Chapter 2
Practical Importance of Tailings for Cemented Paste Backfill

Bayram Ercikdi, Ferdi Cihangir, Ayhan Kesimal, and Haci Deveci

1 Introduction

Mineral processing methods, such as flotation, are used to treat low-grade ores from mining operations; however, a significant amount of tailings are then generated (typically 95–98% of the feed ore). Therefore, mineral processing must also be essentially regarded as a "waste/tailings management" project (Ercikdi et al. 2012). The disposal, stability and safety of tailings, and their effects on water and soil, are important technical and environmental problems. For example, sulphide (i.e. pyritic) tailings can lead to the generation of acid mine drainage (AMD) when they are disposed under atmospheric conditions. This results in the release/mobility of heavy metals, such as arsenic (As), copper (Cu) and zinc (Zn) with the concomitant pollution of water resources and soil (Fig. 2.1).

The increasingly stringent environmental and regulatory constraints today require the management of tailings in a safe and secure manner. Today, tailings generated during ore processing are managed via (a) disposal into tailings dams, (b) discharging into available deep sea zones or (c) backfilling into underground mine openings.

In practice, deep-sea discharging is infrequently used since the mine site is required to be very close to the sea to provide a suitable environment for the disposal of tailings (Cetiner et al. 2006). Instead, tailings dams, which are well constructed, supervised and controlled, are widely used for tailings management/disposal around the world. Chambers and Higman (2011) reported that more than 3500 tailings dams are found worldwide. However, a number of tailings dam accidents have occurred, especially between 1960–1980 and 1980–2011, which is an average of 2–5 incidents per year, respectively. These accidents have caused loss of human lives, structural

B. Ercikdi (✉) • F. Cihangir • A. Kesimal • H. Deveci
Mining Engineering Department, Karadeniz Technical University, Trabzon 61080, Turkey
e-mail: bercikdi@ktu.edu.tr

E. Yilmaz, M. Fall (eds.), *Paste Tailings Management*,
DOI 10.1007/978-3-319-39682-8_2

Fig. 2.1 The formation of acid mine drainage as a result of mineral processing

damage, devastation of agricultural and forestry lands and adverse environmental impacts (such as water pollution) (Rico et al. 2008). A total of 198 tailings dam accidents took place prior to 2000, and 22 after 2000 worldwide (Azam and Li 2010; WISE 2016). These incidents are a result of (a) inappropriate designs, construction, operation and management of the tailings dams; (b) adverse climatic conditions (such as heavy rainfall); (c) inadequate height of the body of the dam and excessive disposal; (d) soil conditions, liquefaction, slope instability and displacement; and (e) the drainage conditions, leakage and pore water pressure (Azam and Li 2010). Paste backfill technology, which was first successfully used in the Bad Grund mine in Germany in 1980, is a safe way of storing tailings into underground mined-out voids (Landriault 2006). However, the success of a tailings backfill design and operation ultimately depends on the characteristics and flowability properties of the tailings material, and environmental conditions of the underground voids.

2 Paste Backfill Technology

Cemented paste backfilling is regarded as a proper waste management method for mill tailings since it leads to the disposal of the tailings back into underground mines. Compared with rock and hydraulic fill, cemented paste backfill (CPB) offers significant technical, economic and environment benefits as follows.

- Cemented paste backfilling permits the placement of a large portion of the tailings back into underground openings and thereby space for tailings disposal and rehabilitation costs are substantially reduced.
- There is no segregation of the paste backfill during its transportation to the mined-out underground voids. Therefore, the use of CPB allows the entire production opening to be filled, thus preventing the collapse of the hanging and side walls and providing a safe work environment.
- About 90% of the processed water can be recovered via thickening and filtration processes prior to the cement backfilling of the tailings. Additionally, this prevents the leakage of pore water outside and the passing of underground water through the paste backfill material owing to its low permeability and high degree of saturation.
- CPB has a low permeability and hence acts as a barrier to prevent underground water seepage. It also reduces the formation of acid mine drainage (AMD) by inhibiting the diffusion of oxygen.
- The transportation of CPB through a pipeline system reduces problems (damage to support systems, traffic problems, etc.) caused by conventional transport systems (conveyors, mobile equipment, etc.).
- Paste backfilling is a relatively fast operation in which the CPB shows a rapid gain of strength for a given binder content. This shortens the mining cycle period compared to hydraulic filling.
- Cement added into CPB provides strength gain, and reduces permeability and the formation of AMD by increasing acid neutralisation potential.
- Cemented paste backfilling increases the volume of ore extraction via substitution and recovery of the ore from pillars, and allows safe working platforms.

However, there are some drawbacks to paste backfilling, which are as follows.

- The dewatering of tailings and pumping operations are capital-intensive and expensive operations.
- Paste backfilling requires a high pumping pressure to transfer high-density backfill material into the underground voids. This increases the pumping maintenance and energy costs.
- The oxidation of sulphide minerals in the presence of oxygen and water may cause long-term instability problems in the CPB of sulphide-rich tailings.
- Transportation problems may occur with changes in the particle size, density and specific gravity of the tailings, and amount of water.
- Paste backfilling requires qualified and accurate engineering work.

In underground mining, the use of CPB to fill production voids or provide support is common, particularly in Canada and Australia. Paste backfill technology has made significant progress over the last 30 years. Over 100 paste backfill plants with capacities that range from 12 to 200 m^3/h are active throughout the world. Additionally, around 30 plants are known to be at the design and installation stage (Fig. 2.2) (Yumlu 2010).

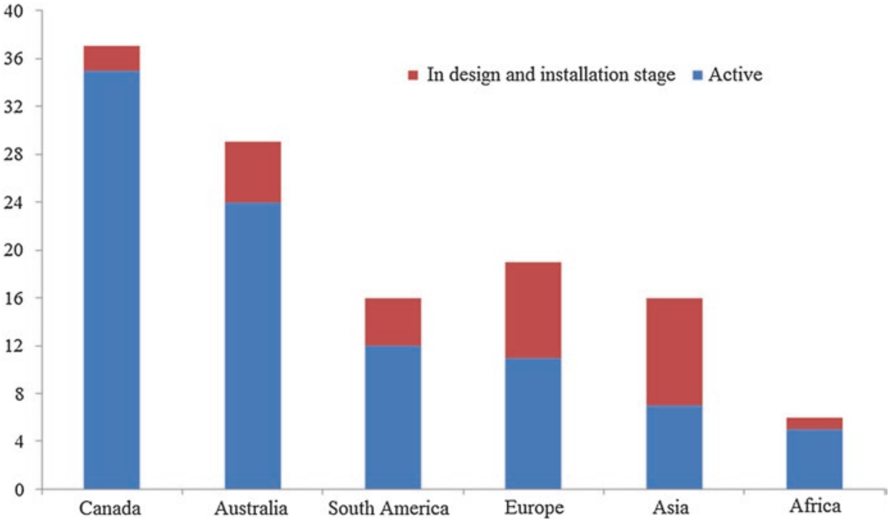


Fig. 2.2 Use of paste backfill technology worldwide (data from Yumlu 2010)

3 Operational Aspects of Cemented Paste Backfilling

Cemented paste backfill (CPB) is an engineered mixture of fine process tailings (75–85% solids by weight), a hydraulic binder (3–9% by total dry paste weight) and mixing water for a solid density of 70–80% by weight (Fig. 2.3). The addition of a binder is essential for the strength and stability of CPB. CPB has to contain sufficient water content to achieve the desired consistency for its transport from the paste plant to the underground openings. In general, a granular material must have at least 15 wt.% finer material than 20 μm to retain sufficient colloidal water so as to form paste with the desired flow properties for its transport through a borehole or pipeline. The index testing consists of a series of water separation and standard slump cone tests that are designed for the assessment of the colloidal properties of an uncemented material (Brackebusch 1994; Kesimal et al. 2003; Ercikdi et al. 2013). The physical, chemical and mineralogical characteristics of the components of CPB, that is, the tailings, binder and mixing water, have a significant role in its short- and long-term performances (i.e. strength and stability), transportation and placement into underground openings.

