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# A study of the shear behavior of a Portland cement grout with the triaxial test

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## HIGHLIGHTS

- The shear behavior of a Portland cement grout was studied with the triaxial test.
- During the test, the confining pressure was ranged from a small value of 1 MPa to a high value of 35 MPa.
- The influence of water-to-cement ratio and confining pressure on the shear behavior of the cement grout was investigated.

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## ABSTRACT

Numerous research has been conducted on the axial performance of cement-based grouts. However, much less work has been focused on the shear behavior of cement-based grouts. In this study, the shear behavior of a Portland cement grout was investigated with the triaxial test. Cylindrical samples with two different water-to-cement (w/c) ratios: 0.42 and 0.35 were cast and prepared. In the test process, a series of confining pressures was applied on the samples and the confining pressure was ranged from 1 MPa to 35 MPa. The results show that there is a bi-linear relationship between the maximum vertical stress and the confining pressure independent of the w/c ratio. Low w/c ratio can effectively increase the maximum vertical stress of grouts. Mohr-Coulomb models were used to fit the shear strength envelopes of grouts. The results show that the shear strength of grout with a w/c ratio of 0.35 is much higher than that with a w/c ratio of 0.42. When a w/c ratio of 0.42 was used, the grout has a cohesive strength of 31.4 MPa and an internal friction angle of 15.1° while when the w/c ratio was decreased to 0.35, the cohesive strength of grout increases to 34.2 MPa and the internal friction angle rises to 24.3°.



## 1. Introduction

Portland cement grouts have been used in the mining industry for a long time. They are mainly used as bonding agents to bond the rock reinforcement tendons, such as rock bolts and cable bolts, with the surrounding rock masses [1–9]. For example, Thorne and Muller [9] used a cement grout as the agent, bonding cable bolts with surrounding rock masses to control the roof in underground engine chambers at the Free State Geduld Mine. Davis [10] also used cement grouts, installing fully grouted cable bolts at West Coast Mines to keep the stability of open stopes. Schmuck [11] reported that cement grouts were used as the bonding agent in cable bolting at the Homestake Gold Mine. Kashiwayanagi, Shimizu [12] conducted field tests in Japan, using cement grouts to bond cable bolts with rock masses to keep the stability of an underground powerhouse. Pile, Bessinger [13] pumped cement grout into drilled boreholes and then installed cable bolts to prevent bed separation at the BHP Billiton's San Juan Mine.

Numerous laboratory tests have focused on the axial performance of Portland cement grouts. For example, Domone and Thurairatnam [10] tested the compressive performance of grouts. The influence of curing time on the compressive strength of grouts was studied. It was found that the Unconfined Compressive Strength (UCS) of grouts increased directly with the curing time rising from 1 day to 28 days. Hyett, Bawden [11] carried out a comprehensive study on the axial performance of grouts. The influence of water-to-cement (w/c) ratio and curing time on the performance of grouts was investigated. They found that both the w/c ratio and curing time have a significant effect on the UCS of grouts. Specifically, the UCS of grouts decreases from around 80 MPa to around 21 MPa when the w/c ratio increases from 0.3 to 0.7. Boumiz, Vernet [12] conducted experimental tests to evaluate the influence

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of curing time on the Young's modulus of grouts. The results showed that with the setting time increasing from 7 h to 16 h, there is a positive linear relationship between the setting time and Young's modulus. While when the setting time increases from 16 h to 47 h, there is a non-linear relationship between the setting time and Young's modulus, as shown in Fig. 1.

Li, Xiao [13] added nano-$SiO_2$ to plain cement grouts and compared the performance of plain cement grouts with the gouts having nano-$SiO_2$. It was found that adding nanophase materials is beneficial to improving the axial strength of grouts. Su and Fang [14] investigated the influence of sample size on the UCS of grouts. Cubic samples with the edge length ranging from 70 mm to 200 mm were tested. It was found that the sample size has a marked influence on the UCS of grouts and the grout UCS decreases with the sample size increasing, as shown in Fig. 2.

Chen, Hagan [15] evaluated the axial performance of grouts with different w/c ratios. It was found that the w/c ratio has a negative impact on the Young's modulus of grouts. Specifically, the Young's modulus of grouts decreases from 11.8 GPa to 8.7 GPa with the w/c ratio rising from 0.35 to 0.45. Li, Kristjansson [16] tested the UCS of cubic samples and found that the UCS of grouts decreases apparently with the w/c ratio increasing from 0.4 to 0.5, as shown in Fig. 3.

On the other hand, only a few studies have evaluated the shear performance of Portland cement grouts. Reichert [17] used triaxial tests to investigate the shear performance of grouts, finding that the grout is obviously plastic in the confined condition and the internal friction angle of the grout is quite low. Similar triaxial tests were conducted by Hyett, Bawden [18] and Moosavi [19]. The cohesive strength and internal friction angle of grouts were acquired. Furthermore, Moosavi and Bawden [20] used direct shear tests to study the shear performance of grouts, finding that there is a non-linear relationship between the shear strength of grouts and normal stresses. Chen, Hagan [21] used direct shear test to study the shear performance of a Portland cement grout under the constant normal load and constant normal stiffness conditions. The shear strength envelope of the cement grout under those two different boundary conditions was acquired.

