ULTRASONIC EMISSIONS IN SNOW

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ABSTRACT

Burst type acoustic signals have been monitored in snow subjected to various load and deformation histories over a wide range of frequencies. The pattern of the acoustic response is closely related to the particular load or deformation history applied. Examination of the emission pattern suggests a description of the deformation of snow in terms of a structural mechanism. The results of a number of experiments are given and interpreted in terms of their acoustic response.

Also presented is a discussion of the possible application of the acoustic emission technique for making *in situ* measurements of the state of stress in an active snow slope.

Introduction

A number of different types of acoustic signals which emanate from snow subjected to mechanical loadings have been detected. These signals can be broadly classified into two groups: audible and subaudible. In terms of audible signals we can cite such examples as the squeaking which can often be heard when walking on snow on a cold day, or the sharp report which accompanies a rapidly propagating crack in the tensile region of a snow slope. Less familiar examples of audible sounds that can be detected in snow are the sound of a collapsing snowpack, and the sound of one layer of snow slipping over an adjacent layer.

The second category, subaudible noise, can be subdivided into frequency related classifications. In one instance the sound is in the audible spectrum, but is of such low intensity that it cannot be detected by the unaided ear. To date we have detected this type of signal only in snow samples subjected to deformation rates which induce a brittle response in the snow. The second type of noise is ultrasonic. This type of acoustic emission has been monitored in snow over a wide range of loadings. It is this kind of emission that will be dealt with in this paper.

Emission Characteristics and Possible Sources

To investigate the nature of ultrasonic emissions in snow, consideration must be given to the possible source of the acoustic event, and to the system used for detecting it. Consideration of the acoustic emission monitoring system, and in particular the transducer, is important since information obtained in terms of frequency content, amplitude, and duration of an acoustic event in general reflect system characteristics. The source disturbances probably bear little resemblance to the signal that is recorded. In defining ultrasonic emissions we are indicating that the transducer used is most sensitive to excitation in the ultrasonic region of the frequency spectrum.

Since the energy release associated with a burst emission is small (an estimate in the neighborhood of 10^{-13} Joules has been suggested by Liptai et al. 1971), it is customary to monitor the transducer used to detect the acoustic signal in the vicinity of one of its resonance peaks. This method makes it possible to detect small amplitude signals, but provides little information about the form of the exciting signal. Using this technique limits the information obtained to establishing a transient disturbance has taken place, and that the disturbance has sufficient energy in the region of the transducer resonant frequency to excite the transducer to resonance. A definite advantage in working in the ultrasonic region of the frequency spectrum is that for frequencies above 30 KHz interference from extraneous noise is minimal.

As indicated above, it is difficult to describe in any detail or with any precision the form of the acoustic emission as it originates. The fact that acoustic signals are detected in snow indicates that when snow is subjected to mechanical loadings, a nonconservative energy conversion takes place, with part of this energy being dissipated in the form of noise.

It is probably correct to assume that acoustic energy represents only a small portion of the total energy dissipated. From oscilloscope and magnetic tape records we can establish that the emission of sound from snow occurs in bursts of noise rather than continuously. These bursts take place at intermittent intervals depending on the particular loading applied.

To identify the sources of acoustic emissions in snow we will rely on observations that have been made of the structural changes that take place in snow during the deformation process. From these observations we can tentatively identify possible emission sources. For deformation rates which produce a brittle response in the snow, Kinosita (1967) observes that failure is characterized by the breaking of bonds between ice crystals composing the snow matrix. For this type of deformation we detect both ultrasonic and audio signals emanating from the snow. Since Kinosita indicates that intercrystalline fracture is the only means by which snow deforms at high rates we are probably correct in assuming that for these rates some form of intergranular movement generates the acoustic signal observed.

