Research Article

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Some Observations on Concrete with Phosphogypsum and Glass Fibres

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ABSTRACT

Increasing infrastructural needs have been creating huge stress on available natural resources leading to environmental deterioration. In a developing nation like India, concrete is a commonly adopted material in major infrastructure projects. Environmental burdens associated with the manufacture and processing of raw materials for concrete are enormous. The major impact associated with concrete production is carbon dioxide gas emission during cement manufacturing and the depletion of natural resources for aggregate production. These environmental issues have paved the way for adopting eco-friendly materials and techniques in concrete production. Industrial by-products such as fly ash, blast furnace slag, silica fume, etc., are successfully employed as cement replacements for sustainable concrete production. The present research has been aimed at examining the potential of phosphogypsum, the by-product of the fertilizer industry, as a partial replacement of cement (5, 10, 15 and 20%). The compatibility of phosphogypsum with cement has been initially studied and adopted for the production of M20 concrete. The performance of the processed concrete was analyzed in terms of workability and mechanical properties. Results obtained have proved the potential of phosphogypsum for adaptation as a retarder in concrete production; the optimum replacement was found to be only up to 10%. For enhancing the properties of the concrete, the study has been extended with partial replacement of glass fiber (0.5%, 1%, 1.5% and 2%) for M20 concrete with phosphogypsum content (5% and 10%) of cement replacement. Obtained results have suggested the suitability of utilizing these nanomaterials (with 1.5% glass fiber and 10% phosphogypsum) for M20 concrete.

Keywords: Cement; Glass Fibre; Phosphogypsum; Sustainable Concrete; Sustainable Construction.

1. INTRODUCTION

Concrete has been the vital structural material fostering the infrastructural needs in the current century. In both developed and developing nations, urbanization and population growth have been exerting huge demand for concrete to cater to the infrastructural requirements. Ecological burdens associated with concrete production are enormous, starting from the production of raw materials to finished products. One of the major areas of concern during its lifecycle has been the release of gases such as carbon dioxide, causing global warming. Cement manufacture has been one of the prime factors behind this scenario; estimates predict that one ton of cement production releases one ton of carbon dioxide gas into the atmosphere. Owing to the negative impacts stated above, global researchers are now focusing on sustainable concrete production adopting raw materials with reduced impact on the environment, such as blended cement. Industrial by-products such as fly ash, blast furnace slag, etc. are commercially adopted as cement replacement due to their pozzolanic activity. These developments have highlighted the larger picture of sustainable concrete production providing benefits through resource efficiency and also addressing the negative impacts of improper waste disposal. In the present era, there is an immediate need to focus on exploring such industrial by-products as suitable replacements for raw materials in concrete production (Monteiro *et al.* 2017).

Phosphogypsum (PG), a by-product of phosphoric acid production, has also been studied for various applications in the construction sector. Estimates predict that for every ton of phosphoric acid production, approximately 4 to 6 tonnes of PG are being generated, accounting for the global production of waste exceeding 200 million tonnes per year. Out of this total waste generated, only 15% is being observed to be recycled, and the rest is being disposed of into the environment. Environmental impacts associated with PG are enormous due to the presence of toxic trace impurities such as radioactive elements (such as uranium, radium, and other associated decay Hg and Pb). The impacts associated with this waste are increasing due to the indiscriminate disposal of the by-product into the water bodies or stacking on land areas causing human contact through multiple pathways. In order to reduce these negative effects, the most preferred option has been identified as recycling this waste material for wider applications (Ghazel *et al.* 2018; Rutherford *et al.* 1994).

Despite its toxicity and radioactivity, PG has not been categorized as toxic material by agencies such as EPA due to its non-corrosive nature and the presence of toxic constituents within allowable limits. PG can be beneficially applied for various applications such as agricultural fertilizer, soil stabilizer, manufacture of cementitious and other building products. Some studies have even pointed out that the impurities in the PG could be removed by various techniques employing physical, chemical, thermal and physico-chemical procedures such as washing, wet sieving and chemical treatment with lime, sulphuric acid, nitric acid, calcination, etc. (Al-Hawaiti 2015; Campos *et al.* 2017; Liu *et al.* 2015; Singh 2002; Saadaoui *et al.* 2017).

