A STRAIN GAUGE TECHNIQUE FOR THE DYNAMIC MEASUREMENT OF ICE*

Don B. Clark†

Introduction

IN THE study of ice properties exists a need for a measuring technique that will provide automatic recording of dynamic measurement of strain. Present instrumentation methods are slow, tedious, and limit accurate stress measurements to those of ultimate strength. Samples for these measurements have to be cut, which sometimes causes fractures or stresses to occur in the samples during preparation. Development of a technique to apply the well-tried strain gauge to ice should open to the ice scientist the many strain gauge measurement techniques now possible on metal and concrete.

Early attempts by the author at the U.S. Naval Civil Engineering Laboratory to use strain gauges on ice samples resulted in bridge mismatch and noise that prevented the balancing of instruments and the recording of strain. Paper-backed strain gauges that are commercially available do not have sufficient insulating coating to maintain high electrical impedance when used on materials with moist or wet conducting surfaces.

Gauge preparation and application

To provide the necessary high impedance between gauge and ice a suitable coating material for the gauges was sought. Baldwin Type A-5-1 gauges with the protective felt strip removed were dipped into different coating materials and then immersed in sea-water and allowed to soak. The impedance measurements at various time intervals are shown in Table 1.

Zerok 110, a styrene-butadiene copolymer, was the best coating of those tested. Fig. 1 shows a coated gauge ready for application. Before applying the coated gauge to the ice it was found necessary to face front and back of the gauge with a thin absorbent paper (lens tissue) so that a "glue line" of fresh-water ice could be formed between the gauge and the ice sample. The tissue was coated sparingly with acetone and cemented to the gauge with a slight, well-distributed pressure from a sponge.

* Published by permission of the Commanding Officer and Director, U.S. Naval Civil Engineering Laboratory.

† Senior Project Scientist, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., U.S.A.

Applying the gauges to the ice samples is easier if the sample temperature is reduced below its freezing point. The gauge, after soaking in distilled water, is placed on the ice in the desired orientation and pressed down with a thin rectangular slice of sea sponge whose face has been wetted with distilled water. The gauge and sponge are allowed to freeze to the ice surface. If application without the sponge is desired a piece of dry ice can be used to build up a layer of ice over the gauge by successive applications of drops of water followed by freezing with the dry ice. Fig. 2 shows the gauge mounted on a cylindrical sample of sea-water ice.

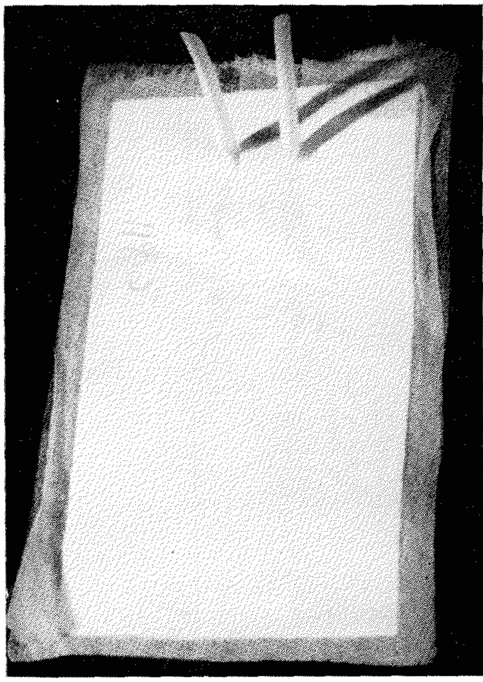

Fig. 1. Coated strain gauge ready for application to ice sample.

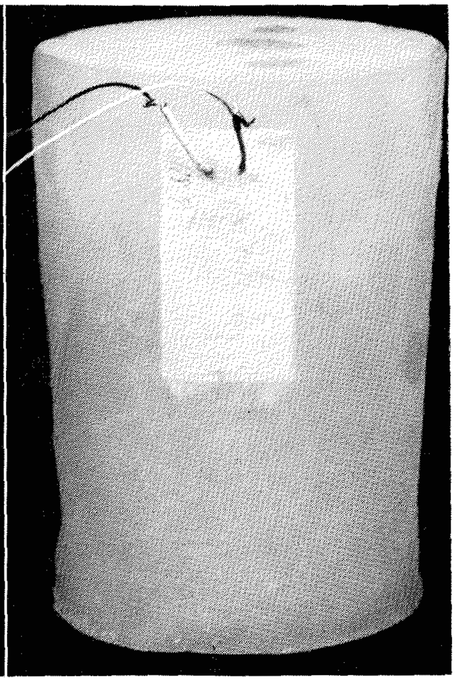

Fig. 2. Strain gauge mounted on cylindrical ice sample.

