Research Paper 15
AUGUST, 1955

Crushing Strength of Lake Ice

SNOW, ICE AND PERMAFROST RESEARCH ESTABLISHMENT
Corps of Engineers, U. S. Army

CRUSHING STRENGTH OF LAKE ICE
Interim Report

by

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ABSTRACT

Tests were made to determine the effects of size of prismatic specimens, cross section, ratio of overall length to length of side of square section, types of ice, both natural clear ice and snow ice, orientation of c-axis, and size of candle. Rough-cut specimens were crushed in a 120,000 lb capacity press. The results of the tests show that: (1) Larger-grained clear ice is stronger in compression. (2) Ice is stronger parallel to the ice sheet than normal to it. (3) Specimens of smaller cross-section have higher crushing strength. (4) Prisms with lower ratios of length to width are stronger. No effect of c-axis orientation was detected.

INTRODUCTION

The work reported in this paper was accomplished at the Keweenaw Field Station near Houghton, Michigan, during the first two weeks of March, 1955, when the lake ice cover was the thickest and the thaw season had not yet begun. This program consisted of crushing strength tests to determine the effect of the following:

1. Size of cross section. A square cross section was used since the apparatus for obtaining circular sections was not available.
2. Ratio of length of specimen to width (length of side of square cross section).
3. Type of ice. Natural clear ice and natural snow ice were tested.
4. Orientation of specimen to the ice sheet. Specimens of both types of ice cut normal and parallel to the ice sheet were tested.

Mr. E. W. Marshall of SIPRE Snow and Ice Basic Research Branch found that the ice obtained from different lakes in the vicinity of the Keweenaw Field Station varied considerably. Therefore the program was modified to include a study of the effect of:

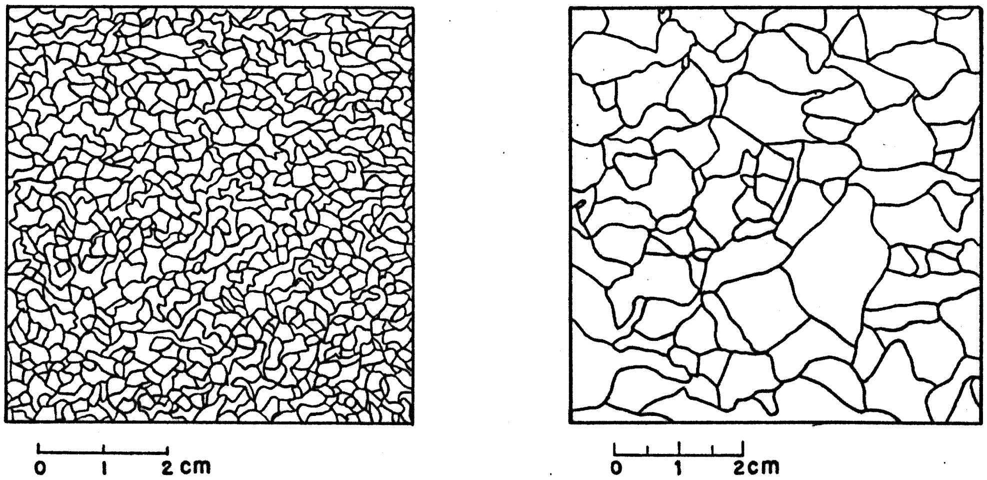
5. Orientation of the c-axis.
6. Size of candles.

Three lakes in which c-axis orientation and the size of the candle-like crystals differed were chosen for the tests. Lake Annie had about 6 in. of clear ice and 12 in. of snow ice. The candle size of clear ice varied from 0.2-0.5 cm dia at the top to 0.5 cm at the bottom (Fig. 1). The c-axis was approximately normal to the candles. Portage Lake had considerably larger candles, varying from 1-3 cm at the top to 2-5 cm at the bottom (Fig. 2), and the c-axis was parallel to the candles. The ice sheet consisted of about 10 in. of clear ice and 8 in. of snow ice. In Rice Lake the candles were similar in size to those in Lake Annie, but the ice sheet had about 9 in. of clear ice and 9 in. of snow ice, and the orientation of the c-axis was normal to the candles (Fig. 3).

