ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

STANDARDIZED CRUMPLING NOISE MEASUREMENT

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Abstract

On request of an industrial partner, a technique was developed to measure the noise of crumpling packaging materials. According to a study with their costumers, the noise produced when unwrapping the product was a major issue. Thus a technique to quantitatively compare different packaging material with regard to acoustic emission during crumpling was needed.

Several questions had to be answered. How to create a system that allows crumpling the material in a reproducible way? What is the influence of the speed of crumpling? How should a low cost standardized method look like and how could it be calibrated? After testing several alternative methods – that will briefly be discussed –, a tubular specimen, crumpled inside a cavity close to a microphone is used. The specimen is slid over a horizontal bar and is only restricted in its movement by the piercing bar, hereby forcing the sample to crumple in a controlled way. A constant, tunable crumpling speed was obtained using a stepping motor. Both SEL and L_{Aeq} during crumpling are found to be useful to discriminate between materials using a single number indicator. Spectral measurements confirm that the acoustic emission is mainly in the kHz frequency range. More interestingly, the temporal fluctuation of sound level during crumpling shows a pattern typical for complex systems for most of the tested materials. A clear effect of aging of samples that are crumpled several times can be observed.

INTRODUCTION

When a product is unwrapped, packaging material is crumpled making a characteristic crackling noise. In some circumstances this noise has to be avoided as much as possible. Thus there is an interest in a "standardised" methodology for comparing packaging materials with regard to this aspect. This paper reports on an effort to design such a methodology that can be used in the average industrial lab. The

use of large infrastructure such as an anechoic room and sophisticated measurement equipment was thus avoided. Reproducibility and resolution of the measurement are of utmost importance. It is also critical that the method is not very sensitive to small variations in the test setup.
Literature reports on acoustic emission of crumpling material have mainly focused on early damage detection. However, Houle and Sethna [1] and Kramer and Lobkovsky [2] have studied the complex behavior of crumpling sheets. Although the theoretical discussion in this work is very interesting, there is no attempt to quantify the noise level in a reproducible way.
We believe that the discussion below is the first attempt of its sort to come to a method that could be used as a standard to compare different types and makes of packaging material.

DESIGN OF A SUITABLE SETUP

General considerations

Designing a suitable setup for “standardised” crumpling noise measurements poses a few challenges:

- As the crackling noise level of crumpling is rather low, background levels should remain low, in particular the noise produced by the crumpling mechanism must be kept under control or shielded.
- Unconstrained crumpling of a flat sheet results is simple folding which is not representative for the unwrapping action.
- Reproducibility of the measurement must be high thus the complex process of crumpling should be guided sufficiently.
- A suitable measurement parameter must be chosen.
- A calibration method for the measurement setup must be co-designed.

Most of the above challenges are met by simple manual crumpling of the material in an anechoic room. However, reproducibility is obviously poor, in particular if different people are performing the test. Mechanical drivers introduced in the anechoic room should not produce a sound level over about 35 dBA at the sample location. Moreover, the aim was to avoid the use of large infrastructure. Thus the setup was based on a small acoustic cavity. This structure, shown in Figure 1, has several resonances within the frequency range of interest. To eliminate the effect of these resonances, two options were compared: damping the cavity by introducing porous absorbers inside and calibrating. Damping proved very efficient for the first order longitudinal mode, but was less practical for the radial modes. Physical damping also reduces the sound level in the cavity during crumpling considerably thus making measurement noise more important. It does however relax the calibration requirements slightly. In this paper we will not elaborate on the damped cavity variant of the setup.
In a first stage, a flat strip of the material under test was clamped at two ends which

were than moved towards each other. The variability between tests was huge since some samples just folded in two producing virtually no acoustic emission. Twisting improved the situation slightly, but eventually a cylindrical sample was crumpled while restricting its sideway motion by a central rod. The photograph in Figure 2 illustrates this mechanism. It shows the crunched sample still on the rod, but removed from the cavity.