3.1 Strength and Stability

Many factors such as the preparation method of the paste backfill mixture, transportation of the paste backfill to the underground openings, barricade design, strength and stability of the paste backfill, flowability properties of the paste backfill, effects on water quality and cost of backfilling all influence the design of a paste backfill system (Belem and Benzaazoua 2008). Problems during the design stage may result in failures, which will cause production and labour loss, subsidence and environmental

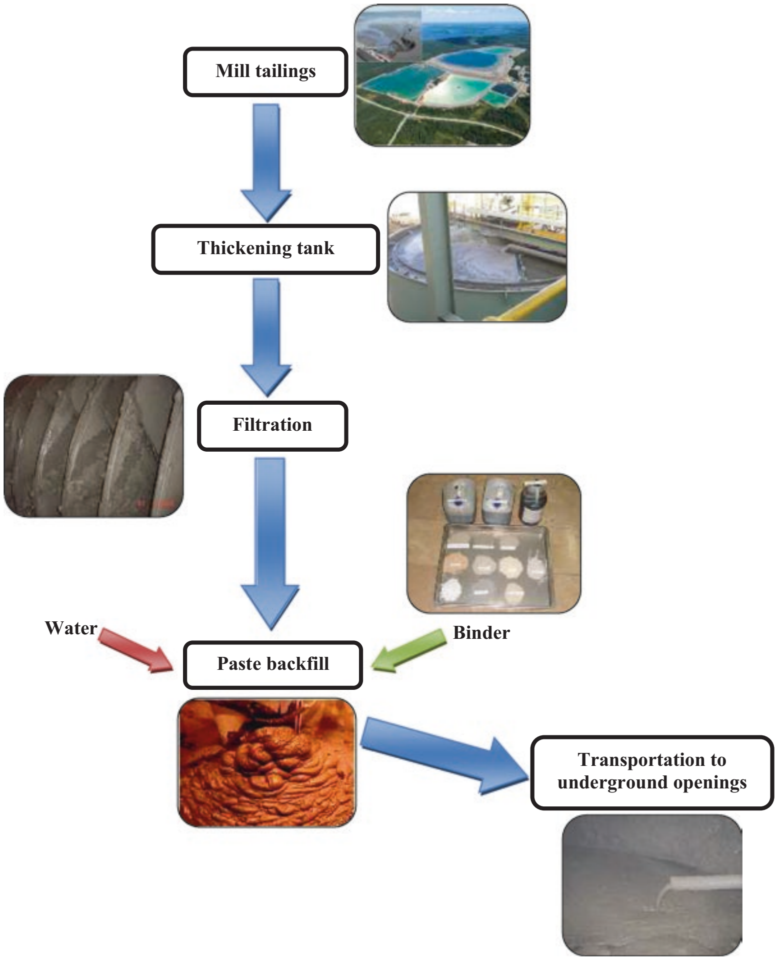


Fig. 2.3 Paste backfill production process

problems. During the paste backfill plant installation, the effect of the paste backfill on groundwater quality, its flowability properties and its short- and long-term strength and stability properties should be examined in detail and optimised. In practice, the strength of paste backfill is determined by unconfined compressive strength testing owing to its simplicity and ease of application as well as low cost (Fig. 2.4).

The required function of CPB in underground stopes determines the designed value of its unconfined strength. For example, to prevent liquefaction risk and barricade collapse, a minimum of 0.15 MPa is required at the early curing stages (Beenet al. 2002; Roux et al. 2004). In mines where cut-and-fill and sublevel mining methods have been used, paste backfill material placed into underground voids provides stability during the mining of the adjacent stopes (Fig. 2.5a). For this purpose, CPB is suggested to have a minimum strength of 0.7 MPa after 28 days of curing (Brackebusch 1994; Landriault 1995). In addition, CPB, which serves as a

Fig. 2.4 Laboratory-scale tests of paste backfill materials: (**a**) preparation of the mixture, (**b**) tamping, (**c**) curing and(**d**) uniaxial compressive and deformation testing

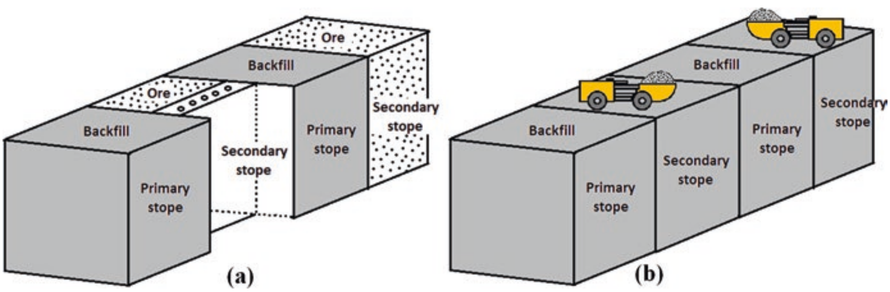


Fig. 2.5 Function of paste backfill in underground mining voids (modified after Hassani and Bois 1992; Belem and Benzaazoua 2008)

working platform for equipment and workers (Fig. 2.5b), is said to have high strength gain at the early ages of curing (Belem and Benzaazoua 2008). Therefore, for roof support, CPB is required to have a uniaxial compressive strength (UCS) value of ≥4 MPa (Grice 1998). The rate in the gain of the desired strength has practical importance for reducing the waiting period for the mining of the adjacent stopes. An appropriate engineering design is therefore required for CPB to achieve the desired strength.

Studies have shown that the CPB design used for a specific type of mill tailings cannot be generalised for use with other mine tailings. Therefore, each type of tailings requires an appropriate and separate mix design with an optimal binder type and mix proportion (Kesimal et al. 2004; Tariq and Nehdi 2007; Ercikdi et al. 2009a, b, 2010a, b; Nasir and Fall 2010; Cihangir et al. 2012).

3.2 Rheology

Rheology is among the most important properties of CPB material which will determine its transportability. CPB mixture should have an appropriate consistency during its transportation through a pipeline system into mined-out underground openings (Simon 2005). An efficient and economical means of transporting paste backfill is only possible when the volume of solid material placed into underground production voids is maximised with minimum energy used. However, an increase in the solids content reduces the fluidity of the mixture, causes friction loss in the pipelines which impedes the rate of material transfer and reduces the efficiency of backfilling (Huynh et al. 2006). Therefore, another important factor that should be considered in the CPB mix design is the flowability properties of the mixture. The physical, chemical and mineralogical characteristics of the paste backfill components significantly affect the paste material consistency.

The main factors that affect the fluidity of paste backfill are the solid ratio, water-to-cement ratio, binder type and proportion, mineral and chemical additives, particle size distribution of the binder and tailings material, shape of the particles, density and surface area of the tailings, surface properties (e.g. zeta potential, water retention), chemical and mineralogical compositions of the tailings, and chemical properties of the mixing water (ion concentration and pH) (Nguyen and Boger 1998; Clayton et al. 2003; Henderson et al. 2005; Huynh et al. 2006).

The flowability properties of paste backfill are usually assessed by slump testing due to its simplicity in practice. For CPB applications, the slump value ranges from 6 to 10 in. A standard slump cone, that is, a right circular cone, is used in slump testing. The right circular cone is 12 in. in height, 8 in. at the base and 4 in. in diameter at the top (Landriault et al. 1997; Cooke 2007). The slump of a mixture is defined as the difference in the level of the original height of the mixture poured into a slump cone (Fig. 2.6a) and the collapse of the material after removal from the slump cone (Fig. 2.6b).

When the water content of a CPB mixture is increased, the slump value also increases (Fig. 2.7) and the mixture can be more easily transported to underground voids through pipelines (Brackebusch 1994; Grabinsky et al. 2002). However, excess water prolongs the curing time of a mixture and also reduces its strength and durability. Chemical plasticisers enhance the flowability properties and thus CPB can be transported at a lower water/cement ratio into the underground voids (Huynh et al. 2006). A reduced water/cement ratio improves the strength and durability of a CPB mixture because the microstructures are refined (i.e. there is a reduction in the

Fig. 2.6 Schematic of the cone slump test

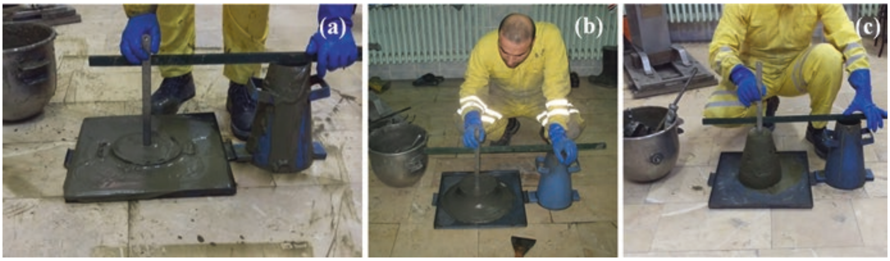


Fig. 2.7 Slump with (**a**) a high value, (**b**) a normal value and (**c**) and a low value

porosity). A reduced water/cement ratio also minimises liquefaction risk in the early curing ages (Kesimal et al. 2005; Ercikdi et al. 2008). An appropriate slump value for CPB mixtures not only prevents **pipeline blockage, but also ensures** safe and efficient transportation of the mixture (Clark et al. 1995). Some researchers have even suggested yield testing and viscosity measurements of CPB mixtures to understand their flowability properties and determine the risk of pipeline blockage in the transportation of these mixtures (Clayton et al. 2003; Fourie and Dunn 2007; Moghaddam and Hassani 2007).

Yield stress is the pressure required for overcoming the static friction of the fluid materials. The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress. Clayton et al. (2003) stated that two mixtures with the same slump value might have different yield stresses. Mixtures with an overly low yield stress can produce low strength values in a given binder dosage. Table 2.1 presents the different yield stresses for materials with the same slump value, but different density. Therefore, in addition to the slump, the yield stress should be determined for tailings with different particle sizes and densities and mineralogical and chemical compositions since it has practical importance for the successful transportation of paste backfill.

