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INSTRUMENTS AND METHODS

A SHEAR-CREEP SYSTEM FOR STUDYING GRAIN-BOUNDARY BEHAVIOUR IN ICE

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ABSTRACT. We present here a shear-creep apparatus. This has been designed to study grain-boundary behaviour in ice bi-crystals. The design and dimensions of this apparatus were determined by taking into account the results of earlier tests, performed on the same types of sample. Improvement with the new device is obtained; it allows a displacement with two degrees of freedom in the grain-boundary plane, and direct observations of micro-structural changes during the test.

INTRODUCTION

The role of grain boundaries in the behaviour of polycrystalline materials is well established. Numerous works have shown that, depending on the deforming conditions exerted on a polycrystal, grain boundaries may induce hardening or softening effects. They can act, for example, as barriers to deformation between two adjacent grains (at lower temperatures), or accommodate their deformation by mechanisms involving transport of matter (grain-boundary sliding and migration at high temperatures).

Concerning polycrystalline ice, the role of grain boundaries during deformation has not yet been clearly elucidated. For example, mechanisms involving grain boundaries as they affect migration or recrystallization have been mentioned in relation to the control of polar ice creep (Pimienta, unpublished). It is worth noting here that the contribution of another important accommodating high-temperature creep mechanism, grain-boundary sliding, has not been mentioned. In spite of the assumptions invoked for the creep of polycrystalline polar ice, the activation of grain-boundary sliding in ice has been observed and analysed for symmetrical grain boundaries (Higashi, 1978; Hondoh and Higashi, 1979; Hondoh, 1986). For high-angle and non-symmetric grain boundaries, we have observed that all three types of mechanism already mentioned (migration, recrystallization, and grain-boundary sliding) can be active in the boundary zone (Ignat and Frost, 1987). However, at a fixed temperature, the activation of the above-mentioned mechanisms can be shown to be dependent both on the relative orientation of the crystals and on the magnitude of the shear stress which acts parallel to the grain-boundary plane. Therefore, in order to clarify these results and to understand better the role of grain boundaries in the creep of polycrystalline ice, we designed and constructed the apparatus described in this note.

GENERAL DESCRIPTION

The experimental apparatus is shown in Figure 1. An aluminium base plate, with a small support at each corner, holds the essential elements of the apparatus and allows easy mounting. The principal parts of the apparatus can be summarized in three main parts depending on their specific function. They are:

Part 1. This part performs the mechanical function of load transfer to the sample with two sets of grips, one mobile and the other fixed. As we wish to study the grain-boundary properties of bi-crystalline samples, the grips are designed to produce a shear zone in the central part of the sample along the grain-boundary plane and to allow any direction of relative displacement in that plane. Therefore, one grip is fixed to the structure of the apparatus while the other is able to move with two degrees of freedom by fixing it to a small carriage guided simultaneously by horizontal and vertical columns (see the schematic drawing in Figure 1b). The load transfer to the central part of the sample is obtained through the mobile grip, whose displacement can be reversed during a test. Two hooks are fixed above and below the mobile grip. This allows the grip to be pulled up by a coated cable attached to a loading platform and passing through a pulley with no detectable friction in the bearings; to reverse the direction of shear, the loading platform can be directly hung beneath the mobile grip.

Part 2. This part of the apparatus contains the light polarizer which helps to detect any structural change in the grain-boundary area. A moveable frame, containing a polarizer and a filter, can be placed in alignment with the sample. The filter and polarizer can then be rotated so that, when the light source is on, the detailed contours of the grain boundary can be observed.

Part 3. This part of the apparatus records the relative horizontal and vertical displacements using two differential capacitance transducers in contact (magnetic fitting) with the mobile grip. Structural evolution at the grain boundary, which induces relative displacement between the grains, can be recorded through sequential macrographs which provide about four times direct magnification.

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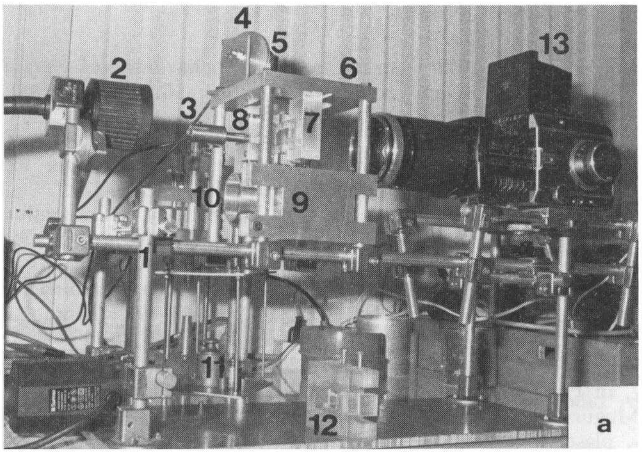