For snow that is deformed at rates which produce a plastic response acoustic emissions may be due to a number of different mechanisms. Observations reported by Wakahama (1967) on the compression of snow at slow rates indicate that the structural changes which take place in the snow matrix are basal glide, slip at grain boundaries and separation of ice grains. It appears plausible that acoustic emissions can originate from the formation of slip planes in the ice grains and also from the separation of ice grains. In the case of the formation of the slip plane this takes place at a rapid rate in the ice grain. A number of these slip planes forming simultaneously in the ice crystals comprising the snow matrix might produce an acoustic signal at a level that can be detected. If the separation of ice grains takes place in a rapid manner this may also represent an acoustic source. In the case of slipping at grain boundaries it would appear that this kind of process would not generate sufficient power to produce a detectable acoustic signal. Wakahama also reports that in addition to these primary mechanisms grain fracture, void formation, and grain boundary migrations are also observed. In considering these mechanisms as possible acoustic sources it is probable that grain fracture and the formation of voids within grains could generate transient acoustic signals. A number of experiments are now being planned which will attempt to look at each of the above mechanisms as possible emission sources; one that is presently being considered on a theoretical basis is the form of the stress wave which might emanate from these mechanisms.

Acoustic Emission Monitoring System

The experimental system which is used to monitor and record acoustic emissions in snow, in the laboratory, is shown schematically in figure 1. This system is typical of many acoustic emission systems presently employed for work in materials research. Since the basic acoustic emission system is well described in the literature, the reader is referred to papers by Tatro (1971) and Dunegan and Harris (1969) for complete details. It is worth commenting on a special modification that is necessary when working with snow.

Since snow is a soft material, mounting the transducer to the snow poses two special problems. Care must be taken so that spurious stress fields are not set up by having the transducer come in direct contact with the snow. Also, many tests are conducted at relatively high rates and to large deformations, so that it is possible to generate pseudo-emissions caused by the relative motion between the specimen and the transducer. Both of these problems are solved by applying a thick coating of silicon grease to the transducer so that it is not in direct contact with the snow sample.

The system used in our present experiments records only the rate at which emissions occur and the total number of emissions.

Experimental Results

In order to establish baseline data on acoustic emissions in snow, we conducted a series of experiments in which a number of load and deformations were applied. These experiments consisted of constant rate tests in tension, compression, and torsion and creep tests in tension and compression. The snow used in these experiments can best be classified as IIB2, using the classification system of Sommerfeld and LaChapelle (1970).

Figure 2 depicts a typical emission response curve (rate of emission vs. time) for a sample of snow subjected to a constant rate of deformation. The stress time curve for this test is also shown. The snow in this test was deformed at a constant angular rate of 2.2° per minute (0.12° per minute per centimeter of length.) for 20 minutes and allowed to relax for 10 minutes. At the end of the 10-minute relaxation period, the specimen was then reloaded at the same rate. The results obtained when the specimen was reloaded are also shown. The stress response curve is for the shear stress calculated at the specimens outer radius. The acoustic response depicted here is typical of the results obtained for snow subject to constant deformation rates, with variations

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Figure 1. Acoustic emission monitoring system for snow.

