

Cemented Aggregate Fill Test Work

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ABSTRACT

There are many forms of backfill that can be considered for a specific mine application and the mine plan, layout and mining method are all key criteria required to develop the appropriate backfill properties. In some instances, a high strength fill may be required for large bulk open stopes and aggregate fill may be the best solution. However, generating suitable aggregate can present logistical challenges and so is often considered an expensive option, but in cases where development waste is readily available, a cemented aggregate fill (CAF) may be an appropriate and cost effective solution. Open stope mining creates large voids and properly designed backfill is used to ensure regional stability as well as to maximize the extraction ratio. CAF is broadly defined as a rock fill that can be modified to suite the mining requirements by:

- Optimizing the particle size distribution through a combination of screening, inclusion of tailings or crushing of the waste rock, and
- Adding binder such as cement.

The requirements to conduct UCS test work on CAF presents unique challenges and a specially designed and constructed 50 tonne load frame was developed for this test work. This paper presents results from a series of laboratory scale tests on CAF to determine the effect of particle size distribution on the unconfined compressive strength (UCS) so as to optimize the binder content of a CAF backfill product.

INTRODUCTION

In general backfilling in mining operations is mainly done by either placing a hydraulic cemented or uncemented material or a paste fill material into the mine out voids. As the particle sizes for these materials are relatively fine with top particle sizes between 75 to 2000 μm , UCS test work on these materials can easily be carried out using small diameter moulds. To minimize wall effects, the mould diameter must be at least six times the largest particle size.

Cemented aggregate fill, however, is classified as a crushed rock material with a top particle size of approximately 50 mm. Due to these large 50 mm top particle sizes, UCS test can only be carried out using large diameter moulds i.e. 300 x 600 mm (h:d) to comply with the D:d ratio of 6:1.

Ideal graded material for CAF referred to as fuller curves (n) with a maximum top particle size of 50 mm is considered to fall between $0.3 < n > 0.7$ (K. Kuganathan 2005), with 0.5 being the optimum. This paper presents the preparation and testing of a bulk sample with a top size of 300 mm that was crushed to produce a fine ($n = 0.5$) and coarse ($n = 0.7$) graded material with a top particle size of 50 mm to determine the effect of particle size distribution and binder content on the UCS.

CASTING PREPARATION PROCEDURE AND TEST EQUIPMENT

310 mm internal diameter cardboard carton pipes were used as moulds with a height to diameter ratio of 2:1. Sunflower seed oil was applied to the inside of the mould to minimise the absorption of water after casting. For each batch, a mix sufficient for three cylinders was made up and prepared using a concrete mixer. The mix was poured in three containers and properly cross mixed to ensure a representative mixture, as shown in Figure 1. Each cylinder was filled to one third, tamped 25 times using a tamping rod to compact the fill and then filled, leaving a 50-75 mm clearance for the capping.



Figure 1. Sample preparation prior to casting cylinders; mixed sample (left) and filled moulds (right)

After casting, each cylinder was covered with plastic and left to cure for 24 hours. After this initial curing, the cylinders were placed in a water bath to cure for 7, 14 and 28 days as shown in Figure 2.



Figure 2. Sample curing and storage

When the material was released from the moulds for testing, a capping layer using tile grout was applied to the base and top of the cylinders to allow for a uniformly flat surface to ensure perpendicular contact when the load is applied. Figure 3 shows the cylinders being capped and levelled using the grout.



Figure 3. Capping of cylinders; level filling (left) and finished cap (right)

Figure 4 shows the specially fabricated load frame used for the tests that is capable of testing these large cylinders. The load frame is fitted with 50 tonne load cell and the load is applied using a piston with a hydraulic power pack. The displacement as the load is applied is measured using a displacement sensor. The load is applied continuously and without shock at a constant rate so that the cylinders do not fail in less than 2 minutes. The maximum load is recorded when the cylinder fails.



Figure 4. 50 tonne load frame (left) and cylinder being testing (right)

MATERIAL PROPERTIES

Solids Density

The solids density of the samples was determined using a helium pycnometer, which measures the skeletal solids density. The crushed rock and cement have solids densities of 2730 and 3054 kg/m³ respectively.

Particle Size Distributions

Samples from the coarse and fine graded material were taken to determine the particle size distributions (PSD) and to confirm the target fuller curve values, n , of 0.5 and 0.7 respectively. The particle size distribution was determined by a combination of dry sieving (+ 2 mm fraction) and wet sieving (-2 mm fraction).

