Durability of Green Concrete ContainingGranite Waste Powder

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Abstract
This paper aims to assess the durability performance of green concrete containing granite waste powder as partial replacement to cement and sand with various percentages. Physical tests including slump test, indirect fire resistance, water absorption, and permeability experimental work are conducted on the concrete samples as indicators for durability. Scanning Electron Microscope (SEM) is also used to investigate the microstructure of concrete by examining the Inter-facial Transition Zone (ITZ) as well as investigating the voids inside concrete specimens at micro-structural level.

The study revealed that the workability of the green concrete decreased than that of the control mix without granite waste powder for all mixes having the same w/c ratio 0.45. Adding 5% of the granite waste powder as a partial replacement for cement showed minimum voids in the SEM images indicating denser concrete mix with the lowest number of pores and the best impermeable properties with the least water absorption among all mixes.
The general conclusion of this study is that the incorporation of fine granite waste powder to the concrete mix was beneficial to some durability-related characteristics. Furthermore, adding the granite waste powder whether as a cement or sand replacement, showed a positive response in terms of enhancementof strength of concrete under elevated temperatures.

Keywords: green concrete, granite waste, durability, permeability, water absorption, cement substitution

INTRODUCTION

The construction industry nowadays is putting great efforts in highlighting the importance of durability in buildings. However, two essential aspects should be considered in construction: the durability of the engineering works and the durability of the materials they are built with. An example of the engineering works is the modular construction that would facilitate partial replacement of defective materials to enhance the durability of the construction. Whereas, to increase the durability of the construction material a measure of the reduction of its negative impact on the environmental in case it required repetition of initial production should be calculated.

This paper investigates the durability of construction building materials with an aim to search for alternate mortar and concrete components, made from granite waste materials. The basic condition for the implementation of such research is the assurance that it will not result in any significant reduction in the qualityof the structures and elements built with the green concrete produced.

LITERATURE REVIEW

Durability is considered as an indicator of the material ability to maintain its original requirements during its lifetime. More durable material requires less time and resources to maintain it [1]. The use of green building materials has low embodies energy, high durability, and low maintenance which lead to sustainable construction development [2]. Jepsen et al. studied durability of different types of green concrete. It was concluded that the use of industrial waste products in concrete industry can lead to sustainable design and a greener environment. Developing concrete with non-conventional aggregates is essential to protect environmentand save cost [3].

Senthamarai and Manoharan [4], Halicka A., [5,6] and Wioletta J. et al. [7] assessed the potential of ceramic industrial waste utilization as a possible substitute for conventional crushed stone coarse aggregates in cement-based mortars. The study was focused on consistency, plasticity, workability retention, and air content. The results showed an improvement in compressive and flexural strength as well as a reduction in shrinkage due to the partial replacement up to 20% by weight. In addition, there was an enhanced of concrete properties as well as cost reduction when industrial and other wastes were used in the concrete mix.

Moriconi, used recycled aggregate fractions of approximately 15mm size, with up to 30% masonry rubble for manufacturing structural concrete as a total substitution of the fine and coarse natural aggregate fractions. The study concluded that adding fly ash to the mixture as a fine aggregate replacement improved the compressive strength of concrete. Aspects related to the durability of recycled aggregate concretes indicated that adding fly ash to improved the pore structure and reduced the macro-pore volume. Concrete showed no difference in resistance against freezing and thawing cycles. Moreover, addition of fly ash reduced carbonation and chloride ion penetration depths in concrete because of pore refinement of the cementitious matrix due to the filler effect and pozzolanic activity of fly ash [8].

Binici, et al. [9] and Hameed & Sekar [10] investigated the durability of green concrete made with granite and marble as substitutes for natural sand and coarse aggregates. It was found that the durability of the green concrete improved compared to the control concrete. Using marble sludge powder as filler reduced the total voids content in concrete and improved micro-aggregate filling, pozzolanic reaction, and concrete durability. In addition, the study showed that the concrete mechanical properties, workability and chemical resistance are improved when using marble and granite waste aggregates. The high fineness of the marble sludge powder provided very good cohesiveness of concrete. Permeability test results indicated that the green concrete permeability is less than that of conventional concrete whereas water absorption of green concrete is slightly higher. The concrete was significantly enhanced in the resistance to sulphate attack. Economical and environmental benefits can be gained due to using these materials as aggregates in the production of more durable concrete mixtures.

