2016

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Publication Details

Ali Mirza, Naj Aziz, Wang Ye and Jan Nemcik, Mechanical Properties of Grouts at Various Curing Times, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 16th Coal Operators' Conference, Mining Engineering, University of Wollongong, 10-12 February 2016, 84-90.

MECHANICAL PROPERTIES OF GROUTS AT VARIOUS CURING TIMES

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ABSTRACT: The uniaxial compressive strength, elastic modulus and creep of two commonly used grout products in Australian coal mining industry, Jennmar Bottom-Up 100 (BU100) and Orica Stratabinder HS were studied. A 50 mm cube mould was used to cast samples. The Uniaxial compressive strength of the samples with curing time, ranging from 1 to 28 days was determined, using an Avery compression testing machine. Secant, tangent and 50 kN range elastic modulus of grout products were investigated under cyclic loading at a 1 mm/min loading rate. Both strain gauged and non-strain gauged samples were tested for determination of the elastic modulus in compression. Strain gauged samples were prepared to evaluate creep values of BU 100 and Stratabinder HS under 100 kN compression load for 15 min. It was found that Stratabinder HS had higher uniaxial compressive strength and elastic modulus after a day of curing in comparison to BU 100. Stratabinder HS showed lower creep values by 0.04% when compared with BU 100.

INTRODUCTION

Application of cable bolts as a common secondary support system to reinforce incompetent strata in Australian underground coal mines goes back to the 1970s. Cable bolts, unlike ordinary rebar bolts, are mostly installed using cementitious grouts. Recent developments in cable bolt design have increased the crucial role of grout products to act as a stable interface between the cable bolt and surrounding rocks with the aim of keeping the underground openings safe and stable for a long period of time.

Cable bolt failures have been observed in various Australian underground coal mines with no evidence of strand rupture. These failures can be attributed to installation practices and premature failure of grout. Encapsulated cable bolts provide an effective support system over a very large span for blocks and wedges formed in roofs or walls of excavations. The cable bolt reinforcement system consists of four main components as:

- Strands
- Barrel and wedge
- Grout
- The rock

The above mentioned components interact with each other to transfer the load of loose strata to deeper and more stable rock structures. Any defects or possible overload in components may deteriorate the whole support system, leading to failure. Therefore, it is of outmost importance to determine the mechanical properties of components, delineating the maximum load at which the whole cable bolt support system can stay in one piece without failure. A series of experimental studies was carried out to investigate the Uniaxial Compressive Strength (UCS), Elastic modulus (E) and creep of two commonly used grout products in the Australian coal mining industry.

There are two main research studies in literature concerning the mechanical properties of resin and grout. The first one was carried out by Aziz *et al.,* (2013*a*, 2013*b*, 2014*a*) with the aim of establishing a general practice standard for determination of mechanical properties of resin used mostly for rebar bolt encapsulation. The study included determination of UCS, E value in compression, shear strength and rheological properties. Mechanical properties were examined at the University of Wollongong laboratory

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in relation to resin sample shape, size, height to width or diameter ratio, resin type, resin age and cure time. The following main conclusions were reported from this investigation:

- 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 to cylindrical specimens at various curing time.
- Similar to UCS values, the average shear strength increased with larger sample 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. The second research study in this area was performed by Hagan and Chen (2015) at the School of Mines, University of New South Wales. The Stratabinder product was selected as a grout material due to its low shrinkage and low viscosity. The UCS values of cube and cylindrical samples at different water to cement ratio were investigated, and it was found that:

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

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

Two types of grout product, Jennmar Bottom-Up 100 (BU100) and Orica Stratabinder HS were selected to prepare samples. Samples were cast using the 50 mm cube mould with mixing ratios of 5 and 7 litres/bag by weight of grout to water, respectively. During sample preparation mild vibration was applied to the mould to release any entrapped air. Samples were then left undisturbed to cure at the room temperature for 1, 7, 14 and 28 days. Also Shown in Figure 1 is the effective process of mixing grouts for cube casting. A Universal 50 t Instron and a 90 t Avery conventional compression testing machine were used in the various tests.

EXPERIMENTAL RESULTS AND DISCUSSION

Uniaxial compressive strength (UCS)

More than 18 compression tests were carried out on prepared samples at 1, 7 and 28 days curing time. Some tests were repeated to ensure accuracy of the collected data. Figure 2 shows one day old, 50 mm cube samples of BU 100 and Stratabinder HS grouts.

