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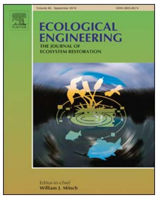

Resistivity of eco-friendly alkali activated industrial solid wastes against sulfur oxidizing bacteria

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ABSTRACT

The key point of this work is to study the impact of sulfur oxidizing bacteria (SOB), namely *Acidithiobacillus Thiooxidans NCIMB 8343*, on the properties of eco-friendly alkali activated slag (AAS), ceramic waste (AACW) and glass waste (AAGW) industrial solid wastes. Ordinary Portland cement (OPC) was used as reference. After 14-days of curing in tap water, all hardened cement pastes were exposed to pure carbon dioxide, which decreased the pH value of hardened cement surface, allowing the bacterial attack. The detrimental impact of biogenic sulfuric acid, induced by SOB, was evaluated by measuring the cationic leaching, weight, compressive strength and total porosity variations. The change in phase composition and the morphology of cement phases was investigated by Fourier transformer infrared (FTIR) spectroscopy and scanning electron microscopy (SEM). The AAS (with low Ca/Si ratio) showed the higher resistivity against SOB attack comparing with OPC-paste (with high Ca/Si ratio) up to 360-days of incubation. On the other hand, the AAGW (containing low alumina content) exhibited biodegradable signs with higher Na-leaching rate, higher compressive strength declination and porosity increment rates as well as larger weight loss as compared to AACW (containing high alumina mass, %).

1. Introduction

Microbially induced deterioration is known to be one of the main factors, which affect the physico-mechanical properties of cement concrete in sewer system (Collepardi, 2002; Beddoe and Dorner, 2005, Marquez-Peñaranda et al., 2016) Sulfur oxidizing bacteria (SOB) regarded as the key point of corrosion and deterioration of concrete in different media such as waste water facilities, swage water and cooling tower (Diercks et al., 1991; Berndt, 2011; Wei et al., 2013; Estokova et al., 2016). Initially, high alkalinity (high pH: 12–13) of fresh concrete acts as protecting agent against the corrosive action of bacteria. After carbonation of cement concrete, the pH decreases to reaches below 9, allowing to a certain type of bacteria to adsorb on concrete surface. The bacterial cells also lead to reduce the pH of concrete surface, enabling acidophil bacteria to growth (Marquez-Peñaranda et al., 2016). In sulfide rich media, *Acidithiobacillus thiooxidans, Halothiobacillus neapolitanus, Starkeya novella,* and *Thiomonas intermedia* (as common SOB species) produce sulfuric acid (H_2SO_4), as a result of hydrogen sulfide (H_2S) oxidation. The biogenic H_2SO_4 has a detrimental effect on concrete by its reaction with $Ca(OH)_2$, yielding gypsum ($CaSO_4{\cdot}2H_2O$); the later reacts with tricalcium aluminate, as one of cement phases, to generate expansive ettringite ($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$) phase, causing internal pressure, leading to the formation of cracks and pitting. The cracks, in turn, produce a larger surface area for corrosion processes and provide additional sites for acid penetration. Furthermore, calcium silicate hydrate (responsible for cement strength) was decomposed by H_2SO_4, weakening the binding capacity of cement concrete (Alexander et al., 2012; Dopson and Johnson, 2012. Heikal et al., 2014; Heikal and Ibrahim, 2015). Characteristics and durability of alkali activated slag-microsilica pastes subjected to sulphate and chloride ions attack, Ceramics–Silikáty 59 (2), 81–89. The addition of supplementary cementitious materials (SCMs) and full replacement of ordinary Portland cement (OPC) by calcium aluminate cement have a positive effect on the resistivity of cement concrete against SOB attack (Berndt, 2011; Erich et al., 1999; Sand et al., 1994; Scrivener et al., 1999).

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In this paper, the resistivity of alkali activated industrial solid wastes (alkali activated slag, glass waste and ceramic waste) towards SOB had been evaluated through measuring of weight, compressive strength and total porosity variations as well as cationic leaching. The impact of SOB on the phase composition and microstructure of alkali activated industrial solid wastes (AAISWs) has been investigated using Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM). The novel contribution of this work, is the evaluation of the resistivity of alternative cements (synthesized by alkali activation of industrial solid wastes) toward SOB. The results of this work give a good evidence about the capability of utilizing these cements (in sewer system) as alternatives to OPC.

2. Experimental program

Acidithiobacillus Thiooxidans microorganism was purchased from National Collection of Industrial and Marine Bacteria, England (NCIMB 8343). OPC was obtained from Benisuif cement company, Benisuif, Egypt. Ground granulated blast-furnace slag (GGBFS) was provided by Helwan Steel Company, Helwan, Egypt. Ceramic waste was collected from Gloria company for ceramic industry, El-Wasta area, Benisuif, Egypt. Glass waste was obtained from San Jobin company, 6 October City, Egypt. The chemical and mineralogical composition of OPC, GGBFS, GW and CW are shown in Table 1 and Fig. 1, respectively. All starting materials were ground well and passed through 75 µm sieve.

