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AN ENVIRONMENTAL SOLUTION FOR PHOSPHATE COARSE WASTE REJECT-USING THEM AS CONCRETE MIX AGGREGATES

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Large quantities of coarse solid wastes are generated during the beneficiation of Egyptian phosphate ores. The volume of the solid waste generated and accumulated from the mineral processing activities, is the main pollution concern in the mining area around the plant. However, these wastes, because of their similarity to conventional aggregates, represent a potentially useful source of material for a variety of applications.

This paper examines the suitability of the coarse solid wastes generated from upgrading phosphate ores as aggregates in concrete mix. The properties of these wastes are tested, according to the Egyptian Standard Test Methods for Concrete Mix (ESTMCM). According to the results obtained, the mean value of uniaxial compressive strength of standard concrete cubes tested after 28 days of curing was found to be in the average 240 kg/cm^2 (ESTMCM ranges between 180 – 300 kg/cm^2). The obtained results proved that this kind of wastes can be used for concrete mix in civil constructions. The positive uses of these wastes are considered beneficial from the economic and environmental points of view.

KEYWORDS: *Phosphate waste utilization, Concrete mix, Aggregates for civil constructions, Environmental cleaning, ESTMCM.*

INTRODUCTION

Deposits of natural gravel, especially those located close to major urban centres, are getting depleted and becoming costly due to transportation costs and environmental restrictions [1]. Furthermore, the same time, the problem of disposing and managing solid wastes from mining and mineral processing plants has become one of the major environmental,economical,and scoial issues [2].

The possibility of using solid wastes as aggregates in concrete has received increasing attention in recent years as one of the promising solutions to the escalating solid waste problem [3]. The use of solid waste, in construction in general and concrete mix in particular, is not a new concept, e.g., industrial wastes are the basis of many concrete admixtures, fly ash has been used as a pozzolanic substance in concrete for several decades**,** and blast furnace slags have been used both as aggregates and as a cementitious material. Also granulated waste plastic, glass, and fiberglass waste materials were used to partially substitute the fine aggregates (sand) in concrete composites [1-4]. The successful utilization of solid wastes in concrete will depend on anticipated potential problems and the ensuing properties of the concrete, and develop uses that comply with these restraints.

The mining industry has traditionally made use of its own waste materials, either by reprocessing to recover additional minerals as economic conditions prevail, for land reclamation, cavity filling, or using them for internal construction purposes [5]. When the location and material property characteristics are favorable, some sources of waste rock or coarse mill tailings my be suitable for use as granular base/subbase, railroad ballast, Portland cement concrete aggregate, asphalt aggregate, and engineered-fill or embankment [5-6].

Aggregates generally occupy about 70 to 80% of the volume of concrete and can therefore be expected to have an important influence on its properties [2]. A good aggregate material, whether fine or coarse, is one that is clean, hard, strong, resistant to weathering action, contains no impurities which affect the strength of the concrete, and is well graded. The latter factor is particularly important in that it controls the workability of the plastic mass [3, 7-9].

Portland cement concrete is made up of: Portland cement, water, and aggregates. Each of these must meet certain requirements in order that quality concrete is produced [7-10]. Compressive strength is the simplest and easiest one of all the characteristics of concrete to be determined, and concrete design is usually based on this property. According to ESTMCM, normal concrete strength ranging between 180 and 300 kg/cm ^{2} is widely accepted in common buildings [9,11].

Specifications and design criteria for concrete depend primarily on the strength requirement, exposure, and placing conditions [7,9]. Detailed proportions can be specified, or general requirements can be given and trial mixes are prepared to design a concrete mix meeting the requirements. In Egypt, for the local and small structural jobs, the general proportions by weight of concrete mix (cement : sand : aggregate : water / cement) is 1:2: 4 : w/c , and w/c is in the range between 0.4 and 0.7 [9]. For ordinary reinforced concrete structures, the concrete should contain 300 kg of cement per cubic meter. The maximum nominal size of the aggregate to be selected for a particular job depends upon the width of the section and the spacing of reinforcement [7, 9, 11].