EXPERIMENTAL PROCEDURE

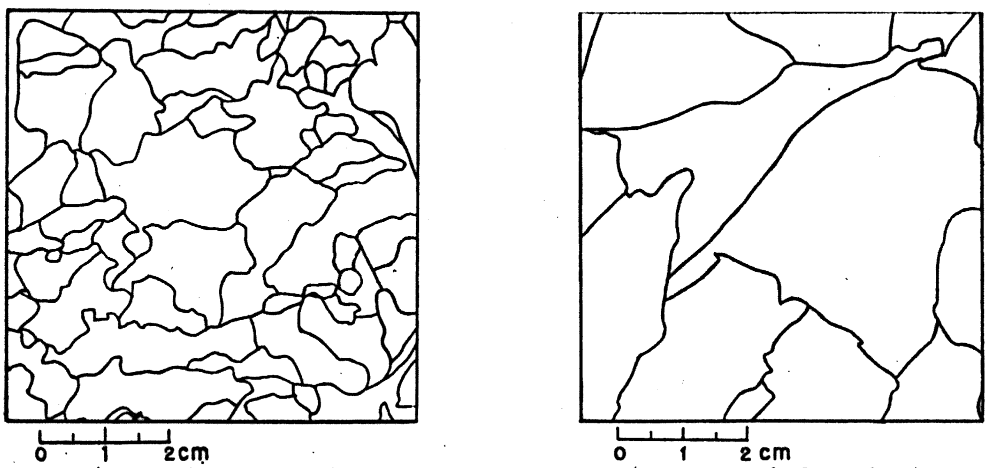
Blocks of ice 18 in. x 18 in. x thickness of the ice sheet were cut from the three lakes previously mentioned. As Portage Lake was more accessible than the other lakes, larger quantities of ice needed for the size and ratio tests were taken from it. For the clear ice, 2 x 2, 3 x 3, 4 x 4, and 5 x 5 in. cross sections were used. Eight specimens each of 2:1 and 3:1 ratios of length to width were tested for each cross section. For snow ice and clear ice from the other two lakes, only 2 x 2 in. cross sections were tested.

All specimens were cut to size with a 10 in. band saw. The sides were rough-cut and unfinished, but checks with a carpenter's square indicated that the sides were very nearly parallel.



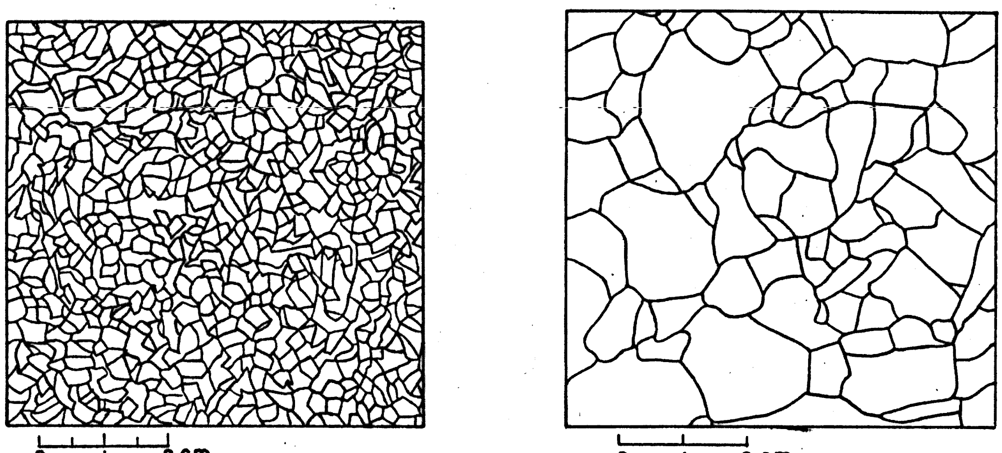
(Top of clear ice) (Bottom of clear ice)

Figure 1. Tracing of rubbing of ice from Lake Annie



(Top of clear ice) (Bottom of clear ice)

Figure 2. Tracing of rubbing of ice from Portage Lake



(Top of clear ice) (Bottom of clear ice)

Figure 3. Tracing of rubbing of ice from Rice Lake

A 120,000 lb capacity Young press with three ranges was used for all the crushing strength tests. The lower range was 6,000 lb full scale, the intermediate range was 30,000 lb full scale, and the high range was 120,000 lb full scale. Only the low and intermediate ranges were used in these tests. The pressure plates on the press were 5 in. in diameter, which limited the maximum size of the specimen.

A 1/8 in. thick piece of foam rubber was placed on each end of the specimen to insure good contact with the pressure plates. The top plate could swivel through 5° in any direction, to compensate for any slight angle between the bearing surfaces of the ice specimens.

All specimens from the three lakes were loaded at approximately the same rate. The rate of loading as indicated by the moving dial on the console of the Young press was not constant; the indicator accelerated from zero to an approximate constant rate at about half the ultimate load.

RESULTS

Figure 4 is a plot of the crushing strength vs. area for the 2:1 ratio of length to width. The points are individual tests; the circled points are means. The curve indicates that higher crushing strengths are obtained with smaller cross sections. Figure 5 shows crushing strength vs. area for the 3:1 ratio. Again higher crushing strengths were obtained for smaller cross-sections, but the curve has shifted to the left, indicating that a lower ratio gives higher values of crushing strength. One exceptionally high value was obtained for a 4 x 4 specimen, but was not included in the mean.

