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POTENTIAL USE OF MINES AND QUARRIES SOLID WASTE IN ROAD CONSTRUCTION AND AS REPLACEMENT SOIL UNDRE FOUNDATIONS

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ABSTRACT

In Egypt, large quantities of coarse solid wastes are produced annually during the processing of phosphate ores and quarrying operations of marble and granite rocks. These wastes are stored in piles around or near mine sites, which are aesthetically unattractive and often degrading the environment. Various solutions have been sought for this major environmental problem and the best solution found is recycling. However, these wastes , because of their similarity to the conventional aggregates , represent a potentially useful source of material for a variety of applications (in roadbed and dam construction , as railroad ballast ,as aggregate in concrete and asphalt mixes , …)

The main purpose of this research is to investigate the possibility of utilizing the above mentioned three waste materials in road construction (base and sub base) and as a replacement layers for the problematic soil in foundations. Experimental tests were carried out on these wastes to assess their physical, mechanical and chemical properties, according to the Egyptian standards. The modified proctor and California bearing ratio (CBR) are the most important tests of soil compaction to assess the suitability of any waste materials. The CBR value of phosphate waste is 88% , 95% for crushed marble and about 41% for crushed granite. The obtained results proved that these kinds of wastes can be used in base and sub-base layers in road construction and as replacement soil under foundations. The potential uses of these wastes are considered beneficial from the economic and environmental points of view and saving the natural resources of aggregate.

Keywords: Phosphate processing wastes, Marble and Granite wastes, Waste recycling, Road construction, Environmental cleaning, Resources conservation.

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1. Introduction

Huge accumulations of over screen rejects (more than 7 million tons), are generated as a result of phosphate ore processing at El-Nasr mining Company, Sebaeya, Egypt. Also, large amounts of rock fragments are produced as by-product of crushing bad qualities blocks during quarrying operations of marble and granite blocks. These solid wastes are stored in piles around or near to mineral processing plant and quarry sites, which cause many environmental problems and must be removed.

The problem of disposing and managing solid wastes generated from mineral processing plants and quarries has become one of the major environmental and social issues [1]. Leaving the waste materials to the environment directly can cause many environmental problems. Hence, many countries have been working on how to recycle the waste materials to reduce hazards to the environment [2-4]. Soil foundation and road construction are the two most important fields of recycling mining and quarrying waste materials, because they consume large amounts of natural resources [3, 6].

Many sites in Egypt, especially those located at desert arid places outside the Nile valley, most of these regions posses a problematic soil formation due to their soil structure formation and its dry state conditions. Problematic soil is the soil that causes additional problems from the engineering point of view as a result of the circumstances of its composition or a change in environmental conditions. The most common kinds of problematic soil in Egypt are: Swelling soil (shale, mudstone, clay stone, and marl), collapsible soil and soft clay soil. Many defects are appeared in buildings due to these types of problematic soils [7, 8]. Several techniques have been proposed for the minimization or complete elimination of the effect of the problematic soils on the structure elements [8, 9]. The using of soil replacement is one of the most common methods used for the treatment of problematic soils in Egypt. Soil replacement can be done using natural resources of sand or gravel or a combination of the both. For that mining and quarrying wastes can be used as a replacement layers instead of the natural gravel in soil foundation [9].

The main mechanism of road construction and soil replacement in foundations is the soil compaction. It is one of the most critical components in the construction of roads, and foundations. The major objectives of soil compaction are: increasing the bearing capacity of foundations, decreasing the undesirable settlement of structures, control undesirable volume changes, and increasing the stability of slopes [18, 19]. The modified Proctor and California bearing ratio are the two most important tests should be carried out to assess the suitability of replacement mining and quarrying waste materials as a recycled aggregates instead of natural aggregates for road construction and soil foundation [9].

