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RE-USE OF GRANITE SLUDGE IN PRODUCING GREEN CONCRETE

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ABSTRACT

The industry of dimensional granite stone has contributed to the development of major environmental problems due to waste generation at different stages of mining and processing operations. Granite waste generation continues from mining process to finished product and contributes about 60-80 % of the worked masses of the mineral mined. Depending on the type of process involved, the sludge generated is estimated over 30% of the volume of the sawn block. To solve the problem of these wastes generated by the granite production industry, several technical solutions consider the incorporation of granite sludge in other industrial activities as a by-product. This paper presents an experimental testing on the compressive strength of the green concrete mixes produced by replacing sand and cement by natural stone sludge. The concrete compressive strength is presented and the technical viability of this new construction material is illustrated. Substitution of 10% sand by the granite waste provided higher compressive strength compared to the control mix at all ages. Replacing cement with granite waste caused decrease of compressive strength at all ages with any replacement proportion. The values of slump tests for all mixes ranged from 5-10 cm.

Keywords: green concrete, granite wastes, slurry-sludge, compressive strength, concrete mix, fine aggregates, cement replacement.

INTRODUCTION

General overview of stone production

The technical importance of using wastes and by-products is expressed by performance improvement of the product. The economical benefit usually attributes to the reduction of the amount of expensive and / or scarce ingredients with cheap materials. Environmentally, when industrial wastes are recycled, less material is dumped as landfill and more natural resources are saved.

Among these by-products or wastes, ornamental stone wastes (marble and granite) which are by-products of ornamental stones - processing factories. Dimension stone industry generates different types of waste: solid waste and stone slurry. Whereas solid waste is resultant from rejects at the mine sites or at the processing units, stone slurry is a semi-liquid substance consisting of particles originated from sawing and polishing processes. These wastes were studied by many researchers for its use in several industrial applications such as cement, concrete mortar, ceramics, composite materials, lime, bricks manufacturing and others that showed positive results and benefits. However as the by-products (i.e. the wastes) differ chemically and physically depending on the parent rocks, and other factors, it is necessary to conduct similar research in our country to incorporate it in some industrial applications such as paving blocks production for reduction of environmental pollution and sustainable use of natural resources.

Sources of granite by-products

Granite quarrying process

Granite quarrying in Aswan area is still concerned only with large isolated granite masses that can be split into smaller masses with sizes that fit the sawing needs. The splitting processes are done manually using splitting wedges and hammers for splitting small masses. For the bigger masses, mechanical drilling is performed horizontally and vertically and the splitting is done by using the expanding mortar that is poured into the drill holes. In Egyptian granite quarries the predominant technology is still explosive splitting although, the use of swelling agent is becoming more and more popular. Continuous cutting technologies are seldom used although interest is growing as the consequence of their successful application by some pioneer companies. This method of quarrying is not effective as the production rates are very low (70-250 m^3 / year) and no control on the quality of the produced blocks regarding the wide color variation observed and the block sizes produced.

Low intensity explosives are still used. The produced wastes are very high (60-80 %) of the worked masses. Most of the wastes produced from granite quarrying are in the form of:

a) Under-size masses unsuitable for sawing with the gang saws,
b) Blocks showing structural defects make them unsuitable for sawing
c) Blocks showing wide color variation in the same block.
d) Blocks have zones of varying crystal sizes.
e) Blocks having many xenoliths of dark colors.
f) Fragmented small masses and granite debris.

These wastes are difficult to be removed away from the quarrying areas as its removal is not economic; they are only removed from the quarry roads to facilitate the transportation and are accumulated in a random way as showed in Figures- 1(a) and (b) (Egyptian marble strategy study, 2005).

Figure-1(a). Wastes of the granite under sized masses using drilling and the expansive mortar.

Figure-1(b). Granite wastes accumulation removal in the quarry sites.

