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Strength properties of grout for strata reinforcement

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STRENGTH PROPERTIES OF GROUT FOR STRATA REINFORCEMENT

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ABSTRACT: An experimental study was carried out on grout samples prepared from both Stratabinder and BU100 cementitious products. Samples were prepared with various water to grout ratios and tested for uniaxial compressive and shear strength. Triaxial tests were performed on cylindrical samples to determine values for internal friction angle, cohesion and tensile strength. It was found that the water to cement ratio affects the uniaxial compressive and shear strength of grout. The triaxial test indicated that both internal friction angle and cohesion of Stratabinder do not differ significantly from BU100.

INTRODUCTION

Prior to the late 1940's, a large proportion of roof supports in underground mines in Australia consisted solely of timber deployed along roadways. The fragile nature of the timber was the cause of a considerable roof failures and rib collapses prior to the introduction of roof bolting. The early roof bolts consisted predominantly of a mechanical anchor positioned at the base of the drill hole. Subsequently, the fully encapsulated rock bolts were developed to bind the bolt and surrounding rock after installation by means of resin or grout. The capability of load transfer of an encapsulated rock bolt is influenced by the resin or grout mechanical properties.

Aziz *et al.,* (2013*a*, 2013*b* and 2014*a*) carried out a detailed research study with the aim of establishing a general practice standard for determination of mechanical properties of resin. The study included; determination of the Uniaxial Compressive Strength (UCS), the Elastic modulus (E) value in compression, shear strength and rheological properties. These mechanical properties were examined at the University of Wollongong laboratory in relation to resin sample shape, size, height to width or diameter ratio, resin type, resin age and cure time. The following conclusions were reported:

- The UCS values determined from various shaped samples differed with respect to the sample shape and size and height to diameter ratio,
- Typically, the UCS values were highest for 40 mm cubes and 40 mm diameter cylindrical sample with height to diameter ratio of two,
- The ratio between cube strength and cylinder strength varied from 1.1 to 1.3,
- The E value increased as the resin sample curing time increased from 7 to 21 days,
- The cube samples exhibited higher E values in comparison with cylindrical specimens at various curing time,
- Similar to UCS values, the average shear strength of grout samples increased with increasing curing time,
- Cube samples were suggested as a universal shape for testing resin products as they can be easily prepared and tested.

A comprehensive report on the above study was further published by Aziz *et al.,* (2014*b*) through the Australian Coal Association Research Scheme (ACARP) organisation.
Hagan and Chen (2015) investigated UCS values of cube and cylindrical grout samples at different water to cement ratio, and it was found that:

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- Cube samples provided higher UCS values when compared to cylindrical specimens, and
- Strength of the material varied with water to cement ratio, showing a reduction trend with increase in the water quantity.

Recently, Mirza *et al.,* (2016) compared UCS values, E modulus and creep of two commonly used grout products (Stratabinder and BU 100 grouts) in Australian coal mining industry. It was reported that:

- Stratabinder HS grout was marginally better than the BU 100 grout for curing time of more than one day. For one day of curing time however, BU 100 samples showed better performance,
- Experiments indicated lower elastic modulus values for BU 100 when compared to Stratabinder HS under compressive cyclic loading,
- The elastic modulus determined by testing the samples using the Instron machine may have been influenced by the pronounced sample end effect, giving non-realistic low values,
- BU 100 showed higher creep value under a compression load of 100 kN for the duration of 15 min compared with Stratabinder HS,
- The difference between creep values of BU 100 and Stratabinder HS products was not significant. Both products suit equally for cable bolt installation in rocks for strata reinforcement.

This paper is a companion paper to the one recently published by Mirza *et al.,* (2016) and investigates following items that had not been studied previously:

- Uniaxial compressive strength (UCS) for a range of grout samples with various water to grout ratios,
- Shear strength for a range of grout samples with various water to grout ratios, and
- Perform triaxial testing of specific grout samples to analyse the effect of confining pressures, and obtain values for cohesion and internal friction angle.

Two commonly used grout products namely, Stratabinder and BU100 were used to cast samples (Figure 1).

