Acoustic Emission in Bonded Elastomer Discs Subjected to Compression. I

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SYNOPSIS

The apparent initial stiffness, M, of a rubber disc subjected to compression was experimentally determined. It was found that the experimental value of M is different than the value theoretically predicted according to Gent's equation. The aim of this study is to prove that this difference in the apparent modulus is due to the existence of microcavities within the testing rubber discs. The microvoids are formed along the curing process of the samples. A new nondestructive experimental technique, the Acoustic Emission (AE) technique, was used for the analysis of microcavitation within rubber discs subjected to compression. The count, event average count rate, amplitude, duration time, and rise time distributions of the received acoustic emission signals from the buckling of voids in the deformed solid, give more insight about the phenomenon of microcavitation.

INTRODUCTION

Rubber-like materials are well known for their low shear modulus and their capability of substaining large, recoverable deformations. However, the poor resistance of rubber-like materials to cavitation when they are subjected to a triaxial state of stress is not well known. Because of its importance to the understanding of the microfracture process, reinforcement, adhesive joint strength, and explosive decompression, several years ago we started investigating the microcavitation in thin elastomer discs with both its top and bottom surfaces glued to rigid metal plates. Following previous researchers,[1,2] we call this type of specimen a "poker chip."

The apparent initial stiffness, M, of a poker chip sample is a function of the aspect ratio, and can be theoretically estimated.[2] However, the effect of voids on the initial stiffness has not been taken into account. Recently, Kakavas[3] has shown a modified relation for the apparent modulus of the poker chip, which takes into account the volume fraction of the voids. Gent et al.[4-6] have experimentally examined the nucleation and growth of gas bubbles in elastomers.

In this article, we examine the voids in unfilled nitrile poker chip samples using the "acoustic emission" technique. Acoustic emission (AE) is a transient, elastic wave, generated by the rapid release of energy within the deformed material. Although the acoustic emission technique has been applied in a variety of engineering materials[7-11] an insignificant amount of work has been dedicated to elastomeric materials. This is due to the high damping and attenuation of rubber-like polymeric materials in high frequencies. These two factors may easily obscure the identity of the acoustic emission signals. In our laboratory, the acoustic emission technique was applied to examine the buckling of voids when the poker chip was subjected to uniform compression.

EXPERIMENTAL

Materials

The chemical composition of the material used for this study is given in Table I. All the ingredients were well mixed in an open, two-roll mill. Thin cylindrical pieces of the mixed material were cut and sandwiched between two metal plates and were placed in an appropriate mold for curing. Thereafter,

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Table I Chemical Composition of the Poker Chip Samples

Chemical Compound	Parts (g)
NBR (Krynac–800)	100.0
Zinc Oxide	5.0
Stearic Acid	1.0
N-isopropyl-N-Phynyl-P-Phenylenediamine	1.0
Magnesium Carbonate (Treated Elemental Sulfur)	2.0
Benzothiazyl Disulfide	1.5
Total	110.5

this type of sample was called a poker chip. The preparation of the poker chip samples is extensively described elsewhere.[3] The geometry of the prepared poker chip samples is depicted in Figure 1. The diameter of the samples was 6 inches and the thickness varied from 0.2 to 0.4 inches. The samples were compressed in an M.T.S. (Machine Testing Specimens) testing machine. The speed of the piston was kept constant at 0.01 in./min for all tests.

Stress–Strain Curve of a Bonded Elastomeric Disc Subjected to Compression

The observed stress–strain curve at low strain from the compression test of a poker chip sample is shown in Figure 2. For all the compression tests, the apparent modulus (M) of the poker chip samples varied from 4400 to 5000 psi. When the samples were tested for the second and third times, the modulus was not reduced as in the case of the tension tests.[12] According to Gent's equation[13] for *incompressible* rubber, the normalized modulus (M/E) of the poker chip is given by:

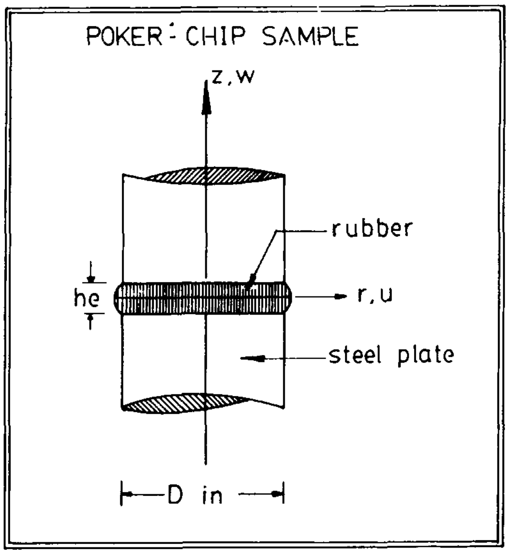

Figure 1 A poker chip sample subjected to compression.

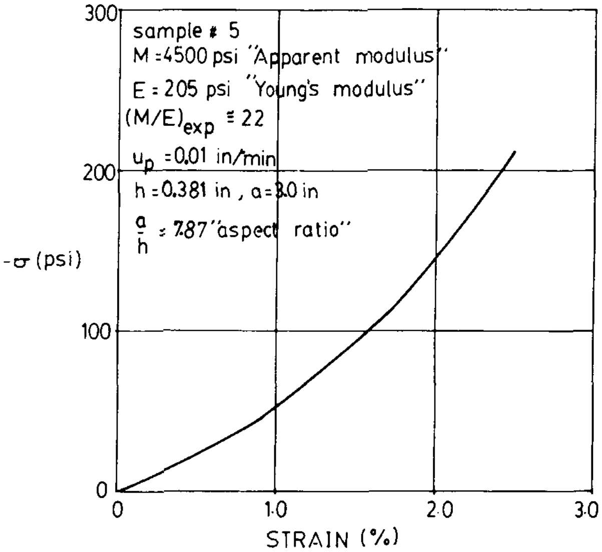

Figure 2 Stress–strain curve of an unfilled, nitrile rubber disc subjected to compression.

$$\frac{M}{E} = 1 + \frac{1}{2}\left(\frac{\alpha}{h}\right)^2 \qquad (1)$$

where α, h defines the radius and the thickness of the poker chip specimen (Fig. 1) and E denotes the Young's modulus of the material.

Several O-ring samples were prepared in our laboratory from the same material, which is described in Table I.[3] The O-rings were pulled on an Instron testing machine and the stress–strain curve is shown in Figure 3. A value of E = 205 psi was determined for the modulus of elasticity of the unfilled nitrile rubber. From the stress–strain curve of the poker chip sample (Fig. 2), a value of M equal to 4500 psi was estimated. Hence, the experimental value of the normalized apparent modulus $(M/E)_{exp}$ is equal to 22, within the experimental error. In contrast (with $\alpha = 3$ in. and h = 0.381 in.), eq. (1) indicates that the theoretical value of $(M/E)_{th}$ should be equal to 32. Therefore, there is a difference between the theoretically predicted value of (M/E) and the experimentally observed value. This drop of the apparent modulus should be attributed either to viscoelasticity of the material or to the existing microvoids within the curing samples. It was proved[3] that the viscoelasticity does not play a significant role in

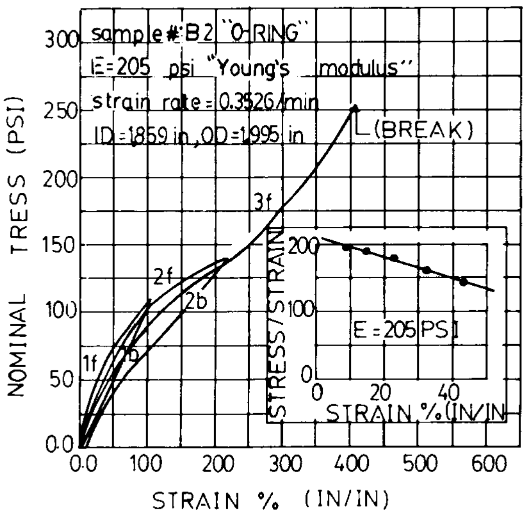

Figure 3 Stress–strain curve from an O-ring, unfilled, nitrile rubber sample.

the testing material. In this article, we will show that the drop in the apparent modulus is due to the voids.