Allam et al. investigated the optimum percentage of cement and sand replacement with granite fine powderto produce green concrete. The study revealed that the splitting tensile strength was 20% higher, the flexural strength was 19% lower, and the bond strength was slightly lower by 1% by comparing the concrete mechanical properties of the control mix to the green concrete mixes containing 5% of fine granite waste as a partial replacement of cement. In addition, by replacing sand in the concrete mixes by 10% granite waste resulted in a significant increase in the splitting tensile strength and the flexural strength while the bond was slightly affected when compared to the control mix [11].

EXPERIMENTAL PROGRAM

- **Materials**

Ordinary/commercial Portland cement (OPC) was used in this study as a binding material. The specific gravity of the cement was tested according to the Egyptian Standard Specifications and the recommended code of practice. Cement specific gravity was 3.15 with fineness of 9 % passing from sieve no.170. It's initial and final setting were 2 hrs and 3hrs 12 minutes resp. Locally available fine aggregate with a maximum size of 4.75 mm was used (Natural sand from pyramids quarries Giza). A maximum nominal size of 19 mm was used as Course aggregate. A by-product saw gang granite waste type from Shaqu - Elteban , Egypt, was used as a sludge powder to substitute conventional cement and fine aggregates in cement-based mortars . The granite waste slurry was dried up, a mud made of powder and water - in order to have a constant mix W/C ratio. Granitewaste was kept on oven at a temperature of 200 C for 6 hours. The granite powder was weighed before and after drying, the difference of weight should be less than 10% to insure minimum water content. The granite waste fine powder with particles passed through sieve no. 300 was used as cement replacement. While, the granite waste granules particle passed through sieve no 4.76.mm was used as sand replacement. Clean tap water between 20-30°C was used to produce the concrete mixes.

- **Concrete Design Mix**

Design mix for 350 grade concrete was prepared, according to Egyptian Standard, by partially replacing cement or fine aggregate with two different percentages by weight of granite fine powder waste (5% and 10% for cement replacement) and granule waste (10% and 17.5% for sand replacement). In addition, a control mix with 0% replacement of granite waste was prepared. Table (I) presents the five series of concrete specimens and their components that were prepared for this study.

TABLE I
MIXTURES COMPONENTS (KG)

	Design Mix			Components Quantity (kg)					W/C Ratio
	No	Name	Description	Cement	Fine Agg.	Course Agg.	Granite waste	Water	
Control Mix	1	CM	Control Mix	33.0	42.0	84.0	0.0.0	15	0.45
Cement Replacement	2	C5	Sawgang Granite 5% Cement Replacement	31.4	42.0	84.0	1.65	15	0.45
	3	C10	Sawgang Granite 10% Cement Replacement	29.7	42.0	84.0	3.30	15	0.45
Sand Replaceme	4	S10	Sawgang Granite 10% Sand Replacement	33.0	37.8	84.0	4.20	15	0.45

nt	5	S17	Sawgang Granite 17.5% Sand Replacement	33.0	34.7	84.0	7.35	15	0.45

- **Specimens**

Specimens of 150x150x150 mm concrete cube were used. The specimens designed for this experiment exceeded the RILEM 7-II128 requirement on clear cover. A laboratory counter-current mixer was used to blend the concrete mixture for five minutes. Mixtures were cast, mechanically vibrated and kept for 24 hours, then; thespecimens were cured in curing basins for 28 days.

- **Laboratory tests conducted**

Slump tests were conducted according to ASTM C143 as shown in figure (2). In order to study the effect of using granite waste on the concrete durability, three types of laboratory tests were carried out: (i) the effect of indirect fire, (ii) water permeability, and (iii) water absorption by immersion. In addition, Scanning Electron Microscopy (SEM) test was conducted to study the concrete morphology and to identify the effect of incorporating granite waste powder on microstructure of concrete.

- **Indirect Fire Test:**

Two temperature values 200 and 400^{o}C were chosen in order to investigate the relation between the concrete compressive strength with high temperatures for the different replacement ratios of granite waste. The specimens were kept for two hours in the oven shown in figure (1) at each of the chosen temperature. The specimens were cooled down to the ambient temperature for 24 hours. The compressive strength of the concrete samples was measured, according to ASTM C39, using Universal testing machine of 1000 KN (Shimadzu).

