Journal of Environmental Management 222 (2018) 250–259

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Utilisation of construction and demolition waste as cemented paste backfill material for underground mine openings

Tekin Yılmaz*, Bayram Ercikdi, Hacı Deveci

Department of Mining Eng., Karadeniz Technical University, 61080, Trabzon, Turkey

ARTICLE INFO

Keywords:
Construction and demolition waste
Waste disposal
Compressive strength
Acid and sulphate attack
Sulphide tailings
Cemented paste backfill

ABSTRACT

This study presents the utilisation of finely ground construction and demolition waste (CDW) as partial replacement (5–15 wt.%) to sulphide tailings on the short- and long-term strength, durability (i.e. no loss of strength) and microstructural properties of cemented paste backfill (CPB) over a curing period of 360 days. The CPB samples containing CDW were prepared at binder dosages of 7.5 and 8.5 wt.%, while control samples (full tailings) were only produced at 8.5 wt.% binder dosage. A total of 108 CPB samples were subjected to the unconfined compressive strength (UCS), acid/sulphate (pH, SO_4^{2-}) and microstructure (MIP, XRD etc.) tests. Despite its limited contribution to the resistance of CPB to acid and sulphate attack, the use of CDW as partial replacement (5–15 wt.%) to sulphide tailings enhanced the strength properties of CPB samples by decreasing the total and macro porosity. The UCSs and pH values of CPB samples increased with increasing the CDW content in CPB mixtures, while the generation of sulphate ions ($SO4^{2-}$) decreased irrespective of the binder dosages. Compared with control samples prepared at 8.5 wt.% binder dosage, 5.3–19.5% higher UCS values were obtained for the CPB samples containing 15 wt.% CDW prepared even at 7.5 wt.% binder dosage. Mercury intrusion porosimetry (MIP) analyses proved the beneficial effect of the use of CDW on the microstructural properties (i.e. total porosity) of CPB. These findings suggest that CDW materials can be suitably used as backfill material in the mining industry to fill underground voids created during the ore production. This offers safe disposal and hence environmentally sound management of CDW.

1. Introduction

Increasingly, large quantities of construction and demolition waste (CDW) are produced as a result of the destruction of end-of-life buildings (Kou et al., 2011; Eguchi et al., 2007). Currently, only about 50% of the over 200 million metric tons of CDW generated by building work, road, bridge, airport construction and renovation were reused in U.S. (Jones and Cetin, 2017). In the all of countries that are member of European Union (EU), 900 million tons per year of CDW has been generated by the construction industry with reference to the data of 2010 (Martínez et al., 2016). As seen in Table 1, a large amount of the CDWs generated in EU are valorized such as recycling, landfilling and backfilling. It was reported that 584 million tons CDW generated by 15 countries of EU in 2012 and about 37% percent of this was recycled in various field of utilisation. In addition, Germany and France generated much more CDWs than those of others, whilst, the rate of recycling of CDWs generated was higher in Denmark, Estonia, Netherland, Spain and Czech Republic (Table 1) (Eurostat, 2015). Similarly, large quantities of CDW (e.g. 20 million tons per year) are annually generated as a result of the destruction of old buildings within the scope of urban renewal projects in Turkey. A total of 129.307 of old and risky buildings were solely destructed by the Turkey's Ministry of Environment and Urban Planning up to the beginning of 2018 with this figure being expected to reach 7.5 million in the next 15 years. In Trabzon where the study was conducted, a total of 1288 old buildings were destructed in only four urban renewal projects (Erdogdu, Pelitli, Bahcecik and Cömlekci) over the last five years. The CDWs consist of concrete, waste brick, mortar, ceramic, metal, plastic, wood and others. The concrete, ceramic, mortar and waste brick constitute 80% percent of construction and demolition wastes (Özalp et al., 2016). If the waste is not recycled, these wastes can cause environmental pollution, shortage of valuable landfill area and economic loss.

In recent years, the use of recycled CDW as coarse and/or fine aggregate or ultra-fine (filler) materials in construction industry has considerably increased because of preservation of natural aggregate resources, deficiency of dump site, increasing cost of waste treatment and environmental protection. Tabsh and Abdelfatah (2009) studied the effect of CDW on strength characteristics of concrete. They reported

---

* Corresponding author.
E-mail address: yilmaz.tekin@ktu.edu.tr (T. Yılmaz).

https://doi.org/10.1016/j.jenvman.2018.05.075
Received 19 March 2018; Received in revised form 8 May 2018; Accepted 23 May 2018

Table 1
The amount of CDW generated in some countries that are member of European Union in 2012 (Eurostat, 2015).

Country	Generated CDW*	Recycled CDW*	Backfilled CDW*	Landfilled CDW*	Uncontrolled CDW*
	*million tonnes				
Denmark	5.571	4.791	NA	0.390	NA
Estonia	1.499	1.349	NA	NA	NA
Netherland	25.706	24.249	NA	0.477	0.16
Spain	27.703	19.011	4.329	4.364	7.368
Germany	201.300	66.200	NA	16.893	NA
Belgium	6.946	14.542	NA	0.271	NA
France	246.700	76.477	39.472	37.005	NA
Sweden	1.310	0.180	0.480	0.15	NA
Finland	16.027	NA	NA	NA	NA
Romania	1.330	NA	NA	NA	NA
Portugal	1.224	0.430	NA	0.227	NA
Latvia	0.397	0.155	NA	NA	NA
Italy	33.756	NA	0.165	9.332	NA
Czech Republic	13.800	10.350	NA	2.405	NA
Slovakia	0.806	NA	NA	NA	NA

