Characterisation of cemented rock fill materials for the Cosmos nickel mine, Western Australia

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ABSTRACT: The Xstrata Nickel Cosmos Mine is located about 500 kilometres north of Kalgoorlie, Western Australia. This paper describes cemented rock fill (CRF) strength testing carried out at the Western Australian School of Mines (WASM). The studies included composition of different mix designs to achieve a target strength at different mining stages. The physical properties of waste rock, binder, mixing water and their influences on the physical and mechanical properties of CRF at different curing times, temperature and humidity are presented.

Keywords: Cosmos nickel mine, Cemented rock fill, Waste rock, Physical properties, Mechanical properties.

1. INTRODUCTION

The Xstrata Nickel Cosmos mine is located about 500 kilometres north of Kalgoorlie, Western Australia. At the Cosmos nickel mine Cemented Rock Fill (CRF) is used to fill the mining voids. The CRF is a mix of a crushed and screened waste rock from mine development, General Purpose cement and fresh water. The core functions of CRF at Cosmos nickel mine are,

i. To provide regional stability to the surrounding rock mass,
ii. To allow for the undercutting of sill stoping levels once the bottom-up sequence reaches the top of a stoping panel,
iii. To retain uncemented (unconsolidated fill) waste rock in the back half of each stope,
iv. To allow for a free-standing face and facilitate the removal of an adjacent stope,
v. Resilience to slot firing activities within close proximity to the CAF.

2. CEMENTED ROCK FILL DESIGN OPTIMISATION

The main objective of the cemented rock fill design optimisation was to reduce the cost of mine fill operation at Cosmos. The procedure for the optimisation included;

i. Determination of the minimum strength required to fulfil a performance criteria,
ii. Optimisation of the mix variables to produce the required minimum strength for the lowest cement usage,
iii. Implementation of quality control procedures and monitoring of the fill performance on a periodic basis to ensure compliance with design.

2.1 Cemented Rock Fill strength

The required mine fill strength is a function of the mining method, geometry of ore body and stope, and the possible failure modes. Mitchell and Roettger (1989) described the potential failure modes of cemented mine fill used to support the uncemented mine fill in steeply dipping ore zones. Failure modes included sliding, crushing, flexural and caving. Sliding occurs due to low frictional resistance between the mine fill and the rock wall. Crushing occurs when the induced stress exceeds the Uniaxial Ccompressive Strength of a fill mass. Flexural failure occurs when a fill mass has a low tensile strength, caving can be a results of arching, and rotational failure due to low shearing resistance at a rock wall. When mine fill is considered as a roof slab, the analysis methods developed by Evans (1941) and later modified by Beer and Meek (1982) can be applied. Such method for roof design procedure considering plane strain is described in Brady and Brown (1993).

The minimum strength required for Cosmos nickel mine was established based on the numerical modelling conducted by AMC Consultants (2009) and stability charts suggested by Stone (1993). Stone developed the stability charts using the pseudo-3D formulations of Mitchell and Roettger (1989). A Safety Factor of two was considered due to the effects of segregation and the potential for an occasional improper mixing by underground operators. A summary of minimum required UCS for different loading mechanisms are shown in Table 1.

Table 1. Summary of minimum required Uniaxial Compressive Strength.

Loading mechanism	Minimum required UCS (Safety Factor - 2) MPa	Design method
Free standing vertical exposures	0.5	Mitchell and Roettger Empirical method
Undercut sill	2.3	
Pillar to retain uncemented rock fill	2.3	

2.2 Material Characterisation

2.2.1 Waste rock

Three batches of crushed and screened waste rock were received from the mine site. The specific gravity (SG), bulk density and Particle size distribution analyses (PSD), water content and water absorption tests were conducted for the material characterisation. Figure 1 shows particle size distribution curves for the waste rock.

