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Research on the mechanical properties of minefill: influences of material particle size, chemical and mineral composition, binder and mixing water

H. SAW and E. VILLAESCUSA
Western Australian School of Mines, Kalgoorlie, Australia

Minefill is the material placed underground to fill the voids created by mining excavations. It provides overall large scale ground stabilization while allowing localized pillar recovery. In addition to providing a working floor or back, minefill has the potential to reduce subsidence and minimize dilution. minefill is essential to cut and fill, benching and sublevel stoping mining methods. This paper describes optimization research carried out at the Western Australian School of Mines (WASM) over the last few years. The research included cemented paste fill (CPF), cemented hydraulic fill (CHF) and cemented aggregates/rock fill (CAF/CRF) optimization projects for a number of mines throughout Australia and overseas. The studies included composition of different mix designs to achieve the required strength at different mining stages. The paper also summarizes key experimental observations, typical results and recommendation for CPF, CHF, CAF and CRF. The physical properties of different types of tailings, binder, mixing water and their influences on the physical and mechanical properties of minefill at different curing times, temperature and humidity are presented.
Keywords: Mining methods, minefill, optimization, cemented paste fill, cemented hydraulic fill, cemented aggregate fill, physical properties, mechanical properties.

Introduction

Minefill technology is in demand not only to fill the voids created by mining excavations, but also to provide overall large-scale ground stabilization and allow localized and systematic pillar recovery (see Figure 1). In addition to providing a working floor or back, minefill may reduce subsidence and minimize dilution. In Australia, the most common minefill types used are cemented paste fill (CPF), cemented hydraulic fill (CHF) and cemented aggregates or rock fill (CAF/CRF). The materials suitable for making a minefill include fresh for reclaimed tailings, waste rock, cement and/or natural pozzolans and different types of water. Over the last few years, the Western Australian School of Mines (WASM) has undertaken a series of minefill research projects to allow the systematic selection of components to achieve cost-effective minefill mix design at a number of sites. The studies included characterization of different types of tailings, cement, natural pozzolans, mixing water, and their influences on the physical and mechanical properties of minefill for different curing time, temperature and humidity. The research was conducted according to the WASM minefill testing standard guidelines[1] and Mine Backfill course notes of Master of Engineering Science in Mining Geomechanics at WASM [2].

Figure 1—Secondary stope extraction using cemented hydraulic fill

Material characterization

The physical, chemical and mineralogical properties of the tailings and waste rock were undertaken to characterise whether the materials were suitable for minefill. The physical properties test included particle size distribution (PSD) analysis, determination of moisture content (w %), specific gravity (SG), bulk density, chemical and mineralogical analyses.

Particles size distribution

Tailings

A particle size distribution (PSD) analysis was conducted to find out whether the tailings contained at least 15% passing

20 micron (0.02 mm) for CPF and 10% passing 10 microns (0.01 mm) for CHF. In addition, to get a better understanding of the likely behaviour, the tailings can be further classified using the Unified Soil Classification System for engineering purposes[3]. Figure 2 shows the typical PSD curves for different types of tailings and natural tuff plotted on Australian Standard particle size limit: AS1289.3.6.1-1995[4]. Figure 3 shows the percentage of particle size contained in the different types tailings and natural tuff tested. According to the Unified Soil Classification System, Figures 2 and 3 suggest that most of the tailings from the Australia mines can be classified as sandy silt (ML). The assumed plasticity index is less than (4), and therefore, some engineering properties of a fresh CPF or CHF mixes may be similar to those of natural sandy silt soil.

Waste rock

Waste rock from underground mine development is often used as a material for minefill. This is known as aggregate or rock fill. The waste rock is crushed down to a size ranging from less than 20 mm to larger 300 mm. Typical PSD curves of waste rock are shown in Figure 4. It can be seen that the PSD curves of the waste rock are outside the limit suggested by 'ASTM C33-08 – Required limit of 1.75 to 37.5 mm graded aggregate for concrete'[5].

Weight-volume relationship

The weigh-volume relationship of minefill is determined by its porosity, void ratio and relative density. In practice, the specific gravity (SG) of the solid constituents in tailings or rock is used. The typical SG of tailings investigated are shown in Figure 5. Another important index property is the minefill mix water content. A variation in water content determination can be a major problem while trying to achieve a required mix design. In geotechnical engineering practice, the water content is defined as:

$$w\ (\%) = \frac{100W_w}{W_s} \qquad [1]$$

where,

w (%) = Water content
W_w = Weight of water
W_s = Weight of oven-dry solid matter

Peck *et. al.*,[6] suggested that the weight of water is referred to the unchanging quantity of (Ws) rather than to the total weight of the sample. It is important to compare the water content of a sample, which is oven dried at a standard temperature. The standard temperature is 105 to 115 °C[7]. As the temperature increases, the sample continues to lose the water content until the mineral or chemical that constitutes the sample break down.

Chemistry and mineralogy

The chemistry and mineralogy of the tailings influence many physical and mechanical properties of a minefill. The analysis results are complex due to the grinding, as this can

