Marble and Granite Waste: Characterization and Utilization in Concrete Bricks

Rania A. Hamza, Salah El-Haggar, and Safwan Khedr

***Abstract*—Marble and granite industry has grown significantly in the last decades with the privatization trend in the early 1990s, and the flourishing construction industry in Egypt. Accordingly, the amount of mining and processing waste has increased. Stone waste is generally a highly polluting waste due to both its highly alkaline nature, and its manufacturing and processing techniques, which impose a health threat to the surroundings. Shaq Al-Thu`ban industrial cluster, the largest marble and granite industrial cluster in Egypt is imposing an alarming threat to the surrounding communities, Zahraa El-Maadi residential area, and the ecology of the neighboring Wadi Degla protectorate. The objective of this paper is to utilize marble and granite waste of different sizes in the manufacturing of concrete bricks, with full replacement of conventional coarse and fine aggregates with marble waste scrapes and slurry powder of content up to 40%. The produced bricks are tested for physical and mechanical properties according to the requirements of the American Standards for Testing Materials (ASTM) and the Egyptian Code. The test results revealed that the recycled products have physical and mechanical properties that qualify them for use in the building sector, where all cement brick samples tested in this study comply with the Egyptian code requirement for structural bricks, with granite slurry having a positive effect on cement brick samples that reach its optimum at 10% slurry incorporation.**

***Index Terms*—Concrete bricks, Granite waste, Marble waste, Recycling of marble and granite waste Shaq Al-Thuban, Slurry powder.**

I. INTRODUCTION

Stone has played a significant role in human endeavors since earliest recorded history and its use has evolved since ancient time. Nature has gifted Egypt with large deposits of high quality marble and granite. World Stone production reached the peak of some 75 million tons (or 820 million m^2 equivalent), net of quarry waste. The official production figures of Egypt are remarkable; yet, the real production is considerably higher than the level indicated by the official statistics and maybe beyond the levels estimated in the course of the study highlighted in [1]. The most likely estimations based on the information retrieved through local assessment attributed to Egypt: a quarry production of about 3.2 million tons and over 25 different types of Egyptian marble and granite in 2004. This indicates that the country lies among the top 8 world producers of raw material. The average annual rate of increase has reached 8.8% since 2002. Concerning quarry production and raw export, Egypt is ranked the fourth respectively with a share of 4.3% and 6.6% of total world market of marble and granite. However, in terms of total processed materials delivered abroad, the role of Egypt is less vivid, representing a 3.7% share of international export and only 1.5% of world consumption. Total export from Egypt, according to the local review evaluation, can be estimated at 1.5 million tons per year: 0.9 million tons as raw materials and 0.6 as processed products. This means that Egypt can be considered the seventh exporter in the world, in terms of volume, after China, India, Italy, Spain, Turkey and Brazil.

The contribution of the natural stone industry to the Egyptian economy has grown tremendously over the past decades and especially post 1990s with the privatization trend. There are around 500 big enterprises in this industry and at least 3000 workshops. About 70% of the industry is located in Shaq Al-Thu`ban, located in Katameyya near Maadi suburb of Cairo as indicated in [2], with a total investment in this place of around 6 billion EGP (equivalent to 970 Million USD)as stated in [3]. Shaq Al - Thu`ban industrial cluster poses the most imminent hazard to residents of neighboring communities: WadiDegla protectorate, situated at the western edge of the Eastern desert and Zahraa El- Maadi residential area, which lies bottom hill west of Shaq Al - Thu`ban.