Figure 5 presents the particle size distribution measured for the coarse and fine graded samples. The data indicates that the coarse graded sample is slightly coarser than the target fuller curve of 0.7 whilst the fine graded sample falls between the 0.3 and 0.5 fuller curves.

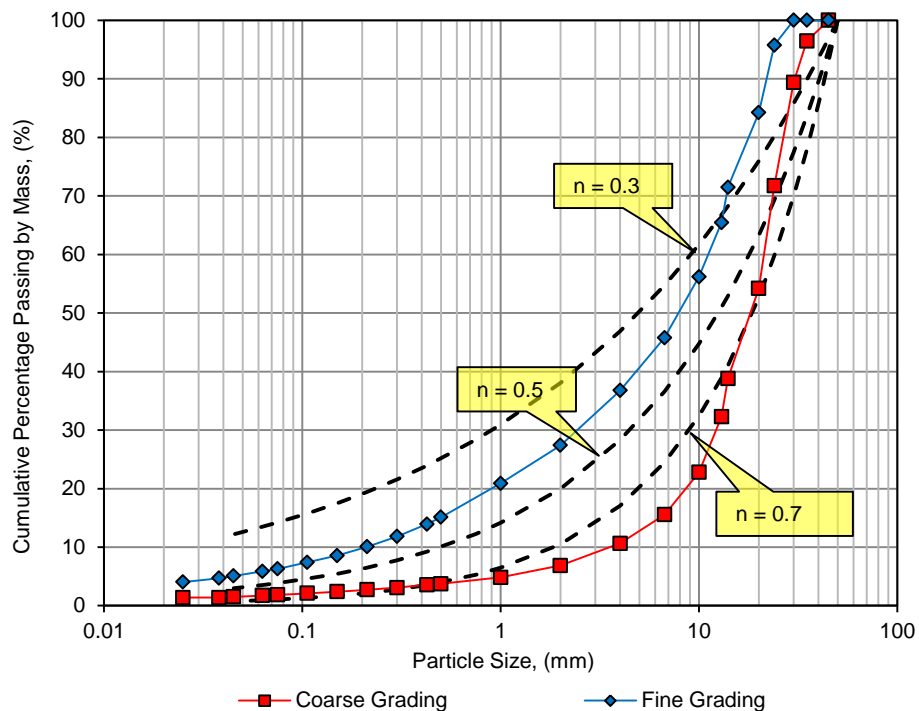


Figure 5. Particle size distributions

Cement Mortar Tests

A CEM II B/L 32.5 N cement was supplied for the test work. Before commencing with the UCS test work, cement mortar tests according to EN 196-1:2005 Edition 2 were carried out to determine the quality of the cement. The 28 day results showed a compression strength of 33.9 MPa which exceeds the minimum required compressive strength of 32.5 MPa indicating that the cement complies with the standards requirements.

UNCONFINED COMPRESSIVE STRENGTH (UCS) TESTS

Cement Addition

The mass of cement added to the material was calculated using the following formula:

$$\% \text{ cement} = \frac{\text{Mass of cement}}{\text{Mass of cement} + \text{mass of crushed rock}} \quad (1)$$

Strength Test Results

Table 1 and Figure 6 present the average strength test results after 7, 14 and 28 days of curing for the coarse and fine graded samples respectively.

Cemented aggregate fill (CAF) is different to paste fill in the sense that the water:cement (w:c) ratio for a paste fill can be varied by either changing the water or cement content in a specific mix to achieve a specified minimum strength, whereas, the water content for a cemented aggregate fill is determined through trial mixes (to achieve a workable mix) and the w:c ratio can only be varied thereafter by changing the cement content.

As the test work was conducted on a coarse and fine graded material with the presence of fines, the trial mixes and actual castings indicated that the mass solids concentration at which the mix is constituted play a significant role on the effective strength as well as the workability of the material. If too much water is added the fines wash out of the mix and if too little water is added the aggregate is not fully covered with cement resulting in inferior strength. The trial mixes indicated that this can be as little as a 1.5% difference in mass solids concentration.