Table I is a summary of all the tests made on the three lakes on the clear ice and the snow ice. Clear ice from Portage Lake (large candles) yielded much higher values than that from Lake Annie or Rice Lake (small candles). No effect of orientation of the c-axis with respect to the candles can be seen from the results of the tests. Prisms cut with the axis parallel to the candles are weaker than those cut normal to the candles. The candles are always vertical in the ice sheet. It is noted here that similar results were obtained with lake ice from Portage Lake, Michigan, in 1954, as reported in SIPRE Research Paper 11.

The snow ice tested was from Portage Lake and Lake Annie. The two ices were visibly different. Portage Lake snow ice contained larger air bubbles, and was noticeably whiter than Lake Annie snow ice. The measured densities varied from 0.78 to 0.82 g/cm^3 for Portage Lake, and from 0.83 to 0.86 g/cm^3 for Lake Annie. The two ices behaved differently under a compressive load. For Lake Annie snow ice, the load would increase to a maximum value, then slowly decay. Portage Lake snow ice was more brittle, and the specimens ruptured and fell apart with no slow decay. The snow ice from Lake Annie was considerably stronger than that of Portage Lake, even though at higher loads it behaved more like a spongy mass.

Tests to determine the effect of loading time on crushing strength were made with specimens of similar orientation from Rice Lake. Figure 6 shows the results. This plot shows a high scatter, although the trend is towards higher strengths at longer loading times. All of the other ice specimens were loaded to failure in the time interval shown by the horizontal lines in this figure.

SUMMARY AND CONCLUSIONS

The results of the tests show that:

1. Large-grained clear ice is stronger in compression than small-grained ice.
2. Ice is stronger parallel to the ice sheet than normal to it.
3. Specimens of smaller cross section have higher crushing strengths.
4. Prisms with lower ratios of length to width are stronger in compression.
5. Orientation of c-axis with respect to the ice sheet does not appear to influence crushing strength.

The fact that different types of ice exist in the same general area gives rise to the question of what conditions influence the variables of crystal size and orientation

TABLE I. CRUSHING STRENGTH OF LAKE ICE

Prism Size (In.)	Prism Cut Parallel to Ice Sheet: Crushing Strength (kg/cm^2) Mean *	Max.	Min.	Temp. (°C)	Prism cut Normal to Ice Sheet: Crushing Strength (kg/cm^2) Mean *	Max.	Min.	Temp. (°C)
PORTAGE LAKE CLEAR ICE								
2x2x4	92.6	106.7	74.1	-8	79.8	91.2	64.6	-7
2x2x6	60.0	63.5	55.5	-6	74.3	106.6	59.3	-8
3x3x6	66.5	92.3	49.1	-6	85.1	155.9	79.8	-8
3x3x9	52.6	67.8	40.6	-6	83.3	135.3	57.8	-6
4x4x8	58.2	72.2	44.0	-8	57.4	84.1	39.3	-7
4x4x12	65.0	109.7	38.9	-8				
5x5x10	58.8	71.3	49.3	-6				
5x5x15	40.0	58.0	33.0	-6				
PORTAGE LAKE SNOW ICE Density = .78 - .82								
2x2x4	29.2	36.6	20.3	-5	33.2	42.9	20.8	-7
2x2x6	32.5	38.0	23.4	-7	38.3	48.3	33.1	-6
LAKE ANNIE CLEAR ICE								
2x2x6	40.0	62.0	31.5	-6	36.9	40.6	31.3	-8
2x2x4					62.3	77.1	51.5	-7
LAKE ANNIE SNOW ICE Density = .83 - .86								
2x2x4	59.6	66.7	51.6	-6	50.3	61.9	38.0	-8
2x2x6	56.2	70.3	43.7	-5.5	55.6	62.4	45.5	-7
RICE LAKE CLEAR ICE								
2x2x4	28.6	34.4	21.1	-5	50.1	69.2	39.7	-6
2x2x6	36.2	43.4	31.0	-6	56.3	73.4	33.9	-8

*Mean of eight tests.

