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CIRCULAR ECONOMY IN MARBLE AND GRANITE INDUSTRY: FROM STONE SCRAPS TO SUSTAINABLE GREEN CONCRETE

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ABSTRACT

This work aims to study the behavior of concrete by replacing sand, aggregate and cement with marble manufacturing waste. The concrete is prepared by partially replacing cement, fine aggregate, and coarse aggregate with marble and granite waste. The impact of partially substituting granite and marble on the characteristics of the cured concrete was investigated. The density, compression strength, durability, and micro-structure of the produced concrete were used for evaluation of the produced concrete. The results showed that there is no significant change of the concrete density. While, the compression strength is improved as a result of partially replacing fine aggregate, and coarse aggregate with marble and granite waste. Substitution of 10% cement by marble dust, 20% sand by granite sludge, and 25-50% coarse aggregate by granite fragment produces concrete that is equivalent to or better than the control mix at all ages. The water permeability increases with increasing substitution compared to the control concrete. Also, the replacement slightly improved the acid resistance.

KEYWORDS: Waste management, Waste treatment, Marble waste, Granite waste, Concrete, Compressive strength, Sustainability, Green Concrete.

الإقتصاد التدويري في صناعة الرخام والجرانيت: إستخدام مخلفات صناعة الرخام والجرانيت في إنتاج الخرسانة الخضراء المستدامة

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الملخص

يهدف هذا البحث إلى دراسة خصائص الخرسانة من خلال الإحلال الجزئي لكل من الأسمنت والرمل والحصى بمخلفات الرخام والجرانيت. وقد تمت الدراسة على عينات من مخلفات الرخام والجرانيت التى تم تجميعها من مصنع بورسعيد للرخام والجرانيت بمنطقة شق الثعبان بطره بالقاهرة ، حيث تم إستخدام نوعين من مخلفات الرخام والجرانيت ، النوع الأول هو القطع الكبيرة (الكسر) والنوع الثاني هو المخلفات الناعمة ، وقد تم تحضير الخرسانة بإحلال الأسمنت والرمل والحصى جزئياً بمخلفات الرخام والجرانيت ، وقد تم قياس الكثافة وتحمل الضغط والمتانة ونفاذية الماء ومقاومة الأحماض والبنية المجهرية للخرسانة المنتجة

لتقييمها. وقد أظهرت النتائج إمكانية الإحلال الجزئي للرمل والحصى بنفايات الرخام والجرانيت في الخلطات الخرسانية ، حيث تم الحصول على خرسانة تكافئ أوأفضل من الخرسانة التقليدية بإحلال 10% من الأسمنت بالرخام الناعم ، و20% من الرمل بالجرانيت الناعم ، و25-50% من الحصى بكسر الجرانيت ، كما أظهرت النتائج عدم وجود تغيير ملحوظ في الكثافة ، في حين تم تحسين تحمل الضغط ونفاذية الماء مع زيادة الإحلال مقارنة بالخرسانة التقليدية ، كما تحسنت مقاومته للأحماض بشكل طفيف.

الكلمات المفتاحية : إدارة المخلفات، معالجة المخلفات، مخلفات الرخام، مخلفات الجرانيت، الخرسانة، قوة الضغط ، الاستدامة ، الخرسانة الخضراء.

1. INTRODUCTION

In order to ensure that natural or physical resources last for a long time, sustainability aims to stop their depletion [1-3]. A sustainable urban system is one that uses resources and produces waste without going beyond the ability of nature to replenish those resources and absorb that waste [4]. The wastes produced during the marble and granite manufacturing process contribute to environmental contamination and are a major cause of pollution in the air, water, and soil.The global output of dimension stones may surpass 100 million tons by 2025 due to the industry's daily growth [5]. However, in 2019 there were around 316 million tons of total quarrying production worldwide [6]. Around 73% of the product's waste worldwide is thought to come from quarrying [7]. Carbonate stones account for over 60% of all dimension stone output, with granites making about 38% [5, 6].