Factories wastes

Wastes in marble and granite factories result from two main sources; irregular unshaped blocks (solid wastes), and sawing processes (slurry). The re-use of these wastes were studied through the evaluation of their quantity and quality (mineralogical and chemical composition) to be used as a raw material substitution in the production of green concrete elements (Egyptian marble strategy study, 2005).

a) Solid wastes

This type of wastes result during the leveling of the unshaped blocks and slabs with huge amounts and consists of stone fragments with variable dimension which present fractures, inadequate dimension, low commercial value or any other factor that does not fit into its use at a technological or economical level. The ratio of this type of wastes to the total volume of the stone blocks may reach up to 20%, this means that 20% of the transporting costs from the quarry site to the factory are considered to be loss, in addition to the costs of removal of these stone wastes that occupy most of the spaces in the factory stockyards that are needed to store raw materials and finished products.

b) Slurry (Sludge) wastes

These wastes result during the sawing and polishing processes of the marble and granite (estimated as >30% of the volume of the sawn block). The equipments used in the processing activities require large amounts of water, which plays an important role in cooling, lubrication and cleaning. Granite blocks require more water than limestone or marble blocks. The amount of water used for cooling varies markedly from one factory to another according to the number, size and type of blocks sawn per year as well as the water recycling efforts of the factory. Some factories use additives like slaked lime and iron powder to act as abrasive and lubricants to facilitate the sawing process (especially of granitic blocks) and to extend the life of the saw blade. This mixture of water and fine powder produces thousands of cubic meters of a semi-liquid substance that is generally known as ‘‘natural stone slurry’’ or “sludge”, due to its appearance. This slurry is then subjected to different treatment activities, according to the technology available in the processing plant. In some factories, the ornamental stone slurry is discharged into settling tanks or ponds; the supernatant water is removed into storage tanks for its reuse as cooling water in the processing line. The settled sludge (with up to 50% water content) is collected and thrown outside the factory on land or in landfills as waste. In other factories, the use of a filter press has decreased the water content of the sludge to about 20%, thereby recovering more water for recycling and generating more quantities of rock powder in the form of coherent cake that is easier to be transported to the disposal sites. Such very fine powder when completely dries is dispersed in the air as suspended particles causing air pollution in the industrial areas and the adjacent areas (Egyptian marble strategy study, 2005).

Literature review

Many studies have been carried out in different countries (including Egypt) to use natural stone waste in mortar and concrete. Most of these researches used marble, granite and lime stone waste as a replacement of cement or sand in concrete mix in order to investigate their effects on the physical and mechanical properties of concrete.

Most of these researchers used marble waste as a replacement of sand in mortar or concrete mix. All the experimental data showed that the addition of these wastes improves the physical and mechanical properties due to its high fineness of the waste particles. It was investigated by Yılmaz, *et al*., 2010 that 90% of the particles are below 200 μm The results of study done by Almeida,N., Branco F., and Santos, J., 2007 showed that the substitution of 5% of the sand content by stone slurry induced higher compressive strength, higher splitting tensile strength and higher modulus of elasticity. Hameed, M., and Sekar, A., 2009 found that the compressive, split tensile strength and durability studies of concrete made of quarry rock dust are nearly 14 % more than the conventional concrete. Valeria C. *et al*., 2010 study revealed that 10% substitution of sand by the marble powder in the presence of a super-

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plasticizing admixture provided maximum compressive strength at the same workability level, comparable to that of the reference mixture. Other studies such as undertaken by Rai, B., *et al*., 2011 and Ali A. *et al*, 2014 concluded that there was an increase in compressive strength (higher than the reference concretes) up to 15% replacement of fine aggregate with marble granules.

Demirel, B., 2010 explained that as the curing age increased, its contribution to the compressive strength of the marble waste dust is reduced. As curing time increases, the waste contribution to the compressive strength decreases. Similar results have been reported earlier by Binici *et al*, 2007 and Patel, N., Raval, A., and Pitroda, J., 2013. To the contrary of all previous research, Hebhoub, H., *et al*., 2011 observed that the substitution of natural aggregates by waste marble aggregates up to 75% of any formulation is beneficial for the concrete resistance.

On the other hand, the concrete resistance to sulphate attack was enhanced greatly (Hameed, M., and Sekar, A., 2009). Omar M. *et al*, 2012 concluded that the workability of green concrete was not affected by the addition of lime stone waste (LSW) to the concrete mix while the compressive strength increased by 12% after 28days when using LSW up to 50% of sand replacement with a super plasticizer. Presence of marble powder (MP) with LSW (up to 50%) increased the compressive strength in the mixes about7%. Indirect tensile strength increased about 17% when using 50 % LSW and 15 % M.P as sand replacement.

