SHORT COMMUNICATION

Monitoring of the deformation of cereal grains by the acoustic emission technique

MICHAL KNAPEK – PETR GABRIEL – ROBERT KRÁL – FRANTIŠEK CHMELÍK – PETR SLADKÝ

Summary

In this work, the deformation behaviour of cereal grains is addressed as a very important physical property reflecting the grain quality. Deformation curves are a graphical measure of mechanical properties and therefore are often used to classify the cereal grains. Up to now, only a limited work has been done to examine the grain quality related to elastic or viscoelastic properties. A method for simultaneous measurements of grain deformation and acoustic emission (AE) data is proposed here, as the AE technique provides information about dynamic processes involved in the deformation and failure of tested materials. A specialized measurement set-up, which has been developed, is presented. First results revealing clear correlations between the load drops and the AE data are shown. Possible applications of this new method in the field of cereal grain quality evaluation are also discussed.

Keywords

cereal grains; compression tests; acoustic emission; mechanical properties

Wheat, maize, rice and barley are, among others, the most important cereal crops in the world's production [1]. Grain properties are determined by the plants' genetics, i.e. variety, and growing as well as environmental conditions (climate, soil type, irrigation, fertilizers). The knowledge of physical properties of grains and seeds is very helpful in classifying and distinguishing between different varieties and kinds of kernels. It is also crucial for quality evaluation of final products. Indeed, the grain quality is an essential attribute for determining its market value. The physical characteristics are also of significance in designing equipment for different stages of processing (e.g. machining, drying or storage) and can determine the efficiency of machines [2]. There are several categories of grain characteristics: mechanical properties related to the reaction of kernels to the applied stress (hardness, deformation behaviour), geometrical properties (shape and size of kernels) and other physical properties connected to moisture content, density or porosity [3]. Many studies were conducted to investigate such properties and they are still of contemporary interest, since new varieties with different properties are being developed [2, 3].

As mentioned above, numerous genetic and agronomic factors are responsible for grain size variations. Grain size and shape are major goals for artificial selection and breeding of common wheat as well as of other cereals. Grain size is significantly related to the quality and usage of the grain; e.g. an increase in the wheat grain size is directly connected to the grain yield and milling quality [4]. Grain size distribution is also important for cleaning, grading and separation [3]. Knowledge of the morphology of cereal grains is usually obtained from light, scanning and transmission electron microscopy. Spectroscopic methods also are used extensively for the analysis of cereal grains. Several other industrial quality criteria are also influenced by grain morphology, e.g. specific weight, where the grain shape and size define the way the individual grains pack, and also its relation to protein content and hydrolytic enzymes activity, which help to determine end-use suitability [5].

Michal Knapek, Robert Král, František Chmelík, Department of Physics of Materials, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 12116 Prague, Czech Republic.

Petr Gabriel, Petr Sladký, Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague, Czech Republic.

Correspondence author:

Michal Knapek, e-mail: knapek@karlov.mff.cuni.cz

Hardness of cereal grains is a key determinant for classification of the end-product quality. It interrelates with grain strength and ductility but has several different meanings depending on the type of test employed to measure it (e.g. the resistance to deformation or crushing). Universal definition has therefore not been established [6]. Grain hardness measurements for wheat, in terms of particle size index (*PSI*) [7, 8], single kernel characterization system (SKCS) and hardness index (*HI*) values, are known to be useful qualitative predictors of end-product quality [9]. Other methods frequently used to investigate the kernel texture are energy required for grinding, pearling value, near infrared reflectance (NIR) [8] and Stenvert test. None of these methods provides direct measurement of physical hardness which, in material sciences, is measured using e.g. Brinell or Vickers indentation methods or microindentation tests [6, 9, 10].

The uniaxial compression tests provide information about elastic and (visco)plastic behaviour of biomaterials, i.e. its response to an applied external force that deforms the body and induces a change in dimension, shape or volume [3]. From deformation curves, a set of properties can be determined such as Young's modulus, bioyield point, failure point and peak strength. Only a limited work has been done to examine grain quality related to elastic or viscoelastic properties of wheat kernels, although the stress–strain behaviour is a very important physical property in the assessment of grain quality. The milling industry often uses this factor to classify wheat varieties as hard or soft [3, 11]. The stress-strain curves are a graphical measure of the mechanical properties of material and may not be interchanged with hardness (resistance to deformation, usually tested by indentation), although there are possible correlations between them. For example, Morris et al. [12] examined kernel texture in the context of compressive strength to failure using different durum wheat varietal grains in a form of endosperm bricks. In the study of Morris et al. [13] the compression tests were compared with the results on whole kernel hardness (hardness index, *HI*) asserting that a correct classification of individual kernels should be attainable by means of their approach.