The ornamental stone industry in Egypt has experienced significant growth in the last several years. In Egypt, this industry is mostly active in Turah, Cairo's Shaq El-Thoaban neighborhood. According to the local estimation, Egypt is responsible for 2.24 million tons of marble and granite waste, which accounts for 70% of the total 3.2 million tons of stone output [8]. Ultra-fine sawdust sludge accounts for 70% of the total trash generated [9]. This enormous amount has been regarded as a true waste for a long time and poses a hazard to the environment and those around us. Therefore, it is incompatible with urgently needed environmental preservation and eco-sustainability. Several technical solutions to solve this issue take into account using these wastes as a by-products in many other industrial applications [10]. Recycling industrial waste benefits the environment by reducing the amount of material disposed of in landfills and conserving natural resources [8, 11].

This work presents the possibility of producing green concrete by replacing sand, aggregate, and cement with waste marble and granite. The enhancement of concrete assets, particularly durability and compressive strength, was the driving force behind the use of leftover marble and granite in addition to cost-effectiveness [27, 28].

Concrete is a composite material made up of loose materials known as aggregates that provide strength and are formed into a homogenous mixture using water and a binder in the form of cement [29]. The application of waste recycling must be expanded by using materials resulting from various industries as waste if they are suitable for that [30]. Certain materials when used in concrete produce favorable results in comparison to regular-use concrete while saving on several environmental and financial fronts. Supplementing cement materials helps to meet the increasing demand for cement and also reduces greenhouse gas emissions [29, 31].

It is incorrect to think of green concrete as a specific color of concrete. This word refers to concrete that emits less greenhouse gases and is more environmentally friendly than traditional concrete [32, 33]. Green concrete is defined as concrete whose manufacture does not harm the environment, has a high-performance level, is sustainable throughout its life cycle, and incorporates at least one waste element into its composition. Green concrete enhances sustainability's effects on the social, environmental, and financial fronts [34].

Based on the previuos studies for employment of marble waste; the important of using marble waste as fine aggregate is its particle size distribution. A 10-15% of the cement can replace by marble depending on its particle size distribution. The effectiveness of using marble waste be increased by combination with fly ash. Also, the silica fume increases the concrete performance. The ultra fine marble powder led to self-compacting concrete which increase cohesivity and all mechanical properties. The marble waste could be used up to 50% as partial replacement of river sand resulting good mechanical properties. Complete replacement of marble (calcium carbonate) aggregate is possible which depends on its density of the concrete constituents. Also, the corase marble waste was crushed to produce desired coarse aggregate to be suitable for concrete production. It is not affect on quality of concrete but it enhanced the mechanical and durability performance of concrete [35 - 44].

2. Materials and Methods

2.1. Raw materials

The primary materials employed in this study were granite stones with an average size of 12.5 mm for the coarse aggregates and natural sand with a maximum size of 4.75 mm for the fine aggregates. Portland cement, water, marble, and granite waste were used as mineral additives. The granite and marble waste samples were supplied by the Port Said Factory for Marble and Granite, Shaque El-Thobaan, Turah, Cairo, Egypt. Coarse and fine fraction sizes were used. The coarse sample was in the form of fragments, while the fine sample was in the form of a slurry. The waste fragments are produced chips during carving, chiseling, and finishing. A jaw crusher was used for crushing the sample followed by classification into coarse aggregates 12.5 mm, 4 mm and 1 mm. The slurry wastes were collected from sawdust sludge settling basins of the stone cutting. The slurry was dried in the sun for 3 days, then in an oven at 100°C for 1 h.

2.2. Design Mix of Concrete

Based on the Egyptian Standard, experimental samples of concrete mixers were prepared by partially replacing cement, fine aggregate, and coarse aggregate with four different percentages by weight of marble and granite waste (0%, 10%, 20%, and 50% for cement replacement with marble sludge), (0%, 10%, 20% and 50% for fine aggregate replacement with granite sludge) and (0%, 25%, 50% and 100% for coarse aggregate replacement with granite fragment). Batching by weight method was used for the concrete preparation. **Table 1** presents the mix design per cubic meter by weight. The percentage of super plasticizer was 2% and kept constant.

The mix's ingredients were combined in a lab counter-current mixer for five minutes. The prepared mixtures were poured into a 150 mm cubic mold. The specimen spent a whole day in the molds. These samples were then cured in curing basins for seven and twenty-eight days. Ten series of concrete specimens, including a control specimen, were prepared in order to examine the impact of partially substituting granite and marble on the characteristics of the concrete. Six concrete specimen pieces were made for each series. In order to study the compressive strength of new concrete (slump test) and concrete that had been cured at various ages, sixty 150 mm cubic specimens were constructed.

