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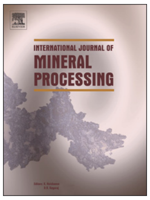

Utilization of sulphidic tailings from gold mine as a raw material in geopolymerization

Jenni Kiventerä [a,*], Lukasz Golek [b], Juho Yliniemi [a], Victor Ferreira [c], Jan Deja [b], Mirja Illikainen [a]

[a] University of Oulu, Fiber and Particle Engineering, P.O. Box 4300, FIN-90014 University of Oulu, Oulu, Finland
[b] Faculty of Materials Science and Ceramics/Wimic, AGH University of Science and Technology, 30-059 Krakow, Poland
[c] Dept. Civil Engineering/CICECO, University of Aveiro, 3810-193, Aveiro, Portugal

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ABSTRACT

The mining industry produces a large quantity of sulphidic mine tailings, which cause several environmental issues during waste management. Currently, there is increasing interest in new technologies to recycle and utilize mine tailings more effectively in the future. In this present study, the geopolymerization of mine tailings has been studied. Sulphidic mine tailings from a gold mining site were activated with a NaOH solution and commercial ground granulated blast furnace slag (GGBFS) was used as a co-binder. Characterization of the mine tailings and the mechanical strength of the specimens produced were investigated. In addition, the effects of different NaOH concentrations and the amount of co-binder materials on a matrix were tested. The porosity of the specimens produced was evaluated using water absorption tests, the microstructure of the fractures was analyzed with field emission scanning electron microscope (FESEM), and the crystalline phases were identified by X-ray diffraction. The results show that the unconfined compressive strength (UCS) of the specimens produced from pure mine tailings was in the range of 1.3–3.5 MPa. The UCS increased and water permeability decreased with 5% GGBFS content in the mixture. By optimizing the NaOH concentration and GGBFS content, the UCS of the specimens varied from 1.8 MPa to 25 MPa. The alkali-activation of mine tailings allows binders to be made with sufficient compressive strength, which can be used as a backfill in mining sites or raw material in the construction industry.

1. Introduction

Every year the mining industry produces a significant quantity of mine tailings mainly in the form of solid waste material. Mine tailings are the leftover from the ore beneficiation process which are stored as slurry in impounding lakes. Such storage facilities require expensive and careful maintenance, specific constructions, and a huge surface area. Some of the mine tailings, including the sulphidic rich tailings, cause both short- and long-term environmental problems such as air pollution and contamination of surface and ground water (Ahmari and Zhang, 2013). Thus, proper management techniques should be carefully designed taking into account the most cost-effective and short- and long-term sustainable storage facilities as well as the reuse potential of mining waste (Mohamed et al., 2002).

Many metals (such as Cu, Pb, Au, and Zn) are mined from sulphidic rich ore deposits. The majority of the minerals in sulphidic tailings are iron sulfides such as pyrite (FeS_2), arsenopyrite (FeAsS) and pyrrhotite ($Fe_{1-x}S$). However, raw mine tailings often also contain other toxic metals such as copper, zinc, and arsenic. Sulphides are oxidized in the presence of air and moisture, producing sulphuric acid, which decreases the pH of surrounding water. Metallic components are released to the environment in lower pH (Ahmari and Zhang, 2013; Alakangas, 2006). Nowadays, the utilization of sulphidic mine tailings is mainly focused on reducing the amount of solid landfill waste material and the leachability of heavy metals by using mine tailings as a backfill material in mining sites. Basically, in the paste backfill method, mine tailings are mixed together with water and cement or some other pozzolanic binder material to improve the strength properties of the tailings. The paste backfill method decreases the oxidation of pyrite and pyrrhotite and the leachability of heavy metals in the short-term (Benzaazoua et al., 2004, 2006; Cihangir et al., 2012; Ercikdi et al., 2009; Kesimal et al., 2004; Nehdi and Tariq, 2007). The most commonly used binder material in the backfill method is Ordinary Portland cement, which has some limitations when using sulphidic rich mine tailings. The production of acid in the presence of oxygen and water leads to chemical weathering and the presence of sulphidic minerals results in sulphate attack which may decrease the strength of the backfill material within cemented composites. The long-term stability problems of the heavy metals in sulphidic rich backfill materials have been examined based on these facts (Benzaazoua et al., 2002). The quantity of mine tailings produced in the mining industry is huge and not all produced tailings can be

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[*] Corresponding author.
E-mail address: jenni.kiventera@oulu.fi (J. Kiventerä).

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utilized as backfill material. This has led to much interest in finding new methods to utilize mining waste for example in the construction industry (Mohamed et al., 2002).

Sulphidic rich tailings contain silica and alumina and can be used as a raw material in the production of alkali-activated binders or geopolymers. Geopolymers are produced by mixing reactive aluminosilicate raw materials with an alkaline activator. Sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate, and potassium silicate are the most commonly used alkaline activators in geopolymerization (Al Bakri et al., 2013; Loyd and Rangann, 2010). Reactive aluminosilicates are dissolved in alkaline conditions and SiO_4^{4-} and AlO_4^{5-} ions are released into the solution. SiO_4^{4-} and AlO_4^{5-} ions are linked together by sharing oxygen atoms and produce an amorphous three-dimensional polymeric structure containing the Si–O–Al bonds (Komnitsas and Zaharaki, 2007). The geopolymerization process takes place in natural conditions at room or slightly elevated temperatures so the energy consumption required to produce such materials is lower than with Portland clincker contained cements. The material produced has excellent properties such as high strength, low density, micro- or nano-porosity, low shrinkage, high thermal stability, and high chemical and fire resistance (Panias and Giannopoulou, 2007). The main application of geopolymers is as a cement replacement material in concrete or mortars (Komnitsas, 2011). Geopolymers have also shown potential for use in the immobilization of hazardous heavy metals, which could be locked into the three-dimensional matrix (Komnitsas et al., 2013). Moreover, the alkali-activation could provide a solution to the use of hazardous mining waste materials in novel products. This method would minimize the storage problems of mining waste dumps and water control structures and increase the stabilization and immobilization of heavy metals (Komnitsas and Zaharaki, 2007).