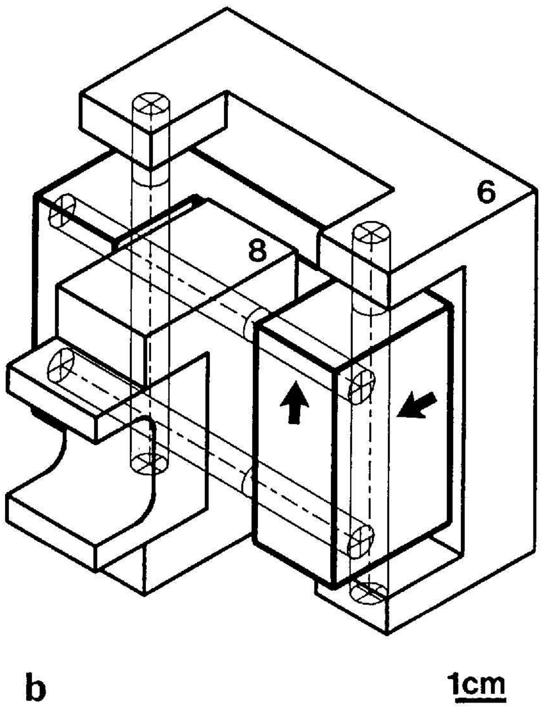

Fig. 1. (a) General view of the shear-creep apparatus. (b) Detailed schematic drawing of the central part of the apparatus. The arrows indicate the vertical and horizontal displacement guiding columns. (1) Columnar structure; (2) Light source; (3, 5) Differential capacitance transducers, following the horizontal and vertical displacements; (4) Pulley; (6) Central part supporting the shearing system; (7) Fixed grip; (8) Mobile grip; (9) Sliding frame with polarizer and filter; (10) Rotating polarizer; (11) Loading platform; (12) Grip holder; (13) Camera.

OPERATION

The bi-crystalline samples are obtained by growing bi-crystals from pre-oriented seeds; the final dimensions of the samples are obtained after extrusion of the bi-crystalline ingots. These methods of obtaining and characterizing bi-crystalline samples have been discussed in detail elsewhere (Ignat and Frost, 1987), but it is important to note that the extruding of ice samples, developed by Itagaki and Sabourin (1980), allows good reproduction and also reduces the work-hardening on the surface that usually results from sawing or drilling. For ice, the advantages of reducing surface work-hardening have already been discussed by Muguruma (1969).

After preparation of the sample, pre-stressing is avoided by placing the sample between two U-shaped pieces moulded from Plexiglass. This fixture then allows the grain boundary to be positioned correctly for testing with a classical polarizer and analyser light system.

To avoid parasitic stresses from awkward movements when loading a sample, we designed a special grip-holder

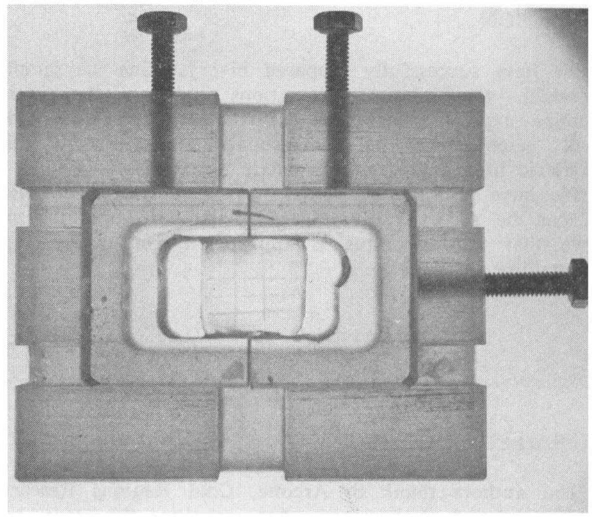

Fig. 2. Grip holder. The sample located in the central part of the apparatus has a rectangular section with a 15 mm fixed length. The width can range from 5 to 10 mm.

(Fig. 2), which serves to place the sample and grips together in the shearing device. Three zones can be distinguished in the grip-holder: the frame with the screws, the grips of the shearing device which are fixed by the screws, and the two U-shaped intermediate pieces. It is important to point out here that, when the grain boundary is located, one grain is fixed with a small frozen water droplet. This process can induce some local stresses. However, because the other grain remains unwelded and the faces of the sample parallel to the grain-boundary plane remain free, stress components acting perpendicularly to the grain-boundary are negligible.

The complete apparatus is set up in an insulated box in which the temperature is known to an accuracy of about 0.2 °C. Sublimation is compensated for by placing crushed ice in containers near the sample, and also by protecting the sample's free surface with a thin film of vacuum grease. At any time, the apparent direction of shearing with respect to the origin (no relative displacement) can be associated with an angle whose tangent is given by the ratio of the displacements. The actual directions of shearing are obtained from the ratio of horizontal and vertical displacements measured during sequential time intervals. Thus, we are able to follow continuous changes in the shear direction and subsequent changes in deformation rate as it occurs during a test.

An example of pronounced relative displacement between two parts of a bi-crystalline sample is shown in Figure 3. The photograph shows no evidence of grain-boundary sliding but strong evidence of intracrystalline shear.

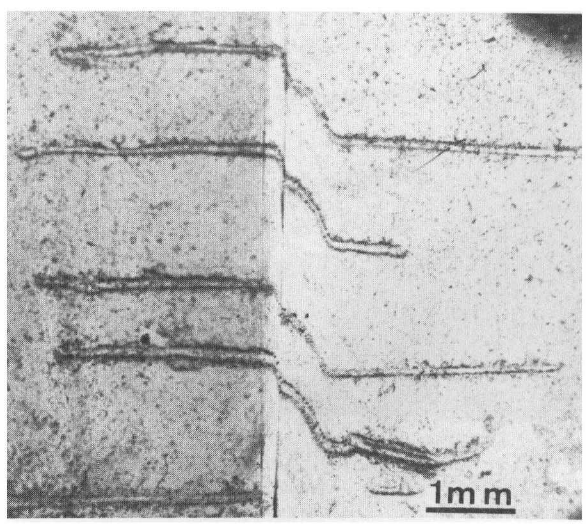

Fig. 3. Intense intragranular shear near a grain boundary.

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CONCLUSION

We have successfully prepared bi-crystalline ice samples for which the mutual orientations between the grains reproduce typical orientations of fabrics, and also other mutual orientations that correspond to symmetric and asymmetric high-angle and low-angle boundaries.

We have also demonstrated that shear and deformation rates can be successfully measured with our apparatus and believe that the apparatus is appropriate for use on any bi-crystalline ice sample.

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