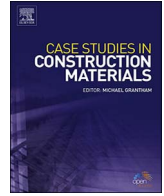




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Incorporation of cement bypass flue dust in fly ash and blast furnace slag-based geopolymer

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ABSTRACT

This work utilizes cement kiln dust in fly ash and blast furnace slag-based geopolymer. Geopolymer cement was produced using different compositions of ground, granulated blast furnace slag with fly ash and cement bypass flue dust. Crystalline sodium metasilicate pentahydrate was used as an activator at 10, 15 and 20% (by weight) of the geopolymer source materials. The geopolymer is formed in the solid state like ordinary Portland cement. The mechanical and chemical properties of the geopolymeric materials were examined. Measuring of mechanical properties by compressive strength of the hardened geopolymer pastes at different curing ages; microstructure was evaluated by X-ray diffraction (XRD) and scanning electron microscope (SEM); thermal properties were estimated by thermogravimetry analysis (TGA) and derivative thermogravimetric analysis (DTG). The results indicate that the compressive strength of the geopolymer pastes is increased with higher $\text{Na}_2\text{SiO}_3 \cdot 5\text{H}_2\text{O}$ content. The geopolymeric properties were enhanced by higher pH, which helps in the dissolution of geopolymer source materials during geopolymerization. SEM showed that mixes containing 15 and 20% sodium metasilicate had more compact and dense structures. On the other hand, GGBFS mix (G-20) exhibits more hydration and geopolymeric products during TGA/DTG compared with other mixes which contain FA with/without GGBFS.

1. Introduction

Cement production has become one of the most environmentally polluting industrial activities. Recent developments in cement manufacturing have reduced the impact of CO_2 emissions. Nevertheless, the production of one ton of cement emits 0.689 t of carbon dioxide gas in addition to other harmful gases such as nitrogen oxides and sulphur oxides. Half the amount of carbon dioxide emitted during combustion of calcium carbonate (limestone) while the rest is associated with the fuel consumed for production process [1].

Researchers have begun to study alternative materials for cement production, such as geopolymers or inorganic polymers. Materials containing sources of SiO_2 and Al_2O_3 can be used to form three-dimensional structures called geopolymers [2]. The main components of geopolymers are geopolymer source materials (GSMs) and alkaline activator. GSMs must be rich in both silicon (Si) and aluminium (Al) such as fly ash, rice-husk ash, silica fume, slag, red mud, etc. Raw materials containing reactive oxides of silicon and aluminium can be activated by highly alkaline sources such as sodium hydroxide, potassium hydroxide, sodium silicates,

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potassium silicates, sodium aluminate, etc. This activation gives rise to inorganic polymeric binding materials [3,4].

Geopolymeric materials have advantages over ordinary Portland cement (OPC) such as high compressive strength [5], good fire resistance [6], low thermal conductivity [7], lower setting times and rapid hardening [8], low shrinkage [9], durability and acid resistant [10,11]. The chemistry of hydrated binders depends on the composition of the precursor chemical. A precursor such as ground granulated blast furnace slag (GGBFS) is rich in calcium content when it was hydrated given C-S-H and C-A-S-H, which are enhanced in the presence of the alkaline activator. Binders containing medium levels of calcium (slag/fly ash, slag/metakaolin blends, and some individual precursor materials) [12] are the more complex chemistry of binder. It was reported that these binders containing phases such as C-N-A-S-H, C-A-S-H and geopolymer gels [13–19].

Cement bypass flue dust (CBFD) is produced during clinker preparation in rotatory kilns and is regarded as a by-product of cement production. CBFD is rich in alkaline oxides and chlorides, which cannot be recycled with raw material feed because it raises the alkalinity of OPC. Previous studies have examined the development of CBFD-OPC blends, in which CBFD is diluted with pozzolanic materials such as FA, MK and GGBFS [20]. The present study examines geopolymerization using different mixes of GGBFS-FA-CBFD as precursors combined with different percentages of sodium metasilicate pentahydrate in the solid state as the alkaline activator to obtain the cementitious material with good mechanical and chemical properties. The synthesis of one mix geopolymer in the solid form like ordinary Portland cement; since almost of prepared geopolymer formed from silica and aluminium sources activated with alkaline solutions.

2. Materials and procedures

2.1. Materials

The present study utilizes the following industrial by-products: Cement bypass flue dust (CBFD) supplied from Amreyah Cement (Inter Cement), Alexandria, Egypt; GGBFS (Iron and Steel Company, Hellwan, Giza Governorate, Egypt); Class-F fly ash (FA; Geos Company). Crystalline sodium metasilicate pentahydrate was used as the alkaline activated material. It has the molar ratio ($\text{SiO}_2/\text{Na}_2\text{O}$) equal to one, and pH of 12.5. The chemical composition of the starting materials was determined by XRF analysis, as shown in Table 1. The mineral compositions of CBFD, FA and GGBFS were estimated by XRD.

2.2. Preparation of binder mixes

Dry mix was blended in a porcelain ball mill for 1 h to form a homogeneous mixture before the casting process. Each binder mixture was stored in an airtight plastic container. The compositions of the various geopolymer mixes are given in Table 2. An amount of the mix was placed on a plain, non-absorbent surface, and a hollow was made in the centre. The water of consistency was transferred into the dry mix. The components were mixed continuously for three minutes [21]. The paste was placed into 1-inch cubic moulds and then vibrated to remove any air voids. Immediately after molding, the specimens were covered with plastic sheet to avoid loss of water through thermal curing at ($65 \pm 1^\circ\text{C}$) for 12 h. The hardened cubes of paste were removed from the moulds and cured in tap water up to the time of the tests.

2.3. Methods of investigation

The water consistency of geopolymer pastes was measured by Vicat apparatus according to ASTM: C191 [22]. Three cubic pastes representing the same binder pastes and curing time were used for measuring of compressive strength according to ASTM C-150 [23], and the average value was recorded. The samples used for the compressive strength tests were then crushed and mixed with 1:1 mixture (by volume) of methyl alcohol and acetone, to prevent further hydration. Dried samples of approximately 10 g were ground in a porcelain mortar, then saved in airtight containers. Thermal gravimetric analysis and differential thermal gravimetry (TGA/DTG) were conducted using dried sample under the nitrogen atmosphere (TGA-50: Shimadzu Co., Tokyo, Japan). X-ray diffraction (XRD) was carried out on selected hydrated binders using a Philips diffractometer with Ni-filtered $\text{Cu-K}\alpha$ radiation and a scanning speed of $20^\circ\text{C}/\text{min}$. After 28 days curing period, the morphologies of the hardened pastes were studied by scanning electron microscope (SEM; FEI Company, Holland).

Table 1
Chemical oxide composition of starting materials, (wt.%).

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	MnO	Cl^-	TiO_2	L.O.I
GGBFS	36.67	10.31	0.50	38.82	2.17	1.70	0.48	1.03	4.04	0.05	0.57	0.12
FA	60.27	27.99	4.54	1.16	0.35	0.37	0.15	0.98	–	–	–	0.91
CBFD	9.85	2.27	1.98	51.58	7.45	2.25	1.74	4.32	0.24	7.71	0.51	10.10

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