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EFFECTS OF RIB DISTANCES ON AXIAL LOAD TRANSFER MECHANISMS OF FULLY GROUTED ROCK BOLTS

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ABSTRACT: Rock bolt systems are widely used for the reinforcement of underground coal mines after excavation. These systems consist of steel bolts installed in drill holes and encapsulated by resin or grout. The spacing between the rock bolt ribs is one of the factors affecting the axial load transfer mechanisms. Steel rebar with a 16 mm diameter, Stratabinder HS grout, and steel pipes with a diameter of 50 mm were used to simulate the rock bolt system. The distance between the ribs on the rebar was doubled for half of the samples to investigate the effects of rib spacing on the pull out capacity of grout encapsulated rock bolts. The water to grout ratio was set to 0.35. Pull-out testing of the samples with curing times 7, 14, and 28 days was carried out using the automated tensile testing machine at the Centre for Future Materials laboratory of the University of Southern Queensland. It was

concluded that the ultimate load was increased when the spacing between the ribs was doubled. The results also showed curing time increases the ultimate pull-out load capacity.

INTRODUCTION

The development of roads, tunnels, dams, underground mines and urban constructions requires a combination of support systems to prevent the collapse of cut rocks into the underground excavations and surface slopes. One of the systems which is wildly used for the reinforcement of underground structures after rock excavation is the rock bolt. They are the rock reinforcing tools used to support the unstable rock strata and prevent further deformation by transferring loads from unstable rock to intact rock. This system has been used in coal mines for the past many years as a means of ground control, and it was observed that roof displacement and speed of fracture openings significantly decreased (Li, 2017). Nowadays, thousands of rock bolts are being installed around the world every year, and the consumption of rock bolts has been increasing. Based on the anchoring mechanisms of rock bolts, they are divided into three groups (Kilic et al., 2002). The first group is the mechanically anchored rock bolt in which a slit and wedge mechanism or an expansion shell are used to anchor them. The second group is the friction anchored rock bolts where the friction between the bolt and the surrounding rock is used to anchor them. The third group, which is the most common, are the fully or partially grouted rock bolts which are anchored by resin or cement. The resin or grout mechanical properties have a significant influence on the capability for load transfer of an encapsulated rock bolt. The grout strength, and the shear resistance between the bolt–grout, and grout–rock interfaces can determine the ultimate anchorage strength of fully and partially grouted rock bolts. Therefore, determining their various properties prior to installation can be useful. (Jeremic and Delaire, 1983) considered five failure types for cable bolting. Rupture of the cable tendon, failure within the surrounding rock mass, relative slippage

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at the grout-rock interface, failure within the grout column and failure at the cable-grout interface. (Potvin et al., 1989) indicated that although failure may occur at either the grout-rock or cable-grout interface, it is more likely to occur between the cable-grout interface, which is subjected to the load transfer between the cable bolt and rock mass. The reason is that the material used to bond the rock bolt or cable bolt to the rock mass surrounding the borehole, transfers the force between the rock mass and the rock bolt through the shearing forces within the grout. On the other hand, due to the smaller contact area between the cable and the grout, the shear stresses at the interface are generally larger than at the grout-rock interface, which then, more likely causes failure between them. (Fabjanczyk and Tarrant, 1992; Windsor, 1997) showed load transfer is composed of three fundamental mechanisms: 1) rock movement, which causes the transfer of load from the unstable rock mass to the reinforcing tendon; 2) transfer of load from the unstable rock mass to the interior stable rock mass using the reinforcing tendon; 3) transfer of load from the reinforcing element tendon to the interior stable rock mass. (Serbousek and Signer, 1987) found that the rate of load transfers from bolt to rock steadily decreased and it depends on the geotechnical properties of grout, material properties of the bar and rock interfaces. Based on several pull-out tests, the results show mechanical interlocking controls the load transfer between the bolt and grout. The mechanical interlock plays an essential role in the load transfer between the bolt and grout (resin) in a rock bolting system which is created by the bolt profile configuration. Bolt surface geometries include the rib profile shape, height, angle of wrap and distance between the ribs. However, experimental and numerical studies (Blanco Martín et al., 2011; Ghadimi et al., 2015; Teymen and Kılıç, 2018) have shown that among bolt surface geometries, rib space and height play an essential role in transferring the load through the rock bolting system. (Fabjanczyk and Tarrant, 1992) carried out some practical tests to investigate the effect of rib heights on loading transfer through rebars. The results showed that different parameters such as the resin mechanical properties, hole diameter and rebar surface geometries have significant effects on load transfer. The results also showed rebars with a lower rib height had lower stiffness. In addition (Kang et al., 2015) performed several experimental studies and they found that the bolting performance is increased by increasing the rib height from 0.48 to 1.42 mm. (Blümel, 1996) was the first person to complete several experimental tests to evaluate the influence of rib space on the load transfer capacity of rock bolts. To conduct the tests, steel pipes, 500 mm in length, were used to simulate the surrounding rock mass, and rebars were anchored, using cement base grout, inside of these steel pipes. The results of pull-out tests showed that by increasing the rib space from 13.7 to 54.8 mm, the ultimate bearing capacity of rock bolts increased. The results of another study conducted by (Blumel et al., 1997) showed the axial stresses in rebars with more space between the ribs are larger when compared to rebars with smaller rib spaces.(Aziz et al., 2008) carried out several tests to determine the effect of rib spacing on the ultimate bearing capacity of pull-out and push-out of the 22 core diameter bolts. 150 mm and 115 mm steel pipes respectively were used for these push-out and pull-out tests. Rebars with different profile spacings for the ribs including 12.5, 25, 37.5, and 50 mm were used for testing. The results demonstrated the bonding capacity of the bolts increases with increased rib spacing.