It is generally advantageous to use as large a maximum size of aggregate as possible, although experimental investigations have indicated that the improvement in the properties of concrete with an increase in the size of aggregates does not extend beyond about 40 mm [9]. The nominal size grading of coarse aggregate used in concrete mix in Egypt are 40, 20, 10 and 5 mm, i.e., the maximum nominal size of 40 mm is commonly used in Egypt.

The most common strength test uses standard cubes of dimensions 15x15x15 cm [12]. They are made in a specified manner, allowed to set, and then cured in the laboratory in a humid atmosphere for a specified period. Proper curing requires water, and a favorable temperature. Usually the strength is determined after 28 days of casting. However, 7-day strength may be obtained either as an indication of the expected 28-day strength or as a specified strength [9, 12].

There are large accumulations of over screen rejects (more than 10.0 million tons) produced from the phosphate milling plants in Egypt [13]. The accumulation of these solid wastes constitutes environmental problems and must be removed. The goal of this investigation is to examine the possibility of using coarse solid wastes generated from the phosphate processing plants in concrete aggregates as a substitute for the natural coarse aggregates (flint or hard rocks) in a Portland cement concrete mix to produce concrete with compressive strength able to satisfy the construction purposes of small buildings. The substantial benefits of using these waste materials in concrete mix are to reduce handling costs of these rejects, to provide a solution for the environmental problems created by the waste accumulation, and for preservation of the natural aggregates for heavy duty concrete jobs.

EXPERIMENTAL WORK

Material

Materials used in Portland cement concrete admixtures are Portland cement, water, fine aggregates, and coarse aggregates [7]. Each of these constituents must meet certain requirements in order that quality concrete is produced. A head sample of 100 kg solid wastes (over screen reject) was obtained from waste dumps of Sebaeya Phosphate Company as a representative sample of the phosphate reject wastes generated at the phosphate processing plants in Egypt. The head sample was crushed to pass 40 mm (the maximum size of aggregates for concrete mix as specified by ESTMCM specifications). The crushed product is thoroughly mixed and split into samples of 10 kg each. Figure 1 shows a picture of the crushed product used as coarse aggregates in this work. The head sample assay was 21.65 % SiO_2 , 42.95 % CaO, 0.040% Na_2O , 0.03 % K_2O and 8.74% LO.I. Natural sand of size less than 5 mm is commercially used in all concrete mixes.

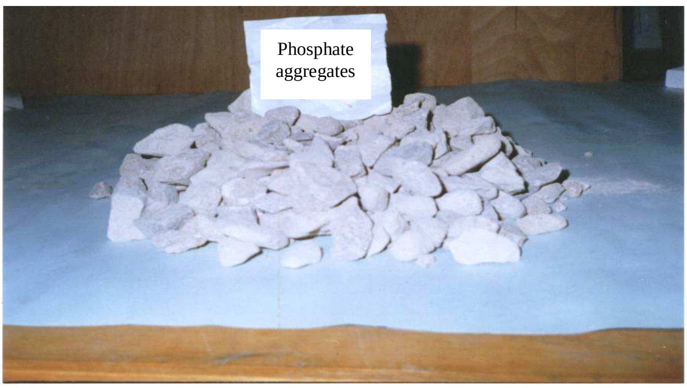

Fig .1: The Coarse aggregate used in concrete mix.

Procedures

Aggregates strongly influence the hardened properties of concrete, its mechanical properties, and economy of the operation. Consequently, selection of aggregates is an important process. Although some variations in aggregate properties are expected, the most important aggregate quality tests are:

1- Physical properties: such as particle shape, surface texture, true density, bulk density, water adsorption, voids in coarse aggregates, specific surface area, and deleterious substances (dust coating, clay and silt, etc.). Details of the test procedure are given in references [7, 10].

2- Chemical properties: such as Efflorescence, chlorine ion percent (Cl^-), sulfate content (SO_3) and alkalinity. The Test procedure is given in details in references [9, 11, 14].

3- Gradation: The purpose of this test is to obtain a specific grain size distribution of fine and coarse aggregates used in concrete mix. The standard set of sieves often used in coarse aggregate gradation is: 40, 20, 10, and 5 mm, and in fine aggregates (natural sand) are: 5, 2.5, 1.25, 0.630, 0.315 and 0.160 mm. The test procedures are given elsewhere [8, 10, 16].