Roads are mainly constructed from layers of compacted materials which generally increase in quality through the pavement layers to road surface [12]. There are four layers of road construction which are collectively termed as pavement as illustrated in Figure 1. The types of aggregates and the thickness of each layer depend on the type of the road and its use. The behavior of all four layers is crucial to the stability and safety of the road. The lowest layer or sub base is a drainage layer made of unbound aggregate. The above layer called road base is the main load- bearing and load-distributing layer and so it must have a high strength. The base-course layer distributes traffic loads on the road base and provides a shaped surface on which to lay the wearing course. It is the layer on which the vehicles run and which really takes the hammering. The base-course and the wearing course together make up the surfacing and usually consist of asphalt mixture of aggregate and bitumen [13-15].The construction and maintenance of the roads require large amounts of aggregates. For example more than 95% of asphalt pavement materials (by weight) consist of aggregates. The use of recycled materials in road construction instead of natural resources materials result in reducing demand of extracting natural materials and also the best way of the utilization mining and quarrying wastes [16-19].

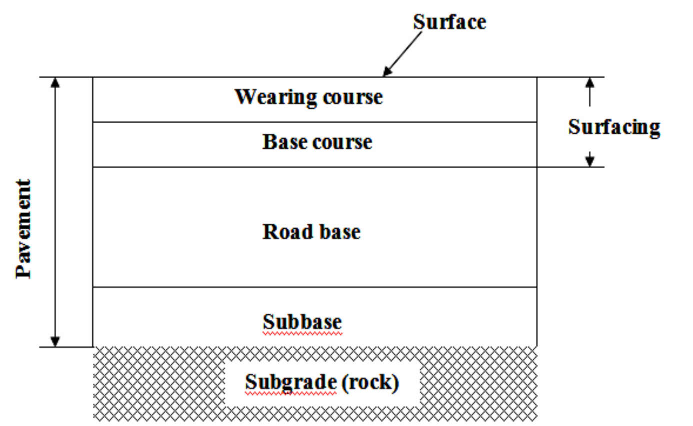


Fig. 1. Structural layers in road construction [12, 13, 17].

The current research focused on the use of coarse aggregates generated from phosphate ore processing, quarrying of marble and granite rocks in the lower courses of the roads

(base, sub-base) and also as a replacement layers for the problematic soil in foundation. These applications absorb coarse natural aggregates in large quantities every year. In order to evaluate these waste materials for their suitability in those applications, it is important to assess their physical, chemical, mechanical and compaction properties.

2. Experimental work

2.1. Materials

Three types of recycled waste materials were used in this study. The main source of these materials is El-Nasr mining company at Sebaeya, Egypt. The first one is over screen rejects of phosphate ore processing. The second and third types of aggregate are rock fragments of the refused marble and granite blocks. Each sample of about 100 kg weight with nominal maximum size of 100 mm. A portion of about 60 Kg from each sample type were crushed to a nominal size of 20 mm for the requirement of the experimental work tests. The crushed product is thoroughly mixed and spitted into batches each of 15 kg by coning and quartering. The pictures of the crushed aggregate used in this work are shown in Figure 1.

(a) (b) (c)

Fig. 2. Crushed aggregated used in this study, a: phosphate wastes, b: marble, c: granite.

The origin of phosphate wastes are sedimentary rocks and consists mainly of hard phosphate particles cemented with siliceous materials. The Crushed marble is a metamorphic rock origin and consists mainly of calcite and dolomite with fine crystalline grains, and the crushed granite is an intrusive volcanic rock (igneous rocks) consists mainly of orthoclase, quartz and mica with coarse crystalline grains.

2.2. Procedures

Roads construction and soil foundation can use large amounts of mining and quarrying wastes directly as materials for embankments, and improved sub grade, road base, sub-base and surface courses. To derive the maximum benefits from these uses , the waste materials must satisfy certain requirements , these are[5,18] :

2.2.1. Physical properties

Such as shape of aggregates, texture, specific gravity, bulk density grading, water absorption, voids in coarse aggregates, and deleterious substances (dust coating, clay and silt, etc.). Details of the tests procedures are well known and published elsewhere [13,20].

2.2.2. Grading of aggregates

The set of sieves used in the laboratory for grading of coarse aggregate which is considered 20, 10 and 5 mm. The test procedure is given elsewhere [13,20].