The average UCS values of BU 100 and Stratabinder HS samples at different curing times are presented in Figure 4. It appears that the UCS strength of BU 100 and Stratabinder HS increased with longer sample curing time from 1 to 28 days. In general, Startabinder HS samples failed at higher compression loads than those of BU 100. The exception was one day cured speciments whereby BU 100 performed better. All samples failed in compression tests along shear planes as a result of combined axial compression and transverse extension (Figure 5).

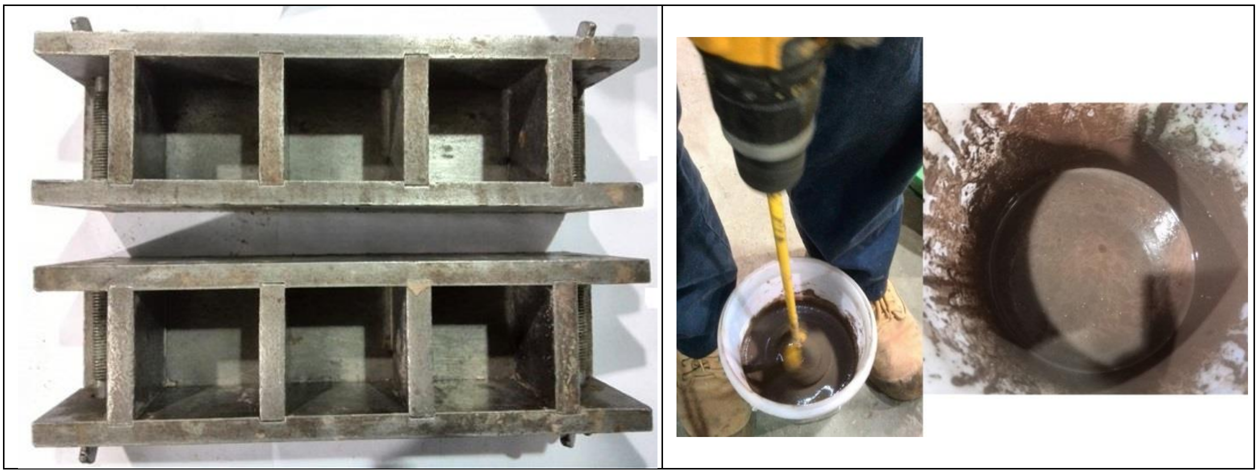

Figure 1: [left] a close view of 50 mm cube mould [right] smooth and consistent slurry

Figure 2: Prepared samples at 1 day curing time [left] BU 100 [right] Stratabinder HS

The UCS values of one day old BU 100 and Stratabinder HS samples are shown in Figure 3. The obtained UCS values varied between 45.46 to 54.18 MPa and 40.09 to 43.2 MPa for BU 100 and Stratabinder HS respectively.

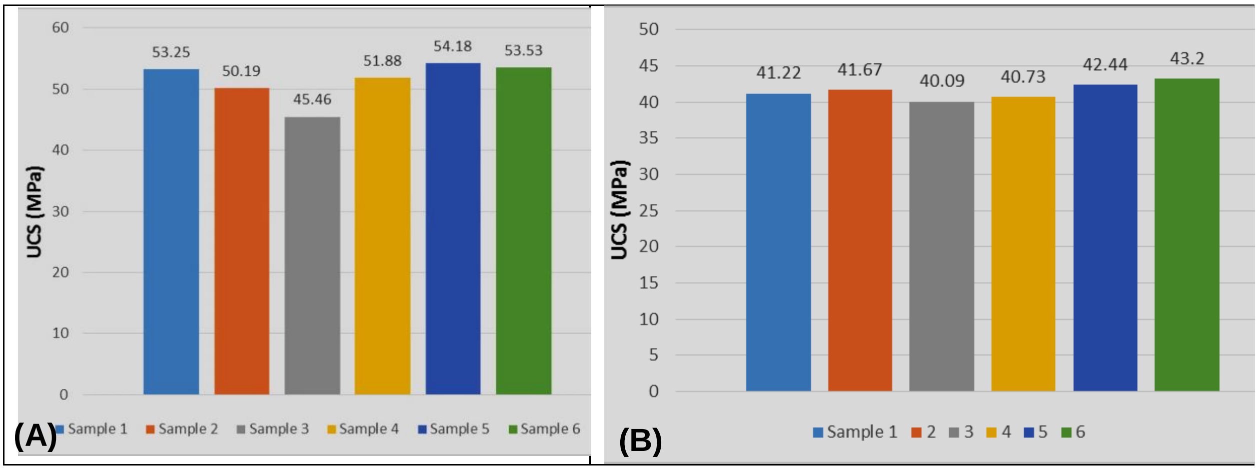

Figure 3: UCS values at one day curing time of (A) BU 100 and (B) Stratabinder HS