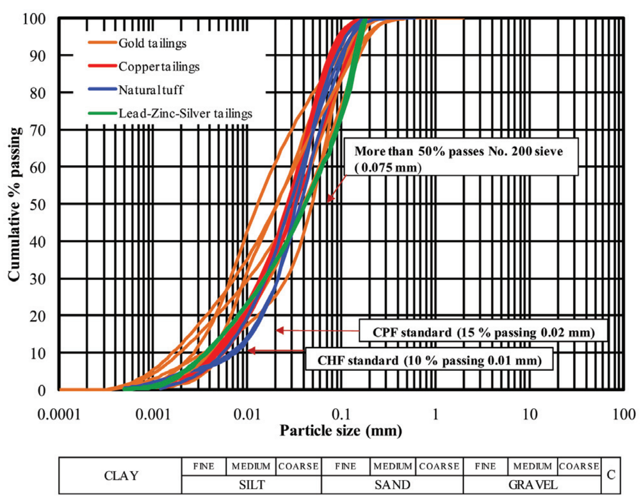

Figure 2—Typical particle size distribution curves of tailings and natural tuff

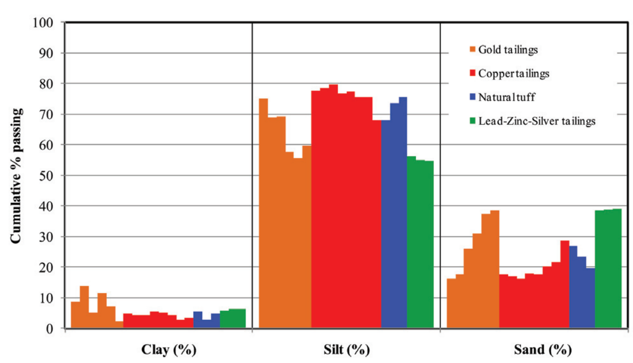

Figure 3—Typical particle size of tailings and natural tuff

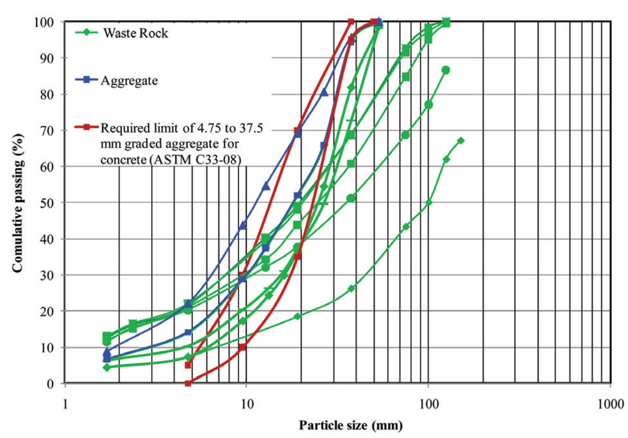

Figure 4—Typical particle size distribution curves of waste rock

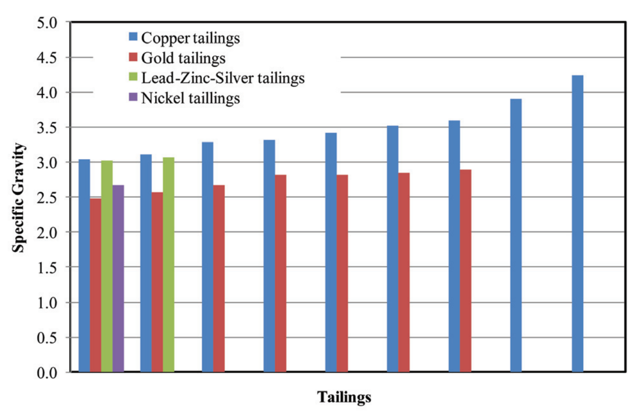

Figure 5—Typical specific gravity of tailings

Table I
Typical mineral composition of tailings and tuff

Mineral	Chemical formula	Lead-Zinc-Silver tailings	Gold tailings 1	Gold tailings 2	Gold tailings 3	Gold tailings 4	Copper tailings 1	Copper tailings 2	Copper tailings 3	Copper tailings 4	Tuff 1	Tuff 2	Tuff 3
Amphibole	$Ca2(Fe,Mg)5Si8O22(OH)_2$	19	-	-	-	-	-	-	-	-	-	-	-
Ankerite	$Ca(Fe+2,Mg)(CO_3)_2$	-	-	9	-	-	-	-	-	-	-	-	-
* Calcite	$CaCO_3$	-	-	5	38	31	-	-	-	11	-	-	-
#Chlorite	$(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$	-	-	16	-	-	15	3	-	31	4	3	-
* Dolomite	$CaCO_3.MgCO_3$	-	29	-	-	-	-	-	-	5	-	8	-
#Gypsum	$CaSO_4.2H_2O$	-	<2	-	-	-	-	-	-	-	-	-	-
Halite	NaCl	-	4	-	-	-	-	-	-	-	-	-	-
#Illite	$K(AlFe)_2AlSi_3O_{10}(OH)_2{\cdot}H_2O$	-	-	-	-	-	3	-	-	-	-	-	-
K Feldspar	$KAlSi3O_8$	9	-	-	18	-	-	-	-	-		-	-
#Kaolin	$Al_2Si_2O_5(OH)_4$	3	-	-	3	7	-	-	6	-	6	5	9
Kyanite	Al_2SiO_5	21	-	-	-	-	-	-	-	-	-	-	-
Magnetite	Fe_3O_4	10	-	-	-	-	7	37	50	-	-	-	-
Muscovite	$(K,Na)Al_2(Si,Al)4O_{10}(OH)_2$	10	23	-	-	-	-	-	-	-	-	-	-
Plagioclase feldspar (Albite)	$(Na,Ca)Al(Si,Al)3O_8$	-	24	27	-	-	4	9	9	8	-	-	-
#Pyrite	FeS_2	-	-	-	-	-	51	11	9	-	-	-	-
# Pyrrhotite	Fe_7S_8	-	-	-		-	-	17	3	-	-	-	-
Quartz	SiO_2	30	18	43	41	62	19	23	23	45	12	12	2
Anorthite	$(Ca, Na)(Si,Al)4O_8$	-	-	-	-	-	-	-	-	-	78	72	84
*Amorphous Materials		-	-	-	-	-	-	-	-	-	Majority	Majority	Majority

* Favourable mineral for cement hydration

#Unfavourable mineral for cement hydration

break down the crystal structure of some minerals present and cause difficulties during the identification of the minerals. Table I shows a typical mineral composition of tailings and natural tuff using X-ray diffraction (XRD) method. The results show that, the tailings mainly contain quartz, feldspar, mica, clay minerals, sulphide minerals and carbonate minerals. Some minerals are not favourable to the cement hydration. The presence of clay minerals (Chlorite, illite, and kaolin) and sulphide minerals (pyrite, pyrrhotite) would reduce the strength of minefill for a given cement type and dosage[1,8]. On the other hand, the presence of carbonate minerals (calcite, dolomite) would increased the strength of the minefill for a given cement type and dosage[9,10].

