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Utilization of granulated marble wastes and waste bricks as mineral admixture in cemented paste backfill of sulphide-rich tailings

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HIGHLIGHTS

- Granulated marble wastes and waste bricks can be used in CPB.
- The use of marble wastes improves acid buffering capacity and microstructure of CPB.
- Increasing additive ratio or decreasing replacement ratio increases the UCS of CPB.
- Fineness significantly affects the pozzolanic activity of waste bricks.
- Calcination temperature and glass phase content plays an important role on the durability of CPB.

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ABSTRACT

This study presents the utilisation of granulated marble wastes (MW) as an additive (10–30 wt%) and waste bricks (WB) as replacement and additive (15–45 wt%) to ordinary Portland cement (OPC) for cemented paste backfill (CPB) of sulphide tailings. OPC was used as binder at 7 wt% dosage. Pozzolanic activity tests showed that the fineness of the WB samples, not the chemical composition, is the major factor affecting their pozzolanic activity. Although they do not exhibit any pozzolanic activity, the use of MW samples as an additive to OPC improves acid buffering capacity of CPB samples and enhances their short and long-term mechanical performance. The UCSs of CPB samples increased with increasing additive rates and decreased with increasing replacement ratios. All CPB samples produced the desired strength and durability when MW and WB were used as an additive to OPC. However, a binder dosage of >7 wt% was required to produce the desired 28-day strength of ⩾0.7 MPa when the OPC was replaced by 15–45 wt% WB samples. The durability (i.e. no loss of strength) of CPB samples is closely inter-related with the calcination temperatures and glass phase content of WB.

1. Introduction

Cemented paste backfill (CPB) is produced from dewatered process tailings (70–85% solids by weight), a hydraulic binder (3–9% by weight) and mixing water. CPB is potentially one of the best practical approaches for the management of process tailings since it offers significant environmental, technical and economic benefits. These include the alleviation of the environmental impact of potentially hazardous mill tailings (e.g. sulphide tailings, in particular) by disposal of them safely into underground (up to 60–75% of the plant tailings), the support of underground openings to provide a safe working environment and minimise surface subsidence, and the reduction of the tailings disposal and rehabilitation costs [1–3]. However, some potentially long-term durability problems of CPB may be encountered when mill tailings with high sulphide (especially pyrite) content are used. Oxidation products (i.e. acid and sulphate) of sulphide minerals present in the tailings or mixing water could lead to chemical reactions with hydration products and binder phases, such as calcium hydroxide (CH) and calcium aluminate (C_3A) and, concomitantly, to the formation of expansive phases such as ettringite and gypsum [4–8]. These could then culminate in the reduced backfill strength and potentially collapse of the backfill. Recently, there has been considerable interest in the utilisation of natural and artificial pozzolans for the partial replacement of ordinary Portland cement (OPC) to reduce binder costs, improve the resistance to acid and sulphate attack, and increase the strength and durability of CPB (Table 1).

Marble waste dust (MW) is an inert material which is obtained as an industrial by product during sawing, shaping and polishing

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Table 1
Pozzolanic materials which are extensively used in cemented paste backfill.

Pozzolans	References
Natural pozzolans	Ercikdi et al. [9]
Fly ash	Hassani et al. [4], Mohammed et al. [10], Benzaazoua et al. [11], Klein and Simon [12], Tariq and Nehdi [5], Ouellet et al. [13], Fall et al. [14], Ercikdi et al. [7], Fall et al. [3]
Waste glass	Archibald et al. [15], Sargeant et al. [16], Ercikdi et al. [7], Peyronnard and Benzaazoua [17]
CALSiFrit, deinking sludge ash	Peyronnard and Benzaazoua [17]
Blast furnace slag	Benzaazoua et al. [11], Ouellet et al. [13], Fall et al. [14], Yilmaz et al. [18], Ercikdi et al. [7], Orejana and Fall [19], Fall et al. [3], Yin et al. [20], Yilmaz et al. [21]
Silica fume	Benzaazoua et al. [11], Ercikdi et al. [7]
Waste brick	This work
Marble waste (non-pozzolan)	This work

of marble and causes a serious environmental problem. There are many studies on the use of MW as reinforcement material or raw material in various areas and applications. Previous researchers investigated the usability of MW as an additive material in composite cement production [22], concrete production [23] and brick industry [24]. Others attempted to assess the efficiency of coarse MW as an aggregate in asphalt pavements [25] and in the production of more durable concrete mixtures [27]. The mechanical properties of self-compacting concrete containing MW as partial replacement of cement in various proportioning rates (5–35%) was also evaluated by previous researchers. Ergün [27] and Aliabdo et al. [23] indicated that the 5.0–10% replacement of MW with cement enhanced the compressive strength of concrete which was associated with the reduction of porosity due to its pore-filling effect. Similar results were also obtained by Topçu et al. [28] who reported that the use of MW (up to 200 kg/m^3) decreases the porosity of self-compacting concrete by increasing its short and long term strength. Tozsin et al. [29] investigated the neutralization potential of MW for acid soil and they showed that MW could be used as an acid-neutralization material.

