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Assessment of the optimal level of basalt pozzolana blended cement replacement against concrete performance

Mohamed S. Moawad[1*], Shimaa Younis[1] and Abd EL- Rahman Ragab[2]

* Correspondence: m.moawad@fief.edu.eg
[1]Department of Structural Engineering, Faculty of Engineering, Future High Institute of Engineering (FIEF), Fayoum, Egypt
Full list of author information is available at the end of the article

Abstract

Different additional cementitious materials can be used to partially replace cement in concrete. these are used in concrete as a partial replacement for cement to reduce the effect of environmental pollution, which can lead to serious health issues. Therefore, it is critical to use locally available pozzolanic materials as a partially replacement for cement because these materials are less expensive than Portland cement and are more environmentally friendly without sacrificing concrete quality. Pozzolana made from basalt natural material was tested for the best amount of weight percentage replacement as a blinding component in cements in this study. Various percentage of basalt as a partial replacement weight percentage of ordinary Portland cement by 7.5%, 15%, and 22.5% is carried out. effect of basalt on workability, setting time, compressive strength, modulus of elasticity, tensile strength, flexural strength, and water absorption were conducted. The parameters were studied and monitored by tested a fresh and hardened concrete samples at ages of 7 days, 28 days, 56 days, and 90 days. Based on the test results, it is concluded that the optimal content of basalt as replacement of ordinary Portland cement in concrete mix is 15%.

Keywords: Pozzolana, Basalt, Blended cement, Compressive strength, Split tensile strength

Introduction

Basalt is an igneous rock that developed during the cooling of magma during the earth's early eras. A pozzolana is a substance capable of interacting with calcium hydroxide ($Ca(OH)_2$) in the presence of water at room temperature to produce cementitious compounds (as C-S-H gel) [1].

In recent years, many researches were investigated that the use supplementary cementitious materials such as basalt as a partially replacement of cement in concrete. Basalt can not only improve the various properties of concrete both in its fresh and hardened states, but also can contribute to economy in construction cost (Ghrici et al. 2007 [2], Yean and Kim [3] 2004, and Shuiet al. 2010 [4]) reported that the using of cement replacement material, improves the early age and the long-term compressive and flexural strength and enhanced the concrete durability properties.

Mineral admixtures are commonly employed in concrete to improve physical and chemical properties, and when industrial by products are used as a partial replacement for energy-intensive Portland cement, significant energy and cost savings can be achieved. The concerns associated with increased environmental pollution during cement production can be addressed by employing supplemental cementitious materials such as natural basalt as a partial replacement for cement in concrete mixes to reducing the quantity of cement used, hence lowering CO_2 emissions [5].

The properties of hardened concrete are determinated by quality of the cement paste. And to achieve a strong and durable concrete rests in the careful proportioning mixing and compacting of the ingredient. So, this study was investigated that the influence of basalt up to 22.5% as a replacement of ordinary Portland cement on the physicochemical properties of cement pasts.

Many studies have looked into the use of additional supplementary materials in hardened concrete, with the goal of replacing the constituents of concrete with low-cost, locally available materials due to the rising cost of materials used in concrete and the environmental issues associated with cement production. As a result, the additional cementitious materials attract more attention [6].

N. Kaarthik Krishna et al. 2016 [7], reported that the usage of ideal quantity of supplementary cementitious material leading to achieve better strength, permeability, workability, and chemical resistance. Abdul G. and Bazid K., 2017 [6], stated that the usage of mineral admixture in concrete was affected in the modulus of elasticity for fresh concrete and improved the strength of concrete. Binici et al. 2007 [8], Habert et al. 2008 [9], investigated that the use of natural pozzolana materials in cement was decreased the early strength. Uysal and Yilmaz, 2011 [10], investigated that the effect of limestone powder, basalt powder, and marble powder as a mineral admixture on the fresh and hardened properties of self-compacting concrete, and the results showed that it possible to successfully utilize waste limestone powder, basalt powder, and marble powder as mineral admixtures according to its observed mechanical advantages, the employment of waste mineral admixtures improved the economic feasibility on a unit strength basis. Hamdy El-didamony and Randa M. Osman, 2015 [5] showed that the basalt in cement pastes have better physico-mechanical properties than ordinary Portland cement pastes in concrete mix. P.M.Hopy, Santhi A.S [1], stated that the using of multi blended cement in concrete mix reduced the chloride intrusion thereby reduction in reinforced corrosion. B. Izal et al. 2010 [11], concluded that the positive results in the behavior of concrete compressive strength using blended cement in concrete mix can be observed. Dobiszewska M. et al. 2019 [12], investigated that the increasing in the fineness of basalt powder only slightly influences the hydration kinetics, as well as mechanical properties of mortar.