1 - Signal Conditioner
2 - Load, displacement record
3 - Tape recorder
4 - Oscilloscope
5 - Event rate counter
6 - Event rate recorder
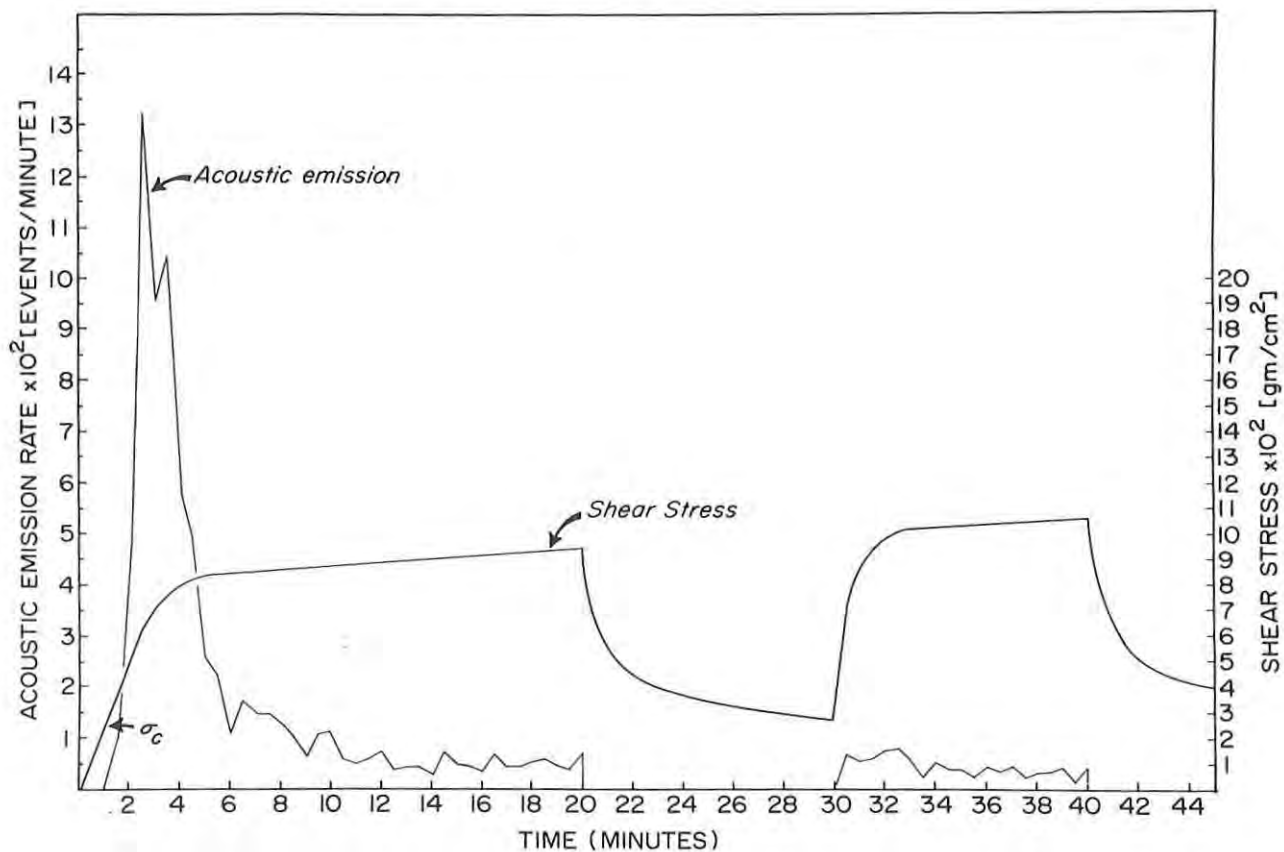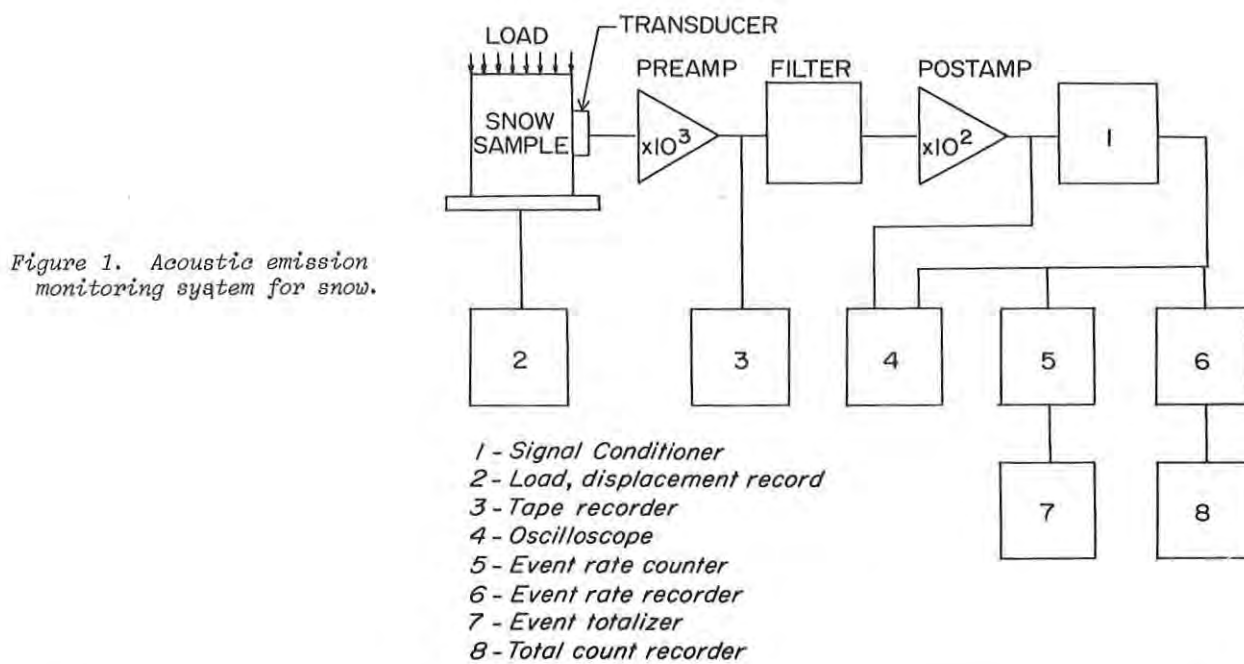7 - Event totalizer
8 - Total count recorder

