Acoustic emission during fracture of ceramic superconducting materials

L Woźni, A Kisiel and K Łysy
Wrocław University of Technology, Faculty of Electrical Engineering, 27 Wybrzeże Wyspińskiego St., 50-370 Wrocław, Poland
E-mail: leszek.wozny@pwr.edu.pl, anna.kisiel@pwr.edu.pl

Abstract. In the ceramic materials acoustic emission (AE) is associated with a rapid elastic energy release due to the formation and expansion of cracks, which causes generation and propagation of the elastic wave. AE pulses measurement allows monitoring of internal stresses changes and the development of macro- and micro-cracks in ceramic materials, and that in turn allows us to evaluate the time to failure of the object. In presented work the acoustic signals generated during cracking of superconducting ceramics were recorded. Results obtained were compared with other ceramic materials tested the same way. An analysis of the signals was carried out. The characteristics of the AE before destruction of the sample were determined, that allow the assessment of the condition of the material during operation and its expected lifetime.

1. Introduction
Year of 1986 was a turning point for superconductivity, because in that year Johannes G. Bednorz and KA Müller discovered superconductivity in ceramic material La-Ba-Cu-O [1]. This discovery was specific, since the critical temperature $T_c$ of this compound is around 30-35 K (approximately -238°C). This temperature is 10°C higher than the highest critical temperatures of conventional superconductors, which are metals, alloys and intermetallic compounds. Since that moment there have been many discoveries of high temperature superconductors based on copper oxide.

One of these is YBa$_2$Cu$_3$O$_x$ [2]. This is the first compound with reproducible properties and, what is important, with $T_c$=90-95 K, which is above the boiling point of liquid nitrogen (77 K). The possibility of cooling the new superconductors by liquid nitrogen is their unquestionable advantage because this coolant is much cheaper and more accessible than liquid helium, which is used for conventional superconductors cooling.

High-temperature superconducting ceramics in most cases containing copper and the copper-oxygen planes (existing in their structure) have a dominant influence on their properties. These compounds have black colour, are hard and brittle and are characterized by high porosity.

Superconducting ceramics are characterized by strongly irreversible magnetization curves thus they are type II superconductors. Their value of the upper magnetic critical field reaches is very high. However, the value of the lower magnetic critical field is relatively small, so that it is easy to induce the mixed state in these materials.

Superconducting ceramics is a brittle substance. It shows a lower real resistance compared with theoretical resistance. Therefore it is necessary to test its microstructure in order to ensure its reliability and safety. One of methods that can be applied to that study is the acoustic emission (AE)
technique [3]. Its big advantage is fastness and non-destructive nature of the research. The phenomenon of acoustic emission allows monitoring changes in internal stresses and the development of macro- and micro-cracks in ceramic materials [4-5]. This in turn allows to evaluate the remaining time to the destruction of the object, etc. [3].

In the ceramic materials acoustic emission is associated with a rapid energy release caused by the formation and expansion of cracks, whereby there is a generation and propagation of the elastic wave. Energy can be released due to the different processes occurring in the material, both in submicroscopic and macroscopic scale. The sub-micron processes include, among others, a jump position adjacent atoms in the crystal lattice, while the macroscopic effect is a catastrophic destruction of the material.

In the presented paper it was carried out preliminary research on acoustic emission during fracture samples of ceramic superconductors YBa$_2$Cu$_3$O$_x$ under the influence of external mechanical action. For comparative purposes, similar tests were conducted for samples of electrical porcelain.

2. Acoustic emission technique

The measurement method consists in recording the AE pulses which are generated as a result of propagation micro damage or changes of stress inside material. Materials that can be studied by acoustic emission are: concrete, reinforced concrete, ceramics, glass, metals, composites, laminates, etc. Each material has a primary or acquired during the operation heterogeneous distribution of elastic energy (residual stresses) and a certain level of defects in the structure, and even micro- and macro damages [2]. Any external factor (change of temperature, applied force) can change this state and release portions of energy in the form of elastic waves. These waves can be registered as AE pulses.

The block diagram of setup for recording acoustic emission is shown in figure 1.

![Block diagram for AE measurement](image)

**Figure 1.** A block diagram for the AE measurement. D - piezoelectric detector, PM - preamplifier, FG – high pass filter, WG - main amplifier, A - discriminator threshold, L - counter, C/A - digital to analog converter, R - recorder.