II. MARBLE AND GRANITE PRODUCTION AND WASTE

A. Manufacturing Process

During the processing of marble and granite, that takes place in Shaq Al-Thu`ban cluster, the raw stone block is cut as demanded either into tiles or slabs of various thicknesses (usually 2 or 4cm), using diamond blades. Water is showered on blades while stone blocks are cut into sheets of varying thickness to cool the blades and absorbs the dust produced during the cutting operation. The amount of wastewater from this operation is very large. It is not recycled as the water so highly alkaline that, if re-used, it can dim the slabs to be polished. In large factories, where the blocks are cut into slabs, the cooling water is stored in pits until the suspended particles settle (sedimentation tanks), then the slurry is collected in trucks and disposed of on the ground and left to dry. This water carries large amounts of stone powder. Eventually, the sludge dries in the sun and its particles become airborne. This causes air pollution problems for the surrounding area. Another solid waste generated by the marble and granite units is the cutting waste which results

Manuscript received November 19, 2011; revised November 23, 2011. This work was supported in part by Environmental Engineering Program in the American University in Cairo.

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from cutting slabs into the required dimensions. After the stone has been cut to the specific dimensions, the slabs are finished either by polishing or texturing, as requested. The polishing operation is fully automated with the use of powdered abrasives that keep on scrubbing the surface of the marble until it becomes smooth and shiny. Water showers are essential to prevent overheating of the blades.

B. Waste Quantification

Actual figures about the quantity of waste produced in Egypt from the marble and granite industry are inaccessible since it is not calculated or monitored by the government or any other party. However, the waste generated in the processing stage can be as low as 39% in 300mm×20mm× free length floor tile production and as high as 53% in 305 × 305 × 10mm tile production per 1 m^3. In other words, as the thickness of the product increases, the portion of waste is reduced as indicated in [4]. Other references estimate that 20 to 25% of the marble/granite produced results in powder in the form of slurry, as for each marble or granite slab of 20mm produced; 5 mm is crushed into powder during the cutting process [5],[6]. This powder flows along with the water forming marble slurry. Based on the lowest estimates of waste percentage, it can be estimated that Shaq Al- Thu`ban industrial cluster produces around 800, 000 tons of waste per year.

C. Environmental Impact

Marble and granite industry is one of the most environmentally unfriendly industries. Cutting the stones produces heat, slurry, rock fragments, and dust. Although marble waste, in general, includes non-radioactive by-products, and thus it does not induce climate changes, it does destroy plant life as highlighted in [1],[4] . Marble waste cannot be considered inert (i.e. reactive), based upon the conventional leaching tests (DIN 38414 or EN 12457) adopted in [7], where these tests confirm that the fines are alkaline materials producing high pH wastes (pH around 12).

The weathering of the worn steel grit and blades used in processing granite transfer some quantities of toxic metals like Chromium. This endangers the quality of surface and ground waters nearby. Marbles usually contain the chemical compounds CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3, Na_2O, TiO_2 and P_2O_5. During the cutting process, chemical compounds release no gases that contribute to global warming and climate changes as water can be used in the cutting process to capture dust. The fine particles can cause more pollution than other forms of marble waste unless stored properly in sedimentation tanks, and further utilized. The fine particles can be easily dispersed after losing humidity, under some atmospheric conditions, such as wind and rain. The white dust particles usually contain $CaCO_3$ and thus can cause visual pollution. Clay and soils have a high cation exchange capacity and can absorb high proportion of heavy metals and cations, such as Ca, Mg, K and Na; yet soils are not as effective as marble and granite fine particles in holding pollutants like Cl. The particle size of the slurry is less than 80 μm; it is later consolidated as a result of accumulation. The waste in the water does not completely sink to the ground, and much of it remains on the surface. As the water on the surface evaporates, the liquid wastes solidify. Meanwhile, relatively wet marble waste, which is subjected to rain and snow, will carried with seepage down into the ground over time, as cited in [4].

The wastes are dumped on the Wadi's roads and the adjacent land and the dust is airborne by the wind and scrap is scattered. The marble slurry could lead in the long run to water clogging of the soil, to increasing soil alkalinity, and to disruption of photosynthesis and transpiration. The net effect is a reduction of soil fertility and plant productivity. Many animal species in the Wadi are exclusively herbivores. Even if those plants did not die out, their internal chemistry will have been altered and their nutritional value poisoned by gases emitted by the industry. The interdependence of the parts of the ecosystem does not seem to be greatly emphasized in environmental public policy. It should also be realized that animal health, like human health, can be adversely impacted by inferior environment quality. Nevertheless, by blanketing plants and surfaces, slurry and dust compromise the aesthetic appeal of the Wadi's scenery, as detailed in[4], [7], [5], [6], [8].