3.3 Cost

One of the most important factors that should be taken into consideration in paste backfill design is the cost of the CPB. Since a typical paste backfill plant would have dewatering equipment, concrete pumps, cement-mixer plants, pipeline transportation

Table 2.1 Slump and yield stress values of different mixtures (Clayton et al. 2003)

	Coal tailings	Gold tailings	Lead-zinc tailings
Specific gravity (kg/m^3)	1450	2800	4100
Solids concentration (%)	36	75	75
Slurry density (kg/m^3)	1120	1930	2310
Slump height (mm)	203	203	203
Yield stress (Pa)	160	275	330

Table 2.2 Initial cost of a sample of paste backfill plants (Golder Associates 2012)

Company name/location	Installation	Project capital cost (USD)
Greens Creek silver mine/Juneau, Alaska, US	Capacity: 84 tons/per hour	6 million
	Pipeline system: 6–8 in.	
Zinkgruvan zinc and copper mine/Zinkgruvan, Sweden	Capacity: 90 tons/per hour and pipeline system	6 million
Red Lake Gold Mine/Ontario, Canada	Capacity: 50 tons/per hour and pipeline system	6 million
Bulyanhulu Gold Mine/Tanzania, Africa	Capacity: 180 tons/per hour and pipeline system	6 million
Campbell Gold Mine/Red Lake, Ontario, Canada	Capacity: 60 tons/per hour and pipeline system	6 million
Cayeli Copper Mine/Rize City, Turkey	Capacity: 90 tons/per hour and pipeline system	6 million
Cannington Silver and Lead Mine/ Queensland, Australia	Capacity: 175 tons/per hour and pipeline system	6 million

system and computer control systems, the cost of the investment is high. However, in recent years, there is a trend in which the cost of dewatering equipment and concrete pumps has declined due to advances in technology. As seen in Table 2.2, the cost of investing in a paste backfill plant could range between $5 and $7 million USD (http://www.golder.com/modules.php?name=Services&sp_id=1221 Golder Associates 2012) depending on the capacity and the pipeline transport system. Paste backfill operation costs make up 10–20% of the total cost of mining operations (Grice 1998). The binder consumption can represent up to 75% of the cost of paste backfill.

Naylor et al. (1997) stated that as a general rule, the cost of a paste backfill mix with a binder of 1 wt.% is $1/ton. De Souza et al. (2003) indicated that the cost of a paste backfill mix with 3 wt.% of cement constitutes 42% of the total paste backfill operation cost. On the other hand, Fall and Benzaazoua (2003) stated that a paste backfill design with a binder of 5–9 wt.% comprises approximately 50–75% of the total paste backfill operation cost. It is evident that a higher binder content results in a higher total operation cost. Therefore, it is practically important to select an optimum binder type and dosage to provide the desired strength and stability so as to reduce operation costs. For this purpose, the utilisation of chemical agents (i.e. plasticisers, aqueous sodium silicate, sodium hydroxide) or pozzolanic minerals (i.e. blast furnace slag, silica fume, fly ash, pumice) as additives to ordinary Portland cement (OPC) has been shown to mitigate the binder cost as well as improve the stability performance of CPB (Benzaazoua et al. 2004; Klein and Simon 2006; Tariq and Nehdi 2007; Ercikdi et al. 2009c, 2010a, b, 2015; Fall et al. 2010; Cihangir 2011; Cihangir et al. 2011, 2012, 2015).

4 Factors That Affect Strength and Stability of Paste Backfill

Many factors affect the short- and long-term strength and stability of paste backfill. They can be mainly classified as intrinsic and extrinsic factors (Table 2.3). Intrinsic factors include all of the parameters related to the physical, chemical and mineralogical properties of the three main components of paste backfill (the tailings, binder and mixing water) as well as its mixing properties (e.g. water-to-cement ratio) (Brackebusch 1994; Landriault 1995; Amaratunga and Yaschyshyn 1997; Ouellet et al. 1998; Bernier et al. 1999; Belem et al. 2000; Benzaazoua et al. 2002, 2004; Cihangir 2011). Extrinsic factors are related to all phenomena that occur on a stope filled with paste backfill and its interaction with the adjacent rock: for example, the effect of the interface of the paste fill–rock wall, consolidation due to pressure changes, ground vibration due to production blasting that could generate crack formation in the fill mass, drainage and cracks in the rock which may have an effect on the amount of water within the paste fill. Another extrinsic factor that could affect CPB properties is the in situ curing temperature, which can vary greatly with depth, the type of rock that surrounds the backfill mass, geographical location of the mine, mine ventilation, blasting operations, etc. (Benzaazoua et al. 1999; Aubertin et al. 2003; Henderson et al. 2005; Fall and Samb 2009; Yilmaz et al. 2006, 2008a, b, 2009; Ercikdi et al. 2008, 2009a).

Table 2.3 Factors that affect strength and stability of paste backfill

Intrinsic factors	Extrinsic factors
Tailings properties	*In situ conditions*
• Particle size distribution	• Curing conditions (temperature)
• Particle shape	• Self-weight consolidation
• Specific gravity	• Drainage conditions
• Mineralogy	• Stope size/geometry
Binder properties	• Groundwater conditions
• Binder type and dosage	• Paste fill–rock wall interface
• Mineral admixture usage	• Blast-induced ground vibrations
• Chemical admixture usage	• Backfill placement type (continuous or gradual)
Mixing water properties	• Stability of backfill barricade
• SO_4^{2-} content (mg/lt)	• Arching effect and fill mass shrinkage
• pH	• Confining pressure
Mixing properties	
• Water/cement ratio	
• Solid ratio (%)	

4.1 Intrinsic Factors

4.1.1 Particle Size Distribution

One of the most important characteristics of a fill material is the particle size distribution. In general, as the fines content increases in a fill, it becomes more difficult for water to flow through the fill. The amount of fines present is very important in the transportation of slurry fills through pipes. The fines help to float the coarse grains in the slurry and provide a non-settling slurry flow within the network of pipes. This is especially important in paste fill applications; there is a certain amount of fines that should be present for the cohesion of the paste fill during transportation through the pipelines (Kuganathan 2005). Generally, the tailings material used in a paste backfill mixture must contain 15 wt.% of particles with size finer than 20 μm in order to retain sufficient water and hence form a paste (Landriault 1995). Mill tailings used in paste backfill mixtures are categorised as coarse, medium and fine depending on the amount of −20 μm fractions in the tailings (Landriault 2001) (Table 2.4).

Modification of the particle size distribution of the tailings material will improve the performance of the paste backfill. For many years, hydrocyclones have been extensively utilised to produce several grain size classes that correspond to fine, medium and coarse tailings by selecting the proper size of hydrocyclones and level of operating variables. However, there is no consensus in the current literature on the optimum size distribution requirements or measurements for backfill materials. This is because different mineralogical contents and variability of tailings on the cement quality need to be taken into consideration as well as variations in delivery systems (e.g. unlined boreholes that allow groundwater to flow into the paste mixture). As shown in Fig. 2.8, a fill material is well graded if its constituent particles demonstrate a wide range of sizes, and poorly graded or uniform if there is a narrow range of sizes. Landriault (2001) suggested that fine particles in a well-graded backfill may fill the voids between larger particles. This reduces the volume occupied by the cement gel (binder) and possibly leads to the formation of stronger bonds as illustrated in Fig. 2.9.

Indices such as the “coefficient of uniformity (C_u)” and “coefficient of curvature (C_c)” are generally used to characterise and quantify the particle size distribution of backfill materials (Eqs. (2.1) and (2.2)). It has been reported that a high proportion of fines leads to a more uniform particle size distribution of the tailings (Kesimal et al. 2003; Fall et al. 2005, Kuganathan 2005; Ercikdi et al. 2013). Kesimal et al.

Table 2.4 Size distribution categories of paste backfill (Landriault 2001)

Tailings type	Finer than 20 μm content (wt.%)	7 in. slump solid content (wt.%)	Explanation (depending on water-to-cement ratio
Coarse	15–35	78–85	High strength acquisition
Medium	35–60	70–78	Lower strength acquisition
Fine	60–90	55–70	Poor strength acquisition

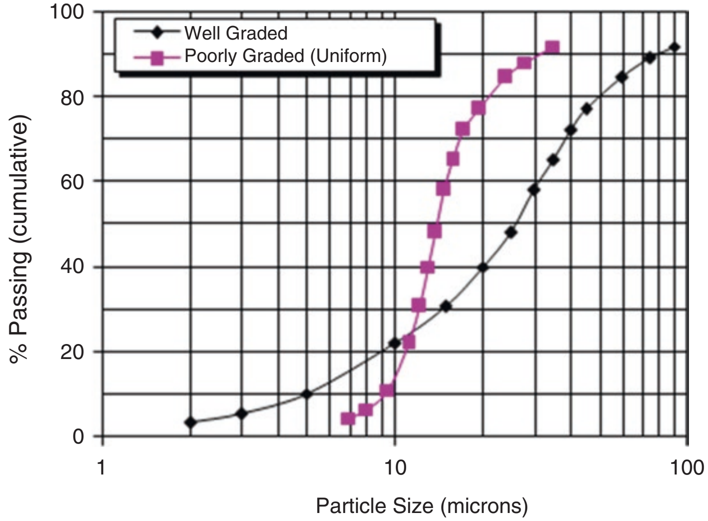


Fig. 2.8 Typical particle size distribution curves for poorly and well-graded backfill materials