Binders

Binder such as cement or natural pozzolans are the main substance for strength development in any types of minefill. It is also the most expensive input of the minefill mix. A choice of binder depends upon on the required strength and durability requirements of a particular minefill operation. The main compound of the different types of cement and pozzolans were calculated according to Bogue's[11] suggestion using XRD scan results and shown in Figure 6.

The major components are tricalcium silicate ($3CaO.SiO_2$) and dicalcium silicate ($2CaO.SiO_2$). Both react with water to produce calcium silicate hydrate (C-S-H) and calcium hydroxide (CH). The strength development is due to the formation of C-S-H. Calcium hydroxide (CH) which can react with aggressive chemicals in tailings and saline water in some underground mines lowering the durability of minefill[13]. Therefore, a cost-effective with optimum strength mix design can be achieved by selecting or blending the right binder for a given tailings and mixing water.

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 paste for the development of hydration products[12]. Research conducted by Lawrence[13] (1992), Wang, *et al.*,[14] (2001), Coxon, *et al.*,[15] (2003), Benzaazoua *et al.*,[16-17] (2002, 2004), showed that impurities in the mixing water can cause a strength reduction in any type of minefill. 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. Table II shows a typical chemical composition of common mixing water

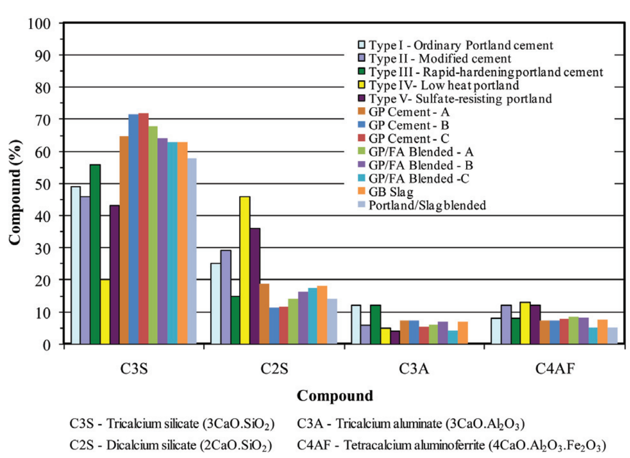

Figure 6—Composition of the main compounds for a number of cement types

Table II
Typical chemical composition of mixing water

Chemical analysis	Bore water	Process water	Saline water 1	Saline water 2	Saline water 3	Saline water 4
pH	8.1	7.8	6.9	6.8	6.7	6.7
Conductivity (uS)	2 137	112	163	167	-	-
Total Dissolved Solids (mg/L)	1 357	196 879	315 087	269 056	180 000	320 000
Total Suspended Solids (mg/L)	0	396	9 287	2 834	-	-
Total Alkalinity – $CaCO_3$ (mg /L)	492	0	80	80	-	-
Carbonate Alkalinity CO_3^{2-}(mg /L)	-	-	48	48	-	-
Bicarbonate Alkalinity HCO_3^{2-} (mg /L)	-	145	98	98	45	25
SO_4^{2-} (mg/L)	119	4 109	21 926	19 035	7 400	7 900
Cl^- (mg/L)	0	11	0	0	190 000	200 000
Ca (ppm)	58	2 600	1,366	1 746	1 000	1 000
Fe (ppm)	0	-	261	87	-	-
K (ppm)	42	908	14 332	12 861	260	470
Mg (ppm)	51	3 530	12 427	10 474	3 300	3 600
Na (ppm)	337	60 900	75 870	65 296	140 000	120 000

used in minefill. It can be seen that the total dissolved solids (TDS) in process water ranges from 180 000 to 320 000 (mg/L). In certain cases, the contaminated water can be used for minefill purposes by mixing it with fresh water. However, it is important to determine whether the impurities may lead a strength reduction.

Yield stress

Yield stress is the stress at the limit of elastic behaviour describing the rheology of a paste fill. In other words, it is the minimum force required to initiate paste flow at almost zero shear rate. Understanding the relationship between the yield stress and the solids percentage is essential for a design of paste fill transportation system. A proper transportation system enables delivery of CPF from surface to underground at the highest solids percentage. A direct yield stress measurement with the vane shear method suggested by Nguyen and Boger[18] was used in conjunction with Haake VT550 viscometer controlled by 'Haake RheoWin 3' software in all the CPF optimizations research conducted at WASM. The vane shear stress is calculated as uniformly distributed within the cylindrical sample. Yield stresses were measured immediately after mixing, i.e. about 5 to 10 minutes after binder and water contact. The vane was rotated with the shear rate of 0.5 rpm for 100 seconds and the stress were recorded during that period. The peak stress is reported as yield stress. Standard conical slump tests in accordance with Australian Standard AS 1012.3.1 were also conducted on different mixes. A typical yield stress, correlation with solids percentage and slump for different mixes are presented in Figures 7 and 8. A slightly different correlation was established for different mixes.