that the concrete samples of CDW can produce lower (1.10–1.25 fold) strength (UCS) than natural concrete. Çakır (2014) indicated that the UCS of concrete decreased when the natural coarse aggregate was replaced with fully CDW. This was interconnected with the higher porosity and lower density of CDW. He also observed that the strength reduction is more remarkable at over 50% recycled CDW content and the UCS of recycled CDW concrete can be enhanced by the addition of pozzolanic admixtures (i.e. silica fume, blast furnace slag) into the mixture. It has been stated that the UCS of the recycled CDW concrete gradually decreases due to increasing the amount of recycled CDW (Çakır, 2014). Özalp et al. (2016) investigated the effect of substitution ratio (20, 30 and 40%) of normal aggregates with recycled CDW on the UCS of concrete specimens and they found that there is a linear reduction in the UCSs of concrete samples with increasing the amount of recycled CDW in concrete mixture. Thomas et al. (2013) investigated the porosity and durability of concrete produced from CDW at different substitution ratios (20, 50 and 100%) and curing days (28, 180 and 360 days) and they found that the durability and porosity of concrete tend to increase with increasing the replacement ratios. Uygunoğlu et al. (2014) performed a study on the reuse of CDW as a raw material for the preparation of self-compacting concrete. It was found that a replacement of limestone aggregate with CDW resulted in 5.6–7% a decrease in the UCS of concrete samples depending on the water-cement ratio (w/c). This was associated with the fact that concrete containing CDW require 5–15% more water than natural concrete to provide the same consistency resulting in lower concrete strength (Jabir, 2012). The decline in UCS was also attributed to the weakness, cracks and fissures, shape, and particle size distribution of CDW. Previous studies also revealed that CDW is highly alkaline (including limestone, calcium-bearing minerals and cement) and can be used as an acid-neutralization material (Chen et al., 2012; Zedan et al., 2017; Jones and Cetin, 2017). Chen et al. (2012) found that fine particles (< 75 μm) of CDW show higher acid neutralization capacity than coarser particles. Zedan et al. (2017) investigated the changes of pH values in alkali activated blast furnace slag (AAS) cement containing different demolition/construction waste (ceramic, red clay brick and concrete). They stated that AAS containing concrete waste shows the higher pH values than those of other waste materials which are likely due to its higher CaO content (37.45% c.f. 1.57 and 8.89% for the ceramic waste and red clay brick waste, respectively) and the presence of hydrated cement in concrete waste. Jones and Cetin (2017) investigated the neutralization capacity of four different CDW materials containing 37.9–55.8% CaO and they reported that the neutralization capacity of CDW materials increases with increasing CaO content and the CaO content of CDW should be higher than 25% for effective neutralization.

In the mining industry, an increasing amount of solid waste/mill tailings ($>$ 30 million tonnes/year only in Turkey) is generated as a result of ore processing operations. Cemented paste backfilling (CPB) is considered to be one of the most suitable technique for the management of mill tailings, allowing the placement of the tailings back into underground openings with important, technical, environmental and economic benefits (Ercikdi et al., 2017). CPB is an engineered material consisting of a mixture of dewatered wet tailings, mixing water and binders (Landriault, 1995; Fall et al., 2004; Yilmaz and Fall 2017). But, there could be potential problems in the long-term durability of paste backfill if tailings the sulphide content of the tailings used is high. The potentially long-term durability problems (i.e. strength losses) encountered in CPB is mainly linked with the generation of sulphate (SO_4^{2-}) and acid due to the oxidation of sulphide minerals (i.e. pyrite) in the existence of moisture and air. The acid can dissolve and weaken the C-S-H gels and portlandite with eventual loss of CPB stability as the hydration products are not stable at low pHs below 9 (Ercikdi et al., 2015; Hassani et al., 2001; Yin et al., 2018; Tariq and Nehdi, 2007; Cihangir and Akyol, 2018). Additionally, the sulphate can combine with free Ca generated by the dissolution of unstable portlandite, leading to the generation of secondary gypsum ($CaSO_4 \cdot 2H_2O$) with swelling properties and highly expansive ettringite ($3CaSO_4 \cdot 3CaO \cdot Al_2O_3 \cdot 32H_2O$) minerals. This may generate cracks and thus, reduce strength and stability (Archibald et al., 1999; Benzaazoua et al., 1999; Fall and Benzaazoua, 2005; Kesimal et al., 2005; Ouellet et al., 2007; Tariq and Nehdi, 2007). It should be noted that the source of sulphate in paste backfill can also be due to the existence of pre-oxidized tailings or sulphate-rich mixing water (Orejarena and Fall 2010).

Ouellet et al. (2007) reported about the benefit of CPB such as the contribution to neutralization potential and the mitigation of metal ions release due to the utilisation of alkaline binders in underground mining operations. They also remarked that the binder added into the paste backfill reduces oxygen diffusion and consumption through the CPB, and hence limits the generation of acid and sulphate due to the reactivity of sulphide minerals. Nonetheless, some studies (Bertrand et al., 2000; Tariq and Nehdi, 2007; Cihangir et al., 2012) on CPB of sulphide rich tailings indicated that cement dosage was insufficient (particularly, in the long term) to counteract the acid generated by sulphide oxidation. Cihangir et al. (2012) observed the formation of acid in CPB samples and they presented that the low pHs (even below pH 6) over 360 days were recorded for CPB samples at 5 wt.% OPC compared with pHs above 9 for those samples at 6–7 wt.% OPC. Tariq and Nehdi (2007) observed the general trend of pH reduction in CPB samples of sulphidic tailings (52.3% pyrite) which was more discernible after 90 days. They reported that the pH of CPB samples prepared from sulphate resistant cement (SRC) reduced from 12 to 6 between 28 and 90 days curing periods although SRC is known to provide better resistance to