SAMPLE PREPARATION AND EXPERIMENTAL SETUP

The last studies provide an essential understanding of the role of bolt geometries and their influence on rock bolting failure. However, the effect of grout strength on the ultimate bearing capacity of rebar bolts with different rib spacing is one of the aspects that should be investigated. This paper presents results from a series of laboratory pull-out tests to evaluate this effect on rebar bolts with different rib spacing. To understand the effect of grout strength and rib space on the ultimate bearing capacity of rock bolts, a series of tests was carried out using bolts with different rib spaces cast into steel sleeves of 50mm diameter with a length of 50mm. For all tests, 16 mm nominal diameter rebars with 1.25 mm rib height and 1.15 mm rib width were used. The rib space was 8 and 16 mm as can be seen in **Figure 1**.

The grout product Minova Stratabinder HS was selected to cast and test the samples. A mixing ratio of 7 liters of water/bag was selected to pour into the steel pipes and then a slight vibration was applied to the samples to remove trapped air. The rebar was then centered inside the sample using a Perspex cap on the top of the steel pipe (**Figure 2**). All samples were stored in a curing room for 7, 14, and 28 days and after the required time, they were tested using a compression testing machine with a loading rate of 1 mm/min as shown in **Figure 3**.

Figure 1: Rebars with two different rib space **Figure 2: prepared samples**

Figure 3: 100kN compression testing machine

RESULTS AND DISCUSSION

Rib space

More than 12 pull-out tests were carried out on prepared samples after 7, 14, and 28 days of curing. To ensure the accuracy of the collected data, two tests were repeated for each case. **Figure 4** shows 7 and 14 days old prepared samples with two different rib spaces before the pull-out test and **Figure 5** shows one of the samples after the pull-out test.

Figure 4: 7 and 14 days old prepared samples

Figure 5: 7days old sample after pull-out test

Figure 6 shows the load-displacement curve for rebars with 8 and 16-mm rib spacing on the seventh day of curing. As can be seen, by increasing the rib space from 8 mm to 16 mm, the ultimate bearing load of the bolts increases from 36.2 to 40.08 kN which is 10.7% higher than the pull-out test results for the 8mm rib spaced bolts. It is evident that the bolt rib spacing is the only factor that has changed the results. The results also show that the average displacements of bolts at peak load increased from 3.7 to 5.1 mm using rebars with a 16 mm rib spacing which is an advantage when used in an area with high ground displacement, not losing their load transfer capacity. The results agree very well with previous studies (Tao et al., 2017) and shows the repeatability of the tests with a reasonable degree of confidence.

