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Effect of Waste Brick as Mineral Admixture on the Mechanical Performance of Cemented Paste Backfill

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Abstract. This study presents the replacement and addition of granulated waste brick (WB) to ordinary Portland cement (OPC) in a cemented paste backfill (CPB) of sulphide tailings. The addition and OPC rate is about 15-45% and 7% in weight respectively. Pozzolanic activity tests indicated the fineness of WB samples being the major factor of pozzolanic activity instead of chemical composition. All CPB samples displayed the required strength and durability when WB was used as an additive to OPC. On the other hand, a binder dosage of >7wt % was needed to apply the required 28-day strength of $\geq$ 0.7 MPa when the OPC was replaced by 15-45 wt% WB samples. The durability of CPB samples is closely inter-related with the calcination temperatures and glass phase content of WB.

1. Introduction

Cemented paste backfill (CPB) is a product of 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 ways for the disposal of process tailings because of its environmental, technical and economic benefits. These include a significant decrease of the environmental impact of potential hazardous mill tailings 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 minimize surface subsidence, and the reduction of the tailings disposal and rehabilitation costs [1, 2].

However, long term durability of CPB may be a problem because of high sulphide content in mill tailings. Oxidation products of sulphide minerals come out from tailings or mixing water could cause chemical reactions with hydration products and binder phases, such as calcium hydroxide (CH) and calcium aluminate (C_3A) and formation of expansive phases like ettringite and gypsum [3, 4].

Waste bricks, generally produced in the brick fabrics, are an artificial pozzolan hydrated in the presence of $Ca(OH)_2$ [5]. Brick manufacturing raw materials are generally natural clays composed of silica and alumina. Clay minerals have the ability to become highly reactive when they are burned at high temperatures (between 600 and 900°C) and ground to cement fineness and finer [6], Figure 1.

Waste bricks show some changes on the microstructure (i.e. total porosity, pore size distribution), workability, compressive strength and sulphate resistance of cementitious materials depending on the type of the WB [7].

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Figure 1. Waste bricks

The cement replacement by 10-20 wt% WB causes the refinement in pore structure at beyond 90 days because of the pozzolanic reaction and increases the compressive strength and sulphide resistance of mortar samples [8]. Lin et al [5] illustrated that the amount of hydration products and the consequent compressive strength of cementitious mixture decrease with increasing the replacement rate of WB with OPC. Filho et al [6] researched the effect of WB as pozzolan on the strength, microstructure and durability of mortar samples at various replacement ratios 10-40% by weight.

Waste bricks (WB), used in the blended cement production, are considered as an alternative and cheap source of pozzolanic material for CPB. Additionally, they are expected to produce a resistance to acid and sulphate attack. Waste bricks have been already produced in Turkey by the 520 brick's factories. Huge quantities of WB are annually produced in brick factories (e.g. 3.8 million tons in 2005) [9]. Furthermore, these wastes lead to environmental problems and economic loss unless they are recycled.

This study includes the performance of waste bricks (WB) as an additive (10-45 wt%) to OPC in CPB that evaluated 7 to 180 days of curing periods. Moreover, effect of partial replacement of OPC with WB (15-45 wt%) on the strength of CPB is investigated. The physical, chemical, mineralogical and pozzolanic characteristics of the WB were examined and correlated with their performance in CPB. Additionally, acid and sulphate generation over the curing period was monitored to determine acid and sulphate resistance of binders OPC and WB in CPB. Furthermore, SEM and XRD studies were also realized to gain an insight into microstructure and mineralogy of CPB samples linked with the mechanical performance of the WB.

2. Materials and Methods

2.1. Tailings material

In this study, tailing sample is taken from tailings dam of a copper flotation plant (Kastamonu Küre, Turkey). The sample was taken 40 m far from tailings discharge point. Yearly, milling operations were composed approximately 0.55 mt of sulphide tailings and discharged into the tailings dam (Figure 2).



Figure 2. Tailing sample

Tailings fineness (-20 μm) was specified as 58.4% by Malvern Mastersizer (Table 1).

