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Development of a transparent triaxial cell and observation of rock deformation in compression and creep tests

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Abstract

A transparent triaxial cell was designed and manufactured using acrylic resin. The cell was used to conduct strength and creep tests. Photographs were taken of the specimens at constant time intervals during the constant strain rate test. Photographs were also taken at constant intervals of strain during the creep test, but this rate was changed to one image per second when the specimens first showed tertiary creep. Comparison of the axial and lateral strains during the constant strain-rate and creep tests indicated no significant differences between the two tests. It is well known that the axial creep strain rate is inversely proportional to remaining life in tertiary creep. This study showed that the lateral creep strain rate is also inversely proportional to remaining life. The constant strain-rate tests were conducted with transparent end pieces attached firmly to the upper and lower ends of the specimens. Three holes were drilled into the end pieces, and water was expelled into the holes when the specimens were compressed. It was clearly observed that the water began flowing from the holes back into the specimen during the volumetric expansion of the specimen. The transparent triaxial cell permitted easy observation of water ejection and re-absorption into the specimens.

Keywords: Triaxial cell; Transparent cell; Triaxial compression test; Creep; Creep life; Permeability

1. Introduction

Many methods have been proposed for measuring lateral strain or deformation in rock specimens subjected to confining pressures. One method is to attach strain gages. However, when the specimen is wet the gages do not adhere very well, and those that remain on the rock surface tend to come off or break at the high strains that occur after the peak strength. Attinger and Koppel [1] suggested wrapping the resistive elements around the specimen to overcome these problems, but their strain gages still tended to break at high strains. A more dependable method is to use an extensometer with a circumferential attachment (chain) [2,3]. The drawbacks of this approach are that it has a chain with a fixed length, meaning that it can only be used with specimens of a limited size range, and a large triaxial cell must be used to accommodate the sensor. The triaxial cell described in the present report was developed to address these issues.

To explain failure mechanisms in rock, it would be useful to visually observe how specimens change over time during strength and creep tests. A variety of methods and equipment have been developed for performing triaxial stress experiments on soil, but most of these use confining pressures below 1 MPa. At these levels, the body of the triaxial cell can be made of transparent glass or plastic that enables the observation of the specimen during the test [4]. There is even a commercially available transparent triaxial cell for rock specimens, but this is mainly intended for experiments involving soft rock, and the maximum allowed confining pressure is about 2 MPa. Tests at higher confining pressures are conducted in metal triaxial cells, making it difficult to observe the specimen [5].

It is important to understand creep behavior in order to assess underground structures for long-term stability. To the best of our knowledge, no previous reports describe observed changes in the shapes of specimens immediately before creep failure when subjected to confining stresses. It

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is unknown as to whether differences exist in the failure processes of strength and creep tests; this represents a fundamental gap in our knowledge.

This study takes advantage of the increasing reliability of engineering plastics in developing a transparent triaxial cell that can bear test pressures of up to 10 MPa. This report describes the cell, the method of use, and how its safety was verified. Results of triaxial compressive strength and creep tests undertaken using the cell are also described. To capture the behavior of the specimens immediately before creep failure, a camera system was installed to take sequential photographs of the deformation of the specimens. We used the photographs to measure lateral deformation of the specimens. After a slight modification of the cell, water ejection and re-absorption into the specimens were also observed.

2. Transparent triaxial cell

2.1. Description

A number of materials were investigated in the course of developing the transparent triaxial cell. Table 1 shows the list of final candidate materials: acrylic, glass, and polycarbonate. The table lists the scores given to each material in terms of the desired parameters of high tensile strength, toughness (energy necessary to cause fracture), and low refractive index. High-quality glass has high tensile strength and excellent transparency, but its low toughness means that it requires great care in handling. Polycarbonate has high toughness and is relatively safe, but was assessed as lacking in transparency. Acrylic resin offers intermediate tensile strength, toughness, and transparency. Its refractive index is 1.49, nearly the same as that of oil (1.48); consequently, it provides low-distortion photography. Acrylic resin (Mitsubishi Rayon, Acrylite) was chosen after a comparison of the three candidates, but all three materials appear to be similar in terms of overall suitability.