Other researchers used marble waste as a replacement of cement in mortar or concrete mix. Results showed that -comparing with the reference sample- there was insignificant variation in compression strength values (Alzboon, K., and Mahasneh, K., 2009). Ali A. *et al*, 2014 revealed that the compressive strength of concrete made with 15% marble dust as cement replacement has been found to be either comparable or less than control mix. However, Valeria C. *et al*., 2010 indicated a decrease in compression strength of 20% than control mix using a substitute of 10% of cement by marble powder in the presence of a super-plasticizing admixture.

Rare researchers investigated the contribution of granite wastes in concrete mix as a replacement of sand or cement. Abukersh, S. and Fairfield, C., 2011 assessed red granite dust (RGD) for suitability as a replacement for up to 30% by mass of the cement content of concrete made with recycled coarse aggregates. The results showed that natural aggregate concretes produced with RGD at 30% cement replacement had strengths either comparable to, or better than, equivalent control mixes. Concrete mixes containing 30% RGD showed good workability, better than expected mechanical properties and excellent surface finish.

Based on the extensive review of research conducted in some stone producing countries in the field of re-using marble and granite wastes in the production of mortar and concrete, it is clear that few Egyptian attempts has been presented to incorporate natural stone waste in other industrial activities. These efforts had been undertaken to re-use marble wastes in concrete on a preliminary basis but rarely investigated granite wastes. This research is part of an on-going project aiming to re-use granite waste in producing green concrete to reduce its negative environmental damage.

Experimental work

Materials

All the materials used in this research were local materials. The properties of these materials were determined according to the Egyptian Standard Specifications and the recommended code of practice.

Portland cement

Commercial Torah Portland-limestone blended cement (OPC) according to the Egyptian standards was used. The fineness of cement was 9 % passing from sieve 170 and its relative density (specific gravity) was 3.15. It's initial and final setting were 2 hrs and 3hrs 12 minutes resp.

Aggregate

Natural sand from pyramids quarries Giza with a maximum size of 4.75 mm was used as fine aggregate. Course aggregate with a maximum nominal size of 19 mm was used.

Granite waste

A granite sludge powder was used, which was obtained as a by-product of granite sawing and shaping from Egyptian marble factory (gang saw granite type from Shaqu Elteban zone). It can be observed that the granite powder had a high specific surface area; this could mean that its addition should confer more cohesiveness to concrete.

The granite waste is produced as ‘‘slurry”, a mud made of powder and water. The wet granite sludge was dried up prior to the preparation of the concrete samples in order to have a constant W/C ratio in the designed mix. Slurry granite waste was weighed before putting in an oven at a temperature of 200 C for 6 hours. The granite powder was then weighed back and the difference of weight (before and after drying) should be less than 10% to insure minimum water content. The granite waste used as cement replacement has particles passed through sieve no. 300. While, the granite waste used as sand replacement has particle passed through sieve no 4.76.mm.

Water

Clean tap water was used in the production of the concrete samples. Water used in mixing and curing concrete is in accordance to ASTM C 94 (1993) specifications. The temperature of mixing water was maintained between 20-30C

Concrete design mix

Based on the Egyptian Standard, design mix for 350 grade of concrete was prepared by partially replacing

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cement or fine aggregate with four different percentages by weight of granite waste (0%, 5%, 10%, and 15% for cement replacement) and (0%, 10%, 17.5% and 25% for sand replacement). The concrete mixtures proportions are reported in Table-1. All concrete mixes were prepared with the constant W/C ratio (0.45%) and same ratio of sand to cement.

A total of seven series of concrete specimens including the control specimen were prepared in order to examine the effect of partially replacing granite waste instead of cement and fine aggregates on the mechanical properties of concrete produced. For each series, total of nine pieces of concrete specimens were prepared, with three specimens being taken from each curing age (7, 28 and 90 days). Therefore, a total of 63 cubic specimens (150 × 150 × 150 mm) were prepared in order to determine the properties of the fresh concretes (slump test) and compressive strength after curing at different ages.

