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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: Past studies on the mechanical properties of grout were critically investigated and classified. Grout samples were cast using a specially designed dog bone mould. Effects of curing time on tensile strength properties were investigated, using a universal tensile testing machine for curing times intervals ranging from 1 to 28 days. In addition, various percentages of fly ash were added to cube grout samples. Fly ash mixed samples were cured for different curing times and subsequently subjected to Uniaxial Compression Testing (UCS). It was found that tensile resistance of grout samples increased with respect to curing time. Moreover, it was concluded that addition of fly ash to grout mixture increased the uniaxial compression strength of grout samples.

INTRODUCTION

Rock bolt systems were first introduced for use as mining ground supports during the late 1940's in the form of mechanical anchoring (Mark 2017). Mechanical anchoring became the preferred support system as they weren't subjected to stiffness weakening due to design length (Mark and Barczak 2000). As a result of the increasing popularity and widespread implementation of rock and cable bolts, numerous design variations were conceived in order to meet the explicit criteria. The development of resin and grout anchorage allowed for greater variation in rock bolt selection in order to meet specific operational requirements (Rajapakse 2008).

Cementitious grout has become a primary method of anchoring cable bolts, due to ease of installation and load transfer abilities (Mirzaghorbanali *et al*. 2016). Additionally, studies conducted by (Ma *et al*. 2013; He *et al*. 2015; Thenevin *et al*. 2017) have investigated the possible uses and mechanical properties of cementitious grouted rock-bolt systems as a method for anchoring ordinary rock bolts. Sample preparation methods proposed in these studies have adopted the grouted cable bolt installation process, and as a result, rock bolts can be susceptible to similar grout failure modes to that of cable bolts due to erroneous installation practices. Correctly installed grouted supports can provide a safe, cost effective and long-term form of reinforcement for; wedge/flake stabilisation, arching, tieback, suspension and forepoling.

Detailed studies have been conducted to determine both the mechanical properties of grouts and chemical resins (Aziz *et al*. 2014; Mirzaghorbanali *et al*. 2016) in addition to their encapsulation properties (Aziz *et al*. 2016). Moreover, these studies have resulted in the determination of the properties of grouts and resins for use with both cable and rock bolts as well as establishing a general practice standard.

The study conducted by Aziz *et al*. (2014) analysed the effects of varying resin sample properties in accordance with the various standards (*ASTM C-759* 1991; *South African Standard (SANS1534)* 2004; *BS 7861* 2009) to determine the effects of:

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- Sample shape,
- Sample size,
- Height to width or diameter ratio,
- Resin type,
- Resin age and
- Curing time

Samples were subjected to the testing procedures in accordance with the various standards of testing to determine:

- Uniaxial Compressive strength (UCS),
- Modulus of Elasticity,
- Shear Strength and
- Creep/rheological properties.

Additionally, Hagan *et al*. (2015) through the Australian Coal Association Research Scheme (ACARP C22010) investigated the effects of water to grout ratio on the UCS of both cylindrical and cube samples. This study identified a declining relationship in UCS strength with the increase of water concentrations. Moreover, when compared to cylindrical samples, cube samples achieved higher UCS values.

The study conducted by Mirzaghorbanali *et al*. (2016) investigated the effects of curing time on the mechanical properties of Jennmar grout BU 100 and Minova Stratabinder. Cube samples were prepared and tested at 1, 7, 14 and 28 days of curing. The study concluded that:

- The compressive strength of grout increased with curing time, and
- Both products are suitable for use in strata reinforcement.

Furthermore, the study conducted by Mirzaghorbanali *et al*. (2018) investigated the effects of curing time on the mechanical properties of both small and large scale samples using Minova Stratabinder. The UCS properties were determined using length /diameter ratio of 2:1 cylinder moulds of 100 mm diameter and small cube samples of 70 mm. The large-scale bending tests were conducted using prismatic moulds of 350 mm x 100 mm x 50 mm. The study concluded that:

- The smaller scale samples achieved a faster strength response to cure while large-scale samples experienced a curing delay,
- Small-scale samples achieved higher peak UCS values, and
- The four point bending test resulted in an unexpected strength weakening due to curing time.