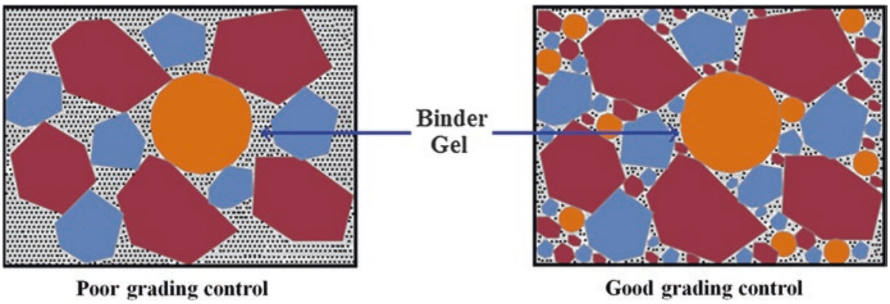


Fig. 2.9 A model of the benefits of fine particles in fill material (modified after Landriault 2001)

(2010) investigated the development of the strength of paste backfill as a function of C_u (D_{60}/D_{10}) for three types of tailings. They noted that paste backfill samples have the highest strength with a C_u of approximately between 4 and 6 (Table 2.5):

$$\left(\text{Coefficient of Uniformity}\right) \quad C_U = \frac{D_{60}}{D_{10}}, \tag{2.1}$$

$$\left(\text{Coefficient of Curvature}\right) \quad C_C = \frac{\left(D_{30}\right)^2}{\left(D_{10}\right)\times\left(D_{60}\right)} \tag{2.2}$$

where D_{10} = grain size at 10% passing, D_{30} = grain size at 30% passing and D_{60} = grain size at 60% passing.

Table 2.5 Evaluation of the mechanical strength (UCS) of paste backfill as function of the coefficient of uniformity C_u (D_{60}/D_{10}) (Kesimal et al. 2010)

Tailings type	Coefficient of uniformity (Cu)	UCS (kPa)		Binder type	Binder dosage (wt.%)	Slump inch
		14 day	28 day			
Tailings T1	13.57	886	954	CEM II 42.5 R	6	7.5
	4.72	1117	1321			
Tailings T2	13.33	377	408			
	3.62	780	817			
Tailings T3	11.36	781	815			
	5.56	1030	1258			

The removal of slimes (i.e. desliming) induces changes in the physical, chemical, mineralogical and flowability properties of tailings (Ercikdi et al. 2013). Figure 2.10 shows a typical particle size distribution of sulphide-rich reference (as-received) and deslimed mill tailings. The details on the physical and chemical characterisation of these tailings are also provided in Table 2.6. The reference tailings samples, SP and BN, which have a similar particle size distribution, contain 49.7 and 51.0 wt.% fines (−20 μm), respectively (Fig. 2.10). After desliming, the fines (−20 μm) content of the SP and BN tailings materials appears to decrease to 27.7 and 16.0 wt.%. These values suggest that the as-received and deslimed tailings can be classified as a medium and coarse size tailings material in accordance with the work by Landriault (2001), respectively. The C_u values for SP and BN are 13.57 and 13.33, respectively, with corresponding values of 4.72 and 3.62 for the deslimed tailings (Table 2.6). Similarly, the C_c is 1.12 and 0.96 for SP and BN, and 1.22 and 1.08 for the deslimed SP and BN tailings, respectively.

The specific gravity of the tailings, which is determined by using a pycnometer, tends to increase with reduced fines content as the sulphide content increases after the removal of the slimes (Table 2.6). However, a reduction in the fines content also reduces the specific surface area of the tailings. The finer particles increase the specific surface of tailings which is the surface area that must be cemented and wetted.

There are many studies in the literature on the effect of the particle size distribution of tailings on the strength and stability of paste backfill. Kesimal et al. (2003) investigated the effect of the fines (−20 μm) content of mill tailings on the short-term strength of paste backfill. They showed that reducing the fines content via desliming has a positive effect on the strength of their paste backfill samples with the highest strength obtained in the tailings that contain 25% fines (Fig. 2.11a). Kesimal et al. (2002) also reported that deslimed tailings are 12–52% higher in strength than as-received tailings. Fall et al. (2005) investigated the effect of tailings fineness on the short-term strength development of paste backfill produced from the tailings of a gold mining plant. They observed that the strength of the paste backfill samples peaks with a fines content of 25–30 wt.% which was interpreted as the optimum fines content (−20 μm) for the design of paste backfill (Fig. 2.11b). Similarly, Ercikdi et al. (2013) indicated that paste backfill samples prepared from

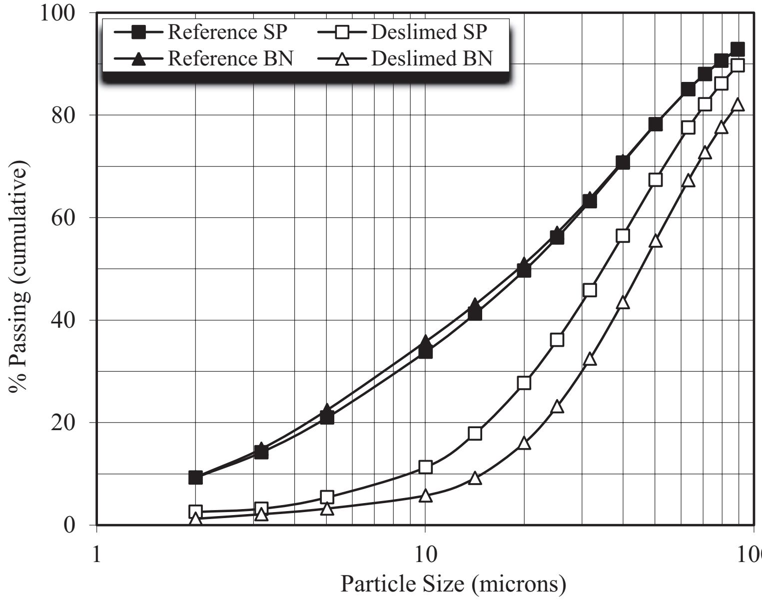


Fig. 2.10 Typical particle size distribution of reference and deslimed tailings

coarse tailings (16–27.7 wt.% finer than −20 μm) result in remarkably higher long-term strength (1.4–4.3-fold) than those prepared from medium tailings (49.7–51 wt.% finer than −20 μm) (Fig. 2.12). They also stated that desliming could allow for a reduction of 13.4–23.1% in binder consumption depending on the inherent characteristics of the tailings. These studies confirm that desliming can be used to improve the strength and stability of paste backfill and reduce binder consumption.

Changes in the tailings properties (e.g. particle size distribution or sulphide content) induced by desliming can affect the flowability properties of paste backfill. It is well known that fine tailings require more water than coarse tailings to reach the targeted consistency, which in turn yield a higher moisture level and lower solids content (Kesimal et al. 2003; Fall et al. 2005). On the other hand, paste backfill samples produced with coarse tailings release more water (by drainage) than those produced with medium or fine tailings. The loss of water through drainage may lead to the settling of the solids (increase in the packing density) and the consequent reduction of the total porosity and void ratio of the backfill material. Ercikdi et al. (2013) performed water separation tests to assess the flowability properties of uncemented as-received and deslimed sulphide-rich mill tailings. They observed that the water retention capacity of the as-received tailings is 7–12 times higher than that of the deslimed tailings over 6 h (Fig. 2.13). In general, as the fines content is reduced in a fill, the settling rate of the tailings increases. The relatively high amount of water separation from the deslimed tailings could lead to settling or segregation problems in a paste plant mixer or pipeline during the transporting of the CPB mixture into underground openings.

Table 2.6 Example of physical and chemical properties of sulphide-rich reference and deslimed mill tailings (Ercikdi et al. 2013)

Characteristic	SP tailings		BN tailings	
	Reference (%)	Deslimed (%)	Reference (%)	Deslimed (%)
Chemical composition				
SiO_2	13.96	11.12	13.16	10.43
Al_2O_3	3.85	2.22	4.81	2.46
Fe_2O_3	46.83	49.47	48.41	53.93
MgO	2.31	1.90	1.13	0.91
CaO	2.05	1.58	1.83	1.28
Na_2O	0.22	0.18	0.19	0.18
K_2O	0.14	0.08	0.64	0.23
TiO_2	0.07	0.06	0.08	0.07
P_2O_5	0.02	0.02	0.02	0.02
MnO	0.08	0.07	0.06	0.05
Cr_2O_3	0.011	0.006	0.012	<0.002
$BaSO_4$	0.84	1.16	2.54	2.02
Loss on ignition (LOI)	27.4	27.6	26.9	28.2
Total	97.78	95.47	99.78	99.78
Sulphide content (S^{-2}) (%)	34.7	39.2	37.4	42.2
Pyrite content (FeS_2) (%)	65.0	73.5	70.1	79.2
Physical property				
Specific gravity	4.12	4.16	4.09	4.32
Specific surface area (cm^2/g)	3594	2432	3662	1956
Coefficient of curvature ($C_c=(D_{30})^2/(D_{10} \times D_{60})$)	1.12	1.22	0.96	1.08
Coefficient of uniformity ($C_u=(D_{60}/D_{10})$)	13.57	4.72	13.33	3.62

The particle size distribution of tailings is also critically important to the microstructure (e.g. total porosity, void ratio) of paste backfill. It has been reported that the overall porosity of backfill tends to decrease with increases in the fines content of the tailings (Kesimal et al. 2003; Fall et al. 2004; Ercikdi et al. 2013; Cihangir et al. 2014). The microstructure of the paste material is strongly influenced by the drainage ability of the fresh backfill. The drained paste backfill samples show both less porosity and smaller void ratios. Fall et al. (2005) reported that the packing density of the tailings decreases when the proportion of fine tailings is less than 45%. A lower packing density is linked to a higher volume of void spaces between the tailings particles that are available for the development of cement hydration products. Indeed, coarse tailings particles mean less particle-to-particle contact per unit volume, and thus, there are larger pores between the particles. Particle size distribution also determines the permeability of paste fill. A higher fines content means lower permeability. As can be observed in Fig. 2.14, the paste backfill samples made of coarse tailings have a higher permeability for a given consistency (Fall et al. 2009).