Figure 2. Acoustic emission rate response and shear stress response vs. time for a snow specimen deformed at a constant angular deformation rate of 2.2° per minute. The specimen was deformed for 20 minutes, allowed to relax for 10 minutes, and reloaded. Shear stress is calculated at the outer radius of the specimen.

being observed depending on the rate and mode of deformation (tension, compression, or torsion). Figure 2 will serve to point out the salient features of the emission response for this type of load history.

The snow used in these experiments was obtained from a collection area on relatively flat ground at a depth of about 1 meter. On this basis we will assume that the maximum stress that it had previously experienced was an overburden stress of 35 gm/cm^2. This fact is significant since prior load history is an important parameter in terms of acoustic response. As loading is initiated no acoustic response is observed until the stress reaches a certain level; this is depicted as σ_c in figure 2. As the stress increases above this value acoustic activity is initiated. The rate of acoustic activity then increases to a maximum which corresponds to the point in the stress deflection curve where the stress begins to fall off rapidly. With further deformation the rate of acoustic activity decreases steadily as the stress raches a steady state response. If the deformation is stopped, the acoustic activity ceases and the stress relaxes. If after a period of relaxation the snow is again subjected to further deformation at the same rate, the acoustic activity resumes at a rate nearly equal to what it was before deformation was terminated. This phenomenon has been observed for relaxation periods of up to 15 hours, which is the longest time that we have allowed specimens to relax before reloading. As indicated earlier, the basic acoustic emission response is similar for the three modes of deformation studied.

The acoustic emission response is very sensitive to the rate at which the snow is deformed. For relatively high rates of deformation, (that is rates close to those which induce fracture in the snow) the rate of emission rises to its maximum value and then decreases rapidly with continued deformation. Figure 2 shows the typical emission response for a high deformation rate. For very low deformation rates (rates several orders of magnitude below those which induce fracture) the acoustic emission rate curve does not show this rapid rise and decay. This rapid rise and decay feature becomes increasingly pronounced as the rate of deformation is increased.

In addition to constant deformation rate experiments a number of constant load tests in uniaxial compression and tension have been conducted and the acoustic response monitored. Figure 3a shows the acoustic response recorded for a snow sample subjected to a number of discreet load steps in uniaxial compression.

The acoustic response that is observed in creep experiments can be described as follows. For low stresses, below approximately 100 gm/cm^2 no emission activity is detected except for a few bursts when the load is initially applied. If the stress is increased an incremental amount, to a level where activity is detected, acoustic emissions are observed throughout the region of primary creep. As the creep rate approaches a steady state the rate of acoustic activity decreases to a near zero value. Again it is important to emphasize that the snow used here was subjected to only overburden stresses prior to testing. Figure 3b shows the results of unloading the above specimen, allowing it to relax and then reloading it. Note that little or no acoustic activity is observed until the stress applied to the specimen is equal to or greater than the maximum stress it had previously experienced. This interesting phenomenon is known as the Kaiser Effect, and may have a possible application for measuring the state of stress in a snowslope.

Like the constant deformation rate the basic pattern of acoustic emission tends to be similar for both tension and compression at relatively low stresses. A number of tension creep tests have been conducted at relatively high stresses (stresses in the vicinity of 500 gm/cm^2) with some interestering results being observed. The results of one such test is reported here.