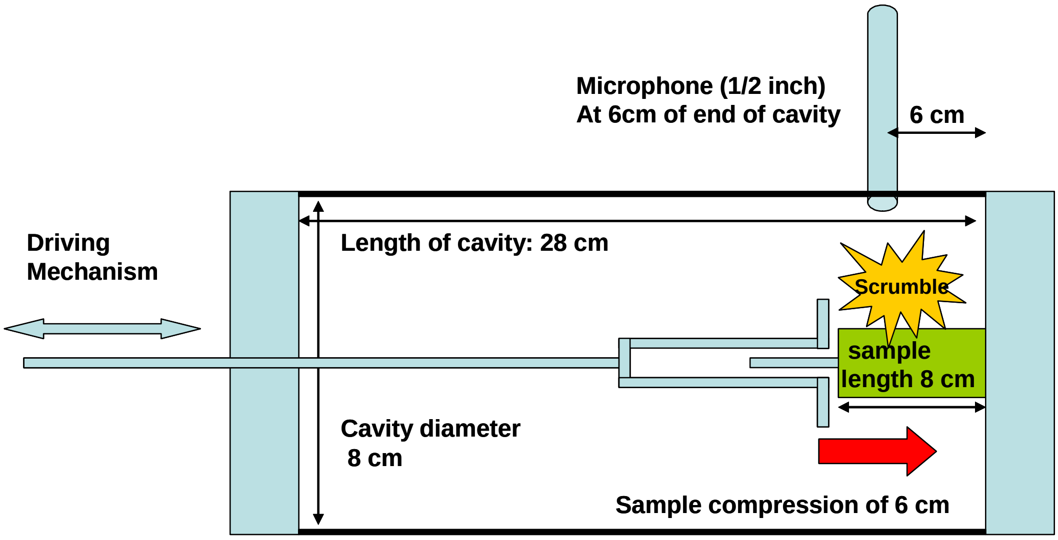

Figure 1 – Schematic representation of crumple measurement setup..

Figure 2 – View of a crumpled sample as measured in the cavity.

To compress the sample in a reproducible way, several options are available. Using a weight to compress the sample by gravity force did not produce the required silent solution. A small stepping motor outside the cavity driving the rod in at uniform speed was eventually used. It allows varying the compression speed. Because of the well shielded cavity, the noise level entering the cavity due to this driving mechanism is well below the crumpling noise as show in Figure 3.

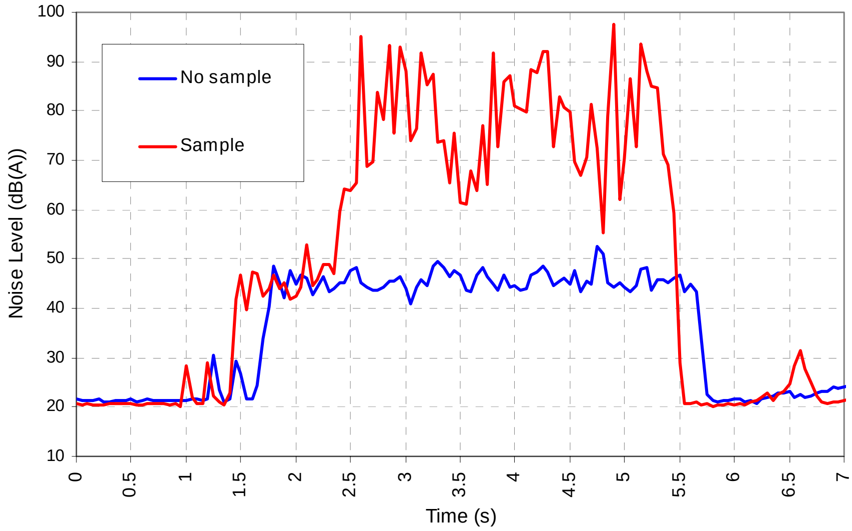

Figure 3 – Background noise produced by driving mechanism compared to crumpling noise.

For testing packaging material we propose to use a Type 1 sound level meter using exponential averaging (time constant 50ms) and standard A-weighting, capable of recording 1/3 octave band data. The equivalent sound level L_{Aeq} and directly derived from that the sound exposure level SEL=L_{Aeq}+10log(T) where T is the duration of the crunching action, are obtained. For validation of the setup more detailed and accurate measurements were also used in this paper.

Calibration

A detailed analysis of the crackling noise [1] shows that it consists of a series of short peaks (order of magnitude 10 msec). After A-weighting the source level peaks at a few kHz (see below). A spark source produces a sound with similar characteristics. Its sound power is not influenced by the presence of the cavity. Hence, for calibration, a spark source was placed in the cavity at 4 locations along the crumpling area, slightly out center. It was ignited several times and the sound level was recorded at exactly the same position as during the actual test. The same spark source was also measured in an anechoic environment. Since the source is tiny and thus its location is known very accurately, the measured level can easily be translated into a sound power level or a sound pressure level at any required distance. In this paper we calibrate to a sound pressure level at 1m. Because both the acoustic emission of crumpling and the spark source contain no tonal components, calibration can be performed per 1/3 octave band. Figure 4 shows the calibration factor that needs to be subtracted from the in-cavity measurement to obtain the noise level at 1m. The error-bars give the combined error due to reproducibility of the spark pulse (measured in anechoic room) and the different locations of the source along the crumpling region. It is an upper estimate of the real error introduced by the calibration step.