All the concrete mixtures were blended for 5min in a laboratory counter-current mixer (Figure-8). Mixtures prepared were cast in cubic mould 150x150x150 mm cubes for the determination of compressive strength at 7, 28 and 90 days. After casting, these specimens were kept in the molds for 24 h. After that, these specimens were cured in curing basins for 7, 28 and 90 days.

Table-1. Design mixes.

Design mix no.	**Design mix abbreviation**	**Design mix name**	**Quantity** (kg)				**Water** (liter)	**W/C ratio**
			Cement	**Fine aggregate**	**Course aggregate**	**Granite waste**		
Control mix								
1	C M	Control mix	18	23.22	46.44	0	8.1	0.45
Cement replacement								
2	S G C 5	Saw gang granite 5% cement replacement	17.1	23.22	46.44	0.9	8.1	0.45
3	S G C 10	Saw gang granite 10% cement replacement	16.2	23.22	46.44	1.8	8.1	0.45
4	S G C 15	Saw gang granite 15% cement replacement	15.3	23.22	46.44	2.7	8.1	0.45
Sand replacement								
5	S G F 10	Saw gang granite 10% sand replacement	18	21	46.44	2.3	8.1	0.45
6	S G F 17.5	Saw gang granite 17.5% sand replacement	18	19.2	46.44	4	8.1	0.45
7	S G F 25	Saw gang granite 25% sand replacement	18	17.4	46.44	5.8	8.1	0.45

Sample testing

All sample preparation and testing were carried out at the National Research Centre, Egypt.

Chemical analysis test

The chemical analysis for granite waste samples was carried out in order to identify their chemical characteristics.

Table-2. Presents the results of sample's chemical analysis.

Main constituents	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**SO_3**	**Ci**	**LOI**
Wt, %	59.58	0.37	13.01	9.77	0.17	0.29	3.8	5.92	4.76	0.07	0.33	0.09	1.56

Slump test

Slump test was carried out for fresh concrete mix. The results of concrete slump tests are presented in Table-3. Figure-2 shows one of the conducted slump tests.

Table-3. Slump test results.

Concrete mix		**Slump** (cm)
Control mix	**C M**	**5**
Cement replacement	S G C 5	8
	S G C 10	7
	S G C 15	6.5
Sand replacement	S G F 10	10
	S G F 17.5	8
	S G F 25	5

Figure-2. Slump test.

Compressive strength test

Compressive strength of concrete mixtures was measured for each mix type (Control Mix, SGC5, SGC10, SGC15, SGF 10, SGF 17.5, and SGF25) in order to study the effect of using granite waste on the concrete compressive strength. Compression tests were carried for ages 7, 28 and 90 days of concrete mix. Universal testing machine of 1000 KN (Shematzo) was used to conduct the Compression tests as seen in Figure-3(a). In addition, compression test plant ToniPact 2000 KN maximum load capacity as shown in Figure-3b for cubes of strength exceeding 1000 KN.

Figure-3(a). Compression test using universal testing machine.

Figure-3(b). Compression test using toni pact 2000 KN.

TEST RESULTS AND DISCUSSIONS

Compressive test results

Mechanical behavior of concrete prepared using granite waste was studied by compression tests at curing times of 7, 28, and 90 days. Results obtained are reported in Table-4. Figures (4a and 4b) demonstrate the relation between compressive strengths at different curing times and the proportions of granite waste used in concrete mixtures.

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Table-4. Compression test results.

Concrete mix		Compressive strength (kg/cm^2)		
		7 days	**28 days**	**90 days**
Control mix	C M	303	347	504
Cement replacement	S G C 5	275	325	480
	S G C 10	237	332	371
	S G C 15	217	222	290
Sand replacement	S G F 10	339	374	543
	S G F 17.5	276	385	478
	S G F 25	270	376	500

DISCUSSIONS

Comparing the compressive strength values of samples including granite sludge to the samples of the control mix indicated that:

- Using 10% replacement of sand with granite waste (SGF10) caused about 8-12% compressive strength increase in all ages. The highest increase was 12% at age 7 days, after that, the increase slightly dropped to be 8% at ages 28 and 90 days
- The compressive strength increased by 11% at age 28 days when replacing 17.5% of sand with granite waste (SGF17.5). It was observed that by using this replacement percentage the compressive strength of the concrete mixes decreased at other ages.
- Using 25% replacement of sand with granite waste (SGF25) caused about 11% compressive strength decrease at age 7, however, it caused increase about 9 % at ages 28. At 90 days, there was an insignificant decrease about 1%.
- Replacing cement with granite waste caused decrease of compressive strength at all ages with any replacement proportion. A significant decrease - between 28-42%- was noticed when 15% replacement was used (SGC15).
- The decrease in compressive strength using granite waste as cement replacement was reasonable only when using 5% replacement (SGC5).
- At age 28 days, all samples of sand replacement (SGF10, SGF17.5 and SGF25) caused increase of compressive strength about 8-11%.
- At early age (7 days), the compressive strength values of control mix are higher than all other mixtures except for SGF10 (10% replacement of sand with granite waste) which is higher than the control mix by about 12%).

❖ The values of slump tests for all mixes were ranging from 5-10 cm.

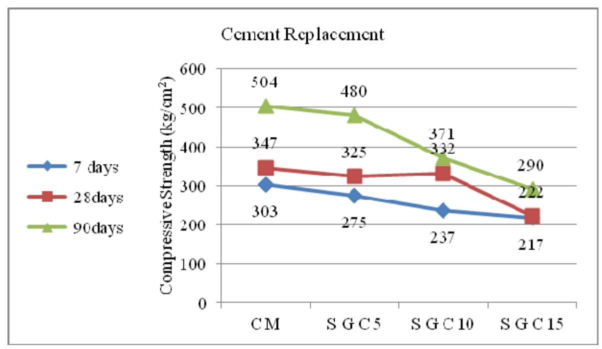

Figure-4(a). Compressive strength of concrete mixes (cement replacement).

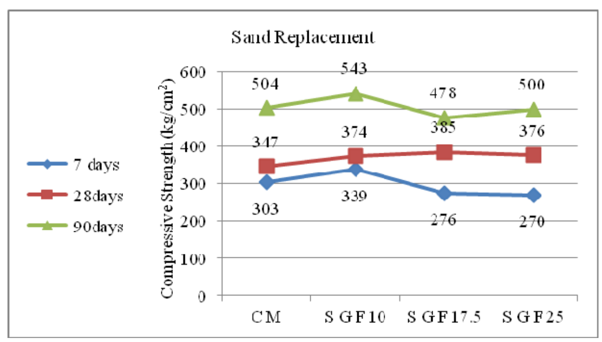

Figure-4(b). Compressive strength of concrete mixes (sand replacement).

5. CONCLUSIONS AND RECOMMENDATIONS

❖ Experimental work done in this project investigated the effect of granite waste (as substitution of cement or sand) on the mechanical properties of green concrete produced. The granite sludge was added with different percentages due to its high fineness which provides good cohesiveness of the mix. No plasticizing admixtures were used in all ages of testing.

It can be concluded that:

- 10% substitution of sand by the granite waste provided higher compressive strength compared to the control mix at all ages.
- 5% substitution of cement by granite waste caused a small decrease in the compressive strength (about 5-9%).
- Exceeding 5% of cement replacement by granite waste caused a dramatic decrease in the compressive strength compared to the control mix. The decrease in the compressive strength reached 42% when using 15% replacement proportion.
- The values of slump tests for all mixes were ranging from 5-10 cm indicating insignificant effects on the workability of concrete produced.
- It was observed that there was an inversely proportional relation between the granite waste as a partial replacement of cement and the compressive strength of the concrete mix produced.

❖ Although several researchers had undertaken efforts in re-using marble in concrete from different points of view, rare researches were conducted on granite wastes either in the quarry stage or during the processing stages especially in Egypt. Therefore, it is recommended to make more future efforts to study the physical and mechanical properties of concrete produced using granite waste.

❖ Using marble and granite waste in concrete mix proved to be very useful to solve environmental problems and produce green concrete. Therefore, it is recommended to re-use these wastes in concrete to move towards sustainable development in construction industry.

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