Methods/experimental

Aim of the study

The purpose of this study is to see how basalt, when used in place of ordinary Portland cement in a concrete mix, affects the properties of fresh and hardened concrete. The optimal amount of basalt to ordinary Portland cement replacement in concrete pastes was also evaluated.

Experimental program

The work presented in this paper that investigates the behavior of concrete produced from partial replacement of cement with reactivity basalt ranging 25–28%. The physical and chemical properties of basalt and OPC were first investigated. Mixture proportioning was performed to produce high workability concrete with target strength of 25 MPa. The effect of basalt on mechanical properties, i.e., compressive strength, split strength, and flexural strength were investigated. And assessment of the optimum suitability of basalt ratio level as a replacement cement in powder concrete to determinate a maximum compressive strength, the various proportions of basalt in this investigation were used as a replacement weight of cement in concrete mix, hence, to understand the influence of basalt (with reactivity 25–28%) on concrete properties as fresh and hardened state of concrete.

Materials and mix design

A) Ordinary Portland cement Ordinary Portland cement (OPC type 1) of 43 grade was used to conduct the experimental work. The chemical analysis of the cement powder was conducted to get the composition and the results were listed in Table 1. The value of its specific gravity is 3.15 and fineness is 3155 ± 50 cm^2/g.

B) Basalt (supplementary cementitious material) OPC was replaced by basalt (Wadi Hagool, Suize, Egypt) in concrete mix, and its chemical analysis were conducted and listed in Table 2. The basalt was ground to pass 90 μm sieve were conducted by sieve analysis test.

C) Aggregates Natural siliceous sand with a maximum size of 4 mm was used as a fine aggregate in concrete mix, and their physical properties were listed in Table 3. Crushed stone dolomite has size from 9 mm to 22 mm was used as a coarse aggregate in concrete mix, and their physical properties were listed in Table 4.

Table 1 Chemical composition of cement

Chemical composition	Concentration %
Lime saturation	0.885
Alumina modulus AL_2O_3	1.229
Insoluble residue	0.25
Magnesia MgO	0.98
Sulphuric anhydride (SO_3)	1.5
Loss in ignition (LOI)	0.8
Alkali	------
Chloride	0.002
Humidity	65±5

Table 2 Chemical composition analysis of basalt

Chemical composition	Concentration %
Silicon dioxide (SIO_2)	44.79
Aluminum oxide (AL_2O_3)	10.16
Iron oxide (Fe_2O_3)	13.89
Calcium oxide (CaO)	13.62
Magnesia MgO	8.89
Sulphuric anhydride (SO_3)	0.26
Potassium oxide (K_2O)	0.6
Sodium oxide (Na_2O)	2.3
Chloride (CL)	0.12
Loss in ignition LOI	4.5
SM (silica modulus)	1.86
AM (aluminum modulus)	0.73
Moisture	4.5

Experimental methodology

Concrete mixtures

Concrete mix design is the process of selecting suitable concrete materials and determining their relative proportions in order to produce a concrete with the required strength, durability, and workability. In this study, a 1:2.46:3.37 mix ratio of cement, fine aggregate, and coarse aggregate was used with a water binder ratio of 0.53. Table 5 shows the concrete mix proportions for various basalt replacements by cement weight. In dry conditions, different amounts of basalt (7.5%, 15%, and 22.5%) were replaced by % weight of cement.

Casting of concrete specimens

Four different proportion of basalt partially replacement by cement weight in concrete mix ranging from 0% up to 22.5% were conducted with a water to binder w/(C + Basalt) ratio of 0.53 for a design concrete cube (150mm × 150mm × 150 mm) compressive strength of 25 MPa. These mixes were designated as B0, B1, B2, and B3 for control specimen and basalt replacement of cement by 7.5%, 15%, and 22.5% in concrete mix respectively.

