GEOTECHNICAL PROPERTIES OF MINE FILL

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Mine fill 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, mine fill has the potential to reduce subsidence and minimize dilution. Mine fill is essential to cut and fill, benching and sublevel stoping mining methods. This paper describes mine fill research carried out at the Western Australian School of Mines (WASM) over the last 10 years or so. 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.

1. INTRODUCTION

Mine fill technology is in demand not only to fill the voids created by mining excavations, but also to provide overall large scale ground stabilisation and allow localized and systematic pillar recovery. In addition to providing a working floor or back, mine fill may reduce subsidence and minimize dilution. The most common mine fill types are cemented paste fill (CPF), cemented hydraulic fill (CHF) and cemented aggregates or rock fill (CAF/CRF). The materials suitable for making a mine fill include fresh reclaimed tailings, waste rock, cement and/or natural pozzolans and different types of water. Over the last 10 years, the Western Australian School of Mines (WASM) has undertaken a series of mine fill research projects to allow the systematic selection of components to achieve a cost effective mine fill mix design at a number of sites [1]. The geotechnical properties of mine fill are highly influenced by the physical, mechanical, chemical, and mineralogical of the constituent materials. This paper describes the typical properties of the constituent materials and geotechnical properties of the fresh and harden mine fill.

2. PHYSICAL AND CHEMICAL PROPERTIES

The physical properties of mine tailings vary from site to site and depend on the ore type, host rock and processing method. Figure 1 shows a typical particle size distribution (PSD) curves of different mine tailings. Generally, a sizing limit of at least 15% passing 20 micron (0.02 mm) is required to achieve a paste flow and 10% passing 10 microns (0.01 mm) for cemented hydraulic fill flow. Grice [2] suggested coarse, medium and fine PSD limit curves to determine whether a particular tailings is suitable for paste fill (PF) or for hydraulic fill (HF). If the PSD curve of tailings falls in the coarse region it is suitable for HF but not

Advances in Geotechnical Infrastructure
Edited by C. F. Leung, S. H. Goh & R. F. Shen
Copyright © 2013 Geotechnical Society of Singapore (GeoSS). *Published by* Research Publishing.
ISBN: 978-981-07-4948-4 :: doi:10.3850/978-981-07-4948-4_158

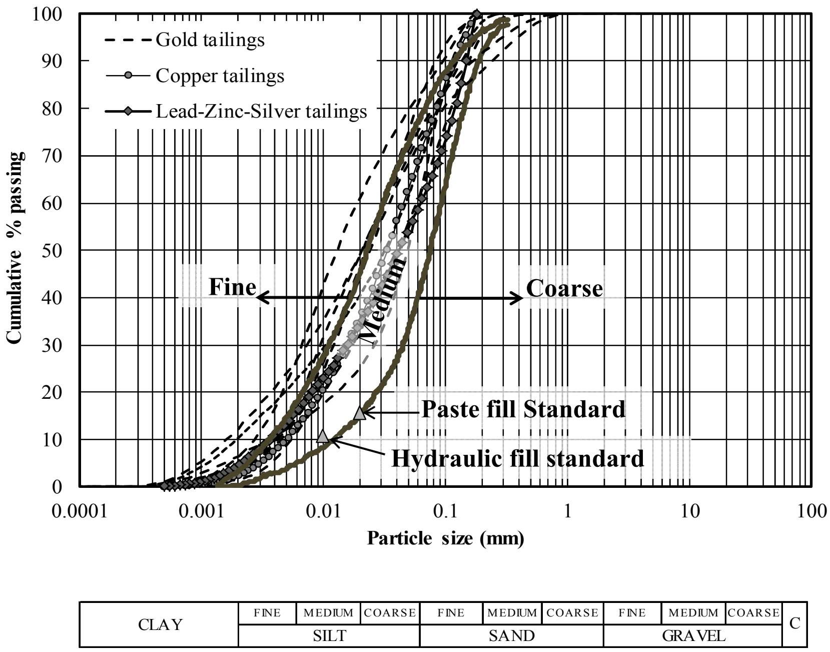

Figure 1. Typical particle size distribution curves of different mine tailings.

suitable to PF. If the PSD curve of tailings falls in the medium region it is suitable for PF and it requires desliming to be used for HF. If the PSD curve of tailings falls in the fine region it is not suitable for HF and requires desliming for use as PF. According to the Unified Soil Classification System most of the tailings from the Australian mines can be classified as Sandy Silt (ML).