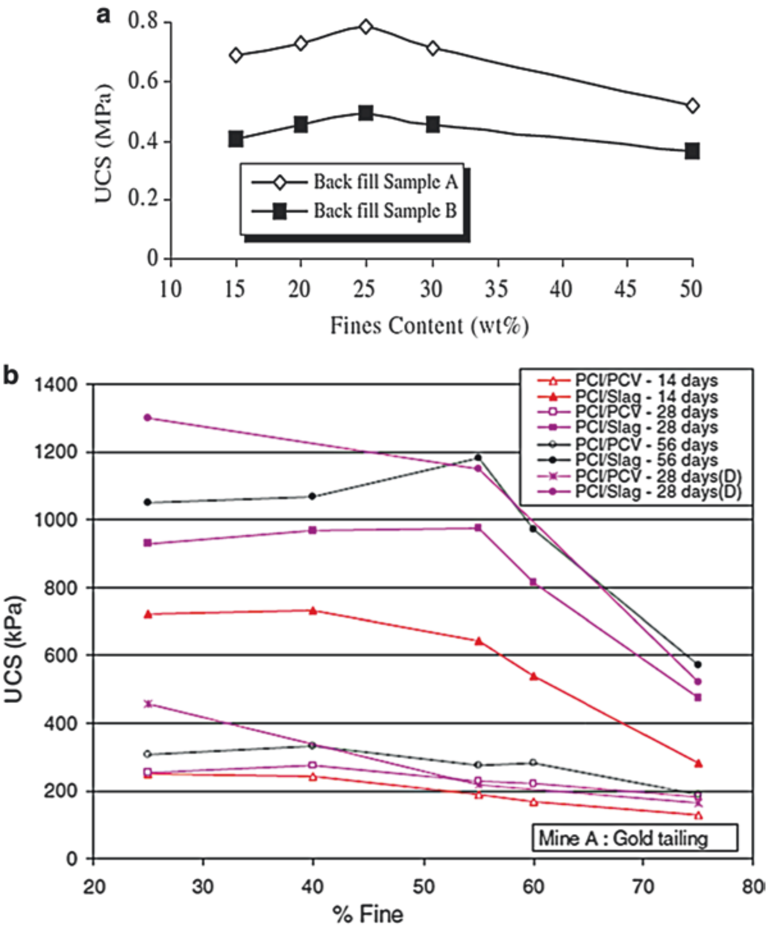


Fig. 2.11 Effect of fines content on strength development of paste backfill: (**a**) Kesimal et al. 2003; (**b**) Fall et al. 2005

4.1.2 Particle Shape and Specific Gravity

The particle shape and specific gravity of tailings material can affect the paste backfill performance. Due to the blasting, crushing and grinding process, most tailings particles are very angular in shape and rough in texture. Henderson and Revell (2005) indicated that mineral particles that are flat in shape will generally settle more slowly than particles that are round with equal specific gravity, thus affecting the thickening and consolidation, and drainage time in the case of fill. For example, mica minerals are characterised by their platy geometry and smooth surface, both of which reduce the strength of fill when cement is used. In addition, the smooth surface of mica makes it difficult for cement to develop high strength aggregation of particles (Revell 2004). Particle shape can also affect the size of voids and path connections to hold and transport fluids (Fig. 2.15).

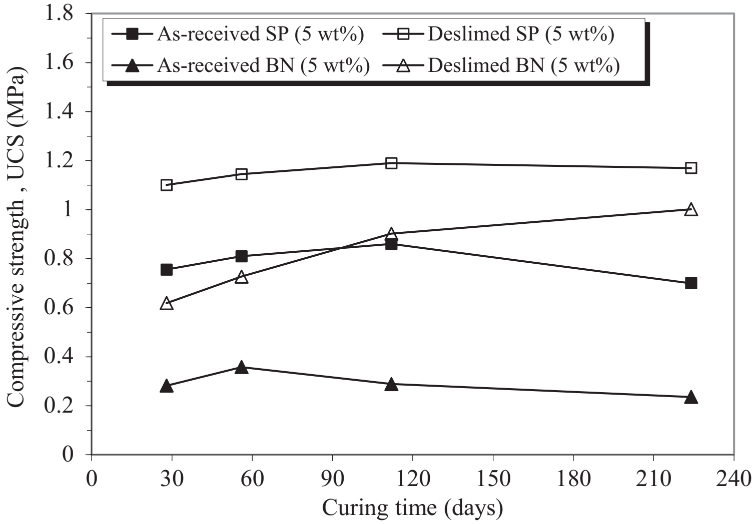


Fig. 2.12 Long-term strength development of paste backfill samples produced from reference and deslimed tailings (Ercikdi et al. 2013)

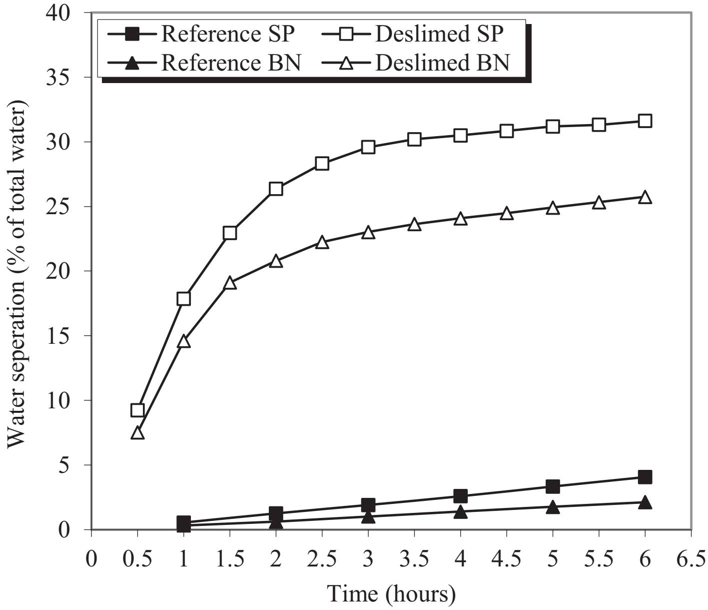


Fig. 2.13 Time-dependent separation of water from reference and deslimed tailings (Ercikdi et al. 2013)

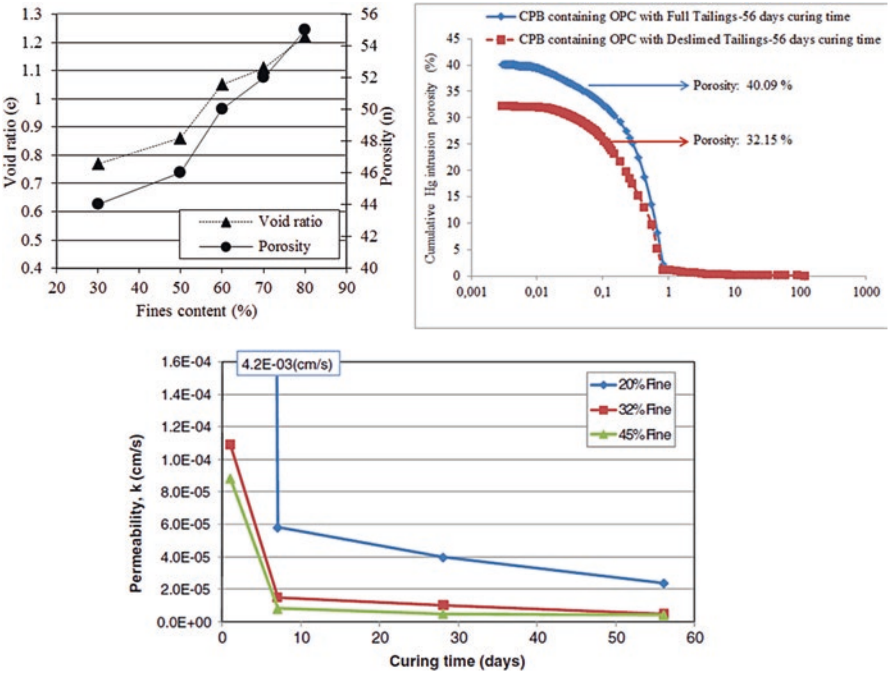
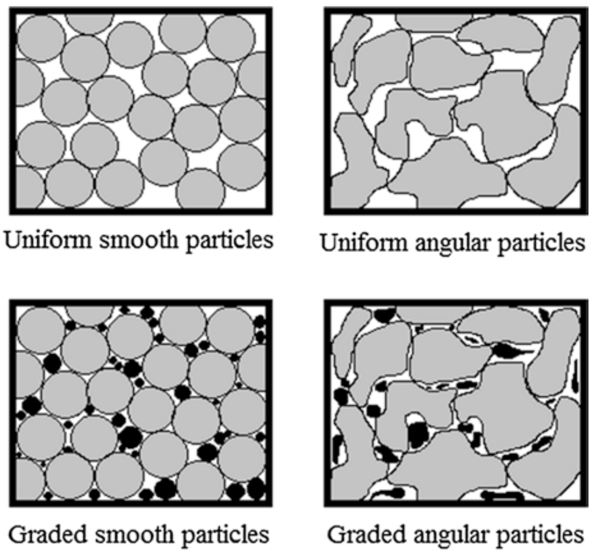