Table1: Ingredients of the concrete mixes (Design Mix).

Mix no.	Design mix	Ingredients for prepared concrete by weight (kg)							
		Cemen	Sand	Aggregate	Fine marble	Fine granite	Coarse granite	Water	Plasticizer
Control mix									
1	**Cement-Sand-Aggregate**	11	22	35.51	–	–	–	6.29	0.22
Cement replacement									
2	**Replacement 10% marble**	9.9	22	35.51	1.1	–	–	6.29	0.22
3	**Replacement 20% marble**	8.8	22	35.51	2.2	–	–	6.29	0.22
4	**Replacement 50% marble**	5.5	22	35.51	5.5	–	–	6.29	0.22
Sand replacement									
5	**Replacement 10% granite**	11	19.8	35.51	–	2.2	–	6.29	0.22
6	**Replacement 15% granite**	11	18.7	35.51	–	3.3	–	6.29	0.22
7	**Replacement 20% granite**	11	17.6	35.51	–	4.4	–	6.29	0.22
Coarse aggregate replacement									
8	**Replacement 25% granite**	11	22	26.63	–	–	8.88	6.29	0.22
9	**Replacement 50% granite**	11	22	17.75	–	–	17.75	6.29	0.22
10	**Replacement 100% granite**	11	22	–	–	–	35.51	6.29	0.22

2.3. Physical and Mechanical Measurements

The density of the concrete samples was determined by the ASTM C373-16 [45]. The compression strength of concrete was carried out according to EN1926:1999. The speed of application loading was 0.5 mm/min until the ultimate failure was reached. Concrete porosity was measured using DIN-1048 Part 5 (1991) by casting and testing cube examples with a 150 mm diameter. In order to test the concrete's resilience to an aggressive, its durability was determined by submerging a concrete cube in a 5% sulfuric acid solution for 28 and 60 days.The immersed cubes were washed and then oven-dried. The durability was evaluated by measuring the compression strength in comparison with untreated concrete. The microstructure of the fracture concrete bodies was evaluated using the scanning electron microscopy (SEM) model TMT3030PLUS manufactured by HITACHI.

3. RESULTS AND DISCUSSION

3.1. Characterization of Marble and Granite Sludge Samples

Table 2 represents the mineral composition of marble and granite sludge obtained by XRD. The granite sludge sample is composed of 44.6% Albite, 15.2% Quartz, and 14.3% Dolomite, while the marble sludge is composed of 2.7% quartz, 2.5% albite, 2.6% illite, 64.3% calcite, 26.9% dolomite, and 1% bentonite. These results were confirmed by the complete chemical analysis, which was determined by XRF, **Table 3**.

Table 2: Mineral composition of the marble and granite sludge samples.

Waste sludge	Mineral	Formula	Weight %
Marble	Calcite	$CaCO_3$	64.3
	Dolomite	$CaMg(CO_3)_2$	26.9
	Quartz	SiO_2	2.7
	Albite	$NaAlSi_3O_8$	2.5
	Illite	$KAl_2Si_3AlO_{10}(OH)_2$	2.6
	Bentonite	$Na\text{-}Al\text{-}Si\text{-}O\text{-}OH\text{-}H_2O$	1.0
Granite	Albite	$NaAlSi_3O_8$	44.6
	Illite	$KAl_2Si_3AlO_{10}(OH)_2$	25.8
	Quartz	SiO_2	15.2
	Dolomite	$CaMg(CO_3)_2$	14.3

Table 3: Complete chemical analysis of the marble and granite sludge samples.

Waste residue	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	P_2O_5	SO_3	Cl^-	TiO_2	Na_2O	K_2O	L.O.I
Marble	7.32	45.52	4.66	2.07	1.55	0.08	0.17	0.035	0.156	0.48	0.29	37.68
Granite	58.66	4.44	3.18	16.95	--	--	--	--	--	5.39	3.21	8.17

Fig.1 shows the particle size distribution. Table 4 shows that the average particle size (D_{50}) of the marble and granite are 6.65 and 11.58 µm while the particle size of the whole sample is less than 57 and 69 µm, respectively. The average surface area is 0.4836 and 0.3507 m^2/g for the marble and granite, respectively. The specific gravity is 2.61 and 2.72 g/cm^3 for the marble and granite, respectively.

