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A MECHANICAL TEST PROCEDURE FOR AVALANCHE SNOW*

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Abstract. The design, construction, and testing of a portable constant strain-rate testing machine for determining the mechanical behavior of avalanche snow is described. The machine is intended for use in determining the stress–strain–time behavior of low-density natural snows in the field. A technique for making direct measurements of strain in the snow sample is described and stress–strain curves are presented for strain-rates ranging from 0.5 to $5.0 \times 10^{-5}\ s^{-1}$. The densities of the snow samples tested range from 186 to 335 kg m^{-3}. Ultimate-strength data and relaxation curves are also presented.

Résumé. *Un appareil pour messurer le comportement mecanique de l'avalanche de neige.* On décrit la conception, la réalisation et les essais d'un appareil portable pour mesurer la vitesse de déformation continue en vue de déterminer le comportement mécanique des avalanches de neige. L'appareil est destiné à servir à déterminer le comportement effort–déformation–temps des neiges naturelles à faible densité sur le terrain. Une technique est décrite pour faire des mesures directes de déformation dans un échantillon de neige et on présente des courbes effort/déformation pour des vitesses de déformation allant de 0,5 à $5,0 \times 10^{-5}\ s^{-1}$. Les densités des échantillons de neige essayés vont de 186 à 335 kg/m^{-3}. Une résistance finale et des courbes de relaxation sont également proposées.

Zusammenfassung. *Ein mechanisches Untersuchungsverfahren für Lawinenschnee.* Es wird der Entwurf, die Konstruktion und Erprobung eines tragbaren Gerätes beschrieben, mit dem das mechanische Verhalten von Lawinenschnee unter konstanter Verformungsgeschwindigkeit bestimmt werden soll. Das Gerät soll das zeitliche Verhalten von Spannung und Verformung in natürlichem Schnee geringer Dichte im Felde feststellen. Eine Technik zur direkten Messung der Verformung in einer Schneeprobe wird angegeben; Spannungs-Verformungskurven für Verformungsgeschwindigkeiten im Bereich von 0,5 bis $5,0 \times 10^{-5}\ s^{-1}$ werden gezeigt. Die Dichten der untersuchten Schneeproben lagen zwischen 186 und 335 kg m^{-3}. Werte der Grenzfestigkeit und Relaxationskurven werden ebenfalls wiedergegeben.

Introduction

A number of investigators have undertaken to apply the finite-element method to the analysis of avalanche snow-packs in an effort to develop insight to avalanche release processes (Smith, 1972; Curtis, unpublished; Curtis and Smith, 1974; Smith and Curtis, [1975]). These studies have indicated that the distribution of stresses in an avalanche snow-pack are significantly affected by the nature of non-linear deformation processes in the snow-pack, most particularly large deformations which may occur in a weak sub-layer. This paper reports on the development of a method by which field data can be obtained on the mechanical behavior of avalanche snow. These data are needed for more detailed analyses of the stress–deformation history in a layered snow-pack.

Objectives

The objectives of this work were as follows:

(1) To develop a constant strain-rate testing machine which can be used in the field to determine stress–strain–time behavior of natural snow.

(2) To develop a method by which strain may be directly measured on a snow sample during the experiment.

(3) To perform tests using the experimental procedures developed to verify the procedures and to provide preliminary data.

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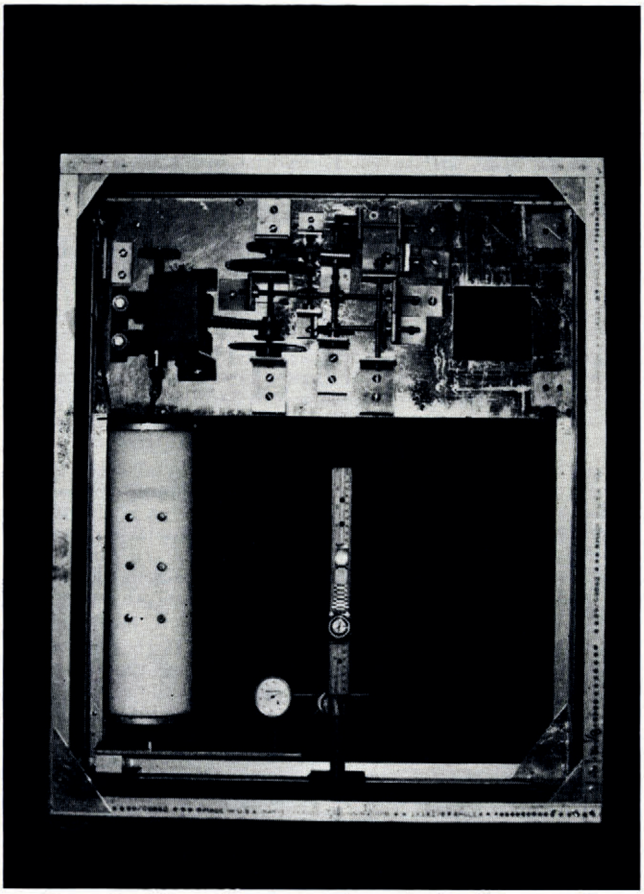

Fig. 1. Load frame for constant strain-rate testing of snow samples.