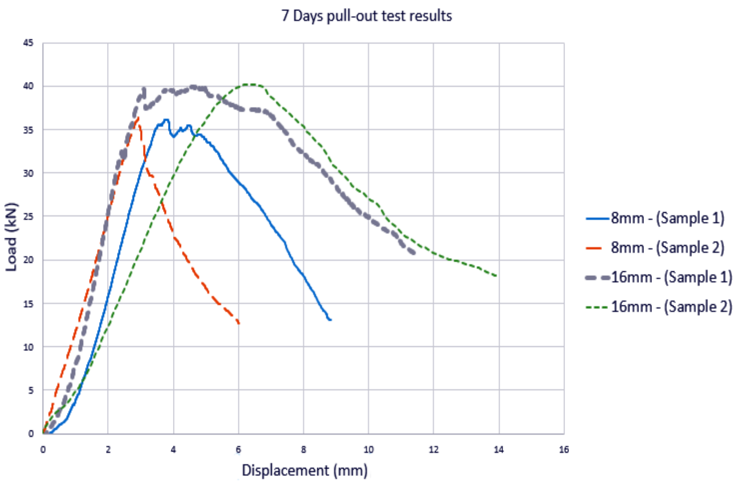

Figure 6: 7Days load-displacement

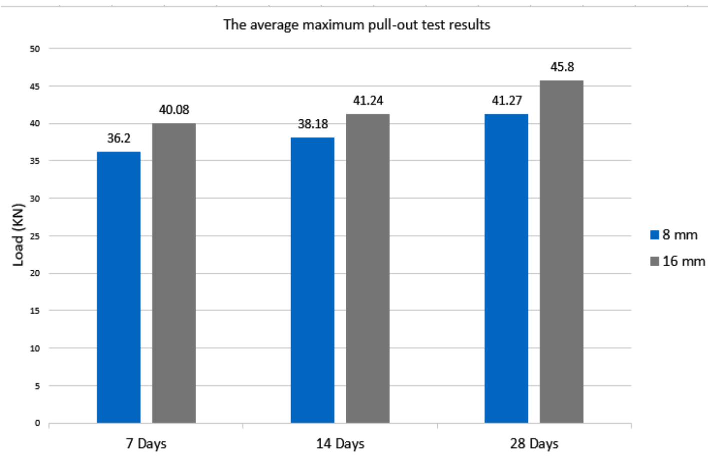

Figure 7: The average max pull-out results

Curing time

The average maximum pull-out test result values for 8 and 16mm rebars for different curing times are presented in **Figure 7**. As can be seen, the average pull-out test result values for rebars with 8 and 16 mm rib spacings increase with extended sample curing times, from 7 to 28 days. It seems that the strength of the grout has a positive effect on the ultimate load capacity of rock bolts. The results also show in **Figure 8** and **9** that the average displacement of bolts at peak loads for 14 and 28 days of curing, increases using rebars with 16 mm rib space.

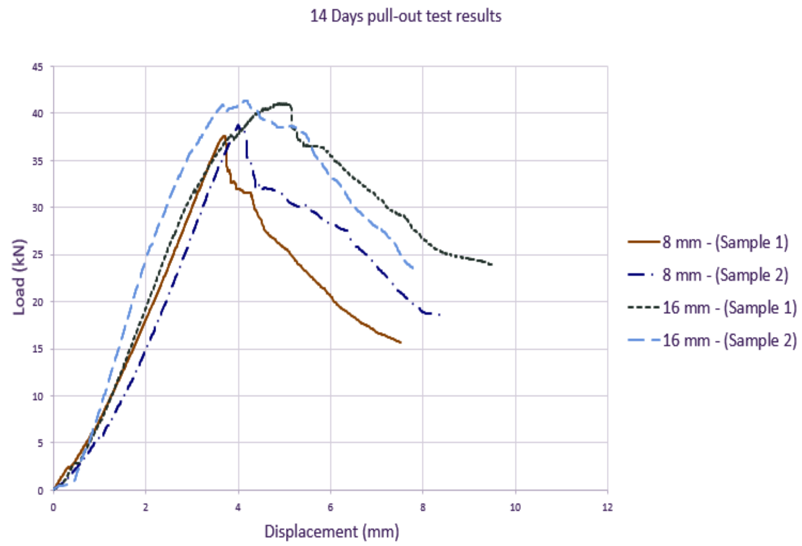

Figure 8: 14Days load-displacement

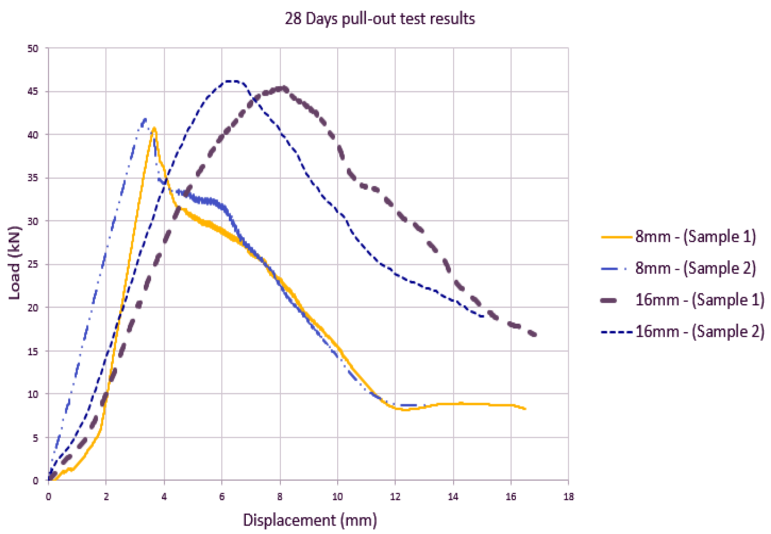

Figure 9: 28Days load-displacement

CONCLUSIONS

This paper aims to investigate the effect of rib spacing on the results of pull-out tests. In this study, pull-out tests were conducted using rebar bolts with two different rib spacings, 8 and 16 mm anchored in steel tubes using Stratabinder HS grout. From this study, the results showed that by increasing the rib space from 8 mm to 16 mm, the peak load of the rock bolts increases from 36.2 to 40.08 kN which is 10.7% higher than the pull-out test results for 8mm rib space bolts. The results also showed the average displacement of bolts at peak load for 7, 14, and 28 days of curing, increased using rebar with a 16 mm rib space. The results of the study demonstrate that the increase of the rib space improves the bolting effect. Such understanding may be used to better design rock bolts for the coal mining industry.

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