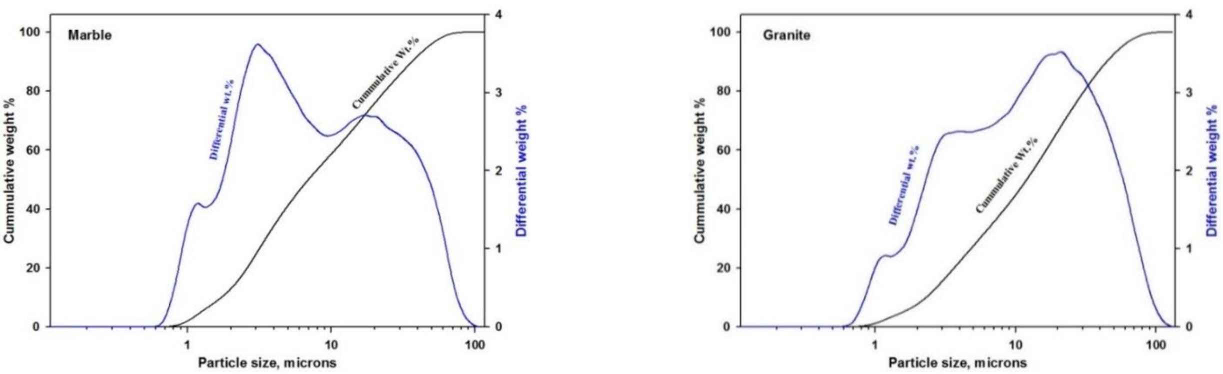

Fig.1. Particle size distribution of the marble and granite sludge.

Table 4: The specific gravity, surface area and average particle size of the sludge samples.

Item	Marble	Granite
D50 (µm)	6.65	11.58
D98 (µm)	57.01	69.29
Surface Area, (m^2/g)	0.4836	0.3507
Specific gravity, (g/cm^3)	2.61	2.72

3.2. Testing of Produced Concrete

3.2.1. Compressive Strength

The effect of partially replacing marble and granite on the concrete properties was investigated. The mechanical tests of the concrete specimens were determined by uniaxial compressive strength tests. Figures 2, 3 & 4 show the uniaxial compressive strength of the concrete specimen after 7 and 28 days of curing. It can be seen that the use of fine or coarse marble and granite wastes improved compressive strength. Cement replacement with marble sludge (10%), produces concrete with higher compressive strength than the control mix. Both the 7-day and 28-day strength increases were notable. The increase in compressive strength of concrete at different curing ages might be attributed to higher carbonate content as aresult of marble addition compared to cement, which enhances the paste bond [46, 47]. Replacement of fine aggregate (sand) with 20% fine granite sludge, produces concrete with higher compressive strength than the control mix. A marginal decrease in the compressive strength with higher replacement was observed. This may be due to the workability decreasing with the increase in the proportion of fine particles present in the mix resulting from the sand replacement with higher proportions of granite sludge, which contains a maximum particle size of 75 µm. Based on the previuos studies of using marble waste; the important of using marble waste as fine aggregate is its particle size distribution [35]. For coarse aggregate replacement with granite fragments (25-50%), produces concrete with equivalent compressive strength to control mix. A slight decrease in compressive strength with higher replacement was likely caused by the lack of fine fraction in marble aggregate. The percentage of voids increases as a result of this insufficiency. Thus strength was marginally decreased.

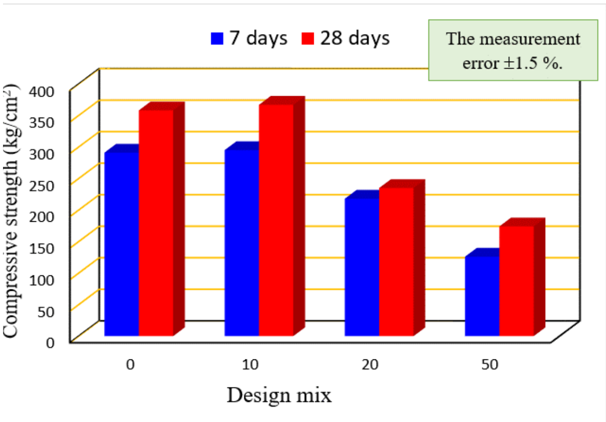

Fig.2. Compressive strength of concrete mixes (cement replacement with marble powder).