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

The grout products Minova Stratabinder HS and Jennmar BU100 were selected to prepare and test samples. The Uniaxial Compressive Strength (UCS) samples were cast using the Stratabinder HS grout and fly-ash with the industry standard 50 mm cube mould. The dog-bone samples were cast using centre dimensions of 90 mm x 10 mm x 9 mm moulds. Shown in Figure 1A is the mixing equipment used to produce grout samples, Figure 1B outlines casting moulds used for the UCS samples and Figure 5 A and B shows the casting mould and cured samples for the dog-bone samples. All samples were tested using universal compression testing machines as shown in Figure 3A and Figure 6B. Samples were cast using a mixing ratio of 7 litres of water/bag and application of slight vibration to remove trapped air. All samples were stored in a controlled fog room to assist in uniform curing and finally prepared at curing times of 1, 7, 14, 21 and 28 days.

EXPERIMENTAL RESULTS

Uniaxial Compressive Strength (UCS)

To conduct the UCS tests, samples were prepared at 1, 7, 14, 21 and 28 days curing time for fly-ash contents of 5%, 10%, 15%, 20%, 25% and 30%. To ensure accuracy of the collected data each tested parameter contained six samples as shown in Figure 2A. A total of one hundred and eighty samples were produced.

The UCS values for fly-ash content at various curing times are presented in Figure 3. It is observed that while there was an overall increase in UCS for all samples, the UCS values of the samples of 10% and 15% ash content were consistently higher than those of other ash content values. The difference between the UCS of each sample was more pronounced form 14 days curing onwards. At 28 days curing the 15% samples had a UCS of 90 MPa, whereas 5% fly-ash samples only achieved 70 MPa. A comprehensive comparison was conducted and concluded that samples containing 15% fly-ash content out performed all other samples after a curing time of 21 days and is shown in Figure 4.

The observed failure mechanisms were similar to that of general grout samples and presented in three stages. In the initial stage of failure, micro-cracks were initiated. In the second stage cracks propagated. Finally, the third stage presented a complete failure as shown in Figure 2B.

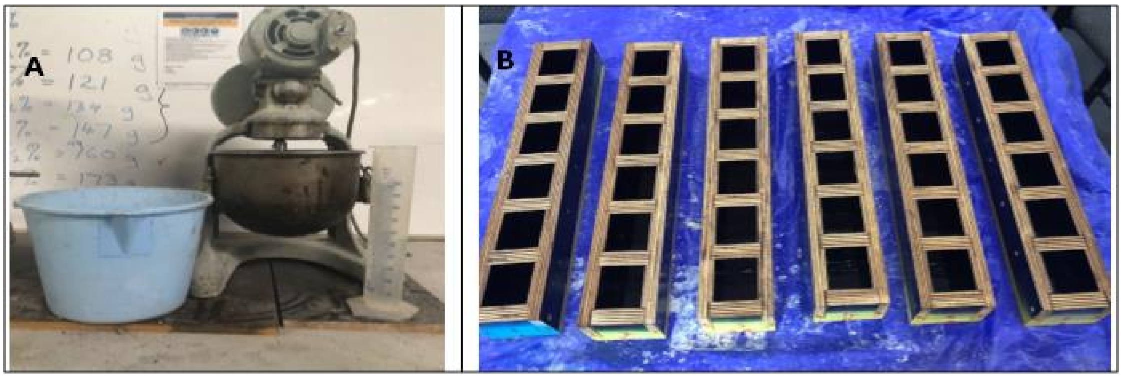

Figure 1: Grout preparation [A] a view of cube moulds [B]