- **Ermeability test apparatusWater Permeability:**

The permeability test measures the steady state permeability coefficient for water flow under a constant pressure head as shown in figure (2). The coefficient of permeability K was determined using Darcy's expression:

- **Water Absorption by Immersion:**

Water absorption test was conducted according to ASTM C642. In order to determine the specimens dry mass (A), the specimens were kept in an oven at a temperature of 100 °C for 24 hours. After removing from the oven, the specimens were cooled in dry air then the mass was determined using a sensitive balance. In order to

Where, Q: fluid flow rate

$$K = \frac{Q\,L}{\Delta P\,A}$$

L: thickness of specimen (150 mm)
ΔP: Pressure head (30 bar)
A: Specimen surface area (150 x 150 mm)

determine the saturated mass (B), the specimens were immersed in water for 48 hours. After drying the surface of the specimens, the saturated mass was determined. The water absorption was calculated as follows:

$$\text{Absorption after immersion, \%} = \left[\frac{B - A}{A}\right] \times 100$$

- **SEM (Scanning Electron Microscopy)**

Scanning Electron Microscope (SEM) was used to investigate the microstructure of concrete by examining the Inter-facial Transition Zone (ITZ) of the concrete samples at micro-structural level. This zone is considered the weakest zone in the sample hence this examination helps in understanding and interpreting the mechanical properties of the concrete mixtures under study. SEM also investigates the pores or voids inside concrete specimens and this helps to assess the concrete samples porosity.

Samples of about 20 x 20 x 10 mm (depth ±5 mm) were obtained from the selected concrete specimens as shown in figure (8) and their microstructure was examined using SEM. The sections were prepared first by polishing and then coated with conducting material, a gold layer, to improve the conductivity of electrons in order to get desired images. The apparatus used in this scanning is Quanta FEG 250.

TEST RESULTS AND DISCUSSION

- **Slump test**

The workability of the freshly prepared concrete was measured through the slump cone test apparatus. The slump values ranged between 30-60 mm – as shown in figure (4) - for the green concrete produced using granite waste indicating medium workability which can be used in various applications. The results revealed that the substitution of the granite waste decreases the workability of the green concrete. Furthermore, an increase in the substitution rate of the waste decreases the workability of the concrete further even more in case of the sand substitution when compared to the control mix. The fineness of the dried granite waste sludge increases the surface of hydration of the green concrete produced, leading to greater water absorption. This result coincides with the study conducted by Filipe G., Gamerio F. et al. and Singh S. et al. [12, 13, 14] which concluded that despite the expected reduced workability caused by the incorporation of marble waste, changing slightly the water/cement ratio proved to be an effective solution to calibrate workability to achieve the required target. However, this slight improvement in the w/c ratio should take into consideration that high water content has an adverse effect on concrete strength.

- **Indirect Fire Test**

In this test, the mechanical properties of green concrete containing granite powder were measured under elevating temperatures 200 and 400°C for 2 hours. In general, the compressive strength of concrete mixtures showed significant reduction under elevated temperatures as demonstrated in figure (5). The results presented in table (II) showed that rising the temperature to 200 and 400 °C for the control mix (CM) reduced the compressive strength by 15% and 23% respectively when compared to the same concrete mix tested in normal room temperature (25 °C).

The compressive strength of the green concrete (C5) containing 5% of granite powder as a partial replacement of cement was reduced by 9% and 15% for specimens subjected to elevated temperatures 200 and 400 °C respectively compared to that of the control mix. By increasing the granite powder to 10% (C10) the reduction in strength was 14% and 17% at 200 and 400 °C , which is considered less than that reduction in the strength values of the control mix. The reduction in strength of the green concrete mixture than that obtained by control mixture under elevated temperatures indicates that addition of granite powder immensely enhanced the concrete matrix.

As for the green concrete containing 10% of granite powder (S10) as a partial replacement of sand, the reduction in compressive strength for specimens subjected to elevated temperatures 200 and 400°C was 13% and 15% which is also considered less than that values obtained by the control mix. Similarly, results obtained for (S17) were less by 6% and 17%. The enhancement in compressive strength for green concrete mixes (S10) and (S17) when compared to that obtained by the control mix is due to the well graded mixture obtained by adding granite powder. This enables the mixture to sustain more stress under elevated temperature which consequently improves the durability of concrete. These results coincide with those presented by Rivumangai and Elixkala [15] which concluded clearly that granite powder as a partial sand replacement has beneficial effects on the green concrete produced.