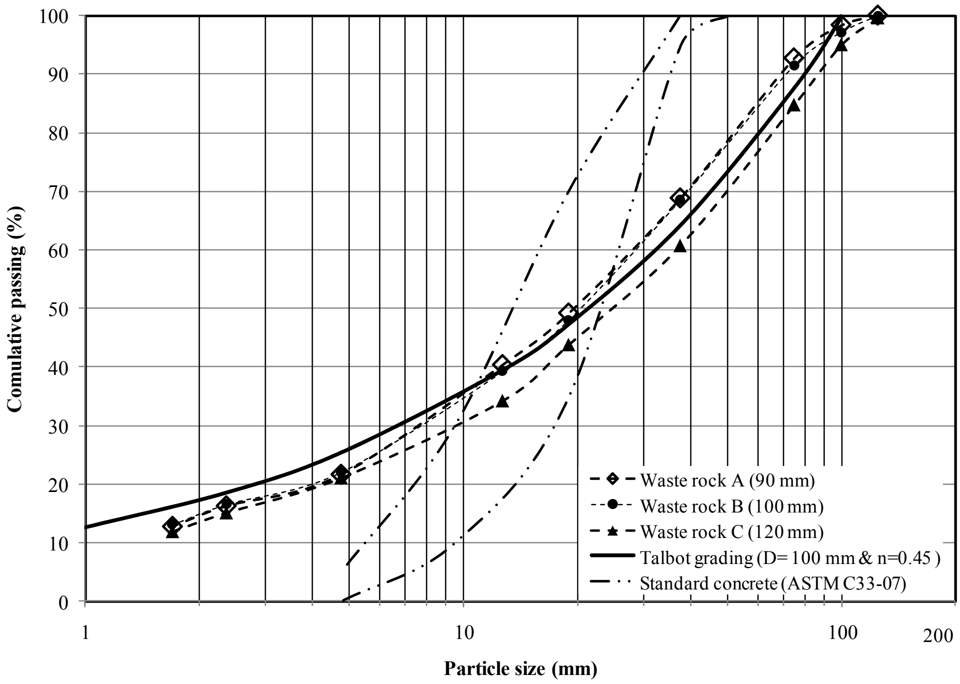

Figure 1. Particle size distribution curves of waste rock from Cosmos nickel mine.

Generally, for CRF application, the particles size less than 10 mm are defined as fine aggregate. The PSD curves suggested that, waste rocks from Cosmos nickel mine consist of 30 to 35 % fine aggregate and 65 to 70 % coarse aggregate. The material is out of the limit of coarse aggregate recommended by ASTM C33-07 for production of a standard concrete. However, it was similar to the Talbot grading. Talbot and Richart (1923) suggested a general equation for combined (fine and coarse) regularly graded aggregates. Swan (1985), suggested that the Talbot grading equation can be used to make an optimal grading of combined aggregates or waste rock for CRF design. Particle size distribution curves of Cosmos Nickel mine waste rock fit Talbot grading equation with a variable exponent, "n" equal to 0.45.

The specific gravity and bulk density ranged from 2.77 to 3.02 and 2 to 2.16 g/cm^3, respectively. The water content and water absorption conducted on coarse aggregate prior to mixing were 0.05 % and 0.14 % respectively. The coarse aggregate was mostly composed of Felsic Volcanic rock. The Uniaxial Compressive Strength of Cosmos Nickel Felsic Volcanic rock ranged from 135 to 252 MPa according to the test conducted at WASM by Machuca et al., (2010).

2.2.2 Binders

Binder such as cement or natural pozzolans are the main substances for strength development in any type of mine fill. It is also the most expensive component of a mine fill mix. A choice of binder depends upon on the strength and durability requirements of a particular mine fill operation. In this research, General Purpose (GP) cement was used for the CRF mixing.

2.2.3 Mixing water

The mixing water has three main functions: (1) it reacts with the cement powder, thus producing hydration; (2) it acts as a lubricant, contributing to the workability the fresh mixture and (3) it secures the necessary space in the cement paste for the development of hydration products.

Research conducted by Lawrence (1992), Wang, et al., (2001), Coxon, et al., (2003), Benzaazoua et at.,(2002 and 2004), showed that impurities in the mixing water can cause a strength reduction in any type of mine fill. The impurities can either be dissolved or suspended in the water. The amount of strength reduction can change with the type of tailings and the binder dosage used. In certain cases, contaminated water can be used for mine fill purposes by mixing it with fresh water. However, it is important to determine whether the impurities may lead a strength reduction. In this optimisation work, Kalgoorlie tap water was used for CRF mixing.