In maintaining high impedance between the coated gauge and sea-water ice the greatest source of trouble was at the points where the uninsulated lead wires leave the gauge. Care must be exercised to prevent mechanical rupture of the insulating coat at these points. A greater thickness of coating at these critical points can be obtained by touching up with coating material after dipping. Replacing the bare solid lead wires with stranded, less rigid, insulated lead wires would be of advantage. Repeated temperature cycling of a gauged sample that causes thawing and freezing at the surface of the sample can lower the gauge-to-ice impedance if the insulating coating has been ruptured at any point.

Table 1. Insulation impedance of various coating materials on strain gauges immersed in sea water.

Coating material	*Measured impedance* After 10 min. megohms	After 1 hour megohms	Overnight megohms
Carboline Neoprene Primer A-10A	60	60	4
Zerok 110 (Styrene-Butadiene Copolymer)	1,000	1,000	10
Amercoat 33 (Vinyl)	500	400	9
Hyperthane Intermediate (Urethane)	600	3	0
Rubber Cement	1,000	750	0.6
Permakote (Synthetic rubber)	1	1	0
Copon, Clear Epoxy	1	0.5	0
Copon, White Epoxy	90	50	0

One sea-ice cylinder was prepared with two coated gauges and allowed to age in a deep freezer at approximately -17°C. This sample is shown in Fig. 2. The impedance was measured daily. After 3 weeks the impedance of one gauge dropped from 1,000 to 2 megohms, whereas the other gauge maintained its initial high impedance. Brine on the surface of the sample indicated that its temperature had risen, and a rupture of the coating at the lead juncture of the gauge with the lowered impedance was found.

Results of dynamic loading of gauged samples of ice

To test the bond between gauge and ice and the response of the gauge to the strain in the ice, strain-gauged cylinders of ice were dynamically loaded under compression, and the gauge strain was recorded with a bridge amplifier and recorder. The first strain-gauged sample tested on the dynamic load machine of the Navy Civil Engineering Laboratory was a specimen cored from commercial ice of 3-inch diameter provided with a single uncoated Type A-5-1 strain gauge. This was applied in a manner similar to that described and was oriented to measure the longitudinal strain from the compression loader. A similar sample was used as a dummy to balance the Baldwin Type N recorder while the other was being stressed. Strain and load readings were taken visually and recorded simultaneously. The results are shown in Fig. 3. The loading rate was approximately 2,000 lbs. per minute. Both ice samples were initially at -10°C., but warmed up to about -7°C. before the test was completed.

Later six core samples of ice were provided with three uncoated Type A-5-1 gauges each. In a cold chamber they were loaded to failure with a manual compression loader. The strain gauges were connected to a bridge amplifier and recorder outside of the chamber. It was impossible to balance the bridge or reduce the noise, and no strain records were obtained. The failure was caused by the lowering of the impedance between gauges and ice. A search for a suitable insulating coating then followed and resulted in the choice of Zerok 110.