The concrete was mixed for about 5 min to 6 min in the laboratory drum mixer for mixes B0 through B3, 12 cube specimens of 150 mm side lengths were cast from each mix for compressive strength testing at ages 7 days, 28 days, 54 days, and 90 days.

Four-cylinder specimens of 150 mm diameter and 300 mm height were also cast from each mix for determining the splitting tensile strength at ages 28 days and 90 days.

Four cubes specimens of 100 mm side lengths were cast from each mix for water penetration test at age 28 days, and 90 days.

Table 3 Physical properties of fine aggregate

Max. particle size (mm)	Fineness modulus	Bulk specific gravity	Water absorption capacity %	Organic impurities
4.00	2.61	2.643	1	nil

Table 4 Physical properties of coarse aggregate

Max. particle size (mm)	Dry rodded unit weight (kg/m^3)	Water absorption capacity %	Organic impurities
22.00	1580.2	0.61	nil

Two beams specimens of 100 mm width, 100 mm height, and 500 mm length were casted from each mix to monitored flexural behavior strength at ages 28 days and 90 days. After casting, all the specimens were left covered in the casting room for 24 h. The specimens were disassembled and curing at room temperature until the age of testing. Table 6 summarized and shows the experimental work plan of specimens.

Results and discussion

Test on fresh concrete

Fresh concrete was tested using slump cone test as shown in Fig. 1 to find the workability of each concrete mix. It was observed that the increasing in ratio of basalt as replacement of ordinary Portland cement increasing in workability up to 20% as compared to control concrete. The gradual increase of basalt shows that gradual increasing in workability by 10%, 16%, and 20% of B1, B2, B3 respectively compared to control concrete specimen B0. This is attributed to lower reaction of basalt with water at early ages compared with ordinary Portland cement.

Decrease in the amount of water demand for consistency of cement paste with partial replacement of ordinary Portland cement type 1 by basalt materials was observed. Due to the non-hydraulic characteristics of basalt compared with ordinary Portland cement where the basalt cannot be hardened when exposed to water like ordinary Portland cement. So, the less water demanding for gauging and then the water of consistency decreases with the increasing of basalt content.

Test on hardened concrete

Compressive strength tests were done as per EN :(12390-3) [9, 13] and were measured at ages 7 days, 28 days, 54 days, 90 days of curing, splitting tensile strength were done as per BS-EN 12390-6/2009 [12, 14] and were measured at ages 28 days, and 90 days, flexural strength tests were done as per BS EN:12390-5/2009) [10] and were measured at ages 28 days, and 90 days, and water absorption at ages 28 days, and 90 days were conducted and monitored also. A different aging time of compressive, splitting, and flexural tests specimens up to 90 days were conducted and monitored due to the basalt powder are pozzolanic material and pozzolanic reactions starts later [4, 15–17].

Table 5 Mix proportions of concrete varying basalt replacement

Specimens	B0	B1	B2	B3
(wt%) replacement of basalt	0	7.5	15	22.5
Cement (kg/m^3)	320	296	272	248
Basalt (kg/m^3)	0	24	48	72
Fine aggregate (kg/m^3)	790	790	790	790
Coarse aggregate. (kg/m^3)	1080	1080	1080	1080
Water (kg/m^3)	170	170	170	170

Table 6 Experimental work program of specimens

Parameters	Tested ages	No. of tested specimens	Specimen ID
Compressive strength	7 days	3 cubes (150 × 150 × 150 mm)	B0 B1 B2 B3
	28 days	3 cubes (150 × 150 × 150 mm)	
	56 days	3 cubes (150 × 150 × 150 mm)	
	90 days	3 cubes (150 × 150 × 150 mm)	
Splitting strength	28 days	2 Cylinders (Ø150 × 300mm – length)	B0 B1 B2 B3
	90 days	2 Cylinders (Ø150 × 300 mm – length)	
Flexural strength	28 days	1 Beam (100 mm × 100 mm × 500mm	B0 B1 B2 B3
	90 days	1 Beam (100 mm × 100mm × 500 mm)	
Water absorption	28 days	2 cubes (100 × 100 × 100 mm)	B0 B1 B2 B3
	90 days	2 cubes (100 × 100 × 100 mm)	

