AMAS COURSE ON NONDESTRUCTIVE TESTING OF MATERIALS
NTM'02 – (PP.127–135) – WARSAW, MAY 20-22, 2002.

The influence of moisture content on spectral characteristic of acoustic signals emitted by flat bread samples

A. MARZEC [1], P. P. LEWICKI [1], Z. RANACHOWSKI [2]
and T. DĘBOWSKI [2]

[1] *Faculty of Food Technology*
Warsaw Agricultural University (SGGW)
Warsaw, Poland
marzec.agata@alpha.sggw.waw.pl

[2] *Institute of Fundamental Technological Research*
Świętokrzyska 21, 00-049 Warszawa, Poland
zranach@ippt.gov.pl

The authors of this paper analysed Acoustic Emission (AE) signal generated during fracturing of flat rye and wheat bread specimen with different moisture content. The details of acoustic emission signal processing and instrumentation used are shown. In authors' opinion there is a good correlation between a proposed acoustic parameter – partition power spectrum slope – and measured moisture content in investigated food specimen.

1. Introduction

In the last years a variety of crunchy cereal foods have appeared on the market. The growing consumer interest focusing at these products is caused by both their dietetic and taste qualities as by their instant serving preparation. However, perceived textural attributes of consumed food are significant part of eating quality estimation, mostly ranked at a second place after its taste – these attributes become of paramount importance when a crunchy products are objects of a survey. Food textural quality, namely its crunchiness depends on *structural moisture content* and an excess of a certain level of this parameter causes by consumers rejection [Katz and Labuza, 1981].

Eating quality of a product can be understood in categories involving the presence of perception of all physiological senses. At present the role of audible sensations is known in a small range. Some authors, however [Vickers, 1987; Rodault et. al., 1998] treat acoustic aspect of eating process with a proper importance.

In the available literature there is a lack of an acknowledged parameter referring to the spectral characteristic of sounds emitted by mastificated food. Therefore the authors of this paper present a method of construction of such a parameter.

2. Material and methods

Acoustic Emission (AE) signals were generated by the samples of flat rye and wheat bread during a three – point breaking process realised by means of a silent Zwick 1445 loading machine. An acoustic accelerometric sensor, Brüel & Kjaer 4370V was mounted near the lower end of the upper head of loading machine to achieve an acoustic contact with the fracturing bread sample. The loading was performed at the constant head speed of 20 mm/min. Each AE signal registering session lasted 30 seconds. The AE sensor was capable to register the acoustic signal at a frequency range of 0.1-15 kHz. AE signal was transmitted from the sensor to a 20 dB low – noise amplifier and finally registered using a 44.1 kHz sampling sound card placed in a PC computer. A special uniformity test, including 0.5 mm pencil break was applied to keep the sensivity control of AE signal processing arrangement described above.

A population of specimen included the material with moisture content varying in the range of 3.8%-12.85%. Five sets of samples indicating the moisture content at increasing levels at 3% steps, 10 samples at each level, were examined.

As the whole amount of the population was examined under the same conditions it was possible to compare the recorded "AE signal energy" of bread specimens differing with their moisture content. The recorded time-dependent AE signal, $v(t)$ of each session is represented by a series of its digital samples where $T_1$is a time delay between the consecutive execution of taking a sample; $v(mT_1)$ is here understood as an amplitude of voltage registered on the AE sensor. An independent variable m represents the consecutive number of a signal sample. Total session time T (equal to 30 seconds) includes N digital AE signal samples. When a 44.1 ksamples/sec recording speed was used, it gives 1323 kilosamples. Thus "AE signal energy" can be calculated in arbitrary units as follows:

$$E = \sum_{m=1}^{N} v(mT_1). \tag{2.1}$$

Experimental results described in the next Section present a linear correlation between "AE signal energy" level and increasing level of specimen

