MONITORING FOUR POINT BENDING OF CONCRETE BEAM BY ACOUSTIC EMISSION METHOD

Libor TOPOLÁŘ*, Luboš PAZDERA*, Vlastimil BÍLEK**, Lenka DĚDEČKOVÁ***, Jaroslav SMUTNY*

*Brno University of Technology, Faculty of Civil Engineering, **ŽPSV a.s., *** KAP ATELIER s.r.o.
Contact e-mail: pazdera.l@fce.vutbr.cz

Abstrakt
Most buildings date back to the first half of the last century. Concrete proved to be a durable construction material in the recent years. Concrete is a composite construction material composed primarily of aggregate, cement and water. There are many different mixture that have varied properties. Knowledge about basic properties and behaviour especially at loading are important for its lifetime. Mechanical properties and their characteristics in co-ordination of quantity and loading type enable to dimension significant construction parts and to determine their reliability, which determine so-called limiting state. A limiting state is a condition of a structure beyond which it no longer fulfils the relevant design criteria. One of the major strength properties is obtained by four-point bending load. Acoustic emission method, which is a part of Non-Destructive Testing techniques, records propagated elastic waves generated from the place of an active crack, can be applied. The Acoustic Emission Method is more sensitive than visual observation, because it enables to monitor acoustic emission activity during loading continually. In the article monitoring of concrete blocks made from different mixtures is described. Behaviour of four different groups of mixtures is described in the paper. The first group was sleeper concrete, the second was sleeper fibre-concrete, the third was alkali activated fibre-concrete and last was alkali activated concrete with steel reinforcement.

Key words: Acoustic Emission Method, concrete, four point bending, load

1. Introduction
Because concrete is one of the most popular building materials, it is important to know its basic properties and behaviour especially at loading. Concrete strength and its lifetime are significant mechanical properties of building structures. Mechanical properties and their characteristics in co-ordination of quantity and loading type enable to dimension significant construction parts and to determine their reliability, which determine so-called limiting state. A limiting state is a condition of a structure beyond which it no longer fulfils the relevant design criteria. One of the major strength properties is obtained by four-point bending load. Recording the force, at which the first surface crack is detected, is the conventional procedure. For location of crazing and crack propagation in loaded concrete structure, which four-point bending load qualified for, the Acoustic Emission Method can be applied.
Acoustic Emission behaviour of a concrete sample under compression is associated with generation of micro-cracks. These micro-cracks are gradually accumulated prior to final failure. The number of AE events, which correspond to the generation of these cracks, increases due to the accumulation of micro-cracks [1].

This method is more sensitive than visual observation, because it enables to monitor acoustic emission activity during loading continually. In the article is described monitoring of concrete blocks made from different mixtures. The first mixture (1N) (meaning in the Table 1) was from self compacted concrete, the second (2N+D) was from self compacted concrete with steel wires, the third (4A+D) was from alkali activated concrete with steel wires and last (5A+D+V) was from alkali activated concrete with steel wires and with steel reinforcement.

Many internal flaws and cracks exist in concrete prior to loading. The mechanical behaviour of concrete subjected to different loading conditions is governed by the initiation and propagation of these internal cracks and flaws during loading. For a concrete structure subjected to tension, the cracks propagate in a direction perpendicular to the applied tensile load. On the other hand, for a concrete structure subjected to purely uniaxial compression, the cracks propagate primarily in the same direction as the applied compressive load. Since different mechanical responses of concrete structures can be explained by fracture processes at different loading conditions, one needs to understand when the internal cracks initiate and how they propagate with increasing load [2].

### Table 1: Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tr>
<td>SCC</td>
<td>Self Compacting Concrete</td>
</tr>
<tr>
<td>AAC</td>
<td>Alkali Activated Concrete</td>
</tr>
<tr>
<td>1N</td>
<td>Mixture of self compacting concrete</td>
</tr>
<tr>
<td>2N+D</td>
<td>Mixture of self compacting concrete with wires</td>
</tr>
<tr>
<td>4A+D</td>
<td>Mixture of alkali activated concrete with wires</td>
</tr>
<tr>
<td>5A+D+V</td>
<td>Mixture of alkali activated concrete with wires and steel reinforcement</td>
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</table>

2. Methods

Three mixtures were chosen for the concreting; the composition and labels of mixtures can be found in the Table 2.

In the first stage, different types of mixtures were placed in two wooden forms. In the second stage of the concreting, only the mixture AAC was used and completed with steel reinforcement.