Hydrogen cyanide (HCN) gas liberation

Minefill made with cyanide-bearing tailings contains weak acid dissociable (WAD) cyanide and it is highly unstable and can emit volatile hydrogen cyanide (HCN) gas when sufficient hydrogen ion concentration occurs in the minefill. Therefore, determination of total cyanide, WAD cyanide and monitoring liberated HCN gas from the crushed CPF samples mixed with gold tailings and mine water was conducted by WASM through SGS Australia Pty Ltd. The results showed that those samples containing 1.5 to 2.0 mg/kg of WAD cyanide and the liberated HCN gas were less than 0.1 mg/kg in all samples[19]. Generally, permeability of CPF in the underground is low and the amount of liberated HNC gas will be lower than that of crushed CPF samples monitored in the laboratory. Although a possibility exists for HCN gas liberation, the amount appears to be insignificant. A graphical presentation of WAD cyanide in crushed CPF samples with different cement dosage is shown in Figure 9.

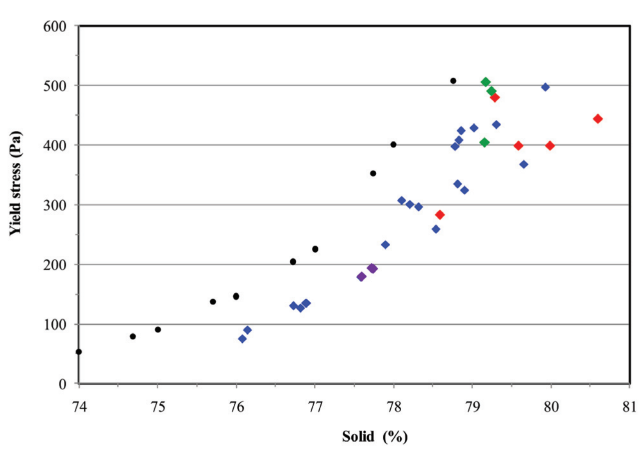

Figure 7—Typical correlation between solids density and yield stress of different CPF mixes

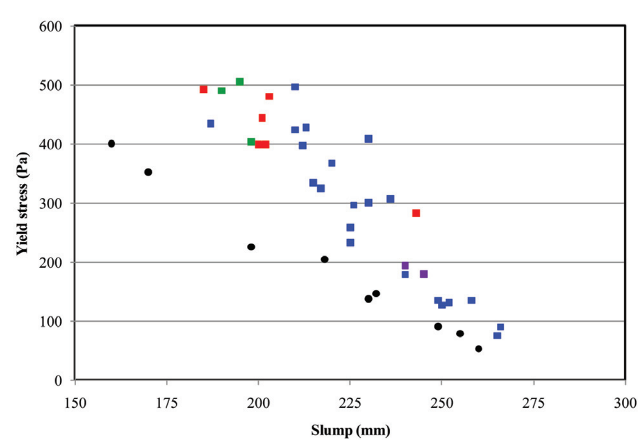

Figure 8—Typical correlation between yield stress and slump of different CPF mixes

Table III
Summary of average UCS test results, Mine A

Mix ID	GP cement (%)	Solids (%)	Yield stress (Pa)	Slump (mm)	1 day - UCS (kPa)	3 days - UCS (kPa)	7 days - UCS (kPa)	14 days - UCS (kPa)	28 days - UCS (kPa)	56 days - UCS (kPa)
A-1	1.5	76.1	90	266			193	167	162	158
A-8	1.5	77.6	179	240			187	212	221	202
A-15	1.5	78.8	397	212			245	249	257	276
A-2	2	76.1	76	265		191	239	247	225	237
A-16	2	78.8	335	215		283	282	322	363	350
A-9	2	79.0	428	213		253	283	329	343	277
A-3	2.5	76.9	135	258	228	240	264	330	411	339
A-17	2.5	77.9	233	225	224	264	362	413	400	514
A-10	2.5	78.9	324	217	244	333	430	459	520	450
A-18	3	76.7	131	252	225	271	463	478	583	465
A-4	3	76.9	135	249	218	268	318	415	407	450
A-11	3	78.3	296	226	265	391	450	591	517	624
A-5	3.5	78.5	259	225	269	380	468	574	597	589
A-12	3.5	79.3	434	187	277	409	619	684	780	1019
A-19-b	3.5	79.9	496	210	230	400	478	533	633	595
A-20	4	76.8	127	250	205	354	503	519	639	639
A-6	4	78.9	424	210	316	463	524	814	859	876
A-13	4	79.7	367	220	283	473	688	708	850	899
A-7	5	78.1	307	236	369	570	767	950	1151	1310
A-14	5	78.2	300	230	380	674	992	1097	1379	1764
A-21	5	78.8	408	230	338	590	802	828	1028	1065

Minefill strength

The required minefill strength is a function of the mining method, geometry of orebody and stope, and the possible failure modes. Mitchell and Roettger[20] describe the potential failure modes of cemented minefill used to support the uncemented minefill in steeply dipping ore zones. Failure modes include sliding, crushing, flexural and caving. Sliding occurs due to low frictional resistance between the minefill and the rock wall. Crushing occurs when the reduced stress exceed the UCS of the fill mass. Flexural failure occurs when the fill mass has a low tensile strength, caving can be a results of arching, and rotational failure due to low shearing resistance at the rock wall. When minefill is considered as a roof slab, the analysis methods developed by Evans[21] and later modified by Beer and Meek[22] can be applied. Such method for roof design procedure considering plane strain is described in Brady and Brown[23]. The mechanical properties for the design are usually determined by laboratory testing. The most common tests are uniaxial compressive strength (UCS) test and triaxial (unconsolidated undrained) test. The following sections briefly describe some of minefill strength optimization research recently carried out at WASM.