Compressive strength

Concrete specimens at ages 7 days, 28 days, 56 days, and 90 days were tested by compression testing machine in the laboratory as shown in Fig. 2 for its compressive strength having different percentage of mixture of basalt as a replacement of ordinary Portland cement. Level of replacement of cement by mixture of basalt was 7.5%, 15%, and 22.5%. The compressive strength of concrete was tested on three specimens of each concrete mix replaced by basalt, and the average of the three cube sample test results was used to determine the compressive strength of concrete. The compression test results are expressed as the maximum load that the cube specimen can carry before

Fig. 1 Slump cone test

Fig. 2 Concrete compression testing machine

Table 7 Compressive strength of concrete with various percentage of mixture of basalt

Mix type	Water to binder ratio W/C	Compressive strength (MPa)			
		7 days	28 days	56 days	90 days
B0	0.53	24.45	25.68	34.00	34.40
B1	0.53	23.45	25.62	33.48	41.25
B2	0.53	17.17	25.62	32.00	40.80
B3	0.53	17.00	23.65	26.66	29.39

failing. By dividing the highest load by the loaded area corresponding to it, the concrete compressive stress can be calculated.

The compressive strength was calculated by formula as follows:

Compressive strength (MPa) = Failure load/cross sectional area.

Table 7 represents all the results of compressive strength and are as a function of percentage basalt content and curing time according to tested days of cube specimens and are graphically plotted in Fig. 3.

The degree of hydration is an essential step towards understanding the rate of strength development. The results show that the compressive strength increases for all cement pastes with curing time up to 90 days. During the hydration processes, cementatious materials were formed such as calcium-silicate hydrate(C-S-H) which is the main binder of cement paste in concrete. It starts forming from the early stages of the contributing to cement hydration and it progressively densifies as cement sets, so can be considered that it is the main source of cement contributing to pastes compressive strength. and consequently, increase in the concrete compressive strength in early ages can be observed. So, the increasing in the amount of basalt percentage as a replacement of ordinary cement leads to decreasing in concrete compressive strength at early ages.

From the tests results in this investigation, the optimum percentage of basalt percentage which was showed a good result related compressive strength of concrete for tested ages of concrete specimens is 15%.

Negative effect by decreasing in compressive strength at early age especially at ages 7 days and 28 days for mixes with varying percentages of basalt as a replacement of ordinary Portland cement (B1, B2, and B3) compared with control concrete mix (B0) up to 27.5%.

Increasing in concrete compressive strength for mixes with varying percentage of basalt up to 15% replacement of cement (B1 and B2) at a long-life age at 56 days and 90 days compared with control concrete mix B0 by up to 20%.

