Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

UTILIZING THE WASTE OF MARBLE AND GRANITE INDUSTRY IN PORTLAND CEMENT CONCRETE

Emam, Hala[1], Naguib, Merna[1],El Rashidy, Nouran[1], Khalil, Rana[1], Awad-Allah, Yasmein[1], Ghaly, Athnasious[1], Abou-Zeid, Mohamed[1]
[1] Department of Construction Engineering, The American University in Cairo, Egypt
[2] yasmein@aucegypt.edu

Abstract: The waste of the marble and granite industry imposes an imminent environmental and health hazard in many parts of the world creating various problems that are not only limited to the aforementioned hazards but are also related to high economic costs. Such waste could be used to replace both the fine and coarse aggregates in a Portland cement concrete mix enhancing its properties while simultaneously offering burial destination to such waste. Hence, it is vital to explore and research the properties of such waste products before incorporating it into Portland cement concrete. In this work, Portland cement concrete mixtures are prepared using the solid debris waste of marble and granite to partially replace coarse aggregates in three dosages. In Addition, 3 mixes using marble debris and slurry to replace both the fine and coarse aggregates is prepared to test the effect of the slurry. Aggregate, thermal, fresh and hardened concrete testing were conducted in addition to other tests such as the water permeability, chemical resistance, RCPT and abrasion. The main aim of this work was to reach a good quality concrete mix that could be positively compared to the conventional concrete; in addition, a feasibility study exploring the means of incorporating such waste in terms of material and transportation costs as well as the costs of the health and environmental hazards is prepared and analyzed. Conclusions and recommendations are acquired to define the most appropriate dosage range to implement as well as to highlight possible advantages of using such waste.

1 INTRODUCTION

Marble and Granite industry is considered one of the largest industries in the world, where the global production capacity of marble and granite have been rising on average by an 8.8% rate of growth annually, starting the year 2000. Moreover, around 60-80% of the entire production process is attributed to waste in the form of debris; as for the generated sludge, it is estimated to be over 30% of the block's volume. The wastes produced from the Marble and Granite industry have the capacity to highly pollute the surroundings and land ecology due to the stones' high alkalinity, imposing an imminent risk to the environment. The waste production cycle starts with the squaring of the marble blocks using the Monolama; then it is placed in the Gang saw to adjust the slab thickness before polishing in the polishing machine. Finally, the slabs are cut into tiles using the cutting machine. The solid waste parts (debris) are mainly produced from the Monolama, cutting machine and the polishing machine; after accumulation the waste is deposited outside the factory. Moreover, there is also wastewater resulting from the process, which is collected in a well and deposited in a water silo after a powder is added for deposition infection. Then, the marble dust particles go through filter presses for slurry treatment. The slurry, which is in a semi-moist dust form, is then accumulated outside the factories and dumped in public waste deposits using trucks. All of the slurry is then dried and scattered all over.

The harming impact of such waste is not only centered on the environmental damage of reduction in soil fertility and plant productivity, but it also contributes the threatening health diseases such as damaging the cells of the respiratory system, chronic coughing, shortening of breath, vision pollution, lung cancer and skin and eye irritation. Hence, it is of vital importance to explore feasible means of utilizing such waste to limit its negative impacts and highlight means of potential positive attributes.

2 LITERATURE REVIEW

2.1 Re-use of Granite Sludge in Producing Green Concrete:

Allam M. E., Bakhoum E. S. and Garas G. L.

In this paper, the environmental hazards and impacts of waste generated in the production process of granite are discussed. A shocking 60-80% is attributed to the waste generated from mining the granite, up to its final finishing process; as for the generated sludge, it was estimated to be over 30% of the block's volume. The work performed in this paper, discusses the possibility and experimental program of utilizing such waste, namely the sludge, to replace the cement and sand to produce a green concrete mix. The compressive strength results indicated that the highest compressive strength in comparison with the control was obtained with a 10% substitution of sand by the granite sludge, while that the replacement of cement, decreased the compressive strength regardless of any replacement percentage. Hence, indicating that the utilization of such waste material in the replacement of sand can have a positive impact on the compressive strength.