Although several researchers have studied the paste backfill method from sulphidic mine tailings, few have studied the utilization of mining waste as a raw material in alkali-activation or in the building materials industry. Ahmari and Zhang (2012) utilized sulphidic copper mine tailings from Arizona, Panias and Giannopoulou (2007) used overburden, red mud, and flotation tailings from the Greek mining industry and Chen et al. (2011) researched hematite tailings in China as a raw material of producing alkali-activated construction bricks. They produced environmentally friendly materials, with excellent water permeability and strength properties. The incorporation of the tailings into bricks reached 84% with the use of some additives such as fly ash. Chen et al. (2011) also indicated that the leachability of the heavy metals from sulphidic mine tailings could be eliminated by alkali-activation. While the properties of the mine tailings depend on the mineralogy of the mining site, in the present study the alkali-activation of Finnish mine tailings from a gold mining site was investigated. Cihangir et al. (2012) found that blast furnace slag has a great potential for use as a binder in paste backfilling of sulphidic rich mine tailings, therefore commercial ground granulated blast furnace slag (GGBFS) has been used as a matrix for geopolymerization in our study. The effect of activator concentration and GGBFS content on the properties of specimens produced has also been investigated.

2. Materials and methods

2.1. Materials

The materials used in this study include sulphidic mine tailings (MT), commercial ground granulated blast furnace slag (GGBFS), sodium hydroxide (NaOH), and de-ionized water. The mine tailings were received as slurry from a gold mining site in Northern Finland. The slurry was dried to a constant weight in 105°C before being used in powder form. Commercial GGBFS (KJ 400), produced by Finnsementti, is a high glassy-state contained material that was used as a geopolymer matrix in these tests. It is also a fine grained material with the mean particle size around 10.8 μm (Fig. 1).

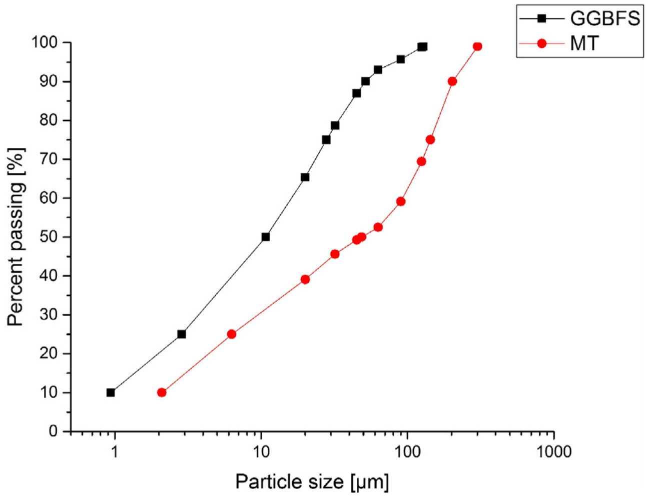

Fig. 1. The particle size distribution of mine tailings (MT) and blast furnace slag (GGBFS).

The chemical composition of the mine tailings (MT) is shown in Table 1. Mine tailings consist mainly of SiO_2, Al_2O_3, and CaO. In addition, some iron oxide was seen — about 10 %. The content of sulphur as SO_3 was 5.2 %. Iron and sulphur originate from arsenopyrite and pyrite minerals which are the main minerals mined in this particular gold mine. This was also confirmed by the ICP-OES-analysis which shows the high content of sulphur and arsenic. Mine tailings are fine grained residues with a slightly higher mean particle size than in GGBFS. The mean particle size of mine tailings was around 49 μm and 90% of all particles were under 203 μm (Fig. 1).

Table 1
Chemical composition of raw materials.

Component	MT	GGBFS
SiO_2 (%)	49.9	32.3
Al_2O_3(%)	10.4	9.6
Fe_2O_3(%)	9.7	1.2
CaO (%)	11.1	38.5
MgO (%)	5.9	10.2
SO_3(%)	5.2	4.0
Na_2O (%)	3.0	0.5
K_2O (%)	1.3	0.5
TiO_2(%)	1.3	2.2
S (mg/kg)	18900	
As (mg/kg)	1520.0	
Cd (mg/kg)	<0.3	
Cr (mg/kg)	74.0	
Cu (mg/kg)	120.0	
Ni (mg/kg)	100.0	
Pb (mg/kg)	4.3	
Zn (mg/kg)	71.0	
B (mg/kg)	9.6	
Be (mg/kg)	<1	
Co (mg/kg)	22.0	
Mo (mg/kg)	1.5	
Sb (mg/kg)	32.0	
Se (mg/kg)	<3	
Sn (mg/kg)	<3	
V (mg/kg)	59.0	
Ba (mg/kg)	29	
BET surface area (m^2/g)	7.2	
pH	9.6	
Loss on ignition 525°C	0.7	
Loss on ignition 950°C	12.9	