Nevertheless, little research has been conducted on the shear behavior of grouts in the high confining pressure condition. Although Reichert [17], Hyett, Bawden [18] and Moosavi [19] used triaxial tests to evaluate the shear performance of grouts, the maximum confining pressure in those tests was 20 MPa. No further attempt was conducted to test the shear behavior of grouts in a higher confining pressure condition. Previous research has already proved that the shear behavior of grouts has a significant effect on the bond failure of the cable/grout interface. Therefore, studying the shear behavior of grouts in high confining pressure is beneficial for understanding the bond failure of the cable/grout interface and preventing cable bolts failing under high stress conditions.

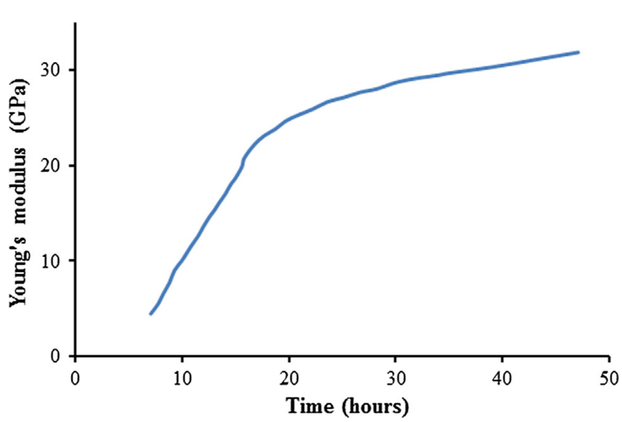


**Fig. 1.** Influence of setting time on the Young's modulus of grouts, after Boumiz, Vernet [12].

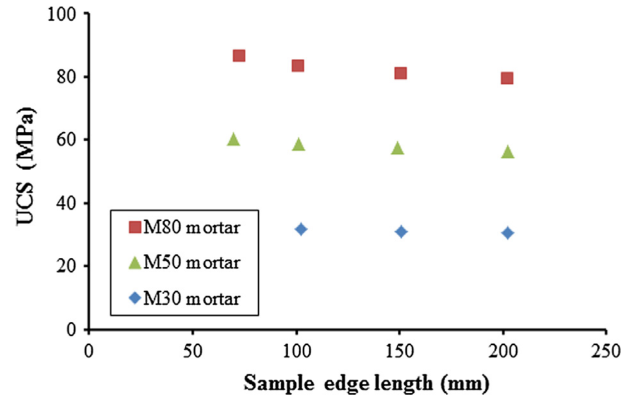


**Fig. 2.** Influence of sample size on the UCS of grouts, after Su and Fang [14].

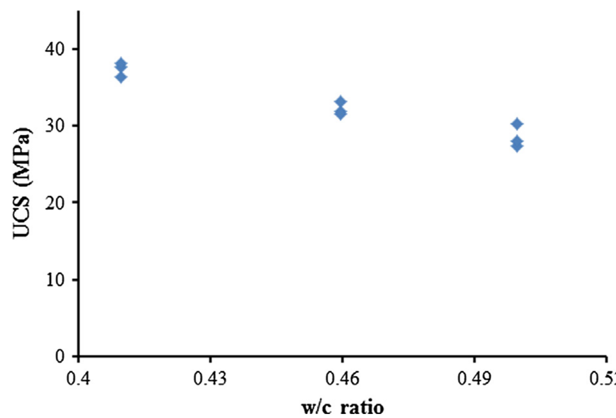


**Fig. 3.** Influence of w/c ratio on the UCS of grouts, after Li, Kristjansson [16].

Therefore, this study aims at studying the shear behavior of Portland cement grouts with the triaxial test especially in the high confining pressure condition. First, the triaxial test process was illustrated. Then, the shear behavior of grouts with two different w/c ratios: 0.42 and 0.35 were given. After that, the shear behavior of grouts with those two different w/c ratios was compared and the influence of w/c ratio on the shear behavior of grouts was analyzed.

## 2. Process of the experiment

### 2.1. Sample preparation

A modified Portland cement grout was used to cast samples. This cement is named Stratabinder HS which is produced by the Minova Company. It was selected in this study because it is commonly used in mining engineering. The Stratabinder HS cement is a grey powder which is composed of angular particles, as shown in Fig. 4. The bulk density of it is 1168 kg/m$^3$.

Two different w/c ratios: 0.42 and 0.35 were used to mix and cast samples. These two w/c ratios were used because field practices show that for cement grouts, UCS strength ranging from 60 MPa to 80 MPa is commonly used in cable bolting [22,23]. Previous UCS test results show that when a w/c ratio of 0.42 is used, the Stratabinder HS cement grout has a UCS of 60 MPa and when a w/c ratio of 0.35 is used, the grout has a UCS of 80 MPa [15]. Cylindrical samples with a height of 120 mm and a diameter of 42 mm were prepared, following the standard recommended by the