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CRACK FORMATION IN ICE DURING CREEP

by

L.W. Gold

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FORMATION DES FISSURES DANS LA GLACE DURANT LE FLUAGE

SOMMAIRE

La rupture graduelle due à la formation des fissures d'un matériel durant le fluage est un sujet qui reçoit une attention universelle. Même si beaucoup de renseignements ont été obtenus sur la façon dont les crevasses individuelles s'assemblent, croissent en volume et finalement s'unissent pour causer la rupture, peu d'attention a été portée à la possibilité d'un rapport entre la formation des fissures et de la déformation en fonction de la contrainte et du temps. Des renseignements disponibles sur le nombre de fissures et le comportement du fluage avec un alliage aluminium-zinc ont récemment été préparés. L'auteur de ce rapport a obtenu des renseignements semblables pour la glace. En plus de démontrer la corrélation entre l'action de fissurage et de la déformation, ces observations démontrent une similarité intéressante dans le comportement, même si le genre de formation des fissures diffère entre les deux matériaux.

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CRACK FORMATION IN ICE DURING CREEP

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(Received March 17, 1969)

The gradual breakdown of a material during creep due to the formation of cracks is a subject receiving widespread attention. Although considerable information has been obtained on how individual cracks are nucleated, grow, and ultimately join together to cause failure, not much attention has been given to the possible interrelation between crack formation and the stress and time dependence of the deformation. Williams (1) has recently presented information on crack density and creep behaviour for an aluminium-zinc alloy. The author has obtained similar information for ice. In addition to demonstrating a correlation between cracking activity and deformation, these observations show an interesting similarity in behaviour, even though the mode of crack formation is different for the two materials.

It is the purpose of this letter to present information on the creep dependence of crack formation in ice to complement that presented by Williams for the aluminium-zinc alloy, and to draw attention to the similarity in cracking activity and deformation behaviour of the two materials.

Crack Formation in Ice

Ice has a hexagonal crystallographic symmetry. The deformation behavior of ice and crack formation in it exhibit many of the characteristics associated with hexagonal metals such as zinc. A technique was developed for preparing polycrystalline columnar-grained ice (2). The average grain width was about 2 mm and the length several times this value. Because of conditions associated with the growth of the ice, there was a marked tendency for the basal plane to be parallel to the long direction of each grain, and for the axis of hexagonal symmetry to have a random orientation in the plane perpendicular to that direction.

Rectangular specimens of ice were cut so that the load could be applied perpendicular to the long direction of the columnar grains. This combination of columnar grain structure, preferred crystallographic orientation, and direction of loading resulted in deformation and crack formation that was essentially two dimensional (2).

Cracks formed during compressive creep when the load applied to the rectangular

specimens exceeded about 4 kg/cm^2 . They were long and narrow, with a ratio of length to width greater than 3:1 (3). The plane of each crack tended to be parallel to the applied compressive stress and to have its long direction in the long direction of the grains. The cracks tended to be transcrystalline, but grain boundary and triple point cracks were also observed (3). In contrast with crack formation in the alloy the formation of a crack in ice had the characteristics of a local brittle event. Once a crack had formed it did not appear to increase in size with subsequent deformation.

The cracks could easily be seen as they formed by using suitable light. Observations for creep strain less than 0.1 per cent showed that the distribution of cracks according to crack width had a maximum in the range 0.1 to 0.3 mm, and that it dropped off sharply in the range 0.05 to 0.1 mm. As cracks of this width were easily observed, it is considered that the drop-off was real, and that practically no cracks formed with widths less than 0.1 mm. Observations on crack density, therefore, are considered to be a true measure of the cracking activity that occurred.

Results

Figure 1 shows the dependence of crack density on strain observed for compressive stresses of 8 and 12 kg/cm^2 and temperature of -10°C . Figure 2 gives the associated creep curves. Each curve is the average of six tests. The crack record was obtained by counting at appropriate times the number of cracks that had formed since the last observation.

Discussion

The similarity in the shape of the crack density curves and associated creep curves for ice and the alloy is quite striking, even though the mode of crack formation is different for the two materials. There is a much stronger dependence of crack density on stress for ice, however, and the comparable cracking activity occurs within a strain at least an order of magnitude smaller. The width of the cracks formed in the ice is also an order of magnitude larger than the width of those formed in the alloy, and it does not increase with deformation.

The difference between the stress and strain dependence of the crack density, and in the crack size is probably due to the difference in mode of crack initiation and propagation. Observations on the ice indicated that cracks tend to form in or adjacent to grains with their basal planes approximately parallel or perpendicular to the applied load (3). These are "hard" orientations for a material with hexagonal symmetry such as ice, and stress concentrations of the type associated with dislocation pile-ups can be expected. The cleavage type cracking activity observed in ice is consistent with models of crack nucleation of the type discussed by Cottrell (4) and Smith (5), the low surface energy of ice (about 100 ergs/cm^2), the large grain size, and the limited degrees of freedom for deformation.

FIG. 1

Dependence of crack density on creep strain.

FIG. 2

Dependence of creep strain on time.

One of the interesting features of the observations is the correspondence between cracking activity and creep behavior for the ice and the alloy. Both sets of experiments show an accelerating rate of strain during the period of maximum cracking activity at the lower stress. For the alloy, this increase can be attributed to a reduction in cross-sectional area owing to crack formation and subsequent growth. This was not so for ice, however, as the cracks were formed in compressive creep. It is considered that the formation of a crack relieved local constraints and allowed the region to deform more readily (i. e. crack formation was a form of work softening). It should be noted that the period of maximum cracking activity for the ice, when the stress was 8 kg/cm^2 , occurred during the primary creep stage. The low cracking activity for strain greater than about 0.8 per cent was associated with secondary creep.

For both sets of experiments the rate of crack formation at the higher stress decreased with strain after an initial maximum, but always remained significant. This type of cracking activity was associated with the condition of direct transition from primary to tertiary creep, with no intervening secondary stage.

One of the factors probably common to both sets of experiments was that crack nucleation was a random process during the first part of the deformation. Observations now being carried out by the author indicate that crack distribution in ice is random when cracking activity is of the type shown in Figure 1 for a load of 8 kg/cm^2 . For the type of activity associated

with a load of 12 kg/cm², crack distribution was random for strain less than about 0.5 per cent and tended to become non-random thereafter. At this stage there was a tendency for the cracks to occur in zones parallel to the planes of maximum shear. It was clear that the development of these failure planes was associated with the occurrence of tertiary creep. Crack formation had gradually modified the structure of the ice until it was no longer able to sustain the applied load.

Observations on the stress, time, strain and temperature dependence of the cracking activity in ice are to be published.

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