2.2.3. Chemical properties

This test is necessary for concrete to be placed as foundation. The most important chemical properties, chlorine ion percent (Cl), sulfate content (SO_3), soundness test and alkalinity. The test procedure of the chemical properties is given in details in reference [20]

2.2.4. Mechanical properties

The most important mechanical properties are:

2.2.4.1. Aggregate crushing strength (ACV)

Aggregates used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the stability of the pavement structure is likely to be adversely affected. Apparatus and test procedure for this purpose are given in reference [13, 20, 21].

2.2.4.2. Aggregate impact value (AIV)

The AIV test is used to determine the effects of shock and impact on the coarse aggregates. Procedures of this test and apparatus are given in details in references [20, 22].

2.2.4.3. Los Angles abrasion value (LAV)

This test is an accepted measure of the hardness property of coarse aggregates. The apparatus and procedure of the test are given elsewhere [13, 20, 21].

2.2.4.4. Aggregate slake durability index (Id_2)

It measures the aggregate durability (resistance to weathering). The apparatus and test procedures are given in details in references [23].

2.4.4.5. Modified proctor compaction test

This test measures the maximum dry density that aggregates can reach under a specified compaction stress, and amount of water adsorbed at maximum dry compacted density. The apparatus used and test procedure are given in details in references [9,13]

2.4.4.6. California bearing ratio (CBR)

It is a penetration test for evaluation of the bearing capacity of base and sub-base coarse for the design of road pavement. The procedure of this test is given in references [9,13]

3. Results and discussion

3.1 Grading of the three aggregates used in this study

The obtained results for the grading of the three types of aggregate used in this study and their properties related to grading are given in Tables 1&2. The grading of aggregates used in the field usually 38 mm for the lower layers base and sub-base [12]. There are no specific specification for the grading of the aggregate used in road construction (base and sub-base) it depends on the type of the road, thickness of the base and sub-base layers and finally on the decision of the project engineer [20].

Table 1.
Grading of the three coarse aggregates.

	Phosphate	**Marble**	**Granite**
Sieve opening(mm)	Passing %	Passing %	Passing %
20	100	100	100
10	33.82	31.36	34.12
5	1.46	2.14	1.08

Table 2.
Properties related to grading of the three coarse aggregates.

Properties related to gradation			
Property	**Phosphate**	**Marble**	**Granite**
Fineness modulus	6.67	6.67	6.65
Shape of particles	Irregular	Angular	Angular
Surface texture	Rough	Smooth	Crystalline
Angularity no.	9.22	7.87	8.14
Angularity index	2.38	2.18	2.22

3.2 Physical properties of aggregate

The measured physical properties of the three coarse aggregates used in this study and their standard values of each property, whenever there are corresponding values, are summarized in Table 3. Results showed that most of the physical properties are within the range of standard specifications and match with the Egyptian Standards of natural aggregates used in road construction and soil foundation [9,13,20].

Table 3
Physical properties of the investigated aggregates.

Test name	Aggregate type			
	Phosphate	**Marble**	**Granite**	**Standard Values***
Flakiness index %	20.72 %	24.49 %	18.04 %	< 25%
Elongation index (%)	19.85 %	22.73%	18.48%	< 25%
Water absorption %	5.38 %	0.4%	0.33%	<10%
Loose bulk density	1.20	1.32	1.36	---
Voids percent	45.25%	41.85%	41.05%	---
Apparent specific gravity	2.42	2.62	2.63	2.5-2.8
Deleterious substances -.071 mm%	0.9	0.09	0.03	<10%

* The standard values are taken from references [9, 11, 20].

3.3 Mechanical properties of aggregates

The mechanical properties of the investigated coarse aggregate samples used in this study are summarized in Table 4. The tests were carried out according to Egyptian standards [20]. It is clear that all the mechanical properties of the samples are within the range of standard specifications and match with the Egyptian specifications of natural coarse aggregates used in road construction [9,20].

Table 4.
Mechanical properties of the investigated aggregates.