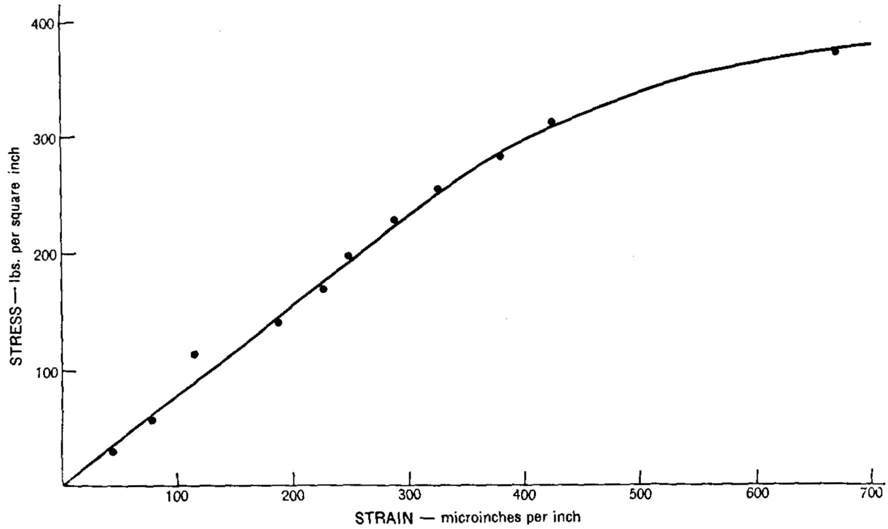

Fig. 3. Stress-strain curve for a cylinder of fresh-water ice of 3-inch diameter. Test 1, August 27, 1958; approximate temperature -7° C. during test; gauge type A-5-1, uncoated.

A series of tests was made using the coated gauges applied as described to cylindrical specimens of both fresh-water and sea-water ice. Stress-strain readings from these tests are shown in Figs. 4 to 9. In Figs. 6 and 7 the outputs of two longitudinally oriented gauges on each sample are seen to compare favourably. Sources of discrepancies between readings of similarly

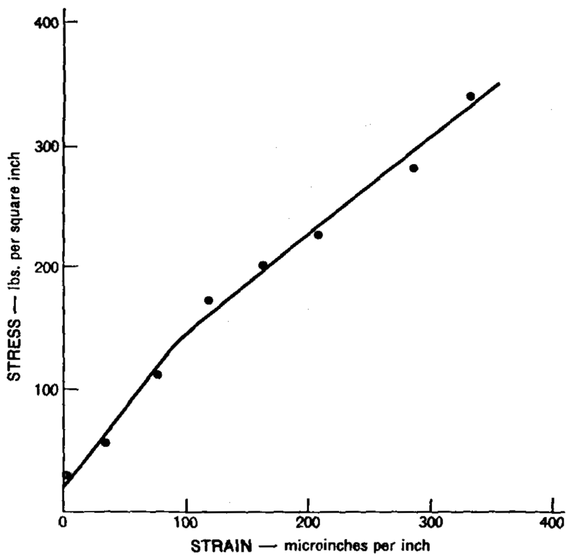

Fig. 4. Stress-strain curve for a cylinder of fresh-water ice of 3-inch diameter. Test 2, February 6, 1959; gauge type A-5-1, coated.

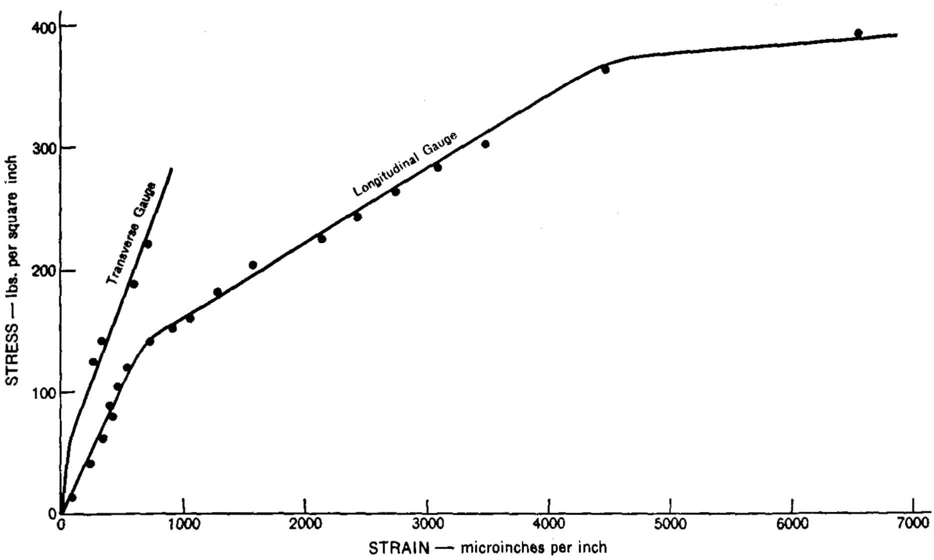

Fig. 5. Stress-strain curve for a cylinder of sea-water ice. Test 3, February 6, 1959. Salinity 26‰; temperature approximately -25°C.; average load rate 25 pounds per square inch per second; gauge type A-5-1, coated.

oriented gauges on the same sample include misalignment of gauges, differences in balance and gain of the strain recorders used, variation in the stress on one side of the ice cylinder and the other, as well as possible variation in the gauges after being applied. Errors due to transverse gauge components and variation of Poisson ratios of materials tested were negligible.