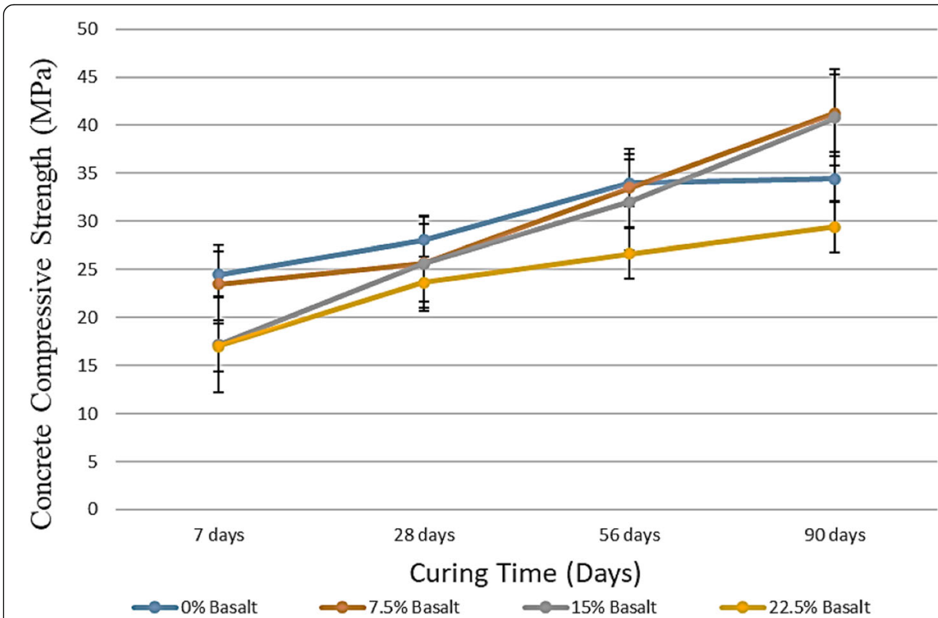

Fig. 3 Compressive strength as a function of curing time-up to 90 days

The test results of concrete compressive strength using basalt as a replacement ordinary Portland cement in concrete mix shows that the increasing in percentage of basalt in blended cement over 15% was not given a good result in concrete compressive strength in early and long-life ages although achieved a target compressive strength at age 28 days.

7.5% and 15% of basalt as replacement of ordinary Portland cement in concrete mix was given a good result in concrete compressive strength. So, the optimum percentage of replacement basalt is 15% related with concrete compressive strength.

Decreasing in concrete compressive strength at early ages for concrete mixes samples B1, B2, and B3 compared with control sample B0 is attributed to the basalt are pozzolanic material and the pozzolanic material reactions starts later regarding to calcium silicate hydrate formation

The test results shows that the target concrete compressive strength was obtained by samples contained 7.5% and 15% of basalt replacement ordinary Portland cement in concrete mix B1 and B2 respectively at age 28 days while the target concrete compressive strength was not obtained by sample contained 22.5% of basalt replacement ordinary Portland cement in concrete mix B3 at age 28 days.

Increasing in the concrete compressive strength of sample B1 at age 7 days compared samples B2 and B3 by 36.5% and 38% respectively but less than by 5% compared with control concrete mix sample B0 this is attributed to that the low hydraulic properties of basalt as compared with Portland cement. Which that the basalt does not take some extent in initial hydration as ordinary Portland cement. So; the dilution of cement with basalt leads to delaying the reaction.

Splitting tensile strength

The splitting tensile strengths of basalt blended cement in concrete mixes after 28 days and 90 days of curing were conducted. This test was done on the cylinder-shaped concrete specimen as shown in Fig. 4.

When the cylinder is placed on its side longitudinally and loaded to induce transverse tension, it actually creates tensile stresses as shown in Fig. 5 and relatively high compressive stresses on the cylinder. When the cylinder is given a load of compression along the plate kept parallel on either side of the cylinder, major tensile stress will be created along the diameter, and can be given by the formula below:

$$f_{ct} = \frac{2f}{\pi dl} \qquad N/mm^2$$

Where

F is the applied compressive failure load over the cylinder's length, d is the cylinder diameter, and L is the cylinder length.

Sixteen of cylinders for total concrete specimens were tested for a different proportion with basalt as a replacement of cement (type 1) in concrete mix after 28 days and 90 days of curing. The test results of specimens as shown in Fig. 6. Two cylinders were examined for each age category, and the average value was recorded.

The using of basalt as a partially replacement of ordinary Portland cement in concrete mix leads to increase in tensile strength up to 26.86% which is attributed to the

Fig. 4 Concrete cylinder specimens

strengthening of interfacial transition zone by the basalt content present as a replacement of Portland cement in concrete mix.

It can be clearly seen that the splitting strength value increases basalt content 7.5% and then 15% by 20.29%, and 26.86%; respectively compared with control concrete mix B0. So it was observed that maximum splitting tensile strength was obtained at 15% basalt as a replacement cement.

Slightly increasing in tensile strength of all concrete mixes samples B0, B1, B2, and B3 at age 90 days compared with tensile strength at age 28 days by 2.08%, 4.21%, 2.35%, and 5.71%, respectively as shown in Fig. 6.

Flexural strength

Concrete sample beams have a standard sizes 100 mm width, 100 mm height, and 500 mm length span of 28 days and 90 days were tested for its flexural strength having different percentages of mixture of basalt as a replacement of cement.

The level of replacement of cement by mixture of basalt was 0%, 7.5%, 15%, and 22.5%. Eight beams samples were tested for control mix (B0) and for replacement cement by basalt B1, B2, and B3. Two samples of each replacement were tested by one beam specimen for each age to calculate flexural strength. All concrete beam specimens were cured before testing at age 28 days and 90 days respectively and the flexural test was performed on two points loading system as shown in Fig. 7.