2.2 Marble and Granite Waste: Characterization and Utilization in Concrete Bricks:

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

This work discusses the impact of the flourishing industry of marble and granite in Egypt, which in turn increased the piles of mined and processed waste. Due to its high alkalinity, the waste generated is immensely polluting, imposing health and environmental hazards on the affiliated surroundings. Moreover, it particularly discusses the large amounts of waste deposited in Shaq Al-Thuban, the largest industrial area in Egypt and its effect on the neighboring areas, their communities and ecology. The work performed in this paper, aimed to utilize the stone waste in the manufacturing process of concrete bricks, fully replacing fine and coarse aggregates with waste debris and slurry reaching 40%. After testing the physical as well as the mechanical properties of the bricks incorporating such waste according to the ASTM and Egyptian Code (EC), it was concluded that such waste was rendered suitable for usage in the building industry as all bricks complied with all the structural bricks requirements in the EC, furthermore, that with 10% granite slurry replacement; the cement bricks reached their optimum properties.

2.3 Impact of Marble Waste as Coarse Aggregate on Properties of Lean Cement Concrete:

Sudarshan D. Kore*, A.K. Vyas

In the following journal entry, the work performed aimed to effectively employ the waste generated from marble, to replace the conventional coarse aggregate in the production of concrete, in order to alleviate the environmental hazards resulting from such waste. In order to conduct multiple experiments to study the validity and feasibility of such an attempt, various concrete mixes were prepared replacing the coarse with marble aggregate by weight through varying percentages (0-100%), with a constant w/c ratio throughout. The results indicated that the mixes containing marble, had a 14% higher workability than that of the control mix. Moreover, that the compressive strength of the mixes utilizing marble waste were observed to increase, on average, by 40% and 18% when tested at 7 days and 28 days, correspondingly.

3 OBJECTIVE AND SCOPE

In this research, the main objective was to explore feasible means to utilize waste resulting from the marble and granite industry not only to be incorporated into Portland cement concrete but also to potentially enhance the concrete industry. This objective was obtained through conducting experimental work for the marble and granite waste in Portland cement concrete.

4 EXPERIMENTAL PROGRAM

4.1 Material Properties

Cement: Type I Ordinary Portland Cement Concrete

Fine Aggregates: Natural sand will be used.

Coarse Aggregates: Well-graded crushed dolomite was used as coarse aggregates. The aggregates had MNA of 38 mm.

***Marble slurry*:** A marble sludge powder was used, which was obtained from the area of Shaq Al Thu'ban, Cairo, Egypt.

Marble debris: Marble waste used was from the area of Shaq Al Thu'ban and crushed into crusher with MNA of 38 mm.

Granite debris: Granite waste used was from the area of Shaq Al Thu'ban and crushed into crusher with MNA of 38 mm.

4.2 Concrete Mix Design

The characteristic concrete mixture that was used in this study has a cement content of 400 kg/m^3 and a water-to-cement ratio of 0.45. based on literature review and material properties other mixtures will be prepared by partially replacing the coarse aggregates with marble debris with dosages of 20%, 40% and 60% and granite debris with dosages of 30%, 60% and 100%. Other mixtures will be made by replacing the fine aggregates by the marble slurry and the coarse aggregate by marble debris. Concrete mixing and casting of specimens were carried out according to ASTM standards.

Table 1 Concrete mix

Mix No.	mix name	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Marble debris (kg/m^3)	Granite debris (kg/m^3)	Marble slurry (kg/m^3)	Water (kg/m^3)	w/c ratio
1	Control Mix	400	621	1117	-	-	-	180	0.45
2	20% Marble	400	620	893	223	-	-	180	0.45
3	40% Marble	400	619	669	446	-	-	180	0.45
4	60% Marble	400	619	446	668	-	-	180	0.45
5	30% Granite	400	623	785	-	336	-	180	0.45
6	60% Granite	400	625	450	-	675	-	180	0.45
7	100%Granite	400	619	-	-	1114	-	180	0.45

Mix No.	mix name	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Marble debris (kg/m^3)	Granite debris (kg/m^3)	Marble slurry (kg/m^3)	Water (kg/m^3)	w/c ratio
8	10% slurry	400	558	893	223	-	62	180	0.45
9	20% slurry	400	496	893	223	-	124	180	0.45
10	30% slurry	400	435	893	223	-	186	180	0.45