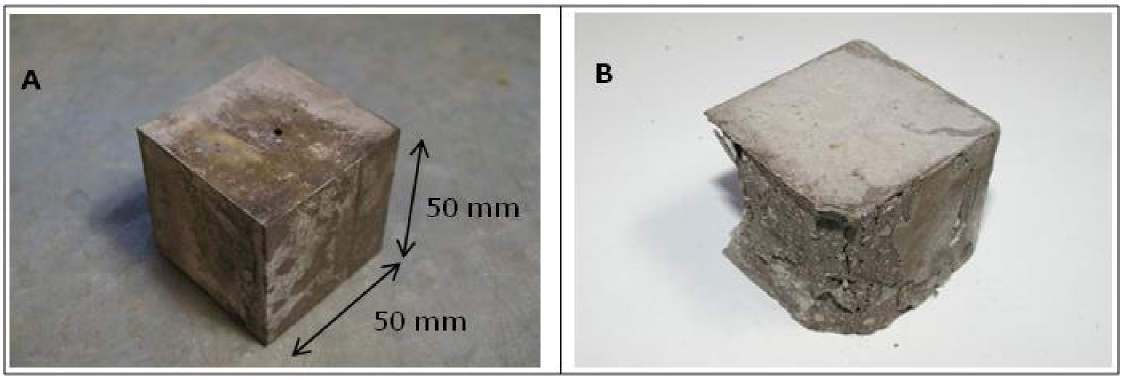

Figure 2: Prepared Sample 50 mm cube UCS [A], failed sample after testing [B]

The UCS values of each fly ash curing time for both the small-scale and large-scale samples are shown in Figure 3 B through F. A comparative analysis was then conducted and is presented in Figure 4 outlining the strengthening process due to the curing time. The obtained UCS values show an increase in strength over the 28 day curing period for the 10%, 15% and 30% achieving 82 MPa, 90 MPa and 80 MPa respectively. It was noted that some samples such as the 5% and 10% fly-ash concentration experienced a strength settling effect. The tested samples reached their peak UCS at 14 and 21 days curing of 76 MPa and 86 MPa and settled to 70 MPa and 82 MPa respectively.

