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Properties Evaluation of Self Compacting Concrete Made with Industrial By-Products

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Abstract

Urbanization with advanced technologies should be economic, sooner operational, and sustainable. In addition to reducing construction time, modern technologies should utilize various left-over materials or by-products to save budget and the environment. The present study examines the potential of using Phosphogypsum, an industrial by-product, in concrete as an environment-friendly, sustainable solution. Various percentages (5%, 10%, 15%, and 20%) of Phosphogypsum have been used to replace Portland cement to produce cost-effective SCC with favorable properties and strength. Conplast SP430 G8 superplasticizer has been used at a fixed amount as a chemical admixture. Laboratory tests have been performed to analyze various material properties together with conducting slump flow test, V-funnel test, and L-box test to evaluate the workability of the SCC. Compressive strength test results at 3-, 7-, 14-, and 28-days' concrete reveals that light replacement of cement with Phosphogypsum may increase the strength, whereas higher replacement would result in a decrease in strength. The present study concludes that a 10% replacement of cement with Phosphogypsum would provide the best result with increased compressive strength. This finding eventually confirms the use of Phosphogypsum, an industrial by-product, in concrete without compromising its strength with a reduction of time and construction cost.

Keywords

Compressive strength, industrial by-product, Phosphogypsum, self-compacting concrete, workability

1. Introduction

The race of urbanization and industrialization, demanded by the advancement in science and technology, triggers the construction of civil structures and infrastructures rapidly with higher strength and faster usage. Increased consumption exhausts natural resources and produces waste by-products, which requires proper management. Concrete (heterogeneous combination of cement paste and aggregates) is the widely used non-natural construction material and is considered as superior to all the other materials in this field. Since ancient times, researchers have been trying to enhance the quality of concrete and, on the other hand, make efforts to minimize the cost and time of construction. Self-compacting concrete (SCC) is a homogeneous blend that allows the self-compaction of concrete by its self-weight, necessitating no external potency, and can be placed in challenging rebar congestion areas. It has been considered the most revolutionary success of the construction industry, which was inspired by the feelings of workmanship-related problems, as inadequate compaction affects the strength of concrete despite the mixed design [1-3]. This high-performance concrete is gaining popularity over standard concrete [1, 4-7] due to its performance in segregation resistance and noiseless construction [2, 3, 8, 9]. Using ample range water-reducing chemical admixture such as superplasticizer at an optimum dose for making concrete self-compacting is a common practice now. Superplasticizer, by providing a low water-cementitious material ratio and increasing the workability of concrete, helps in gaining early strength in concrete and making it durable [10, 11]. Akiije [10] and Dumne [1] used Conplast SP430 G8 as a superplasticizer in their study. Nevertheless, self-compacting concrete has some demerits, and the increased cost allied with superplasticizer use and a vast quantity of Portland cement is one of them. Higher cement contented in SCC, the spawned heat of hydration is susceptible to thermal cracks and plastic shrinkage, for which durability is challenged. Again, Portland cement production leads to a costly, energy-demanding process responsible for emitting a large amount of carbon dioxide (CO_2).

Production of every single ton of cement discharges about one ton of carbon dioxide (CO_2) [12-14], and global demand for cement is expected to increase 4.5% yearly, as [14] estimated. A study by Krishna et al. [15] reveals that over 5% of worldwide CO2 emissions is attributable to the Portland cement industry, while Mehta [16] mentioned 7% emission in the study. Among all the ingredients in concrete, cement is the most expensive one.

Using mineral admixture as a replacement for cement solves the cost-related issue and reduces the hydration heat, which is a matter of concern regarding durability [17, 18]. Again, industrial by-products such as mineral admixture can play a very imperative role in solving these problems of using SCC together with inspiring the reuse of waste for a sustainable environment.

