

PAPER • OPEN ACCESS

Experimental evaluation of the effect of carbon fibres on acoustic emission parameters obtained during compressive strength tests of alkali-activated slag composites

To cite this article: L Topolá *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **379** 012037

View the [article online](#) for updates and enhancements.

Related content

- [Fracture response of alkali-activated slag mortars reinforced by carbon fibres](#)
H Šimonová, L Topolá, P Schmid *et al.*
- [Electrical properties of alkali-activated slag composite with combined graphite/CNT filler](#)
P Rovnaník, M Míková and I Kusák
- [On the effect of addition of carbon nanotubes on the electric conductivity of alkali-activated slag mortars](#)
I Kusak and M Lunak



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Experimental evaluation of the effect of carbon fibres on acoustic emission parameters obtained during compressive strength tests of alkali-activated slag composites

L Topolář¹, P Rovnaník¹ and P Schmid¹

¹ Faculty of Civil Engineering, Brno University of Technology, Veverí 331/95, Brno 602 00, Czech Republic

E-mail: Libor.Topolar@vutbr.cz

Abstract. The generation of acoustic emission signals is directly associated with formation of cracks in materials during loading. This paper deals with possibilities of acoustic emission method application as the tool for the identification of structural damage in alkali-activated composite materials during compressive strength test. In experimental part, the three piezoelectric sensors were occupied for the continuous record of emission signals of stressed material feedback on applied mechanical load in real time. Detection of specific acoustic emission signals in the course of deformation of the test samples indicates that irreversible structural changes occur in the composite. Four different mixtures of alkali-activated slag mortars were prepared, the first one was reference without the addition of carbon fibres. The others contain the carbon fibres in amount 0.5, 1.0 and 2.0 % from the weight of the slag.

1. Introduction

The application of waste products, some of which show hydraulic properties, has grown as an another possible to Portland cement in civil engineering applications [1, 2]. Alkaline activation has become a beneficial procedure to obtain high strength composites without ordinary Portland cement [3]. The advantage is a reusing a waste product and also lower environmental and economic costs related to clinker production, can be reduced. For these reasons, new and more environmentally sustainable composites are being developed [4, 5].

The major advantage composites of alkaline-activated slag are their resistance against aggressive agents for their low porosity [6]. Their main disadvantage is shrinkage drying. The addition of short fibers to brittle composites represents a commonly used technique to improve their mechanical properties, especially those related to their tensile and shrinkage behaviors [7]. Fibers can be made on different materials such as steel, PE, PVA, PP, AR glass fibers or even carbon [8].

Carbon fibers offer among other things, an advantage such as that they can be used for electrical properties improvements of composites [9]. This improvement lies include the measurement of strain or damage sensing, heating control, EMI shielding and so on. And some application has been successfully applied in civil engineering structures, always using with cement composites [10, 11]. To achieve these functionalities, a certain level of electrical conductivity is necessary. Therefore, as concrete is a bad electrical conductor, conductive admixtures are needed. Several researchers have focused on these conductive admixtures in order to achieve a better electrical behavior without deterioration the composite's mechanical properties [12].



This paper deals with possibilities of acoustic emission method application as the tool for the identification of structural damage in alkali-activated composite materials during compressive strength test. Acoustic emission (AE) is a term used for describing elastic waves generated by abrupt localized changes in a stress field within a solid [13]. These waves propagate away from a source and cause transient surface displacements that can be measured with piezoelectric transducers see Figure 1.

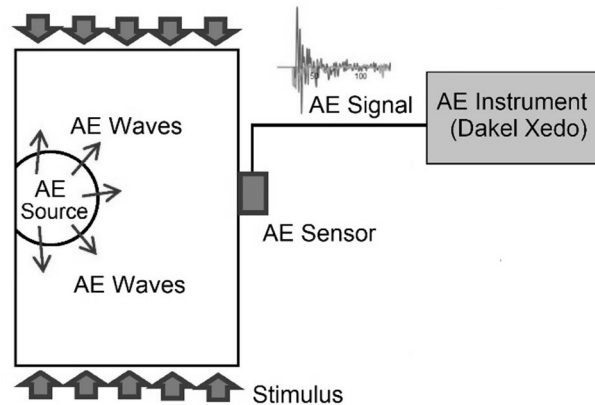


Figure 1. Principle of Acoustic Emission measurement.

Acoustic emission signals which were received during the compressive strength test were analyzed. The attention was focused on three basic parameters: the number of events, and the amplitude, duration of the AE signals (Figure 2). Different types of cracks generate different AE signals, and these differences can be related to the properties of the material [14, 15].