III. Materials and Methods

A. Waste Characterization

Marble and granite waste material is characterized for its physical and chemical properties.

1) Atterberglimits

The plasticity of marble and granite particles (powder resulting from slurry), along with shrinkage limits was determined according to ASTM D 4318-00 – Liquid limit and plastic limit – and ASTM D427-98 – Shrinkage factors of soils by the mercury method. Marble and granite particles are non-plastic materials, with shrinkage limits as a percentage of dry mass (SL) of 23.25, and 27.25 for marble and granite slurry respectively and shrinkage ratio (R) of 1.51 and 1.47 respectively.

2) Grain size

Marble and granite (material mixture) pieces grain size was determined by sieve analysis according to ASTM C136-01. Marble particles and granite particles grain sizes were determined by wet sieving (hydrometer) according to ASTM D 422-63. Marble and granite (material mixture resulting from crushing) pieces grain size distributions are shown Fig. 1and Fig. 2. The nominal maximum aggregate size is 12.5 mm and the coefficient of uniformity (Cu) of the coarse aggregate is 1.9. The fineness modulus (FM) of the mixed coarse sand (A), mixed fine sand (B) and the mixture of 30 % A+ 70 % B, which is selected based on trials for the best gradation curve obtained, are 4.596, 2.755, and 3.307 respectively. Marble and granite slurry powder are of grain size less than 75 microns, with 90% of the samples are of grain size less than 25μm, in marble and 35 μm, in granite, 50% of the particles had a diameter lower than 5μm, in marble and 8 μm, in granite. Twenty five percent in marble powder, and 20%, in granite powder of size less than 2 microns, indicating that the samples range from clay size to silt, with granite of slightly coarser material than marble.

These results show material grain size finer than the finest grain size found in the literature, 90% of the samples are of diameter less than 50 microns, with 50% of the particles had a diameter lower than 7µm, in marble (see Fig. 3and Fig. 4).

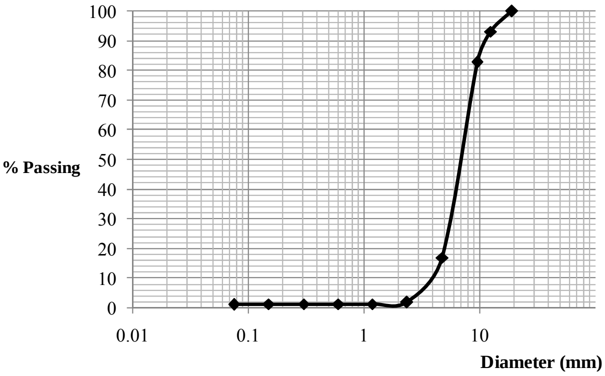

Fig. 1. Mixed coarse aggregates grain size analysis.

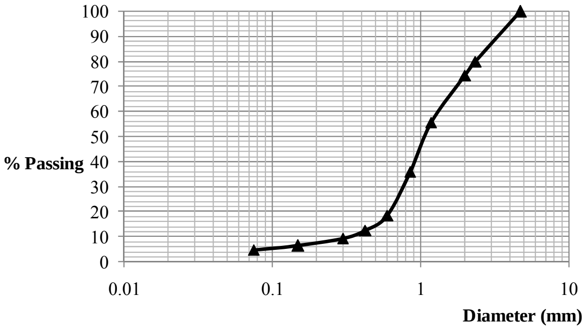

Fig. 2. 30% A + 70% B fine aggregates grain size analysis.

