Construction and Building Materials 166 (2018) 271–279

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Shear behaviour of a cement grout tested in the direct shear test

Jianhang Chen [a,b,*], Paul C. Hagan [b], Serkan Saydam [b]

[a] College of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, China
[b] School of Mining Engineering, UNSW Sydney, Sydney, NSW 2032, Australia

HIGHLIGHTS

- The shear behaviour of a Portland cement was studied with the direct shear test.
- Two different boundary conditions, e.g., constant normal load and constant normal stiffness were applied.
- The shear strength envelope of the tested cement was acquired.

ARTICLE INFO

Article history:
Received 25 June 2017
Received in revised form 9 January 2018
Accepted 25 January 2018

Keywords:
Shear behaviour
Shear strength
CNS

ABSTRACT

Portland cement grouts are widely used in the mining industry to bond cable bolts with the surrounding rockmass. Numerous laboratory and field tests showed that bond failure of the cable/grout interface is the dominant failure mode. Previous research has found that shear behaviour of the grout along a predefined plane plays a significant role in determining the nature of the bond failure in a cable bolt reinforcement system. In this study, the shear behaviour of a Portland cement grout was investigated based on a direct shear test. Two different boundary conditions were considered being a constant normal load (CNL) and constant normal stiffness (CNS). Under CNL condition, five different normal pressures between 0.1 MPa and 6.0 MPa were examined. While under CNS condition, the initial normal pressure was set to value within the same range. Also, a CNS of 10 kN/m was added. The cohesion, internal friction angle and shear strength of the grout were acquired. The results showed that there is a linear relationship between the shear strength of the grout and resultant normal pressure. However, under the CNS condition, the shear strength of the grout was found to be generally higher comparing to the CNL condition, most likely because sample dilation resulted in an increase in the normal pressure. Consequently, shear strength of the grout also increased.

1. Introduction

Portland cement is a product of clay and limestone, which are heated together and then pulverised to form a powder rich in calcium silicates [1].

While there are various types of cement-based grouts, Portland cement grouts are the dominant primary grouting materials widely used in the mining industry. Specifically, this type of grout is commonly used in rock reinforcement systems in mining to ensure the safety of mine personnel. In cable bolt installations, Portland cement is mixed and poured into boreholes to bond cable bolts to the surrounding rockmass [2]. Numerous laboratory and field tests have shown that bond failure at the cable/grout interface is the primary failure mode in field applications [3–7], as shown in Fig. 1.

Bond failure at the cable/grout interface is due to low bond strength between the cable bolt and grout column [9–18]. Moosavi [19] conducted a comprehensive study on the bond failure behaviour of cable bolts, finding that shear of the cement grout is the key parameter in determining the performance of cable bolts. Therefore, understanding the shear behaviour of the grout is beneficial to optimising cable bolt reinforcement design and preventing cable bolts failing in field applications.

Although Portland cement has long been used in the industry, most research only focused on its axial loading performance. Feldman and Beaudoin [20] conducted a number of Uniaxial Compressive Strength (UCS) tests on several grouts, finding that porosity is a main factor in determining the UCS and Young's modulus of the grout. Domone and Thurairatnam [21] tested the axial performance of an ordinary grout with different curing temperatures.

* Corresponding author at: College of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, China.
E-mail address: jianhang.chen@cumtb.edu.cn (J. Chen).

https://doi.org/10.1016/j.conbuildmat.2018.01.151
0950-0618/

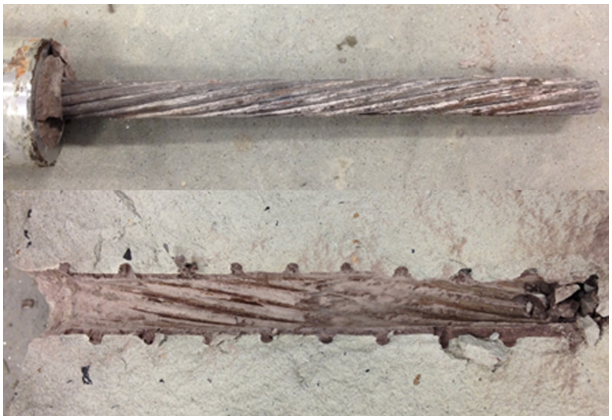

Fig. 1. Bond failure of the cable/grout interface in a pull-out test, after Chen, Hagan [8].

The results showed that the grout strength increased with curing temperature. Hyett, Bawden [22] conducted a detailed study to evaluate the axial performance of grout. The influence of several parameters including water-to-cement (w/c) ratio and curing time, were studied. It was found that the UCS of the grout decreased significantly as the w/c ratio increased from 0.25 to 0.70, as shown in Fig. 2. However, the Poisson's ratio remained almost constant.

Li, Xiao [23] compared the performance of a plain grout and grout containing nanophase materials, finding that adding nanophase materials increased the compressive strength of the grout. Chen, Hagan [24] conducted a series of UCS tests on a Portland cement grout, finding that the w/c ratio obviously influenced the UCS and Young's modulus of the grout when the w/c ratio ranged from 0.35 to 0.45.