Fig. 1 shows a diagram (a) and a photograph (b) of the transparent triaxial cell. The cell consists of a transparent hollow cylindrical case with a metal plate at each end. The outer diameter of the cylinder is 100 mm, the inner diameter is 35 mm, and the cylinder is 50 mm tall. Both ends were ground smooth.

The end plates are attached to the cylinder with six bolts (nominal diameter 12 mm). The holding force applied by the bolts is sufficiently greater than that tending to tear the plates away from the cylinder under the confining pressure; this prevents the leakage of hydraulic oil (Tonen General Sekiyu, K.K., Panol #32) through the joints between the plates and cylinder. O-rings were also placed in the joints to prevent leakage of the oil (Fig. 1).

Table 1
Comparison of the properties of acryl and other transparent materials

	Acryl	Glass	Polycarbonate
Strength	2	1	2
Toughness	2	3	1
Transparency	2	1	3
Refractive index	1	2	3

Numbers indicate relative rankings.

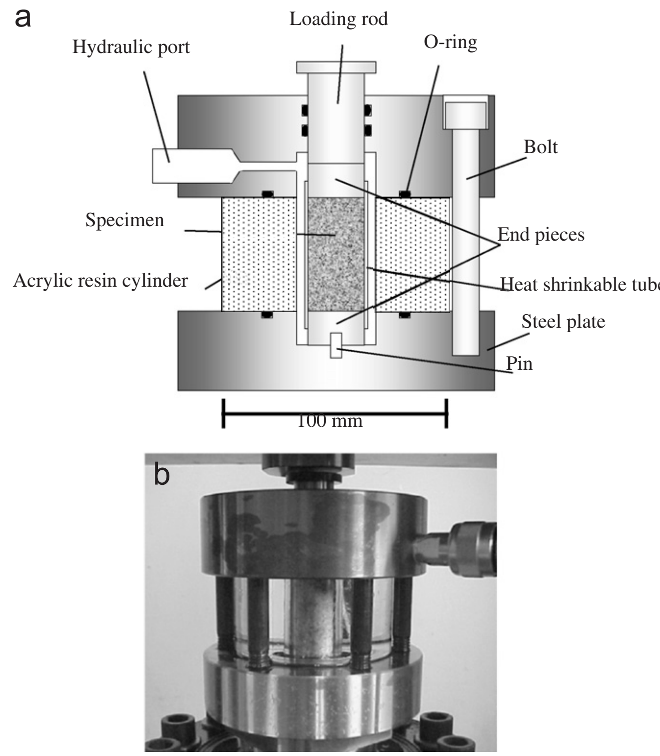

Fig. 1. Details of the transparent triaxial cell. (a) schematic illustration of the celland (b) photograph of the cell.

An oil port in the upper plate was connected to the pump. A loading rod (25 mm in diameter) was inserted through a round hole in the upper plate to apply an axial load to the rock specimen (25 mm in diameter and 50 mm in length).

Two steel end-pieces of the same diameter as the rock specimen were fixed to the specimen ends, and heat-shrink tubing (Mitsubishi Plastics Inc., Hishi-tube, type: VW(CE), thickness: 0.1 mm) was placed over the specimen and end pieces to prevent the infiltration of oil into the specimen. Super-glue was injected between the end piece and the tubing to reinforce the seal against oil. Clear tubing was used to enable observation of the specimen face during the test. The specimen was located using a pin that extends from the lower end plate.

The following basic procedure is used to assemble the transparent triaxial cell. First, the specimen and end pieces covered with the heat-shrink tube are placed on the lower plate and positioned using the protruding pin. The acrylic cylinder is then placed on the lower plate and the end plates are fastened together using the six bolts. Finally, the loading rod is placed through the upper plate and the bolts are tightened. As is apparent from the above explanation, the labor involved in assembling this cell is nearly the same