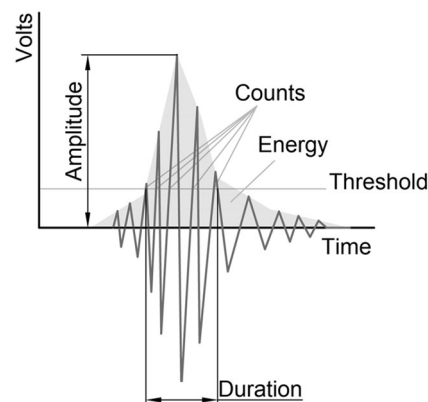


Figure 2. Parameters of Acoustic Emission signal.

2. Experimental Setup

2.1. Materials

Principal samples for the testing of electrical properties were prepared by alkaline activation of ground granulated blast furnace slag. The slag was supplied by Kotouč (CZ) and its fineness was $383 \text{ m}^2/\text{kg}$ by Blaine. The average grain size of the slag obtained by laser granulometry was $d_{50} = 15.5 \text{ }\mu\text{m}$ and $d_{90} = 38.3 \text{ }\mu\text{m}$. Solid sodium water glass SUSIL MP 2.0 (Vodní sklo, CZ) having a $\text{SiO}_2/\text{Na}_2\text{O}$ ratio of 2, was used as alkaline activator. Since all properties were tested on mortars, standard quartz sand with maximum grain size of 2.5 mm was used as aggregate. Carbon fibres Tenax A HT C124 having the average length of 3 mm were admixed to basic AAS mortar in order to enhance the electrical

properties. The amount of carbon fibres added was 0.5, 1, and 2 % with respect to the mass of the slag. The composition of mixtures is presented in Table 1.

Table 1. Composition of AAS mixtures.

Component	Slag (g)	SUSIL (g)	CF (g)	Sand (g)	Water (ml)
REF			-		185
CF 0.5	450	90	2.25	1350	200
CF 1.0			4.5		218
CF 2.0			9		230

Sodium silicate activator was suspended and partially dissolved in water. Then, slag and quartz aggregate was added and the mixture was stirred in a planetary mixer for about 5 min to prepare a fresh mortar. Finally, carbon fibres were added into the slurry and further mixed for about 5 minutes in order to separate fibres from the clusters.

The mixes were cast into cubic moulds of the size $100 \times 100 \times 100$ mm. After 24 h the hardened specimens were immersed in a water bath at 20°C for another 27 days. Before mechanical testing, all specimens were dried for 5 days at 80°C to get rid of excess moisture.

2.2. Methods

When loading into the destruction, each sample was placed in a testing FORM+TEST hydraulic press with a range of 0 – 200 kN (Figure 3). In addition, three acoustic type-IDK 09 emission sensors with 35dB preamplifiers were fixed to each sample using beeswax. Acoustic emission signals were taken by measuring equipment DAKEL XEDO. Universal measurement and diagnostic system DAKEL-XEDO was developed by ZD Rpety-Dakel company. XEDO is a modular system. One communication card and up to 15 various input cards can be located in a metal box. Communication between cards within a box is realized by hi-speed bus. An allows sampling of the signal from one sensor (speed up to 8 MSamples/sec), enumerates standard acoustic emission parameters, process emission events parameters for possible emission source localization.



Figure 3. Sample during and after the test.

3. Results and Discussions

The Figure 4 shows maximal force achieved for each mixture. The increasing amount of carbon fibres caused a decrease in the maximal force.

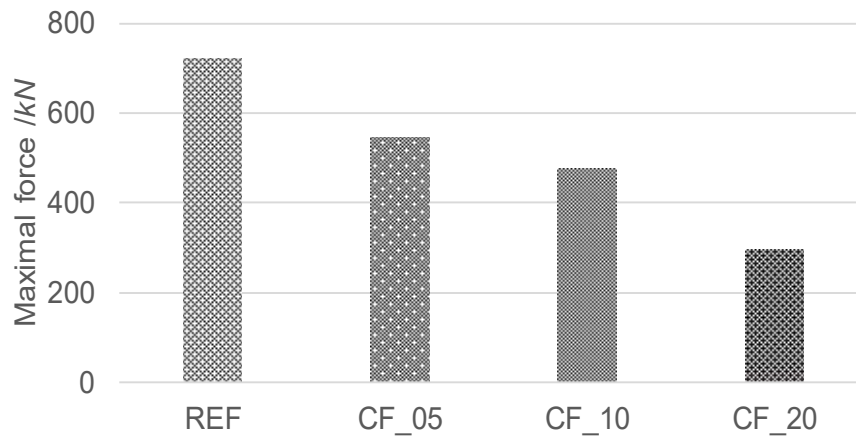


Figure 4. Maximal force for each mixture.