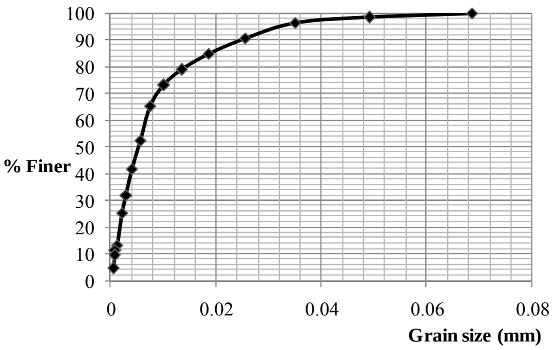

Fig. 3. Marble slurry powder grain size analysis.

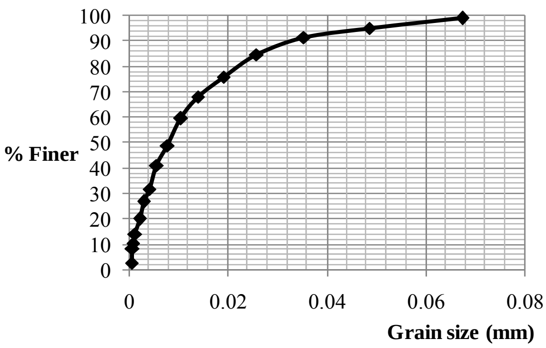

Fig. 4. Granite slurry powder grain size analysis.

3) Specific gravity, density, and water absorption

Density, relative density (specific gravity), and water absorption of marble and granite mixture pieces of diameter greater than 4.75 mm was determined according to ASTM C127-07. Specific gravity of Marble and granite mixture pieces of diameters less than 4.75 mm was determined according to ASTM C128-07a. Specific gravity of Marble and granite mixture particles of diameters less than 75 µm was determined according to ASTM D 854-00. The values of specific gravity of the raw material used, both Oven Dry (OD), and Saturated Surface Dry (SSD) are shown in Table I and Table II. The results are in agreement with the literature [9],[10],[11],[12],[13]. For slurry powder, the measured specific gravity is as low as 2.55 and as high as 3.0, which is higher than what is expected to calcite materials. This is due to the presence of abrasive powder (iron grit and lime) used in sawing operations in large units. Thus, the specific gravity of slurry powder varies considerably according to cutting and processing operations. Aggregate absorption is from one to two percent in coarse and fine stone aggregates, while it is as high as 27% in granite slurry powder. This is due to the high surface area of the particles which requires high water content for saturation.

4) Surface area

The surface area of marble particles and granite particles is determined by Blaine test according to ASTM C204-07. The measured surface areas of marble and granite slurry particles are 4209 cm^2/g and 4377 cm^2/g respectively, which are comparable to that of cement, 2600-4300 cm^2/g. However, these values are considerably lower than that found in literature, 0.7-2.5 m^2/g [1],[14],[15]. The high surface area of ornamental stone powder should confer more cohesiveness to mortars and concrete [12].

TABLE I: SPECIFIC GRAVITY OF MARBLE AND GRANITE SLURRY PARTICLES

Material	specific gravity (OD)	specific gravity (SSD)	% water absorption
Coarse aggregate	2.407	2.434	1.131
Fine aggregate (A)	2.733 (solids) , 2.587	2.632	1.729
Fine Aggregate (B)	2.791(solids), 2.632	2.688	2.145

TABLE II: SPECIFIC GRAVITY OF MARBLE AND GRANITE PIECES

Material	specific gravity of solids	% water absorption
Marble slurry	2.768	23.25 (SL)
Granite slurry	2.837	27.24 (SL)

