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Effect of Phosphogypsum on the Properties of Portland Cement

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Abstract

Use of industrial by-products as construction material can help to achieve sustainability in this industry. Phosphogypsum, a by-product in phosphoric acid manufacturing process, produced in bulk quantity especially from the fertilizer industry, typically used as a supplementary fertilizer for soil treatment. Alternatively, disposal of these materials in the form of landfill also need huge land area although environmental hazard concern from these activities has been raised by researches. The material has therefore, tried to incorporate in cement manufacturing considering its sustainable use. Phosphogypsum could be used as a substitute of natural gypsum in the production of Portland cement to control the hydration reaction rate of cement. In this study, raw phosphogypsum was collected from a local fertilizer industry. Properties of phosphogypsum were evaluated and then the effect of various level phosphogypsum addition (2, 5, 10 and 15 percent by weight of cement) with Portland cement clinker was investigated. The raw material was treated to remove additional water and impurity by washing, air drying and oven drying. Both treated and untreated materials were used in experimental work. Setting time, flow and compressive strength behavior of the prepared paste, mortar and concrete samples were evaluated to find an effective percentage of phosphogypsum to be used in Portland cement manufacturing. By evaluating properties of cement paste, mortar and concrete it was concluded that 5-10% phosphogypsum addition in cement clinker gave good results. In general, the processing of phosphogypsum by washing and drying gave better performance in all the media.

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*Keywords:*Phosphogypsum, Sustainibility, By product, Portland cement clinker

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1. Introduction

Phosphogypsum is a by-product from the wet manufacturing process of phosphoric acid (ammonium phosphate fertilizer) by the action of sulphuric acid on the rock phosphate. Approximately 4.5-5.5 tons of phosphogypsum is generated per ton of phosphoric acid production using wet process. Phosphoric acid is produced by reacting phosphate ore (apatite) with sulphuric acid according to the following reaction, where X may include OH, F, Cl, or Br. [1]

$$Ca_5 (PO_4)_3X + 5H_2SO_4 + 2H_2O \rightarrow 3H_3PO_4 + 5CaSO_4.\ 2H_2O + HX \quad (1)$$

Dumping of phosphogypsum into open land could have environmental and health concerns. The stockpiled material dominated by calcium sulphate dehydrate (around 94-98% by wt.), also contains approximately 5-6% of impurities including heavy metals, fluoride and radionuclides [2]. These toxic substances can be transported by wind over long distances. In consequence, it could contaminate soil and or groundwater. Detailed studies are necessary in order to fully understand the transfer process of toxic sub-stances into the adjacent environment and to assess their impact [3, 4, 5] but not within the scope of this work.

Treated phosphogypsum can be used as an ingredient of plaster [6, 7, 8]. The most important and motivating use of phosphogypsum could be in the construction industry. In the manufacturing process of cement, phosphogypsum could be used as a replacement of natural gypsum which plays the role of a set retarder [9, 10], or to reduce the clinkerization temperature [11]. Study also conducted with weathered (stored in open air) phosphogypsum as a set retarder in Portland cement [10]. Partly refined boric acid and phosphogypsum mixture can be used in place of natural gypsum for Portland and Trass cements [12]. It can be processed by wet sieving and washing process in the plant. The impurities of phosphate, fluoride, organic matter and alkalies are reduced by considerable extent. The beneficiated phosphogypsum can be used as an additive in place of mineral gypsum in the manufacturing of Portland cement and Portland slag cement. Phosphogypsum-slag based aggregate was prepared and tested for compressive, flexural and splitting tensile strength by using in concrete. It was recommended that the slag aggregate performed well as a coarse aggregate in cement concrete and should perform satisfactorily in highway pavement system [13]. In the manufacturing of building materials phosphogypsum was used as raw and calcined materials, however, the mechanical properties was found unsatisfactory [14]. Heated phosphogypsum used as a binder, improved the compressive and flexure strength of the material. Phosphogypsum based aggregate used in Roller Compacted Concrete (RCC) slabs gave good result for set retardation and drying shrinkage compensation [15]. Study on partial replacement of cement by various percentage of phosphogypsum gave good result with concrete specimens [16]. Researches [17,18] on the basic engineering properties of phosphogypsum-based concrete mixtures concluded that the unique properties of dihydrate phosphogypsum under compaction-consolidation can significantly contribute to the compressive strength of concrete mixes. However, with higher percentage of phosphogypsum, the strength of concrete mixtures is affected by the moisture at the time of testing. Better compressive strength attained with calcined phosphogypsum [19]. Study with up to 40% cement replacement by phosphogypsum gave 10% level optimum [20]. Another study with both OPC and PPC replacement in mortars found decreased compressive strength but increased flexural strength comparing with conventional mix [21]. Phosphogypsum's presence in the cement has increased its initial strength rapidly. This strength development was due to the formation of anhydrate at higher temperatures. Self-compacting concrete mixes using 0-30% percent replacement of cement also gave maximum flexural strength with 10% phosphogypsum. Study on the properties of both cement pastes and mortars using Ordinary Portland cement, Limestone Blended cement and Slag cement gave compressive strengths at 7 and 28 days satisfactory up to 8% phosphogypsum replacement for all the three types of cements at standard mix proportion. These three types of cement also met the limit of initial setting time and soundness requirements set by standards [22]. Study suggested modification in concrete mix process to incorporate raw phosphogypsum as partial replacement in cement mortar and concrete [23].

In view of the characteristics of phosphogypsum and its attractive economic potential at the present time there is a prodigious curiosity in using phosphogypsum as an alternative raw material for many applications. Replacement of cement clinker with certain percentage of phosphogypsum could give positive outcomes in mortar and concrete although there is still debate in related literatures. This research mainly investigated the effect of phosphogypsum addition with cement clinker on the properties of paste, mortar and concrete. In this regard, both field condition and