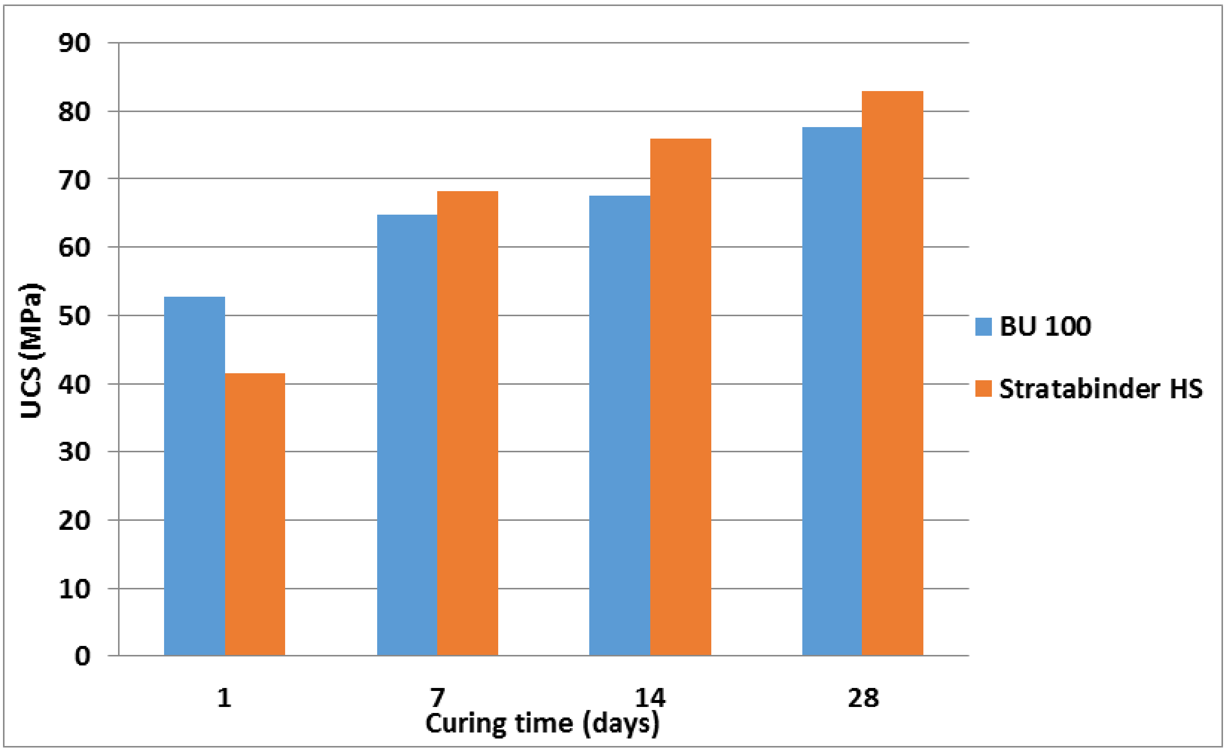

Figure 4: UCS strength of BU 100 and Stratabinder HS at various curing time

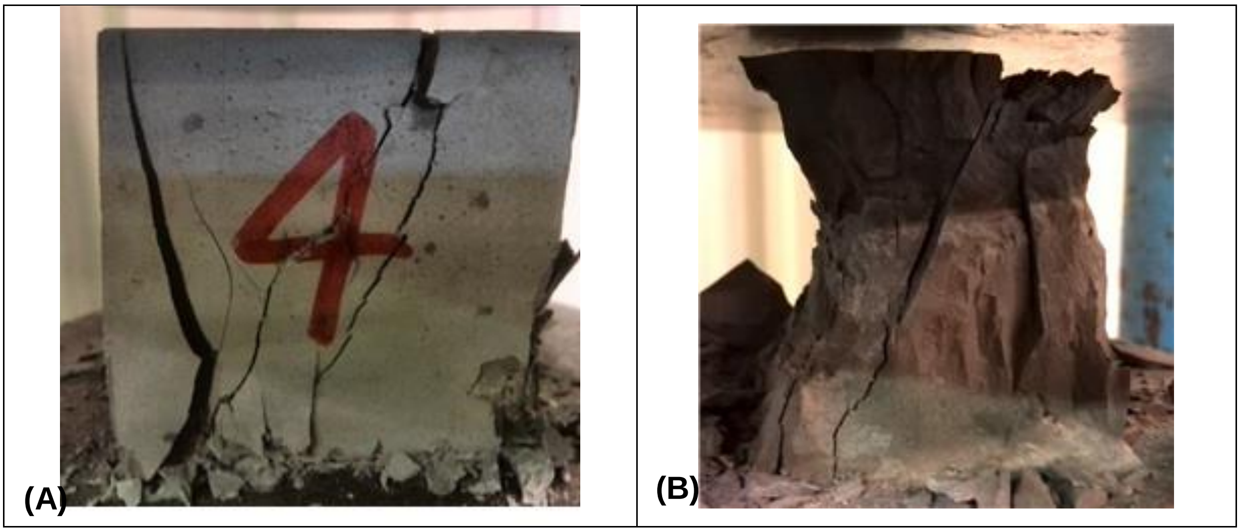

Figure 5: Sample after compression testing (A) BU 100 and (B) Stratabinder HS

Modulus of elasticity in compression (E)

In the determination of E values, samples were subjected to a cyclic loading program for three repetitive cycles, at loading rate of 1 mm/min (Figure 6). The maximum load at each cycle was limited to about 80% of the failure load. After three loading cycles, the prescribed load increased monotonically until failure. Both strain gauged and non-strain gauged samples were tested at 14 days curing time. Three methods (secant, tangent and 50 kN loading range) were used to calculate E values as described by Aziz *et al.,* (2014*a* and *b*).

Figure 7 presents elastic modulus where strain values were obtained using the Instron machine for BU 100 and Stratabinder HS products. The E value for both products was found to range between 2.63 to 4.33 GPa. Stratabinder HS showed higher E values when compared with BU 100. The maximum difference between E values of BU 100 and Stratabinder HS products is 0.98 GPa in tangent elastic modulus while minimum difference is 0.19 GPa in the 50 kN range method.

