Journal of Glaciology, Vol. 39, No. 133, 1993

Instruments and Methods

End-capping procedure for cored ice samples used in tension tests

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ABSTRACT. This note describes an end-capping procedure used to prepare cylindrical ice-core samples for direct tension testing. The techniques developed build on work done by Cole and others (1985) and Lee (1986), and include a design modification to the loading train and a more reliable approach to establishing the fresh-water bond used to mount the end caps on the sample. Using these techniques, an 88% success rate was achieved in a recent series of uniaxial tension tests.

INTRODUCTION

A review of the literature describing the mechanical properties of ice (e.g. Mellor, 1983) shows that much more work has been done to determine the behavior of ice in compression than in tension. However, this is not an indication of the relative importance of one loading state as compared to the other. The tensile strength of the ice controls the load the ice can withstand under flexure, which is frequently observed in the field (Sanderson, 1988). Instead, it reflects the higher degree of difficulty in performing tension tests due, in large part, to developing a technique to apply the tensile load.

The most common approach for preparing tension-test specimens from ice samples that have been cored or cut from an ice sheet has been to reduce the central cross-section, creating a region of maximum stress (Peyton, 1966; Dykins, 1970; Hawkes and Mellor, 1972; Saeki and others, 1978; Cox and Richter-Menge, 1985; Sinha, 1989). While this technique does result in a high rate of successful tests (defined by failure within the central third of the sample), it is time-consuming. Samples must be lathed or the end dimensions increased by successively adding layers of ice.

Recently, an end-capping system developed by Cole and others (1985) was used to test cored cylindrical samples without a reduced section (Lee, 1986; Kuehn and others, 1990). In these tension tests a 75% success rate was achieved. Two elements were critical in the approach. First was the use of a sabot, or holder, that grips the roughly surfaced sample via a series of O rings. The machined surface of the sabot rather than the irregular surface of the cored sample can then be used as a guide while machining the end planes and mounting the end caps. Thus, the extremely high tolerances in end-plane parallelism necessary for successful tension tests can be realized. Secondly, stresses that develop in the ice near the ice–end-cap bond had to be minimized. Lee and Kuehn and others achieved this by using Synthane end caps with carpeting glued to the bond face. The carpeting not only dissipated the shear stresses at the interface but also increased the bond strength of the end caps.

Although we also followed the end-capping procedures suggested by Cole and others (1985) for a program designed to study the tensile behavior of first-year sea ice (Richter-Menge and Jones, 1993), we were initially unable to duplicate the achievements of Lee and Kuehn and others. Our difficulty stemmed from the fact that we could not find appropriate carpeting for the end caps and, without the carpeting, failure consistently occurred at the ice–end-cap bond. We did eventually achieve an 88% success rate by making modifications to the loading train and the technique for bonding the end caps to the ice. This short note describes these modifications.

LOADING TRAIN

Like Cole and others (1985) and Lee (1986), our end caps were made from Synthane which is a phenolic resin reinforced by linen fabric. In our early tests, the Synthane end cap was attached to the testing machine via a central, 1 in [25.4 mm] diameter threaded connection. Post-test observations of the failure pattern of the ice at the ice–end-cap interface indicated that the Synthane end cap was undergoing differential displacement during the application of the tensile load. Maximum displacement of the Synthane was occurring at the threaded connection. The non-uniform stress state created by this localized displacement was transmitted to the ice and caused consistent failure at the ice–end-cap bond.

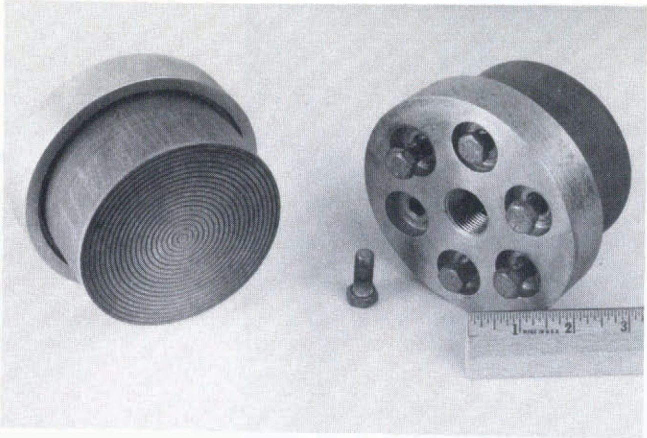

Fig. 1. Synthane end caps with steel end plates.