The AE parameter values measured during sample loading until destruction (Figure 5–7) already show the different response of the samples to loading.

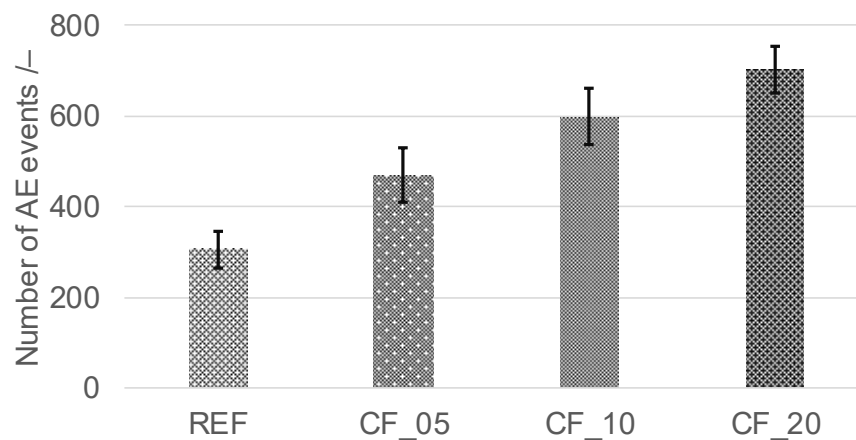


Figure 5. Number of AE events for each mixture.

If the AE sensor captures a signal over a definite level, an AE event is detected and recorded. The number of AE events accords to the material's ability to resist destruction. The occurrence of a large number of cracks generates a rather large number of events prior to destruction. The lowest number of events was shown by the reference sample (Figure 5). As the amount of carbon fibers increases, the number of AE events becomes higher. It can be assumed that the greater the number of acoustic events detected during the process of destruction, the smaller is the resistance against complete destroy.

The amplitude is the greatest measured voltage in a caught AE signal (Figure 2). This is a very significant parameter in AE inspection because it determines the detectability of the AE signal. Signals with small amplitudes (below the operator-defined minimum threshold) are not detected and not even recorded. The higher amplitudes indicate more significant structural damage to the sample. The amplitude values varied between 1852 and 2216 mV. With the addition of carbon fibers, the amplitude slightly decreased, which is probably caused the easier crushing of the matrix by

the samples with addition of carbon fibers. The highest amplitude was recorded by the reference samples (Figure 6).

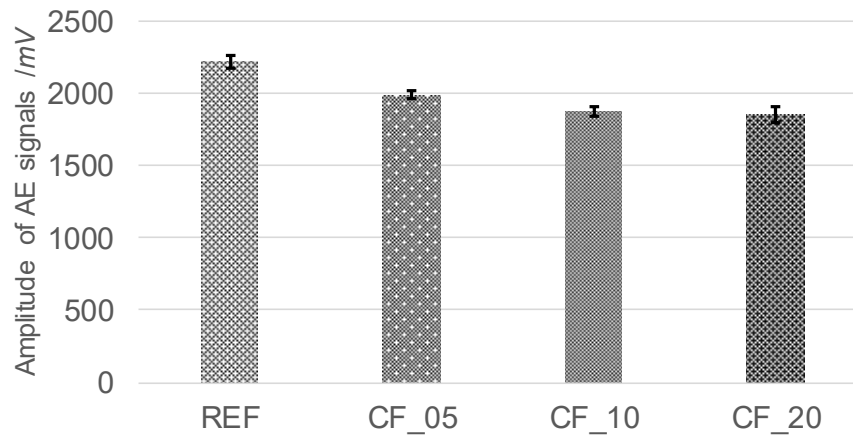


Figure 6. Amplitude of AE signals for each mixture.

The duration of AE signal is the time difference between the crossing of the first and last threshold (Figure 2). As the amount of carbon fibers increases, the value of the duration of AE signal becomes slightly higher too (Figure 7), but this increase is not significant.

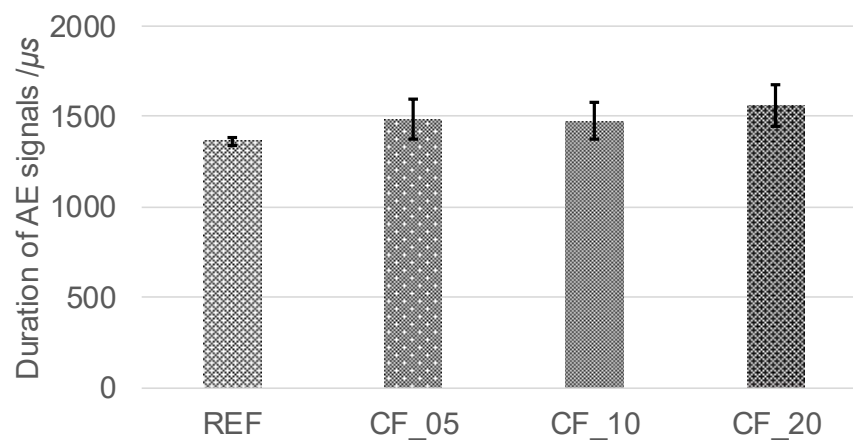


Figure 7. Duration of AE signals for each mixture.