5) Chemical analysis

Chemical analysis of slurry powder resulting from processing activities in Shaq Al-Thu'ban is determined by INCAx sight by OXFORD instruments, and WD-XRF Spectrometer, PANalytical 2005 (see Table III for marble slurry sample resulting from gang saw, Table IV for granite slurry sample resulting from gang saw, and Table V for granite slurry sample resulting from multi disk operation). Marble powder shows calcium oxide as the major component (>49%) with loss of ignition (LOI) around 40%, and small amounts of SiO_2(<5%), MgO(<3%), and Fe_2O_3(<2%), as indicated in the literature. On the contrary, granite shows SiO_2 as the major component (>60%), with much lower level of LOI (<2%), with Al_2O_3 values between 6 and 14 %, CaO values of 0 to 6%, and traces of Na_2O and K_2O (0 to 3.5 %), in agreement with the values indicated in the literature [8],[11],[12]. It is worth mentioning that the chemical analysis of granite slurry resulted from cutting operations using gang saws showed higher values of Fe_2O_3, 7.73, as compared to 0 to 6.5%, in the literature[13],[15],[16], which indicate the use of iron grit in the cutting procedure as abrasive material. In addition, some granite samples show small values of CaO, around 3% (see Table IV), which indicates a mix of marble and granite waste.

TABLE III: CHEMICAL ANALYSIS OF MARBLE GANG SAW SAMPLE

Concentration of major constituents	Wt,%
SiO_2	0.57
Al_2O_3	0.16
Fe_2O_3	0.11
MgO	0.2
CaO	55.26
Na_2O	0.05
SO_3	0.06
ZrO_2	0.01
P_2O_5	0.02
SrO	0.03
Cl	0.01
LOI	43.52

TABLE IV: CHEMICAL ANALYSIS OF GRANITE GANG SAW SAMPLE

Concentration of major constituents	Wt,%
SiO_2	**69.88**
TiO_2	0.05
Al_2O_3	12.21
Fe_2O_3	7.73
MgO	0.07
CaO	3.17
Na_2O	3.00
K_2O	3.65
Cr_2O_3	0.07
P_2O_5	0.03
SO_3	0.05
MnO	0.07
Cl	0.01
LOI	---
Trace elements	*Ppm*
Cu	44
Rb	147
Sr	57
Y	36
Zn	46
Zr	46

TABLE V: CHEMICAL ANALYSIS OF GRANITE MULTI DISK SAMPLE

Concentration of major constituents	Wt,%
SiO_2	69.99
TiO_2	0.34
Al_2O_3	14.01
Fe_2O_3	2.98
MgO	0.82
CaO	1.68
Na_2O	3.57
K_2O	4.3
P_2O_5	0.10
SO_3	0.02
MnO	0.07
Cl	0.02
LOI	1.9
Trace elements	*Ppm*
Cu	90
Rb	111
Sr	172
Y	58
Zn	64
Co	79
Nb	38

B. Utilization of Waste in Concrete Bricks

Concrete bricks can be the best application to utilize marble and granite waste in large quantities to replace the conventional sand and aggregates. Normally, aggregates in concrete bricks are dolomite as the coarse aggregate, and sand as the fine component. These can be replaced by marble and granite waste aggregates of different sizes with slurry powder addition. The slurry powder, with its very low grain size (less than 70 micron) and its high surface area (more than 4200 cm^2/g); can add cohesion to the bricks and micro-filling ability.

The mix design incorporates around 10wt% cement, 30wt% fine aggregates with ratio 3:7 A:B (FM 3.307), 50 wt% coarse aggregates, and marble (M) or granite (G) slurry powder of 10, 20, 30 and 40 wt%, with proportional re-distribution of coarse and fine aggregates to accommodate the added slurry powder, beyond 10%. In addition, zero percent slurry brick, and control brick, with conventional dolomite coarse aggregates and sand, were tested, as shown in Table IV.

1) Sampling and testing

The bricks produced are of dimensions 250 mm length, 120 mm width and 60 mm height in agreement with the brick dimensions specified by the Egyptian code for masonry works. Three samples of each brick formula are tested after 7 and 28 days for compression, moisture, absorption and durability (heating and cooling cycles and saturated salt solution, sodium chloride, immersion cycles followed by heating, of a 24±2 hours cycle for 7 days). Results are compared to ASTM C140, the Egyptian Code and the control samples. In addition, Bricks abrasion resistance is compared to ASTM C902-09.