Experimental Procedure for the Evaluation of the Acoustic Emission in Bonded Elastomer Discs Subjected to Compression

A typical experimental set up for the evaluation of the buckling of existing microvoids in bonded, unfilled nitrile rubber discs, subjected to compression, is shown in Figure 4. A uniform compression was applied on the poker chip samples in an M.T.S. testing machine. When the bonded elastomeric discs were subjected to compression, elastic waves were released from the buckling of the existing microvoids within the material. The voids were formed in the poker chip specimens along with the curing process of the samples. The elastic waves generated were propagated spherically in all directions within the material until they struck the elastomer–metal interface. A set of four piezoelectric transducers were attached to the upper and lower plates of the poker chip. The transducers were used for the conversion of the elastic waves to low level and high impedance electrical signals.

The output signal of each sensor was amplified by 40 decibels (db), using a preamplifier. The preamplifier converts the signal into low inpendance for transmission over long distances. The preamplifiers used were of low band frequency, between 20 KHz and 1 MHz. Thereafter, the acoustic emission electrical signals were stored and analyzed by Dynegan 8000 equipment.[3] An oscilloscope was placed after the preamplifiers in order to observe visually the received acoustic emission signals from the acoustic voids. A video recorder (model AV-3650) was used for storing the detected events for further analysis.

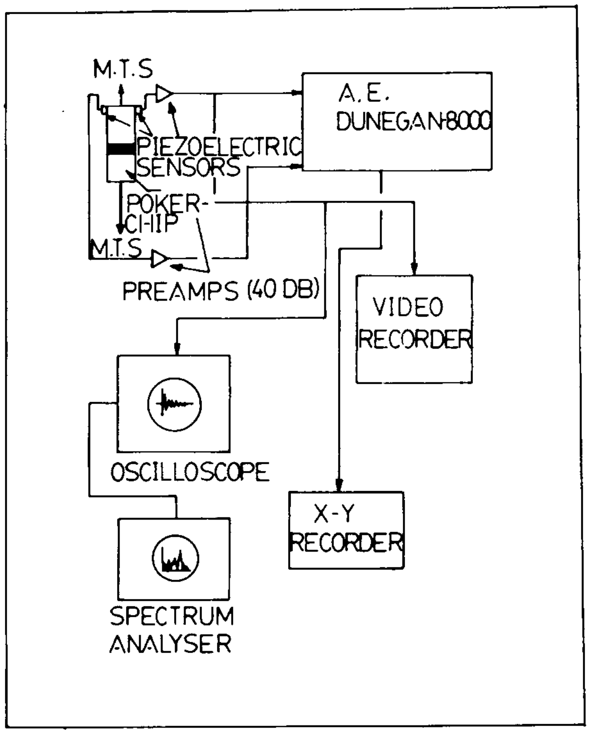

Figure 4 Experimental set up.

Acoustic Emission Data from Bonded Elastomer Discs Subjected to Compression

The standard definitions of terms related to the acoustic emission are given elsewhere.[12]

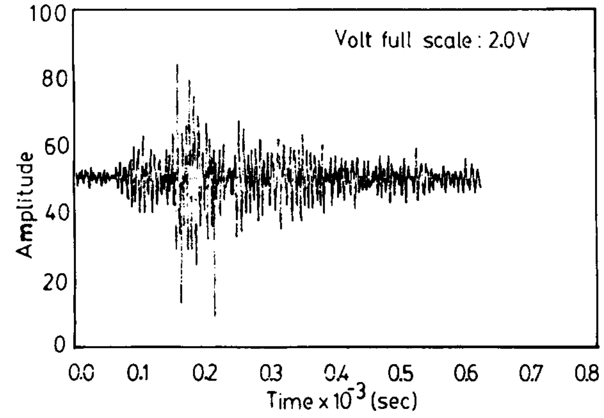

Figure 5 Acoustic emission waveform (Volts full scale: 2V).