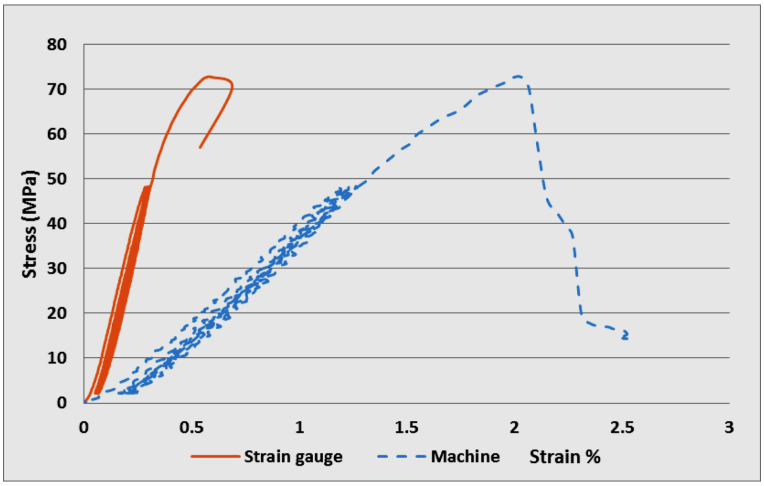

Figure 6: Typical loading program on Stratabinder HS sample

Table 1 compares the elastic modulus in compression where strain values were recorded through strain gauges and Instron machine. It is observed that E values obtained from strain gauges are higher than those of the Instron machine. This is because the strain gauge measures displacement in the middle of the sample unlike the Instron machine, which records total sample height compression. Similar results were reported by Aziz *et al.,* (2014*a*) for resin products.

Creep property

Creep is a measure to represent deformation under the influence of mechanical stress which is less than the yield stress. Strain gauged samples of BU 100 and Stratabinder HS with curing time of 42 days were subjected to a constant compression load of 100 kN for 15 min. The loading rate from 0 to 100 kN was set at 2 kN/sec. The creep was calculated as the percentage difference between strain values at the end of the test and the onset of 100 kN loading.