Waste bricks (WB), which is generated by the manufacture of bricks, are an artificial pozzolana which can be hydrated in the presence of $Ca(OH)_2$ [30]. The raw materials used in the manufacture of bricks are mainly natural clays which are predominantly composed of silica and alumina. Clay minerals become highly reactive when they are incinerated at temperatures between 600 and 900 °C and then ground to cement fineness and finer [31]. Depending on the type of the WB, it induces some changes on the microstructure (i.e. total porosity, pore size distribution), workability, compressive strength and sulphate resistance of cementitious materials [32]. The potential use of WB as pozzolanic material in cement and concrete production has recently been investigated [30,31,33]. It has been reported that a partial replacement of cement by 10 wt% WB improves the grinding time (reduction of the consumption of energy) of the cement, reduces CO_2 emissions and increases mechanical properties of mortar [30,31]. Similarly, the replacement of cement by 10–20 wt% WB led to the refinement in pore structure (i.e. a reduction in porosity) at later curing periods (i.e. beyond 90 days) due to the pozzolanic reaction and hence, increased the compressive strength and sulphate resistance of mortar samples [31,34]. Lin et al. [30] demonstrated that, the amount of hydration products and the consequent compressive strength of cementitious mixtures reduce with increasing the replacement rate of WB with OPC. Filho et al. [31] investigated the effect of WB as pozzolan on the strength, microstructure and durability of mortar samples at various replacement ratios (10–40% by weight). They observed that the mortar samples containing 10–20% of WB as cement replacement were found to produce equal UCSs to reference samples (containing only OPC) and this range (10–20% replacement ratio) was interpreted as the optimum replacement level for the mortar samples.

Waste bricks (WB), which are used in the production of blended cements, may be considered as an alternative and cheap source of pozzolanic material for CPB. Similarly, the use of MW as an additive material due to their great acid-neutralizing potential could reduce acid generation by producing alkalinity in CPB and negative effects of these materials on environment. In this regard, WB and MW could be expected to produce a moderate resistance to acid and sulphate attack when used as an admixture in the binder phase. Furthermore, these waste materials are also readily available in countries such as Turkey, which has approximately 3872 million m^3 of valuable marble reserve and 520 brick production plant [35,36]. Large quantities of MW and WB (e.g. 2.6 and 3.8 million tons in 2005, respectively) are annually produced as a result of marble and brick production activities at quarries and processing plants [35]. Furthermore, these wastes can cause environmental problem and economic loss if the waste is not recycled. Despite extensive research on the use of artificial and natural pozzolans, the use of MW and WB in CPB has received apparently no attention.

In this study, the performance of WB and MW as an additive (10–45 wt%) to OPC in CPB was evaluated over 7–180 days of curing periods. Effect of partial replacement of OPC with WB (15–45 wt%) on the strength of CPB was also investigated. The physical, chemical, mineralogical and pozzolanic characteristics of the MW and WB were examined and correlated with their performance in CPB. Furthermore, generation of acid and sulphate over the curing period was monitored to contribute to the understanding of acid and sulphate attack phenomenon and to assess comparative acid/sulphate resistance of binders OPC, MW and WB in CPB. SEM and XRD studies were also performed to provide an insight into microstructure and mineralogy of CPB samples linked with the mechanical performance of the MW and WB.

2. Materials and methods

2.1. Tailings material

In this study, a tailings sample was obtained from the tailings dam of a copper flotation plant (Kastamonu Kure, Turkey). The tailings sample was collected from the point that is 40 m far away from the tailings discharge point by hydraulic excavator. Annually, approximately 0.55 Mt of sulphide tailings were produced as a result of milling operations and disposed into the tailings dam. Fines (−20 μm) content of the tailings was determined to be 58.4% using a Malvern Mastersizer.

The tailings was found to be rich in sulphide with a sulphide content of 43.5% and pyrite was identified to be the major sulphide phase in the tailings sample. The detailed physical, chemical and mineralogical properties of the tailings used in this study are summarised in Table 2 [37].

2.2. Binder reagents

The ordinary Portland cement (CEM I 42.5 R) was used alone and in combination with the mineral admixtures at different replacement and additive levels (10–45% by weight). Two different waste brick samples (Araklı Waste Brick (AWB) and Corum Waste Brick (CWB)) and marble waste samples (Gümüshane Marble Waste (GMW) and Bayburt Marble Waste (BMW)) were used as an admixture. GMW and BMW were only used as an additive (10–30% by weight) to OPC in CPB mixtures. These mineral