Table 1. Physical and mineralogical properties of tailings, cement and binders used in the tests, [10]

Characteristics	Tailings (%)	Cement (%)	AWB (%)	CWB (%)
Physical properties				
Specific gravity	3.66	3.14	2.68	2.62
Specific surface area (cm^2/g)	4630	4335	5670	3348
Grinding time (min)	-	-	15	15
7th days pozzolanic activity (MPa)	-	-	9.3	8.7
Calcination temperature (°C)			700-800	1000-1100
Mineralogical properties				
Glass phase content (%)	Pyrite, Quartz, Chlorite, Calcite, Muscovite, Albite	-	55.15 Quartz, Albite, Anorthite, Hematite, Illite	67.89 Quartz, Mullite, Opal, Andalusite

With regards to chemical content, beside the tailings' high content of Al_2O_3+Fe_2O_3 and SiO_2, the tailing was found rich in sulphide (43.5%). Pyrite was the major source of sulphide in the tailings sample (Table 2).

Table 2. Chemical properties of tailings, cement and binders used in the tests [10]

Characteristics	Tailings (%)	Cement (%)	AWB (%)	CWB (%)
Chemical composition				
Al_2O_3+Fe_2O_3	46.51	8.79	19.26	30.95
MgO+Na_2O	2.49	2.39	3.54	2.00
SiO_2	25.80	20.61	69.01	63.35
Reactive SiO_2	-	-	17.75	28.75
CaO	2.79	63.50	3.11	0.80
Loss-on-ignition (LOI)	20.6	3.1	1.8	0.0
Sulphide content (S^{-2}) (%)	23.18	-	-	-
Pyrite content (FeS_2) (%)	43.47	-	-	-

2.2. Binder reagents

The ordinary Portland cement (CEM I 42.5 R) alone and mineral admixtures as a different replacement in additive stages (10-45% by weight) were used. For the mineral admixtures, two different waste brick samples were used, which were Arakli waste brick (AWB) and Çorum waste brick (CWB). These additives were dried and crushed in a roll crusher (-4 mm) and then the product was fed to a ball mill (Figure 3).



Figure 3. Ground waste bricks samples

To achieve the grind time required for fineness of the grind (≥3000 cm^2/g), some preliminary grinding tests were applied. The optimal grind time was kept at 60 min constant. Grinding was followed by the determination of physical, chemical and mineralogical characterization of the admixture. Reactive silica content of the AWB and CWB was also determined as indicated in TS EN 197-1 [11]. Pozzolanic activities were also determined by using graded standard sand as described in TS 25 [12], [10].

2.3. Preparation and testing of CPB samples

For this study, 270 CPB samples were prepared in a Univex SRMF20 Stand model blender with a double spiral. Tailing sample, binder (OPC and OPC/WB) and mixing waters were blended in this blender. The experimental situations are given in Table 3.

Table 3. A summary of the experimental conditions used in the preparation of CPB samples.

Admixture Type	Replacement Level	Additive Level	Opc	Binder Dosage (wt%)	Slump (inch)
AWB	15, 30, 45	-	85, 70, 55		
AWB	-	15, 45	100		
CWB	15, 30, 45		85, 70, 55	7.0	7.3-7.5
CWB	-	15, 45	100		
Control	-	-	-		

The CPB mixtures were homogeneously mixed and poured into plastic cylinders being 10x20 cm (DxH cm) in size. The paste mixture solid content was set to 74.58 wt% to achieve the 7.5-inch slump consistency. The mixing water of the tailings was determined to include 2482 mg/l SO_4^{2-}, which can be classified "aggressive" towards concrete durability as suggested by DIN 4030[13]. The cylinders (open-head) were put in a humid room for curing. During the curing period, the humidity in the room was kept at approximately 80% ±1 humidity and 25 °C temperature to set similar underground mines conditions. Following the standard period (7, 14, 28, 56, 90 and 180 days) of curing, the CPB samples were tested for unconfined compressive strength (UCS) according to ASTM C 39 [14]. Before UCS tests, samples' both ends were evened to obtain flat surfaces. UCS tests were performed using a computer-controlled mechanical press, which offers 50 kN load capacity and 0.5 mm displacement speed per minute. CPB systems are arranged for giving 0.7-2 MPa unconfined compressive strength in 28-day [15]. In this study, CPB strength and durability performance is set to 0.7 MPa for 28-day and 180 days' durability (Figure 4).