Piezoelectric detector is the most important part of the apparatus. Its task is to transform ultrasonic wave energy to the energy of the electrical signal [5]. This change is connected with the piezoelectric effect during mechanical deformation. Between the walls of the piezoelectric crystal transducer it is formed the potential difference proportional to the force inducing strain [3]. The transmitter housing is the most common shape of a cylinder and is made of high quality stainless steel to eliminate electromagnetic interference.

The detector is acoustically coupled with the test object and electrically connected with the preamplifier. A preamplifier with a low noise level provides preamplifier and matching between the transducer and the transmission cable. Then the signals go to a high-pass filter, where noises are filtered through cutting the bandwidth from the bottom. Next the signals are amplified by the main amplifier. AE signal reaches the threshold discriminator, whose task is to pass signals above the fixed amplitude. Pulses with an amplitude exceeding the lower threshold are counted in the counter and transmitted by the D/A converter to the recorder. The result of measurement is the number of counted pulses of acoustic emission whose amplitude is between the lower and upper threshold of amplitude discriminator.

3. Cracks in ceramics

Crack is macroscopic gap located in the material. The propagation of cracks is the main source of EA in ceramics [2]. Cracks and their development cause that the theoretical strength is different than the
real strength. This is due to the presence of defects in the material structure. Defects can be divided into two types.

Defects of first kind include all kinds of stress concentrators in the form of sharp gaps or notches of any shape - they are hence the defects of a geometrical nature, not related to the structure and construction material.

Defects of the second kind are stress concentrators in the form of dislocations, voids deployed along the grain boundaries, inclusions of foreign material (e.g., coal in metals) causing contact stresses and all other defects in the internal structure of the material.

There are described 3 crack deformation modes that are distinguished because of the way to get around the edges of the gap: mode I - tearing, mode II - transverse shear, mode III - longitudinal shear. The crack is in the form of shear, if its surfaces diverge in the direction perpendicular to its front. The transverse shear occurs when the crack surfaces slide against each other toward the front. The longitudinal shear occurs when the crack surfaces slide past each other in a direction parallel to the front of the slot.

Analysis of the body with defects in the structure was described by Griffith theory [6]. In the stress state, the dependence between the free energy and the length of the slot has maximum value, which constitutes a barrier for the spread of cracks. For this reason, in the fixed state of stress it can be developed only these defects, which lengths are greater than critical length that corresponds to the maximum value of the free energy.

4. The measurement results
Measuring setup used for measurement of AE consisted of a source of external stress (steel jaws), that evoked cracking in the sample by its compression. The piezoelectric transducer was pressed to the source of stress. It was connected with other parts of the measurement system.

The tested materials were electrotechnical porcelain and ceramic YBa$_2$Cu$_3$O$_x$ superconductors.

Figures 2 and 3 present dependences of the AE rate on time during slowly destroying by crushing for porcelain and superconducting ceramics respectively.

Figure 2. The amplitude of the AE for electrotechnical porcelain during cracking.
Figure 3. The amplitude of the AE for YBCO superconducting ceramics during cracking.

Waveforms for both samples are presented in figures 4 and 5. Figures 6 and 7 show the detailed frequency characteristics for them.
Figure 5. Oscilloscope image of AE pulses during cracking of ceramic superconducting.

Figure 6. The frequency characteristic for electrotechnical porcelain during cracking.
5. Conclusions
On the basis of the test results the following conclusions can be drawn:

- Acoustic emission during fracture of superconducting ceramics is less intense than in electrotechnical porcelain. Both the amplitude and pulse sum AE for YBaCuO is significantly lower.
- The reason for this could be the difference in defect structure of materials, for example different porosity.
- The dominant frequency recorded during cracking superconducting ceramics and porcelain materials are very similar (65-80 kHz and 130-140 kHz).

An extension of the work should be to examine the AE during ceramic superconducting cracking at low temperatures (in the superconducting state).

6. References
[1] Bednorz J G and Müller K A, 1986 Z. Phys. B Cond. Mat. 64 189
[2] Wu M K, Ashburn J R, Torng C J, Hor P H, Meng R L, Gao L, Huang Z J, Wang Y Q and Chu C W 1987 Phys. Rev. Lett. 58 908
[3] Roberts T M and Talebzadeh M 2003 J. Constr. Steel Res. 59 695
[4] Zeng J, Yong H D and Zhou Y H 2011 J. Appl. Phys. 109 093920
[5] Gao Z, Zheng Z and Li X, 2015 Physica C 519 5
[6] Griffith A A 1920 Philosophical Transactions, Series A 221 163

Acknowledgments
This work was funded by the statutory research.