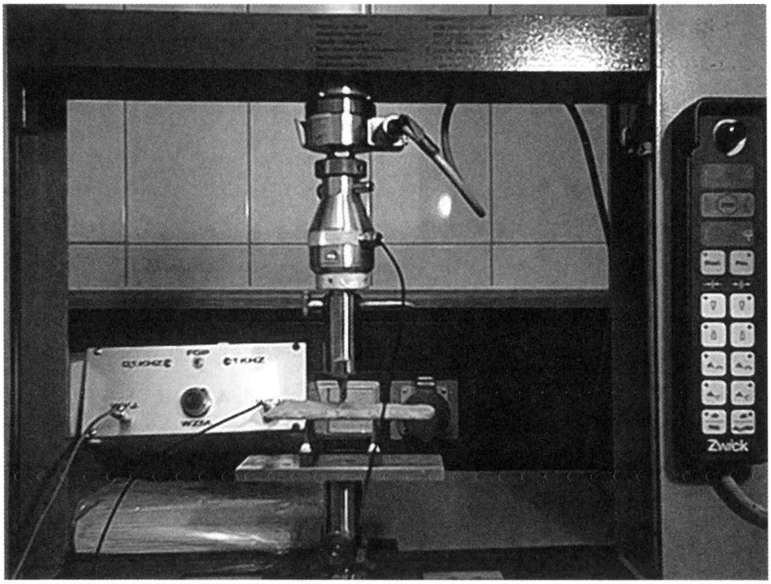

FIGURE 1. A flat rye bread sample placed in the loading machine. A cable from the acoustic sensor is visible over the sample. Acoustic Emission amplifier is situated on the left side of the sample.

moisture content. The authors of the present paper worked at evaluation of other acoustic parameter which was not dependent on the specimen volume – as it was observed calculating E. The idea was to consider a specific attribute of emitted sound – a shape of its power spectrum. The continuous AE signal can be, in frequency domain, characterised by its power spectrum function $A(\omega)$ where ω is a linear analogue of frequency f, $\omega = 2\pi f$. If $v(t)$ is absolutely integrable, it can be associated with its spectral density function $A(\omega)$ using a Fourier transform:

$$v(t) = \frac{1}{\pi} \int_0^\infty A(\omega) \sin\left[\omega t + \varphi(\omega)\right] d\omega, \tag{2.2}$$

where φ is an argument representing a phase of transformed signal.

We used a computer procedure to derive a discrete image of $A(\omega)$. The procedure analysed recorded AE signal samples in sections of 1 second length. To reject the influence of background noise one dominant AE burst was detected (if any was present) in each section. All the bursts were processed to obtain its power spectrum function keeping the same phase of each burst at the transformation process. This algorithm is sometimes called "event filtering" enabling to suppress the random noise accompanying the recording signal. As the result for each time section the procedure produced a series of coefficients c_n and each of them represented AE signal power in frequency range of 11 Hz. The whole series of c_n covered the desired spectral range of 100–1500 Hz. The algorithm performing the $v(mT_1) \Rightarrow c_n(\omega)$ transform is based on the following approximating formula:

$$c_n \approx \frac{1}{N} \sum_{m=0}^{N-1} v(mT_1) \bmod \left(e^{\frac{jn2\pi m}{N}} \right) \tag{2.3}$$

where j denotes $\sqrt{-1}$.

As the AE signals generated during entire breaking process of bread specimen were characterised by a similar spectral density function it was possible to average all the series of c_n derived from one specimen to obtain *the average power spectrum function*. It was found experimentally that there are two regions in the frequency domain where the high level of power spectrum function is measured. These regions are 1-3 kHz and 7-15 kHz. This led us to propose the following AE signal derived, practically independently from the sample volume. This coefficient is called the *partition power spectrum slope* S and is calculated as the ratio of AE signal power spectrum registered in the frequency range 7-15 kHz, labelled P_{7-15} and AE signal power registered in the frequency range 1-3 kHz, labelled P_{1-3}:

$$P_{7-15} = \sum_{n\to 7\,\mathrm{kHz}}^{n\to 15\,\mathrm{kHz}} c_n, \qquad P_{1-3} = \sum_{n\to 1\,\mathrm{kHz}}^{n\to 3\,\mathrm{kHz}} c_n, \qquad S = \frac{P_{7-15}}{P_{1-3}}. \tag{2.4}$$

3. Measurement results

The dependence of "AE signal energy" E calculated by formula (2.1) versus moisture content for investigated flat rye bread specimen is shown in Fig. 2.