Figure 4. Paste backfill text samples

3. Results and Discussions

3.1. Characterization of mineral admixtures

It is important for the materials to have certain chemical and physical properties showing their suitability for potential use as a pozzolanic admixture. According to TS 25 Turkish Standard [12], a pozzolan should contain min. 70% SiO_2+Al_2O_3+Fe_2O_3 and ≥4 MPa at 7-days. The chemical mixture of AWB and CWB samples proposed that these materials meet the TS 25 with a SiO_2+Al_2O_3+Fe_2O_3 content of 88.3%

(Table 2). These samples also indicated to contain different levels of reactive silica that being one of the most important component largely controlling their pozzolanic activity. As seen in Table 2, reactive silica content of CWB (28.75%) is importantly higher than AWB, which was consistent with its high content of glass phase (i.e. 67.89% c.f. 55.15% for AWB).

Pozzolanic activity test results illustrated that the unconfined strengths of CWB and AWB included mortar samples found 2.2 and 2.3 times higher than TS 25 specified [12], (Table 1). Previous studies [16, 17, 18] showed that pozzolanic activity and their compressive strengths were directly proportional to reactive SiO_2. In spite of high content of reactive SiO_2 and glass phase content, the pozzolanic activity of CWB was relatively lower than AWB because of its lower surface area.

3.2. Effect of waste bricks on the paste backfill strength development

Figure 5 illustrates the WB sample effects as pozzolanic admixtures in the partial replacement of OPC (up to 45% by weight) on the CPB samples strength and durability performances over a curing period of 180 days. CWB contained CPB samples give strength relatively slower than AWB contained ones at the same replacement levels. The CPB samples including 15 wt % AWB and CWB produced higher short and long term UCSs than those of OPC at all curing periods. This replacement level can be interpreted as the optimum for AWB and CWB. The advantageous impact of the addition of pozzolanic materials on the strength and durability of CPB can be attributed for the most part to the utilization of $CaOH_2$ liberated during hydration of OPC through pozzolanic reactions to create auxiliary C-S-H with bonding properties. This could likewise enhance the microstructure delivering a denser pressing with the feasible decrease in porosity and permeability. This, thusly, lightens the oxidation of pyrite present in CPB because of the conceivable moderation of entrance of moist and air [17, 19, 20, 21].

However, those CPB samples failed to give 28 day UCS of ≥0.7 MPa even at the 15 wt% replacement level. In this regard, the binder dosage should be expanded beyond 7 wt% to enhance the quality acquisition/durability attributes of CPB samples when AWB and CWB were incorporated into the binder phase as partial replacement of OPC. It is likewise pertinent to note that the improvement of strength of CPB samples turned out to be slower with expanding the extent of WB samples, which could be connected with the lessening of the clinker in the binder phase. Pozzolanic material activation in the binder phase is addicted to the existence of alkaline phases like portlandite, $Ca(OH)_2$, becoming available as the hydration of OPC progressed.

Strength loss amounts were measured between 25.4-26.6 % for CPB samples including 30-45% AWB as partial OPC replacement. Contrary to the CPB samples of OPC and AWB (at 30-45 wt% replacement level), CWB showed no strength loss over the curing period of 180 days. According to long term CPB samples performance, CPB samples including CWB showed a much better resistance to acid and sulphate attach than AWB ones (Figure 5a and b). CPB samples including WB samples can be adjusted well by their reactive silica, glass phase content and calcination temperatures for acid and sulphate attack, Wild et al [8] supports that mortars containing WB calcined at a temperature higher than 900 $^{\circ}$C give stronger sulphate resistance related to temperature below 900 $^{\circ}$C. They also illustrated that mortar samples sulphate resistance increases with WB replacement increasing above 1000 $^{\circ}$C. Also, Farrel et al [7] indicated that C-S-H gel amount formed from pozzolanic activity was proportional to glass phase content. These findings are consistent with this study.