Test name	Aggregate type			
	Phosphate	**Granite**	**Marble**	**Standard values***
Crushing value (ACV) %	23.27%	20.87%	18.8%	<30 %
Slake durability index (Id_2)	97.85	99.44	99.31	100
Los Angeles abrasion value (LAV) %	31.6 %	28.6 %	29.38%	<25-50 %
Impact value % (AIV)	15.87%	9.00%	9.44%	<30 %

*The standard values are taken from references [9,13,20].

3.4 Chemical properties of aggregates

The chemical properties of the three coarse samples are summarized in Table 5. The chemical tests were carried out according to Egyptian Standards [20]. It is clear from Table 6 that the chemical properties of the tested samples are within the standard specifications and match with the Egyptian specifications of natural aggregates used in road construction [9, 20]. Soundness test measures aggregate

Table 5.

Chemical properties of the aggregates used in this study.

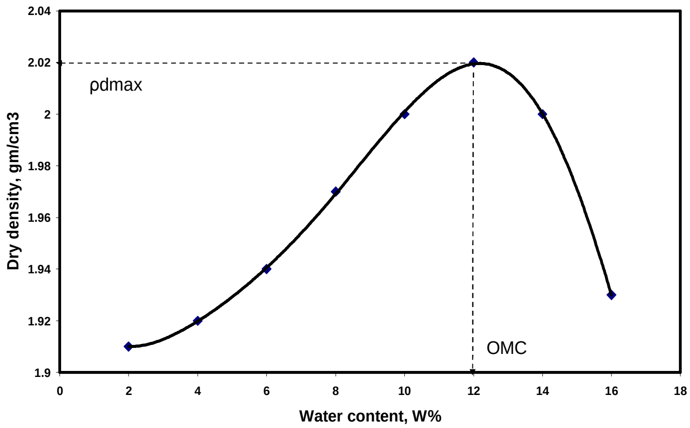
Property	Type of aggregate				
	Phosphate	Granite	Marble	Sand	Standard values*
Soundness test %	9.39	2.51	0.71	----	<12 %
Chlorine ion, wt,. %	0.006	0.0023	0.0049	0.028	<0.04%
Sulfate content, wt.%	0.116	0.00517	0.0071	0.056	<0.4%
PH	7.46	7.67	8.7	7.7	Alkaline
Organic impurities	3.02	0.57	5.17	0.90	----

*References [9, 20, 22].

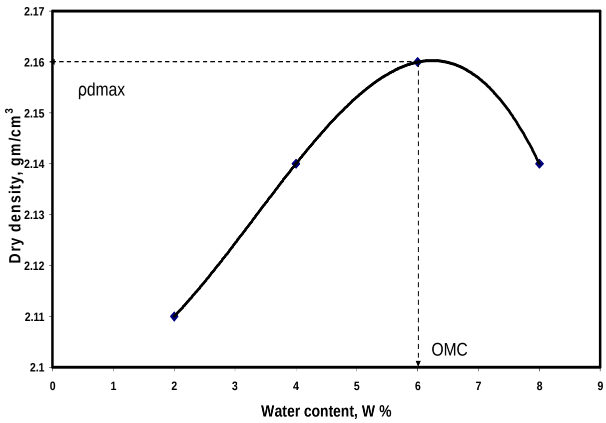
Resistance to disintegration. It is carried out with sodium sulfate solution of specific gravity 1.15 to 1.17 as specified by Egyptian standard [20]. The three coarse aggregates tested having soundness value less than 12%. The phosphate aggregates presented the highest soundness value than marble and granite aggregates because the last two wastes are denser and more durable.