Deformation of solid materials is usually accompanied by the generation of acoustic waves. Acoustic emission (AE) stems from transient elastic waves generated within the material due to sudden localized structural changes. Thus, it yields in situ information on dynamic processes involved in deformation and failure of the material. In materials science, a combination of deformation tests and AE measurement technique has been effectively used for decades. In the field of food research, or more precisely cereal research, a very limited number of studies can be found. For instance, Marzec et al. [14] and Gondek et al. [15] used a contact AE method during uniaxial compression of grains of different wheat varieties with the aim to characterize them in terms of several AE parameters (acoustic energy, number of events, spectral analysis). In the study of Marzec et al. [16], an even broader set of AE parameters was evaluated and correlated to various mechanical properties of grains. The authors suggested that the AE technique may be applied to wheat grain differentiation, as the force of compression (hardness) correlated quite well with the number of recorded AE events. However, to the authors' best knowledge, the AE technique has so far not been applied as a complementary method to deformation tests conducted on cereal grains in a way where deformation curves were directly correlated with the simultaneously measured AE response.

In this work, we present preliminary results of an attempt to extend conventional compression tests by the use of AE measurement technique. The main objective was to build a measurement set-up, which would allow for time-correlated measurements of deformation curves and AE data, and to propose possible future applications of this method in the field of cereal grain quality evaluation.

MATERIALS AND METHODS

As reference samples for the tests, dried traditional Czech (Pilsner-type) barley malt grains were used. Compression tests were performed using a universal testing machine (UTM) Instron 5882 (Instron, Norwood, Massachusetts, USA) at room temperature with a constant cross-head speed of 0.1 $mm\cdot s^{-1}$. The AE response during the mechanical tests was monitored using a computer-controlled Conti 4 system (Dakel, Rpety, Czech Republic) on the basis of four channel data acquisition (amplification at each channel was set to a different value: *ch*1 = 0 dB, *ch*2 = 10 dB, *ch*3 = 20 dB, *ch*4 = 30 dB; pre-amplification was 35 dB), which allowed for continuous sampling (sampling frequency, 2 MHz) of the AE signal registered by a 6 mm piezoelectric transducer MIDI-410-02 (Dakel) with a frequency band 100–600 kHz. This made possible comprehensive post-processing of the complete stored signal based on a standard two-threshold level detection (recommended by ASTM standard E1067-85) using various parameters of individualization of the AE events [17]. Further information on the instrumentation and AE parameters was previously published [17–19].

In order to record AE signals accompanying the deformation of cereal grains, a set-up (presented in Fig. 1) has been developed. A plastic plate was placed on top of the lower anvil of UTM to prevent possible vibrations and noise produced by the machine to be registered by the AE sensor. A flat steel plate, which was supposed to be in direct contact with the grains, was placed over the plastic plate. Due to the relatively good "acoustic conductivity" of steel, the sound waves originating in the deformed kernels propagated towards the AE sensor, which was, with the help of a wooden clip, attached to the end of the plate. The recorded AE signal was then transmitted to the Conti 4 system where it was stored and further processed. In this way, mutual correlations between the deformation curves and AE data could be evaluated.

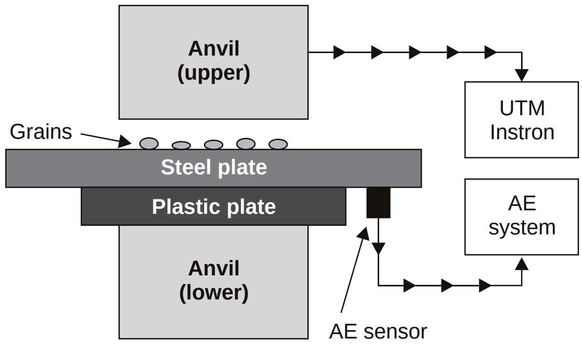

Fig. 1. Experimental set-up allowing for simultaneous recording of deformation curves and acoustic emission response of mechanically tested cereal grains.

UTM – universal testing machine, AE – acoustic emission.

RESULTS AND DISCUSSION

The deformation curve and the AE count rate (channel 4, total gain 65 dB) of the sample grain, which was placed horizontally, are shown in Fig. 2. Two stages of the deformation process can be identified. The first stage, where the curve is smooth, can be ascribed to squeezing of the grain with very few AE signals being recorded. At the deformation of approx. 0.4 mm, a significant load drop occurs most likely as a result of a large crack having been rapidly formed across the grain. This effect is accompanied by a high AE activity marked by a large arrow. From this moment on, a second stage sets off where the curve is serrated as a result of numerous smaller ruptures evolving within the grain structure (small arrows). In this region, the applied load is rather constant and strong AE activity is present. Raw AE signal at the highlighted load jumps exhibits typical burst-like characteristics (shown in Fig. 3). The test was repeated eight times by the means of eight grains of the same quality but naturally varying in weight (36.7–61.3 mg). Since all tests delivered similar results, providing a good reproducibility, only one deformation curve is presented here (Fig. 2). Detailed characteristics, stages and parameters of typical deformation curves of cereal grains can be found in literature [3, 6, 20] and are not discussed in the present paper.