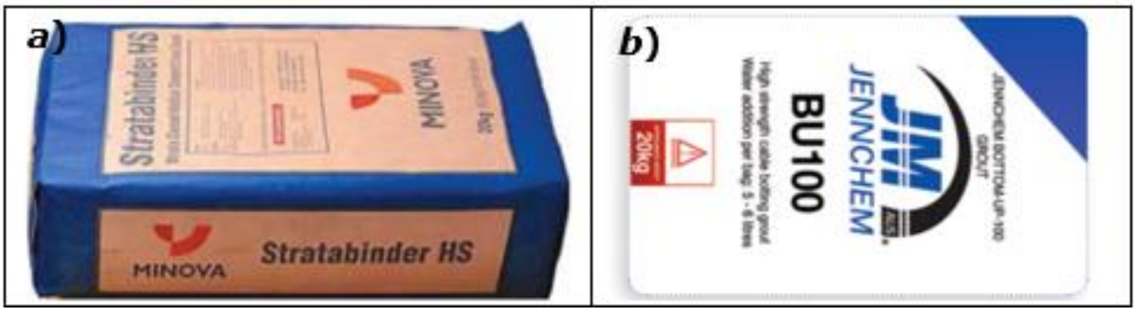

Figure 1: *a*) Stratabinder HS *b*) BU100

EFFECT OF WATER TO CEMENT RATIO ON UCS

The procedure for sample preparation and testing for determination of UCS were the same as discussed by Mirza *et al.,* (2016). The curing time for samples prior to testing was seven days. Table 1 shows water to grout ratios that were used to cast samples. As the water to grout ratio increased, the sample mixtures contained more water per unit weight of grout. Mix 'A' contained the industry recommendation for the water to grout ratio for both Stratabinder HS and BU-100.

Table 1: Water to grout ratios

Water-Grout Ratios						
	Stratabinder HS			BU-100		
Mix ID	Litres/Bag	Water per 100g	Water:Grout	Litres/Bag	Water per 100g	Water:Grout
1	5.6	28ml	0.28:1	3.6	18ml	0.18:1
2	6.4	32ml	0.32:1	4.4	22ml	0.22:1
A	7	35ml	0.35:1	5	25ml	0.25:1
3	7.6	38ml	0.38.1	5.6	28ml	0.28:1
4	8.4	42ml	0.42:1	6.4	32ml	0.32:1
5	9	45ml	0.45:1	7	35ml	0.35:1

Figure 2 shows a comparative chart showing the differences in Stratabinder and BU-100 uniaxial compressive strength for various water to grout ratios. The industry recommended water to grout ratio for each type of grout were used as a basis for comparison. Under these test conditions, Stratabinder HS was approximately 18% stronger than BU-100. It is clear from the position of the two curves that Stratabinder HS (shown in blue) operates at a higher water to grout ratio, considering the differences in peak values. This signifies that for any compressive strength value, the BU-100 mixture would need an 8%-12% reduction in water to match the strength of Stratabinder. The general shape and perpendicular deviation between each curve remains constant, which further demonstrates the homogenous effects of water content on the compressive strength, regardless of the specific grout type. There was an obvious correlation between compressive strength and the ratio of water to grout in the mixture. Adding water increased the space between grout particles, which prevented the formation of strong, close-knit bonds. As the sample cured, excess water evaporated, leaving pores of air throughout the sample. These pores offered no structural support and therefore contributed to the lower strength that observed. Results obtained during this testing coincided with the expected outcomes; showing a decreasing trend in UCS with increase in water to cement ratios.

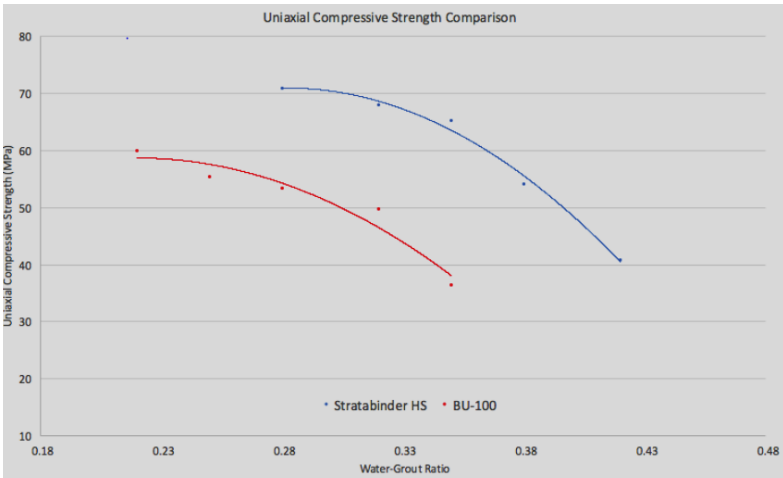

Figure 2: UCS values for different water to grout ratios

EFFECT OF WATER TO CEMENT RATIO ON SHEAR STRENGTH

Punch shear tests were carried out on grout samples to determine the shear strength for various water to grout ratios. Samples were cast and tested following the procedure reported by Aziz *et al.,* (2014*b*). Samples were allowed to cure for seven days prior to testing. A typical disc sample and punch shear instrument that were used as part of this study are shown in Figure 3.