Table 1. Average strength results

Ideal CAF Grading (n)	Mix Number	% Cement	Mass Solids Concentration (%m)	W:C Ratio	7 Day Strength (kPa)	14 Day Strength (kPa)	28 Day Strength (kPa)
Fine grading Fuller n = 0.3 – 0.5	001	4	91%m	2.47	945	1112	1382
	002	6		1.65	1767	2016	2198
	003	8		1.24	2840	3919	4218
Coarse grading Fuller n = 0.7	004	4	94%m	1.60	731	1031	1089
	005	6		1.06	1918	2241	2175
	006	8		0.80	3015	3301	4467

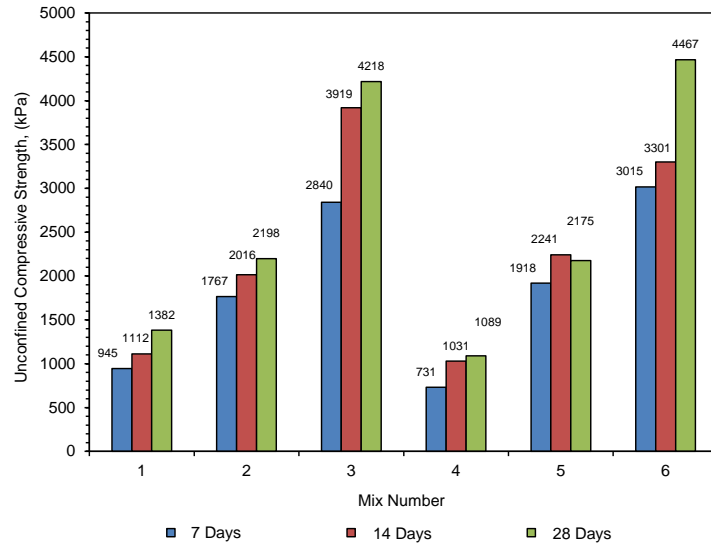


Figure 6. Average strength result comparison

Figure 7 to Figure 9 present the w:c ratio versus unconfined compressive strength (UCS) for the two gradings at 7, 14 and 28 day data respectively.

The UCS results for both graded materials show that high strengths can be achieved with relatively low additions of cement, provided that the w:c ratio is low but still sufficient to allow for a workable mixture. The data also indicates that variances in strength can be expected due to inadequate mixing and transfer of solids into the castings which can be attributed to the particle size distributions and especially the top particle sizes, making this a difficult task to obtain consistent mixtures.

Trend lines fitted to the average recorded values for each mix and grading show the typical increase in strength as the w:c ratio decreases.

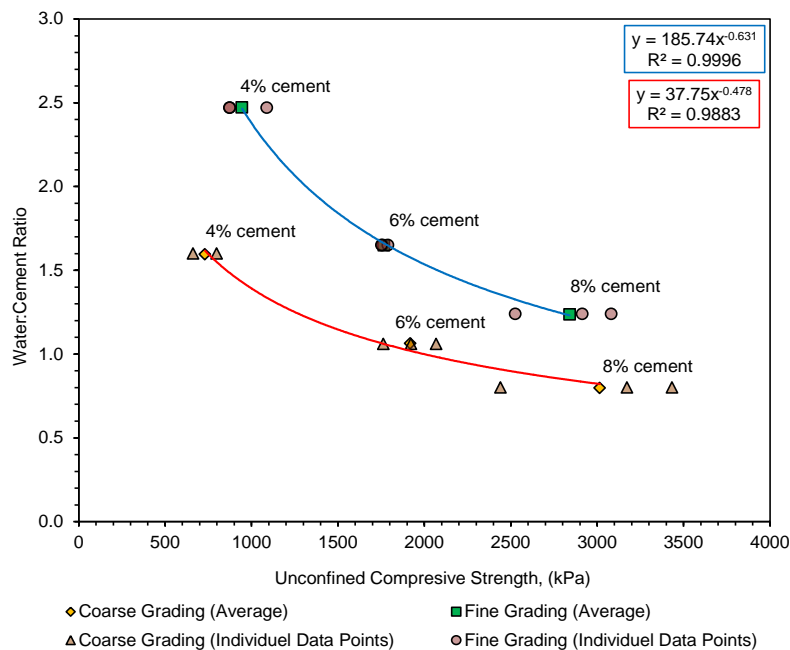


Figure 7. Water:Cement ratio versus unconfined compressive strength – 7 day results