4.3 Tests

4.3.1 Aggregate Tests:

- Sieve analysis: Sieve analysis was performed to determine the gradation of aggregates
- Specific gravity: Test was conducted to determining the specific gravity of the aggregates.
- Absorption: Test was conducted to determine the percentage of water absorption by weight of the aggregates.
- LAA (Los Angeles abrasion): Test was conducted to determine the degradation of aggregates by abrasion

4.3.2 Fresh Concrete Tests:

- Slump: This test is conducted to check the workability of freshly made concrete in accordance with [ASTM C232]
- Air content: This test is conducted to determine the air content of concrete in accordance with [ASTM C231]
- Unit weight: This test is conducted to determine the unit weight of concrete.

4.3.3 Hardened Concrete Tests:

- Compressive Strength: The test is conducted to evaluate the strength of concrete using cubes in accordance with British Standards [BS 1881]. This test was performed on cubes of 15cm*15cm*45cm at 7 days and 28 days.
- Flexural Strength: The test is conducted in accordance with the ASTM standards [ASTM C78] to measure the flexural strength of the mixes. Three Point Test was performed on beams of 15cm*15cm*15cm at 3 days, 7 days and 28 days.
- Thermal Expansion: The test is conducted to evaluate the thermal expansion, where samples of 2.5cm*2.5cm*8cm, where a steam generator is used to heat the samples.
- Thermal Conductivity: The test is conducted to evaluate the thermal conductivity of the concrete cubes in accordance with the ASTM Standards [ASTM C518] on a sample of 15cm*15cm*5cm after 28 days of curing.
- Water permeability: This test measures the permeability of mortar or concrete to water by measuring how deep the water penetrates the specimen through three days under pressure. The test is done on specimen after 28 days.
- Chemical resistance:
  - Sulphuric acid (H_2SO_4): cubes were submerged in diluted sulphuric acid with concentration 10% for 1 cycle.
  - Sulphate salts ($MgSO_4$): cubes were submerged in solution of salt with concentration of 60% for 4 cycles.
- RCPT (rapid chloride penetration test): In this test, we were trying to study the performance of concrete in resisting the flow of chloride ions through it. This can help us in determining whether this material can be used in applications that require less permeability of chloride ions.

- Abrasion: This test is based on relative value comparison, specimens of 5cm*5cm*5cm cubes was fixed on a rotating surface and abrasive material and water was added to find the reduction in length.
- Results and Discussion

4.4 Aggregate tests:

4.4.1 Sieve analysis:

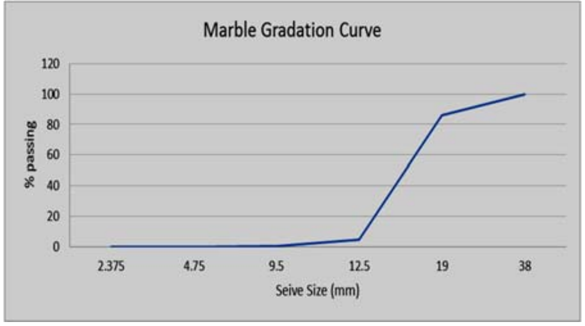


Figure 1

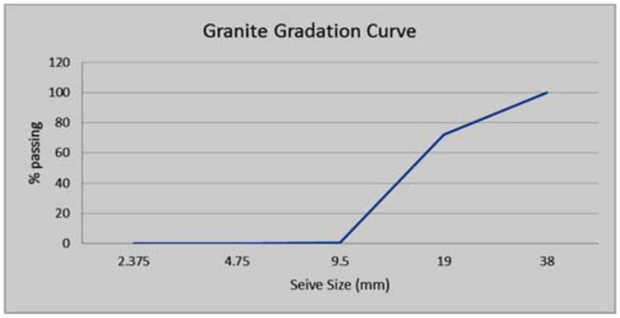


Figure 2

Table 2 Aggregates properties

	Marble	granite	Course aggregates	Fine aggregates
specific gravity	2.58	2.59	2.57	2.55
Absorption	1.55%	0.50%	1.80%	0.40%
LAA	24.50%	48.10%	-	-

The sieve analysis tests for both the marble and granite showed that both samples were poorly graded; however other properties such as the specific gravity and the absorption percentage were aligning with the materials' properties from the research done. The LAA Abrasion test, used to measure the aggregates' resistance to abrasion and impact, produced an adequate result for the marble, but a slightly higher than average percentage loss in the granite.