Figure 3 illustrates calculated spectral density function for rye bread specimen tested at low and high level of moisture content. Power spectrum density is presented in logarithmic scale (decibels), referred to 1 mV standard source signal. The regions of high power level (1-3 kHz and 10-15 kHz) of AE signal can be noticed here. This can be caused by the resonance abilities of vibrating system, including a specimen, loading machine traverse and AE sensor. However, it is worth of note that during the loading of a more watery specimen the power spectrum function includes significant increase of high frequency components, especially when compared to the partitions of lower frequencies. It is obvious that propagation of high frequencies is less damped when the presence of water is increased. It shows an accordance with the

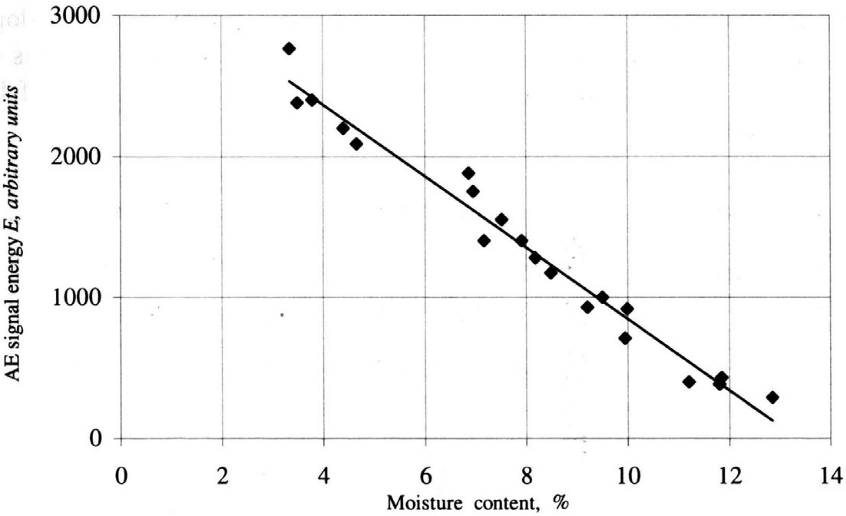

FIGURE 2. Influence of moisture content on "AE signal energy" E in flat rye bread specimen.

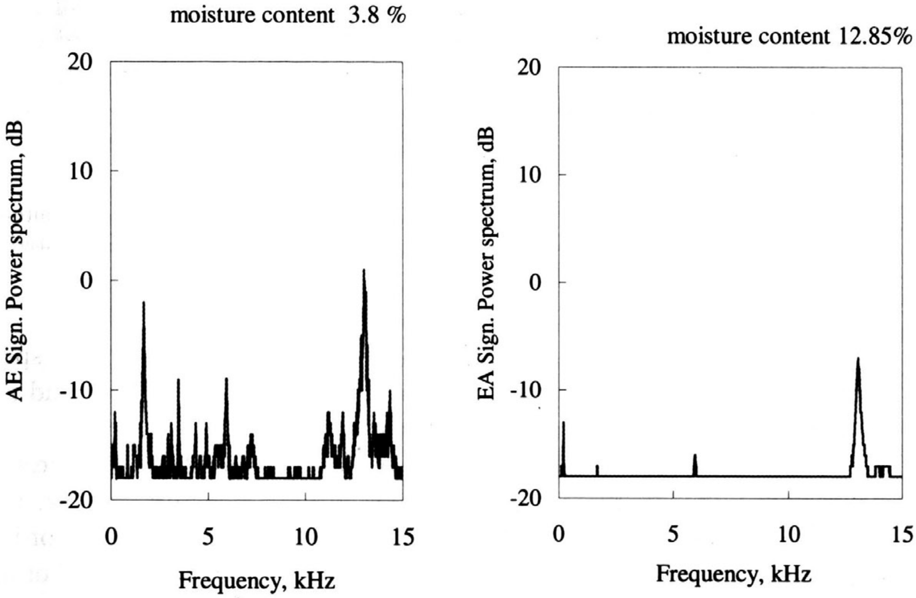

FIGURE 3. AE signal spectral power calculated in specimen differing in moisture content.

reports of the other authors stating that when the moisture level of ca. 9% is overridden that a "glass transition" effect appears, being a crispness loss of a structure that then it becomes a plastic body.

Such effect could explain the increase of partition power spectrum slope S coefficient according to sample moisture content increase. This trend is seen in Fig. 4., where AE signal spectral power is shown as a function of both moisture content and chosen frequency region.