TABLE II
COMPRESSIVE STRENGTH OF SPECIMENS UNDER NORMAL AND ELEVATED TEMPERATURES

Mix Compressive strength (kg/cm^2) / Temperature	CM	C5	C10	S10	S17
25 °C	463	466	400	468	341
200 °C	391	424	341	404	319
400 °C	358	396	331	396	284

- **Permeability**

The results of the permeability test in figure (6a,b) showed that replacing the cement in the mix by 5% and 10% of granite powder, the permeability of the green concrete produced was enhanced. The coefficient of permeability values were reduced by 4% and 8% for the 5% and 10% granite powder replacement ratios when compared to that of the control mix. This is probably due to the micro-filler action of the granite powder that fills up most of the gaps in the concrete paste during the hydration process.

As for sand replacement, it was noticed that by replacing sand with granite powder at 10% and 17% replacement ratios, the coefficient of permeability was reduced also by 6% and 16 % respectively than that of the control mix. The reduction in water permeability for these samples was referred to the gradation enhancement of fine aggregate due to addition of small sized particles of granite powder. These particles reduce
voids and improve the paste compaction. These results are supported by Singh S. et al, 2016 conclusions that reported reduction in the concrete permeability after adding granite waste, and hence enhanced its durability.

- **Water Absorption**

Water absorption of concrete is considered one of the most important indicators for its quality and durability. The water absorption test results (Table III) showed very similar behavior to water permeability test results. Replacing cement by granite powder reduced water absorption for concrete samples produced for samples (C5) and (C10). This result was expected, due to the filling effect of granite micro-size particles which reduced the volume and connectivity of capillary pores. By replacing sand with granite powder in the concrete mixes, results show also that water absorption ratio decreases than control mix. This indicates that the presence of granite powder enhances the mixture grading and thus leads to more compacted mixture with fewer voids to permit water to go through.

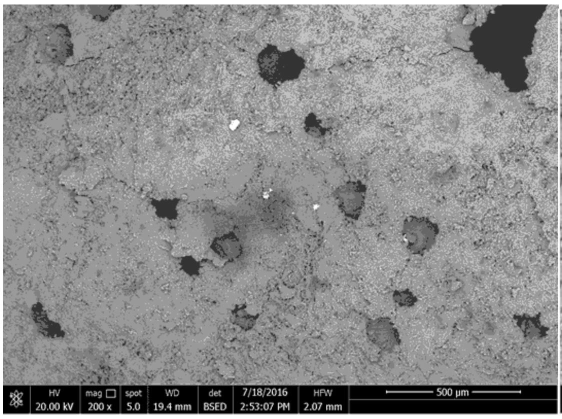
TABLE III
WATER ABSORPTION PERCENTAGES FOR CONCRETE MIXES

Mix	CM	C5	C10	S10	S17
Water absorption %	3.70	1.65	3.00	2.77	2.81

- **SEM (Scanning Electron Microscopy)**

The SEM images for the concrete control mix (figure 8a, 8b), the 5% cement replacement mix (figures 9a & 9b), the 10% cement replacement (figures 10), and sand replacement mixes (figures 11 &12) at different magnifications were conducted after 56 days. The dark portions represent the voids or pores in the examined samples.

The SEM image or micrograph of control mix (CM) at 200X magnification (figure 8a) shows large amount of pores. At 800X (figure 8b), the SEM image of control mix (CM) presents one of these voids and its relatively large size (183 µm diameter). Micro cracks can be clearly seen across the void expressing weak points.



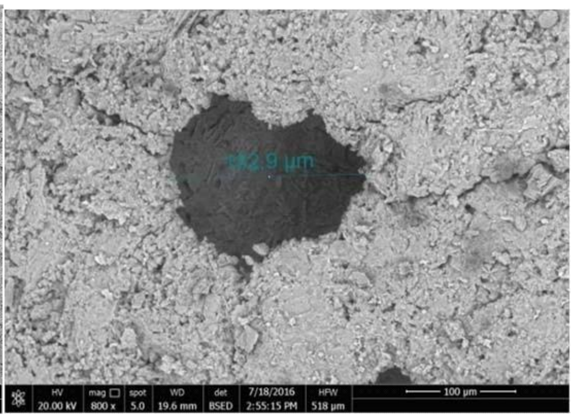
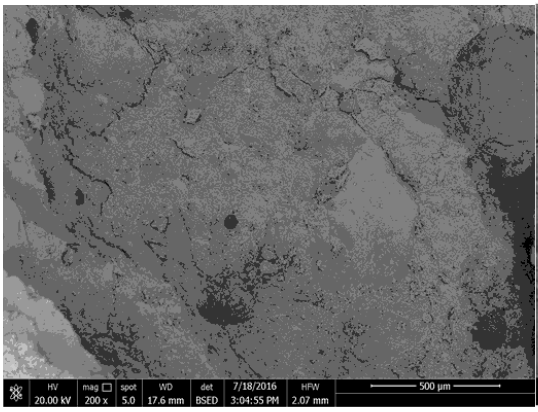