A specimen was incrementally loaded over a 100-minute time interval to a stress of 500 gm/cm^2 and the acoustic response observed. Within a minute after the load was applied to produce this stress in the specimen, the acoustic emission rate was 100 events per minute. Over the next 63 minutes the acoustic emission rate dropped to 25 per minute. The emission rate then showed some sign of increasing for the next 3 minutes. It then increased in a monotonic manner for 5 minutes to a rate of 169 events per minute, at which point the specimen failed catastrophically. This experiment was repeated with essentially the same result observed. The implication from this experiment is that for this type of load condition the onset of failure could be detected some minutes in advance.
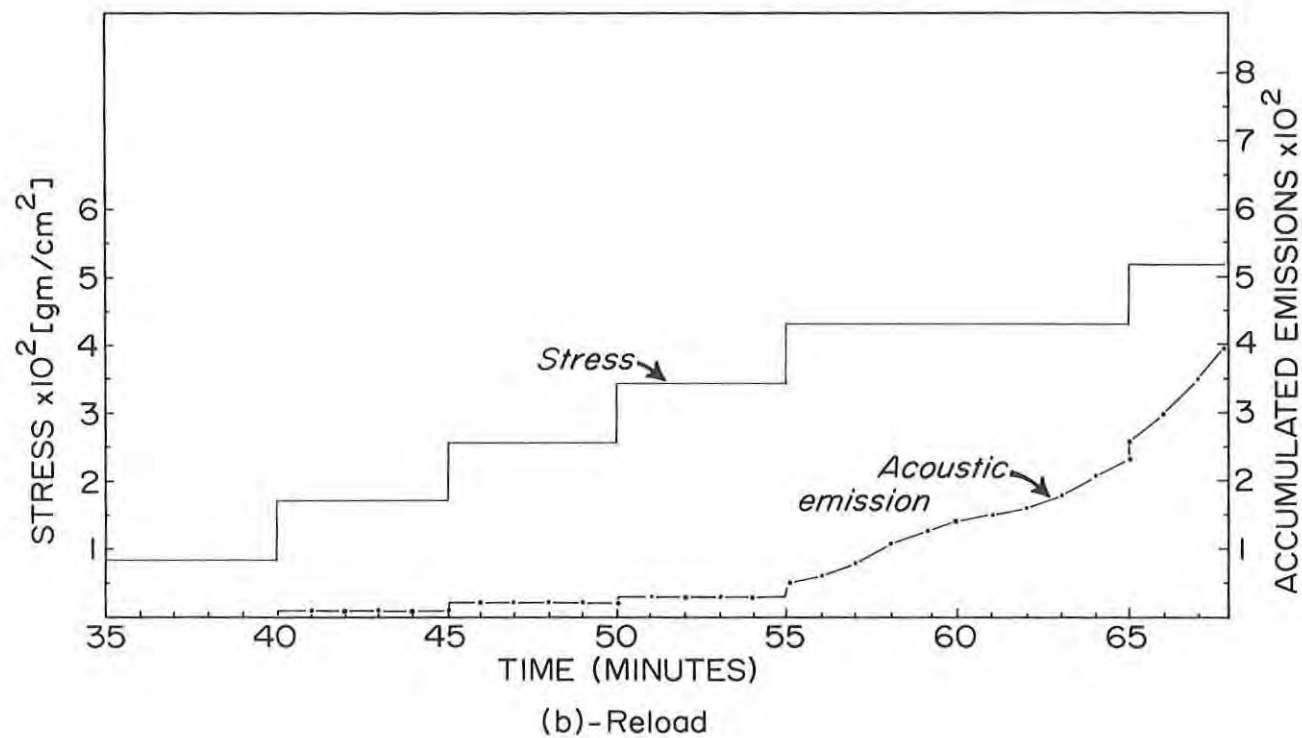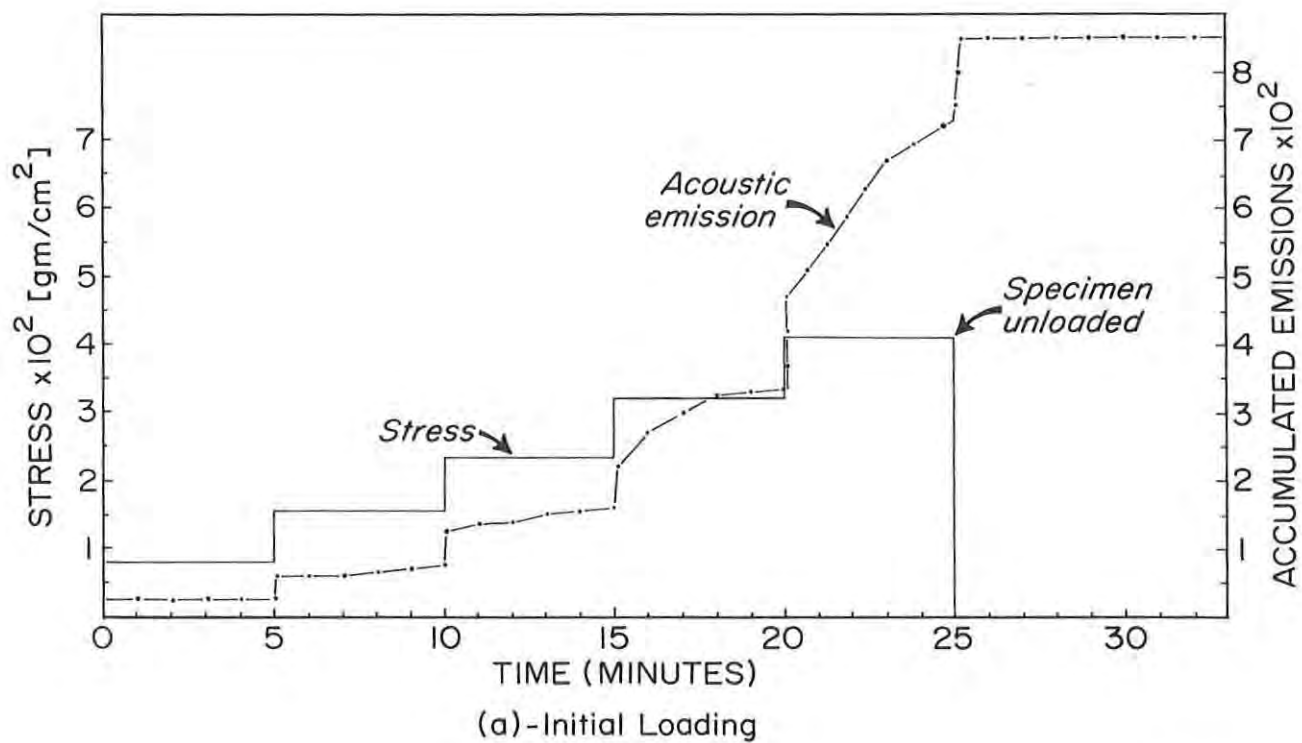
Figure 3. Accumulated acoustic emission response for a specimen subjected to an incremental load history: (a) Results of initial loading and unloading of snow sample; (b) Results obtained when specimen was reloaded.