The typical SG of tailings ranges from 2.5 to 4.1. The tailings mainly contains quartz, feldspar, mica, clay minerals, sulphide minerals and carbonate minerals. Some minerals are not favorable to cement hydration. The presence of clay minerals (Chlorite, Illite, and Kaolin) and sulphide minerals (Pyrite, Pyrrhotite) would reduce the strength of mine fill for a given cement type and dosage [3]. On the other hand, the presence of carbonate minerals (Calcite, Dolomite) would increase the strength of mine fill for a given cement type and dosage [4]. Waste rock from underground mine development is crushed down to a size ranging from less than 20 mm to larger 300 mm and often used as aggregate or rock fill. Binder such as cement or natural pozzolans are the main substance for strength development in any types of mine fill. It is also the most expensive component of a mine fill mix. A choice of binder and the dosage depend upon on the strength and durability requirements of a particular mine fill operation. The water use for mixing mine fill ranges from potable, recycled water from metallurgical processing or hyper saline water. Impurities in the mixing water can cause a strength reduction in any type of mine fill [5]. 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, the 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.

Table 1. Typical mine fill mix design.

Description	CPF	CHF	CAF	CRF
Tailings (%)	96	94	–	–
Waste rock < 2 mm to 300 mm diameter (kg/m^3)	–	–	–	2017
Coarse aggregate 10 to 40 mm diameter (%)	–	–	86	–
Sand (%)	–	–	10	–
Cement (%)	4	6	4	5
Solids (%)	70	76	–	–
Water cement ratio	10	5	2	2

CPF = Cemented paste fill CAF = Cemented aggregate fill
CHF = Cemented hydraulic fill CRF = Cemented rock fill

3. MIX DESIGN

Mine fill design largely depends upon the availability of constituent materials and its physical and chemical properties, the required fresh properties (flowability), strength and durability. A typical mix design for CPF, CHF, CAF and CHF is shown in Table 1.

4. PROPERTIES OF FRESH MINE FILL

Understanding the relationship between the yield stress and the solids percentage is essential for a design of a paste fill transportation system. Yield stress is the minimum force required to initiate paste flow at almost zero shear rate. A proper transportation system enables delivery of CPF from surface to underground at the highest solids percentage. A correlation between yield stress and solids percentage for different mixes is presented in Figure 2. Generally, yield stress increases exponentially with an increased solids percentage. The relationship for a particular CPF mix is highly influenced by the PSD of the tailings used for the mix. For example, a tailings with PSD curve falling in the "Fine" region as

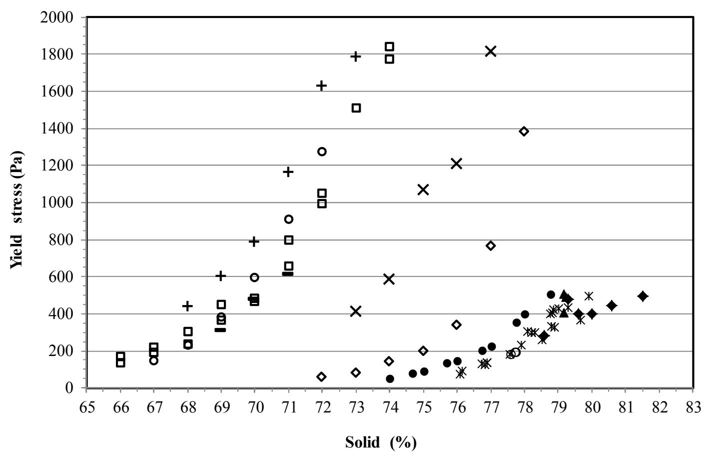

Figure 2. Correlation between solids density and yield stress for different CPF mixes.

shown in Figure 1, will return high ranges of yield stress (200 – 1800 Pa) with a low ranges of solids percentage (67–74%). In a hydraulic fill system it is critical to understand its permeability at its fresh state for the design of fill barricades. The coefficient of permeability (k) of a fresh CHF ranges from 552 to 1467 (mm/hour). The flow properties of a fresh CAF or CRF are difficult to assess with a standard test method, such as slump measurement. This is due to the contained aggregate having particle size 40 to 300 mm in size. Usually, CRF is mixed underground and directly dumped into the mining stopes.