Fig. 8a. SEM image of control mix (CM) at 200X
Fig. 8b. SEM image of control mix (CM) at 800X

On the contrary, the SEM image of control mix (C5) at 200X (figure 9a) shows that the voids are minimum and that (C5) has a denser concrete mix with the lowest number of pores. This supports our previously stated findings which stated that (C5) has the best impermeable properties with the least water absorption among all mixes. The SEM image of (C5) at 800X (figure 9b) presents one of these voids and it is shown that the voids diameter is nearly 55 µm which is considered significantly less than that shown in the control mix. The inter- facial zone between aggregate and paste marked in (figure 9b) is dense with very small micro cracks along it. This observation reveals that when comparing (CM) with (C5) mix, a decrease in porosity and increase in strength is observed in the latest due to the addition of granite content as a partial replacement of cement.



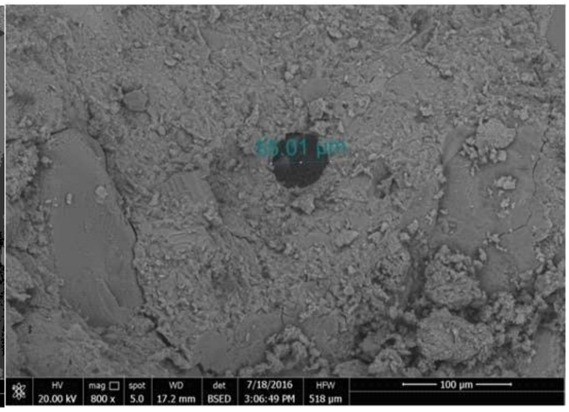


Fig. 9a. SEM image of 5% cement replacement (C5)at 200X
Fig. 9b. SEM image of 5% cement replacement (C5)at 800X

As shown in figure (10) the concrete mix with 10% replacement ratio of granite waste instead of cement (C10) has fewer voids than (CM). At 800X, the SEM image of mix (C10) magnifies one of these voids with a diameter nearly 191 µm.

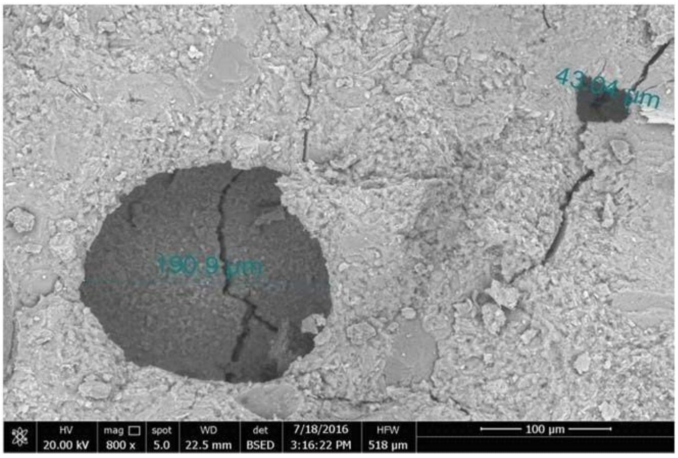


Fig. 10. SEM image of 10% cement replacement (C10) at 800X

The voids in (S10) demonstrated in figure (11) showed that the mix has fewer pores than the (CM) while the pores are shallower. The pores size in (S10) ranges between 125 - 137 µm. Micro cracks can be clearly seen along the voids expressing weak points. The SEM image or micrograph of concrete mix (S17) at 200X shown in figure (12) shows wide shear cracks at aggregate cement interface which supports the experimental results stating that mix (S17) has less dense properties and accordingly tends to be more permeable with relatively high water absorption.