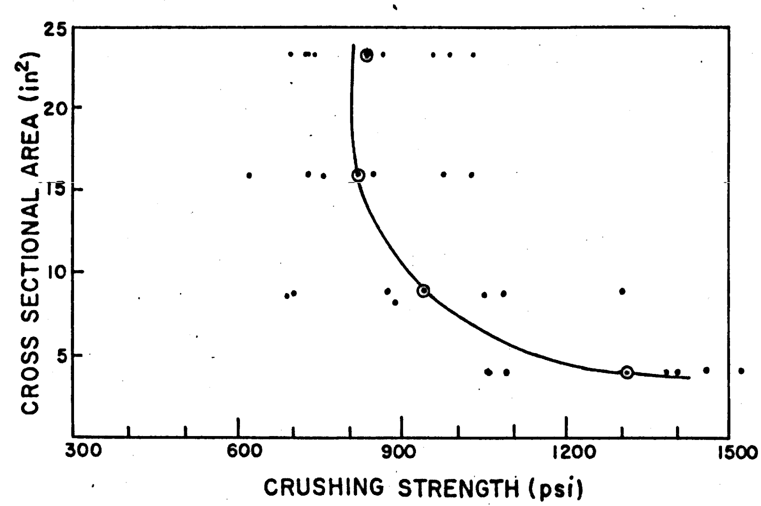


Figure 4. Crushing strength vs. area, Portage Lake Ice 2:1 ratio of length to width. Parallel to ice sheet.

of the c-axis with respect to the candles. It is now known that candle size influences the crushing strength. It probably is reasonable to assume that the orientation of the c-axis is determined at the moment the crystal begins to grow, but other things would influence the size of the crystals. Perhaps it is the changing temperature gradient in the overlying ice. Another factor may be the depth of the water below the ice sheet or its impurities.

In order to study all of the variables which may influence structure, and consequently crushing strength, it would be necessary to grow ice sheets in a laboratory where these variables could be controlled.

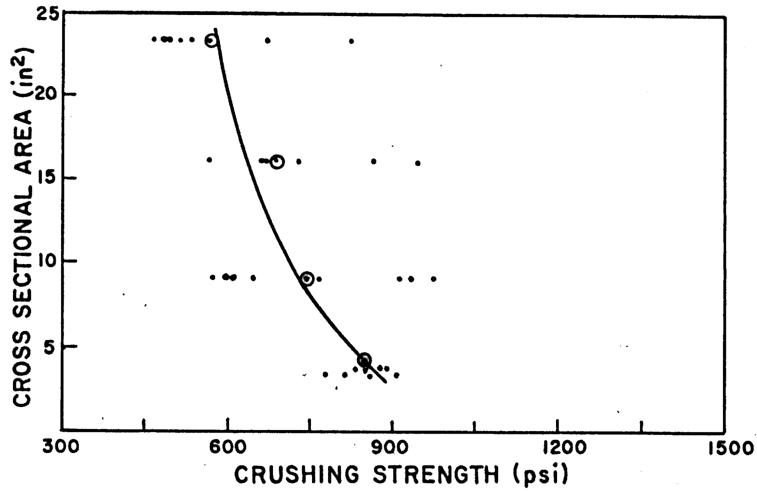


Figure 5. Crushing strength vs. area, Portage Lake Ice 3:1 ratio of length to width. Parallel to ice sheet.

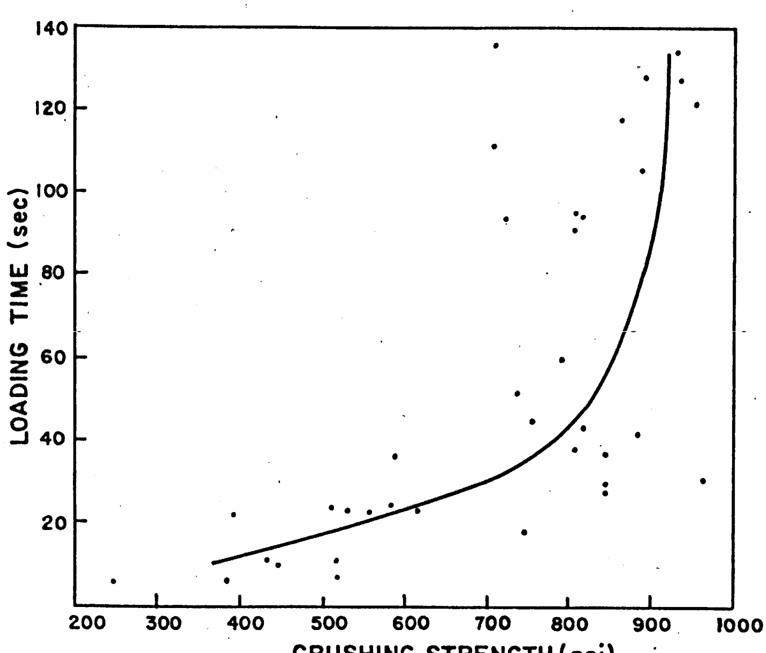


Figure 6. Crushing strength vs. loading time, Rice Lake Ice Temperature = -7°C.

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