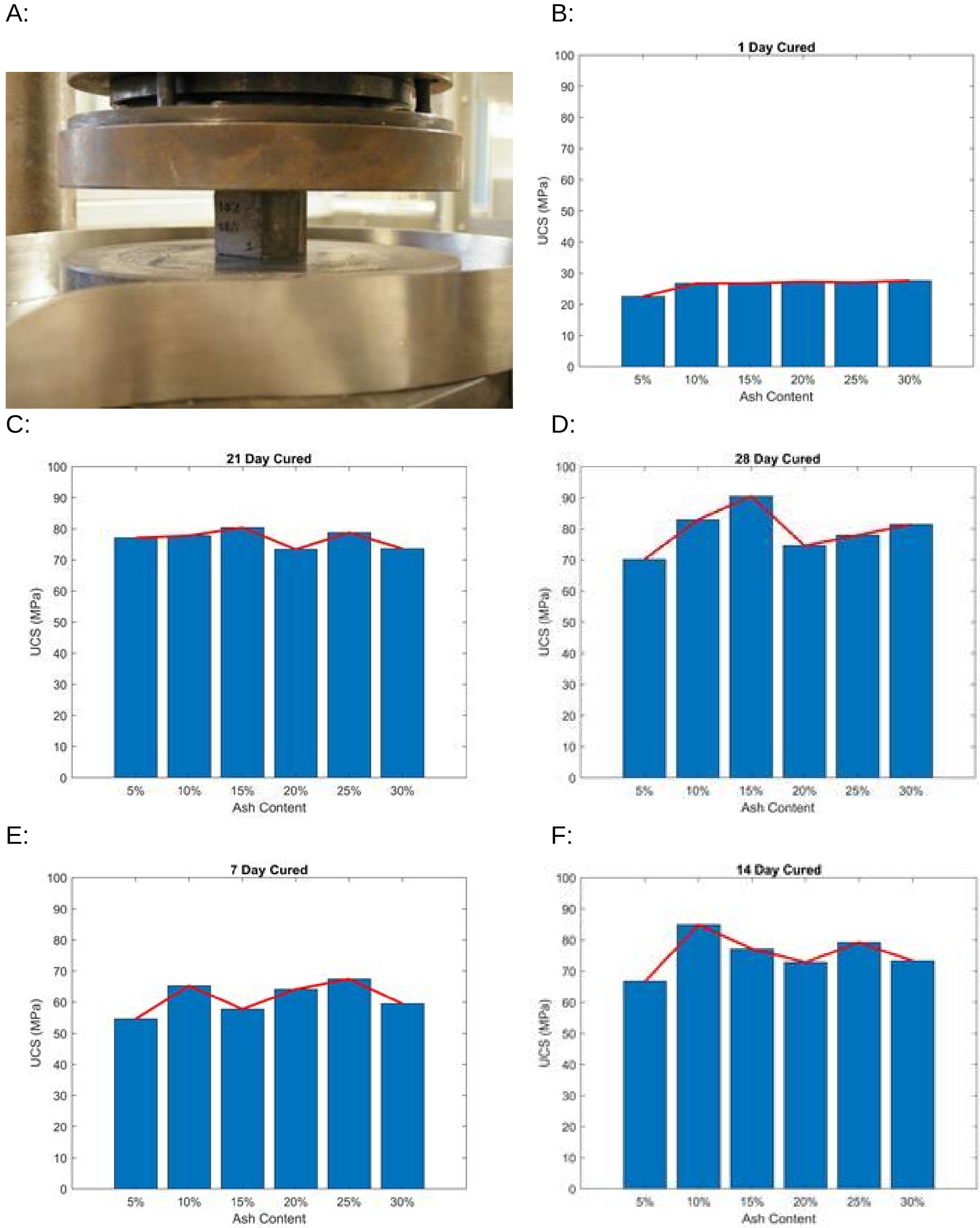

Figure 3: Compression tester set up [A]. UCS values at 1 to 28 curing days [B - F]

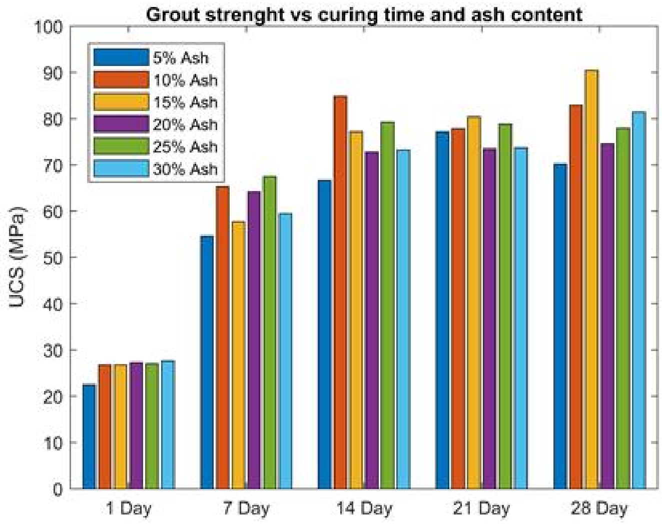

Figure 4: Comparative analysis of fly-ash content and curing times

Tensile testing

Small-scale dog-bone tests were carried out on prepared samples at 1, 7, 14, 21 and 28 day curing times using both Stratabinder HS and BU100 grouts. To ensure accuracy of the collected data six samples were cast and tested for each curing time with a total of 30 samples for each grout type. Figure 6 A, B and C shows the dog-bone samples, the testing process and the sample failure respectively.

Shown in Figure 7 are the tensile failure loads at various curing times. Comparatively to the UCS tests, the tensile strength of grout increased over time with initial values of 2.5 – 2.75 MPa and 3.5 – 3.9 MPa achieved at the end of the curing period. The failure mechanism presented in the tensile tests was identical to that of the UCS tests.

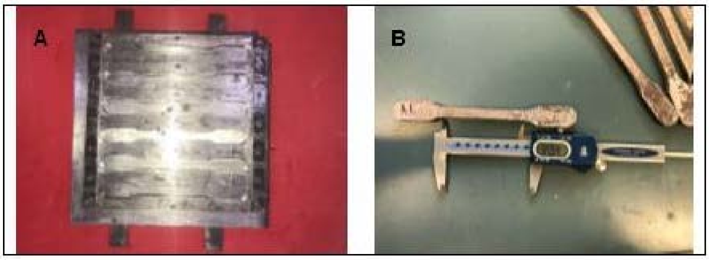

Figure 5: Dog-bone mould [A], Cured dog bone sample [B]