1.1 Applications of Phosphogypsum

PG (both processed and unprocessed) has extensive applications in agriculture, providing positive effects on vegetation such as fertilization of the soil, enhancing water retention and reclamation/remediation of land (Ghazel *et al.* 2018; Saadaoui *et al.* 2017). Mahmoud and Abd El-Kader (2015) have investigated the application of PG for immobilizing heavy metals in contaminated soil containing canola plants. The results have suggested that the application of PG has minimized the uptake of Pb, Cd and Zn by canola plants and increased their dry weight. Degirmenci *et al.* (2007) have observed the potential of PG in combination with cement and Class C fly ash for stabilizing the expansive and non-expansive soils in Turkey. Contreras *et al.* (2018) have evaluated the benefit of incorporating PG (5, 7.5 and 10% by weight to natural clay) in ceramic manufacturing by sintering at 950, 1050 and 1150 °C. The results have proved that the sintering behavior and bending strength of the ceramics improved with PG addition. Katamine (2000) has studied the efficiency of direct addition of PG as filler material in asphalt mixtures for road construction and the study has shown that PG blended with asphaltic bitumen has better temperature performance in comparison to normal bitumen.

Saadaoui *et al.* (2017) have illustrated the benefits of adopting PG in optimum contents in bricks and cement manufacturing for satisfying the requirements. Islam *et al.* (2017) have conducted studies on PG (at 2, 5, 10 and 15% by weight of cement) as a substitute for natural gypsum for controlling the hydration reaction rate of cement. 5-10% of PG addition have shown good results in the properties and the benefits could be further extended through the processing of waste by washing and drying. Singh (2002) and Al-Hwaiti (2015) have proposed the application of PG as a replacement of natural gypsum after suitable treatment with citric acid, lime water, sulphuric acid and nitric acid for removing the impurities in PG. Dvorkin *et al.* (2018) have highlighted certain important benefits of PG; it can act as a binder for natural gypsum and it can be used for sulphate activation of low-clinker blast furnace slag cement.

2. BACKGROUND OF THE RESEARCH AND METHODOLOGY

One of the key factors limiting the wider applicability of industrial by-products in sustainable concrete production has been the economics associated with their processing and treatment for their utilization as virgin material. Unprocessed wastes have serious implications for the properties and performance of the concrete. Considering this fact, the present work has adopted the raw PG obtained from the nearby industry in the study. Hua *et al.* (2016) have indicated the vulnerability of PG to water and temperature resulting in the cracking of concrete members and the benefits of fiber addition for improving its performance. Kasagani and Rao (2018) have also pointed out the benefits of incorporating fibers for arresting cracks in concrete specimens. Numerous researches undertaken globally have observed that glass fibers up to 2% replacement could reduce shrinkage cracking and improve the modulus of rupture. A further increase could result in the segregation of concrete mix. These aspects have been considered in the study through the application of glass fiber for understanding its influence on bond, workability and mechanical properties of PG-containing concrete.

Considering these stark facts, the present research has been carried out in three phases:

- In the first phase, compatibility of PG (5, 10, 15 and 20% of cement weight) with cement has been studied through normal consistency, setting time and soundness tests (Lechatilier method).
- In the second phase, the influence of PG on properties of fresh (workability by slump cone test) and hardened nominal mix M20 grade concrete (compressive strength) have been studied.
- In the third phase, at optimum replacement of PG as studied previously, the properties of M20 grade concrete (workability, compressive strength and split-tensile strength) with PG and glass fiber (0.5, 1%, 1.5 and 2% of concrete mix) were evaluated.

3. MATERIALS USED

Cement: Ordinary Portland cement, 53 grade conforming to IS: 12269 – 1987 (ACC Cement) was used in the study.