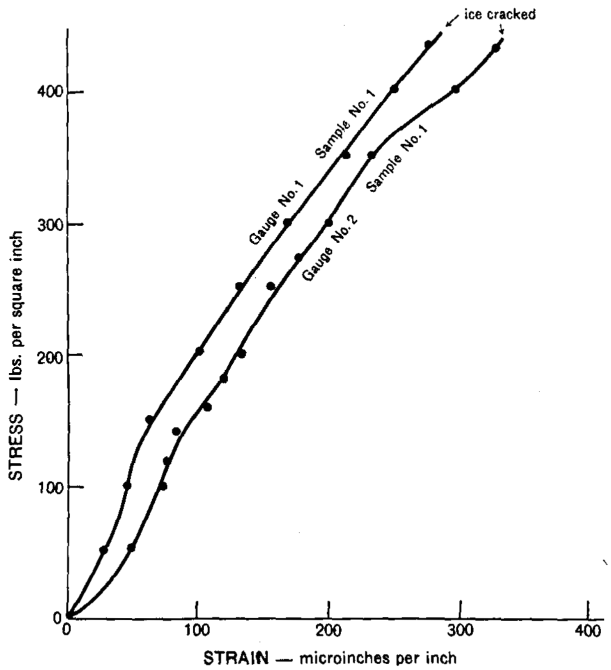

Fig. 6. Stress-strain curve for a cylinder of fresh-water ice. Test 4, February 12, 1959; compression; sample 1, pure ice, longitudinal crystals, temperature approximately -13°C.; load rate approximately 11 pounds per square inch per second; gauge type A-5-1, coated.

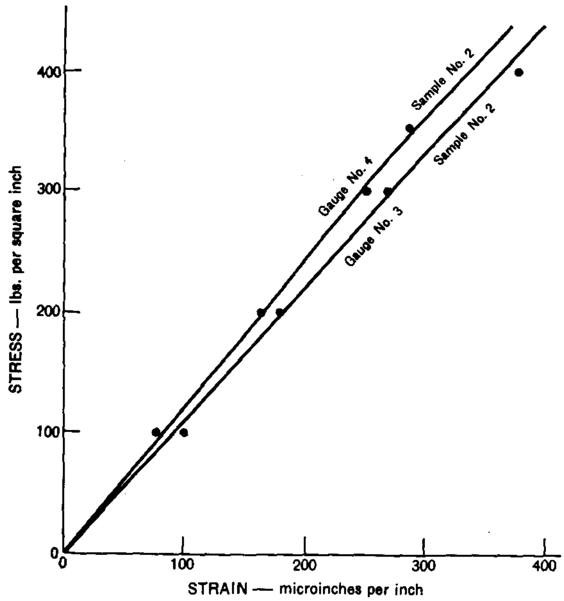

Fig. 7. Stress-strain curve for a cylinder of fresh-water ice. Test 5, February 12, 1959; compression; sample 2, pure ice, longitudinal crystals, temperature approximately -10°C.; gauge type A-5-1, coated.

The curves of Figs. 5, 8, and 9 shows the relationship of readings taken with two gauges on each cylinder, one mounted to measure the transverse, the other the longitudinal strain. A difference between the slopes of the stress-strain curves of similar specimens was observed. This was probably due to the differences in temperature of the samples at the time of the test.

