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A Review of Effective Utilization of Waste Phosphogypsum as a Building Material

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Abstract : ***The phosphogypsum (factory .Over 6 million tons of PG is produced per annum in India and poses various environmental and storage problems. Out of these some quantities are utilized for of production of ammonium sulphate and few for other uses, there is accumulated stock of PG) is the industrial waste by-product produced in various industries like fertilizer industry, phosphate ore, phosphoric chemical more than 10 million metric tons of PG at various plant sites. This paper covers the literature review of effective and economical utilization of PG as building material in the various ways. The phosphate industry has been searching different ways of reducing the size of PG stacks. Researchers have also been seeking new application areas for PG use as studies have indicated that it would be more environmentally sound to use by-products rather than to dump them. In today' world, there is an ever increasing demand for construction due to population expansion and shortage of building materials. Utilization of industrial waste such as phosphogypsum not only solves environmental problems but also provides a new resource for construction industry.***

Keywords: Phosphogypsum, Solid waste, Environmental pollution, Building material.

I. Introduction

Traditionally materials like clay, sand, stone, gravels, cement, brick, block, tiles, distemper, paint, timber and steel are being used as major building components in construction sector. All these materials have been produced from the existing natural resources and will have intrinsic distinctiveness for damaging the environment due to their continuous exploitation. The cost of construction materials is increasing incrementally. In India the cost of cement during 1995 was Rs. 1.25/kg and in 2015 the price increased five times. In case of bricks the price was Rs. 0.66 per brick in 1995 and the present rate is Rs. 7 per brick. Similarly, over a period of 20 years from the year 1995 the price of sand has increased five times.

Also due to high transportation costs of these raw materials, demand, environmental restrictions, it is essential to find functional substitutes for conventional building materials in the construction industry.

In India, about 6 MT of waste gypsum such as phosphogypsum, flurogypsum etc., are being generated annually there for it is necessary to set a secondary industries and recycling these waste into useful material. About twelve fertilizer plants in the country produce nearly 4 to 5 million tons of Phosphogypsum as a by-product. While some quantities are utilized for production of ammonium sulphate and few other uses, there are accumulated stocks of more than 10 million metric tons of Phosphogypsum at various plant sites. Major producers are Coromandel Fertilisers (Andhra Pradesh), Fertilisers & Chemicals, Travancore (Kerala), Gujarat State Fertilizer Co. (Gujarat), Hindustan Lever Ltd. (West Bengal), Southern Petrochemical Industries Corporation (Tamil Nadu) & Paradeep Phosphates Ltd. (Orissa). Disposal of Phosphogypsum is not only a serious techno-economic problem but creates environmental pollution and requires large land area for dumping. So by using Gypsum as a building material problem of dumping waste can be solved in eco friendly manner. Gypsum has been in use since ancient times. First known use of Gypsum dates back to 3700 BC in Egypt for the construction of Pyramids. In modern times with the help of advancement in technology for calcining of gypsum and various innovative production processes a range of gypsum based products and construction applications have been developed. These technologies have shown potential for commercialization and wide spread adoption in building materials production and variety of civil works.

II. Material

Generation of Phosphogypsum

Phosphogypsum is generated from filtration process in phosphoric acid plants where insoluble gypsum and other insoluble are separated from the product i.e. phosphoric acid as efficiently as possible .Depending on the source of rock phosphate, about 4.5 - 5 Tonnes (dry basis) of phosphogypsum is generated per Tonne of phosphoric acid (as P2O5) recovered.

The quality & quantum of phosphogypsum generation depends upon the quality of the phosphate rock, process route used to produce phosphoric acid, calcium sulphate generated either in di-hydrate (CaSO4.2H2O) or the hemi-hydrate (CaSO4.1/2 H2O) form. Phosphogypsum generation in the Country is about 11 Million Tonnes per annum (based on the assumption that 5 Tonnes of phosphogypsum generated per Tonne of phosphoric acid production). The industry-wise production of phosphoric acid and estimated phosphogypsum scenario in the country as per the information provided by the phosphatic fertiliser units is compiled and given in **Table below**

year	Phosphoric acid production*	Estimated Phophogypsum generation**
2000-01	1042.4	4690.8
2001-02	1134.7	5106.15
2002-03	1085.6	4885.2
2003-04	990.1	4455.45
2004-05	1242.5	5591.25
2005-06	1067.8	4805.1
2006-07	1331.8	5993.1
2007-08(p)	1206.5	5429.25
2008-09(p)	1201.7	5407.65

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2009-10(p)	1160	5407.65
2010-11(p)	1544.6	5220
2011-12(p)	1740.4	6950.7
2012-13(p)	1394.7	6276.15

Source: Fertilizer Association of India.