This problem was overcome by incorporating a steel end plate into the loading train. It works by redistributing the centrally applied load more uniformly to the Synthane end cap. As shown in Figure 1, the steel end plate is attached to the end cap using six evenly spaced bolts around its circumference so that the area of the end cap to either side of the bolt is approximately equal (0.707 × radius). The Synthane end cap with a steel end plate was chosen over a single steel end cap based on our previous success with bonding the Synthane to the ice. As described by Mellor and others (1984), the bond face of the Synthane end caps are deeply incised with a set of concentric grooves and then roughened to expose fine linen fibers. This surface preparation creates a high contact area and, consequently, a strong bond with the ice.

BONDING PROCEDURE

While the introduction of the steel end plate reduced the number of failures that occurred at the ice–end-cap interface, we were still unable to achieve the success rate reported by Lee (1986). It was soon recognized that the end-cap failures were now associated with air bubbles in the bond layer that acted as stress risers. To alleviate this problem, modifications were made to the bonding process described by Cole and others (1985).

Before end-capping began, the acceptability of the ice sample as a test specimen was determined by measuring the parallelism of the milled end planes. In order for a sample to be a candidate for testing, this variation could be no more than 0.127 mm. Our initial work indicated that, at height differentials greater than this, failure involved a measurable amount of bending. Using the same criteria, this evaluation was made again after the end caps were bonded to the ice and the steel end plates bolted into place. If, at this point, the end-plane parallelism was not acceptable, the end caps were removed using a bandsaw and the sample was remilled.

The first modification made to the end-capping procedure was to place a latex collar around the end cap before it was set in the alignment fixture, as described by Cole and others (1985) (Fig. 2). This created a 3–4 mm high reservoir for the distilled fresh water used to form the bond. Unlike Cole and others, we found that this layer of water needed to be reasonably thick so that air bubbles could be actively displaced by lowering the ice sample into the water. Another modification was to place a shim under the front edge of the alignment fixture to give it a slight tilt. This limited the initial contact between the ice and the water to the back edge. As the sample was lowered further, most of the air bubbles could be pushed out ahead of the increasing contact area. Paper towels were also laid around the end cap, after it was placed on the locater, to absorb any water that might overflow. In the absence of the paper towels, water that ran down the sides of the end caps to the end plate of the alignment jig was wicked under the end cap and froze. This resulted in an undesirable decrease of end-plane flatness.

Once distilled water was poured on to the end cap, filling the latex collar, the sample was lowered until the ice surface was approximately midway between the top of the latex collar and the face of the end cap. Once the collar could be removed without leakage, the water layer was inspected for the presence of bubbles. If a bubble was detected near the edge of the water layer, the carriage was lowered more until the bubble was pushed out the side. A bubble in the center of the water, visible as a dark spot within the water layer, indicated that the bond was unsatisfactory. In this case, the ice was immediately moved upward, away from the water surface, and the face of the ice was inspected for any indication that freezing had begun. If no freezing was detected, we repeated the bonding procedure. If freezing had begun, milling of the ice sample had to be repeated before proceeding.