TABLE VI: CONCRETE BRICKS MIX DESIGN

Mix ID	Cement (kg/m^3)	Slurry (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)
Control	300	-	800	1000
Zero	235	0	704	1173
M10, G10	232	232	696	1160
M20, G20	220	441	579	965
M30, G30	210	630	472	787
M40, G40	204	818	383	639

2) Results

The results show that the marble and the granite slurry samples yield similar mechanical, in terms of compressive strength, and physical, in terms of density and absorption, properties. In terms of compressive strength, although both marble and granite show similar results, granite slurry samples show slightly higher values, as illustrated in Fig. 5 and Fig. 6, which is predictable due to the higher strength of natural granite stone and the apparent stronger bond with cement paste. This increase in strength in granite slurry bricks compared to the marble slurry ones is around 10%, 11%, 14%, and 33% in 10, 20, 30, and 40% samples respectively at 7 days. As for the 28 days test, the increase is 9%, 23%, 9%, and 48% for 10, 20, 30, and 40% samples respectively. It is worth mentioning, however, that the 40% granite slurry samples (G40) show much higher values of compressive strength (33%, and 48%), as compared to marble slurry. This can indicate that granite slurry can have a better interface with cement paste in the mix beyond purely physical micro filling action. This is more noticeable in higher incorporation percentages of granite fines. In addition, both marble and granite samples show similar trend in terms of the degree of strength achieved after 7 days when compared to that after 28 days. For example, the 10% slurry samples, both marble and granite, achieve 80% of the 28 days strength whereas the 20% marble and granite slurry samples, achieve 83% and 72% of the 28 days strength, respectively.

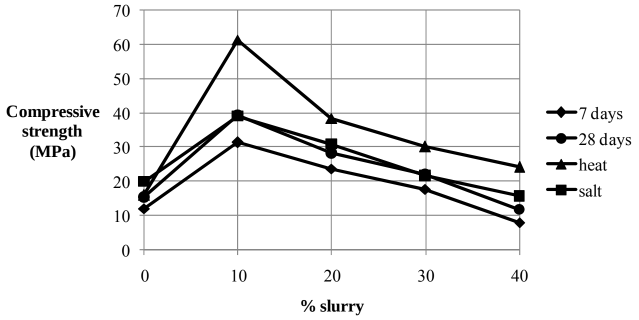

Fig. 5. Compressive strength for marble slurry samples.

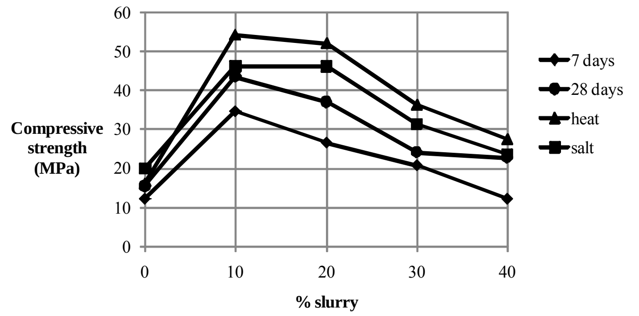

Fig. 6. Compressive strength for granite slurry samples.

Comparing with the control sample, in terms of compressive strength at 28 days, the 10% marble slurry (39.4 MPa) and granite slurry (43.48 MPa) samples yield results close to that of the control (39.6 MPa). The 20% granite slurry samples also show similar results (36.95) to that of the control. These results emphasize the positive effect of granite slurry on brick samples that reach its optimum at 10% slurry incorporation, while at higher percentages, agglomeration of slurry started to appear, which acts as media discontinuities, thus decreasing the compressive strength of samples. It is worth mentioning that zero slurry samples showed the lowest compressive strength of all samples and this is basically due to the poor grain size distribution and the lack of filling materials.

