only).

Fig. 9. Amplitude and loading force versus time plots for cementing compound - porosity level $P_c$

Fig. 10. Amplitude versus time plots for cementing compounds of porosity levels $P_a$, $P_b$, $P_c$
Conclusion

The acoustic emission method was successfully used to verify the results obtained by the impedance spectroscopy method application. Characterization of the set cement specimens showing different porosity levels was carried out. The resulting change in the frequency characteristics fits the assumption that the respective physical property changes are reflected in the impedance loss factor. The method reproducibility has proved to be very good. [5,6]

There are new techniques for signal analysis by help High Order Spectral Analysis [9].

Acknowledgment

This research was conducted as a part of a GAČR Project No. 104/10/P012 and P104/10/0535 and MSM 0021630519. The authors of this paper express their thanks for this support.

References