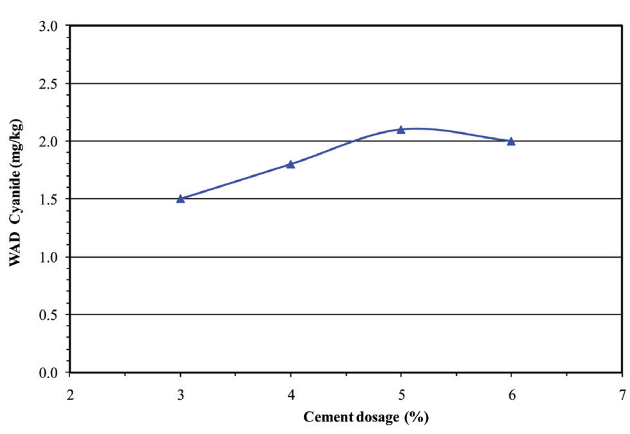

Figure 9—Weak Acid Dissociable Cyanide in CPF mixed with gold tailings (Saw & Villaescusa, 2007)

Results for Mine A—cemented paste fill (lead-zinc-silver mine, Australia)

Mix design parameters

- Fill material: lead-zinc-silver tailings
- Water: metallurgical process water
- Binder: general purpose cement (GP)—A, B and C
- General purpose (GP)/ fly ash (FA) blended cement—A, B and C
- GB slag and Portland/slag blended cement
- Calculated solid percentage: 76–80%
- Measured yield stress: 76–496 Pa
- Curing: temperature 40°C and 90 % humidity
- Sample size: 50 × 110 mm (diameter × length)

Uniaxial compressive strength

A summary of mix properties and average UCS development of CPF mixed with GP cement-A is shown in Table III. Figure 10 shows the average UCS development with time for the different cement dosages and solid percentages. No significant strength reduction was found until 56 days' curing in all mixes. CPF mixed with 1.5% and 2% cement showed a strength increase until 7 days of curing and did not change notably after it reached the peak strength. Similarly, the peak strength for 2.5% and 3.5 % cement was reached at 14 days and at 28 days for the 3.5% and 4% cement respectively. The strength significantly developed in CPF mixed with 4% and 5% cement. The strength development is also highly influenced by the curing temperature and humidity. For example, CPF mix No. A12 and A14 were placed (unplanned) close to the curing chamber heater. Therefore, mix No. A12 and A14 developed higher strength compared to the mixes with similar cement dosages and higher solids percentage, but cured away from the heater.

Figure 11 shows the average UCS development of CPF mixed with 4 % GP cement from three different suppliers A, B and C. The comparison shows that, although it was mixed with slightly higher solids percentage, GP cement B gained slightly less peak strength compared to the others. The peak strengths were similar for GP cement A and C.

Figure 12 shows a strength development comparison for CPF mixed with 4% GP/FA blended cement from three different suppliers A, B and C. It can be seen that, although it was mixed with lower solids percentage, GP/FA blended cement C achieved a significantly higher strength.

Figure 13 shows the strength development of CPF mixed with 4% GP cement A, GP/FA blended cement A, GB slag and portland/slag blended cement. The highest strength development for given cement dosage was observed in CPF using portland/slag blended cement.

Results for Mine B—cemented paste fill (gold mine, Australia)

Mix design parameters

- Fill material: gold tailings
- Water: fresh, salt and blended fresh/salt water
- Binder: general purpose (GP) cement
- Water reducing admixture: 0.4% of binder
- Solid percentage: 72–75%
- Measured Slump: 130–215 mm
- Curing: Temperature 30°C and 90% humidity
- Sample size: 50 × 110 mm (diameter × length)

Uniaxial compressive strength

The UCS development of CPF mixed with fresh and fresh-salt blended water is shown in Figure 14. The data show that a slight difference on strength development was found for mixes having 100% fresh water compared to those having 75% fresh water and salt water. However, a significant strength reduction was found for mixes having a (50:50) ratio of fresh water and salt water.

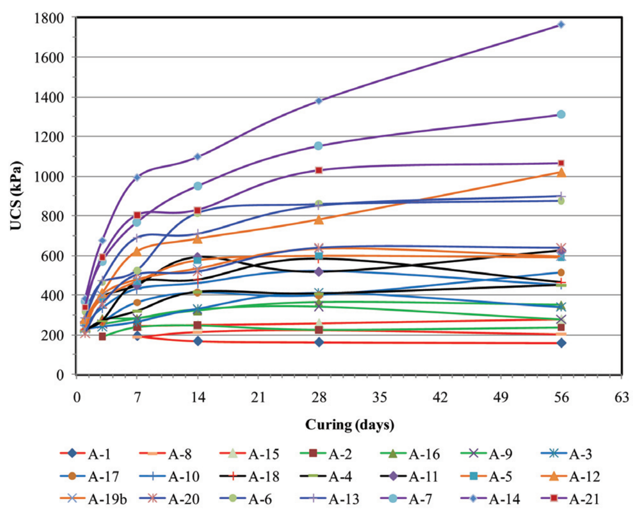

Figure 10—Average UCS development with time (GP cement A)

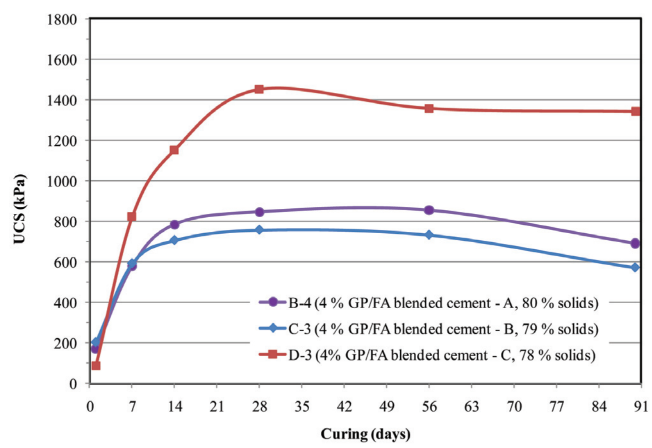

Figure 12—Average UCS development with time (GP/FA blended cement A, B and C)