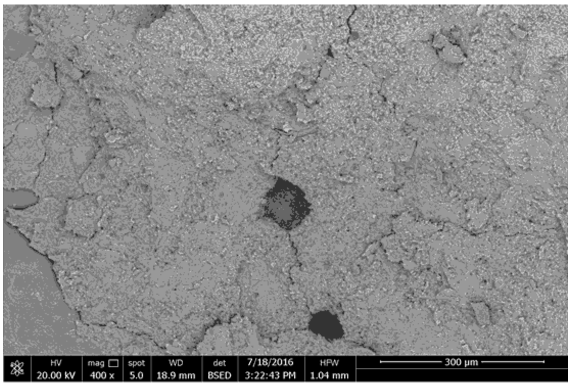


Fig. 11. SEM image of 10% sand replacement (S10) at 400X

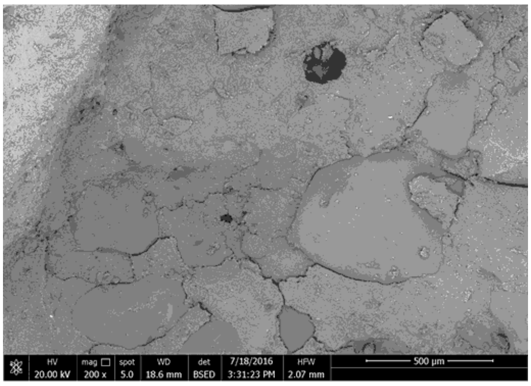


Fig. 12. SEM image of 17% sand replacement (S17)at 200X

The SEM images reinforce the compressive strength results of the different concrete mixes under elevated temperatures which were presented before. The results indicate that (C5), which possess maximum compressive strength at room temperature, has minimum reduction in compressive strength under elevated temperatures. This comply with the SEM images of (C)5 that had denser mix with the lowest number of pores when compared to that of the (CM) mix with large sized pores.

In addition, (S10) has the highest compressive strength when compared to (S17) and (CM) in the ambient room temperature. This observation also complies with the SEM images of (S10) as it shows few small sized pores when compared to that of the (CM) which has several large sized pores clear in its microstructure images. For (S17) a noticeable reduction in compressive strength under elevated temperatures were found as a result of the wide shear cracks observed at aggregate cement interface. This clearly indicates that adding the granite waste powder fines shows a positive response in terms of enhancement of strength of concrete until a certain optimum amount after which the waste presence is not of great benefit to the compaction or density of the concrete matrix.

CONCLUSIONS

The aim of this study is to evaluate the durability performance of the green concrete containing granite powder (waste from processing industry). The experimental procedures revealed that:

The fineness and high surface area of the granite powder waste increased the water demand of the concrete by water absorption, resulting in decreased workability.

- The reduction in compressive strength of green concrete (C5) and (C10) (partially containing granite powder instead of cement) subjected to elevated temperatures were less than that obtained from normal concrete mixtures.

- The reduction in compressive strength of green concrete (S10) and (S17) (partially containing granite powder instead of sand) subjected to elevated temperatures were less than that obtained from normal concrete mixtures.
- Replacing 5-10% of cement by granite powder enhances the permeability of the green concrete produced.
- Replacing sand with granite powder at 10 and 17 % in the concrete mixes reduced the coefficient of permeability leading to better durability properties
- Results of water absorption test were similar and compatible to those of water permeability tests and which reveal that replacing cement or sand with certain ratios by granite powder reduces water absorption for concrete samples which considered good indicator of quality and durability of green concrete produced.
- The SEM images or micrograph of the control mix (CM) showed large amount of pores relatively large in size (183 µm diameter). Micro cracks were clearly seen across the voids expressing weak points.
- Adding 5% of the granite waste powder (C5) as a replacement for cement showed minimum voids indicating denser concrete mix with the lowest number of pores . These observations of the SEM images supported the findings which stated that (C5) has the best impermeable properties with the leastwater absorption among all mixes.
- Replacing 10% and 17% of the sand in the mix with granite waste powder showed number of pores less than that in the control mix especially for the (S10) mix. This complies with permeability and water absorption results obtained.

The general conclusion of this study is that the incorporation of fine granite waste powderto the concretemix is beneficial to some durability-related characteristics. Furthermore, adding the granite waste powder whether as a cement or sand replacement, showed a positiveresponse in terms of enhancement of strength of concrete under elevated temperatures.

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