Phosphogypsum is a solid by-product from phosphate fertilizer industries and chemical manufacturing industries. The agribusiness sector consumes massive quantities of chemical fertilizers to complement the plant nutrients from soil [19], and the amount of produced Phosphogypsum is thus increasing with the amplified demand for crops. About 4.5 to 6 tons of Phosphogypsum is produced from one-ton phosphoric acid recovered [20]. Containing various impurities, including toxic heavy metals, dumping Phosphogypsum in open areas without any treatment possesses detrimental oddity to the environment, especially to the nearby surface or groundwater sources [14, 20-22]. Though the existence of impurities in Phosphogypsum sets restrictions on utilizing it [23-24], researchers are trying their best to use Phosphogypsum in numerous reprocessing manner to lessen the problems induced by either environmental and economic issues or in concrete technology. Analysts other than only in concrete have been using Phosphogypsum in various manners, such as for improving the properties of cement composites or cement mortars, integrating it in binder materials with feasibility analysis, applying it in aluminum powder composites, using it as filling material, converting into valuable products, analyzing the influence on properties of ceramic tiles, assessing the radon exhalation rate and radiological impacts by using in building materials, adding in self-leveling mortar, utilizing in formulating foam concrete, using in making non-fired bricks, applying as calcined material, dropping clinkerization temperature, using as a set retarder in cement, examining the influence on initial and final set time of cement, using in roller compacted concrete, assessing the impact on soil [23-32]. Phosphogypsum as a partial replacement of cement has been studied by many researchers, and it is reported that ordinary Portland cement can be substituted with

Phosphogypsum to some extent to produce sound concrete to attain reduced budget. Thus, they concluded that this was low-cost concrete. Literature reveals that about 10% of the Portland cement can be replaced with Phosphogypsum [33, 34], while [14, 35] found that 7.5% and 8% replacement can be achieved, respectively. Islam et al. [22] concluded that 5-10% replacement of cement with Phosphogypsum offered a good outcome. Again, [36] shows that 15-20% of natural sand and glue can be replaced by Phosphogypsum.

In Bangladesh, the triple superphosphate (TSP) complex, situated at Chattogram, is the main source for forming Phosphogypsum [22]. Many such industries produce massive amounts of Phosphogypsum, which commonly goes for dumping. This study is encouraged by the potential of Phosphogypsum as a low-cost complementary material to be utilized in self-compacting concrete to minimize the cost of using SCC. The novelty of this study is to assess the possibility of using Phosphogypsum in Bangladesh for reducing landfilling and thus achieving environmental sustainability.

2. Materials and Method

2.1 Materials

Materials used in this research involves Ordinary Portland Cement (OPC), Phosphogypsum, aggregates (fine and coarse) and chemical admixture Conplast SP430 G8. Grade 43 OPC was used in the current study. Water-cement ratio was calculated as 0.56. Tests of cement were conducted to find out the specific gravity and the initial and final set time. Locally available fine and coarse aggregate were used. Phosphogypsum was collected from Triple superphosphate industry. Before using Phosphogypsum powder in concrete, it has to be in dry condition. The properties of cement, fine and coarse aggregate and the Phosphogypsum are tabulated in Table 1.

Conplast SP430 G8 was used by taking 1% of cement (by weight). For concrete mixing, potable water was used. From the X-ray Diffraction of

Phosphogypsum sample as studied earlier (shown in Fig. 1), it is directed that this material is principally composed of Gypsum [22]. The final required materials are listed in Table 2.

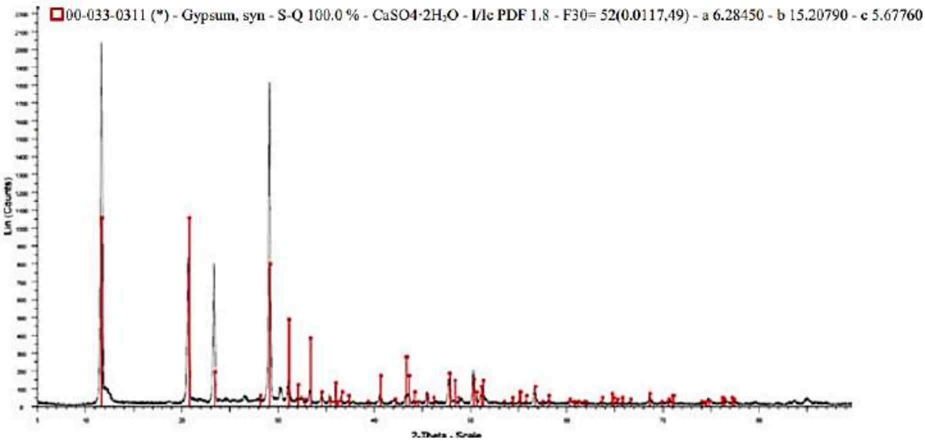


Figure 1. X-ray Diffraction of Phosphogypsum [22]

Table 1. Properties of Material from Laboratory Test Results

Material	Figure	Properties from laboratory experiments
Cement		a. Specific gravity: 3.1 b. Initial setting time: 30 minutes c. Final setting time: 600 minutes.