4- Mechanical properties: The most important mechanical proerties are**:**

a- Crushing strength: the coarse aggregates used in concrete mix should be strong enough to withstand heavy loads. The crushing strength of coarse aggregate is expressed as "Aggregate crushing value" which is the percent of minus 2.5 mm material in the crushed load. The apparatus used for this purpose is given in references [8, 16] and shown in Fig. 2. The procedure of the test is given in details in references [7, 8, 10] .

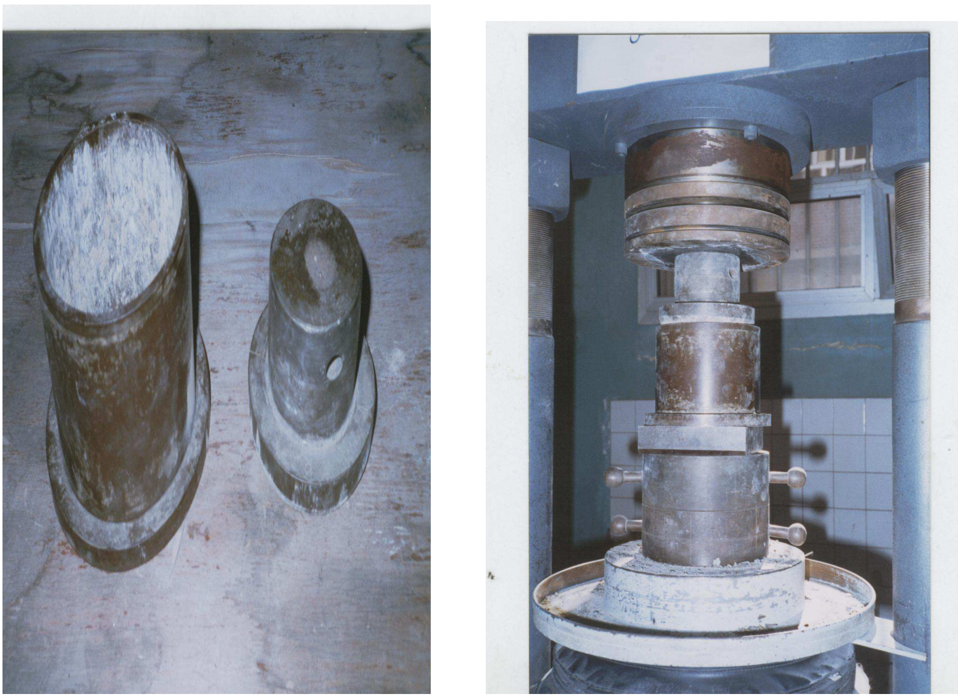

Figure 2 : The crushing strength apparatus

b- Compressive strength: It is the simplest, easiest and most important test of all for determining the properties of concrete. The compressive strength of concrete is the most common measure for judging the quality of concrete. To study the mechanical properties of concrete made from phosphate solid waste rejects, standard dimensions of concrete cubes of 15 x 15 x 15 cm (as shown in figure 3) were prepared with ratio of

1:2:4 : w/c (cement : sand : aggregate : water/ cement ratio). The water/cement ratio used was between 0.4 and 0.7. Extra water may be required to produce an easy flow and more workable concrete mix. A thin layer of oil was applied on the internal faces of molds to ensure that demolding of casted cubes is easy without damaging the cubes. All the cubes were demolded after 24 hours and immersed into water for further curing. Uni-axial compressive strength (Figure 4) was determined at aging periods of 7 and 28 days after casting. Procedures for making and testing the cubes are given in references [9, 11, 12, 14] .