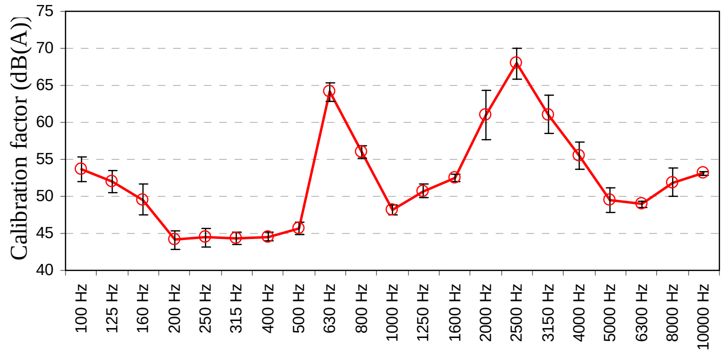

Figure 4 – Third octave spectra of the calibration factor for the resonant cavity.

MEASUREMENTS

Reproducibility and resolution

A suitable measurement procedure should allow discriminating between similar but different materials (high resolution). At the same time variation between measurement results between samples taken from the same product must be low (reproducibility). To test the procedure the acoustic emission cause by crumpling packaging material of five common products was measured. Figure 5 shows the calibrated sound exposure level when the sample is crunched from 8 to 2 cm. The difference in overall level between materials is significant. The standard error lies within a few dBA based on three sample measurements. The spectra of different type of material are very similar; they all peak around 6000 Hz (A-weighted).

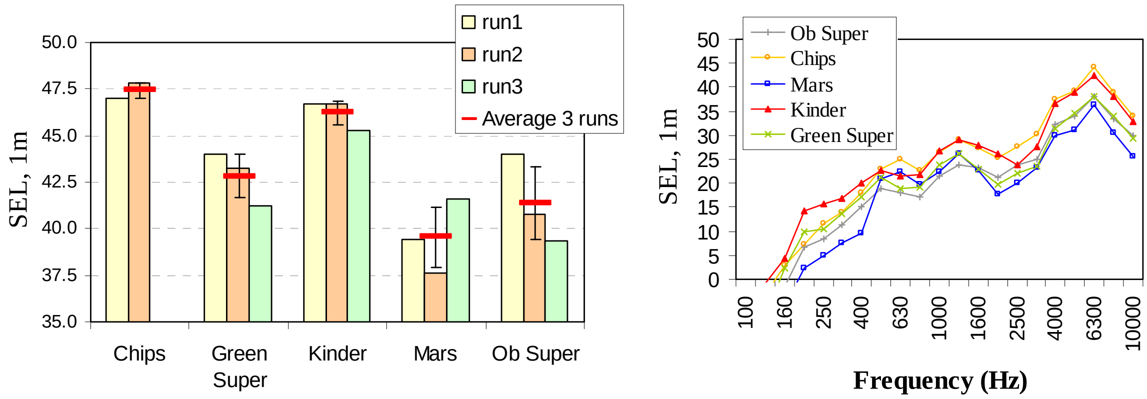

Figure 5 – Sound exposure level (SEL) at 1m for five packaging material; left:. comparison of different runs on samples of the same material; right: average spectra

Influence of crunching speed

The speed of crunching can only be controlled accurately with a suitable driving mechanism. To investigate the tolerance that can be allowed on this speed, the acoustic emission is investigated as a function of crumpling speed (Figure 6, left). The fluctuation in measured sound exposure level is of the order of a few dBA but no systematic trend is found. There is little theoretical work that can confirm this finding. The results obtained in [3] can be interpreted broadly to read that the damage is proportional to the product of strain rate and time. The integrated acoustic emission is proportional to the damage. As we are crunching the sample over a fixed length, the time needed reduces inversely proportional to the speed and the total acoustic energy emitted becomes theoretically independent of crunching speed.