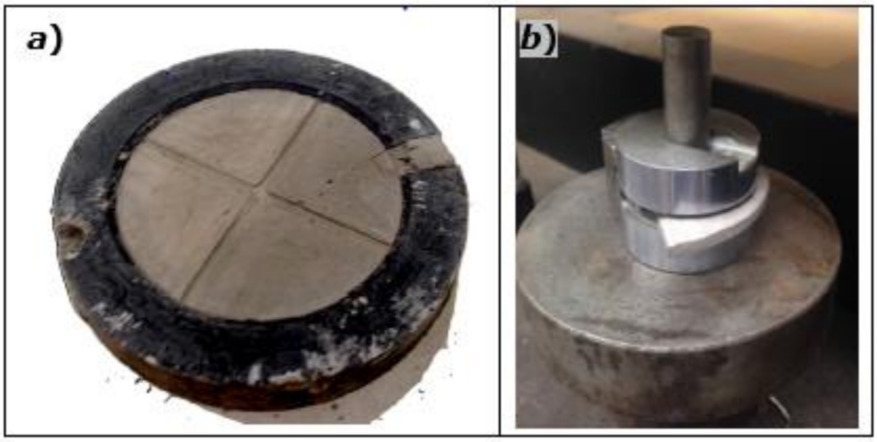

Figure 3: *a*) Typical disc sample *b*) Punch shear apparatus

Results from the punch shear test of Stratabinder HS and BU-100 are shown in Figures 4 and 5, respectively. Punch shear testing of Stratabinder HS samples provided inconclusive results, due to the broad spread of collected data while a general decreasing trend line is observed with increase in water to grout ratio. The relationship observed between strength and water to grout ratio corresponds with uniaxial compressive strength tests. It is inferred from the punch shear tests performed on BU-100 grout samples that increased water content subsequently decreased the grout shear strength. The shear strength values for BU100 samples ranged from 12.35 MPa to 9.01 MPa across an array of water to grout ratios.