Figure 3 : Molded concrete cubes

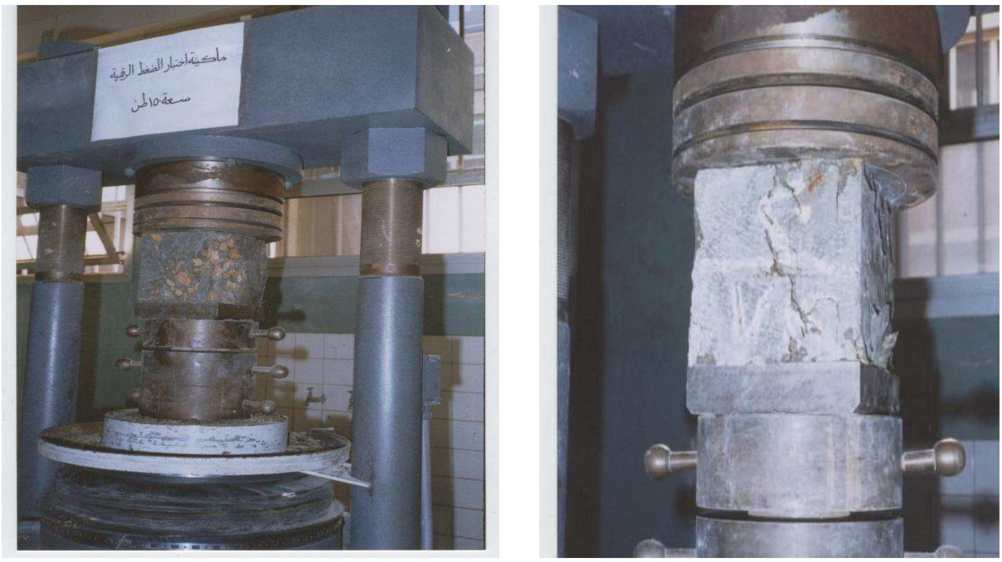

Figure 4 : Hardened concrete cube under compression test.

RESULTS AND DISCUSSION

Aggregates should consist of clean, hard, strong and durable particles. The most important properties of aggregates which influence the properties of concrete are their physical, chemical, and mechanical properties. The mandatory tests of concrete aggregates which have been studied in this research work include the following properties:

1-Physical properties:

The measured physical properties of coarse aggregates used in this study as well as the standard values of each property, whenever there are corresponding standard values, are summarized in Table 1.

Table 1: physical properties of the investigated phosphate aggregates.

Property	Measured values	Standard values*
Particle shape	Irregular	-
Surface texture	Rough	-
True density g/cm^3	2.65	2.5-2.9
Bulk density g/cm^3	1.4	-
Water absorption, wt. %.	6.0	≥ 2.5
Deleterious substances	1.51	< 3
Voids, %	40%	30-50%

*The standard values are taken from references [8-11 ,17- 20]

Most of the physical properties of the tested sample were within the range of standard specifications and matched the Egyptian Standards of natural aggregates [10].

2. Chemical properties:

The chemical properties of sand and coarse aggregates used in this study are summarized in Table 2. The chemical tests were carried out according to Egyptian standards 1108-1971 [14].

Table 2: Chemical properties of the tested phosphate aggregates sample and natural sand.

Property	Coarse Aggregates		Sand	
	Measured results	Standard values*	Measured results	Standard values*
Chlorine ion, wt. %	0.0238	<0.04	0.034	<0.06
Sulfate content, wt. %	0.0709	0.40	0.083	0.40
pH	7.6	alkaline	8.2	Alkaline
Efflorescence	Non	-	Non	-

*References [8, 10, 11, 14, 16]

It is clear from Table 2 that the chemical properties of the tested sample fall within the ESTMCM Standards and they are suitable to be used as aggregates in concrete mixes [14, 16].

3. Grading of aggregates and natural sand:

Grading of aggregates is one of the common tests performed on the aggregates before using for concrete mixes, as it is important for concrete workability and strength. This grading test is performed for coarse aggregates as well as sand. The governing parameter for aggregates, coarse and fine, is the Fineness Modulus. This modulus is defined as "The cumulative percent retained on nine sieves, (which are 40, 20, 10, and 5 mm. for the coarse aggregate and 2.5, 1.25, 0.630, 0.315, and 0.160 mm. for the sand [8].

a - Gradation of coarse aggregates: The obtained results for the grading of aggregate sample are given in Table 3. Based on this information, the Fineness Modulus and specific surface area can be calculated [8]. The sieve analysis was carried out according to the Egyptian Standards [10].