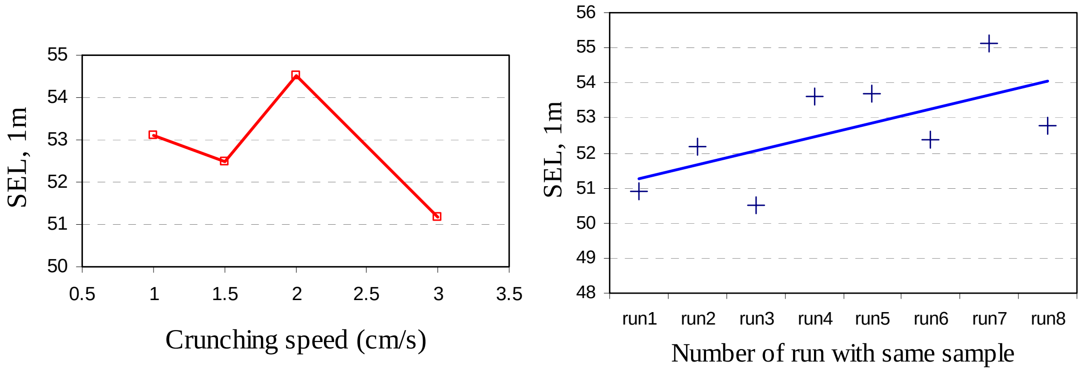

Figure 6 – Sound exposure level (SEL) at 1m; left: for different crunching speed; right: for different crumpling tests performed on the same sample.

Aging of the samples

To obtain an accurate and stable result several samples have to be crumpled and the emission averaged. Using the same sample multiple times would be more efficient. It is not certain however that this would not influence results. Crumpling the sample multiple times creates more creases in the sample at the start of each consecutive run. The influence of this initial condition is hard to predict. In Figure 6 (right) the effect of running the test on the same sample multiple times is illustrated. The crumpling noise increases with the number of runs, at least for as long as we tested it. A possible explanation for the higher acoustic emission for used samples could be the existence of more creases. In line with the discussion in [1] a network of creases on the material surface would lead to a higher number of small energy pulses to be released rather than a few high energy pulses. This in turn would shift frequencies in the range 100 to 1000 Hz upward making them more important in the A-weighted signal. This test shows that the same sample should not be used more than a couple of times.

COMPLEXITY

It has been well established that the crackling noise that is heard when crumpling a thin sheet of material is made up from a series of pulses with both their energy probability distribution and emission time following a complex pattern [1,2]. Let us analyze the current measurements within this context. Figure 7 shows a time series of acoustic pulses recorded when crumpling a typical packaging material in an anechoic room and the sound power spectrum of a few selected pulses. The sound spectrum of individual pulses falls between about 500 and about 8000 Hz. This explains the most important part of the octave band spectra shown in Figure 5. The lower frequency part of the spectrum, up to a few hundred Hz is determined by the sequence of pulses and should show complex behavior. Due to A-weighting this part of the spectrum becomes very small and does not contribute to the overall A-weighted level.

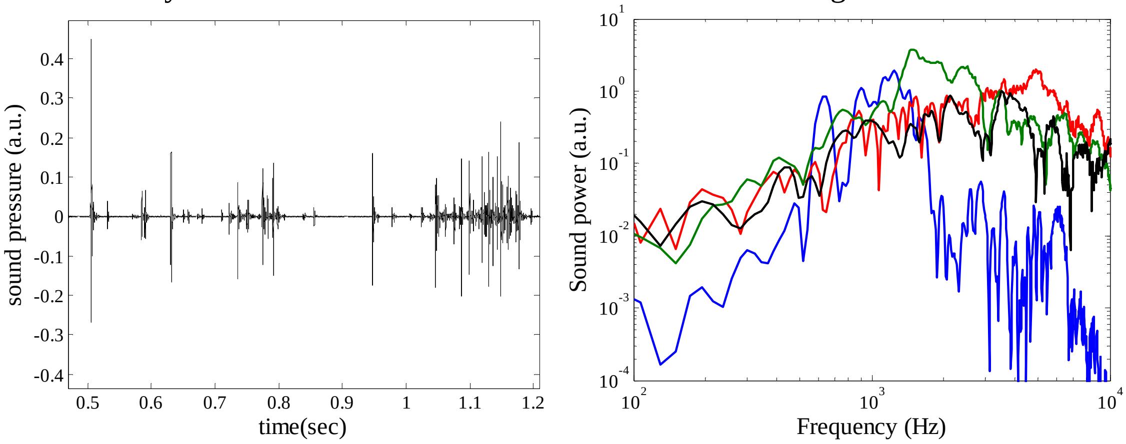

Figure 7 – Time series of acoustic emission (left) and sound power spectrum of individual pulses emitted during crumpling (right).