Fine aggregate		a. Bulk specific gravity (Oven Dry): 2.8. b. Bulk specific gravity (SSD): 2.5 c. Absorption Capacity: 2.65% d. Moisture Content: 5% e. Fineness Modulus: 2.61 f. Unit weight: 1604 kg/m3
Coarse aggregate		a. Bulk specific gravity (Oven Dry): 2.88. b. Bulk specific gravity (SSD): 2.9 c. Dry rodded unit weight: 1666 kg/m3 d. Absorption Capacity: 3% e. Fineness Modulus: 7.2
Phosphogypsum		a. Bulk specific gravity (Oven Dry): 2.4. b. Bulk specific gravity (SSD): 2.46 c. Absorption Capacity: 1%

Table 2. Required materials quantity

Material	**Quantity (Kg)**
Cement	314
Coarse Aggregate	1048
Fine Aggregate	804
Superplasticizer	3.14

2.2 Experimental Investigations

2.2.1 Workability

Workability is an essential property of SCC as it determines its ability to flow and fill intricate spaces without segregation or blockages. The workability of SCC is typically assessed through various tests, including the slump flow, V-funnel, L-box, and U-box test, etc. In order to examine the workability of the self-compacting concrete, three tests have been performed in the current study namely, slump flow test, V-funnel and L-box test.

SCC is designed to be highly flowable, with a slump flow value ranging from 600 to 800 mm. This is achieved by using a combination of water-reducing admixtures, viscosity-modifying agents, and sometimes, superplasticizers. The use of these admixtures ensures that SCC can flow effortlessly, filling all voids and spaces within the formwork. The V-funnel and L-box tests are used to evaluate the filling and passing ability of SCC, respectively. The V-funnel test measures the time that SCC takes to pass through a funnel, while the L-box test measures the time it takes for SCC to flow through an L-shaped channel. These tests ensure that SCC can easily flow through narrow spaces and around obstacles.

2.2.2 Compressive Strength

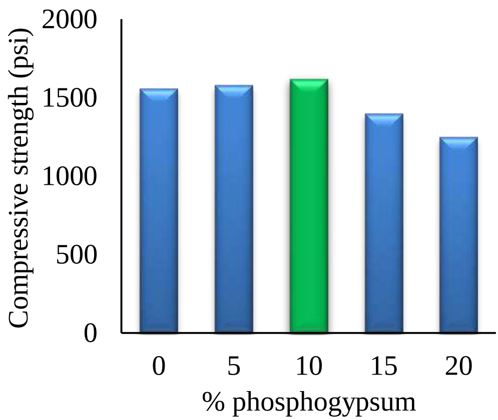
Taking target compressive strength of 28 MPa, the ratio of the materials selected for experimental program is 1:2.5:3.3 with 0.56 water-cement ratio. Tests for compressive strength evaluation were performed following the ASTM C39 [37]. Total 30 nos. of cylinder specimens with diameter 6 inch and height 12 inch were prepared. The moulds used for experiment were correctly greased to confirm easier demoulding after 24 hours drying. Hardened concrete specimens were then demoulded after 24 hour and then cured for 3, 7, 14, and 28 days in a standard curing condition.

3. Results and Discussions

3.1 Compressive Strength

The compressive strength of concrete was estimated as 28 MPa from the concrete mix design. Replacement of cement with Phosphogypsum has been 0%, 5%, 10%, 15%, and 20% in terms of weight. Experimental results of the compressive strength test of concrete for 3, 7, 14, and 28 days are shown in Fig. 2.