Figure 8 shows measured strain values under the prescribed constant load of 100 kN compression load for BU 100 and Stratabinder HS samples. Three tests were carried out on each type, giving maximum strain values of 0.27 % and 0.22 % for BU 100 and Stratabinder HS respectively. Comparison between average creep values of BU 100 and Stratabinder HS is presented in Figure 9. Stratabinder HS offers higher resistance against constant load of 100 kN rather than BU 100. However, the difference between creep values of BU 100 and Stratabinder HS is 0.04% which is not significant.

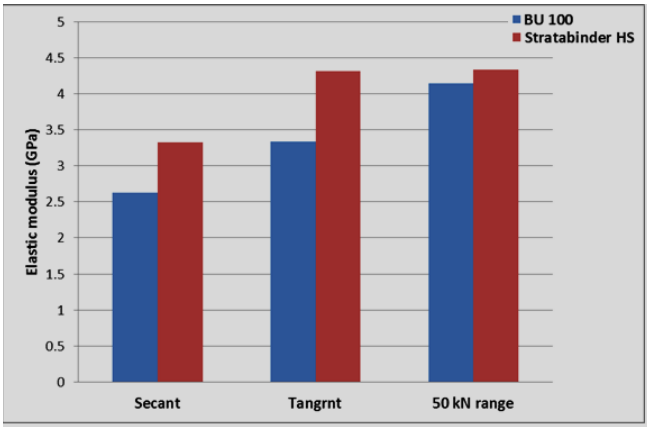

Figure 7: Comparison between elastic modulus of BU 100 and Stratabinder HS products

Table 1 Comparison between elastic modulus determined from strain gauges and the Instron machine

Elastic modulus	BU 100 - Gauge	BU 100 - machine	Stratabinder HS - gauge	Stratabinder HS - machine
Secant (GPa)	18.21	2.62	13.9	3.33
Tangent (GPa)	26.84	3.33	26.84	4.31

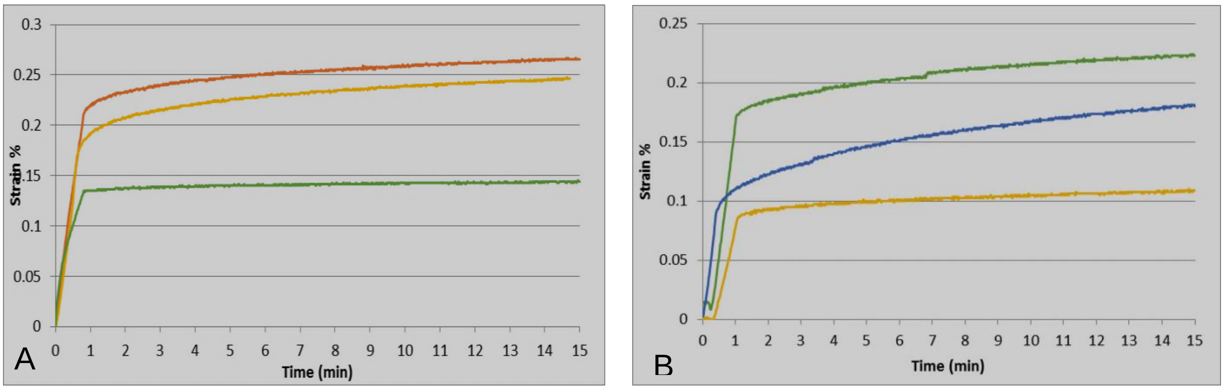

Figure 8: Creep test under 100 kN compression load for (A) BU 100 and (B) Stratabinder HS

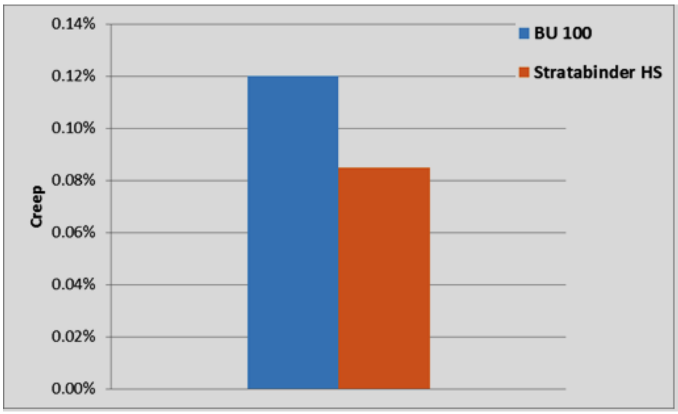

Figure 9: Comparison between creep values of BU 100 and Stratabinder HS

CONCLUSION

The experimental study found 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. It was also observed that 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 installtion in rocks for strata reinforcement.

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