Comparing to the specifications, all samples are acceptable, in terms of compressive strength, compared to the Egyptian specifications even for structural requirements (7 MPa). However, as compared to ASTM C55, the control (39.6 MPa), M10 (39.4 MPa), M20 (28.3 MPa), G10 (43.5 MPa), G20 (37.0 MPa), and G30 (24.1 MPa) are acceptable for grade N (for architectural veneer and facing units in exterior walls and for use where high strength and resistance to moisture penetration and severe frost action are desired; 24.1 MPa, average of 3, and 20.7MPa, individual unit), and M30 (22.0 MPa) and G40 (22.8 MPa) are acceptable for Grade S (for general use where moderate strength and resistance to frost action and moisture are required; 17.3MPa, average of 3) and 13.8 MPa, individual unit). M40 is rejected for falling below the limits of Grade S. As for density, most samples, including the control, are of normal weight (>2000 kg/m^3), according to both the Egyptian specifications and ASTM C55, except for M30, G30, and G40, which are of medium weight (1680 – 2000 kg/m^3) .

Both heating and salt solution soaking and heating cycles increased the compressive strength of all samples with different ratios. Thus, it can be concluded that heating and cooling cycles did not adversely affect samples; on the contrary, they enhance compressive strength. This may be attributed to the accelerated cement hydration with higher temperature which apparently counter effected heat-associated volumetric changes.

Absorption is the major drawback of slurry incorporation in bricks, although the Egyptian specifications for concrete bricks do not impose limits for absorption in concrete bricks, but it specifies a maximum of 16% for wall bearing bricks, and 20% for non-wall bearing for fired clay bricks. All samples show absorption less than 15%. As for ASTM specifications, Zero, M10, G10, M20, G20, fulfill the requirements for grade S (208 kg/m^3, 10.1% for normal weight and 240 kg/m^3 for medium weight), with absorption values of 168 kg/m^3, 168 kg/m^3 ,185 kg/m^3, 193 kg/m^3, 201 kg/m^3, 179 kg/m^3 and 184 kg/m^3 (See Fig. 7).

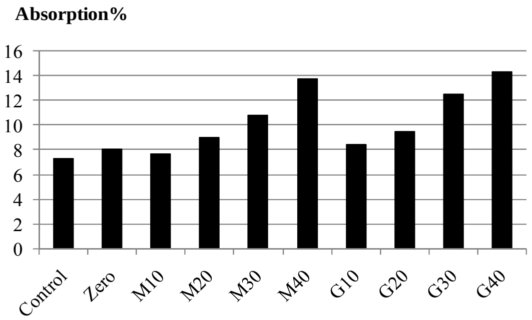

Fig. 7. Water absorption for marble and granite slurry samples.

As for the abrasion resistance of bricks for pedestrian and light traffic use according to ASTM C902, the control sample, zero, M10, M20, M30, G10, and G20, are all classified as class MX – brick intended for exterior use where resistance to freezing is not a factor, type II – brick subjected to intermediate abrasion. G30 is classified as class MX, type III – Brick subjected to low abrasion, while G40 is classified as class NX – brick not intended for exterior use but which may be acceptable for interior use where protected from freezing when wet, Type III.

IV. Conclusion

Marble and granite slurry cement bricks yield similar mechanical, in terms of compressive strength, and physical, in terms of density and absorption, properties. There is a positive effect of granite slurry on cement brick samples that reach its optimum at 10% slurry incorporation. Absorption is the major drawback of slurry incorporation in cement bricks according to the ASTM C55 where water absorption requirement is fulfilled only at Zero, 10 %, and 20% slurry samples for grade S. The accelerated hydration, endued by heating, compensated the detrimental effect of volumetric changes associated with temperature variation. Most cement brick samples, including the control, are of normal weight according to both the Egyptian specifications and ASTM

C55.All cement brick samples tested in this study comply with the Egyptian code requirement for structural bricks. This is not true when compared to ASTM C55. Instead, 10% and 20% marble and granite slurry yield Grade S. Most cement brick samples which contain marble and granite waste had sufficient abrasion resistance according to ASTM C902.

