Construction and Building Materials 63 (2014) 49–55

Contents lists available at ScienceDirect

Construction and Building Materials

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

Strength and microstructure analysis of bacterial treated cement kiln dust mortar

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HIGHLIGHTS

- Paper presents strength and SEM analysis of bacterial treated CKD mortar.
- Bacterial treatment reduces 67% alkalinity and 84% chloride in CKD leachate.
- Increased normal consistency, hydration and decreased setting time is observed.
- Increase in 19.54% strength is observed in 10% bacterial treated CKD mortar.
- SEM confirms formation of calcium silicate hydrate gel in CKD mortar.

ARTICLE INFO

Article history:
Received 17 December 2013
Received in revised form 27 February 2014
Accepted 1 April 2014
Available online 21 April 2014

Keywords:
Alkalinity
Bacteria
Cement kiln dust-mortar
Compressive strength
CSH
Ettringite

ABSTRACT

Cement kiln dust (CKD), a waste by-product material, is generated during manufacturing of cement clinker and possess cementitious characteristics as of cement. CKD represents significant environment concern related to its emission, disposal and reuse due to high alkalinity. In this study, attempts are made in utilizing the bacterial (*Bacillus* sp.) treated cement kiln dust as partial replacement of Portland cement (10, 20 and 30% w/w) and its effect on the normal consistency, setting times and hydration process of blended cement pastes, and on compressive strength (at 7, 28 and 91 days) of blended cement mortars. Test results show increase in water consistency with CKD concentration where as setting time is decreased up to 10% CKD addition, above which setting time increases due to reduced hydration process. At later curing ages hydration process increases up to 10% bacterial treated CKD–cement paste which later on decreases as CKD content increases. This increase in hydration at later curing ages (91 days) responsible for increase in compressive strength in 10% bacterial treated CKD mortar compared with 0% and 10% untreated CKD mortar, respectively. Scanning electron microscopy (SEM) results exhibits increased calcium silicate hydrate and formation of non-expansive ettringite in pores which dense the mortar structure and increases the compressive strength in bacterial treated 10% CKD mortar.

1. Introduction

Portland cement plays an important role in the production of mortar and concrete, and thus acts as a major constructional material of choice in building and structures. Due to increasing urbanization and industrialization from the last few years, the increasing cement generation has arisen certain challenges such as energy and resource conservation, cost of production and above all cement kiln dust (CKD) generation during cement clinker manufacturing has become one of the major environmental and economical issues. Cement kiln dust (CKD) is characterized by solid highly alkaline material removed from the cement kiln with exhaust gases and collected at bag house filters or electrostatic precipitators. Modern manufacturing technique makes it possible to reuse the cement CKD into cement kiln as raw feed that not only reduces the amount of CKD managed outside the kiln but also reduces the use of limestone and other raw materials, thus saves natural resources and helps to conserve energy. But, the high alkaline nature of CKD restricts its reuse in kiln as it makes the frequent shutdown of the plant by deposition on the walls and the removal of which is non-economical and laborious. Millions of tons of CKD are produced annually throughout the world and major part of it is sent to landfills. Disposal of waste CKD is not only associated with the problem of land use but also with contamination of ground water from leachate.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.04.011
0950-0618/

The reuse of industrial by-products as a part of constructional material in cement mortar and concrete is gaining popularity since last few decades due to its long term performance characteristics. The use of CKD as partial replacement of Portland cement alone and along with other pozzolanic materials, activators and binders has been investigated by number of researchers. Kunal et al. [1] provides a general review on the CKD utilization in making cement paste/mortar or concrete. As CKD is generated from cement kiln during cement manufacturing, it shows properties similar to cement and thus, acts as potential replacement to Portland cement (PC). Al-Mabrook [2] studied the ability of using CKD in cement mortar and hollow cement bricks by replacing cement (10%, 20%, 30%, 40% and 50%). Increase in compressive strength was observed in mixtures containing 30% CKD and it was concluded that increasing CKD quantity in mixtures increases the tricalcium silicate content that led to an increase in compressive strength at early stages.

Pavia and Regan [3] investigated the influence of cement kiln dust (CKD) on the compressive strength of mortars made with a non-hydraulic binder of high available lime content (calcium lime – CL) and observed increase in compressive strength with the CKD content up to 20% additions. El-Aleem et al. [4] reported that up to 6% CKD replacement in mortars slight decrease in compressive strength was observed where as above this percentage, the compressive strength decreased sharply. This reduction in compressive strength is suggested to be caused by the reduction in the cement content, an increase in the w/b ratio, increase in free lime content in cement dust, the formation of chloro and sulfoaluminate phases which leads to the softening and expansion of the hydration products, and increased the porosity.

Wang et al. [5] also studied the effect of CKD at partial replacement levels (0%, 15%, and 25%) of PC on 28-day compressive strength with mortars having the w/b ratio of 0.50. The authors found that up to 15% of cement replaced by CKD, the compressive strength increases where as above this percentage, such as at 25% CKD lower compressive strength than the plain cement mortar was observed which is due to the low hydraulic property of CKD. The increased strength in the specimen with 15% CKD may be attributed to an appropriate alkalinity that increases the dissolution of silicate species and formation of C–S–H. These results confirmed the investigation done by Shoaib et al. [6].