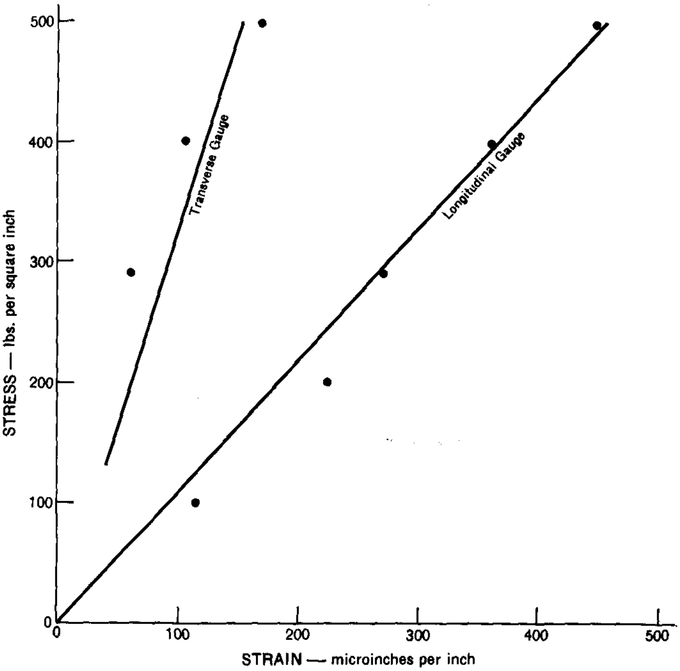

Fig. 8. Stress-strain curve for a cylinder of fresh-water ice. Test 6, March 10, 1959; pure ice, longitudinal crystals; temperature approximately -15°C.; gauge type A-5-1, coated.

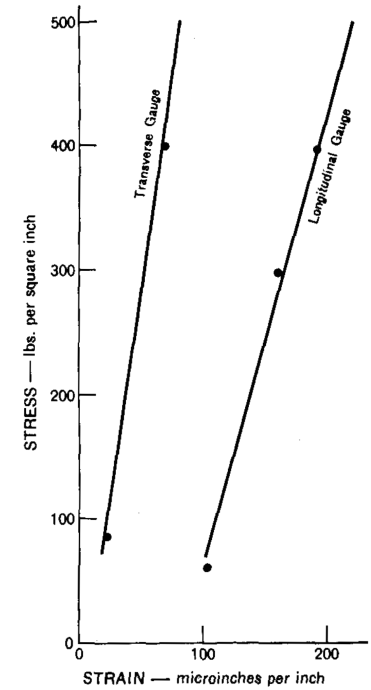

Fig. 9. Stress-strain curve for a cylinder of fresh-water ice. Test 7, May 10, 1959; pure ice, longitudinal crystals; temperature approximately -17°C.; gauge type A-5-1, coated.

In Fig. 10 we see this relationship for five values of slope taken from five separate tests, where the approximate temperatures of the fresh-water ice samples during the tests were known. To determine if slippage of gauges or plastic flow of the ice could occur at the loading rates used in the series of tests, one sample was cycled in 1,000-lb. steps. Fig. 11 shows tracings

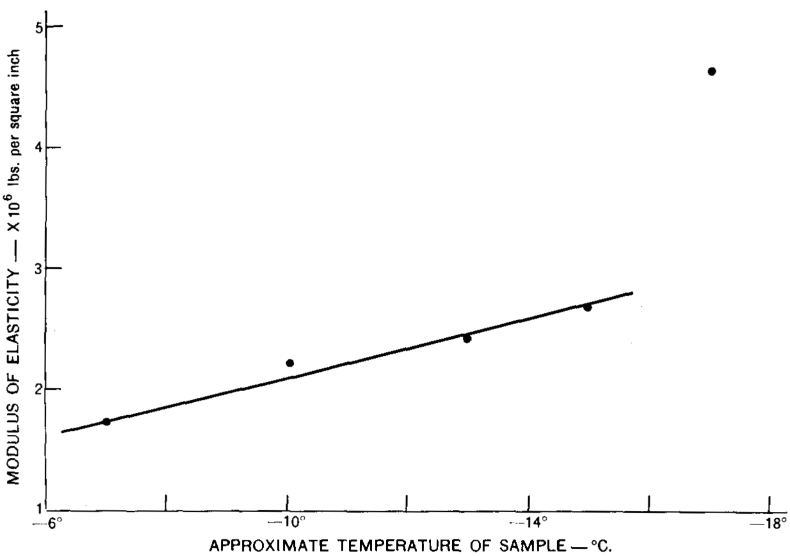

Fig. 10. Modulus of elasticity against temperature for fresh-water ice.

from the oscillograph record of this series of loads. The record was obtained from one of two longitudinal gauges. The tracing from the other gauge was similar, but reduced in amplitude due to a higher attenuation setting on its recorder. It can be seen that the trace returns to its initial value after each loading, indicating the absence of discernable slippage of the gauge or of plastic flow of the ice at these loading rates. The stress-strain relationship for this test is shown in Fig. 7.

