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Utilization of phosphogypsum as raw and calcined material in manufacturing of building products

Nurhayat Değirmenci *

Engineering and Architecture Faculty, Balikesir University, Cagis Campus, 10145 Balikesir, Turkey

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Abstract

The main objective of this research was to investigate the utilization potential of phosphogypsum with fly ash and lime in construction industry. Phosphogypsum was used as raw and calcined material for making the cementitous binder. A series of the tests were conducted to determine the compressive and flexural strength, water absorption and unit weight after 28 days of the specimen preparation. On the basis of the test results, it was concluded that the curing conditions have an important influence on the compressive and flexural strength of the binder specimens. It was also concluded that the cementitous binder obtained can be used for the production of interior wall materials such as bricks and blocks.

Keywords: Fly ash; Phosphogypsum; Lime; Cementitious binder

1. Introduction

Phosphogypsum and fly ash are industrial by-products that are generated by the phosphorus fertilizer industry and by thermal power plants, respectively. Approximately 15 million tons of fly ash and 3 million tons of phosphogypsum are generated each year in Turkey; these waste products are discarded in landfills, rivers and ponds.

Phosphogypsum consists primarily of calcium sulphate and contains some impurities, such as phosphate, fluorides, organic matter and alkalies. The presence of impurities puts restrictions on the use of phosphogypsum in building materials. Relatively little of this by-product is currently used by the cement and gypsum industries as a set retarder for cement and for making gypsum plaster and bricks [1–8].

The main way to reuse of fly ash and phosphogypsum is the manufacture of building products. Singh and Garg [9], studied the cementitous binder from flourogypsum, phosphogypsum and fly ash. They concluded that the cementitous binders are eminently suitable for use in masonry mortars and making concrete. In the study of Marinkovich et al. [10], the possible uses of fly ash and fgd gypsum were investigated in manufacturing of building products. It was concluded that FaL–G binder obtained in their study can be used for the production of interior wall materials. Kostich-Pulek et al. [11] studied a binder composed of two industrial wastes; calcined nitrogypsum and bottom ash with water, both with and without lime addition. These mixtures gave solidified products at room temperature and atmospheric pressure after 28 days and had satisfactory compressive strength for application in the civil industry. Kumar made [12] a perspective study on fly ash–lime–gypsum bricks and hollow blocks for low cost housing development. In another research by Kumar [13], the durability of FaL–G hollow blocks in sulfate environments was also determined. It was reported that these blocks have sufficient strength for their use in general building construction.

The enormous volume of unused phosphogypsum can be re-used by combining fly ash and Portland cement in

* Corresponding author. Tel.: +90 0266 6121194; fax: +90 0266 6121257.
E-mail address: nurhayat@balikesir.edu.tr.

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the building industry. However, environmental concerns have developed in the past 10 years due to the presence of radionuclides in phosphogypsum. This material contains naturally occurring radioactivity and ^{226}Ra is a major source of radioactivity. Phosphogypsum that exceeds 370 Bq kg^{-1} (10 pCi g^{-1}) of radioactivity has been banned from all uses by the Environmental Protection Agency (EPA) since 1992. EPA revised the standard to permit use but a safe limit was set 10 pCi g^{-1} and the international limit prescribed by European Atomic Commission (EURATOM) is 500 Bq kg^{-1} (13.5 pCi g^{-1}) [14,15].

There is no unanimity on the safe limit for the radioactivity exposure due to phosphogypsum. The phosphate industry has been looking into different ways of reducing the size of stacks. Researchers have also been seeking new application areas for phosphogypsum use as research has indicated that it would be more environmentally sound to use by-products rather than to dump them.

The aim of this study was to investigate the possibility of the utilization of two industrial wastes, fly ash and phosphogypsum with lime to produce the cementitous binder. The unit weight, water absorption, volume stability, compressive strength and flexural strength of the binder specimens were determined after 28 days of their preparation. These cementitous binders can be used in civil industry, primarily for use in masonry and for the manufacture of bricks and blocks.