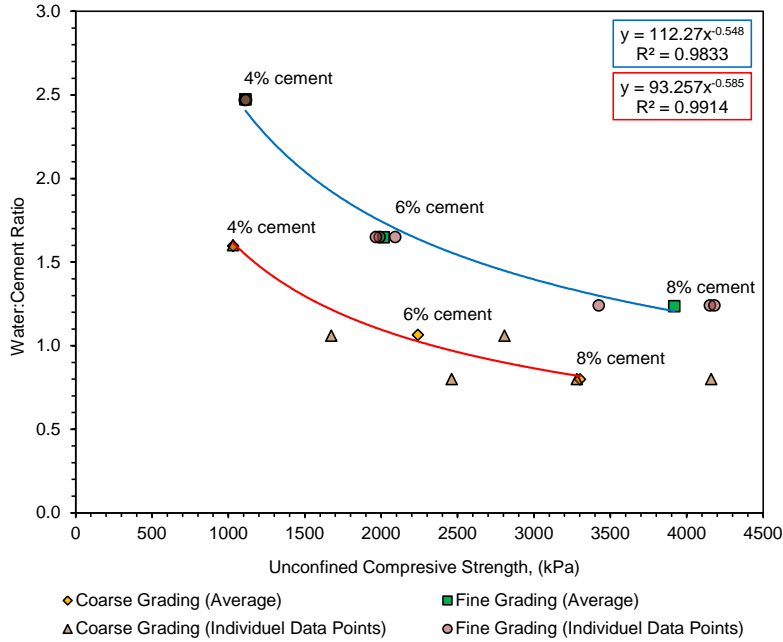


Figure 8. Water:Cement ratio versus unconfined compressive strength – 14 day results

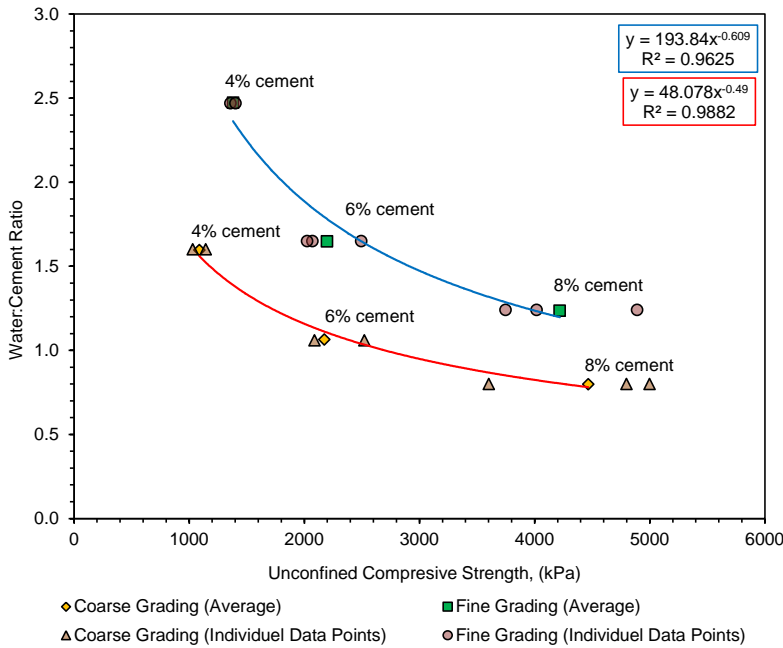


Figure 9. Water:Cement ratio versus unconfined compressive strength – 28 day results

Modulus of Elasticity

The modulus of elasticity (E) was determined from the measured stress and direct strain test data. The modulus of elasticity is determined from the slope of the tangent line between the 25% and 75% of failure stress as shown in Figure 10.