After failure of the ice cylinder in the dynamic load machine most strain gauges were still intact on the surface of a piece of ice larger than the gauge.

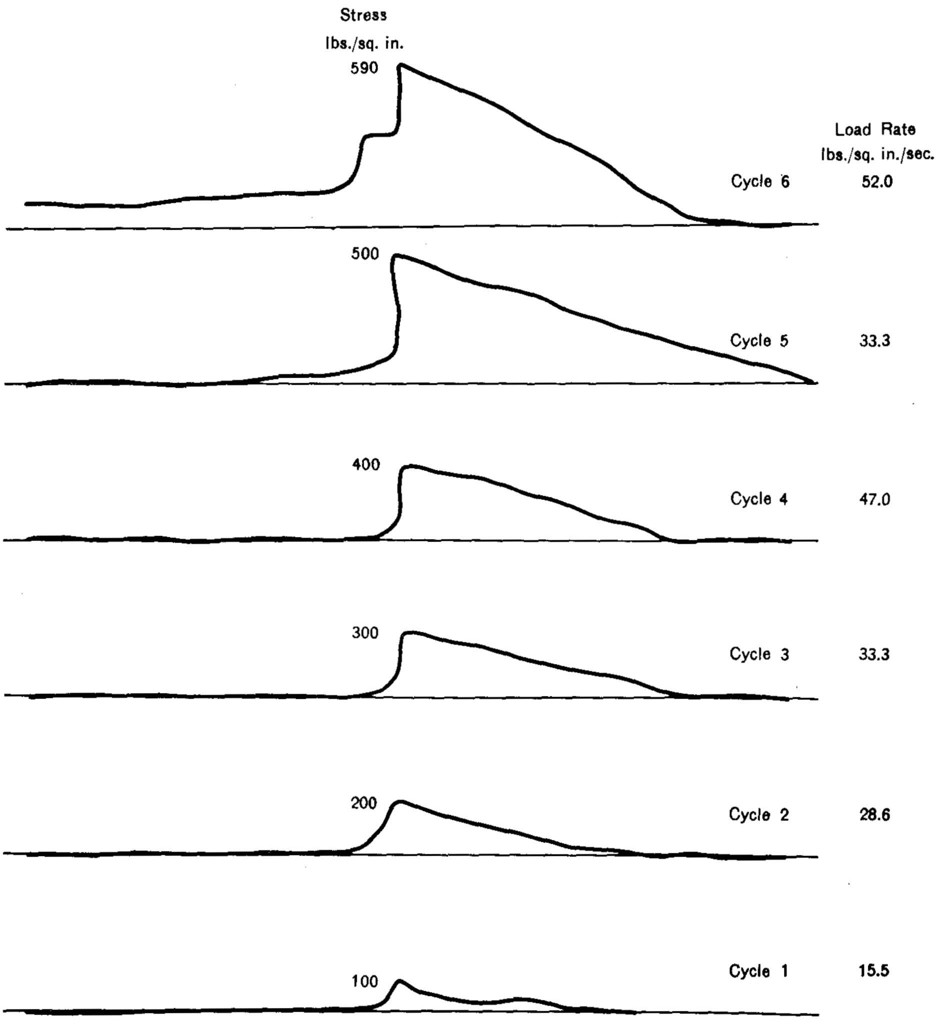

Fig. 11. Load cycling for a cylinder of fresh-water ice. Tests February 12, 1959; pure ice, longitudinal crystals; gauge type A-5-1, coated.

Conclusion

The techniques described above that were developed for preparing and applying strain gauges can be used to meaure and record dynamic strain in both fresh-water and sea-water ice. The dynamic tests described were made to show that strain gauges can be successfully applied to ice samples. They can be used to determine the physical properties of ice, such as the Poisson ratio and Young's Modulus, with a considerable degree of accuracy if the measurements are made under conditions of controlled temperature and with properly calibrated measuring equipment. The author hopes to make further tests using these techniques under field conditions.