* = Out of indigenous production

** = Estimated quantity of phosphogypsum generated (Apprx. 4.5 tons of phosphogypsum/ton of phosphoric acid produced)

(P) = Provisional;

Note: Phosphoric acid is expressed as 100% **P2O5**

Plaster developed from this waste gypsum has showed improved engineering properties without any harmful effect. Phosphogypsum and lime sludge were recycled for manufacture of portland cement, masonry cement, sand lime bricks, partition walls, flooring tiles, blocks, gypsum plaster, fibrous gypsum boards, and super-sulphate cement Phosphogypsum could also be used as a soil conditioner for calcium and sulphur deficient-soils and it also has fertilizer value due to the presence of ammonium sulphate.

III. Literature and Discussion

Dr. Manjit Singh carried out research and shown that gypsum produced from Phophogypsum can used for making blocks and boards suitable for internal partition wall and in false ceiling works. Blocks of different densities (900-1100 kg/m^3) have been prepared by adjusting the consistency of slurry. Fibrous gypsum plaster board have also been prepared from gypsum slurry and reinforced with sisal/coir/jute fibre. A process for manufacturing of board of size 120×60×12mm has been developed. a high strength hemihydrates plaster(a- plaster)has been developed from the beneficiated Phosphogypsum using autoclave process. Recently cementitious binder has been produced using a-plaster for use in boards, blocks, masonry, plastering works etc. A review also shows that water resistant gypsum binder has been developed by blending ground granulated blast furnace slag or fly ash, opc and chemical additive with calcined phosphogypsum.

Phosphogypsum has been used for glass reinforced gypsum binder boards (GRGB) of dimensions 400×750mm by reinforcing E-type of glass fibers in gypsum binder matrix by suction process. These boards are recommended for partial replacement of depleting timber in view of their wood like properties. The phosphogypsum binder has been found suitable for making masonry mortars of properties: mix 1:4(binder: sand) compressive strength 3.5-4.5 MPa bond strength 0.017-0.018 N/mm^2 and water retentivity

65-67%.higher water retentivity implies superior workability of mortar. [**vi**]

S. S. Bhadauria and Rajesh B. Thakare conducted experiment and their study shown that the mixture in which cement replaced with five percent phosphogypsum having almost same standard or normal consistency than that of plain cement and thus water requirement of the cement – phosphogypsum mix minutely affected. But, further replacements of ordinary Portland cement with raw PG seriously affect the consistency.

Phosphogypsum in ordinary Portland cement mixes considerably retards setting time but does not contribute to produce unsound cement paste. Phosphogypsum can be economically used up to five percent as an ingredient or admixture of cement-mortar mix, both for stone and brick masonry work. The degree of workability of concrete mix with five percent phosphogypsum decreases as compared to conventional concrete, but it improves cohesiveness of the concrete mix and thus reduction in segregation and bleeding.

The compressive strength of phosphogypsum cement concrete (with five percent PG) is improved indicates that phosphogypsum has immense potential to be utilized in concrete applications, especially mass concrete work. [**xv**]

Ouyang, Nanni and Chang studied sulphate attack resistance of Portland cement mixture containing phosphogypsum and conventional aggregate. A wide range of SO3 and C3A contents were investigated with respect to linear expansion and compressive strength development for specimen submerged in fresh and seawater. The cement contents were varied between 10% - 30% by weight, whereas phosphogypsum varied from 0 – 50%, lime rock aggregate was used. The results indicated that, the optimum C3A content, which corresponds to minimum expansion, is about 1.1% for Portland cement having C3A content less than 7%. And phosphogypsum contents directly proportional to expansion in cement mixes. Seawater immersion decreases the strength development rate of cylinders and increases linear expansion of bars [iv].

W. F. Chang investigated the effectiveness of phosphogypsum based concrete by 10% cement and 90% phosphogypsum in corrosion protection of reinforcement. Test results indicated that pH value increased rapidly when phosphogypsum mix contained small amount of cement. Other effective way of protecting against corrosion was increasing thickness of cover. [**xvii**]

Nanni produced bench model phosphogypsum bricks of size 45 X 95 X 203 mm with semi automatic press having a capacity of 1780 kN. The bricks thus produced were handled immediately after fabrication. The bricks were found good in appearance and strength [**ii**].

Chang, Chin and Ho published state of art report on phosphogypsum for secondary road construction. It was concluded phosphogypsum when subjected to compaction could be transformed into a solid of valuable strength. It could be used very effectively as binder to stabilized soil, replace shell or clay in secondary road and aggregate and water. A base course was built by spreading 5 inch of loose phosphogypsum on existing soil, over which the concrete was laid. This pavement was tested for abrasion, durability, shrinkage, compensation, onsite deflection and radiation monitoring. The project demonstrated that PG based RCC was suitable for construction of parking facilities. [**x**].