And the flexural strength can be calculated by the formula given below:

Fig. 5 Splitting tensile test samples

$$f_{cf} = \frac{F\,L}{d_1 d_2^2}$$

Where

f_{cf} = flexural strength

F = is the failure load, in (N)

L = is the distance between the supporting rollers, in (mm)

d_1, d_2 = are the lateral dimensions of the specimens, in (mm)

The change in the flexural strength with respect to different percentages of basalt is presented in Fig. 8, which shows that the maximum flexural tensile strength was reached corresponding to 15% addition of basalt.

The flexural strength after 28 days drops by 9.3%, 16%, and 10.7% in case of 7.5%, 15%, and 22.5% basalt powder addition as replacement ordinary Portland cement in concrete mix respectively in later time; i.e., after 90 days, the flexural strength of the reference mortar with 7.5% and 15% basalt powder addition does not differ much. Only slightly decrement was observed, while the flexural strength of mortar with 22.5% addition of basalt powder increases by 4.7% after 90 days.

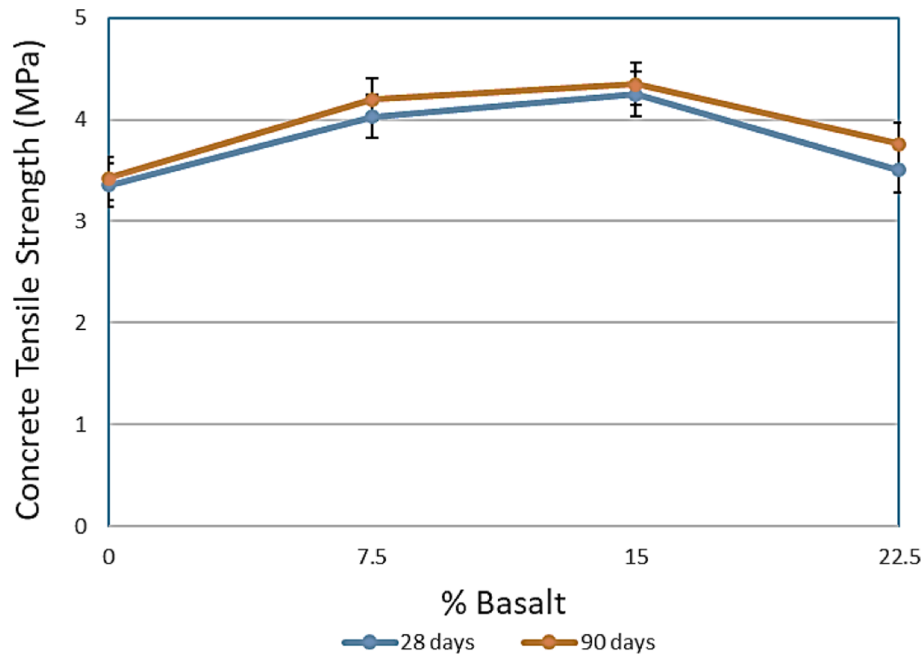

Fig. 6 Tensile strength of specimens at age 28 days and 90 days

Fig. 7 Flexural testing machine

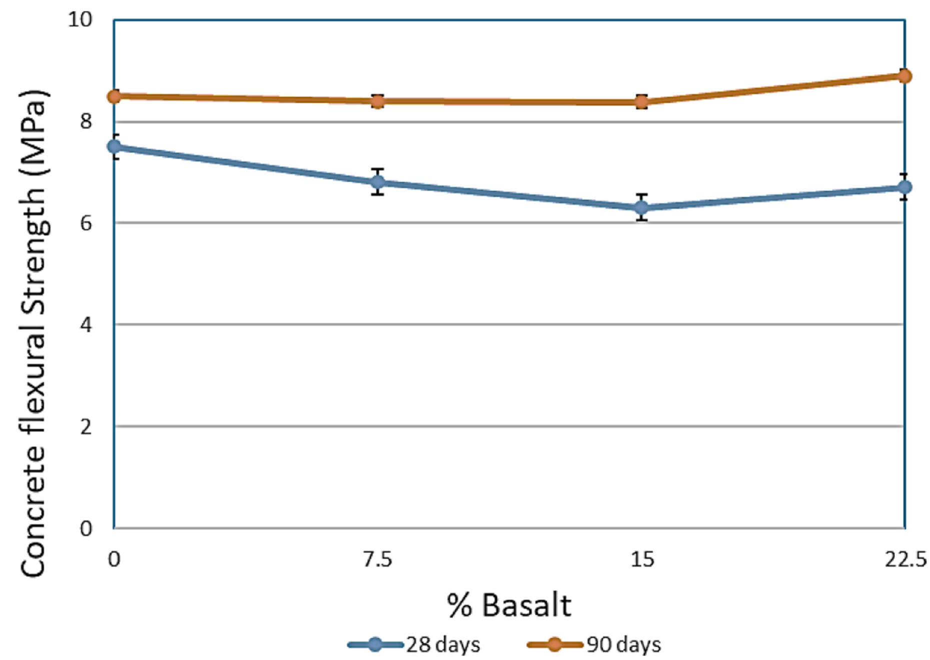

Fig. 8 Flexural strength of specimens at age 28 days and 90 days

Decreasing in flexural due to increasing in basalt powder as a replacement ordinary Portland cement in concrete mix was observed. This is attributed to the large irregularity and roughness of the surface of basalt grains which have the ability to mechanical wedging in the cement matrix.

Table 8 shows a comparison of the compressive, splitting, and flexural strengths for all tested specimens at all aging ages in the present investigation

Water absorption

Water absorption and penetration property was determinate by saturated water absorption of concrete cubs have dimensions 100 mm × 100 mm × 100 mm for various of cement pastes which it was blended of various percentages of basalt as a replacement of ordinary Portland cement in concrete mixes after 28 days and 90 days.