Table 3: Grading of coarse aggregate.

Maximum nominal size, mm	40	20	10	5
Cumulative passed ,%	100	31.40	10.33	4.83
* Standard values, %	95-100	30-75	10-40	0-5

* References [7, 8, 10, 11, 18]

Fineness modulus (FM) = 7.53, Standard values of FM = 5 to 8,

Specific Surface area S.A. = 2.48 cm^2/g , Standard values of S.A = 2 to 5 cm^2/g

Table 3 shows that the aggregate gradation matches the limits for all sieve sizes. As the value of Fineness Modulus gets higher, the coarser is the particle size of the aggregates. It is not necessary that 100 % of aggregate particles can be within the specified size range. For construction purposes about 5 % to 10 % is allowed to be either larger or smaller than the specified size. It would be economically impossible to ensure that 100 % of the particles are within any specified size range [7]. Also, the Fineness Modulus, FM, and specific surface area, S.A., are within the standard values.

b- Grading of natural sand: The grading of sand is usually carried out for its size distribution, surface area, and Fineness Modulus. The sieve analysis of the sand is given in Table 4.

Table (4): Sieve analysis of natural sand

Maximum nominal size, mm	5	2.5	1.25	0.630	0.315	0.160
Cumulative passed, wt. %	100	99	92	55	21	03
* Standard values, wt. %	90-100	75-100	55-90	35-59	8-30	0-10

* References [7, 8, 10, 16, 18]

Fineness modulus (FM) = 2.3, Standard values of FM = 2 to 3.75

Grading of sand = medium Bulk density = 1.60 g/cm^3 ,

True density = 2.55 g/cm^3

Specific Surface area = 67.35 cm^2/g, Standard values of S.A. = 60-100 cm^2/g

The above results show that the sand gradation matches the limits for most of the sieve sizes, and falls within the Standard range.

4- Mechanical Properties:

a- Crushing strength:

It is the compressive load that aggregate particles can carry during the breaking test. The crushing strength of coarse aggregate is usually determined by means of special standard test procedure. The crushing strength of coarse aggregates (Aggregates Crushing Value) is usually expressed by the percent of minus 2.5 mm material in the crushed load. The crushing strength test results for three replicates carried out for evaluating the crushing strength of the used phosphate waste aggregates are given in Table 5.

Table 5: Crushing strength test results

Item	Test 1	Test 2	Test 3
Crushing strength, %	29.18	30.20	28.62
Average measured, %		29.33	
* Standard values , %		30-40	

* References [8, 16, 19]

The crushing strength percent for the three replicates is reproducible. The average measured value of the crushing strength, although in the low limit, it falls within the limits of the standard value.

b-. Compressive strength:

Quality of concrete can be determined by the compressive strength of hardened concrete cubes with dimensions of 15x15x15 cm made from working concrete mix, after 7 and 28 days curing periods. The conventional concrete used for both plain and reinforced concrete members may be of strength levels of: 150, 175, 200, 225, 250, 275 and 300 kg/cm^2 [17, 18, 19, 20]. In moderate-size buildings, concrete of strength level between 180 and 300 kg/cm^2 is recommended [9, 11, 15]. The compressive strength and weight of the hardened concrete cubes of curing period 7-day and 28-day are given in Tables 6 and 7, respectively.

It is observed that the increase in compressive strength after 28 days curing period represents about 28.5 % from the compressive strength value after 7 days curing period.

Table 6: The results of compressive test at 7-day curing period

Test No.	Weight, kg	Compressive strength, kg/cm^2
1	8.450	191.72
2	8.270	189.27
3	8.630	179.30
Average value	8.450	186.76

Table 7: Compressive strength test results of 12 cubes, cured for 28 days.

Test No.	Cube weight, kg	Compressive strength, kg/cm^2
1	8.300	247.29
2	8.400	243.75
3	8.350	193.05
4	8.450	260.49
5	8.530	192.16
6	8.420	268.22
7	8.420	230.04
8	8.510	274.34
9	8.540	222.72
10	8.400	257.55
11	8.355	227.40
12	8.420	262.24
Average	8.425	239.94

It should be noted that, the variation in compressive strength values of the tested cubes (Table 7) may be due to the segregation phenomenon that may have taken place in concrete mixtures during casting [9,15].