Fig. 2.14 Effect of fines content on microstructure and permeability of paste backfill (Fall et al. 2004, 2009; Kesimal et al. 2015)

Fig. 2.15 Effect of particle shape on interconnection of tailings in backfill (modified after Hassani and Archibald 1998)



There is a linear relationship between paste backfill strength and the specific gravity of tailings material. Binder is generally added into a paste fill mixture based on the solids content (tailings plus binder on a dry basis). Therefore, tailings with a high specific gravity require more binder (in volume). However, an increased binder content will add to the operating cost of using paste backfill.

4.1.3 Mineralogy

The mineralogy of tailings influences a number of other paste backfill characteristics, such as water retention, strength, settling characteristics and abrasive action. Clay minerals, mica and sericite have been identified to contribute to water retention in paste fill (Henderson and Revell 2005; Kesimal et al. 2005; Ercikdi et al. 2013). Silicate minerals (particularly quartz) can be very abrasive and result in a high wear rate of a pipeline system. Similarly, sulphide minerals (e.g. pyrite) found in tailings may adversely affect the strength and stability of paste backfill. Sulphide reactivity is dependent on the sulphide type. Hassani and Archibald (1998) listed the order of sulphide mineral reactivity as pyrrhotite > arsenopyrite > pyrite > chalcopyrite > sphalerite > galena > chalcocite. Increased specific surface area, oxygen availability and temperature increase the rate of sulphide oxidation (Hassani and Archibald 1998). Pyrite is prone to oxidation when cured in the presence of air and moisture with the concomitant formation of acid and sulphate (Eq. (2.3)):

$$4FeS_2 + 15O_2 + 8H_2O \rightarrow 2Fe_2O_3 + 8SO_4^{-2} + 16H^+ \tag{2.3}$$

The acid generated by the oxidation of sulphide tailings can attack and destroy the structure of the calcium silicate hydrate (C–S–H) bonds. Hence, there is a reduction in the binding properties with the eventual loss of the paste backfill stability as none of the hydration products are stable at pH < 9 (Benzaazoua et al. 1999; Hassani et al. 2001; Tariq and Nehdi 2007; Ercikdi et al. 2009b, c; Cihangir et al. 2011, 2012). Cihangir et al. (2012) monitored the generation of acidity (i.e. decrease in the pH) in CPB samples prepared with different binder dosages (5–7 wt.%) and found that an increase in the binder dosage mitigates the generation of free acidity. The benefits of increasing the binder dosage are an increase in the quantity of hydration products (calcium hydroxide (CH) and C–S–H) with a resultant increase in the binding component and buffering capacity of CPB samples towards acid attack. Moreover, an increase in the binder dosage could also increase the surface of the tailings which are fully covered by the cement hydration products with a resultant reduction in the tailings surface available for reaction/oxidation.

There are four primary internal sources of sulphate in paste backfill systems (Orejarena and Fall 2010). The most significant source of sulphate originates from the tailings (Kesimal et al. 2005) and, depending on the type of mineral extraction, it is common to find pyrite (FeS_2) as an important constituent of these tailings. Ercikdi et al. (2013) reported up to 80% pyrite in the tailings in their study, with concentrations of up to 24,000 ppm of sulphate in the processing waters. Fall and Benzaazoua (2005) reported that the presence of sulphate in the paste can be due to the presence of pre-oxidised tailings. Once the tailings are mixed with a binder, tailings oxidation is considered to be negligible due to the high degree of saturation of the paste backfill, which impedes oxygen diffusion through the paste. Another source of sulphate in paste backfill, apart from the sulphide-rich tailings, is the sulphur dioxide/air used for the destroying of cyanide in gold mining (Akcil 2003).

Sulphate can also be found in paste backfill mass based on the type of cement used for the mixture. It is known that gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$) is often added in the clinker to control the setting of cement and therefore small amounts of sulphate are introduced into the mixture. Finally, the water added to the mixture for hydration may contain free sulphate ions, either from the pre-oxidised tailings or processing water (Orejarena and Fall 2010). Sulphate that is present in the sulphate-rich water of tailings and that produced by the oxidation of pyrite (FeS_2) can react with free calcium ions produced by the dissolution of unstable portlandite ($Ca(OH)_2$) and calcium aluminate (C_3A), thus giving rise to the precipitation of secondary expansive gypsum ($CaSO_4.2H_2O$) and highly expansive ettringite ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) (Eqs. (2.4) and (2.5)). Gypsum and ettringite can expand 2.2 and 2.8 times in volume, respectively, and generate 70–200 MPa of internal stress due to the crystallisation pressure. The stresses generated by the expansion can produce cracking and loss of cohesion between components (Fig. 2.16), which could then culminate in reduced backfill strength and potential collapse of CPB (Ouellet et al. 1998; Benzaazoua et al. 1999; Hassani et al. 2001; Benzaazoua et. 2002; Kesimal et al. 2004, 2005; Fall and Benzaazoua 2005; Tariq and Nehdi 2007; Ercikdi et al. 2009b, c, 2013; Cihangir et al. 2012):

$$Ca(OH)_2 + SO_4^{-2} + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2OH \quad (2.4)$$

$$3CaO \cdot Al_2O_3 + 3CaSO_4 \cdot 2H_2O + 30H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \quad (2.5)$$

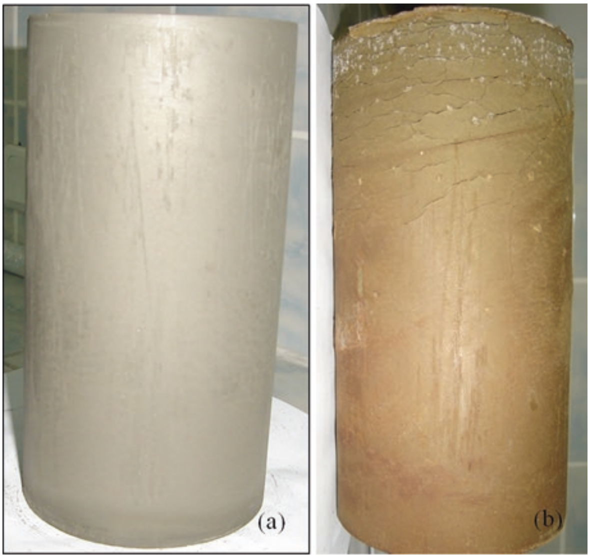


Fig. 2.16 Visual appearance of 28- (**a**) and 360-day (**b**) cured CPB samples. Crack formation due to long-term acid and sulphate attacks

The effect of sulphate on the strength of CPB depends on the sulphate concentration, curing time and cement composition and content (Fall and Benzaazoua 2005). Some studies have demonstrated that there is a reduction in the strength of CPB with time due to internal sulphate attack, which results from the chemical interactions of the sulphate ions with Portland cement hydration products (Hassani et al. 2001, Benzaazoua et al. 2002; Kesimal et al. 2004; Fall and Benzaazoua 2005; Tarig and Nehdi 2007; Cihangir et al. 2012, Ercikdi et al. 2013). These reactions typically form secondary ettringite, gypsum and monosulphoaluminate, which are highly expansive products that generate high internal pressure, thereby deteriorating the strength of the CPB. Fall and Benzaazoua (2005) also found that the early strength of CPB (at less than 28 days) is enhanced with sulphate concentrations less than 2000 ppm due to the precipitation of secondary hydration products (e.g. gypsum, ettringite and brucite). These precipitates fill the void spaces within the CPB, thus contributing to an increase in strength.

4.1.4 New Developments for Characterisation of Paste Backfill Performance

The strength of paste backfill at any given time is one of the most important parameters since the paste backfill structure must remain stable during the extraction of adjacent stopes to ensure the safety of mine workers and avoid ore dilution. UCS testing is often used in practice to evaluate the paste backfill quality since this test is relatively inexpensive and can be incorporated into routine quality control programmes at a mine site. Recently, ultrasonic pulse velocity (UPV) testing has been applied as a non-destructive, low-cost, less time-consuming and easy method in both the field and laboratory, and has been suggested for use in the assessment of the strength properties of paste backfill instead of the conventional compressive strength testing (Yilmaz 2013; Ercikdi et al. 2014; Yilmaz et al. 2014; Yilmaz and Ercikdi 2016). UPV testing applies the principle of measuring the travel velocity of ultrasonic pulses through a material medium. UPV is measured on paste backfill samples by using a portable ultrasonic non-destructive digital indicating tester (PUNDIT) that measures the time of propagation of ultrasound pulses with a precision of 0.1 μs. The 54 kHz transducers of PUNDIT are 42 mm in diameter (Fig. 2.17). The length of the measuring base is determined within an accuracy of 0.1 mm. The end surfaces of CPB samples are polished to provide a good coupling between the transducer face and the sample surface to maximise the accuracy of the transit time measurement.