Fine aggregate: Locally available river sand conforming to grading Zone 2 as per IS: 383-1970 was used.

Coarse aggregate: Majorly two sizes of aggregates were used in the study: 20 mm aggregates passing through 20 mm sieve, but retained on a 10 mm sieve and 10 mm aggregates passing through 10 mm sieve, but retained on 4.75 mm sieve in conformance with IS: 383- 1970.

Phosphogypsum: Raw phosphogypsum procured from Shakshi Phosphate, Indore, M.P., India has been adopted in the present study. The following information has been obtained from the supplier: it is a grey-colored, damp, fine-grained powder, silt or silty sand with a maximum size range of 0.5 mm, and the majority of the particles (50-75%) are finer than 0.075 mm. The specific gravity of phosphogypsum ranges between 2.3 to 2.6. The maximum dry bulk density is likely to range from 1470 to 1670 kg/m^3. Permeability in un-stabilized phosphogypsum has been found to range from 1.3 x 10^{-4} cm/s down to 2.1 x 10^{-5} cm/s for stabilized phosphogypsum. Typical chemical characteristics of the phosphogypsum were as follows:

Table 1. Chemical composition of raw Phosphogypsum.

Constituent	Composition (%)
H_2O crystal	18
SO_3	43.6
CaO	32
MgO	0.4
Al_2O3 + Fe_2O_3	1.82
SiO_2 ins. In HCl	1.64
Na_2O	0.36
P_2O_5 total	1.03
F total	0.76
Organic matter	0.26

Glass fiber: Alkali-resistant glass fiber has been procured from PRP Enterprises, Bhopal, M.P., India for the study.

Properties of glass fiber, as obtained from the manufacturer, were as follows: Filament dia.: 14 microns, Length: 12 mm, Tensile strength: 2500 MPa, Modulus of elasticity: 70 GPa, Color: White, Density: 2780 kg/m^3. Fig. 1 shows the raw materials used in the study.

Fig. 1: Raw materials used in the study - Cement and PG and Glass fiber.

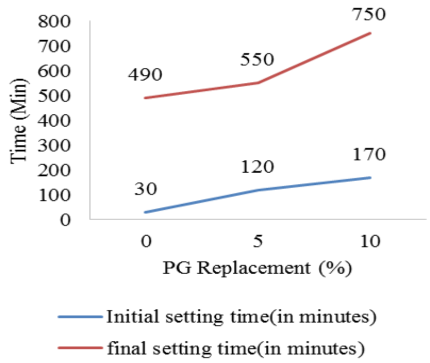

Fig. 2: Setting time with varying percentages of PG replacement

4. RESULTS AND DISCUSSION

4.1 Compatibility with Cement

Results of the normal consistency of cement replaced with PG (0, 5, 10, 15 and 20%) indicate its compatibility with cement paste at normal water content. The results of setting times (initial and final) were shown in Fig. 2. The study has been conducted only up to 10% replacement of PG.

The results have shown that the delay in the setting could be attributed due to the impurities present in the PG. The results also highlight the suitability of PG as a retarder in the place of conventional chemical admixture for wider application in hot weather concreting and mass construction works. The soundness of the cement paste with PG (up to 20% replacement) was observed to be within acceptable limits, indicating the absence of undesirable volume changes. The above results have indicated that greater compatibility for wider application with cement could be observed up to 10% replacement.

4.2 Workability

Results of slump test with 5, 10 and 15% PG replacement (Fig. 3), have shown the consistency of fresh concrete with PG up to 15% replacement, but the homogeneity of the mix was found to vary which could be due to lesser specific surface area of PG in comparison to the cement. Further studies with glass fiber replacement at 0.5, 1, 1.5 and 2% indicate a sudden drop in the slump value beyond 1%; indicating increasing chances of segregation and harshness in the concrete mix in both cases (5 and 10 % PG), as shown in Fig. 4. However, the concrete was found to be workable up to 1.5% glass fiber replacement.