Data in Table 7 were analyzed statistically for the quality control of the product [15, 21]. The obtained values of σ and υ are reasonable compared with those reported in the literature [15, 21]. A standard deviation of 28 kg / cm ^{2} would indicate very consistent concrete. Values up to 35 kg / cm ^{2} are considered acceptable [7, 15, 21]. The following technique was used for the statistical analysis:

$$\bar{x} = 239.94 \text{ kg/cm}^2$$

$$\sigma = \sqrt{\frac{\sum\left(x - \bar{x}\right)^2}{n-1}} = \pm 27.49\ \mathrm{kg/cm}^2$$

$$v = \frac{\sigma}{\bar{x}} * 100 = 11.46\%$$

where:

x is the tested strength vlues

$\bar{x}$ is the mean strength vlue

σ is the standard deviation

υ is the coefficient of variation

SUMMARY AND CONCLUSIONS

The present study focused on the use of solid wastes (over screen reject) produced during processing of phosphate ores, as a replacement of the coarse natural aggregates in concrete mix. Generally, a high quality material may not be used where a lower quality aggregates are available at reasonable cost and with the appropriate properties. This study matches society's need for clean environment in the vicinity of the phosphate mining and processing areas in an economic way. The obtained results in this research work, as correlated with the standard values, can be summarized as follows:

1- The properties (physical & chemical) of coarse phosphate waste aggregates are similar to those of the natural aggregates used in concrete for civil construction.
2- Such kind of solid wastes can be used in concrete mix without seriously hindering the mechanical properties of the concrete.
3- Concrete of about 240 kg/cm^2 compressive strength can be obtained, which is suitable for the construction of ordinary buildings, especially, those in local communities around the mining regions.
4- The convenient use of such solid wastes will render them as useful profitable products. The coarse phosphate processing waste rejects can be considered, generally as useful resources, and particularly as aggregates in concrete mixes.
5- Finally, a critical environmental problem for the neighboring society and for the phosphate company can be solved.

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حل المشكلة البيئية الناتجة عن تراكم النفايات الخشنة الناتجة من تركيز الفوسفات – باستخدامها كركام في خلطات الخرسانة

ينتج من تركيز خامات الفوسفات كميات كبيرة من النفايات منها الناعم ومنها الخشن حسب طريقة التركيز المستخدمة. وكلا النوعين ملوث للبيئة ويحتاج الى أماكن للتخزين وتكلفة للنقل. وهذه الكميات المشونة تتراكم بمرور الوقت وتزداد أخطارها البيئية وأعباؤها المالية. غير أنه من الممكن تحويل هذه النفايات الى مصدر هام من مصادر الخامات الطبيعية التى تستخدم فى العديد من الأغراض المفيدة.

وهذا البحث يركزعلى اختبار مدى صلاحية النفايات الخشنة الناتجة من محطات التركيز لتحل محل المكونات الخشنة (الركام) المستخدمة فى خلطات الخرسانة. وقد تم اختبار خواص هذه النفايات ومقارنتها بالكود المصرى (المواصفات المصرية) لخلطات الخراسانة. وقد أثبتت نتائج الاختبارات التى تم الحصول عليها– والتى أجريت على مكعبات قياسية من الخرساتة المحتوية على النفايات الخشنة– أن القيمة المتوسطة لاختبار الضغط المحوري أحادى الاتجاه بعد مرور 28 يوما من الصب هي حوالي 240 كجم/سم2 ، علما بأن متوسط هذا الاختبار فى المواصفات المصرية يتراوح بين 180 و 300 كجم/سم2 . كما أن الاختبارات الأخرى أثبتت أن هذه النفايات يمكن استخدامها بنجاح فى خلطات الخرسانة المستخدمة فى المنشات المدنية البسيطة. وتعتبر مثل هذه الاستخدامات الايجابية نوع من التخلص المفيد من هذه النفايات حماية للبيئة وتقليلا للتكلفة وتوفيرا للخامات المشابهة (البديلة) والتى يمكن أن تستخدم فى أغراض أهم.