3.5 Modified proctor compaction test:

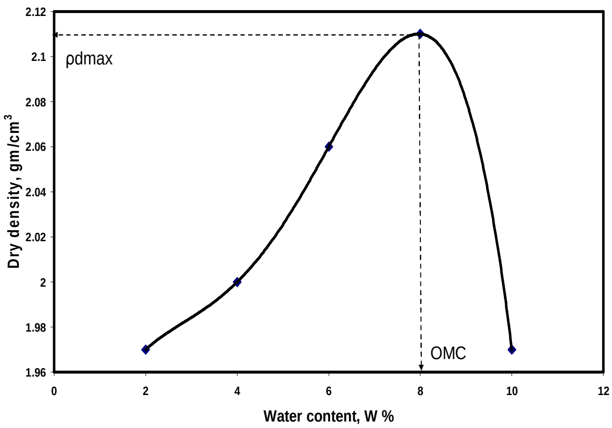
The main purpose of this test is determining the optimum moisture content and the corresponding maximum dry density to achieve optimum compaction in the field for the soil layers in road construction and soil foundation [9,13]. Figure 3 (a, b &c) shows the relation between the water content and dry density for the three types of waste, from each graph the optimum moisture content and the corresponding maximum dry density is determined .The result of the modified proctor test for the three recycled aggregate are summarized in Table 6. Usually road construction base and sub-base layers must be compacted to a dry density greater than 95% of the dry density obtained from a laboratory test [9, 20].



(a) Phosphate waste



(b) Marble waste



(c) Granite waste

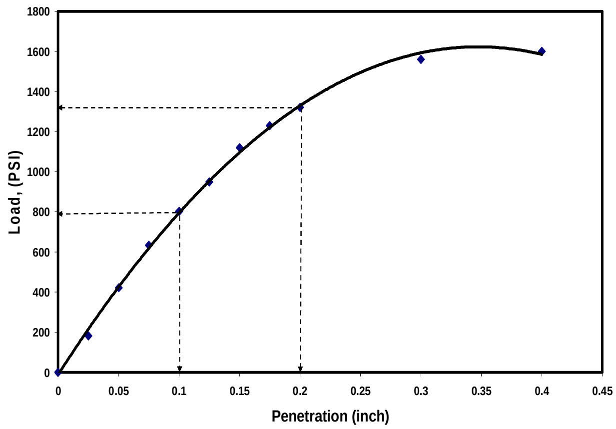
Fig. 3. The relation between dry density and water content for the three studied waste materials: phosphate, marble, and granite.

Table 6.
The results of the modified proctor test on the three waste materials.

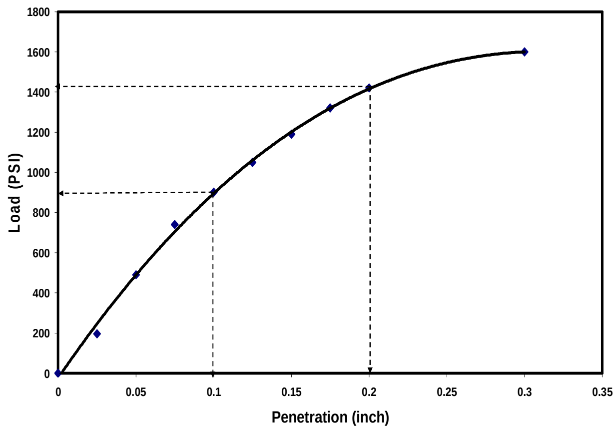
Property	phosphate	Marble	Granite
Optimum Moisture Content (OMC), %	12	6	8
Maximum Dry Density, (ρ_{dmax}) g/cm^3	2.02	2.16	2.11

3.6. California Bearing Ratio (CBR)

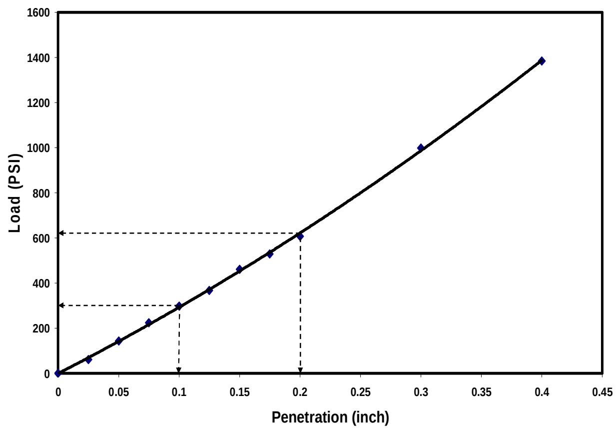
CBR value is used as an index of soil strength and bearing capacity. This value is broadly used and applied in design of the base and the sub-base material for pavement. The test was conducted to characterize the strength and the bearing capacity of the three studied aggregates, compacted at optimum water content (OMC). Figure 4(a,b&c) shows the relation between the load and penetration for the CBR test for the three recycled wastes, also Table 8 summarize the determined results from the curves. The CBR values are calculated at 0.1 &0.2 inch penetration and usually the greater value is considered in soil foundation. It is clear from the results that the CBR values are matching the Egyptian standards (CBR<25-50 %) [9, 20].