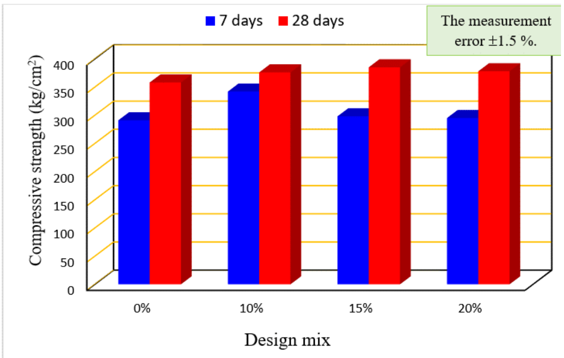

Fig.3. Compressive strength of concrete mixes (sand replacement with granite

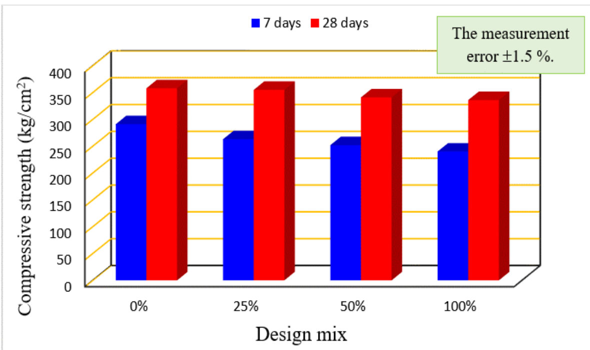

Fig.4. Compressive strength of concrete mixes (coarse aggregate replacement with granite fragments).

3.2.2. Water Permeability

Due to the importance of these characteristics of the hardened concrete, tests on the generated concrete's density and water permeability are conducted. When the mixing or substitution rate is changed, the density of the concrete mixes (Figs 5, 6 & 7) does not vary much. As a result, the density value fluctuation is normally acceptable and rather small. The beginning material densities, mix ratios, initial and final water contents, and degree of hydration all affect the density of concrete. It is reasonable to assume that recycled aggregates will impact concrete's density [46]. Various mixes have various densities because of the variable replacement content percentages.

The purpose of the water permeability test was to evaluate the porosity of concrete. The control specimen had a depth of penetration of 27 cm, while the observed lowest and maximum depths were 14.6 and 32 cm, respectively. When compared to control concrete, the amount of dried marble sludge that replaced cement increased, resulting in a 28.14% penetration depth was decreased at cement replacement with marble powder (10%) When compared to control concrete, the percentage of fine granite that replaced sand rose, resulting in a 45.9% penetration depth was decreased at sand replacement with granite powder (15%). When comparing the percentage of granite aggregate used to replace natural coarse aggregate with that of control concrete, the penetration depth of water decreased by 7.4% at coarse aggregate replacement with granite fragments (25%). The interconnectedness of the pores in concrete determines its permeability. These findings demonstrate that, in comparison to control concrete, the interconnectivity of pores was higher in the concrete mixes containing marble aggregate. This came about as a result of the aggregate lacking enough fine particles [48]. The ultra fine marble powder led to self-compacting concrete which increase cohesivity and all mechanical properties. The corase marble waste as coarse aggregates doesn't affect the concrete quality but it enhanced the mechanical and durability performance of concrete [35].

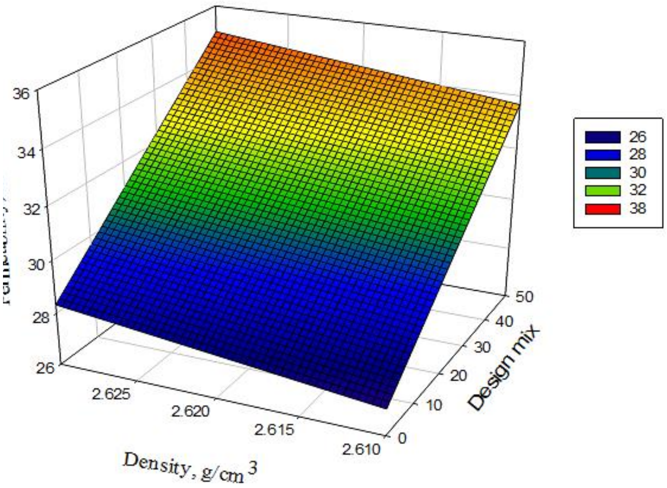

Fig.5. Permeability and Density of concrete mixes (cement replacement with marble