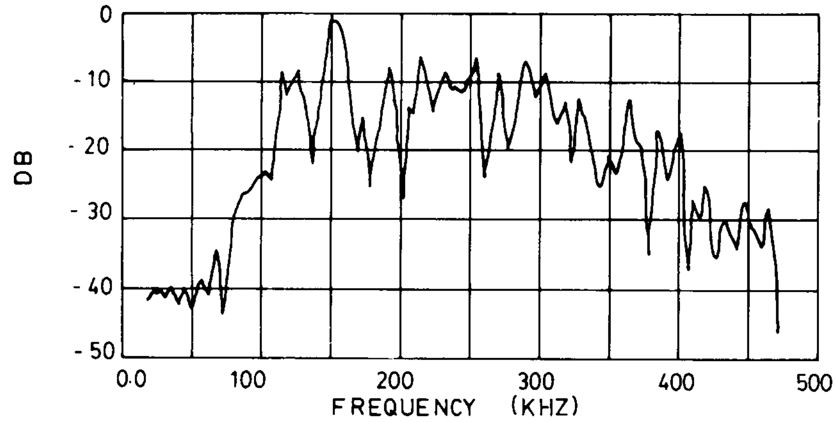

Figure 6 Frequency spectrum of the acoustic emission signal of Figure 5.

A typical acoustic emission waveform, received from the compression tests, is shown in Figure 5. The peak amplitude of the detected event is about 1.5 V at the output of the transducers, which corresponds to 10 mV at the source of the acoustic pulse. The "duration time" and the "rice time" of the depicted AE event are about 300 and 100 μsec, respectively. The waveform of the emission carries information about the fine structure of the source event. A detailed interpretation of the waveforms is complicated by the multiple reflections within the testing specimen. This effect largely determines the waveform of the observed pulse and the nature of the source event.

Frequency analysis of the detected pulse may also yield information about the source and the variations in the transmission properties of the structure being tested. One possible use of frequency analysis is the detection of growing structural weakness and of the initial stability. Figure 6 shows the frequency spectrum of the waveform depicted in Figure 5. The spectrum has some strong peaks between 120 and 150 KHz and between 200 and 400 KHz. The resonance of the transducer (model S140) is 150 KHz and the remaining peaks are attributed in the frequency spectrum of the AE pulse.

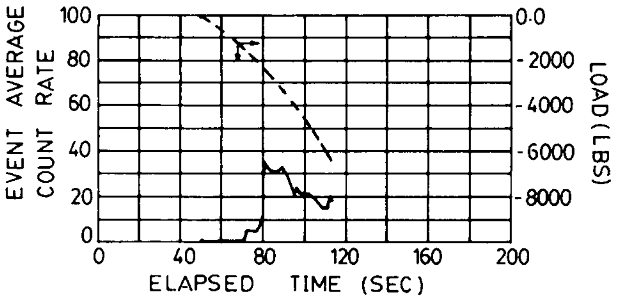

Figure 7 Load (lbs) and event average count rate (N) vs. the elapsed time (sec) of deformation.

Figure 7 shows the "load" and the "event average count rate (N)" vs. the "elapsed time" of the deformation of the specimen. All the other tests have shown almost the same behavior within the experimental error. A number of acoustic emission events were generated within the compressed rubber disc after 30 sec of deformation, which corresponds to 1.3% strain. The detected events may be attributed readily to the closing of the existing voids within the unfilled nitrile rubber (poker chip) sample.

The "amplitude distribution" of the detected acoustic emission is shown in Figure 8. A wide distribution of the amplitude, between 55 db and 70 db, was observed. The threshold of the amplitude was specified at 50 db in order to eliminate the noise from the M.T.S. testing machine. Since an amplitude of 0 db corresponds to 1 μV at the source of the acoustic pulse within the material, Figure 8 indicates that most of the waveforms released from the microvoids had an amplitude between 560 μV and 10 mV.