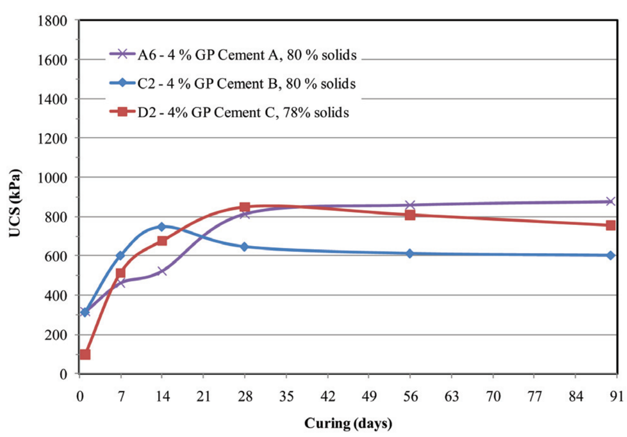

Figure 11—Average UCS development with time (GP cement A, B and C)

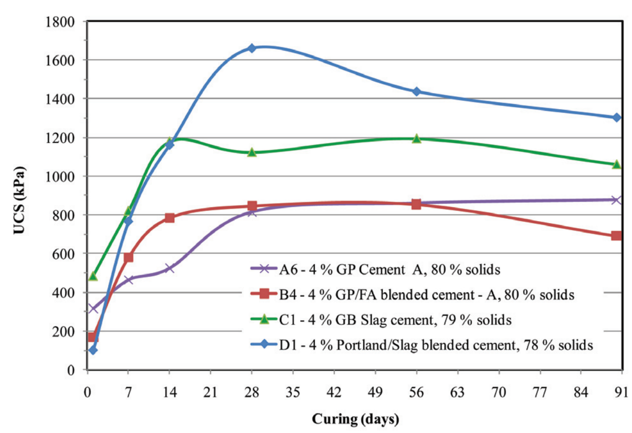

Figure 13—Average UCS development with time (GP A, GP/FA blended A, GB slag and Portland/slag blended cement)

Results for Mine C—cemented paste fill (gold mine, Indonesia)

Mix design parameters
- Fill material: gold tailings, river sand and tuff
- Water: bore water
- Binder: general purpose (GP) cement
- Solid percentage: 66–71%
- Measured yield stress: 230–393 Pa
- Curing: temperature 30°C and 90% humidity
- Sample size: 50 × 110 mm (diameter × length)

Uniaxial compressive strength

The UCS development of CPF mixed with blended tailings and tuff is presented in Figure 15. The results show that the strength gradually developed in all the mixes. The UCS slightly increased for the CPF mixed with 50% tuff and 50% tailings, and 10% cement. The strength increased significantly after 14 days of hydration, in the sample mixed with 90% tuff 1 and 10 % cement (GM-7). The pozzolanic analysis of tuff shows that the total of the three oxides (SiO_2+Al_2O_3+Fe_2O_3) is 84.3%. The SO_3 content is 0.1 % and the loss on ignition (LOI) is 4.2%. The free moisture H_2O and available alkalinity are 0.2% and 0.4%, respectively. Therefore, 'tuff' used in this research was classified as 'Class N' natural pozzolan based on ASTM C 618-a[24].

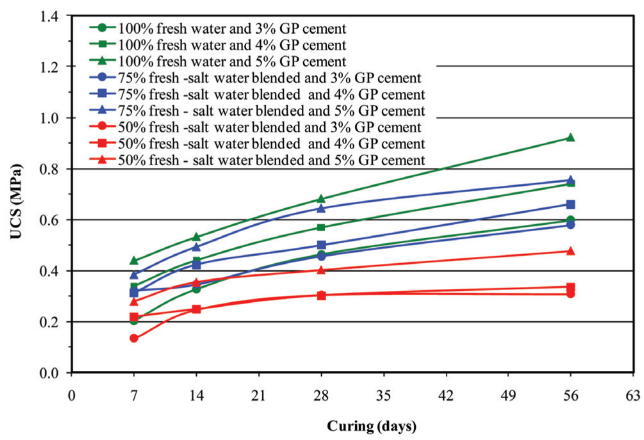

Figure 14—Average UCS development CPF with fresh and fresh-salt blended water

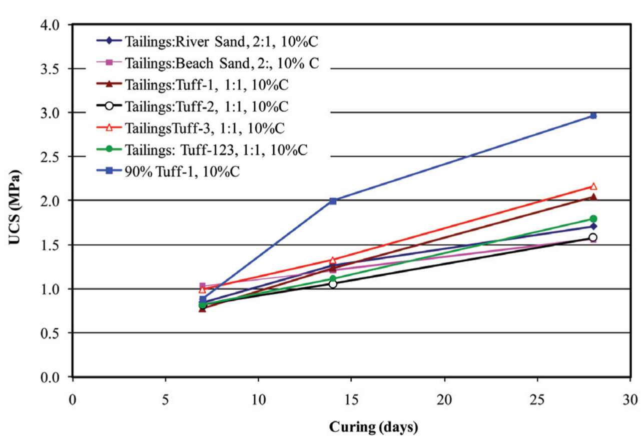

Figure 15—Average UCS development CPF with blended tailings and tuff

Results for Mine D—cemented paste fill (copper mine, Saudi Arabia)

Mix design parameters
- Fill material: cyclone underflow copper tailings
- Water: fresh water
- Binder: general purpose (GP) cement
- Solid percentage: 77–78%
- Measured yield stress: 103–107 Pa
- CPF sample curing: Temperature 30°C and 90% humidity
- Sample size: 50 × 110 mm (diameter × length)

Uniaxial compressive strength

The UCS development with time for this project is shown in Figure 16. Usually, UCS of cemented materials mixed with GP cement become stable at 28 days curing, when the degree of hydration is believed to be more than 90%. In this research, the UCS in all the mixes was found to increase until 56 days of curing. This might be due to the preset of calcium carbonate ($CaCO_3$) in the tailings, which may increase the amount of hydration products in the long term.