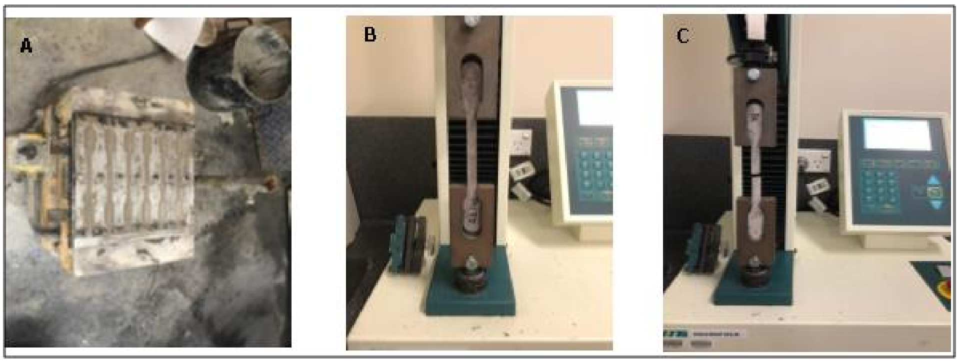

Figure 6: Dog-bone mould used for casting [A] tensile testing equipment with dog-bone attachment [B] failed dog-bone sample [C]

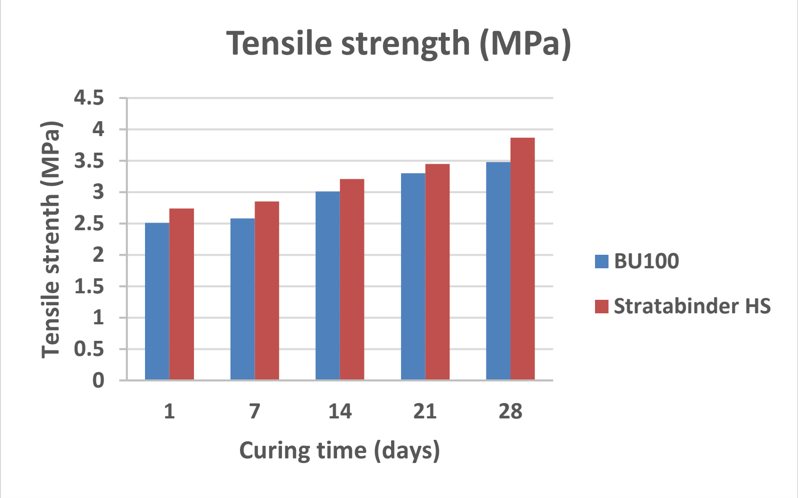

Figure 7: Comparison of Stratabinder and BU100 at various curing times

DISCUSSION

The experimental study found that the UCS of composite grout samples increased with respect to curing time and achieved an optimum strength at 15% of flyash concentration of 90 MPa. Samples containing 10% fly-ash performed similarly to the 30% fly-ash samples, however the pourability of the 30% samples were greatly reduced and samples behaved similar to wet putty. Experiments indicated an increased performance to that of standard grout tests of the not 10%, 15% and 30% concentrations. While also producing the best results, the 15% samples remained fluid and easy to pour. Further studies need to be conducted on the ability to pump of the composite samples to ensure viability in the field.

Results of the tensile tests closely matched the initial expectations based on which the peak tensile load should increase with an increase in the curing time. Additionally, the Stratabinder grout performed closely to the BU100 grout while consistently achieving results 0.2 MPa greater.

CONCLUSIONS

For the purpose of this study, a new composite grout was created and tests were conducted to determine the uniaxial compressive strength. The novel grout was subject to the same testing parameters as previous cube grout studies. Additionally, ordinary Jennmar BU 100 and Minova Stratabinder HS grout samples were subjected to small-scale dog-bone tensile test. The study resulted in the following.

- Increased strength properties when comparing the novel composite grout to standard grout.
- Grout containing 15% fly-ash content achieved the highest strength at the end of the curing period.
- The novel grout maintained a similar strength to curing time relationship as standard grout.
- The increasing of fly-ash greatly impacted the viscosity of the wet grout mixture.
- When standard grout samples were subjected to tensile loading the tensile resistance increased with respect to curing time

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