5. PROPERTIES OF HARDENED MINE FILL

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 [6] describe a potential failure modes of cemented mine fill used to support steeply dipping ore zones. Failure modes include 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 UCS 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 stope rock wall. When mine fill is considered as a roof slab, the analysis methods developed by Evans [7] and later modified by Beer and Meek [8] can be applied. Such method for roof design procedure considers plane strain and it is described in Brady and Brown [9]. The mechanical properties for design are usually determined by laboratory testing. The most common tests are Uniaxial Compressive Strength (UCS) test and Triaxial (Unconsolidated Undrained) test. The strength development is a function of the type of fill material (tailings or waste rock), cement type, cement dosage, water, solid percentage and water:cement ratio, curing days and temperature. Figure 3 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 typical UCS of CPF at 28 days ranges from 0.4 to

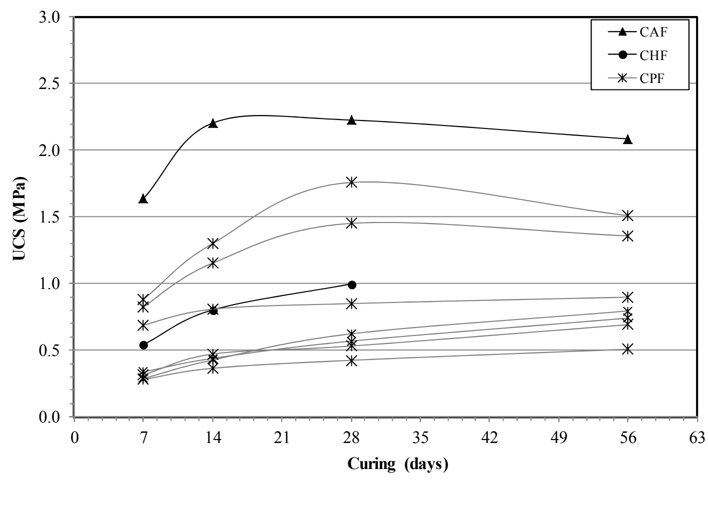

Figure 3. UCS development of CPF, CHF and CAF sample mix with 4% cement.

Table 2. Typical shear strength of mine fill.

			Total stress		Effective stress	
Mine fill type	Curing (Days)	Test method	Cohesion (c) (kPa)	Friction (ϕ) (Degree)	Cohesion (c′) (kPa)	Cohesion (ϕ') (Degree)
CPF	28	UU	208	39	–	–
CPF	2	CU	–	–	147	31
CPF	2	CD	–	–	85	38
CAF	106	UU	400	32	–	–
CAF	93	UU	1450	44	–	–

1.7 MPa. The UCS of CHF and CAF is about 1 MPa and 2.5 MPa, respectively. The Uniaxial tensile strength (UTS) strength is obtained according to the test method suggested by International Society of Rock Mechanics [10]. The typical UTS of CPF at 28 days ranges from 0.1 to 0.3 MPa and the UTS of CAF ranges from 0.2 to 0.8 MPa. The shear strength of a mine fill is usually obtained by Unconsolidated Undrained (UU) triaxial compression testing. Occasionally, Consolidated Undrained (CU) and Consolidated Drained (CD) tests are conducted to get the effective stress parameter used in the design for mine fill barricade systems. A typical shear strength of mine fill is presented in Table 2.

6. CONCLUSIONS

Mine fill technology is in demand not only to fill the voids created by mining excavations, but also to provide overall large scale ground stabilisation and allow localized and systematic pillar recovery. The physical properties of mine tailings vary from site to site depends on the ore type, host rock and processing method. Mine fill design largely depends upon the availability of constituent materials and its physical and chemical properties, the required fresh properties, strength and durability. 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. The required mine fill strength is a function of the mining method, geometry of ore body and stope, and the possible failure modes. The strength development is a function of the type of fill material, cement type, cement dosage, water, solid percentage and water:cement ratio, curing days and temperature.

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