2.2.4 Mixing and sample casting

A mix design was calculated based on the specific gravity, bulk density of the waste rock, cement percentage and water:cement ratio. The mix design is shown in Table 2. The waste rock and cement were weighted and placed into the concrete mixer and mixed dry. Water was also weighted and placed into the concrete mixer and mixed continuously until the batch was thoroughly mixed. The CRF was cast into a 400 x 800 mm and 500 x 1000 mm (diameter x length) moulds. After casting, all samples were kept in a curing chamber, which was set up a temperature of 30˚C and humidity of 90% similar to underground mine conditions at Cosmos. Figure 2 shows CRF mixing, sample casting and curing in the WASM curing chamber.

Table 2. CRF mix design.

Mix ID	CN-1	CN-2	CN-3
Aggregate size	< 2 mm to 100 mm	< 2 mm to 90 mm	< 2mm to 120 mm
Cement % by weight (by volume) %	4 (2)	4 (2)	4 (2)
Weight of Aggregate for 1 m^3 CRF (kg)	1995	2104	2156
Weight of cement for 1 m^3 CRF (kg)	79.81	84.16	86.23
Water for 1 m^3 CRF (kg)	159.61	168.33	172.45
Estimate fresh CRF mix density (kg/m^3)	2235	2357	2414

Figure 2. Concrete mixer, CRF mixing, sample casting and curing.

2.3 Uniaxial compressive strength (UCS) testing

The uniaxial compressive strength of the (400 × 800) and (500 x 1000) mm samples were determined using the WASM large scale static test machine, Morton et al., (2007). The loading rate was approximately 2mm/minute. The axial displacement was measured with four potentiometers, which were attached to the base plate of the specimen. The test machines automatically acquire load and displacement with Signal Express data logging system. A top cap was prepared with Boral dental plaster before setting up the sample for testing to ensure the load was evenly applied during testing. The large scale WASM static test machine set up for UCS test is shown in Figure 3. A summary of UCS test results are presented in Table 3.

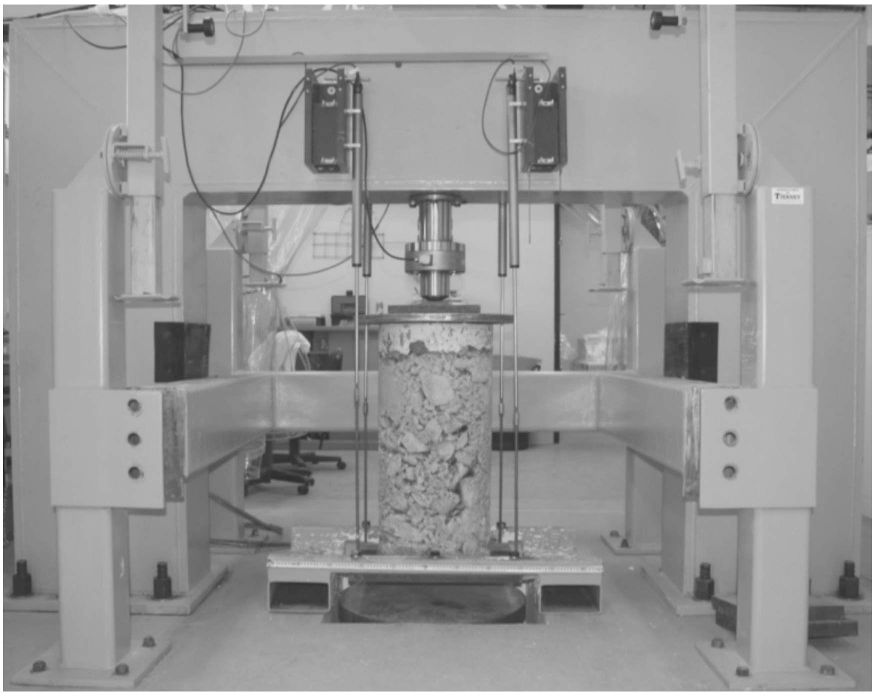

Figure 3. WASM static test machine set up for large scale UCS test.

Table 3. Summary of large scale UCS test results.

Mix ID	28 days - UCS (MPa)
CN-1 (400 mm diameter, 800 mm long sample)	2.9
CN-2 (400 mm diameter, 800 mm long sample)	1.6
CN-3 (500 mm diameter, 1000 mm long sample)	1.6
	1.9

3. UNDERGROUND MIXING AND FILLING PROCESS

Based on the laboratory test results discussed in section 2, it was envisaged that the required minimum strength of CRF for Cosmos Nickel mine can be achieved by adding 2 to 3 % cement by the total volume of a given CRF batch. The main steps for underground CRF filling process are construction of waste rock bund and bogger stop, batch up cement slurry, tram waste rock and cement slurry, mixing CRF with bogger and filling into the stope. Mixing and filling CRF samples with bogger at underground stockpile is presented in Figure 4. A schematic of cemented and uncemented rock filled stope is shown in Figure 5.