4.4.2 Fresh concrete results

Table 3 Fresh test results

	Slump (cm)	Unit Weight (kg/m^3)	Air Content
Control Mix	2.5	2417	2.4%
20% Marble	2.5	2399	2.5%
40% Marble	3.5	2393	2.0%
60% Marble	4.0	2379	2.4%
30% Granite	4.0	2376	2.5%
60% Granite	6.5	2376	1.7%
100% Granite	5.0	2390	2.0%
10% Slurry	7.5	2374	2.7%
20% Slurry	11.0	2366	1.5%
20% Slurry	11.0	2340	1.4%

The slump test gave adequate results for the marble and granite mixes; however, it was high in the slurry mixes due to its unique behaviour when it's mixed with the rest of the concrete components. Moreover, the unit weight and the air content tests gave similar results to those obtained from the research.

4.5 Hardened tests:

4.5.1 Compressive Strength

Table 4 compressive strength results

Mix	3 days (MPa)	7 days (MPa)	28 days (MPa)
Control Mix	28.1	34.4	40.5
20% Marble	25.2	34.3	43.5
40% Marble	26.2	29.4	34.7
60% Marble	27	29.8	39.8
30% Granite	27.2	28.1	33
60% Granite	24.1	25.7	33.1
100% Granite	22.6	19.2	31.1
10% Slurry	20.9	28.3	34.9
20% Slurry	21.7	27.5	33.1
30% Slurry	17.5	20.7	27.1

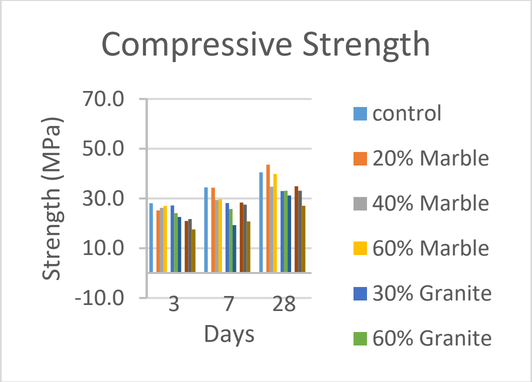


Figure 3 Compressive strength results

The compressive strength at 3 days, 7 days and 28 days was tested for all of the samples and compared with the performance of the control mix. For the marble mix the results show that there is a slightly decrease trend and that all of the three samples at 28 days were of adequate values with respect to the control mix with the 20% marble replacement dosage reaching the maximum compressive strength with a value of 43 Mpa. As for the granite mix, the results exhibit adequate results as well with a minimum of 30 Mpa for the 100% replacement, although they were all less than the value of the control mix. Finally, for the slurry mixes at 28 days, the compressive strength results ranged from 26-35 Mpa which could also be considered adequate. The value of the 40% marble is very low compared with the 20% and 60% as it may be because of an error in compaction.

4.5.2 Flexural Strength (ASTM C-78)

Table 5 Flexural strength results

Mix	7 days (MPa)	28 days (MPa)
Control	3.4	3.9
20% Marble	3.5	3.9
40% Marble	3.7	4.5
60% Marble	4	5.6
30% Granite	3.4	3.6
60% Granite	3.1	3.5
100% Granite	3.1	3.5
10% slurry	2.9	2.8
20% slurry	2.7	2.7
30% slurry	2.4	3

