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FORMATION OF CRACKS IN ICE PLATES BY THERMAL SHOCK

By

L. W. GOLD

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FORMATION OF CRACKS IN ICE PLATES BY THERMAL SHOCK

By L. W. GOLD

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IN work on crack formation in multi-grained ice during creep under constant compressive load¹, the question arose as to whether the direction of the formation of a crack depended on the crystallographic orientation of the grains in which it formed. Experiments were undertaken to investigate this possible dependence. In one set of experiments a thermal shock was applied to the flat surface of an ice plate in such a way that the resulting thermal stress exceeded the cohesive strength of the ice almost instantaneously.

The first observations were made on irregularly shaped ice plates prepared from single crystals grown by a technique described by Landauer². The plates were about 10 cm. in length and width and about 2 cm. thick. They were prepared with a milling machine using a helical cutter about 15 cm. long. Some plates were machined so that the axis of hexagonal symmetry, or 'c' axis, of the ice crystal was normal to the surface and some so that the 'c' axis was parallel to the surface. After machining, the plates were stored in kerosene at -10°C . for at least 24 hr. Earlier work on the elastic and strength properties of ice had shown that immersion of the ice in kerosene for periods of up to 30 days or more did not appear to affect these properties.

Thermal shock was applied by bringing the smooth surface of an ice plate, at -10°C ., in contact with the smooth flat surface of a brass plate cooled to below -45°C . with dry ice. To ensure good thermal contact, the brass plate was immersed in kerosene just deeply enough to ensure that a very thin film of the liquid lay over the surface to which the ice plate was applied.

When the ice plates were brought into contact with the brass plate, cracks formed very quickly, certainly within 1 sec. For this stress condition, outside the region influenced by the edge the principal stresses are equal and the shear stresses are zero on any plane parallel to the ice surface. Therefore very little, if any, creep could have occurred in such planes or perpendicular to them in the short time that it took for the cracks to form.

The crack pattern which developed was found to depend almost entirely on the crystallographic orientation of the ice with respect to the shocked surface. An example is shown in Fig. 1a for the case where the axis of hexagonal symmetry is perpendicular to the plate surface. The crack pattern is a system of equilateral triangles. As shown in Fig. 1b, the trace of the cracks on the surface was found to be parallel to the sides of hexagonal etch pits obtained by a technique described by Higuchi³. This shows, accepting Higuchi's conclusions on the orientation of the pits with respect to the crystallographic orientation, that with the symmetry axis perpendicular to the surface, there is a preference for the trace of the cracks at the surface to be parallel to the crystallographic 'a' directions.

The rectangular crack pattern which develops when the symmetry axis lies in the plane of the plate surface is shown in Fig. 2a. Fig. 2b shows that the edges of the cracked segments are parallel to the sides of the rectangular etch pits that form on an ice surface with this orientation. The long dimension of the cracked segment was usually perpendicular to the crystallographic 'c' direction, that is, this edge was normally in the basal plane.

The edges of each plate were cut in an irregular shape to see if this would have any influence on the crack pattern. It was observed, as can be seen in Figs. 1a and 2a, that only very close to the edge did the boundary conditions have an influence.

Fig. 1b and 2b show that there is a preference for the trace of the crack at the plate surface to be in the planes containing the 'a' and 'c' crystallographic directions. Etch pits formed on surfaces machined perpendicular to the plane of the crack and to the plate surface showed that near the plate surface the cracks tend to be parallel to the planes containing the 'a' and 'c' directions, but often curve out of these planes farther into the interior of the ice. This is considered to be due to the tendency for the cracked segments to curl under the tensile stresses parallel to the plate surface. This curving of the crack may be aided by the fact that the maximum tensile stress at the root of a crack is not perpendicular to the plane of the crack but at an angle to this plane⁴. The shaded area parallel to some of the cracks is due to the curving of the crack below the surface. If the thermal shock is severe and long enough, some of the crack segments will separate from the plate in a way similar to the spalling of concrete.

The experiments have now been extended to multi-grained ice of average grain size as small as 2 mm.

and with the crystallographic orientation of the grains at various angles to the surface. The preference for the trace of the cracks at the surface to be parallel to the planes containing the 'a' and 'c' directions is maintained for all grain sizes observed so far, a crack often changing direction abruptly as it passes from one grain to the next.

Some refinements have been made in the experimental technique. By using ice instead of brass for the cold plate and making both plates quite thick the change in temperature at the surface can be calculated and readily controlled and expressions obtained for the dependence on time of the temperature in the ice plates and the associated thermal stress. Using these expressions, a cohesive strength of 40-50 kgm./cm.² has been obtained for ice for the particular stress condition applied. The experiments and their analysis are continuing and will be reported in full when completed.

¹ Gold, L. W., *Canad. J. Phys.*, **38**, 1137 (1960).

² Landauer, J. K., *Res. Rep.*, No. 48, Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army (1958).

³ Higuchi, K., *Acta Metal.*, **6**, 636 (1958).

⁴ Williams, M. L., *Trans. Amer. Soc. Mech. Eng., J. App. Mech.*, **79**, 109 (1957).

(a)

(b)

Fig. 1. (a) Crack pattern for axis of hexagonal symmetry perpendicular to surface of plate; (b) orientation of cracks with respect to hexagonal etch pits. Crack is line running from upper left to lower right. ($\times 50$)

(a)

(b)

Fig. 2. (a) Crack pattern for axis of hexagonal symmetry parallel to surface of plate; (b) orientation of cracks with respect to rectangular etch pits. Basal plane of ice perpendicular to surface and parallel to the bottom edge of the photograph. ($\times 40$)