2. Experimental

The basic ingredients of the cementitous binder were fly ash (FA), hydrated lime (L), phosphogypsum (PG) and water. Phosphogypsum as a by-product of the phosphoric acid process was procured from the Bagfas fertilizer factory in Bandirma, Turkey. The specific gravity of phosphogypsum is 2.89, the optimum moisture content is 13% and the maximum dry density is 14.70 kN/m^3, based on the standard Proctor compaction. Phosphogypsum is a damp, powdery material that is predominantly silt-sized and has little or no plasticity. The maximum size range is 0.5–1.0 mm. The results of radioactivity analyses of phosphogypsum determined by the Turkish Atomic Energy Association (Cekmece Nuclear Research and Training Center) are ^{226}Ra: 22 Bq kg^{-1}, ^{238}U: 9.0 Bq kg^{-1}, ^{232}Th: 1.0 Bq kg^{-1} and ^{40} K: 11 Bq kg^{-1}. Measures carried out on the radioactivity of phosphogypsum obtained from Bagfas Fertilizer Plant permit its classification as a weakly radioactive material.

Fly ash used in this study was procured from Soma Seas Thermal Plant in Manisa, Turkey. The Soma fly ash was produced from lignite coal and contains a significant amount of CaO with a lime content of 15.34%. Based on chemical characteristics, Soma fly ash can be classified as class-C fly ash according to ASTM C 618 [16]. The total amount of SiO_2, Al_2O_3 and Fe_2O_3 is 74.32%, which was a larger quantity than the value given by ASTM as the standard for a type C class fly ash. Free lime content of fly ash complies with TSI (Turkish Standard Institute) [17] and EN [18] standards because it is present in 1.90%. The amount of SO_3 (at 0.99%) is less than the value given by the standards. Pozzolanic activity index (PAI) of Soma fly ash is 88% at 28 days; this value satisfies the ASTM C 618 limit (75%). PAI also meets the TSI and EN criteria of 75% and 85% at 28 days and 90 days, respectively. The remaining on the 45-μm sieve was 16%, which was less than the 40% requirement of the TSI and of EN, and less than 34% of the ASTM standards.

Hydrated lime was a commercial hydrated lime and it was procured in paper sacks from local suppliers. The chemical composition and physical properties of fly ash, phosphogypsum and lime used in production of the cementitous material is given in Table 1.

The mixtures were composed of varying percentage of fly ash and phosphogypsum by holding the lime ratio constant as 10%. The mix proportions of the binders are given in Table 2. Phosphogypsum was used as raw and calcined materials for making the cementitous binder. A suitable amount of phosphogypsum was air dried and sieved through a 4.75 mm sieve before using. In order to obtain calcined gypsum, phosphogypsum was heated in an electric oven at 150 °C for 2 h. The calcined material was desiccated in a closed vessel to room temperature to avoid any contamination.

The weighed quantity of fly ash, phosphogypsum and lime passing through 4.75 mm sieve were thoroughly mixed in dry state. The dry compositions were then mixed in Hobart mixer with addition of water for 60 s. The water content for each mix was determined by flow test. The flow table was used to adjust the flow within 110–115 mm. The water was regular tap water. The mixed cementitous binders were cast in two layers into three-gang molds compacting by a vibration table for 60 s.

Table 1
Chemical composition and physical properties of FA, L and PG

Constituent (%)	FA	L	PG
SiO_2	45.98	1.1	3.44
Al_2O_3	23.75	–	0.88
Fe_2O_3	4.59	0.5	0.32
CaO	15.34	–	32.04
MgO	2.10	1.5	–
SO_3	0.99	–	44.67
K_2O	1.19	–	–
Na_2O	0.21	–	0.13
P_2O_5	–	–	0.50
F	–	–	0.79
$CaCO_3$	–	5.90	–
$Ca(OH)_2$	–	90.80	–
Loss on ignition	1.62	2.15	21.06
Specific gravity	2.24		2.96
Blaine (m^2/kg)	390		467
Retained on			
# 200 (75 μm) sieve (%)	16.00	8.00	20.13
# 325 (45 μm) sieve (%)	31.20	14.00	38.00