The "cumulative amplitude distribution" of the acoustic pulses is shown in Figure 9. Obviously, the cumulative distribution function of all the detected

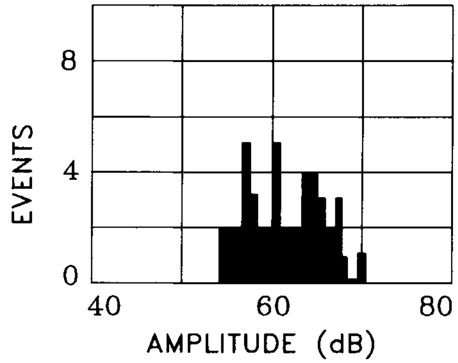

Figure 8 Amplitude distribution (db) of the detected acoustic emission events.

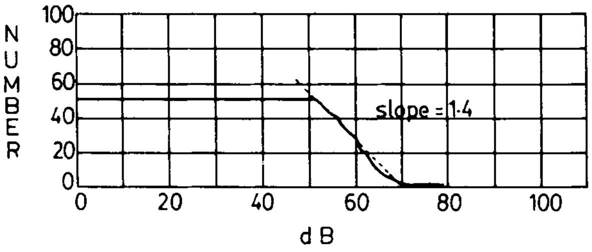

Figure 9 Cumulative amplitude distribution of the acoustic emission pulses.

events is almost linear to slope $b = 1.4$. This value depends on the material and the deformation mechanism. However, the way the material parameter b depends on the deformation mechanism is not clear. Further studies must be performed on this subject.

The normal distribution of the "duration time" of the detected signals is shown in Figure 10. Most of the events have duration time of approximately 100 μsecs. The distribution of the "rise time" of the detected events is shown in Figure 11. Most of the events had a rise time of between 0 μsecs and 300 μsecs.

CONCLUSIONS

It was found that the drop in the apparent initial stiffness of a poker chip rubber sample, subjected to compression, was due to the existence of voids within the testing material. An analysis of the detected voids within the deformed poker chip specimen was experimentally performed using the acoustic emission technique. It was shown that the AE method is a valuable, nondestructive, experimental technique for the analysis of existing microvoids in unfilled nitrile rubber discs subjected to compression. Some useful information may be extracted using the waveform and the frequency spectrum of the AE signals. The amplitude of the received AE events may be correlated to the amplitude of the source of the acoustic signal within the material.

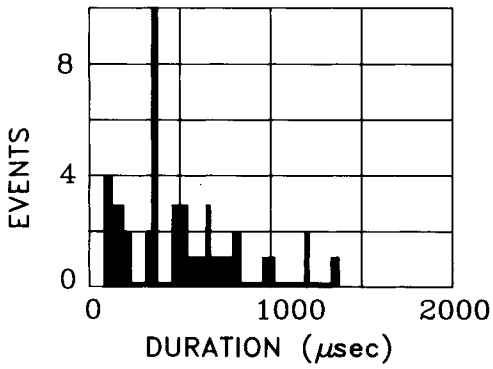

Figure 10 Duration time (sec) distribution of the detected AE signals.

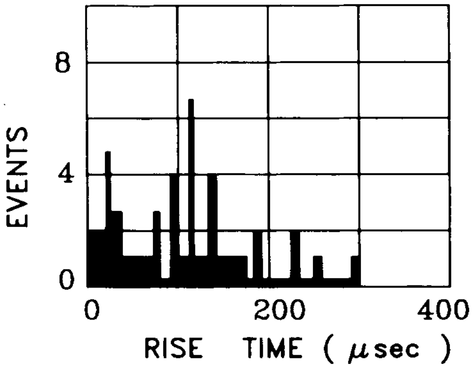

Figure 11 Rise time (sec) distribution of the AE signals.

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