Results for Mine E—cemented hydraulic fill (lead-zinc-silver mine, Australia)

Mix design parameters
- Fill material: zinc tailings
- Water: fresh water
- Binder: 4 to 9%, low heat (LH) cement
- Solid percentage: 76 %
- Curing: temperature 30°C and 90% humidity
- Sample size: 50 × 110 mm (diameter × length)

Uniaxial compressive strength

The strength development of CHF mixed with low heat cement is shown in Figure 17. Generally, the UCS gradually increased with cement dosage and curing time. However, the CHF mixed with 4% and 5% cement showed an increase until 14 days of curing and did not change significantly after it reached its peak strength.

Results for Mine F—cemented aggregate fill (copper-zinc mine, Australia)

Mix design parameters
- Fill material: crushed aggregates maximum size 40 mm with and without sand.

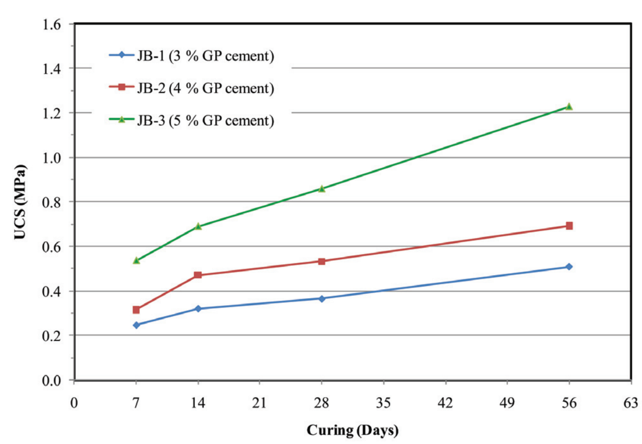

Figure 16—Average UCS development with time

- Water: fresh water
- Binder: 2 to 8 % Minecem cement
- Mixing: CAF mixing was achieved by adding water to the blended cement and aggregates. When the cement particles coated the aggregates, adding of water was stopped and the water: cement ratio was calculated. The water and cement ratio ranges from 0.75 to 4.
- Curing: temperature 30°C and 90 % humidity
- Sample size: 150 × 300 mm (diameter × length)

Uniaxial compressive strength

Figure 18 shows the strength development with curing time for different mixes. The UCS increased with decreasing water and cement ratio. A higher strength development was observed in the CAF samples mixed with 15% sand addition compared with mixes without sand. The UCS increased significantly in CAF mix J7 (6% cement, 15% sand and w:c ratio 1.44) and J8 (8% cement, 15% sand and w:c ratio 1).

Results for Mine G—Ccemented rock fill (gold mine, Australia)

Mix design parameters

- Fill material: 2 107 kg/m3, waste rock size less than 2 mm to 300 mm
- Water: mine water
- Binder: 105 kg/m^3 (5%) general purpose (GP) cement
- Mixing: a trial mix was done by adding mine water to a blended cement and waste rock. When the cement particles coated the waste rock, adding of water was stopped and the water: cement ratio was calculated. The optimum water and cement ratio for a given waste rock PSD was 2.13.
- Curing: temperature 30°C and 90 % humidity
- Sample size: 400 × 800 mm and 500 × 1000 mm (diameter × length)

Uniaxial compressive strength

The uniaxial compressive strength (UCS) for the large scale (800 × 800) and (500 × 1 000) mm samples was determined using the recently developed WASM 200 static test machine[25]. The WASM static test machine set up for UCS test is shown in Figure 19. Figure 20 shows UCS development with curing time for different mixes. A higher strength development was observed in the CRF samples of Mix 1 and 3 which contain high percentage of fine particles compared with Mix 2.

Summary of minefill UCS

The UCS development is a function of the type of fill material (tailings, waste rock), cement type, cement dosage, water, solid percentage and water:cement ratio, curing days