The temporal fluctuation of the sound level in the cavity is recorded at a rate of 20 Hz. The power spectrum of level fluctuation, obtained by FFT, is plotted on a log-log scale in Figure 8 for two measurements on each of the five materials studied. These spectra show the almost linear decrease typical for complex systems. In [1,2] the same underlying physics is expressed by plotting the probability distribution over the energy of individual pulses. This result also relates to the 1/f behavior found in music [4] or in natural and some urban soundscapes [5]. As a 1/f fluctuation in level (and pitch) seems to be appreciated in general by man, it could be envisaged that this characteristic is also appreciated in the crackling noise heard when unwrapping a product. Whether this is indeed the case needs further investigation.

CONCLUSION

A methodology for assessing the noise emission by crumpling packaging material in a reproducible way was designed and is described in this paper. For this measurement procedure to possibly become the standard in future, it has to be simple, produce reproducible results and be insensitive to the parameters that are most difficult to control. These aspects were studied in this paper. A measurement error of a few dBA has to be expected but even with this uncertainty the method is able to distinguish between similar but different packaging materials.

We were able to link some of the observations to theoretical work on crumpling noise found in literature. In particular the universal power law typical for complex systems was recovered in the spectrum of fluctuations of the noise level over time.

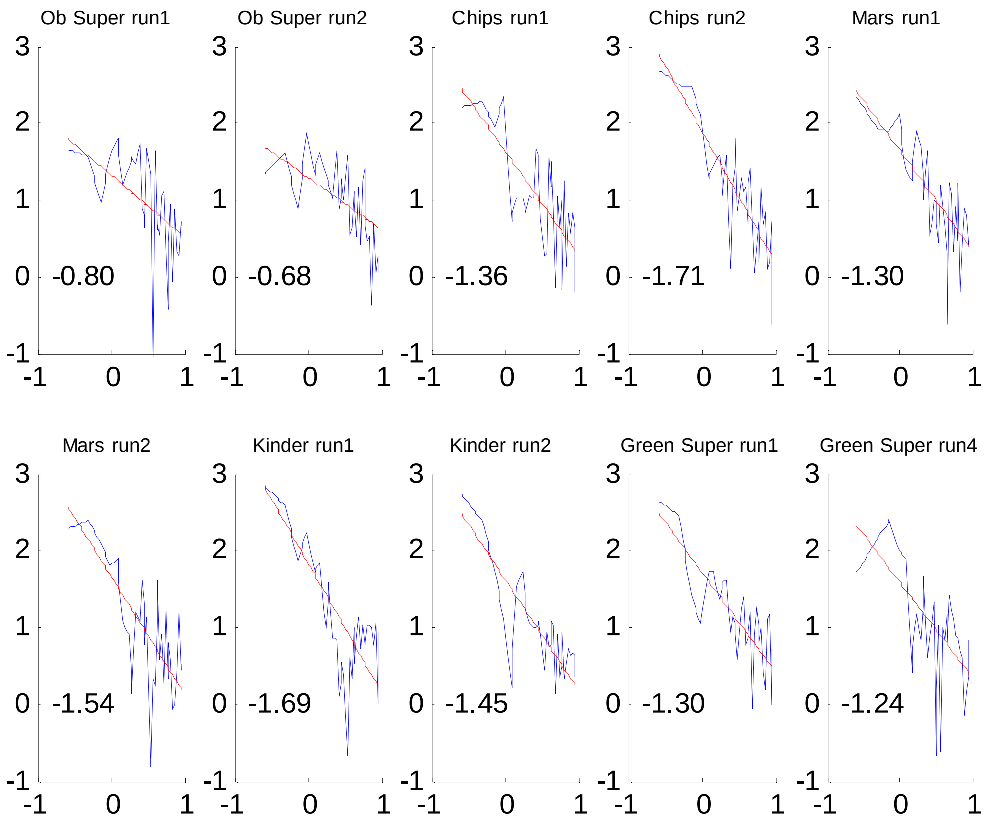

Figure 8 – Spectrum of level fluctuations; x-axis: $\log_{10}$(frequency), y-axis. $\log_{10}$(amplitude^2)

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