Regarding culture media preparation, 3 g KH_2PO_4, 5 g $Na_2S_2O_3$, 0.3 g $MgSO_4$ and 0.25 g $CaCl_2{\cdot}2H_2O$ were dissolved in one liter of sterilized distilled water. The pH of the medium was adjusted to 4 by 1N HCl, then autoclaved at 121 °C for 15 min. The sterilized media was inoculated by bacteria in Laminar flow, followed by cultivation under aerobic condition for 10 days at 23 ± 2 °C. The relation between cultivation time, bacterial growth and pH was graphically represented in Fig. 2. After cultivation, the growth bacterial cells were centrifuged with rpm of 4000 cycle/min at 4 °C for 10 min, the supernatant was removed, the collected bacterial cells re-suspended in freshly prepared culture media, immediately before the immersion of hardened cement pastes in these media.

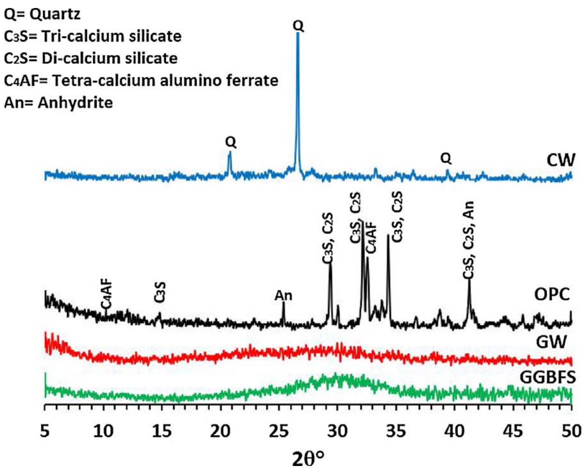

Fig. 1. XRD-patterns of OPC and industrial solid wastes.

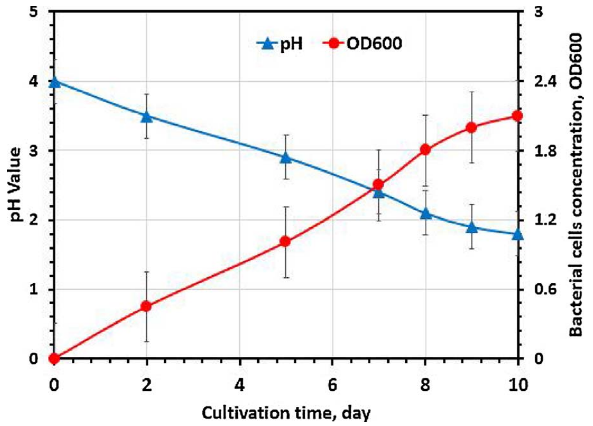

Fig. 2. Relation between pH, cells concentation as a function of cultivation time.

Table 2
Mix proportions of different mixtures (mass, %).

Mix notation	OPC	GGBFS	CW	GW	MK	NaOH	Na_2SiO_3
OPC	100	–	–	–	–	–	–
AAS	–	100	–	–	–	3	3
AACW	–	–	100	–	–	14	–
AAGW	–	–	–	100	–	10	–

For preparation of OPC-pastes, OPC was individually mixed with 30% water to make workable and homogenous pastes. Ground industrial solid wastes (ISWs) were activated by alkaline solution. Firstly, alkali activators were dissolved in 30% by weight of ISWs, then mixed with ISWs in automatic mixer to attain complete homogeneity. The activator percentages used are mainly depend on the chemical composition of ISWs. Where, GGBFS was activated by 3% NaOH and 3% Na_2SiO_3; this percentage was chosen according to previous study (Abdel Gawwad et al., 2016). We were tried different alkali percentages for GW and CW activation; the optimum percentages, which gave high mechanical properties were 10% NaOH in case of GW and 14% in case of CW. It is noted that the activator mass, % used for the motivation of GW- is lower than that required for CW-hydration. This should be explained by the presence of high Al percentage in CW. Where, the Al amphoteric element, which require higher alkali content comparing with Si (where GW is mainly composed of silicates). The details of mix proportion are given in Table 2. OPC, alkali activated slag (AAS), ceramic waste (AACW) and glass waste (AAGW)-fresh pastes are placed in one-inch cubic molds. The Ca-rich cements (OPC and AAS) are cured in humidity chamber with 100% relative humidity at 23 ± 2 °C for 24 h; whereas AACW and AAGW (with low Ca content) are cured in oven at 80 °C for 24 h the hardened cubes were demolded and cured under tap water for 14 days. After curing, all hardened cubes were exposed to accelerated carbonation in CO_2 chamber under static condition for another 14-days to decrease pH of cement surface, allowing the bacterial action (Vollertsen et al., 2008). After this period, all cement pastes give pH values between 8 and 8.5.

After carbonation, A part of carbonated OPC, AAS, AACW and AAGW cubes are immersed in culture media with 2.1 OD_{600} of bacterial

Table 1
Chemical oxide compositions of starting materials (mass, %).

Oxide, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	P_2O_5	MnO	BaO
GGBFS	38.70	11.90	0.51	32.90	4.08	0.68	0.78	2.42	0.49	–	3.92	3.29
CW	65.13	21.15	4.26	0.89	1.25	1.29	1.39	2.35	1.17	0.19	–	–
GW	88.42	0.81	1.29	2.14	1.16	4.28	0.27	0.59	0.18	0.07	–	–
OPC	21.09	4.79	3.65	61.78	2.71	0.22	0.12	3.11	–	–	–	–