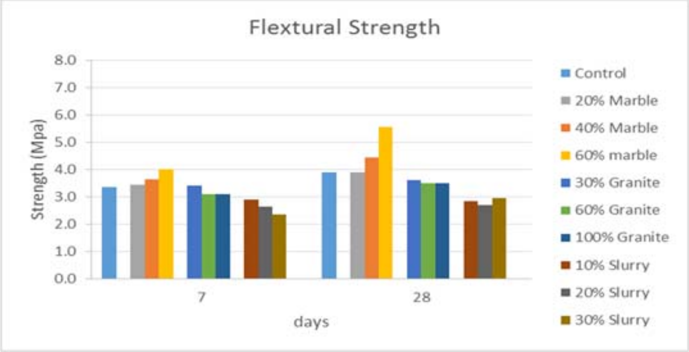


Figure 3 Flexural strength results

The flexural strength results showed an optimum replacement of 60% marble with 5.56 Mpa, which is greater than the control mix. Moreover, the remaining results showed comparable values to that of the control. Moreover, there was an observable trend in the Marble mixes; as we increased the dosage of the marble replacement, the flexural strength increased. The Granite and the slurry mixes show approximately similar results for the three percentages.

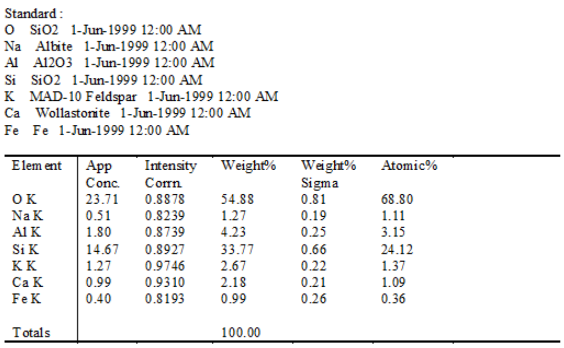
4.5.3 RCPT:

Table 6 RCPT test results

	Charge Passed (Coulombs)
Control	3640
20% Marble	4674
40% Marble	4267
60% Marble	4130
30% Granite	3375
60% Granite	4046
100% Granite	7474
10% Slurry	3641
20% Slurry	4838
30% Slurry	4860

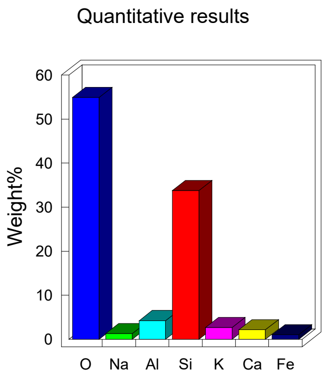
Since some mixes resulted in very high results, the EDX (Energy Dispersive X-Ray) test was conducted in order to know and asses the different components in the marble and granite debris. The test resulted in finding some steel in the granite aggregates and hence, interfered with the RCPT results. Moreover, since all of the waste is deposited in the same area, there is a possibility that the marble and the slurry would be affected as well. Hence, the RCPT test results were deemed not reliable to assess the concrete properties.

Contaminated granite (EDX Test):

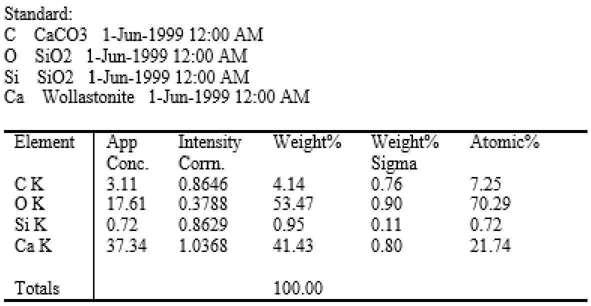


Standard :
O SiO2 1-Jun-1999 12:00 AM
Na Albite 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
K MAD-10 Feldspar 1-Jun-1999 12:00 AM
Ca Wollastonite 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
O K	23.71	0.8878	54.88	0.81	68.80
Na K	0.51	0.8239	1.27	0.19	1.11
Al K	1.80	0.8739	4.23	0.25	3.15
Si K	14.67	0.8927	33.77	0.66	24.12
K K	1.27	0.9746	2.67	0.22	1.37
Ca K	0.99	0.9310	2.18	0.21	1.09
Fe K	0.40	0.8193	0.99	0.26	0.36
Totals			100.00		

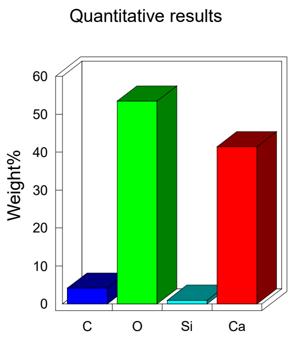


Contaminated Marble (EDX Test):