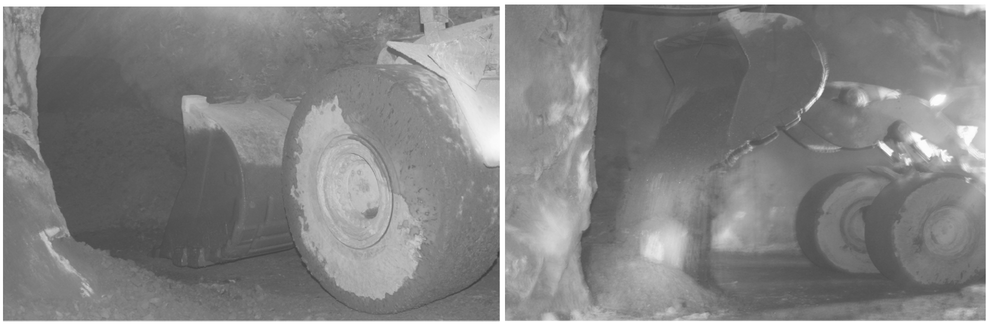

Figure 4. Mixing and filling CRF sample.

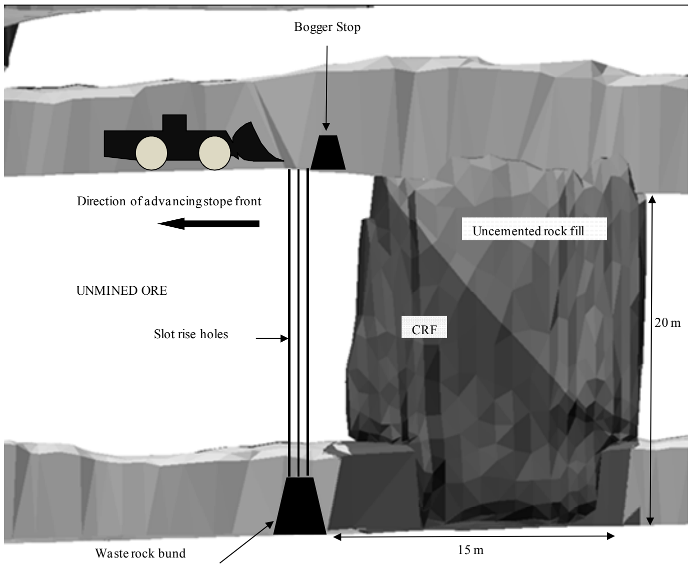

Figure 5. Schematic of cemented and uncemented rock filled stope (After, Van Der Merwe, 2009).

4. QUALITY ASSURANCE AND CONTROL

Quality assurance and control (QA/QC) and performance monitoring were undertaken at different stages of the CRF preparation and filling process. A routine QA/QC programme included,

- Sampling of the crushed and screened waste rock from stockpile for regular PSD analysis,
- Sampling 2 cylinders (500 mm diameter and 1000 mm long) of CRF sample from each stope for UCS test to check the target strength of CRF
- Conducting survey with Cavity Monitoring System (CMS) on the stope before and after CRF placement

The CRF samples were cured in underground for 28 days before transporting them to the WASM laboratory. A summary of UCS test results conducted for QA/QC is presented in Table 4.

Table 4. Summary of UCS testing from underground mixes.