4. Conclusions

Studying the properties of alkali-activated composites under loading is equally important for civil engineering as the study of steel in mechanical engineering. To have a good understanding of the changes in microstructure under loading is instrumental in understanding the behaviour of alkali-activated-based building materials. Using acoustic non-destructive methods in the civil engineering is not easy as many building materials are heterogeneous. This paper presents the experiments focused on a detailed analysis of selected acoustic emission parameters captured during the compressive strength test of alkali-activated composites. The acoustic emission method is often used for the failure of a structure at an early stage of damage long before the structure breaks down. The acoustic emission method proves to be an efficient instrument for detecting the appearance of micro-cracks when fine-grained alkali-activated composites are loaded.

The conclusion may be summarized as follows:

- a large number of the acoustic emission events are caused by the increased number of micro-cracks in the samples; the samples without and/or with lower amount carbon fibers showed smaller acoustic emission activity during the test, and thus probably fewer micro-cracks generated,
- the higher amplitudes indicate more significant structural damage to the sample especially at the end of the test,
- the addition of carbon fibers has not significantly influence on duration of AE signals.

Acknowledgement

This outcome has been achieved with the financial support of the Czech Science Foundation under project No 16-00567S and the Ministry of Education, Youth and Sports of the Czech Republic under the “National Sustainability Programme I” (project No. LO1408 AdMaS UP).

References

- [1] Ravikumar D and Neithalath N 2012 Effects of activator characteristics on the reaction product formation in slag binders activated using alkali silicate powder and NaOH *Cem. Concr. Compos.* **34** 7
- [2] Bilim C and Duran C 2012 Alkali activation of mortars containing different replacement levels of ground granulated blast furnace slag *Constr. Build. Mater.* **28** 1
- [3] Fernández-Jiménez A and Palomo A 2009 Properties and uses of alkali cements *Rev. Ing. Constr.* **24** 3
- [4] Rashad A M 2013 A comprehensive overview about the influence of different additives on the properties of alkali-activated slag – A guide for Civil Engineer *Constr. Build. Mater.* **47**
- [5] Natali A, Manzi S and Bignozzi M C 2011 Novel fiber-reinforced composite materials based on sustainable geopolymer matrix *Proc. Eng.* **21**
- [6] Puertas F, de Gutiérrez R, Fernández-Jiménez A, Delvasto S and Maldonado J 2002 Alkaline cement mortars. Chemical resistance to sulfate and seawater attack *Mater. Constr.* **52** p 267
- [7] Melo Neto A A, Cincotto M A and Repette W 2008 Drying and autogenous shrinkage of pastes and mortars with activated slag cement *Cem. Concr. Res.* **38** 4
- [8] Alcaide J S, Alcocel E G, Puertas F, Lapuente R and Garcés P 2007 Carbon fibrereinforced, alkali-activated slag mortars *Mater. Constr.* **57** p 288
- [9] Baeza F J, Chung D D L, Zornoza L, Andi6n L G and Garcés P 2010 Triple percolation in concrete reinforced with carbon fiber *ACI Mater. J.* **107** 4
- [10] Baeza F J, Galao O, Zornoza E and Garcés P 2013 Multifunctional cement composites strain and damage sensors applied on reinforced concrete (RC) structural elements *Materials* **6** 3
- [11] Veselý V, Keršner Z and Merta I 2017 Quasi-brittle Behaviour of Composites as a Key to Generalized Understanding of Material Structure *Procedia Engineering* **190**
- [12] Baeza F J, Galao O, Zornoza E and Garcés P 2013 Effect of aspect ratio on strain sensing capacity of carbon fiber reinforced cement composites *Materials & Design* **51**
- [13] Ono K 2005 J. Current understanding of mechanisms of acoustic emission *Strain Anal. Eng. Des.* **40** 1
- [14] Iwanami M, Kamada T and Nagataki S 1997 Application of AE technique for crack monitoring in RC beams *Cem. Concr.* **51**
- [15] Li Z and Xi Y 1995 Application of Acoustic Emission Technique to Detection of Concrete Cracking and Rebar Corrosion In: *NDT-CE: Int. Symposium Non-Destructive Testing in Civil Engineering* (Berlin) pp 613–620