Standard:
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Ca Wollastonite 1-Jun-1999 12:00 AM

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C K	3.11	0.8646	4.14	0.76	7.25
O K	17.61	0.3788	53.47	0.90	70.29
Si K	0.72	0.8629	0.95	0.11	0.72
Ca K	37.34	1.0368	41.43	0.80	21.74
Totals			100.00		



4.5.4 Water permeability:

Table 7 Water permeability results

	Average (cm)
Control	1.0
20% marble	1.2
40% marble	1.4
60% marble	1.5
30% granite	3.3
60% granite	3.5
100% granite	3.7
10% Slurry	2.2
20% Slurry	2.7
30% Slurry	3.1

Figure 6

The water permeability test exhibited a common trend in all of the waste mixes, since the water permeability increased with increasing the percentage replacement of waste. However, the results are not prohibitive to utilize the marble and slurry waste as their values are comparable to that of the control mix.

4.5.5 Abrasion:

Table 8 Abrasion test results

	% loss
Control	1.83%
60% Marble	2.44%
60% Granite	0.50%
20% Slurry	0.90%

The results show that the properties of the Granite and slurry are better in abrasion than those of the control mix; Moreover, even though the percentage loss in the marble mix was about 0.6% more than that in the control mix, it is still a relatively small increase and does not disqualify the usage of marble waste.

4.5.6 Chemical Resistance:

- Sulphuric Acid Resistance:

Table 9 chemical test results

Mix	% Reduction
Control Mix	8.50%
Marble 20%	8.50%
Marble 40%	7.00%
Marble 60%	2.20%
Granite 30%	0.50%
Granite 60%	0.40%
Granite 100%	0.10%
Slurry 10%	1.50%
Slurry 20%	0.50%
Slurry 30%	0.40%

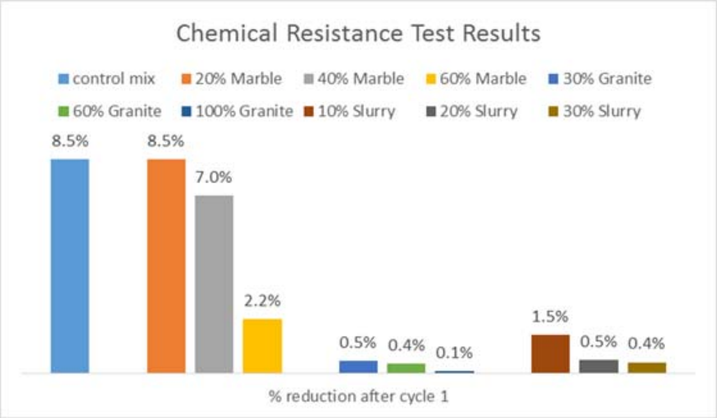


Figure 7 chemical resistance results

The results of the acid chemical tests indicate a common trend amongst all waste materials; as we increase the percentage replacement, the percentage reduction is decreased indicating superior chemical resistance qualities of the marble, granite and slurry.

- Sulphate Salts Resistance:

	% reduction after cycle 1	% reduction after cycle 2	% reduction after cycle 3	% reduction after cycle 4
control mix	5.0%	3.7%	2.2%	3.2%
marble 20%	5.1%	3.7%	2.2%	3.3%
marble 40%	4.7%	0.3%	-0.8%	-0.1%
marble 60%	0.9%	-1.6%	0.6%	1.8%
Granite 30%	-1.6%	-0.1%	-0.9%	-2.5%
Granite 60%	-1.9%	-0.3%	0.3%	-0.8%
Granite 100%	-2.6%	-0.3%	0.3%	-0.5%
Slurry 10%	2.1%	2.4%	-0.7%	1.9%
Slurry 20%	1.6%	2.1%	-0.5%	0.4%
Slurry 30%	1.3%	1.1%	0.1%	-1.5%

The magnesium sulfate test is deemed not reliable in assessing the salts chemical resistance of the mixes due to the fact that the salts and other chemicals significantly precipitate inside the mixes as we add the magnesium sulfate giving negative percentage reduction at cases; and hence, the results of this test will not be deemed reliable in assessing the concrete properties.