(a) Phoshate waste



(b)Marble waste



(c) Granite waste

Fig. 4. CBR results for the studied three of waste materials: Phosphate, marble ,and granite .

Table 8.
Results of California bearing ratio test (CBR).

Property	phosphate	Marble	Granite
CBR value at 0.1 inch penetration, %	80.2	90.1	29.78
CBR value at 0.2 inch penetration, %	88	94.67	40.47

4. Conclusions

From the results of the experimental work and their discussion, it can be concluded that:

1. Recycling waste without properly based scientific research may result in environmental problems greater than the waste itself.
2. The physical, chemical and mechanical properties of the three recycled waste materials used as aggregates to substitute the natural gravel in road construction and as replacement soil under foundations of the problematic soil are within the requirements of Egyptian standards.
3. The three kinds of waste materials can be safely used in the construction of local low- volume roads.
4. Phosphate and marble wastes can be safely used as replacement soil under foundations because of their high CBR. Granite wastes due its lower CBR (about 41%) can be used in water- bound macadam roads (WBM).
5. The convenient use of such solid wastes will render them as useful profitable products .Natural resources will be conserved and environmental pollution will be reduced.

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الإستخدام الإيجابى للنفايات الصلبه للمناجم والمحاجر فى انشاء الطرق وكتربه احلال اسفل الأساسات

الملخص العربى

فى هذا البحث تم دراسة إمكانية إستغلال الكميات المتراكمة من النفايات الصلبه الناتجه من تركيز خام فوسفات شركه النصر للفوسفات بمنطقه السباعية – مصر والتى تقدر بحوالى 7 مليون طن وكذلك كسر صخور الرخام والجرانيت الناتج من عملية تحجير هذه الصخور كركام خشن لتحل محل الركام الطبيعى فى انشاء الطرق فى طبقه الاساس والاساس المساعد والمكدام وكطبقات احلال للتربه ذات المشاكل في الأساسات ، ولقد تم معمليا إختبار الخواص الطبيعيه والميكانيكيه والكيميائيه وخواص الدمك لكل منها طبقا للكود المصرى، ووجد من النتائج أنها فى حدود المواصفات القياسيه المصريه للركام الطبيعى المستخدم فى انشاء الطرق واساسات المباني ومن اهم الاختبارات اللازمه لانشاء الطرق والاساسات اختبار نسبه تحمل كاليفورنيا ولقد وجد من النتائج التى تم الحصول عليها معمليا أن نسبة تحمل كاليفورنيا لركام النفايات موضوع الدراسة كالآتي : 88% لركام الفوسفات و 95% لركام الرخام و 41 % لركام الجرانيت وأن هذة القيم تتوافق مع قيم مواد انشاء الطرق وتربه التأسيس المذكوره فى الكود المصرى .والنتائج التى تم الحصول عليها يمكن استخدامها فى تاسيس الطرق البريه والخلويه وخاصه بمناطق التعدين والمناطق المجاوره لها و كتربة احلال أسفل الأساسات للمباني في هذة المناطق. وتعتبر عملية تدوير النفايات نوع من التخلص المفيد لها وحمايه للبيئه مع الحفاظ على الثروات الطبيعيه من الركام الطبيعي بالإضافة إلى زياده عائد شركات المناجم والمحاجر من الاستغلال الايجابي للنفايات .