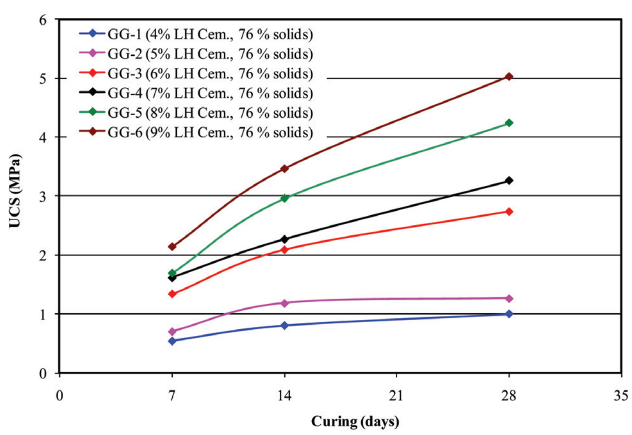

Figure 17—Average UCS development CHF mixed with low heat cement

Figure 19—CRF sample (400 × 800) mm set up for UCS test

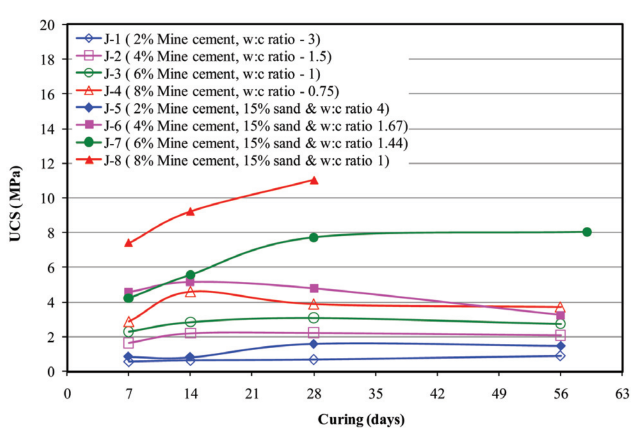

Figure 18—Average UCS development of CAF

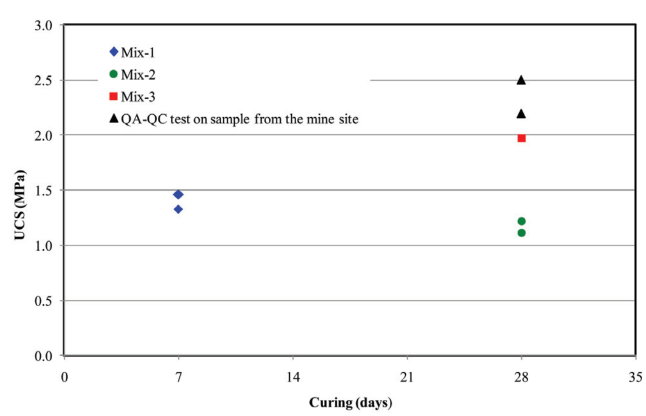

Figure 20—UCS development of CRF large-scale sample

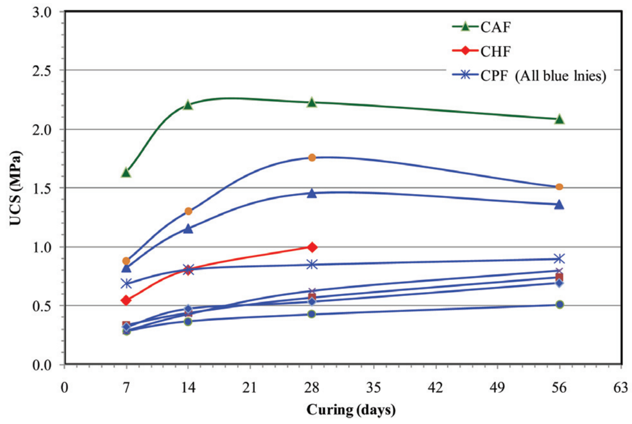

Figure 21—UCS development of CPF, CHF and CAF sample mix with 4% cement

and temperature. Figure 21 shows a comparison of strength development in CPF, CHF and CAF sample mixed with 4% cement. The results show that although mixed with the same cement dosage, the strength development change as a function of the components. The UCS of CPF at 28 days ranges from about 0.4 to 1.7 MPa. The UCS of CHF and CAF was about 1 MPa and 2.5 MPa, respectively.

Conclusions

Based on a series of minefill research conducted over the last few years at WASM, the following conclusions can be drawn to provide procedures for the systematic selection and optimization of cost-effective minefill mix design.

- Material characterization is required before starting any minefill operation. The materials includes: tailings or waste rock, binder and mixing water. The basic test required to characterize the materials are PSD, SG, bulk density, chemical and mineralogical analysis.
- Based on the PSD analysis results, tailings used in all CPF and CHF optimization research contains about 25–60 % passing 20 micron (0.02 mm) and about 15–40% passing 10 microns (0.01 mm). The tailings can be classified as sandy silt (ML) according to the Unified Soil classification System.
- The weight-volume relations of minefill is determined by its water content, SG, porosity, void ratios and relative density. A variation in water content determination can be a major problem in achieving a required mix design.
- Mine tailings generally contains quartz, feldspar, mica, clay minerals, sulphide minerals and carbonate minerals. Some minerals are not favourable to the cement hydration. The presence of clay minerals (chlorite, illite, and kaolin) and sulphide minerals (pyrite, pyrrhotite) can reduce the strength. However, the presence of carbonate minerals (calcite, dolomite) would increase the strength of minefill for a given cement type and dosage.
- For all minefill types, binder such as cement or natural pozzolans are the main substance for strength development. The percentage of the main binder compound varies from different types and suppliers. A cost effective with optimum strength mix design can be achieved by selecting or blending the right binder for a given tailings and mixing water.
- Mixing water impurities may cause a strength reduction in any type of minefill. In certain cases, water with impurities can be used for minefill mixing it with fresh water. However, it is important to determine whether the impurities level is acceptable for the strength reduction.
- Correlation of yield stress, with solids percentage and slump is slightly different in different CPF mixes. The variation is mainly caused by different PSD, SG and binder dosages.
- Laboratory test shows that, minefill made with cyanide-bearing tailings contains 1.5 to 2.0 mg/kg of weak acid dissociable (WAD) cyanide and the liberated HCN gas were less than 0.1 mg/kg. Although a possibility exists for HCN gas liberation, the amount appears to be insignificant.
- The required minefill strength is dependent on the mining methods, geometry of orebody and stope, and the possible failure modes. It is specific to each minefill operation. The mechanical properties for the design can be determined by laboratory testing. The most commonly used test is the uniaxial compressive strength (UCS) test.

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Hla Aye Saw (Nixon)

Senior Research Fellow, Western Australian School of Mines

Mr. Hla Aye Saw is a senior research fellow and PhD student from Western Australian School of Mines. His current research interests are “Mine backfill strength and deformability” and “The strength of shotcrete”. Prior to joining WASM in March 2005, he worked in Singapore as a geotechnical engineer for 6 years. He obtained his bachelor degree in Geology from University of Yangon, Myanmar and his M.Sc. degree in Geotechnical Engineering from Asian Institute of Technology, Bangkok, Thailand. He is also a certified gemmologist.