In this test, a dried specimen of known weight was immersed in water for a specified period of time after that period, the specimen was weighted a gain and the increase in weight with respect to the percentage of the original weight was expressed as its water

Table 8 Compressive, splitting, and flexural strengths of tested specimens

Mix designed specimens	Basalt %	Compressive strength (MPa)				Splitting strength (MPa)		Flexural strength (MPa)	
		7 days	28 days	56 days	90 days	28 days	90 days	28 days	90 days
B0	0	24.45	25.68	34.00	34.40	3.35	3.42	7.5	8.5
B1	7.5	23.45	25.62	33.48	41.25	4.03	4.2	6.8	8.4
B2	15	17.17	25.62	32.00	40.80	4.25	4.35	6.3	8.38
B3	22.5	17.00	23.65	26.66	29.39	3.5	3.76	6.7	8.9

Table 9 Percentage of water absorbed for varying percentage of basalt

Basalt percentage	Water absorbed %	
	28 days	90 days
0%	1.30	1.25
7.5%	1.43	1.40
15%	1.49	1.44
22.5%	1.62	1.58

absorption (in percentage). Values of water absorbed for different basalt percentage for ages 28 days and 90 days were listed in Table 9.

The water absorption percentage were listed in Table 8, and it was found that the water absorption increases as the percentage of basalt increased; this is attributed to the basalt powder particles is finer than of ordinary Portland cement and also it is hygroscopic in natural. Consequently, using basalt as replacement ordinary Portland cement in concrete mix was created a porous water fills, the pores which increase the water absorption rate. The water absorption percentage was decreasing at ages 90 days as shown in previous table.

SEM analysis

The Microstructure of the B1, B2, and B3 as a pozzolanic basalt specimens and B0 as an ordinary Portland cement specimen (the ones with the lowest and highest strength) was evaluated using the scanning electron microscope (SEM), as shown in Fig. 9. The porosities were marked by yellow squares in the figure. As can be seen, minor porosities are evident for basalt pozzolana while large pores in OPC compared to pozzolanic cement due to the high level of microstructure formation. Accordingly, both the