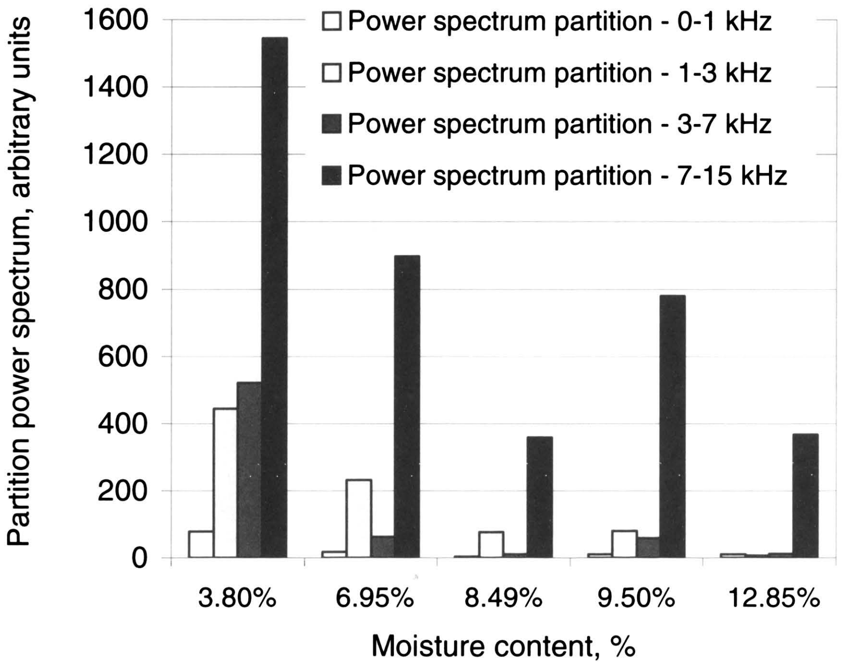

FIGURE 4. AE signal partition power spectrum as a function of both moisture content and chosen frequency region, defined according to formulas (2.4). Investigated material – flat rye bread samples.

In Table 1 values, averaged of ten measurements, of partition power spectrum slope S in relation to moisture content are presented. Wheat and rye samples show similar dependence of S versus moisture content.

Another efficient tool to analyse the records of mechano-acoustic test of loading the crunchy products are acoustograms. In the figures below, two records of such examination are presented. Figure 5 illustrates the record of loading process of the product with partition power spectrum slope S of 5.3 and Fig. 6 illustrates the record of loading process of the product with partition power spectrum slope S of 15. At the vertical axis the spectral content

TABLE 1.

Moisture content [%]	**Averaged spectral density slope S** [dimensionsless ratio]	
	Wheat samples	**Rye samples**
3.80	4.06 ± 0.50	3.48 ± 0.50
6.95	4.52 ± 0.37	3.87 ± 0.37
8.49	8.11 ± 1.0	6.95 ± 1.0
9.50	23.0 ± 2.0	18.20 ± 2.0
12.85	48.57 ± 9.1	52.43 ± 9.1

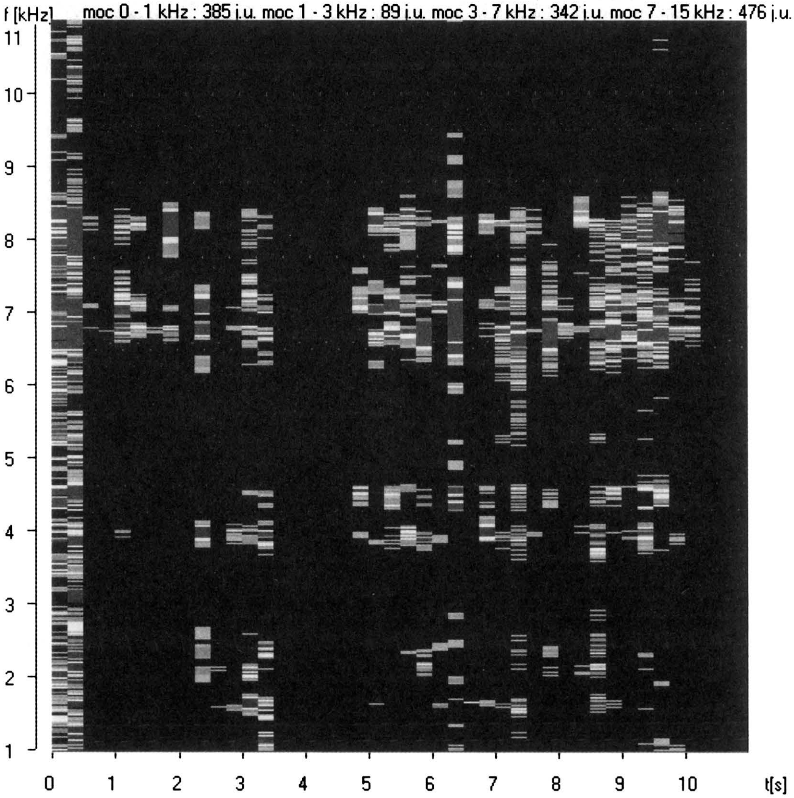

FIGURE 5. The record of loading process of product with partition power spectrum slope S of 5.3.