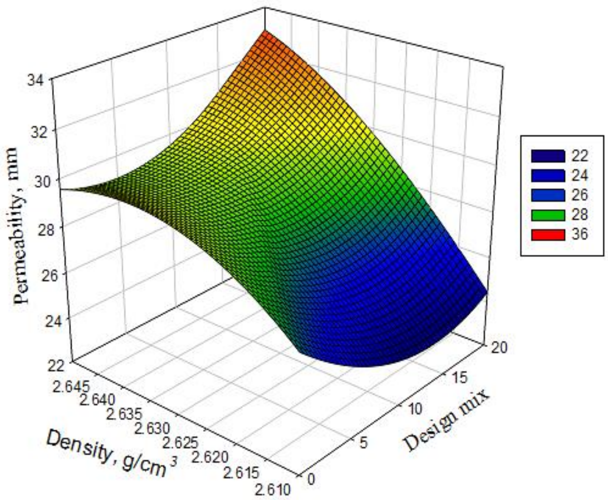

Fig.6. Permeability and Density of concrete mixes (sand replacement with granite

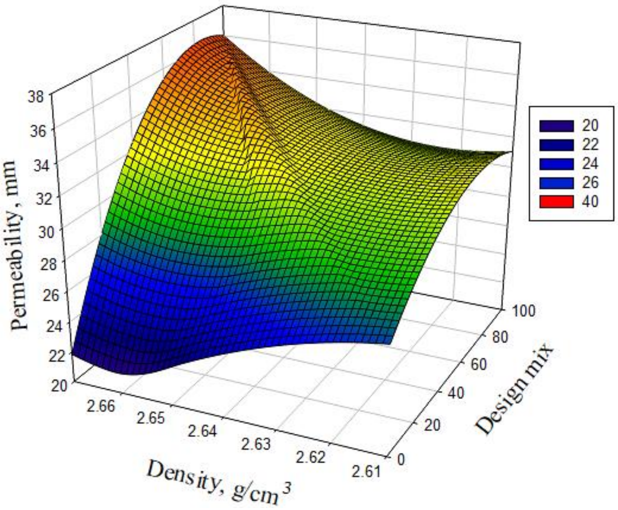

Fig.7. Permeability and Density of concrete mixes (coarse aggregate replacement with granite fragment).

3.2.3. Durability or Acid Resistance

The durability properties of concrete containing marble waste were not investigated by the researchers. So, this concrete can be used in construction away from industrial areas. Thus, it is necessary to investigate the durability of the produced concrete containing marble waste. Because the carbonate aggregates are acid soluble. Hence to investigate its performance in an acid environment is important.

For 28 and 60 days, the concrete specimens were submerged in a 5% sulfuric acid solution to test their resilience to a harsh environment. Figures 8, 9 & 10 show the compressive strength values of several concrete specimens following their immersion in diluted sulfuric acid. After being submerged in diluted sulfuric acid for 28 days, it was found that all concrete specimens had a 38–43% drop in compressive strength and a 57–60% reduction after 60 days. The sulfuric acid had a negative effect that weakened the concrete matrix, and the loss of cement paste caused the specimens to shrink in size. Concrete's compressive strength decreased as a result of this [48]. When control concrete is exposed to acids, its compressive strength decreases by 41% after 28 days and by 59% after 60 days.

When marble sludge is exposed to acids, the compressive strength of cement replacement is typically reduced by 35%–40% after 28 days and by around ≈ 60% after 60 days. When granite sludge is subjected to acids, the compressive strength of fine aggregate replacement (sand) is reduced on average by 37–39% after 28 days and by around ≈ 60% after 60 days. When granite aggregates are subjected to acids, the average decline in compressive strength of coarse aggregate replacement is 40–43% at 28 days and ≈ 59% at 60 days. It is clear that the cement replacement by marble sludge improves the acid resistance. Also, the replacement of fine aggregate (sand) with granite sludge of up to 20%, or the replacement of natural aggregates with granite aggregates of up to 50%, produced concrete with higher acid resistance than the control mix.