Discussion

This paper has attempted to give a brief view of the acoustic emission phenomenon in snow. We have considered some possible emission sources and also presented the results of a number of laboratory experiments. In observing the acoustic emission phenomenon in snow, two possible applications in snow mechanics are suggested. As a purely empirical tool it appears that a great deal of information about stress and strain in an avalance slope may be gined by an acoustical monitoring system. Observations could be made both by placing transucers in an avalanche slope and making *in situ* observations and by removing samples and testing them in the laboratory. Using laboratory data as a basis, a comparative analysis could be made to interpret field data. One such test presently being investigated will utilize the Kaiser Effect to measure the state of stress over a period of time in a typical avalanche slope. If an oriented sample can be removed from the snowpacj without introducing spurious overstress in the process, it appears feasible that its *in situ* stress can be determined by controlled reloading in the laboratory.

A second possible research function of acoustic emissions would utilize this phenomenon, in conjunction with more standard techniques of experimental stress analysis, as an aid in the development of a constitutive relation for snow. At present the relation between acoustic emissions and the deformation mechanism in snow is not well understood. Consideration of the patterned acoustic response observed for various load and deformation histories indicates that it is related to the mechanical response. Since burst type emissions detected in snow originate from transient disturbances that take place in and between ice grains which compose the snow matrix, it appears reasonable to interpret the acoustic phenomenon at the structural level.

Acknowledgments

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