Nanni and Chang reported application of phosphogypsum was investigated as an aggregate in construction of various Roller Compacted Concrete (RCC) slabs. Several phosphogypsum-based mixtures were prepared in three different mixing procedures and were compacted using suitable vibrator. A thickness design procedure of this concrete pavement was also suggested. The project indicated that phosphogypsum based RCC was suitable for pavement construction applications. Moreover, phosphogypsum was suitable, as it provide set retardation and drying shrinkage compensation. [**I**]

Ong, Metcalf, Seals and Taha studied unconfined compressive strength of various cement stabilized Phosphogypsum (CSPG) and it was shown that the mix behaves like cement-stabilized soil. The strength and its relation between parameters were studied for different curing

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conditions. It was concluded phosphogypsum could be stabilized with cement to produce an adequate material for road base construction to the requirement of the local codes [**xiv**].

Foxworthy, Ott and Seals utilized phosphogypsum based slag aggregate in Portland cement concrete mixtures. The durability behaviour of such aggregate was explored. The entire preliminary tests on phosphogypsum were performed. The phosphogypsum slag aggregate based concrete mix
was prepared and tested for compressive strength, flexural and splitting tensile strength. The result indicated that the slag aggregate performed well as a coarse aggregate in cement concrete and should perform satisfactorily in highway pavement system [**x**].

Roy, Kalvakaalava and Seals were studied micro structural and phase characteristics of phosphogypsum cement mixtures. The effect of tricalcium aluminate (C3A) content of the stabilizing cement (with two different C3A percentage), curing time (7, 28, 45 and 90 days), proportion of phosphogypsum (5% to 60%), grain size, impurities in phosphogypsum on microstructure (SEM) and phase properties of mix was studied. Derivative thermogravitimetric analysis (DTA) was used in this study for hydrated products of these mixes. The study was concluded the addition of phosphogypsum to Portland cement produced large amount of ettringite. Phosphogypsum increased the degree of hydration of cement in the mixtures in the long term. The amount of carbonation in phosphogypsum based mixture was found relatively low **[iii**].

Smadi, Haddad and Akour studied utilization of phosphogypsum as cement (OPC and PPC) replacement agents in mortars and found decrease in compressive strength and increase in flexural strength as compared with conventional mix. The incorporation of phosphogypsum in the cement has drastically increased its initial strength. This strength development was attributed to formation of anhydrate at higher temperatures [7].

S. Kumar investigated the physical and mechanical properties of FALG bricks and hollow blocks by using different proportions of fly ash, lime and gypsum. The durability of these blocks was also investigated. It was concluded that these blocks were sufficient strength for their use in load bearing walls [**xiii].**

Rapid Building System Pvt. Ltd. An Australian building industry for a decade where it is called Rapid wall. Shown that in there broacher until 2001 more than 3000 dwellings have been built out of Rapid wall panels across Australia. Rapid wall technology was introduced to Malaysia in 1997. It has also been exported to China since 2001 to satisfy the demand for an alternative residential walling product to replace clay bricks. The use of clay bricks is being outlawed by the Chinese authorities as an environmental protection measure, which has resulted in an unprecedented interest in Rapid wall panels.

Rapid wall panels have undergone testing by Indian authorities and are presently imported to India to satisfy the need for a cost-effective, easy to construct and environment-friendly solution to their housing crisis. Rapid wall panels are Australian developed and manufactured walling product used in building industry to provide habitable enclosures for residential, commercial and industrial buildings. Now in India method of construction of building using Rapid wall panels is prepared by IIT Madras to suit Indian situation. ***RCF (Rashtriya Chemical and Fertilizers)*** is a PSU of Government of India's undertaken setting their plant at Chembur to meet the huge demand of Mumbai market. [**xii**]

Nurhayat Degirmenci in his research waste phosphogypsum (PG) and natural gypsum were used as stabilization material to improve the properties of adobe soil and to reduce its disadvantages at least partially. The compressive and flexural strength, softening in water, drying shrinkage and unit weight values were determined on adobe samples. The strength values of adobe samples increased with both gypsum additions. The most resistance of the adobe samples against softening in water was obtained with 25% PG addition. Drying shrinkage of test samples reduced with increasing PG content. The dry unit weight of the specimens was not in the recommended range specified in the standards. Test results showed that PG can be used as alternative material in adobe stabilization to bring economy and to reduce environmental pollution.

Adobe is one of the oldest and most widely used building materials in the world. Adobe, or as it is called in Turkey ''kerpic'', has been a traditional construction material especially in rural regions because of its simplicity and low cost. In addition to these, adobe construction has other advantages as well, such as good thermal and acoustical properties. Adobe also is an ecological building material as it uses natural elements. At the end of a building's life, adobe can easily be reused by grinding and wetting or returned to the ground without any interference with the environment. [**ix**]

III Conclusion

After studying all these papers it is come to know that phosphogypsum is in use from ancient period to till date and it necessary to be continued because of its tremendous availability as waste product in order to reduce problem of disposal as solid waste. It is used as building and construction material in various ways. This paper will help to new researchers and user how and where the waste phosphogypsum can be used as building and construction material in glance. Phosphogypsum can be used as separate building material or as admixture in concrete, cement mortar, pop, stabilizer or in combination with other waste material.

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