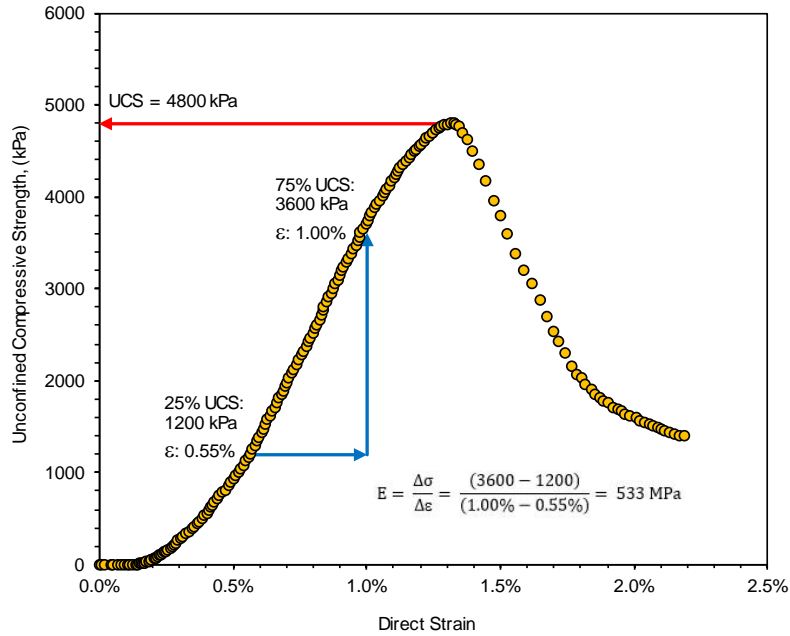


Figure 10.: Stress versus strain and modulus of elasticity calculation

Figure 11 presents the modulus of elasticity versus percentage cement addition (28 day curing) for the fine and coarse graded samples. As the cement content increases an increase in modulus of elasticity is seen with the coarse graded being slightly higher compared to the fine graded material for similar percentage cement additions. This indicates that, for a similar UCS requirements, the coarse graded material will displace less compared to the fine graded material.

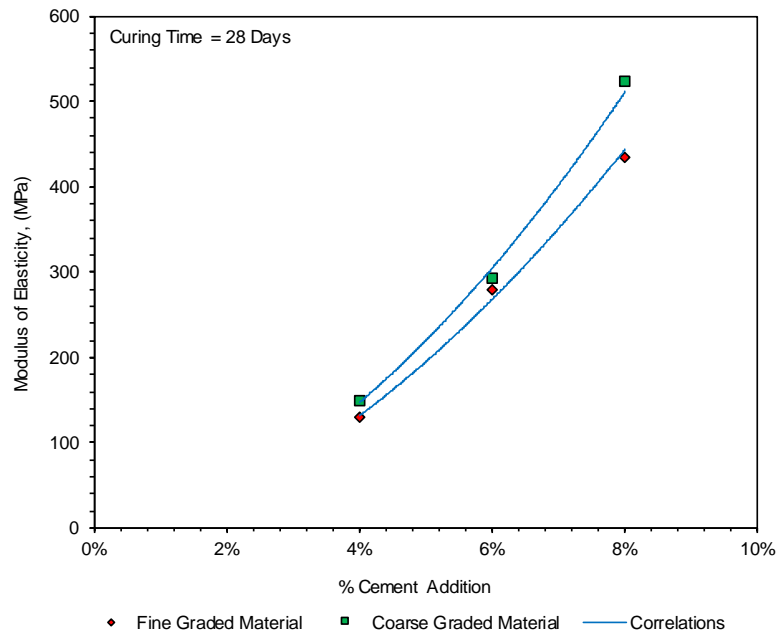


Figure 11. Modulus of elasticity versus percentage cement addition for the fine graded material

CONCLUSIONS

1. This paper presents the results of a series of UCS tests conducted on coarse and fine graded cemented aggregate fill sample using a large 50 tonne load frame designed and constructed for the test work. The main conclusions are as follows:
2. Conducting trial mixes before commencing with test work is very important as it plays a significant role on the effective strength as well as the workability of the material. It is important to note that if too much water is added, the fines wash out from the mixture and if too little water is added the aggregate is not fully covered with cement resulting in inferior strength. The trial mixes indicated that this can occur when there is as little as a 1.5% difference in mass solids concentration.
3. The UCS results for both graded materials show that high strengths can be achieved with relatively low additions of cement, provided that the w:c ratio is low but still sufficient to allow for a workable mixture. The data also indicates that variances in strength can be expected due to inadequate mixing and transfer of solids into the moulds which can be attributed to the particle size distributions, especially the top particle sizes, making it a difficult task to obtain consistent mixtures.
4. The modulus of elasticity is determined from the slope of the tangent line between the 25% and 75% of failure stress. As the cement content increases an increase in modulus of elasticity is seen with the coarse graded being slightly higher compared to the fine graded material for similar percentage cement additions. This indicates that, for a similar UCS requirements, the coarse graded material will displace less compared to the fine graded material.

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