A thin film of Vaseline® is applied to the surface of the transducers (transmitter and receiver) in order to ensure full contact and eliminate the air pocket between the transducers and the test medium. The direct transmission technique, which is the most satisfactory and reliable method, is used in the testing in which the transmitter and receiver are positioned onto opposite end surfaces of the specimens tested. Repeated readings at a particular location are taken and the minimum transit time is taken as the experimental result. After the measurements, the velocity of the *P*-wave,

Fig. 2.17 Ultrasonic pulse velocity testing on paste backfill samples

Table 2.7 Relationship between UCS and UPV of paste backfill samples (Ercikdi et al. 2014)

Strength (MPa) (10 × 20)	UPV (m/s) (10 × 20–5 × 10)	
	Tailings T1	Tailings T2
UCS < 0.5	<1450	<1370
0.5 < UCS < 1.0	1450–1690	1370–1600
UCS > 1.0	>1690	>1600

i.e. the UPV, is calculated from the measured travel time and the distance between the transmitter and receiver, as follows (Eq. (2.6)):

$$UPV\left(x,t\right) = x / t \tag{2.6}$$

where UPV (*x,t*) is the velocity of the *P*-wave in CPB, *x* is the distance between the transmitter and receiver and *t* is the travel time.

Ercikdi et al. (2014) conducted UPV tests on paste backfill samples with a diameter x height of 5 × 10 cm and 10 × 20 cm and found a linear relation with a high correlation coefficient between the UCS and UPV of the samples. They also indicated that the strength of large paste backfill samples (10 × 20) can be determined by measuring the UPV in large or small samples over curing time, which can considerably reduce the number of paste backfill samples required and tailings material used (Table 2.7). Furthermore, UPV testing allows the strength of paste backfill in underground environments to be quickly determined.

References

Akcil A (2003) Destruction of cyanide in gold mill effluents: biological versus chemical treatments. Biotechnol Adv 21:501–511

Amaratunga LM, Yaschyshyn DN (1997) Development of a high modulus paste fill using fine gold mill tailings. Geotech Geol Eng 15(3):205–219

Aubertin M, Li L, Arnoldi S, Belem T, Bussiere B, Benzaazoua M, Simon R (2003) Interaction between backfill and rock mass in narrow stopes. In: Soil and rock America mechanics symposium, Essen, Germany, p 1157–1164
Azam S, Li Q (2010) Tailings dam failures: a review of the last one hundred years. Waste Geotech 28:50–53
Been K, Brown ET, Hepworth N (2002) Liquefaction potential of paste fill at Neves Corvo Mine, Portugal. IMM Transact Sect A 111(1):47–58
Belem T, Benzaazoua M (2008) Design and application of underground mine paste backfill technology. Geotech Geol Eng 26:147–174
Belem T, Benzaazoua M, Bussiere B (2000) Mechanical behaviour of cemented paste backfill. In: Proceedings of 53th Canadian geotechnical conference, Montreal, p 373–380
Benzaazoua M, Ouellet J, Servant S, Newman P, Verburg R (1999) Cementitious backfill with high sulfur content: physical, chemical, and mineralogical characterization. Cem Concr Res 29(5):719–725
Benzaazoua M, Belem T, Bussiere B (2002) Chemical factors that influence the performance of mine sulphidic paste backfill. Cem Concr Res 32(7):1133–1144
Benzaazoua M, Fall M, Belem T (2004) A contributing to understanding the hardening process of cemented pastefill. Miner Eng 17(2):141–152
Bernier RL, Lee MG, Moerman A (1999) Effects of tailings and binder geochemistry on the physical strength of paste backfill. In: Proceedings of Sudbury '99, Mining and the environment II, Sudbury, Canada, p 1113–1122
Brackebusch FW (1994) Basics of paste backfill systems. Miner Eng 46(10):1175–1178
Cetiner EG, Unver B, Hindistan MA (2006) Regulations related with mining wastes: European community and turkey. J Mining 45(1):23–34 (in Turkish)
Chambers DM, Higman B (2011) Long term risks of tailings dam failure. Center for Science in Public Participation. Report, 34p
Cihangir F (2011) Investigation of utilisation of alkali activated blast furnace slag as binder in paste backfill. Ph.D. Thesis, Karadeniz Technical University, The Graduate School of Natural and Applied Sciences, Trabzon, Turkey, 207p (in Turkish)
Cihangir F, Ercikdi B, Turan A, Kesimal A, Deveci H, Yazıcı M, Karaoğlu K (2011) Utilisation of sodium silicate activated blast furnace slag as an alternative binder in paste backfill of high-sulphide mill tailings. In: Proceedings of the 14th international seminar on paste and thickened tailings, Perth, Australia, p 465–475
Cihangir F, Ercikdi B, Kesimal A, Turan A, Deveci H (2012) Utilisation of alkali-activated blast furnace slag in paste backfill of high-sulphide mill tailings: effect of binder type and dosage. Miner Eng 30:33–43
Cihangir F, Ercikdi B, Kesimal A, Deveci H, Akyol Y, Ocak S, Kurtuluş M (2014) The effect of binder type on porous structure development of paste backfill. In: Proceedings of the XIth regional rock mechanics symposium, Afyon, Turkey, p 205–212 (in Turkish)
Cihangir F, Ercikdi B, Kesimal A, Deveci H, Erdemir F (2015) Paste backfill of high-sulphide mill tailings using alkali-activated blast furnace slag: effect of activator nature, concentration and slag properties. Miner Eng 83(117–127):2015
Clark CC, Vickery JD, Backer RR (1995) Transport of total tailings paste backfill: results of full-scale pipe test loop pumping tests, USBM, RI 9573, USA
Clayton S, Grice T, Boger DV (2003) Analysis of the slump test for on-site yield stress measurement of mineral suspensions. Int J Miner Process 70(1–4):3–21
Cooke R (2007) Backfill pipeline distribution systems-design methodology review. In: 9th international symposium on mining with backfill, Minefill 2007, Montreal, Canada, 9p
De Souza E, Archibald JF, Dirige APE (2003) Economics and perspectives of underground backfill practices in Canadian mining. In: 105th annual general meeting of the Canadian institute of mining, Metallurgy and Petroleum, Montreal, Canada, 15p
Ercikdi B, Cihangir F, Kesimal A, Deveci H, Alp I (2008) Effect of drainage conditions on the strength of paste backfill. J Mining 47(2):15–24 (in Turkish)
Ercikdi B, Kesimal A, Cihangir F, Deveci H, Alp İ, Yazıcı M, Şahin B (2009a) An environmentally friendly technology: paste backfill—a case study in Cayeli copper mine 3. In: Mining and environment symposium, Ankara, p 139–152 (in Turkish)