Generally, the cement kiln dust is alkaline in nature (pH 12) and if used in concrete, the alkaline nature needs to be monitored to avoid expansive reaction between alkalis and certain aggregates, which leads to cracking, causes deterioration and affects the hydration and microstructure of cement paste, therefore influences the cement mortar and concrete properties [7]. Bhatty [8–12] found that CKD blended cement had reduced workability, setting times and strength which was due to the presence of alkalies in the dust. Cement kiln dust after reducing the alkalinity can be used in cement–concrete system and may have positive effect on cement–concrete properties. Mohamed and El-Gamal [13] and Gebhardt [14] used carbon dioxide gas to remove the alkalinity of cement kiln dust, but the methods are highly expensive, laborious and above all CKD is not reutilized rather landfilled. The better alternative to the use of chemical process (involves use of carbon dioxide gas) is the biological treatment of alkaline wastes using bacterial system which grow well at high pH. Studies reported that alkaliphilic or alkalitolerant bacteria could degrade pollutants under highly alkaline conditions and had the significant advantage of not being easily contaminated by neutral microorganisms [15–17]. However, reports on the application of alkaliphilic bacteria in treatment of solid alkaline waste are very rare. Thus, in the present study an alkalitolerant bacterial strain (*Bacillus* sp. strain KG1) was isolated and utilized in reducing the alkalinity of the CKD. The treated CKD then utilized in cement mortar as partial replacement to cement in different percentages (0–30%) and investigated the effect on the hydration and strength properties of cement mortars.

2. Materials and methods

2.1. Material used

Cement of Indian Standards (IS) mark 43 grade UltraTech brand was used for all mixes. Testing of cement was conducted as per IS: 8112-1989 [18]. The test results conducted on cement are reported in Tables 1 and 2. Fine aggregate (natural sand) with 4.75 mm maximum size was used. Testing of fine aggregate was done as per IS: 383-1970 [19] and its properties are shown in Table 1. Cement kiln dust (CKD) is fine powdery material and relatively uniform in size. Tables 1 and 2 represents the physical and chemical properties of CKD, respectively.

2.2. Bacterial treatment of CKD

Alkalitolerant bacteria (that tolerate high pH) were isolated from rhizospheric soil on enrichment growth medium containing glucose (10 g/l), peptone (10 g/l), yeast extract (5 g/l), KH_2PO_4 (1 g/l), agar (15 g/l) and pH 10.5 (adjusted with 1 N NaOH) using serial dilution plating method. The agar plates were incubated at 37 °C for 48 h. The selected colonies were then screened for their tolerance to pH 11 and 12 and performed on minimal (M9) medium containing sucrose (10 g/l), KH_2PO_4 (2.5 g/l), K_2HPO_4 (2.5 g/l), $(NH_4)_2HPO_4$ (1 g/l), $MgSO_4{\cdot}7H_2O$ (2 g/l), $FeSO_4{\cdot}7H_2O$ (0.01 g/l), $MnSO_4{\cdot}4H_2O$ (0.007 g/l) and agar (15 g/l). pH was adjusted to 11 and 12 by KCl–NaOH buffer. The cultures were maintained on M9 medium and stored at 4 °C for further experimentation.

On the basis of neutralizing the alkaline medium, isolate KG1 showed the promising results and utilized for the treatment of CKD. The CKD was mixed with 0.8 OD (optical density; measured by spectrophotometer at λ_{max} 600 nm) value of the selected bacterial strain KG1 in the ratio CKD to culture (4:1). The treatment mixture was incubated at 35 ± 2 °C for 20 days and moisture was maintained by spraying water for the growth of bacterial strain. After 5 days of incubation, sucrose solution (10%) was added only once during the treatment of 20 days to provide carbon source for the bacterial strain KG1. After the completion of the incubation period, samples were collected randomly from different places, mixed with water (1:10) in conical flasks with shaking (@ 130 rpm for 1 h) to generate leachate and analyzed for alkalinity and chloride along with control treatment [20].

To confirm the decrease in alkalinity, bacterial treated CKD sample was air dried and analyzed with energy dispersive X-ray spectrometry (EDX, JEOL JSM-6510 LV, USA) for change in chemical composition of CKD and with powder X-ray diffraction (XRD; PANalytical X'Pro) for change in phases. The peaks in the new positions of the spectrum were marked, compared and identified from the Joint Committee on Powder Diffraction Standards (JCPDS) data file and from the published literature.

2.3. Casting and analysis of test mortar specimens

The bacterial treated cement dust (moisture content 0.02%) was used for the preparation of CKD-mortar mixtures along with series of control mixtures (untreated CKD). From the seven mix proportions, first was the control mix (without CKD) and the other six mixtures contained CKD (three mixes each contained untreated and bacterial treated CKD). Cement was replaced with CKD by weight in proportion of 10%, 20% and 30%. The mix proportion of control mortar (without CKD) was prepared using cement and fine aggregate in the ratio (1:3). The water to cementitious material ratio was taken as per cement consistency with different percentages of CKD.

Mortar cubes of size 5000 mm^2 were prepared for compressive strength. The casting of specimens was in accordance with Indian Standard IS: 4031-1988 (part 6) [21]. After casting, the specimens were allowed to remain in iron molds for first 24 h at room temperature (27 ± 2 °C), then demolded and placed in the water tank at room temperature for curing (7, 28 and 91 days).

Table 1
Properties of cement, CKD and fine aggregate.

Characteristics	Cement	CKD	Fine aggregate
Fineness (%)	1%	–	–
Fineness modulus	–	2.25	2.72
Specific gravity	3.03	2.39	2.62
Water absorption (%)	–	–	1.02
Size (mm)	–	–	4.75 max.
Moisture content (%)	–	0.02	0.16
pH	>13	>12	–