In Fig. 4, the deformation curve and the AE count rate (channel 4, total gain 65 dB) of five

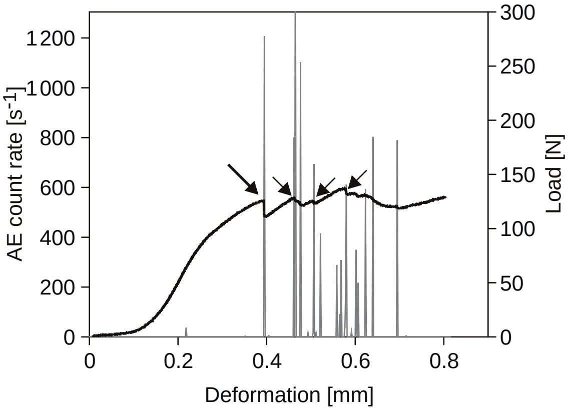

Fig. 2. Deformation curve and acoustic emission count rate recorded simultaneously during the uniaxial compression test of a single barley grain.

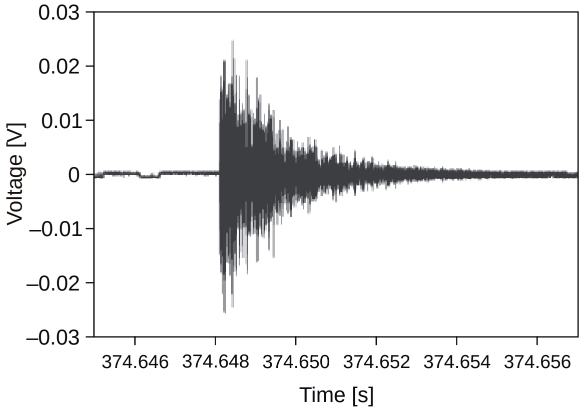

Fig. 3. Typical acoustic emission signal recorded along with the load drops during the compression test.

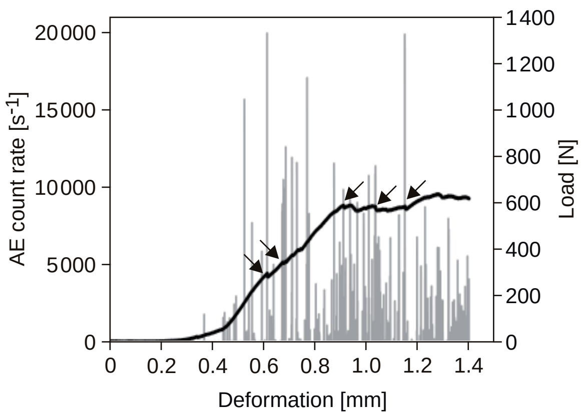

Fig. 4. Deformation curve and acoustic emission count rate recorded simultaneously during the uniaxial compression test of five barley grains.

grains compressed simultaneously is shown. The load required for the compression was proportionally higher by comparison with the single grain test. Numerous load drops on the deformation curve are present again along with a very high AE count rate in these points, supposedly brought about by the cracks initiation and propagation. A number of distinct correlations is marked by the arrows.

The interpretation and further analysis of the recorded AE data is out of scope of the present paper. However, future applications of the presented method may be envisaged, based on the fact that the acoustic signals originating in the material depend on its structure, chemical composition and stress distribution, and thus possibly reveal a characteristic picture of the underlying processes. Similar approach was successfully used for the identification of typical deformation processes, dislocation glide and twinning, in metallic single crystals [21] or, by utilizing the spectral analysis method, the AE technique was shown to be suitable for distinguishing among different wheat varieties [14]. The authors believe that the method of study presented here can be extended and effectively applied to the assessment of physical properties of cereal grains.

CONCLUSIONS

A new method for the evaluation of cereal grain quality was proposed, based on the typical compression tests complemented by concurrent acoustic emission (AE) measurements. A specialized measurement set-up has been developed and successfully applied. The first results show clear time correlations between the load drops related to the crack initiation and propagation, and the AE data in the single kernel deformation test. During the deformation test of five grains, similar behaviour was observed, although the load required to keep the strain rate constant and the AE activity were proportionally higher. The typical raw AE signal recorded at the load drops was shown to have a burst-like character. Advanced analysis of the AE signal will be the objective of further investigations, particularly to provide a basis for practical applications.

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