The partial replacement of OPC with pozzolanic additive decreases the amount of C_3A in the binder phase and hence the formation of secondary ettringite by the C_3A and sulphate (SO_4^{-2}) reaction. These are also essential factors controlling the resistance of CPB to sulphate attack. The usage of WB samples as an additive to OPC at 7 wt% binder dosage increased the UCSs of CPB samples with increasing the additive level. The CPB samples containing 15 - 45 wt% WB additive were marked to give 1.38-3.67 times higher UCSs than those of marked from only OPC.

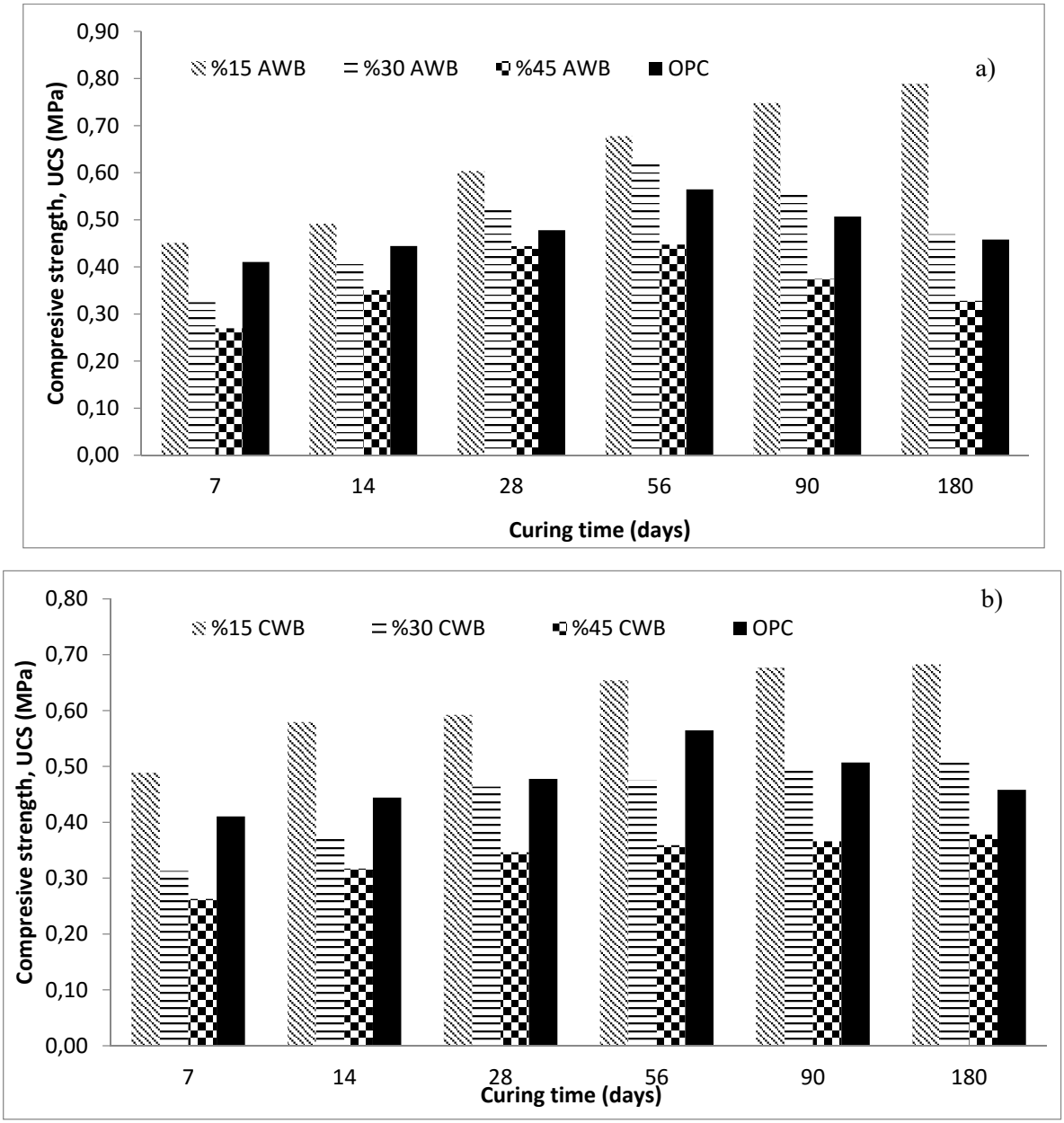


Figure 5. Effect of AWB (a) and CWB (b) as partial replacement (15–45 wt%) of OPC on the short and long term strength of CPB samples