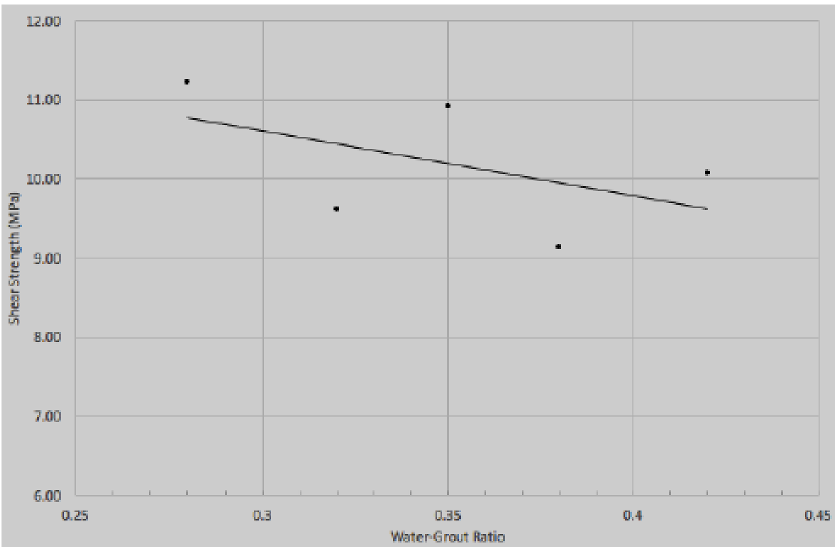

Figure 4: Stratabinder shear strength against water to grout ratio

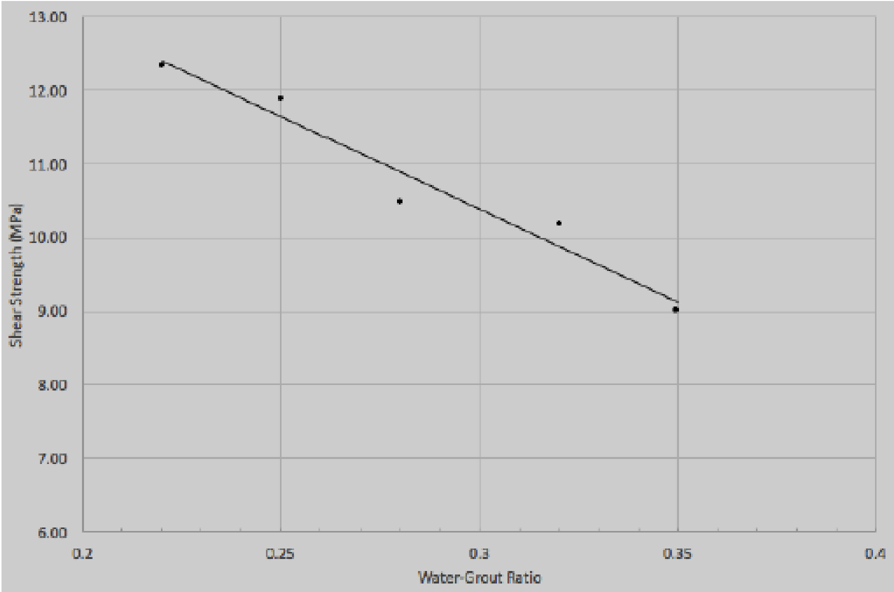

Figure 5: BU100 shear strength against water to grout ratio

In general, it was observed that higher water to grout ratio in the mixture causes a reduction in the shear strength. The mechanism behind this relationship corresponds to the particle structure of the samples, which was previously discussed. However, changing the water to grout ratio had a less effect on the shear strength in comparison with the UCS. Over the range of water to grout ratio, the shear strength of grout samples decreased by 27%, in comparison with UCS result's which decreased by 43%.

TRIAXIAL TESTING ON GROUT SAMPLES

Triaxial tests were conducted to determine internal friction angle (ϕ), cohesion (c) and tensile strength of grout samples. Grout samples were prepared on 100mm long cylinder moulds using a PVC pipe with a diameter of 50mm using mixture ID of A (Table 1). Samples were cured for seven days prior to testing in triaxial cell as shown in Figure 6. Three values of confining pressure including 2, 4 and 6 MPa were selected for testing. Each test was repeated three times and the average value was taken into account to calculate mechanical properties.

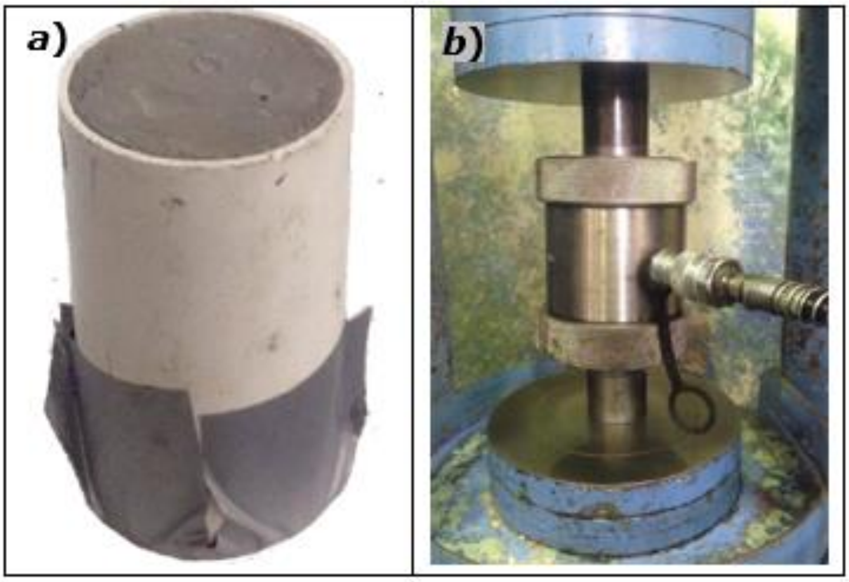

Figure 6: *a*) PVC mould containing prepared sample *b*) Triaxial cell in testing arrangement

The stress states is graphically represented in Figures 7 (Stratabinder) and 8 (BU100) by blue, red, and green arcs, which correspond to 2 MPa, 4 MPa and 6 MPa of confining pressure, respectively. The peak axial load and confining pressure for each set of samples are denoted by two intersection points on the x-axis. Mohr's Envelope was established and incorporated to calculate values for cohesive strength and internal friction angle. Values for cohesion and internal friction angle for Stratabinder samples were computed to range from 7.0 to 70 MPa and 50 to 70º respectively. These values for BU100 samples were 7.5 MPa and 52.76º. The data shown in Figure 7 suggests that Stratabinder cylinders exhibited a tensile strength of -5.5 MPa and for BU-100 cylinders the tensile strength was -5.05 MPa (Figure 8).