On the other hand, less work has concentrated on the shear behaviour of the Portland cement grout. For example, Reichert [25] used triaxial compressive tests to evaluate the shear performance of grout. In his work, three different w/c ratios including 0.3, 0.4 and 0.5, were used. It was found that the internal friction angle of the grout is very low, which was likely due to the presence of very fine particles in the grout. Hyett, Bawden [26] also tested the shear behaviour of grout using a triaxial test. It was found that the shear strength and internal friction angle of the grout were much smaller than rock. Moosavi [19] adopted triaxial tests to evaluate the shear performance of cement grout. He found that the w/c ratio has an impact in determining the shear strength of the grout. Specifically, the shear strength and internal friction angle of the grout increased as the w/c ratio decreased from 0.5 to 0.4. This work has been beneficial for researchers and engineers in understanding the shear performance of Portland cement grout. Furthermore, it provides input values in numerical simulation work to study the shear behaviour of the grout column and bond failure mechanism in cable bolt reinforcement systems.

Nevertheless, Moosavi and Bawden [27] indicated that for cable bolts, the direct shear test is more appropriate to study the shear behaviour of the cement grout, compared with triaxial testing. This is because in cable bolt reinforcement, bond failure usually occurs along the cable/grout interface that is a pre-defined plane. Since the shear failure in the direct shear test is also a pre-defined plane, they recommended using the direct shear test to evaluate the shear behaviour of the grout. They conducted a number of direct shear tests and the shear strength envelopes of the grout with two different w/c ratios were acquired as shown in Fig. 3. However, their test was only conducted under CNL condition and the influence of normal stiffness was not considered.

Until now, no research has been conducted on the shear behaviour of the Portland cement grout under CNS condition using a direct shear test. It should be noted that in the case of cable bolt reinforcement, the boundary of CNS does occur [26,28]. For example, researchers have generally preferred to use metal pipes to confine the grouted cable bolt and conduct pull-out tests on cable bolts [29,30]. Either split-pipe pull test or double embedment pull test can be used to test cable bolts [31–33]. For these scenarios, the cable bolt can be prevented from rotating during testing. For example, Satola [30] welded steel rods on the pipe surface to prevent the cable bolt rotating, as shown in Fig. 4. Under this condition, the cable bolt does not rotate and the cable wires cross over grout ridges due to cable wire/grout printed images, creating CNS condition, as shown in Fig. 5. This paper aims at examining the differences in behaviour of the Portland cement grout between CNL and CNS conditions.

In this paper, the experimental direct shear test process is firstly illustrated. Then, the results from shear behaviour of the cement grout under CNL condition are presented. After that, the shear behaviour of the grout under CNS condition was provided. Finally, the shear behaviour of the grout under CNL and CNS conditions are compared and analysed.

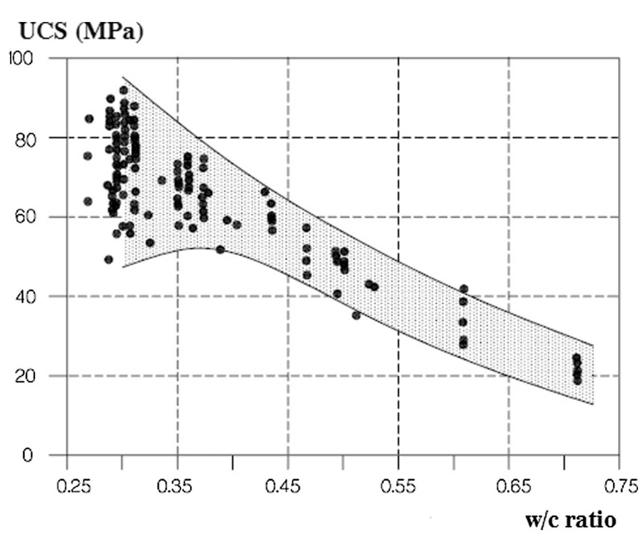

Fig. 2. Influence of w/c ratio on the UCS of the Portland cement grout, after Hyett, Bawden [22].

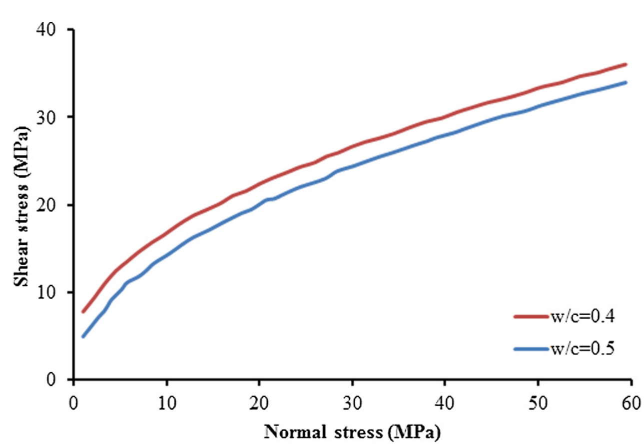

Fig. 3. Shear strength envelopes of the Portland cement grout, after Moosavi and Bawden [27].