All CPB samples gave the strengths beyond the 28-day strength of ≥0.7 MPa with no strength loss at 180 days of curing period (Figure 6a and b). The useful effect of clinker content and pozzolanic material increasing in the binder phase can be based on the increase in quantity of hydration products (CH and C-S-H) with the resultant reduction in void ratio and porosity. Also, these additional C-S-H gels could cover the surface area of the sulphide tailings available for oxidation [1, 4, 16, 21].

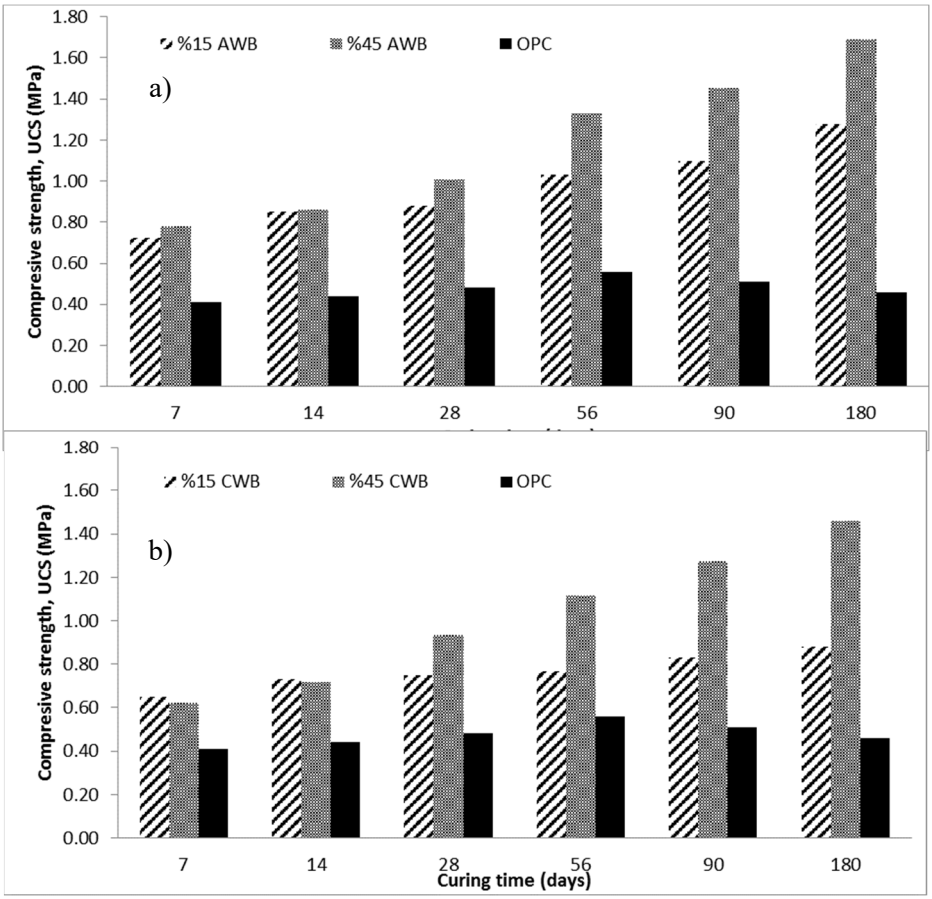


Figure 6. Effect of AWB (a) and CWB (b) as an additive on the short and long term strength of CPB samples

4. Conclusions

In this study, the effects of brick wastes as an additive and replacement of ordinary Portland cement (up to 45 % by weight) on the short- and long-term strength stability of CPB were investigated. CPB samples were subjected to the uniaxial compressive strength tests at 7-180 days and the most suitable pozzolanic type and dosage were determined. The UCSs of CPB samples increased with increasing additive rates and decreased with increasing replacement ratios. All CPB samples produced the desired strength and stability when 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 stability (i.e. no loss of strength) of CPB samples is closely inter-related with the calcination temperatures and glass phase content of WB.

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