Ercikdi B, Cihangir F, Kesimal A, Deveci H, Alp İ (2009b) Utilization of industrial waste products as pozzolanic material in cemented paste backfill of high sulphide mill tailings. J Hazard Mater 168(2–3):848–856
Ercikdi B, Kesimal A, Cihangir F, Deveci H, Alp İ (2009c) Cemented paste backfill of sulphide-rich tailings: importance of binder type and dosage. Cement Concrete Comp 31(4):268–274
Ercikdi B, Cihangir F, Kesimal A, Deveci H, Alp İ (2010a) Effect of natural pozzolans as mineral admixture on the performance of cemented paste backfill of sulphide-rich tailings. Waste Manag Res 28:430–435
Ercikdi B, Cihangir F, Kesimal A, Deveci H, Alp İ (2010b) Utilization of water-reducing admixtures in cemented paste backfill of sulphide-rich mill tailings. J Hazard Mater 179:940–946
Ercikdi B, Cihangir F, Kesimal A, Deveci H (2012) Waste management method for mill tailings: paste backfill technology. Mining Turkey 24:70–75 (in Turkish)
Ercikdi B, Baki H, İzki M (2013) Effect of desliming of sulphide-rich mill tailings on the long-term strength of cemented paste backfill. J Environ Manage 115:5–13
Ercikdi B, Yılmaz T, Külekçi G (2014) Strength and ultrasonic properties of cemented paste backfill. Ultrasonics 54:195–204
Ercikdi B, Külekci G, Yılmaz T (2015) Utilization of granulated marble wastes and waste bricks as mineral admixture in cemented paste backfill of sulphide-rich tailings. Construct Build Mater 93:573–583
Fall M, Benzaazoua M (2003) Advances in predicting performance properties and cost of paste backfill. In: Proceedings on tailings and mine waste'03, Vail, USA, p 73–85
Fall M, Benzaazoua M (2005) Modelling the effect of sulphate on strength development of paste backfill and binder mixture optimization. Cem Concr Res 35(2):301–314
Fall M, Samb SS (2009) Effect of high temperature on strength and microstructural properties of cemented paste backfill. Fire Safety J 44:642–651
Fall M, Benzaazoua M, Ouellet S (2004) Effect of tailings properties on paste backfill performance. In: The 8th international symposium on mining with backfill, Beijing, China, p 193–202
Fall M, Benzaazoua M, Ouellet S (2005) Experimental characterization of the effect of tailings fineness and density on the quality of cemented paste backfill. Miner Eng 18(1):41–44
Fall M, Adrien D, Jelestin JC, Pokharel M, Toure M (2009) Saturated hydraulic conductivity of cemented paste backfill. Miner Eng 22(15):1307–1317
Fall M, Celestin JC, Pokharel M, Toure M (2010) A contribution to understanding the effects of curing temperature on the mechanical properties of mine cemented tailings backfill. Eng Geol 114:397–413
Fourie A, Dunn F (2007) Limitations to the use of the modified slump test for yield stress determination. In: Proceedings of the tenth international seminar on paste and thickened tailings, Paste 2007, Perth, Australia, p 219–228
Golder Associates (2012) Golder associates paste engineering and design services. http://www.golder.com/modules.php?name=Services&sp_id=1221 (23 May 2012)
Grabinsky MW, Theriault J, Welch D (2002) An overview of paste and thickened tailings disposal on surface. In: Proceedings of the symposium sur l'environnement et les mines: Defis et perspectives. Rouyn-Noranda, Canada, 8 p
Grice T (1998) Underground mining with backfill. In: The second annual summit on mine tailings disposal systems, Brisbane, Australia, p 5–15
Hassani F, Archibald J (1998) Mine backfill. In: Canadian Institute of Mine, Metallurgy and Petroleum, Published on CD-ROM Proceedings, Canada, 263p
Hassani F, Bois D (1992) Economic and technical feasibility for backfill design in Quebec underground mines. Final report 1/2, Canada-Quebec Mineral Development Agreement, Research & Development in Quebec Mines. Contract no. EADM 1989–1992, File no. 71226002
Hassani FP, Ouellet J, Hossein M (2001) Strength development in underground high sulphate paste backfill operation. CIM Bullet 94(1050):57–62
Henderson A, Revell MB (2005) Basic mine fill materials. In: Handbook on mine fill, Australian Centre for Geomechanics, 179p

Henderson A, Revell MB, Landriault D, Coxon J (2005) Paste fill. In: Handbook on mine fill. Australian Centre for Geomechanics, 179p

Huynh L, Beattie DA, Fornasiero D, Ralston J (2006) Effect of polyphosphate and naphthalene sulfonate formaldehyde condensate on the rheological properties of dewatered tailings and cemented paste backfill. Miner Eng 19:28–36

Kesimal A, Alp I, Yilmaz E, Ercikdi B (2002) Optimisation of test results obtained from different size slumps with varying cement contents for Cayeli Mine's clastic and spec ore tailings. Karadeniz Technical University, Revolving Fund Project, Turkey

Kesimal A, Ercikdi B, Yılmaz E (2003) The effect of desliming by sedimentation on paste backfill performance. Miner Eng 16(10):1009–1011

Kesimal A, Yılmaz E, Ercikdi B (2004) Evaluation of paste backfill test results obtained from different size slumps with varying cement contents for sulphure rich mill tailings. Cem Concr Res 34:1817–1822

Kesimal A, Yılmaz E, Erçıkdı B, Deveci H, Alp İ (2005) Effect of properties of tailings and binder on the short- and long-term strength and stability of cemented paste backfill. Mater Lett 59(28):3703–3709

Kesimal A, Cihangir F, Ercikdi B, Deveci H, Alp I (2010) Optimization of paste backfill performance for different ore types in cayeli copper mine. Karadeniz Technical University, Revolving Fond Project, Turkey

Kesimal A, Cihangir F, Ercikdi B, Deveci H, Ocak S, Akyol Y (2015) Utilization of alkali activated blast furnace slag cement as an alternative binder to cement in paste backfill of sulphide-rich mine tailings having different fineness and investigation of the performance properties. The Scientific and Technological Research Council of Turkey (TUBITAK Project No: 112 M378), 95p, Turkey (in Turkish)

Klein K, Simon D (2006) Effect of specimen composition on the strength development in cemented paste backfill. Canad Geotech J 43:310–324

Kuganathan K (2005) Rock fill in mine fill. In: Handbook on Mine Fill, Australian Centre for Geomechanics, 179p

Landriault D (1995) Paste backfill mix design for Canadian underground hard rock mining. In: Proceedings of the 97th annual general meeting of the CIM rock mechanics and strata control session, Nova Scotia, Canada, p 652–663

Landriault D (2001) Backfill in underground mining. In: Hustrulid WA (ed) Underground mining methods engineering fundamentals and international case studies. SME, New York, pp 608–609

Landriault D (2006) They said "It will never work"—25 years of paste backfill 1981–2006. In: Proceedings of 9th international seminar on paste and thickened tailings, Limerick, Ireland, p 277–292

Landriault D, Verburg R, Cincilla W, Welch D (1997) Paste technology for underground backfill and surface tailings disposal applications. CIM Bullet 54:112–120

Moghaddam AS, Hassani FP (2007) Yield stress measurement of cemented paste backfill with the vane method and slump tests. In: 9th international symposium on mining with backfill, Minefill 2007, Montreal, Canada, 8p

Nasir O, Fall M (2010) Coupling binder hydration, temperature and compressive strength development of underground cemented paste backfill at early ages. Tunnell Underground Spaces 25:9–20

Naylor J, Farmery RA, Tenbergen RA (1997) Paste backfill at the Macassa mine with flash paste production in a paste production and storage mechanism. In: Proceedings of the 29th annual meeting of the Canadian mineral processors, Canada, p 408–420

Nguyen QD, Boger DV (1998) Application of rheology to solving tailings disposal problems. Int J Miner Process 54:217–233

Orejarena L, Fall M (2010) The use of artificial neural networks to predict the effect of sulphate attack on the strength of cemented paste backfill. Bullet Eng Geol Environ 69:659–670

Ouellet J, Benzaazoua M, Servant S (1998) Mechanical, mineralogical and chemical characterization of a paste backfill. In: Proceedings of the 4th international conference on tailings and mine waste, Colorado, p 139–146

Revell M (2004) Paste-how strong is it? In: Proceedings of the 8th international symposium on backfill, Beijing, China, p 286–294

Rico M, Benito G, Salgueiro AR, Herrero AD, Pereira HG (2008) Reported tailings dam failures: a review of the European incidents in the worldwide context. J Hazard Mater 152:846–852

Roux LK, Bawden WF, Grabinsky MW (2004) Liquefaction analysis of early age cemented paste backfill. In: 8th international symposia on mining with backfill, Beijing, China, p 233–241

Simon D (2005) Microscale analysis of cemented paste backfill. Ph.D. Thesis. Graduate Department of Civil Engineering, University of Toronto, 208p

Tariq A, Nehdi M (2007) Developing durable paste backfill from sulphidic tailings. Waste Res Manage 160(4):155–166

WISE Uranium Project (2016) Chronology of Major Tailings Dam Failures. http://www.wise-uranium.org/mdaf.html (03 March 2012)

Yilmaz E, Belem T, Bussiere B, Benzaazoua M (2008a) Consolidation characteristics of early age cemented paste backfill. In: Proceedings of the 61st Canadian geotechnical conference and the 9th joint CGS/IAH-CNC groundwater conference, Edmonton, Canada, p 797–804

Yilmaz T (2013) Effect of sample size on the strength and ultrasonic pulse velocity of paste backfill, M.Sc. Thesis. Karadeniz Technical University, The Graduate School of Natural and Applied Sciences, 93p (in Turkish)

Yilmaz T, Ercikdi B (2016) Predicting the uniaxial compressive strength of cemented paste backfill from ultrasonic pulse velocity test. Nondestructive Testing and Evaluation, doi:10.1080/10589759.2015.1111891

Yilmaz E, El Aatar O, Belem T, Benzaazoua M, Bussiere B (2006) Effect of consolidation on the performance of cemented paste backfill, Underground Support'06, Quebec, Canada, p 1–14

Yilmaz E, Belem T, Benzaazoua M, Bussiere B (2008b) Experimental characterization of the influence of curing under stress on the hydromechanical and geotechnical properties of cemented paste backfill. In: Proceedings of the 15th international conference on tailings and mine waste, Colorado, p 139–152

Yilmaz E, Benzaazoua M, Belem T, Bussiere B (2009) Effect of curing under pressure on compressive strength development of cemented paste backfill. Miner Eng 22(9–10):772–785

Yilmaz T, Ercikdi B, Karaman K, Külekçi G (2014) Assessment of strength properties of cemented paste backfill by ultrasonic pulse velocity test. Ultrasonics 54:1386–1394

Yumlu M (2010) Mining with paste fill. AusIMM Cobar Mining Seminar, 26p

http://www.springer.com/978-3-319-39680-4

Paste Tailings Management
Yilmaz, E.; Fall, M. (Eds.)
2017, VII, 303 p. 190 illus., 162 illus. in color.,
Hardcover
ISBN: 978-3-319-39680-4