The source of the acoustic emission energy is the elastic stress field in the material. Without stress, there is no acoustic emission. Therefore, an acoustic emission inspection is usually carried out during a controlled loading of the structure. This can be a proof load before service a controlled variation of load while the structure is in service a fatigue test, creep test, or a complex loading program. Often, a structure is going to be loaded anyway and acoustic emission inspection is used because it gives valuable additional information about the performance of the structure under load [3,4].
Table 2: Composition of mixture

<table>
<thead>
<tr>
<th>Component</th>
<th>CCC [kg]</th>
<th>AAC [kg]</th>
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</thead>
<tbody>
<tr>
<td>Cement</td>
<td>385</td>
<td>0</td>
</tr>
<tr>
<td>Blast furnace slag</td>
<td>250</td>
<td>450</td>
</tr>
<tr>
<td>50% dilution KOH</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>Water glasses (sodium)</td>
<td>0</td>
<td>65</td>
</tr>
<tr>
<td>Water</td>
<td>210</td>
<td>160</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>4.3</td>
<td>0</td>
</tr>
<tr>
<td>Sand 0/4</td>
<td>775</td>
<td>840</td>
</tr>
<tr>
<td>Rubble 4/8</td>
<td>355</td>
<td>380</td>
</tr>
<tr>
<td>Rubble 8/16</td>
<td>360</td>
<td>390</td>
</tr>
</tbody>
</table>

The pure bending shown in the (Fig. 1) can be produced by applying four forces to the beam, two of opposite direction at each end. This configuration is known as 'four point bending' and produces a uniform bending moment over the centre section of the beam [5,6]. Beam flexure represents one of the three most common loading categories for mechanical systems. The maximum stresses are located at the loads. When a 'beam' experiences a bending moment it will change its shape and internal stresses (forces) will be developed. The photograph (Fig. 2) shows the shape change of a beam in bending. Note that the material is in compression on the inside of the curve and tension on the outside of the curve, and that transverse planes in the material remain parallel to the radius during bending.

Fig. 1. Four point bending – illustrative picture

Fig. 2. Photography of real experiment

The four-stage fracture model was proposed that can likely be applied to many different types of materials, ranging from brittle (cement, glass), to quasi-brittle (mortar, concrete), to ductile (metals, hybrid fibre concrete). The model is schematically shown in Fig. 3 and basically the following four stages in mechanical behaviour can be distinguished [7]:

- (0) elastic stage,
- (A) microcrack stage (stable),
- (B) macrocrack stage (un-stable if no pre-cautions are taken),
- (C) bridging stage.
3. Results

The measurement was done on device Dakel XEDO with seven channels. Channels 5 to 8 had filter of frequency set to from 27 kHz to 400 kHz with amplification of 20 dB. The channels 3, 4 and 9 had a frequency filter set to from 500 kHz to 2 MHz with amplification 35 dB. Sensors IDK 09 (channels 3, 4 and 9) and sensors MTPA-15 (channels 5 to 8) were used for measuring. Approximate location of sensors is shown in Figure 4. To evaluate the origin of micro cracks during stress, we focused on the activity of acoustic emission, respectively on the most used parameter which is the number overshoot preset threshold. The all graphs are created from data generated by the sensors which are located the closest to the visible crack.

Fig. 3. Four-stage fracture model for cement, plain concrete and fibre concrete [7]

Fig. 4. Approximate location of sensors. (dimensions in mm)
The graph in Figure 5 shows the dependence of force $F$ on deflection $y$ for all mixtures. The increase in deflection together with force is evident for all mixtures to the first maximum. After first maximum is the visible crack appeared. The decrease of force occurs with continued of deflection. At some point comes to rebound until the second maximum of force where there is a total destruction of the specimen. The specimen from mixture marked 1N has got only the first maximum because after this maximum occurs a total destruction of the specimen. The maximum does not occur at the mixture marked 5A+D+V because specimen from this mixture did not break during the measurement.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Dependence of force ($F$) on deflection ($y$)}
\end{figure}

The graphs in Fig. 6 and Fig. 7 are created from data generated by the sensor which are located the closest to the visible crack. Dependence of cumulative count of events acoustic emission on the force (Fig. 6) shows that the mixture 5A+D+V has the greatest increase in counts acoustic emission from 175 kN load. The increase of events of counts of acoustic emission of other mixtures are in the area below 50 kN load.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Dependence of cumulative count of events acoustic emission on force}
\end{figure}
A mixture of SCC with wires (Fig. 7) has the first increase in emission activities on the value of 10 kN load, which is not be significant and may be caused by outside interference. A mixture of 5A+D+V is compared to other mixtures first increase of acoustic emission events has on the value of forces between 20 kN and 30 kN load, but a mixture 5A+D+V continue to resist stress. Other mixtures show a significant increase number of events of acoustic emission from the of 40 kN load and thus the deformation of the whole structure. An increasing number of events of acoustic emission together with a decrease in stress show finite deformation structure.
4. Conclusion
By measurements it was found that alkali-activated concrete is more fragile than concrete based on Portland cement. The activity of acoustic emission mixture marked 4A+D is rapidly increasing, while at the mixture marked 2N+D the activity is gradual. The mixture of alkali activated concrete shows lower compressive and flexural strength and a considerably larger contraction. The results obtained from large beams are quite different from the results obtained on small specimens, which is caused by the so-called "size effect". Acoustic emission is a useful tool in determining the time of the crack creation under load. The method of acoustic emission had warned about crack approaching which appeared after a while on the surface of the sample. Combining the standard methods with a non traditional one, in this case Acoustic Emission Method contributes to a more detailed description of material behaviour during its loading.

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References