From the test results, it is evident that compressive strength increases with the increase of Phosphogypsum percentage up to 10% and further increase of Phosphogypsum reduces the strength. Compressive strength increases by 3.8%, 4.3%, 4.1%, and 3.7% for the concrete with 10% Phosphogypsum for 3-, 7-, 14-, and 28-day curing periods. On the contrary, 7-day compressive strength decreases by 12.5% and 15.2%, and 28-day compressive strength reduces by 8.6% and 13.6%, respectively, for concrete 15% and 20% Phosphogypsum. Thus, 10% replacement of cement with Phosphogypsum provides optimal concrete compressive strength which is found higher than the conventional concrete specimens.



a)

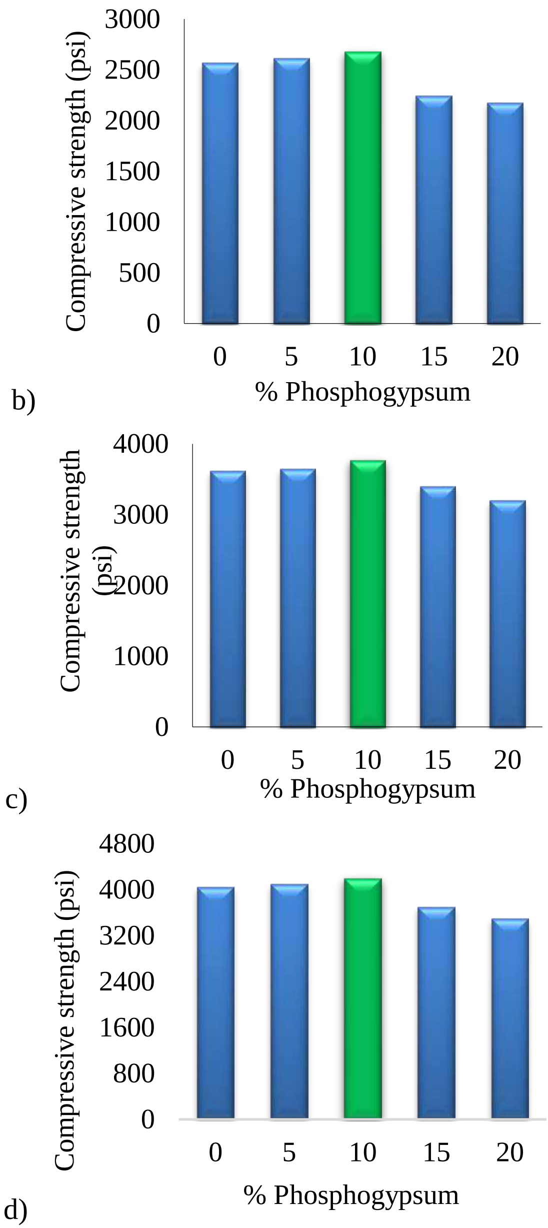


Figure 2. Compressive strength of concrete– a) 3, b) 7, c) 14, and d) 28 days

3.2 Workability

At the time of placing SCC, workability properties are to be conformed as there may be complications in building strength of concrete if not transported/appropriately placed. Attained results are 660 mm, 8 mm, and 0.82 (blocking ratio) for the slump flow test, V-funnel, and L box- test, respectively. Table 3 represents workability test results compared with standard values.

Table 3. Workability Test Results with Standard Value

Test Name	Value	Minimum	Maximum
Slump Flow (mm)	660	650	800
V- Funnel (mm)	8	6	12
L- Box (h_2/h_1)	0.82	0.80	1.00

4. Conclusion and Recommendation

Phosphogypsum is a waste material generated from phosphoric acid and phosphate fertilizer production. The disposal of Phosphogypsum has become an environmental concern due to its high sulfur content and radioactivity. Reusing industrial by-products not only establishes viability in economic aspects but also conveys environmental sustainability by distracting waste from being landfilled/ dumped in open areas. The findings of this study express that the addition of 10% Phosphogypsum in exchange for cement as a low-cost material in self-compacting concrete is optimum. Thus, Phosphogypsum can be used as a partial replacement for cement in SCC without compromising its strength and properties.

The addition of Phosphogypsum to SCC not only improves its workability and reduces its water content but also reduces the carbon footprint of concrete production. Phosphogypsum-based SCC also exhibits good durability properties and can withstand exposure to harsh environmental conditions. However, further investigation can be performed to find out the optimum percentage of Phosphogypsum to produce concrete with better strength and durability.

Overall, using Phosphogypsum in SCC is a promising approach for sustainable concrete production. However, further research is needed to explore the several other properties evaluation along with the long-term effects of Phosphogypsum-based SCC on human health.

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