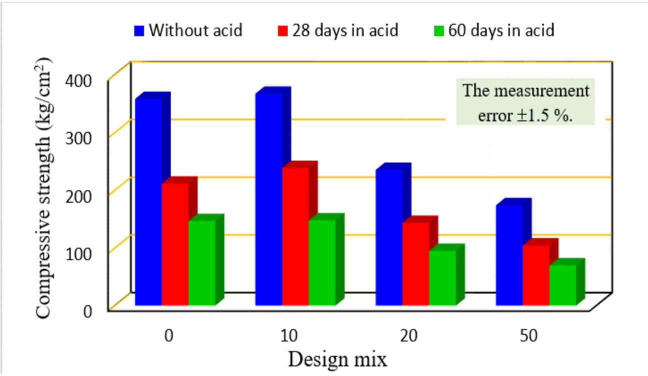

Fig.8. Effect of partially cement replacement on the durability of concrete.

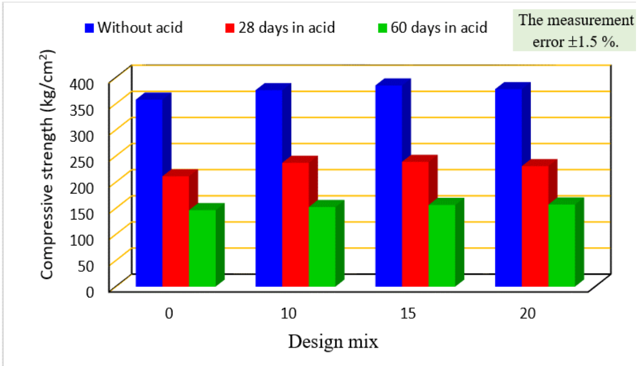

Fig.9. Effect of partially sand replacement on the durability of concrete.

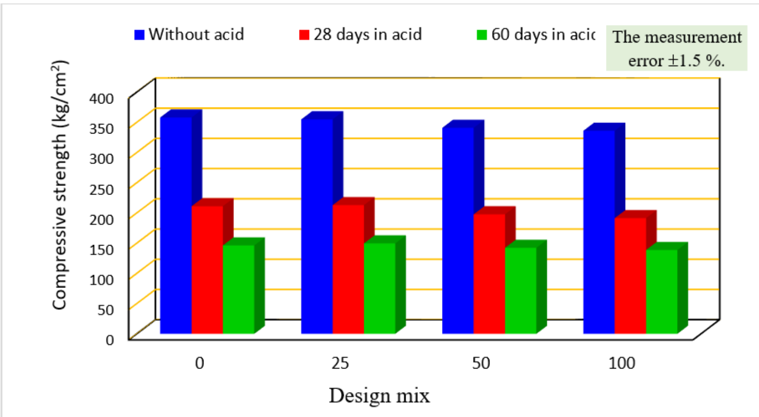

Fig.10. Effect of partially coarse aggregate replacement on the durability of concrete.

3.2.4. Microstructure Investigation

According to scientific definitions, marble and granite are metamorphic rocks made of silicate minerals like albite and illite and recrystallized carbonate minerals like calcite or dolomite. Depending on the kind of stone utilized, different marble and granite dusts have different chemical compositions.

Fig.11 presents scanning electron microscope (SEM) micrographs of the concrete containing 10% replacement of cement by dried marble sludge, 20% replacement of sand by fine granite, and 25% replacement of natural coarse aggregate by granite aggregate. The SEM micrographs show that the presence of marble and granite improves the concrete's pores' interconnectivity. The enhanced binding between cement pastes and aggregate in concrete was caused by carbonate compounds, which led to a higher compressive strength of concrete including waste marble and granite [46, 47].

