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Analysis of Acoustic Emission Signals Generated by Cracks Formed During the Spontaneous Drying and Hardening of Alkali-Activated Slag Cured Different Times

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Abstract: This paper reports the results of measurements during hardening and drying of specimens made of alkali activated slag mortars. The aim of this paper is introduce the effect of curing method and time on the microstructure of alkali activated slag mortars. An understanding of microstructure-performance relationships is the key to true understanding of material behaviour. The results obtained in the laboratory are useful to understand the various stages of micro-cracking activity during the hardening process in quasi-brittle materials such as alkali activated slag mortars and extend them for field applications.

Keywords: Alkali-Activated Slag; Acoustic Emission Method; Hardening; Amplitude; Micro Crack.

1 Introduction

Alkali-activated aluminosilicate (AAA) materials are a new generation of alternative building materials. Compared with conventional composites, the production of AAA composites is associated with low energy consumption and low CO_2 emission, along with the potential to reach high mechanical strength at early ages of curing, high stability in aggressive environments and resistance to high temperatures, among others. The major disadvantage of some AAA composites is an increased shrinkage compared to cement based composites, which may limit a wider application in building industry [1].

The Alkali-activated slag cement is a combination of blast furnace slag and activators, which are chemical type capable of enhancing slag reactivity during process hydration. When compared with standard Portland cement, sodium silicate activated slag cement presents higher strengths but increased shrinkage [2]. The elaboration of activated slag cement compositions that develop mechanical properties extremely fast [3] making them advantageous for reducing operational downtimes, such as during the repair of roads or industrial structures. Alkali-activated slag cement hydrated products are highly resistant to chemical attacks, especially under acidic conditions [4, 5], which makes them suitable as the binder for protecting overly formulations.
The increased shrinkage during hardening period is caused by both autogenous and drying shrinkage, which finally results in volume contraction, micro cracking and deterioration of tensile and bending properties [5]. The understanding of shrinkage development and its relationship to the evolution hydration is essential for the selection of adequate alternatives for reducing shrinkage, such as the use of shrinkage compensating, shrinkage reducing admixtures and appropriate methods of curing. Because shrinkage usually occurs at very early stages, it may be responsible for the early age micro cracking reported for alkali-activated slag cement based elements [6].

Acoustic emission (AE) is the term for the noise emitted by material and structures when they are subjected to stress. Types of stresses can be mechanical, thermal or chemical. This emission is caused by the rapid release of energy within a material due to events such as crack formation and their subsequent extension occurring under an applied stress, generating transient elastic waves which can be detected by piezoelectric sensors. AE method can monitors change in material behaviour over a long time and without moving one of its components i.e. sensors. This makes the technique quite unique along with the ability to detect crack propagation occurring

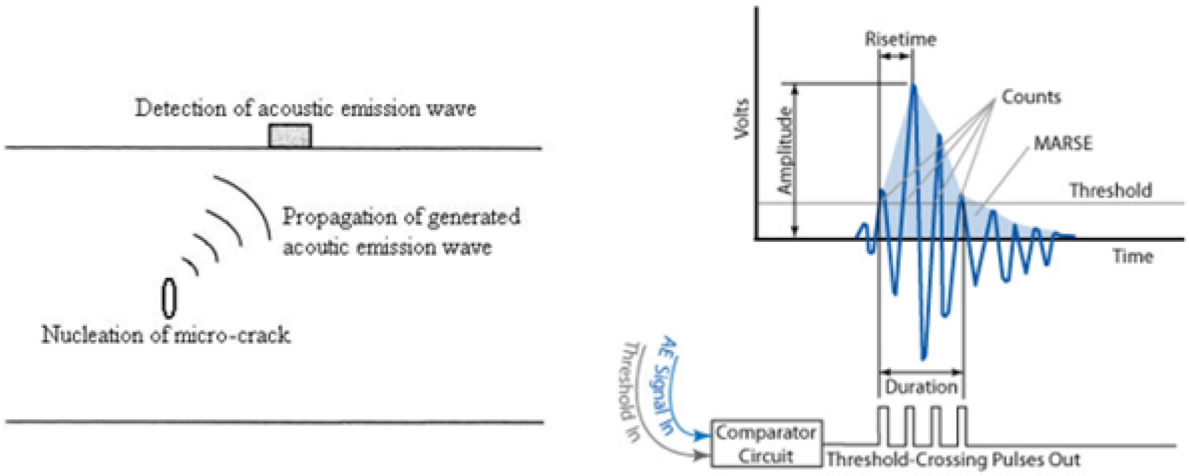

Fig. 1: Detection of AE wave [7] and typically AE signal [8].

not only on the surface but also deep inside the material [7]. The AE method is considered to be a ”passive” non-destructive technique, because usually identifies defects while they develop during the test.

Different types of cracks generate different types of AE signals (Fig. 1) with varying frequency ranges and amplitudes. These differences can be related to the degree of damage of the structure. Microcracks generate a large number of events of a small amplitude while macro cracks generate fewer events but of a larger amplitude. When the cracks are opening up, as most of the energy has already been released, many events are created, but of a small amplitude. Furthermore, tensile cracks spawn large amplitude events while shear cracks create smaller amplitude signals [9, 10].