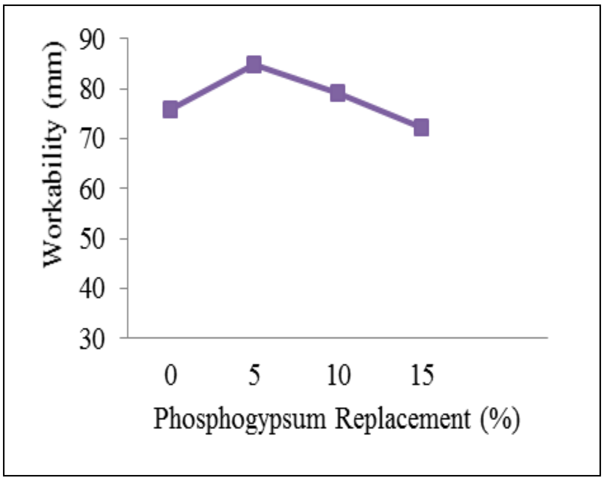

Fig. 3: Workability at varying percentages of PG replacement.

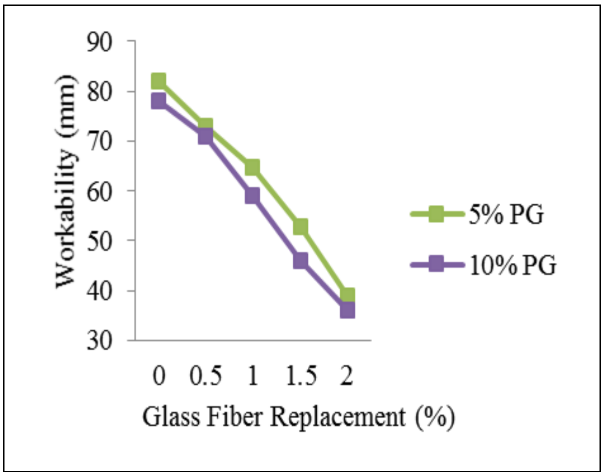

Fig. 4: Workability at varying percentages of Glass fiber replacement for 5% and 10% PG replacement.

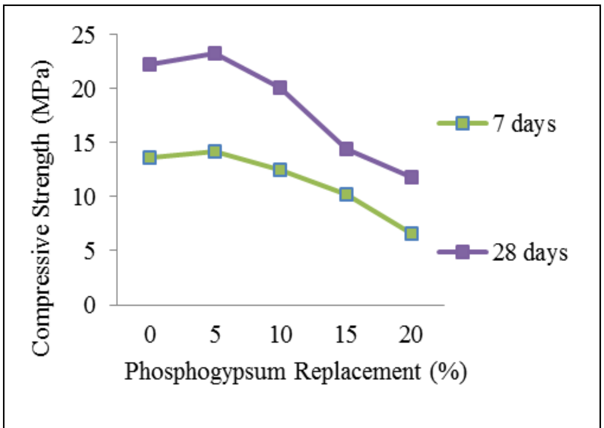

Fig. 5: Compressive strength at varying percentages of PG replacement.

4.3 Compressive Strength

Compressive strengths (7 days and 28 days) with 5, 10 and 15% PG replacements were shown in Fig. 5. The results have shown a decrease in the strength beyond 10% PG replacement; however, up to 10% replacement of PG, the early strength gain and 28-day compressive strength results were observed to be in good accordance with OPC. Further studies with 5% and 10% PG, glass fiber at 0.5, 1, 1.5 and 2% highlight the enhancement in both early and 28 days' strength for both replacements as shown in Fig. 6. The results obtained from specimens have shown better performance in comparison with OPC. At 5% PG and 1.5 % glass fiber, maximum compressive strength gain has been noticed both in 7-day and 28-day trials. The enhancement in the results could be due to the ability of the fibers used in the study to arrest macro-cracks, increasing the load resistance of the specimens.

