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A Comparison of the Ductile Compressive Strength of Columnar Saline Ice Under Proportional and Conventional Triaxial Loading

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ABSTRACT

Much of the available triaxial compressive strength data for columnar saline ice has been generated from conventional triaxial tests. The advent of hydraulic "true" triaxial testing systems has allowed researchers to determine the compressive strength of ice using loading paths that were not accessible with conventional triaxial tests systems. The question that is considered here is whether data obtained from different loading paths can be directly compared.

The deformation of laboratory-grown S2 columnar saline ice (LGSI) under triaxial compressive loading was investigated at a temperature of -10°C at a constant strain rate of 3.9 x 10^{-5} s^{-1} applied in the direction of greatest load, using an MTS multiaxial servo-hydraulic testing system. All of the tests were carried out on 160 mm cubic samples. In one set of tests the samples were proportionally loaded with confinement ratios of $R_{21}=\sigma_{22}/\sigma_{11}=0.25$ and 0.50, with $R_{31}=\sigma_{33}/\sigma_{11}$ variable; σ_{11} and σ_{22} are the normal stresses applied in two orthogonal directions across the columns and σ_{33} is the normal stress applied along the columns. A second set of tests was performed to simulate conventional triaxial loading. In this case the samples were loaded hydrostatically to an initial pressure σ_o and then further loaded along x_1 at a constant strain rate of 3.9 x 10^{-5} s^{-1} while σ_{22} and σ_{33} were held constant at σ_o. In this scheme x_1 and x_2 are perpendicular to the long axis of the columns; x_3 is parallel to the column axis.

Comparison of the yield stresses from the proportional loading tests and simulated conventional loading tests did not reveal any significant difference in the yield strengths from the two loading paths, within experimental scatter. Further analysis has shown that there is statistically no significant difference in the flow stresses taken at other points on the stress-strain curve (σ_{11} vs. ε_{11}), up to 2% inelastic deformation.

1. INTRODUCTION

The multiaxial compressive strength of columnar (S2) saline ice strongly depends on the degree of confinement. Timco and Frederking (1986) used plane-strain tests and Häusler (1981) and Melton and Schulson (1998) used true triaxial tests to show that increased across-column confinement will raise the failure stress of the ice to 3-4 times the uniaxial strength. Nawwar *et al.* (1983) and Richter-Menge *et al.* (1986) reported that increased confining pressure also raised the failure strength of ice when loaded in a conventional triaxial cell, Nawwar *et al.* (1983) stating that the failure stress at a confining pressure of 2.753 MPa was 2-3 times the uniaxial strength. However, there has not been a systematic study to determine if the loading path affects the multiaxial strength of the ice. This paper addresses that point. Specifically, it compares the ductile triaxial compressive strength of columnar S2 saline ice loaded under proportional and simulated conventional triaxial testing schemes.

Generally, in conventional triaxial tests a right cylindrical specimen of ice is loaded axially at a constant strain rate while confined radially by a fluid kept at a constant pressure σ_o. The stresses are defined with respect to a cartesian coordinate system such that σ_{11} is parallel to the long axis of the sample and $\sigma_{22}=\sigma_{33}=\sigma_o$ are two orthogonal stresses in the plane normal to the long axis. Nawwar *et al.* (1983) used this type of conventional triaxial test cell to investigate the behavior of laboratory grown (S2) saline ice at different strain rates, temperatures, salinities and confining pressures. The confining pressure was varied between 0.689 and 2.758 MPa. They found that when the long axes of the columnar grains were oriented perpendicular to the applied load σ_{11} the peak strength increased by as much as 200% with increasing confining pressure.

An improved triaxial cell developed at the Cold Regions Research and Engineering Laboratory (CRREL) allowed the confining pressure σ_o to be varied in a fixed proportion to the master load, i.e. $\sigma_{22}=\sigma_{33}=\sigma_o=R\sigma_{11}$, where R was varied between 0 and 1. However, this improved test system is still considered a conventional test system because σ_{22} and σ_{33} can not be varied independently. Tests on aligned first year sea ice also showed that