2 Experimental Setup

The investigated material based on alkali activated slag (AAS) was consisted of 450 g of fine grained granulated blast furnace slag Štramberk 380 (specific surface area 380 $m^2 \cdot kg^{-1}$), 180 g of sodium silicate (water glass) with modulus 1.6, 1350 g of silica sand and 95 ml of water. AAS slurry was poured into steel moulds (40 $\times$ 40 $\times$ 160 mm) to set and after 24 hours the specimens were demoulded and immersed in water for another 2, 7 and 28 days before testing. AE signals during spontaneous drying and hardening of specimen were detected by measuring equipment DAKEL XEDO with ten channels. The AE sensors (type IDK09 with 35 dB preamplifier) were attached to specimen surface by beeswax (in Fig. 2) after removal from water bath.

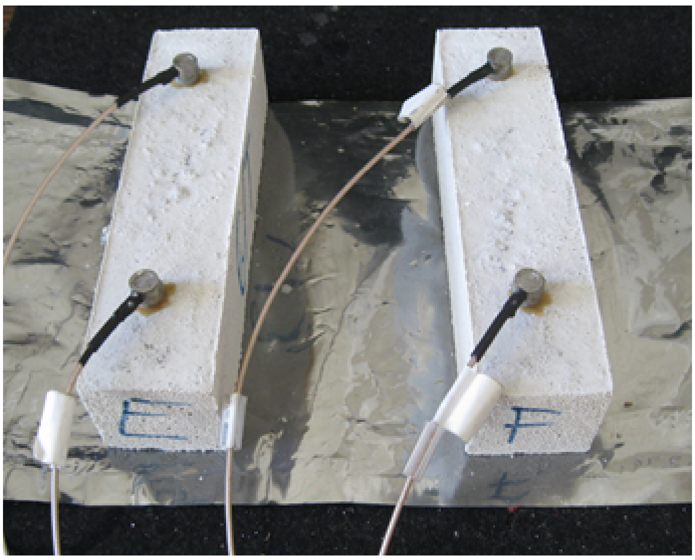

Fig. 2: Photo of measurement.

Tab. 1: Relative number of overshooting a preset threshold in different time intervals for various time of curing.

Time of Curing [days] Measurement interval time [h]	0 [%]	2 [%]	7 [%]	28 [%]
0-24	27.650	98.166	99.189	99.902
24-48	5.087	0.837	0.348	0.047
48-72	7.163	0.314	0.200	0.011
72-96	7.880	0.169	0.115	0.012
96-120	5.158	0.138	0.115	0.009
120-144	5.660	0.086	0.109	0.004
144-168	10.602	0.084	0.021	0.003
168-192	10.530	0.100	0.003	0.005
192-216	10.814	0.087	0.000	0.004
216-240	9.456	0.019	0.000	0.003

Tab. 2: The relative AE parameters for each specimen for various time of curing.

Time of Curing [days]	Relative amplitude of AE signals [%]	Relative duration of AE signals [%]	Relative energy of AE signals [%]
0	32.5	118.8	0.3
2	73.2	100.6	15.1
7	86.8	99.5	31.2
28	100.0	100.0	100.0

3 Results

To evaluation the origin of micro cracks during drying and hardening process, we focused on the parameters of AE signals such as number of overshooting a preset threshold, amplitude, duration and energy. Amplitude is the greatest measured voltage in a waveform. This is an important parameter in AE inspection because it determines the detectability of the signal. Signals with amplitudes below the operator-defined, minimum threshold will not be recorded. Duration of acoustic emission signal is the time difference between the first and last threshold crossings. The acoustic emission energy is directly proportional to the area under the acoustic emission waveform (in Fig. 1 the highlighted area).

The Tab. 1 shows the relative number of overshooting a preset threshold in different time intervals for various time of curing. Unfortunately, the AE signals originate not only from the crack formation but also from the process of water evaporation. However, the most of AE activity was observed within the first 24 h of spontaneous drying except the samples were not in a water bath (in Tab. 1 as 0). A higher number of micro-cracks in the specimen can be inferred from the higher AE activity after first 24 h.

The Tab. 2 shows the other relative AE parameters for each specimen. For comparison have been selected specimens for 28 days in water bath. The specimens with lower amplitudes and energy were in water bath shorter time. It is caused by that the matrix was not sufficiently created and lower amplitude and energy are formed by microcracks. It can be stated that time of curing have not significant effect duration of AE signals.

4 Conclusion

The paper deals with the use acoustic emission method during drying and hardening alkali-activated slag mortars. The rate of moisture release is in good accordance with the number of signals detected by AE method. We assume that most of these signals can be attributed to crack formation event; therefore, it can be concluded that the main process resulting in the deterioration of AAS binder is associated with drying shrinkage. The measurement results show the importance of curing AAS mortar during hardening. Application of acoustic emission method during the hardening and the setting of AAS mortar structure can help to obtain better properties of AAS mortar structures.

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