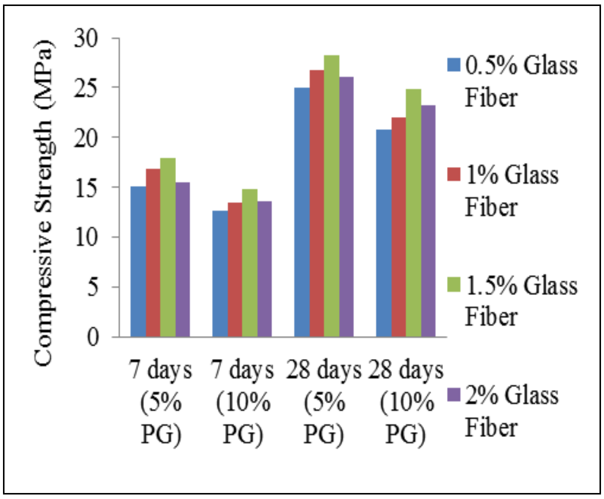

Fig. 6: Compressive strength at varying percentages of Glass fiber replacement for 5% and 10% PG replacement.

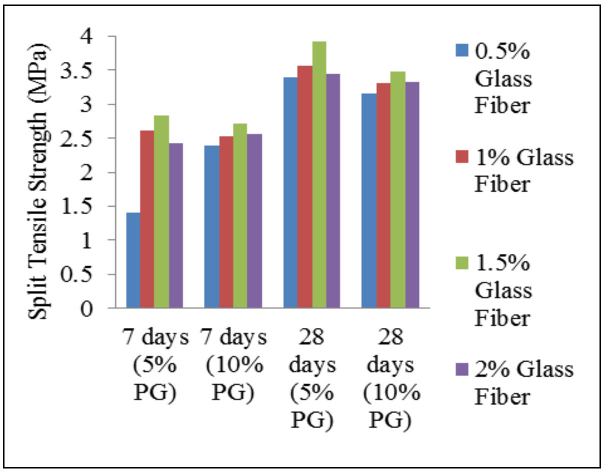

Fig. 7: Split-tensile strength at varying glass fiber replacement for 5% and 10% PG replacement.

4.4 Split-tensile Strength

The influence of glass fibers on tensile strength has been evaluated for 5% and 10% PG replacement with at 0.5, 1, 1.5 and 2% glass fiber replacement, respectively. Results obtained (Fig. 7) have shown an increase in tensile strength at the end of 7 days and 28 days for both replacements. Maximum tensile strength was obtained at 5% PG and 1.5 % glass fiber for 7-day and 28-day trials. The results have proved that fibers used in the study have increased the tensile strength of concrete specimens by bridging the cracks.

5. CONCLUSION

The study has proved the possibility of adopting industrial by-products such as phosphogypsum for the production of sustainable concretes. Adaptation of such concretes provides substantial ecological and economic benefits. The study was performed with raw unprocessed PG and the possible issues were addressed with glass fiber replacement for nominal M20 concrete mix. Raw PG was observed to be compatible with cement without causing any changes in the volume. PG was observed to be well-suited as an admixture for retarding the setting time in construction works. Experiments on fresh and hardened concrete have substantiated the suitability of PG at 10% replacement with 1.5% glass fiber replacement. The obtained results were found to be better in comparison with OPC.

The present work has broadly examined the feasibility of sustainable concrete processed with phosphogypsum and glass fiber, which has been in conformance for M20 concrete. The following aspects could be considered for further research:

- The influence of atmospheric agents on concrete specimens incorporating these materials has to be further investigated for a wider application.
- Adaptation of processed phosphogypsum and will extend the research to high-strength mixes.
- Studying the influence of nature of the fiber, fiber geometry, orientation and distribution of fibers on the concrete mixes is a promising avenue.
- Technical and cost analyses in processing, transport and manufacturing of concrete with waste materials for application at a commercial scale can be done.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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