Apparatus and procedures

A photograph of the load frame with a mock snow sample is shown in Figure 1. The load frame is constructed of light-weight aluminum angles and the overall size is comparable to the size of a large suitcase. The complete system has a total weight of 18 kg and the machine has a gear-drive loading mechanism which provides a total of 21 different constant strain-rate settings ranging from $0.5 \times 10^{-8}\ s^{-1}$ to $2.0 \times 10^{-2}\ s^{-1}$. Figure 2 shows the details of the sample tube used to make snow samples. The cylindrical sample tube is pushed into a snow layer and is then carefully removed holding the intended snow sample inside. The tube is relieved on the sides so that a dog-bone shaped sample may be easily fashioned. The snow sample is attached to the machine by freezing grooved aluminum plates to the ends of the sample and then using pinned connections to secure the plates to the machine (Salm, 1971).

Measurement techniques

The load on the sample is measured by using a dial indicator to measure the end deflection of a calibrated cantilever beam attached to the lower sample jaw. The measured deflection is used to compute the force applied to the sample and the force value is divided by the reduced area of the sample to determine the stress.

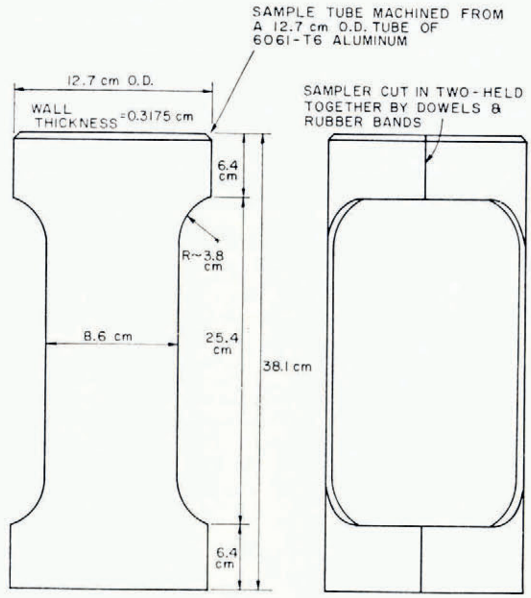

Fig. 2. Drawing of sample tube.

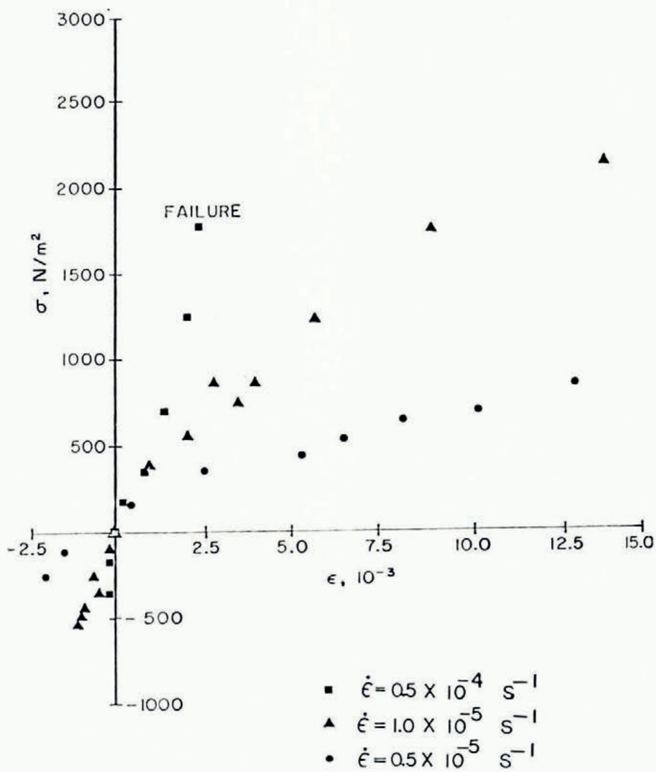

Fig. 3. Comparison of stress–strain curves.

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Strain measurement of the snow is accomplished by using a modified photogrid technique (Durelli and others, 1958). Six small targets are embedded in one side of the snow sample and the sample is photographed at intervals during the test to record the position of the targets in space and to record the dial-indicator reading and the time. A stereo comparator is then used to measure and to digitize the coordinates of the targets. The target coordinate data were reduced using a computer program which calculates longitudinal strain, lateral strain, and Poisson's ratio for each of the six longitudinal and three lateral gauge lengths in the data photograph.