4.5.7 Thermal Conductivity:

Table 10 Thermal conductivity test results

Sample Type	Density (Kg/m3)	Thermal Conductivity (W/m.K)
control	2317	1.29
60% marble	2320	1.34
60% Granite	2270	0.92
20% Slurry	2213	0.70

The thermal conductivity test results show that the marble has a slightly higher thermal conductivity coefficient than the control mix, while the granite and slurry mixes had lower values than that of the control indicating superior thermal properties; which means the heat transfer at low rate from one side to another.

4.5.8 Thermal expansion

Table 11 Thermal expansion results

Mix	Thermal Expansion Coefficient (c$^{0-1}$)
Control	9.6x10^{-6}
60% Marble	9.5x10^{-6}
60% Granite	9.2x10^{-6}
20% Slurry	9.4x10^{-6}

The thermal expansion test shows that the control has the highest coefficient and the granite showed the lowest thermal coefficient.

5 CONCLUSIONS

While our study was limited in time and scope the following conclusions could be withdrawn:

- The aggregate testing revealed that all of the waste material was poorly graded while the granite in particular was flaky and elongated
- The fresh test results were quite similar while the slurry had a unique behaviour in the slump tests
- The compressive test results were comparable and the variations in strengths don't show a low value not to be used in construction applications while flexural results showed adequate results for the waste materials compared to the control and the reduction in flexural strength was less than the compressive strength for waste materials
- The RCPT test was deemed not reliable due to the inclusion of metallic deposits and hence, the water permeability test was found more suitable in assessing the permeability of waste mixes. It is also important to note that the granite and slurry exhibited better performance in abrasion than the control mix and that the waste materials exhibited a superior performance and advantageous qualities in the chemical durability acid test and in the thermal tests.

6 RECOMMENDATIONS

The recommendations of our study are as follows:

- Conduct a larger scope experimental work to verify the findings of this study as well as to carry out further tests on non-reinforced as well as reinforced concrete
- Conduct the Radon test to test for radioactive materials, as well as conduct tests for long term properties such as creep and fatigue.
- Use this concrete in structures exposed to acids and high temperatures due to their beneficial properties in such conditions.
- Urge the Egyptian Government as well as the construction industry to not only consider investing in utilizing the waste products but to also consider including them in the Egyptian code of practice
- Include this study as one of several steps towards more environmentally friendly and greener construction industry.

Acknowledgements

- Mr. Ashraf Awad, CEO of KiroMarble Factory
- Dr. Mahmoud Abd El Razek, HBRC
- Dr. Medhat Al- Mahalawy, HBRC
- Engineer Mohamed Salah, Physics Department, American University in Cairo
- Engineer Dina, Mechanical Department, American University in Cairo
- Dr. Ahmed Noor, Research Centre, American University in Cairo

References

Abukersh, S.A., and C.A. Farfield. "Recycled aggregate concrete produced with red granite dust as a partial cement replacement." pag. *School of Engineering and the Built Environment, Edinburgh Napier University, 10 Colinton Road, Edinburgh, EH10 5DT, UK*. Web. 20 Jan. 2017.

Allam, M.E., E.S. Bakhoum, and G.L. Garas. "Re-use of granite sludge in producing green concrete." pag. *Department of Civil Engineering, National Research Centre, Egypt*. Web. 20 Jan. 2017.

Al-Zboon, Kamel, and Jehad Al-Zouby. "Recycling of stone cutting slurry in concrete mixes." *Springer Japan* (2014): Web. 20 Jan. 2017.

ASTM C518-15, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus, ASTM International, West Conshohocken, PA, 2015, www.astm.org

Haggag, Farah." Economic and financial valuation of the marble industry in Egypt". *Department of Economics, American university in Cairo, Egypt*. Web. May. 2012.

"Health Risks of Marble Dust." *LIVESTRONG.COM*. Leaf Group, 24 Oct. 2015. Web. 11 Feb. 2017.

Khedr, Safwan, Salah El- Haggar, and Rania Hamza. "Marble and Granite Waste: Characterization and Utilization in Concrete Bricks." *International Journal of Bioscience, Biochemistry and Bioinformatics* 1.4 (2011): Web. 20 Jan. 2017.