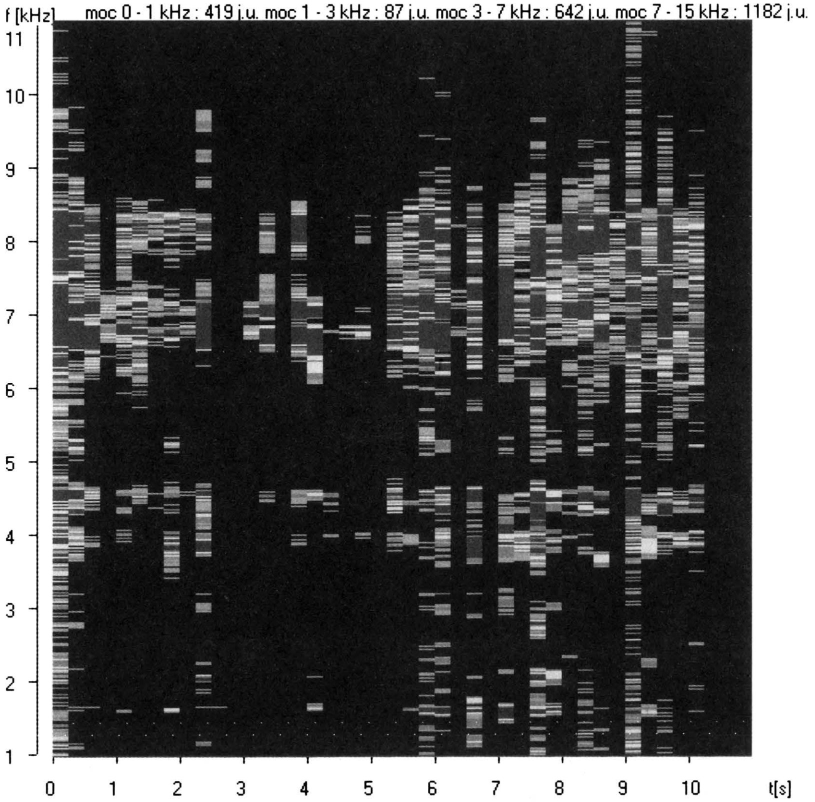

FIGURE 6. The record of loading process of product with partition power spectrum slope S of 15.

of the analysed signal is shown while at the horizontal axis the running time of the loading process is visualised. Relative changes of the signal intensity are shown using a method of altering the colour pattern.

In our opinion the presented data prove that changes of moisture content of flat bread specimen cause a significant changes in outlook of power spectrum function of emitted acoustic emission signal. Therefore a coefficient describing these changes can be applied as a qualitative measure of investigated crunchy product.

References

1. C. DECREMONT, Spectral composition of eating sounds generated by crispy, crunchy and crackly foods, *Journal of Texture Studies*, Vol.26, pp.27-43, 1995.

2. E.E. Katz, T.P.J. Labuza, Effect of water on the sensory crispness and mechanical deformation of snack food products, *Journal of Food Sciences*, Vol.46, pp.403-409, 1981.

3. G. Roudaut, C. Dacremont, M. Le Meste, Influence of water on the crispness of cereal – based foods: acoustic, mechanical, and sensory studies, *Journal of Texture Studies*, Vol.29, pp.199-213, 1998.

4. R.W.B. Stephens, A.A. Pollock, Waveforms and frequency spectra of Acoustic Emission, *Journal of the Acoustic Society of America*, Vol.50, No.3, pp.904-910, 1971.

5. R. Tesch, M. Normand, M. Peleg, Comparison of the acoustic and mechanical signatures of two cellular crunchy cereal foods at various water activity levels, *Journal of Food and Agricultural Sciences*, Vol.70, pp.347-354, 1996.

6. Z.M. Vickers, Sensory, acoustical and force-deformation measurements of potato chip crispness, *Journal of Food Sciences* Vol.52, pp.138-140, 1987.

◆