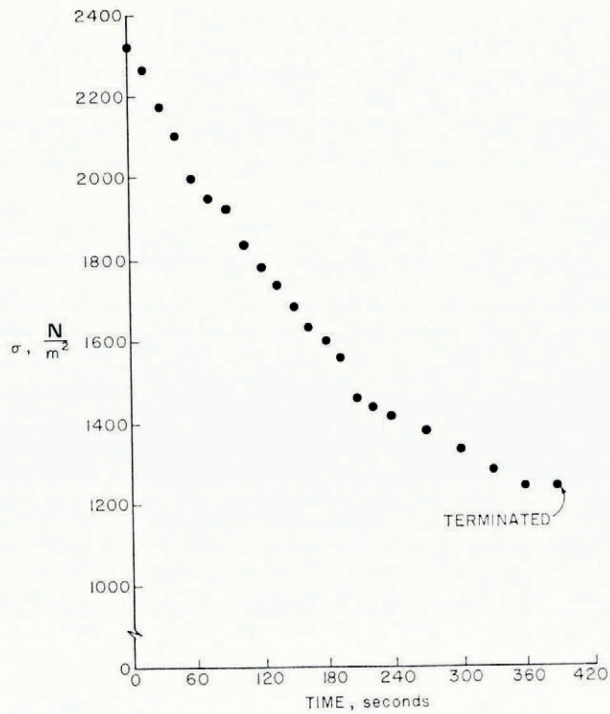

Fig. 4. Relaxation curve test 2/6-6, $\rho = 186$ kg/m³.

Test results

A total of seven tensile tests were successfully conducted at strain-rates from $(0.5$ to $5.0) \times 10^{-5}$ s^{-1} for the three snow densities: 186 kg/m³, 300 kg/m³, and 335 kg/m³. The typical behavior of snow under tensile loading seen during these tests is shown in Figure 3.

Several relaxation tests were also conducted. Figure 4 shows the result of a typical relaxation experiment for a density snow of 186 kg/m³. Tests of this type were conducted for densities of 186 and 335 kg/m³.

Discussion

The photogrid strain-measurement technique proved to be quite satisfactory in this application with the greatest advantage being that it requires no force to operate. The handling and analysis of the photographs becomes quite tedious even though the data analysis is automated, but the accuracy of the procedure was found to be adequate. Analyses of the data taken indicated that the standard deviation in the strain measurements is about

0.25×10^{-3} m/m. On Figure 3, this error corresponds to an error band in the strain which is about the width of three plotting symbols.

The effect of strain-rate on the shape of the stress–strain curve can be seen in Figure 3 where the results of tests for three different strain-rates at the same density are plotted with the expected result that the test with the highest strain-rate produced the highest slope and that with the lowest strain-rate produced the lowest slope. Research by Hawkes and Mellor (1972) indicated this same behavior in ice. St. Lawrence and Bradley ([1975]) have also noted this strain-rate–stiffness relationship in their research.

The present work indicated that there is a difference between the directly measured strain and the strain which would be deduced from the cross-head motion, indicating an effective slippage of the loading plates frozen to the sample ends. It is therefore important to make direct strain measurements in order to obtain correct stress–strain diagrams which may be used in finite-element modelling of avalanche snow-pack stress and deformation behavior.

Comparisons

To aid in assessing the validity of the test procedures described here, Table I compares the results of this research with values taken from the literature.

The ultimate stress values fall between those obtained with small spin-test samples (Martinelli, 1971) and the predicted values using large samples (Sommerfeld, 1973). This is consistent with the effect of sample volume on strength noted by Sommerfeld (1973). The sample volume used in the present experiments is about 3 200 cm^3 which lies between the volume to which Sommerfeld's prediction is applicable, 1×10^6 cm^3, and the volume used in his experiments, 2 300 cm^3.

Table I. Comparison of mechanical properties

Present experiments				*Comparative values*		
Test date and no.	*Density* kg/m^3	*Strain-rate* s^{-1}	*Strength* N/m^2	*Strength* (Martinelli, 1971)* N/m^2	*Strength* (Sommerfeld, 1973)† N/m^2	*Strength* (Sommerfeld, 1973)‡ N/m^2
21 November— 4	300	2.8×10^{-5}	6 690	30 000	12 000	1 800
6 February— 6	186	1.0×10^{-5}	—	3 500	3 000	1 000
6 February— 7	186	1.0×10^{-5}	2 318	3 500	3 000	1 000
6 February—10	186	0.5×10^{-5}	—	3 500	3 000	1 000
6 February—11	186	5.0×10^{-5}	1 778	3 500	3 000	1 000
20 March— 1	335	5.0×10^{-5}	2 400	35 000	17 000	2 000
20 March— 8	335	2.0×10^{-5}	—	35 000	17 000	2 000

* Averages from Martinelli's data, spin-test sample size 500 cm^3.
† Averages from Sommerfeld's data, spin-test sample size 2 300 cm^3.
‡ Sommerfeld's prediction for snow volumes of 1×10^6 cm^3.

Conclusion

A light-weight, portable, constant strain-rate tensile testing machine was designed, built and tested. A technique for measurement of strain directly on the snow sample was also developed and preliminary stress–strain experiments were conducted. It was found that the direct measurement of strain is necessary to avoid the errors in strain values computed from cross-head motion. Strain-rate effects similar to those obtained by other investigators were observed, and strength and Poisson's ratio data were found to be comparable with data from the literature.

In order to provide stress–strain–strain-rate data which will be useful for stress and deformation finite-element modelling of avalanche snow-packs, it will be necessary to conduct tests at lower strain-rates and for longer time periods. It may also be necessary to conduct tests with larger samples to avoid problems caused by the presence of flaws in the snow.

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