Once a bubble-free water layer was established

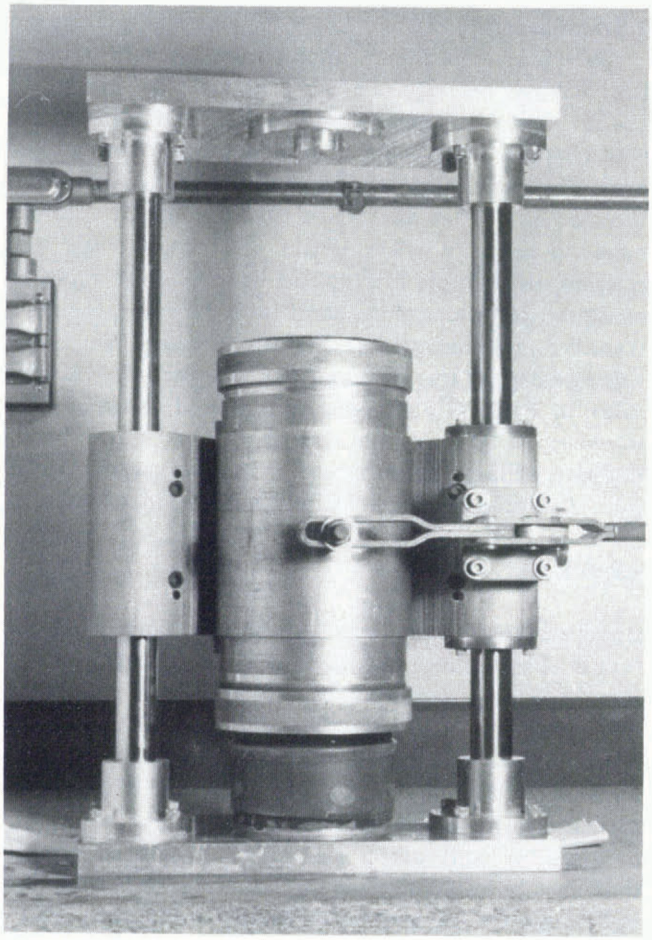

Fig. 2. End-cap bonding procedure: ice sample and sabot mounted in the alignment fixture.

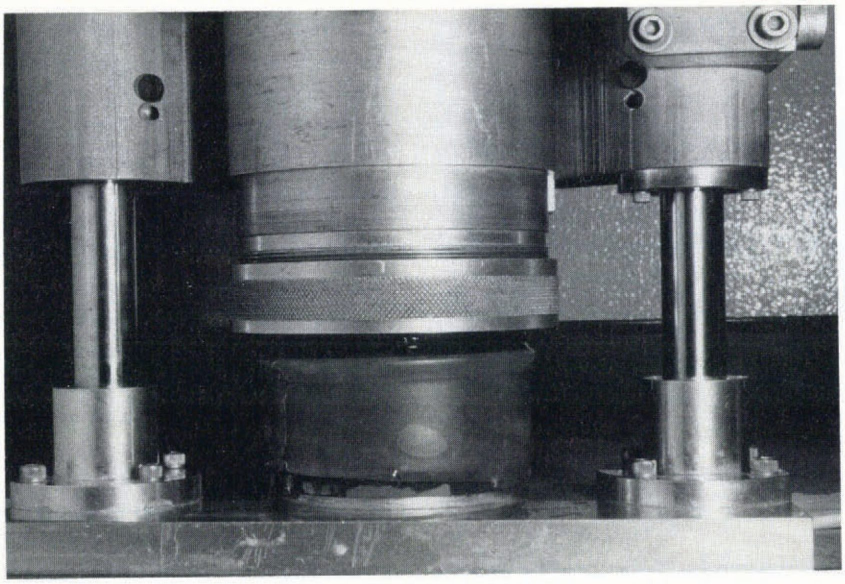

Fig. 3. End-cap bonding procedure: fresh-water layer.

between the ice and the end cap, the set-up was left undisturbed so that freezing could take place (Fig. 3). Complete freezing of the water layer at the −7°C temperature used for bonding took from 15 to 30 min depending on its final thickness. The bonding procedure was then repeated for the other end of the sample by inverting the alignment fixture so that the newly bonded end cap was at the top. A slight tilt of the fixture was again established before end-capping proceeded. This process resulted in fresh ice bonds that were typically 2.5 mm thick.

As a final step in end-capping, the concave meniscus that formed between the ice and end cap along the outside edge of the bond was filled. This was done by first replacing the latex collar so that it covered the bonded area. The latex collar was then pulled slightly away from the side of the ice and water was introduced into the meniscus using a water bottle. The latex collar was released, the sample rotated and the procedure repeated along the perimeter of the bond until the entire meniscus was filled. The sample was then inverted and the process was repeated at the other end cap. The sample was then taken to a −20°C cold room and allowed to stand for a minimum of 5 min so that this water could freeze before the latex collars were removed. The sample remained in the −20°C cold room until it was needed for testing.

RESULTS

Richter-Menge and Jones (1993) have reported the results of the direct tension tests done on cored sea-ice samples using the procedures described in this note. An 88% success rate was achieved in that program, indicating the effectiveness of the end-capping and load-application techniques that we developed. This rate of success is comparable to those described by Lee (1986) and Kuehn and others (1990). The most significant difference between the two approaches is that ours does not require the use of carpeted Synthane end caps. This is advantageous because the carpeting used by Lee (1986) and Kuehn and others (1990) is difficult to find and not easily substituted.

ACKNOWLEDGEMENTS

Support for this work was provided by the David Taylor Navy Ship Research and Development Center.

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MS received 2 March 1992 and in revised form 5 March 1993