REFERENCES

[1] R. Ciccu, R. Cosentino, C. Montani, A. El Kotb, and H. Hamdy. "Strategic Study on the Egyptian Marble and Granite Sector". *Industrial Modernisation Centre,* August 2005. Retrieved May 5, 2007 from the World Wide Web: http://www.imc-egypt.org/en/studies/ Strategic%20study%20on%20the%20Egyptian%20Marble%20and% 20Granite%20Sector.pdf

[2] A. Kandil and T. Selim, "Characteristics of the Marble Industry in Egypt". Retrieved May 7, 2007 from the World Wide Web: www.aucegypt.edu/academics/dept/econ/Documents/marble.pdf

[3] Istitutonazonake per Commercio Estero. "EGITTO reference period: 2003". Retrieved May 5, 2007 from the World Wide Web: www.ice.gov.it/new_settori/main/egitto_II_03.pdf

[4] M. Celik and E. Sabah, "Geological and Technical Characterisation of Iscehisar (Afyon-Turkey) Marble Deposits and the Impact of Marble Waste on Environment Pollution". *Journal of Environmental Management*, 87, 106-116, 2008. [On-line]. ScienceDirect.

[5] S. El Haggar. *Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development*. Elsevier Academic Press, 2007, Ch. 10. pp. 346-350.

[6] S. Pareek. "Gainful Utilization of Marble Waste – An Effort towards Protection of Ecology & Environment". *Centre for Development of Stones*. Retrieved May 5, 2007 from the World Wide Web: http://www.cdos-india.com/Papers%20technical.htm

[7] J. Delgado, A. Va'zquez, R. Juncosa, and V. Barrientos. "Geochemical Assessment of the Contaminant Potential of Granite Fines Produced during Sawing and Related Processes Associated to the Dimension Stone Industry". *Journal of Geochemical Exploration*, 88, 24-27. 2006. [On-line]. *ScienceDirect*

[8] V. Vijayalakshmi, S. Singh, and D. Bhatnagar. "Developmental Efforts in R & D for Gainful Utilization of Marble Slurry in India". *Centre for Development of Stones*, 2003. Retrieved January 3, 2010 from the Web: http://www.cdos-india.com/Papers%20technical. htm

[9] N. Almeida, F. Branco, and J. Santos. "Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures". *Building and Environment*, 42, 810-819, 2007. [On-line]. ScienceDirect.

[10] M. Kumar, K. Suryanarayana, and T. Venkatesh. "Value Added Products from Marble Slurry Waste". *Centre for Development of Stones*, 2003. Retrieved January 3, 2010 from the World Wide Web: http://www.cdos-india.com/Papers%20technical.htm

[11] G. Rizzo, F. D'Agostino, and L. Ercoli. "Problems of Soil and Groundwater Pollution in the Disposal of "Marble" Slurries in NW Sicily". *Environmental Geology*, 55, 929-935. 2008. [On-line]. Springer Science and Business Media

[12] F. Saboya, G. Xavier, and J. Alexandre. "The Use of Powder Marble By-product to Enhance the Properties of Brick Ceramic". *Construction and Building Materials*, 21, 1950-1960, 2007 [On-line]. ScienceDirect.

[13] P. Torres, H. Fernandes, S. Olhero, and J. Ferreira. "Incorporation of Wastes from Granite Rock Cutting and Polishing Industries to Produce Roof Tiles". *Journal of the European Ceramic Society*, 29, 23-30, 2009. [On-line]. ScienceDirect

[14] V. Corinaldesi, G. Moriconi, and T. Naik,. "Charactarization of Marble Powder for its Use in Mortar Concrete". *Construction and Building Materials*, 24, 113-117, 2010. [On-line]. ScienceDirect.

[15] R. Menezes, H. Ferreira, G. Neves, H. Libra, and H. Ferreira, "Use of Granite Sawing Wastes in the Production of Ceramic Bricks and Tile"s. J*ournal of the European Ceramic Society*, 25, 1149-115, 2005. [On-line]. ScienceDirect.

[16] S. Monteiro, L. Pecanha, and C.Vieira. "Reformulation of Roofing Tiles Body with Addition of Granite Waste from Sawing Operations". *Journal of the European Ceramic Society*, 24, 2349-2356, 2004. [On-line]. ScienceDirect.