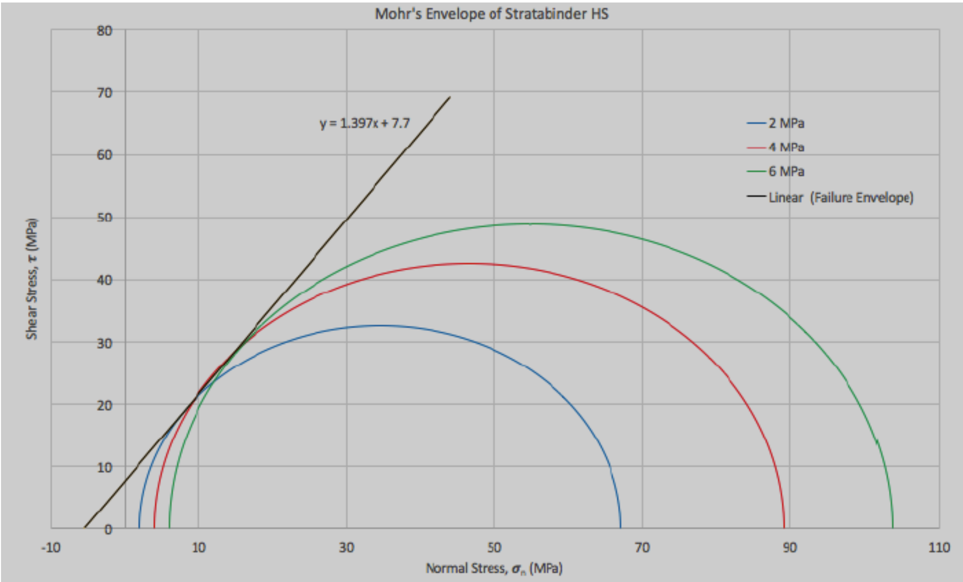

Figure 7: Mohr's envelope for Stratabinder

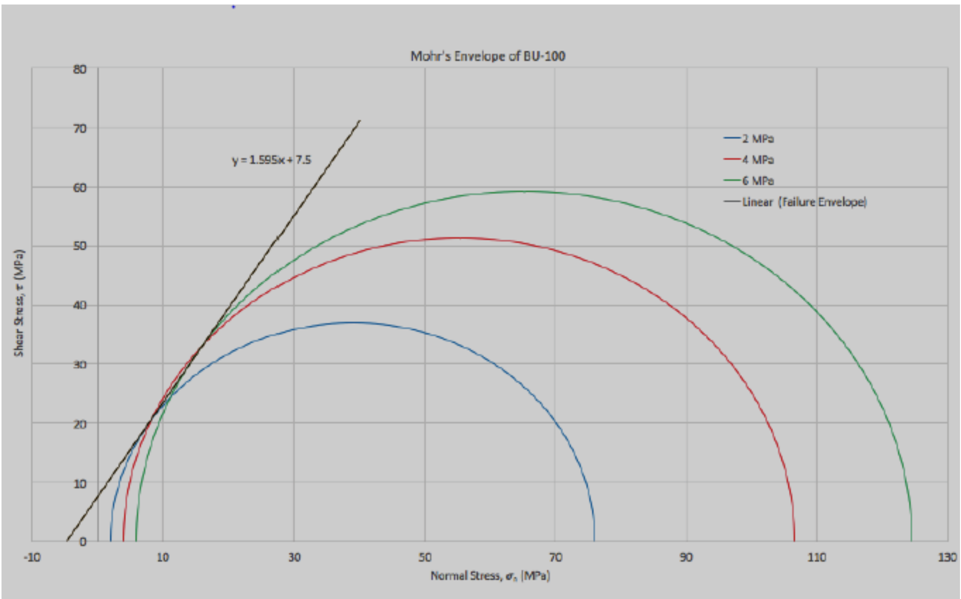

Figure 8: Mohr's envelope for BU100

CONCLUSION

Results of a systematic experimental study on grout samples cast using Stratabinder and BU100 were presented in this paper. Following main conclusions are drawn from this investigation:

- Water to grout ratio was a significant factor, which influences both the uniaxial compressive strength and the shear strength of grout,
- The UCS and he shear strength of grout samples decreased as water to grout ratio increased,
- Stratabinder and BU-100 had a cohesion of 7.70 MPa and 7.50 MPa, respectively, which showed a negligible difference, and
- The friction angle of Stratabinder ranged 50.70º as opposed to 52.76º for BU-100, these differences were relatively in significant difference.

Further shear tests on BU100 grout samples are recommended to increase the precision of collected data.

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