Test date	Cement (%) by volume	Curing (day)	Unit Weight (kN/m^3)	Peak Force (kN)	UCS (MPa)	Displacement at peak force (mm)	Strain at peak force (%)
21-Jan-10	3	34	17.21	247.80	1.26	-	-
24-May-10	3	More than 28	18.79	197.38	1.01	5.0	0.5
25-May-10	3	More than 28	19.56	623.20	3.17	5.6	0.6
26-May-10	3	More than 28	20.17	402.33	2.05	7.4	0.7
26-May-10	3	More than 28	20.42	769.11	3.92	5.5	0.5
28-May-10	3	More than 28	20.37	707.82	3.60	5.0	0.5
31-May-10	3	More than 28	20.22	449.82	2.29	5.1	0.5
31-May-10	3	More than 28	18.33	128.46	0.65	5.9	0.6
16-Jun-10	3	More than 28	22.31	793.81	4.04	6.3	0.6
04-Feb-10	4	32	19.76	503.20	2.56	-	-
16-Feb-10	4	44	18.64	337.60	1.72	-	-
18-Feb-10	4	26	19.10	260.15	1.32	-	-
04-Mar-10	4	28	21.59	444.67	2.26	8.5	0.9
11-Mar-10	4	34	19.05	340.09	1.73	5.4	0.5
12-Mar-10	4	35	20.32	232.07	1.18	7.1	0.7
20-Jan-10	5	30	18.95	527.00	2.68	-	-
30-Jun-10	5	More than 28	22.41	1037.00	5.28	-	-
01-Jul-10	5	More than 28	22.31	1038.60	5.29	7.1	0.7

The underground samples were collected from different batches and cured at different temperature and humidity conditions. Figure 6 shows a comparison of UCS for CRF for different cement percentages and at different testing dates at Cosmos.

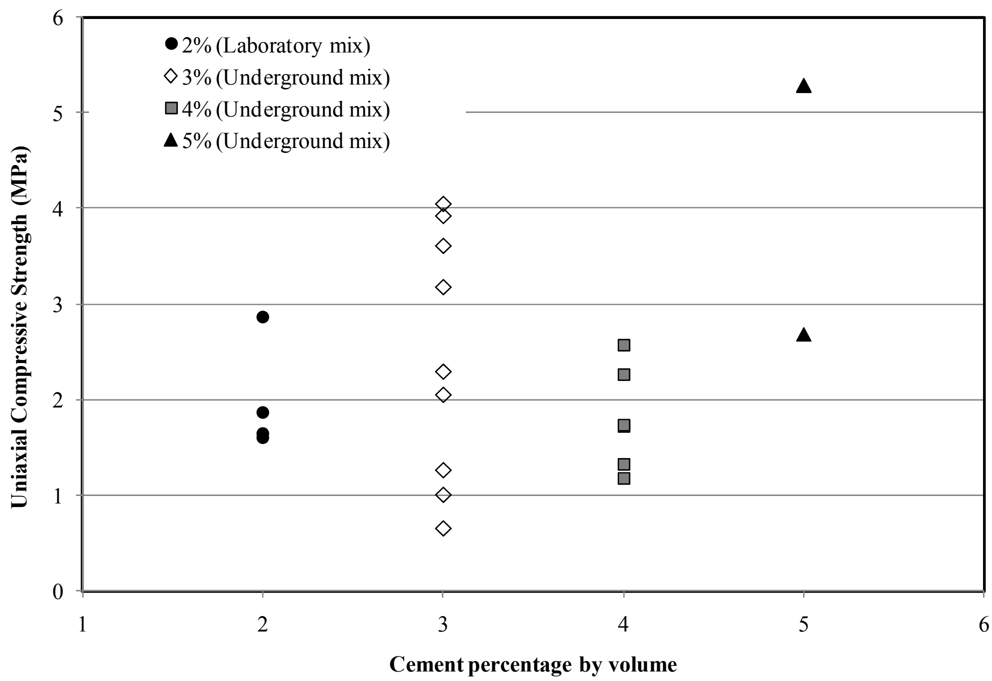

Figure 6. Comparison of UCS for CRF mixed in laboratory and underground.

5. CONCLUSIONS

Mine fill mix design optimisation was conducted at the Cosmos Nickel mine in order to reduce the cost of mine fill operations. The design optimisation included, identification of the required minimum strength, materials characterisation and strength testing. The implementation was monitored through QA/QC test programme. A required minimum strength for free standing vertical CRF exposures was achieved with 2 % cement by volume. Similarly, a required minimum strength for undercut sill and CRF pillar to retain uncemented rock fill was achieved with 3 % cement by volume. Generally the UCS increased with an increased cement percentage. However, large variations for UCS were also found in the CRF with the same cement percentage. It shows that the strength development is highly influenced by other variables such as waste rock physical properties (PSD, SG and Bulk density), waste rock mechanical properties (UCS), curing time, temperature, humidity, mixing water and water - cement ratio of the mix.

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