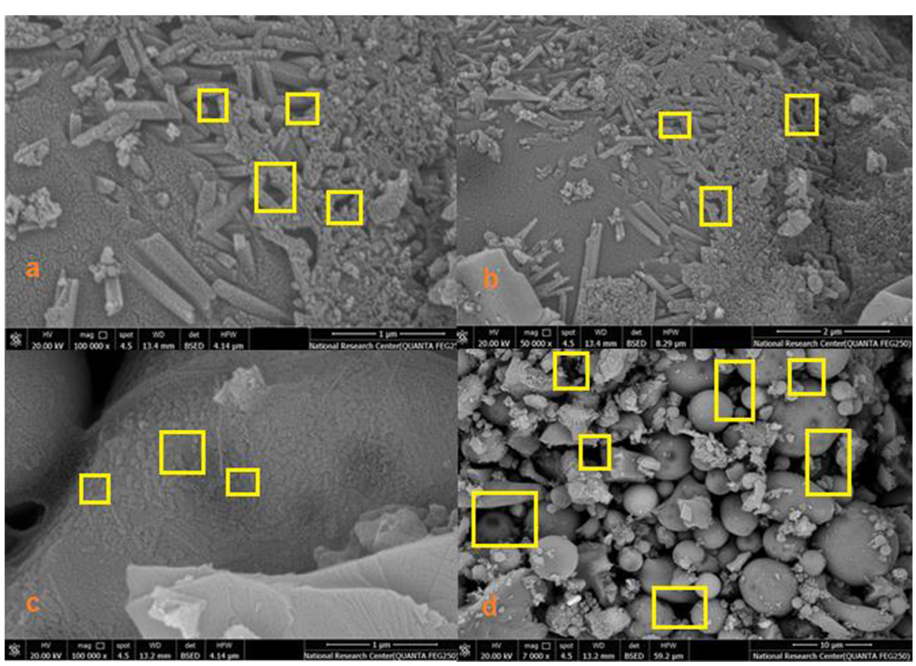

Fig. 9 SEM micrographs of the fracture surface of samples: **a** B1, **b** B2, **c** B3, and **d** B0

positive impact of chemical composition of basalt and the enhancement of pores formation were confirmed. The results of compressive strength, porosity, and SEM-photographs are harmonious with each other. From an ecological science perspective, the technique used in this work is a CO2 emission-free technique.

Conclusions

The following conclusions can be derived from the analysis and discussion of the test findings obtained in this study:

1- Industrial wastes formed from basalt which has a potential replacement of ordinary cement in concrete mix.
2- Using blended cement by basalt in reinforced concrete building becomes environmentally safe and also economically.
3- Compressive, tensile, flexural strength of concrete is affected by presence of basalt as a partial replacement of cement in concrete mix.
4- Maximum compressive strength of concrete was achieved by 15% replacement of cement by mixture of basalt at 56 days and 90 days curing.
5- Optimum replacing of cement by mixture of basalt percentage beyond 15% reduce the concrete compressive strength.
6- The maximum splitting tensile strength was obtained by 15% basalt replacement of ordinary Portland cement in concrete mix.
7- Decreasing in flexural strength due to increasing in basalt replacement ordinary Portland cement in concrete mix.
8- Increasing in water absorption due to increasing in basalt replacement ordinary Portland cement percentage.
9- Modulus of elasticity decreased by increasing basalt percentage in concrete at early ages.
10- An increase in the basalt content in the concrete will impact on its workability of the concrete.

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Authors' contributions
MSM designed concrete mix proportions and determinate types of mechanical tests of tested specimens and analyzed the test results and also major wrote the manuscript. SY casted the concrete tested samples in laboratory and tested a specimen in laboratory. MSM and SY monitored and recorded the test results of specimens. AER determined the types of pozzolanic material and performed all chemical tests for all materials included this research. All authors read and approved the final manuscript. All authors MSM, SY, and AER have approved the manuscript before submission, including the names and order of authors, and that all authors receive the submission and all substantive correspondence with editors, as well as the full reviews, verifying that all data, figures, materials. All authors MSM, SY, and AER have read and approved the manuscript.

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Availability of data and materials
The datasets collected and/or analyzed during the current study are available from the corresponding author on request. The corresponding author had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author details
[1]Department of Structural Engineering, Faculty of Engineering, Future High Institute of Engineering (FIEF), Fayoum, Egypt. [2]Department of Basic Science Department, Faculty of Engineering, Future High Institute of Engineering (FIEF), Fayoum, Egypt.

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