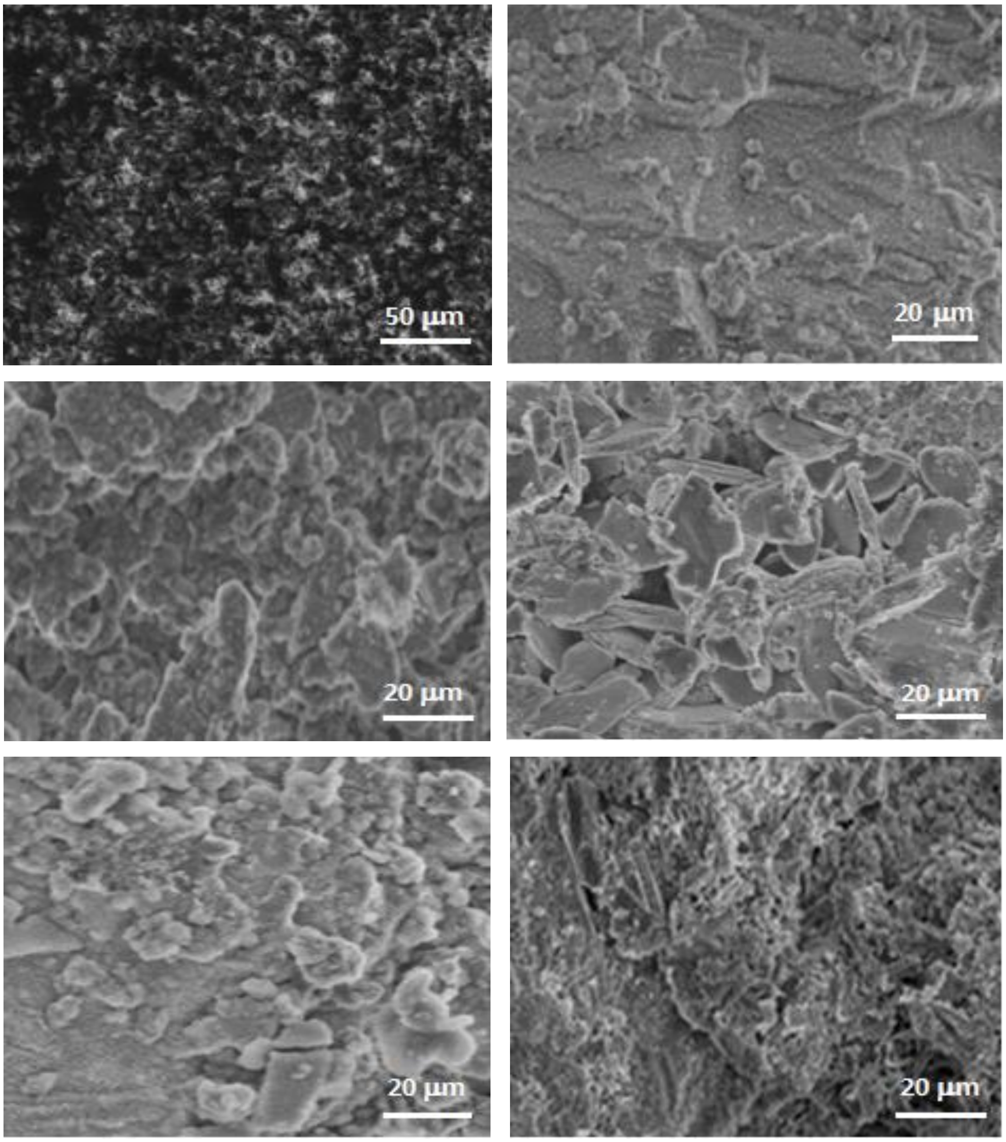

Fig.11. SEM micrographs of the concrete produced with marble and granite waste replacment.

Conclusions

The marble and granite wastes were used as additives rather than sand, aggregate, and cement in concrete. They are composed of calcite, dolomite, quartz, albite, illite, and bentonite minerals. Their average particle size is 6.65 and 11.58 µm and average surface area is 0.4836 and 0.3507 m^2/g.

The Addition of fine or coarse marble and granite wastes improved the compressive strength of the produced concerete. Cement replacement with 10% fine marble or sand replacement with 20% fine granite led to higher compressive strength than the control mix which attributed to the carbonate which enhances the paste bond. Coarse aggregate replacement with 25-50% granite fragments produces concrete with equivalent compressive strength to control mix.

There is no significant change of the produced concrete while its water permeability was decreased by 3.7 to 33% with increasing of cement, sand, and aggregate replacement. The duability test showed that the compressive strength is reduced by 35% – 43% after 28 days and by around 60% after 60 days. Although, the concrete containing marble or granite has higher acid resistance (durability), its compressive strength is reduced as a result of immersion in dilute sulfuric acid.

The SEM micrographs proved that the marble and granite improves the concrete's pores' interconnectivity. The enhanced binding between cement pastes and aggregate in concrete was caused by carbonate compounds, which led to a higher compressive strength of concrete including marble and granite waste.

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